MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 12

PALEOECOLOGY OF THE CHOPTANK FORMATION (MIOCENE) OF MARYLAND AND VIRGINIA

by

Robert E. Gernant

1970

MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 12

PALEOECOLOGY OF THE CHOPTANK FORMATION (MIOCENE) OF MARYLAND AND VIRGINIA

by

Robert E. Gernant

1970

COMMISSION OF
MARYLAND GEOLOGICAL SURVEY

ERNST CLOOS, Chairman ..... Towson

S. JAMES CAMPBELL ..... Towson

RICHARD W. COOPER ..... Salisbury

G. VICTOR CUSHWA ..... Williamsport

JOHN C. GEYER ..... Baltimore

CONTENTS

	Page
Abstract	1
Introduction	2
Acknowledgements	2
Regional geological setting	3
History of previous investigations	3
Procedures in field and laboratory	4
Fossil classifications	5
Stratigraphy	6
Correlation	6
Geographic distribution	6
General stratigraphic relationships	6
Stratigraphic nomenclature	10
Subdivisions of the Choptank Formation	10
Calvert Beach Member	10
Drumcliff Member	13
St. Leonard Member	17
Boston Cliffs Member	20
Conoy Member	22
Problem of the "North Keys Sand"	23
Paleoautecology	25
Summary of known and inferred ecological information	27
Foraminifera	27
Ostracoda	27
Gastropoda	33
Bivalvia	33
Size-frequency study of selected bivalves	33
Orientation data	37
Interrelationships of Choptank organisms	39
Foraminifera	40
Porifera	40
Annelida	41
Bryozoa	41
Mollusca	42
Paleosynecology	45
Calvert Beach Member	45
Drumcliff Member	47
St. Leonard Member	48
Boston Cliffs Member	49
Conoy Member	51
Origin of the Choptank shell beds	53
Depositional history of the Choptank Formation	58
References	59
Appendix I—Description of outcrops	64
Appendix II—Foraminifera and ostracoda in Choptank samples	78

ILLUSTRATIONS

Figure — Page

1. Supposed Calvert-Choptank "unconformity" ... 8
2. Calvert-Choptank contact, Governor Run ... 9
3. Calvert-Choptank contact, Kenwood Beach ... 9
4. Choptank-St. Marys unconformity ... 10
5. Choptank-St. Marys unconformity ... 11
6. Members of the Choptank Formation, Calvert Cliffs ... 12
7. Type locality of Calvert Beach Member ... 13
8. Burrows in Calvert Beach Member ... 14
9. Lower Drumcliff Member at type locality ... 14
10. Type section of Drumcliff Member ... 15
11. Increased and reduced macrofossil beds at Drumcliff ... 16
12. Upper Drumcliff Member at type locality ... 16
13. Increased and reduced macrofossil beds in Boston Cliffs Member near Drumcliff ... 17
14. *Turritella plebeia* lenses ... 18
15. Biogenic sedimentary structures in St. Leonard Member ... 19
16. Biogenic sedimentary structures in St. Leonard Member ... 19
17. Articulated *Anadara staminea;* scour and fill structures ... 20
18. Type section of Choptank Formation and Boston Cliffs Member ... 21
19. Increased and reduced macrofossil beds, Boston Cliffs ... 22
20. Central Boston Cliffs Member ... 23
21. Boston Cliffs Member, Camp Conoy ... 24
22. Upper Boston Cliffs Member, Conoy Member, and lower St. Marys Formation ... 25
23. Borings at the Choptank-St. Marys unconformity ... 26
24. Concentrated *Turritella plebeia* in Conoy Member ... 27
25. Size-frequency distributions: *Glossus fraternus marylandicus* ... 34
26. Size-frequency distributions: *Lyropecten madisonius, Glossus fraternus marylandicus* ... 34
27. Size-frequency distributions: *Anadara staminea, Glossus fraternus marylandicus* ... 35
28. Size-frequency distributions: *Glossus fraternus marylandicus, Anadara staminea* ... 35
29. Size-frequency distributions: *Lyropecten madisonius* ... 36
30. Size-frequency distributions: *Anadara staminea, Lyropecten madisonius* ... 36
31. Size-frequency distributions: *Macrocallista marylandica, Anadara staminea* ... 37
32. Size-frequency distributions: *Anadara staminea* ... 38
33. Size-frequency distributions: *Anadara staminea* ... 39
34. Size-frequency distributions: *Anadara staminea* ... 39
35. Size-frequency distributions: *Anadara staminea* ... 40
36. Size-frequency distributions: *Turritella plebeia, Anadara staminea* ... 41
37. Size-frequency distributions: *Astarte obruta* ... 42
38. Size-frequency distributions: *Dosinia acetabula, Crassatella marylandica* ... 43
39. Orientation data: *Turritella plebeia* ... 44
40. Orientation data: *Turritella plebeia* ... 44
41. Organisms in the Calvert Beach Member ... 46
42. Organisms in the St. Leonard Member ... 50
43. Organisms in the Boston Cliffs Member ... 52
44. Mechanism of shell bed accumulation ... 56

Plate

1. Locations of outcrops studied ... separate

TABLES

Table

1. Ecological data on Choptank foraminifera ... 28
2. Ecological data on Choptank ostracoda ... 29
3. Ecological data on Choptank gastropoda ... 31
4. Ecological data on Choptank bivalvia ... 31

PALEOECOLOGY OF THE CHOPTANK FORMATION (MIOCENE) OF MARYLAND AND VIRGINIA

by

Robert E. Gernant[1]

ABSTRACT

A rarely used interdisciplinary approach is employed to reconstruct the depositional history and ecology of the Choptank Formation and its fossil organisms. Analysis of microfaunal and macrofaunal assemblages is supplemented by study of biogenic and inorganic sedimentary structures, sedimentary textures, and stratigraphic relationships.

The fossils and sediments of the Middle Miocene Choptank Formation accumulated primarily in inner shelf marine environments. In addition, faunal evidence indicates that this unit originated in the central and southern regions of a cool temperate marine climate.

One of the more important results of this investigation is the hypothesis that the major Choptank shell beds were formed by passing marine swells possibly related to tropical storms. The effect on the substrate was the establishment of a pressure gradient causing flow into the bottom deposits and flow out accompanied by effusion of the sediments. This lifting action and vertical sorting created zones of traction and accumulation providing a mechanism sufficient to explain the significant characteristics of the Choptank shell beds. In fact, this process of shell accumulation may be much more important in modern and ancient seas than indicated by the little attention given to it.

The lowest unit of the formation, the Calvert Beach Member, was deposited in the coldest water of any unit in the Choptank. Its environments were slightly inimical to many types of bottom communities as evidenced by the bivalve dominance of the Lucinacea. The Drumcliff Member represents a shallowing of environments on the inner shelf and possibly slight warming. During the deposition of this unit marine swells passed through the area concentrating shells into great beds.

Maximum shallowing occurred during the St. Leonard Member. Marginal marine environments dominated this unit in outcrop. The best delineated of these was the lower bay environment, which occurred in the area of the modern Calvert Cliffs. The slight warming trend continued into the Boston Cliffs Member, but the shallowing trend of the lowest three members was reversed. This member represents a return to open inner shelf environments, where the bottom was again swept by marine swells concentrating great volumes of shells.

Sediments of the Conoy Member were deposited in distinctly deeper water but still probably shallower than 50 meters. The warming trend continued, placing deposition in the southern end of the cool temperature region. The St. Marys Formation generally continues the deepening trend started in the Boston Cliffs Member.

Previously, five subdivisions of the Choptank Fm. were numbered and given biostratigraphic designations. However, they are here considered rock-stratigraphic units and given the following names: Calvert Beach Member, Drumcliff Member, St. Leonard Member, Boston Cliffs Member, and Conoy Member. The "unconformity" with the underlying Calvert Formation, as described by Shattuck (1904), may exist but is visually much less impressive than he suggested. Although he considered the Choptank conformable with the overlying St. Marys, the present evidence indicates that the contact between the two formations is an erosional-depositional unconformity. To supplement the unrepresentative type section, a principal reference section is designated in the Calvert Cliffs, 0.9 mile southeast of Western Shores, Maryland and 1.0 mile northwest of Calvert Beach, Maryland.

[1] Present address University of Wisconsin (Milwaukee)

INTRODUCTION

With the publication of the monumental Miocene Volume in 1904 by the Maryland Geological Survey, the fossils and stratigraphy of the Chesapeake Group became well known. This thorough systematic investigation of the Maryland Miocene prepared the foundation for paleoecological and paleoenvironmental studies. Unfortunately over 60 years have passed and still very little is known of these aspects.

Many characteristics of the Choptank Formation of Maryland and Virginia favor paleoecological studies: the famous Calvert Cliffs of the Western Shore of Maryland present a nearly continuous dip section, nearly 15 miles long, allowing excellent lateral correlation of units; the fauna is well preserved; the fossils are easily extracted from the unconsolidated sediment; the comparatively small stratigraphic thickness of the Choptank provides the opportunity for a bed-by-bed analysis and study of individual horizons; the taxonomy of the macrofauna and the Foraminifera has been well studied; and several species of this Miocene fauna are thought to be extant, so their ecology may be directly inferred from the living forms.

Fossils from two prolific shell beds of the Choptank have been extensively sought for private and public collections. Yet attempts to explain the abnormal quantity of shells have used only speculative intuition. This study offers new insight into their nature and origin.

The purpose of this investigation is to enlarge the understanding of the paleoecology and sequence of geological events recorded within the Choptank Formation. Firm basis for conclusions is provided by a rarely used interdisciplinary approach combining analysis of microfaunal and macrofaunal assemblages with study of biogenic and inorganic sedimentary structures, sedimentary textures, and stratigraphic relationships.

ACKNOWLEDGEMENTS

This investigation was financially supported by National Science Foundation Research Grant GB4959. This study is based on work submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Horace H. Racham School of Graduate Studies at the University of Michigan.

I gratefully acknowledge Prof. R. V. Kesling, University of Michigan, for serving as principal investigator on National Science Foundation Research Grant GB4959, for visitation during field investigation, and for very useful suggestions. Appreciation is also extended to Drs. D. B. Macurda, Jr., Henry van der Schalie, C. I. Smith, and the late E. C. Stumm, all of the University of Michigan, for review of the manuscript and helpful advice.

Dr. J. E. Hazel, U. S. Geological Survey, and Dr. R. N. Smith, State University of New York at Stony Brook, helped substantially with problems concerning ostracode taxomony. Dr. Richard Benson, U. S. National Museum, offered advice on general approaches to the paleoecological aspects of this study. Mr. Charles Buddenhagen, State University of New York at Stony Brook, discussed problems of stratigraphy and paleoecology. Dr. John Glaser, Maryland Geological Survey, directed me to several key outcrops. Dr. Robert Biggs, Solomons Biological Laboratory, Solomons, Maryland, offered various suggestions for the origin of the Choptank shell beds. Dr. E. G. Kauffman, U. S. National Museum, provided very stimulating discussion on the paleoecology of the Choptank molluscs and on the origin of the shell beds. Dr. T. G. Gibson, U. S. Geological Survey, accompanied me in the field several times, offered much helpful advice and discussed many aspects of paleocology and depositional history. Grateful appreciation is extended to all these people.

Thomas Kelly, William Kramer, and David Showalter superbly assisted during different stages of field and laboratory investigations. Sincere appreciation is also extended to Mr. and Mrs. L. E. Smith and family, St. Leonard, Maryland, for help with problems of field logistics and for much encouragement.

I am also indebted to Mr. Karoly Kutasi, University of Michigan, for valuable help with photography. Thanks go to Mr. Derwin Bell, University of Michigan, for the very skillful preparation of text-figures 17-20 and the location map.

My wife, Virginia K. Gernant, acted as recorder in the field, prepared the graphs, typed part of the draft, and helped edit the manuscript. Her constant encouragement made this study possible.

REGIONAL GEOLOGICAL SETTING

Around 15 to 20 million years ago the sediments of the Choptank Formation were deposited in the Atlantic Coastal Plain, but the regional geological setting was beginning to take form a few hundred million years prior to that. Structural lineaments, regional negative areas, local basins, sediment supply areas, river tributary systems, the strike of the Choptank, and other characteristics of the formation were probably established by the late Paleozoic Appalachian orogeny and possibly by early Paleozoic orogenies. Deeply buried Precambrian and Paleozoic crystalline rocks of the Piedmont underlie the wedges of Mesozoic and Cenozoic sediments. The boundary separating the Piedmont from the Coastal Plain is marked by the fall line (pl. 1) which passes through Philadelphia, Baltimore, Washington, Fredericksburg, and Richmond. The Choptank outcrops in a belt from about 30 to 50 miles east of the Piedmont, which undoubtedly supplied most of the terrigenous detritus to the formation.

Geophysical work and well sections have revealed a deep basin in the basement rocks, its axis trending approximately through Berlin, Salisbury, and Cambridge, Maryland, and almost to Washington, D. C. Richards (1948) named this structure the Salisbury Embayment. The deepest known part of the basin is at Ocean City, Maryland, where the Coastal Plain sediments are 7710+ feet thick. Maher (1965, p. 6) said, "this embayment is fairly prominent in the basement rocks, but loses form in the younger beds, suggesting that it is a pre-Cretaceous feature filled by Cretaceous sedimentation." My field investigations indicate that this basin was indeed a locus of increased Tertiary deposition, particularly Miocene. The thickest surface and subsurface sections of the Choptank occur over the axis of the Salisbury Embayment and thin away from the axis. The other formations of the Chesapeake Group have similar distributions. The Maryland Miocene sediments would seem to indicate that the basin was mobile and affected deposition at least for that part of the Tertiary.

The Appalachian Mountains went through episodes of uplift and dissection during the Tertiary. River systems, such as the ancient Susquehanna, Patuxent, Potomac, Rappahannock, York, and James, must have carried tremendous volumes of terrigenous detritus to the Middle Atlantic Coastal Plain. Another major regional influence on both the sediments and the biota was the configuration of ocean and longshore currents. The results of this study indicate that the animals and sediments of the Chesapeake Group were found in a temperate marine climate. This climate results from a very delicate balance of factors primarily relating to cold water currents flowing from the north and warm water currents flowing from the south. Longshore currents are sculpturing numerous barrier islands along the present Atlantic Coast and may well have done the same during the Miocene; there certainly would have been enough sand available.

Within this complex framework the sediments of the Maryland Miocene were deposited. The interplay of geological parameters produced units unique enough to receive different names. The major subdivisions have been called, from oldest to youngest, the Calvert, Choptank, and St. Marys Formations. These, in turn, were subdivided into "zones" and given numbers by Shattuck (1904) with "zone 16" through "zone 20" representing the Choptank. In the Chesapeake Group of Virginia the Yorktown Formation lies above the other three.

HISTORY OF PREVIOUS INVESTIGATIONS

Investigations of the Maryland Miocene prior to 1904 were summarized by Shattuck (1904, pp. *xxxiii-lxiv*.) The only paleoecological conclusions offered before 1904 were those of Lardner Vanuxem (1828, p. 67). In discussion of the Maryland Miocene, he said,

> "This region is characterized by littoral shells, analogous to those of the Tertiary deposits of

the Paris and English Basins: unlike the Secondary, this formation contains a vast number of genera, of which few or none are extinct; indeed very many of the species differ but little from the littoral shells now existing on various parts of the American coast."

Those statements mark Vanuxem as the senior paleoecologist of the Chesapeake Group.

Dall, (1904, p. *cxliii*), thought the molluscan fauna of the Chesapeake Group "derived from cool-temperate seas." He added (p. cxlv),

> "In all cases and throughout its extent the fauna has the characteristics of a shallow-water assembly, without any marked littoral elements, but which might well have existed in the immediate vicinity of low, nearly level, muddy or sandy shores, and have extended off-shore to a distance more or less indefinite, but which did not include any area subject to the influences of an open and unsheltered ocean."

Either misprints were introduced or he presented contradictory statements, since on page *cxlix* he introduced evidence to suggest that the molluscan fauna was of warm temperate origin. On the same page he said, "Between the several horizons of the Maryland Chesapeake there is but very slight indication of any temperature difference; so far as there is any, it points toward a progressive but slight cooling of the water from the Calvert to the St. Marys . . ."

Schoonover (1941a) reported a nest of echinoids near the Calvert-Choptank unconformity. She was not certain as to which formation contained the fossils, but from her stratigraphic description they must have been in the Calvert. As a result this occurrence is potentially very important paleoecologically for the Calvert only. In the same year (Schoonover, 1941b) she presented a very careful biostratigraphic investigation, which contained some paleoecological statements about individual bivalve species, particularly regarding their morphologic variations in time and space.

Malkin (1953) worked on the Maryland Miocene ostracodes and concluded that the Miocene sediments of New Jersey, Maryland, and Virginia were deposited in 10 to 150 meters of open ocean water "of average salinity (35 o/oo) and average calcium carbonate content." She felt the Miocene assemblages were "similar to the Atlantic south of Cape Hatteras, and to the Caribbean Sea" (Malkin 1953, p. 772).

Study of both autecology and synecology of the Chesapeake Group molluscs, particularly the bivalves, led Mongin (1959) to conclude that the fauna was more warm temperate or tropical than cold temperate and that the prolific shell beds of the Choptank represented transgressive beach accumulations.

Gibson (1962) made the most intensive paleoecological investigation to date. He concluded that the Choptank was deposited in very shallow, cool to moderately warm waters with a general warming trend throughout the Miocene. The foraminiferal evidence suggested that "zone 17" (of Shattuck, 1904) was the shallowest of the Choptank units.

In 1966 Gibson was more precise with his paleotemperature determinations by claiming the Calvert Foraminifera were cool temperate, while those of the Choptank, St. Marys, and lower Yorktown were slightly warmer. The upper Yorktown was thought to be warm temperate.

PROCEDURES IN FIELD AND LABORATORY

Because outcrops of the Choptank are typically unconsolidated and fresh, a result of nearly continual mass wasting, study and procurement of samples are relatively easy. Each bed or unit that was visually distinct from units above and below in faunal or lithologic content was measured, described, and sampled in nearly 80 sections. Most all units were less than two or three feet thick and many were less than one foot. For each of the thinner units only one sample was taken, but for units over two feet thick multiple samples were taken. Not all samples collected were analyzed in the laboratory, however.

Sediment colors were compared in fresh exposures to the Geological Society of America Rock-Color Chart. Sediment sizes were determined in the field with the aid of a ten-power hand lens and a pocket guide to grain size. All macrofossils were identified in the field and their relative abundances were determined according to a scale of logarithmic progression with the following classes: rare (approximately 1 to 3 specimens per square meter), few (approximately 3 to 6 specimens), numerous (approximately 6 to 15 specimens), common (approximately 15 to 30 specimens), very common (approximately 30 to 60 specimens),

abundant (approximately 60 to 150 specimens), and flood (more than approximately 150 specimens). Other distributional and orientation characteristics including size of specimens, measured to the nearest hundredth of a centimeter, and orientation and inclination measurements were determined from particular beds in the field.

Samples for microfauna analysis were dried at room temperature and warmed in a solution of sodium bicarbonate. After washing, Ostracoda and Foraminifera were separated from the residue using a variation of the soap flotation method suggested by Howe (1941, p. 691). Previously, this technique had been used only to concentrate ostracodes, but it was found completely satisfactory for Choptank foraminifers as well. Microscopic examination of washed residues indicated that the procedure worked equally well with the two kinds of microfossils.

A sample splitter was used to reduce accurately excessively large microfaunal assemblages to 300-500 specimens of ostracodes and of foraminifers. Phleger (1960, pp. 33-35) presented data leading to the conclusion, "that little if anything is to be gained by counting samples much larger than approximately 300 specimens and that the illusion of accuracy tends to be misleading".

Counting Foraminifera is relatively straightforward, but making a meaningful count of Ostracoda is no easy matter. In order to grow, ostracodes molt their former valves and secrete new ones. Thus one living individual could be represented by as many as eighteen isolated fossil valves in one sample. However, these molts are often difficult to correlate with the proper adults, and indeed many juvenile fossil valves have been described as separate species. Ulrich and Bassler (1904) committed this error in the case of the Maryland Miocene. The strong sexual dimorphism in some species introduces problems of assigning the proper forms to the same species in addition to knowing whether to count males and females separately or together. A precedent can be found for practically any method of counting ostracodes. Considering the widespread lack of agreement, I devised what seemed the most meaningful system to me. Separate counts were made for right and left valves of juvenile carapaces where they could be correlated with adults, of male carapaces, and of female carapaces where sexual dimorphs could be rcognized. The supposed number of individuals was computed by adding the greater of either left or right male valves, left or right female valves, and left or right juvenile valves. Statistical studies of living populations and their relationship to fossil populations could greatly improve the accuracy of counting fossil assemblages.

FOSSIL CLASSIFICATIONS

Identifications of the Choptank Foraminifera followed Gibson (1962) quite closely. The Ostracoda were more of a problem. The first work was that of Ulrich and Bassler (1904), which was extremely important since it described many of the Miocene to modern ostracodes of the northwestern Atlantic area. Unfortunately, several taxonomic problems result from their species and the way subsequent workers have used their species. All of the Ulrich and Bassler type specimens at the U.S. National Museum were compared with specimens of the present study. The only other worker who has published on Choptank ostracodes is Malkin (1953). Although she corrected several existing taxonomic problems, she also perpetuated a few and created others. A significant study by Edwards (1944) on the Ostracoda of the Duplin Marl of North Carolina recognized many species currently found in Miocene through Holocene sediments. Swain (1951) described species from the Miocene of North Carolina, some of which occur as well in the Choptank. Edwards' and Swain's types were studied at the U.S. National Museum. Generic classification largely follows that of van Morkhoven (1963) and Hazel (1967).

The classification of molluscs follows the specific determinations of Martin and Glenn (1904) and Schoonover (1941b). Since the former report only a very few subspecies have been added.

STRATIGRAPHY

The Choptank Formation is part of the Middle and Late Miocene sediments in Maryland and Virginia which Darton (1891) called the Chesapeake Group. In Maryland this sequence consists of the Calvert, Choptank, and St. Marys Formations, in ascending order. The Yorktown Formation overlies these three in Virginia.

The Choptank was named in 1902 by G. B. Shattuck for its exposure in the western bank of the Choptank River on the Eastern Shore of Maryland. It is better known from its exposures in the Calvert Cliffs along the Western Shore of the Chesapeake Bay and its stratigraphic relationships are much more easily studied in these exposures and those along the Patuxent and Potomac Rivers.

CORRELATION

The present consensus among stratigraphers is that the age of the Choptank is Middle Miocene, correlating with the Helvetian of Europe. To date, correlation with other exposed units in the Atlantic Coastal Plain remains doubtful, or at best uncertain.

The only outcropping formation that seems to have any possibility of equivalency with the Choptank is the Kirkwood of New Jersey. Based on the fossil molluscs, however, Shattuck (1904), p. *cxxiv-cxxxvii*) and Richards and Harbison (1942, p. 170) felt that the Kirkwood correlated best with the Calvert Formation. Malkin (1953, p. 771) related the Kirkwood to the Calvert using Ostracoda as evidence. Her data were inconclusive, however, since all of the species she listed as confined to the Calvert and Kirkwood have been found in the present study in the Choptank as well.

GEOGRAPHIC DISTRIBUTION

Exposures of the Choptank Formation are found in Caroline, Talbot, and Dorchester Counties on the Eastern Shore of Maryland, Calvert and St. Marys Counties on the Western Shore of Maryland, and Westmoreland County in northeastern Virginia (pl. 1). On the Eastern Shore the unconsolidated, non-resistant beds are obscured by Pleistocene deposits, and their distribution and character are very imperfectly known. Nearly all of the known outcrops are in the banks of the Choptank River, but even there they are sparse and widely separated.

The Choptank Formation is best known from its exposures along the Western Shore of the Chesapeake Bay from Parker Creek in the north to just north of Cove Point in the south (pl. 1). This nearly continuous line of outcrops makes up part of the Calvert Cliffs. Many excellent exposures may also be found along the Patuxent River and its tributaries in Calvert and St. Marys Counties. A few, small, good sections occur in the bluffs facing Breton Bay adjacent to the Potomac River in St. Marys County. The Nomini, Stratford, and Horsehead Cliffs of Westmoreland County, Virginia, form a nearly continuous section for about 6 miles along the Potomac River. Inland outcrops are very rare. The major rivers of the Western Shore of Maryland and Virginia are approximately perpendicular to the regional strike of the formation, exposing a few major dip sections for study. Unfortunately, some facies changes between dip sections are not easy to understand. However, the lateral control of the Choptank Formation is better than for most formations in this region.

GENERAL STRATIGRAPHIC RELATIONSHIPS

In the area of surface exposure the formational strike is approximately northeast-southwest. The dip is approximately 10 feet per mile to the southeast. Hence, the Choptank crops out on the hilltops to the north and gradually occupies lower levels until it dips under beach or sea level to the south.

The outcrop thins from approximately 75 feet thick along the Calvert Cliffs to approximately 55 feet in the Nomini Cliffs of Virginia and to 29 feet in the Horsehead Cliffs of Virginia. Pronounced thickening occurs in the subsurface. Several examples have been reported of the Chesapeake Group increasing in thickness down dip. Anderson (1948, p. 19) reported that in the Ohio Oil Company's Larry G. Hammond Well No. 1 near Salisbury, Maryland "the thickness of Choptank is 125 feet and it extends from 515 feet to 640 feet." Shattuck (1904, p. *lxxx*) reported that the Choptank Formation was 175 feet thick in a well drilled at Crisfield, Maryland. McLean (1956, 1966) reported a thickness of 20 feet for the Choptank in the Camp Manufacturing Company Well 4 at Franklin, Virginia. It is difficult to understand from the remainder of his information how thick the Choptank is in the other test borings. His drawn sections of test wells on the Norfolk, Virginia, side of

the Chesapeake Bay Bridge and Tunnel seem to indicate that he interprets the Choptank thickness to average about 30 feet. If I interpret McLean's data correctly, it illustrates the fundamental significance of the Salisbury Embayment on the development of the Choptank deposition. Thickest accumulation occurs near the center of this structure, and thinner sequences occur on the flanks of the embayment. At this time lateral boundaries of the formation have not been located.

The Choptank formational boundaries have been significant stratigraphic problems. In considering the lower contact, Shattuck (1904, p. *lxxx*) said,

> "the Choptank Formation lies unconformably on the Calvert Formation. This unconformity is in the nature of an over-lap but is not easily discernible even where the contact is visible. The best place to observe the unconformity is in that portion of the Calvert Cliffs just below the mouth of Parker Creek. Even here, the unconformity cannot be seen while standing on the beach but may be observed from a boat a short distance from the shore."

Subsequent investigators have had difficulty in recognizing the unconformity. Unfortunately, the character of the sediments and fossils on both sides of the formation boundary is very similar, and Shattuck did not clearly differentiate the units on either side of the formational boundary. According to his described sections, Shattuck (1904, pp. *lxxxix-xc*) measured 9, 5, and 4 feet of his "zone 15" of the Calvert at ½ mile south of Parker Creek, 1 mile south of Parker Creek, and Governor Run respectively. In his "zone 16" of the Choptank he measured 0, 10, and 13 feet, respectively, at the same localities. The absence of "zone 16" at Parker Creek and the thickening toward Governor Run should constitute the visual evidence of an overlapping unconformity.

Even though I visited this area several times, I failed to find an overlapping unconformity. One feature of the outcrop, however, might be confused with an unconformity. Figure 1 shows what appears to be a prominent stratigraphic break in the "zone 15"—"zone 16" interval south of Parker Creek. Upon examination of the outcrop, it is clear that this feature is not a depositional break. The only change across this boundary is a color change which probably resulted from leaching above. Very close study reveals no bedding plane or textural change at this horizon. In fact, the color change cuts through sedimentary structures and fossils. Moreover if this peculiarity is traced far enough to the south, it is seen to cut all the way down to "zone 14".

Since Shattuck's conception of the formational contact at Parker Creek is controversial, I studied the sections of this interval in the Governor Run—Kenwood Beach area and to the north. In this area there is a slight change in fossil quantity where Shattuck placed the boundary (fig. 2, 3). This break can be traced as far south as Calvert Beach and as far north as Parker Creek (see locality 67-65 in Appendix I). If this stratigraphic break is accepted as the formational boundary, "zone 15" is 3 feet 6 inches thick and "zone 16" is 15 feet 3 inches thick at Kenwood Beach; and "zone 15" is 3 feet 9 inches thick and "zone 16" is 13 feet thick in the first cliffs south of Parker Creek. Since the units above and below the contact maintain uniform thickness, the evidence hardly indicates an impressive overlapping unconformity.

Shattuck cited additional evidence (1904, p. *lxxx*) for an overlapping unconformity:

> "The unconformity of the Choptank on the Calvert formation is also proved from the fact that at the above-mentioned locality (Parker Creek) the fossil bed which lies lowest in the Choptank formation rests on the Calvert, while at Mt. Harmony and northward the upper fossil bed of the Choptank rests on the Calvert Formation."

This may well be the best structural evidence of an unconformity. Study of this relationship near Paris (locality 67-58) shows it to be something less than straightforward. Locality 67-58 is a hill between state highways 260 and 613 between Paris and West Beach. The Calvert Formation can be found low on the north side of the hill, but the upper part of the north side is covered. Shattuck's "zone 19" of the Choptank is exposed at the top of the south side. This would be what Shattuck said, "rests on the Calvert." However, about 6 feet of fine sand occur below the bed and grade into it. Analysis of a sample from the sand produced Ostracoda and Foraminifera very typical of shallow-water Choptank assemblages. Additionally, the ostracodes *Campylocythere laevissima, Pokornyella punctistriata,* and *Bensonocythere whitei* and the foraminifer *Nonion marylandicum* have been reported by Malkin (1963, p. 769) and Gibson (1962, p. 46) as occurring in the Choptank but not the Calvert. Establishing this sand as Choptank certainly does not disprove Shattuck's con-

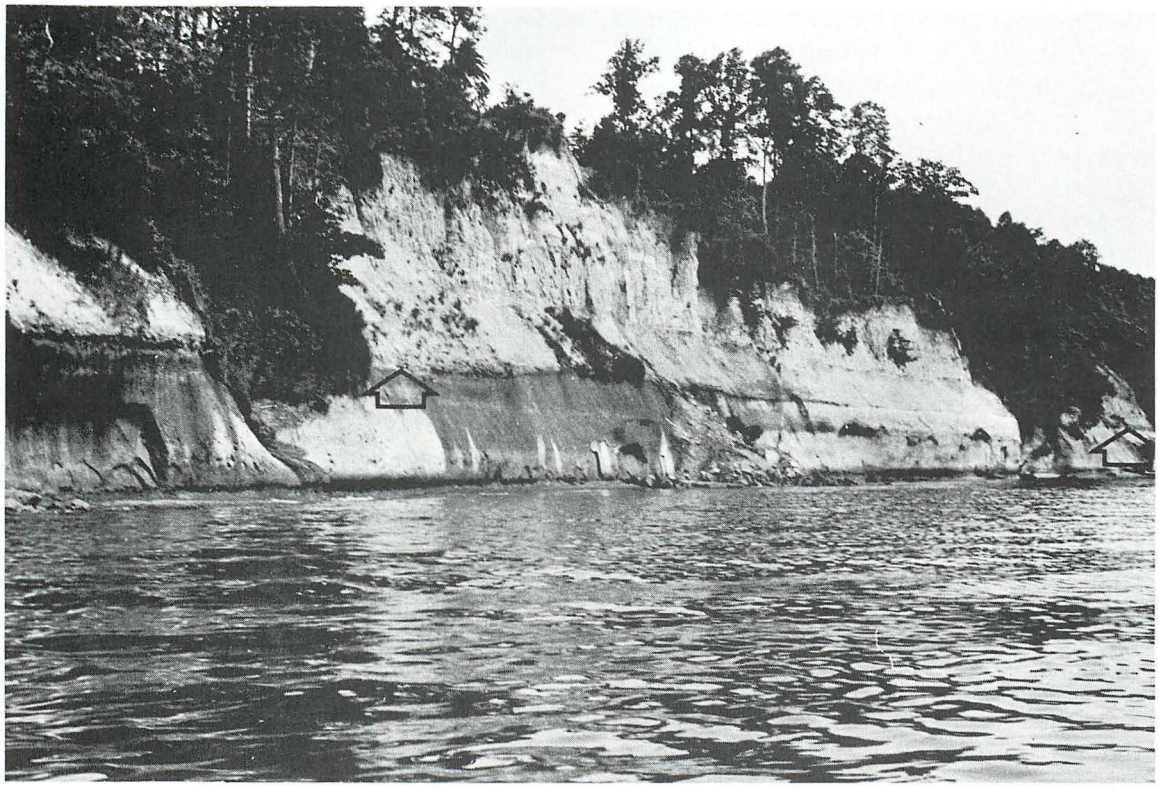


Figure 1: First cliffs south of Parker Creek along Chesapeake Bay. Arrows point out line of leaching which probably correspond to the "unconformity" recognized by G. B. Shattuck. Lighter band below "unconformity" and intersecting arrow at left is "zone 14" of the Calvert Formation. The lighter colored beds at the center peak of the cliffs are in the Boston Cliffs Member. The beds two-thirds up from the base and weathering into blocky fractures are in the St. Leonard Member.

tention that this section showed the unconformity. An unconformity may exist at the base of the sand, rather than at the top as he envisioned. From topographic and stratigraphic considerations, it appears that the only beds above the Calvert at this locality are those exposed on the south side of the hill. Possibly, this could be regarded as evidence for an overlapping unconformity.

The problem of the Choptank-Calvert boundary is far from settled. Away from the area of the Calvert Cliffs, where the boundary is defined, it becomes more difficult to locate. A few exposures on the Patuxent River contain the interval under consideration. At Sandgates (locality 67-59) the unconformity is very difficult to locate by correlating the sequence of lithologic characteristics from the reference area; elsewhere on the Patuxent it is probably impossible. The formational contact needs more study. Subsurface investigations combined with micropaleontological analyses hold promise for a more satisfactory solution.

In spite of the uncertainties based on physical criteria, the formational boundary certainly appears justified. The general fauna and sediment types of the Choptank are sufficiently different from the Calvert to warrant two distinct formational designations. In addition, Gibson (1962, p. 13) suggested a significant change in the paleotemperature across the subtle physical boundary.

While the lower contact has been the subject of some debate, the upper contact has experienced little controversy. All accounts to date of Miocene stratigraphy assert that the Choptank is conformably overlain by the St. Marys Formation. However, my analysis of the contact indicates a surface of either erosion or nondeposition, namely an unconformity. Unfortunately, the exposures of the contact are not readily accessible. At Camp Conoy (pl. 1), ample evidence exists for an unconformity. Structure around the formational contact is typical of unconformities. One of the most striking bits of evidence is the pinching out from one end of the locality to the other of about 20 feet of the lowermost St. Marys. Further, the uppermost sediments of the Choptank Formation contain abundant bivalve borings which have all been filled by

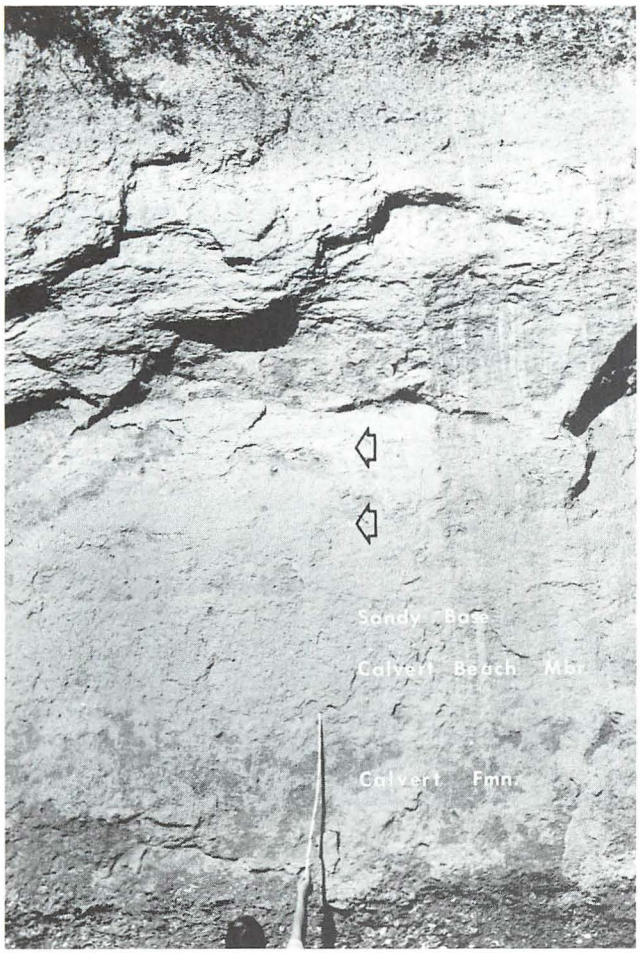


Figure 2: T. M. Kelly pointing to contact between the Calvert Formation and Choptank Formation (Calvert Beach Member). Shelly bed at level of Kelly's face is "zone 14" of the Calvert. "Zone 15" of the Calvert extends from that bed to the end of the pointer. Shelly bed at top is in the Drumcliff Member. Note sandy beds in the lower part of the Calvert Beach Member marked by arrows. Near locality 67-53, approximately one half mile north of Governor Run, Maryland.

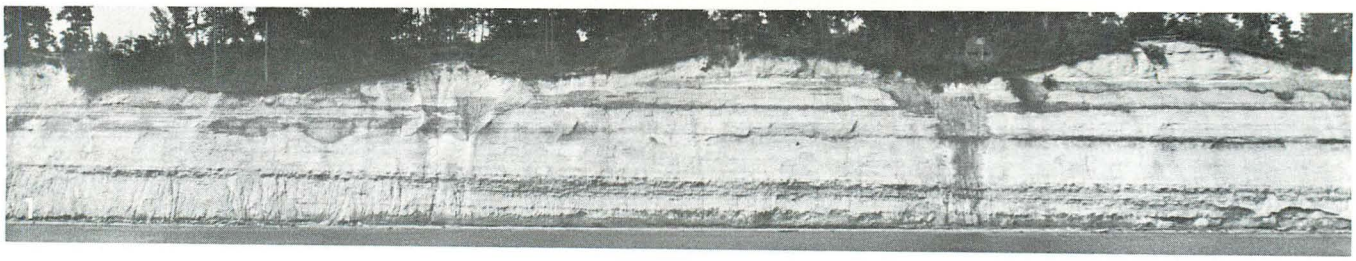
very distinct sediment from the overlying St. Marys, suggesting a surface of nondeposition or erosion. Additionally, there occurs immediately above the contact a stringy, discontinuous, very well sorted, "basal sand".

This unconformity is not without complexities however. The structural discordance can be seen only in this outcrop. To the south, all the way to Cove Point, the units of the Choptank and St. Marys are parallel, but the sequence of beds indicated on the right in figure 4 is absent. To the north, at least to Flag Ponds, the Choptank and St. Marys units appear conformable, including the additional units at the base of the St. Marys.

In order to compare the Choptank microfossils with those in the lower St. Marys Formation, samples were taken at Flag Ponds, locality 66-25. Analyses of faunal assemblages indicate that the advent of the St. Marys brought distinctly shallower and warmer waters to this area. Of course, the warmer temperature could in part be a function of the shallower water. In any case, a distinct environmental change marked the lowest St. Marys.

The evidence seems to suggest that after the deposition of the Conoy Member a local shallow basin was created, possibly by slight uplift to the south, in which the sequence of sediments in question was deposited. In spite of the fact that the normal regional dip is to the southeast, figure 4 shows that the beds below the unconformity at Camp Conoy dip slightly to the north and that the beds above are nearly horizontal. This reversal of dip may well have formed the local basin.

Figure 3: T. M. Kelly pointing to Choptank-Calvert boundary in Calvert Cliffs, south of Kenwood Beach, Maryland. Note slight increase in shell content in Choptank from Calvert. Shelly bed at base is in "zone 14" of the Calvert.



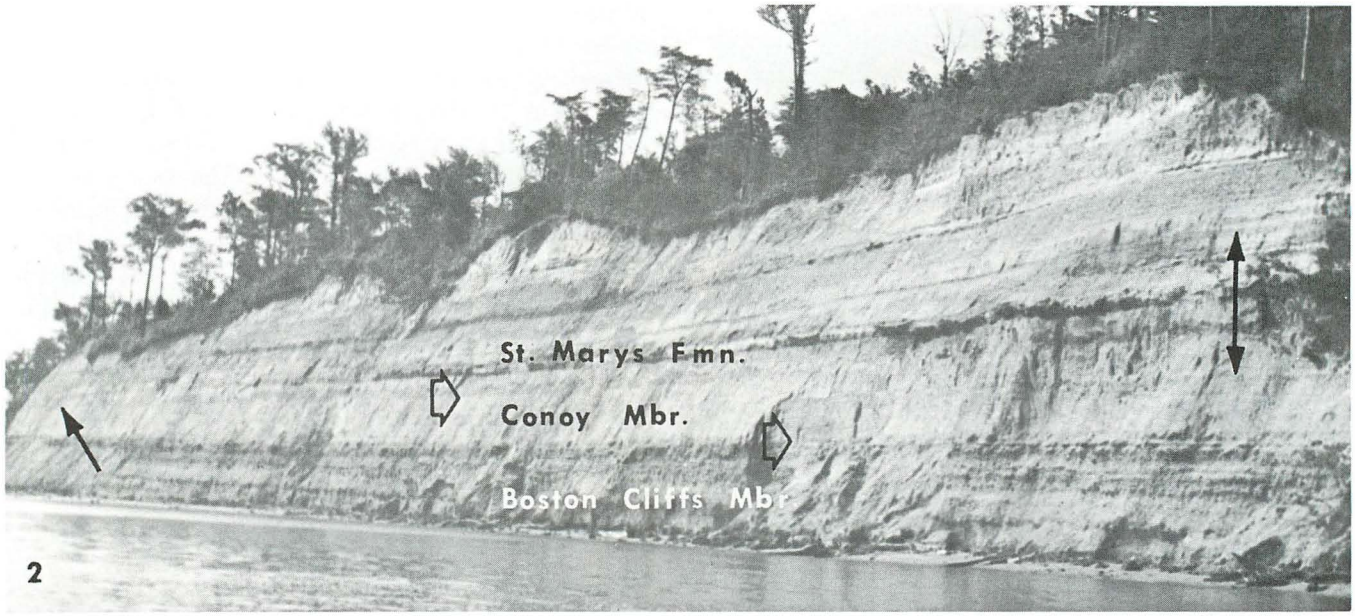


Figure 4: (Different perspectives of same cliff section.) Calvert Cliffs at Camp Conoy Y. M. C. A. Good view of unconformable relationships around Choptank-St. Marys boundary. Type area for Conoy Member. Double-headed arrow on right of lower photo shows thickness of St. Marys at north end of Conoy Cliff not present at south end of Conoy Cliff. Single-headed arrow at left marks Choptank-St. Marys unconformity.

Close examination of the formational contact at locality 67-71 (fig. 5) reveals this to be a surface of erosion. The upper Choptank member is abnormally thin, being only a little over 4 feet thick. Within 500 feet southeast this unit is 8 to 9 feet thick, as can be seen in figure 6. Figure 5 shows the broadly but deeply undulating formation boundary. It also shows the "basal sand" of the St. Marys filling lows in this undulating surface.

STRATIGRAPHIC NOMENCLATURE

Within the Chesapeake Group of Maryland, Shattuck (1904, pp. *lxix-lxxxvi*) recognized and delineated 24 sub-divisions or "zones". The Choptank consists of "zones 16" through "zone 20". Each "zone" was defined on the basis of lithologic characteristics and the relative quantity of fossil shells, not by the occurrence of particular species. As such, each "zone" is a rock stratigraphic unit (Krumbein & Sloss, 1963, p. 625).

The five subdivisions of the Choptank as recognized by Shattuck are redefined, named, and given type sections in the discussion below.

SUBDIVISIONS OF THE CHOPTANK FORMATION

Calvert Beach Member.—This member corresponds to "zone 16" of Shattuck and lies at the base of the Choptank (fig. 6). The type section, here designated, is the low bluff in the Calvert Cliffs at Calvert Beach, Maryland ((fig. 7,8) ; also see locality 67-65 in Appendix I for detailed description of the type section). The sediments vary from dusky green to dusky blue, rarely yellowish-brown to dark brown, very muddy to slightly muddy, fine sand to very fine sand. The nature of the lower contact is not clear (see previous discussion) but can be described as subtle (fig. 2,3). The location of the upper contact is difficult to fix because of its gradational character. Inasmuch as the overlying bed is defined in part as a major shell bed, the contact has been placed at the base of the first major influx of shells (fig. 2). Sedimentary structures included in this member are small scour and fill structures (fig. 3), burrows (fig. 7,8), sand stringers and lenses (fig. 2), localized low-angle planar cross laminations, and irregular bedding laminations. In general, macro-

fossils are scarce, but in a few localities they are somewhat more abundant. The fossils at Calvert Beach superbly show what appear to be life assemblages (fig. 7,8). Some of the more common macrofossils in the Calvert Beach Member are *Turritella plebeia, Lucinoma contracta, Diplodonta subvexa, Glossus fraternus marylandicus, Anomia aculeata, Yoldia laevis, Ensis ensiformis, Hiatella arctica, Ecphora quadricostata umbilicata, Dosinia acetabula,* and cheilostome bryozonans.

The Calvert Beach Member is present in the Calvert Cliffs from Parker Creek to the vicinity of Long Beach and varies from about 12 to 16 feet in thickness. The best reference localities are those at Calvert Beach, Kenwood Beach, and Governor Run. This interpretation contrasts with Shattuck's (1904, p. *lxxxi*) who believed zone 17 overlapped zone 16 at Parker Creek.

No exposures have ever been reported from the Eastern Shore. Localities 67-80, 67-81, and 67-82 on the Choptank River south of Greensboro might possibly contain the Calvert Beach Member. By stratigraphic sequence this interbedded lithology could be the Calvert Beach. However, since the sediments in these three Eastern Shore localities do not look at all like exposures on the Western Shore, they may well represent an entirely different depositional environment, *e.g.*, marginal marine. Shallow subsurface studies are needed on the Eastern Shore.

Several exposures are found on the Patuxent River, particularly on the western side, with the best one at Sandgates. Here "zone 14" of the Calvert and the Drumcliff Member of the Choptank are clearly discernible, but the intervening sequence seems nearly homogeneous. Micro- and

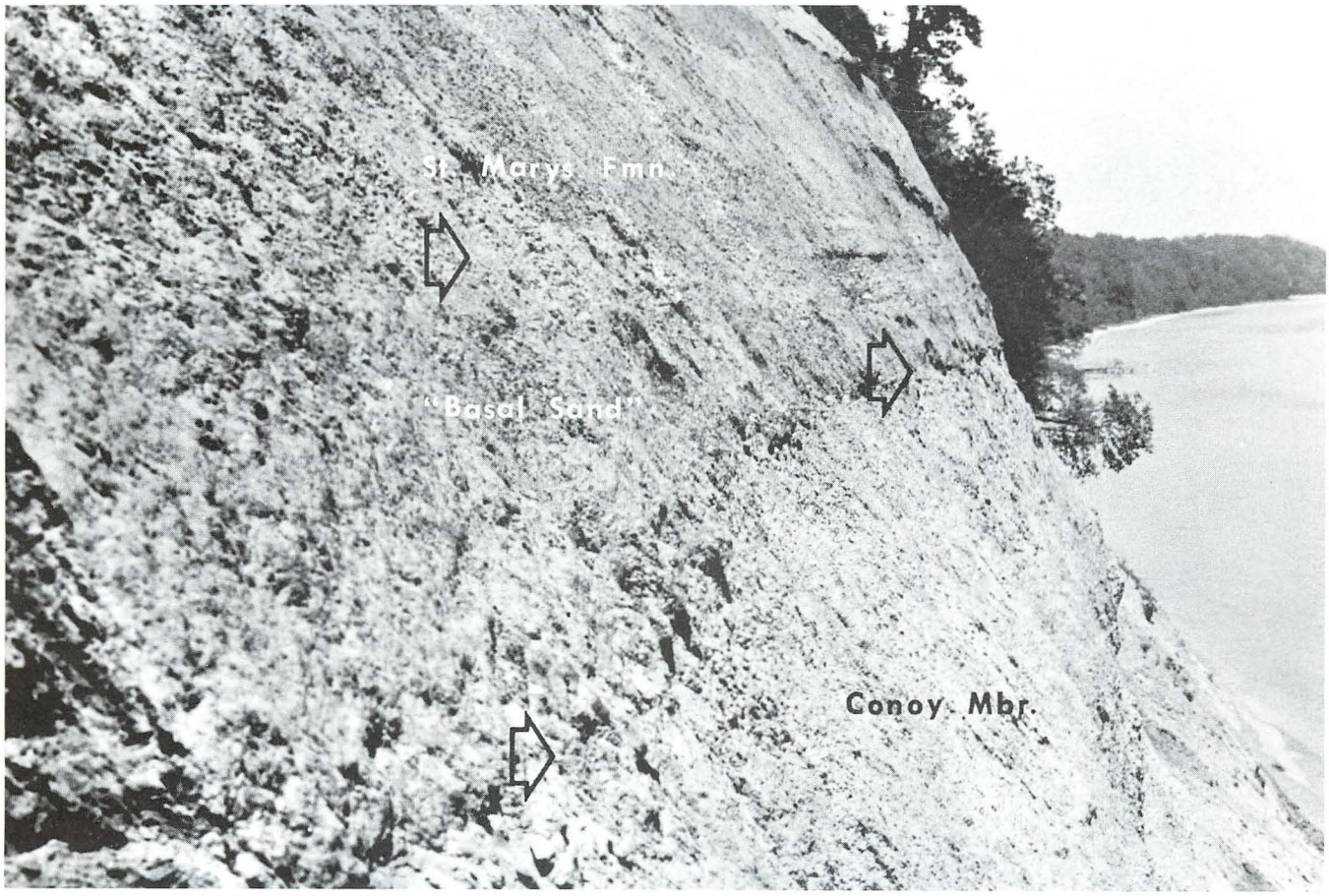


Figure 5: Close-up of top of Choptank and base of St. Marys as seen at locality 66-5. Conoy Member here is 53 inches thick. Undulating unconformity between Choptank and St. Marys. Immediately above that is a three-inch concretion bed. Main body of St. Marys "basal sand" varies in thickness along here from about one foot to two feet.

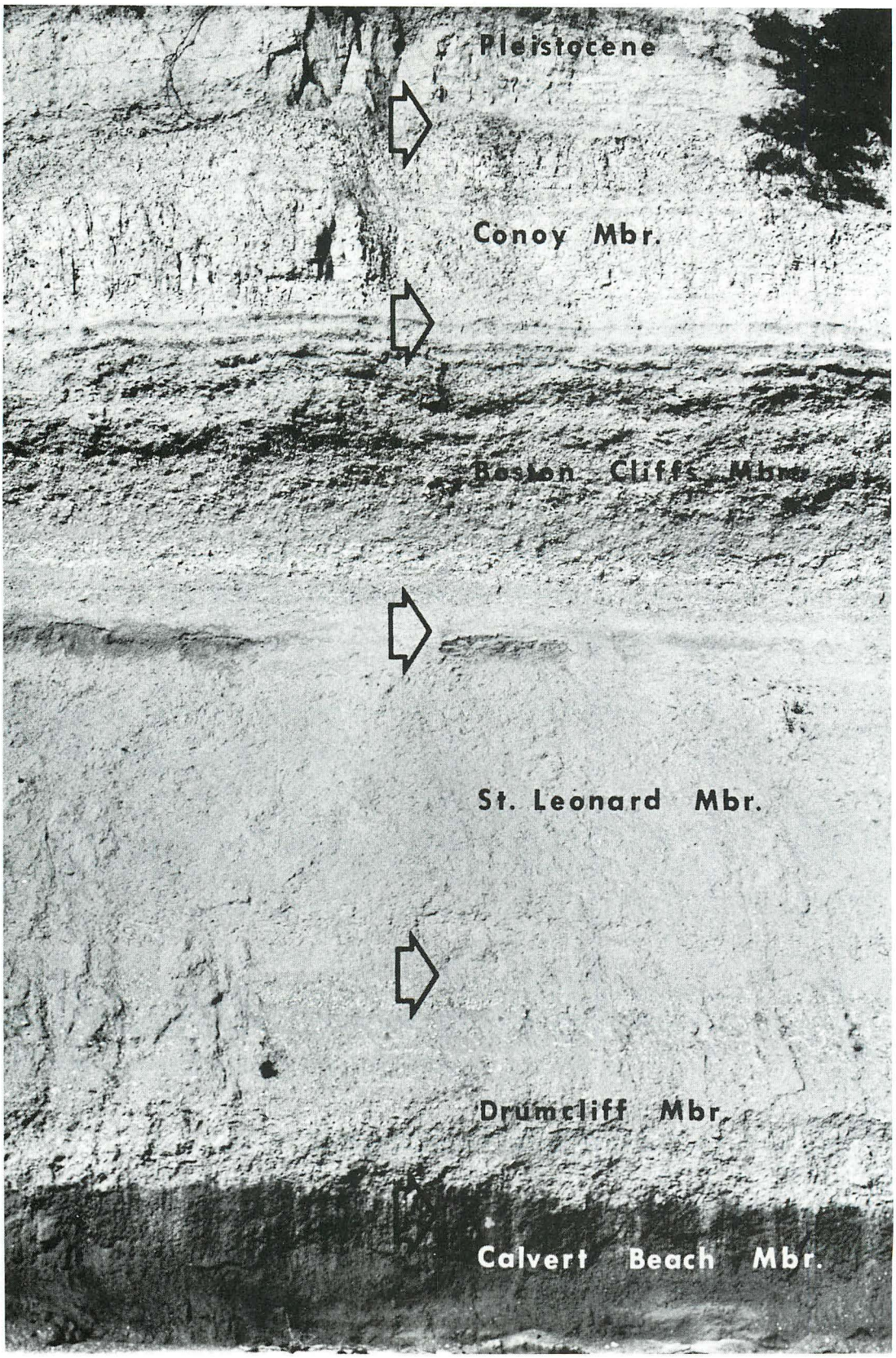


Figure 6: A nearly complete section of the Choptank Formation between localities 66-6 and 66-4, Calvert Cliffs, Calvert Co., Maryland. (Vicinity of principal reference section and type section of the St. Leonard Member.) Note basal sand of St. Leonard Member.

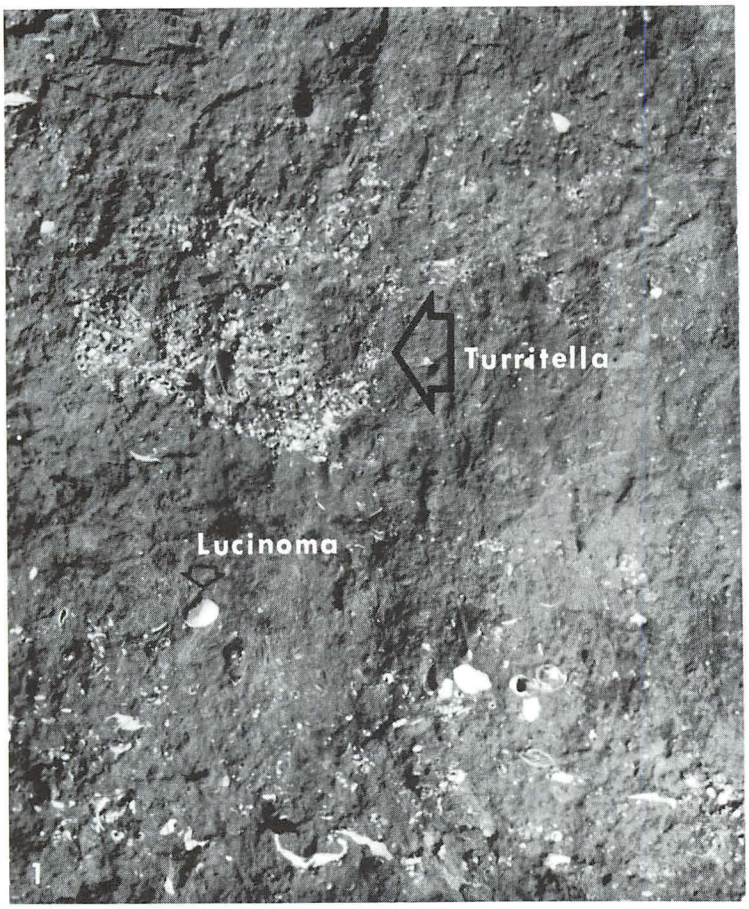


Figure 7: Type locality of the Calvert Beach Member, Calvert Beach, Maryland.
left: Large pocket of snails, *Turritella plebeia*. *Lucinoma contracta* in life orientation.
right: Burrowed central portion of member.

macrofaunas from the upper part of this interval along the Patuxent River are typical Choptank assemblages but it is extremely difficult to locate the lower boundary of the Calvert Beach Member at this point.

The upper part of the member is present in Pawpaw Hollow (locality 66-35) along Breton Bay. The Horsehead, Stratford, and Nomini Cliffs of Virginia all expose this unit, but in many places there is a problem of differentiating the three lowest members of the Choptank. Perhaps this interval should not be divided in the exposures south of the Potomac River.

Drumcliff Member.—This member corresponds to "zone 17" of Shattuck and is the lower shell bed of the Choptank (fig. 6). The type section is here designated at Drumcliff (called Jones Wharf in the 1904 Maryland Geological Survey Miocene Volume) along the southwestern shore of the Patuxent River (figs. 9-13; also see locality 66-14 in Appendix I for detailed description of the type section). The dominant sediment type varies from pale yellowish-brown to very pale orange, slightly muddy to very well sorted, fine sand. At the base, particularly in sections in St. Marys County, the sediment is usually dusky blue to dusky green, very fine sand to fine sand. The most distinct characteristic of this member is the prolific accumulation of shells, in some places so densely packed that there is scarcely any sediment. At some localities, certain beds are indurated (fig. 13). The induration of these layers appears to be post-depositional, created by the dissolving of calcitic shells and later precipitation of calcareous cement binding the fine sand grains. The lower contact is nearly always gradational and marked by the first major influx of shells (fig. 9). The upper contact is usually sharp and distinct, marked by the upper limit of abundant shells (fig. 12,13). At Drumcliff this contact appears to represent a channeled surface (fig. 12). Biogenic and inorganic sedimentary structures are extremely

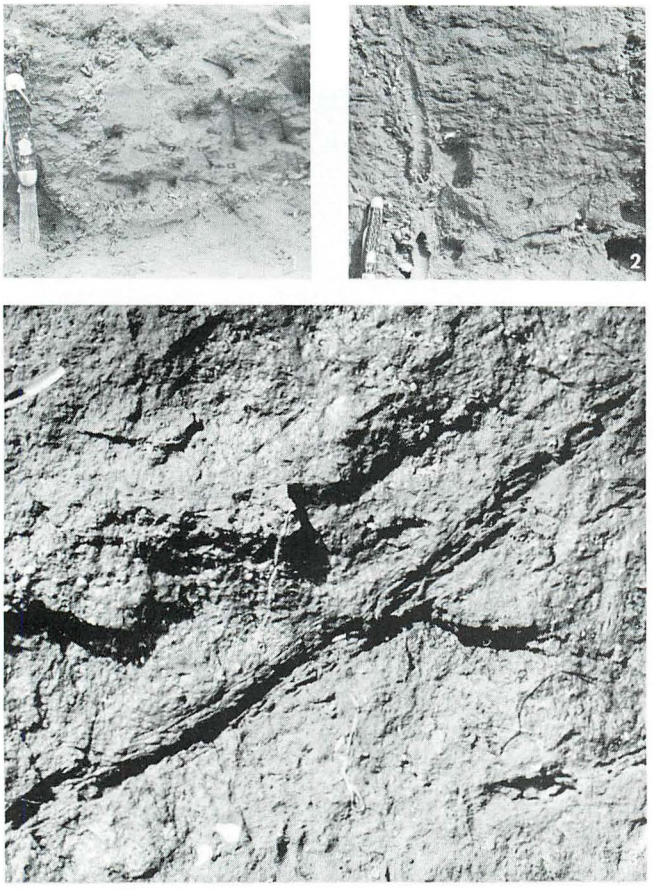


Figure 8: Burrows in Calvert Beach Member. upper left: Shell-lined burrow possibly of a marine worm. Locality 66-6, Calvert Cliffs, Calvert County, Maryland. upper right: Slime-lined burrow, some minor biogenically concentrated shell accumulations, and some blebs of finer textured sediment. Locality 66-6, Calvert Cliffs, Calvert County, Maryland. lower: *Ensis ensiformis* in upper left-hand corner and long, thin, diagonal, multi-walled burrow (of *Ensis*?). Locality 67-65, Calvert Cliffs at Calvert Beach, Maryland.

rare. In St. Marys and Calvert Counties the base of the member contains a prolific concentration of the epifaunal bivalve *Isognomon maxillata* (fig. 9), occasionally accompanied by abundant fragments of the ahermatypic coral *Astrhelia palmata*. This lower accumulation of *Isognomon maxillata* is abnormally thick at the mouth of St. Leonard Creek. At Mackall's Landing, locality 66-43, this bed is 14 feet 9 inches thick. The *Isognomon* units are conspicuously absent north of Calvert Beach in the Calvert Cliffs (fig. 2) and in the exposures in Virginia. Above the *Isognomon* units, abundant, densely packed large shells alternate with beds of less abundant, less densely packed smaller shells. In the figures these are labeled "increased" and "reduced" macrofossil beds, respectively (figs. 9-12). North of Calvert Beach in the Calvert Cliffs the upper part of the member contains beds with low faunal diversity and great lateral variability.

Macrofaunas of the Drumcliff Member generally have much greater faunal diversity, more numerous epifauna, and many more species of snails than the upper shell bed (Boston Cliffs Member) of the Choptank. Life assemblages of the epifaunal bivalve *Atrina harrisii* on the eastern side of Breton Bay (locality 66-36) deserve special mention. Species of the deep-burrowing bivalve genus *Panope* are nearly unique in that they are always found double-valved and in living position (fig. 12). Nearly all other bivalves are flat lying and the shells are usually disarticulated (figs. 11,12). Specimens of *Turritella plebeia,* the most abundant mollusc of the member, normally appear randomly distributed, but in some places they are clumped in lenses or pockets (fig. 14). Some of the more common macrofossils are:

Figure 9: Lower Drumcliff Member at its type locality. Lower half of figure shows dominant *Isognomon maxillata,* also the coral, *Astrhelia palmata,* and the scallop, *Placopecten marylandicus.* Note reduced macrofossil bed above that, followed by an increased macrofossil bed. Drumcliff along the Patuxent River, St. Marys County, Maryland.

gastropods—

Busycon coronatum rugosum
Calliostoma aphelia
Calliostoma philanthropa
Cancellaria alternata
Crepidula fornicata
Crepidula plana
Crucibulum costatum
Crucibulum multilineatum
Drillia limatula
Ecphora quadricostata umbilicata
Epitonium marylandicum
Epitonium sayanum
Fissuridea griscomi
Hastula inornata
Lunatia heros
Mangelia parva
Nassarius peraltoides
Pleurotoma (Hemipleurotoma) choptankensis
Polynices duplicatus
Rhizorus iotus marylandicus
Scaphella typa
Siphonalia devexa
Turricula rugata
Turritella plebeia
Turritella variabilis cumberlandia
Urolsalpinx cinerea

coral—
Astrhelia palmata

echinoderm—
Abertella aberti

brachiopod—
Discinisca lugubris

bivalves—

Aligena aequata
Anadara staminea
Anodontia anodonta
Anomia aculeata
Apolymetic biplicata
Astarte thisphila
Atrina harrisii
Callocardia subnasuta
Cardita protracta
Cerastoderma laqueata
Corbula cuneata
Corbula idonea
Corbula inaequalis
Crassatella turgidula
Diplodonta acclinis
Dosinea acetabula
Ensis ensiformis
Glossus fraternus marylandicus
Isognomon maxillata
Lucina crenulata
Lucinoma contracta
Lyropecten madisonius
Macrocallista marylandica
Martesia ovalis
Mercenaria campechiensis cuneata
Mercenaria mercenaria
Mytilus conradinus
Panope americana
Placopecten marylandica
Pleiorytis centenaria
Semele subovata
Spisula marylandica
Spisula subparilis
Venericardia granulata

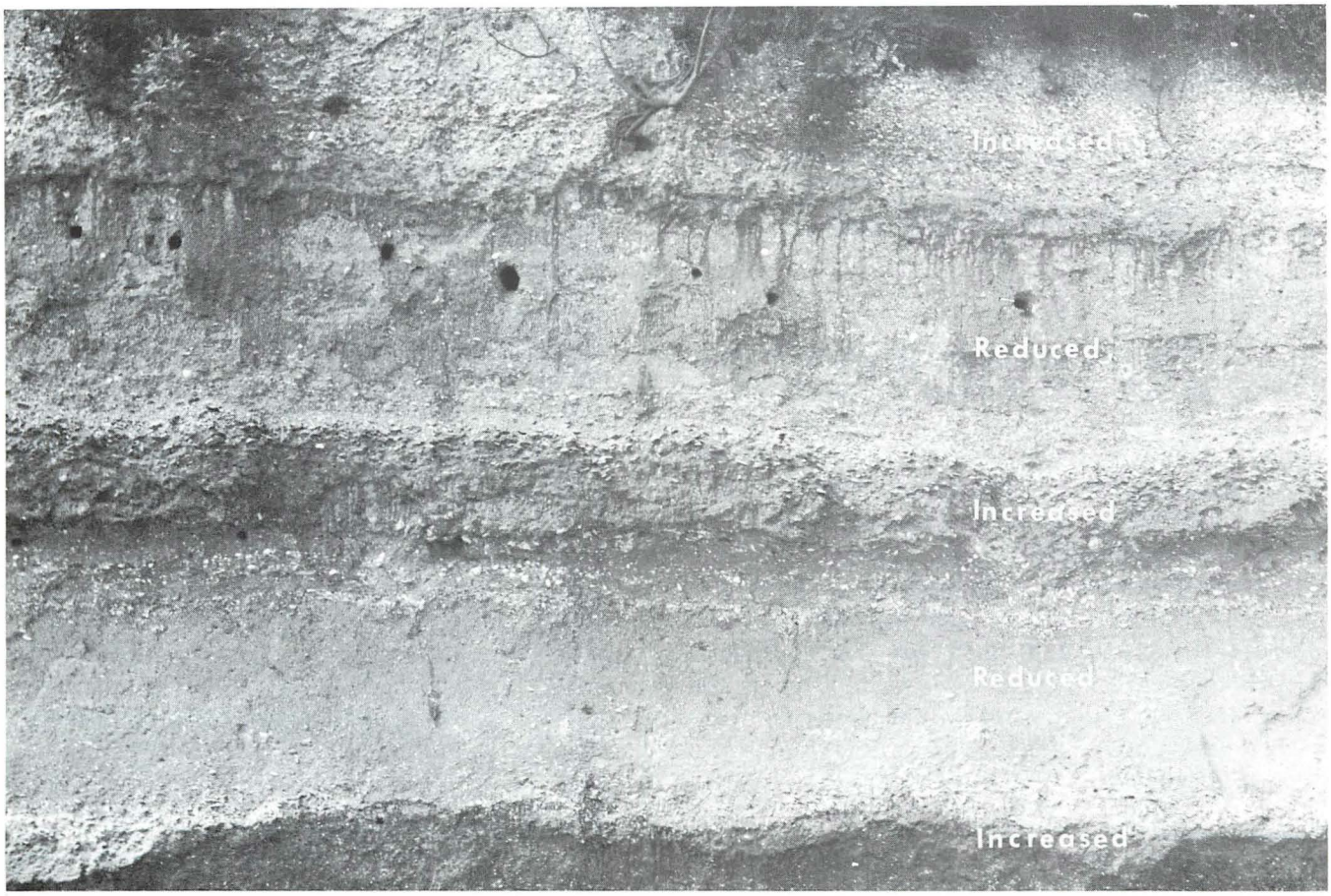


Figure 10: Type section of the Drumcliff Member. Note distinct reduced and increased macrofossil beds. Increased shell beds form a somewhat more resistant ledge than reduced shell beds.

Reduced shell beds have fairly well sorted sands while increased shell beds contain sediments somewhat poorly sorted. Drumcliff along Patuxent River, St. Marys County, Maryland.

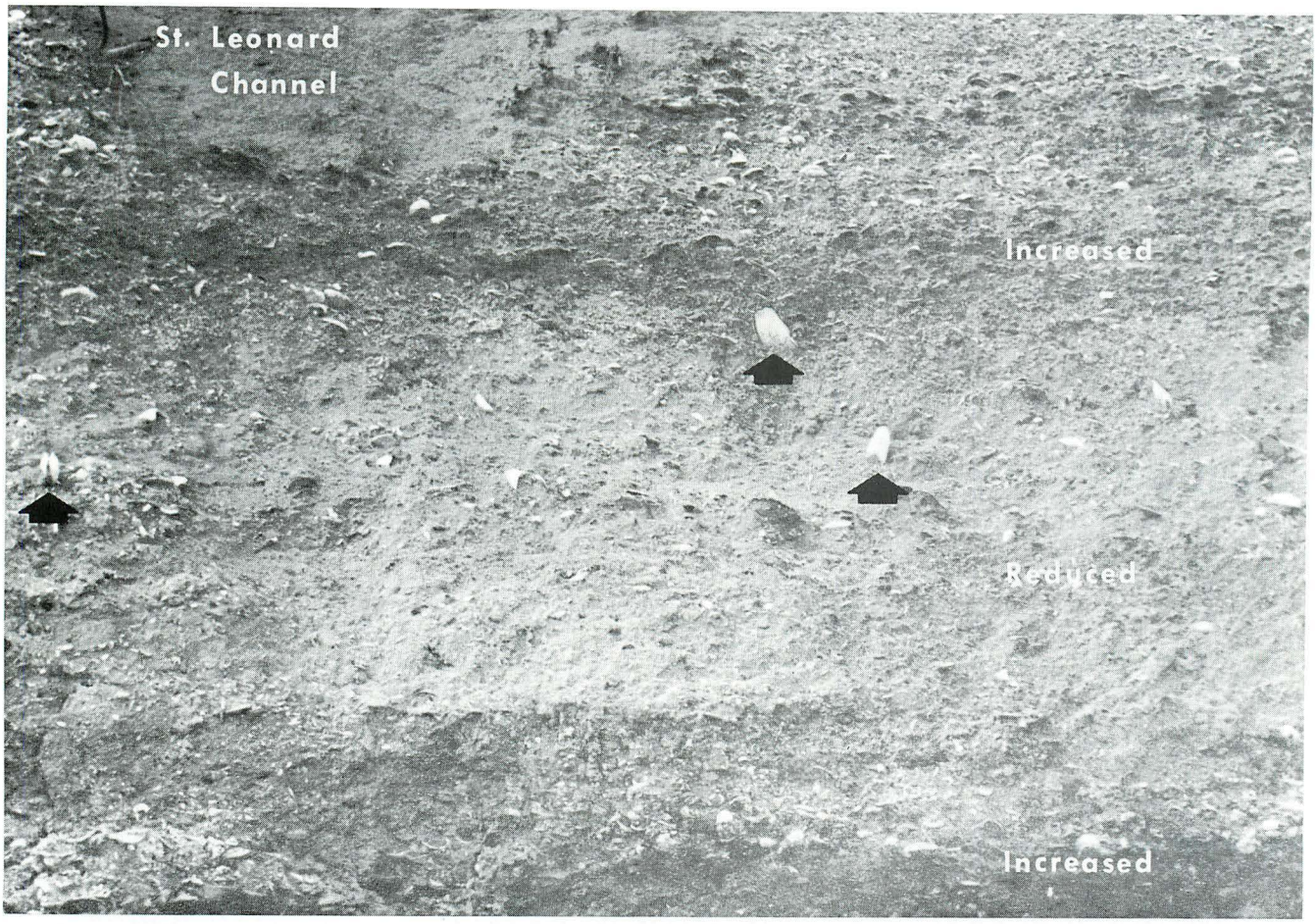


Figure 12: Upper Drumcliff Member. Note reduced and increased macrofossil beds and *Panope* (marked by arrows) with articulated valves and in living position. Note St. Leonard channel into Drumcliff Member. Drumcliff along the Patuxent River, St. Marys County, Maryland.

The thickest exposure of the Drumcliff Member is at Drumcliff where it measures about 30 feet. Outcrops can be found downstream along the Patuxent, where slight reversal of the regional dip has brought up the Calvert Beach-Drumcliff contact in low bluffs south of Captain Point. This reversal of dip can also be seen in exposures along creeks to the southwest of that area. Numerous outcrops contain the member in the Cuckold Creek—Hickory Landing Creek—Mill Creek—Mill Cove complex off the Patuxent River to the southwest. Many exposures occur along St. Leonard Creek with the thickest sections around the mouth. At Mackall's Landing, a particularly good

Figure 11: Section from top of lower increased macrofossil bed of Figure 10 to lower part of central increased macrofossil bed. Drumcliff Member at Drumcliff along Patuxent River, St. Marys County, Maryland.

section is nearly overgrown by poison ivy. One of the better exposures along the creek is at Breedens Point.

Along the Calvert Cliffs the member is much thinner, averaging 6 to 8 feet. It may be found from Parker Creek in the north to 0.3 mile north of Point of Rocks in the south. South of Long Beach the unit contains much more mud than to the north and is commonly locally indurated.

No proven exposures of the Drumcliff occur on the Eastern Shore, only an uncertain one. Shattuck (1904, pp. *xxxii-cxxxvii*) reported a Choptank outcrop at "Greensboro" containing an unmistakably Drumcliff molluscan assemblage. An extensive search was made in the vicinity of Greensboro but unfortunately the only finding (locality 67-82) was a 1½ foot bed containing molds and casts at the top of a section of 6½ feet of sediments which may be part of the Drumcliff. This is another problem on the Eastern Shore that might be solved by subsurface studies.

The only exposures southwest of Drumcliff in Maryland are those along Breton Bay. However, farther southwest the member is difficult to identify. In the Horsehead, Stratford, and Nomini Cliffs of Virginia some thin layers of shells look like Drumcliff assemblages and occur approximately in the same stratigraphic position. Even though these layers lack the characteristic concentration of shells, I believe they resulted from the episode that produced the densely packed macrofossil beds at Drumcliff.

St. Leonard Member.—This member corresponds to "zone 18" of Shattuck and is the bed between the two major shell beds of the Choptank (fig. 6). The type section is here designated as the exposure in the Calvert Cliffs 1¼ mile east of St. Leonard, Maryland and 0.3 mile north of Calvert Beach, Maryland (see locality 66-6 in Appendix I for detailed description of the type section). The sediments vary considerably. Along the Calvert

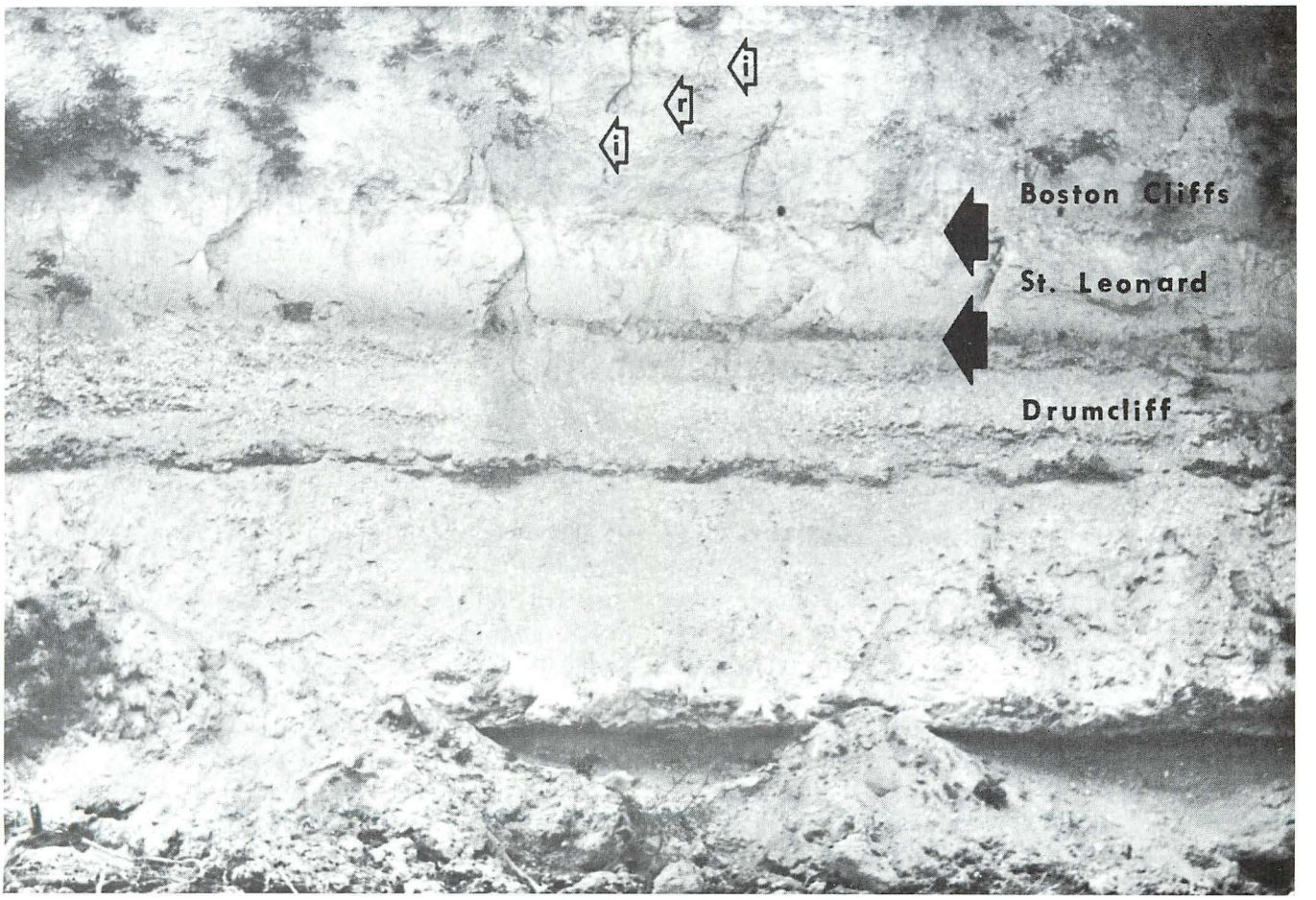


Figure 13: Section at locality 66-19, downstream end of Drumcliff along the Patuxent River, St. Marys County, Maryland. Note strongly indurated increased macrofossil beds forming prominent ledges. Note reduced and increased macrofossil beds in Boston Cliffs Member (arrow with "r" points out reduced macrofossil bed and arrows with "i" point out increased macrofossil beds).

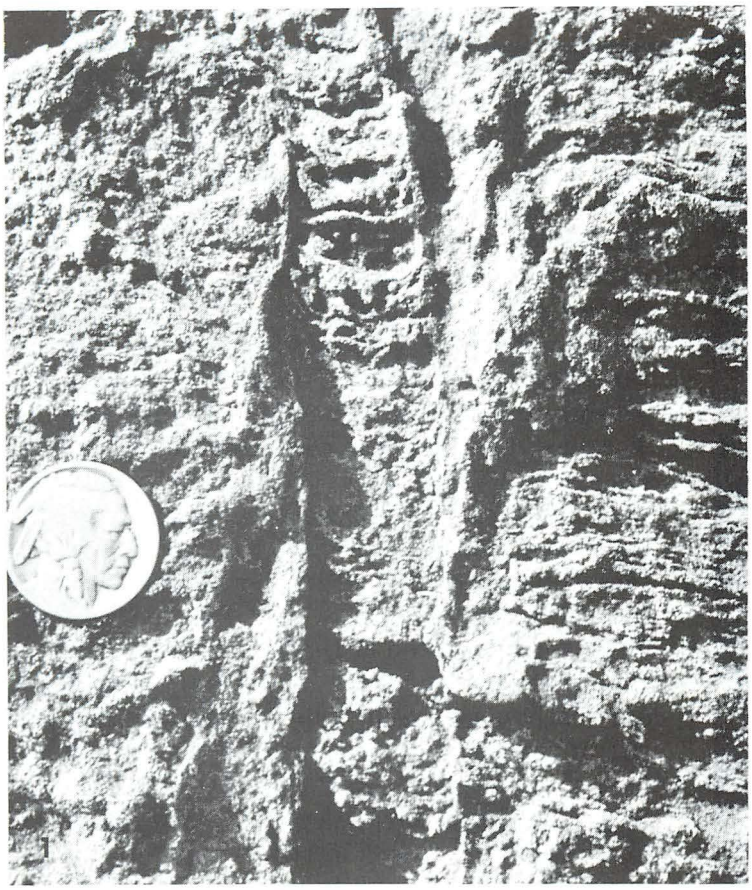
Figure 14: One of the common lensoid pockets of the high-spired snail *Turritella plebeia*. Drumcliff Member. Locality 66-34, Pawpaw Point on the eastern shore of Breton Bay, St. Marys County, Maryland.

Cliffs they are predominately dusky blue to dusky greenish-blue, muddy, fine sand to nearly silt. Exposures along the Patuxent appear oxidized and with heterogeneous sediments varying from light olive-green to pale yellowish-brown, muddy, fairly well sorted to poorly sorted, fine sand. The St. Leonard in Virginia varies from dusky olive to dark brown, slightly muddy to very muddy, fine sand to very fine sand.

Along the Calvert Cliffs and the Patuxent River there is typically a thin basal unit (fig. 6,13) of dark brown, poorly sorted fine to medium sand. Biogenic and inorganic sedimentary structures are fairly common. Biogenic activity is undoubtedly the cause of much of the sediment mottling. Figures 15 and 16 illustrate some of the many types of traces left by biogenic activity in the St. Leonard Member. Inorganic structures consist of irregular discontinuous bedding and some local bedding laminations which appear to be either wave ripple marks or distorted laminations (fig. 17, fig. 2). The lower contact is nearly always sharp and distinct, occurring at the base of a tremendous decrease in the quantity of shells and occasionally, as at Drumcliff, at the base of deep channeling (fig. 12). The upper contact is nearly always gradational and should be placed at the base of the first major influx of shells.

Macrofaunas of the St. Leonard Member are generally sparse. Some of the more common fossils are: *Yoldia laevis, Ensis ensiformis, Discinisca lugubris, Mytilus conradinus, Cerastoderma laqueata, Balanus concavus, Anadara staminea,* and *Crucibulum multilineatum*. The St. Leonard can be found in the Calvert Cliffs from Parker Creek to between Point of Rocks and Camp Baybreeze (Girl Scout camp). The most extensive exposures lie north of Calvert Beach where the thickness varies from about 18 to 22 feet. From Flag Ponds to its southern extent the member averages about 12 feet. The last downdip exposure of the entire member along the Calvert Cliffs is a short distance north of Point of Rocks, where it measures 11 feet 11 inches.

The Eastern Shore has no certain exposures of the St. Leonard Member, but an outcrop (locality



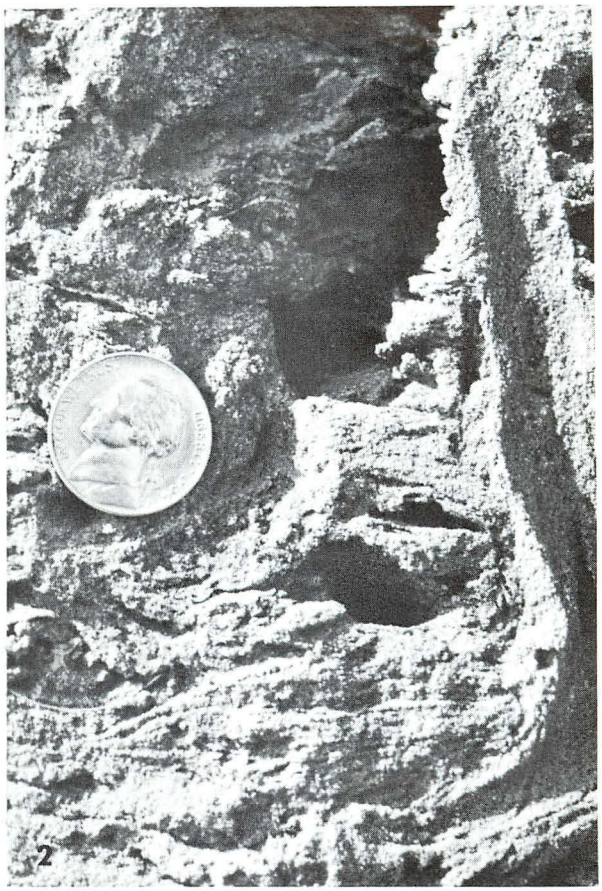


Figure 15: Biogenic sedimentary structures in St. Leonard Member between Flag Ponds and Camp Conoy, Calvert County, Maryland. left: Bivalve burrow and wavy laminations. right: Polychaete? tube and wavy laminations.

67-83) along the Choptank River near Lyford Landing may contain part of the unit. The sediments are nearly identical to those of the member in the Calvert Cliffs, and the only fossil found is *Yoldia laevis* which is found frequently in the St. Leonard but certainly not confined to it. The Boston Cliffs Member is exposed downstream from Lyford Landing, while a probable outcrop of the Drumcliff occurs upstream. The preceding evidence, although not conclusive, does suggest that the St. Leonard Member is exposed at Lyford Landing.

Figure 16: Biogenic sedimentary structures in St. Leonard Member between Camp Conoy and 67-51, Calvert Cliffs, Calvert County, Maryland. left: Prominent bivalve multi-walled, slime-lined burrow and biogenically disturbed sedimentary laminations. upper right: "*Xenohelix*" burrow of unknown origin and wavy laminations. lower right: Slime-lined, multi-walled burrow with nodose exterior.

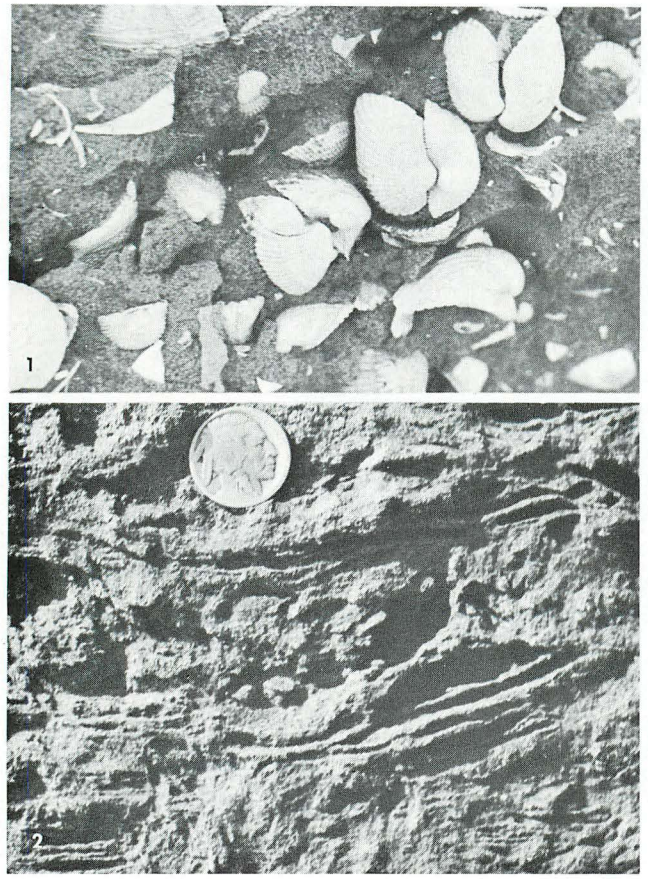


Figure 17: top: Close-up of double *Anadara staminea* at locality 67-52. Note maximum ligamental opening. bottom: Scour and fill sedimentary structures. St. Leonard Member. Between Flag Ponds and Camp Conoy, Calvert Cliffs, Calvert County, Maryland.

Southwest of the Calvert Cliffs the St. Leonard thins considerably and becomes a light brown sand. At Breedens Point on St. Leonard Creek, about 3 miles from the Calvert Cliffs, the thickness is only 4 feet. At the mouth of the St. Leonard Creek (locality 66-43) the unit measures 5 feet.

Incomplete sections are exposed along Hellen Creek off the Patuxent (locality 66-46 and locality 67-68). Near Drumcliff the St. Leonard varies from 6 to 8 feet (fig. 13). In the Cuckold Creek vicinity it is 6 feet 6 inches and 5 feet 2 inches at locality 66-29 and locality 66-41, respectively. Variable thicknesses from 5 feet to 13 feet can be found on the Virginia side of the Potomac River. The base of the member is difficult to locate in the Nomini Cliffs, as a result of the slightly atypical expression of the Drumcliff Member (see Drumcliff discussion).

Boston Cliffs Member.—This member corresponds to "zone 19" of Shattuck and is the upper shell bed of the Choptank (fig. 6). The type section is here designated at Boston Cliffs on the Choptank River, 4 miles southeast of Easton, Maryland and 1.8 miles south of Dover Bridge (figs. 18,19; also see locality 66-12 in Appendix I). The dominant sediment type varies from reddish-brown to moderate brown, muddy to slightly muddy, fine sand. The top of the member is very distinctively marked by a resistant, oxidized, indurated series of varicolored units. In some places (*e.g.*, between Flag Ponds and Cove Point) exceedingly hard slabs of this upper series are piled up in front of the cliffs serving as effective deterrents of wave erosion. The most distinguishing characteristic of the Boston Cliffs Member as a whole is its prolific accumulation of shells. The lower contact is gradational and usually somewhat arbitrary. The upper contact is sharp and distinct with the oxidized, indurated sequence below and the nonresistant, dusky blue, fine sand of the Conoy Member above. Biogenic and inorganic sedimentary structures are nearly nonexistent. Typically, the number and size of fragments increase gradationally from the base of the member to a lower bed of abundant, large, flat-lying bivalves (figs. 13,18,19,21,17). Commonly this lower increased macrofossil bed has distinct smaller units with low faunal diversity. For example, near the top of this unit a thin bed of valves of *Anadara staminea* is amazingly continuous and can be traced for miles (figs. 17, 20, 21). Next in succession is a reduced macrofossil bed, followed by another increased macrofossil bed, which are characterized by reduced size and number of shells and increased size and number of shells, respectively (figs. 18-21). The more common fossils of all the above-described beds are: bivalves—*Macrocallista marylandica, Lyropecten madisonius, Anadara staminea, Dosinia acetabula, Cerastoderma laqueata, Corbula idonea, Astarte obruta, Crassatella marylandica, Mercenaria* spp., *Anodontia anodonta, Corbula inaequalis,* and the gastropod—*Ecphora quadricostata umbilicata.* Typically, another sequence of reduced and increased macrofossil beds follows, but the faunal composition is somewhat different and usually shell fragments are much more abundant (figs. 17, 21). Normally, the fauna is strongly dominated by oysters and scallops, with barnacles of somewhat lesser significance. Locally, however, cockles may be dominant. The more common fossils in this sequence, then, are: *Crassostrea carolinensis. Lyropecten madisonius, Cerastoderma laqueata,* and *Balanus concavus.* In some outcrops this oyster-scallop-barnacle assemblage is significant in other portions of, and in some exposures throughout the Boston Cliffs Member. Faunal ac-

Figure 18: Type section of Choptank Formation and Boston Cliffs Member. Writer's hands mark bottom and top of reduced macrofossil bed. Locality 66-12, Boston Cliffs along Choptank River, Talbot County, Maryland.

cumulations above the last described sequence are somewhat obscured by intense oxidation and induration. Where the relationships were relatively clear, the alternation of increased and reduced macrofossil beds continued.

Macrofaunal assemblages of the Boston Cliffs Member generally have a lower faunal diversity, fewer epifaunal individuals, and considerably fewer snails than the Drumcliff Member. An exceptionally well-preserved assemblage of bivalves occurs in the lower increased macrofossil bed of the southern Calvert Cliffs, particularly between Flag Ponds and Camp Conoy. Some of these bivalves still retain remnants of the hinge ligament, and some still show shell coloration, which is uniformly dark yellowish-brown. In the same area, between Flag Ponds and Camp Conoy, individual shells of *Anondontia anondonta* are much stouter than elsewhere in the Choptank. Unusually large specimens of *Lyropecten madisonius* occur from Point of Rocks to Cove Point. At Boston Cliffs infaunal bivalves are unusually large.

The best of the Eastern Shore exposures is at Boston Cliffs. Outcrops and fossils at Peach Blossom Creek and Trappe Landing were reported by Shattuck (1904, pp. *xxxiii-cxxxvii*) but were not found during this investigation. A previously unreported section was located on the south bank of Island Creek (locality 66-13). On the Eastern Shore and along the Calvert Cliffs, where the Boston Cliffs is exposed from Parker Creek to a little north of Cove Point, the thickness averages 14 to 15 feet. A very thin, inland exposure can be found at locality 67-58, near Paris, Maryland. Locality 66-46, Hellen Creek, is very similar to sections to the northeast, except for some large crab burrows partially obscuring relationships. Exposures at the mouth of St. Leonard Creek and on the southwestern side of the Patuxent are only 9 to 11 feet thick, and the oyster-scallop-barnacle assemblage dominates the fauna throughout. The member at the western end of Nomini Cliffs (locality 67-72) is very much like the section along Chesapeake Bay. To the east the section thins to

3 feet (locality 67-70), and to the west at Horsehead Cliffs (locality 67-73) a rather uncharacteristic section measures 5 feet 2 inches.

Conoy Member.—This corresponds to "zone 20" of Shattuck and is the upper member of the Choptank (fig. 6). The type section is here designated as the first major cliffs northwest of Camp Conoy (Y.M.C.A.) along the Chesapeake Bay (see locality 66-25 in Appendix I; also figs. 4, 22, 23). Although somewhat unorthodox to name a rock-stratigraphic unit after a Y.M.C.A. Camp, there is a general scarcity of named geographic features in the vicinity. Since the United States Geological Survey 7.5 minute topographic map officially includes "Camp Conoy", it seems perfectly within the limits of the Code of Stratigraphic Nomenclature. The Calvert Cliffs at Flag Ponds would serve better for a type section, but unfortunately there already is a "Flag Pond Granite Group" in North Carolina and Tennessee. An excellent reference area for this member is the section of the Calvert Cliffs from Camp Conoy to Flag Ponds (localities 66-21, 66-44, 67-50, 66-25, and 66-15). The dominant sediment type is dusky grayish-green to dusky greenish-blue to dusky blue, very muddy, very fine sand to silt. Thickly-spaced, continuous, parallel, thin, bedding laminations are common (fig. 22). The lower contact of the Conoy is sharp and distinct with the oxidized, indurated sequence of the Boston Cliffs below. The unconformable relationship with the overlying St. Marys Formation has been discussed above.

The general sparsity of macrofauna is interrupted in a few outcrops by a thin, concentrated accumulation of *Turritella plebeia* (fig. 24). The more common fossils of the Conoy are: the gastropod—*Turritella plebeia* and bivalves—*Cerastoderma laqueata, Yoldia laevis, Mytilus conradinus, Atrina harrisii, Lyropecten madisonius, Balanus concavus,* and *Dosinia acetabula.*

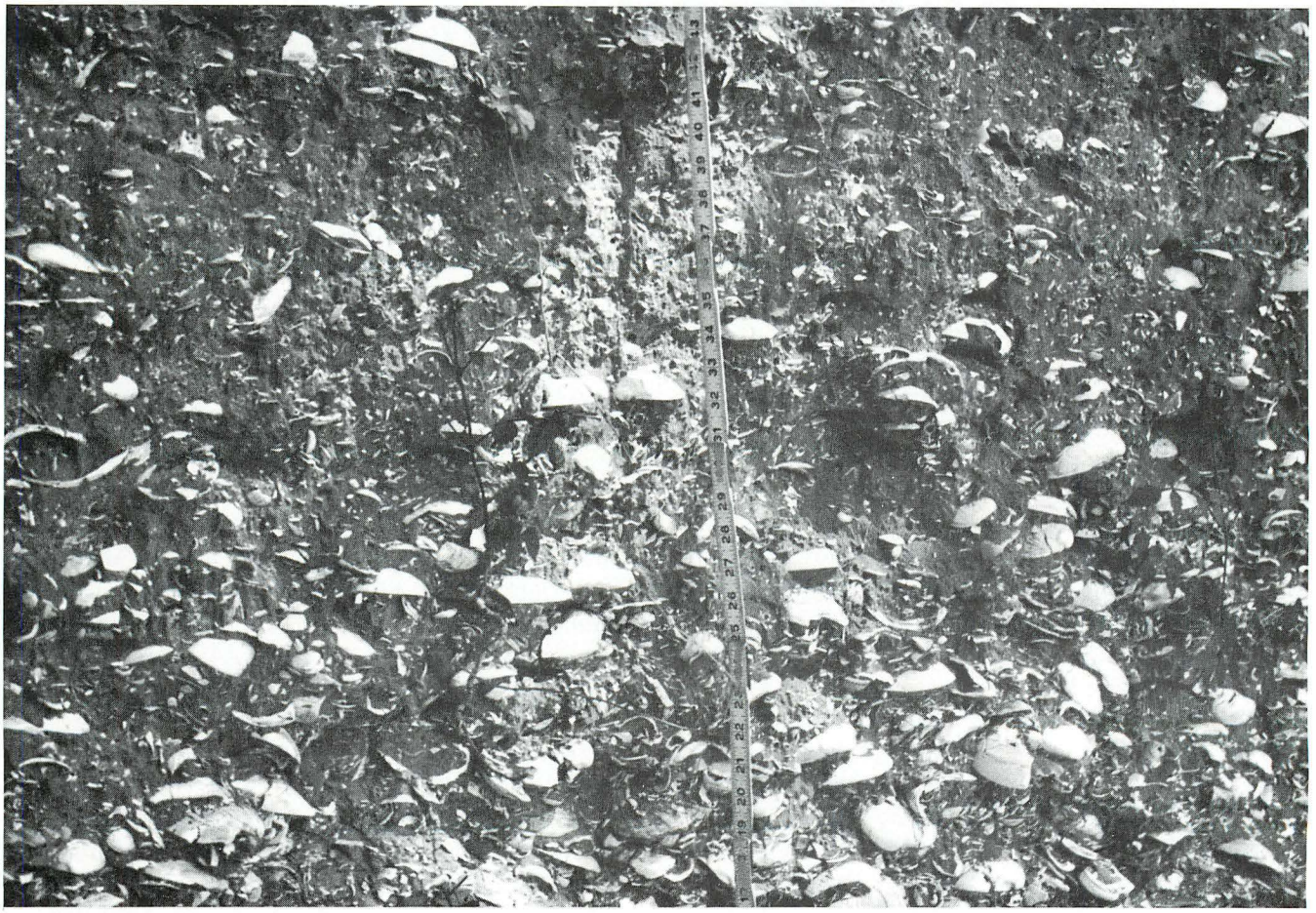


Figure 19: Lower increased and reduced macrofossil beds. Second plate of three showing vertical sequence at type section of Boston Cliffs Member and Choptank Formation. Locality 66-12, Boston Cliffs along Choptank River, Talbot County, Maryland.

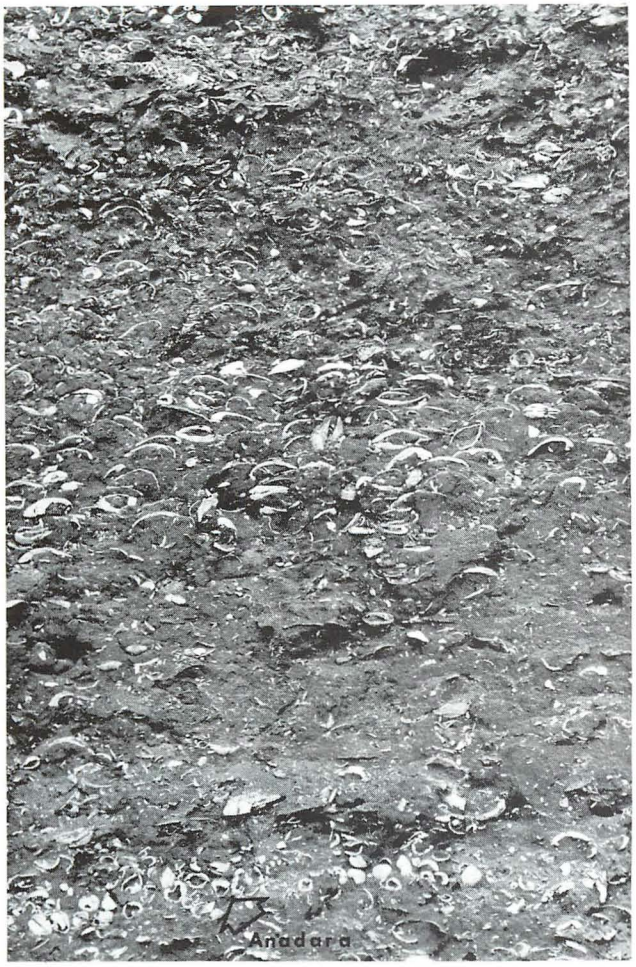


Figure 20: Boston Cliffs Member from upper portion of lower increased macrofossil bed to about the base of the sequence of indurated beds. Note thin band of *Anadara staminea* in top of lower increased macrofossil bed. Note predominant flat-lying, convex-upward orientation of bivalves. Note partially reduced macrofossils above lower part of upper increased macrofossil bed. About one half mile south of Camp Conoy, Calvert Cliffs, Calvert County, Maryland.

A few partial exposures of the Conoy Member occur along the shores of the Choptank River in the vicinity of Cambridge. This unit is in the Calvert Cliffs from Parker Creek to Cove Point. Along the Patuxent River the only outcrops are in the vicinity of Hellen and Hungerford Creeks. No exposures are known in St. Marys County, but in Westmoreland County, Virginia the member is present all along the Horsehead, Stratford, and Nomini Cliffs. The thickness of the Conoy seems fairly constant throughout the outcrop belt, varying from over 9 feet to 15 feet.

In general, the five members of the Choptank are quite persistent and constant in thickness. Unfortunately, nothing is known of them in the subsurface. Depositional environments and the geologic setting will be much better understood when information is produced on subsurface facies.

As mentioned at the beginning of the section on stratigraphy, Shattuck designated the Choptank River exposures below the Dover Bridge as the type locality. This was unfortunate since the type locality included only one of the five members, the Boston Cliffs Member. Under article 13 of the Code of Stratigraphic Nomenclature (Krumbein & Sloss, 1963, p. 629) provision has been made for supplementing a type section with reference sections. In an effort to correct problems raised by the type section, the Calvert Cliffs from Calvert Beach to Governor Run, Maryland is here designated as the reference area for the Choptank Formation. Locality 66-5, 0.9 mile southeast of Western Shores, Maryland and 1.0 mile northwest of Calvert Beach, Maryland in the Calvert Cliffs, is here designated as the principal reference section (see locality 66-5 in Appendix I for a detailed description of the principal reference section).

THE PROBLEM OF THE "NORTH KEYS SAND"

The name "North Keys Sand" was proposed by Hack (1955, p. 8) for "a bed of fine yellowish-orange sand which rests conformably on the top clay bed of the Calvert formation, and in the Brandywine (Maryland) area, underlies the gravel of the Brandywine formation (Pliocene?)." He added:

> "The sand is at least in part Miocene in age, and in this area is equivalent to zone 19 in the Choptank . . . The North Keys Sand is traceable on the basis of lithology over a wide area in southern Maryland and may not be equivalent everywhere to zone 19. The writer believes that it may overlap the younger Miocene formations becoming younger to the south where it is equivalent to higher zones. For this reason, a new name defined on the basis of stratigraphic position and lithology is proposed even though in the Brandywine area fossil evidence nearby appears to identify the North Keys Sand with the Choptank."

In view of the available stratigraphic evidence, Hack (1955, p. 10) considered two interpretations as possible: "Either the North Keys Sand represents an overlap of sandy beds of the Choptank on the eroded Calvert formation, or the North Keys Sand becomes younger to the south and overlaps the Choptank as well as the Calvert." His paper makes it quite clear that of the two he favored the regressive-overlap interpretation.

I disagree. The evidence presented in Hack's own paper makes a regressive-overlap relationship stratigraphically and geometrically impossible. In his text and in the diagrammatic columnar sec-

tions (1955, p. 7, fig. 4), Hack stressed that the North Keys Sand is equivalent to the Choptank in age because "zone 19" (=Boston Cliffs Member) is superjacent in an exposure near Paris (1955, p. 9). I examined the same key outcrops (locality 67-58) and agreed that the prolific shell bed near the top of the section is unmistakably Boston Cliffs. The conflict within Hack's reasoning arises from his claim that at Paris the North Keys Sand occurs stratigraphically below the Boston Cliffs, but downdip their relative positions are reversed with the North Keys above the Boston Cliffs. Somewhere between Paris and the Calvert Cliffs these two sedimentary facies must intersect and cross according to his hypothesis. Even though Hack could find no fossils in the North Keys itself, he did try to understand something of its origin through size analysis of the sediment. Cumulative frequency curves "indicate that the North Keys Sand probably is a marine sand deposited in shallow water, on the shore, or as dunes behind the beach. Possibly it was deposited in all three environments and those parts of the formation which are free of clay or silt, and are devoid of fossils may represent a shore or shore-dune facies" (1955, p. 9). My sample, 67-58-1, from 4 feet 9 inches to 5 feet 9 inches below the "North Keys"—Boston Cliffs contact contained an assemblage of Ostracoda and Foraminifera that are very typical of the shallow, open marine Choptank. As mentioned in the discussion on the Choptank-Calvert contact, this fauna is indicative of only the Choptank, in light of our present knowledge. The stratigraphic probability of a shallow, open marine "North Keys Sand" overlapping the Choptank, St. Marys, and Yorktown Formations, all predominately shallow marine in their outcrops, is highly unlikely. Even more unlikely would be the intersection and reversal of the Boston Cliffs and "North Keys", both shallow, open- marine deposits in the outcrop area.

In comparing this problem unit with other Miocene deposits Hack said (1955, p. 10) "The North Keys sand is lithologically unlike the Choptank

Figure 21: Boston Cliffs Member about half of a mile south of Camp Conoy Y. M. C. A., Calvert Cliffs, Calvert County, Maryland. Note large scale cross stratification in shells (predominantly *Anadara staminea*) in lower increased macrofossil bed.

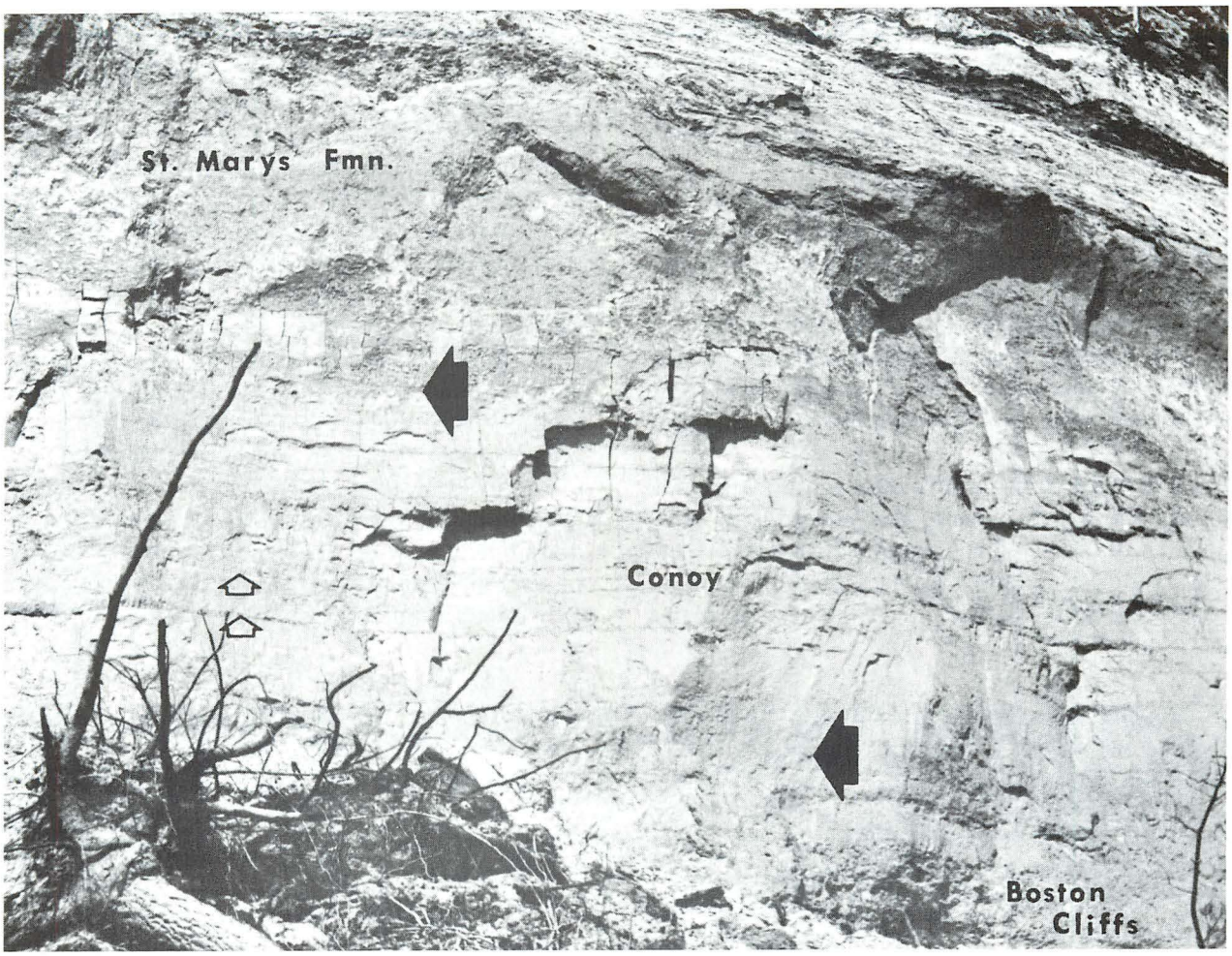


Figure 22: Upper Boston Cliffs Member, Conoy Member, and lower St. Marys Formation. Note parallel laminations (marked by small arrows) and thick bedding in Conoy Member. Note blocky fracturing and steep face of outcrop expression of Conoy Member. Formation boundary bored from above. Locality 66-44, between Flag Ponds and Camp Conoy, Calvert Cliffs, Calvert County, Maryland.

formation as it is exposed in the Calvert Cliffs . . ." I agree for the most part with that statement. Since the "North Keys" grades into the Boston Cliffs at the Paris section, the counterpart in the Calvert Cliffs would be the St. Leonard Member which grades into the Boston Cliffs Member there. Admittedly the St. Leonard is typically dusky blue, muddy, fine sand where the "North Keys" is yellowish-orange, oxidized, muddy, fine sand. On the other hand, the only real difference is in the color—one is oxidized, and the other is not. In fact, some exposures of the St. Leonard along the Calvert Cliffs northwest of Point of Rocks are oxidized and appear very similar to the socalled "North Keys sand". The best correlation of the Paris section, however, is with the Choptank along the Patuxent River. Outcrops at Drumcliff, the mouth of St. Leonard Creek, and in the Cockold Creek—Hickory Landing Creek—Mill Creek—Mill Cove complex expose a St. Leonard—Boston Cliffs sequence similar to the "North Keys"—Boston Cliffs sequence at Paris. It is my contention that the "North Keys sand" of Hack is in certain places nothing more than oxidized Choptank Formation.

PALEOAUTECOLOGY

Analysis of Miocene paleoautecology has certain distinct advantages over Mesozoic, Paleozoic, or Precambrian biotic investigations. With older fossils the study must necessarily be much more empirical. For the most part, my approach utilizes direct extrapolation of ecological information from the present to the past.

The first statements concerning the paleoecol-

ogy of the Choptank foraminifers were made by Malkin (1953, pp. 773-775) and were actually made about the Chesapeake Group as a whole. Because her paper primarily concerned Ostracoda, her treatment of the foraminifers was extremely sketchy.

The really important study on the foraminiferal paleoecology was that of Gibson (1962). Basically, he extrapolated directly the known ecology of the extant species to the Miocene. In addition, he relied upon these factors in planktonic Foraminifera. This method was greatly facilitated by the fact that 68 percent of the Choptank benthonic foraminifers were considered to belong to extant species.

One weakness of the approach used by Gibson is that only the extant species are considered while the extinct ones are disregarded. The extreme possibility could arise that the neglected part of an assemblage might contain several key organisms which would indicate a depositional environment other than that indicated by the extant species. This problem is somewhat amplified by the fact that Gibson's approach largely was to contrast the number of key living species representing different environments. Then applied to fossil occurrences, the paleoenvironment was considered to be whatever the majority of species indicated. With this system it requires only a very few species indicating one environment or the other to completely change the outcome.

It should be made clear that this criticism is really aimed at the approach and not Gibson's study. Within his study the foraminifers were between 60 to 80 percent extant, so the probability of accuracy was in his favor.

Gibson was pessimistic about including generic distributions as a basis for interpretation of paleoenvironments and said (1962, p. 52), "Using only genera and not species may give either an

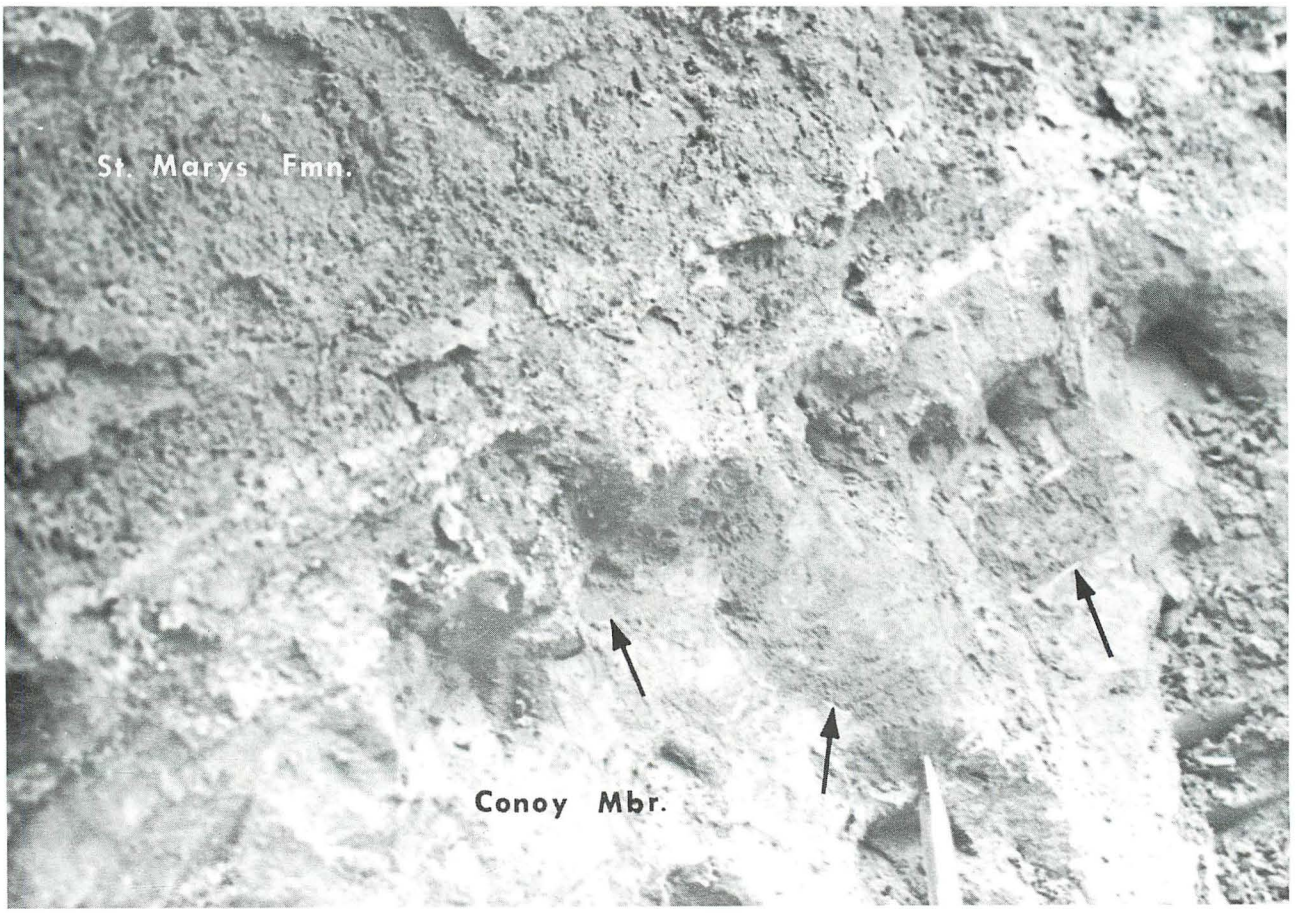


Figure 23: (See Plate 1 for location.) Choptank-St. Marys unconformity. Note borings (unretouched photo) down into Conoy and filled with sediment from the St. Marys. Note stringy, discontinuous, very well sorted "basal sand" of St. Marys. Arrows point out some borings. Mechanical pencil in lower right provides scale.

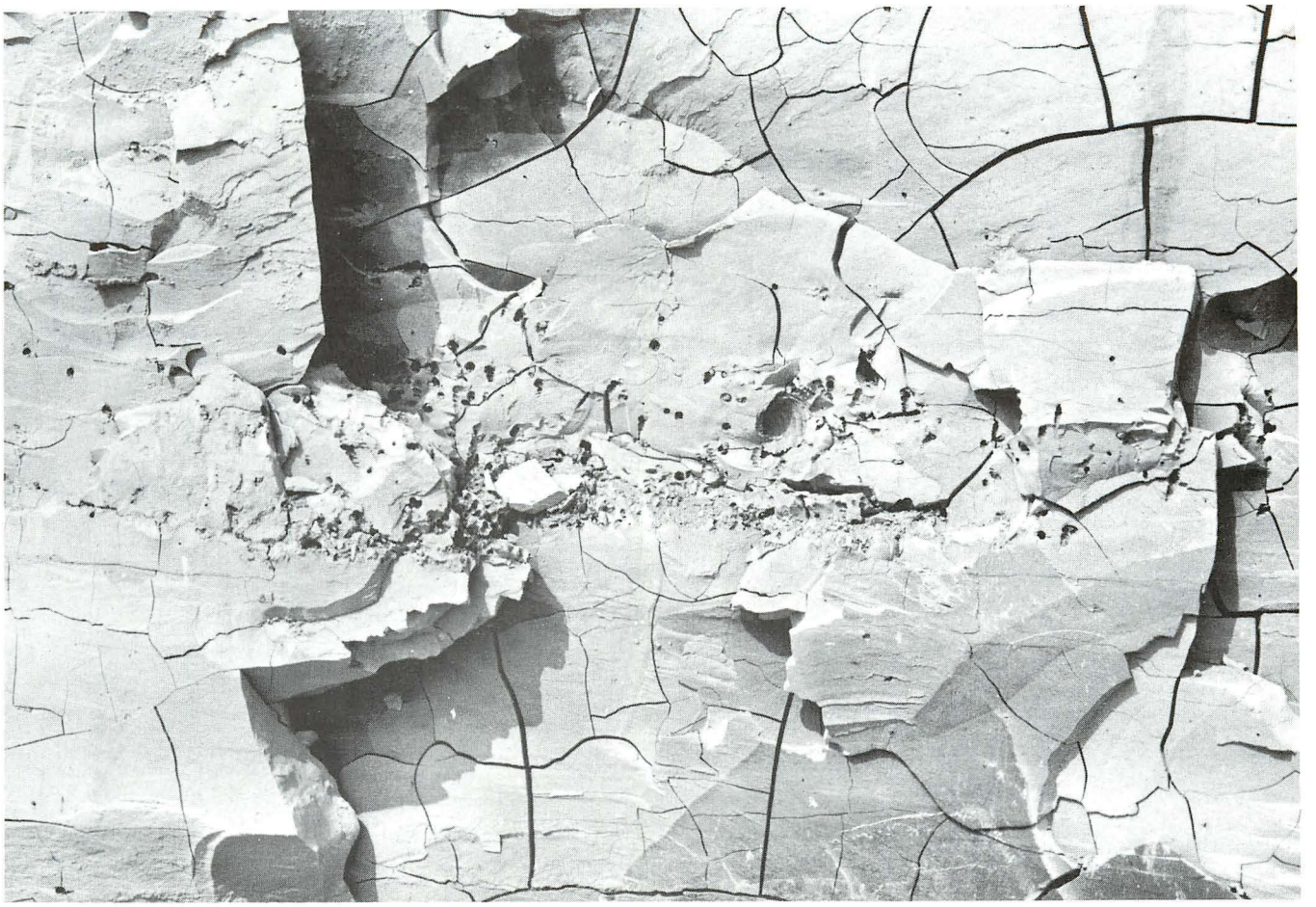


Figure 24: Conoy Member with thin, concentrated accumulation of *Turritella plebeia* molds and casts. Locality 66-47, north of Cove Point Marsh, Calvert Cliffs, Calvert County, Maryland.

incorrect interpretation of the environment or be so widely tolerant as to give only a very broad interpretation." I agree in part, for using only genera or only extant species as Gibson did may introduce shortcomings into the final analysis. If, however, these two criteria in addition to various general characteristics of foraminiferal distribution, as reviewed by Gernant and Kesling (1966, pp. 135-136), are considered in the interpretation, the deficiencies of the various approaches may be dampened. Yet direct extrapolation from extant species should have the highest resolving power of any single foraminiferal criterion.

SUMMARY OF KNOWN AND INFERRED ECOLOGICAL INFORMATION

Foraminifera:—All of the available environmental data pertaining to Choptank foraminifers is summarized in Table 1. For a more detailed discussion, see Gibson (1962, p. 82-193).

Ostracoda:—The two basic pioneering studies on Miocene to modern ostracodes of the Western Atlantic were by Ulrich and Bassler (1904) and Edwards (1944). Most subsequent investigations involved identifying or misidentifying their species. Some valid species have been added to the confusion. Fortunately for this study, many Miocene to modern ostracodes of the area are based on Ulrich and Bassler's work. Considering the various problems it was most instructive to study the type specimens designated by Ulrich and Bassler, Edwards, and others located at the U.S. National Museum, Washington, D.C. To date only four Choptank samples have been examined for ostracodes, two by Ulrich and Bassler (1904) and two by Malkin (1953).

Ecological data on Choptank ostracodes is assembled in Table 2.

Table 1: Ecological data on Choptank foraminifera

Species	Survival of species	Temperature	Depth (in meters) Most common	Depth (in meters) Occasional	Choptank distribution: Calvert Beach	Drumcliff	St. Leonard	Boston Cliffs	Conoy	Mode of life	Remarks	Choptank environmental preference
Bolivina paula C. & P.	L	W	9-183		R	R	R	R			Rare in modern seas	
Bolivina plicatella C.	L	B, C, M, W, T	1-50	1-100	R							
Buccella depressa A.	L	B, C, M, W, T	7-223		R	N	N	A	N			
Buccella mansfieldi (C.)	L	W	1-18	1-92	N	N	A	A	A		One of the most abundant in the Choptank	Very abundant in lower bay
Bulimina elongata d'O.	L	E		9	R	R	R	R	R		Preference for cold temperature boreal, arctic	
Buliminella elegantissima (d'O.)	L	B, C, M, W, T	1-40	1-80	N	R	R	R			Prefers sandy substrates	Prefers sandy substrates
Buliminella subfusiformis (C.)	L	B, C, M, W, T		4-732		R					Rare in modern seas	
Cancris sagra (d'O.)	L	B, C, M, W, T	20-120	1-1200	R	R	R	R	R			
Cibicides floridanus (C.)	L	W, T	55-146	1-339	R	R	R	R	R			
Cibicides lobatulus (W. & J.)	L	E	1-73		A	A	N	A	N	Commonly attached to objects	Grossman (1967) regarded as indicative of boreal and arctic. Most abundant foraminifer in Choptank	
Dentalina communis d'O.	L	E	46-4790			R						
Dentalina sp.	D					R						
Discorbis floridana C.	L	M, W, T	1-30	1-522	R	R	R	R	R		Mostly indicative of tropics	
Elphidium advenum (C.)	L	C, M, W, T	1-70	1-117	R	R					Mostly indicative of warm water	
Elphidium poeyanum (d'O.)	L	C, M, W, T	1-18	1-250	R	R		R				
Elphidium lucida W.	L	A, B, C, M	1-55	1-201	R	R		R				
Epistominella pontoni (C.)	L	W			R	R					Modern occurrence very rare and in deeper water	
Globulina inaequalis R.	L	M, W	1-68	1-193	R	R	R				Mildly indicative of mild temperate	
Hanzawaia concentrica (C.)	L	C, M, W, T	1-80	1-200	R	R	R	R	R			
Lagena acuticosta R.	L	B	18-1281		R	R	R					
Lagena clavata (d'O.)	L	B, T	6-104		R	R	R	R				
Lagena laevis (M.)	L	A	15-92	15-401		R		R	R		Occurs in bathyl and abyssal of tropics	Deeper than most Choptank species
Lagena substriata W.	L	B, C, M, W, T	55-2798	11-2798	R	R	R	R	R		Rare in warm temperate and tropics	
Lagena tenuis (B.)	L	C, C, M, W, T	2-50	2-142	R	R	R	R	R			
Lagena sp. A	D				R	R	R	R	R		May be the same as Dorsey's (1948) Lagena sp. A	
Lagena sp. B	D								R			
Lagena sp. C	D				R							
Marginulina sp. A	D					R						
Marginulina sp. B	D				R						May be the same as Dorsey's (1948) Marginulina sp. C	
Massilina glutinosa C. & C.	D				R	R	R	R	R			Probably very shallow
Massilina mansfieldi C. & C.	D					R						Probably shallow
Massilina quadrans C. & P.	D					R						Probably shallow
Massilina sp.	D					R						Probably shallow
Miliammina fusca B.	L	E	B, VS	S, VS		R	R	R	R			
Nodosaria catesby d'O.	L	W, T	4-60	4-433		R					Virginia only	
Nonion marylandicum D.	D				N	N	R	N	R		Confined to Choptank Fm.	
Nonion mediocostatum (C.)	D				N	N	R	R	A			Deeper shelf environments
Nonion pizarrense B.	L	B, C	15-18		A	N	R	R	A			Most abundant in deeper Choptank assemblages
Nonionella auris (d'O.)	L	B, C, M, W	S		R	R		R	R		Rare in warm temperate seas	
Nonionella sp.	D				R							In deeper Choptank assemblages
Pseudopolymorphina dumblei (C. & A.)	D					R		R	R			Sandier substrates
Pseudopolymorphina striata (B.)	L	W	27-120		R	N	R	R	R		Occurs consistently in Drumcliff	
Pyrgo subsphaerica (d'O.)	L	C, M, W, T	VS	1-300		R					Virginia only	

Table 1 (cont'd)

Species	Survival of species	Temperature	Depth (in meters) Most common	Depth (in meters) Occasional	Choptank distribution: Calvert Beach	Drumcliff	St. Leonard	Boston Cliffs	Conoy	Mode of life	Remarks	Choptank environmental preference
Quinqueloculina contorta d'O.	L	B, C	S			R						
Quinqueloculina seminula (L.)	L	E	S	1-90	R	N	R	R			Most common cool temperate, boreal, and arctic	
Robulus americanus (C.)	D				R	R	R	R	R			
Rotalia bassleri (C. & C.)	D				R	R	R	R	R		Genus very shallow marine to marginal marine	Most abundant in brackish assemblages
Sigmomorphina concava (W.)	L	C, M, W	1-40		R	R	R	R				
Sigmomorphina williamsoni (T.)	L	C	S		R	R						
Spiroplectammina exilis D.	D				R	N	R	R	R		Occurs consistently in Drumcliff	
Spiroplectammina cf. exilis D.	D						N				Distinctly different from true exilis	
Spiroplectammina mississippiensis (C.)	D				R							
Textularia candeiana d'O.	L	B, C, M, W, T	90-300	18-300	N	R	R	R	N			In deeper water assemblages
Textularia consecta d'O.	D				R	N		N	R			
Textularia gramen d'O.	L	C, M, W, T	1-110		N	N	N	N	R		Abundant in Boston Cliffs Member of Eastern Shore	Brackish assemblages
Textularia ultimainflata D.	D				R	R	R	R	R			
Textularia sp.	D								R			
Uvigerina subperegrina C. & K.	L	B, C	100-386	26-386	N	R	R		R			
Valvulineria floridana C.	D				A	A	A	N	N			
Virgulina miocenica C. & P.	D				R	R		R	R			
Virgulina punctata d.'O.	L	B, C, M, W, T	1-40								Preference for warm temperate and tropical	

Key to symbols: Survival of species: L—species living; D—species extinct. Temperature: A—arctic; B—boreal; C—cold temperate; M—mild temperate; W—warm temperate; T—tropical; E—eurythermal. Depth: B—brackish; S—shallow; VS—very shallow. Choptank distribution: R—rare; N—numerous; A—abundant.

Table 2: Ecological data on Choptank ostracoda

Species	Survival of species	Temperature	Depth (in meters) Most common	Depth (in meters) Occasional	Choptank distribution: Calvert Beach	Drumcliff	St. Leonard	Boston Cliffs	Conoy	Mode of life	Remarks	Choptank environmental preference
Actinocythereis exanthemata U. & B.	D				R	R	R	R	R		Reports from modern seas are misidentifications	
Actinocythereis aff. gomillioneusis (H. & E.)	L	M		2-31	R	R		R	R			
Actinocythereis aff. mundorffi (S.)	D						A				Abundant only in lower bay facies of St. Leonard	Lower bay
Actinocythereis sp.	D?								R		Virginia only	
Aurila laevicula (E.)	L	M, W	MM-23		R	R		R			Abundant in brackish facies of Boston Cliffs Member of Eastern Shore	Brackish assemblage
Basslerites tenmilecreekensis P.	L	W	MM, 3-9						R		Sole modern record in northern warm temperate (Pamlico Sound, N.C.)	

Table 2 (cont'd)

Species	Survival of species	Temperature	Depth (in meters) Most common	Depth (in meters) Occasional	Choptank distribution: Calvert Beach	Drumcliff	St. Leonard	Boston Cliffs	Conoy	Mode of life	Remarks	Choptank environmental preference
Bensonocythere whitei (S.)	L	M, W	3-61	3-201	R	N	R	R	R			
Bythocythere bifurcata (P.)	L	W	29-60		R						Very rare in Choptank	
Campylocythere laevissima (E.)	L	M, W, T	I-29	I-375	R	R	R	R				Sandy substates
Campylocythere sp.	D								R		Virginia only	
Cushmanidea agricola (H. & H.)	L	M, W	12-40	12-332	N	R	R	R	N			More common in deeper water assemblages
Cushmanidea seminuda (C.)	L	C, M	MM-35	B	R	R	R	R	R			
Cushmanidea ulrichi (H. & J.)	L	M	I-25	I-160	A	A	A	A	N		Possibly warm temperate; most common Choptank ostracode	
Cyprideis floridana (H. & H.)	L	W, T	VS, MM, B					R			One assemblage only	Brackish
Cytherella sp.	D								R		Very rare; Virginia only	
Cytheretta burnsi (U. & B.)	D				N	A	N	A	A		Common in shallow marine waters	Shallow marine
Cytheretta ulrichi P.	D				R	R	R	R	R		Common in shallow marine waters	
Cytheridea subovalis (U. & B.)	D				N	N	N	R	N		Syn. Clithrocytheridea diagonalis (Malkin, 1953)	
Cytherois fischeri (Sars)	L	B, C, M, W	I-34			R		R		Phytal	Euryhaline	
Cytheromorpha warneri H. & S.	L	M, W, T	I-55		R	N	R	R	R		Euryhaline	May favor marginal marine
Cytheropteron sp.	D				N	R	R	R	N		Deep water	Deeper shelf
Echinocythereis clarkana (U. & B.)	D				N	R	R	R	N		Primarily deeper shelf environments	Deeper shelf
Eucythere declivis (N.)	L	B, C, M, W	S	7-230	R	R						Shallow marine
Eucythere gibba E.	L?	W?		130-200?	R	R	R	R				
Haplocytheridea bassleri S.	L	W	MM, S	MM-26	R	R	A	N			Eurhyaline	Shallow and marginal marine
Haplocytheridea sp.	D					R					Virginia only	
Henryhowella evax (U. & B.)	L	C, M, W, T	155-677		N	R	R	R	N		Most abundant in Calvert Beach and Conoy Members as well as Drumcliff in Virginia	Deep shelf
Hulingsina ashermani (U. & B.)	L	C, M, W	2-40	2-200	N	A	N	A	R		Salinity tolerant to 25%	Clean sand substrate
Loxoconcha granulata S.	L	B, C, M	2-38		N	A	N	N	N			
Loxoconcha reticularis E.	L	W	12-50	12-328	R	R	R	N	R			
Machaerina ? sp.	D							R		Phytal		
Muellerina lienenklausi (U. & B.)	L	B, C, M, W	7-201		N	N	R	N	N			
Murrayina howei P.	D				R	N	R	N	N			
Neocytherideis fasciata (B. & R.)	L	C, M, W	11-232		R	R		R		Phytal	Numerous in upper Drumcliff	
Paracypris choctawhatcheensis P.	D				R	R						
Paradoxostoma robusta P.	D					R	R	R		Phytal		
Pokornyella punctistriata (U. & B.)	D				R	N	N	N	R			Very shallow euryhaline; favoring brackish
Propontocypris howei C.	L	M, W	I-155		R	R		R		Free-swimming	Common in Drumcliff	
Propontocypris sp.	D					R				Free-swimming		
Pterygocythereis americana (U. & B.)	L	B, C, M, W		12-238	N	R	R	R	A			Deeper shelf; mud substrate
Semicytherura coryelli (M.)	D				N	N	R	N			Genus marginal marine to shallow shelf	Marginal marine to very shallow shelf
Semicytherura forulata (E.)	L	M, W, T	MM-40	MM-201		R		R				Marginal marine to very shallow shelf
Semicytherura reticulata (E.)	D							R			Genus marginal marine to shallow shelf	Marginal marine to very shallows shelf
Tetracytherura shattucki (U. & B.)	D				R	R	R	R			Shallow shelf	

See bottom of table IV for Key to symbols.

Table 3: Ecological data on Choptank gastropods

Species	Survival of species	Temperature	Depth (in meters) Most common	Depth (in meters) Occasional	Choptank distribution: Calvert Beach	Drumcliff	St. Leonard	Boston Cliffs	Conoy	Mode of life	Remarks	Choptank environmental preference
Busycon sp.	D	C, M, W				R				Surface dwelling	Carrion eaters	
Caecum sp.	D		S		R	N	R	N		Under stones and in crevices	Suspension feeders	
Calliostoma sp.	D		S			R		R			Deposit scraper	
Cancellaria sp.	D					R					Carnivores	
Crepidula fornicata (L.)	L	B, C, M, W	I-27			R				Attached in stacks to others of same species	Suspension feeder	
Crepidula plana S.	L	B, C, M, W	S			R				Sedentary; attached to dead shells	Suspension feeder	
Crucibulum sp.	D		S		R	R	R	R		Sedentary	Suspension feeder	
Ecphora quadricostata umbilicata (W.)	D				R	R	R	R		Probably active predators		
Epitonium sp.	D		S			R		R			Carnivores	
Fissuridea sp.	D		VS			R					Deposit scrapers	
Hastula sp.	D					R				Vagile, just under the sediments	Poisons prey	
Lunatia heros (S.)	L	B, C, M	VS	I-31		N		N		Plows through sediment just beneath surface	Bores hole in prey and extracts flesh	
Nassarius sp.	D					R				Plows along sea floor surface	Carrion feeder	
Polinices duplicatus (S.)	L	M, W	VS		R	R	R	R		Plows through sediment just beneath surface	Bores hole in prey and extracts flesh	
Rhizorus sp.	D					R				Burrows		
Scaphella typa (C.)	D					R		R		Burrows in sand		
Siphonalia devexa (C.)	D					R					Carnivores, scavengers	
Teinostoma sp.	D					N		N			Very small and commonly overlooked	
Turritella sp.	D				A	A	N	A	N	Vagile, gregarious	Ciliary feeders; found just below sediment surface	
Urosalpinx cinerea (S.)	L	C, M, W, B	VS			R				Bores in living mollusks	Carnivores	
Vermetus graniferus (S.)	D					R				Sessile	Ciliary feeders	

See bottom of table IV for Key to symbols.

Table 4: Ecological data on Choptank bivalvia

Species	Survival of species	Temperature	Depth (in meters) Most common	Depth (in meters) Occasional	Choptank distribution: Calvert Beach	Drumcliff	St. Leonard	Boston Cliffs	Conoy	Mode of life	Remarks	Choptank environmental preference
Aligena aequata (C.)	D					N		R		Symbiotic with annelids		
Anadara staminea (S.)	D				R	N	N	C	R	Byssus attached	Suspension feeder	
Anodontia anodonta (S.)	D					N		N		Infaunal	Mucous tube feeder	Shallow; sandy substrates
Anomia aculeata G.	L	A, B, C, M	I-146		N	N	R	R		Byssus attached	Suspension feeder; small and easily overlooked	
Apolymetis biblicata (C.)	D					R		R		Medium depth burrower	Infaunal siphon feeder	
Astarte obruta C.	D						R	A		Shallow burrower	Suspension feeder; genus primarily cold water	
Astarte thisphila G.	D				R	A				Shallow burrower	Suspension feeder; genus primarily cold water	
Atrina harrisii D.	D				N	N		N		Byssus attached, anterior end buried in sediment	Suspension feeder; life position specimens in Calvert Beach, Drumcliff, and Conoy Members	
Callocardia subnasuta (C.)	D				R	R		R		Shallow infauna	Siphon feeder	
Cardita granulata (S.)	D					N		R		Byssus attached	Suspension feeder; shallow water	

Table 4 (cont'd)

Species	Survival of species	Temperature	Depth (in meters) Most common	Depth (in meters) Occasional	Choptank distribution: Calvert Beach	Drumcliff	St. Leonard	Boston Cliffs	Conoy	Mode of life	Remarks	Choptank environmental preference
Cardita protracta (C.)	D					R		R		Byssus attached	Suspension feeder; shallow water	
Cerastoderma laqueata (C.)	D				R	A	R	A		Lives just below sediment—water interface	Suspension feeder by short siphons	Sandy substrates
Corbula idonea C.	D					N	R	A		Shallow burrower; byssus attached	Suspension feeder by short siphons	
Corbula inaequalis S.	D				N	A	N	A			Suspension feeder by short siphons	
Crassatella turgidula (C.)	D				N	N	R			Shallow burrowers	Suspension feeders; prefers cool water	
Crassatella marylandica (C.)	D							N	R	Shallow burrowers	Suspension feeders; prefers cool water	
Crassostrea carolinensis (C.)	D					R		A		Attached, gregarious, above substrate	Suspension feeder; prefers brackish water	
Diplodonta acclinis (C.)	D				R	R		R		Infaunal	Mucus tube feeder	
Diplodonta subvexa (C.)	D				N	N				Infaunal	Mucus tube feeder; frequent in life position	
Dosinia acetabula C.	D				R	N	R	A	R	Infaunal: shallow water	Suspension feeder by long siphons	Sandy substrates
Ensis ensiformis C.	D				R	R	N	R	N	Active shallow water burrower	Suspension feeder by long siphons	
Glossus fraternus marylandicus (S.)	D				R	N		R		Shallow infauna	Suspension feeder by short siphons	
Hiatella arctica (L.)	L	E	I-46	I-350	R	R		R		Attached by byssus	Siphonate feeder	
Isognomon maxillata (D.)	D				R	A		N		Byssus attached	Suspension feeder; genus occurs in warm temperate and tropical modern seas	Shallow, brackish water
Lucina crenulata C.	D				R	N	R	R		Substrate burrower	Mucus tube feeder	
Lucinoma contracta (S.)	D				N	N				Substrate burrower	Mucus tube feeder; frequent in life position	
Lyropecten madisonius (S.)	D				R	N	R	A	R	Free-swimming	Suspension feeder	
Macrocallista marylandica (C.)	D					N		N		Shallow burrower	Suspension feeder through short siphons	
Martesia ovalis (S.)	D				R	A		N		Bored into valves of Isognomon maxillata	Siphonate, suspension feeding	
Mercenaria mercenaria (L.)	L	B, C, M, W	I-11	I-24		R				Shallow infauna	Siphonate feeding; prefers sandy substrate	
Mercenaria sp.	D					R		R	R	Shallow infauna	Siphonate feeding; suspension	
Modiolus ducatelli C.	D					R		R	R	Byssus attazhed	Suspension feeder; prolific in cool water	
Mytilus conradinus d'O.	D					R	R	N		Byssus attached	Suspension feeder	
Nucula proxima S.	L	B, C, M, W	I-183			R		R		Shallow burrower	Labial palp feeder	
Panope sp.	D				R	N	R	N		Deep burrower	Siphonate feeder; primarily in cold water	Shallow marine
Placopecten marylandicus (W.)	D					N				Free-swimming	Suspension feeder	
Pleiorytis centenaria (C.)	D				R	N		R		Infaunal; active burrowers	Siphonate feeding	
Semele subovata (S.)	D					N	R	N		Infaunal	Siphonate, suspension feeder	Shallow; sandy substrates
Spisula subparilis (C.)	D					A				Infaunal	Siphonate, suspension feeder; prefers nearshore sandy substrates	Sandy substrates
Yoldia laevis (S.)	D				N	R	N		N	Infaunal	Modern representatives of genus in cool water; labial palp feeders	Mud substrates

Key to symbols: Survival of species: L—species living; D—species extinct

Temperature: A—arctic; B—boreal; C—cold temperate; M—mild temperate; W—warm temperate; T—tropical; E—eurythermal

Depth: I—intertidal; MM—marginal marine; S—shallow; VS—very shallow; B—brackish

Choptank distribution: R—rare; N—numerous; A—abundant

Gastropoda:—The Choptank Formation is rather unexciting for snail lovers, as this class of molluscs is sparsely represented. In fact, if all specimens of the genus *Turritella* were removed from the fauna, the snails could be described as "rare". However, the species *Turritella plebeia* is so prolific that gastropods as a group are common. This one species is far more abundant than all others combined.

Shattuck (1904, pp. *xcviii-cvii*) lists 82 species of snails found by all workers prior to that time. In about six months of field study of the Choptank, I saw approximately one-third of those listed, nearly half of them based on less than a half dozen specimens each. Approximately ten species occur fairly frequently in the Drumcliff Member. In the other four members *Turritella plebeia* is frequent.

Table 3 summarizes environmental data regarding a number of Choptank gastropods.

Bivalvia:—Bivalves are much more abundant in the Choptank than snails. A very careful stratigraphic study of these molluscs including important taxonomic and distributional data was presented by Schoonover (1941b). The following table (Table 4) of the more common Choptank bivalves includes brief descriptions of their life habits.

SIZE-FREQUENCY STUDY OF SELECTED BIVALVES

Size-frequency distributions have the potential for increasing the understanding of the paleoecology of fossil organisms. Seemingly, the uniformitarian approach of extrapolating principles of size-frequency distributions of living populations to fossil assemblages is the most rational. Studies by Crag and Hallam (1963), Craig and Oertel (1966), Craig (1967), and Hallam (1967) are the most helpful for this approach.

From their analyses of living populations and from the work of population ecologists, such as Deevey (1947) and Slobodkin (1961), it is apparent that many complex, interrelating parameters function to produce a size-frequency distribution. In fact, at this stage of development these parameters cannot really be adequately identified in fossil distributions. Hallam (1967, p. 40) made the summary statement, ". . . . information is unfortunately insufficient for the rigorous disentanglement of the several variables involved. . . ."

The primary factors considered (Craig & Oertel, 1966, and Hallam, 1967) are recruitment, growth-rate, coefficient of variation of growth-rate, mortality rate, cessation of growth, sorting by water currents, solution of small, thin shells, and selective fracturing and crushing of certain size-grades. (For a discussing of these factors, the reader should refer to the two papers cited.)

Size-frequency distributions of selected Choptank bivalves are presented in figures 25 through 38. Numbers on the abscissa correspond to bivalve height measured in hundredths of a centimeter. Class sizes were selected in consideration of the data available. Numbers on the ordinate correspond to frequency of observations within class intervals.

For most of the data sources, separate graphs were made for right valves, left valves, and combined right and left valves. Comparisons of size-frequency distribution for opposed valves shows no significant diffierence. Minor differences occur in more or less accentuated peaks and presence and absence of very small peaks on "tails" of skewed distributions. This lack of significant variation suggests no selective sorting of either right or left valves, as shown by Lever, *et al.* (1958 and 1964), to occur on beaches.

One obvious generalization is the lack of the smallest sizes of shells. Of course, one problem with fossil bivalves is that the larval stage is not preserved. Thus the fossil distribution does not represent all of the ontogeny.

This explanation does not seem sufficient to explain the extreme lack of smaller shells as observed in text-figures 25A and 31A-D. These show the distributions for *Dosinia acetabula* and *Macrocallista marylandica* both primarily clumped around 6 to 8 centimeters. Yet they have very rare occurrences of smaller individuals. This type of distribution would be interpreted as a "residual fossil community" according to the assessment procedures of Fagerstrom (1964). However, since the deposit from which these distributions came have innumerable small shells of other species, this does not seem to be a reasonable interpretation. It might seem more reasonable to suggest that these species grew rapidly while young followed by a sudden reduction of the rate in the large animals. Possibly added to this was an increasing mortality rate.

Growth rings assist the study of *Glossus fraternus marylandicus* (figs. 25-28). The size-frequency distributions are slightly left-skewed and several subtle peaks can be seen (see particularly fig. 27F). These peaks correspond to the growth rings, except for the peak near 1.0 centimeters which must be qualified. For most valves the first ring corresponds to the mode, around 2.5 centimeters. Only a few valves have a ring near

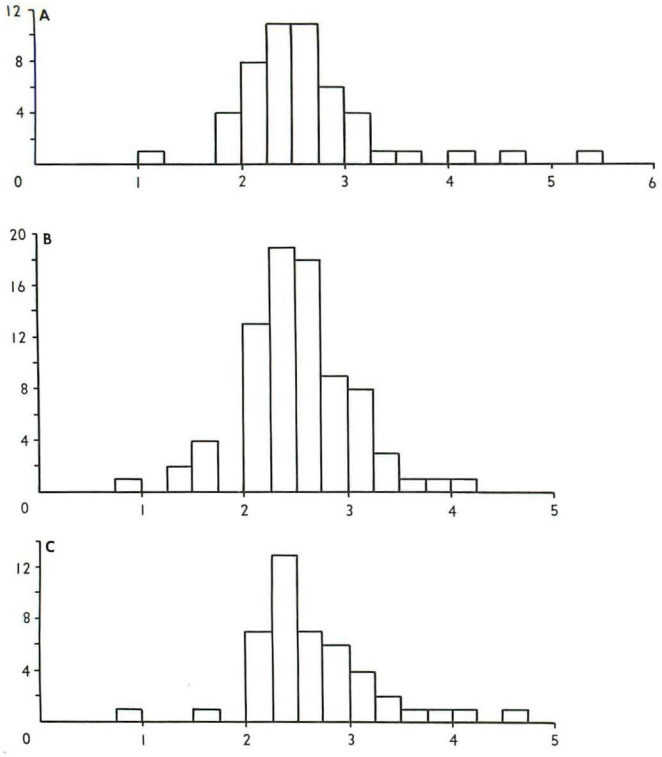


Figure 25: Size frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.

A. Right valves of *Glossus fraternus marylandicus*. *Glossus-Turritella* bed, upper Drumcliff Member. Locality 66-4.

B. Right, left, and double valves of *Glossus fraternus marylandicus*. (Location as above.)

C. Left valves of *Glossus fraternus marylandicus*. (Location as above.)

1.0 centimeters. Assuming that the growth rings represent cessation of growth in the winter and are therefore annular, and that there are two waves of recruitment each year (as known in the living animals in temperate and colder regions), the hypothesis put forward here is that *G. f. marylandicus* had a large spring recruitment followed by a small fall recruitment. Initial growth was great but rapidly declined.

The size-frequency distributions for the scallops (figs. 26, 29, 30) are quite interesting. The polymodal distributions point out the fact that recruitment came in distinctly separated waves. The closer spacing of peaks at the right suggests a slight slowing of growth. One of the unique qualities of this distribution seems to be the very high initial mortality followed by a very low mortality. The distributions seem to suggest that the critical interval was up to 6 centimeters and that if a scallop could live to that size it could live to a very old age. Deevey (1947) suggested similar mortality to oysters and barnacles. Is it just a coincidence that these three organisms are all epifaunal, filter-feeding invertebrates or is this the characteristic mortality for all in this category? Slobodkin said (1961, p. 36), "Most of the animals that have a distinctive larval stage followed by metamorphosis into an adult condition have extremely high mortality in the young stages or in the transition from one mode of life to another." This may give some insight into the high initial mortality but still leaves unanswered the decreasing mortality and extremely large size of older individuals of *Lyropecten madisonius*.

Anadara staminea shows distributions that vary from being left-skewed to normal to right-skewed (figs. 27, 28, 30, 31, 32, 33, 34, 35, 36). This species may be more phenotypically controlled than some of the other species. For example, the distribution is strongly right-skewed at Boston Cliffs (fig. 30), where the Boston Cliffs Member represents a shal-

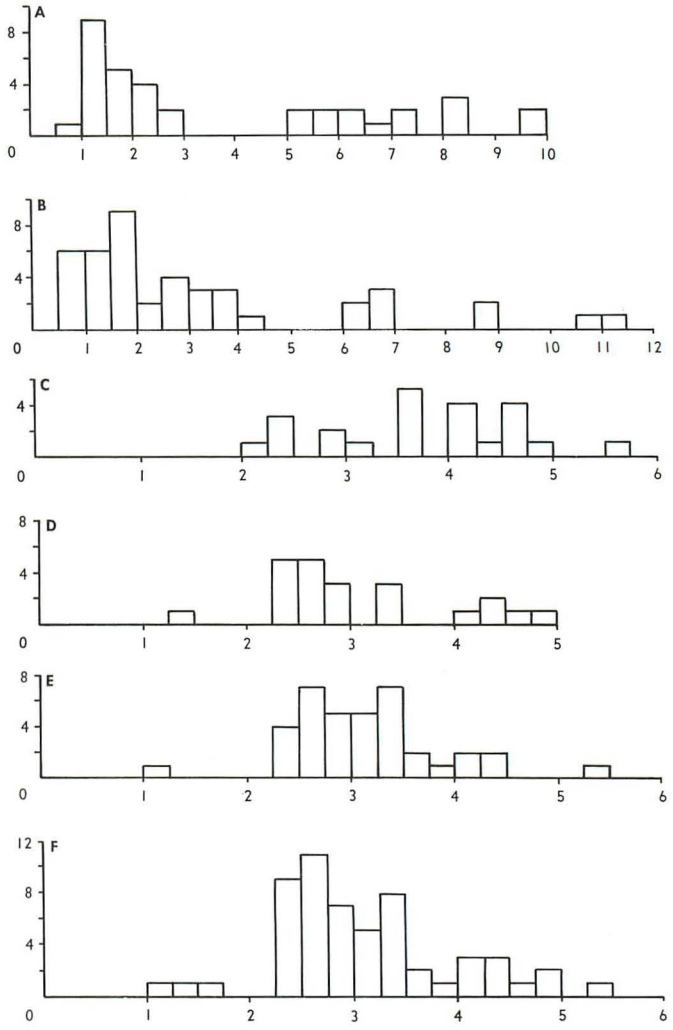


Figure 26: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.

A. Right valves of *Lyropecten madisonius*. 1 foot 6 inches below Drumcliff-St. Leonard contact. Locality 66-6.

B. Left valves of *Lyropecten madisonius*. (Location as above.)

C. Right, left, and double valves of *Glossus fraternus marylandicus*. 1 foot 6 inches to 4 feet below Drumcliff-St. Leonard contact. Locality 66-6.

D. Left valves of *Glossus fraternus marylandicus*. 6 inches to 2 feet below Drumcliff-St. Leonard contact. Locality 66-7.

E. Right valves of *Glossus fraternus marylandicus*. Locality 66-7.

F. Right, left, and double valves of *Glossus fraternus marylandicus*. Locality 66-7.

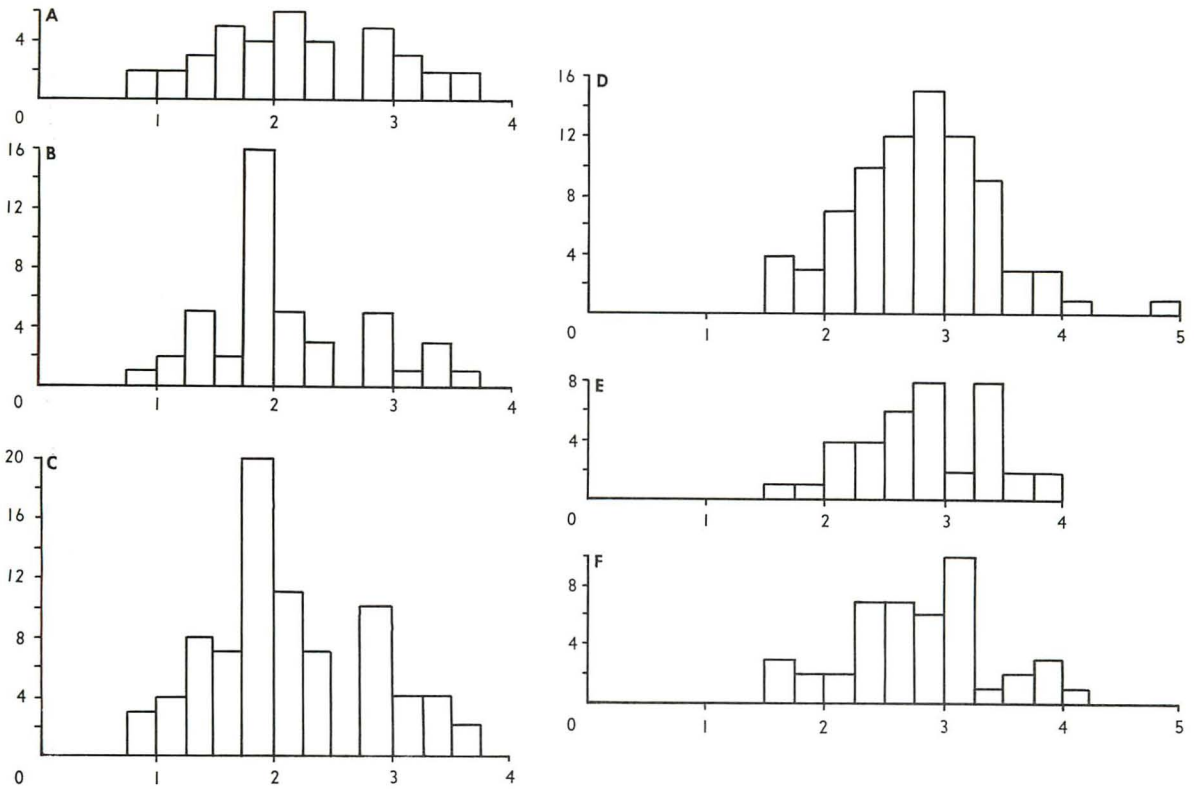


Figure 27: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Left valves of *Anadara staminea*. *Anadara* unit in the lower increased macrofossil bed. Boston Cliffs Member. Locality 67-52.
B. Right valves of *Anadara staminea*. (Location as above.)
C. Right, left, and double valves of *Anadara staminea*. (Location as above.)
D. Right, left, and double valves of *Glossus fraternus marylandicus*. Upper Drumcliff Member. Locality 66-5.
E. Left valves of *Glossus fraternus marylandicus*. Locality 66-5.
F. Right valves of *Glossus fraternus marylandicus*. Locality 66-5.

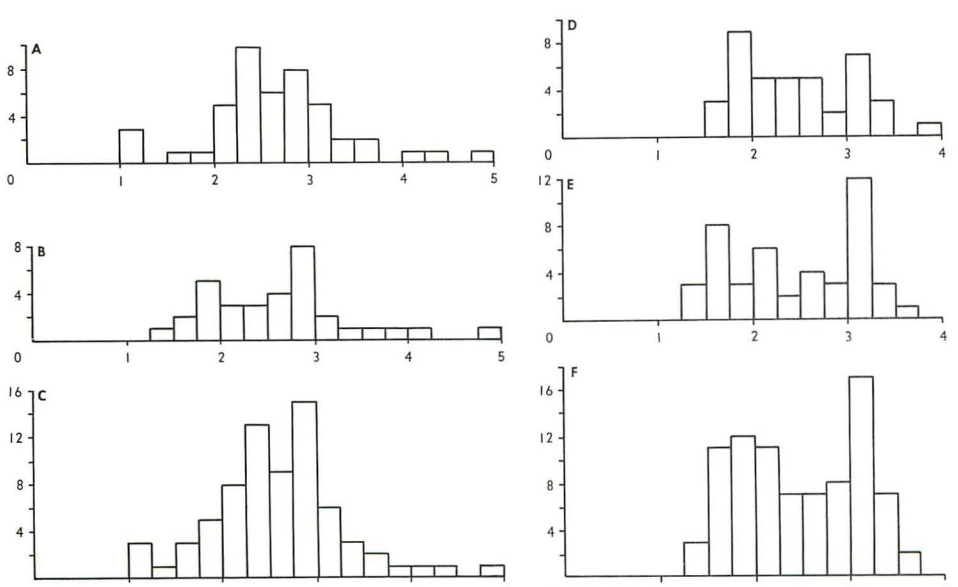


Figure 28: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Left valves of *Glossus fraternus marylandicus*. 6 inches to 1 foot 6 inches below Drumcliff-St. Leonard contact. *Glossus-Turritella* bed. Locality 66-6.
B. Right valves of *Glossus fraternus marylandicus*. (Location as above.)
C. Right, left, and double valves of *Glossus fraternus marylandicus*. (Location as above.)
D. Left valves of *Anadara staminea*. *Anadara* unit in the lower increased macrofossil bed. Boston Cliffs Member. Locality 67-66.
E. Right valves of *Anadara staminea*. Locality 67-66.
F. Right, left, and double valves of *Anadara staminea*. Locality 67-66.

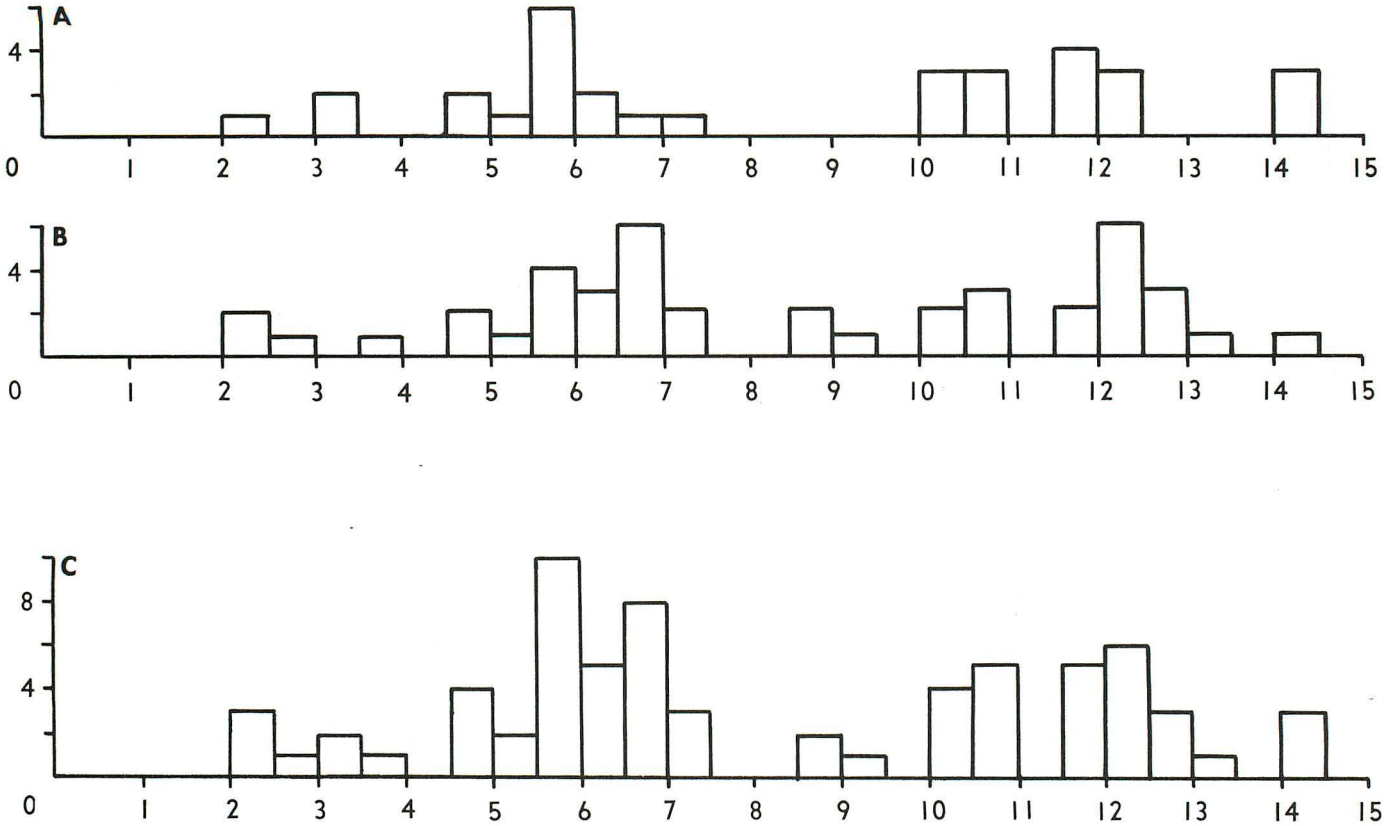


Figure 29: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.

A. Right valves of *Lyropecten madisonius*. Lower increased macrofossil bed. Boston Cliffs Member. Locality 67-48.

B. Left valves of *Lyropecten madisonius*. (Location as above.)

C. Right, left, and double valves of *Lyropecten madisonius*. (Location as above.)

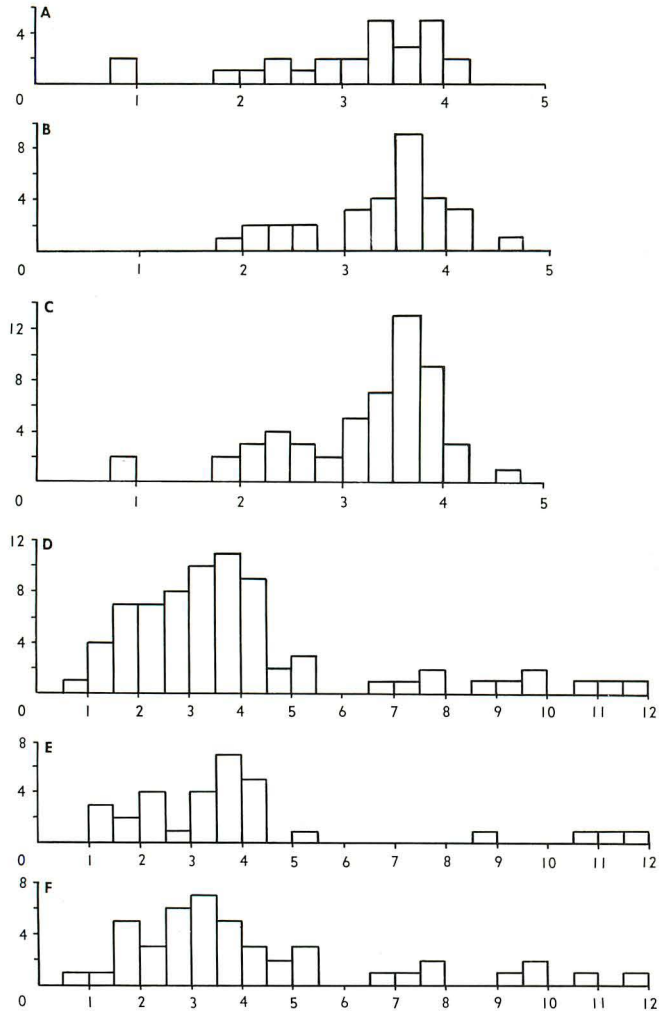


Figure 30: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.

A. Right valves of *Anadara staminea*. Lower increased macrofossil bed. Boston Cliffs Member. Locality 66-12.

B. Left valves of *Anadara staminea*. (Location as above.)

C. Right, left, and double valves of *Anadara staminea*. (Location as above.)

D. Right, left, and double valves of *Lyropecten madisonius*. (Location as above.)

E. Right valves of *Lyropecten madisonius*. (Location as above.)

F. Left valves of *Lyropecten madisonius*. (Location as above.)

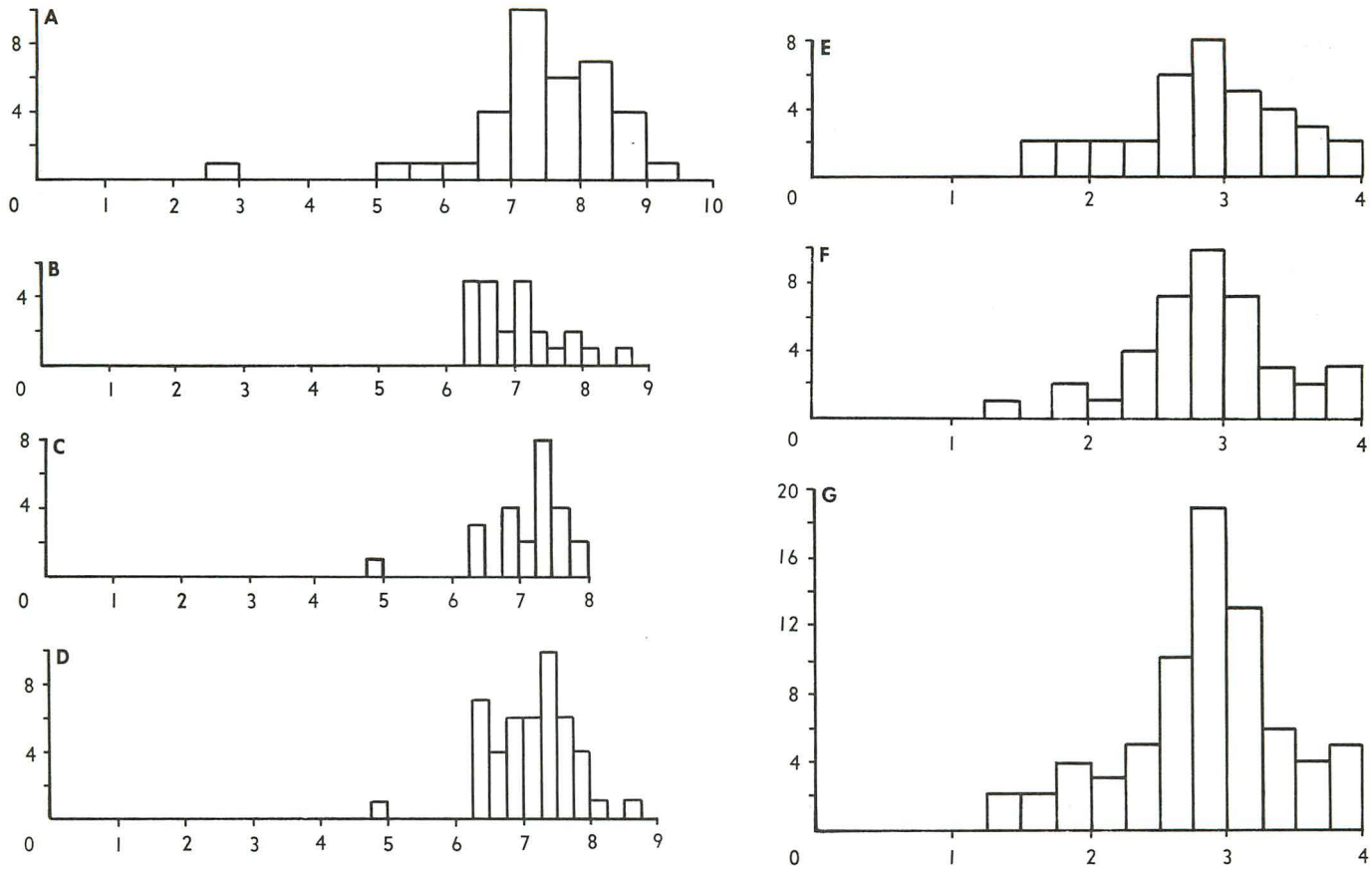


Figure 31: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Right, left, and double valves of *Macrocallista marylandica*. Lower increased macrofossil bed. Boston Cliffs Member. From unit of sample 66-5-25.
B. Right valves of *Macrocallista marylandica*. Lower increased macrofossil bed. Boston Cliffs Member. Locality 66-12.
C. Left valves of *Macrocallista marylandica*. Locality 66-12.
D. Right, left, and double valves of *Macrocallista marylandica*. Locality 66-12.
E. Left valves of *Anadara staminea*. *Anadara* bed from lower increased macrofossil bed. Boston Cliffs Member. Locality 67-48.
F. Right valves of *Anadara staminea*. (Location as Text-fig. 7E.)
G. Right, left, and double valves of *Anadara staminea*. (Location as Text-fig. 7E.)

lower water environment than at any of the other localities for the member. Bi-valves are often bigger and more robust in shallow water, thus tending to make right-skewed, size-frequency distributions. Again, the polymodal distribution likely is indicative of distinctly separated waves of recruitment. These may be preserved as a result of the special mechanism of shell concentration, described later in this paper.

Size-frequency distributions for *Astarte obruta* (fig. 37) and *Crassatella marylandica* (fig. 38) from Boston Cliffs are essentially the same but with larger adults of *Crassatella*. Both distributions are strongly right-skewed and have almost no individuals larger than the adult mode. This pattern is very similar to the *Anadara staminea* population (fig. 30) at this same locality. Infant mortality was probably very low yet adult mortality was likely very high. This type of distribution, as suggested above, may be phenotypically controlled as a result of this very shallow environment. This configuration possibly resulted from selective sorting particularly relating to the origin of the shell beds. A mechanism is suggested later in this paper for the genesis of these deposits which may in fact remove some of the smaller shells. Yet, inasmuch as the deposit contains many small molluscs, ostracodes, and foraminifers it seems somewhat risky to ascribe to a hypothesis of selective sorting.

ORIENTATION DATA

The direction of the apical end of *Turritella plebeia* shells was measured at five localities of the Drumcliff Member, and the data are presented in the form of rose diagrams (figs. 36, 39). Potter and Pettijohn (1963) have summarized interpretations of directional data.

Visual inspections of the snails in the outcrops gives the impression that they are randomly oriented. However, the plotted data reveal some opposed modes. For instance, in figure 39 a west mode is opposed by an east mode and a north-northwest mode opposed by a southeast mode.

Experimental studies, *e.g.*, Kelling and Williams (1967), indicate that the current direction is parallel to the bisector of the angle made by opposed modes or perpendicular to modes if they are directly opposed.

None of the *Turritella* distributions show unequivocally a single current direction. However, there does seem to be a general trend in the Calvert Cliffs data (figs. 36, 39) indicating a northeast-southwest current. Because this direction parallels the depositional strike, the current may have been longshore current. There also seems to be some indication of a north-south current. In the Breton Bay data there appears to be evidence for northeasterly, easterly, and south-easterly flowing currents.

One significant problem deserves mention. Measuring a random population from unconsolidated sediments is difficult. Study of fossils in lithified sediments is aided by the use of bedding-plane surfaces, but in unconsolidated sediments specimens are found on vertical surfaces. Even if an investigator concentrates on taking a random sample it is still easier to see a specimen parallel with the outcrop face than one perpendicular to it. It may be simple coincidence or it may be simple bias, but every direction graph in this paper shows prominent modes parallel with the face of the respective outcrops. Techniques for random sampling of directional properties will have to be developed to ensure credibility of data from unconsolidated sediments.

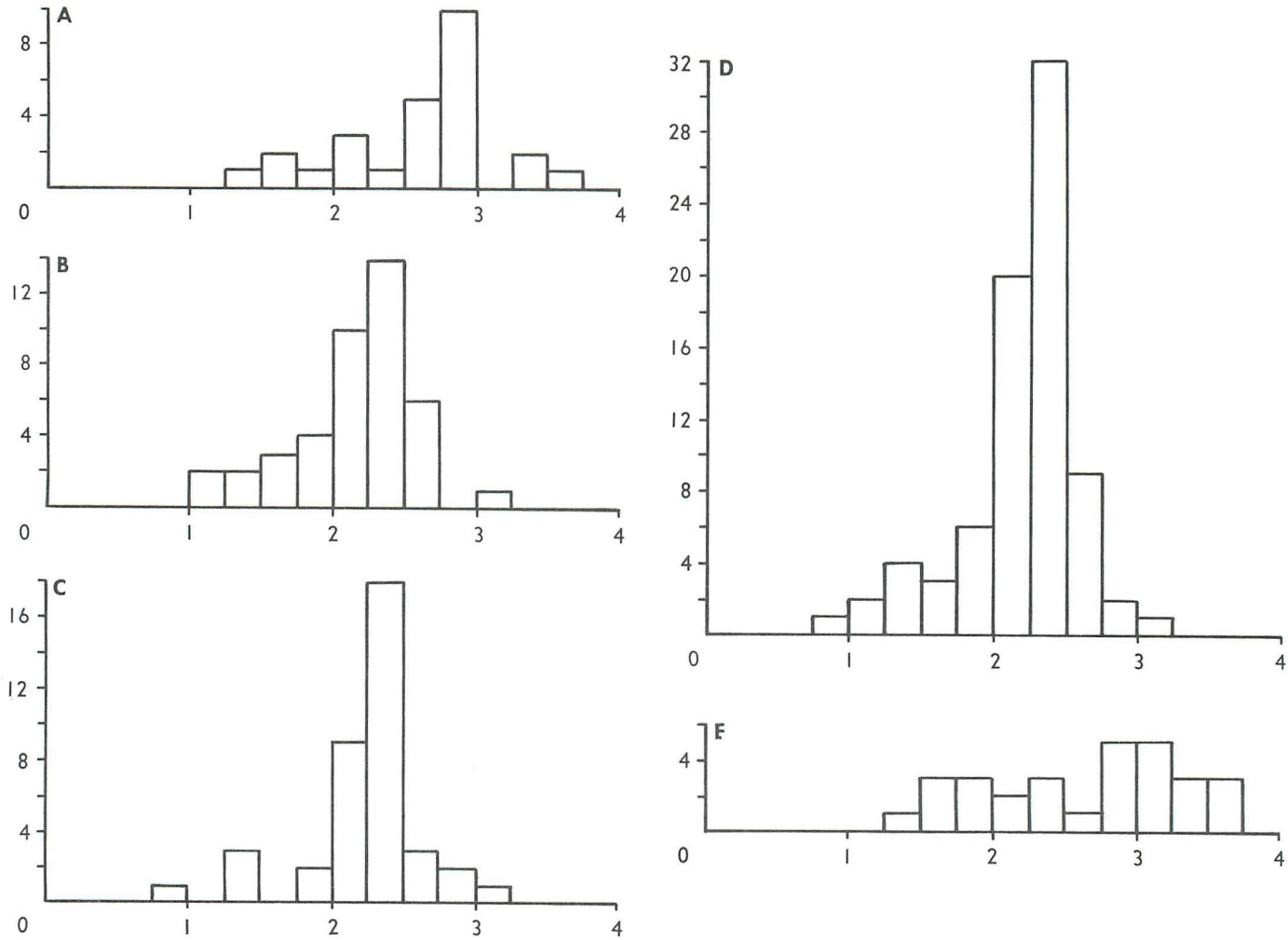


Figure 32: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Right, left, and double valves of *Anadara staminea*. Lower Drumcliff Member. Locality 66-5.
B. Left valves of *Anadara staminea*. *Anadara* bed of upper Drumcliff Member. Locality 66-6.
C. Right valves of *Anadara staminea*. Locality 66-6.
D. Right, left, and double valves of *Anadara staminea*. Locality 66-6.
E. Right, left, and double valves of *Anadara staminea*. 1 foot 6 inches to 6 feet below Drumcliff-St. Leonard contact. Locality 66-6.

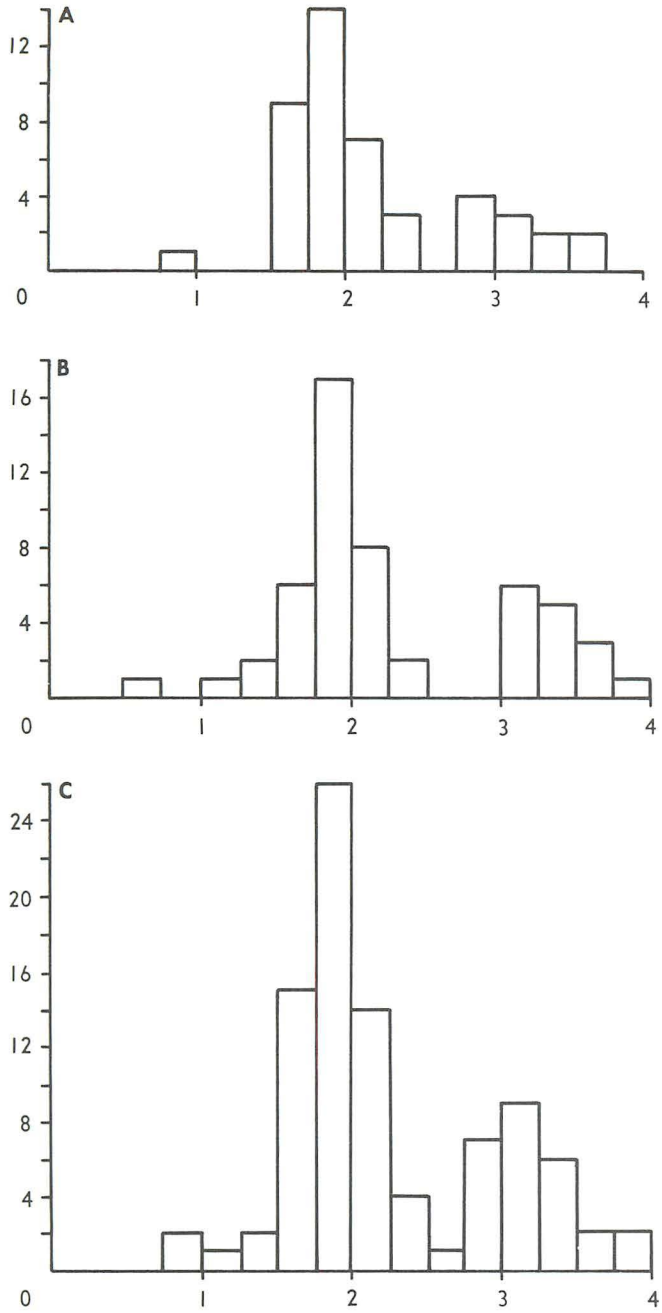


Figure 33: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Right valves of *Anadara staminea*. *Anadara* bed of lower increased macrofossil bed. Boston Cliffs Member. Locality 67-51.
B. Left valves of *Anadara staminea*. (Location as above.)
C. Right, left, and double valves of *Anadara staminea*. (Location as above.)

Accompanying the rose diagrams are four graphs (fig. 40) of the inclination of specimens of *Turritella*. Figure 40 also shows whether the apical tip was up or down. These serve to show the strong tendency for flat-lying specimens.

INTERRELATIONSHIPS OF CHOPTANK ORGANISMS

Interrelationships were undoubtedly as complex among organisms of the Choptank as among organisms living today. Ecologists are increasingly aware of symbiosis, commensalism, parasitism, and competition among the living biota. They have an enviable advantage over the paleoecologist in identifying and understanding these relationships. Yet, most of the conclusions about living animals have come from laboratory investigations. Of course, the student of fossilized remains cannot observe this type of laboratory phenomenon in ancient life.

The prime prerequisites for identifying interrelationships of the past are either to find the fossils associated consistently in some arrangement or to see preservable marks left on a fossil

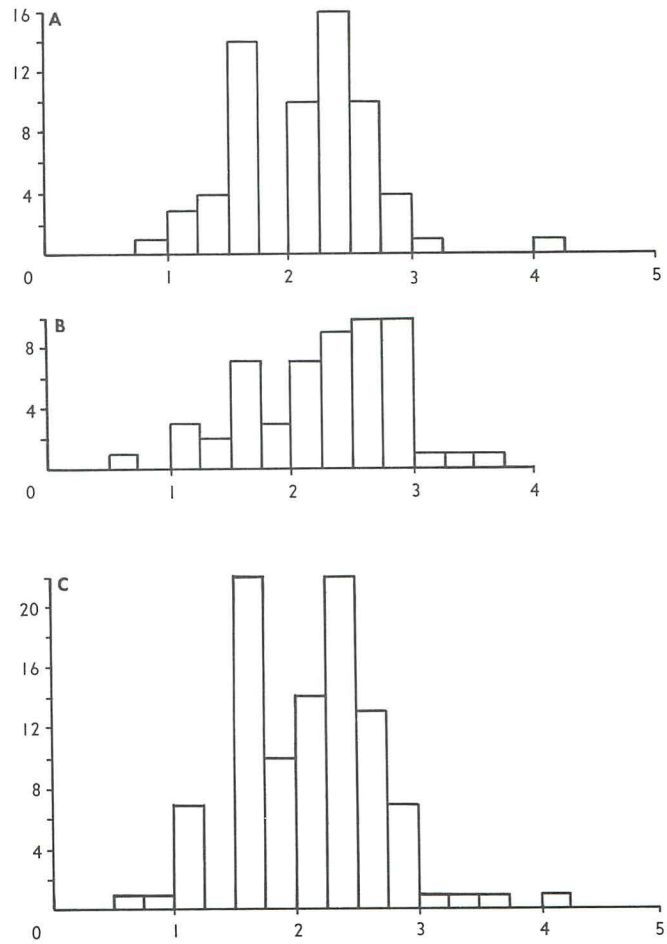


Figure 34: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Left valves of *Anadara staminea*. Boston Cliffs Member. Specimens from sample unit 66-5-25.
B. Right valves of *Anadara staminea*. (Location as above.)
C. Right, left, and double valves of *Anadara staminea*. (Location as above.)

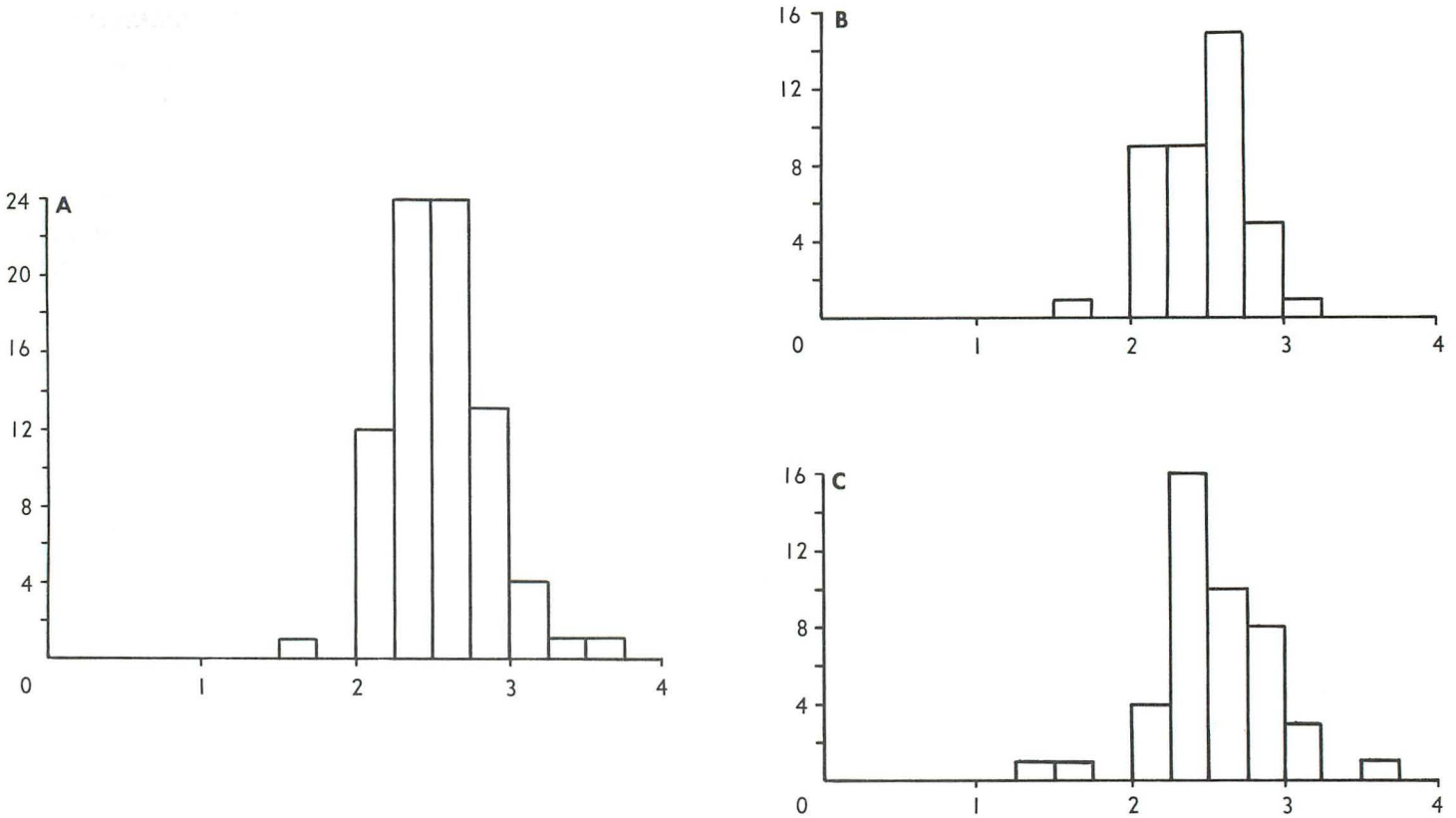


Figure 35: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Right, left, and double valves of *Anadara staminea*. Lowest 1 foot of Boston Cliffs Member. Locality 66-5.
B. Right valves of *Anadara staminea*. (Location as above.)
C. Left valves of *Anadara staminea*. (Location as above.)

by its comrade or enemy. This latter type of evidence is most easily recognized and probably holds the best hope for future analysis. A fine, pioneering work on general shell markings was presented by Boekschoten (1966, 1967).

More intensive study, specifically on boreholes of naticid and muricid snails, was undertaken by Carriker and Yochelson (1968). In the same year Carter also discussed predation of bivalves as related to paleoecology.

Foraminifera: Of the Foraminifera, only *Cibicides lobatulus* was seen in obvious association with other organisms. The shape of the dorsal side of this species strongly suggests that most individuals lived attached to objects. In fact, specimens were found attached to the external surface of bivalves, particularly epifaunal bivalves. The highest degree of association found was the scallops. If *C. lobatulus* was attached to the living scallop, it may have derived a feeding advantage from life on a free-swimming invertebrate. Of course, the foraminifer may have used the shell as a place of attachment after the death of the host. At any rate, attachment during or after the life of the bivalves could scarcely be considered deleterious to the host but also of no advantage. This must be considered then as an example of commensalism.

Porifera: The sponge *Cliona* left its distinctive small borings in Choptank bivalves, but showed preference for specific hosts. All sponge borings are found on epifaunal molluscs. The most strongly attached were the shells of the oyster, *Crassostrea carolinensis*. Many of the oysters, particularly those in the Boston Cliffs Member along the Choptank and Patuxent Rivers, are heavily riddled. Some limpet, scallop, and *Isognomon* shells have also been converted into sievelike objects.

It is particularly interesting that the Choptank shells of infaunal molluscs do not show sponge borings. As Boekschotten (1966) pointed out, any calcareous shell lying on the sea floor of the continental shelf is undoubtedly destined for sponge boring. This has special significance for the Choptank Formation, which in the two major shell beds contains millions of flat-lying, calcareous, infaunal bivalves that have not been riddled by sponges. Seemingly, these valves could not possibly have accumulated "normally" on the sea floor.

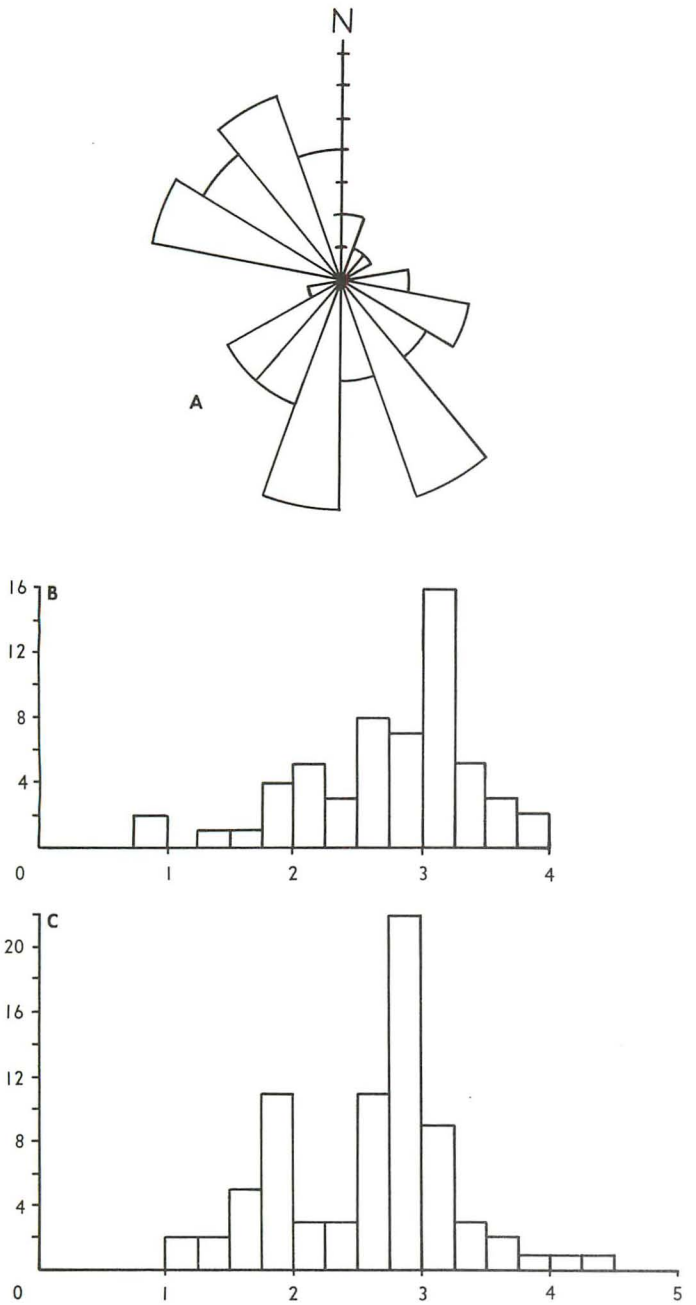


Figure 36: Size-frequency distribution and orientation data. Size in centimeters along abscissa. Frequency along ordinate. Orientation data grouped in 20° classes. Marks along North axis each correspond to one observation.

A. Orientation of *Turritella plebeia. Glossus-Turritella* bed of upper Drumcliff Member. Locality 66-6.

B. Right valves of *Anadara staminea. Anadara* bed of lower increased macrofossil bed. Boston Cliffs Member. Locality 66-9.

C. Left valves of *Anadara staminea.* Locality 66-9.

Additional ecological information on *Cliona* indicates that the sponges avoid the heavy water movement and sedimentation of beach and near-beach environments. Boekschoten (1966, p. 349) wrote: "*Cliona* is a marine sponge; only one occurrence in slightly brackish water is recorded from the coast of North Carolina. . . . Because calcareous substrata are less frequent in deeper water, the sponge is somewhat rarer below 200 m. It occurs at least down to 927 m."

Annelida: Marine annelids bore characteristic small tubes in shells. The best-known boring polychaete is *Polydora*, which excavates short, U-shaped, irregular tubes in shells. About the genus, Boekschoten said (1967, p. 353) that it "is restricted to shallow waters; a record from 52 m. depth near Helizoland is already very deep." Additionally he said, "Polydora is more prevalent below low water mark, on soft and muddy bottoms and in areas of low salinity."

Another interesting observation of Boekschoten (1966, p. 358) is that "there also is a difference in length of the tunnels, dependent on the substratum." Apparently, the tubes on living infaunal bivalves are about one-half as long as those on shells free on the sea floor. On Choptank infaunal bivalves the tubes ranged in length from about 0.1 to 0.2 centimeter while tubes on epifaunal scallops were as long as 1.0 centimeter.

In a discussion of the manner in which *Polydora* encounters its host Boekschoten (1966, p. 354) said,

> "*Cardium* lives directly below the sediment, with the posterior part of the shell (from which the siphons issue) turned upward. When *Polydora* starts burrowing in the sediment this side of the shell is always encountered first. Thus all *Cardium* shells with bored posterior were attached in living position . . . . only dead, loose, allochthonous specimens are bored all over the shell."

Of course, this is what we would intuitively expect, but with this insight it is difficult to understand the history of some shells collected from the Drumcliff Member at its type locality and some from the Boston Cliffs Member at its type locality. Some shells of *Mercenaria campechiensis cuneata, M. mercenaria, M. plena,* and *Macrocallista marylandica,* all infaunal bivalves, have concentrations of *Polydora* tubes centralized on the extreme anterior end. Apparently, the living habits of this boring annelid are imperfectly known.

Bryozoa: Animal interrelations involving Choptank bryozoans exist in two categories. The first and more commonplace are encrustations on bivalve, snail, and barnacle shells. Most examples of this type are found on the exterior surface of epifaunal shells, *e.g.,* scallops, barnacles, and oysters. In general, encrustations on internal sur-

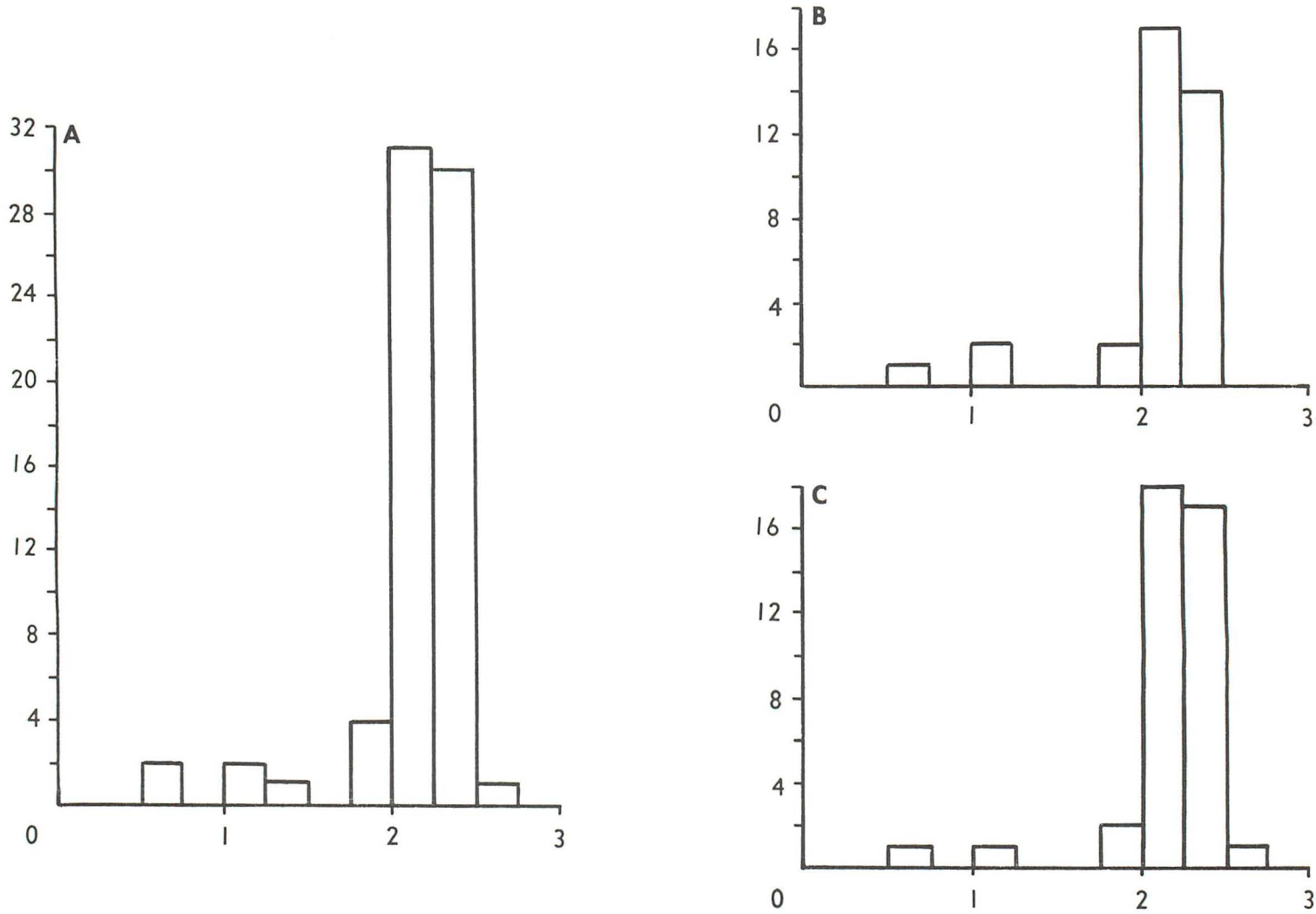


Figure 37: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Right, left, and double valves of *Astarte obruta*. Lower increased macrofossil bed. Boston Cliffs Member. Locality 66-12.
B. Right valves of *Astarte obruta*. (Location as above.)
C. Left valves of *Astarte obruta*. (Location as above.)

faces are rare, but this is the mode of occurrence on nearly all infaunal bivalves. Usually these shells are also more worn. In light of the fact that on modern, shallow ocean floors nearly everything from loose shells to beer bottles are encrusted by brozoans, it seems valid to conclude that very few infaunal molluscs were lying loose on the Choptank sea floor.

The second major category of bryozoan association is in the form of small bore holes. Boekschoten said (1966, p. 366), "The traces left by *Electra monostachys* in a shell consist of shallow oral depressions which are arranged in rows. The latter generally show a dendritic pattern." *Electra* is predominantly marine and sometimes brackish. Subtly defined pits characteristic of this genus were seen on only one Choptank shell.

Mollusca: The most common markings on Choptank shells are snail boreholes, primarily the work of naticids. The second most common snail in the Choptank, *Lunatia heros,* is an efficient borer. The snail plows about just beneath the surface of the sea floor in search of prey. It wraps its large massive foot around the victim and begins a two-phased drilling program as described by Carriker and Yochelson (1968, p. 135).

In the chemical phase an accessory boring organ secretes an acid substance which acts on the shell at the site of penetration. In the mechanical phase the radula rasps off the weakened shell as minute flakes which are swallowed. Only the radula moves freely about the borehole. The description of the naticid borehole as a "truncated spherical paraboloid" fits the Choptank boreholes well. Of course, the goal of the snail is to consume the flesh of the host. This is the best example of predation in the Choptank.

This basic understanding of the predation process raises two interesting problems. The first of these involves boreholes of the geometry described by Carriker and Yochelson (1968) in valves of Choptank ostracodes. It is difficult to comprehend why snails would prey on such small victims. Even for very small snails it would intuitively seem that the nourishment derived would not sufficiently replenish the energy expended.

The second problem is trying to explain why large numbers of scallops are bored by snails. The naticids plow around under the sea floor, while scallops enjoy a free-swimming existence. The question is, where does the predator meet the prey? When a dead scallop sinks to the bottom, the adductor muscle relaxes, and the valves open. Since the snails are known to search for the best location for drilling, it would be obvious that a week of drilling would be unnecessary. A second possibility is a scallop resting on the bottom found by the snail. However, the swimming ability is considered to have developed for the express purpose of escape from predation by invertebrates. With one quick "flap" of the valves the scallop should be able to escape the snail. I suggest that the scallops were buried alive by the passing of marine swell and became easy prey for the rapacious naticids. This proposed mechanism is discussed in much greater detail in the section on the origin of the shell beds.

In addition to the naticids some rare muricids occur in the Choptank. These are also boring snails and are discussed by Carriker and Yochelson (1968). Their characteristic boreholes were not seen in any of the Choptank material, however.

Associations involving Choptank bivalves are in two categories. The first is more of an inferred association. Erycinacean bivalves, of which *Ali-*

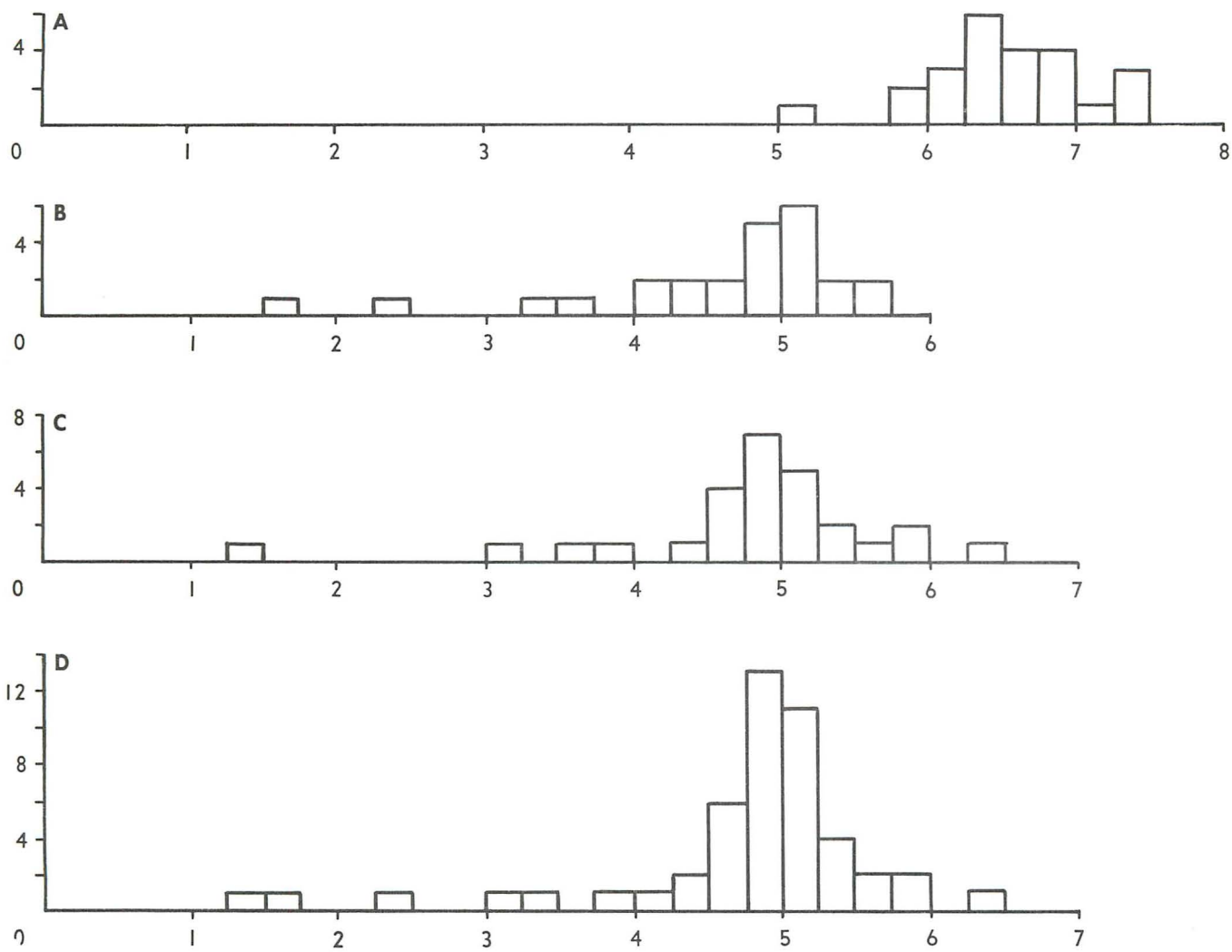


Figure 38: Size-frequency distributions. Size in centimeters along abscissa. Frequency along ordinate.
A. Right, left, and double valves of *Dosinia acetabula*. Lower increased macrofossil bed. Boston Cliffs Member. Locality 66-12.
B. Right valves of *Crassatella marylandica*. (Location as above.)
C. Left valves of *Crassatella marylandica*. (Location as above.)
D. Right, left, and double valves of *Crassatella marylandica*. (Location as above.)

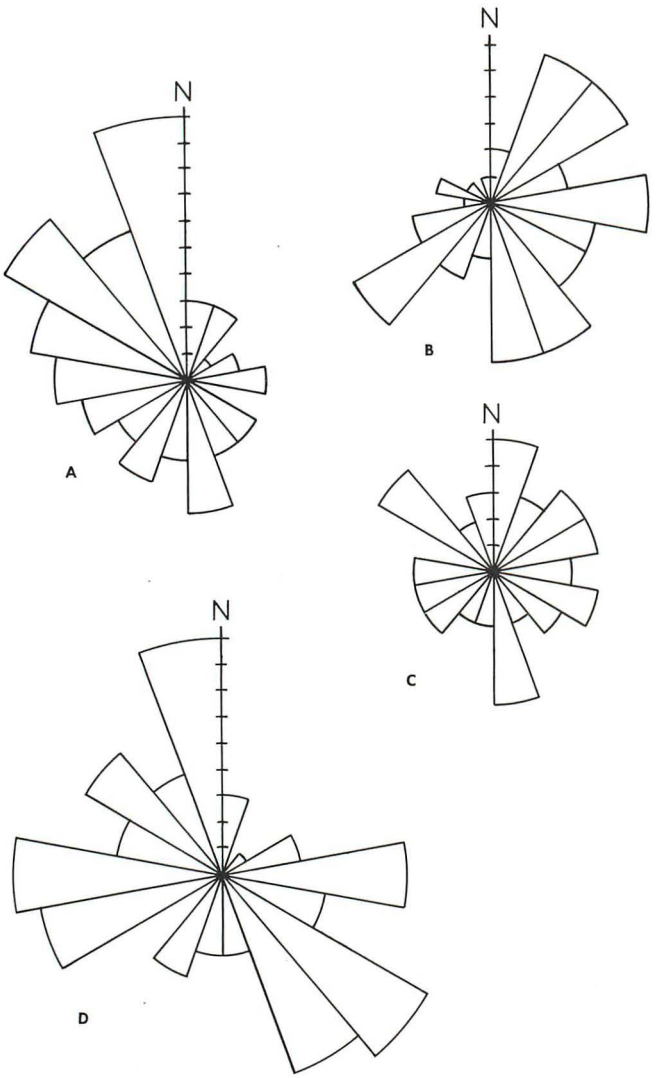


Figure 39: Orientation data. Grouped in 20° classes. Marks along North axis each correspond to one observation. All specimens measured are *Turritella plebeia.*

A. 3 feet 6 inches below Drumcliff-St. Leonard contact. Locality 66-5.

B. Drumcliff Member. Locality 66-34.

C. Drumcliff Member. Locality 66-36.

D. Drumcliff Member. Specimens from sample unit 66-4-1.

gena aequata is a member, are commensalistic with various hosts. Living species of the genus mentioned are known to live with marine annelids in their burrow. As Boss explained (1965, p. 190), "The relative immobility of the hosts facilitates simple attachment or association by the commensal and the currents created by the processes of filter feeding generate a favorable environment for the small mollusks, which are themselves filter feeders." Apparently the host is not harmed by the relationship.

The second type of bivalve association involves the small bivalve *Martesia ovalis* which bores into the large, thick valves of the epifaunal bivalve *Isognomon maxillata.* The relationship appears to be commensalistic with the shell of the host serving as a home for *Martesia. Isognomon* initially has thick shells but also has the ability of the "pearl-making" bivalves to secrete coats of nacre on sources of irritation. In spite of extensive boring in some valves it appears that *Isognomon* was able to maintain the interior as his exclusive domain. The host specificity shown by *Martesia* was

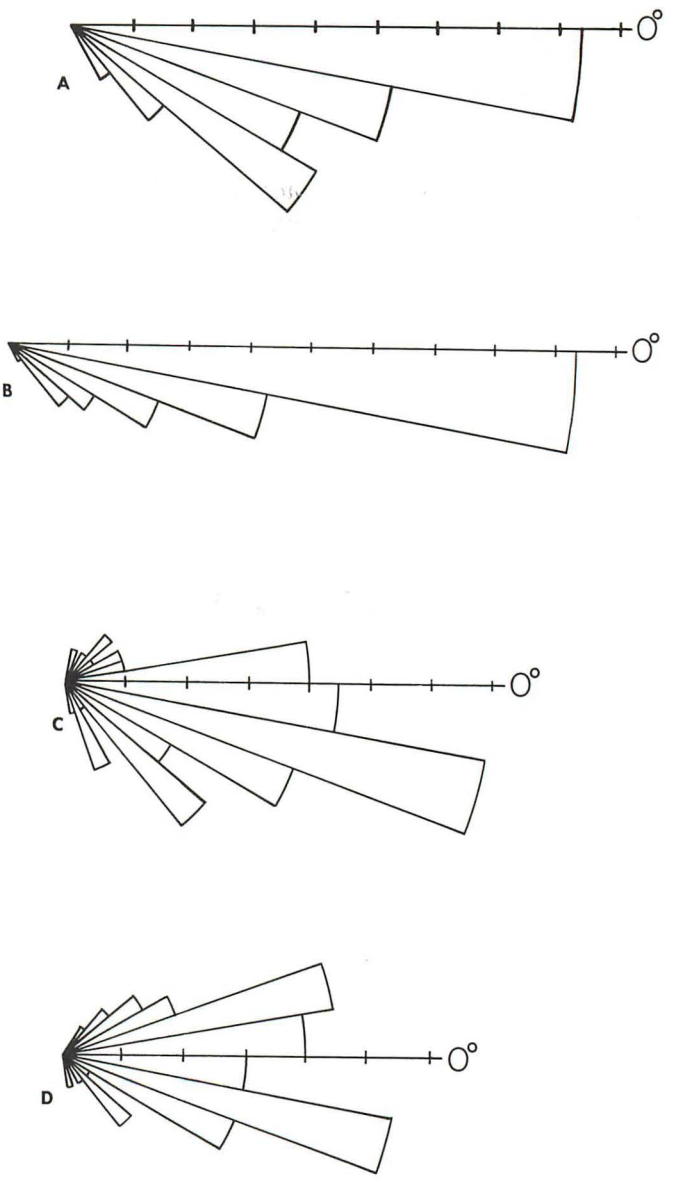


Figure 40: *Turritella plebeia* inclination data. Grouped in 10° classes. Marks along 0° axis each correspond to three observations.

A. Inclination of shells from horizontal position. 3 feet 6 inches below Drumcliff-St. Leonard contact. Locality 66-5.

B. Inclination of shells from horizontal. *Glossus-Turritella* bed of upper Drumcliff Member. Locality 66-6.

C. Inclination of apical tip of shells from horizontal. Drumcliff Member. Locality 66-34.

D. Inclination of apical tip of shells from horizontal. Drumcliff Member. Locality 66-36.

very strong, although its borings were found in four other valves. One oyster, two *Anadara*, and one, well-worn *Mercenaria* were found with *Martesia* borings, but no well-preserved infaunal organisms were attacked.

The ubiquitous barnacle, *Balanus concavus*, lived attached to exposed objects, *e.g.*, loose shells and epifauna. In light of the knowledge that modern barnacles attach to nearly all hard objects in the sea, their very rare presence on infaunal, shelled animals suggests these potential attachment sites were never exposed above the sediment-water interface. The occurrences of gigantic as well as smaller specimens of *Balanus* are common on scallops. The barnacles show a definite preference for alignment parallel to the outer margin and very near to it, and somewhat surprisingly are nearly always on the lower valve. Considering the fact that large, ocean vessels and pleasure yachts are periodically forced into "dry dock" for removal of barnacles, it seems that Balanus must have upset the hydrodynamic qualities of the Choptank scallops to a considerable degree. It is difficult to imagine the association of *Balanus* with *Lyropecten* not being somewhat harmful to the host. Choptank oysters are also found with barnacles attached, but these are usually small.

PALEOSYNECOLOGY

This section deals with the ecology of fossil assemblages and their paleoenvironmental significance. For convenience the discussions of paleosynecology are grouped according to member.

CALVERT BEACH MEMBER

According to Gibson (1962, p. 63) the lowest Choptank represents warmer and shallower water environments than the upper Calvert Formation. Although I have not investigated the Calvert Formation, my data from the lowest Calvert Beach Member of the Choptank at the type locality (sample 67-65-2) suggest cooler and deeper water than Gibson postulated for beds at Governor Run. His fauna contained the first Maryland Miocene occurrence of three warm water species, *Textularia gramen, Angulogerina occidentalis,* and *Elphidium advenum*. My fauna contained none of these but contained two other warm species, *Discorbis floridana* and *Pseudopolymorphina striata*. However, Gibson also reported the latter species from the Calvert, so that in the present study only one additional warm foraminifer is known to occur at the base of the Choptank.

With regard to the depth range between formations, Gibson reported that five new shallow-water species first appeared in the lower Choptank. Only one of these occurred in sample 67-65-2, and that was present in less than one percent of the foraminiferal assemblage. However, two of the five most abundant species are considered to be most common in deeper water. Empirical evidence in this study has shown *Textularia candeiana* and *Nonion pizarrense* to be most numerous in assemblages with large percentages of the deeper-water ostracodes. Supportive evidence for deeper occurrences of *Textularia candeiana* is found off the present coast of New England, where Phleger (1952) found this species confined to a depth zone bounded by 90 and 300 meters.

The ostracode assemblage in 67-65-2 suggests the deepest, coldest environment in the lower four members of the Choptank. Three of the five most abundant ostracodes, including *Henryhowella evax, Echinocythereis clarkana,* and *Cytheropteron* sp., are all considered to indicate deep water. In fact, the second most numerous, *H. evax*, has a known modern depth range of 155 to 677 meters.

Most of the ostracodes are found in cold water. *Cushmanidea seminuda, Loxoconcha granulata,* and *Actinocythereis* aff. *A. gomillionensis* are confined to cold temperate or colder water; and *Cushmanidea ulrichi* is primarily found in cold water. The only exclusively warm-water species found was *Loxoconcha reticularis*, making up less than one percent of the assemblage.

The snail *Turritella plebeia* is the dominant mollusc in the lower Calvert Beach Member. Specimens occur in lenticular and tabular clumps.

As mentioned previously, my approach to paleoenvironmental reconstruction in this study is primarily through direct extrapolation of ecological information from the present to the past. Additionally, the interpretations result from analysis of functional morphology. These are the main factors considered in establishing the paleoenvironments listed below for the various parts of the Choptank.

The basal sediments of the Calvert Beach Member at its type locality appear to have accumulated in about 45 to 60 meters of open ocean water. Biogeographically, the organisms indicate occurrence in a cold temperate province, possibly similar to the conditions existing today off the Atlantic Coast of southern Delmarva Peninsula.

Probably, Gibson's sample at Governor Run was taken from a group of sand lenses and stringers shown in fig. 2. These local deposits represent much shallower conditions than sediments in sample 67-65-2. My sample 67-53-1 from Governor Run contains the first Chesapeake Group appearance of certain warm water species, that were previously listed by Gibson. His suggested introduction of *Textularia gramen* is strongly supported by sample 67-53-1 in which this species is the third most abundant foraminifer.

The warm-water ostracode *Haplocytheridea bassleri* also appears in the sand lenses at Governor Run. Of the five most abundant Ostracoda at both localities, only *Cushmanidea ulrichi* is common to the two. The remaining four species at Governor Run are all very shallow water organisms, whereas the remaining four at Calvert Beach are much deeper. The sandy units at Governor Run were probably deposited in 15 to 25 meters of the open sea.

This same type of shallow-water sand lens occur from Governor Run updip to Parker Creek, the northernmost Choptank appearance in the Calvert Cliffs. Sample 67-74-4 from the finer-grained sediments of the Calvert Beach Member at Parker Creek is definitely from deeper water than the sand lenses. *Uvigerina subperegrina* and *Pterygocythereis americana, a* deeper-water foraminifer and ostracode respectively, are abundant faunal elements.

The upper Calvert Beach Member at Pawpaw Hollow appears representative of shallower water conditions. In sample 66-35-1, *Cibicides lobatulus* strongly dominates the foraminiferal assemblage, certainly suggesting shallow, inner shelf conditions. The most abundant ostracodes are *Cush-*

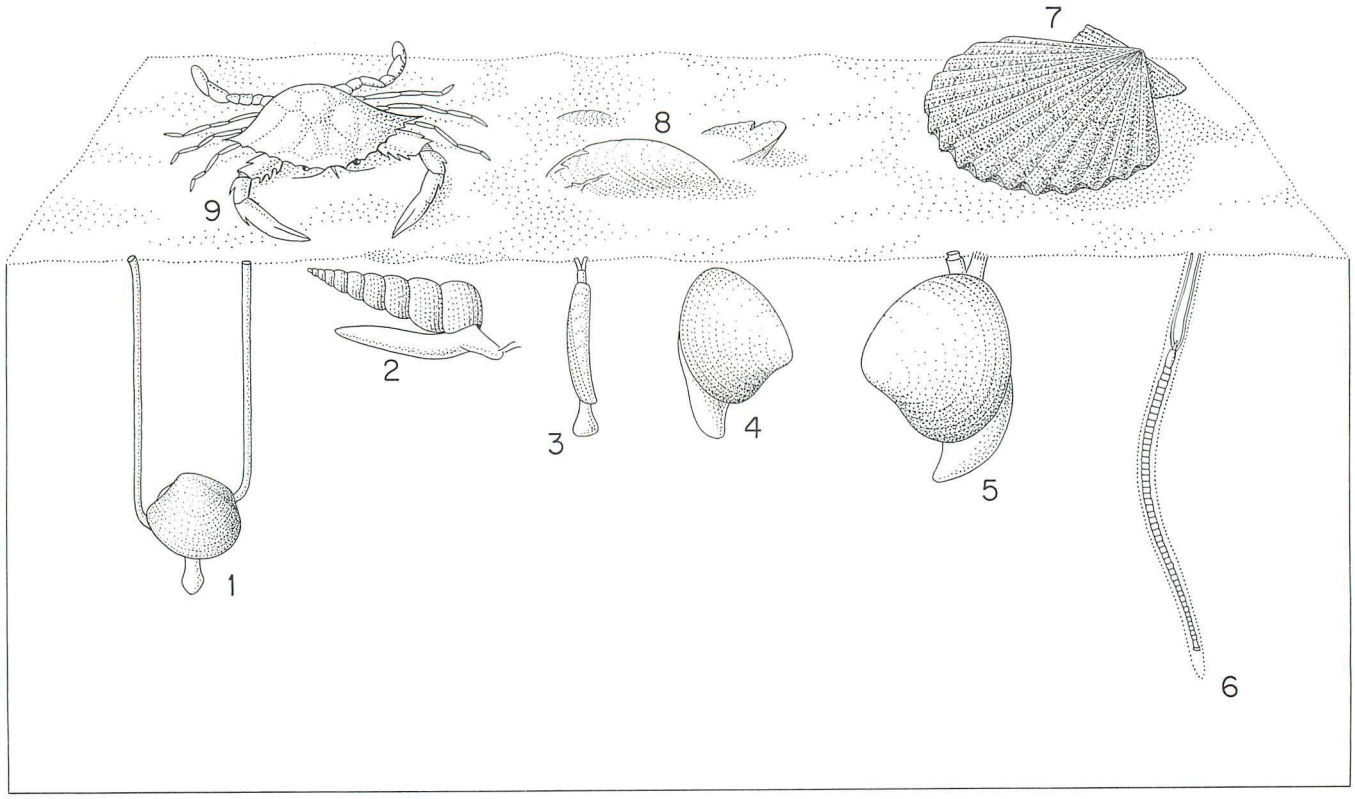


Figure 41: Organisms occurring in the Calvert Beach Member. The following illustrations show reconstructions of the life habits or occurrences: 1, lucinid bivalve; 2, *Turritella plebeia;* 3, *Ensis ensiformis;* 4, *Glossus fraternus marylandicus;* 5, *Mercenaria* sp.; 6, polychaete worm; 7, *Lyropecten madisonius*, free swimming; 8, loose shells of epifaunal bivalves; 9, crab. (In part after Abbott, 1954; Allen, 1958; Ansell, 1961; Fretter and Graham, 1962; Keen, 1958; Mac Ginitie and Mac Ginitie, 1949; Tebble, 1966; Yonge, 1949b).

manidea ulrichi, Murrayina martini, Cushmanidea agricola, and *Cytheretta burnsi* with other very shallow ostracodes such as *Aurila laevicula, Cytheromorpha warneri, Pokornyella punctistriata,* and *Smicytherura coryelli.*

The microfauna indicates a shallowing and warming trend through the Calvert Beach Member. Probably these two factors are interrelated, as shallower waters even at the same latitude are warmer. Inasmuch as most of the microfauna indicates cold temperate seas but a few species suggest warmer water, the sediments of this member were probably deposited in conditions similar to that found today off the southern Delmarva Peninsula where the mean annual surface-water temperature is approximately 15°C. (Ekman, 1953, p. 57).

Macrofauna is scarce in the Calvert Beach Member. However, a few well-preserved life assemblages occur at Calvert Beach, Maryland (fig. 41). The organisms are predominately shallow to medium depth burrowers and infaunal plowers. Cheilostome bryozoans and rare small scallops are the only epifaunal animals.

The macrofauna is dominated by the ubiquitous, gregarious snail *Turritella plebeia* (fig. 7). Of particular interest are the several lucinid bivalves, double-valved and in their characteristic living position. Allen (1958) indicated that the Lucinacea were successfully adapted to conditions in which food was at a minimum and where the oxygen content of the substrate was very low. He also observed that they tended to live in substrates possessing a very sparse fauna and often several species of Lucinacea occur together. This insight into the lucinid habitat may help to explain the predominantly turritellid-lucinid communities at Calvert Beach.

This member also contains numerous biogenic sedimentary structures most of which do not appear to have been made by bivalves (fig. 8). Probably marine, polychaete worms were also significant members of the Calvert Beach fauna. One striking characteristic of these burrows is that they are nearly all inclined or horizontal as opposed to vertical. McAlester and Rhoads (1967) suggested that horizontal burrowing is characteristic of deeper subtidal environments. This corroborates the microfaunal evidence.

DRUMCLIFF MEMBER

The shell beds of this member continued the shallowing trend of the Calvert Beach Member. In general, these deposits require a special explanation as to their nature and origin and are treated in another section of this paper.

The lowest Drumcliff shell beds in St. Marys County, however, do not need to be explained by a special mechanism. They are peculiar in that the dense accumulation of shells occurs in a continuation of the dusky blue, very muddy, very fine sand typical of the Calvert Beach (fig. 9). The organisms which produced these accumulations were all epifaunal, living attached to the hard substrate provided by this dense mud, attached to other organisms, or freed from substrate control by a swimming existence. In a slow-sedimentation environment dead animals could make up large parts of the substrate without impeding development of future epifaunal generations. They would merely create new places of attachment.

The most important fossil in these beds is the bivalve *Isognomon maxillata,* which frequently is the host for the boring bivalve *Martesia ovalis.* Of lesser importance are the ahermatypic coral *Astrhelia palmata,* the inarticulate brachiopod *Discinisca lugubris,* the scallops *Placopecten marylandicus* and *Lyropecten madisonius,* and the barnacle *Balanus concavus.*

Additionally, the abundant epifauna is in itself an indication of the shallowing water. This mode of life is more common in shallow water than in deep and more common in warm water than in cold.

The microfaunal assemblages studied from these deposits are quite unusual. The Foraminifera are greatly dominated by *Cibicides lobatulus.* North of Cole Creek this species makes up 94 percent of the Foraminifera, and at Sotterly, Maryland, it makes up 93 percent. Modern assemblages that are so strongly dominated by hyaline species are nearly always found in normal-to-high salinity, marginal-marine environments. The ostracode assemblage dominated by *Hulingsina ashermani, Pokornyella punctistriata,* and *Cytheromorpha warneri* indicates a very shallow environment, as well.

The basal Drumcliff beds along the Calvert Cliffs are not the same as along the Patuxent River. The sediment found along the Calvert Cliffs is a much better sorted sand with very little mud. The same fossils are present but many infaunal molluscs are mixed in. The basal beds here are much more typical of the member as a whole and are considered to have been created by the mechanism responsible for concentrating Choptank shell beds.

Most of the Drumcliff Member consists of alternating beds of increased number and size of densely packed shells with beds of reduced number and size of less densely packed shells. The macrofauna is very diverse and well preserved. Epifaunal specimens and species of snails are very

abundant. In addition, the burrowing Veneracea and Pholodacea are very common. Also *Polydora* shell borings are abundant at some localities. All of these general characteristics of the macrofauna suggest very shallow marine environments for the Drumcliff.

Macrofaunal assemblages of this member are typically dominated by the snail *Turritella plebeia* with *Lunatia heros* usually the second most abundant gastropod. Thorson (1957) discussed and listed many marine bottom communities, and in his cold water communities the most common snails were *Turritella* and *Lunatia*. The dominance of cold-water snail assemblages by these two species is probably a result of their infaunal life. This is contrary to the epifaunal life of most prosobranchs.

Assemblages of this member compare closely with Thorson's (1957) *"Venus"* communities in the cold water of the North Atlantic. In his *"Venus"* (=*Mercenaria*)—*Spisula*—*Turritella*—*"Polynices"* (=*Lunatia*) community an increase in loose sand would produce an increase in the number of individuals of *Spisula* and *Turritella*. This situation is a parallel of the Drumcliff assemblages where a great deal of loose sand occurs with a corresponding predominance of *Turritella* and *Spisula*.

The most common Drumcliff Foraminifera, in order of abundance, are *Cibicides lobatulus*, *Valvulineria floridana*, and *Textularia gramen*, all shallow shelf organisms. Ostracode assemblages are not as strongly dominated but clearly the most important species are *Hulingsina ashermani*, *Cushmanidea ulrichi*, *Cytheretta burnsi*, and *Loxoconcha granulata*, a typical shallow shelf assemblage.

In applying the knowledge of these assemblages of micro- and macroorganisms to physical aspects of the environment, the Drumcliff Member must have had a very shallow marine origin, with a probable depth range of 8 to 25 meters. Of course, it is reasonable to assume that downdip in the subsurface the unit should have been deposited in deeper water.

The only outcrop exception to a very shallow marine interpretation is that found in the Nomini Cliffs of Virginia. Here the member contains very thin shell beds, and the microfauna suggests a distinctly deeper water environment than that for the Maryland Drumcliff. Four deep water ostracodes, *Henryhowella evax*, *Echinocythereis clarkana*, *Pterygocythereis americana*, and *Cytheropteron* sp., constitute 26 percent of the assemblage. This deeper water suggestion is echoed by the Foraminifera with an increase in *Lagena* spp. and *Nonion* spp. and a drastic decrease in the importance of *Cibicides lobatulus*. The Drumcliff Member in the Nomini Cliffs, such as it is, appears to have been deposited in about 35 to 50 meters of open ocean water. This somewhat different environment may help to explain the atypical outcrop expression.

Some unique shell beds appear in the upper Drumcliff Member from just north of Calvert Beach to just south of Parker Creek in the Calvert Cliffs. Typically, the shells of this member have a very jumbled appearance or at least have been concentrated in an unusual manner. Such is not the case with the upper few inches to four feet in the member north of Calvert Beach. Here lenses and other discontinuous beds with fairly well sorted to muddy sand contain discrete assemblages of infaunal molluscs, and some lenses with only well-sorted, fine to medium sand are barren of macrofossils. Most of the bivalves are double-valved and excellently preserved. Some of the various molluscan associations are: *Turritella*, *Turritella-Glossus*, *Glossus-Turritella-Corbula-Cerastoderma-Crassatella*, *Glossus-Turritella-Cerastoderma-Astarte*, *Anadara-Astarte-Glossus*, *Anadara*, *Astarte*, and *Anadara-Astarte*.

Cursory and detailed examination of various microfaunal assemblages from these beds revealed very few specimens. Of those found, the predominant fossils are indicative of shallow water.

The discontinuous nature of the beds, the well-sorted sand, the discrete shallow-water, infaunal molluscan associations, and the rare shallow-water microfossils are all strong evidence of extremely shallow-water marine environments. This shifting sand substrate probably occurred in less than 10 meters of sea water.

ST. LEONARD MEMBER

At the same localities, north of Calvert Beach, an undulating, heterogeneous bed of mixed fossils and sediments occurs as a transition unit between the Drumcliff and St. Leonard Members. The latter, unlike any other member of the formation, decreases in thickness in the downdip direction. Even more interesting is the fact that the blue, muddy units measuring 20 feet thick in the Calvert Cliffs are correlated with a brown sand measuring only 4 feet thick along St. Leonard Creek only 3 miles to the southeast.

A profile was established along the "blue clay" in the Calvert Cliffs by examining samples from this member at Parker Creek, the type locality at

the Matoaka Cottages, Flag Ponds, and at Point of Rocks. In all samples the predominant foraminifer is *Buccella mansfieldi.* The most interesting characteristic of its distribution is the decrease in abundance and faunal dominance in the downdip direction. At Parker Creek the species comprises 77 percent of the foraminiferal assemblage, whereas, at Matoaka and Flag Ponds it is about 55 percent and at Point of Rocks it makes up 28 percent of the Foraminifera. The first three occurrences, particularly the first, are unusually large. Faunal dominance to this degree is typical of marginal-marine environments.

At the two most northern localities the most numerous ostracode is *Actinocythereis* aff. *A. mundorffi,* which was found nowhere else in this investigation. A little over half of sample 67-74-9 at Parker Creek and about one-quarter of sample 66-6-14 at Matoaka are made up of this species. However, in the next sample downdip at Flag Ponds *Actinocythereis* is totally absent with *Haplocytheridea bassleri* the most abundant ostracode here. This latter species is a marginal-marine to very shallow marine animal. In the last sample downdip the most common forms are *Hulingsina ashermani* and *Cushmanidea ulrichi,* which are very typical shallow shelf ostracodes.

Actinocythereis aff. *A. mundorffi* is extinct, but living species of the genus are well-known from marginal-marine and nearshore environments. Based on the sedimentological facies relationships and the variation in micro-faunal associations, the St. Leonard Member as seen along the Calvert Cliffs probably represents accumulation in a lower bay environment. Inasmuch as *Actinocythereis* aff. *A. mundorffi* only occurs in the St. Leonard Member north of Calvert Beach, it is considered confined to the lower bay environment. The fauna requires either normal marine salinity or higher. Mixing with more typical marine faunas occurs between Matoaka and Flag Ponds. Very shallow marine or near-marine conditions exist at Point of Rocks.

No microfauna was recovered from samples of the laterally equivalent thin, brown sand. However, the mottled sedimentary textures, the small lenses of well-sorted, fine sand, the elliptical burrows, and the few irregular, discontinuous laminations suggest the unit was deposited in a subaqueous, marginal-marine environment.

Inasmuch as epifaunal macroorganisms (fig. 42) are very important in the St. Leonard, it is clear that it is not a repeat of the conditions which produced the Calvert Beach Member. Epifaunal animals in this unit include: *Discinisca lugubris, Balanus concavus, Mytilus conradinus, Anadara staminea,* and the cold-water *Anomia aculeata.* In addition some bivalves that burrow into mud substrates are found: *Yoldia laevis, Ensis ensiformis,* and *Nuculana liciata.* In general, however, macrofossils are sparse.

In addition, the microfaunal change from the Drumcliff Member shows that the deep-water animals either decreased in abundance or disappeared while the shallow-water animals increased in abundance or first appeared. Infaunal organisms left traces of vertical burrowing (figs. 15, 16), which according to McAlester and Rhoads (1967) signifies shallow water. Faunal assemblages and sedimentological characteristics indicate that most of the exposed St. Leonard was deposited in marginal-marine environments. Thus, the shallowing trend of the lowest two members continued into the third.

BOSTON CLIFFS MEMBER

The upper shell bed of the Choptank has many characteristics similar to the lower shell bed and probably represents a repetition of the same process of shell concentration. However, the Boston Cliffs Member contains several different species of molluscs.

The macrofaunal assemblages generally have a lower diversity of species, fewer epifaunal individuals, considerably fewer snails, slightly lower quality of specimens per volume, and fewer small species. These characteristics all indicate either deeper or colder water than for the Drumcliff Member.

In general the microfaunal assemblages suggest that the Boston Cliffs Member was deposited in deeper and warmer water than the lower shell bed. However, the depth of water was still less than 30 to 35 meters, and the paleotemperature regime remained the cool temperate. The increased abundance and consistent occurrence of warm-water species, *e.g., Haplocytheridea bassleri, Loxoconcha reticularis, Buccella mansfieldi,* and the decreased abundance of cold-water species, *e.g., Loxoconcha granulata, Globulina inaequalis, Lagena acuticosta, Lagena clavata, Uvigerina subperegrina,* locate the Boston Cliffs Member farther south in the cool temperate water than the Drumcliff. This would then place the upper shell bed in the marine climate analogous to that found today between the mouth of the Chesapeake Bay and Cape Hatteras. The surface water of this area has a mean annual temperature of about 15 to 20°C. (Ekman, 1953, p. 57).

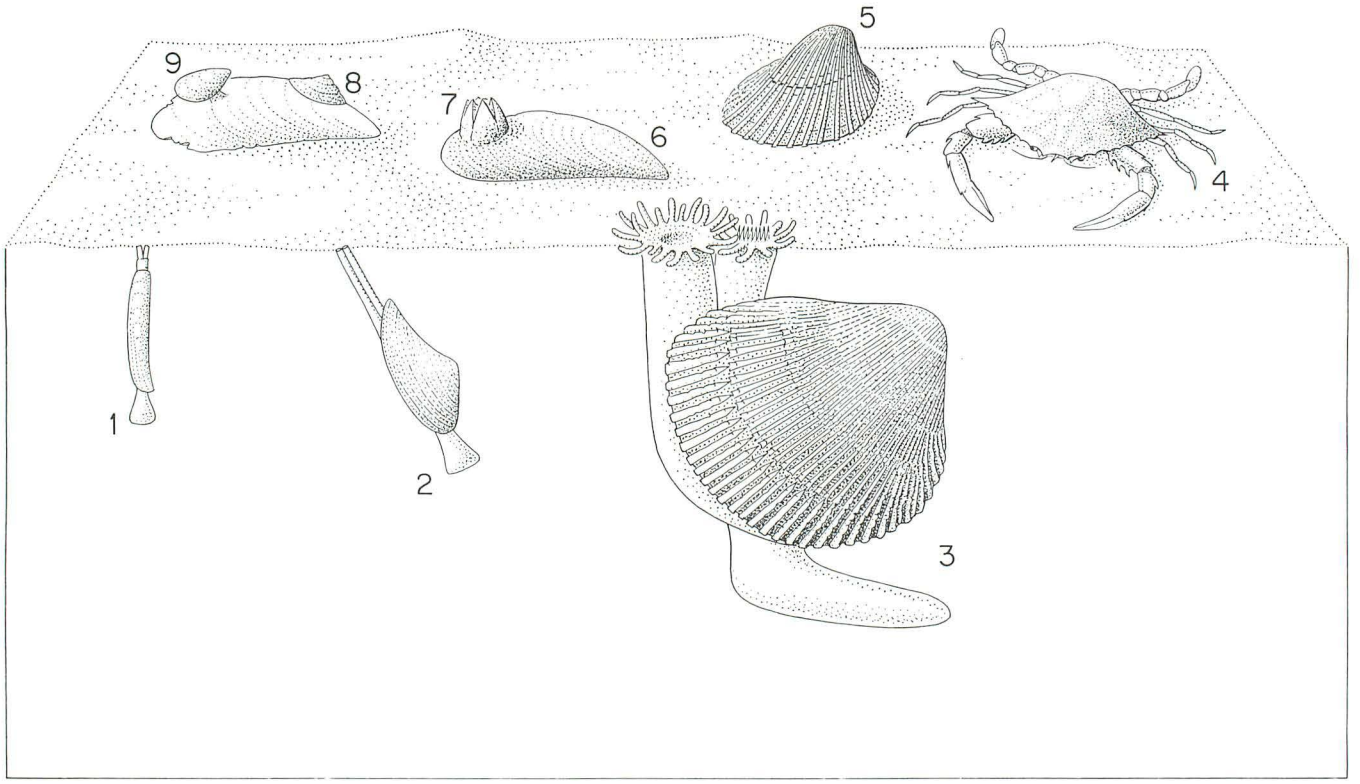


Figure 42: Organisms occurring in the St. Leonard Member. The following illustrations show reconstructions of the life habits or occurrences: 1, *Ensis ensiformis;* 2, *Yoldia laevis;* 3, *Cerastoderma laqueata;* 4, crab; 5, *Anadara staminea;* 6, loose shells of *Mytilus conradinus;* 7, *Balanus concavus;* 8, *Crucibulum* sp.; 9, *Discinisca lugubris.* (In part after Abbott, 1954; Keen, 1958; Mac Ginitie and Mac Ginitie, 1949; Tebble, 1966; Thorson, 1957; Yonge, 1939, 1949b).

While the typical Boston Cliffs Member deviates distinctly from the Drumcliff Member, the Choptank River sections of the former differ little. Of the difference listed above for the member in general only the characteristic of "lower abundance of specimens per volume" is a significant variance of the Choptank River sections from the Drumcliff Member. In addition, most bivalves found in the Choptank River sections are bigger and more robust than the average specimens of the member. These observations of macroscopic characteristics, in addition to more abundant *Polydora* borings, indicate that the Boston Cliffs Member on the Eastern Shore was deposited in shallower water than its sediments on the Western Shore. Furthermore, sediments and fossils of the type localities of the Drumcliff and Boston Cliffs Members were deposited in similar depth environments, probably less than 20 meters.

The microfaunal evidence supports this analysis. Sample 66-12-4 from the central part of the Boston Cliffs Member at its type locality contains a very shallow water foraminiferal assemblage. The most abundant Foraminifera in order are: *Cibicides lobatulus, Textularia gramen, Buccella mansfieldi, Valvulineria floridana,* and *Buccella depressa.* Additionally, the percentage of arenaceous foraminifers is high, which generally indicates an environment of lower than normal marine salinity. The most common species of the very shallow water, ostracode assemblage in order are: *Cushmandea ulrichi, Pokornyella punctistriata, Muellerina lienenklausi, Cytheretta burnsi,* and *Hulingsina ashermani.*

In the same area the Boston Cliffs Member has an atypical lower portion which contains an accumulation of *Isognomon* and *Crassostrea* shells. These beds show the strongest brackish water influence of any observed in the Choptank. Sample 67-79-2 contains a shallow inner shelf of brackish-water foraminiferal assemblage including, in order of abundance: *Textularia gramen, Cibicides lobatulus, Buccella mansfieldi, Rotalia bassleri,* and *Quinqueloculina seminula.* Additionally, of all the samples studied, this sample contains the highest percentage of agglutinated

foraminifers. The Ostracoda are even more indicative of brackish water and are dominated by *Pokornyella punctistriata, Cytheromorpha warneri, Aurila laevicula,* and *Semicytherura coryelli.* In addition, each of the following brackish and very shallow-marine species occurs as two percent of the ostracodes: *Cyprideis floridana, Haplocytheridea bassleri, Semicytherura reticulata,* and *Semicytherura forulata.* This evidence may indicate the nearby effluence of the ancestral Patapsco or Patuxent Rivers, possibly even the Susquehanna River.

The typical macrofauna of the lower and middle Boston Cliffs is predominantly composed of infaunal bivalves (fig. 43). The commonly associated macrofossils are: *Macrocallista marylandica, Dosinea acetabula, Corbula idonea, Cerastoderma laqueata, Crassatella marylandica, Anadara staminea, Lyropecten madisonius, Balanus concavus, Astarte obruta, Mercenaria* spp., and *Panope americana.* This assemblage is somewhat similar to the "*Venus*" bottom communities of the North Atlantic as described by Thorson (1957, pp. 508-510).

In the upper part of the member, but below the oxidized and indurated beds, is a series of thin units containing predominantly epifaunal animals. Shells of these oyster-scallop-barnacle assemblages are some of the largest found in the Choptank. However, these large shells grade below and above into accumulation of well-worn fragments. These epifaunal assemblages are an indication of shallowing water in the upper part of the Boston Cliffs Member.

Another special problem associated with the Boston Cliffs Member is the origin and environmental history of the strongly oxidized and indurated series of beds in its upper part. These characteristics and the leached out fossils make the upper units difficult for study.

Analysis above of the oyster-scallop-barnacle assemblage indicated shallowing water on the shallow inner shelf. Possibly this trend of environmental change may help resolve the problem of the oxidized and indurated beds immediately above in stratigraphic sequence.

The only sample from the oxidized-indurated series that produced a microfauna was 66-24-13, from a short distance north of Point of Rocks. Since only 19 foraminifers were found the data are insufficient, but of the species present the shallow-water *Cibicides lobatulus* and *Textularia gramen* are the most common. The ostracode data are much more adequate, with the presence of 173 specimens. The most numerous species of this very shallow marine assemblage are: *Hulingsina ashermani, Cushmanidea ulrichi, Haplocytheridea bassleri, Semicytherura coryelli,* and *Cytheretta burnsi.*

Where molds and casts can be identified, the predominant macrofaunal species are *Lyropecten madisonius, Cerastoderma laqueata, Mytilus conradinus, Mercenaria* spp., and *Macrocallista marylandica.* Since epifaunal species constitute a high percentage of the assemblages observed, these beds must have been deposited in shallow water. The history of the actual oxidation and lithification is uncertain. The shallowing trend of the depositional environments supports the possibility that the ocean receded sufficiently to subaerially expose the top of the Boston Cliffs Member. Sediments of the upper Boston Cliffs were then oxidized and indurated. A second possibility is that percolating ground water was the lithifying and oxidizing agent.

In a very rare mode of preservation the upper Boston Cliffs Member was found neither oxidized nor indurated at locality 66-44 (fig. 22), north of Camp Conoy. Here the macrofauna consists of *Lyropecten madisonius, Turritella plebeia, Crassatella marylandica, Cerastoderma laqueata, Macrocallista marylandica, Dosinea acetabula,* and *Crucibulum costatum.* The Foraminifera indicate a very shallow-marine environment and are strongly dominated by *Cibicides lobatulus* which is followed in importance by *Buccella mansfieldi, Buccella depressa, Textularia gramen,* and *Bulimina elongata.* The very shallow-marine ostracode assemblage contains the following as most abundant: *Loxoconcha granulata, Cytheretta burnsi, Cushmanidea ulrichi Murrayina martini,* and *Cytheromorpha warneri.* This bed from the uppermost Boston Cliffs Member must have been deposited on the shallow, inner shelf. Because the only significant macroscopic difference between members is the quantity of shells and not the sedimentological characteristics, the break between members here is much less striking than is typically found. The characteristics of the Boston Cliffs Member at this locality discredits somewhat the idea of subaerial exposure but lends support to alteration by percolating ground water.

CONOY MEMBER

Sediments of this member are the most consistently fine-grained and muddy of any member in the Choptank. The Conoy is distinct from the other members in that it commonly exhibits thin, parallel, bedding laminations (fig. 22). Biogenic sedimentary structures are very rare. From an

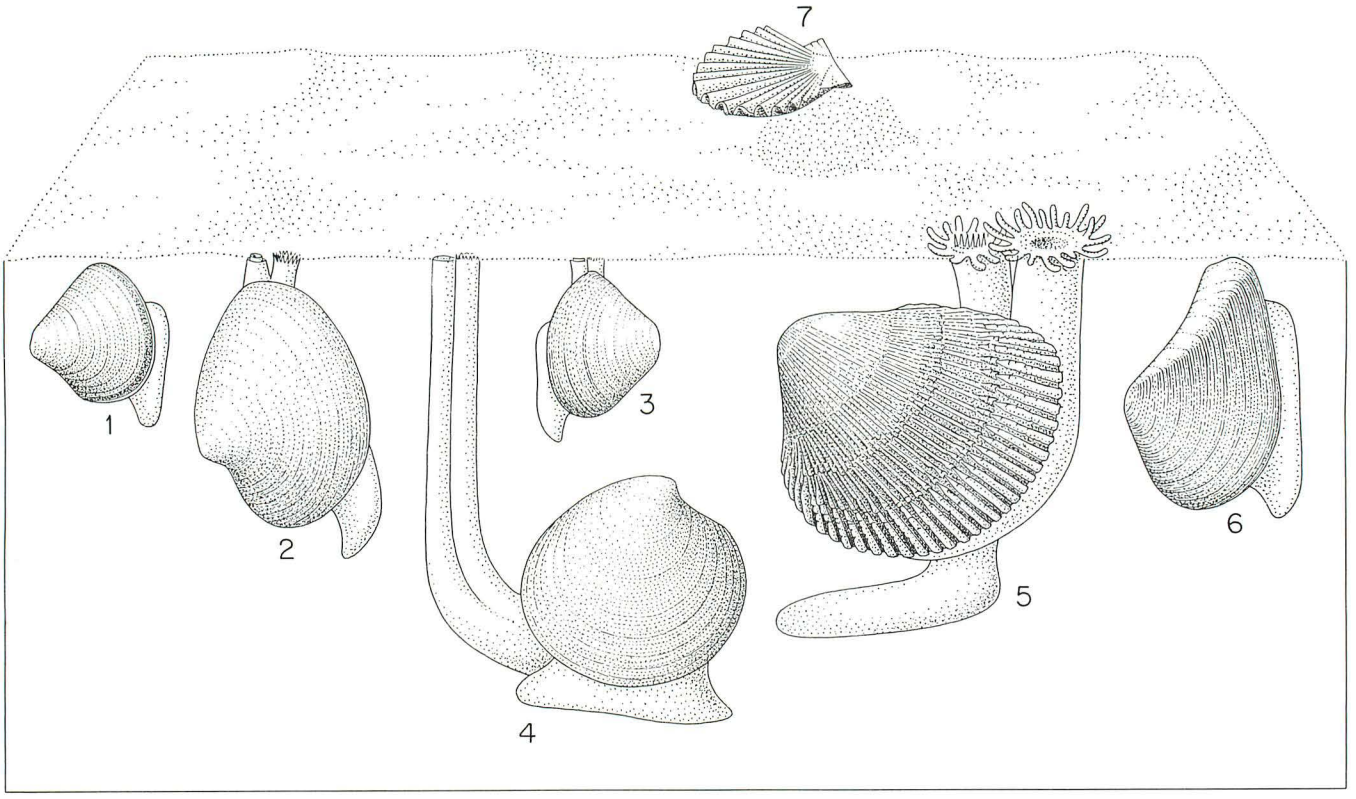


Figure 43: Organisms commonly occurring in the Boston Cliffs Member. The following illustrations show reconstructions of the life habits or occurrences: 1, *Astarte obruta;* 2, *Macrocallista marylandica;* 3, *Corbula idonea;* 4, *Dosinia acetabula;* 5, *Cerastoderma laqueata;* 6, *Crassatella marylandica;* 7, *Lyropecten madisonius.* (In part after Abbott, 1954; Ansell, 1961; Keen, 1958; Mac Ginitie and Mac Ginitie, 1949; Salenddin, 1965; Tebble, 1966; Thorson, 1957; Yonge, 1949b).

analysis of these sedimentological characteristics, it appears that the Conoy Member was deposited in deeper environments than the preceding members.

This interpretation is supported by the microfauna. In comparison with assemblages from lower units of the Choptank, many deeper-water species have increased in abundance in the Conoy Member while many shallow-water species have decreased.

Foraminifera that are markedly increased in abundance and importance in the Conoy Member are: *Nonion mediocostatum, Nonion pizarrense, Textularia candeiana,* and *Lagena* spp. The following shallow-water species show a distinct decrease in abundance and importance: *Bolivina paula, Buliminella elegantissima, Cibicides lobatulus, Quinqueloculina seminula, Sigmomorphina concava,* and *Textularia gramen.*

A similar trend occurs in the Ostracoda. The following deep-water species show an increase in abundance and importance in the Conoy Member: *Cytheropteron* sp., *Echinocythereis clarkana, Henryhowella evax, Pterygocythereis americana.* Complementing that increase, several shallow-water ostracodes decrease in abundance and importance: *Campylocythere laevissima, Semicytherura coryelli, Semicytherura forulata, Semicytherura reticulata, Eucythere gibba, Haplocytheridea bassleri, Hulingsina ashermani,* and *Tetracytherura shattucki.*

Even though the faunal and sedimentological characteristics of the Conoy Member indicate that it was deposited in significantly deeper water than the other members, it still represents environments of the fairly shallow continental shelf. In the outcrop area sediments of the Conoy were probably deposited in about 35 to 50 meters of open ocean water.

The fauna strongly indicates that the Conoy sediments were deposited in cool temperate water. A few species indicating warmer water occur as very small percentages of the fauna. This probably indicates closer proximity to the warm temperate boundary than to the cold temperate boundary. In fact, the only Choptank occurrence of *Cytherella* sp., a warm-water ostracode, was in the Conoy Member at Horsehead Cliffs, Virginia.

Fossils indicate that this member was probably deposited in environments similar to those found today between the mouth of the Chesapeake Bay and Cape Hatteras. The surface water of this area has a mean annual temperature of about 15 to 20°C. (Ekman, 1953, p. 57).

The Conoy Member and the Choptank Formation are terminated above by an erosional and depositional unconformity (figs. 4, 23) as discussed previously. Possible local uplift followed the Choptank creating a shallow basin in the Camp Conoy—Flag Ponds vicinity. This basin was then filled with sediments of the St. Marys Formation. The erosional nature of the unconformity may be seen elsewhere as well (fig. 5).

ORIGIN OF THE CHOPTANK SHELL BEDS

Since 1685, when Martin Lister published a figure of *Ecphora quadricostata* from the Maryland Miocene, investigators have sought fossils from the prolific shell beds of the Chesapeake Group. Even though these deposits have been well collected for nearly 300 years, very few investigators have been concerned over the manner in which they were formed. Consequently, to date little speculation has been raised as to their origin. Mongin (1959) felt they represented transgressive beach accumulations. A second suggestion was made by Fowler (1966) who thought they were "concentrations formed by storm waves which winnowed out the clay sized particles."

While the two major shell beds, the Drumcliff and Boston Cliffs Members, are distinctly different, they share several characteristics critical to the understanding of their origins and are considered to have been deposited in the same way. Probably the most striking feature of the shell beds is the prolific concentration of fossils (figs. 18, 20, 21). Their common coloration is very light to dark brown with shades of orange and yellow, in contrast to the "non-shell" beds which are predominantly dusky blue to dusky green. Additionally, these units show a general lack of inorganic and biogenic sedimentary structures.

Closer examination of these deposits reveals that they are not homogeneous. Rather, they consist of intergrading beds of abundant, densely packed, large shells with beds of less abundant, less densely packed, smaller shells (figs. 10, 12, 18). At some localities the macrofossil beds which are reduced in concentration, quantity, and size of shells are much better sorted than the increased beds. This sedimentological association is much more common in the Drumcliff than in the Boston Cliffs Member. The difference in sorting rarely involves variation in the larger grain sizes but instead concerns the quantity of mud and silt. As a result, where the difference in sorting is very pronounced, as at Drumcliff, an accompanying color change makes the units even more distinct. The well-sorted units, predominantly sand, are light tan to very pale orange, whereas those poorly sorted, with increased mud and silt, are darker browns. Thus the reduced macrofossil beds are much lighter in color than the increased macrofossil beds.

One very important characteristic is that nearly all of the infaunal bivalves are found flat lying (fig. 20) as are most of the other large bivalves. In addition, many of these flat-lying shells are articulated, double valves. Of course, the living position of most infaunal bivalves is with the hingeline perpendicular to the sea floor, not parallel as in the Choptank shell beds.

This constitutes an important reorientation rule for the shallow- burrowing bivalves. The one exception to the rule is the group of very deep-burrowing bivalves, which includes *Panope* and *Mya*. These shells are always found vertical and double-valved in the Choptank, yet with no associated burrow structure.

If Mongin (1959) was correct in suggesting that the shell beds were transgressive beach deposits, the shells should be well-worn, fragmented, and covered with encrusting organisms such as bryozoans, barnacles, worm tubes, molluscs etc. Even if these shells merely rested on the ocean floor after death and were forming prolific beds by a more or less "normal" accumulation, they should be covered with attached animals. However, encrusted infaunal bivalves are exceedingly rare in the Choptank. The shells are usually very well preserved with nearly all features of ornamentation remaining. In fact, some seldom-preserved features, *e.g.* hinge ligament and shell coloration, are present at various localities. Markings are found on a few infaunal bivalves suggesting inter-

relationship with other animals. However, these marks are predominantly the traces of two groups of animals—the naticid snails and the polychaete worms. Since these animals themselves are burrowers, the infaunal bivalves were victims of "subsurface attacks", not "seafloor attacks" as would occur with exposed shells.

As pointed out by E. G. Kauffman (personal communication), the hard shell substrate, formed by preexisting shell beds, would be impossible burrowing locations for future generations. Hence, after a shell pavement was formed, even a thin one, future generations of infaunal bivalves would not return until a soft bottom was once again established. Yet, these shell beds range from a few feet to about 30 feet thick.

Another problem that must be resolved is the apparent "super-productivity" of the shell beds. A tremendously large number of fossils, not to mention unpreserved organisms, occur in a comparatively small volume of sediments. Such apparently high productivity is unknown in modern environments.

One of the most amazing characteristics of the Drumcliff and Boston Cliffs Members is their extreme lateral extent. The beds can be traced in dip section, particularly along the Chesapeake Bay, for miles and can be correlated along strike for even greater distances. In short, these beds are found throughout the area of outcrop. One notable example of this great extent is found in the Boston Cliffs Member in which the same sequence of units can be found both at its type locality on the Choptank River and 60 miles away at the Nomini Cliffs of Virginia.

Mongin's (1959) suggestion that the shell beds were transgressive beach accumulations can be eliminated on the basis of the following considerations. First, a deposit as she envisioned would be made up almost entirely of shells that are well worn, fragmented, and covered with encrusting organisms. Such is not the case in the Choptank, especially for the infaunal bivalves. Second, the faunal evidence indicates deposition occurred on the inner shelf and not on a beach. Third, inorganic sedimentary structures indicative of a beach are absent. Lastly, while the Drumcliff Member developed during moderate transgressive conditions, the lower and central parts of the Boston Cliffs Member were produced during a regression.

Fowler's (1966) idea that storm waves winnowed out clay sized particles to concentrate shells approaches a more reasonable explanation of the facts. Unfortunately, his brief remark gave neither adequate understanding of how he envisioned the mechanism to operate nor any evidence to support his contention. Additionally, no attempt was made to explain the relationship of the hypothesis to the various characteristics of the shell beds. In fact his mechanism in itself does not appear to explain the alternating densities of shells, the color differences from shell to non-shell beds, the flat-lying nature of infaunal bivalves as contrasted with the living position of deep burrowers, the lack of encrusting organisms on infaunal organisms contrasted with their presence on epifauna, and how future bivalves would burrow through hard shell substrates. This last point is very important since several generations of organisms are required to produce deposits the thickness of the Drumcliff or Boston Cliffs Members.

Van Straaten (1952) recognized a shell bed at 20 to 30 centimeters below the sediment-water interface in the Dutch Wadden Sea. Since he found the worm *Arenicola* burrowing to the same depth and drawing food down through a tunnel, he suggested that the shell bed was a biogenic concentration. It seems unbelievable that the feeding of marine worms could concentrate such an even bed extending for miles as he described it. According to his own diagram (Van Straaten, 1952 fig. 4), the larger bivalves would be much too large to "tumble" down a worm's feeding shaft. Perhaps Van Straaten had the cause and effect reversed. Possibly because the hard shell horizon was present the worms did not burrow through it but only to it. At any rate, it seems beyond the ability of marine worms to concentrate the large Choptank bivalves (*e.g.*, 15-centimeter *Lycropectens*, 11 centimeter *Macrocallistas*, 12 centimeter *Mercenarias*, 8 centimeter *Crassatellas*). This feat is further complicated in the Choptank by the extreme lateral extent of the shell beds. The final evidence against this theory is the lack of biogenic structures in the shell beds.

Haas (1940) described molluscan accumulations resulting from tropical storms. However, the deposits he described were much more local and variable than the Choptank shell beds. He also mentioned that one of the important zones of accumulation involved shells ground and pulverized to beach sand. No comparable unit exists in the Choptank.

Different types of mass mortality in the sea were reviewed by Brongersma-Sanders (1957). Investigators have attributed large-scale dying to such factors as volcanism, earthquakes, tsunamis, salinity changes, temperature changes, "red tide", and poisonous gases. However, these phenomena generally act only on a very few species, and seldom, if ever, cause great disasters for the infaunal

communities. Mass mortalities are also insufficient for explaining the thickly stacked appearance of flat-lying bivalves.

One possible solution that must be considered is what might be called a "normal biological accumulation". In order to have so many fossils in the given amount of sediment some modification must be applied to the basic mechanism, *e.g.*, winnowing of fine sediment or very little accompanying sedimentation.

Unfortunately, this mechanism, even with modifications, fails to explain several of the characteristics of the Choptank shell beds. Probably the most basic problems associated with this mechanism concerns the life habits of the burrowing bivalves. Since the shallow and medium depth infaunal bivalves are not found in living position but are found flat-lying, their reorientation must be explained. If a bivalve ascended from its burrow, it might die on its side; but then the muscles and hinge ligament would decompose, the paired valves would be disassociated, and the hard shells would become encrusted by several types of organisms. The mechanism fails to explain the articulation and absence of epifauna on valves in the Choptank. Maybe even more fundamental is the question "Why would the bivalves leave their homes in the first place?" The ability to construct burrows is their adaptation for protection. These are not structures to be abandoned in time of trouble.

In addition to not accounting for the flat-lying occurrence of the shallow-burrowers, the "normal biological accumulation" mechanism fails to explain why the deep-burrowing bivalves are always found in the opposite orientation, that is, the normal, vertical, living position. It also does not justify the absence of burrows of the deep infaunal bivalves. The dusky blue to dusky green color of the "non-shell" beds must be a result of slightly reducing conditions below the sediment-water interface, whereas the light brown colors of the shell beds must be a result of slight oxidation. The "normal accumulation" mechanism cannot account for the difference.

This mechanism was used to explain shell deposits that may be near-modern analogs of the Choptank. Coleman and Gagliano (1964, p. 70) reported a "four foot thick concentration of shells and shell debris" in the vicinity of the Mississippi River Delta. Microfaunal evidence from the shell beds indicated deposition in 60 to 80 feet of marine water. Later they added (Coleman and Gagliano, 1965, p. 143): "Shell concentrations or 'hashes' range in thickness from 5 cm. to 1 meter or more and show a dominance of organic over detrital deposition. Shell 'hashes' represent conditions of virtually no deposition or erosion. . . . Deep borings in the birdfood delta have demonstrated that these shell beds are widespread and continuous, forming excellent stratigraphic markers."

The Gulf of Mexico shell beds appear very much like those of the Choptank. A "normal accumulation" with little sedimentation and erosion could be a valid explanation for these beds only if all the organisms are epifaunal. No mention was made about the life habits of animals in the deposits.

The continental shelf off the mouth of the Chesapeake Bay is another area known to have shell concentrations below the sediment-water interface. These deposits were skillfully described by Powers and Kinsman (1953) suggesting relationship to the traction zone in underwater sediments. They recognized two zones in the substrate. The upper zone had better sorting, smaller grain size, more abundant microfauna, and less abundant macrofauna than the lower zone. Conversely, the lower zone had poorer sorting, larger grain size occasionally including gravel, less abundant microfauna, and more abundant macrofauna than the upper. They called the upper the "traction zone" and the lower one the "accumulation zone". These two zones seem to be essentially the same as the reduced and increased macrofossil beds in the Choptank.

Powers and Kinsman (1953) related the vertical sorting, which creates the traction and accumulation zones, to the passing of marine swell. The typical period of swell reaching the U. S. coast is from 6 to 16 seconds with rare reports to as high as 22.5 seconds. According to Powers and Kinsman (1953) a swell with a period of 12 seconds would produce horizontal current velocities of more than 0.3 foot per second in water 70 feet deep. This would be sufficient to establish a pressure gradient on the bottom causing flow into the sediment and flow out accompanied by effusion of the substrate. At some depth the lifting action ceases and at that level they identified the base of the traction zone.

They suggested that "for a given water depth and swell period the permeability of the sediment is the most important factor determining the traction zone thickness. In other words, the more freely the water can circulate in the sediment, the greater will be the lifting effect." This would explain why the traction zone is thinner where the grain size and sorting is less, as Powers and Kinsman observed. In fact, they found no traction zone in the clay cores.

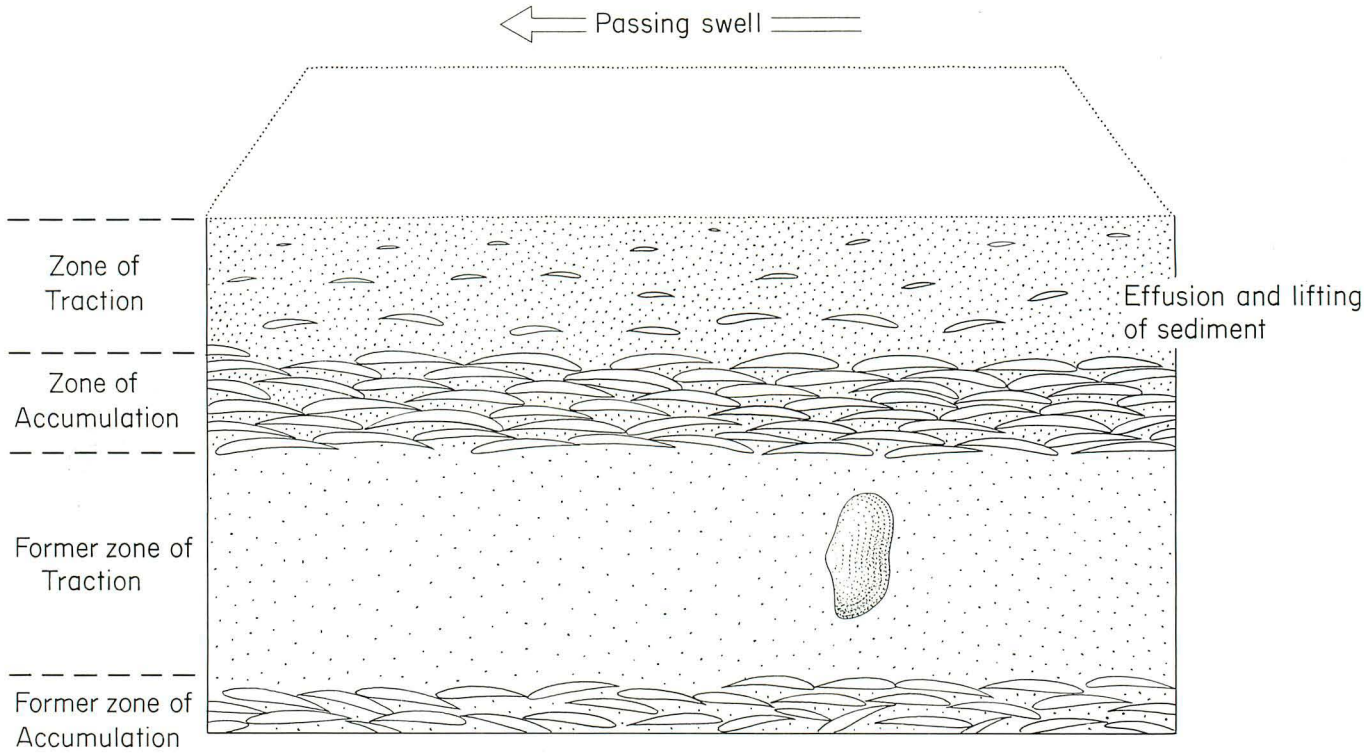


Figure 44: Mechanism of shell bed accumulation. Note shallow and medium depth infaunal bivalves in flat-lying position in zone of accumulation and deep burrowing *Panope* in living position.

They also recognized the importance of diminished wave energy with increased water depth. In their investigation (Powers and Kinsman, 1953) shell beds were found in 45 to 145 feet of open marine water.

This mechanism of passing marine swell creating zones of traction and accumulation seems quite sufficient to account for the alternation of reduced and increased macrofossil beds (figs. 10, 44) in the Choptank. The lifting effect caused by traction would also result in slight oxidation of the organic matter in the sediments, thus explaining color differences between the shell beds and the "non-shell" beds.

Traction on the bottom sediments also resolves the problems associated with the shallow infaunal bivalves. Since any given swell consists of a group of waves, the effect on the bottom is an alternation of flow into the substrate, accompanied by pressure, and flow out of the substrate, accompanied by release of pressure, with lifting and effusion of the sediment. During this confusion the bivalve, stationed in the middle of all the action, must have taken in quantities of harmful sediment. Even more likely though would be a reorientation of the bivalve as a result of the physical threshing. As the animal is lifted and released a more likely position is relocation on a flat side rather than on edge. Experimental evidence by Armstrong (1925) in the nearshore waters of California showed that reorientation of infaunal bivalves to greater than 45° away from the preferred living position would be fatal. Thus it appears that mere reorientation in the animal's own domain would leave it dead. This may account for well-preserved, double-valved, flat-lying specimens in the Choptank shell beds.

The passing of swell and subsequent swells could concentrate single and articulated valves in a subsurface zone of accumulation. In addition, this mechanism alleviates the need for accumulation of shells on the seafloor where they would get worn and be encrusted. Constant submersion in the substrate explains the lack of encrusting organisms on the shallow infauna.

One of the curious characteristics of the Choptank shell beds is that the snails do not seem as selectively confined to the increased and reduced macrofossil units as do the bivalves. In light of the traction mechanism, it might be that the empty snail shells were concentrated as the other shells, but the live snails had the ability to readjust after the passing of the swell.

The effective depth of the lifting force is indicated by the deep burrowing species of *Panope*. Since specimens of this genus are always found in living position, the operative limit of traction must have been less than their living depth of about 2 feet. Effusion of sediment above the bivalves also explains the lack of burrow structures associated with them.

The problem of concentrating specimens of scallop shells, particularly of living animals, is more complicated because of their free-swimming existence. However, a bivalve is not a very efficient swimmer and the churning of water with the passing swell may have thrown it to the sea-floor. The animal would be even more helpless if it were pressed upside down on the floor, and due to the convexity of the lower valve, the most stable resting position is upside down. With the effusion of silt and sand the scallop might have become partially mired in sediment, presenting a hopeless situation for its swimming mechanism to correct. Subsequent waves in the same swell buried the animal alive, thus preserving the valves intact as they are often found in the Choptank.

The lifting action in the zone of traction undoubtedly would remove existing sedimentary structures. This accounts for the absence of inorganic and biogenic structures in the Choptank shell beds.

Another observation of Powers and Kinsman (1953) correlates very well with the Choptank. They noted that the traction zone thickness varies with the degree of sorting, i.e., the thickness is greater in better sorted sediments and less in more poorly sorted sediments. This was explained to be a result of the greater degree of permeability in the sediments containing little mud. In the Choptank the Drumcliff Member sediments are better sorted and contain less mud than the sediments of the Boston Cliffs Member. To complete this contrast, the reduced macrofossil beds (=traction zone) of the Drumcliff are thicker than those of the Boston Cliffs Member.

One of the strongest attributes of the traction mechanism is its ability to account for the apparent "super-productivity" in the Choptank. Sandy and silty substrates of the shallow inner shelf typically support some of the largest bottom communities, but by themselves they could not produce the quantity seen in the shell beds. However, as each swell passes, a large part of the fossilizable bottom community is killed off and concentrated in the zone of accumulation. This leaves the substrate that was initially teeming with life barren of part of its population. A new recruitment of organisms finds the bottom nearly virgin. This cycle of events could continue until there is a major change in depositional environment. Enticement of recruits to virgin substrates followed by mortal threshing qualifies the Choptank as a sort of Venus's flytrap.

Since swells at any given location are fairly frequent and since the Choptank shell beds typically contain fossils at various stages of growth, it may be that only infrequent marine swells of very great magnitude produced these deposits. It is also possible that only major swells are sufficient to reorient entrenched infaunal bivalves. If these restrictions do require abnormally intense energy, the dense concentration of shells may have been related to tropical storms. At this stage of investigation the frequency and magnitude of marine swells sufficient to account for the Choptank shell beds is unknown.

The Choptank Formation has three "non-shell" members, in addition to the two major shell beds. As result, any theory for the origin of the shell accumulations must account for their absence elsewhere. In light of the mechanism proposed and data about modern deposits, an effective lower depth limit appears evident. The deeper environments and the high mud content in the Calvert Beach and Conoy Members probably account for the absence of concentrated shells in their sediments. In its outcrop the St. Leonard Member seems to represent marginal marine deposits. Powers and Kinsman (1953) did not find concentrated shell beds in the marginal marine Chesapeake Bay and suggested that this was a result of very little swell.

Inasmuch as inner shelf, concentrated shell beds have been found in modern sediments of the northwstern Atlantic Ocean, the Gulf of Mexico, and the Dutch Wadden Sea, and inasmuch as concentrated fossil shell beds have been found in inner shelf environments, these beds are likely to be much more important constituents in modern and fossil sediments than the little attention given to them indicates. The proposed swell-traction mechanism may have played a major role in inner shelf environments of the geological past.

DEPOSITIONAL HISTORY OF THE CHOPTANK FORMATION

The history of the Choptank Formation had its beginnings hundreds of millions of years before the Middle Miocene. Episodes of mountain building in the Paleozoic established structural trends and sediment source areas. During the Mesozoic, mobility of the Salisbury Embayment first appeared to be significant.

However, the events of the Tertiary gave the Choptank its real uniqueness. The mid-Tertiary was a time of great structural disturbance. The major Antillean Revolution in the Antillean-Caribbean region was shaping the destiny of the Gulf Stream which is of major significance to the marine and coastal climates of Eastern United States. More locally, regional uplift of the ancient Appalachian Mountains supplied great volumes of terrigenous detritus to streams that emptied into the Atlantic Ocean.

The mobile Salisbury Embayment was a locus of accumulation for such discharged sediment. The Chesapeake Group was deposited during the Middle and Late Miocene. While all of the units of this sequence were formed in the temperate marine climate of the Atlantic Coastal Plain, a definite warming trend persists from the earliest beds to the latest.

The first of the Chesapeake Group formations, the Calvert, was deposited in cool temperate marine waters on the continental shelf. The exact structural relationship between the Calvert and overlying Choptank Formation is uncertain, but it appears that the latter represented a shift to warmer and shallower water.

The lowest unit of the Choptank, the Calvert Beach Member, was deposited in the coldest water of any unit in the formation. Its environments were slightly inimical to many types of bottom communities as evidenced by the bivalve dominance of the Lucinacea. The Drumcliff Member represents a shallowing of environments on the inner shelf and possibly slight warming. According to the hypothesis set forward in this paper, marine swells, possibly related to tropical storms, passed through the area establishing zones of traction and accumulation in the bottom deposits. This physical mechanism concentrated shells into great beds.

Maximum shallowing occurred during the St. Leonard Member. Marginal marine depositional environments dominate this unit in outcrop. The best delineated of these is the lower bay environment, which occurs in the area of the modern Calvert Cliffs. The slight warming trend continued into the Boston Cliffs Member, but the shallowing trend of the lowest three members was reversed. This member represents a return to open inner shelf environments, where the bottom was again swept by marine swells concentrating great volumes of shells.

Sediments of the Conoy Member were deposited in distinctly deeper water yet still probably shallower than 50 meters. Like the previous Choptank Members, the Conoy was deposited under cold temperate marine climatic conditions. An erosional and depositional unconformity separates the Conoy from the overlying St. Marys Formation, which generally continues the deepening trend started in the Boston Cliffs Member.

REFERENCES

ABBOTT, R. T., *1954, American seashells: Princeton, New Jersey, D. Van Nostrand Company, 541 pp.*

ALLEN, J. A., *1958, On the basic form and adaptations to habitat in the Lucinacea: Phil. Trans. Royal Soc. London, ser. B, vol. 241, pp. 421-484.*

ANDERSON, J. L., *1948, Cretaceous and Tertiary subsurface geology: in Cretaceous and Tertiary subsurface geology, Dept. of Geology, Mines, and Water Resources, Bull. 2, pp. 1-112.*

ANSELL, A. D., *1961, The functional morphology of the British species of Veneracea (Eulamillibranchia): Jour. Mar. Biol. Assoc. United Kingdom, vol. 41, pp. 489-515.*

ARMSTRONG, LEE R., *1965, Burrowing limitations in Pelecypoda: The Veliger, vol. 7, no. 3, pp. 195-200.*

BANDY, ORVILLE L., *1961, Distribution of Foraminifera, Radiolaria, and diatoms in sediments of the Gulf of California: Micropaleontology, vol. 7, no. 1, pp. 1-26.*

BENDA, W. K. & PURI, H. S., *1962, The distribution of Foraminifera and Ostracoda off the Gulf Coast of Cape Romano area, Florida: Gulf Coast Assoc. Geol. Socs., Trans., vol. 12, pp. 303-341.*

BENSON, R. H. & COLEMAN, G. L., *1963, Recent marine ostracodes from the eastern Gulf of Mexico: The Univ. of Kansas Paleont. Contr., Arthropoda, article 2, pp. 1-52.*

BOEKSCHOTEN, G. J., *1966, Shell borings of sessile epibiontic organisms as palaeoecological guides (with examples from the Dutch Coast): Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 2, pp. 333-379.*

———, *1967, Palaeoecology of some Mollusca from the Tielrode sands (Pliocene, Belgium): Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 3, pp. 311-362.*

BOSS, K. J., *1965, Symbiotic Erycinacean bivalves: Malacologia, vol. 3, no. 2, pp. 183-195.*

BRADY, G. S., *1870, Contributions to the study of Entomostraca, V, Recent Ostracoda from the Gulf of St. Lawrence: Ann. Mag. Nat. History, ser. 4, vol. 6, pp. 450-454.*

——— & NORMAN, A. M., *1896, A monograph of the marine and freshwater Ostracoda of the North Atlantic and of Northwestern Europe, Section 1, Podocopa: Sci. Trans. Royal Dublin Soc., vol. 5, ser. 2, pp. 63-270.*

BRONGERSMA-SANDERS, M., *1957, Mass mortality in the sea: Geol. Soc. America, Mem. 67, vol. 1, pp. 941-1010.*

CARRIKER, M. R. & YOCHELSON, E. L., *1968, Recent gastropod boreholes and Ordovician cylindrical borings: U. S. Geol. Survey Prof. Paper 593-B, 26 pp.*

CARTER, R. M., *1968, On the biology and palaeontology of some predators of bivalved Mollusca: Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 4, pp. 29-65.*

COLEMAN, J. M. & GAGLIANO, S. M., *1964, Cyclic sedimentation in the Mississippi River deltaic plain: Gulf Coast Assoc. Geol. Soc., Trans., vol. 14, pp. 67-80.*

——— & ———, *1965, Sedimentary structures: Mississippi River deltaic plain: In: Primary sedimentary structures and their hydrodynamic interpretation, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. no. 12, pp. 133-148.*

CRAIG, G. Y., *1967, Size-frequency distributions of living and dead populations of pelecypods from Bimini, Bahamas, B. W. I.: Jour. Geol., vol. 75, no. 1, pp. 34-45.*

——— & HALLAM, A., *1963, Size-frequency and growth ring analyses of Mytilus edulis and Cardium edule, and their palaeoecological significance: Palaeontology, vol. 6, pp. 731-750.*

——— & OERTEL, *1966, Deterministic models of living and fossil populations of animals: Geol. Soc. London Quart. Jour., vol. 122, pp. 315-355.*

CURTIS, DORIS MALKIN, *1960, Relation of environmental energy levels and ostracod biofacies in east Mississippi Delta area: Am. Assoc. Petroleum Geologists, vol. 44, no. 4, pp. 471-494.*

CUSHMAN, J. A., *1906, Marine Ostracoda of Vineyard Sound and adjacent waters: Boston Soc. Nat. History, Proc., vol. 32, no. 10, pp. 359-385.*

——— & CAHILL, E. D., *1933, Miocene Foraminifera of the Coastal plain of eastern United States: U. S. Geol. Survey Prof. Paper 175-A, 50 pp.*

DALL, W. H., *1904, The relations of the Miocene of Maryland to that of other regions and to the Recent fauna: in Miocene Volume, Maryland Geol. Survey, pp. cxxxix-clv.*

DARBY, DAVID G., *1965, Ecology and Taxonomy of Ostracoda in the vicinity of Sapelo Island, Georgia: in Four Reports of Ostracod Investigations Conducted under National Science Foundation Project GB-26, rept. no. 4, 76 pp.*

DARTON, N. H., *1891, Mesozoic and Cenozoic formations of eastern Virginia and Maryland: Bull. Geol. Soc. America, vol. 2, pp. 431-450.*

DEEVEY, E. S., *1947, Life tables for natural populations of animals: Quart. Rev. Biology, vol. 22, pp. 283-314.*

DORSEY, A., *1948, Miocene Foraminifera from the Chesapeake Group of Southern Maryland, in Cretaceous and Tertiary subsurface geology: Dept. Geology, Mines and Water Resources, State of Maryland, Bull. 2, pp. 268-321.*

EDWARDS, R. A., *1944, Ostracoda from the Duplin Marl (Upper Miocene) of North Carolina: Jour. Paleontology, vol. 18, no. 6, pp. 505-528.*

EKMAN, S., *1953, Zoogeography of the sea: London, Sidgwick and Jackson Limited, 417 pp.*

ELLIOTT, H. A., ELLISON, R. & NICHOLS, M. M., *1966, Distribution of Recent Ostracoda in the Rappahannock Estuary, Virginia: Chesapeake Science, vol. 7, no. 4, pp. 203-207.*

ENGEL, P. L., & SWAIN, F. M., *1967, Environmental relationships of Recent Ostracoda in Mesquite, Aransas, and Copano Bays, Texas Gulf Coast: Gulf Coast Assoc. Geol. Soc., Trans., vol. 17, pp. 408-427.*

FAGERSTROM, *J. A., 1964, Fossil communities in paleoecology: their recognition and significance: Geol. Soc. America Bull., vol. 75, pp. 1197-1216.*

FOWLER, D. R., *1966, Miocene paleoecology in Calvert County, Maryland: unpubl. MS Thesis, Northwestern University, 109 pp.*

FRETTER, V. & GRAHAM, A., *1962, British prosobranch molluscs: London, Ray Soc., no. 144, 755 pp.*

GALTSOFF, PAUL S., *1964, The American oyster Crassostrea virginica Gmelin: Fishery Bull. of the Fish and Wildlife Service, Vol. 64, 480 pp.*

GARDNER, JULIA, *1917, The environment of the Tertiary marine faunas of the Atlantic Coastal Plain: The Johns Hopkins Univ. Circular, no. 293, pp. 234-242.*

———, *1943, Mollusca from the Miocene and Lower Pliocene of Virginia and North Carolina, Pt. 1, Pelecypoda: U. S. Geol. Survey Prof. Paper 199-A, 144 pp.*

———, *1948, Mollusca from the Miocene and Lower Pliocene of Virginia and North Carolina, Pt. 2, Scaphoda and Gastropoda: U. S. Geol. Survey Prof. Paper 199-B, 100 pp.*

GERNANT, R. E. & KESLING, R. V., *1966, Foraminiferal paleoecology and paleoenvironmental reconstruction of the Oligocene Middle Frio in Chambers County, Texas: Gulf Coast Assoc. Geol. Soc., Trans., vol. 16, pp. 131-158.*

GIBSON, T. G., *1962, Benthonic Foraminifera and paleoecology of the Miocene deposits of the middle Atlantic Coastal Plain: unpublished Ph.D. dissertation, Princeton Univ., v + 198 pp.*

———, *1966, Paleoenvironments and basin mobility in the Miocene of the Atlantic Coastal Plain abst.: in Abstracts for 1966, Geol. Soc. America, Spec. Paper no. 101, p. 436.*

GLENN, L. C., *1904, Systematic paleontology, Miocene Pelecypoda: in Maryland Geol. Survey, Miocene Vol., pp. 274-401.*

GROSSMAN, STUART, *1961, Living and subfossil rhizopod and ostracode populations: in Ecology of Rhizopeda and Ostracoda of southern Pamlico Sound region, North Carolina, Univ. Kansas Paleont. Contr., article 1, part 1, pp. 1-82.*

HAAS, FRITZ, *1940, Ecological observations on the common mollusks of Sanibel Island, Florida: Am. Midland Naturalist, vol. 24, no. 2, pp. 369-378.*

HACK, JOHN T., *1955, Geology of the Brandywine area and origin of the upland of southern Maryland: U. S. Geol. Survey Prof. Paper 267-A, iv + 42 pp.*

HALL, D. D., *1965, Paleoecology and taxonomy of fossil Ostracoda in the vicinity of Sapelo Island, Georgia: in Four Reports of Ostracod Investigations Conducted under National Science Foundation Project GB-26, Rept. 4, vi + 79 pp.*

HALLAM, A., *1967, The interpretation of size-frequency distributions in molluscan death assemblages: Palaeontology, vol. 10, pt. 1, pp. 25-42.*

HAZEL, JOSEPH E., *1967, Classification and distribution of Recent Hemicytheridae and Trachylebridae (Ostracoda) off Northeastern North America: U. S. Geol. Survey Prof. Paper 564, 49 pp.*

HOWE, H. V., *1941, Use of soap in the preparation of samples for micropaleontologic study: Jour. Paleontology, vol. 15, p. 691.*

HOWE, H. V., *and others, 1935, Ostracoda of the* Arca *zone of the Choctawhatchee Miocene of Florida: Florida Geol. Survey Bull. 13, 47 pp.*

HULINGS, NEIL, C., *1966, Marine Ostracoda from western North Atlantic Ocean off the Virginia Coast: Chesapeake Science, vol. 7, no. 1, pp. 40-56.*

———, *1967a, A review of the Recent marine podocopid and platycopid ostracods of the Gulf of Mexico: Contr. Marine Sci., vol. 12, pp. 80-100.*

———, *1967b, Marine ostracoda from the western North Atlantic Ocean between Cape Hatteras, North Carolina and Jupiter Inlet, Florida: Bull. Marine Sci., vol. 17, pp. 629-659.*

——— & PURI, H. S., *1964, The ecology of shallow-water ostracods of the west coast of Florida: Publ. Stazione zool. Napoli, vol. 33, pp. 308-344.*

HUNTER, W. R., *1949, The structure and behavior of* Hiatella: *Proc. Royal Soc. Edinburgh, B, vol. 63, pp. 271-289.*

JOHNSON, C. W., *1934, List of the marine mollusca of the Atlantic Coast from Labrador to Texas: Proc. of the Boston Soc. of Nat. History, vol. 40, no. 1, pp. 1-204.*

KEEN, A. MYRA, *1958, Sea shells of tropical West America: Stanford, California, Stanford Univ. Press, xii + 624 pp.*

KELLING, G. & WILLIAMS, P. F., *1967, Flume studies of the reorientation of pebbles and shells: Jour. Geology, vol. 75, no. 3, pp. 243-267.*

KRUMBEIN, W. C., & SLOSS, L. L. *1963, Stratigraphy and sedimentation, San Francisco, W. H. Freeman & Company, 660 p.*

LEVER, J., *1958, Quantitative beach research, I: the left-right phenomenon: sorting of lamellibranch valves on sandy beaches: Basteria, vol. 22, pp. 21-51.*

———, BOSCH, M. VAN DEN, COOK, H., DIJK, T. VON, THIADENS, A. J. H., & THIJSSEN, R., *1964, Quantitative beach research: III. An experiment with artificial valves of* Donax vittatus: *Neth. Jour. Sea Research, vol. 2, pp. 458-492.*

MAHER, JOHN C., *1965, Correlations of subsurface Mesozoic and Cenozoic rocks along the Atlantic Coast: Tulsa, Oklahoma, Am. Assoc. Petroleum Geologists, 18 pp.*

MACGINITIE, G. E. & MACGINITIE, N., *1949, Natural history of marine animals: New York, McGraw-Hill Book Company, Inc., xii + 473 pp.*

MALKIN, DORIS S., *1953, Biostratigraphic study of Miocene Ostracoda of New Jersey, Maryland, and Virginia: Jour. Paleontology, vol. 27, no. 6, pp. 761-799.*

MARTIN, G. C., *1904, Systematic paleontology, Miocene Gastropoda: in Maryland Geol. Survey, Miocene Vol., pp. 131-270.*

MCALESTER, A. L. & RHOADS, D. C., *1967, Bivalves as bathymetric indicators: Marine Geology, vol. 5, pp. 383-388.*

MCLEAN, J. D., JR., *1956, The Foraminifera of the Yorktown formation in the York-James Peninsula of Virginia, with notes on the associated mollusks: Bull. Am. Paleontology, vol. 36, no. 160, 113 pp.*

———, *1957, The Ostracoda of the Yorktown formation in the York-James Peninsula of Virginia: Bull. Am. Paleontology, vol. 38, no. 167, pp. 52-103.*

MONGIN, DENISE, *1959, Study of some American Miocene lamellebranchs and comparison with related European species: Bull. Am. Paleontology, vol. 39, no. 180, pp. 283-343.*

MORKHOVEN, F. P. C. M. VAN, *1963, Post-Paleozoic Ostracoda, their morphology, taxonomy, and economic use: Amsterdam, Elsevier, vol. 2 (generic descriptions), 478 pp.*

PARKER, F. L., *1948, Foraminfera of the continental shelf from the Gulf of Maine to Maryland: Bull. Mus. Comp. Zoology, vol. 100, no. 2, pp. 213-241.*

———, *1952, Foraminiferal distribution in the Long Island Sound-Buzzards Bay area: Bull. Mus. Comp. Zoology, vol. 106, no. 10, pp. 427-473.*

PHLEGER, FRED B., *1952, Foraminifera ecology off Portsmouth, New Hampshire: Bull. Mus. Comp. Zoology, vol. 106, no. 8, pp. 315-390.*

———, *1960, Ecology and distribution of Recent Foraminifera: Baltimore, The Johns Hopkins Press, 297 pp.*

POTTER, P. E. & PETTIJOHN, F. J., *1963, Paleocurrents and basin analysis: New York, Academic Press, 296 pp.*

POWERS, MAURICE C. & KINSMAN, BLAIR, *1953, Shell accumulations in underwater sediments and their relation to the thickness of the traction zone: Jour. Sedimentary Petrology, vol. 23, no. 4, pp. 229-234.*

PURI, H. S., *1953, Contribution to the study of the Miocene of the Florida panhandle: Florida Geol. Survey Bull. 36, 354 pp.*

———, *1958, Ostracode genus Cushmanidea: Gulf Coast Assoc. Geol. Soc., Trans., vol. 8, pp. 171-180.*

———, *1960, Recent Ostracoda from the west coast of Florida: Gulf Coast Assoc. Geol. Soc., Trans., vol. 10, pp. 107-149.*

———, *1966, Ecologic distribution of Recent Ostracoda: Proc. of the Symposium on Crustacea, part 1, Mar. Biol. Assoc. of India, Mandapam Camp., pp. 457-495.*

———, BONADUCE, GIOACCHINO, & MALLOY, JOHN, *1964, Ecology of the Gulf of Naples: Publ. staz. zool. Napoli, vol. 33 suppl., pp. 87-199.*

———, & HULINGS, N. C., *1957, Recent ostracode facies from Panama City to Florida Bay area: Gulf Coast Assoc. Geol. Soc., Trans., vol. 7, pp. 167-190.*

REINECK, HANS-ERICH, *1958, Wühlbau-Gefüge in Abhängigkeit von Sediment-Umlagerungen: Senckenbergiana leth., vol. 39, pp. 1-23.*

RICHARDS, H. G., *1948, Studies on the geology and paleontology of the Atlantic Coastal Plain: Acad. Nat. Sci. Philadelphia Proc., vol. 100, 39-76.*

———, & HARBISON, A., *1942, Miocene invertebrate fauna of New Jersey: Proc. Acad. Nat. Sci. Phila., vol. 94, pp. 167-250.*

SALEUDDIN, A. S. M., *1965, The mode of life and functional anatomy of* Astarte *spp. (Eulamellibranchia): Proc. Malac. Soc. London, vol. 36, pp. 229-257.*

SCHAFER, WILHELM, *1962, Aktuo-Paläontologie nach Studien in der Nordsee: Frankfurt-am-Main, Verlag Waldemar Kramer, 666 pp.*

SCHOONOVER, L. M., *1941a, A Miocene echinoid colony from Maryland: Jour. Paleontology, vol. 15, no. 1, pp. 92-93.*

———, *1941b, A stratigraphic study of the mollusks of the Calvert and Choptank formations of southern Maryland: Bul. Am. Paleontology, vol. 25, no. 94B, pp. 169-299.*

SHATTUCK, G. B., *1904, Geological and paleontological relations, with a review of earlier investigations: in Miocene Vol., Maryland Geol. Survey, pp. xxxiii-cxxxvii.*

SLOBODKIN, L. B., *1961, Growth and regulation of animal populations: New York, Holt, Rinehart & Winston, 184 pp.*

STRAATEN, L. M. J. U. VAN, *1952, Biogene textures and the formation of shell beds in the Dutch Wadden Sea: Koninkl: Nederl. Akad. Wettensch, ser. B, vol. 55, pp. 500-516.*

SUMNER, F. B., OSBURN, R. C., & COLE, L. J., *1913, A biological survey of the waters of Woods Hole and vicinity, 2 parts: U. S. Bur. Fisheries Bull., vol. 31, pp. 1-860.*

SWAIN, F. M., *1948, Ostracoda from the Hammond well: Maryland Dept. Geology, Mines, and Water Resources, Bull. 2, pp. 187-212.*

———, *1951, Ostracoda from wells in North Carolina, Part 1, Cenozoic Ostracoda: U. S. Geol. Survey Prof. Paper 234-A, 58 pp.*

———, *1955, Ostracoda of San Antonio Bay, Texas: Jour. Paleontology, vol. 29, pp. 561-646.*

TEBBLE, NORMAN, *1966, British bivalve seashells: Trustees of the British Museum (Natural History), London, 212 pp.*

THORSON, GUNNAR, *1957, Bottom communities (sublittoral or shallow shelf): Geol. Soc. America, Mem. 67, vol. 1, pp. 461-534.*

TODD, RUTH & LOW, DORIS, *1961, Near-shore Foraminifera of Martha's Vineyard Island, Massachusetts: Contr. Cushman Foundation for Foraminiferal Research, vol. 12, part 1, pp. 5-21.*

TRESSLER, W. L. & SMITH, ESSIE M., *1948, An ecological study of seasonal distribution of Ostracoda, Solomons Island, Maryland: Chesapeake Biol. Lab. Pub., no. 71, pp. 3-57.*

ULRICH, E. O. & BASSLER, R. S., *1904, Systematic paleontology, Miocene Ostracoda: in Maryland Geol. Survey, Miocene Vol., pp. 98-130.*

VANUXEM, LARDNER, *1828, Geological observations on the Secondary, Tertiary, and Alluvial Formations of the Atlantic Coast of the United States of America. Arranged from the notes of Lardner Vanuxem, by S. G. Morton: Jour. Acad. Nat. Sci. Philadelphia, vol. vi, part 1, pp. 59-71.*

VOKES, HAROLD E., *1957, Miocene fossils of Maryland: Dept. Geology, Mines, and Water Resources, Bull. 20, 85 pp.*

WAGNER, C. W., *1957, Sur les Ostracodes du Quaternaire Récent des Pays-Bas et leur Utilization dans L'Étude Géologigue des Dépots Holocènes: The Hague, Netherlands, Mouton & Co., 158 pp.*

WILCOXON, J. A., *1964, Distribution of Foraminifera off the southern Atlantic Coast of the United States: Contr. Cushman Foundation for Foraminiferal Research, vol. 15, part 1, pp. 1-24.*

WILLIAMS, ROGER B., *1966, Recent marine podocopid Ostracoda of Narragansett Bay, Rhode Island: The Univ. of Kansas Paleont. Contr. Paper 11, 36 pp.*

YONGE, C. M., *1939, The protobranchiate Mollusca: a functional interpretation of their structure and evolution: Phil. Trans. Royal Soc. London, ser. B, vol. 230, pp. 79-149.*

———, *1946, On the habits of* Turritella communis *Risso: Jour. Marine Biol. Assoc., vol. 26, pp. 377-380.*

———, *1949a, On the structure and adaptations of the Tellinacea, deposit-feeding Eulamellibranchia: Phil. Trans. Royal Soc. London, ser. B, vol. 234, pp. 29-76.*

———, *1949b, The sea shore: London, Collins Cleartype Press, 311 pp.*

APPENDICES

APPENDIX I

DESCRIPTION OF SELECTED OUTCROPS

All of the Choptank outcrops visited were studied in detail. Considering the great length of these descriptions, the decision was made to include only the type sections of the five members and the principal reference section. The remaining ones will be kept on open file by the Maryland Geological Survey, Baltimore, Maryland. In addition, all descriptions are available under the same title as this publication through University Microfilm, Ann Arbor, Michigan.

For the descriptions included, the following abbreviations are used to designate logarithmically increasing relative abundances of fossils: R — rare (approximately 1 to 3 specimens per square meter), F — few (aproximately 3 to 6 specimens), N — numerous (approximately 6 to 15 specimens), C — common (approximately 15 to 30 specimens), VC — very common (approximately 30 to 60 specimens), A — abundant (approximately 60 to 150 specimens), Fl — flood (more than 150 specimens).

Locality 66-5. 1600 Feet North of Harper's Creek. 0.9 mile south of Western Shores, Md. Calvert Cliffs on Chesapeake Bay, Calvert Co., Md. 38° 28′ 43″ N. Lat.; 76° 29′ 21″ W. Long.

Unit		*Thickness*
	Choptank Formation	
	Conoy Member	
31	*Lithology:* Dark grayish-blue, very muddy, very fine sand. Outcrop weathers to very light gray. Lithology similar to unit 30 except with deletion of black organic? specks and clay mottled structures. Lower contact gradational. Upper contact distinct, erosional top of Choptank Fmn. *Fossils:* None found. Sample 66-5-35 from 1′ 0″ to 2′ 0″ above base of unit.	3′ 0″
30	*Lithology:* Dark grayish-blue, very muddy, very fine sand. Outcrop weathers to very light gray. Includes black organic? specks up to 1.0 cm. long. Irregular bedding highlighted by small black specks. Mottled by greenish-gray clay with some inclusions up to 3″ long. Contacts gradational. *Fossils:* Calcareous macrofossils nearly absent. One small, unidentified mollusc fragment. Sample 66-5-34 from 1′ 0″ to 2′ 0″ above base of unit.	2′ 0″
29	*Lithology:* Dark grayish-blue, very muddy, very fine sand. No sedimentary structures seen. Outcrop weathers to light bluish-gray. Lower contact slightly undulating but distinct. Upper contact gradational. *Fossils:* Calcareous shells leached out but molds common. Random distribution. Faunal list: C-*Discinisca lugubris, Lyropecten madisonius,* R-*Yoldia laevis, Anodontia anodonta.* Sample 66-5-33 from 0′ 6″ to 1′ 6″ above base of unit.	1′ 6″
	Total thickness of exposed Conoy Member	6′ 6″
	Boston Cliffs Member	
28	*Lithology:* Yellowish-gray, slightly muddy, very fine sand. Weathers to "iron oxide" brown and forms a very hard ledge. Most resistant bed in this section. No apparent sedimentary structures. Lower contact distinct and slightly undulating. Upper contact distinct and slightly undulating. *Fossils:* None. Sample 66-5-32 from entire interval.	0′ 9″
27	*Lithology:* Light-gray, poorly sorted, fine sand. Mottled slightly with darker fine sand. Lower contact gradational. Upper contact undulating. Bed in Boston Cliffs indurated series. *Fossils:* Calcareous shells all leached out. Molds only. Apparently only flat lying *Lyropecten madisonius.* Sample 66-5-31 from 0′ 6″ to 1′ 6″ above base of unit.	1′ 6″
26	*Lithology:* Grayish-olive slightly muddy, fine sand. Weathered surface indurated. No sedimentary structures. Lower contact undulating. Upper contact undulating. *Fossils:* Calcareous shells completely leached. Fauna all flat lying *Lyropecten madisonius.* Sample 66-5-30 from entire unit.	1′ 0″
25	*Lithology:* Light-olive, slightly muddy very fine sand. No sedimentary structures. Lower contact gradational and slightly undulating. Upper contact undulating. Weathers to a very resistant unit.	1′ 0″

Fossils: Within bed there is an undulating line between shells which have been leached and those which have not. Even those below line show some chemical deterioration. Fauna dominated by *Lyropecten madisonius* (both double and single valves). Also *Balanus concavus.*
Sample 66-5-29 from entire interval.

24 *Lithology:* Light olive-brown slightly muddy, very fine sand. Nonresistant outcrop unit. No sedimentary structures. Lower contact undulating. Upper contact gradational. Unit weathers to reddish brown. 1′ ″0
Fossils: Smaller shells protruding on weathered surface. Chemical deterioration very pronounced. Fragmentation common. Wear common. Random distribution and orientation.
Faunal list: A-*Lyropecten madisonius*, C-*Cerastoderma laqueata*, *Balanus concavus*, N-*Macrocallista marylandica*, *Anadara staminea*, *Corbula idonea*, F-*Turritella plebeia*, *Corbula inaequalis*, R-*Crucibulum costatum.*
Sample 66-5-28 from entire interval.

23 Lithology: Dark olive-brown, slightly muddy, fine sand. No bedding laminations. Lower contact gradational and undulating. Upper contact undulating and fairly distinct. 0′ 6″
Fossils: On weathered surface appears as a coarse shell unit. Some shells heavily worn, others not. Large shells are flat lying and predominantly convex upward. Local concentration of *Lyropecten* and *Crassostrea*, or heterogeneous fauna.
Faunal list: A-*Lyropecten madisonius* (some double valves), C-*Crassostrea carolinensis*, N-*Cerastoderma laqueata*, *Corbula idonea* (some double valves), *Macrocallista marylandica*, *Anadara staminea*, *Balanus concavus.*
Sample 66-5-27 from entire unit.

22 *Lithology:* Dark olive-brown, muddy, fine sand. Weathers to light brown with smaller shells appearing at surface than in unit 21. Mottled by yellowish-gray, moderately well sorted, fine sand (some pockets up to 9 cm. diameter). No bedding laminations. Contacts gradational and undulating. 2′ 3″
Fossils: Shells constitute approximately 30% of unit. Well preserved. Apparently random orientation. Numerous fragments. One thin, concentrated bed of larger bivalves at 1′ 6″ above base of unit.
Faunal list: F-*Macrocallista marylandica*, *Corbula idonea* (some double valves), *Lyropecten madisonius*, *Cerastoderma laqueata* (some double valves), *Balanus concavus*, *Astarte obruta*, *Dosinia acetabula*, *Ecphora quadricostata.*
Sample 66-5-26 from 1′ 0″ to 2′ 0″ above base of unit.

21 *Lithology:* Dark yellowish-brown, slightly muddy, fine sand. Mottles of yellowish-gray, moderately well sorted, fine sand. No sedimentary structures. Contacts gradational. Matrix better sorted than 2 lower units. 1′ 6″
Fossils: Coarse, heavy shell bed. No secondary chemical deterioration. Most shells appear randomly distributed but large shells (particularly *Lyropecten* and *Macrocallista*) are flat lying and most of these are with the convex surface upward. Concentrated thin beds of *Anadara*, *Lyropecten*, *Macrocallista.*
Faunal list: A-*Anadara staminea*, C-*Macrocallista marylandica*, *Lyropecten madisonius*, N-*Crassatella marylandica*, *Corbula idonea* (some double valves), *Astarte obruta*, *Dosinia acetabula*, R-*Ecphora quadricostata umbilicata*, *Turritella plebeia* var. A, *Anodontia anodonta*, *Corbula inaequalis*, *Diplodonta acclinis*, *Astrhelia palmata* (very worn).
Sample: 66-5-25 from 0′ 0″ to 1′ 0″ above base of unit.

20 *Lithology:* Dark olive-brown, muddy, fine sand. Mottled with yellowish-gray, moderately well sorted, fine sand. No bedding laminations. Contacts gradational. 1′ 0″
Fossils: Increase in shell size from unit 19. Shells are partially leached and stained by iron oxide. Shells appear to have had very little wear or fragmentation before chemical deterioration. Apparently random orientation and distribution. No articulated, double valves. Mollusc shells constitute approximately 30% of unit.
Faunal list: A-*Anadara staminea*, C-*Lyropecten madisonius*, N-*Dosinia acetabula*, F-*Balanus concavus*, *Astarte obruta*, R-*Anodontia anodonta*, *Cerastoderma laqueata*, *Macrocallista marylandica*, *Ecphora quadricostata.*
Sample 66-5-24 from entire interval.

19 *Lithology:* Dark olive-brown, poorly sorted, muddy, fine sand. Additionally, small lenses of yellowish-gray, well-sorted, fine sand, some of which appear to be small scour and fill structures. Some irregular, iron-stained mottles. Also a few irregular mottles of St. Leonard dark-blue, muddy, very fine sand. No bedding laminations. Outcrop expression shows break to a nearly vertical slope. Contacts gradational. 1′ 0″
Fossils: Abundant fossil molluscan shells. Minor amounts of leaching of shell material. Except for 2 to 3 inch bed of *Anadara*, random distribution. No preferred orientation.
Faunal list: C-*Lyropecten madisonius*, *Anadara staminea*, N-*Macrocallista marylandica*, R-*Lunatia heros.*
Sample 66-5-22 from entire unit.

Total thickness of Boston Cliffs Member 11′ 6″

St. Leonard Member

18 *Lithology:* As unit 17 except dark olive-brown mottlings more common. Additionally, small lenses of yellow-gray, well-sorted, fine to medium sand. Contacts gradational. 1′ 3″
Fossils: Shell fragments common. Some wood fragments. Probably many species of molluscs, but difficult to recognize from fragments. Fragments seem randomly arranged.
Faunal List: F-*Lyropecten madisonius, Anadara staminea.*
Sample 66-5-23 from entire unit.

17 *Lithology:* Dark-blue, somewhat muddy, very fine sand. (Less mud than St. Leonard beds below.) Dark olive-brown mottlings more common. Many mottled structures seem to have burrow morphology. Contacts gradational. 1′ 0″
Fossils: Calcareous macrofossils common but mostly fragments. Some shells partially leached. Species are difficult to identify. Small, rare *Lyropecten madisonius.*
Sample 66-5-21 from entire unit.

16 *Lithology:* Dark-blue, muddy, very fine sand. Minor mottling of dark olive-brown, muddy, fine sand in pockets less than 1.5 cm. diameter. No bedding laminations. Contacts gradational. 4′ 0″
Fossils: Numerous unidentified molds as in unit 15. In addition, some very poorly preserved calcareous shells.
Sample 66-5-19 from 0′ 0″ to 1′ 0″ above base of unit.
Sample 66-5-20 from 2′ 0″ to 3′ 0″ above base of unit.

15 *Lithology:* Dark-blue, muddy, very fine sand. Minor mottling of dark olive-brown, muddy, fine sand in pockets less than 1.5 cm. diameter. No bedding laminations. Contacts gradational.
Fossils: No calcareous shell material preserved. Numerous unidentified molds. Numerous phosphatic *Discinisca lugubris.*
Sample 66-5-18 from 0′ 0″ to 1′ 0″ above base of unit.

14 *Lithology:* Dark-blue, muddy, very fine sand. Minor mottling of dark olive-brown, fine sand in pockets less than 1.5 cm. diameter. No bedding laminations. Contacts gradational. 2′ 0″
Fossils: None.
Sample 66-5-17 from 0′ 0″ to 1′ 0″ above base of unit.

13 *Lithology:* Dark-blue, muddy, very fine sand. Minor mottling of dark olive-brown, muddy, fine sand in pockets less than 1.5 cm. diameter. No bedding laminations. Contacts gradational. 2′ 0″
Fossils: No calcareous shell material preserved. Molds numerous but difficult to identify. ?*Cerastoderma laqueata.*
Sample 66-5-16 from 0′ 0″ to 1′ 0″ above base of unit.

12 *Lithology:* Dark-blue, muddy, very fine sand. Weathered surface dark olive-brown. Weathered outcrop surface has prominent vertical fractures. No sedimentary structures, apparently homogeneous. Contacts gradational. 2′ 0″
Fossils: None seen.
Sample 66-5-15 from 0′ 0″ to 1′ 0″ above base of unit.

11 *Lithology:* Dark-blue, muddy, very fine sand. Weathered outcrop surface has prominent vertical fractures. No apparent sedimentary structures. Contacts gradational. 2′ 0″
Fossils: No preserved calcareous shells. Molds common, however, of *Yoldia laevis.*
Sample 66-5-14 from 0′ 0″ to 1′ 0″ above base of unit.

10 *Lithology:* Dark-blue, muddy, very fine sand. Weathered outcrop surface has prominent vertical fractures. No apparent sedimentary structures. Contacts gradational. 2′ 0″
Fossils: No preserved calcareous shells. A few molds. Only one identified, *Ensis ensiformis.*
Sample 66-5-13 from 0′ 0″ to 1′ 0″ above base of unit.

9 *Lithology:* Dusky-blue, poorly sorted, very muddy, very fine sand. No apparent sedimentary structures. Lower contact undulating. Upper contact gradational. 2′ 6″
Fossils: Macrofossils absent. A few molds of *Cerastoderma laqueata* and *Anadara staminea.*
Sample 66-5-12 from 0′ 6″ to 1′ 6″ above base of unit.

8 *Lithology:* Dusky yellow-green, poorly sorted, muddy, very fine sand. Color mottlings of grayish olive-green, yellowish-gray, and dusky reddish-brown. Texture mottlings range from mud to fine sand. No bedding laminations. Contacts undulating. 1′ 0″
Fossils: Preserved shells absent. A few molds of ?*Anodontia anodonta.*
Sample 66-5-11 from entire unit.

Total thickness of St. Leonard Member 21′ 9″

Drumcliff Member

7 *Lithology:* Heterogeneous lithology. Mixture of dusky-olive, muddy, very fine sand and dark iron-brown, muddy, fine sand. More dusky-olive sand and less brown sand than in unit 6. No apparent sedimentary structures. Lower contact gradational. Upper contact undulating but distinct. 1′ 4″
Fossils: Shells well preserved. Random distribution except for occasional thin lenses of very densely packed *Turritella.* Approximately 25-40% of bed mollusc shells. Fauna strongly dominated by *Glossus* and *Turritella,* which must account for 98% of fauna.
Faunal list: F1-*Glossus fraternus mary-*

landicus (with quantity of single valves about equal to quantity of double valves), *Turritella plebeia*, F-*Cerastoderma laqueata*, *Lunatia heros*, R-*Corbula idonea*, *Lunatia hemicrypta*.
Additionally, pieces of wood.
Sample 66-5-10 from 0′ 0″ to 1′ 0″ above base of unit.

6 *Lithology*: Heterogeneous lithology. Mixing of dusky-olive, muddy, very fine sand with dark iron-brown, muddy, fine sand. Mottled. No bedding laminations. Lower contact quite undulating appearing as slight channeling. Upper contact gradational. 2′ 6″
Fossils: Nicely preserved mollusc shells. Wear almost nonexistent. Decrease in density of accumulation. Unit 6 is approximately 30 to 40% fossil mollusc shells. Abundant articulated, double valves.
Faunal list: A-*Turritella plebeia*, C-*Glossus fraternus marylandicus* (double valves), *Cerastoderma laqueata* (double valves), N-*Crassatella turgidula* (double valves), *Diplodonta acclinis* (double valves), *Astarte thisphila* (double valves), *Lyropecten madisonius*, *Lunatia heros*, *Lunatia hemicrypta*, F-*Anadara staminea*, *Venericardia granulata* (double valves), R-*Siphonalia devexa*, *Isognomon maxillata*, *Dosinia acetabula* (double valves), *Corbula idonea*. Additionally, pieces of wood.
Sample 66-559 from 0′ 6″ to 1′ 6″ above base of unit.

5 *Lithology:* Yellowish-gray, slightly muddy, fine sand. Some small lenses of very light-gray, well-sorted, fine to medium sand. Sorting increases upward. Due to fantastic accumulation of shells no sedimentary structures can be seen. Lower contact gradational. Upper contact distinct, undulating, appearing to be scour and fill. 4′ 0″
Fossils: Tremendous accumulation with appearance of having been dumped. Extremely dense. Great range in sizes of shells. Many shells very well worn, in addition many well preserved. Abundant shell fragments. Average size of shells gradually increases upward.
Faunal list: A-*Lyropecten madisonius*, C-*Turritella plebeia*, *Turritella plebeia* var. A, *Macrocallista marylandica*, *Balanus concavus*, *Isognomon maxillata*, F-*Cardita protracta*, *Crucibulum multilineatum*, *Mercenaria* spp., *Astarte thisphila*, *Cerastoderma laqueata*, *Lunatia heros*, *Lunatia hemicrypta*, *Corbula idonea*, *Lucinoma contracta*, *Anodontia anodonta*, *Martesia ovalis*, *Panope goldfussi*, (double articulated valves and in living position), *Panope americana* (double, articulated valves and in living position), *Diplodonta acclinis*, *Anadara staminea*, *Glossus fraternus marylandicus*, *Cadulus newtonensis*, *Mercenaria campechiensis capax*, *Mercenaria plena*, *Asaphis centenaria*, *Corbula inaequalis*, *Dosinia acetabula*, *Aligena aequata*, *Crassatella turgidula*, *Fissuridea griscomi*, *Abertella aberti*.
Sample 66-5-7 from 0′ 6″ to 1′ 6″ above base of unit.
Sample 66-5-8 from 2′ 6″ to 3′ 6″ above base of unit.

Total thickness of Drumcliff Member 7′ 10″

Calvert Beach Member

4 *Lithology:* Olive-gray, slightly muddy, fine sand. First bed above vertical break in slope of outcrop. Easily distinguished from bed above, which is dry on the surface, by being quite wet. Heavily burrowed unit with burrows filled with shell hash. Lower contact gradational but designated at break to larger shell fragments. Upper contact gradational to larger shell sizes but on weathered surface placed at water line.
Fossils: Predominantly shell filled burrows. Shell material from Drumcliff Member above. Shell material grades in size from smaller at base of unit to larger at top. Wear on shells common. Fragmentation of shells common. Articulated, double valves rare. Most fragments not identified. Shells 50 to 75% of bed.
Faunal list: R-*Astarte thisphila*, *Lyropecten madisonius*, *Turritella plebeia*.
Sample 66-5-6 from 0′ 9″ to 1′ 9″ above base of unit.

3 *Lithology*: Dusky olive-gray, muddy, very fine sand. No apparent sedimentary structures. Lower contact gradational. Upper contact gradational. Burrowing intense. 1′ 0″
Fossils: This unit is highly burrowed. Burrows filled with shell hash mixed in burrow from above. Approximately 30% of unit is shell hash, all pieces less than 2 cm. Size and number of shell fragments grading upward in unit.
No species identified.
Sample 66-5-5 from 0′ 0″ to 1′ 0″ above base of unit.

2 *Lithology:* As unit 1, except: 1) burrows are longer (average 2.0 to 3.0 cm., 2) most burrows contain concentrated shell hash, and 3) shell filled burrows increase from base of unit upward. 4′ 0″
Fossils: Abundant shell hash in burrows. Rare *Lyropecten madisonius*.
Sample 66-5-3 from 0′ 0″ to 1′ 0″ above base of unit.
Sample 66-5-4 from 2′ 0″ to 3′ 0″ above base of unit.

1 *Lithology:* Very dusky blue-green, muddy, very fine sand. Contains thin clay stringers (average about 2 cm. thick) laterally continuous at least a few hundred feet. Also a few discontinuous clay stringers. Many interesting sedimentary structures, including multi-walled, slime-lined, bi-

valve burrows, possible polychaete burrow, other burrows of unknown affinity, mottles, distorted laminations, and scour and fill structures. Nearly all burrows range in diameter from 1.5 to 2.0 cm. Lower contact covered. Upper contact gradational and rather arbitrary.
Fossils: Macrofossils extremely scarce fragments and unidentified. A few very small bivalves.
Sample 66-5-2 from 1′ 6″ to 2′ 6″ above base of unit.

Total thickness of exposed Calvert Beach Member — 10′ 6″

Total thickness of exposed Choptank Formation — 58′ 1″

Locality 66-6. Matoaka Cottages.
0.3 mile north of Calvert Beach, Md. Calvert Cliffs on Chesapeake Bay, Calvert Co., Md. 38° 28′ 21″ N. Lat.; 76° 28′ 58° W. Long.

Unit		*Thickness*
	Choptank Formation	
	Boston Cliffs Member	
17	*Lithology:* Light orangish-brown, muddy, fine sand. Mottled by iron oxide color streaks. No other apparent sedimentary structures. Lower contact gradational. Upper contact distinct. *Fossils:* Sparse. Calcareous shell material all leached. Random orientation and distribution. Species not identified. No sample.	1′ 0″
16	*Lithology:* Light orangish-brown, muddy, fine sand. Rather unique base for Boston Cliffs Member which is usually gradational from St. Leonard Member. No apparent sedimentary structures. Lower contact distinct and quite sharp. Upper contacts gradational. *Fossils:* Very jumbled with fragmentation common. Random orientation and distribution. Dense accumulation. Faunal list: *Lyropecten madisonius, Crassostrea carolinensis, Balanus concavus, Mytilus conradinus, Crucibulum costatum, Anadara staminea, Cardita protracta, Discinisca lugubris,* and bryozoans. Sample 66-6-23 from entire interval.	1′ 0″
	Total thickness of exposed Boston Cliffs Member	2′ 0″
	St. Leonard Member—Type Section	
15	*Lithology:* Dusky greenish-blue, very muddy, very fine sand. With fairly big mottles and lenses of very light gray, well-sorted, fine sand. Lower contact gradational. Upper contact distinct and fairly straight. *Fossils:* Mottles probably result of bivalve burrowing. Some burrows also contain concentrated shell hash. Other fossils random orientation and distribution. Faunal list: C-*Mytilus conradinus,* N-*Balanus concavus,* F-*Turritella plebeia* var. A. Sample 66-6-21 from 0′ 6″ to 1′ 6″ above base of unit. Sample 66-6-22 from 1′ 6″ to 2′ 6″ above base of unit.	
14	*Lithology:* Dusky greenish-blue, very muddy, very fine sand. Mottled by dusky-green clay and pale yellowish-brown, slightly muddy, fine sand. Lower contact gradational. Upper contact gradational to different fauna and increase in fauna. *Fossils:* Distinct increase in number of shells but still not a prolific accumulation. Some thin, undulating beds of thin shelled molluscs (*Mytilus conradinus*) but random distribution and orientation of other shells. Faunal list: VC-*Mytilus conradinus,* C-*Discinisca lugubris,* bryozoans, N-*Lyropecten madisonius, Cerostoderma laqueata, Crucibulum multilineatum.* R-*Cardita protracta.* Sample 66-6-18 from 0′ 6″ to 1′ 6″ above base of unit. Sample 66-6-19 from 2′ 6″ to 3′ 6″ above base of unit. Sample 66-6-20 from 4′ 6″ to 5′ 6″ above base of unit.	6′ 0″
13	*Lithology:* Dusky greenish-blue, very muddy, very fine sand. Mottled by dusky-green clay and pale yellowish-brown, slightly muddy, fine sand. Contacts gradational. *Fossils:* Sparse. Well preserved. Small fossils and small fragments. Random distribution and orientation. Faunal list: N-*Ensis ensiformis, Yoldia laevis,* F-*Cerastoderma laqueata,* R-*Mytilus conradinus, Balanus concavus, Anadara staminea.* Sample 66-6-16 from 0′ 6″ to 1′ 6″ above base of unit. Sample 66-6-17 from 2′ 6″ to 3′ 6″ above base of unit.	4′ 0″
12	*Lithology:* Dusky-blue, very muddy, very fine sand. No apparent sedimentary structures. Contacts gradational. *Fossils:* Sparse. Well preserved. Random distribution and orientation. All disarticulated. Faunal list: C-*Ensis ensiformis, Yoldia laevis,* N-*Cerastoderma laqueata, Anadara staminea.* Sample 66-6-15 from 0′ 6″ to 1′ 6″ above base of unit.	2′ 0″
11	*Lithology:* Dusky greenish-blue, very muddy, very fine sand. No apparent sedimentary structures. Contacts gradational. *Fossils:* Sparse. Well preserved. Nearly all disarticulated. Faunal list: C-*Discinisca lugubris,* N-*Crassatella turgidula,* R-*Mercenaria* sp., *Cadulus newtonensis, Ensis ensiformis, Corbula idonea, Lyropecten madisonius, Anadara staminea, Lucinoma contracta.* Sample 66-6-14 from 0′ 6″ to 1′ 6″ above base of unit.	2′ 0″

10 *Lithology: Heterogeneous.* Main lithology brownish-olive, muddy, fine sand. Mottled by dusky blue-green, very muddy, very fine sand. Latter lithology increasing toward top of unit and grading into it. Additional rare inclusions of very light gray, well sorted, fine sand. Possibly some poorly defined, irregular, color-bedding laminations. Lower contact undulating but distinct. Upper contact undulating and somewhat gradational. 1′ 3″

Fossils: Somewhat sparse. Some may be reworked from Drumcliff Member below.
Faunal List: N-*Dosinia acetabula* (nearly all double valves and increasing in abundance toward top of unit), *Lucinoma contracta* (nearly all double valves), F-*Anadara staminea* (in small pocket, possibly reworked from Drumcliff Member), R-*Discinisca lugubris, Corbula idonea, Glossus fraternus marylandicus, Crassatella turgidula, Cerastoderma laqueata.*
Sample 66-6-13 from entire interval.

Total thickness of St. Leonard Member 19′ 3″

Drumcliff Member

9 *Lithology:* Brownish-gray, muddy, fine sand. Rare small lenses of well-sorted, medium sand. One *Panope americana,* double valved and in living position filled with second lithology. No bedding laminations. Lower contact undulating strongly. Upper contact undulating slightly. Unit almost appears to pinch out in places. 0′ 8″

Fossils: Very well preserved shells. Many double valves. Slight tendency for localized pockets. Fauna strongly dominated by *Anadara* and *Astarte.*
Faunal list: A-*Anadara staminea* (some doubles), VC-*Astarte thisphila* (more double valves than single, dissociated valves), F-*Glossus fraternus marylandicus* (more double valves than single, dissociated valves); R-*Panope americana* (all double valves, oriented in living position).
Sample 66-6-12 from entire interval.

8 *Lithology:* Dusky-blue, muddy, fine sand. No sedimentary structures. Contacts undulating. 0′ 10″

Fossils: Shells excellently preserved. Bivalves predominantly double valves. Fauna dominated by *Glossus fraternus marylandicus.* Fauna not very diverse.
Fauna list: VC-*Glossus fraternus marylandicus* (double valves and single, dissociated valves approximately equal in number), C-*Turritella plebeia,* N-*Cerastoderma laqueata, Astarte thisphila.*
Sample 66-6-11 from entire interval.

7 *Lithology:* Very pale orange, well-sorted, fine sand. Color mottled pale yellowish-brown. Thickness varies from 0′ 0″ to 0′ 6″. Contacts undulating. 0′ 6″

Fossils: None.
Sample 6-6-10 from entire interval.

6 *Lithology:* Heterogeneous lithology. Very dark yellowish-brown, muddy, fine sand. Dusky brownish-blue, poorly sorted, muddy, very fine sand. Very pale orange, well-sorted, fine sand. Bed thickness distinctly varies within short distances. Mottles of different sediment textures and colors. No bedding laminations. Lower contact undulating. Upper contact undulating. 0′ 11″

Fossils: Heterogeneous distributions. Well preserved. Bed contains wood fragments all less than 3.0 cm. long. Three main "end member" distributions: 1) Beds up to 10.0 cm. thick of extremely dense *Turritella plebeia* but varying greatly in thickness, even pinching out entirely. Contacts undulating considerably; 2) Faunas strongly dominated by *Glossus fraternus marylandicus* and *Turritella plebeia.* Thickness and corresponding preserved variable; 3) Very excellently preserved shells, some with remnants of the original hinge ligament, most bivalves with double, articulated valves. Thickness and corresponding lithology variable.
Faunal List: C-*Glossus fraternus marylandicus, Turritella plebeia, Corbula idonea Cerastoderma laqueata,* F-*Crassatella turgidula,* N-*Lunatia heros,* R-*Scaphella typa,* and an unidentified Lucinid.
Sample 66-6-9 from entire interval.

5 *Lithology:* Pale yellowish-gray, moderately well sorted, fine sand. But with occasional pebble size quartz grains. No sedimentary structures. Lower contact gradational. Upper contact distinct and undulating. 6′ 0″

Fossils: Extremely dense. Wear and fragmentation fairly common. Random orientation of all except *Panope* which always occurs in living position and *Lyropecten madisonius* near the center of the unit where large valves are flat lying. Seems to be a general gradation to larger shells and fragments from base of unit to central area followed by a gradational decrease in size toward top of unit. Very diverse fauna with no faunal domination by a single or a few species.
Faunal list: Gastropods-*Turritella plebeia, Lunatia heros, Crucibulum multilineatum, Crucibulum costatum, Lunatia hemicrypta, Ecpohra quadricostata umbilicata, Vermetus graniferus, Scaphella typa, Siphonalia devexa, Urosalpinx cinerea, Turbonilla gubernatoria, Lunatia duplicata, Calliostroma aphelia, Calliostoma philanthropa, Teinostoma calvertense, Fissuridea griscomi, Caecum patuxentium, Pleurotoma choptankensis, Nassarius* sp.; Bivalves—*Lyropecten madisonius, Venericardia granulata, Glossus, fraternus marylandicus, Crassatella turgidula, Anadara staminea, Corbula idonea, Dosinia acetabula, Cerastoderma laqueata, Anodontia anodonta, Macrocallista maryland-ica, Isognomon maxillata, Pleiorytis cen-*

tenaria, Astarte thisphila, Mercenaria plena, Mercenaria mercenaria, Mercenaria campechiensis capax, Nucula proxima, Yoldia laevis, Atrina harrisi, Cardita protracta, Lucinoma contracta, Lucina crenulata, Diplodonta subvexa, Aligena aequata, Apolymetis biplicata, Gari gubernatoria, Ensis ensiformis, Hiatella arctica, Panope americana, Anomia aculeata, Callocardia (Agriopoma) subnasuta, Mytilus conradinus, Semele subovata, Spisula subparilis, Panope goldfussi. Miscellaneous—*Astrhelia palmata, Balanus concavus.*
Sample 66-6-6 from 0′ 6″ to 1′ 6″ from base of unit.
Sample 66-6-7 from 2′ 6″ to 3′ 6″ from base of unit.
Sample 66-6-8 from 4′ 6″ to 5′ 6″ from base of unit.

4 *Lithology:* Olive-brown, muddy, fine sand. Weathers to pale yellowish-brown. Small lenses of very pale orange, well-sorted, fine sand with lenses less than 4 cm. No bedding laminations. Outcrop forms steeper slope than units above and below. Lower contact subtle, marked by 2 mm. iron-oxide stained fine sand. Upper contact gradational. — 0′ 11¼″
Fossils: Dense accumulation. All shells less than 4 cm. Fragmentation common. Wear common. Articulation common in small individuals but not in large ones. Many fragments not easily identified.
Partial Faunal List: N-*Astarte thisphila, Turritella plebeia, Isognomon maxillata, Crucibulum multilineatum, Balanus concavus, Lyropecten madisonius, Turritella plebeia* var. A, *Lunatia heros.*
Sample 66-6-5 from entire bed.

Total thickness of Drumcliff Member — 9′ 10¼″

Calvert Beach Member

3 *Lithology:* Bluish olive-green, muddy, fine sand. Weathers to pale yellowish-brown. Rare small lenses of very pale orange, well-sorted, fine sand, with lenses less than 4 cm. No bedding laminations. Lower contact gradational. Upper contact subtle 2 mm. iron-oxide stained, fine sand. — 1′ 4″
Fossils: All shells less than 2 cm. Most fragments. Wear common. Apparent random distribution. Fragments not identified. Identified mollusks are *Turritella plebeia* and *Astarte thisphila.*
Sample 66-6-3 from upper 0′ 6″ of unit 3 and bottom 0′ 6″ of unit 4.
Sample 66-6-4 from 0′ 6″ to 1′ 4″ above base of unit.

2 *Lithology:* Dark grayish-blue, muddy, fine sand. Mottled by dark greenish-yellow mud. Lower contact gradational but marked by break to more vertical slope. Upper contact gradational. — 2′ 0″
Fossils: Fragments concentrated in burrows. Little wear on shell fragments. All shells and fragments less than 2.0 cm. Most fragments near sides of burrows are parallel to the walls; most fragments near center of burrows are perpendicular to the walls. No fragments identified.
Sample 66-6-2 from 0′ 3″ to 1′ 0″ above base of unit.

1 *Lithology:* Dark grayish-blue, muddy, fine sand. No bedding laminations. Mottled by grayish blue-green clay. Lower contact covered. Upper contact gradational. — 1′ 8″
Fossils: Macrofossils scarce. Rare concentrated pockets of shell fragments which may be biogenic concentrations. No complete burrow profile seen. Shell concentrations are generally round and contain grayish blue-green clay as the mottles. No fragments identified.
Sample 66-6-1 from 0′ 6″ to 1′ 4″ above base of unit.

Total thickness of exposed Calvert Beach Member — 5′ 0″

Total thickness of exposed Choptank Formation — 36′ 1¼″

Locality 66-12. Boston Cliffs.

Choptank River. (Type section for the Choptank Fm. and for the Boston Cliffs Mbr.) 1.8 mile south southeast of Dover Bridge (bridge over Choptank River for Maryland Highway #331). Across Choptank River from Frazier Neck. 4.0 miles southeast of Easton, Md., Talbot County. 38° 44′ 00″ N. Lat.; 76° 00′ 53″ W. Long.

Unit — *Thickness*

Choptank Formation

Boston Cliffs Member—Type section

7 *Lithology:* Yellowish-brown, well-sorted, fine sand. No sedimentary structures. Lower contact distinct and straight. Upper contact covered. — 0′ 8″
Fossils: Extremely dense accumulation. Predominantly shell hash. Sponge boring common.
Faunal list: A-*Lyropecten madisonius,* C-*Balanus concavus,* F-*Mercenaria* sp.

6 *Lithology:* Yellowish-brown, slightly muddy, fine sand. No sedimentary structures. Oxidized upper Boston Cliffs bed. Slightly and locally indurated. — 1′ 3″
Fossils: Large flat-lying bivalves. Dense accumulation. Random distribution.
Faunal list: F1-*Lyropecten madisonius,* C-*Isognomon maxillata,* F-*Macrocallista marylandica.*
Sample 66-12-6 from entire interval.

5 *Lithology:* Reddish-brown, slightly fine sand. Rare mottles of very pale-orange, well-sorted, fine sand. No bedding laminations. Lower contact slightly undulating. Upper contact distinct and straight. — 1′ 6″
Fossils: Increased macrofossil bed. Increased in number of large, flat-lying bivalves. Increased in number of shells. Very well preserved. Dense accumulation.

Distribution random. Sponge boring common. Large bivalves flat lying.
Faunal list: A-*Lyropecten madisonius*, *Crassostrea carolinensis*, VC-*Macrocallista marylandica*, *Anadara staminea*, C-*Mercenaria* spp., *Balanus concavus*, N-*Corbula idonea*, F-*Lunatia heros*, *Turritella plebeia* var A., R-*Epitonium marylandicum*.
Sample 66-12-5 from entire interval.

4 *Lithology:* Reddish-brown, slightly muddy, fine sand. No bedding laminations. Contacts slightly gradational and slightly undulating. 1′ 6″
Fossils: Reduced macrofossil bed. Reduced number of fossil shells and reduced number of large, flat-lying bivalves. Very nicely preserved shells.
Faunal list: N-*Crassatella marylandica*, *Macrocallista marylandica*, *Lyropecten madisonius* (small), F-*Cerastoderma laqueata*, *Crassostrea carolinensis*, R-*Diplodonta* sp., *Semele subovata*, *Lunatia heros*, *Astarte obruta*, *Anadara staminea*, *Balanus concavus*, *Calliostoma wagneri*, *Caecum patuxentium*, *Polinices duplicatus*, *Callocardia* (*Agriopoma*) *subnasuta*, *Dosinia acetabula*, *Lucina crenulata*.
Sample 66-12-4 from 0′ 3″ to 1′ 3″ above base of unit.

3 *Lithology:* Moderate reddish-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted, fine sand. No sedimentary structures. Contacts slightly gradational and slightly undulating. 2′ 6″
Fossils: Increased macrofossil bed. Most strikingly increased in large, flat-lying bivalves. Also increased in numbers of fossils. Very prolific accumulation. Nearly all large bivalves are flat lying, and most of those lie convex upward. Average size of bivalves here seems significantly larger than in outcrops on the Western Shore. Faunal diversity also seems higher than in Western Shore outcrops. Very nicely preserved fossils.
Faunal list: A-*Astarte obruta*, VC-*Crasatella marylandica*, *Anadara staminea* (some double valves), N-*Corbula idonea*, F-*Lunatia heros*, *Lyropecten madisonius*, *Turritella variabilis cumberlandia*, *Mercenaria* spp., R-*Turritella plebeia* var. A, *Balanus concavus*, *Ecphora quadricostata umbilicata*, *Discinisca lugubris*, *Calliostoma wagneri*, *Crucibulum costatum*, *Busycon* sp.
Sample 66-12-3 from 1′ 0″ to 2′ 0″ above base of unit.

2 *Lithology:* Reddish-brown, fairly well sorted, fine sand. No sedimentary structures. Lower contact slightly gradational and undulating. Upper contact slightly gradational and slightly undulating. 2′ 6″
Fossils: Very sparse. A few fragments, mostly unidentified. Only a small *Lyropecten madisonius* identified.
Sample 66-12-2 from 1′ 0″ to 2′ 0″ above base of unit.

1 *Lithology:* Reddish-brown, muddy, fine sand. No apparent sedimentary structures. Lower contact covered. Upper contact undulating and gradational. 2′ 10″
Fossils: Very dense accumulation. Apparent random orientation and distribution. Wear and fragmentation common. Oysters particularly worn. Sponge boring common. Faunal diversity low.
Faunal list: F1-*Crassostrea carolinensis* (many in clusters but nearly no double valves), A-*Balanus concavus*, F-*Mercenaria* sp., *Isognomon maxillata*.
Sample 66-12-1 from 0′ 6″ to 1′ 6″ above base of unit.

Total thickness of exposed Boston Cliffs Member 12′ 9″

Locality 66-14. Drumcliff.

Natural cliff in southwestern bank of Patuxent River. Between Cole Cr. and St. Thomas Cr. 3.0 miles south of Hollywood, Md. Across Patuxent River, straight south, from Broomes Island. St. Marys Co., Md. 38° 23′ 19″ N. Lat.; 76° 33′ 37″ W. Long.
(Called both "Drum Cliff" and "Jones Wharf" in the Md. Geol. Surv. 1904 Miocene Report).
Lower part of this outcrop was seen only after high, heavy wave erosion had cleaned out debris from base of outcrop. Additionally, Calvert Beach Member was seen only at low tide.

Unit *Thickness*

Choptank Formation

Boston Cliffs Member
Undescribed and unmeasured.

St. Leonard Member
St. Leonard sand filling deep channels down into Drumcliff Member. Channels 3 to 5 feet wide and 3 to 4 feet deep. Unmeasured.

Drumcliff Member—Type section

16 *Lithology:* Light orangish-brown, slightly muddy, fine sand. Gradational unit from unit 15 below and forming a receding ledge away from prominence of unit 15 ledge. No sedimentary structures. Lower contact gradational. Upper contact sharp and distinct—channeled from above and filled with non-fossiliferous St. Leonard sand. 3′ 0″
Fossils: Tremendous accumulation of shells with appearance of having been dumped in. Decrease in shell size from unit 15. Fauna even more diverse than unit 15. Tremendous abundance of very small molluscs. Fragments abundant.
Partial faunal list: *Isognomon maxillata*, *Cerastoderma laqueata*, *Anadara staminea*, *Lunatia heros*, *Macrocallista mary-*

landica, Corbula idonea, Ecphora quadricostata umbilicata, Turritella plebeia, Balanus concavus, Lyropecten madisonius.
Sample 66-14-11 from 0′ 6″ to 1′ 6″ above base of unit.

15 *Lithology:* Reddish-brown, muddy, fine sand. Upper prominent ledge. No sedimentary structures. Contacts gradational. 2′ 0″
Fossils: Tremendous accumulation of shells with appearance of having been dumped in. Random distribution and orientation. Very diverse fauna. Tremendous abundance of very small molluscs. Increased macrofossil bed. Partial faunal list: *Macrocallista marylandica, Lunatia heros, Turritella plebeia, Turritella plebeia* var. A., *Lyropecten madisonius, Cerastoderma laqueata, Corbula idonea, Balanus concavus, Crassatella turgidula, Anadara staminea.*
Sample 66-14-10 from 0′ 6″ to 1′ 6″ above base of unit.

14 *Lithology:* Very pale-orange, well-sorted, medium sand. Nonresistant bed. No sedimentary structures. Contacts gradational. 2′ 0″
Fossils: Gradational between reduced macrofossil bed below (unit 13) and increased macrofossil bed above (unit 15). Vertical concentrations of *Turritella.* Most bivalves and *Turritella* flat lying. Well preserved.
Partial faunal list: Fl-*Turritella plebeia,* N-*Lyropecten madisonius Panope americana* (all double valves in living position), *Corbula idonea,* F-*Lunatia Heros, Macrocallista marylandica, Mercenaria campechiensis cuneata.*
Sample 66-14-9 from 0′ 6″ to 1′ 6″ above base of unit.

13 *Lithology:* Very pale-orange, well-sorted, fine to medium sand. Minor resistant layer. No sedimentary structures. Contacts gradational. 0′ 6″
Fossils: Well preserved. Moderate accumulation. Random distribution. Reduced macrofossil bed—reduced number of large, flat-lying bivalves.
Partial faunal list: VC-*Turritella plebeia,* F-*Lyropecten madisonius, Panope americana.*
Sample 66-14-8 from entire interval.

12 *Lithology:* Very pale-orange, well-sorted, fine to medium sand. Rarely mottled by orangish-white, well-sorted, fine sand. No bedding laminations. Forms nonresistant outcrop. Contacts gradational. 3′ 0″
Fossils: Reduced macrofossil bed. Reduced number of large macrofossils. Reduced number of shells. Some *Turritella* appear in vertical concentrations. Well preserved. *Panope* all occur with double valves and in living position.
Faunal list: VC-*Turritella plebeia,* F-*Panope americana, Cerastoderma laqueata.*
Sample 66-14-7 from 1′ 0″ to 2′ 0″ above base of unit.

11 *Lithology:* Moderate-brown, muddy, fine sand. Forms prominent resistant ledge. 1′ 6″
No sedimentary structures. Contacts gradational.
Fossils: Increased macrofossil bed. Increased number of fossil shells and increased number of large, flat-lying bivalves. Well preserved. Random distribution.
Partial faunal list: F1-*Isognomon maxillata,* A-*Lunatia heros, Turritella plebeia,* C-*Lyropecten madisonius,* N-*Balanus concavus, Mercenaria campechiensis cuneata* (some double valves), *Cerastoderma laquesta, Macrocallista marylandica.*
Sample 66-14-6 from entire interval.

10 *Lithology:* Very pale-orange, fairly well sorted, fine sand. No sedimentary structures. Contacts gradational. 0′ 6″
Fossils: Reduced macrofossil bed. Reduced number of fossils and number of large, flat-lying bivalves. Well preserved. Random distribution.
Faunal list: N-*Turritella plebeia,* F-*Lunatia heros, Cerastoderma laqueata.*
Sample (None).

9 *Lithology:* Pale yellowish-brown, slightly muddy, fine sand. No sedimentary structures. Contacts gradational. 0′ 6″
Fossils: Increased macrofossil bed. Increased number of large, flat-lying bivalves. Well preserved. Random distribution.
Faunal list: C-*Cerastoderma laqueata, Lunatia heros, Mercenaria campechiensis cuneata, Macrocallista marylandica,* N-*Corbula idonea.*
Sample 66-14-5 includes units 7, 8, and 9.

8 *Lithology:* Very pale-orange, fairly well sorted, fine sand. No sedimentary structures. Contacts gradational. 0′ 6″
Fossils: Reduced macrofossil bed. Reduced number of fossils and number of large flat-lying bivalves. Well preserved. Random distribution.
Faunal list: N-*Turritella plebeia,* F-*Lunatia heros, Cerastoderma laqueata.*
Sample 66-14-5 includes units 7, 8 and 9.

7 *Lithology:* Pale yellowish-brown, slightly muddy, fine sand. No sedimentary structures. Contacts gradational. 0′ 6″
Fossils: Increased macrofossil bed. Increased number of large, flat-lying bivalves. Well preserved. Random distribution.
Faunal list: C-*Cerastoderma laqueata, Lunatia heros, Mercenaria campechiensis cuneata, Macrocallista marylandica,* N-*Corbula idonea,* F-*Panope americana* (double valves and in living position).
Sample 66-14-5 includes units 7, 8, and 9.

6 *Lithology:* Very pale-orange, fairly well sorted, fine sand. No sedimentary structures. Contacts gradational. 4′ 0″
Fossils: Reduced macrofossil bed. Reduced in overall number and reduced in number of large, flat-lying bivalves. Well preserved. Slight indication of some vertical concentrations possibly representing burrow fillings.
Faunal list: N-*Turritella plebeia,* F-*Lun-*

atia heros, Cerastoderma laqueata, Mercenaria campechiensis cuneata.
Sample 66-14-4 from 1′ 6″ to 2′ 6″ above base of unit.

5 *Lithology:* Very pale-orange, well-sorted, fine sand. No sedimentary structures. Contacts gradational. 1′ 10″
Fossils: Slightly increased macrofossil bed. Bed of increased large, flat-lying bivalves. Well preserved. Many articulated, double valves.
Faunal list: C-*Mercenaria* spp., F-*Anodontia anodonta, Turritella plebeia.*
Sample 66-14-3 from 0′ 0″ to 1′ 0″ above base of unit.

4 *Lithology:* Very pale-orange, well-sorted, fine sand. Lenses of light orangish-brown, slightly muddy, fine sand. No bedding laminations. Forms non-resistant outcrop. Contacts gradational. 4′ 0″
Fossils: Small macrofossils. Reduced macrofossil bed. No large macrofossils. Some fragments. *Turritella plebeia* only macrofossil identified.
Sample 66-14-2 from 2′ 0″ to 3′ 0″ above base of unit.

3 *Lithology:* Very pale yellowish-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted, fine sand. Unit forms a slight ledge. Lower contact slightly undulating and slightly gradational. Upper contact gradational. 2′ 0″
Fossils: Fragments very abundant. Larger bivalves predominantly flat lying. Most fragments unidentified.
Partial faunal list: A-*Turritella plebeia,* VC-*Cerastoderma laqueata.*
Sample 66-14-1 from 0′ 10″ to 1′ 6″ above base of unit.

2 *Lithology:* Olive-gray, muddy, fine sand. Extensively burrowed, possibly by bivalves. Lower contact slightly undulating and marked by appearance of *Isognomon.* Upper contact gradational. 1′ 11″
Fossils: Low faunal diversity. High faunal dominance. Four dominant forms are well preserved. Large bivalves exhibit tendency for flat-lying. Corals tend to be clumped.
Faunal list: F1-*Isognomon maxillata,* VC-*Astrhelia palmata,* C-*Lyropecten madisonius,* N-*Placopecten marylandicus.* Additionally, some rare pockets of unidentified shell hash.
Sample (None).

Total thickness of Drumcliff Member 27′ 9″

Calvert Beach Member

1 *Lithology:* Olive-gray, muddy, fine sand. Extensively burrowed possibly by bivalves. Lower contact Patuxent River water level at low tide. Upper contact slightly undulating and marked by appearance of *Isognomon.* 1′ 0″
Fossils: No preserved hard parts of macroscopic animals. Biogenic activity preserved as burrows.
Sample (None).

Total thickness of measured Choptank Formation 28′ 9″

Locality 66-25. Flag Pond II.

At south end of long line of continuous cliffs south of Flag Ponds. 2.0 miles south of Long Beach, Md. Natural outcrop in Calvert Cliffs along the Chesapeake Bay. Calvert Co., Md. 38° 26′ 16″ N. Lat.; 76° 26′ 40″ W. Long.

Unit *Thickness*

St. Marys Formation

Lowest unit has dark chocolate-brown, muddy, fine sand and contains a shell hash.
Sample 66-25-23 from 0′ 0″ to 0′ 7″ above base of formation.
Sample 66-25-24 from 1′ 11″ to 2′ 11″ above base of formation.
Sample 66-25-25 from 4′ 6″ to 5′ 5″ above base of formation.
Sample 66-25-26 from 6′ 11″ to 7′ 11″ above base of formation.
Sample 66-25-27 from 9′ 5″ to 10′ 5″ above base of formation.
0′ 7″ Prominent indurated ledge starting 12′ 7″ above base of St. Marys Formation.

Choptank Formation

Conoy Member

21 *Lithology:* Dusky greenish-blue, muddy, very fine sand. Subtle mottles of light grayish-green, muddy, very fine sand. Parallel, continuous, thin, bedding laminations. Variable distance separating laminae, up to 2.0′. Lower contact distinct and slightly undulating. Upper contact distinct and slightly undulating. 8′ 1″
Fossils: Rare. Predominantly thin-shelled bivalves. Rare small ?burrow concentrations of small fragments, otherwise random distribution.
Faunal list: R-*Yoldia laevis, Atrina harrisii,* ?*Ensis ensiformis, Ecphora quadricostata.*
Sample 66-25-19 from 0′ 0″ to 1′ 0″ above base of unit.
Sample 66-25-20 from 2′ 6″ to 3′ 6″ above base of unit.
Sample 66-25-21 from 5′ 0″ to 6′ 0″ above base of unit.
Sample 66-25-22 from 7′ 6″ to 8′ 1″ above base of unit.

20 *Lithology:* Dark olive-brown, very muddy, fine sand. Mottled by reddish-brown, slightly muddy, fine sand. Rare mottles of dusky greenish-blue, muddy, very fine sand. No bedding laminations. Heterogeneous sediments. Contacts slightly undulating. 1′ 6″
Fossils: Quite common. Many probably reworked from Boston Cliffs Member. Wear and fragmentation common. Random distribution. Larger shells flat lying. Smaller shells seem randomly oriented.

Faunal list: C-*Lyropecten madisonius*, N-*Mytilus conradinus*, *Balanus concavus*, *Dosinia acetabula*, *Turritella plebeia*, F-*Cerastoderma laqueata*, *Mercenaria* sp. (some double valves), R-*Isognomon maxillata*.
Sample 66-25-18 from 0′ 3″ to 1′ 3″ above base of unit.

Total thickness of Conoy Member — 9′ 7″

Boston Cliffs Member

19 *Lithology:* Grayish-blue, very muddy, very fine sand. Indurated unit. No apparent sedimentary structures. Contacts slightly undulating and distinct. — 0′ 10″
Fossils: Abundant, large, flat-lying *Lyropecten madisonius*. Some molds and casts. Shells partially or completely leached.
No sample.

18 *Lithology:* Reddish-brown, muddy, fine sand. Oxidation causing color mottling with various browns, reds, and oranges. Contacts slightly undulating and distinct. — 0′ 6″
Fossils: Abundant, large, flat-lying *Lyropecten madisonius*.
Sample 66-25-17 from entire interval.

17 *Lithology:* Light-gray, very poorly sorted, fine sand. No apparent sedimentary structures. Contacts undulating and distinct. — 0′ 10″
Fossils: Prolific accumulation. Predominantly large, flat-lying bivalves. Random distribution.
Faunal list: A-*Lyropecten madisonius*, VC-*Atrina harrisi*, C-*Macrocallista marylandica*, R-*Crucibulum multilineatum*.
No sample.

16 *Lithology:* Dark-brown, slightly muddy, fine sand. No sedimentary structures. Lower contact slightly gradational and essentially straight. Upper contact undulating and distinct. — 2′ 0″
Fossils: Prolific accumulation of shells. Fragments common but distinct proportionate increase in large, complete bivalves. Large bivalves predominantly flat lying. Some wear on specimens. Random distribution.
Faunal list: C-*Lyropecten madisonius*, *Dosinia acetabula*, *Macrocallista marylandica*, N-*Cerastoderma laqueata*, *Balanus concavus*, *Corbula idonea*.
Sample 66-25-16 from 1′ 0″ to 2′ 0″ above base of unit.

15 *Lithology:* Light-gray, well-sorted fine sand. Mottled by reddish-brown, muddy, fine sand. Also small lenses of light-gray clay which are indurated. No bedding laminations. Contacts slightly gradational.
Fossils: Prolific accumulation. Very hashy. Abundant fragmentation of shells. Wear common. Large proportion of fragments are flat lying. Random distribution.
Faunal list: VC-*Lyropecten madisonius*, *Anadara staminea*, N-*Balanus concavus*, *Turritella plebeia* var. A., *Corbula idonea*, F-*Mytilus conradinus*, *Dosinia acetabula*, R-*Astarte obruta*, *Crassostrea carolinensis*.
Sample 66-25-14 from 0′ 3″ to 1′ 3″ above base of unit.
Sample 66-25-15 from 2′ 3″ to 3′ 3″ above base of unit.

14 *Lithology:* Moderate-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted, fine sand. No bedding laminations. Contacts undulating and slightly gradational. — 2′ 3″
Fossils: Prolific accumulation. Very hashy. Some specimens well worn, others well preserved. A concentrated pocket of *Anadara staminea*, otherwise, random orientation and distribution. Abundant fragmentation of shells.
Faunal list: VC-*Lyropecten madisonius*, *Crassostrea carolinensis*, C-*Anadara staminea*, *Balanus concavus*, *Cerastoderma laqueata*, N-*Corbula idonea*, *Dosinia acetabula*, F-*Turritella plebeia* var. A, R-*Astarte obruta*.
Sample 66-25-13 from 1′ 0″ to 2′ 0″ above base of unit.

13 *Lithology:* Moderate-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted, fine sand. No bedding laminations. Contacts undulating and slightly gradational. — 1′ 0″
Fossils: Reduced macrofossil bed. Reduced number of macrofossils. Reduced number of large, flat-lying bivalves. Whole assemblage looks more jumbled and dumped than unit 12. Random orientation and distribution. Fragments numerous. Some specimens worn.
Faunal list: C-*Balanus concavus*, N-*Lyropecten madisonius*, *Corbula idonea*, *Anadara staminea*, *Cerastoderma laqueata*, *Turritella plebeia* var. A, F-*Macrocallista marylandica*, *Mercenaria* sp., R-*Mytilus* sp.
Sample 66-25-12 from entire unit.

12 *Lithology*: Moderate-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted, fine sand. No bedding laminations. Contacts undulating and slightly gradational. — 1′ 0″
Fossils: Increased macrofossil bed. Large, flat-lying bivalves abundant. No wear. Beautifully preserved. Some bivalves with remnants of original hinge ligament. Some bivalves with shell coloraticn preserved. Few fragments.
Faunal list: VC-*Macrocallista marylandica* (many double valves), *Dosinia acetabula* (many double valves), *Corbula idonea* (many double valves) C-*Cerastoderma laqueata*, N-*Crassatella marylandica* (many double valves).
Sample 66-25-11 from entire interval.

11 *Lithology:* Moderate-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted, fine sand. No bedding laminations. Contacts undulating and slightly gradational. — 0′ 8″
Fossils: Anadara staminea bed. Increased macrofossil bed. Well preserved. Little wear. A few large, flat-lying bivalves. Rare fragments. A great concentration of *Anadara*, both double and single valves.

Faunal list: F1-*Anadara staminea*, R-*Macrocallista marylandica*, *Cerastoderma laqueata*, *Astarte obruta*, *Dosinia acetabula*, *Turritella variabilis cumberlandia*. Sample 66-25-10 from entire interval.

Total thickness of Boston Cliffs Member — 13′ 2″

St. Leonard Member

10 *Lithology:* Moderate-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted fine sand. No bedding laminations. Lower contact fairly distinct, marked by appearance of large complete bivalves. Upper contact undulating and slightly gradational.
Fossils: Increased macrofossil bed. Great increase in complete, large, flat-lying bivalves. Well preserved. Little wear. Few fragments. Faunal list: A-*Anadara staminea* (some tremendous local layers), VC-*Lyropecten madisonius* (many double valves), *Macrocallista marylandica* (many double valves), C-*Cerastoderma laqueata*, F-*Mercenaria* sp., *Crassatella marylandica*.
Sample 66-25-9 from 0′ 0″ to 1′ 0″ above base of unit.

9 *Lithology:* Moderate-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted, fine sand. No bedding laminations. Contacts gradational. — 2′ 2″
Fossils: Prolific shell bed. Increased amount of shell material. Increasing shell size to appearance of complete specimens. Wear abundant. Fragments very common. Faunal list: *Mytilus conradinus*, *Turritella plebeia* var. A., *Lyropecten madisonius*, *Crassatella marylandica*, *Anadara staminea*, *Macrocallista marylandica*, *Dosinia acetabula*, *Astarte obruta*, *Balanus concavus*, *Crassostrea carolinensis*, *Anodontia anodonta*.
Samples 66-25-8 from 0′ 6″ to 1′ 6″ above base of unit.

8 *Lithology:* Moderate-brown, slightly muddy, fine sand. Mottled by very pale-orange, well-sorted, fine sand. Also some mottles of dark olive-brown, slightly muddy, fine sand. No bedding laminations. Contacts gradational. — 1′ 6″
Fossils: A nonprolific shell unit. Wear common. Fragments common, but none identified. Fragments may have come from unit 9, above, as a result of biogenic activity.
Sample 66-25-7 from 0′ 0″ to 1′ 0″ above base of unit.

7 *Lithology:* Dark olive-brown, muddy, fine sand. Mottled by moderate-brown, slightly muddy, very fine sand. Rare small dusky greenish-blue, muddy, very fine sand. No bedding laminations. Contacts gradational. — 2′ 6″
Fossils: Very rare. Only one identified, *Astarte thisphila*?
Sample 66-25-6 from 0′ 6″ to 1′ 6″ above base of unit.

6 *Lithology:* Dark olive-brown, muddy, fine sand. Mottled by moderate-brown, slightly mottled, fine sand. Rare dusky greenish-blue, muddy, very fine sand. No macrofossils seen. — 2′ 0″
Sample 66-25-5 from 0′ 6″ to 1′ 6″ above base of unit.

5 *Lithology:* Dark olive-brown, muddy, fine sand. Rare mottles of dusky greenish-blue, muddy, very fine sand. Mottling probably result of biogenic activity. Contacts gradational. — 1′ 6″
Fossils: Few unidentifiable fragments seen.
Sample 66-25-4 from 0′ 0″ to 1′ 0″ above base of unit.

4 *Lithology:* Strikingly mottled. Dusky greenish-blue, very muddy, very fine sand. Mottled by dark olive-brown, very muddy, very fine sand. Mottled by moderate-brown, slightly muddy, fine sand. Mottling probably the result of biogenic activity. Contacts gradational. — 1′ 0″
Fossils: Few unidentifiable fragments of calcareous shells.
Samples 66-25-3 from entire interval.

3 *Lithology:* Dusky greenish-blue, very muddy, fine sand. Mottled by light-gray, well-sorted, fine sand. Also mottled by moderate-brown, slightly muddy, fine sand. Intensely burrowed. Contacts gradational. — 2′ 0″
Fossils: Mostly small unidentifiable fragments. Nonprolific shell unit. Random distribution.
Faunal list: N-*Ensis ensiformis*, F-*Discinisca lugubris*, R-*Cerastoderma laqueata*.
Sample 66-25-2 from 0′ 0″ to 1′ 0″ above base of unit.

2 *Lithology:* Dusky greenish-blue, very muddy, very fine sand. Rare mottles of light-gray, well-sorted, fine sand. Heavily burrowed. No bedding laminations. On weathered surface unit is bluer and muddier than St. Leonard sediments above. Lower contact gradational and irregular. Upper contact gradational. — 1′ 0″
Fossils: A nonprolific shell unit, but still a few shells. Nearly all specimens double valved and in living positions. No single bivalve found. Profuse biogenic activity. Difficult to dig out enough of thin shells from dense sediments to identify. Well preserved.
Faunal list: F-*Gari gubernatoria* (all double valved and in living position), *Discinisca lugubris*, R-*Cerastoderma laqueata*.
Sample 66-25-1 from entire interval.

Total thickness of St. Leonard Member — 15′ 4″

Drumcliff Member

1 *Lithology:* Dusky-blue, muddy, fine sand. No sedimentary structures. Lower contact covered. Upper contact gradational and irregular, based on presence of fossils be- — 1′ 0″

low contact and absence of prolific fossils above.
Fossils: Prolific accumulation of shells. Mostly thin-shelled individuals. Random orientation and distribution. Fairly high faunal diversity. Well preserved.
Partial faunal list: VC-*Mytilus conradinus*, C-*Cerastoderma laqueata*, *Balanus concavus*, N-*Corbula idonea*, *Anodontia anodonta*, F-*Macrocallista marylandica*, *Lyropecten madisonius*.
Sample 66-25-28 from entire interval.

Total thickness of exposed Choptank Formation — 39′ 1″

Locality 67-65. Calvert Beach.

Natural exposure in Calvert Cliffs along western shore of Chesapeake Bay at Calvert Beach, Md. Calvert Co., Md. 38° 28′ 05″ N. Lat.; 76° 28′ 37″ W. Long.

Unit		*Thickness*
	Choptank Formation	
	Drumcliff Member	
12	*Lithology:* Pale reddish-brown, very muddy, fine to medium sand. No apparent sedimentary structures. Lower contact gradational. Upper contact distinct. *Fossils:* Very dense accumulation. Accumulation very jumbled. Shells all leached out. No species identified. No sample.	6′ 0″
11	*Lithology:* Pale reddish-brown, very muddy, fine to medium sand. No sedimentary structures seen. Contacts gradational. *Fossils:* Dense accumulation of shells. Jumbled accumulation. Great range in sizes of specimens. Little wear. High faunal diversity. Faunal list: VC-*Turritella plebeia*, C-*Cerastoderma laqueata*, *Lyropecten madisonius*, N-*Macrocallista marylandica*, *Discinisca lugubris*, F-*Lunatia heros*, *Glossus fraternus marylandicus*, *Mercenaria* sp., R-*Astarte thisphila*, *Panope americana* (double valves and in living position), *Pleiorytis centenaria*. Sample 67-65-10 from 0′ 6″ to 1′ 0″ above base of unit.	1′ 0″
10	*Lithology:* Heterogeneous. Dusky yellow ish-brown, muddy, fine sand. Pale yellowish-brown, muddy, fine sand. Dusky-blue, muddy, fine sand. Some definite burrowing. Contacts gradational. *Fossils:* Very dense accumulation of shells, very jumbled accumulation. High faunal diversity. Fairly high faunal dominance. Partial faunal list: F1-*Isognomon maxillata* (many double valves), *Astrhelia palmata*, VC-*Balanus concavus*, C-*Turritella plebeia*, N-*Discinisca lugubris*, F-*Lyropecten madisonius*. Sample 67-65-9 from 0′ 6″ to 1′ 6″ above base of unit.	2′ 1″
	Total thickness of exposed Drumcliff Member	9′ 1″
	Calvert Beach Member—Type section	
9	*Lithology:* Dark greenish-gray, muddy, fine sand. Mottled by light-gray, well-sorted, fine sand probably as a result of burrowing. No bedding laminations. Lower contact straight and clearly defined. Upper contact gradational. *Fossils:* Only fine shell hash. All fragments less than ½ inch. Sample 67-65-8 from 0′ 6″ to 1′ 6″ above base of unit.	1′ 9″
8	*Lithology:* Olive-gray, muddy, very fine sand. Local scour and fill structures. Multi-walled, slime-lined, vertical, bivalve burrows. Burrow laminae flat bottomed in vertical burrows. Burrows constant diameter. Many burrows filled with light-gray, well sorted, fine sand, and some filled with dark greenish-yellow, muddy fine sand. Contacts straight and clearly defined. *Fossils:* Bivalves all double and in living position. Some subtle layering of *Turritella*. Strong pocketing of *Turritella*. Faunal list: VC-*Turritella plebeia*, F-*Lucinoma contracta*, *Diplodonta subvexa*, R-*Lyropecten madisonius*. Sample 67-65-7 from 0′ 9″ to 1′ 9″ above base of unit.	2′ 6″
7	*Lithology*: Dark grayish-green, very muddy, very fine sand. Local scour and fill structures. Multiwalled, slime-lined, bivalve burrows inclined, vertical, and nearly horizontal. Burrow laminae flat bottomed in vertical burrows. Laminae slightly concave in inclined or nearly horizontal burrows. Burrows constant diameter. Contacts straight and clearly defined. *Fossils:* Bivalves all double and in living position. Some subtle layering of *Turritella*. Strong pocketing of *Turritella*. Largest *Turritella* pocket 13 inches across and 4 inches deep. Some *Turritella* pockets appear as scour and fill structures. Faunal list: VC-*Turritella plebeia*, F-*Lucinoma contracta*, *Diplodonta subvexa*, R-*Lyropecten madisonius*. Sample 67-65-6 from 0′ 9″ to 1′ 9″ above base of unit.	2′ 6″
6	*Lithology:* Dark grayish-green, muddy, silt. Profusely burrowed. No bedding laminations. Lower contact straight and clearly defined. Upper contact straight and distinct. *Fossils:* Rare small snails. Faunal list: R-*Turritella plebeia*. Sample 67-65-5 from entire interval.	0′ 3″
5	*Lithology:* Dark grayish-green, muddy, very fine sand. Scour and fill structures	0′ 11″

up to ten inches across and four inches deep. Multiwalled, slime-lined burrows vertical, inclined, and nearly horizontal. Most all bottom laminae in burrows flat except in inclined burrows where some are curved downward approaching shape of burrow. Burrows nearly constant diameter. Contacts straight and clearly defined.

Fossils: Somewhat reduced in number of shells from unit 4. Nearly all complete specimens. May well be a living assemblage. Well preserved. Bivalves double and in living position.

Faunal list: VC-*Turritella plebeia*, C-bryozoans, F-*Diplodonta subvexa*, *Glossus fraternus marylandicus*, *Balanus concavus*, R-*Ensis ensiformis*, *Lucinoma contracta*.

No sample.

4 *Lithology:* Dark grayish-green, very muddy, very fine sand. Possibly some localized, thin, irregular, wavy bedding. Some scour and fill structures. Profusely burrowed by bivalves and possibly polychaetes. Abundant multi-walled, slime-lined burrows. Lower contact slightly gradational. Upper contact straight and clearly defined. 1′ 5″

Fossils: Increase in shell material from unit 3. Shell hash more common than lower beds. Strongly dominated by *Turritella plebeia*.

Faunal list: A-*Turritella plebeia*, C-bryozoans, N-*Glossus fraternus marylandicus*, F-*Lucinoma contracta*, *Lyropecten madisonius*, R-*Turritella variabilis cumberlandia*, *Discinisca lugubris*, *Mercenaria* sp., and pieces of wood.

Sample 67-65-4 from 0′ 5″ to 1′ 1″ above base of unit.

3 *Lithology:* Dark grayish-green, muddy, fine sand. Possibly some localized, thin, irregular, wavy bedding. Some scour and fill structures up to six inches across. Profusely burrowed by bivalves and possibly polychaetes. Abundant multi-walled, slime-lined burrows. Burrows all seem constant diameter. Contacts slightly gradational. 0′ 11″

Fossils: Appears to be a life assemblage. Double valves in living position very common. All well preserved.

Faunal list: C-*Turritella plebeia*, N-*Lucinoma contracta*, *Glossus fraternus marylandicus*, F-*Diplodonta subvexa*, *Mercenaria* sp.

Sample 67-65-3 from 0′ 3″ to 0′ 10″ above base of unit.

2 *Lithology:* Dark grayish-green, muddy, fine sand. Possibly some localized, thin, irregular, wavy bedding. Some scour and fill structures up to six inches across. Profusely burrowed by bivalves and possibly polychaetes. Abundant multi-walled, slime-lined burrows. Contacts slightly gradational. 0′ 4″

Fossils: Concentrated layer of *Turritella*. Very heavily concentrated in some burrows. Specimens nearly all complete. Piece of wood.

Faunal list: F1-*Turritella plebeia*, N-*Cerastoderma laqueata*, R-*Lyropecten madisonius*.

Sample 67-65-2 from entire interval.

Total thickness of Calvert Beach Member	10′ 7″
Total thickness of exposed Choptank Formation	19′ 8″

Calvert Formation ("Zone 15")

1 *Lithology:* Dark grayish-green, muddy, fine sand. Possibly some thin, irregular, wavy bedding in pockets—not throughout unit. Some scour and fill structures up to six inches across. Profusely burrowed by bivalves and possibly polychaetes. Abundant multi-walled, slime-lined burrows. Lower contact under water. Upper contact slightly gradational. 1′ 7″

Fossils: Rare fragments of *Turritella plebeia*.

Sample 67-65-1 from 0′ 6″ to 1′ 3″ above base of unit.

APPENDIX II

FORAMINIFERA AND OSTRACODA IN CHOPTANK SAMPLES

This section contains lists of the microfauna found in certain samples collected from the Choptank Formation. For more complete information about each of the localities, the reader should refer to Appendix I.

The notations with each sample signify the following: n_b = number of benthonic Foraminifera, $\%_a$ = percentage of agglutinated specimens in the total benthonic foraminiferal assemblage, $\%_i$ = percentage of calcareous, imperforate specimens in the total benthonic foraminifera assemblage, $\%_p$ = percentage of planktonic Foraminifera in the total foraminiferal assemblage, n_o = number of ostracodes, and x = specimens present but percentage not computed. The number to the left of each species corresponds to the percentage occurrence of that species in the benthonic foraminiferal assemblage or in the ostracode assemblage. Where the species constituted less than 1.0 percent of the total, the designation "t" signifies trace proportions.

Sample 66-4-6.-0.5 mile north of Calvert Beach, Maryland. Lower St. Leonard Member.

(No specimens present.)

Sample 66-5-10.-08 mile north of Calvert Beach, Maryland. Upper Drumcliff Member.

$n_b = 5$ $\%_a = 0$
$n_o = 10$ $\%_i = 0$
$\%_p = 38$

Foraminifera
40 *Lagena substriata*
20 *L. laevis*
20 *Pseudopolymorphina dumblei*
20 *P. striata*

Ostracoda
40 *Pterygocythereis americana*
20 *Cushmanidea ulrichi*
20 *Bensonocythere whitei*
10 *Hulingsina ashermani*
10 *Muellerina lienenklausi*

Sample 66-5-11.-0.8 mile north of Calvert Beach, Maryland. Lower St. Leonard Member.

(No specimens present.)

Sample 66-5-25.-0.8 mile north of Calvert Beach, Maryland. Central Boston Cliffs Member.

$n_b = 68$ $\%_a = 6$
$n_o = 76$ $\%_i = 0$
$\%_p = 1$

Foraminifera
31 *Buccella mansfieldi*
31 *Cibicides lobatulus*
22 *Buccella depressa*
4 *Textularia gramen*
3 *Pseudopolymorphina dumblei*
3 *Discorbis candeiana*
1 *Nonion marylandicum*
1 *N. pizarrense*
1 *Valvulineria floridana*

Ostracoda
51 *Hulingsina ashermani*
17 *Cytheretta burnsi*
8 *Cushmanidea ulrichi*
7 *Bensonocythere whitei*
7 *Murrayina martini*
5 *M. howei*
1 *Cushmanidea seminuda*
1 *Cytheropteron* sp.
1 *Echinocythereis clarkana*
1 *Loxoconcha granulata*

Sample 66-5-27.-0.8 mile north of Calvert Beach, Maryland. Central Boston Cliffs Member.

$n_b = 165$ $\%_a = 2$
$n_o = 129$ $\%_i = 0$
$\%_p = 0$

Foraminifera
49 *Cibicides lobatulus*
22 *Buccella depressa*
19 *B. mansfieldi*
2 *Nonion marylandicum*
2 *N. pizarrense*
2 *Valvulineria floridana*
2 *Textularia gramen*
t *Pseudopolymorphina dumblei*
t *Discorbis floridana*

Ostracoda
35 *Cushmanidea ulrichi*
12 *Hulingsina ashermani*
11 *Muellerina lienenklausi*
11 *Cytheretta burnsi*
10 *Murrayina martini*
3 *Campylocythere laevissima*
3 *Pokornyella punctistriata*
2 *Cytheridea subovalis*
2 *Cytheromorpha warneri*
2 *Eucythere gibba*
2 *Loxoconcha granulata*
2 *L. reticularis*
2 *Tetracytherura shattucki*
t *Cytheropteron* sp.
t *Semicytherura coryelli*
t *Bensonocythere whitei*

Sample 66-5-28.-0.8 mile north of Calvert Beach, Maryland. Central Boston Cliffs Member.

$n_b = 25$ $\%_a = 0$
$n_o = 0$ $\%_i = 0$
$\%_p = 0$

Foraminifera
84 *Buccella mansfieldi*
8 *Cibicides lobatulus*
4 *Discorbis floridana*
4 *Nonion medio-costatum*

Sample 66-5-33.-0.8 mile north of Calver Beach, Maryland. Lower Conoy Member.

(No specimens present.)

Sample 66-6-7.-Matoaka Cottages, Maryland. Central Drumcliff Member.

$n_b = 4152$ $\%_a = 19$
$n_o = 1065$ $\%_i = 5$
$\%_p = t$

Foraminifera
45 *Valculineria floridana*
13 *Cibicides lobatulus*
8 *Textularia consecta*
6 *T. gramen*
5 *Quinqueloculina seminula*
3 *Spiroplectammina exilis*
2 *Buccella depressa*
2 *Nonion pizarrense*
2 *Pseudopolymorphina striata*
2 *Rotalia bassleri*
2 *Virgulina miocenica*
1 *Buccella mansfieldi*
1 *Nonion marylandicum*
1 *N. medio-costatum*
1 *Textularia candeiana*
t *Bulimina elongata*
t *Entosolenia lucida*
t *Hanzawaia concentrica*
t *Lagena substriata*
t *L. tenuis*
t *Massilina glutinosa*
t *Robulus americanus*
t *Textularia ultima-inflata*
t *Uvigerina subperegrina*
t *Sigmormorphina concava*
t *Discorbis floridana*
t *Lagena* sp. *L. A.*
t *Massilina* sp. *M. A.*
t *Massilina mansfieldi*
t *Globulina inaequalis*
t *M. quadrans*
t *Quinqueloculina contorta*
t *Cibicides floridana*
t *Sigmomorphina williamsoni*
t *Buliminella sub-fusiformis*
t *Marginulina* sp.
x *Bolivina paula*
x *Buliminella elegan-tissima*

Ostracoda
19 *Loxconcha granulata*
16 *Cytheretta burnsi*
15 *Cushmanidea ulrichi*
11 *Hulingsina ashermani*
10 *Muellerina lienenklausi*
5 *Bensonocythere whitei*
4 *Cytheropteron* sp.
3 *Propontocypris howei*
2 *Actinocythereis exan-themata*
2 *Cytheridea subovalis*
2 *Cytheromorpha warneri*
2 *Semicytherura coryelli*
2 *Loxoconcha reticularis*
2 *Tetrachthtrura shat-tucki*
2 *Pterygocythereis americana*
1 *Murrayina martini*
t *Echinocythereis clarkana*
t *Eucythere declivis*
t *E. gibba*
t *Haplocytheridea bassleri*
t *Henryhowella evax*
t *Pokornyella puncti-striata*
t *Murrayina howei*
t *Neocytheridels fasciata*
t *Paradoxostoma robusta*

Sample 66-6-10.-Matoaka Cottages, Maryland. Upper Drumcliff Member.

$n_b = 83$ $\%_a = 14$
$n_o = 14$ $\%_i = 0$
$\%_p = 0$

Foraminifera
36 *Valvulineria floridana*
24 *Cibicides lobatulus*
13 *Pseudopolymorphina striata*
10 *Textularia consecta*
5 *Spiroplectammina exilis*
4 *Buccella mansfieldi*
4 *Rotalia bassleri*
1 *Bulimina elongata*
1 *Lagena laevis*
1 *Nonion marylandicum*
1 *Virgulina miocenica*

Ostracoda
36 *Hulingsina ashermani*
14 *Cytheretta burnsi*
7 *Actinocythereis exanthemata*
7 *Loxoconcha granulata*
7 *Propontocypris howei*
7 *Pterygocythereis americana*
7 *Bensonocythere whitei*
7 *Muellerina lienenklausi*

Sample 66-6-14.-Matoaka Cottages, Maryland. Lower St. Leonard Member.

$n_b = 1190$ $\%_a = 17$
$n_o = 3531$ $\%_i = 0$
$\%_p = 0$

Foraminifera
53 *Buccella mansfieldi*
9 *B. depressa*
9 *Textularia gramen*
5 *Valvulineria floridana*
5 *Discorbis floridana*
4 *Spiroplectammina* aff. *S. exilis*
4 *Cibicides lobatulus*
3 *Massilina glutinosa*
2 *Bulimina elongata*
1 *Miliammina fusca*
t *Hanzawaia concentrica*

Ostracoda
23 *Actinocythereis* aff. *A. mundorffi*
20 *Cushmanidea ulrichi*
18 *Cytheridea subovalis*
8 *Loxoconcha granulata*
7 *Cytheretta burnsi*
5 *Cytheromorpha warneri*
3 *Pokornyella puncti-striata*
3 *Murrayina martini*
2 *Actinocythereis exanthemata*
2 *Cushmanidea agricola*
2 *Loxoconcha reticularis*
1 *Semicytherura coryelli*
1 *Haplocytheridea bassleri*
1 *Murrayina howei*
1 *Tetracytherura shat-tucki*
t *Henryhowella evax*
t *Hulingsina ashermani*
t *Muellerina lienenklausi*
t *Pterygocythereis americana*
t *Bensonocythere whitei*
t *Paradoxostoma robusta*

Sample 66-8-3.-South of Grover Creek, Maryland. Central Boston Cliffs.

$n_b = 3046$ $\%_a = 16$
$n_o = 1432$ $\%_i = t$
$\%_p = t$

Foraminifera
42 *Buccella mansfieldi*
18 *Cibicides lobatulus*
12 *Buccella depressa*
7 *Textularia consecta*
7 *T. gramen*
4 *Nonion marylandicum*
4 *Valvulineria floridana*
3 *Textularia ultima-inflata*
1 *Pseudopolymorphina dumblei*
1 *Discorbis floridana*
t *Bulimina elongata*
t *Hanzawaia concentrica*
t *Nonion medio-costatum*
t *N. pizarrense*

Ostracoda
37 *Cushmanidea ulrichi*
15 *Cytheretta burnsi*
12 *Hulingsina ashermani*
8 *Muellerina lienenklausi*
6 *Cytheridea subovalis*
5 *Loxoconcha granulata*
4 *Murrayina martini*
2 *Pokornyella puncti-striata*
1 *Campylocythere laevis-sima*
1 *Haplocytheridea bassleri*
1 *Murrayina howei*
1 *Tetracytherura shat-tucki*
1 *Bensonocythere whitei*

t *Pseudopolymorphina striata*
t *Quinqueloculina seminula*
t *Textularia candeiana*
x *Bolivina paula*
x *Buliminella elegantissima*

t *Actinocythereis exanthemata*
t *Cytheromorpha warneri*
t *Cytheropteron* sp.
t *Semicytherura coryelli*
t *Echinocythereis clarkana*
t *Eucythere gibba*
t *Propontocypris howei*
t *Pterygocythereis americana*

Sample 66-1-5.-¼ mile south of Camp Conoy, Maryland. Central St. Leonard Member.

(No specimens present.)

Sample 66-11-7.-¼ mile south of Camp Conoy, Maryland. Upper St. Leonard Member.

(No specimens present.)

Sample 66-12-4.-Boston Cliffs, Maryland. Central Boston Cliffs Member.

$n_b = 9672$ $\%_a = 25$
$n_o = 1860$ $\%_i = 0$
$\%_p = 0$

Foraminifera
41 *Cibicides lobatulus*
22 *Textularia gramen*
17 *Buccella mansfieldi*
8 *Valvulineria floridana*
7 *Buccella depressa*
1 *Textularia consecta*
t *Nonion marylandicum*
t *N. medio-costatum*
t *N. pizarrense*
t *Pseudopolymorphina dumblei*
t *Textularia candeiana*
t *T. ultima-inflata*
t *Discorbis floridana*
t *Sigmomorphina concava*

Ostracoda
33 *Cushmanidea ulrichi*
14 *Pokornyella punctistriata*
14 *Muellerina lienenklausi*
11 *Cytheretta burnsi*
9 *Hulingsina ashermani*
6 *Murrayina martini*
3 *M. howei*
2 *Cushmanidea seminuda*
2 *Bensonocythere whitei*
1 *Cytheromorpha warneri*
t *Actinocythereis exanthemata*
t *Campylocythere laevissima*
t *Cytheridea subovalis*
t *Cytheropteron* sp.
t *Haplochteridea subovata*
t *Henryhowella evax*
t *Loxoconcha granulata*
t *Pterygocythereis americana*
t *Propontocypris howei*

Sample 66-14-7.-Drumcliff, Maryland. Central Drumcliff Member.

$n_b = 114$ $\%_a = 5$
$n_o = 51$ $\%_i = t$
$\%_p = 2$

Foraminifera
39 *Cibicides lobatulus*
17 *Valvulineria floridana*
15 *Pseudopolymorphina striata*
8 *P. dumblei*
3 *Buccella depressa*
3 *Nonion pizarrense*
3 *Spiroplectammina exilis*
3 *Textularia consecta*

Ostracoda
31 *Hulingsina ashermani*
27 *Cytheretta burnsi*
16 *Cushmanidea ulrichi*
8 *Loxoconcha granulata*
6 *Murrayina howei*
4 *Cytheropteron* sp.
2 *Actinocythereis exanthemata*
2 *Cushmanidea seminuda*

2 *Buccella mansfieldi*
2 *Lagena substriata*
2 *Nonion marylandicum*
2 *Virgulina miocenica*
t *Bulimina elongata*
t *Hanzawaia concentrica*
t *Lagena tenuis*
t *Quinqueloculina seminula*
t *Discorbis floridana*

2 *Tetracytherura shattucki*
2 *Bensonocythere whitei*

Sample 66-17-1.-North of Cole Creek, Maryland. Lower Drumcliff Member.

$n_b = 6375$ $\%_a = 2$
$n_o = 185$ $\%_i = 0$
$\%_p = 0$

Foraminifera
94 *Cibicides lobatulus*
2 *Valvulineria floridana*
2 *Textularia gramen*
t *Hanzawaia concentrica trica*
t *Nonion medio-costatum*
t *Discorbis floridana*
t *Textularia consecta*
t *Nonion pizarrense*
t *Pseudopolymorphina striata*
t *Buccella depressa*
t *B. mansfieldi*
t *Lagena clavata*
t *L. substriata*
t *Nonion marylandicum*
t *Pseudopolymorphina dumblei*
t *Bulimina elongata*
t *Spiroplectammina exilis*
t *Uvigerina subperegrina*
t *Virgulina miocenica*
t *Robulus americana*
t *Textularia candeiana*

Ostracoda
32 *Pokornyella punctistriata*
18 *Hulingsina ashermani*
14 *Cytheromorpha warneri*
8 *Cushmanidea ulrichi*
6 *Murrayina martini*
5 *Muellerina lienenklausi*
4 *Loxoconcha granulata*
2 *Cytheretta burnsi*
2 *Semicytherura coryelli*
2 *Bensonocythere whitei*
2 *Paracypris choctawhatcheensis*
1 *Actinocythereis exanthemata*
1 *Tetracytherura shattucki*
t *Cytheretta ulrichi*
t *Cytheropteron* sp.

Sample 66-18-1.-Drumcliff, Maryland. Central Drumcliff Member.

$n_b = 374$ $\%_a = 11$
$n_o = 87$ $\%_i = 6$
$\%_p = 0$

Foraminifera
60 *Cibicides lobatulus*
8 *Valvulineria floridana*
8 *Hanzawaia concentrica*
6 *Quinqueloculina seminula*
6 *Spiroplectammina exilis*
3 *Textularia consecta*
2 *Buccella depressa*
2 *Nonion marylandicum*
2 *Pseudopolymorphina striata*
2 *Discorbis floridana*
1 *Textularia candeiana*
t *Bulimina elongata*
t *Pseudopolymorphina dumblei*
t *Textularia gramen*
t *T. ultima-inflata*

Ostracoda
24 *Cytherretta burnsi*
17 *Loxoconcha granulata*
16 *Cushmanidea ulrichi*
13 *Hulingsina ashermani*
8 *Murrayina martini*
7 *Semicytherura coryelli*
6 *Loxoconcha reticularis*
3 *Tetracytherura shattucki*
3 *Bensonocythere whitei*
1 *Cushmanidea seminuda*
1 *Eucythere declivis*

Sample 66-20-1.-Sotterly, Maryland. Lower Drumcliff Member.

$n_b = 7767$ $\%_a = 2$
$n_o = 905$ $\%_i = t$
$\%_p = t$

Foraminifera
93 *Cibicides lobatulus*
2 *Textularia gramen*
2 *Valvulineria floridana*
t *Uvigerina subperegrina*
t *Bulimina elongata*
t *Nonion medio-costatum*
t *N. pizarrense*
t *Quinqueloculina seminula*
t *Hanzawaia concentrica*
t *Lagena substriata*
t *L. clavata*
t *L. laevis*
t *Rotalia bassleri*
t *Nonion marylandicum*
t *Textularia consecta*
t *Virgulina miocenica*
t *Nonionella auris*
t *Spiroplectammina exilis*
t *Dentalina communis*

Ostracoda
29 *Hulingsina ashermani*
14 *Cytheromorpha warneri*
12 *Pokornyella punctistriata*
8 *Muellerina lienenklausi*
7 *Semicytherura coryelli*
6 *Loxoconcha granulata*
6 *Cushmanidea ulrichi*
3 *Cytheridea subovalis*
2 *Cytheretta burnsi*
2 *Campylocythere laevissima*
2 *Murrayina martini*
2 *Bensonocythere whitei*
1 *Eucythere declivis*
t *Actinocythereis exanthemata*
t *Aurila laevicula*
t *Haplocytheridea bassleri*
t *Loxoconcha reticularis*
t *Bythocythere bifurcata*
t *Paracypris choctawhatcheenis*
t *Tetracytherura shattucki*
t *Paradoxostoma robusta*
t *Pterygocythereis americana*
t *Propontocypris howei*
t *P.* sp. *P.* A

Sample 66-21-4.-Camp Conoy, Maryland. Upper Conoy Member.

(No specimens present.)

Sample 66-23-1. Point of Rocks, Maryland. Upper St. Leonard Member.

$n_b = 29$ $\%_a = 3$
$n_o = 28$ $\%_i = 0$
$\%_p = 0$

Foraminifera
28 *Buccella mansfieldi*
24 *Cibicides lobatulus*
21 *Valvulineria floridana*
10 *Nonion marylandicum*
7 *Lagena substriata*
3 *Buccella depressa*
3 *Nonion medio-costatum*
3 *Textularia gramen*

Ostracoda
32 *Hulingsina ashermani*
29 *Cushmanidea ulrichi*
7 *Pokornyella punctistriata*
7 *Loxoconcha granulata*
4 *Actinocythereis exanthemata*
4 *Cytheridea subovalis*
4 *Cytheretta burnsi*
4 *Murrayina martini*
4 *Tetracytherura shattucki*
4 *Pterygocythereis americana*
4 *Bensonocythere whitei*

Sample 66-23-4.-Point of Rocks, Maryland. Lower Boston Cliffs Member.

$n_b = 133$ $\%_a = 4$
$n_o = 58$ $\%_i = 0$
$\%_p = 1$

Foraminifera
31 *Buccella depressa*
26 *B. mansfieldi*
18 *Cibicides lobatulus*
8 *Valvulineria floridana*
5 *Nonion medio-costatum*
2 *Hanzawaia concentrica*
2 *Lagena clavata*
2 *L. substriata*
2 *Nonion pizarrense*
2 *Textularia consecta*
2 *T. gramen*
t *Bulimina elongata*
t *Pseudopolymorphina dumblei*
t *Virgulina miocenica*

Ostracoda
47 *Cushmanidea ulrichi*
12 *Loxoconcha reticularis*
9 *Hulingsina ashermani*
8 *Muellerina lienenklausi*
7 *Cytheretta burnsi*
5 *Murrayina martini*
4 *Pokornyella punctistriata*
3 *Cytheromorpha warneri*
3 *Haplocytheridea bassleri*
3 *Murrayina howei*
1 *Semicytherura coryelli*
1 *Echinocythereis clarkana*
1 *Loxoconcha granulata*
1 *Bensonocythere whitei*

Sample 66-23-9.-Point of Rocks, Maryland. Upper Boston Cliffs Member.

$n_b = 1131$ $\%_a = 7$
$n_o = 484$ $\%_i = 1$
$\%_p = 9$

Foraminifera
42 *Buccella depressa*
24 *Cibicides lobatulus*
20 *Buccella mansfieldi*
6 *Textularia gramen*
2 *Valvulineria floridana*
1 *Hanzawaia concentrica*
1 *Nonion marylandicum*
1 *Quinqueloculina seminula*
1 *Textularia consecta*
t *Massilina glutinosa*
t *Nonion media-costatum*
t *N. pizarrense*
t *Pseudopolymorphina dumblei*
t *Robulus americanus*
t *Textularia ultima-inflata*
t *Discorbis floridana*

Ostracoda
26 *Cushmanidea ulrichi*
26 *Hulingsina ashermani*
24 *Cytheretta burnsi*
4 *Muellerina lienenklausi*
4 *Murrayina martini*
3 *Pokornyella punctistriata*
3 *Haplocytheridea bassleri*
3 *Loxoconcha reticularis*
1 *L. granulata*
1 *Bensonocythere whitei*
t *Actinocythereis exanthemata*
t *Cushmanidea seminuda*
t *C. agricola*
t *Cytheromorpha warneri*
t *Cytheropteron* sp.
t *Semicytherura coryelli*
t S. *forulata*
t *Murrayina howei*
t *Tetracytherura shattucki*
t *Pterygocythereis americana*

Sample *66-23-13.*-Point of Rocks, Maryland. Lower Conoy Member.

(No specimens present.)

Sample 66-24-7.-North Point of Rocks, Maryland. Lower Boston Cliffs Member.

$n_b = 11$ $\%_a = 9$
$n_o = 19$ $\%_i = 0$
$\%_p = 8$

Foraminifera
36 *Buccella depressa*
18 *Nonion marylandicum*
18 *N. medio-costatum*
9 *Pseudopolymorphina dumblei*
9 *Textularia gramen*
9 *Discorbis floridana*

Ostracoda
42 *Cushmanidea ulrichi*
16 *Murrayina martini*
11 *Tetracytherura shattucki*
5 *Cytheretta burnsi*
5 *Cytheropteron* sp.
5 *Haplocytheridea bassleri*
5 *PPokornyella punctistriata*
5 *Loxoconcha granulata*
5 *L. reticularis*
t *L. substriata*
t *Nonion marylandicum*
t *Pseudopolymorphina striata*
t *Textularia ultima-inflata*
t *Uvigerina subperegrina*
t *Globulina inaequalis*
t *Sigmomorphina concava*
t *Elphidum advenum*
1 *Murrayina martini*
1 *Tetracytherura shattucki*
t *Pterygocythereis americana*

Sample 66-24-13.-North Point of Rocks. Upper Boston Cliffs Member.

$n_b = 19$ $\%_a = 21$
$n_o = 173$ $\%_i = 0$
$\%_p = 0$

Foraminifera
42 *Cibicides lobatulus*
16 *Textularia gramen*
11 *Nonion marylandicum*
11 *Virgulina miocenica*
5 *Buccella depressa*
5 *B. mansfieldi*
5 *Hanzawaia concentrica*
5 *Textularia consecta*

Ostracoda
28 *Hulingsina ashermani*
17 *Cushmanidea ulrichi*
11 *Haplocytheridea bassleri*
10 *Semicytherura coryelli*
9 *Cytheretta burnsi*
6 *Loxoconcha granulata*
6 *Muellerina lienenklausi*
4 *Tetracytherura shattucki*
3 *Semicytherura forulata*
1 *Campylocythere laevissima*
1 *Cytheromorpha warneri*
1 *Pokornyella punctistriata*
t *Cytheropteron* sp.
t *Echinocythereis clarkana*
t *Eucythere gibba*
t *Murrayina martini*

Sample 66-24-16.-North Point of Rocks. Lower Conoy Member.

(No specimens present.)

Sample 66-25-4.-Flag Ponds II, Maryland. Central St. Leonard Member.

$n_b = 1382$ $\%_a = 2$
$n_o = 150$ $\%_i = 0$
$\%_p = t$

Foraminifera
57 *Buccella mansfieldi*
29 *Valvulineria floridana*
5 *Cibicides lobatulus*
4 *Discorbis floridana*
1 *Hanzawaia concentrica*
1 *Nonion medio-costatum*
1 *Textularia gramen*
t *Buccella depressa*
t *Bulimina elongata*
t *Lagena acuticostata*

Ostracoda
46 *Haplocytheridea bassleri*
29 *Cushmanidea ulrichi*
7 *Hulingsina ashermani*
4 *Pokornyella punctistriata*
3 *Cushmanidea seminuda*
3 *Loxoconcha reticularis*
2 *Muellerina lienenklausi*
1 *Cytheretta burnsi*
1 *Semicytherura coryelli*

Sample 66-25-11.-Flag Ponds II, Maryland. Central Boston Cliffs Member.

$n_b = 68$ $\%_a = 15$
$n_o = 76$ $\%_i = 1$
$\%_p = 1$

Foraminifera
37 *Cibicides lobatulus*
32 *Buccella depressa*
10 *Textularia gramen*
6 *Buccella mansfieldi*
4 *Textularia consecta*
3 *Nonion marylandicum*
1 *Hanzawaia concentrica*
1 *Quinqueloculina seminula*
1 *Valvulineria floridana*
1 *Virgulina miocenica*
1 *Elphidium poeyanum*

Ostracoda
28 *Cushmanidea ulrichi*
24 *Hulingsina ashermani*
21 *Cytheretta burnsi*
5 *Loxoconcha reticularis*
4 *Murrayina martini*
4 *Muellerina lienenklausi*
3 *Haplocytheridea bassleri*
3 *Loxoconcha granulata*
3 *Tetracytherura shattucki*
1 *Semicytherura coryelli*
1 *Pokornyella punctistriata*
1 *Murrayina howei*
1 *Pterygocythereis americana*
1 *Bensonocythere whitei*

Sample 66-25-12.-Flag Ponds II, Maryland. Central Boston Cliffs Member.

$n_b = 130$ $\%_a = 16$
$n_o = 141$ $\%_i = 4$
$\%_p = 0$

Foraminifera
31 *Cibicides lobatulus*
21 *Buccella mansfieldi*
16 *B. depressa*
10 *Textularia gramen*
4 *Nonion marylandicum*
4 *Quinqueloculina seminula*
3 *Hanzawaia concentrica*
3 *Textularia consecta*
3 *T. ultima-inflata*
2 *Nonion pizarrense*
2 *Pseudopolymorphina dumblei*
2 *Valvulineria floridana*

Ostracoda
24 *Cushmanidea ulrichi*
24 *Cytheretta burnsi*
20 *Hulingsina ashermani*
6 *Haplocytheridea bassleri*
5 *Loxoconcha granulata*
4 *Pokornyella punctistriata*
4 *Murrayina martini*
4 *Muellerina lienenklausi*
2 *Tetracytherura shattucki*
1 *Semicytherura coryelli*
1 *Bensonocythere whitei*
t *Campylocythere laevissima*
t *Cushmanidea seminuda*
t *Echinocythereis clarkana*
t *Loxoconcha reticularis*

Sample 66-25-15.-Flag Ponds II, Maryland. Upper Boston Cliffs Member.

$n_b = 47$ $\%_a = 11$
$n_o = 397$ $\%_i = 0$
$\%_p = 0$

Foraminifera
45 *Cibicides lobatulus*
17 *Buccella mansfieldi*
15 *B. depressa*
11 *Textularia gramen*
2 *Hanzawaia concentrica*
2 *Lagena substriata*
2 *Pseudopolymorphina dumblei*
2 *Valvulineria floridana*
2 *Virgulina miocenica*
2 *Cibicides floridanus*

Ostracoda
42 *Haplocytheridea bassleri*
19 *Cytheretta burnsi*
15 *Hulingsina ashermani*
6 *Cushmanidea ulrichi*
4 *Semicytherura coryelli*
4 *Loxoconcha granulata*
2 *Campylocythere laevissima*
2 *Pokornyella punctistriata*
2 *Muellerina lienenklausi*
1 *Cytheromorpha warneri*
1 *Tetracytherura shattucki*
t *Echinocythereis clarkana*
t *Loxoconcha reticularis*
t *Murrayina howei*
t *M. martini*
t *Pterygocythereis americana*
t *Bensonocythere whitei*

Sample 66-25-21.-Flag Ponds II, Maryland. Central Conoy Member.

$n_b = 635$ $\%_a = 5$
$n_o = 669$ $\%_i = 0$
$\%_p = t$

Foraminifera
40 *Nonion medio-costatum*
22 *Buccella depressa*
10 *Lagena laevis*
8 *Nonion pizarrense*
8 *Buccella mansfieldi*
3 *Cibicides lobatulus*
3 *Textularia candeiana*
2 *Vavulineria floridana*
t *Bulimina elongata*
t *Hanzawaia concentrica*
t *Lagena tenuis*
t *Massilina glutinosa*
t *Miliammina fusca*
t *Nonionella auris*
t *Pseudopolymorphina dumblei*
t *Rotalia bassleri*
t *Textularia consecta*
t *T. gramen*

Ostracoda
46 *Pterygocythereis americana*
16 *Cytheretta burnsi*
11 *Murrayina martini*
10 *Cushmanidea ulrichi*
3 *Cytheridea subovalis*
3 *Cushmanidea agricola*
3 *Murrayina howei*
2 *Cytheretta ulrichi*
2 *Cytheropteron* sp.
1 *Cytheromorpha warneri*
1 *Echinocythereis clarkana*
t *Henryhowella evax*
t *Loxoconcha granulata*
t *L. reticularis*
t *Actinocythereis* aff. *A. gomillionensis*
t *Bensonocythere whitei*

Sample 66-25-23.-Flag Ponds, II Maryland. Lower St. Marys Formation.

$n_b = 1255$ $\%_a = 3$
$n_o = 676$ $\%_i = 0$
$\%_p = 0$

Foraminifera
39 *Cibicides lobatulus*
21 *Nonion pizarrense*
18 *Buccella mansfieldi*
12 *Nonion medio-costatum*
3 *Bulimina elongata*
3 *Discorbis floridana*
2 *Miliammina fusca*
1 *Textularia candeiana*
1 *Valvulineria floridana*
t *Hanzawaia concentrica*
t *Textularia gramen*

Ostracoda
21 *Actinocythereis exanthemata*
20 *Cytheretta burnsi*
15 *Murrayina martini*
9 *M. howei*
9 *Cytheretta ulrichi*
5 *Loxoconcha reticularis*
5 *Pterygocythereis americana*
4 *Cytheridea subovalis*
3 *Cushmanidea ulrichi*
3 *Loxoconcha granulata*
2 *Cytheromorpha warneri*
2 *Henryhowella evax*
t *Cytheropteron* sp.
t *Echinocythereis clarkana*
t *Muellerina lienenklausi*

Sample 66-25-27.-Flag Ponds II, Maryland. Lower St. Marys Formation.

$n_b = 513$ $\%_a = t$
$n_o = 774$ $\%_i = 0$
$\%_p = t$

Foraminifera
47 *Buccella mansfieldi*
27 *Cibicides lobatulus*
20 *Buccella depressa*
3 *Hanzawaia concentrica*
t *Lagena substriata*
t *Rotalia bassleri*
t *Textularia gramen*
t *Valvulineria floridana*
t *Discorbis floridana*

Ostracoda
40 *Cushmanidea agricola*
12 *Cytheridea subovalis*
12 *Murrayina martini*
11 *Cushmanidea ulrichi*
11 *Cytheretta burnsi*
4 *Murrayina howei*
4 *Pterygocythereis americana*
2 *Cytheromorpha warneri*
t *Actinocythereis exanthemata*
t *Cytheropteron* sp.
t *Semicytherura coryelli*
t *Echinocythereis clarkana*
t *Haplocytheridea bassleri*
t *Loxoconcha granulata*
t *Tetracytherura shattucki*

Sample 66-25-28.-Flag Ponds II, Maryland. Upper Drumcliff Member.

$n_b = 3255$ $\%_a = 9$
$n_o = 2147$ $\%_i = t$
$\%_p = t$

Foraminifera
52 *Buccella mansfieldi*
14 *Cibicides lobatulus*
10 *Valvulineria floridana*
9 *Textularia gramen*
8 *Buccella depressa*
3 *Hanzawaia concentrica*
3 *Discorbis floridana*
1 *Rotalia bassleri*
t *Bulimina elongata*
t *Nonion marylandicum*

Ostracoda
25 *Haplocytheridea bassleri*
22 *Cushmanidea ulrichi*
12 *Pokornyella punctistriata*
11 *Cytheromorpha warneri*
7 *Hulingsina ashermani*
5 *Loxoconcha reticularis*
3 *Semicytherura coryelli*
3 *Paracytheridea shattucki*

t *Pseudopolymorphina dumblei*
t *Quinqueloculina seminula*
t *Spiroplectammina exilis*
t *Lagena* sp. *L. A*
t *Elphidium poeyanum*

2 *Cytheretta burnsi*
2 *Loxoconcha granulata*
2 *Bensonocythere whitei*
1 *Campylocythere laevissima*
1 *Murrayina martini*
t *Actinocythereis exanthemata*
t *Aurila laevicula*
t *Cytheridea subovalis*
t *Cushmanidea agricola*
t *Henryhowella evax*
t *Muellerina lienenklausi*
t *Murrayina howei*
t *Neocytherideis fasciata*
t *Pterygocythereis americana*

Sample 66-26-2.-South Point of Rocks, Maryland. Lower Boston Cliffs Member.

(No specimens present.)

Sample 66-26-5.-South Point of Rocks, Maryland. Central Boston Cliffs Member.

$n_b = 2590$ $\%_a = 9$
$n_o = 912$ $\%_i = t$
$\%_p = t$

Foraminifera
42 *Buccella mansfieldi*
31 *Cibicides lobatulus*
7 *Textularia gramen*
5 *Buccella depressa*
5 *Valvulineria floridana*
5 *Nonion marylandicum*
1 *Pseudopolymorphina dumblei*
t *Bulimina elongata*
t *Entosolenia lucida*
t *Nonion medio-costatum*
t *N. pizarrense*
t *Pseudopolymorphina striata*
t *Quinqueloculina seminula*
t *Textularia consecta*
t *T. ultima-inflata*
t *Virgulina miocenica*
t *Sigmomorphina concava*
x *Bolivina paula*
x *Buliminella elegantissima*

Ostracoda
40 *Cushmanidea ulrichi*
14 *Cytheretta burnsi*
13 *Hulingsina ashermani*
8 *Muellerina lienenklausi*
4 *Murrayina martini*
4 *Loxoconcha reticularis*
3 *Cytheridea subovalis*
3 *Pokornyella punctistriata*
2 *Campylocythere laevissima*
2 *Loxoconcha granulata*
2 *Murrayina howei*
2 *Bensonocythere whitei*
1 *Cytheromorpha warneri*
t *Cytheropteron* sp.
t *Semicytherura coryelli*
t *Echinocythereis clarkana*
t *Eucythere gibba*
t *Haplocytheridea bassleri*
t *Tetracytherura shattucki*
t *Pterygocythereis americana*

Sample 66-26-7.-South Point of Rocks, Maryland. Central Boston Cliffs Member.

$n_b = 707$ $\%_a = 7$
$n_o = 315$ $\%_i = t$
$\%_p = 0$

Foraminifera
35 *Buccella mansfieldi*
28 *Cibicides lobatulus*
11 *Nonion marylandicum*
10 *Buccella depressa*
7 *Textularia gramen*
Entosolenia lucida

Ostracoda
39 *Cushmanidea ulrichi*
15 *Cytheretta burnsi*
14 *Loxoconcha reticularis*
9 *Hulingsina ashermani*
6 *Murrayina martini*
3 *M. howei*

1 *Nonion pizarrense*
t *N. medio-costatum*
t *Bolivina paula*
t *Buliminella elegantissima*
t *Bulimina elongata*
t *Pseudopolymorphina dumblei*
t *P. striata*
t *Quinqueloculina seminula*
t *Textularia consecta*
t *Valvulineria floridana*
t *Virgulina miocenica*
t *Discorbis floridana*

2 *Semicytherura coryelli*
2 *Echinocythereis clarkana*
2 *Haplocytheridea bassleri*
2 *Bensonocythere whitei*
2 *Muellerina lienenklausi*
t *Cushmanidea seminuda*
t *Pokornyella punctistriata*
t *Loxoconcha granulata*
t *Tetracytherura shattucki*
t *Propontocypris howei*
t *Pterygocythereis americana*

Sample 66-26-15.-South Point of Rocks, Maryland. Central Conoy Member.

(No specimens present.)

Sample 66-29-2.-Cuckold Creek III, Maryland. Central St. Leonard Member.

(No specimens present.)

Sample 66-34-2.-Pawpaw Point II, Maryland. Lower Drumcliff Member.

$n_b = 14{,}612$ $\%_a = 19$
$n_o = 982$ $\%_i = t$
$\%_p = t$

Foraminifera
31 *Cibicides lobatulus*
19 *Valvulineria floridana*
12 *Textularia consecta*
7 *Buccella mansfieldi*
6 *Spiroplectammina exilis*
5 *Buccella depressa*
4 *Hanzawaia concentrica*
3 *Nonion marylandicum*
3 *N. pizarrense*
3 *Virgulina miocenica*
2 *Nonion medio-costatum*
1 *Bulimina elongata*
t *Bolivina paula*
t *Buliminella elegantissima*
t *Lagena acuticostata*
t *L. clavata*
t *L. substriata*
t *Nonionella auris*
t *Pseudopolymorphina dumblei*
t *P. striata*
t *Quinqueloculina seminula*
t *Robulus americanus*
t *Textularia candeiana*
t *T. gramen*
t *Uvigerina subperegrina*
t *Discorbis floridana*
x *Entosolenia lucida*
x *Lagena* sp. *L. A*

Ostracoda
18 *Cushmanidea ulrichi*
12 *Cytheridea subovalis*
11 *Murrayina martini*
10 *Hulingsina ashermani*
8 *Cytheretta burnsi*
7 *Loxoconcha granulata*
6 *Cytheretta ulrichi*
4 *Muellerina lienenklausi*
4 *Murrayina howei*
3 *Cytheromorpha warneri*
3 *Echinocythereis clarkana*
3 *Bensonocythere whitei*
2 *Actinocythereis exanthemata*
2 *Cytheropteron* sp.
2 *Semicytherura coryelli*
2 *Pterygocythereis americana*
1 *Cushmanidea agricola*
t *C. seminuda*
t *Henryhowella evax*
t *Propontocypris howei*
t *Cytherois fischeri*

Sample 66-34-4.-Pawpaw Point II, Maryland. Central Drumcliff Member.

$n_b = 7959$ $\%_a = 14$
$n_o = 842$ $\%_i = 0$
$\%_p = t$

Foraminifera
21 *Valvulineria floridana*
18 *Buccella mansfieldi*
17 *Cibicides lobatulus*
10 *Buccella depressa*
7 *Textularia consecta*
6 *Spiroplectammina exilis*
6 *Nonion marylandicum*
3 *N. medio-costatum*
3 *N. pizarrense*
3 *Virgulina miocenica*
t *Bolivina paula*
t *Bulimina elongata*
t *Epistominella pontoni*
t *Entosolenia lucida*
t *Hanzawaia concentrica*
t *Lagena clavata*
t *L. laevis*
t *L. substriata*
t *Pseudopolymorphina dumblei*
t *P. striata*
t *Rotalia bassleri*
t *Textularia candeiana*
t *T. gramen*
t *Uvigerina subperegrina*
t *Sigmomorphina concava*
t *Discorbis floridana*

Ostracoda
33 *Cushmanidea ulrichi*
16 *Murrayina martini*
9 *Hulingsina ashermani*
7 *Cytheridea subovalis*
6 *Cytheretta burnsi*
4 *Muellerina lienenklausi*
3 *Cushmanidea seminuda*
3 *Loxoconcha granulata*
3 *Murrayina howei*
2 *Actinocythereis exanthemata*
2 *Cushmanidea agricola*
2 *Cytheretta ulrichi*
2 *Cytheromorpha warneri*
2 *Paracytheridea shattucki*
1 *Cytheropteron* sp.
1 *Echinocythereis clarkana*
1 *Propontocypris howei*
1 *Pterygocythereis americana*
t *Bensonocythere whitei*

Sample 66-35-1.-Pawpaw Hollow, Maryland. Upper Calvert Beach Member.

$n_b = 1856$ $\%_a = 6$
$n_o = 435$ $\%_i = 0$
$\%_p = t$

Foraminifera
62 *Cibicides lobatulus*
8 *Buccella mansfieldi*
6 *Valvulineria floridana*
5 *Textularia gramen*
4 *Nonion pizarrense*
4 *Buccella depressa*
3 *Nonion marylandicum*
2 *Hanzawaia concentrica*
2 *Discorbis floridana*
1 *Nonion medio-costatum*
t *Bulimina elongata*
t *Elphidium advenum*
t *Lagena substriata*
t *Massilina glutinosa*
t *Robulus americanus*
t *Textularia consecta*
t *Virgulina miocenica*

Ostracoda
38 *Cushmanidea ulrichi*
12 *Murrayina martini*
10 *Cushmanidea agricola*
7 *Cytheretta burnsi*
7 *Murrayina howei*
7 *Hulingsina ashermani*
4 *Semicytherura coryelli*
3 *Cytheromorpha warneri*
3 *Bensonocythere whitei*
2 *Cytheridea subovalis*
2 *Pokornyella punctistriata*
2 *Loxoconcha granulata*
1 *Actinocythereis exanthemata*
t *Aurila laevicula*
t *Cytheretta ulrichi*
t *Muellerina lienenklausi*
t *Pterygocythereis americana*

Sample 66-36-5.-East Breton Bay, Maryland. Central Drumcliff.

$n_b = 2517$ $\%_a = 5$
$n_o = 151$ $\%_i = 0$
$\%_p = 7$

Foraminifera
59 *Cibicides lobatulus*
15 *Valvulineria floridana*
5 *Buccella depressa*
5 *Spiroplectammina exilis*
3 *Nonion marylandicum*
3 *Buccella mansfieldi*
2 *Nonion pizarrense*
2 *Discorbis floridana*
t *Bulimina elongata*
t *Entosolenia lucida*
t *Hanzawaia concentrica*
t *Lagena clavata*
t *L. substriata*
t *L. tenuis*
t *Nonion medio-costatum*
t *Pseudopolymorphina dumblei*
t *P. striata*
t *Rotalia bassleri*
t *Textularia consecta*
t *T. gramen*
t *Uvigerina subperegrina*
t *Virgulina miocenica*
t *Lagena* sp. *L. A*

Ostracoda
42 *Cushmanidea ulrichi*
13 *Murrayina martini*
11 *M. howei*
8 *Cytheretta burnsi*
5 *Hulingsina ashermani*
5 *Loxoconcha granulata*
3 *Actinocythereis exanthemata*
3 *Cushmanidea seminuda*
3 *Cytheropteron* sp.
1 *Cytheromorpha warneri*
1 *Semicytherura coryelli*
1 *Propontocypris howei*
1 *Pterygocythereis americana*
1 *Bensonocythere whitei*
1 *Muellerina lienenklausi*

Sample 66-40-1. Mill Creek II, Maryland. Upper Drumcliff Member.

$n_b = 1495$ $\%_a = 12$
$n_o = 378$ $\%_i = t$
$\%_p = t$

Foraminifera
36 *Valvulineria floridana*
26 *Cibicides lobatulus*
10 *Nonion pizarrense*
9 *Textularia consecta*
4 *Buccella depressa*
2 *Nonion medio-costatum*
2 *Pseudopolymorphina striata*
2 *Globulina inaequalis*
1 *Pseudopolymorphina dumblei*
1 *Textularia gramen*
1 *Sigmomorphina concava*
t *Buccella mansfieldi*
t *Bulimina elongata*
t *Hanzawaia concentrica*
t *Lagena substriata*
t *L. tenuis*
t *Nonion marylandicum*
t *Spiroplectammina exilis*
t *Robulus americanus*
t *Rotalia bassleri*
t *Textularia candeiana*
t *T. ultima-inflata*
t *Virgulina miocenica*
t *Discorbis floridana*

Ostracoda
28 *Hulingsina ashermani*
22 *Loxoconcha granulata*
15 *Cytheretta burnsi*
6 *Cushmanidea ulrichi*
6 *Murrayina howei*
4 *Tetracytherura shattucki*
3 *Cytheropteron* sp.
3 *Bensonocythere whitei*
2 *Cushmanidea seminuda*
2 *Murrayina martini*
2 *Pterygocythereis americana*
2 *Neocytherideis fasciata*
1 *Actinocythereis exanthemata*
1 *Cushmanidea agricola*
1 *Cytheromorpha warneri*
t *Campylocythere laevissima*
t *Cytheridea subovalis*
t *Semicytherura coryelli*
t *Eucythere declivis*
t *E. gibba*
t *Pokornyella punctistriata*

Sample 66-40-3.-Mill Creek II, Maryland. Upper Drumcliff Member.

$n_b = 11,356$ $\%_a = 10$
$n_o = 1,042$ $\%_i = t$
$\%_p = t$

Foraminifera
54 *Cibicides lobatulus*
18 *Valvulineria floridana*
5 *Textularia gramen*
4 *Nonion pizarrense*
3 *N. medio-costatum*
3 *Textularia consecta*
2 *Hanzawaia concentrica*
2 *Rotalia bassleri*
1 *Buccella depressa*
1 *Spiroplectammina exilis*
1 *Pseudopolymorphina dumblei*
t *P. striata*
t *Buccella mansfieldi*
t *Bulimina elongata*
t *Lagena laevis*
t *L. substriata*
t *L. tenuis*
t *Massilina glutinosa*
t *Quinqueloculina seminula*
t *Robulus americanus*
t *Textularia candeiana*
t *Virgulina miocenica*
t *Discorbis floridana*
t *Cancris sagra*
t *Sigmomorphina concava*
t *Marginulina* sp. *M. A.*
t *Dentalina* sp.
t *D. communis*
t *Globulina inaequalis*

Ostracoda
17 *Hulingsina ashermani*
16 *Loxoconcha granulata*
13 *Cushmanidea ulrichi*
10 *Muellerina lienenklausi*
10 *Cytheretta burnsi*
5 *Cytheropteron* sp.
3 *Actinocythereis exanthemata*
3 *Cytheromorpha warneri*
3 *Tetracytherura shattucki*
3 *Pterygocythereis americana*
3 *Neocytherideis fasciata*
2 *Semicytherura coryelli*
2 *Echinocythereis clarkana*
2 *Murrayina martini*
2 *Bensonocythere whitei*
1 *Eucythere declivis*
1 *E. gibba*
t *Cytheridea subovalis*
t *Semicytherura forulata*
t *Pokornyella punctistriata*
t *Loxoconcha reticularis*
t *Paradoxostoma robusta*

Sample 66-41-1.-Cuckold Creek VI, Maryland. Upper Drumcliff Member.

$n_b = 579$ $\%_a = 14$
$n_o = 475$ $\%_i = 0$
$\%_p = t$

Foraminifera
66 *Cibicides lobatulus*
13 *Textularia gramen*
10 *Valvulineria floridana*
2 *Discorbis candeiana*
2 *Pseudopolymorphina striata*
2 *Buccella mansfieldi*
t *B. depressa*
t *Bulimina elongata*
t *Nonion medio-costatum*
t *N. pizarrense*
t *Pseudopolymorphina dumblei*
t *Spiroplectammina exilis*
t *Rotalia bassleri*
t *Textularia consecta*
t *T. ultima-inflata*
t *Virgulina miocenica*
t *Globulina inaequalis*

Ostracoda
28 *Cytheretta burnsi*
18 *Hulingsina ashermani*
13 *Loxoconcha granulata*
11 *Muellerina lienenklausi*
10 *Bensonocythere whitei*
6 *Cushmanidea ulrichi*
2 *Cytheridea subovalis*
2 *Cytheropteron* sp.
2 *Pokornyella punctistriata*
2 *Tetracytherura shattucki*
2 *Neocytherideis fasciata*
t *Actinocythereis exanthemata*
t *Cushmanidea seminuda*
t *Cytheromorpha warneri*
t *Echinocythereis clarkana*
t *Eucythere declivis*
t *Haplocytheridea bassleri*
t *Murrayina martini*
t *Pterygocythereis americana*
t *Propontocypris howei*

Sample 66-41-2.-Cuckold Creek VI, Maryland. Lower St. Leonard Member.

(No specimens present.)

Sample 66-43-2.-Mackall's Landing, Maryland. Central Drumcliff Member.

$n_b = 540$ $\%_a = 5$
$n_o = 218$ $\%_i = t$
$\%_p = t$

Foraminifera
54 *Valvulineria floridana*
32 *Cibicides lobatulus*
5 *Buccella depressa*
5 *Textularia gramen*
x *Bolivina paula*
x *Buliminella elegantissima*
t *Bulimina elongata*
t *Hanzawaia concentrica*
t *Nonion marylandicum*
t *Quinqueloculina seminula*
t *Robulus americanus*
t *Rotalia bassleri*
t *Discorbis floridana*

Ostracoda
57 *Cushmanidea ulrichi*
14 *Murrayina martini*
8 *Hulingsina ashermani*
7 *Aurila laevicula*
5 *Muellerina lienenklausi*
2 *Murrayina howei*
2 *Bensonocythere whitei*
1 *Cytheretta burnsi*
1 *Semicytherura coryelli*
t *Cytheromorpha warneri*
t *Loxoconcha granulata*
t *Pterygocythereis americana*

Sample 66-44-2.-½ mile north of Camp Conoy, Maryland. Upper Boston Cliffs Member.

$n_b = 989$ $\%_a = 10$
$n_o = 679$ $\%_i = 0$
$\%_p = t$

Foraminifera
40 *Cibicides lobatulus*
27 *Buccella mansfieldi*
9 *B. depressa*
7 *Textularia gramen*
4 *Bulimina elongata*
3 *Massilina glutinosa*
2 *Discorbis floridana*
2 *Nonion pizarrense*
2 *Lagena substriata*
2 *L.* sp. *L. A*
t *L. laevis*
t *L. tenuis*
t *Nonion medio-costatum*
t *Nonionella auris*
t *Pseudopolymorphina dumblei*
t *Textularia consecta*
t *Valvulineria floridana*

Ostracoda
24 *Loxoconcha granulata*
19 *Cytheretta burnsi*
15 *Cushmanidea ulrichi*
13 *Murrayina martini*
12 *Cytheromorpha warneri*
4 *Pterygocythereis americana*
3 *Hermanites* sp.
2 *Echinocythereis clarkana*
2 *Loxoconcha reticularis*
2 *Murrayina howei*
1 *Cytheropteron* sp.
t *Actinocythereis exanthemata*
t *Cytheridea subovalis*
t *Cushmanidea agricola*
t *Semicytherura coryelli*
t *Neocytherideis fasciata*
t *Tetracytherura shattucki*
t *Propontocypris howei*
t *Paradoxostoma robusta*
t *Cytherois fischeri*
t ?*Machaerina* sp.

Sample 66-44-3.-½ mile north of Camp Conoy, Maryland. Lower Conoy Member.

$n_b = 15{,}390$ $\%_a = 7$
$n_o = 3{,}724$ $\%_i = 0$
$\%_p = t$

Foraminifera
82 *Buccella mansfieldi*
5 *Bulimina elongata*
4 *Textularia consecta*
2 *Massilina glutinosa*
2 *Lagena substriata*
1 *Nonion pizarrense*
t *Lagena* sp. *L. B*
t *L. laevis*
t *Buccella depressa*
t *Cibicides lobatulus*
t *Hanzawaia concentrica*
t *Nonion medio-costatum*
t *Nonionella auris*
t *Robulus americanus*
t *Textularia gramen*
t *T. ultima-inflata*
t *Valvulineria floridana*
t *Discorbis floridana*
t *Textularia* sp.

Ostracoda
21 *Cushmanidea ulrichi*
16 *Murrayina martini*
15 *Cytheretta burnsi*
10 *Murrayina howei*
8 *Pterygocythereis americana*
6 *Cytheromorpha warneri*
5 *Cushmanidea agricola*
5 *Echinocythereis clarkana*
4 *Loxoconcha granulata*
3 *Cytheropteron* sp.
2 *Cytheridea subovalis*
2 *Loxoconcha reticularis*
t *Actinocythereis exanthemata*
t *Cytheretta ulrichi*
t *Pokornyella punctistriata*
t *Hulingsina ashermani*
t *Muellerina lienenklausi*

Sample 66-47-1.-North of Cove Point, Maryland. Lower Conoy Member.

(No specimens present.)

Sample 67-53-1.-Governor Run, Maryland. Central Calvert Beach Member.

$n_b = 20{,}008$ $\%_a = 15$
$n_o = 12{,}536$ $\%_i = 0$
$\%_p = t$

Foraminifera
46 *Cibicides lobatulus*
20 *Valvulineria floridana*
15 *Textularia gramen*
7 *Nonion marylandicum*
3 *N. pizarrense*
3 *Bulimina elongata*
2 *Nonion medio-costatum*
1 *Discorbis floridana*
t *Buccella mansfieldi*
t *Hanzawaia concentrica*
t *Nonionella auris*
t *Sigmomorphina concava*
t *Spiroplectammina exilis*
t *Robulus americanus*
t *Rotalia bassleri*
t *Textularia ultima-inflata*
t *Uvigerina subperegrina*
t *Cancris sagra*
t *Virgulina punctata*
x *Bolivina paula*

Ostracoda
30 *Semicytherura coryelli*
24 *Cushmanidea ulrichi*
13 *Hulingsina ashermani*
8 *Haplocytheridea bassleri*
3 *Pokornyella punctistriata*
6 *Tetracytherura shattucki*
4 *Bensonocythere whitei*
3 *Pokornyella punctistriata*
2 *Cushmanidea seminuda*
2 *Cytheretta burnsi*
1 *Loxoconcha granulata*
1 *Muellerina lienenklausi*
t *Actinocythereis exanthemata*
t *Cytheromorpha warneri*
t *Eucythere declivis*
t *E. gibba*
t *Henryhowella evax*
t *Loxoconcha reticularis*
t *Murrayina howei*

Sample 67-58-1.-Paris, Maryland. Probably upper St. Leonard Member.

$n_b = 1709$ $\%_a = 8$
$n_o = 200$ $\%_i = t$
$\%_p = t$

Foraminifera
44 *Buccella mansfieldi*
28 *Valvulineria floridana*
11 *Cibicides lobatulus*
7 *Textularia gramen*
4 *Nonion marylandicum*
2 *Discorbis floridana*
t *Cibicides floridanus*
t *Bolivina paula*
t *Buccella depressa*
t *Bulimina elongata*
t *Hanzawaia concentrica*
t *Lagena clavata*
t *L. substriata*
t *L. tenuis*
t *Nonion medio-costatum*
t *Quinqueloculina seminula*
t *Sigmomorphina concava*
t *Robulus americanus*
t *Textularia candeiana*
t *Cancris sagra*
t *Globulina inaequalis*
t *Lagena* sp. *L. A*

Ostracoda
32 *Cushmanidea ulrichi*
20 *Cytheretta burnsi*
18 *Hulingsina ashermani*
10 *Haplocytheridea bassleri*
8 *Bensonocythere whitei*
4 *Muellerina lienenklausi*
3 *Pokornyella punctistriata*
1 *Actinocythereis exanthemata*
1 *Campylocythere laevissima*
1 *Cushmanidea seminuda*
1 *Murrayina howei*
t *Cytheridea subovalis*
t *Eucythere gibba*
t *Henryhowella evax*
t *Murrayina martini*

Sample 67-65-2.-Calvert Beach, Maryland. Lower Calvert Beach Member.

$n_b = 19{,}136$ $\%_a = 13$
$n_o = 1{,}669$ $\%_i = t$
$\%_p = 0$

Foraminifera
38 *Cibicides lobatulus*
26 *Valvulineria floridana*
15 *Nonion pizarrense*
7 *Spiroplectammina exilis*
6 *Textularia candeiana*
4 *Nonion medio-costatum*
t *N. marylandicum*
t *Discorbis floridana*
t *Lagena substriata*
t *L. tenuis*
t *Massilina glutinosa*
t *Robulus americanus*
t *Entosolenia lucida*
t *Bulimina elongata*
t *Quinqueloculina seminula*
t *Sigmomorphina williamsoni*
t *Pseudopolymorphina striata*
t *Rotalia bassleri*
t *Globulina inaequalis*
t *Nonionella* sp.
t *Uvigerina subperegrina*

Ostracoda
17 *Muellerina lienenklausi*
16 *Henryhowella evax*
15 *Cushmanidea ulrichi*
7 *Echinocythereis clarkana*
6 *Cytheropteron* sp.
5 *Hulingsina ashermani*
4 *Loxoconcha granulata*
4 *Cytheromorpha warneri*
3 *Pterygocythereis americana*
3 *Actinocythereis exanthemata*
2 *A.* sp. *A. gomillionensis*
2 *Cushmanidea agricola*
2 *Cytheretta burnsi*
2 *C. ulrichi*
2 *Semicytherura coryelli*
2 *Murrayina martini*
1 *Cytheridea subovalis*
1 *Cushmanidea seminuda*
t *Pokornyella punctistriata*
t *Loxoconcha reticularis*
t *Murrayina howei*
t *Paracypris choctawhatcheenis*
t *Tetracytherura shattucki*
t *Bensonocythere whitei*
t *Propontocypris howei*

Sample 67-65-9.-Calvert Beach, Maryland. Lower Drumcliff Member.

$n_b = 25{,}870$ $\%_a = 14$
$n_o = 2{,}218$ $\%_i = t$
$\%_p = t$

Foraminifera
38 *Cibicides lobatulus*
23 *Valvulineria floridana*
8 *Textularia gramen*
3 *Bulimina elongata*
3 *Uvigerina subperegrina*
2 *Hanzawaia concentrica*
2 *Nonion pizarrense*
2 *Textularia candeiana*
2 *T. consecta*
1 *Buccella mansfieldi*
1 *Nonion marylandicum*
1 *N. medio-costatum*
t *Buccella depressa*
t *Cibicides floridanus*
t *Lagena tenuis*
t *Massilina glutinosa*
t *Pseudopolymorphina striata*
t *Quinqueloculina seminula*
t *Sigmomorphina concava*
t *Spiroplectammina exilis*
t *Robulus americanus*
t *Textularia ultima-inflata*
t *Virgulina miocenica*
t *Globulina inaequalis*

Ostracoda
24 *Cushmanidea ulrichi*
14 *Semicytherura coryelli*
11 *Hulingsina ashermani*
10 *Cytheretta burnsi*
8 *Pokornyella puncti-striata*
5 *Loxoconcha granulata*
5 *Muellerina lienenklausi*
5 *Murrayina martini*
4 *Cushmanidea seminuda*
3 *Bensonocythere whitei*
2 *Cytheridea subovalis*
2 *Henryhowella evax*
2 *Murrayina howei*
1 *Loxoconcha reticularis*
1 *Tetracytherura shattucki*
t *Actinocythereis exanthemata*
t *A.* sp. *A. gomillionensis*
t *Campylocythere laevissima*
t *Cushmanidea agricola*
t *Haplocytheridea bassleri*

Sample 67-70-15.-East Nomini Cliffs, Virginia. Lower St. Marys Formation.

(No specimens present.)

Sample 67-71-1.-1.1 mile south of Western Shores, Maryland. Central Conoy Member.

(No specimens present.)

Sample 67-72-3.-West Nomini Cliffs, Virginia. Central Drumcliff Member.

$n_b = 1427$ $\%_a = 18$
$n_o = 331$ $\%_i = 0$
$\%_p = 0$

Foraminifera
35 *Valvulineria floridana*
14 *Spiroplectammina exilis*
11 *Nonion medio-costatum*
11 *Buccella mansfieldi*
9 *Nonion pizarrense*
5 *Cibicides lobatulus*
3 *Bulimina elongata*
3 *Lagena substriata*
2 *Textularia consecta*
2 *Virgulina miocenia*
1 *Textularia gramen*
t *Buccella depressa*
t *Hanzawai concentrica*
t *Lagena tenuis*
t *Miliammina fusca*
t *Nonion marylandicum*
t *Pseudopolymorphina striata*
t *Discorbis floridana*

Ostracoda
15 *Cytheretta ulrichi*
14 *Muellerina lienenklausi*
11 *Henryhowella evax*
9 *Hulingsina ashermani*
9 *Loxoconcha granulata*
7 *Echinocythereis clarkana*
6 *Cytheridea subovalis*
5 *Actinocythereis exanthemata*
5 *Pterygocythereis americana*
4 *Cytheretta burnsi*
3 *Cytheropteron* sp.
2 *Actinocythereis* sp. *A. gomillionensis*
2 *Cushmanidea ulrichi*
2 *Cytheromorpha warneri*
2 *Murrayina howei*
2 *M. gunteri*
1 *Tetracytherura shattucki*
t *Cushmanidea agricola*
t *Haplocytheridea*? sp.

Sample 67-72-8.-West Nomini Cliffs, Virginia. Central Boston Cliffs Member.

$n_b = 3256$ $\%_a = 11$
$n_o = 7261$ $\%_i =$ t
$\%_p =$ t

Foraminifera
43 *Buccella mansfieldi*
31 *Cibicides lobatulus*
7 *Textularia gramen*
5 *Nonion pizarrense*
4 *Textularia consecta*
2 *Hanzawaia concentrica*
2 *Nonion marylandicum*
2 *Valvulineria floridana*
1 *Virgulina miocenica*
t *Buccella depressa*
t *Miliammina fusca*
t *Nonion medio-costatum*
t *Pseudopolymorphina striata*
t *Quinqueloculina seminula*
t *Spiroplectammina exilis*
t *Textularia candeiana*
t *T. ultima-inflata*
t *Discorbis floridana*

Ostracoda
56 *Haplocytheridea bassleri*
12 *Cytheretta burnsi*
11 *Cushmanidea ulrichi*
7 *Hulingsina ashermani*
4 *Loxoconcha reticularis*
2 *Basslerites tenmile-creekensis*
2 *Muellerina lienenklausi*
1 *Murrayina howei*
1 *M. martini*
t *Actinocythereis* sp. *A. gomillionensis*
t *Cushmanidea seminuda*
t *C. argicola*
t *Cytheretta ulrichi*
t *Cytheromorpha warneri*
t *Pokornyella puncti-striata*
t *Loxoconcha granulata*
t *Tetracytherura shattucki*
t *Pterygocythereis americana*

Sample 67-73-2.-Horsehead Cliffs, Virginia. Upper Calvert Beach Member.

(No specimens present.)

Sample 67-73-4.-Horsehead Cliffs, Virginia. Central Drumcliff Member.

$n_b = 66{,}444$ $\%_a = 15$
$n_o = 2{,}692$ $\%_i =$ t
$\%_p =$ t

Foraminifera
48 *Cibicides lobatulus*
15 *Valvulineria floridana*
8 *Bulimina elongata*
7 *Textularia gramen*
5 *Spiroplectammina exilis*
4 *Nonion pizarrense*
3 *Virgulina miocenica*
2 *Textularia candeiana*
1 *Nonion medio-costatum*
1 *Nonionella auris*
t *Hanzawaia concentrica*
t *Lagena clavata*
t *L. substriata*
t *Massilina glutinosa*
t *Nonion marylandicum*
t *Quinqueloculina seminula*
t *Robulus americanus*
t *Rotalia bassleri*
t *Textularia ultima-inflata*
t *Uvigerina subperegrina*
t *Discorbis floridana*

Ostracoda
14 *Cytheromorpha warneri*
13 *Muellerina lienenklausi*
12 *Cushmanidea ulrichi*
9 *Cytheridea subovalis*
9 *Loxoconcha granulata*
7 *Hulingsina ashermani*
6 *Pokornyella puncti-striata*
4 *Pterygocythereis americana*
4 *Murrayina martini*
3 *M. howei*
3 *Cytheretta burnsi*
3 *Cytheropteron* sp.
2 *Actinocythereis exanthemata*
2 *Semicytherura coryelli*
2 *Eucythere gibba*
2 *Henryhowella evax*
1 *Cytheretta ulrichi*
t *Actinocythereis* aff. *A. gomillionensis*
t *Cushmanidea seminuda*

t *Pyrgo subsphaerica*
t *Nodosaria catesbyi*

t *C. agricola*
t *Echinocythereis clarkana*
t *Haplocytheridea bassleri*
t *Tetracytherura shattucki*
t *Bensonocythere whitei*

Sample 67-63-8.-Horsehead Cliffs, Virginia. Lower Conoy Member.

$n_b = 16{,}968$ $\%_a = 15$
$n_o = 435$ $\%_i = 0$
$\%_p = t$

Foraminifera
29 *Nonion pizarrense*
23 *Valvulineria floridana*
14 *Nonion medio-costatum*
12 *Spiroplectammina exilis*
7 *Buccella mansfieldi*
5 *Bulimina elongata*
2 *Cibicides lobatulus*
2 *Textularia candeiana*
2 *Uvigerina subperegrina*
1 *Nonion marylandicum*
1 *Virgulina miocenica*
t *Buccella depressa*
t *Lagena substriata*
t *Massilina glutinosa*
t *Pseudopolymorphina striata*
t *Rotalia bassleri*
t *Textularia gramen*
t *Cancris sagra*
t *Discorbis floridana*

Ostracoda
17 *Cytheridea subovalis*
15 *Cytheropteron* sp.
11 *Pterygocythereis americana*
10 *Loxoconcha granulata*
10 *Henryhowella evax*
9 *Cushmanidea ulrichi*
8 *Cytheretta ulrichi*
8 *Muellerina lienenklausi*
6 *Echinocythereis clarkana*
4 *Cytheromorpha warneri*
2 *Actinocythereis* sp.
t *Campylocythere* sp.
t *Cushmanidea seminuda*
t *Hulingsina ashermani*
t *Cytherella* sp.

Sample 67-73-9.-Horsehead Cliffs, Virginia. Central Conoy Member.

(No specimens present.)

Sample 67-74-4.-Parker Creek, Maryland. Central Calvert Beach Member.

$n_b = 13{,}061$ $\%_a = 6$
$n_o = 3{,}412$ $\%_i = t$
$\%_p = t$

Foraminifera
33 *Cibicides lobatulus*
30 *Valvulineria floridana*
10 *Uvigerina subperegrina*
5 *Textularia gramen*
5 *Nonion marylandicum*
4 *N. medio-costatum*
2 *Bulimina elongata*
2 *Hanzawaia concentrica*
2 *Nonion pizarrense*
1 *Lagena substriata*
1 *Nonionella auris*
t *Marginulina* sp. *M. B*
t *Cibicides floridana*
t *Bolivina plicatella*
t *Buccella mansfieldi*
t *Entosolenia lucida*
t *Lagena acuticostata*
t *L. clavata*
t *L. tenuis*
t *Quinqueloculina seminula*
t *Robulus americanus*
t *Rotalia bassleri*
t *Textularia consecta*
t *T. ultima-inflata*
t *Virgulina miocenica*
t *Discorbis floridana*
t *Lagena* sp. *L. A*
t *Elphidium poeyanum*
t *Spiroplectammina mississippiensis*

Ostracoda
28 *Cushmanidea ulrichi*
13 *Cytheridea subovalis*
8 *Cushmanidea agricola*
7 *Pterygocythereis americana*
6 *Loxoconcha granulata*
6 *Cytheretta ulrichi*
6 *Semicytherura coryelli*
5 *Cytheromorpha warneri*
5 *Hulingsina ashermani*
5 *Muellerina lienenklausi*
3 *Echinocythereis clarkana*
2 *Murrayina martini*
1 *Cushmanidea seminuda*
t *Actinocythereis exanthemata*
t *Cytheretta burnsi*
t *Cytheropteron* sp.
t *Eucythere gibba*
t *Haplocytheridea bassleri*
t *Henryhowella evax*
t *Pokornyella punctistriata*
t *Loxoconcha reticularis*
t *Murrayina howei*
t *Neocytherideis fasciata*
t *Tetracytherura shattucki*
t *Bensonocythere whitei*

Sample 67-74-9.-Parker Creek, Maryland. Lower St. Leonard Member.

$n_b = 1387$ $\%_a = 13$
$n_o = 1868$ $\%_i = 0$
$\%_p = 0$

Foraminifera
77 *Buccella mansfieldi*
5 *Spiroplectammina* aff. *S. exilis*
4 *Textularia gramen*
2 *Bulimina elongata*
2 *Discorbis floridana*
2 *Massilina glutinosa*
2 *Rotalia bassleri*
2 *Textularia candeiana*
1 *Nonion pizarrense*
t *Buliminella elegantissima*
t *Cibicides lobatulus*
t *Hanzawaia concentrica*
t *Lagena substriata*
t *Nonion medio-costatum*

Ostracoda
51 *Actinocythereis* sp. *A. mundorffi*
26 *Cytheridea subovalis*
6 *Loxoconcha granulata*
3 *Cushmanidea ulrichi*
3 *Loxoconcha reticularis*
2 *Cytheretta burnsi*
2 *Cytheromorpha warneri*
2 *Murrayina martini*
2 *Pterygocythereis americana*
1 *Cytheretta ulrichi*
t *Actinocythereis exanthemata*
t *Cytheropteron* sp.
t *Echinocythereis clarkana*
t *Pokornyella punctistriata*
t *Murrayina howei*

Sample 67-74-10.-Parker Creek, Maryland. Lower Boston Cliffs Member.

$n_b = 3623$ $\%_a = 4$
$n_o = 2736$ $\%_i = 0$
$\%_p = t$

Foraminifera
46 *Cibicides lobatulus*
21 *Discorbis floridana*
11 *Buccella mansfieldi*
10 *Rotalia bassleri*
3 *Hanzawaia concentrica*
2 *Massilina glutinosa*
2 *Textularia gramen*
2 *Valvulineria floridana*
t *Buccella depressa*
t *Bulimina elongata*
t *Miliammina fusca*
t *Nonion marylandicum*
t *N. medio-costatum*
t *Virgulina miocenica*
t *Cancris sagra*

Ostracoda
25 *Loxoconcha granulata*
12 *Cytheridea subovalis*
12 *Cushmanidea ulrichi*
10 *Murrayina martini*
7 *Cytheretta burnsi*
6 *Hermanites* sp.
6 *Cytheromorpha warneri*
5 *Pokornyella punctistriata*
4 *Actinocythereis exanthemata*
3 *Loxoconcha reticularis*
2 *Pterygocythereis americana*
1 *Semicytherura coryelli*
1 *S. reticulata*
1 *Murrayina howei*

t *Aurila laevicula*
t *Campylocythere laevissima*
t *Cushmanidea seminuda*
t *C. agricola*
t *Semicytherura forulata*
t *Haplocytheridea bassleri*
t *Hulingsina ashermani*
t *Muellerina lienenklausi*
t *Tetracytherura shattucki*
t *Bensonocythere whitei*
t *Propontocypris howei*
t *Paradoxostoma robusta*

Sample 67-77-1.-Grubin Neck, Maryland. Central Conoy? Member.

(No specimens present.)

Sample 67-79-2.-South Boston Cliffs, Maryland. Lower Boston Cliffs Member.

$n_b = 29{,}560$ $\%_a = 29$
$n_o = 36{,}002$ $\%_i = 8$
$\%_p = t$

Foraminifera
29 *Textularia gramen*
26 *Cibicides lobatulus*
19 *Buccella mansfieldi*
8 *Rotalia bassleri*
8 *Quinqueloculina seminula*
5 *Hanzawaia concentrica*
2 *Valvulineria floridana*
t *Elphidium poeyanum*
t *Buccella depressa*
t *Nonion pizarrense*
t *Pseudopolymorphina dumblei*
t *Robulus americanus*
t *Textularia consecta*
t *T. ultima-inflata*
t *Cancris sagra*
t *Discorbis floridana*
x *Bulimina elongata*

Ostracoda
32 *Pokornyella punctistriata*
22 *Cytheromorpha warneri*
16 *Aurila laevicula*
8 *Semicytherura coryelli*
4 *Muellerina lienenklausi*
3 *Cushmanidea ulrichi*
2 *Haplocytheridea bassleri*
2 *Semicytherura forulata*
2 *S. reticulata*
2 *Tetracytherura shattucki*
2 *Cyprideis floridana*
1 *Bensonocythere whitei*
t *Actinocythereis exanthemata*
t *Campylocythere laevissima*
t *Hermanites* sp.
t *Cushmanidea seminuda*
t *Cytheretta burnsi*
t *Hulingsina ashermani*
t *Loxoconcha granulata*
t *L. reticularis*
t *Pterygocythereis americana*
t *Cytherois fischeri*
t *Propontocypris* sp.

Sample 67-81-1.-South of Greensboro, Maryland. Central Calvert Beach Member.

(No specimens present.)

Maryland Geological Survey
Latrobe Hall
The Johns Hopkins University
Baltimore, Maryland 21218

Reports of Investigation

1. Chemical quality of water and trace elements in the Patuxent River Basin, by S. G. Heidel and W. W. Frenier, 1965, 52 p. . . . $1.00
2. Pleistocene stratigraphy of the Salisbury area, Maryland and its relationship to the lower Eastern Shore: a subsurface approach, by H. J. Hansen, 1966, 56 p. 2.25
3. Water resources of the Salisbury area, Maryland, by D. H. Boggess, R. A. Gardner, and S. G. Heidel, 1968, 69 p. 3.00
4. Expandable clay in the St. Marys Formation of Southern Maryland, by M. M. Knechtel, H. P. Hamlin, and J. W. Hosterman, 1968, 19 p. 1.00
5. Chemical quality reconnaissance of water of Maryland streams, by J. D. Thomas, 1966, 61 p. 2.00
6. Revision of stratigraphic nomenclature—Glenarm Series of the Appalachian Piedmont, by D. L. Southwick and G. W. Fisher, 1968, 19 p. 1.50
7. Geophysical log cross-section network of the Cretaceous sediments of Southern Maryland, by H. J. Hansen, 1968, 46 p. 4.00
8. Piedmont and Coastal Plain geology along the Susquehanna Aqueduct: Baltimore to Aberdeen, Maryland, by E. T. Cleaves, 1968, 45 p. 2.00
9. Chemical and physical character of municipal water supplies in Maryland, by J. D. Thomas and S. G. Heidel, 1969, 52 p. 1.00
10. Ground-water occurrence in the Maryland Piedmont, by L. J. Nutter and E. G. Otton, 1969, 56 p. 2.50
11. Petrology and origin of Potomac and Magothy (Cretaceous) sediments, Middle Atlantic Coastal Plain, 1969, 101 p., by J. D. Glaser 3.50
12. Paleoecology of the Choptank Formation (Miocene) of Maryland and Virginia, by R. E. Gernant, 1970 . . . . . 4.50

Maryland residents add 4% tax.

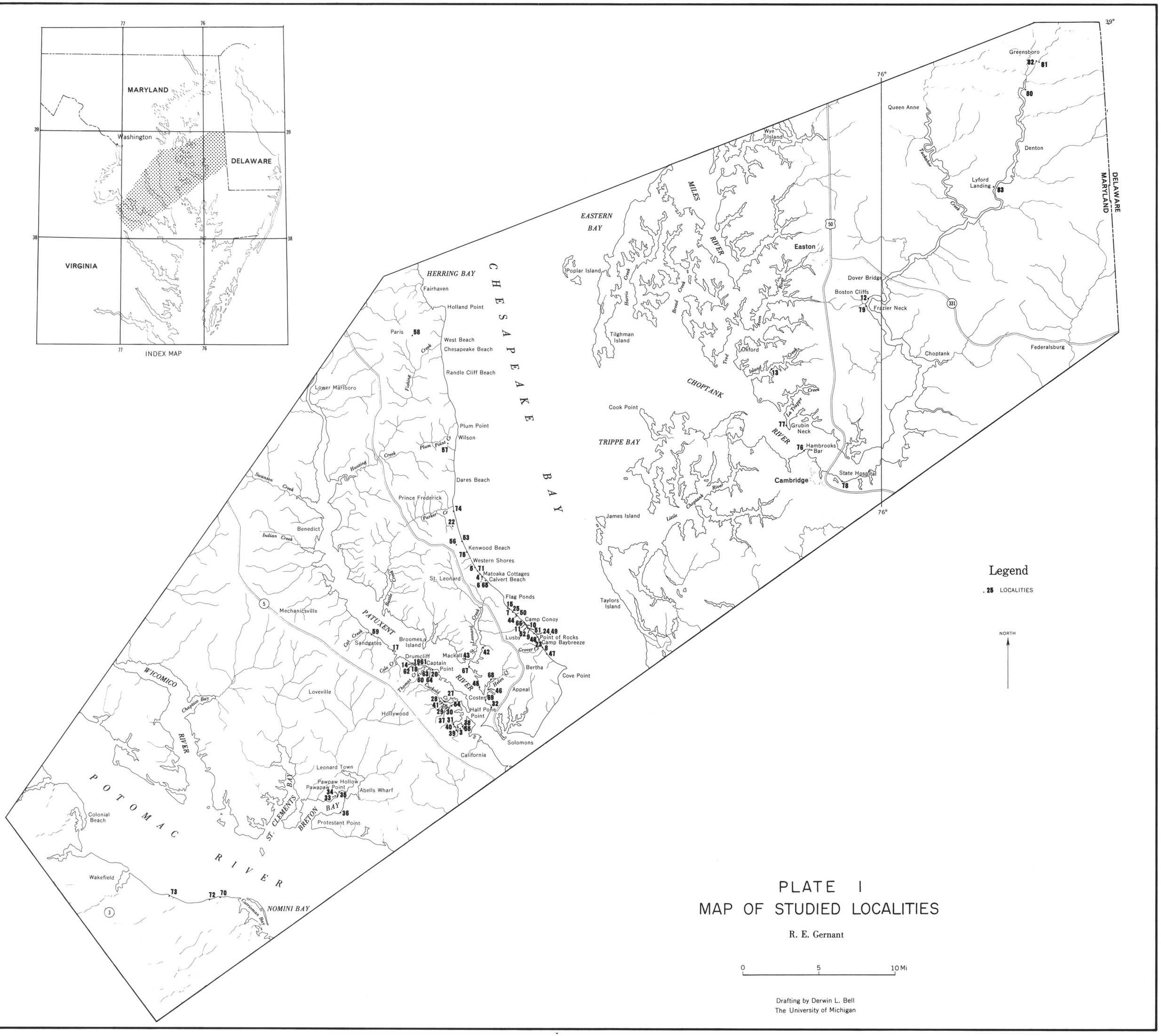


PLATE I
MAP OF STUDIED LOCALITIES

R. E. Gernant

Drafting by Derwin L. Bell
The University of Michigan

PALEOECOLOGY OF THE CHOPTANK FORMATION (MIOCENE) OF MARYLAND AND VIRGINIA

REPORT OF INVESTIGATIONS NO. 12