LATE MIOCENE PALEOECOLOGY AND BIOSTRATIGRAPHY OF SOUTHEASTERN MARYLAND

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ABSTRACT OF THE THESIS

Late Miocene Foraminiferal Paleoecology and

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Thesis Director: Professor R. K. Olsson

The Choptank, St. Mary's, and Yorktown Formations in southeastern Maryland are predominantly terrigenous, unconsolidated clays, silts, and sands deposited in the Salisbury Embayment. Growth faulting in the Salisbury Embayment during deeposition has resulted in rapid downdip thickening of these formations. Subsurface demarcation of the formations is achieved by use of benthic foraminiferal biofacies generated by cluster analysis.

Planktonic foraminifera indicate that the St. Mary's and Choptank Formations are of late Miocene (Tortonian Stage) age. Both formations are placed within the Globorotalia acostaensis zone. Planktonic foraminifera are absent in the Yorktown Formation, but its stratigraphic position and paleoenvironmental setting suggest a Pliocene age. The deposition of the Choptank, St. Mary's, and Yorktown Formations occurred during three cycles of global sea-level rise. The cycles are correlated with Miocene cycles of sea level rise identified by Vail and others (1977) and Vail (1981).

Paleobathymetries obtained through benthic foraminiferal assemblages indicate that the Yorktown and the St. Mary's Formations

were deposited in an inner continental shelf environment of 0-40 and 30-50 m water depth, respectively. The Choptank Formation was deposited in an outer continental shelf or slope environment of approximately 180-220 m water depth.

Faunal diversity and distribution suggest that ecological conditions have remained largely unchanged on the Maryland continental shelf since the Miocene. The geographic distribution of Miocene and modern water masses on the shelf and slope are similar, also.

Benthic foraminiferal assemblages reveal a cooling trend in the Maryland shelf waters during the late Miocene and early Pliocene. These trends correspond to Antarctic glacial cycles which apparently influenced the thermal regime of Middle Atlantic shelf waters.

ACKNOWLEDGEMENTS

Much gratitude is expressed to Dr. R.K. Olsson, the project director and supervisor, who also initiated the study. Drs. G.R. McGhee and S.K. Fox, the thesis committee members, provided considerable direction and assistance. Many thanks to Allan Melillo, Larry Muller, and Robert Starcher for help along the way.

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INTRODUCTION

In Maryland Miocene deposits are known as the Chesapeake Group because of the prominent exposures found along Chesapeake Bay (Shattuck, 1904). The Miocene was originally divided into three formations by Shattuck. They are, in order of decreasing age, the Calvert, the Choptank, and the St. Mary's. The Yorktown Formation, which overlies the St. Mary's, was later included in the Miocene Chesapeake Group on the basis of lithology (Ryan, 1953). Recent studies, however, suggest that it is probably Pliocene in age (Melillo, 1982).

Miocene sediments of the Middle Atlantic coastal plain comprise part of a seaward-thickening wedge of Mesozoic and Cenozoic sediments that overlie a Precambrian crystalline complex (Gernant et al., 1977). The Atlantic margin developed following the separation of North America from Africa in the late Triassic (Schlee and Jansa, 1981). A block-faulted, fractured, trailing-edge margin was formed. Subsequent sedimentary infilling over basins and platforms created a continental shelf that is aqpproximately 150 kilometers wide off Maryland (Schlee and Jansa, 1981).

Although Miocene deposition was extensive along the Atlantic coastal plain, local structural features created peculiar depositional conditions (Gibson, 1970). This resulted in various structural lineaments, regional negative areas, basins, river tributary systems, and sediment supply areas (Gernant, 1970). The axes of these structural

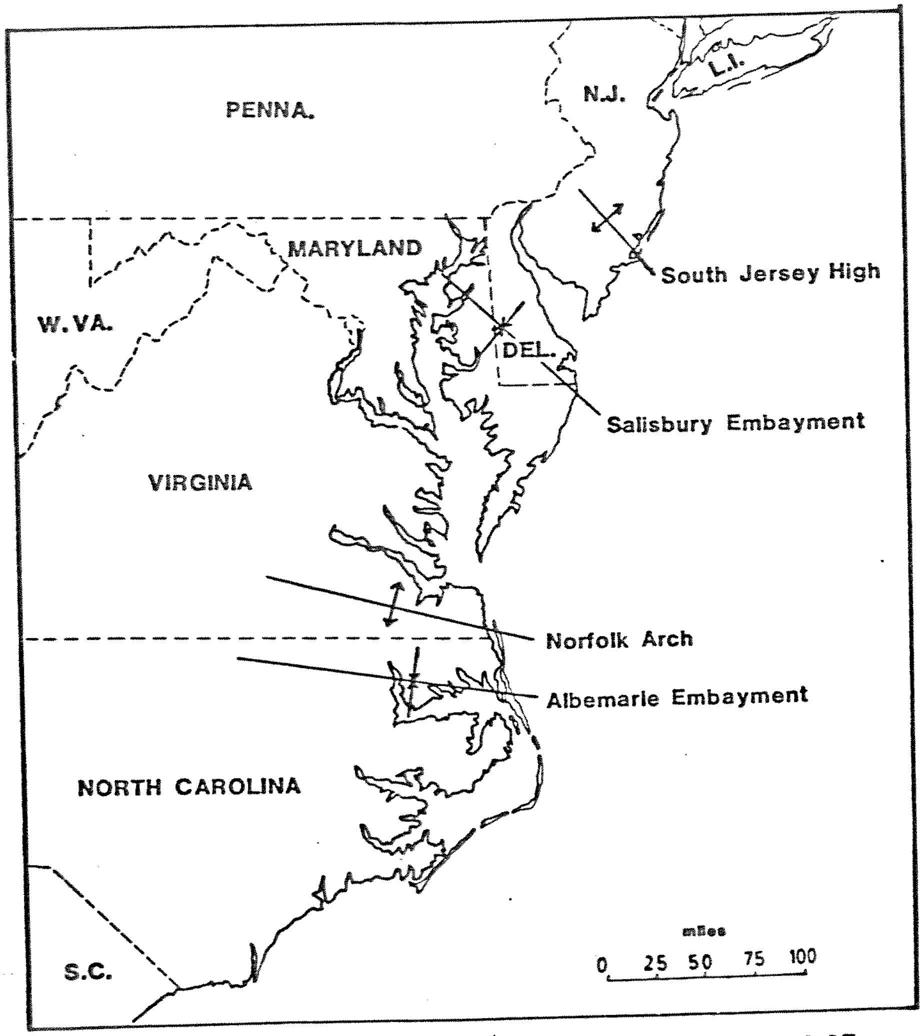
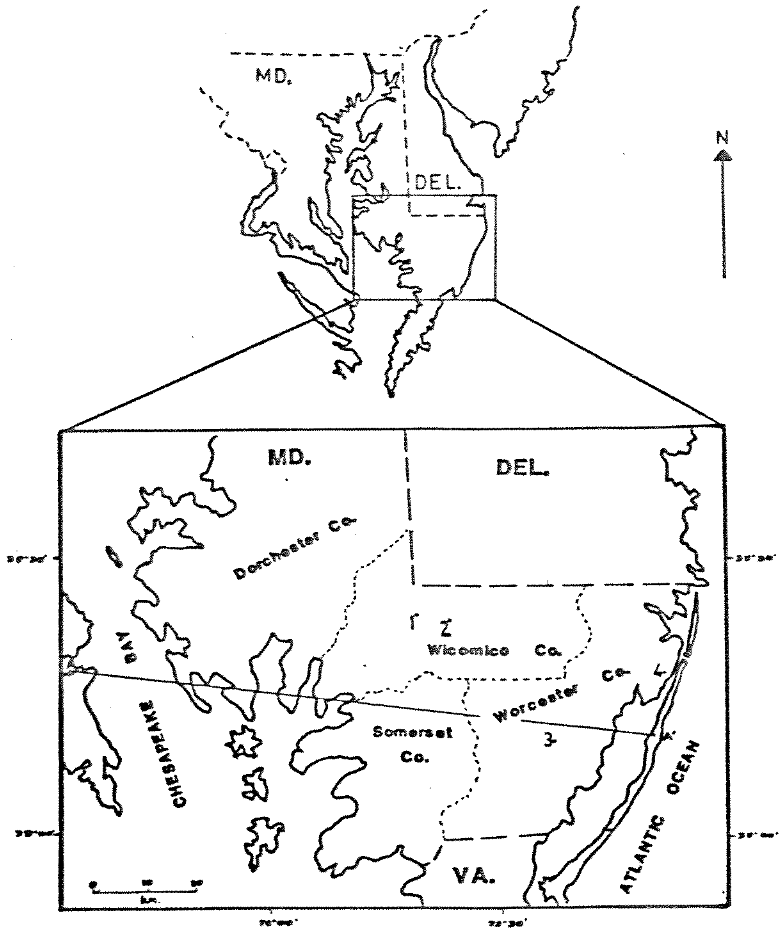


FIGURE 1. MAP SHOWING MAJOR STRUCTURAL FEATURES OF MIDDLE ATLANTIC COASTAL PLAIN (AFTER GERNANT ET AL., 1977)

features generally trended in a northwest-southeast direction (Figure 1). The source area of most of the sediment was the Appalachian Mountains. Important river systems were the ancient Susquehanna, Patuxent, Potomac, Rappahannock, York, and James (Gernant, 1970).

The Salisbury Embayment was a well-developed basin that lay to the east of, and occupied parts of, Maryland and Delaware. It was the locus of thick Tertiary deposition, particularly in the Miocene (Gernant, 1970). The depositional center within the basin shifted over time resulting in a widespread geographic distribution of Miocene formations (Gernant et al., 1977).

The purpose of this study is to examine, through the use of planktonic and benthic foraminifera, lithiology, and electrical resistivity log profiles, the paleoecology, paleobathymetry, stratigraphy, and biostratigraphy of the Choptank, St. Mary's, and Yorktown Formations in Maryland. Paleoecology allows reconstruction of ancient depositional environments and oceanographic regimes. Paleobathymetry is a good indicator of sea level fluctuations. Stratigraphy and biostratigraphy can accurately age-date and differentiate the strata as well as provide information on depositional conditions and continuity. Finally, comparison of this study to similar ones done of the modern ocean demonstrates the degree of relative change of various conditions between the late Miocene and the present.



	WELLS	LATITUDE	LONGITUDE
1	WICD 65	38° 23.43′	75° 34.49′
2	WICE 213	38° 20.55′	75° 36.43′
3	WORDD 60	38° 10.30′	75° 22.84′
4	WORCG 73	38° 18.61′	75° 07.07′

FIGURE 2. EASTERN MARYLAND BASE MAP

METHODS

Raw data for this study was obtained from cuttings from four wells drilled in southeastern Maryland (Figure 2). The four wells are located in a west-northwest to east-southeast trend and are in a progressively downdip position to the local formations. Electrical resistivity log profiles were provided by the Maryland Geological Survey.

All four wells penetrated Holocene through Miocene deposits. WI-CD-65 and WI-CE-213 were drilled to 1000 feet (330 m) depth and reached the Calvert Formation. WOR-DD-60 was drilled to 800 feet (244 m) and WOR-CG-73 to 1000 feet (330 m). Both these wells terminated in the Choptank Formation. All wells were sampled at 10 ft. (3.3 m) intervals.

Dry samples were first disaggregated and deflocculated using sodium carbonate and a 220 mesh sieve. Foraminifera were then separated from the sediment by flotation in perchlorethylene. Identification and absolute counts were made on the foraminifera from each of the intervals.

Intervals varied in specimen content from less than 5 to over 600. Before any statistical tests were conducted on the data they were normalized by transformation to logarithms of base ten.

Downhole contamination of foraminifera was a minor problem and negligible in three wells. Faunal contamination was a problem only in certain intervals of well WOR-CG-73.

STRATIGRAPHY

Miocene deposits in southeastern Maryland conformably overlie the Oligocene Piney Point Formation (Ungrady, 1979) and are unconformably overlain by the Pliocene Yorktown Formation. The Miocene beds themselves are separated by subtle unconformities (Olsson, personal communication). They are thicker than other Tertiary strata in the area and are more coarse and terrigenous in nature (Gernant et al., 1977). This has been ascribed to a rejuvenation of the source area, the Appalachians, at the time (Ryan, 1953). Miocene sediments are predominantly clastic in the northern and central Atlantic coastal plain and show an increasing carbonate content southwards (Gernant et al., 1977).

The Calvert Formation, of early Miocene age (Gernant et al., 1977), consists of clay, silt, marl, and fine sand. Diatomaceous clays are common (Ryan, 1953). The formation is very abundant in vertebrate and invertebrate fossils. The overlying Choptank Formation consists of fine and medium-grained sand interbedded with clay and silt. It is less fossiliferous and coarser in nature than the Calvert. The Choptank contains large amounts of fragmented molluscan shells and glauconite is present in minor amounts in the upper Choptank.

The St. Mary's Formation is predominantly sandy with an admixture of clay and marl. The upper portion of the formation is micaceous and contains gypsum, glauconite, and heavy minerals. This is especially true in the updip wells. Large, fragmented mollusc shells and some

A-A' APPEARS IN FIG. 2

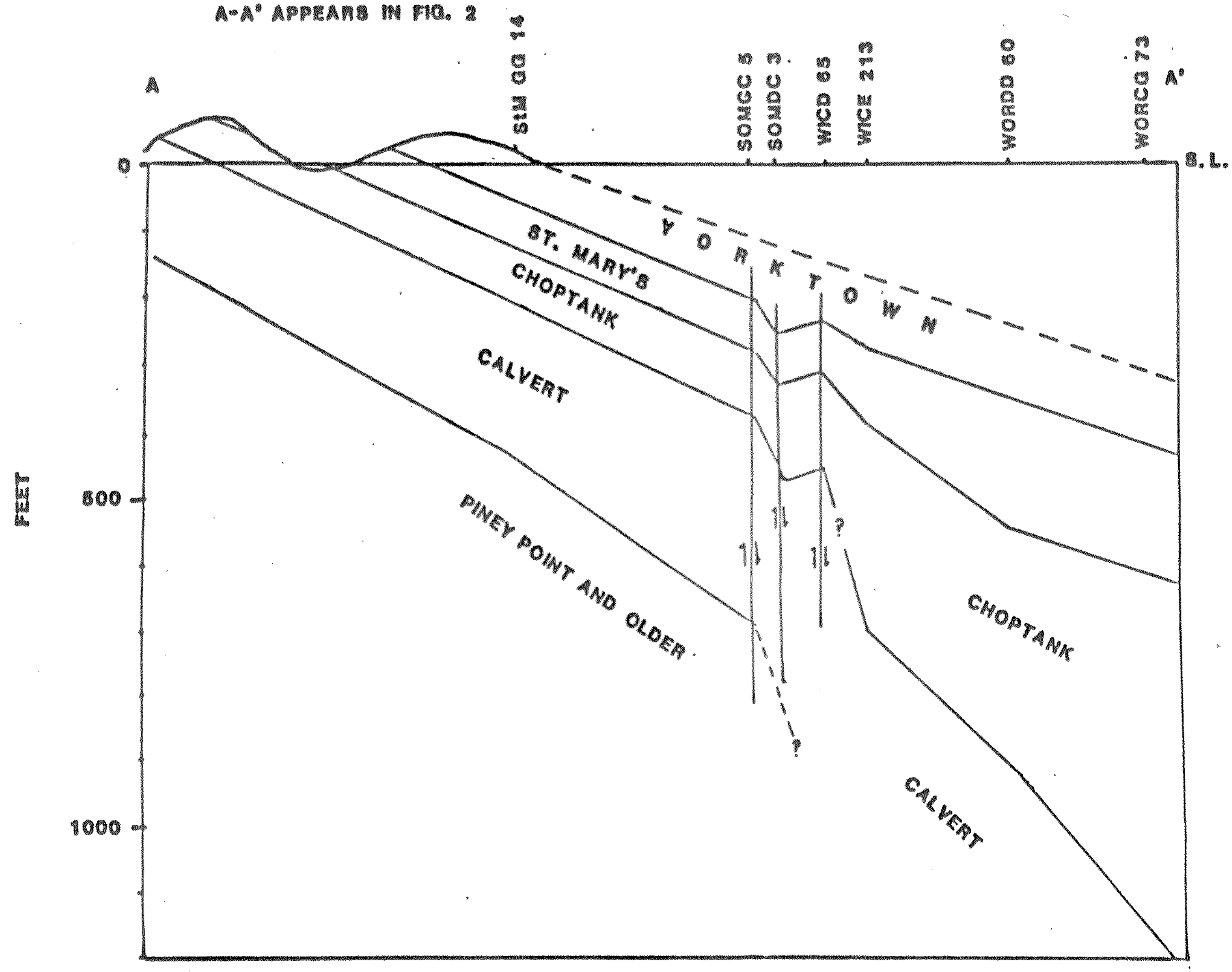


FIGURE 3 CROSS SECTION PARALLEL TO DIP

wood are also present and stained and recrystallized foraminifera are common. These are characteristics of nearshore and beach environments, but the foraminiferal species indicate deeper water. The uppermost St. Mary's seems to represent an erosional surface that was subaerially exposed and reworked.

The Yorktown Formation is an irregularly stratified gravel and sand with small amounts of silt and clay. Coarse and medium-grained sand are the most common sediment types. Heavy mineral grains and large molluscan fragments are frequently encountered. Glauconite is occasionally present. Some quartz grains show limonite staining.

PALEOECOLOGY

Paleoecological studies of benthic foraminifera are conducted mainly with concepts taken from modern ecology (Douglas, 1979). Data on the distribution of modern benthic species provide empiric models useful for the construction and comparison of paleoenvironments (Douglas, 1979). This approach can be readily applied to Neogene studies as many of the species are still extant (Gibson and Buzas, 1973). In Neogene paleoecological studies extant species are assumed to be relatively unchanged in their ecological preferences of habitat over time (Bandy and Arnal, 1960). Extant homeomorphs of extinct species are believed to exhibit convergent adaption in response to similar environmental demands (Bandy and Arnal, 1960).

Modern ecology is derived primarily from distributional patterns of benthic foraminifera. The main factors affecting distribution are water-mass and substrate characteristics (Douglas, 1979). These vary with bathymetry along the continental shelf and slope.

Altogether thirty-three species of benthic foraminifera were recovered from the Yorktown, St. Mary's, and Choptank Formations. These are listed in Appendix 1. Twenty-one commonly occurring species were utilized in numeerical analyses (Appendix 2). Of these twenty-one species, fourteen are extant.

Recent through Pliocene deposits contain very few forammininfera. In WI-CD-65, the most updip well, the first fauna appears in the Choptank Formation. In wells WI-CE-213 and WOR-DD-60 the first intervals to produce statistically analysable yields are in the St. Mary's Formation. Only in well WOR-CG-73 is there abundant faunal recovery in the Yorktown, St. Mary's, and Choptank Formations. The abundance of foraminifera in the four wells increases downdip progressively.

The Yorktown Formation contains fourteen species of benthic foraminifera (Appendix 1). Occurrences are sporadic and abundances low. The common species are Elphidium gunteri Cole, Nonionella auris (d'Orbigny), Buliminella elegantissima (d'Orbigny), and Florilus incisum (Cushman). E. gunteri and N. auris are the dominant species. They account for between 60-70% and 55-65% of most assemblages, respectively. E. gunteri and Nonionella miocenica stella (Cushman and Moyer), an extant homeomorph of N. auris, have bathymetric preferences of less than 50 m (Table 1 and Figure 6). E. gunteri is extremely tolerant of a variety of environments ranging from hypo- and hypersaline tidal marshes to beaches, lagoons, and the shallow shelf (Murray, 1973).

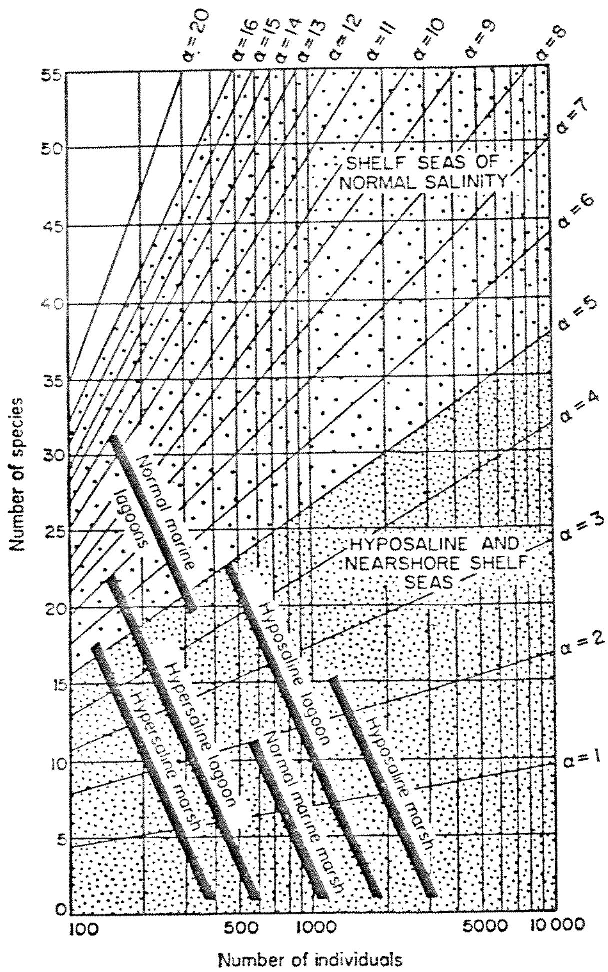
The St. Mary's shows a sharp increase in the number of benthic species (25) and has much higher abundances than the Yorktown. The most commonly occurring foraminifera are Bolivina paula (Cushman and Cahill), Florilus pizarrensis (Berry), Buliminella elongata (d'Orbigny), Buccella mansfieldi (Cushman), E. gunteri and B. elegantissima. These species usually account for 12-35% each of the St. Mary's assemblages.

Other commonly occurring species are N. auris, Hanzawaia concentrica (Cushman), Textularia agglutinans (d'Orbigny), and F. incisum.

The Choptank Formation contains a total of thirty benthic species. The abundance of specimens is greater than in the St. Mary's. The most common species are B. elongata, F. pizarrensis, B. mansfieldi, Cassidulina carinata (Cushman), and Uvigerina peregrina peregrina (Cushman). Dominance is less in the Choptank than in the St. Mary's. Single species do not account for more than 12-25% of the assemblages. Other benthic species occurring frequently, but in small numbers, throughout the Choptank are Bolivina marginata multicostata (Cushman), Lagena costata anphora Reuss, Bolivina marginata Cushman, and Guttulina austriaca d'Orbigny.

Taxonomic diversity of benthic foraminifera tends to be a direct function of bathymetry on the continental shelf (Gibson and Buzas, 1973). Higher diversities are found with increasing distance from shore and greater depths of water. Because of the relationship that generally exists between diversity and environment, a knowledge of the diversity of fossil assemblages can shed light on the paleoecology.

The Fisher Alpha Index (Murray, 1973) is a graphical diversity measure obtained by the comparison of the number of species in an assemblage to the log series distribution of the total individuals (Figure 4). The logarithmic distribution of individuals attempts to account for the distortion that small sample size or the presence of



FORMATION	MEAN α VALUE
YORKTOWN	1 – 2
ST. MARY'S	3 – 4
CHOPTANK	4 – 5

FIGURE 4 COMPARISON OF ALPHA INDEX VALUES OF VARIOUS MARINE ENVIRONMENTS (AFTER MURRAY, 1973)

rare species might impose on the results. As expected, plots of the sampling intervals show increasing diversity for the Yorktown, St. Mary's and Choptank Formations. Their Alpha Index values are 1-2, 3-4, and 4-5 respectively.

The Shannon-Wiener Information Function is another common measure of diversity (Gibson and Buzas, 1973). It is defined as :

$$H(S) = -\sum p_i \ln p_i$$

where pi is the proportion of the ith species. The Information Function accounts for species abundance independently of any fixed mathematical model such as a log-series distribution of individuals. Mean H(S) values calculated are 1.35 for the Yorktown, 1.70 for the St. Mary's, and 2.02 for the Choptank.

Foraminiferal assemblages were defined by R-mode cluster analysis. Cluster analysis is a statistical technnique frequently used in paleoecological studies whereby large amounts of data can be grouped together in varying degrees of association. Cluster analysis was accomplished using several sub-routines of the Numerical Taxonomy System of Multivariate Statistical Programs (NT-SYS) compiled at the State University of New York at Stony Brook.

The R-mode analysis groups species together according to the degree of their common occurrence. A single analysis was performed on cumulative interval counts from all four wells (Appendix 2). The correlation coefficient was utilized in the computations. The resulting dendrogram is illustrated in Figure 5. This analysis had a cophenetic

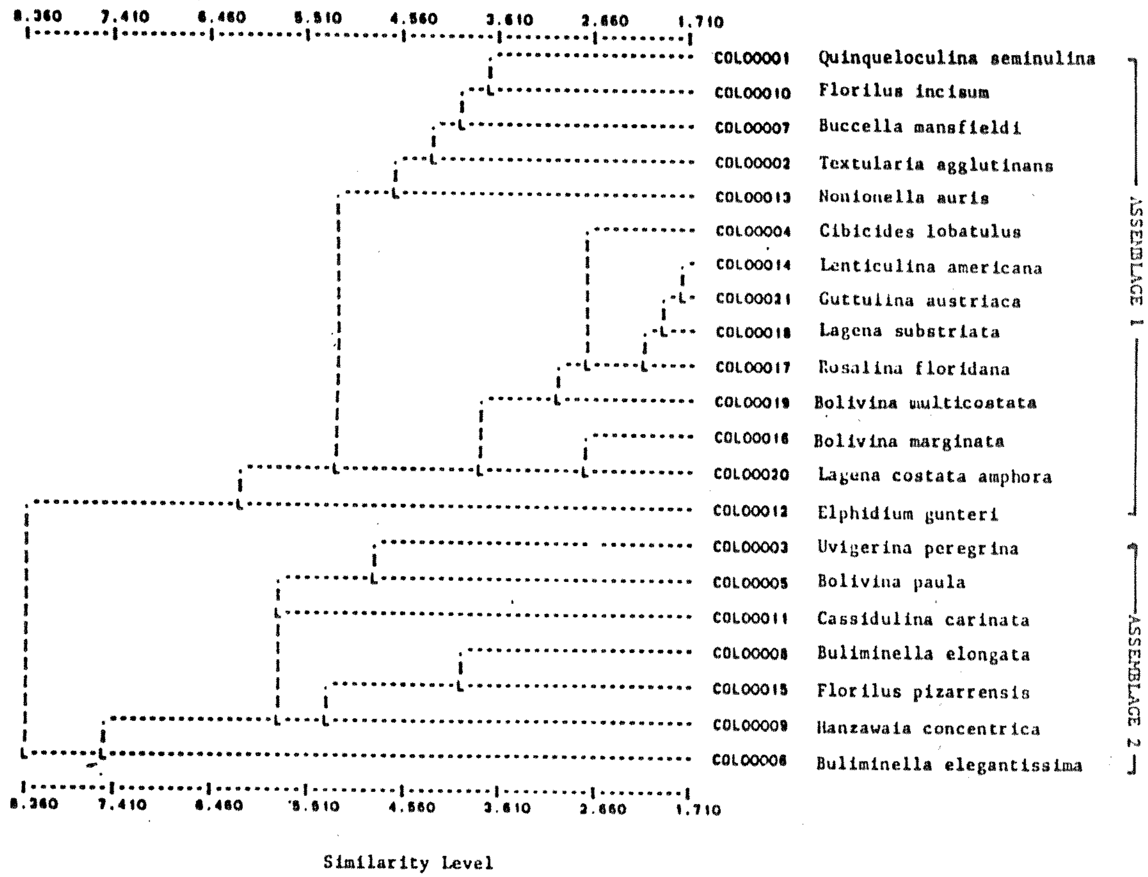


FIGURE 5. R-mode cluster analysis dendrogram. Cophenetic correlation value: .86

correlation value of 0.86, which places it well within the acceptable range of accuracy.

Two assemblages are evident in Figure 5. Assemblage 1 is representative of the St. Mary's Formation in terms of the dominant species encountered. Assemblage 2 is characteristic of the Choptank Formation. No cluster or sub-cluster representative of the Yorktown Formation developed.

A major shortcoming of cluster analysis is that species are unequivocally placed in one cluster or another, whereas they may belong to both clusters equally in real occurrence. Such is the case with *B. mansfieldi*, *B. elongata*, *B. elegantissima*, and *F. incisum.*

A plot of bathymetric ranges of extant species and extant homeomorphs suggests that the St. Mary's was deposited in an inner-shelf environment of 30-50 m water depth (see Table 1 and Figure 6). Important bathymetric indicators for the St. Mary's are *Q. seminulina*, *E. gunteri*, *C. lobatulus*, and *R. floridana.*

The Choptank Formation appears to have been deposited in approximately 180 to 220 m water depth. Important bathymetric indicators are *U. peregrina*, *C. carinata*, *H. concentrica*, and *Florilus atlanticus*, a homeomorph of *F. pizarrensis*. *U. peregrina* and *C. carinata*, which are present in large numbers, are especially good indicators of outer shelf and slope bathymetries (Pflum and Frerichs,

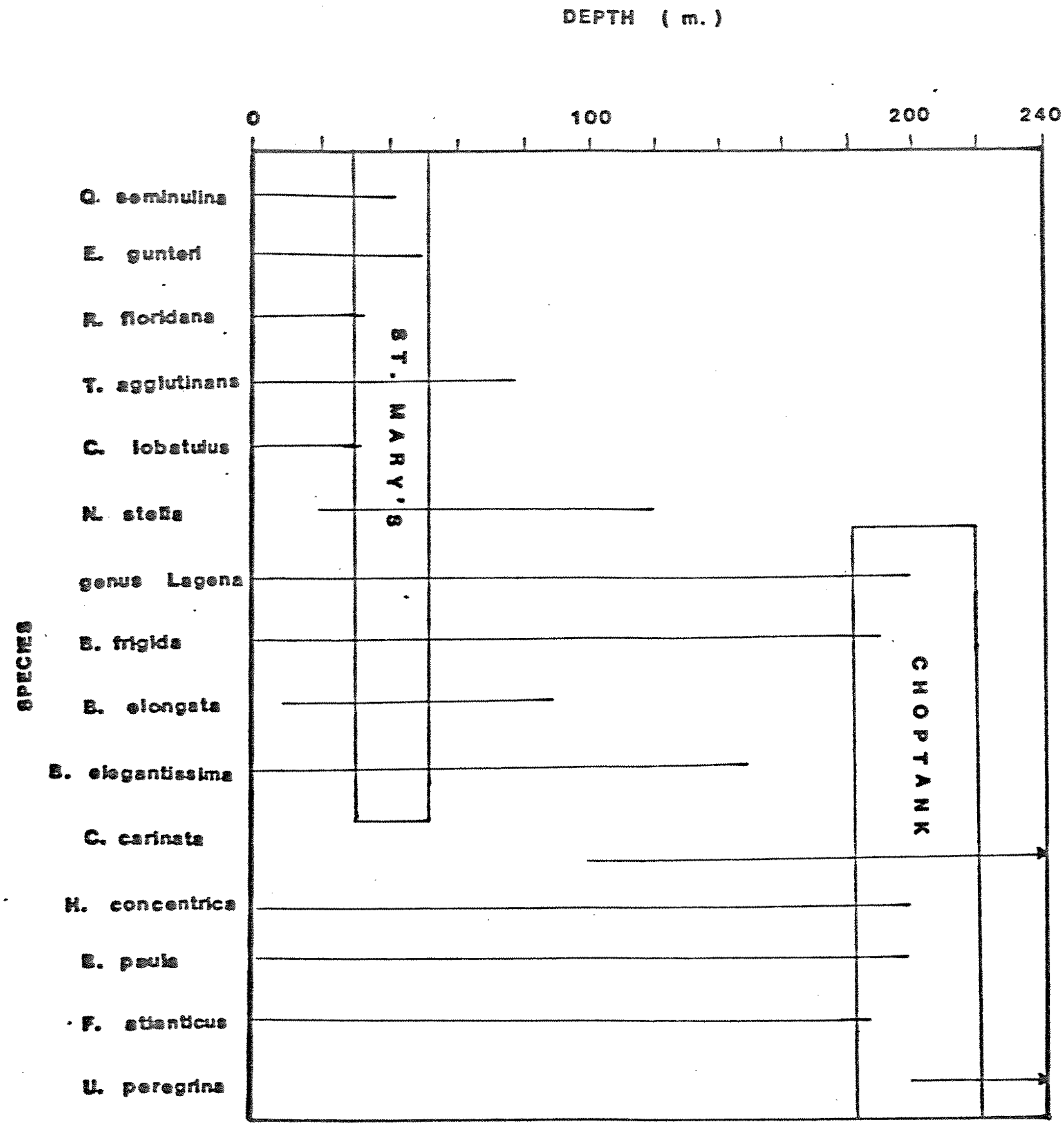


FIGURE 6 EXTANT SPECIES DEPTH RANGES

TABLE 1

Bathymetric ranges of selected extant species*

Species	Range	Reference
Q. seminulina	0-40 m	Murray, 1973
E. gunteri	0-50 m	Murray, 1973
R. floridana	0-30 m	Schnitker, 1970
T. agglutinans	0-80 m	Smith, 1964
N. stella (auris)	20-120 m	Murray, 1973
B. frigida (mansfieldi)	0-180 m	Murray, 1973
C. lobatulus	0-30 m	Phleger, 1960
genus Lagena	<200 m	Culver & Buzas, 1980
U. peregrina	>200 m	Pflum & Frerichs, 1976
B. elegantissima	0-150 m	Murray, 1973
C. carinata	100-1000 m	Phleger, 1960
H. concentrica	<200 m	Culver & Buzas, 1980
B. paula	<200 m	Culver & Buzas, 1980
B. elongata	15-90 m	Murray, 1973
F. atlanticus (pizarrensis)	<180 m	Pflum & Frerichs, 1976

* extinct homeomorphs in parentheses

1976).

With the absence of a statistically-derived species assemblage, *E. gunteri* is the best depth-diagnostic species in the Yorktown Formation. Its bathymetric range (Figure 5), wide environmental tolerances (Murray, 1973), and the coarse nature of the sediments in which it occurs suggest thst the Yorktown was deposited in water shallower than that of the St. Mary's, probably in the 0-40 m range.

A comparison of Miocene species diversity and dominance patterns to that of the Recent provides reference to a well-studied model. This can give a better understanding of the paleoecology. The Shannon-Wiener Information Function (H(S)) and the species equitability (E) provide measures for diversity and dominance, respectively. E, defined as :

$$E = \frac{e^{H(s)}}{S}$$

measures the distribution of species within a sample. High values of E indicate a more equal distribution of species, which is believed to rerflect relatively stable environments.

Gibson and Buzas (1973) found that Recent foraminiferal species diversity increases with water-depth from the shoreline to the outer continental shelf (Figure 7). A sharp decrease occurs at the relatively unstable continental slope, followed by another increase in the abyss. Dominance, measured through equitability, shows no clear pattern with increasing depth (Figure 7). This may be because no simple or clear pattern of species proportions exists on the continental shelf

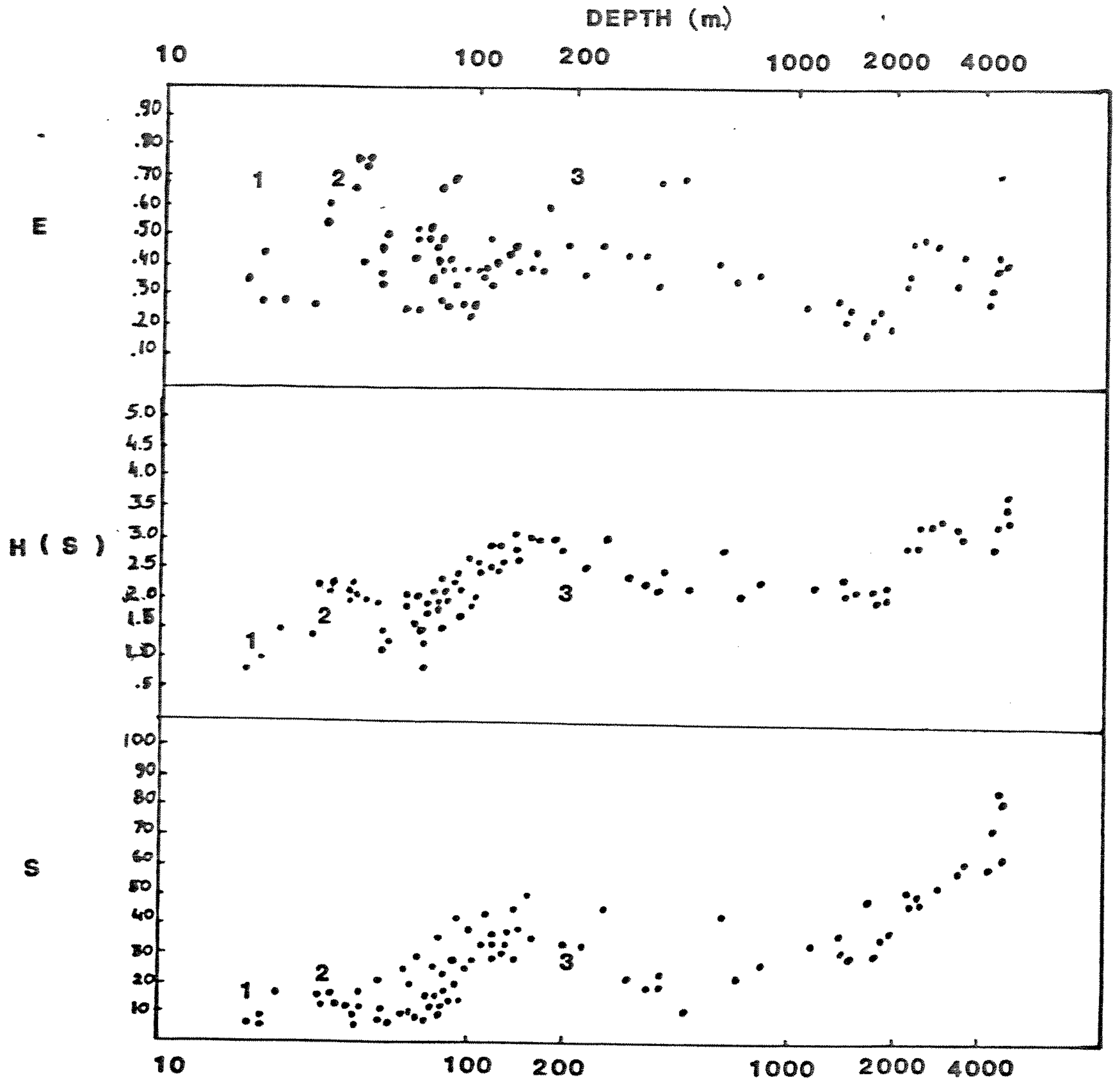
(Gibson and Buzas, 1973).

Mean Information Function, equitability, and species distribution values for the Choptank, St. Mary's, and Yorktown Formations (Table 2) are compared (Figure 7) to those found between Cape Cod and Maryland by Gibson and Buzas (1973). Information function and species distribution values are similar to the Recent and follow the same trend with increasing depth of water. Equitability values are slightly higher in the Miocene. No significant differences are apparent between Miocene and modern distribution patterns of shelf foraminifera.

The variable lithology of the Choptank, St. Mary's, and Yorktown Formations does not permit accurate lithologic demarcation of the formations in the subsurface. Electrical resistivity log profiles and faunal separation of the formations increases accuracy (Figure 8). Relatively unambiguous separation of the formations is possible by the use of biofacies generated by Q-mode cluster analyses in conjunction with electric logs. The Q-mode technique utilizes species counts from each interval and groups the intervals together on the degree of similarity of their fauna.

A Q-mode cluster analysis was run separately for each well (Appendix 3). The correlation coefficient was used in each case. The cophenetic correlation values of the four runs range from .66 to .89.

Three biofacies are present in wells WOR-DD-60 and WOR-CG-73



FORMATION	SYMBOL
YORKTOWN	1
ST. MARY'S	2
CHOPTANK	3

FIGURE 7. Comparison of mean values of equitability (E), diversity (H(S)), and species distribution (S) of the Yorktown, St. Mary's, and Choptank Formations to modern values found between Cape Cod and Maryland (after Gibson and Buzas, 1973).

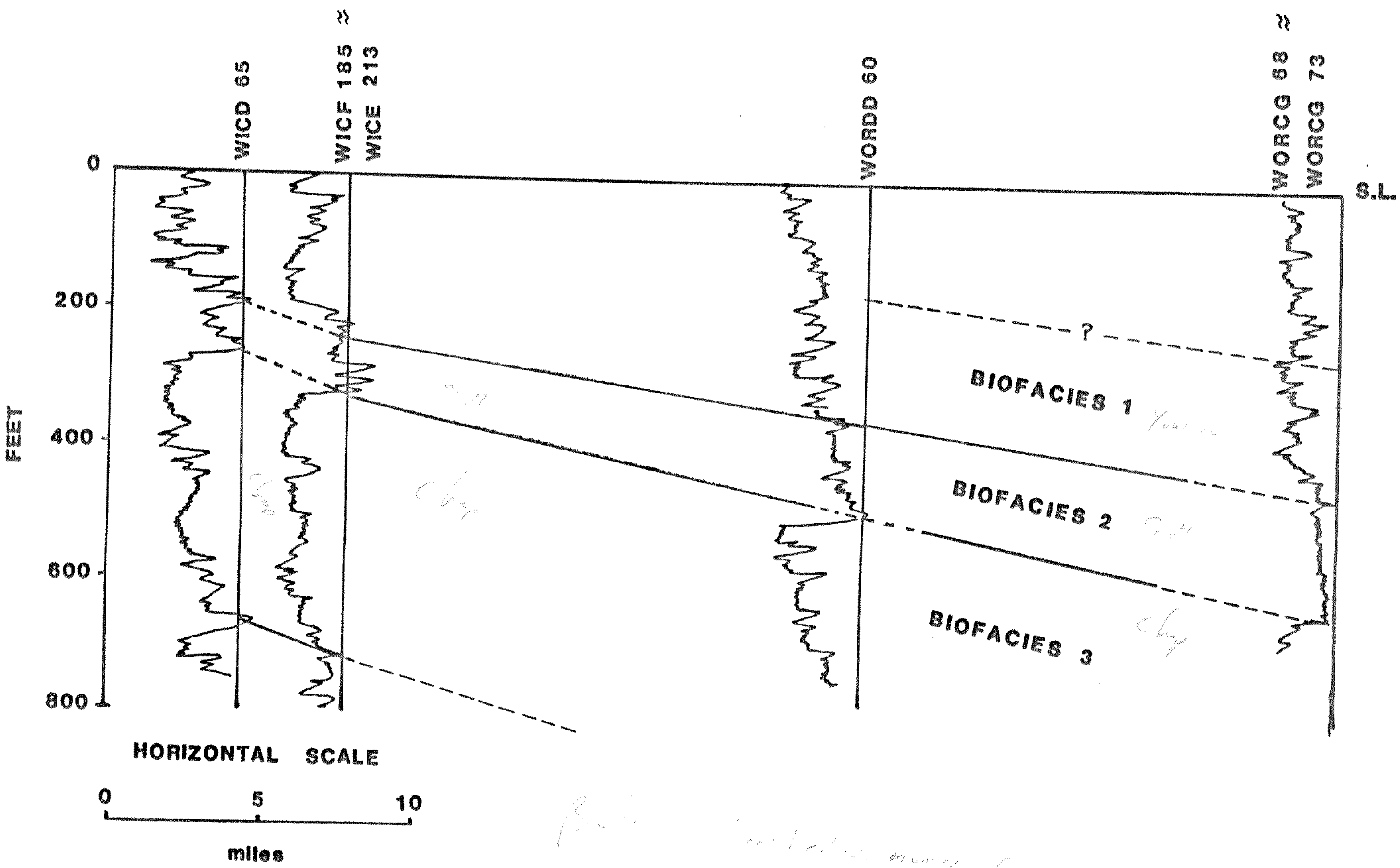


FIGURE 8 BIOFACIES CROSS SECTION

(Figure 8). These correspond, in terms of species present and stratigraphic position, to the Yorktown (Biofacies 1), the St. Mary's (Biofacies 2), and the Choptank (Biofacies 3). Two biofacies, or those corresponding to the St. Mary's and the Choptank, are present in well WI-CE-213, and only one, the Choptank, appears in well WI-CD-65. Biofacies boundaries are generally clear, although in some instances in wells WOR-DD-60 and WOR-CG-73 the biofacies are gradational. The boundaries in Figure 8 represent the best possible compromise between the electric logs and the foraminiferal biofacies.

BIOSTRATIGRAPHY

The Choptank and St. Mary's Formations contain a total of eleven species of planktonic foraminifera (Appendix 1). Planktonic species are few in comparison with benthic species. Well-preserved specimens of diagnostic planktonic species are present in small numbers. Approximately half the total number of planktonic specimens recovered are juveniles.

Several planktonic species are important in dating the formations. *Globorotalia acostaensis* Blow and *Globorotalia continuosa* (Blow) which are present throughout the St. Mary's place the formation in the *Globorotalia acostaensis* zone (Tortonian and Messinian) of Stainforth et al. (1975). *Globorotalia* cf. *praehumerosa*, a five-chambered form ancestral to *Globorotalia humerosa* Takayanagi and Saito, occurs in association with *G. acostaensis* in the upper portions of the St. Mary's. Other Miocene species that appear in the St. Mary's are *Globorotalia menardii* (d'Orbigny), *Globoquadrina dehiscens* (Chapman, Parr, and Collins), *Globigerinoides obliquus* (Bolli), *Globigerinoides conglomerata* (Schwager), and *Globigerina praebulloides* (Blow). The concurrent range zones of these foraminifera (Figure 9) and ther absence of a well-developed form of *G. humerosa* suggest the St. Mary's Formation was deposited during the Tortonian Stage.

The Choptank Formation contains a *G. acostaensis*-*G. continuosa* association, which like the St. Mary's, places this formation in the

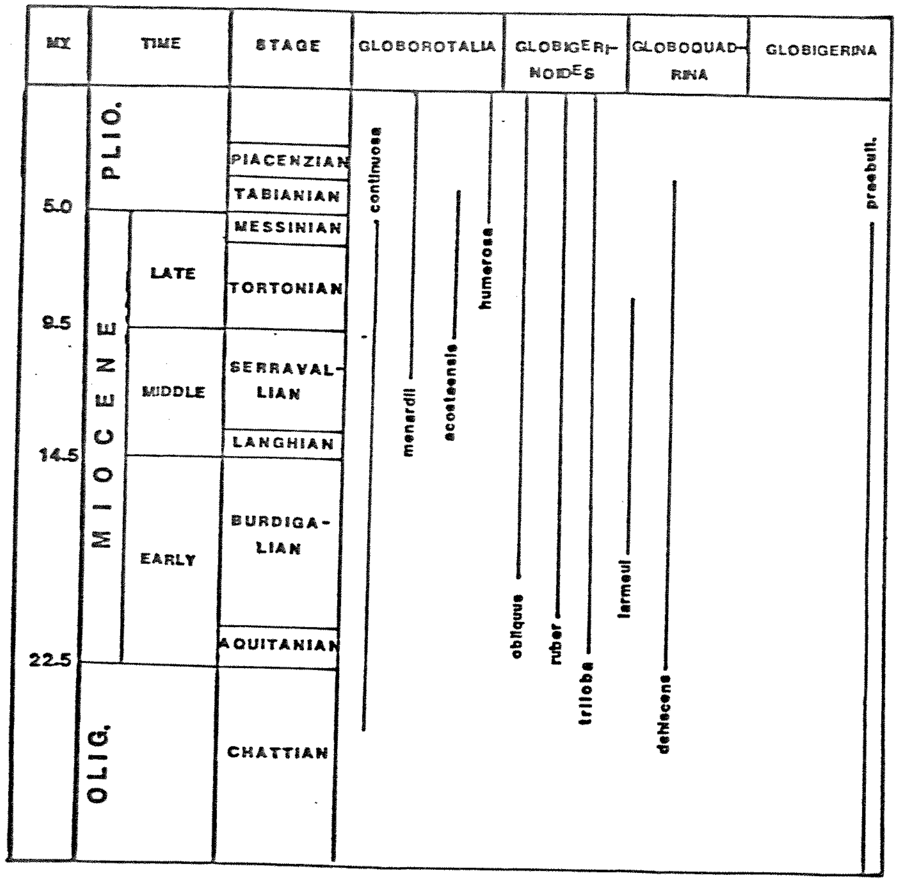


FIGURE 9 STRATIGRAPHIC RANGES OF SELECTED PLANKTONIC SPECIES

(AFTER STAINFORTH ET AL., 1975)

Tortonian _G. acostaensis_ zone. Other planktonic species found in the Choptank are _G. menardii_, _G. dehiscens_, _G. praebulloides_, _Globigerinoides triloba_ (Reuss), _Globigerinoides ruber_ (d'Orbigny), and _Globoquadrina larmeui larmeui_ Blow.

No planktonic foraminifera are present in the Yorktown Formation. Melillo (1982) suggests that it is probably Pliocene. The stratigraphic position of the Yorktown indicates that it is Pliocene. The formation rests disconformably on an erosional surface of the St. Mary's. The exposure and reworking of the uppermost St. Mary's is believed to be a result of the Messinian drop in sea level (Melillo, 1982). Deposition of the Yorktown Formation probably accompanied the subsequent Pliocene rise in sea level (Figure 12).

PALEOGEOGRAPHY

The North American continent has undergone northward and westward drift ever since the opening of the North Atlantic Ocean in the late Triassic (Press and Siever, 1974). Based on average rates of drift, the position of southeastern Maryland would be at approximately 37°W latitude and 74°N longitude in the late Miocene (Press and Siever, 1974). Relatively little change has taken place in its geographic setting since the late Miocene.

Culver and Buzas (1981) compiled ecological data on Recent benthic foraminifera of the Atlantic continental margin. They established seven distinct faunal provinces (Figure 10). Species distribution appears to be controlled mainly by the temperature of the water (a function of latitude and bathymetry) and water depth.

The St. Mary's assemblage of foraminifera resembles the fauna of the Northern Coastal Province of Culver and Buzas. Four species are common to the province: Buliminella elegantissima, Cibicides lobatulus, Quinqueloculina seminulina, and Rosalina floridana. Ammonia beccarrii Linné, which occurs infrequently in the St. Mary's, is also common. The similarity of faunas suggests that the St. Mary's was deposited in cool, marginal waters.

The two dominant species of the Yorktown Formation, Buliminella elegantissima and Elphidium gunteri, are characteristic of the Northern

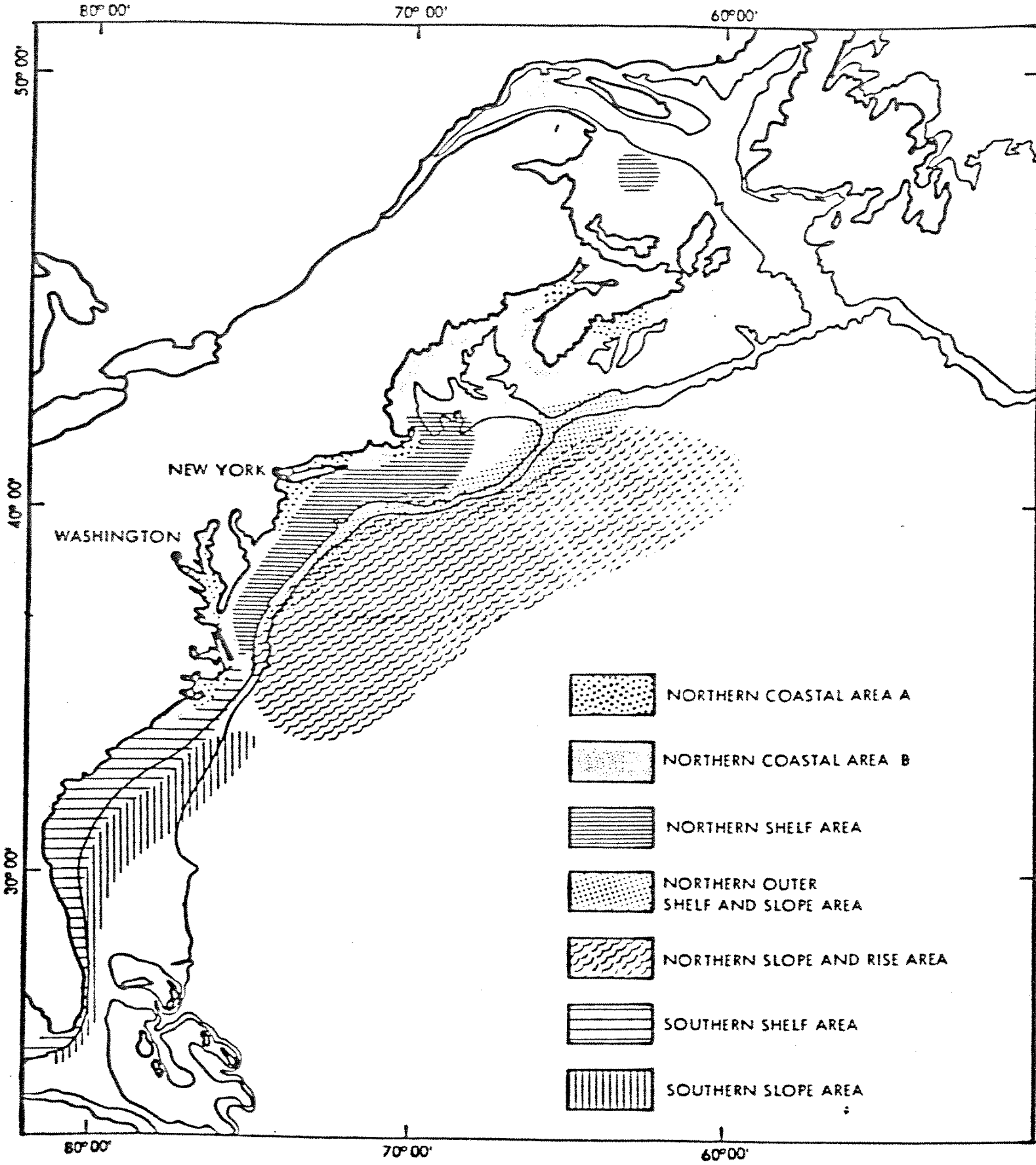


FIGURE 1 0. MODERN BENTHIC FORAMINIFERAL PROVINCES OF THE EASTERN MARGIN OF NORTH AMERICA (AFTER CULVER AND BUZAS, 1981)

Coastal Province today. The Yorktown, like the St. Mary's, appears to represent cool, marginal waters.

The Choptank assemblage contains species of the Northern Coastal Province (Buccella mansfieldi, an extinct homeomorph of Buccella frigida (Cushman)), the Southern Shelf Province (Hanzawaia concentrica, Bolivina paula), and the Northern Outer Shelf Province (Uvigerina peregrina). It appears that the Choptank water-masses were of complex patterns that resulted in faunal mixing, although they were somewhat warmer than those of the St. Mary's and Yorktown.

The outer continental shelf off the middle Atlantic margin today is an area of interaction between several water-masses: the marginal waters, slope water, the Western Boundary Undercurrent, and the Gulf Stream (Culver and Buzas, 1981). A similar hydrologic environment is hypothesized for the Choptank Formation.

The earth's climate underwent major changes during the Oligocene and Miocene Epochs (Woodruff et al., 1981). Northward drift of the Gondwanaland continents away from their polar positions permitted the development of unimpeded circum-Antarctic circulation at the Eocene-Oligocene boundary (Loutit and Kennett, 1980). This was followed by thermal isolation and a significant drop in surface water temperature (Loutit and Kennett, 1981). Further continental drift improved the deep-water circum-Antarctic circulation between 30 and 22 million years B.P. This resulted in the development of sea-ice. Limited Antarctic glaciation in the early Miocene was followed

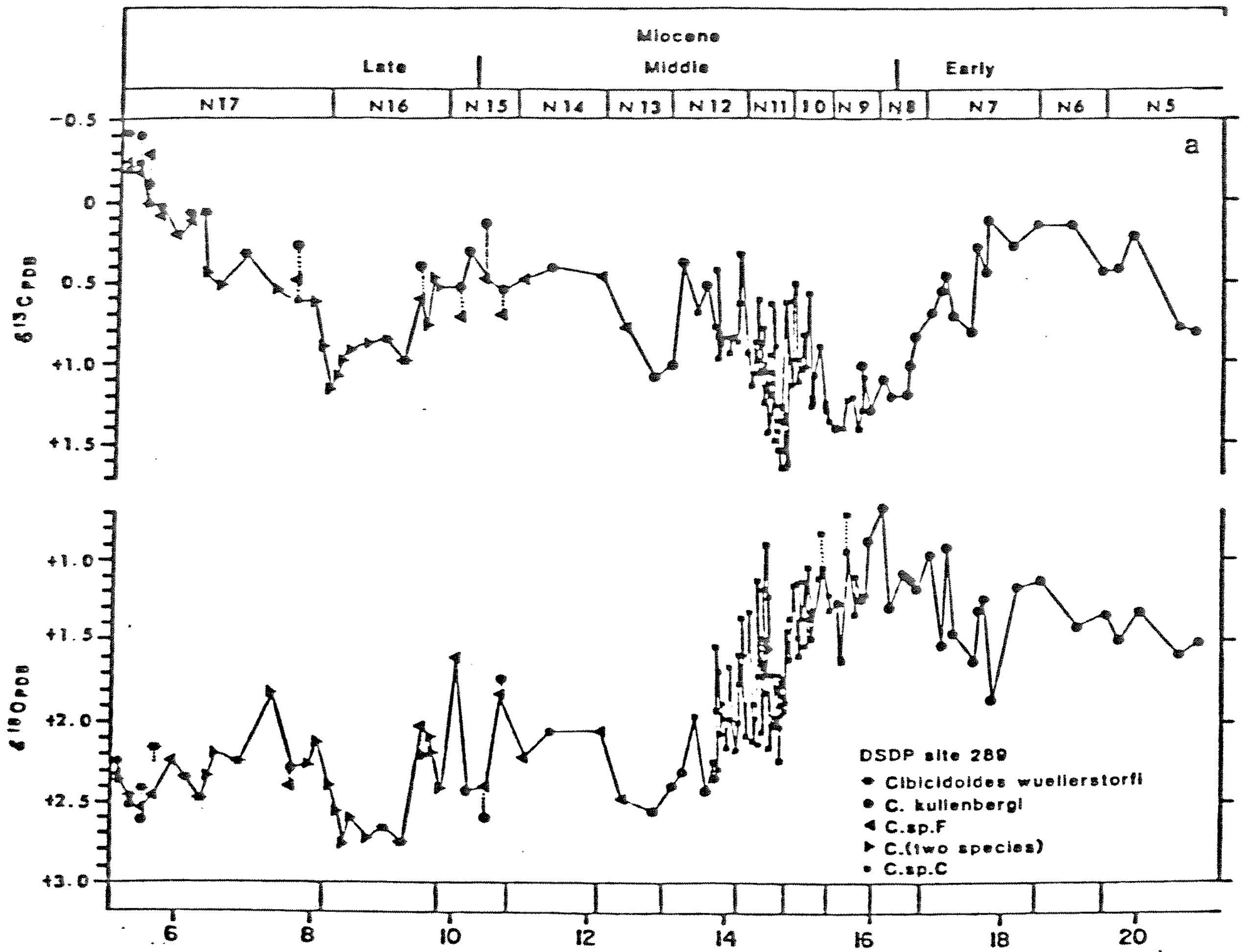


FIGURE 11. $\delta^{18}O$ and $\delta^{13}C$ record of the Miocene obtained from benthic foraminifera of the Pacific Ocean. From Woodruff, Savin, and Douglas, 1981.

by large scale continental glaciation in the early middle Miocene (Loutit and Kennett, 1980). Glacial and interglacial modes became established by approximately 15 million years B.P. (Woodruff et al., 1981).

Woodruff et al. (1981) investigated thermal trends in the Miocene oceans. This was accomplished by $\delta^{18}O$ and $\delta^{13}C$ studies on tests of the benthic foraminiferal species Cibicidoides wuellerstorfi in the southern Pacific Ocean. Thermal fluctuations of the Miocene oceans were found to correspond closely to Antarctic glacial and interglacial periods.

The foraminiferal assemblages of the Yorktown, St. Mary's, and Choptank Formations display thermal trends consistent with the isotope record for the middle and late Miocene (Figure 11). The cooling trend from the Choptank to the St. Mary's and Yorktown is in agreement with the thermal history of the late middle and late Miocene. This suggests that the middle Atlantic continental shelf was responding to major, world-wide thermal fluctuations.

GROWTH FAULTING

A cross-section parallel to dip of southeastern Maryland was constructed with the aid of electrical resistivity log profiles, lithology, and paleontology (Figure 3). Updip stratigraphic information from wells St. M-GG-14, SOM-CC-5, and SOM-DC-3 was obtained from Melillo (1982).

The section between wells SOM-CC-5 and WI-CD-65 appears to be extensively faulted. Further downdip, between wells WI-CD-65 and WOR-CG-73, the St. Mary's and Choptank Formations show a large amount of thickening. This is especially true for the Choptank, which thickens almost by a factor of three.

Using benthic foraminiferal assemblages, Melillo (1982) estimated paleobathymetries of approximately 25 to 40 m for the St. Mary's and 35 to 50 m for the Choptank. The environments of deposition were interpreted as inner to middle continental shelf. Paleobathymetries established in this study indicate similar values for the St. Mary's (30 to 50 m). The paleobathymetry of the Choptank, however, is 180 to 220 m. <u>Cassidulina carinata</u> and <u>Uvigerina peregrina</u> dominate the assemblages of this formation. The optimum environment for these species is outer continental shelf and slope.

Diversity (H(S)), equitability (E), and species distribution (S) values obtained in this study are compared to those of Melillo

TABLE 2

Comparison of diversity (H(S)), equitability (E), and benthic species distribution (S) values obtained in this study with those of Melillo (1982).

Yorktown Formation	H(S)	S	E
This study	1.35	14	.66
Melillo (1982)	.87	6	.55
St. Mary's Formation			
This study	1.70	25	.65
Melillo (1982)	2.00	16	.64
Choptank Formation			
This study	2.02	30	.70
Melillo (1982)	2.12	22	.54

in Table 2. The Yorktown, the St. Mary's, and the Choptank all show sudden increases in species distribution and equitability downdip. The increase in equitability is most marked in the Choptank. This abrupt change in the paleoenvironment as well as the rapid downdip thickening of the St. Mary's and Choptank Formations appear to be the result of basinward growth-faulting in the Salisbury Embayment. Tensional forces produced normal faults and accompanying antithetic faults. The progressively downdropped blocks experienced increasing paleobathymetries and acted as sediment traps. Figure 3 indicates that growth faulting was greater during the deposition of the Choptank than during deposition of the St. Mary's. Growth faulting may have continued during deposition of the Yorktown, although stratigraphic information is insufficient to confirm this.

EUSTATIC HISTORY

Vail and others (1977) and Vail (1981) determined global cycles of sea level change by the use of seismic stratigraphy. The cycles are divided into three categories based on their duration : first-order cycles of between 200 and 300 million years, second-order cycles of between 10 and 80 million years, and third-order cycles of between 1 and 10 million years. These cycles are recognizable on a world-wide basis, although the third-order cycles are prone to local deviation by forces such as uplift and subsidence.

The Calvert, Choptank, and St. Mary's Formations correspond in time to three third-order cycles of the middle and late Miocene. The Yorktown Formation corresponds to third-order cycles of the Pliocene. These cycles are transgressive pulses separated by relatively brief and rapid regressions. Transgression resulted in the deposition of a formation and regression produced a depositional hiatus sometimes accompanied by exposure and erosion of the preceding deposits.

Tectonic or thermal subsidence of the trailing Atlantic margin since the Miocene is negligible. The passive middle Atlantic margin has been recognized to have a continental shelf that slopes at approximately at 5 feet/mile (Wolfe, 1977). Using this value as the slope of the Miocene paleo-seafloor and a cross-section parallel to dip (Figure 3), subsidence caused by compaction and overloading can be determined. Eustatic sea-level stands can then be estimated by the application of the already-determined paleobathymetries for each formation (Table 3).

A curve representing eustatic sea-level movements of the late Miocene is presented in Figure 10. The curve is incomplete for the maxima of the transgressions because it is only farther updip, where each formation terminates, that maximum eustatic stands can be determined. Only the earlier portions of the transgressions can be determined in this study. However, the eustatic levels established here are similar in relative proportion to the high-stands of the Vail (1981) curve. Their timings are also in close conformity.

The nature of the rise and fall in sea level with each cycle can be better understood by examining the change in foraminiferal abundance within a formation (Appendix 2). The highest values of abundance in the Choptank and St. Mary's are found towards the bottom of the formations. Values decrease upward. This suggests that transgressions were rapid and achieved stillstand quickly, followed by gradual shoaling due to continental sedimentary influx.

TABLE 3

Eustatic sea level values determined at well WI-CE-213.

Yorktown Formation	
Depth of formation below sea level (adjusted for subsidence)	-43 m
Mean paleobathymetry	+20 m
Eustatic level	-23 m
St. Mary's Formation	
Depth of formation below sea level (adjusted for subsidence)	-79 m
Mean paleobathymetry	+40 m
Eustatic level	-39 m
Choptank Formation	
Depth of formation below sea level (adjusted for subsidence)	-128 m
Mean paleobathymetry	+200 m
Eustatic level	+ 72 m

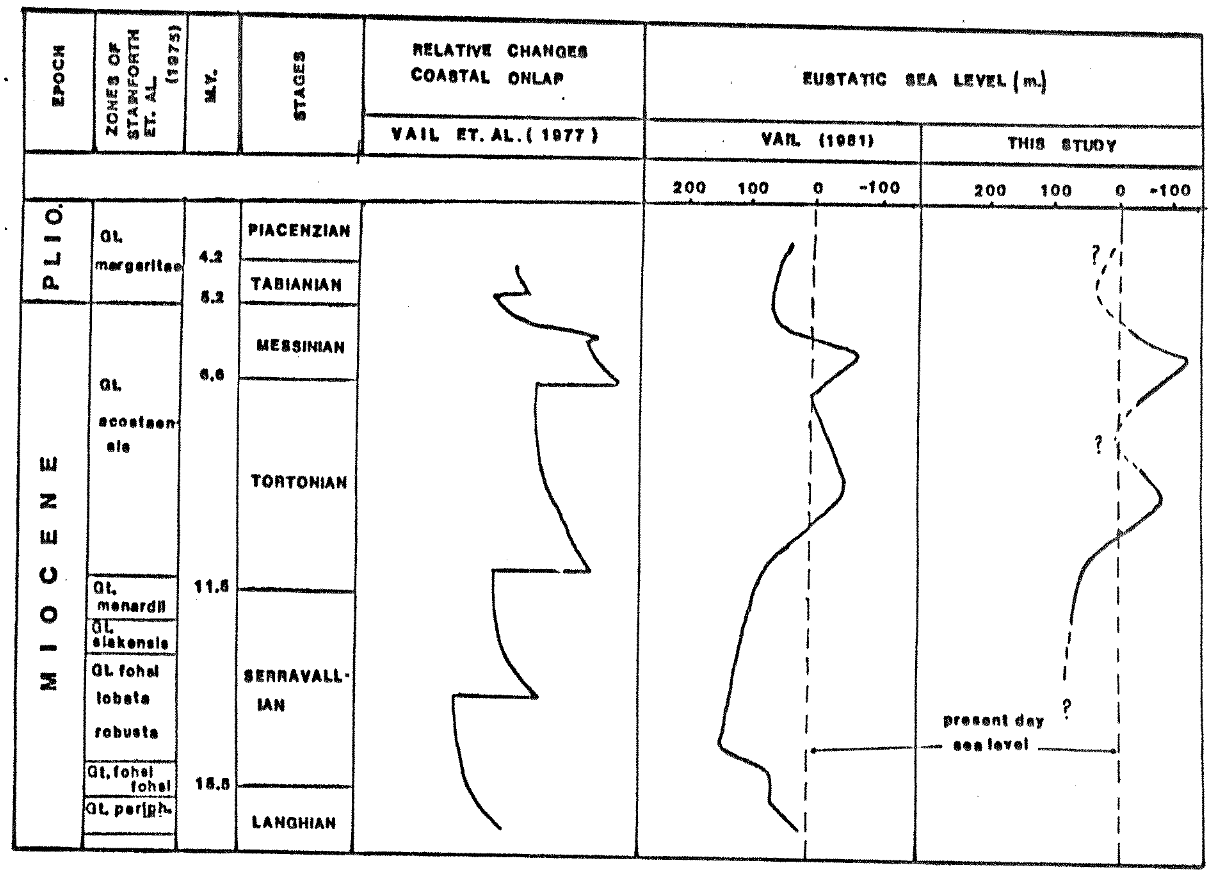


FIGURE 12 EUSTATIC SEA LEVEL HISTORY OF SOUTHEASTERN MARYLAND

CONCLUSIONS

The Choptank, St. Mary's and Yorktown Formations of southeastern Maryland can be distinguished by their benthic foraminiferal assemblages. Foraminiferal biofacies and electrical resistivity log profiles are neccesary to determine accurately formational boundaries in the subsurface. Planktonic foraminifera in the Choptank and St. Mary's Formations indicate a late Miocene (Tortonian Stage) age for both the formations. Although the Yorktown Formation lacks planktonic foraminifera, its stratigraphic position suggests a Pliocene age.

Inner to middle continental shelf environments of deposition are suggtested for the St. Mary's and Yorktown Formations. Paleobathymetries are estimated to be 0-40 m for the Yorktown and 30-50 m for the St. Mary's. The Choptank appears to have been deposited in outer shelf or continental slope environments of 180-220 m water depth.

Miocene diversity, equitability, and species distribution confirm an increase in paleobathymetry from the Yorktown through the St. Mary's and Choptank Formations. These values fall within the range of modern values of diversity, equitability, and species distribution on the middle Atlantic continental shelf. This suggests that faunal conditions on the shelf have remained broadly similar since the Miocene. The geographical distribution of water masses on the shelf appears to be largely unchanged also.

Growth faulting occurred in the Salisbury Embayment during deposition of the St. Mary's and Choptank Formations. The downdropped blocks experienced progressively greater paleobathymetries and acted as sediment traps, which led to rapid downdip thickening of the formations.

The development of Antarctic glacial and interglacial periods in the Miocene resulted in thermal fluctuations in the world's oceans. The composition of benthic foraminiferal assemblages of the Maryland late Miocene and early Pliocene formations record a lowering in the temperature of the shelf waters. These changes correspond in time to glaciation in Antarctica. Thermal control of Miocene shelf waters off Maryland was apparently influenced by Antarctic thermal fluctuations.

The eustatic sea level history is in close agreement with global cycles of eustatic change determined by Vail and others (1977) and Vail (1981).

APPENDIX 1

Within-formation distribution of all foraminifera encountered.

	YORKTOWN	ST. MARY'S	CHOPTANK
Ammonia beccarrii Linne		X	
Bolivina marginata (Cushman)		X	X
Bolivina multicostata (Cushman)		X	X
Bolivina paula (Cushman and Cahill)	X	X	X
Bolivina subaeriensis Cushman			X
Buccella mansfieldi (Cushman)	X	X	X
Buliminella elegantissima (d'Orbigny)	X	X	X
Buliminella elongata (d'Orbigny)	X	X	X
Cassidulina carinata (Cushman)	X	X	X
Cassidulina crassa d'Orbigny			X
Cibicides lobatulus (Walker and Jacob)		X	X
Discorbis consobrina d'Orbigny			X
Elphidium gunteri Cole	X	X	X
Epistominella pontoni Cushman			X
Fissurina lucida (Williamson)		X	X
Florilus incisum Cushman	X	X	X
Florilus pizarrensis (Berry)	X	X	X
Globigerina praebulloides Blow		X	X
Globigerinoides conglomerata Schwager		X	
Globigerinoides obliquus Bolli		X	

APPENDIX 1 (contd.)

	YORKTOWN	ST. MARY'S	CHOPTANK
Globigerinoides triloba (Reuss)			X
Globigerinoides ruber (d'Orbigny)		X	
Globoquadrina dehiscens (Chapman, Parr, and Collins)		X	X
Globoquadrina larmeui Blow			X
Globorotalia acostaensis Blow		X	X
Globorotalia continuosa (Blow)		X	X
Globorotalia menardii (d'Orbigny)		X	X
Globorotalia cf. *praehumerosa*		X	X
Guttulina austriaca (d'Orbigny)		X	X
Hanzawaia concentrica (Cushman)	X	X	X
Lagena costata anphora Reuss		X	X
Lagena laevis (Montagu)		X	X
Lagena substriata Williamson	X	X	X
Lenticulina americana (Cushman)		X	X
Lenticulina americana spinosa (Cushman)			X
Nonionella auris (d'Orbigny)	X	X	X
Pseudopolymorphina striata (Bagg)			X
Pyrgo subsphaerica (d'Orbigny)		X	
Quinqueloculina seminulina Linne	X	X	X
Rosalina floridana (Cushman)	X	X	X

APPENDIX 1 (contd.)

	YORKTOWN	ST. MARY'S	CHOPTANK
Siphogenerina lamellata Cushman			X
Spiroplectammina gracilis (von Meunster)		X	
Textularia agglutinans d'Orbigny	X	X	X
Uvigerina peregrina (Cushman)		X	X

APPENDIX 2

Benthic foraminiferal counts used in cluster analyses from well WI-CD-65.

Interval	Q. seminulina	T. agglutinans	U. peregrina	C. lobatulus	B. paula	B. elegantissima	B. mansfieldi	B. elongata	H. concentrica	F. incisum	C. carinata	E. gunteri	N. auris	L. americana	F. pizarrensis	B. marginata	R. floridana	L. substriata	B. multicostata	L.c. anphora	G. austriaca
360-70	00	00	00	00	00	00	01	00	00	00	00	00	01	00	00	00	00	00	00	00	00
420-30	00	00	00	00	02	00	01	00	00	00	00	00	00	00	00	00	00	00	00	00	00
440-50	00	00	01	00	02	00	00	00	00	00	00	00	00	00	00	01	00	00	00	00	00
450-60	00	00	02	00	02	00	02	04	01	06	00	00	00	00	02	00	00	00	00	00	00
460-70	00	00	01	01	00	02	00	01	01	00	00	00	00	00	02	00	00	00	00	00	00
470-80	00	02	10	00	10	03	00	04	07	00	00	00	00	00	05	04	00	00	00	00	00
480-90	00	01	06	01	04	02	03	03	04	03	01	00	02	01	09	00	00	00	00	00	00
490-500	00	00	01	00	02	04	00	02	00	00	01	00	01	00	00	00	00	00	00	00	00
500-10	00	00	02	00	01	02	01	03	01	02	03	01	00	00	01	02	00	00	00	00	00
510-20	01	01	03	00	01	02	00	03	05	04	01	00	00	00	07	03	00	00	00	00	00
520-30	00	00	06	00	03	01	01	03	02	00	00	00	01	00	03	01	00	01	00	00	00
530-40	00	01	05	00	04	04	01	03	01	01	02	01	01	01	08	00	00	01	00	00	00
540-50	03	00	11	00	08	01	01	06	04	03	04	00	02	00	15	01	00	05	00	00	00
550-60	01	01	16	02	03	05	05	11	09	00	04	00	07	00	11	02	02	02	00	00	00
560-70	00	00	06	00	02	04	01	10	03	03	02	00	01	00	07	04	00	00	00	00	00
570-80	00	00	07	00	01	00	00	01	00	03	00	00	00	00	08	00	00	00	00	00	00
580-90	01	02	14	00	01	00	04	03	06	01	13	01	00	00	11	01	01	00	00	00	00
599-600	02	01	06	00	06	04	00	05	06	03	01	00	07	00	05	00	00	00	00	00	00
600-10	01	00	14	00	07	06	00	12	03	04	04	03	04	01	06	02	00	00	00	00	00
610-20	01	00	13	00	05	12	02	04	10	00	03	00	02	00	09	02	01	03	00	00	00
620-30	00	00	00	00	01	00	00	00	02	00	00	00	00	00	00	00	00	00	00	00	00
630-40	00	01	01	01	00	00	01	01	02	01	01	00	00	00	04	00	00	00	00	00	00
640-50	00	00	01	01	03	03	01	01	04	00	01	00	01	00	02	02	00	00	00	00	00
650-60	01	00	00	01	07	06	02	03	05	01	00	01	00	00	05	04	00	00	00	00	00

APPENDIX 2 (contd.)
Benthic foraminiferal counts used in cluster analyses from well WI-CE-213.

Interval	Q. seminulina	T. agglutinans	U. peregrina	C. lobatulus	B. paula	B. elegantissima	B. mansfieldi	B. elongata	H. concentrica	F. incisum	C. carinata	E. gunteri	N. auris	L. americana	F. pizarrensis	B. marginata	R. floridana	L. substriata	B. multicostata	L.c. anphora	G. austriaca
220-30	00	00	00	00	00	00	00	01	00	00	00	03	00	00	00	00	00	00	00	00	00
230-40	00	00	00	00	00	00	04	00	00	08	02	06	15	00	02	00	00	00	00	00	00
240-50	00	00	00	00	00	00	02	01	00	08	00	01	10	00	02	00	00	00	00	00	00
250-60	00	00	00	00	00	00	03	00	00	14	02	04	13	00	00	00	00	00	00	00	00
260-70	00	00	00	00	00	00	01	00	00	00	00	04	09	00	00	00	00	00	00	00	00
270-80	01	00	00	00	00	00	03	01	01	13	00	04	05	00	00	00	00	00	00	00	00
280-90	09	05	00	00	01	00	01	00	00	11	00	00	34	00	00	00	01	00	00	00	00
290-30	08	01	00	03	00	02	01	00	02	06	01	00	22	00	01	00	00	00	00	00	00
300-10	00	00	00	00	00	00	00	01	03	00	00	00	09	00	00	00	00	00	00	00	00
310-20	06	02	00	00	03	03	01	01	00	13	00	00	35	00	01	00	00	01	00	00	00
320-30	12	04	00	00	00	00	02	03	00	13	00	06	55	00	01	00	00	02	00	00	00
330-40	06	10	00	00	00	01	13	03	00	07	02	02	13	00	08	00	01	00	00	00	00
340-50	07	02	00	00	01	00	02	02	00	04	00	01	18	00	10	00	00	00	00	00	00
350-60	01	01	00	00	01	00	04	04	00	06	00	01	14	00	08	00	00	00	00	00	00
360-70	02	06	00	00	03	06	07	07	01	01	03	09	17	00	05	00	00	00	00	00	00
370-80	14	13	00	00	00	02	35	29	00	37	07	01	24	00	67	00	00	02	00	00	00
380-90	01	01	01	00	01	00	02	04	23	02	01	02	00	00	04	00	00	00	00	00	00
390-40	01	03	09	01	01	01	01	03	01	00	00	05	02	00	05	00	00	00	00	00	00
400-10	05	09	01	00	01	00	10	17	00	06	05	02	13	00	10	00	00	02	00	00	00
410-20	02	01	00	00	00	01	11	08	00	14	04	04	03	00	17	00	00	00	00	00	00
420-30	00	00	01	00	00	01	01	07	08	00	00	01	01	00	03	00	00	00	00	00	00
430-40	04	00	15	01	16	05	08	35	30	07	09	00	10	00	10	00	00	00	00	00	00
440-50	01	02	13	01	01	00	03	09	01	04	01	02	02	00	20	00	00	00	00	00	00
450-60	02	04	12	01	04	01	00	23	32	04	00	04	02	00	15	00	02	00	00	00	00
460-70	00	03	02	00	06	03	05	08	26	06	03	03	02	00	20	00	00	00	00	00	00
470-80	02	04	10	00	11	05	03	15	31	08	01	01	07	00	15	03	00	00	00	00	00
480-90	01	07	04	00	04	00	04	16	13	08	03	02	06	00	15	00	00	01	00	00	00
500-10	00	01	00	00	01	00	00	02	01	00	01	00	00	00	02	00	00	00	00	00	00
510-20	01	00	00	01	06	08	01	05	10	00	03	01	00	00	05	01	01	00	00	00	00
520-30	01	00	03	00	02	05	01	09	10	00	01	07	00	00	07	00	00	01	00	00	00
530-40	01	08	01	02	00	05	05	20	26	07	00	02	01	00	18	00	00	00	00	00	00
560-70	02	01	05	02	03	01	04	08	18	03	01	04	03	00	09	00	00	00	00	00	00
610-20	00	02	00	03	00	03	01	02	03	02	02	06	01	00	09	00	00	01	00	00	00
660-70	00	00	01	01	04	01	00	04	05	00	00	00	01	00	05	02	00	00	00	00	00
670-80	01	04	02	03	37	00	02	09	21	00	02	03	01	00	14	07	00	00	00	00	00
690-70	02	01	00	00	01	01	01	01	01	02	00	00	02	00	06	01	00	00	00	00	00
700-10	00	01	03	02	04	00	05	11	04	02	02	02	05	00	04	04	00	00	00	00	00
710-20	06	03	02	03	17	16	03	12	03	03	03	01	12	00	15	06	00	00	00	00	00

APPENDIX 2 (contd.)

Benthic foraminiferal counts used in cluster analyses from well WOR-DD-60.

Interval	Q. seminulina	T. agglutinans	U. peregrina	C. lobatulus	B. paula	B. elegantissima	B. mansfieldi	B. elongata	H. concentrica	F. incisum	C. carinata	E. gunteri	N. auris	L. americana	F. pizarrensis	B. marginata	R. floridana	L. substriata	B. multicostata	L.c. anphora	G. austriaca
90-100	00	00	01	00	00	00	00	01	00	00	00	00	00	00	00	00	00	00	00	00	00
140-50	00	00	00	00	00	00	00	00	00	00	00	02	00	00	00	00	01	00	00	00	00
150-60	00	01	00	00	01	00	00	00	00	00	00	01	00	00	00	00	00	00	00	00	00
180-90	00	02	00	01	01	04	00	01	00	00	01	06	01	00	00	00	01	00	00	00	00
190-20	00	00	00	00	00	02	05	00	00	00	00	01	00	00	00	00	00	00	00	00	00
200-10	00	01	00	00	00	03	01	01	00	00	00	12	00	00	00	00	00	00	00	00	00
210-20	00	00	00	00	01	00	00	00	00	00	00	02	00	00	00	00	01	00	00	00	00
220-30	00	03	00	00	01	02	03	00	00	00	00	04	00	00	00	00	00	00	00	00	00
230-40	01	04	00	00	00	02	00	00	00	00	00	08	00	00	00	00	00	00	00	00	00
240-50	00	02	00	00	00	00	00	06	01	00	00	17	00	00	00	00	00	00	00	00	00
250-60	00	01	00	01	00	02	00	00	00	00	00	14	00	00	00	00	00	00	00	00	00
260-70	00	26	00	00	00	08	04	00	04	00	00	19	00	00	00	00	04	00	00	00	00
270-80	00	06	00	00	00	02	01	00	00	00	00	08	00	00	00	00	00	00	00	00	00
280-90	00	07	00	00	00	02	01	00	01	00	00	13	00	00	00	02	00	00	00	00	00
290-30	00	03	00	00	00	00	01	01	00	00	00	09	00	00	00	00	00	00	00	00	00
300-10	00	02	00	01	02	00	03	00	00	00	01	20	00	00	00	00	00	00	00	00	00
310-20	00	02	00	00	05	07	00	01	00	00	01	18	01	00	02	00	00	00	00	00	00
320-30	00	03	00	00	00	02	00	00	02	01	00	14	00	00	01	00	01	00	00	00	00
330-40	00	00	00	00	00	01	00	00	00	00	00	01	00	00	00	00	00	00	00	00	00
350-60	00	00	00	00	00	01	00	01	00	00	00	03	00	00	01	00	00	00	00	00	00
360-70	00	00	00	00	00	04	00	00	01	00	00	01	00	00	01	00	00	00	00	00	00
370-80	00	03	03	00	31	17	00	23	48	00	10	02	01	00	10	00	00	00	00	00	00
380-90	00	00	00	01	00	09	01	00	04	00	00	01	00	00	00	00	00	00	00	00	00
390-40	00	00	00	00	00	12	02	00	00	01	00	00	00	00	00	00	00	00	00	00	00
410-20	00	00	00	00	00	07	00	00	00	00	00	01	00	00	00	00	00	00	00	00	00
420-30	00	00	00	00	00	06	02	00	00	00	00	00	00	00	00	00	00	00	00	00	00
430-40	00	00	00	00	00	07	00	00	00	00	01	00	00	00	00	00	00	00	00	00	00
440-50	00	00	00	00	01	07	00	00	00	00	00	02	00	00	00	00	00	00	00	00	00
450-60	00	01	00	00	00	06	00	00	00	00	00	01	00	00	00	00	01	00	00	00	00
460-70	00	00	00	00	01	17	01	01	00	00	00	01	00	00	03	01	00	00	00	00	00
470-80	00	00	00	00	00	02	00	00	00	00	00	02	00	00	00	00	00	00	00	00	00
480-90	00	00	00	00	00	02	00	00	00	00	00	00	01	00	01	00	00	00	00	00	00
490-50	00	00	00	00	00	01	00	00	00	00	00	00	00	00	01	00	00	00	00	00	00
500-10	00	00	00	00	00	07	00	01	00	00	00	03	00	00	01	00	00	00	00	00	00
510-20	00	00	00	00	00	13	00	00	00	00	00	06	00	00	02	00	00	00	00	00	00
520-30	00	00	00	01	00	24	02	01	00	00	00	03	00	00	02	00	00	00	00	00	00
530-40	00	00	00	00	00	13	01	00	00	00	00	02	00	00	02	00	00	00	00	00	00
540-50	00	00	00	00	02	29	00	01	00	00	00	03	00	00	10	00	00	00	00	00	00

APPENDIX 2 (contd.)

Benthic foraminiferal counts used in cluster analyses from well WOR-DD-60.

Interval	Q. seminulina	T. agglutinans	U. peregrina	C. lobatulus	B. paula	B. elegantissima	B. mansfieldi	B. elongata	H. concentrica	F. incisum	C. carinata	E. gunteri	N. auris	L. americana	F. pizarrensis	B. marginata	R. floridana	L. substriata	B. multicostata	L.c. anphora	G. austriaca
550-60	00	00	00	00	00	01	00	02	00	01	00	01	00	00	04	00	00	00	00	00	00
560-70	00	00	00	00	00	06	00	00	00	00	00	01	00	00	03	00	00	00	00	00	00
570-80	00	00	00	00	00	11	00	00	00	00	00	00	01	00	00	00	00	00	00	00	00
580-90	00	00	00	00	00	03	00	00	00	00	00	00	00	00	02	00	00	00	00	00	00
590-60	00	00	00	00	00	06	01	01	00	00	00	02	00	00	01	00	00	00	00	00	00
600-10	00	00	01	00	01	05	01	00	00	00	00	01	00	00	00	00	00	00	00	00	00
610-20	00	00	00	00	00	11	00	00	00	00	00	04	00	00	03	01	00	00	00	00	00
620-30	00	00	00	00	01	02	00	01	00	00	00	00	00	00	02	00	00	00	00	00	00
630-40	00	00	00	00	01	02	02	03	00	00	00	01	00	00	01	00	00	00	00	00	00
650-60	00	00	00	00	01	09	03	09	00	00	00	01	00	00	04	00	00	00	00	00	00
660-70	00	00	00	00	00	26	01	02	00	00	00	01	00	00	00	01	00	00	00	00	00
670-80	00	00	00	00	00	06	00	03	01	00	00	00	00	00	05	00	00	00	00	00	00
690-70	00	01	00	00	02	13	00	12	01	01	01	03	00	00	07	00	00	00	00	00	00
700-10	00	00	03	00	02	30	01	14	04	00	02	05	01	00	08	01	00	00	00	00	00
710-20	03	01	00	00	09	76	01	14	22	01	05	01	03	01	13	02	02	00	00	00	00
720-30	00	00	00	00	01	04	00	11	03	00	01	01	01	00	03	00	00	00	00	00	00
740-50	01	02	09	00	21	25	03	29	43	00	11	00	00	00	15	01	00	00	00	00	00
760-70	00	02	01	01	16	13	01	10	59	00	06	01	00	00	06	01	00	00	00	00	00
770-80	00	00	00	00	00	07	01	00	10	00	01	02	00	00	04	00	01	00	00	00	00
780-90	00	00	02	02	04	06	02	03	18	01	00	06	00	01	04	03	00	00	00	00	00
790-80	00	01	00	04	19	12	01	25	50	02	03	00	01	01	10	02	00	00	00	00	00

APPENDIX 2 (contd.)

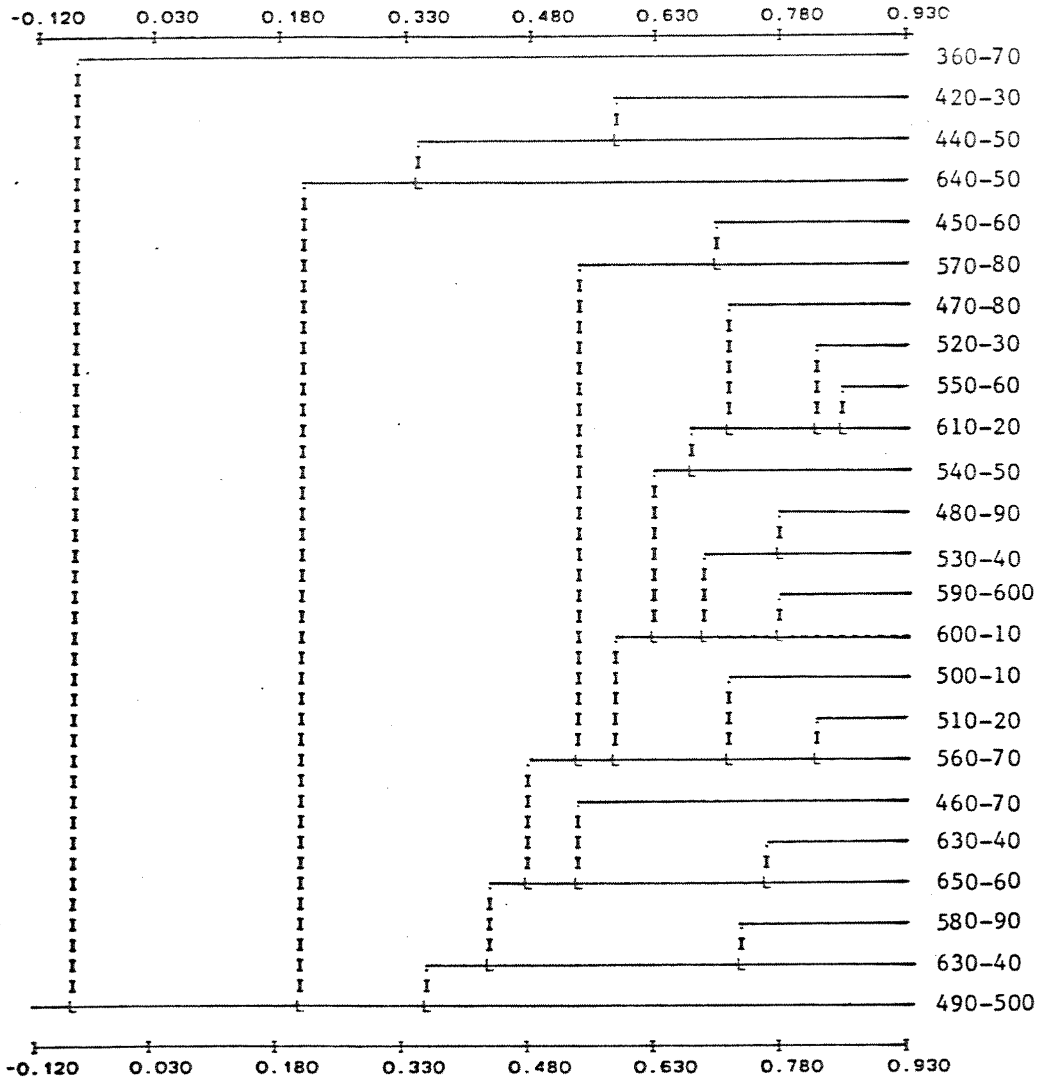
Benthic foraminiferal counts used in cluster analyses from well WOR-CG-73.

Interval	Q. seminulina	T. agglutinans	U. peregrina	C. lobatulus	B. paula	B. elegantissima	B. mansfieldi	B. elongata	H. concentrica	F. incisum	C. carinata	E. gunteri	N. auris	L. americana	F. pizarrensis	B. marginata	R. floridana	L. substriata	B. multicostata	L.c. anphora	G. austriaca
450-60	00	01	34	00	84	04	02	42	05	00	00	08	02	00	07	04	00	00	02	04	00
460-70	00	01	26	04	78	01	00	12	06	01	00	04	00	00	06	07	00	00	16	07	00
470-80	00	01	03	00	03	01	00	05	00	00	01	00	00	01	01	00	00	00	02	00	00
480-90	00	00	14	00	21	01	00	13	05	02	00	01	00	00	01	00	00	00	02	00	00
490-500	00	03	22	00	23	03	00	08	02	01	00	02	00	01	02	01	00	00	02	01	00
510-20	00	00	13	00	05	02	00	13	02	00	05	01	02	00	05	01	00	00	00	01	00
570-80	00	00	07	00	02	00	00	01	00	00	00	00	00	00	00	00	00	00	00	00	01
590-600	00	02	04	00	11	09	00	03	02	02	00	05	00	00	03	00	00	00	02	00	00
600-10	00	00	07	00	06	06	00	03	00	01	01	01	01	00	05	01	00	00	00	01	00
610-20	00	00	05	00	25	11	00	07	02	01	02	02	03	00	07	09	00	00	02	09	05
640-50	00	00	03	00	06	06	00	12	02	00	08	01	02	00	06	03	00	00	00	03	04
660-70	02	00	10	00	28	10	00	06	01	01	25	03	03	00	13	02	00	00	02	02	02
670-80	00	00	11	00	09	04	00	15	02	01	16	00	08	00	17	00	00	00	00	00	00
680-90	00	00	03	00	05	01	00	01	01	00	04	00	00	00	05	01	00	00	02	01	00
690-700	00	00	01	00	03	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
710-20	00	00	10	01	08	01	00	08	00	00	02	02	01	00	01	01	00	00	02	01	00
720-30	00	02	10	00	07	00	00	00	00	00	00	00	00	00	05	01	00	00	00	01	00
730-40	00	00	07	00	05	00	00	01	00	00	01	01	00	00	01	00	00	00	00	00	00
740-50	00	00	05	01	03	00	00	05	01	00	01	00	00	00	01	03	00	00	00	03	00
750-60	00	01	19	00	08	00	00	02	05	00	01	00	00	00	02	00	00	00	02	00	01
760-70	00	01	07	01	26	01	00	06	02	00	02	00	00	00	02	03	00	00	04	03	00
770-80	00	00	18	00	08	01	00	04	04	00	05	00	00	00	06	01	01	00	05	01	00
780-90	00	02	22	01	05	03	00	11	04	01	06	00	01	00	10	01	01	00	00	01	00
790-800	00	00	13	01	10	05	00	10	02	01	14	00	00	02	02	06	00	00	00	06	00
800-10	00	00	18	00	03	01	00	10	05	00	13	01	00	00	05	00	00	00	00	00	00
810-20	00	02	05	00	06	01	00	04	04	00	06	00	00	00	01	00	00	00	00	00	00
820-30	01	00	31	00	16	08	00	13	03	01	05	00	05	00	07	03	00	00	01	03	03
830-40	00	01	17	00	08	02	01	14	04	00	13	00	00	00	03	04	01	00	00	04	00
840-50	00	00	06	00	03	00	00	06	04	00	00	00	01	00	02	00	00	00	00	00	00
850-60	00	01	03	00	05	00	01	02	01	00	01	00	00	00	01	02	00	00	00	02	00
860-70	00	00	62	00	06	01	00	17	10	02	11	00	01	00	11	02	02	00	00	02	00
870-80	00	00	29	00	20	11	02	15	06	01	14	00	00	00	10	07	01	00	01	07	00
880-90	00	01	71	00	13	05	00	30	13	00	21	00	01	00	10	05	01	00	02	05	00
890-900	00	00	78	00	12	05	02	46	27	01	53	01	01	00	24	06	02	00	07	06	00
900-10	00	02	35	00	05	01	00	17	12	00	13	00	00	00	08	01	00	00	00	01	00
910-20	00	00	19	01	08	06	01	06	03	00	05	00	02	00	05	04	00	00	00	04	01
920-30	00	00	16	00	09	00	00	10	04	00	05	00	00	00	08	00	00	00	00	00	00

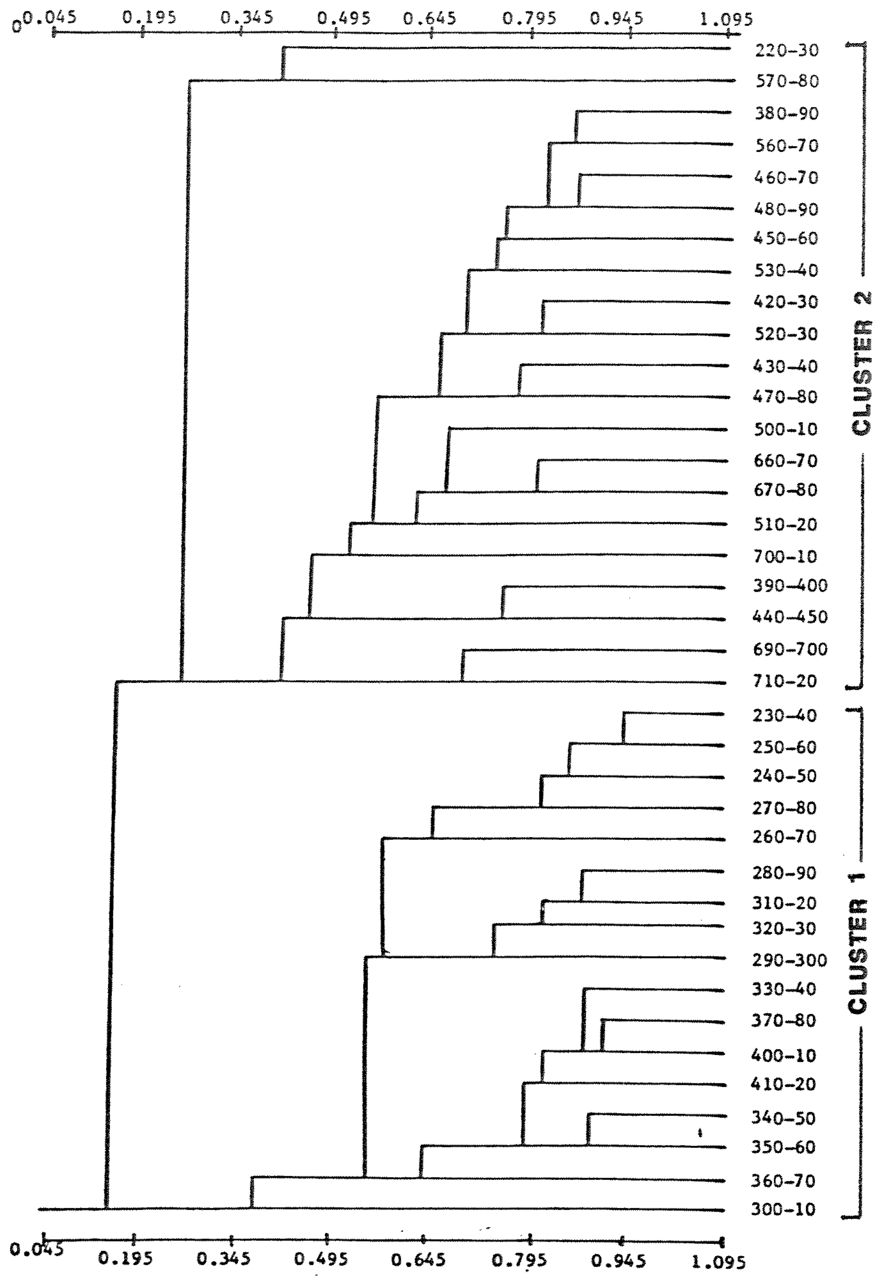
APPENDIX 2 (contd.)

Benthic foraminiferal counts used in cluster analyses from well WOR-CG-73.

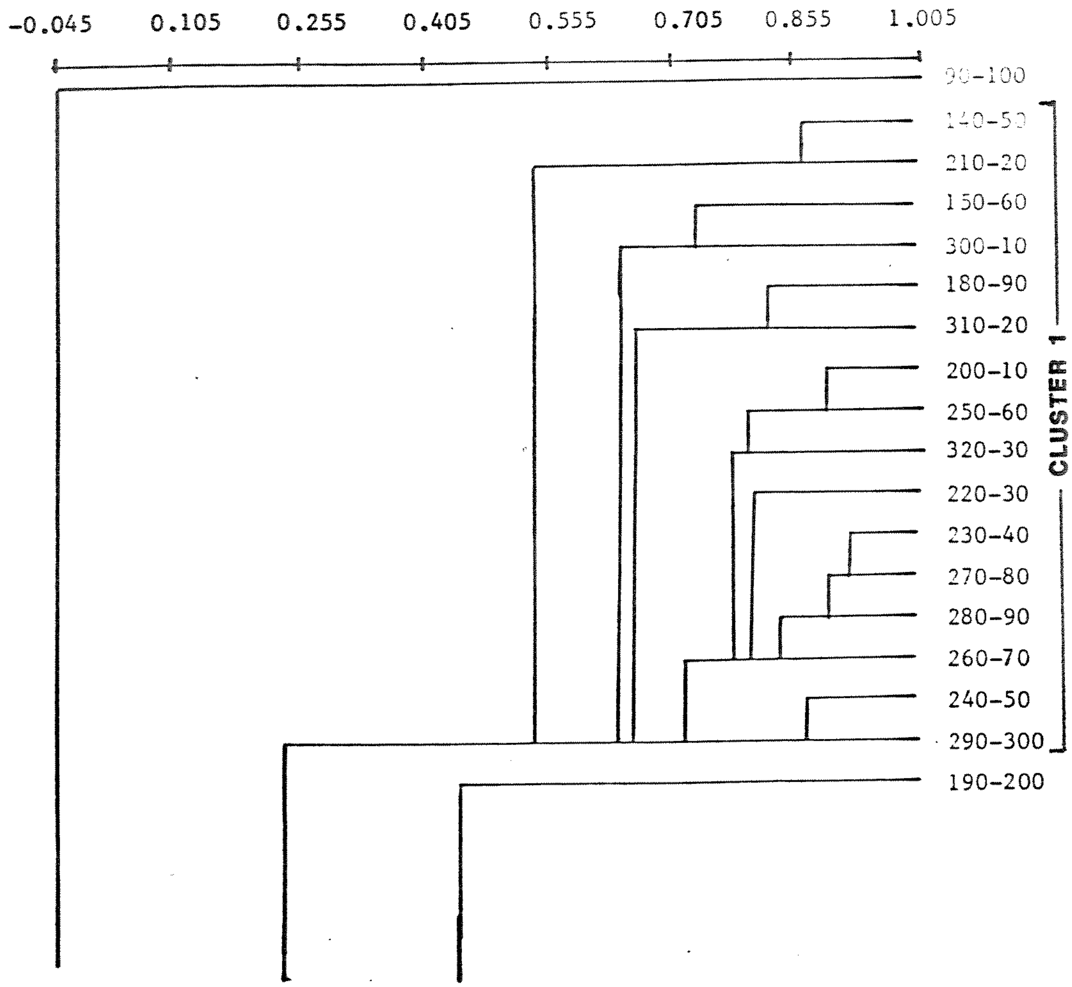
Interval	Q. seminulina	T. agglutinans	U. peregrina	C. lobatulus	B. paula	B. elegantissima	B. mansfieldi	B. elongata	H. concentrica	F. incisum	C. carinata	E. gunteri	N. auris	L. americana	F. pizarrensis	B. marginata	R. floridana	L. substriata	B. multicostata	L.c. anphora	G. austriaca
930-40	00	02	87	02	50	32	02	37	47	00	43	00	02	02	19	00	00	00	11	00	00
940-50	00	00	07	00	23	09	01	10	06	00	10	00	00	00	11	00	01	00	02	00	00
950-60	00	02	71	00	20	06	02	33	14	01	20	01	00	01	38	00	01	00	03	00	00
960-70	00	00	51	00	22	09	03	17	12	01	23	01	03	00	13	03	01	00	01	03	01
970-80	01	00	22	00	08	04	00	09	04	00	15	00	00	00	05	00	00	00	00	00	00
980-90	00	03	23	00	62	20	02	17	11	02	15	03	02	00	05	14	00	00	00	14	00
990-100	00	00	14	03	66	33	01	16	17	00	22	00	00	01	13	08	01	00	00	08	00



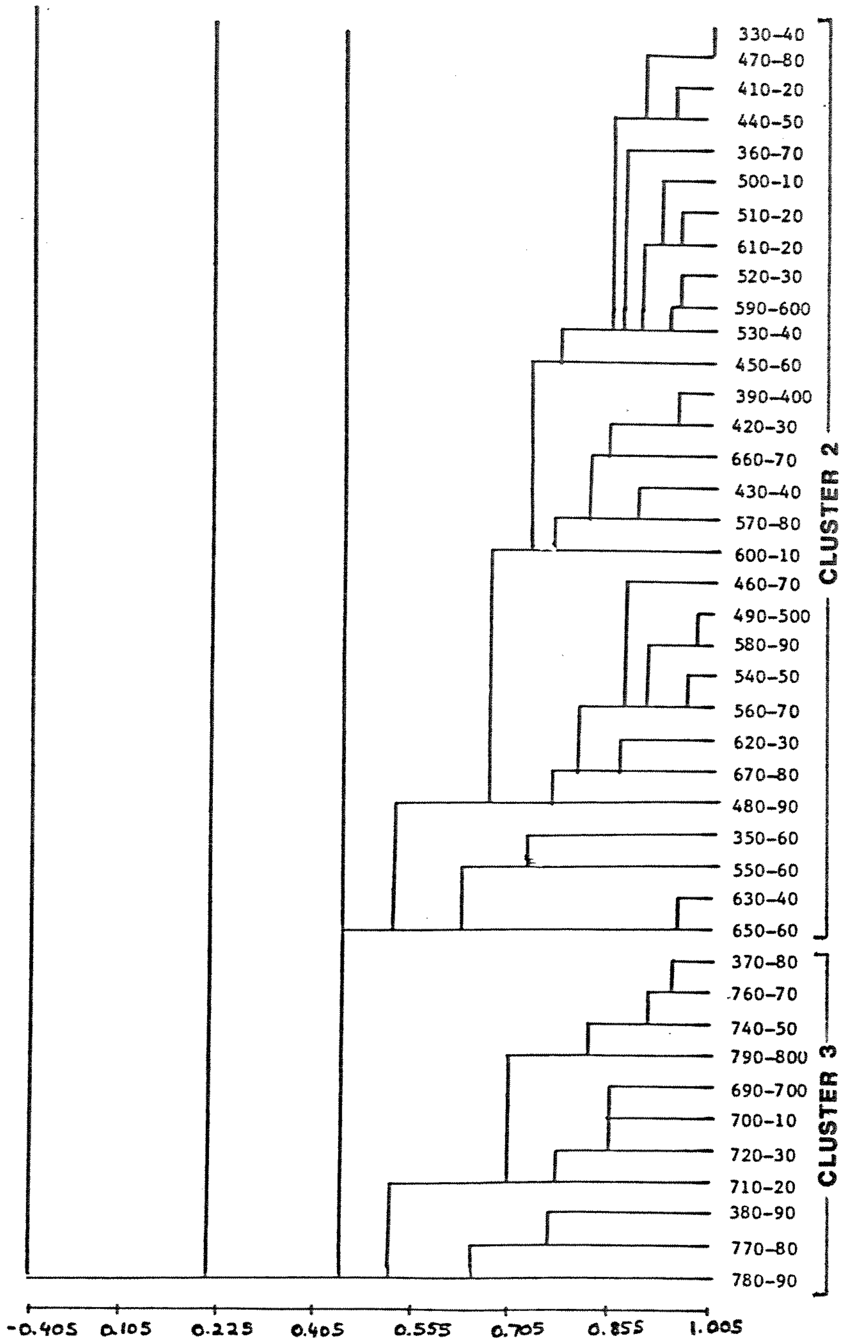
APPENDIX 3. Q-mode cluster analysis dendrogram from well WI-CD-65. Cophenetic correlation value: .66



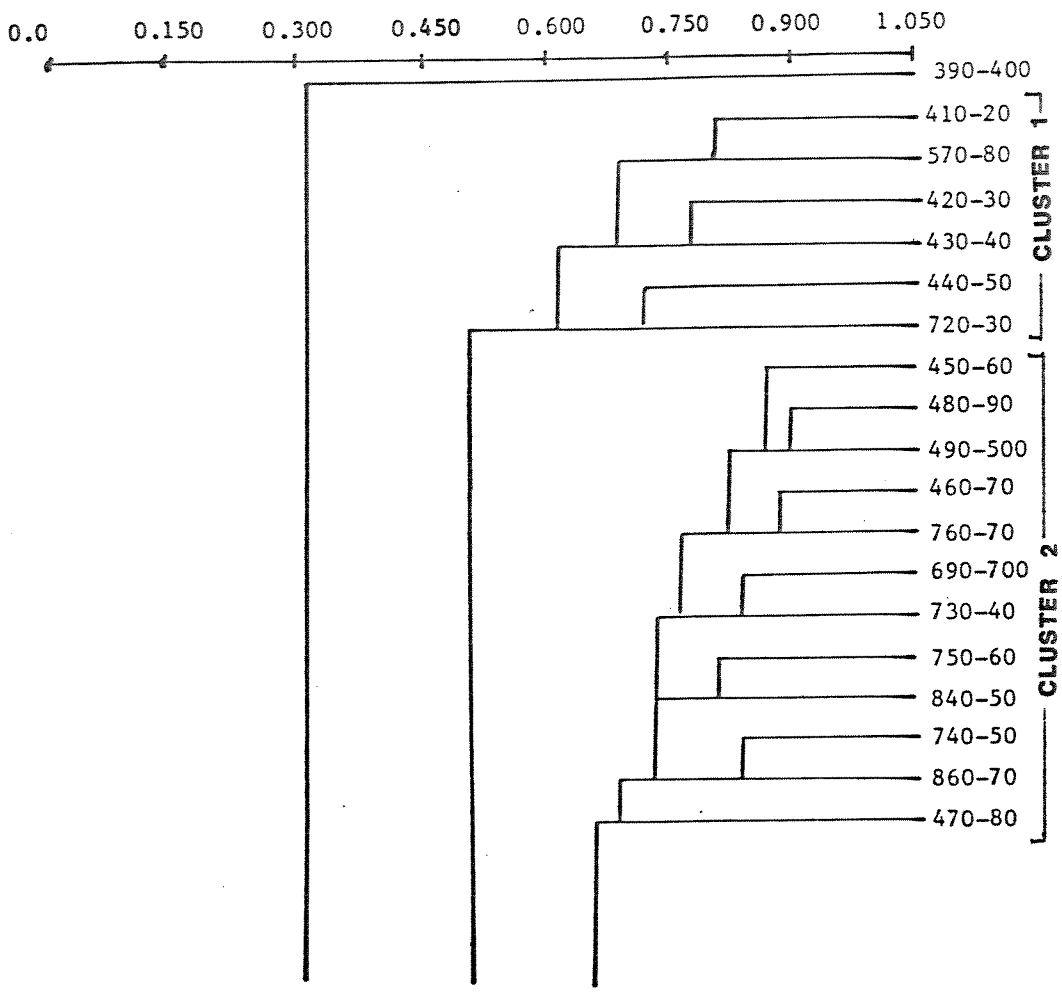
APPENDIX 3 (contd.). Q-mode cluster analysis dendrogram from well WI-CE-213. Cophenetic correlation value: .76



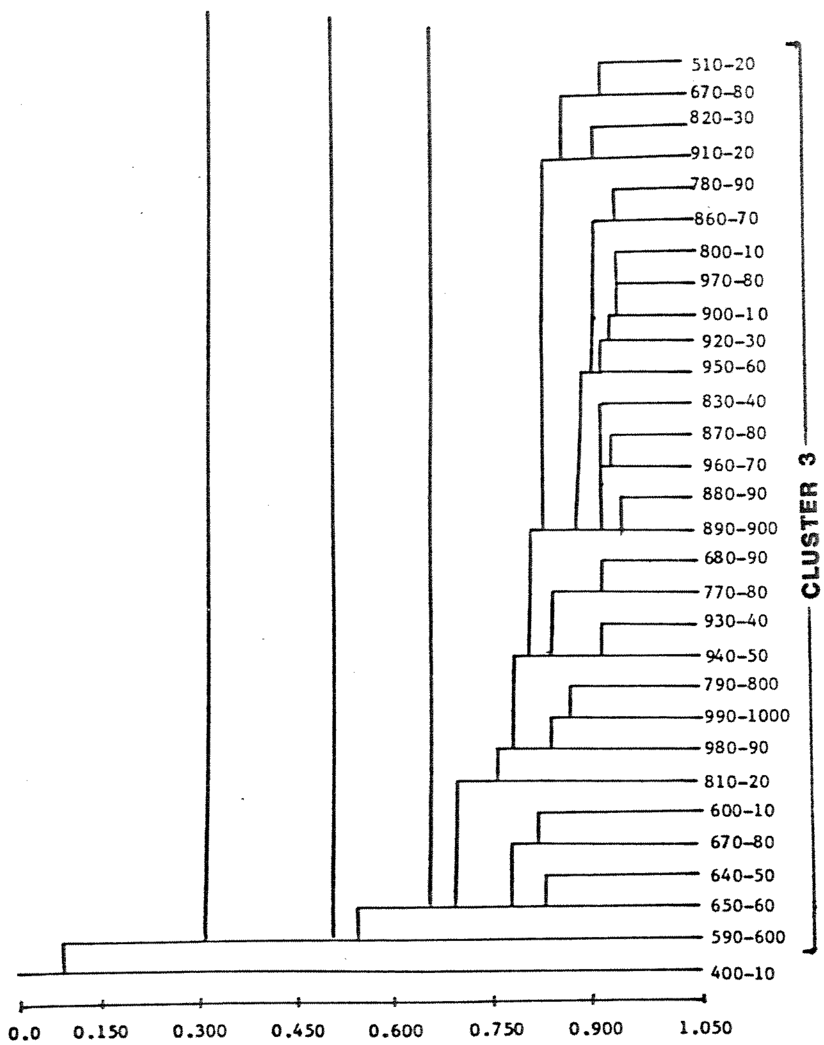
<u>APPENDIX 3 (contd.)</u>. Q-mode cluster analysis dendrogram from well WOR-DD-60 (part I). Cophenetic correlation value: .75



APPENDIX 3 (contd.). Q-mode cluster analysis dendrogram from well WOR-DD-60 (part II). Cophenetic correlation value: .75



APPENDIX 3 (contd.). Q-mode cluster analysis dendrogram from well WOR-CG-73 (part I). Cophenetic correlation coefficient: .89



APPENDIX 3 (contd.). Q-mode cluster analysis dendrogram from well WOR-CG-73 (part II). Cophenetic correlation value: .89

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Lagena anphora Reuss, 1862, Akad. Wiss. Wien Sitz., vol. 46, pt. 1, p. 330, pl. 4, fig. 57.

Lagena laevis (Montagu)
Serpula (Lagena) laevis ovalis Walker and Boys, 1784, Test. Min. p. 3, pl. 1, fig. 9.

Lagena substriata Williamson
Lagena substriata Williamson, 1848, Ann. Mag. Nat. His., sec. ser. vol. 1, p. 15, pl. 1, fig. 12.

Lenticulina americana americana (Cushman)
Cristellaria americana Cushman, 1918, U.S. Geol. Surv. Bull. 676, p. 50, pl. 10, figs. 5,6.

Lenticulina americana spinosa (Cushman)
Cristellaria americana spinosa Cushman, 1918, U.S. Geol. Surv. Bull. 676, p. 51, pl. 10, fig. 7.

Nonionella auris (d'Orbigny)
Valvulina auris d'Orbigny, 1839, Voy. Amer. Merid., Foraminiferes, p. 47, pl. 2, figs. 15-17

Pseudopolimorphina striata (Bagg)
Polymorphina compressa var. striata Bagg, 1904, Maryland Geol. Survey Miocene, p. 476, pl. 133, fig. 2.

Pyrgo subsphaerica (d'Orbigny)
Biloculina subsphaerica d'Orbigny, 1839, in de la Sagra, His. Phys. Pol. Nat. Cuba, Foraminiferes, p. 162, pl. 3, figs. 25-27

Quinqueloculina seminulina (Linne)
Serpula seminulinum Linne, 1767, Sys. Naturae, 12 ed., p. 1264.

Rosalina floridana (Cushman)
Discorbis floridana Cushman, 1922, Carnegie Inst. Washigton, Publ. 311, p. 39, pl. 5, figs. 11-12.

Siphogenerina lamellata Cushman

Siphogenerina lamellata Cushman, 1918, U.S. Geol. Survey Bull. 676, p. 55, pl. 12, fig. 3.

Spiroplectammina gracilis (von Meunster)
Textularia gracilis von Meunster , 1938, in Roemer, Neues Jahrb. p. 384, pl. 3, fig. 14.

Textularia agglutinans d'Orbigny
Textularia agglutinans d'Orbigny, 1839, in de la Sagra, His. Phys. Pol. Nat. Cuba, Foraminiferes, p. 136, pl. 1, figs. 17, 18, 32, 34.

Uvigerina peregrina Cushman
Uvigerina peregrina Cushman, 1923, U.S> Nat. Mus. Bull. 104, pt. 4, p. 168, pl. 42, fig. 11.

EXPLANATION OF PLATE

Figure 1. Elphidium gunteri Cole
Well WI-CD-65, 600-10 ft. Side view X 200

Figure 2. Bolivina marginata multicostata (Cushman)
Well WOR-CG-73, 960-970 ft. Side view X 150

Figure 3. Quinqueloculina seminulina (Linne)
Well WI-CE-213, 320-30 ft. Side view X 100

Figure 4. Nonionella auris (d'Orbigny)
Well WI-CE-213, 320-30 ft. Side view X 200

Figure 5. Buliminella elegantissima (d'Orbigny)
Well WOR-DD-60, 390-400 ft. Side view X 250

Figure 6. Bolivina paula Cushman and Cahill
Well WOR-DD-60, 370-80 ft. Side view X 250

Figure 7. Cassidulina carinata Cushman
Well WOR-CG-73, 790-800 ft. Dorsal view X 200

Figure 8. Uvigerina peregrina Cushman
Well WOR-CG-73, 960-70 ft. Side view X 120

Figure 9. Buliminella elongata (d'Orbigny)
Well WI-CE-213, 370-80 ft. Side view X 150

Figure 10. Florilus pizarrensis (Berry)
Well WI-CE-213, 710-20 ft. Side view X 100

Figure 11. Textularia agglutinans d'Orbigny
Well WI-CE-213, 410-20 ft. Side view X 140

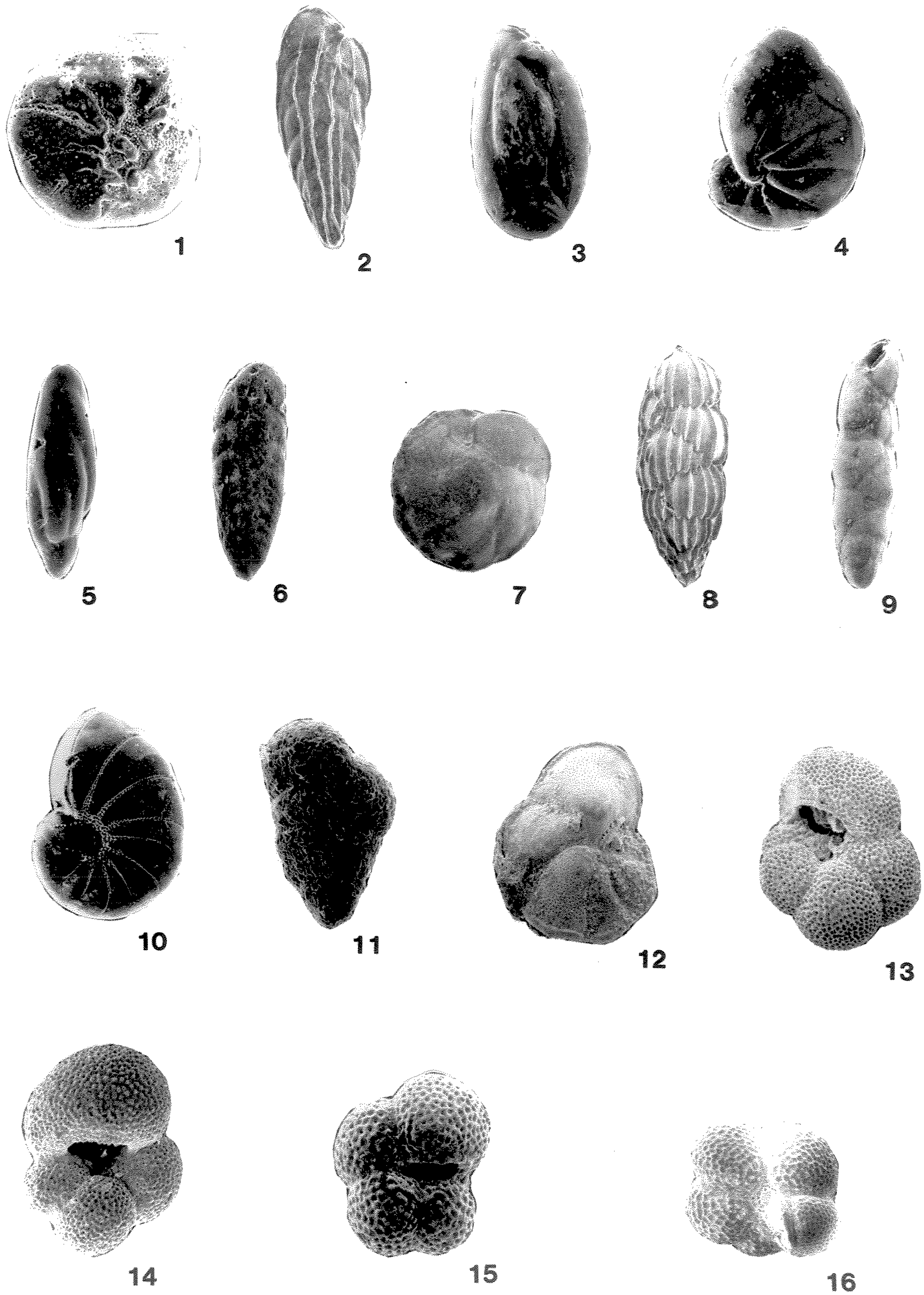
Figure 12. Globorotalia menardii (d'Orbigny)
Well WI-CE-213, 230-40 ft. Side view X 160

Figure 13. Globorotalia cf. humerosa Takayanagi and Saito
Well WOR-CG-73, 990-1000 ft. Umbilical view X 200

Figure 14. Globigerina praebulloides praebulloides Blow
Well WI-CD-65, 470-80 ft. Umbilical view X 210

Figure 15. Globorotalia continuosa Blow
Well WOR-DD-60, 760-70 ft. Umbilical view X 300

Figure 16. Globorotalia acostaensis acostaensis Blow
Well WOR-CG-73, 720-30 ft. Umbilical view X 200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VITA

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