EOCENE BENTHIC FORAMINIFERAL PALEOECOLOGY AND PALEOBATHYMETRY OF THE NEW JERSEY CONTINENTAL MARGIN

By ANTHONY CHARLES CHARLETTA

A thesis submitted to

The Graduate School

of

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

Graduate Program in Geology

Written under the direction of

Professor Richard K. Olsson

and approved by

____

____

____

____

New Brunswick, New Jersey

May 1980

ABSTRACT OF THE THESIS

Eocene Benthic Foraminiferal Paleoecology and

Paleobathymetry of the New Jersey Continental Margin

by ANTHONY CHARLES CHARLETTA, Ph.D.

Thesis director: Professor Richard K. Olsson

Analysis of Eocene benthic foraminifera and associated diversity trends of six wells of the New Jersey continental margin indicates that Eocene sediments were deposited in depths ranging from less than 100 meters on the New Jersey coastal plain to approximately 500 to 600 meters in the C.O.S.T. B-2 Well.

Benthic foraminifera cluster into eleven distinct biofacies. Distribution of these biofacies in the Eocene section of New Jersey indicates a rapid transgression within the Early Eocene; a gradual upward shoaling toward the Early-Middle Eocene boundary; relatively stable conditions during the Middle Eocene; and a gradual upward shoaling toward the Eocene-Oligocene boundary during Late Eocene time.

Paleobathymetric contouring of Eocene deposits indicates a more gradual shelf-slope profile than that of present day continental margins, and illustrates the negative and positive effects of the Salisbury Embayment and South Jersey High during Eocene time.

ACKNOWLEDGEMENTS

The author would like to express his appreciation to Dr. Richard K. Olsson who originally suggested this study, and whose suggestions, advice, and helpful criticisms were essential toward the completion of this paper.

My appreciation is also extended to Drs. Steven K. Fox, Gail M. Ashley, and Paul S. Boyer, who were committee members for this thesis.

Special thanks to Dr. Robert A. Holzer who took the scanning electron micrographs; Dr. Richard Aurisano who on numerous occasions offered helpful criticism and advice; Elsie Miller, Nancy Cerchiaro, and Henry Wieck for their help and comments; and ERA North America for supplying samples from the C.O.S.T. B-2 Well.

Acknowledgement is made to the Donors of the Petroleum Research Fund, administered by the American Chemical Society, for the support of this research.

Finally, the author would like to thank his wife for her patience, encouragement, and numerous sacrifices, which made made this study possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

INTRODUCTION

Eocene sediments of the New Jersey continental margin outcrop along the northern New Jersey coastal plain, and dip to the southeast under the continental shelf. These sediments, deposited during a marine transgression, are dominated by fine quartz sands, silts, calcareous clays and limestones (Enright, 1969; Olsson, 1978; Poag, 1979). In outcrop and the shallow subsurface Eocene sediments are separated from the Paleocene below by a small disconformity, which disappears further downdip. An extensive disconformity separating Eocene and Oligocene sediments can be traced from outcrop to the outer continental shelf. In outcrop and the shallow subsurface, either part of the Middle, or all of the Middle and Upper Eocene is missing, whereas on the outer continental shelf only the uppermost part of the Upper Eocene is missing. This disconformity resulted from a major regression, which probably occurred near the end of Eocene time (Olsson, 1978; Olsson and Miller, 1979).

Beneath the New Jersey continental margin the westward extension of the Baltimore Canyon Trough is delineated by the Salisbury Embayment, Raritan Embayment and South Jersey High (fig. 1). These lows and high are interpreted as part of a block-faulted, rifted type margin which formed during the separation of North America and Africa (Brown et al., 1972; Sheridan, 1974). The effect of these structures landward of the main hinge zone of sediment accumulation can be seen in facies changes between structural elements, and the greater thickness of sediments within embayments (Olsson, 1978). In outcrop and the shallow subsurface the dominant Eocene facies (Deal Member-

Manasquan Formation) of the New Jersey continental margin thins, and is replaced in part by three distinct facies (Enright, 1969); a slightly clayey, medium to coarse, quartzose glauconite sand (Farmingdale Member-Manasquan Formation; fig. 2), an argillaceous glauconite sand (Squankum Member-Shark River Formation; fig. 3), and a slightly clayey, slightly glauconitic, medium-grained quartz sand (Toms River Member-Shark River Formation; fig. 4). In areal extent the glauconite facies are restricted to the Raritan Embayment, thin to the southwest over the South Jersey HIgh, and are replaced by the Toms River and Deal members (fig. 5).

The planktic foraminiferal zonation of Eocene sediments of the New Jersey continental margin is illustrated in Figure 6. In the Lower Eocene sediments the low-latitude planktic foraminiferal zonation of Trinidad (Bolli, 1957, 1966) is applicable. In uppermost Lower, Middle, and Upper Eocene sediments the Acarinina pentacamerata Zone (Krasheninnikov, 1965) of the eastern Mediterranean region, and the mid-latitude zonation, based on the evolution of Globorotalia cerroazulensis (Cole), of the Possagno section of Italy (Toumarkine and Bolli, 1970) are recognized. The occurrence of Globigerinatheka index index, and G. subconglobata subconglobata, of the evolutionary lineage Globigerinatheka Bronnimann (Bolli, 1972), offers additional biostratigraphic evidence in defining Middle Eocene sediments of New Jersey (Ulrich, 1976).

Zonation of shallow updip wells is difficult because of the low abundance of planktic foraminifera, and predominance of juvenile forms, and only general recognition of Lower and Middle Eocene sediments is possible. Downdip wells (Island Beach, Anchor Dickinson I, C.O.S.T. B2) contain a well developed planktic foraminiferal assemblage, and can be accurately zoned.

Previous studies of benthic foraminiferal distribution and paleoecology, and the depositional environments of the Eocene section of the New Jersey continental margin have been limited in nature (Enright, 1969; Olsson, 1978; Poag, 1979).

The purpose of this study is to provide a detailed analysis of Eocene benthic foraminifera from four rotary wells (Transco 15, Island Beach, Anchor Dickinson I, C.O.S.T. B2), and two cores (Allaire State Park, Leggette) of the New Jersey continental margin (fig. 1), and to determine:

1. benthic foraminiferal biofacies through cluster analysis,

2. the paleobathymetric ranges of these biofacies through the comparison to modern benthic foraminifera distributional trends,

3. the distribution of these biofacies in the Eocene section of New Jersey,

4. benthic foraminifera species diversity and dominance trends, and their comparison to that of recent trends,

5. relative sea level changes, and their comparison to global sea level cycles of Vail et al. (1977),

6. the paleobathymetric profile of the New Jersey continental margin during Eocene time,

7. the relative paleobathymetric positive and negative effects of structural elements (Salisbury and Raritan embayments, South Jersey High).

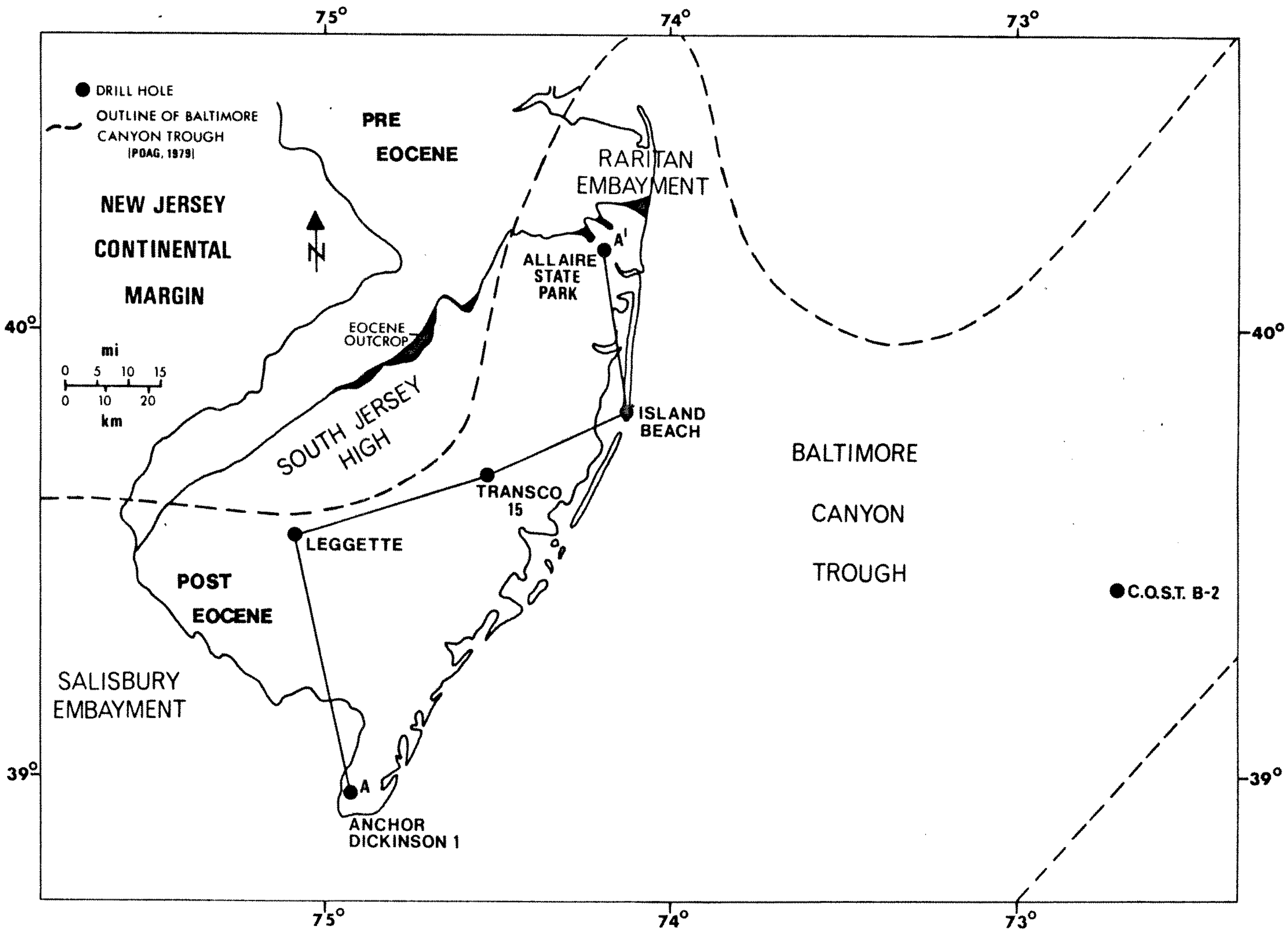

75°
74°
73°
DRILL HOLE
OUTLINE OF BALTIMORE CANYON TROUGH (POAG, 1979)
NEW JERSEY CONTINENTAL MARGIN
PRE EOCENE
N
RARITAN EMBAYMENT
A'
ALLAIRE STATE PARK
EOCENE OUTCROP
40°
mi
0 5 10 15
0 10 20
km
SOUTH JERSEY HIGH
ISLAND BEACH
BALTIMORE CANYON TROUGH
TRANSCO 15
LEGGETTE
POST EOCENE
C.O.S.T. B-2
SALISBURY EMBAYMENT
39°
A
ANCHOR DICKINSON 1

FIGURE 1

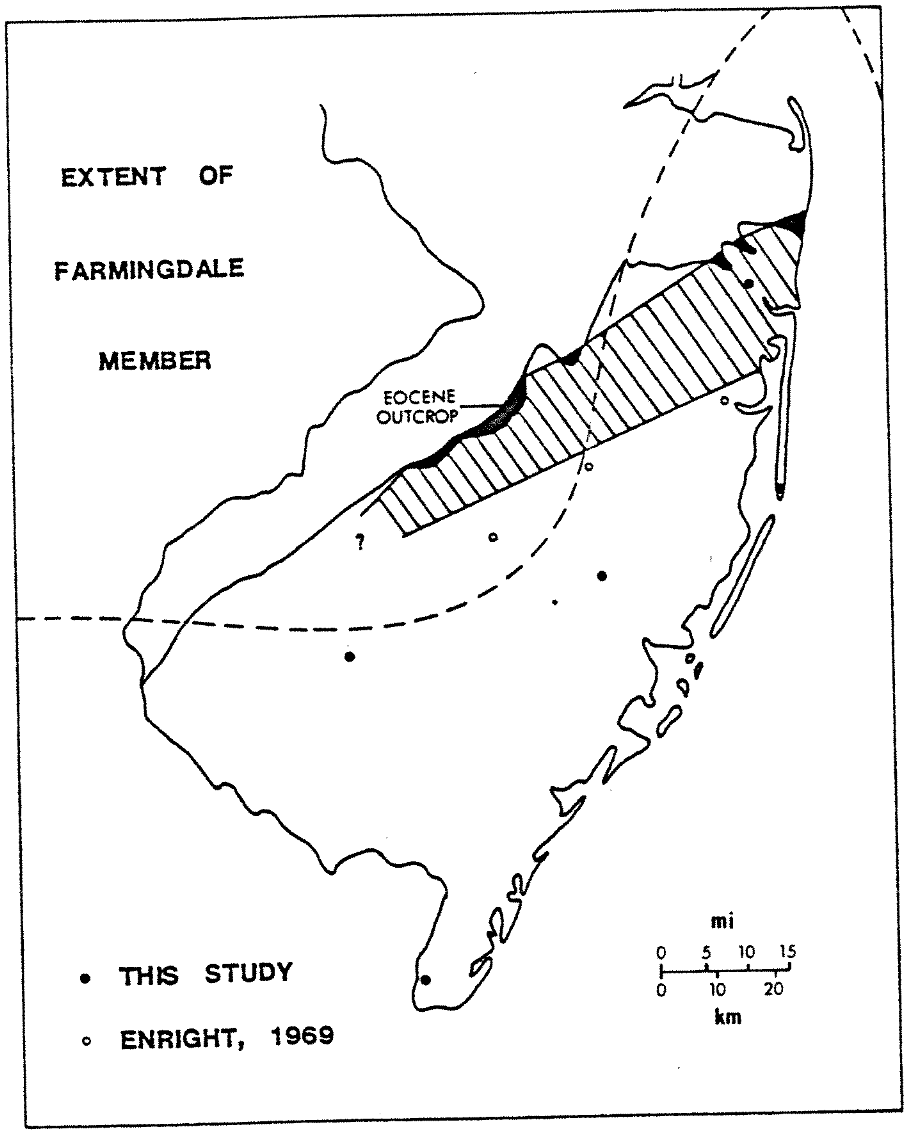

EXTENT OF
FARMINGDALE
MEMBER
EOCENE OUTCROP
?
• THIS STUDY
○ ENRIGHT, 1969
mi
0 5 10 15
0 10 20
km

FIGURE 2

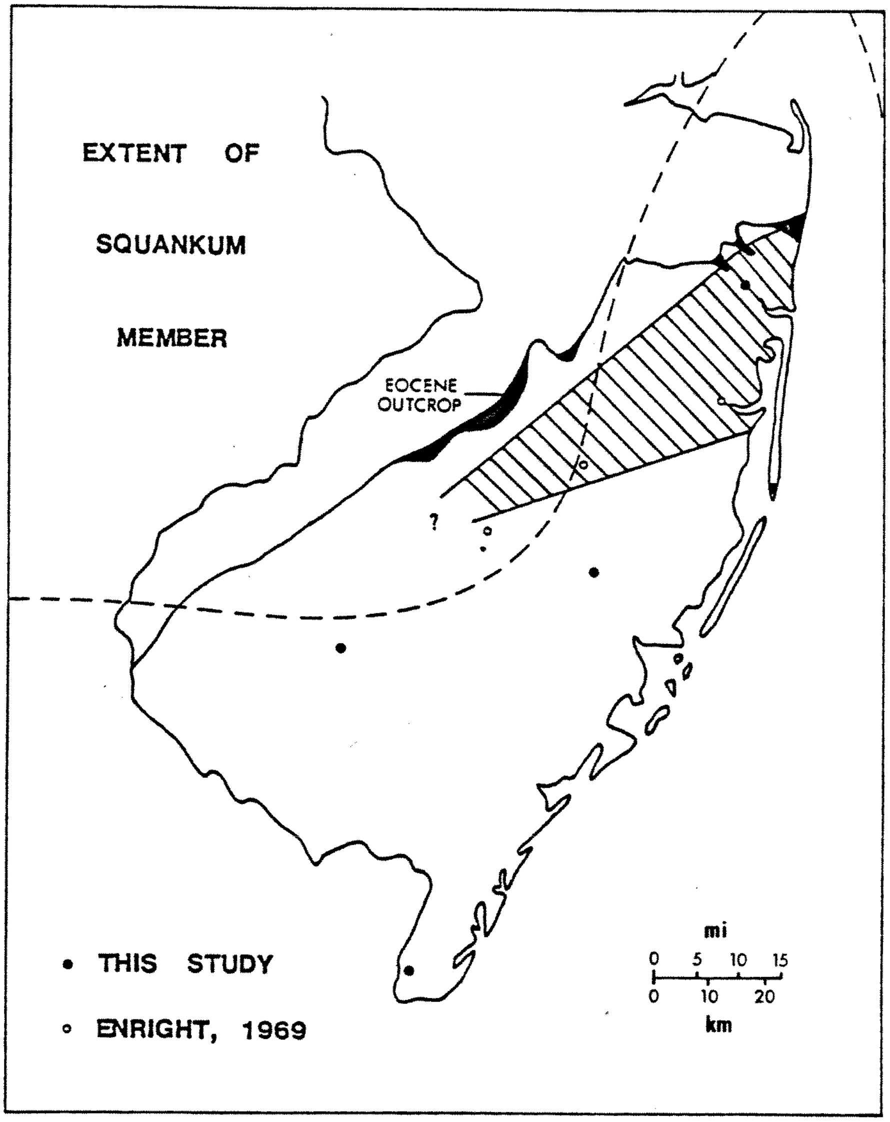

EXTENT OF
SQUANKUM
MEMBER
EOCENE OUTCROP
?
mi
0 5 10 15
0 10 20
km
• THIS STUDY
◦ ENRIGHT, 1969

FIGURE 3

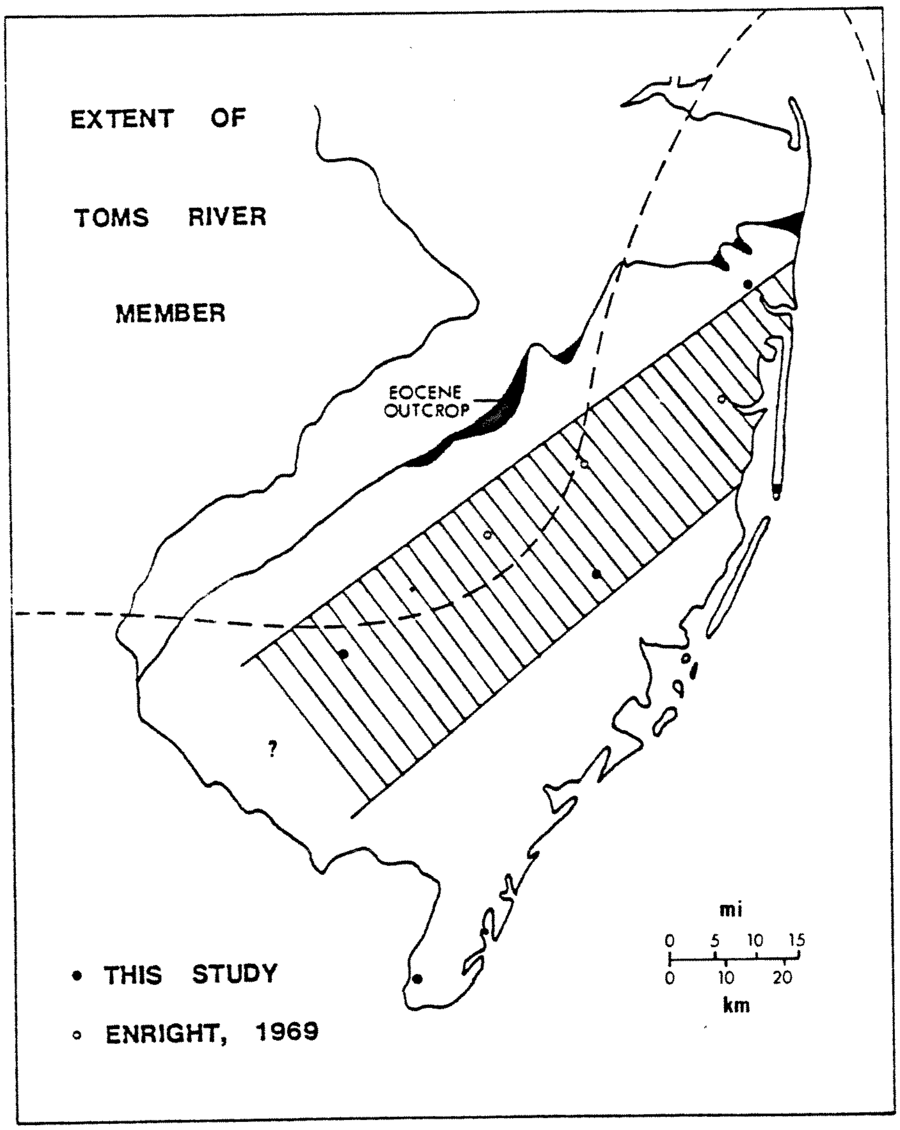

EXTENT OF
TOMS RIVER
MEMBER
EOCENE
OUTCROP
?
• THIS STUDY
∘ ENRIGHT, 1969
mi
0 5 10 15
0 10 20
km

FIGURE 4

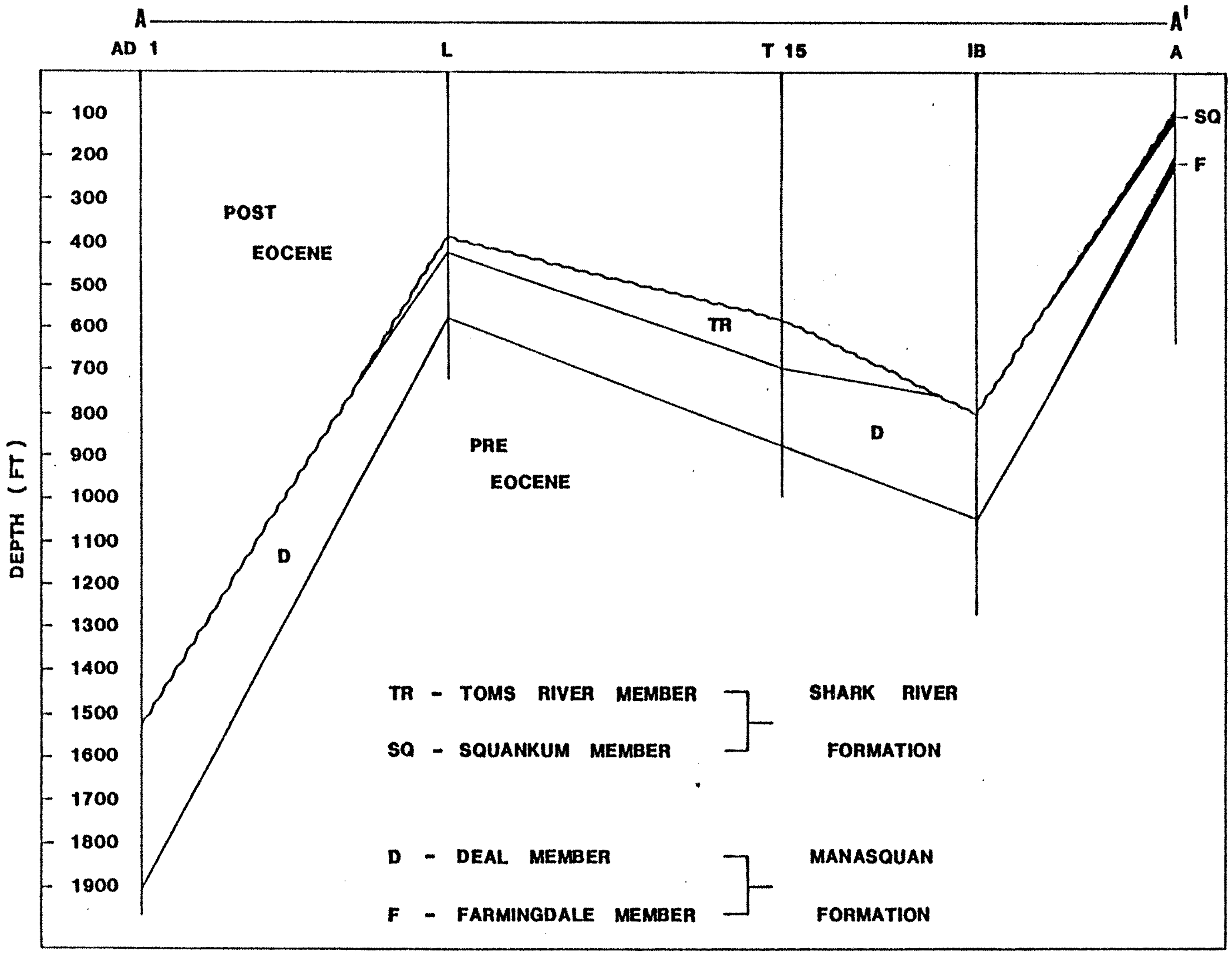

A
A'
AD 1
L
T 15
IB
A
DEPTH (FT)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
POST
EOCENE
PRE
EOCENE
D
TR
D
SQ
F
TR - TOMS RIVER MEMBER
SQ - SQUANKUM MEMBER
SHARK RIVER
FORMATION
D - DEAL MEMBER
F - FARMINGDALE MEMBER
MANASQUAN
FORMATION

FIGURE 5

AGE		PLANKTIC FORAM ZONES	AUTHOR
EOCENE	LATE	Globorotalia cerroazulensis cunialensis	TOUMARKINE and BOLLI (1970)
		Globorotalia cerroazulensis cocoaensis	
		Globorotalia cerroazulensis cerroazulensis	
	MIDDLE	Globorotalia c. cerroazulensis - c. pomeroli	
		Globorotalia cerroazulensis pomeroli	
		Globorotalia cerroazulensis possagnoensis	
		Globorotalia cerroazulesis frontosa	
	EARLY	Acarinina pentacamerata	KRASHENINNIKOV (1965)
		Morozovella aragonensis	BOLLI (1957, 1960, 1966)
		Morozovella formosa formosa	
		Morozovella subbotinae	

FIGURE 6

PALEOENVIRONMENTAL ANALYSIS

Bandy (1960), and Bandy and Arnal (1960) were the first to suggest the idea of convergent adoption as a tool in foraminiferal paleo-ecology. They proposed that benthic foraminifera, which occupy similar environments, have responded in similar ways, and developed similar morphologic characteristics (i.e. size, ornamentation, form). Based on this concept, the comparison of fossil and living species that are morphologically alike, especially where several species are involved, is very useful in paleoenvironmental analysis (Bandy and Arnal, 1960). Though the depth limits of living benthic foraminifera vary from one geographic area to another the sequence of benthic foraminifera with increasing water depth has been shown by various workers to remain similar (Parker, 1954; Phleger, 1956, 1960; Bandy, 1960; Walton, 1964; Murray, 1973; Pflum and Frerichs, 1976; and others).

Planktic foraminiferal abundance has been observed to increase with increasing depth of water (Grimsdale and Morkhoven, 1955; Bandy and Arnal, 1960; Bandy, 1956; Phleger, 1960; Pflum and Frerichs, 1976; and others). In general, planktic foraminifera are very rare to absent in nearshore waters where juvenille forms predominate, and become progressively more abundant with increasing distance from shore and increasing depth of water. It should be noted that any set of particular values pertains only to a general area, and attempts to quantify water depth and planktic foraminiferal abundance have been generally unsuccessful because of the variation in sedimentation rates, fresh water inflow, and carbonate dissolution along continental margins (Pflum and Frerichs, 1976; Douglas, 1979).

The New Jersey continental margin, formed by the opening of the Atlantic Ocean probably during Jurassic time, is one of general subsidence and minor structural complexity (Olsson, 1978; Poag, 1979). It can be assumed that seaward of the main hinge zone of sediment accumulation of the Eocene section of New Jersey represents an increase in water depth. This is reflected by the greater thickness in section downdip, the replacement of quartz sands by calcareous clays and limestones, and the increase in planktic foraminiferal abundance. The downdip distribution of Eocene sections examined in this study, and the absence of any significant structural movements within the New Jersey continental margin, allows an analysis of the lateral changes of Eocene benthic foraminiferal assemblages with increasing depth of water. These lateral changes can be compared to that of modern benthic foraminifera bathymetric trends.

METHODS

Samples analyzed in this study were obtained from both rotary wells and cores. Samples were washed through a 230 mesh sieve, and the clay fraction discarded. Foraminifera were then concentrated by flotation. The residue left behind was examined to determine whether the floated concentrate was representative of the total foraminiferal population. The flotation technique used here was successful, and is supported by the similar occurrence and abundance trends of benthic foraminifera in well samples not subjected to flotation (Anchor Dickinson 1, C.O.S.T. B-2). The floated concentration was passed through a microsplitter until a manageable portion was obtained for counting. The amount of specimens counted per sample was dependent on sample preservation, and foraminiferal abundance, but approximately 300 specimens were counted whenever possible. Because of the variation in the number of counted specimens, relative abundances were converted to percentages for better comparison of sample intervals.

Downward mixing of foraminifera in rotary wells is a problem in paleoecological-paleobathymetric analysis. This problem can be greatly reduced by the recognition of first occurrences down section, comparison to core samples wherever possible, and the complete analysis of faunal composition and relative abundances. Relative peak abundances are very useful in determining in place faunal components (figs. 7-12), and their paleoecological distribution. The common practice of examining only larger size fractions of foraminiferal populations can lead to an inaccurate representation of faunal composition, and foraminiferal abundances.

PALEOECOLOGY

Johnson (1972) proposed a conceptual model for benthic marine communities in which he states that just as substrates intergrade so do communities, and adjacent communities are likely to replace one another as environments of deposition change. Johnson suggests that these relationships between coexisting communities may be used in vertical succession through time in determining environmental disturbances.

Figures 7-12 illustrate the distribution and relative abundances of benthic and planktic foraminifera of the Eocene section of the New Jersey continental margin. In general, three benthic foraminiferal assemblages can be readily recognized in the Eocene section of New Jersey; a *Gyroidinoides*-*Alabamina*-*Uvigerina* dominated assemblage, a brizalinid-*Pyramidina*-*Epistominella* dominated assemblage, and a buliminid-*Anomalinoides*-*Trifarina* dominated assemblage. In shallow updip wells (Allaire State Park, Leggette, Transco 15; figs. 7-9) the buliminid-*Anomalinoides*-*Trifarina* assemblage is restricted in occurrence to Lower Eocene sediments, the brizalinid-*Pyramidina*-*Epistominella* assemblage occurs in Lower and lowermost Middle Eocene sediments, and the *Gyroidinoides*-*Alabamina*-*Uvigerina* assemblage is restricted in occurrence to Middle Eocene sediments. Downdip in the Island Beach, Anchor Dickinson 1, and C.O.S.T. B-2 wells (figs. 10-12) the buliminid-*Anomalinoides*-*Trifarina* assemblage replaces the brizalinid-*Pyramidina*-*Epistominella* assemblage in Lower Eocene sediments, whereas the *Gyroidinoides*-*Alabamina*-*Uvigerina* assemblage is replaced by the brizalinid-*Pyramidina*-*Epistominella* assemblage. These lateral and vertical changes in benthic foraminiferal assemblages also correlate with changes in planktic foraminiferal abundance. Two trends in planktic foraminiferal abundance are recognized in the Eocene of New Jersey; an increase in abundance downdip, and a decrease in abundance through Eocene time. The lateral and vertical changes in benthic and planktic foraminiferal distribution and abundance correlate throughout the Eocene section of New Jersey, and can be explained by changes in bathymetry.

Figure 13 summarizes the distribution and estimated paleobathymetric ranges of benthic foraminifera of the six Eocene sections examined in this study. Neritic foraminiferal assemblages are characterized by small brizalinids (bolivinids of others), cibicidids, small uvigerinids, Alabamina midwayensis, Epistominella minuta, Pyramidina subrotundata, Hanzawaia and Gyroidinoides. Bulimina whitei, Turritilina sp., and Kolesnikovella elongata occur in abundance in both neritic and upper bathyal assemblages. Distributional studies of modern benthic foraminifera (Table 1) indicate a paleodepth of approximately 50 to 200 meters for this assemblage.

Upper bathyal benthic foraminiferal assemblages are characterized by the dominance of buliminids, Planulina? ammophila, Anomalinoides acuta, Aragonia aragonensis, Trifarina wilcoxensis, Cibicidoides whitei, Fursenkoina? sp., and Nuttallides truempyi. Distributional studies of modern benthic foraminifera (Table 1), and the following line of reasoning indicate paleodepths to have ranged from approximately 200 to 600 meters for these assemblages.

Nuttallides truempyi, a dominant lower bathyal-abyssal form, has a stratigraphic range of late Cretaceous (Maestrichtian) to latest Eocene (Laughton, et al., 1972; Douglas, 1973). It's upper bathymetric limit is not known with certainty, but it's occurrence in late Eocene deposits at DSDP Site 116 in estimated paleodepths of less

Figures 7-12	The distribution and relative abundances of benthic and planktic foraminifera of the Eocene well sections examined in this study. Absence of data in intervals of the Island Beach and Anchor Dickinson 1 wells is due to the recrystallization of benthic foraminifera.
Figure 13	Summary of the distribution, relative abundances, and estimated paleobathymetry of benthic foraminifera of the Eocene sections examined in this study.
Table 1	Comparison of Eocene benthic foraminifera species, recent homeomorphs and their bathymetric ranges.

ALLAIRE STATE PARK WELL

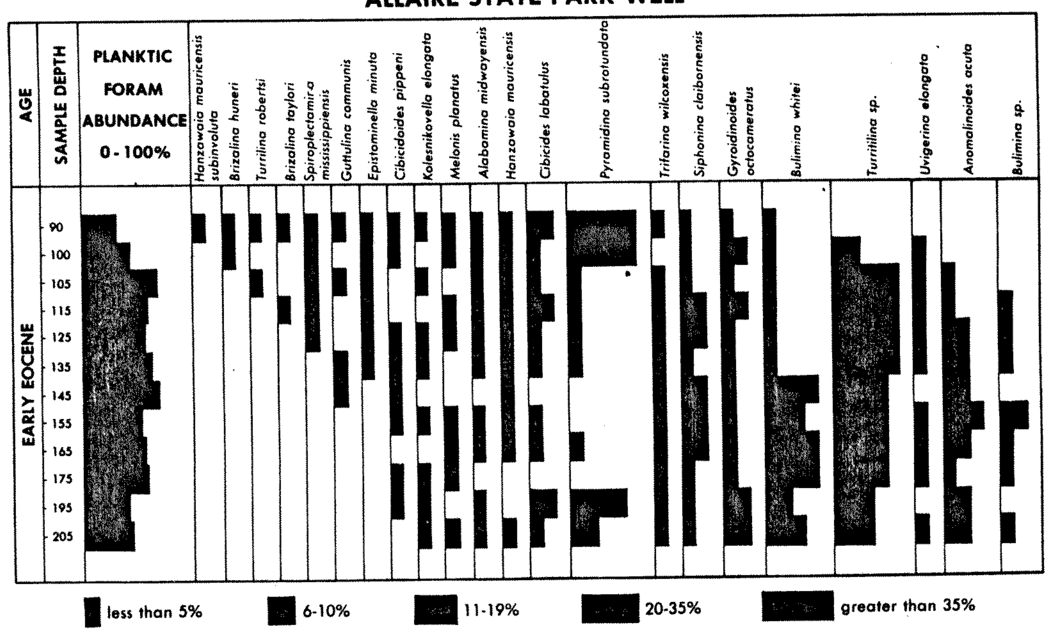
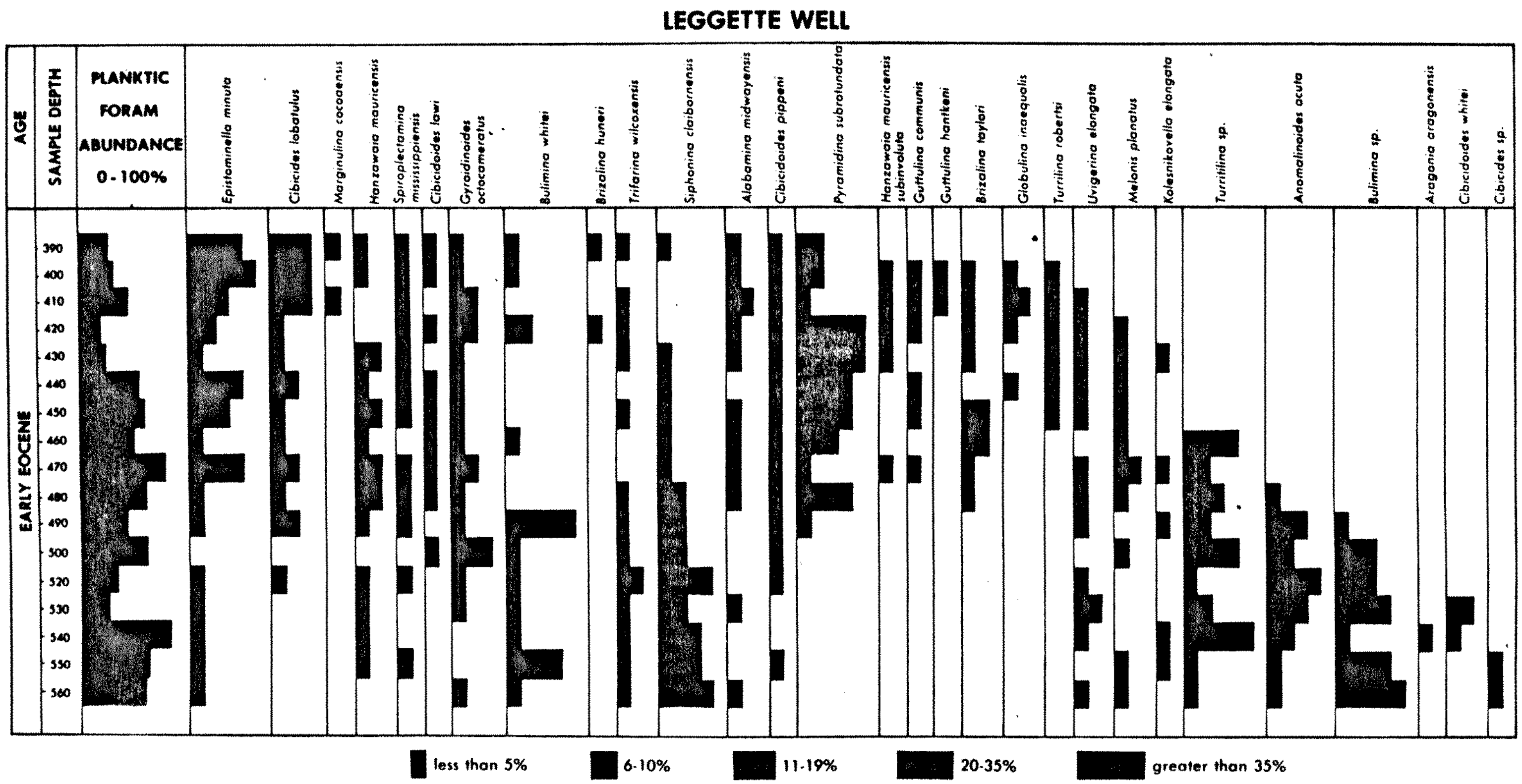


FIGURE 7



LEGGETTE WELL
AGE
SAMPLE DEPTH
PLANKTIC FORAM ABUNDANCE 0-100%
Epistominella minuta
Cibicides lobatulus
Marginulina cocoaensis
Hanzawaia mauricensis
Spiroplectamina mississippiensis
Cibicidoides lawi
Gyroidinoides octocameratus
Bulimina whitei
Brizalina huneri
Trifarina wilcoxensis
Siphonina clairbornensis
Alabamina midwayensis
Cibicidoides pippeni
Pyramidina subrotundata
Hanzawaia mauricensis subinvoluta
Guttulina communis
Guttulina hantkeni
Brizalina taylori
Globulina inaequalis
Turrilina robertsi
Uvigerina elongata
Melonis planatus
Kolesnikovella elongata
Turritilina sp.
Anomalinoides acuta
Bulimina sp.
Aragonia aragonensis
Cibicidoides whitei
Cibicides sp.
EARLY EOCENE
390
400
410
420
430
440
450
460
470
480
490
500
520
530
540
550
560
less than 5%
6-10%
11-19%
20-35%
greater than 35%

FIGURE 8

TRANSCO 15 WELL

FIGURE 9

ISLAND BEACH WELL

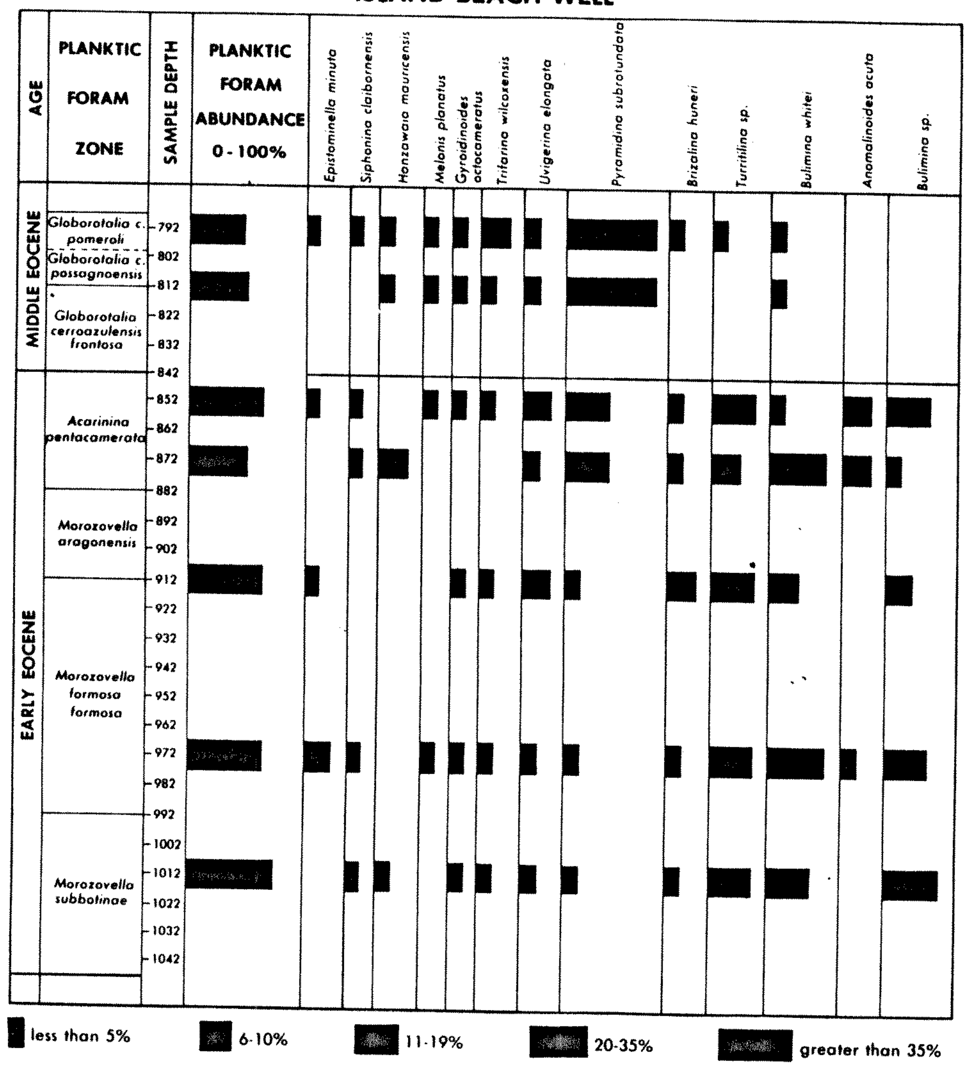


FIGURE 10

ANCHOR DICKINSON 1 WELL

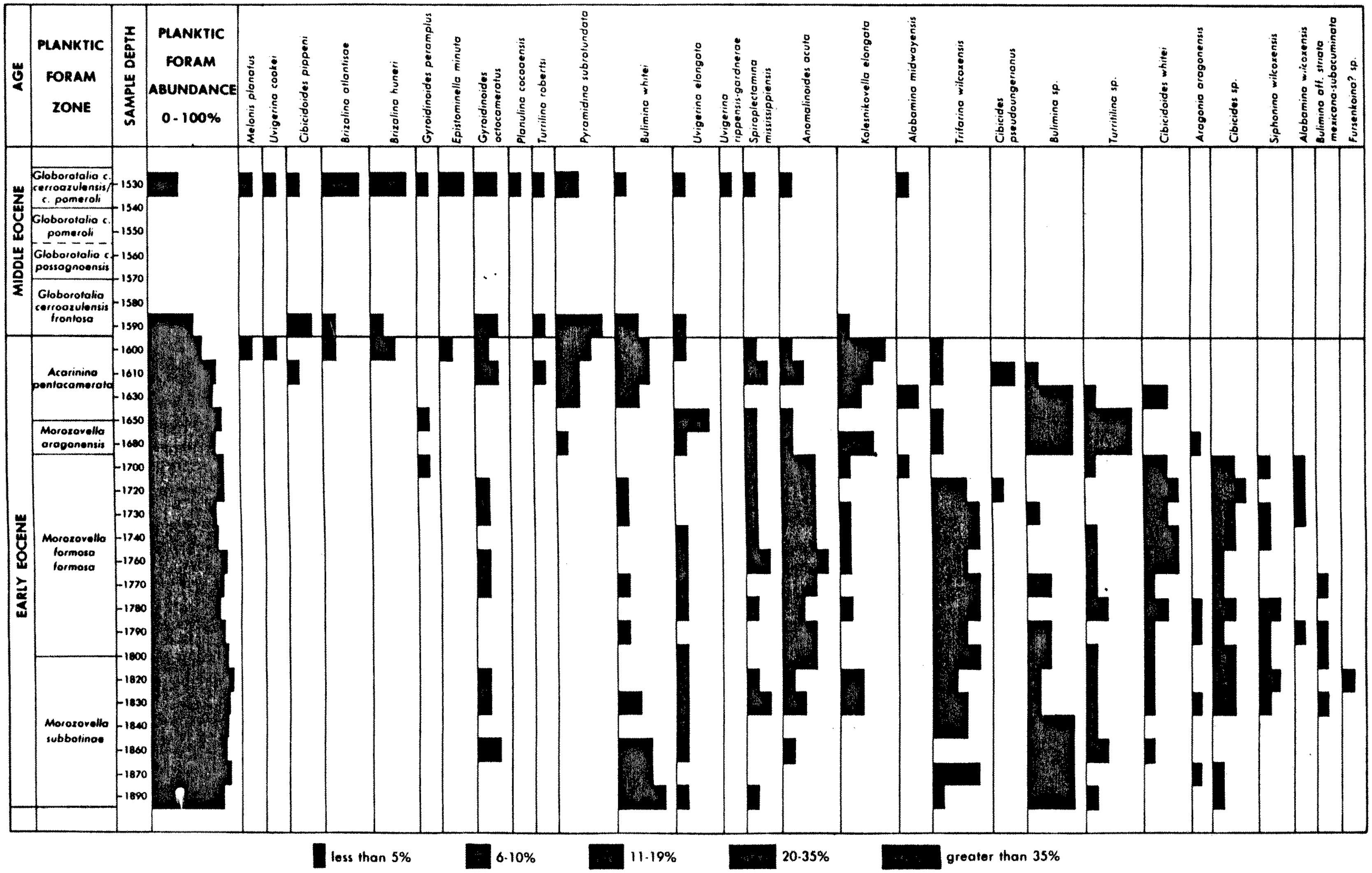


FIGURE 11

C.O.S.T. B2 WELL

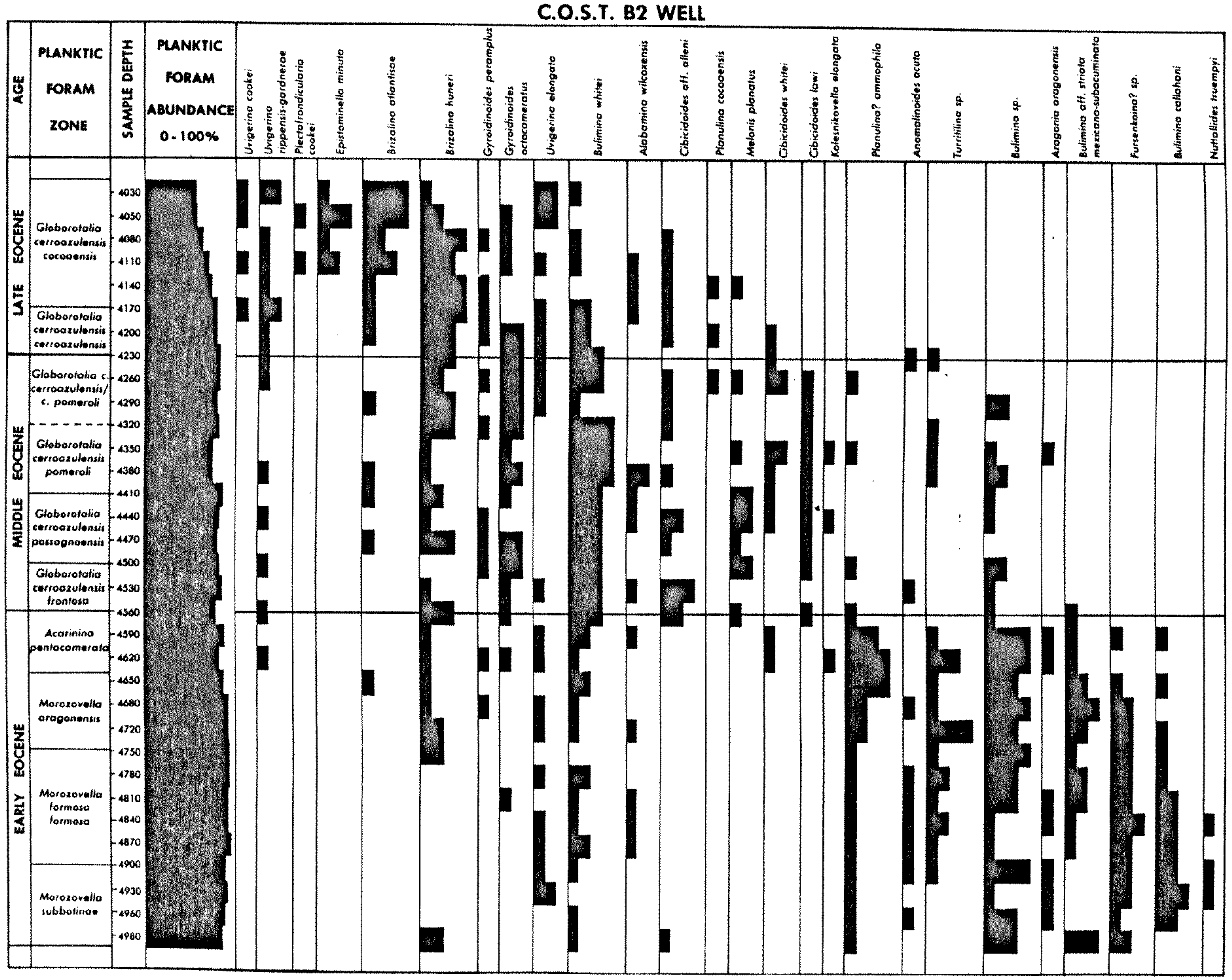


FIGURE 12

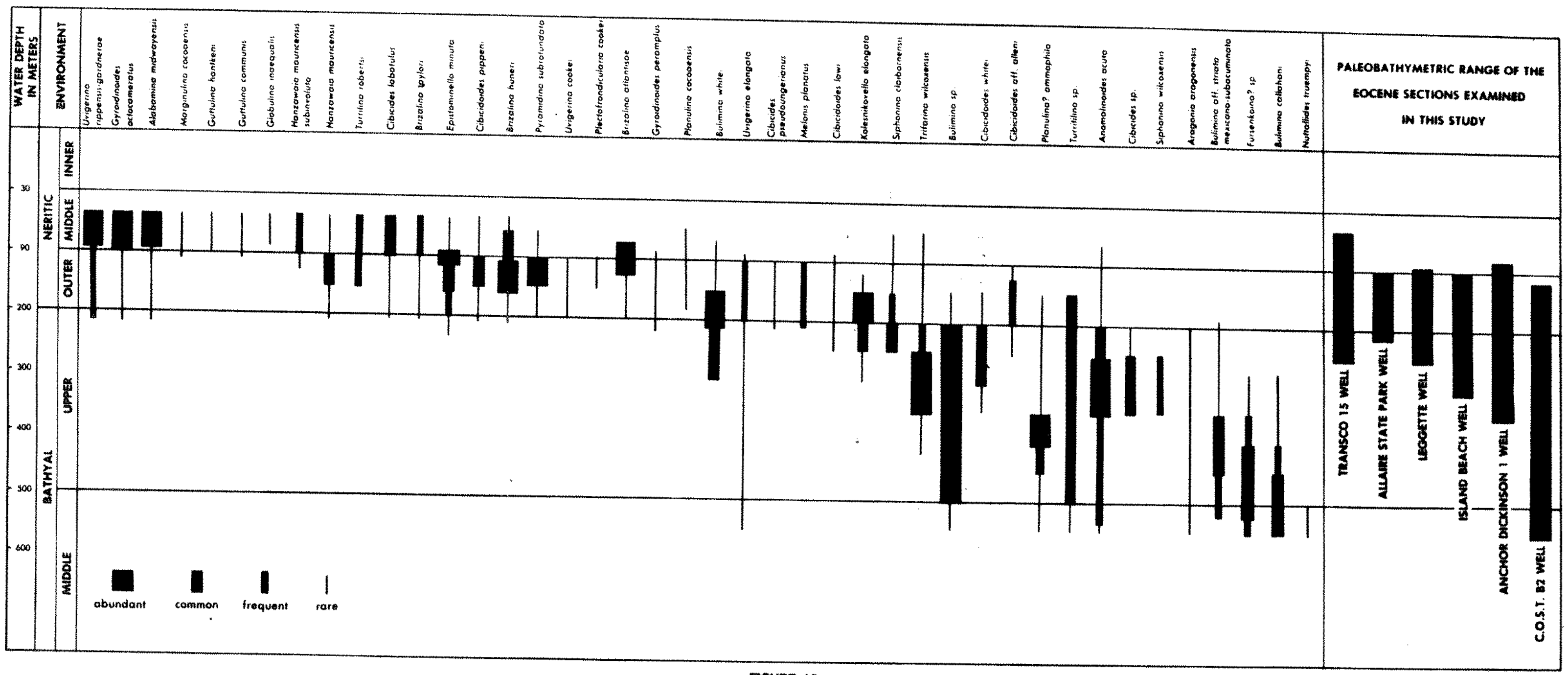

WATER DEPTH IN METERS
ENVIRONMENT
NERITIC
INNER
MIDDLE
OUTER
BATHYAL
UPPER
MIDDLE
30
90
200
300
400
500
600
Uvigerina rippensis-gardnerae
Gyroidinoides octocameratus
Alabamina midwayensis
Marginulina cocoaensis
Guttulina hantkeni
Guttulina communis
Globulina inaequalis
Hanzawaia mauricensis subinvoluta
Hanzawaia mauricensis
Turrilina robertsi
Cibicides lobatulus
Brizalina tyylori
Epistominella minuta
Cibicidoides pippeni
Brizalina huneri
Pyramidina subrotundata
Uvigerina cookei
Plectofrondicularia cookei
Brizalina atlantisae
Gyroidinoides perampius
Planulina cocoaensis
Bulimina whitei
Uvigerina elongata
Cibicides pseudoungerianus
Melonis planatus
Cibicidoides lowi
Kolesnikovella elongata
Siphonina claibornensis
Trifarina wilcoxensis
Bulimina sp.
Cibicidoides whitei
Cibicidoides aff. alleni
Planulina? ammophila
Turrilina sp.
Anomalinoides acuta
Cibicides sp.
Siphonina wilcoxensis
Aragonia aragonensis
Bulimina aff. striata mexicana-subacuminata
Fursenkoina? sp.
Bulimina collahani
Nuttallides truempyi
PALEOBATHYMETRIC RANGE OF THE EOCENE SECTIONS EXAMINED IN THIS STUDY
TRANSCO 15 WELL
ALLAIRE STATE PARK WELL
LEGGETTE WELL
ISLAND BEACH WELL
ANCHOR DICKINSON 1 WELL
C.O.S.T. B2 WELL
abundant
common
frequent
rare

FIGURE 13

TABLE 1

EOCENE SPECIES	RECENT ANALOGY	BATHYMETRIC RANGE	REFERENCE
Globulina inaequalis	*Globulina*	0 - 60 meters	Murray, 1973
Hanzawaia	*Hanzawaia*		Bandy, 1960
	sharp edge	inner-outer shelf	Pflum and Frerichs, 1976
	simple interior		Walton, 1964
Hanzawaia mauricensis subinvoluta	*Hanzawaia strattoni*	inner-middle shelf	
Hanzawaia mauricensis	*Hanzawaia concentrica*	middle-outer shelf	
Brizalina	*Bolivina*		Bandy, 1960
Brizalina taylori	small, smooth	inner-middle shelf	
Brizalina atlantisae			
Brazalina huneri	small, striate	middle-outer shelf	

TABLE 1 (continued)

EOCENE SPECIES	RECENT ANALOGY	BATHYMETRIC RANGE	REFERENCES
Epistominella	Epistominella		Bandy, 1960
	small, rounded edge	middle shelf-bathyal	
Epistominella minuta	Epistominella vitrea	most frequent	Parker, 1954
		50 - 150 meters	Walton, 1964
Cibicides lobatulus	same	most frequent	Phleger, 1960
		less than 60 - 75 meters	Murray, 1973
		less than 100 meters	
Planulina	Planulina		Bandy, 1960
Planulina cocoaensis	coarsely perforate	middle-outer shelf	
	raised limbate sutures		

TABLE 1 (continued)

EOCENE SPECIES	RECENT ANALOGY	BATHYMETRIC RANGE	REFERENCES
Planulina? *ammophila*	raised irregular sutures	outer shelf-upper bathyal	Bandy, 1960
Cibicidoides lawi, aff. *alleni*, *pippeni*, *whitei*	*Cibicides* thick test sutures curved	middle shelf-upper bathyal	Bandy, 1960
Cibicides pseudoungerianus	same	middle shelf-bathyal	Pflum and Frerichs, 1976
Uvigerina elongata	*Uvigerina laevis*	greater than 90 meters most frequent 90 - 400 meters	Parker, 1954 Phleger, 1956, 1960

TABLE 1 (continued)

EOCENE SPECIES	RECENT ANALOGY	BATHYMETRIC RANGE	REFERENCES
Siphonina Claibornensis	Siphonina pulchra	30 - 500 meters most frequent 100 - 200 meters	Parker, 1954
Bulimina Bulimina sp.	Bulimina small, unornamented	outer shelf-upper bathyal	Bandy, 1960
Trifarina wilcoxensis	Trifarina bradyi	30 - 900 meters most frequent 250 - 700 meters	Phleger and Parker, 1951 Parker, 1954

TABLE 1 (continued)

EOCENE SPECIES	RECENT ANALOGY	BATHYMETRIC RANGE	REFERENCE
Bulimina striata mexicana-subacuminata	same	upper-middle bathyal	Parker, 1954
		most frequent	Bandy, 1960
		200 - 700 meters	Pflum and Frerichs, 1976

than 1000 meters (Laughton, et al., 1972), and it's absence in neritic faunas suggests an upper bathymetric limit of 500 to 600 meters (Berggren and Aubert, 1980). The stratigraphically limited, and rare occurrence of Nuttallides truempyi in the Lower Eocene of the C.O.S.T. B-2 Well (fig. 12) therefore suggests a maximum paleodepth of approximately 500 to 600 meters for the Eocene bathyal assemblages of New Jersey. The common occurrence of the costate-spinose buliminid, of the Bulimina aff. striata mexicana-subacuminata group (fig. 12), is indicative of middle to upper bathyal environments (Pflum and Frerichs, 1976; Bandy and Chierici, 1966; Parker, 1954). The small test size (less than 0.5 mm) of this buliminid suggests the shallower portion of the bathymetric range (upper bathyal) of it's modern homeomorphs (Bandy, 1960), and supports the interpretation of a paleodepth of 200 to 600 meters for these assemblages.

Modern costate uvigerinids commonly occur in outer neritic and bathyal environments (Bandy, 1960; Pflum and Frerichs, 1976; and others). Uvigerina rippensis-gardnerae, a small (less than 0.5 mm) highly variable costate to costate-spinose form is an abundant component in the Middle Eocene of the Transco 15 Well (fig. 9). The co-occurrence of Uvigerina rippensis-gardnerae with that of demonstrably shallower water forms (Cibicides lobatulus, Globulina inaequalis, Hanzawaia mauricensis subinvoluta), the local termination of outer shelf species (Uvigerina elongata, Cibicidoides lawi, Cibicides pseudoungerianus, Melonis planatus) below this interval, the low planktic foraminiferal abundance (less than 5%), and the predominance of juvenile planktic foraminifera suggests a paleodepth of less than 100 meters. In Eocene deposits of Northeastern Libya *Uvigerina rippensis-gardnerae* commonly occurs in paleodepths interpreted as 50 to 200 meters (Barr and Berggren, 1980). Therefore, it would seem that costate uvigerinids had a significantly shallower depth range, at least prior to the Oligocene, and should be used with caution as outer shelf and bathyal paleoenvironmental indicators.

Cluster analysis allows the reduction of large amounts of data into meaningful patterns, and is here used to determine individual assemblages within the neritic and upper bathyal assemblages discussed above. The downward displacement of species within rotary wells is a problem in attempting to delineate natural groupings, and the use of presence-absence data alone has little meaning; more meaningful patterns can be obtained by the incorporation of relative abundance data. The Q-mode type cluster analysis, which relates sample intervals to each other on the basis of species in common, is used in this study. Calculations were performed using the Q-mode clustering routines of the NT-SYS (1974 version) system. The correlation coefficient was used as a similarity measure.

Eleven distinct groupings are recognized from the Q-mode dendogram (fig. 14). The biofacies discussed below are transitional to one another, and the paleodepths cited represent the principle range of these biofacies. Figure 15 illustrates the distribution of these biofacies in the Eocene section of the New Jersey continental margin.

Group 1 is the shallowest biofacies recognized, and is characterized by *Uvigerina rippensis-gardnerae*, *Gyroidinoides octocameratus*, and *Alabamina midwayensis*. Other species characteristic of this group include *Marginulina cocoaensis*, *Guttulina hantkeni*, *Guttulina communis*, *Globulina inaequalis*, *Hanzawaia mauricensis subinvoluta*, *Turrilina robertsi*, and *Cibicides lobatulus*. Comparison of this assemblage with that of recent homeomorphs and general correlation of form, structure and environment (Table 1) suggests a paleodepth of 50 to 100 meters. The absence of the outer shelf forms *Uvigerina elongata*, *Melonis planatus* *Cibicides pseudoungerianus*, *Cibicidoides lawi*, the low planktic foraminiferal abundance (less than 5%) and the predominance of planktic juvenile forms supports this interpretation. Since the species *Alabamina* and *Gyroidinoides* have no living counterparts, direct comparison to modern distributional trends are impossible. *Gyroidinoides octocameratus* and *Alabamina midwayensis*, though, have been shown to be characteristic of paleodepths of less than 100 meters in Paleocene deposits of the Gulf and Atlantic coasts, and Rockall Bank (Berggren, 1974; Youssefnia, 1974, 1978).

Groups 3, 4, and 11 are dominated by *Pyramidina subrotundata*, *Epistominella minuta*, and small brizalinids, respectively. Groups 2, 7, and 10 are dominated by *Bulimina whitei*, *Turritilina sp*., and *Kolesnikovella elongata*. Other species characteristic of these groups include *Hanzawaia mauricensis*, *Cibicidoides* aff. *alleni*, *Cibicidoides lawi*, *Cibicidoides pippeni*, *Cibicides pseudoungerianus*, *Uvigerina*, *cookei*, *Uvigerina elongata*, *Melonis planatus*, and *Planulina* cocoaensis. Comparison of Groups 2, 3, 4, 7, 10, and 11 to that of the distribution of recent homeomorphs (Table 1) indicates a paleodepth of 90 to 200 meters. The high abundance of Epistominella minuta and small brizalinids suggests a paleodepth of 90 to 150 meters for Groups 3, 4, and 11. The decrease in abundance of these forms, and the increase in abundance of small buliminids suggests a paleodepth of 150 to 200 meters for Groups 2, 7, and 10.

Groups 5 and 8 are dominated by Anomalinoides acuta, Bulimina sp., Turritilina sp., and Trifarina wilcoxensis. Other species characteristic of these groups include Siphonina claibornensis, Siphonina wilcoxensis, Cibicides sp., Cibicidoides whitei, and Aragonia aragonensis. The high abundance of Bulimina sp., a small (less than 0.5 mm) unornamented form, and Trifarina wilcoxensis suggests a paleodepth of 200 to 600 meters (Table 1). Siphonina calaibornensis and S. wilcoxensis reach their maximum abundance within this assemblage, though modern forms of Siphonina are most common in depths ranging from 100 to 200 meters. The absence of the deeper water forms Bulimina callahani, and Nuttallides truempyi, and the minor occurrence of Fursenkoina? sp. and Bulimina striata mexicana-subacuminata, which are common to Group 9, suggests the shallower portion of this bathymetric range (200 to 350 meters).

Group 9 is the deepest biofacies recognized, and is dominated by Bulimina sp., Bulimina striata mexicana-subacuminata, Bulimina callahani, Fursenkoina? sp., Turritilina, sp., and Planulina? ammophila. Other species characteristic of this group include Aragonia aragonensis, Anomalinoides acuta, and Nuttallides truempyi. The absence and/or significant decrease in abundance of neritic forms (fig. 13), the increase in abundance of Bulimina striata mexicana-subacuminata, and the occurrence of the bathyal-abyssal forms Bulimina callahani, and Nuttallides truempyi suggests a paleodepth of 350 to 600 meters for Group 9.

Group 6 is nearly the same as Group 9 except for the high abundance of a small cibicidid not distinquished in this study.

Figure 14 Dendogram illustrating Q-mode clusters based on percentage data of well samples.

A = Allaire State Park Well; IB = Island Beach Well; T = Transco 15 Well; L = Leggette Well; AD = Anchor Dickinson I Well; B = C.O.S.T. B-2 Well.

Figure 15 Distribution of cluster groupings (Figure 14) in the Eocene section of New Jersey.

A - Group 1; B - Groups 2, 3, 4, 7, 10 and 11; C - Groups 5 and 8; D - Groups 6 and 9.

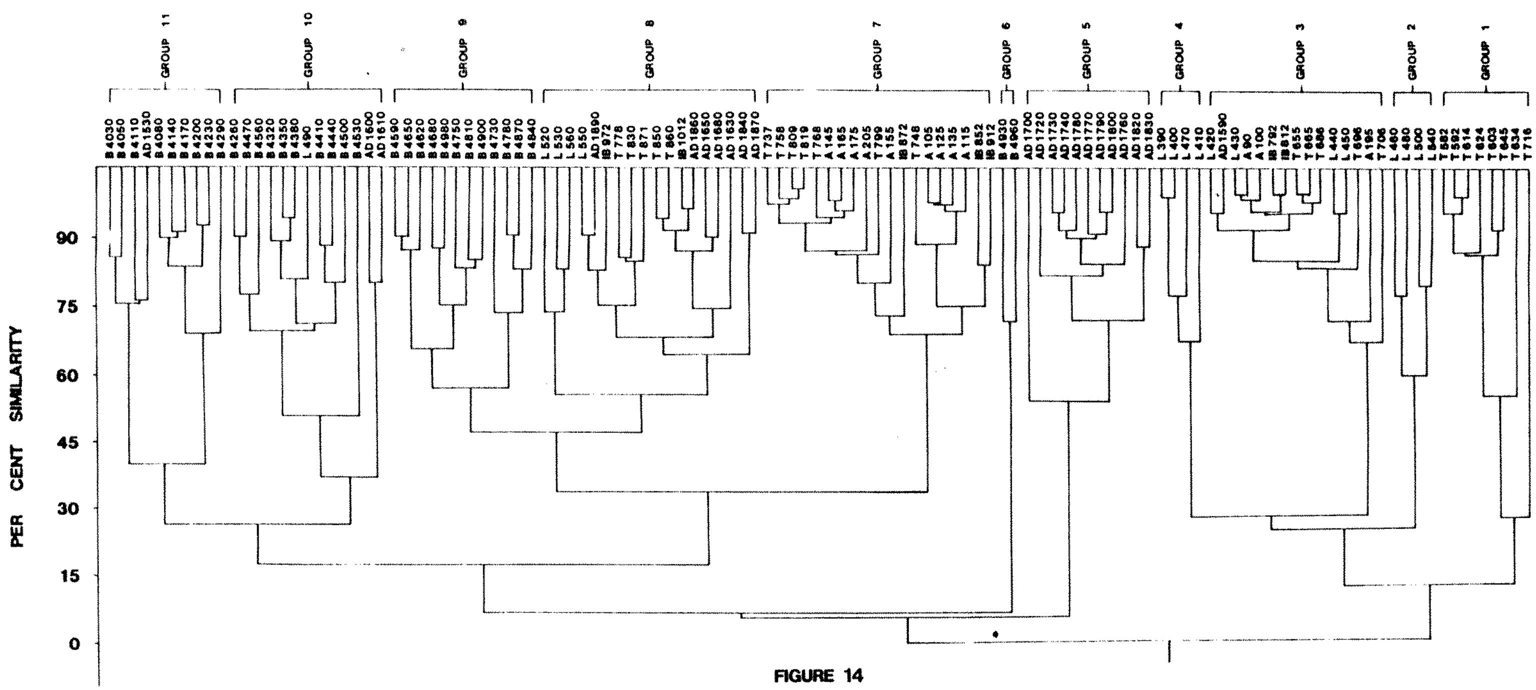

GROUP 11
GROUP 10
GROUP 9
GROUP 8
GROUP 7
GROUP 6
GROUP 5
GROUP 4
GROUP 3
GROUP 2
GROUP 1
B4030 B4050 B4110 AD1530 B4080 B4140 B4170 B4200 B4230 B4290
B4260 B4470 B4560 B4320 B4350 B4380 L 490 B4410 B4440 B4500 B4530 AD1600 AD1610
B4590 B4650 B4620 B4680 B4980 B4750 B4810 B4900 B4730 B4780 B4870 B4840
L 520 L 530 L 560 L 550 AD1890 IB972 T 778 T 830 T 871 T 850 T 860 IB1012 AD1860 AD1650 AD1680 AD1630 AD1840 AD1870
T 737 T 758 T 809 T 819 T 768 A 145 A 165 A 175 A 205 T 799 A 155 IB872 T 748 A 105 A 125 A 135 A 115 IB852 IB912
B4930 B4960
AD1700 AD1720 AD1730 AD1740 AD1780 AD1770 AD1790 AD1800 AD1760 AD1820 AD1830
L 390 L 400 L 470 L 410
L 420 AD1590 L 430 A 90 A 100 IB792 IB812 T 655 T 665 T 686 L 440 L 450 T 696 A 195 T 706
L 460 L 480 L 500 L 540
T 582 T 592 T 614 T 624 T 603 T 645 T 634 T 716
PER CENT SIMILARITY
90
75
60
45
30
15
0

FIGURE 14

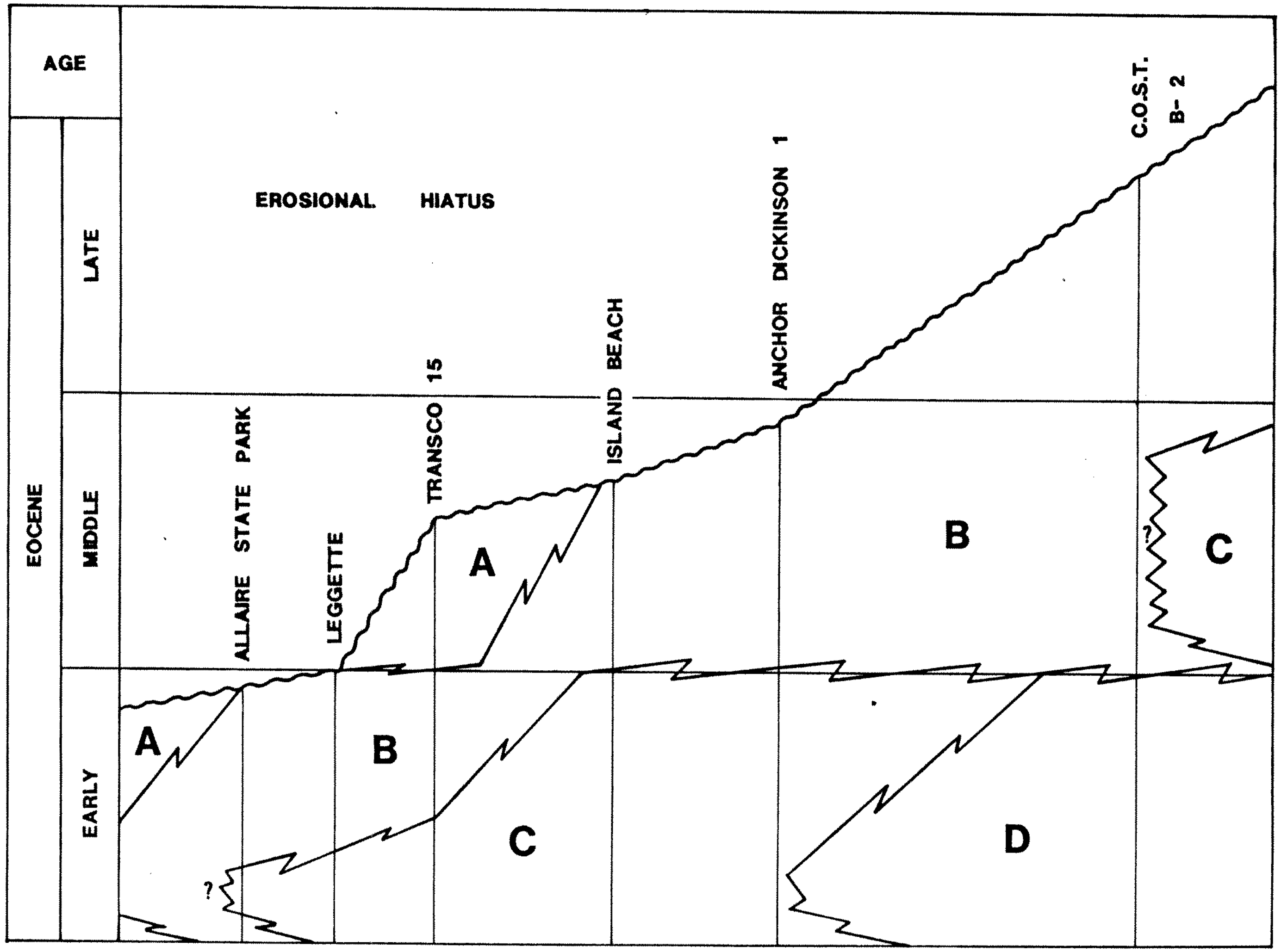

AGE
EOCENE
LATE
MIDDLE
EARLY
EROSIONAL HIATUS
ALLAIRE STATE PARK
LEGGETTE
TRANSCO 15
ISLAND BEACH
ANCHOR DICKINSON 1
C.O.S.T. B- 2
A
B
C
D
?

FIGURE 15

SPECIES DIVERSITY AND DOMINANCE TRENDS

Benthic foraminifera species diversity tends to change with increasing depth of water and distance from shore, and is useful in determining relative paleobathymetry. Diversity trends of Recent benthic foraminifera show an increase in species numbers from the shoreline to the outer continental shelf, and either decrease or remain the same on the continental slope (Bandy and Arnal, 1957; Walton, 1964; Buzas and Gibson, 1969 and others).

A useful diversity index, the Fisher alpha index (Murray, 1973), can be readily determined by plotting the number of species against the total number of individuals. This index takes into account the rarer species of a population, and variation in sample size. The Fisher alpha index is used here to characterize the diversity trends of the eleven distinct groupings of benthic foraminifera of the Eocene section of New Jersey. Diversity trends of fossil foraminiferal assemblages are easily determined, but can be influenced by downward mixing of foraminifera within rotary wells, and selective preservation. Therefore, core samples were used wherever possible, and poorly preserved samples were not used in determining diversity and dominance values.

Figure 16 illustrates the diversity (FISHER ALPHA INDEX) and dominance (% DOMINANCE) trends of the Eocene benthic foraminifera cluster groupings, their associated paleodepths, and recent benthic foraminiferal diversity (S) and dominance ($E^{H(S)}/S$) trends of the western North Atlantic (Buzas and Gibson, 1969). Eocene species diversity trends of New Jersey compare well to that of the western

North Atlantic and support the paleobathymetric interpretations of the Eocene cluster groupings of this study. These trends include:

- an increase in diversity from shoreline to the outer continental shelf (Groups 1, 3, 4, and 11).

- a peak in diversity between 100 and 200 meters (Groups 2, 3,4, 7, 10, and 11).

- and a decrease in diversity across the shelf-slope boundary (Groups 2, 5, 7, 8, and 10).

Below 200 meters, in the western North Atlantic, diversity values decrease down the continental slope, whereas Eocene diversity values for groups 6 and 9 show an increase. Group 9 is divided into two subgroups to better illustrate the diversity-dominance trends with increasing water depth. Since rotary well samples were used in the determination of diversity values for groups 6 and 9, the increase in diversity may represent downward mixing of foraminifera, and not an ecological trend.

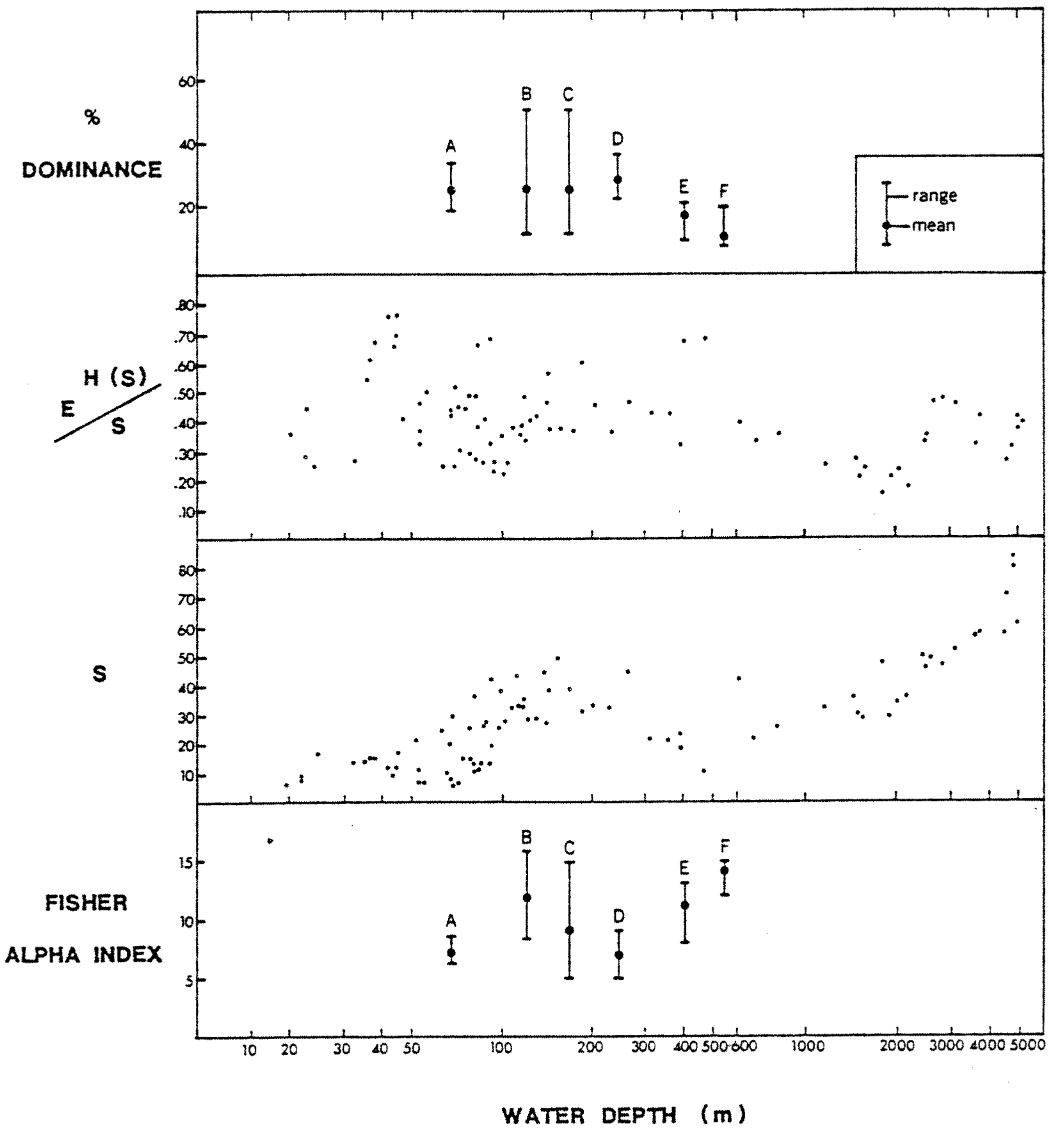
Species diversity and dominance patterns have been suggested to be related to the degree of environmental stability (Valentine, 1971, 1972; Johnson, 1972; and others). In unstable environments only a few generalized populations can be supported, and are characterized by low species diversity and high dominance. Conversely, benthic marine communities of stable environments are characterized by high species diversity and low dominance. The low species diversity of the Eocene middle shelf assemblage (Group 1) can be explained by the instability of nearshore environments. The higher diversity values on the outer continental shelf and continental slope indicate a relative increase in stability for these environments.

Faunal dominance is defined as the percentage occurrence of the most common species in a foraminiferal population, and is inversely proportional to diversity (Walton, 1964). Faunal dominance values in the western North Atlantic, represented by species equitability ($E^{H(S)}/S$), have a large distributional range in most environments. Eocene mean dominance values (% DOMINANCE) remain relatively the same across the continental shelf and show little relationship to changes in diversity. On the continental slope Eocene dominance values (Groups 6 and 9) steadily decrease with increasing depth of water and diversity. This decrease in dominance, though, may be due to downward mixing of foraminifera in rotary well samples, and not an ecological trend. The consistently high dominance values across the Eocene continental shelf, and seemingly little relationship to changes in diversity suggests that modern environmental stability models may not be applicable to dominance trends during Eocene time.

Figure 16 Comparison of diversity (Fisher Alpha Index) and dominance values (% dominance) of the Eocene benthic foraminifera cluster groupings, and recent benthic foraminiferal diversity (S) and dominance ($E^{H(S)}/S$; 1.0 = low dominance, 0.1 = high dominance) trends of the western North Atlantic.

A = Group 1; B = Groups 3, 4, 11; C = Groups 2, 7, 10; D = Groups 5 and 8; E = Group 9; F = Groups 6 and 9.

FIGURE 16



%
DOMINANCE
60
40
20
A
B
C
D
E
F
range
mean
E H(S)/S
.80
.70
.60
.50
.40
.30
.20
.10
S
80
70
60
50
40
30
20
10
FISHER
ALPHA INDEX
15
10
5
10
20
30
40
50
100
200
300
400
500
600
1000
2000
3000
4000
5000
WATER DEPTH (m)

PALEOBATHYMETRIC HISTORY

Figure 17 illustrates the relative paleobathymetric history of the six wells examined in this study. Variations in relative fall of sea level during Early Eocene time are seen throughout the Lower Eocene sections of New Jersey. In the C.O.S.T. B-2 Well, during Early Eocene deposition, a fall in sea level of approximately 300 to 400 meters is indicated, whereas over the South Jersey High (Transco 15 Well) a fall in sea level of approximately 150 meters is indicated. These variations in Early Eocene sea level fall, which increase in magnitude in the downdip direction, suggest greater crustal rebound seaward of the main hinge zone of sediment accumulation as sea level retreated across the New Jersey continental margin. Shallow updip wells landward of the main hinge zone of sediment accumulation seem to have been least affected by uplift of the continental margin, and suggest a eustatic sea level change of approximately 100 to 200 meters.

The neritic benthic foraminiferal biofacies of Lower and Middle Eocene sediments of the New Jersey coastal plain are also recognized downdip in Middle and Late Eocene sediments of the C.O.S.T. B-2 Well. This downdip time transgressive pattern, and upwell transition from deeper to shallower water forms is typical of a regressive sequence, and a similar downdip to updip pattern is typical of a transgressive sequence. Based on these distributional patterns (figs. 7-12) the following bathymetric history emerges for the Eocene section of the New Jersey continental margin (fig. 17).

1. A rapid rise in sea level, beginning in the Early Eocene, and reaching it's maximum stand within the <u>Morozovella</u> <u>subbotinae</u>

and *M. formosa formosa* zones, is indicated by the upwell transition from shallower to deeper water forms, and increase in planktic foraminiferal abundance (figs. 7-12).

2. A gradual upward shoaling, beginning in the *Morozovella formosa formosa* Zone, is indicated by the sequential replacement of deeper to shallower water forms, and the decrease in planktic foraminiferal abundance (figs. 7-12).

3. Near the Early-Middle Eocene boundary an abrupt shoaling is indicated by the local termination and significant decrease in abundance of deeper water forms, their replacement by demonstrably shallower water forms, and the significant decrease in planktic foraminiferal abundance (figs. 9-12).

4. During Middle Eocene time bathymetric conditions remained relatively the same, with a slight increase in bathymetry occurring within the *Globorotalia cerroazulensis pomeroli* and *Globorotalia cerroazulensis cerroazulensis*/ *G. c. pomeroli* zones. This is indicated by the relative stability of the benthic foraminiferal assemblages, and planktic foraminiferal abundance (figs. 9-12).

5. A gradual upward shoaling beginning in the uppermost Middle Eocene (C.O.S.T. B-2 Well), and continuing through the Upper Eocene (fig. 12), is indicated by the termination of deeper water forms, their replacement by demonstrably shallower forms, and the decrease in planktic foraminiferal abundance.

6. Analysis of Oligocene deposits of the New Jersey continental margin indicates a major fall in sea level, probably occurring near the end of Eocene time, and resulting in the erosion of Late Eocene

sediments (Olsson, 1978; Olsson and Miller, 1979; Olsson, Miller, Ungrady, 1980).

Based on seismic stratigraphic studies, Vail et al. (1977) have delineated a series of global cycles of relative sea level change for the Cenozoic (fig. 18). These cycles are characterized by an asymmetry in which a gradual rise in sea level is followed by an abrupt fall. Evidence from this study, and Olsson and Miller (1979) suggests a somewhat different pattern of sea level change for Eocene and Oligocene time (fig. 18).

The relative negative and positive effects of structural elements (Salisbury Embayment, South Jersey High) suggested by the distribution fo sedimentary facies landward of the main hinge zone of sediment accumulation, is also suggested by the distribution of Eocene benthic foraminiferal biofacies. Figures 19 and 20 illustrate the general paleobathymetric trends of the New Jersey continental margin during Early Eocene maximum sea level stand, and Middle Eocene time, respectively. Early Eocene benthic foraminiferal assemblages of the Transco 15 and Leggette wells indicate a paleodepth of approximately 200 to 300 meters. The Leggette Well, being updip from the Transco 15 Well, and of approximately equal paleobathymetry indicates a pronounced deepening toward the Salisbury Embayment. Analysis of the benthic foraminiferal assemblages in Eocene sediments of the Allaire State Park Well indicates no negative paleobathymetric effect of the Raritan Embayment during Eocene time.

A profile of Early Eocene paleodepths of the Transco 15, Island Beach, and C.O.S.T. B-2 wells indicates a bathyal paleoslope of approximately 2m/km (fig. 19). Similarly, Middle Eocene paleodepths indicate a shelf paleoslope of approximately 1m/km (fig. 20). These paleoslopes indicate a much more gradual profile for the New Jersey continental margin, during Eocene time, in contrast to the present day margin profile.

Figure 17 Relative paleobathymetric history of the Eocene sections examined in this study.

Figure 18 Comparison of Eocene global cycles of relative sea level change (Vail et al., 1977), and the relative sea level changes on the New Jersey continental margin during Eocene time.

Figures 19,20 General paleobathymetry of the New Jersey continental margin during Early Eocene maximum sea level stand, and Middle Eocene time.

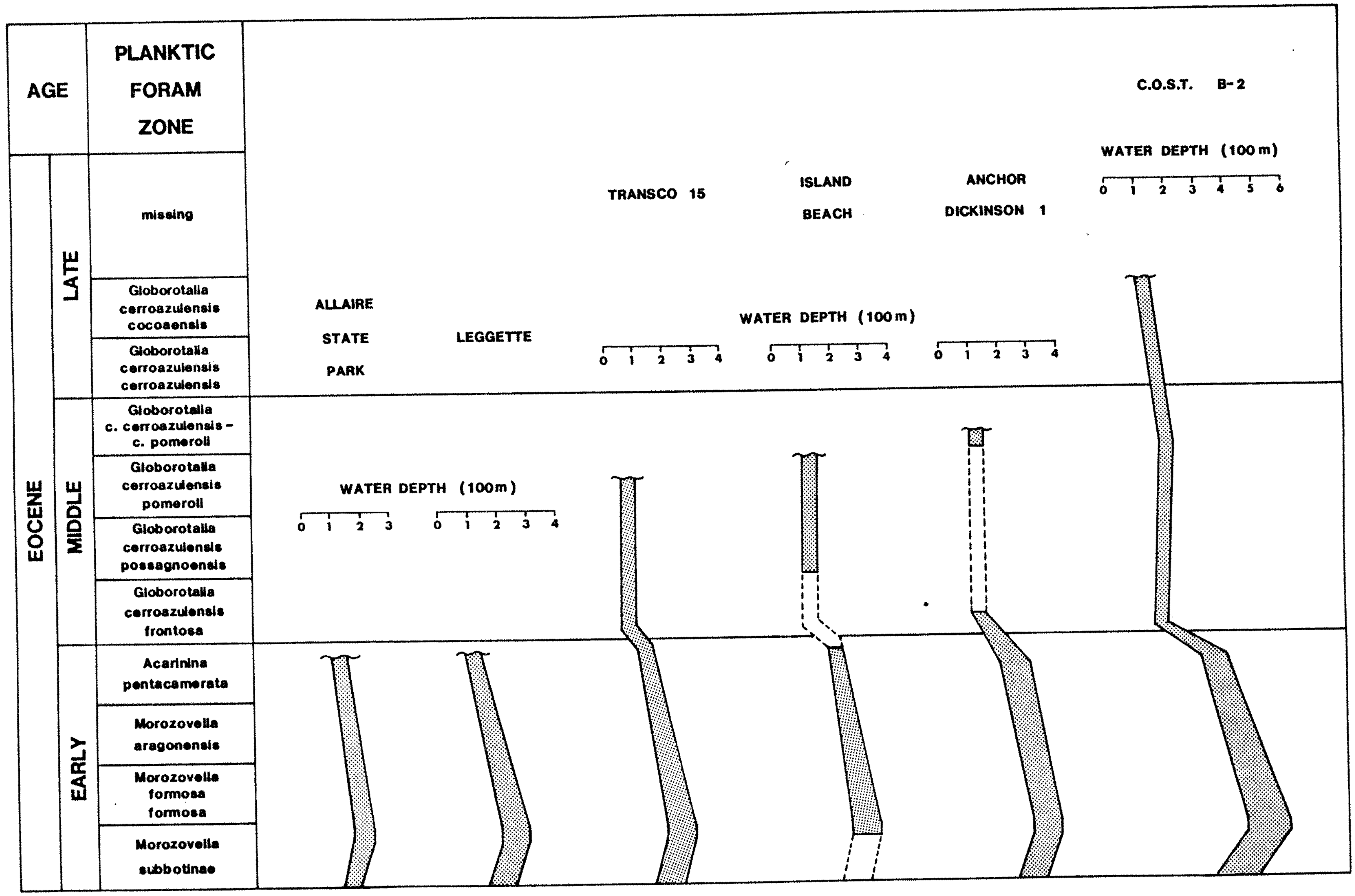

AGE
PLANKTIC FORAM ZONE
EOCENE
LATE
MIDDLE
EARLY
missing
Globorotalia cerroazulensis cocoaensis
Globorotalia cerroazulensis cerroazulensis
Globorotalia c. cerroazulensis - c. pomeroli
Globorotalia cerroazulensis pomeroli
Globorotalia cerroazulensis possagnoensis
Globorotalia cerroazulensis frontosa
Acarinina pentacamerata
Morozovella aragonensis
Morozovella formosa formosa
Morozovella subbotinae
ALLAIRE STATE PARK
LEGGETTE
TRANSCO 15
ISLAND BEACH
ANCHOR DICKINSON 1
C.O.S.T. B-2
WATER DEPTH (100 m)
0 1 2 3
0 1 2 3 4
0 1 2 3 4 5 6

FIGURE 17

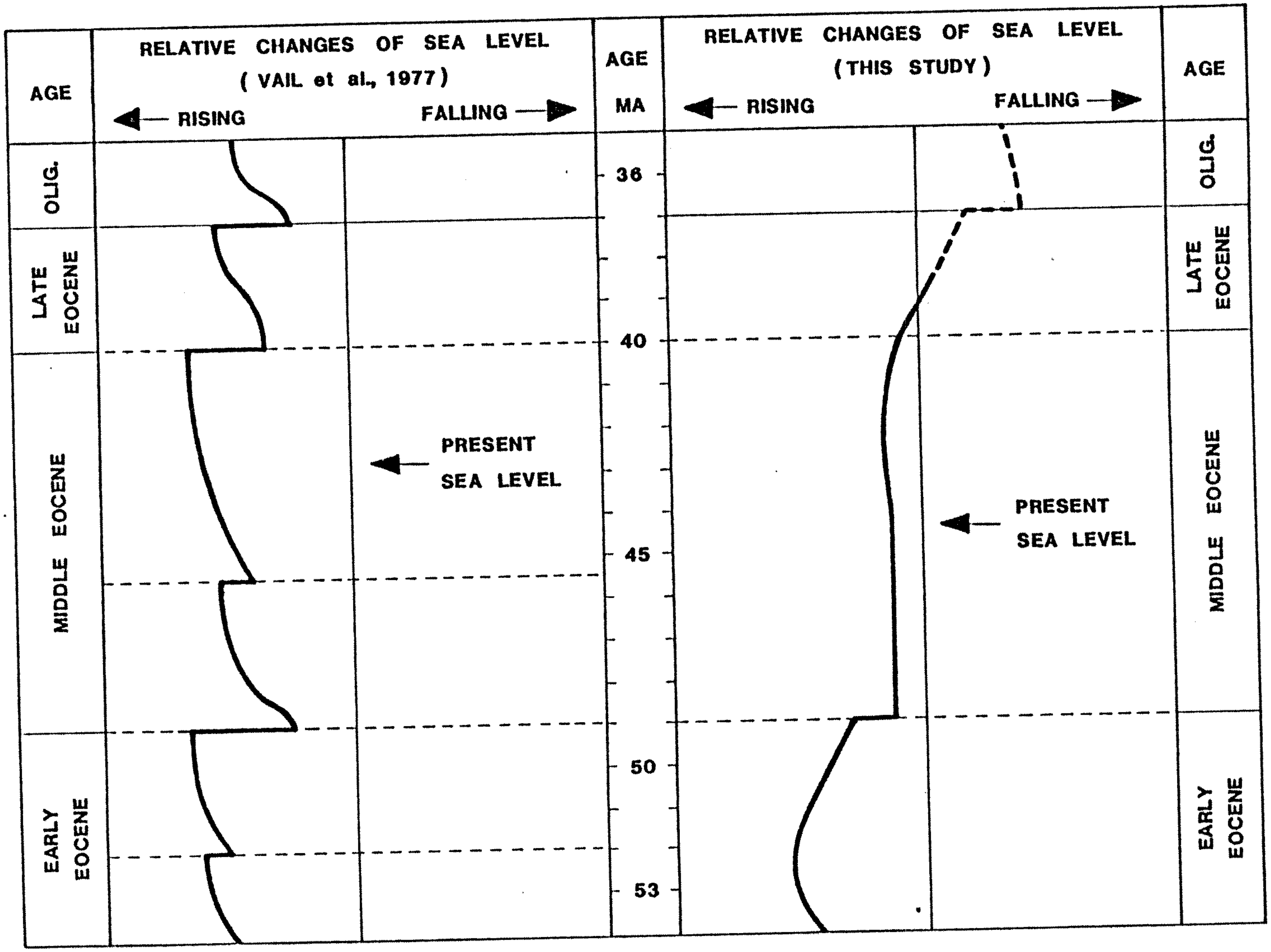
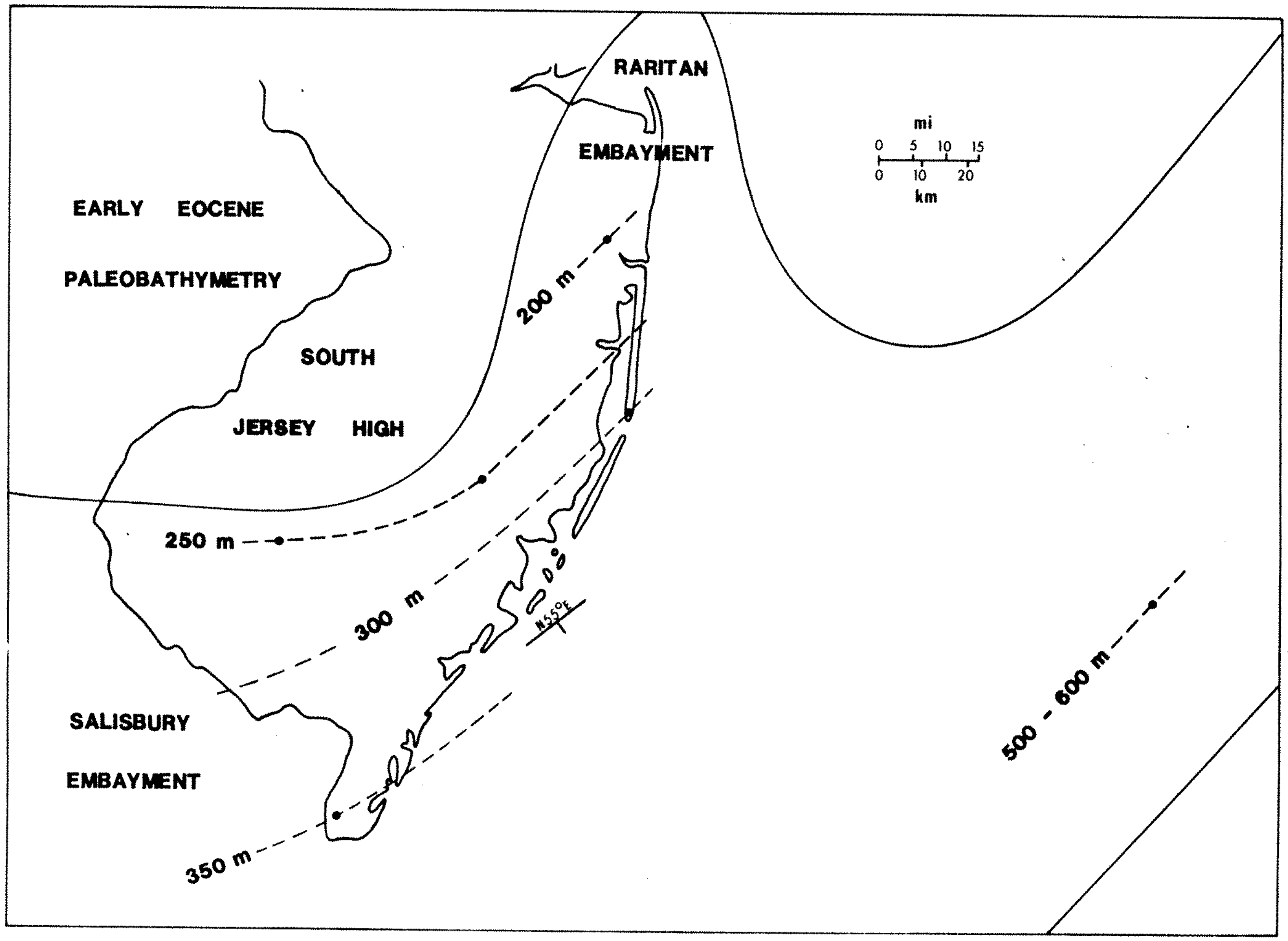

AGE
RELATIVE CHANGES OF SEA LEVEL
(VAIL et al., 1977)
RISING
FALLING
AGE
MA
RELATIVE CHANGES OF SEA LEVEL
(THIS STUDY)
RISING
FALLING
AGE
OLIG.
LATE EOCENE
MIDDLE EOCENE
EARLY EOCENE
36
40
45
50
53
PRESENT SEA LEVEL
PRESENT SEA LEVEL
OLIG.
LATE EOCENE
MIDDLE EOCENE
EARLY EOCENE

FIGURE 18



EARLY EOCENE
PALEOBATHYMETRY
SOUTH
JERSEY HIGH
RARITAN
EMBAYMENT
SALISBURY
EMBAYMENT
mi
0 5 10 15
0 10 20
km
200 m
250 m
300 m
350 m
500 - 600 m
N55°E

FIGURE 19

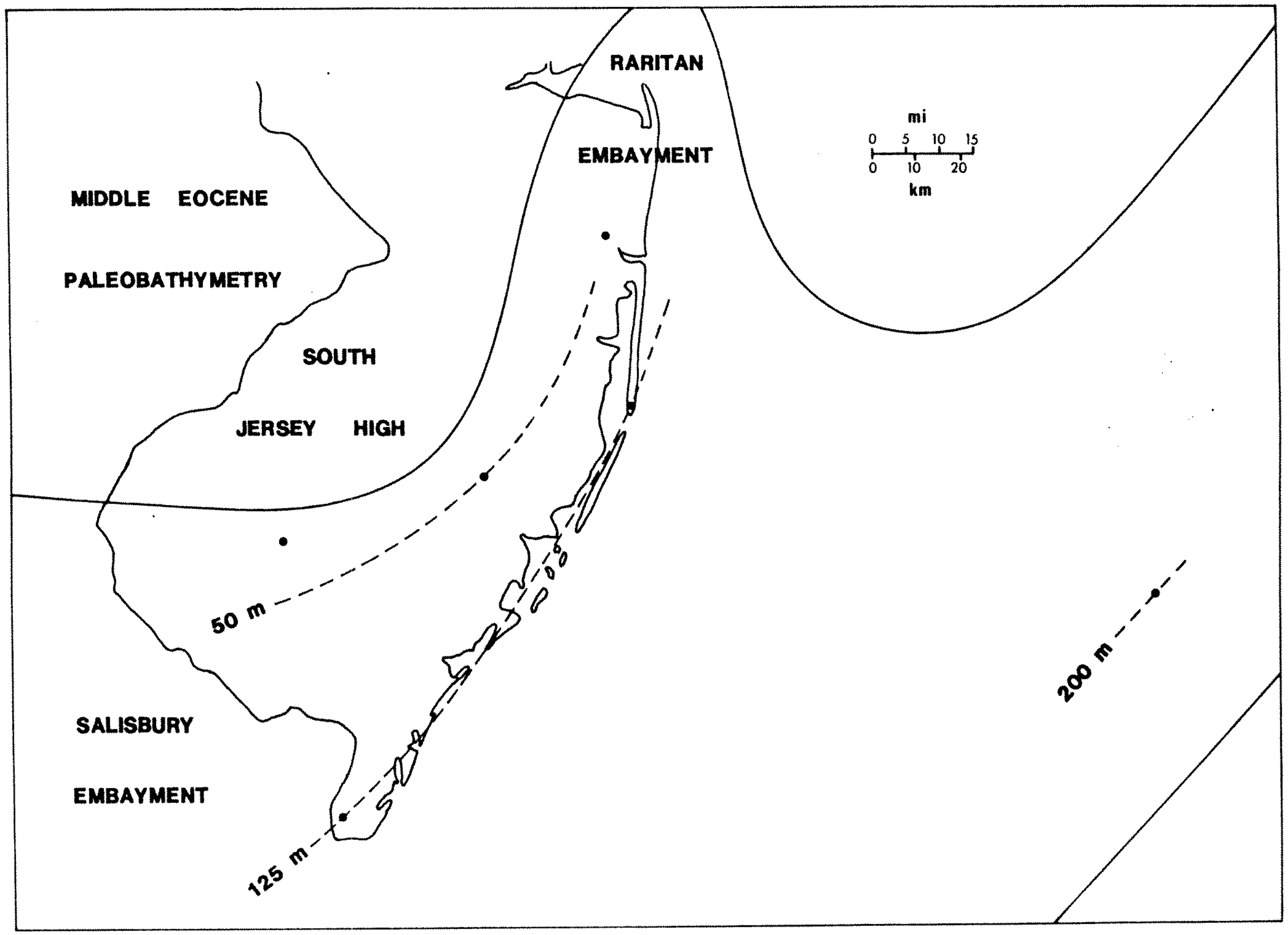

MIDDLE EOCENE
PALEOBATHYMETRY
RARITAN
EMBAYMENT
SOUTH
JERSEY HIGH
SALISBURY
EMBAYMENT
mi
0 5 10 15
0 10 20
km
50 m
125 m
200 m

FIGURE 20

SUMMARY

Benthic foraminifera of the Eocene section of the New Jersey continental margin cluster into eleven distinct biofacies. Comparison of these biofacies to that of recent benthic foraminifera distributional patterns indicates paleodepths to have ranged from less than 100 meters on the New Jersey coastal plain to approximately 500 to 600 meters in the C.O.S.T. B-2 Well.

Eocene species diversity trends are similar to those of modern continental shelf and upper slope environments, and support the paleobathymetric interpretations of the benthic foraminiferal biofacies.

The upwell transition from deeper to shallower water biofacies is seen throughout the continental margin, and is indicative of a transgressive-regressive sequence. After sea level reached a maximum stand in the lowermost Early Eocene a gradual upward shoaling followed, which culminated with an abrupt shoaling near the Early-Middle Eocene boundary. Thereafter, bathymetric conditions remained relatively stable throughout most of the Middle Eocene with a gradual upward shoaling beginning in the uppermost Middle Eocene, and ending with a major fall in sea level near the end of Eocene time.

The effect of structural elements landward of the main hinge zone of sediment accumulation is indicated by the distribution of sedimentary facies, and benthic foraminiferal faunas. Paleobathymetric trends of the New Jersey coastal plain show a pronounced deepening toward the Salisbury Embayment. To the north the distribution of benthic foraminifera shows no effect of the Raritan Embayment, though sedimentary facies changes between the Raritan Embayment and South Jersey High suggest some influence.

TAXONOMIC NOTES

A brief discussion is presented of the taxonomy and distribution of characteristic species of Eocene neritic and upper bathyal environments of the New Jersey Continental margin.

MIDDLE SHELF - 50 TO 100 METERS

Uvigerina rippensis Cole, 1927 - *Uvigerina gardnerae* Chushman, 1926 species group

Plate 1, figures 1-4

Uvigerina rippensis Cole, 1927, Bull. Am. Pal., vol. 14, no. 51, p. 27, pl. 2, fig. 16.

Uvigerina gardnerae Cushman, 1926, Bull. Amer. Assoc. Petr. Geol., vol. 10, p. 175, pl. 8, figs. 16, 17.

Remarks - This species group is highly variable morphologically. Specimens range in size from 0.2 to 0.4 mm in length, and vary in form from short to broad, to elongate and narrow. Ornamentation varies from costate to fine striae. The costate are discontinuous and tend to break up into spines on the last formed chamber. The striae tend to be more continuous, and cover the entire test.

Occurrence - This species group is abundant in Middle Eocene deposits of the Transco 15 Well, and in general is a minor component of Eocene deposits of the New Jersey continental margin. Barr and Berggren (1980) have recognized this species group in the Eocene of Northeastern Libya where it is an important component of middle and outer neritic environments.

Epistominella minuta (Olsson), 1960

Plate 1, figures 5-7

Pseudoparrella minuta Olsson, 1960, Jour. Pal., p. 40, pl. 6, figs. 7-9.

Epistominella minuta (Olsson), Nogan, 1964, p. 36, pl. 3, figs. 7, 8.

Remarks - This species is characterized by the slightly lobulate, small test, and an interiomarginal aperture parallel to the plane of coiling.

Occurrence - Epistominella minuta is present throughout the New Jersey continental margin.

Alabamina midwayensis Brotzen, 1948

Plate 1, figures 8-10

Alabamina midwayensis Brotzen, 1948, Sver. Geol. Unders., Ser. C, no. 493, p. 99, pl. 16, figs. 1, 2, test-figs., 25, 26.

Remarks - Diagnostic features of this species are the closed coiled, unequally biconvex test, bluntly acute axial periphery, and interiomarginal aperture.

Occurrence - Alabamina midwayensis is an abundant component in Middle Eocene deposits of the Transco 15 Well, but in general is a minor component of Eocene deposits of New Jersey.

Spiroplectamina mississippiensis (Cushman), 1922

Plate 1, figure 11

Textularia missippiensis Cushman, 1922, U.S. Geol. Sur., Prof. Paper 129-E, p. 90, pl. 14, fig. 4.

Spiroplectamina missippiensis (Cushman), Cushman and Todd, 1945, Contr. Cushman Lab. Foram Res., vol. 21, p. 80, pl. 13, fig. 1.

Remarks - This species is characterized by a broad, kite shaped test, and irregularly carinate periphery.

Occurrence - *Spiroplectamina mississippiensis* is a common component in Middle Eocene sediments of the Transco 15 Well, but in general is a minor component of Eocene deposits of New Jersey.

Cibicides lobatulus (Walker and Jacob), 1798

Plate 1, figures 12-14

Nautilus lobatula Walker and Jacob, 1798, Adam's Essays on the microscope, Kanmacher's ed., p. 642, pl. 14, fig. 36.

Truncatulina lobatula (Walker and Jacob), D'Orbigny, 1839, in Barker-Webb and Berthelot, Histoire naturelle des iles Canaries, vol. 2, pt. 2, Foraminiferes, p. 134, pl. 2, figs. 22-24.

Cibicides lobatulus (Walker and Jacob), Cushman, 1927, Jour. Pal., vol. 1, p. 170, pl. 27, figs. 12-13.

Remarks - *Cibicides lobatulus* is characterized by a plano-convex to concavo-convex test, sub-acute periphery, and smooth perforate surface.

Occurrence - This species reaches it's maximum abundance within Middle Eocene sediments of the Transco 15 Well, but in general is a minor component in Eocene deposits of New Jersey.

Gyroidinoides octocameratus (Cushman and Hanna), 1927

Plate 1, figures 15-17

Gyroidina soldanii var. *octocamerata* Cushman and Hanna, 1927, Proc.

Calif. Acad. Sci., ser. 4, vol. 16, p. 223, pl. 14, figs. 16-18.

Gyroidinoides octocameratus (Cushman and Hanna), Nogan, 1964, Cushman Found. Foram Res., Spec. Publ., no. 7, p. 35, pl. 3, figs. 3, 4, 8.

Remarks - This species is characterized by a circular, trochospiral test, an umbilical-extraumbilical, interiomarginal aperture covered by an umbilical flap.

Occurrence - *Gyroidinoides octocameratus* is present throughout the Eocene of New Jersey, and reaches a maximum abundance within Middle Eocene sediments of the Transco 15 Well.

OUTER SHELF - 100 TO 200 METERS

Cibicides pseudoungerianus (Cushman), 1922

Plate 2, figures 1-3

Truncatulina pseudoungeriana Cushman, 1922, U.S. Geol. Sur., Prof. Paper 129-E, p. 97, pl. 20, fig. 9.

Cibicides pseudoungerianus (Cushman), Cole and Gillespie, 1930, Bull. Amer. Pal., vol. 15, no. 57b, p. 15, pl. 3, figs. 10-11.

Remarks - This species is characterized by a nearly equally biconvex test, a dorsal surface thickening concealing the early spire, and slightly lobulate periphery.

Occurrence - *Cibicides pseudoungerianus* is relatively rare and occurs sporadically throughout Eocene deposits of New Jersey.

Cibicidoides lawi (Howe), 1939

Plate 2, figures 7-9

Cibicides lawi Howe, 1939, Louisiana Dept. Cons., Geol. Bull. 14, p. 87, pl. 13, figs. 12-14.

Cibicidoides lawi (Howe), Barr and Berggren, 1980, Lower Tertiary Biostratigraphy and Tectonics of Northeastern Libya.

Remarks - This species is characterized by a low convex test, thin, non-limbate sutures, and slit-like aperture.

Occurrence - Cibicidoides lawi is relatively rare, but consistently present throughout Eocene deposits of New Jersey.

Cibicidoides aff. alleni (Plummer), 1927

Plate 3, figures 1-3

Truncatulina alleni Plummer, 1927, Texas Univ. Bull. 2644, p. 144, pl. 10, fig. 4.

Cibicides alleni Plummer, 1933, Texas Univ. Bull. 3201, pp. 54, 61 (lists).

Cibicidoides alleni (Plummer), Berggren and Aubert, 1975, Paleogeography, Paleoclimatology, Paleoecology, vol. 18, no. 2, pp. 151, 152, pl. 5, fig. 1.

Remarks - This species is characterized by a strongly, almost equally, biconvex test, subacute periphery, dorsal surface thickening concealing the early spire, and arched aperture.

Occurrence - Cibicidoides aff. alleni is recognized in Middle and Late Eocene sediments of the C.O.S.T. B-2 Well.

Cibicidoides pippeni (Cushman and Garrett), 1938

Plate 3, figures 11-13

Cibicides pippeni Cushman and Garrett, 1938, Contr. Cushman Lab. Foram. Res., vol. 14, p. 64, pl. 11, fig. 2.

Cibicidoides pippeni (Cushman and Garrett), Barr and Berggren, 1980, Lower Tertiary Biostratigraphy and Tectonics of Northeastern Libya.

Remarks - This species is characterized by a plano-convex to biconvex test, limbate sutures throughout, and the spiral sutures coalescing in the umbonal area forming a thickened covering.

Occurrence - Cibicidoides pippeni is a common component of the Eocene deposits of the New Jersey coastal plain.

Planulina cocoaensis Cushman, 1928

Plate 2, figures 10-12

Planulina cocoaensis Cushman, 1928, Contr. Cushman Lab. Foram. Res., vol. 4, p. 76, pl. 10, fig. 1.

Remarks - This species is characterized by a discoidal compressed test, flush to raised limbate sutures, and acute periphery.

Occurrence - Planulina cocoaensis is relatively rare and occurrs sporadically in Middle and Late Eocene deposits of New Jersey.

Uvigerina elongata Cole, 1927

Plate 2, figure 13

Uvigerina elongata Cole, 1927, Bull. Amer. Pal., vol. 14, no. 51, p. 26, pl. 4, figs. 2, 3.

Remarks - This species is characterized by a small, elongate, hispid test, and the tendency of the last formed chamber to be added uniserially.

Occurrence - *Uvigerina elongata* occurrs throughout most Eocene deposits of New Jersey, but is conspicuously absent in Middle Eocene sediments of the Transco 15 Well.

Brizalina huneri (Howe), 1939

Plate 2, figures 14, 15

Bolivina huneri Howe, 1939, Louisiana Dept. Cons., Geol. Bull. 14, p. 66, pl. 9, figs. 3, 4.

Remarks - This species is characterized by a small, slightly compressed test, and fine anastomizing striae covering the lower two thirds of the test.

Occurrence - *Brizalina huneri* occurs throughout Eocene deposits of New Jersey, and is especially abundant in Upper Eocene sediments of the C.O.S.T. B-2 Well.

Brizalina atlantisae (Cushman), 1939

Plate 3, figures 14, 15

Bolivina atlantisae Cushman, 1939, Contr. Cushman Lab. Foram. Res., p. 65, pl. 11, figs, 6, 7.

Remarks - This species is characterized by a small slightly compressed test, and raised limbate sutures.

Occurrence - *Brizalina atlantisae* is most common in Middle Eocene sediments of the Anchor Dickinson 1 Well, and Upper Eocene sediments of the C.O.S.T. B-2 Well.

Pyramidina subrotundata (Cushman and Thomas), 1930

Plate 2, figures 16, 17

Reussia subrotundata Cushman and Thomas, 1930, Jour. Pal., vol. 4, p. 38, pl. 3, fig. 7.

Reussella subrotundata Cushman and Thomas, Howe, 1939, Louisiana Dept. Cons., Geol. Bull. 14, p. 70, pl. 8, figs. 40-42.

Remarks - This species is characterized by a small, tapering, triserial test, triangular transverse section, and loop-shaped aperture.

Occurrence - *Pyramidina subrotundata* is one of the most abundant forms of the New Jersey coastal plain. It is not present in the C.O.S.T. B-2 Well.

Hanzawaia mauricensis (Howe and Roberts), 1939

Plate 3, figures 8-10

Cibicidina mauricensis Howe and Roberts, 1939, Louisiana Dept. Cons., Geol. Bull. 14, p. 87, pl. 13, figs. 4, 5.

Remarks - This species is characterized by a small, planoconvex test, a small central boss, minor papillae on the dorsal side, and small elevated flaps on the lower margins of the last formed chambers.

Occurrence - *Hanzawaia mauricensis* is rare to common in abundance in Eocene sediments of New Jersey.

Kolesnikovella elongata (Halkyard), 1918

Plate 3, figure 7

Tritaxia elongata Halkyard, 1918, Manchester Lit. and Philos. Soc., Mem. and Proc., vol. 62, pt. 2, p. 45.

Kolesnikovella elongata (Halkyard), Bykova *et al.*, 1958, VNIGRI, Trudy, no. 115, Mikrofauna SSSR, vol. 9, p. 68.

Remarks - This species is characterized by an elongate test similar to *Trifarina*, retral processes on the lower chamber margins, and a tendency of the last formed chambers to be added uniserially.

Occurrence - This species occurs sporadically throughout Eocene deposits of New Jersey, and is a common component of uppermost Lower Eocene deposits of the Anchor Dickinson I Well.

Bulimina whitei Martin, 1943

Plate 3, figures 4-6

Bulimina whitei, Martin, 1943, Stanford Univ. Pub., Geol. Sci., vol. 3, no. 3, pp. 20-21, pl. 6, fig. 5.

Remarks - This species is characterized by a small, tapering, triserial test, ornamented with low longitudinal costate which extend over the length of the test to halfway up the last formed chamber

Occurrence - *Bulimina whitei* is one of the most common forms of the New Jersey continental margin, and has been reported from Eocene sections of the Central Coast Ranges of California (Berggren and Aubert, 1980).

UPPER BATHYAL - 200 TO 350 METERS

Turritilina sp.

Plate 3, figures 11-13

Remarks - This form is characterized by a small, smooth test, inflated chambers, and a slit-like aperture located at the base of the last formed chamber.

Occurrence - This species occurs in abundance in Lower Eocene deposits throughout New Jersey.

Bulimina sp.

Plate 4, figures 3, 4

Remarks - This form is characterized by a small, tapering, twisted triserial test, rounded transverse section, and smooth perforate surface. Aperture is slightly loop-shaped, and located at the base of the last formed chamber.

Occurrence - This species is one of the abundant forms of the New Jersey continental margin, and is restricted in occurrence to the Deal Member of the Manasquan Formation.

Trifarina wilcoxensis (Cushman and Ponton), 1932

Plate 4, figure 5

Pseudouvigerina wilcoxensis Cushman and Ponton, 1932, Contr. Cushman Lab. Foram. Res., vol. 8, p. 66, pl. 8, fig. 18.

Angulogerina wilcoxensis (Cushman and Ponton), Cushman and Garrett, 1939, Contr. Cushman Lab. Foram. Res., vol. 15, p. 84, pl. 14, figs. 24, 25.

Trifarina wilcoxensis (Cushman and Ponton), Bandy, 1949, Bull. Amer. Pal., vol. 32, no. 131, pp. 145-146, pl. 27, fig. 11.

Remarks - This species is characterized by a pointed trihedral test, two parallel costae along each edge, and a terminal aperture at the end of a short neck.

Occurrence - *Trifarina wilcoxensis* is found throughout the New Jersey coastal plain, but is absent in the C.O.S.T. B-2 Well.

Cibicides sp.

Plate 4, figures 6-8

Remarks - This species is characterized by a plano-convex test, strongly curved, raised limbate sutures, and periumbilical crenulations on the spiral side. This form is similar to *Cibicidoides howelli* figured by Berggren and Aubert (1975).

Occurrence - *Cibicides sp*. is a common form in Lower Eocene sediments of the Anchor Dickinson I Well.

Cibicidoides whitei (Martin), 1943

Plate 4, figures 9-11

Cibicides whitei Martin, 1943, Stanford Univ. Pub., Geol. Sci., vol. 3, no. 3, p. 32, pl. 8, fig. 7.

Cibicidoides whitei (Martin), Berggren and Aubert, 1980, Paleogene Benthonic Foraminiferal Biostratigraphy and bathymetry of the Central Coast Ranges.

Remarks - This species is characterized by a biconvex test, approximately eight chambers in the last whorl, slit-like aperture, and earlier dorsal sutures obscured by a clear layer of calcite.

Occurrence - *Cibicidoides whitei* is a common component in Lower Eocene sediments of the Anchor Dickinson I Well, and Middle Eocene sediments of the C.O.S.T. B-2 Well.

Spiroplectamina sp.

Plate 4, figure 12

Remarks - This species is characterized by an elongate, compressed test, lobulate periphery, and sharp edge.

Occurrence - *Spiroplectamina sp.* is present in Lower Eocene sediments of the Anchor Dickinson I Well.

Siphonina claibornensis (Cushman), 1927

Plate 4, figures 13-15

Siphonina claibornensis Cushman, 1927, U.S. Nat. Mus., Proc., vol. 72, p. 4, pl. 3, fig. 5.

Remarks - This species is characterized by a coarsely perforate, biconvex test, sharp edge with a slight keel, and an eliptical aperture.

Occurrence - *Siphonina claibornensis* is common throughout Lower Eocene deposits of the New Jersey coastal plain, and reaches it's maximum abundance in the Leggette Well.

Anomalinoides acuta (Plummer), 1927

Plate 4, figures 16-18

Anomalina ammonides (Reuss) var. *acuta* Plummer, 1927, Univ. Texas Bull., no. 2644, p. 149, pl. 10, fig. 2.

Anomalina acuta Plummer. Glaessner, 1937, Moscow Univ., Problems in

Paleontology, vol. 2-23, p. 386, pl. 5. no. 40.

Anomalinoides acuta (Plummer), Brotzen, 1948, Sver. Geol. Unders., Ser. C, no. 493, p. 87, pl. 15, fig. 2.

Remarks - This species is characterized by an involute test, limbate surtures, and distinct dorsal umbilical plug.

Occurrence - *Anomalinoides acuta* is present throughout the New Jersey continental margin, and reaches a maximum abundance within the Lower Eocene deposits of the Anchor Dickinson I Well.

UPPER BATHYAL - 350 TO 600 METERS

Bulimina callahani Galloway and Morrey, 1931

Plate 5, figures 1-3

Bulimina callahani Galloway and Morrey, 1931, Jour, Pal., vol. 5, p. 350, pl. 40, fig. 6.

Remarks - Specimens from the New Jersey continental margin are identical to the figured holotype. This species is characterized by a reticulate ornamentation covering the lower two-thirds of the test.

Occurrence - This species is common in Early Eocene deep sea deposits, and appears to be restricted to this interval (Berggren and Aubert, 1980; Barr and Berggren, 1980). *Bulimina callahani* is present within Lower Eocene sediments of the C.O.S.T. B-2 Well. The occurrence of this species in deposits from California, New Jersey, Orphan Knoll, and Libya, and it's restricted occurrence to deeper water sections makes it a useful biostratigraphic-paleobathymetric indicator.

Bulimina aff. striata mexicana Cushman, 1922 -

Bulimina aff. subacuminata Cushman and Stewart, 1930

Plate 5, figures 12-15

Bulimina striata mexicana Cushman, 1922, U.S. Nat. Mus. Bull. 104, pt. 3, p. 95, pl. 21, fig. 2.

Bulimina subacuminata Cushman and Stewart, 1930, San Diego Soc. Nat. Hist. Trans., vol. 6, p. 65, pl. 5, figs. 2, 3.

Remarks - This species compares favorably to Bulimina subacuminata but differs in having short spines on the earlier whorls at the ends of the plate-like costae as in B. striata mexicana.

Occurrence - This form is common in Lower Eocene sediments of the C.O.S.T. B-2 Well, and is present within Lower Eocene sediments of the Anchor Dickinson I Well.

Planulina? ammophila (Guembel), 1868

Plate 5, figures 7-9

Rotalia ammophila Guembel, 1868, K. Bayer, Akad. Wiss. Munchen, Math.-Physik. Cl., Abh., Bd. 10 (1870), Abt. 2, p. 652, pl. 2, fig. 90.

Cibicides cushmani Nuttall, 1930, Jour. Pal., vol. 4, p. 291, pl. 25, figs. 3, 5, 6.

Cibicides ammophilus (Guembel), Hagn, 1956, Palaontographica, Abt. A, H. 107, p. 179, pl. 17, fig. 7.

Planulina? Ammophila (Guembel), Proto-Decima and de Biase, 1975, in Braga, de Biase, Grunig, and Proto-Decima, Schweiz. Palaont. Abh., vol. 97, p. 95, pl. 2, fig. 11.

Remarks - This species is characterized by a plano-convex test, and biumbilicate convavity. Dorsally the sutures are curved, slightly raised and limbate. Ventrally the sutures are curved, and either depressed or slightly raised.

Occurrence - *Planulina*? *ammophila* occurs within Lower and Middle Eocene sediments of the C.O.S.T. B-2 Well. This species is a common form in the Wadi Atrun section of Libya (Barr and Berggren, 1980). Distributional data of this species suggests that it may be a reliable guide to neritic and upper bathyal depths.

Nuttallides truempyi (Nuttall), 1930

Plate 5, figures 4-6

Eponides truempyi Nuttall, 1930, Jour. Pal., vol. 4, pp. 287-288, pl. 24, figs. 9, 13, 14.

Nuttallides truempyi (Nuttall), Finlay, 1939, Trans. Roy. Soc. New Zealand, vol. 68, pp. 520, 521.

Remarks - This speceis is characterized by an unequally biconvex text, sinuous ventral sutures, and a slit-like aperture extending from the periphery to the ventral boss.

Occurrence - *Nuttallides truempyi* is restricted in occurrence to Lower Eocene sediments of the C.O.S.T. B-2 Well.

Fursenkoina? *sp*.

Plate 5, figure 10

Remarks - This form is characterized by it's small elongate test, elongate chambers, and elongate eliptical aperture.

Occurrence - *Fursenkoina*? *sp*. is an abundant component in the Lower Eocene sediments of the C.O.S.T. B-2 Well.

Aragonia aragonensis (Nuttall), 1930

Plate 5, figure 11

Textularia aragonensis Nuttall, 1930, Jour. Pal., vol. 4, p. 280, pl. 23, fig. 6.

Bolivina aragonensis (Nuttall), Cushman and Siegfus, 1942, Trans. San Diego Soc. Nat. Hist., vol. 9, p. 413, pl. 19, figs. 7, 8.

Aragonia aragonensis (Nuttall), Graham and Classen, 1955, Contr. Cushman Found. Foram. Res., vol. 6, pt. 1, p. 19, pl. 3, fig. 13.

Remarks - This species is characterized by it's compressed test, thin, raised, limbate sutures. The aperture is a thin, transverse slit at the base of the last formed chamber.

Occurrence - Aragonia aragonensis occurs sporadically in Lower Eocene deposits of the New Jersey continental margin.

REFERENCES

Bandy, O.L., 1956, Ecology of Foraminifera in northeastern Gulf of Mexico: U.S. Geol. Survey, Prof. Paper 274G, pp. 179-204.

Bandy, O.L., 1960, General correlation of foraminiferal structure with environment: International Geol. Congress, 21st, Copenhagen, vol. 22, pp. 7-19.

Bandy, O.L. and Arnal, R., 1957, Distribution of Recent foraminifera off the west coast of Central America: Am. Assoc. Petrol. Geol. Bull., vol. 41, pp. 2037-2053.

Bandy, O.L. and Arnal, R., 1960, Concepts in foraminiferal paleo-ecology: Am. Assoc. Petrol. Geol. Bull., vol. 44, pp. 1921-1932.

Bandy, O.L. and Chierici, M., 1966, Depth-Temperature evaluation of selected California and Mediterranean bathyal foraminifera: Marine Geology, vol. 4, pp. 254-271.

Barr, F.T. and Berggren, W.A., 1980, Lower Tertiary biostratigraphy and tectonics of northeastern Libya.

Berggren, W.A., 1974, Late Paleocene-Early Eocene benthonic foramini-feral biostratigraphy and paleoecology of Rockall Bank: Micro-paleontology, vol. 20, no. 4, pp. 426-448.

Berggren, W.A., and Aubert, J., 1980, Paleogene benthonic foraminiferal biostratigraphy and bathymetry of the Central California Coast Ranges: U.S. Geol. Survey, Prof. Paper.

Bolli, H.M., 1957a, The Genera Globigerina and Globorotalia in the Paleocene-Lower Eocene Lizard Springs Formation of Trinadad, B.W.I.: U.S. Nat. Museum Bull., no. 215, pp. 61-81.

Bolli, H.M., 1957b, Planktonic Foraminifera from the Eocene Navet and

San Fernando Formations of Trinidad, B.W.I.: U.S. Nat. Museum Bull., no. 215, pp. 155-172.

Bolli, H.M., 1966, Zonation of Cretaceous to Pliocene Marine sediments based on Planktonic Foraminifera: Asociacion Venezolana de Geologia, Mineria Y Petroleo Bol., vol. 9, no. 1, pp. 1-33.

Bolli, H.M., 1972, The Genus _Globigerinatheka_ Bronnimann: Jour. Foram. Research, vol. 2, no. 3, pp. 109-136.

Brown, P.M., Miller, J.A., and Swain, F.M., 1972, Structural and stratigraphic framework and spacial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U.S. Geol. Surv. Prof Paper 796, pp. 1-79.

Buzas, M.A. and Gibson, T.G., 1969, Species diversity: Benthonic foraminifera in western North Atlantic: Science, vol. 163, pp. 72-75.

Douglas, R.G., 1972, Benthonic foraminiferal biostratigraphy in the central North Pacific, Leg 17, Deep Sea Drilling Project: _In_ Winterer, E.L., Ewing, J.I. _et al_., 1973, Initial Reports of the Deep Sea Drilling Project, vol. 17, Washington (U.S. Government Printing Office) pp. 607-671.

Enright, R. Jr., 1969a, The stratigraphy, micropaleontology, and paleoenvironmental analysis of the Eocene sediments of the New Jersey Coastal Plain: Unpublished Ph.D. thesis, Rutgers University, New Brunswick, N.J., 242 pp.

Enright, R. Jr., 1969b, The stratigraphy and clay mineralogy of the northern New Jersey Coastal Plain: _In_ S. Subitsky, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions, pp. 14-20.

Grimsdale, T. and Morkhoven, F., 1955, The ratio between pelagic and benthonic foraminifera as a means of estimating depth of deposition of sedimentary rocks: IV World Petrology Congress, Proceedings, Sect. I/D Rept. 4, p. 473-491.

Johnson, R.G., 1972, Conceptual models of benthic marine communities: In Schopf, ed., Freeman, Cooper, and Co., California.

Krasheninniko, V.A., 1965b, Zonalnaya stratigrafiya paleogena vostochnogo Sredizemnomoriya: Akad, Nauk SSSR Geol. Inst. Trudy, no. 133, 76 p.

Laughton, A.S., et al., 1972, Initial Reports of the Deep Sea Drilling Project, vol. 12, Washington (U.S. Government Printing Office) 1243 pp.

Murray, J.W., 1973, Distribution and ecology of living benthic foraminiferids: Crane, Russak, and Company, New York, 273 pp.

Olsson, R.K., 1978, Summary of lithostratigraphy and biostratigraphy of Atlantic Coastal plain (northern part): In Benson, W.E., et al., 1978, Initial Reports of the Deep Sea Drilling Project, vol. 44, Washington (U.S. Government Printing Office) pp. 941-947.

Olsson R.K. and Miller, K.G., 1979, Oligocene transgressive sediments of New Jersey continental margin: Unpublished Report.

Olsson, R.K., Miller, K.G. and Ungrady, T.E., 1980, Late Oligocene Piney Point transgression of Atlantic coastal plain: Abstracts with Program, Northeast Section of Geol. Soc. Am., Annual Meeting, Philadelphia, Pennsylvania, vol. 12, p. 76.

Parker, F.L., 1954, Distribution of the Foraminifera in the northeastern Gulf of Mexico, Bull. Mus. comp. Zool. Harv., vol. 3, pp. 452-4588.

Pflum, C. and Frerichs, W., 1976, Gulf of Mexico deep water foraminifers: Cush. Found. Foram. Res., Special Publications, no. 14, 125 pp.

Phleger, F.B., 1956, Significance of living Foraminiferal populations along the Central Texas coast: Contr. Cushman Found. Foram. Res., vol. 7, pp. 106-151.

Phleger, F.B., 1960a, Ecology and distribution of Recent Foraminifera: John Hopkins Press, Baltimore, 297 pp.

Phleger, F.B. and Parker, F.L., 1951, Ecology of foraminifera, northwest Gulf of Mexico: Geol. Soc. Am., Mem. 46, 64 p.

Sheridan, R.E., 1974, Conceptual model for the block-fault origin of the North American continental margin geosyncline: Geology, vol. 2, pp. 465-468.

Sokal, R.R., 1961, Distance as a measure of taxonomic similarity: Systematic Zoology, vol. 10, pp. 70-79.

Toumarkine, M. and Bolli, H.M., 1970, Evolution de _Globorotalia cerroazulensis_ (Cole) dans L'Eocene Moyen et Superieur de Possagno (Italie): Rev. Micropaleontologie, vol. 13, pp. 131-145.

Ulrich, B.C., 1976, The Eocene foraminiferal biostratigraphy of the Atlantic Coastal Plain of New Jersey: Unpublished Masters Thesis, Rutgers University.

Vail, P., Mitchum, Jr., R.M. and Thompson, III, S., 1977, Seismic stratigraphy and global changes of sea level, Part 4: Global Cycles of Relative Changes in Sea Level. _In_ Charles E. Payton, ed., _Seismic Stratigraphy-Applications to Hydrocarbon Exploration_, Am. Assoc. Petrol. Geol. Mem. 26, pp. 83-97.

Valentine, J.W., 1971, Resource supply and species diversity patterns:

Lethaia, vol. 4, no. 1, pp. 51-62.

Valentine, J.W., 1972, Conceptual models of ecosysteme evolution: In T.J.M. Schopf, ed., Models in Palecology, pp. 192-216.

Walton, W.R., 1964, Recent foraminiferal ecology and paleoecology: In Imbrie and Newell, eds., Approaches in Paleoecology, pp. 151-237.

Youssefnia, I., 1974, Western North Atlantic Paleocene benthonic foraminiferal paleoecology: Ph.D. Thesis, Rutgers University.

Youssefnia, I., 1978, Paleocene benthonic foraminiferal paleoecology of Atlantic coastal plain: Jour. Foram. Res., vol. 8, no. 2, pp. 114-126.

PLATE 1

MID-SHELF 50-100 METERS

Figure	
1-4	Uvigerina rippensis Cole - gardnerae Cushman species group. 1, 174x (Transco 15, 582'). 2, 220x (Transco 15, 592'). 3, 154x (Transco 15, 582'). 4, 160x (Transco 15, 603').
5-7	Epistominella minuta Olsson. 5, 400x (Bricktown Ship Intermediate School, 210'). 6, 288x (Transco 15, 634'). 7, 315x (Leggette, 430').
8-10	Alabamina midwayensis Brotzen. 8, 181x. 9, 161x. 10, 134x. (Transco 15, 603')
11	Spiroplectamina mississippiensis (Cushman). 107x (Transco 15, 614').
12-14	Cibicides lobatulus (Walker and Jacob). 12, 120x (Transco 15, 614'). 13, 120x (Leggette, 430'). 14, 120x (Transco 15, 614').
15-17	Gyroidinoides octocameratus (Cushman and Hanna). 15, 120x (Transco 15, 645'). 16, 147x (Transco 15, 624'). 17, 147x (Transco 15, 850').

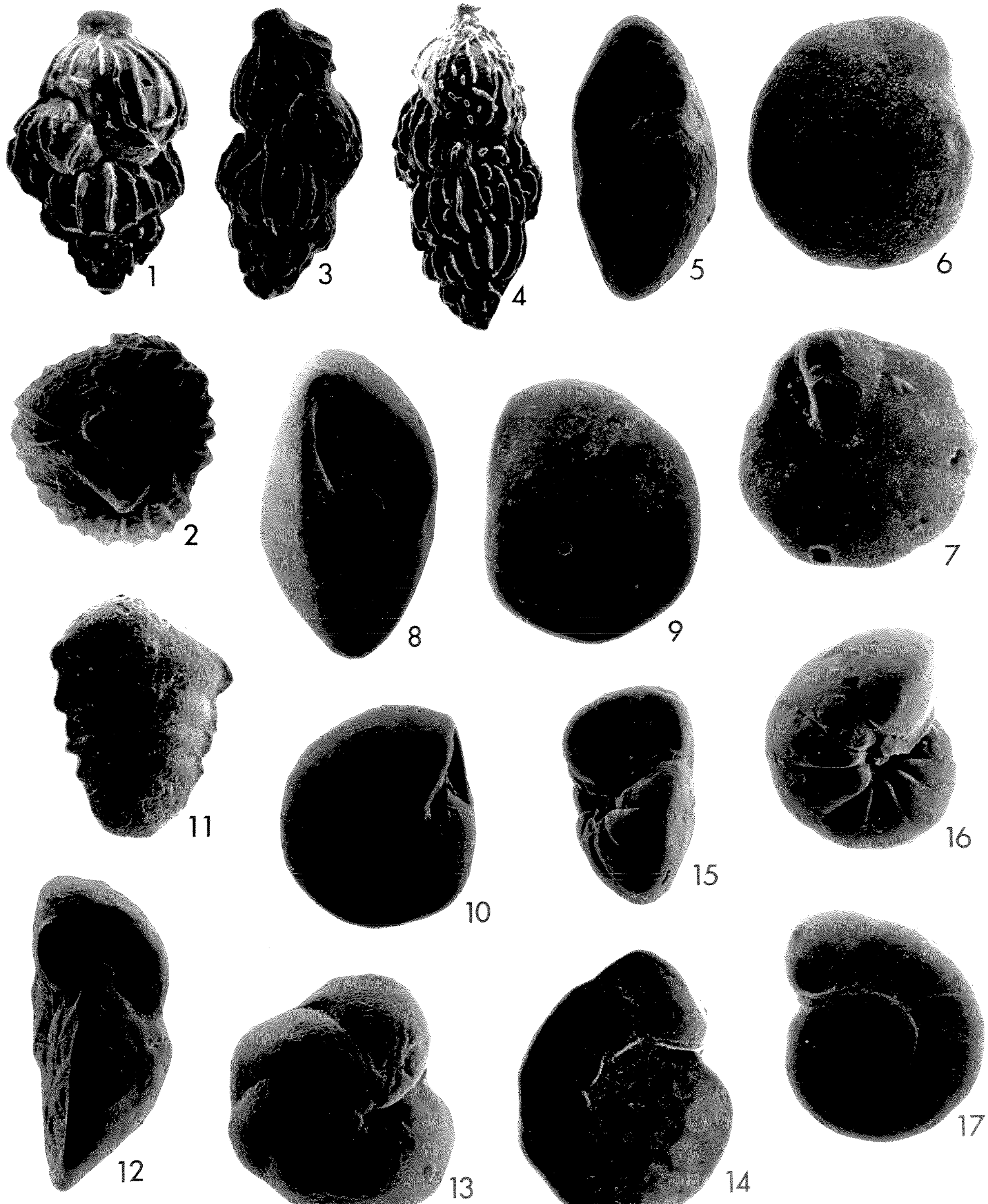

1
3
4
5
6
2
7
8
9
11
16
15
10
12
13
14
17

PLATE 2

OUTER SHELF 100-200 METERS

Figure	
1-3	Cibicides pseudoungerianus (Cushman). 1, 60x (C.O.S.T. B-2, 4230'). 2, 67x (C.O.S.T. B-2, 4200'). 3, 100x (C.O.S.T. B-2, 4230').
4-6	Gyroidinoides peramplus (Cushman and Stainforth). 4, 134x. 5, 100x. 6, 87x. (Anchor Dickinson I, 1530').
7-9	Cibicidoides lawi (Howe). 7, 147x (Transco 15, 706'). 8, 147x (C.O.S.T. B-2, 4440'). 9, 120x (C.O.S.T. B-2, 4350').
10-12	Planulina cocoaensis Cushman. 10, 67x (C.O.S.T. B-2, 4140'). 11, 67x (C.O.S.T. B-2, 4200'). 12, 54x (C.O.S.T. B-2, 4260').
13	Uvigerina elongata Cole. 134x (Transco, 716').
14, 15	Brizalina huneri (Howe). 14, 134x. 15, 315x (Transco 15, 696').
16, 17	Pyramidina subrotundata (Cushman and Thomas). 16, 200x. 17, 335x (Leggette, 420').

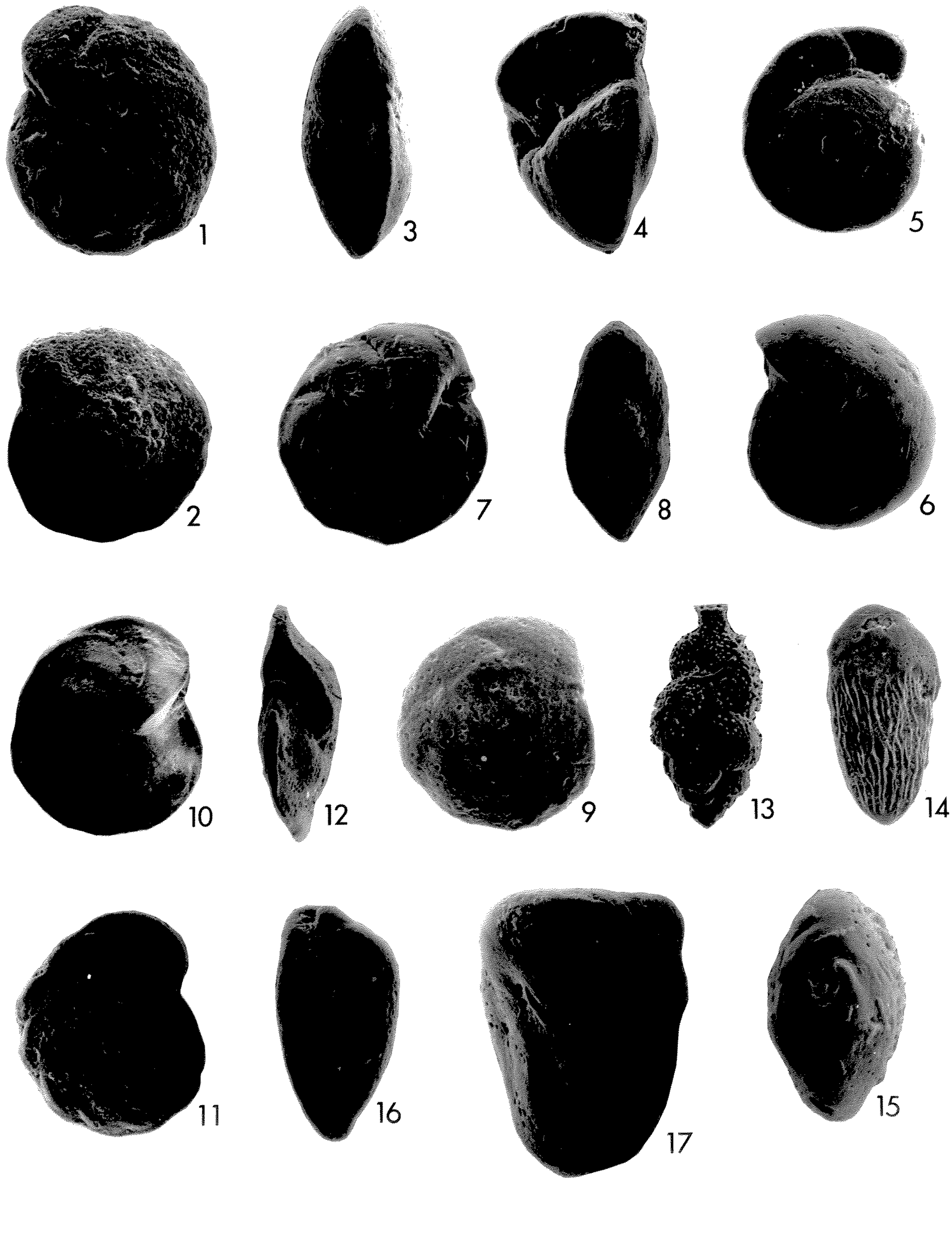

1
3
4
5
2
7
8
6
10
12
9
13
14
11
16
17
15

PLATE 3

OUTER SHELF 100-200 METERS

Figure	
1-3	Cibicidoides aff. alleni (Plummer). 1, 2, 74x. 3, 87x. (C.O.S.T. B-2, 4290').
4-6	Bulimina whitei Martin. 4, 402x (Leggette, 550'). 5, 268x (Transco, 737'). 6, 221x (C.O.S.T. B-2, 4170').
7	Kolesnikovella elongata (Halkyard) 174x, (Anchor Dickinson I, 1600').
8-10	Hanzawaia mauricensis (Howe and Roberts). 8, 120x. 9, 200x. 10, 160x. (Transco 15, 582').
11-13	Cibicidoides pippeni (Cushman and Garrett). 11, 67x (Transco 15, 686'). 12, 67x (Leggette, 430'). 13, 134x (Transco 15, 778').
14, 15	Brizalina altantisae (Cushman). 14, 470x (Anchor Dickinson I, 1530'). 15, 221x (Anchor Dickinson I, 1600').

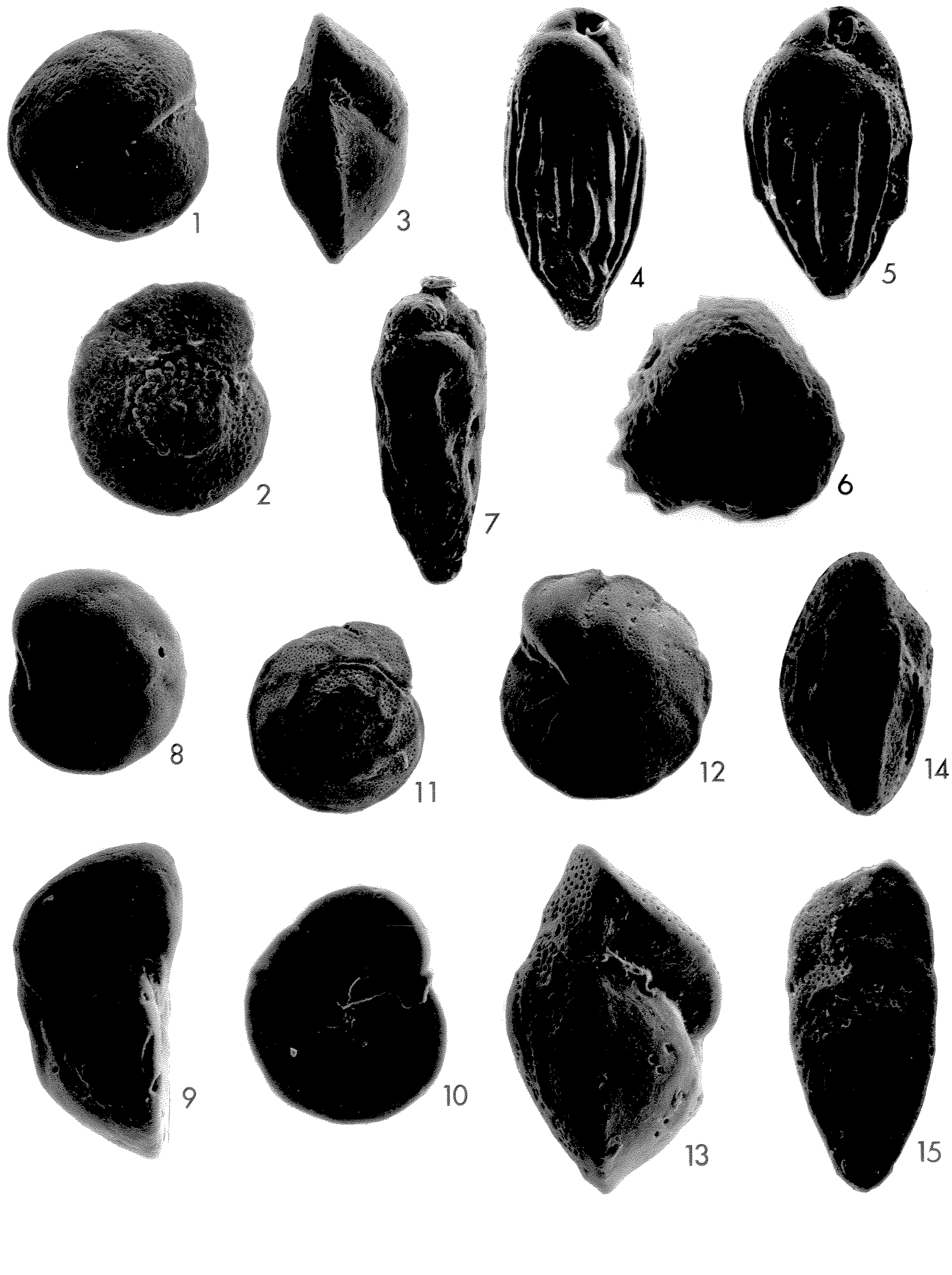

1
3
4
5
2
7
6
8
11
12
14
9
10
13
15

PLATE 4

UPPER BATHYAL 200-350 METERS

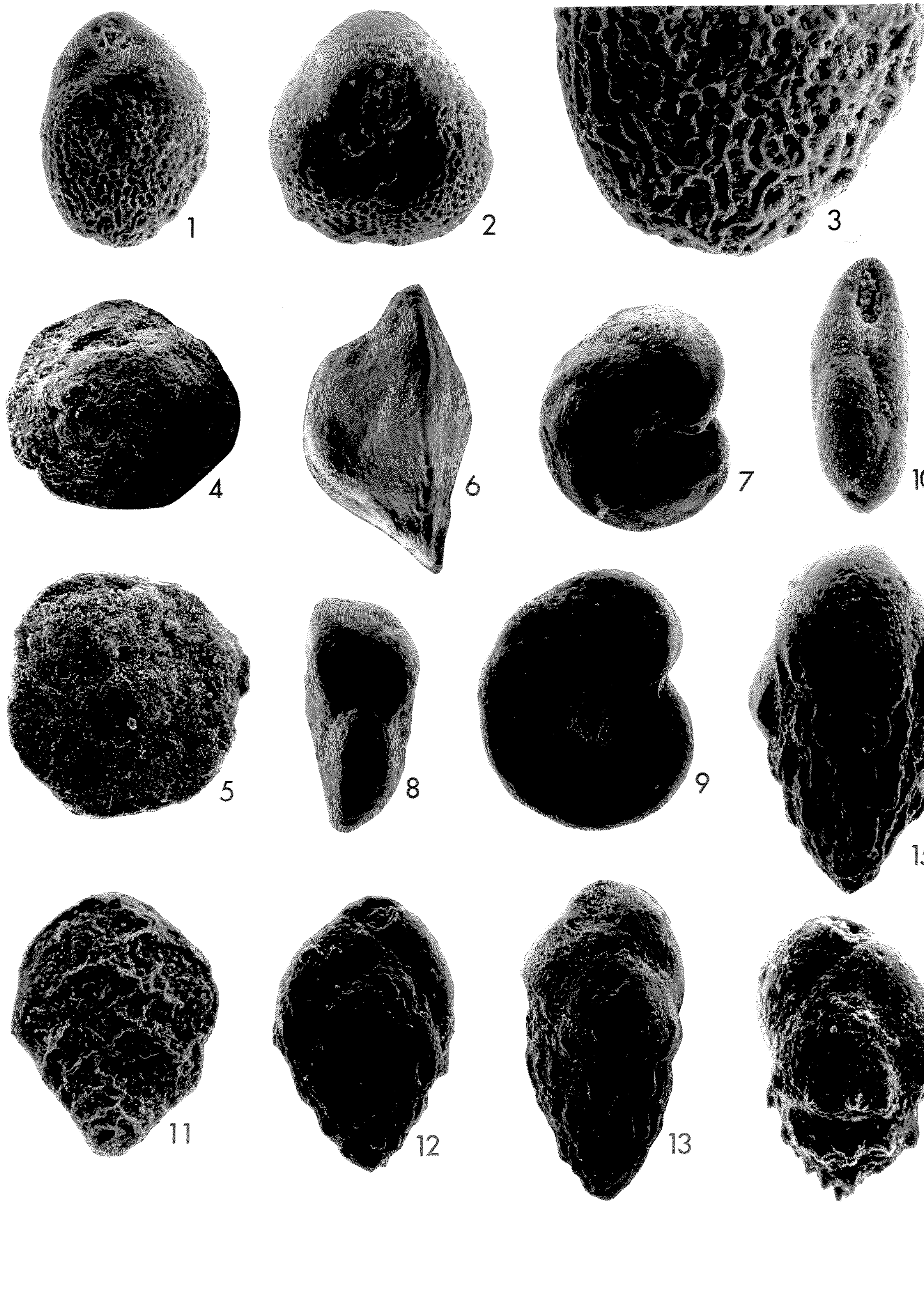
Figure	
1, 2	*Turritilina sp*. 181x (Leggette, 550').
3, 4	*Bulimina sp*. 3, 369x. 4, 288x. (Leggette, 560').
5	*Trifarina wilcoxensis* (Cushman and Ponton) 107x (Transco 15, 871').
6-8	*Cibicides sp*. 6, 87x. 7, 80x. (Anchor Dickinson I, 1740'). 8, 80x (Anchor Dickinson I, 1760').
9-11	*Cibicidoides whitei* (Martin). 9, 87x (Leggette, 560'). 10, 200x (Leggette, 550'). 11, 87x (Anchor Dickinson I, 1720').
12	*Spiroplectamina sp*. 87x (Anchor Dickenson I, 1770').
13-15	*Siphonina claibornensis* Cushman. 13, 107x (Transco 15, 665'). 14, 147x (Transco 15, 614'). 15, 134x (Transco 15, 686').
16-18	*Anomalinoides acuta* (Plummer). 16, 241x. 17, 134x. 18, 200x. (Leggette, 560').


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

PLATE 5

UPPER BATHYAL 350-600 METERS

Figure	
1-3	*Bulimina callahani* Galloway and Morrey. 1, 200x. 2, 288x. 3, 435x. (C.O.S.T. B-2, 4780').
4-6	*Nuttallides truempyi* (Nuttall). 4, 120x (C.O.S.T. B-2, 4930'). 5, 120x. 6, 100x. (C.O.S.T. B-2, 4900').
7-9	*Planulina*? *ammophila* (Nuttall). 67x. 7, 9 (C.O.S.T. B-2, 4260'). 8 (C.O.S.T. B-2, 4350').
10	*Fursenkoina*? *sp*. 160x (C.O.S.T. B-2, 4840').
11	*Aragonia aragonensis* (Nuttall). 147x (C.O.S.T. B-2, 4810').
12-15	*Bulimina* aff. *striata mexicana* Cushman - *subacuminata* Cushman and Stewart. 12, 268x (C.O.S.T. B-2, 468o'). 13, 100x (C.O.S.T. B-2, 4650'). 14, 335x (C.O.S.T. B-2, 4680'). 15, 107x (C.O.S.T. B-2, 4650').


1
2
3
4
6
7
10
5
8
9
15
11
12
13
14

Vita

Anthony Charles Charletta

1951	Born June 26 in Newark, New Jersey.
1969	Graduated from Union High School, Union New Jersey.
1970-73	Attended Fairleigh Dickinson University, Madison, New Jersey.
1973	B.A. in Geology
1974	Abstract: "Scolecodonts from the Upper Cretaceous greensand of the New Jersey Coastal Plain," Annual Meetings Abstracts, AAPG and SEPM, vol. 1, p. 17.
1974	Article: "Scolecodonts from Cretaceous greensand of the New Jersey coastal plain," Micropaleontology, vol. 20, no. 3, pp. 354-366, pls. 1-4.
1973-75	Graduate work in Geology, Rutgers University, Newark, New Jersey.
1973-75	Teaching Assistantship, Department of Geology, Rutgers University, Newark, New Jersey.
1976	M.S. in Geology, Rutgers University.
1975-80	Graduate work in Geology, Rutgers University, New Brunswick, New Jersey.
1975-76	Laboratory Instructor, Department of Earth Sciences, Fairleigh Dickinson University, Madison, New Jersey.
1976	Henry Rutgers Fellowship.
1976-79	Teaching Assistantship, Department of Geology, Rutgers University, New Brunswick, New Jersey.
1980	Ph.D. in Geology, Rutgers University.