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

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The Graduate School
of
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Written under the direction of
Professor Richard K. Olsson

and approved by

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ABSTRACT OF THE THESIS

Eocene Benthic Foraminiferal Paleoeocology 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 this study possible.
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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 HHigh, 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).
Figure 1  Base map showing well sites, Eocene outcrops, outline of Baltimore Canyon Trough, and location of cross-section A-A' illustrated in Figure 5.

Figures 2-4  Generalized areal extent of Farmingdale, Squankum, and Toms River members.

Figure 5  Schematic stratigraphic strike section through the New Jersey coastal plain (A-A' of Figure 2).

A = Allaire State Park Well; IB = Island Beach Well; Tl5 = Transco 15 Well; L = Leggette Well; AD1 = Anchor Dickinson 1 Well.

Figure 6  Planktic foraminiferal zonation of the Eocene section of the New Jersey continental margin.
EXTENT OF
SQUANKUM
MEMBER

EOCENE
OUTCROP

• THIS STUDY
• ENRIGHT, 1969

FIGURE 3
<table>
<thead>
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<th>AGE</th>
<th>PLANKTIC FORAM ZONES</th>
<th>AUTHOR</th>
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<tr>
<td>LATE</td>
<td>Globorotalia cerroazulensis cunialensis</td>
<td>TOUMARKINE</td>
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<tr>
<td></td>
<td>Globorotalia cerroazulensis cocoensis</td>
<td>and</td>
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<td></td>
<td>Globorotalia cerroazulensis cerroazulensis</td>
<td>BOLLI (1970)</td>
</tr>
<tr>
<td>MIDDLE</td>
<td>Globorotalia c. cerroazulensis – c. pomeroli</td>
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<td>Globorotalia cerroazulensis pomeroli</td>
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<td>Globorotalia cerroazulensis posagnoensis</td>
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<td>Globorotalia cerroazulensis frontosa</td>
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</tr>
<tr>
<td>EOcene</td>
<td>Acarinina pentacamerata</td>
<td>KRASHENINNIKOV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1965)</td>
</tr>
<tr>
<td>EARLY</td>
<td>Morozovella aragonensis</td>
<td>BOLLI</td>
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<tr>
<td></td>
<td>Morozovella formosa formosa</td>
<td>(1957, 1960, 1966)</td>
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<tr>
<td></td>
<td>Morozovella subbotinae</td>
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</table>

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 paleoecology. 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 juvenile 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

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 paleo-bathymetric 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*, *Buliminia 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.
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<tr>
<td>MIDDLE EOCENE</td>
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**FIGURE 10**
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- Less than 5%
- 6-10%
- 11-19%
- 20-35%
- Greater than 35%

FIGURE 11
<table>
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<th>BATHYMETRIC RANGE</th>
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<td>Globulina inaequalis</td>
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<td>0 - 60 meters</td>
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<td>Hanzawaia</td>
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</tr>
<tr>
<td></td>
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<td>simple interior</td>
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</tr>
<tr>
<td>Hanzawaia mauricensis</td>
<td>Hanzawaia strattoni</td>
<td>inner-middle shelf</td>
<td>Pflum and Frerichs, 1976</td>
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<tr>
<td>subinvoluta</td>
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<td></td>
<td>Walton, 1964</td>
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<td>50 - 150 meters</td>
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<td>same</td>
<td>most frequent</td>
<td>Phleger, 1960</td>
</tr>
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<td>less than 60 - 75 meters</td>
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<td>raised limbate sutures</td>
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<td><strong>Cibicides</strong></td>
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<td>Pflum and Frerichs, 1976</td>
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<tr>
<td>pseudoungerianus</td>
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<tr>
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<td><strong>Uvigerina laevis</strong></td>
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<tr>
<td></td>
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<td>Phleger, 1956, 1960</td>
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<tr>
<td>Siphonina</td>
<td>Siphonina pulchra</td>
<td>30 - 500 meters</td>
<td>Parker, 1954</td>
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<tr>
<td>Claibornensis</td>
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<td>100 - 200 meters</td>
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<tr>
<td>Bulimina</td>
<td>Bulimina</td>
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<td>Bandy, 1960</td>
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<tr>
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<td></td>
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<td>bathyal</td>
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<tr>
<td>Trifarina wilcoxensis</td>
<td>Trifarina bradyi</td>
<td>30 - 900 meters</td>
<td>Phleger and Parker, 1951</td>
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<td></td>
<td></td>
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<td>Parker, 1954</td>
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<tr>
<td><em>Bulimina striata</em></td>
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<td><em>mexicana-subacuminata</em></td>
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<td></td>
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<td>200 - 700 meters</td>
<td>Pflum and Frerichs, 1976</td>
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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 paleo-
depth 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 com-
ponent in the Middle Eocene of the Transco 15 Well (fig. 9). The
co-occurrence of *Uvigerina rippensis-gardnerae* with that of demon-
strably 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 \textit{Uvigerina rippensis-gardnerae}, \textit{Gyroidinoides octocameratus}, and \textit{Alabamina midwayensis}. Other species characteristic of this group include \textit{Marginulina cocoaensis}, \textit{Gutulina hantkeni}, \textit{Gutulina communis}, \textit{Globulina inaequalis}, \textit{Hanzaawaia mauricensis subinvoluta}, \textit{Turrilina robertsi}, and \textit{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 \textit{Uvigerina elongata}, \textit{Melonis planatus} \textit{Cibicides pseudoungerianus}, \textit{Cibicidoides lawi}, the low planktic foraminiferal abundance (less than 5%) and the predominance of planktic juvenile forms supports this interpretation. Since the species \textit{Alabamina} and \textit{Gyroidinoides} have no living counterparts, direct comparison to modern distributional trends are impossible. \textit{Gyroidinoides octocameratus} and \textit{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 \textit{Pyramidina subrotundata}, \textit{Epistominella minuta}, and small brizalinids, respectively. Groups 2, 7, and 10 are dominated by \textit{Bulimina whitei}, \textit{Turrilina sp.}, and \textit{Kolesnikovella elongata}. Other species characteristic of these groups include \textit{Hanzaawaia mauricensis}, \textit{Cibicidoides aff. alleni}, \textit{Cibicidoides lawi}, \textit{Cibicidoides pippeni}, \textit{Cibicides pseudoungerianus}, \textit{Uvigerina cookei}, \textit{Uvigerina elongata}, \textit{Melonis planatus}, and \textit{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 calaibornensis*, *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, Anomalinoidea 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 distinguished 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.
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.
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 Morozovella subbotinae
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 for 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.
<table>
<thead>
<tr>
<th>AGE</th>
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<tr>
<td>EOCENE</td>
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<tr>
<td>MIDDLE</td>
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<td>Globorotalia c. carrozulensis pomeroli</td>
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<td>Globorotalia c. carrozulensis frontosa</td>
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**FIGURE 17**
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 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


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

Spiroplectamina mississippiensis (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.


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.
Gyroidinoides octocameratus (Cushman and Hanna), Nogan, 1964, Cushman
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


*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.

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**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 pipeni_ (Cushman and Garrett), 1938

Plate 3, figures 11-13


_Cibicidoides pipeni_ (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 pipeni_ is a common component of the Eocene deposits of the New Jersey coastal plain.

_Planulina cocoensis_ Cushman, 1928

Plate 2, figures 10-12


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

Occurrence - _Planulina cocoensis_ is relatively rare and occurs sporadically in Middle and Late Eocene deposits of New Jersey.

_Uvigerina elongata_ Cole, 1927

Plate 2, figure 13

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* occurs 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


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


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


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


Kolesnikovella elongata (Halkyard), Bykova et al., 1958, VNIIGRI, 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

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


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 elliptical aperture.

Occurrence - *Siphonina claibornensis* is common throughout Lower Eocene deposits of the New Jersey coastal plain, and reaches its 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

Remarks - This species is characterized by an involute test, limbate sutures, 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 its 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


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


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 truemysi (Nuttall), 1930
Plate 5, figures 4-6


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

Occurrence - Nuttallides truemysi 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 its small elongate test, elongate chambers, and elongate elliptical 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.


Aragonia aragonensis (Nuttall), Graham and Classen, 1955, Contr.


Remarks - This species is characterized by its 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.
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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 Inter-
mediate School, 210').  6, 288x (Transco 15, 634').  7, 315x
(Leggette, 430').

8-10  *Alabamina midwayensis* Broten.  8, 181x.  9, 161x.  10, 134x.
(Transco 15, 603')

11  *Spiroplectamina mississipiensis* (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').
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 cocoensis* 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').
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 pippensi (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').
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 claiibornensis** Cushman. 13, 107x (Transco 15, 665').
      14, 147x (Transco 15, 614'). 15, 134x (Transco 15, 686').

16-18  **Anomalinaoides acuta** (Plummer). 16, 241x. 17, 134x. 18, 200x. (Leggette, 560').
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').


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, 4680').  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').
Vita

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