ALBIAN TO TURONIAN PALEOSLOPE MODEL OF BENTHIC FORAMINIFERA OF THE NEW JERSEY ATLANTIC MARGIN AND NORTH ATLANTIC BASIN

By PAUL J. SIKORA

A dissertation submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

Graduate Program in Geological Sciences

Written under the direction of

Professor Richard K. Olsson

and approved by

_____

_____

_____

_____

New Brunswick, New Jersey

October 1989

ABSTRACT OF THE DISSERTATION

Albian to Turonian Paleoslope Model of Benthic Foraminifera of the New Jersey Atlantic Margin and North Atlantic Basin

by PAUL J. SIKORA

Dissertation Director: Professor Richard K. Olsson

A paleoslope model of Albian to Turonian benthic Foraminifera reveals seven successive biofacies which are associated with increasing paleodepth. Biofacies 1 and 2 characterize paleodepths of less than 60m and contain abundant species of Epistomina and Gavelinella. Species of Globorotalites, Eggerellina and Neobulimina form biofacies 3 and principally occur between 60m and 130m paleodepth. Biofacies 4 is composed of species of Gavelinella, Gyroidinoides and Valvulineria and is abundant from 130m to 600m. However, it is largely replaced by biofacies 5 during times of maximum flooding. A diverse assemblage of species of Lingulogavelinella and Lenticulina characterize biofacies 5. Paleodepths of 600m to greater than 3000m contain abundant species of Osangularia, Pleurostomella, Praebulimina and Quadrimorphina which define biofacies 6 and 7.

A middle bathyal oxygen minimum zone expanded in the early Turonian to include outer-neritic and upper-bathyal regions. Calcareous biofacies 4 and 5 were replaced by

predominately agglutinate biofacies DSA and DSB.

Stratigraphic succession of biofacies in response to sea level change aids in the identification of depositional sequences in the New Jersey coastal plain. Sequence stratigraphy allows correlation of a nearshore biostratigraphic zonation based on benthic species of Epistomina with a planktic foraminiferal zonation in shelf facies in Baltimore Canyon wells.

Evidence for phylogenetic lineages of middle Cretaceous benthic foraminifers is consistent over wide areas. Biostratigraphy and species composition of the studied biofacies are very similar to European and South Atlantic assemblages. Well defined neritic and bathyal biofacies formed during a sudden late Albian species diversification concomitant with the first major Cretaceous flooding of continental margins.

ACKNOWLEDGMENTS

I wish to thank my committee members, Dr. George McGhee and Dr. Robert Sheridan, for their useful comments and criticisms. I would especially like to thank my advisor, Dr. Richard Olsson, for his advice and guidance during the preparation of this dissertation.

Finally, I express my greatest appreciation to my mother and father for their unfailing support throughout this project and my graduate career.

TABLE OF CONTENTS

ABSTRACT.....ii

ACKNOWLEDGMENTS.....iv

LIST OF TABLES.....vi

LIST OF FIGURES.....vii

INTRODUCTION.....1

Structural Setting.....7
Biostratigraphy.....9
Lithostratigraphy.....12
Depositional Environments.....16
Depositional Sequence Stratigraphy.....19
Methods and Techniques.....24

RESULTS.....34

Depositional Sequences of the New Jersey Coastal Plain.....34
Benthic Foraminiferal Distribution - New Jersey Continental Margin.....43
Benthic Foraminiferal Distribution - North Atlantic DSDP Sites.....100

DISCUSSION.....124

Paleoslope Model and Paleoecologic Implications....124
Depositional Sequences and Paleobathymetry of Sea Level Changes.....154
Conclusions.....161

SYSTEMATIC DESCRIPTIONS.....165

REFERENCES.....208

PLATES.....216

VITA.....229

LIST OF TABLES

Table	Descriptions	Page
1	Biofacies of the New Jersey continental margin.	45
2	Key to species abbreviations and symbols used in Oxly cluster and factor analysis.	48
3	Key to species abbreviations and symbols used in BTMA cluster and factor analysis.	54
4	Key to abbreviations used in cluster and factor analysis of Shell 272 and COST B2 species.	65
5	Key to abbreviations used for Shell 586 and 587 species cluster and factor analysis.	77
6	Biofacies of the DSDP sites.	102
7	Abbreviations for DSDP species used in R-mode cluster analysis.	103

LIST OF FIGURES

Figure	Description	Page
1	Paleoslope line (A-A') and continental margin well site locations with structure contours of pre-Mesozoic basement (after Benson, 1984).	4
2	Deep Sea Drilling Project Sites utilized in this study.	6
3	Line drawing interpretation of USGS seismic reflection profile 25 which is nearly parallel to the paleoslope line (from Grow, 1981).	8
4	Principal planktic foraminiferal species employed in the study.	10
5	Lithostratigraphy of the coastal plain wells.	13
6	Diagram illustrating change in lithology from Oxly well downdip into the Baltimore Canyon Trough.	15
7	Concepts of sequence stratigraphy. Depositional model showing system tracts in relation to; A) depth, and B) time (from Haq et al., 1987).	20
8	Middle and late Cretaceous chronostratigraphy and sea level fluctuation cycle chart (after Haq et al., 1987).	23
9	Relative abundance of E. aff. ripleyensis and E. stelligera, Oxly-1A, illustrating typical pattern of downwell contamination in the lower (Albian) marine unit.	26
10	A) Cumulative variance and, B) eigenvalue decay plots of first 10 factors of R-mode analysis of Oxly-1A data.	29
11	A)Cumulative variance and, B) eigenvalue decay plots of first 10 factors of R-mode analysis of DSDP data.	30
12	Correlation between depositional sequence stratigraphy, lithology and ceratobuliminid relative abundance - Oxly-1A.	36

13 Correlation between depositional sequence stratigraphy, lithology and ceratobuliminid relative abundance - BTMA. 40

14 Correlation of depositional sequences of the studied interval - New Jersey coastal plain. 42

15 R-mode cluster analysis of Oxly-1A data with numbered biofaces. 49

16 Sequence stratigraphy and relative abundance distribution of species composing clusters C and D, Oxly-1A. 50

17 R-mode factor analysis, Oxly 1A, showing defined clusters in three dimensional factor space. 53

18 R-mode cluster analysis of BTMA data with numbered biofacies. 55

19 Sequence stratigraphy and relative abundance distribution of species composing clusters G and H, Cenomanian-Turonian sections of BTMA. 56

20 R-mode factor analysis showing defined clusters in three dimensional factor space, BTMA well. 57

21 Sequence stratgraphy and relative abundance distribution of species composing clusters A and B, Oxly 1A. 60

22 Sequence stratigraphy and relative abundance distribution of species composing clusters E and F, Cenomanian-Turonian sections of BTMA. 61

23 R-mode cluster analysis of Shell 272 species data with interpreted biofacies. 66

24 Relative abundance distribution of species comprising Shell 272 clusters K and L. 67

25 R-mode factor analysis showing Shell 272 clusters in three-dimensional factor space. 68

26 R-mode cluster analysis of COST B2 species data with interpreted biofacies. 69

27 Relative abundance distribution of species comprising COST B2 clusters N and P. 70

28	R-mode factor analysis showing COST B2 species clusters in three-dimensional factor space.	72
29	Relative abundance distribution of species comprising Shell 272 clusters I and J.	73
30	Relative abundance distribution of species comprising COST B2 clusters M and R.	75
31	R-mode cluster analysis of Shell 586 species with interpreted biofacies.	79
32	Relative abundance distribution of species comprising Shell 586 clusters S, T and U.	80
33	R-mode factor analysis showing Shell 586 species clusters in three-dimensional factor space.	82
34	Relative abundance distribution of assemblage U′ and factor group T′, Shell 586.	83
35	Relative abundance distribution of species comprising COST B2 clusters Q and O.	86
36	Factor 1 X 3 plot, Shell 586, indicating species factor group T′.	88
37	Relative abundance distribution of species comprising Shell 586 clusters V, X and W.	91
38	R-mode cluster analysis of Shell 587 species data with postulated biofacies.	92
39	Relative abundance distribution of Shell 587 species clusters Y, Z, and CC.	93
40	R-mode factor analysis showing Shell 587 species clusters in three-dimensional factor space.	95
41	Relative abundance distribution of Shell 587 species clusters AA and BB.	98
42	R-mode cluster analysis of DSDP data (based upon loading from three-factor analysis) and proposed biofacies.	104
43	Q-mode cluster analysis of DSDP data (based upon loadings of three-factor analysis) and indicated sample groupings.	105

44	Relative abundance of DSDP species cluster A, showing greatest abundance in sample cluster 5.	106
45	Map showing DSDP sites from which came most of the samples contained in clusters 4 and 5.	108
46	Relative abundance distribution of species cluster B, showing a pattern uncorrelative to any sample cluster.	112
47	Relative abundance of DSDP species cluster C, showing no correlation to any sample cluster, but also showing a preference for lower-latitude, bathyal sites.	114
48	Map showing DSDP sites from which came most of the samples contained in clusters 1, 2 and 3.	117
49	Relative abundance of DSDP species cluster D, plotted against sample clusters, showing greatest abundance in abyssal clusters 2 and 3.	121
50	Downslope distribution of biofacies of the New Jersey Continental Margin.	125
51	Integration of biofacies onto paleoslope baseline.	127
52	Superposition of Baltimore Canyon wells on reconstructed Cretaceous margin profiles along USGS multichannel seismic line 25 (after Steckler et al., 1988).	131
53	Upper Albian to lower Turonian paleoslope model of benthic species from BTMA, Oxly, Shell 272 and COST B2.	132
54	Upper Albian to upper Cenomanian paleoslope model of bathyal and abyssal benthic species.	134
55	Turonian paleoslope model of outer-neritic to middle-bathyal benthic species.	136
56	Diagram illustrating the position and expansion of the oxygen minimum zone from the Albian-Cenomanian to the early Turonian.	139
57	Summary of the major conclusions of the upper Albian to Cenomanian paleoslope model of the New Jersey continental margin.	140

58 Coastal plain stratigraphy of defined biofacies and correlation to depositional sequences. 143

59 Stratigraphy of Baltimore Canyon Trough biofacies with biostratigraphic correlations. 146

60 Stratigraphic ranges of examined species of Gavelinella, Lingulogavelinella and Valvulineria, illustrating late Albian diversification. 151

61 Biostratigraphic ranges of Epistomina species of the New Jersey coastal plain, based upon the BTMA and Oxly wells. 153

62 Correlation of the formations of the New Jersey coastal plain with third order cycles of Haq et al. (1987) and the distribution of biofacies. 155

63 Depositional sequence correlation of Oxly-1A and Shell 272. 158

I. INTRODUCTION

Benthic foraminifers are among the most useful fossils for paleoecologic study because they occur in all marine environments. Many species and genera are known to be restricted in their depth distribution (e.g., Parker, 1954; Phleger, 1956; Bandy, 1960). Thus it is as paleobathymetric indicators that they have received their most widespread use. Paleobathymetric study has traditionally been done by comparing fossil species with the bathymetric ranges of modern homologues or analogues. Also commonly used are non-taxonomic methods including calculation of planktic/benthic ratios and benthic diversity indices, both of which have been shown to have a positive correlation with water depth (e.g., Gibson and Buzas, 1973; Pflum and Frerichs, 1976). However, all these methods share a common problem; the data gathered from fossil species must be correlated to the bathymetric distribution of modern species. This correlation becomes progressively more difficult in older strata which contain many extinct genera and species. This is especially true for the Cretaceous because of the large number of foraminiferal extinctions which occurred at the end of the period.

A more recently developed non-taxonomic method, the paleoslope model, eliminates this problem. This method is a graphic reconstruction of the distribution of

foraminiferal biofacies along a transect (the paleoslope) parallel to the dip slope of the basin. Biofacies are superimposed on the transect and their downdip distance is directly related to paleodepth. Thus no correlation to modern bathymetric distributions is needed. The paleoslope model has been used to construct inner-neritic to upper bathyal biofacies for foraminifers of the upper Cretaceous New Jersey coastal plain (Olsson and Nyong, 1984). This model was subsequently extended into bathyal and abyssal paleoenvironments of the Baltimore Canyon Trough and Deep Sea Drilling Project (DSDP) Sites of the western Atlantic Basin (Nyong and Olsson, 1984). In the Paleocene and Eocene of New Jersey (Olsson et al., 1987) and the Miocene of Maryland (Olsson and Wise, 1987), paleoslope models of neritic biofacies were constructed and used to estimate the relative magnitude of sea level changes.

This study constructs a paleoslope model in older strata than previous studies; the upper Albian through lower Turonian (middle Cretaceous) of the western Atlantic Margin and the North Atlantic Basin. Cretaceous paleoceanography underwent major changes during the middle Cretaceous. Mid-depth water exchange was established for the first time between the Atlantic and the Tethys Ocean (Sliter, 1980). Increase in the volume of oceanic ridges caused the beginning of a eustatic sea level rise which continued until the end of the Cretaceous (Pitman, 1978).

The result was broad continental shelves and epicontinental seas which provided large, new habitats for benthic foraminifers.

Prior to this time, mid-depth waters were weakly stratified and were occupied by low-diversity assemblages of Foraminifera (Sliter, 1980). As middle Cretaceous sea level rose, species radiated into shelf and slope environments and developed characteristic assemblages. Many new genera appeared for the first time including, Globorotalites, Gyroidinoides, Lingulogavelinella Neobulimina, Osangularia, Pleurostomella, Quadrimorphina and Valvulineria. Major increases in species diversity accompanied these radiations especially among the genera Epistomina (Ohm, 1967), Gavelinella (Malapris, 1965; Price, 1977), Lingulogavelinella (Malapris-Bizouard, 1967) and Valvulineria (Jannin, 1967).

The western Atlantic Margin of New Jersey contains an extensive record of middle Cretaceous marine strata (Libby-French, 1984; Olsson et al., 1988; Poag, 1976). Wells used in this study include, in the coastal plain, the Oxly and Brick Township Municipal Authority (BTMA) wells (figure 1) and, in the Baltimore Canyon Trough, the Continental Outer Shelf Test (COST) B2 and Shell Oil Company 272, 586 and 587 wells (figure 1). In addition, many DSDP Sites, which contain middle Cretaceous sequences rich in deep-water benthic

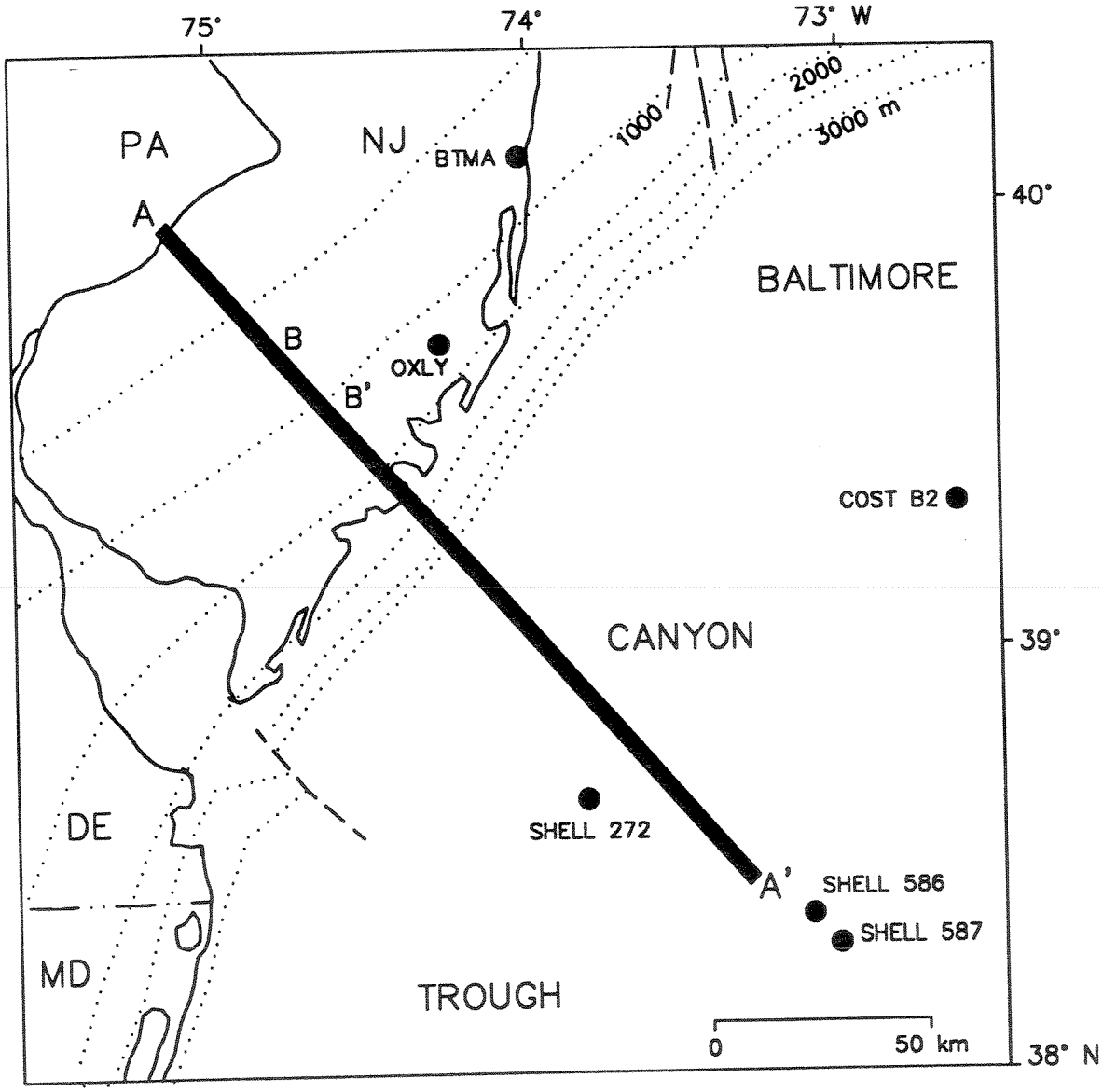


Figure 1: Paleoslope line (A–A') and continental margin well site locations with structure contours of pre–Mesozoic basement (after Benson, 1984).

foraminifers, were examined (figure 2). The data set made it possible to trace biofacies from inner-neritic to the abyssal paleodepths.

Five major objectives define this study.

1. To establish biofacies and a paleoslope model for Albian, Cenomanian and lower Turonian Foraminifera of the western Atlantic margin and North Atlantic Basin. The model will place relative paleodepth limits on each biofacies, thereby providing valuable information on the paleoecology of constituent species. Biofacies migration in response to sea level change will aid in the identification of depositional sequences.

2. To develop a computer-storage base of information on the relative abundance distribution of the middle Cretaceous species. This base will provide a ready source of comparison for future similar models of middle Cretaceous stratigraphic intervals in other basins.

3. To provide an accurate model for paleo-bathymetric estimates in the middle Cretaceous. Such estimates may be used for more precise geohistory analysis in which paleodepths are needed as load factors (Watts, 1981). Also estimation of the magnitude and duration of relative sea level changes may help to resolve whether they are primarily due to the effects of eustacy (Haq et al., 1987) or flexure (Watts, 1982).

4. To provide information on the diversification and

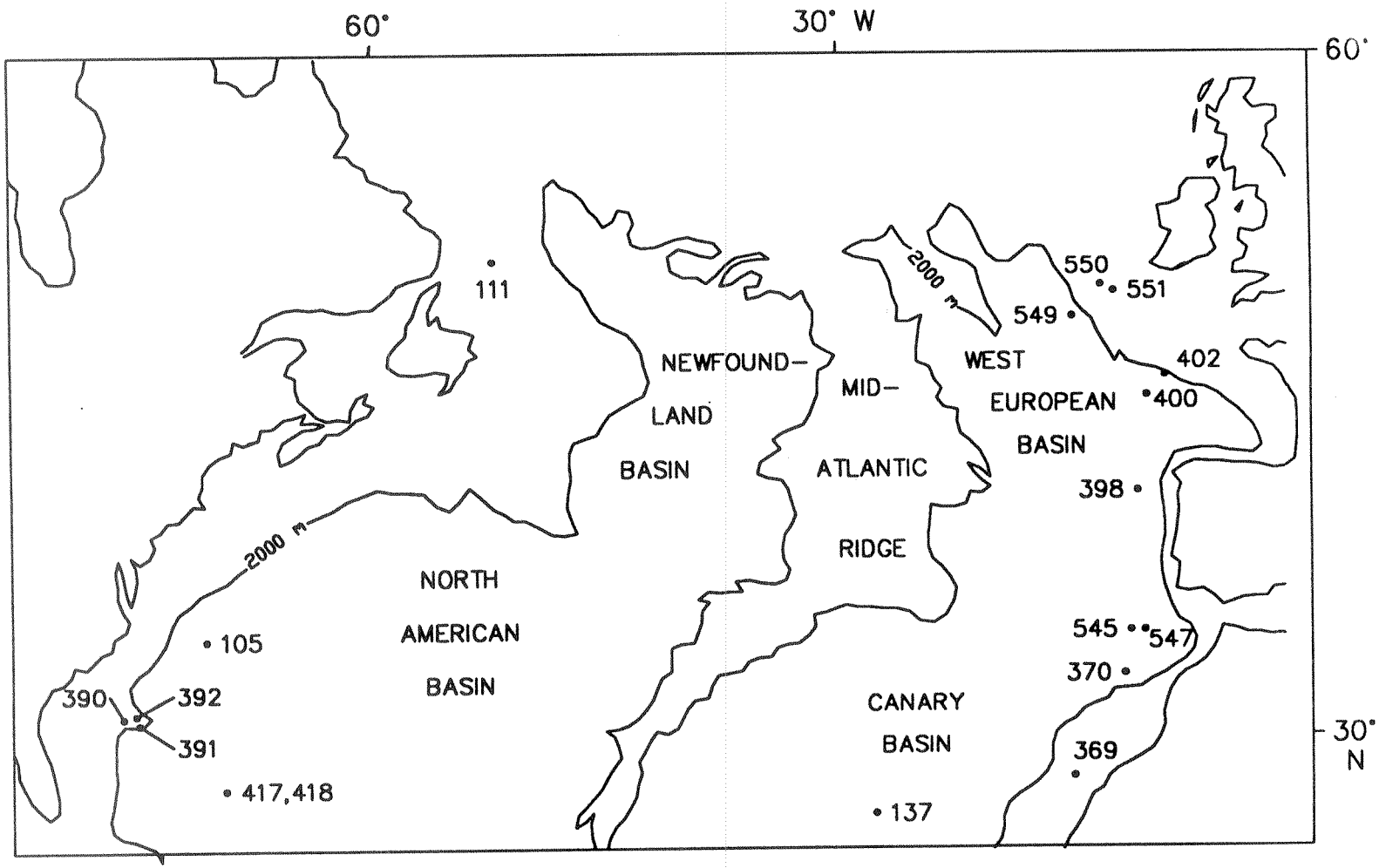


Figure 2: Deep Sea Drilling Project Sites utilized in this study.

and biostratigraphy of middle Cretaceous benthic foraminiferal genera and species. A detailed taxonomic study should allow for better estimation of the timing and rate of the diversification as well as more precisely defining the biostratigraphic ranges of many species.

5. To analyze the distribution of species to yield information on middle Cretaceous paleobiogeography and paleoceanography. The numerous and widespread DSDP samples examined will allow recognition of any regional or latitudinal gradients among deep-sea species. The extent and nature of middle Cretaceous, anaerobic, bottom-water environments should also be clarified by biofacies distribution.

Structural Setting

A major requirement for use of the paleoslope model is a structurally uncomplicated setting so that downdip distance along the paleoslope transect can be used as a direct measure of increasing paleodepth. The western North Atlantic passive margin provides such a setting. Lithostratigraphic intervals can be traced seismically without major interruption, from the coastal plain into the ocean basin (figure 3).

Extending from the New Jersey coastal plain, the paleoslope transect crosses the Baltimore Canyon Trough at

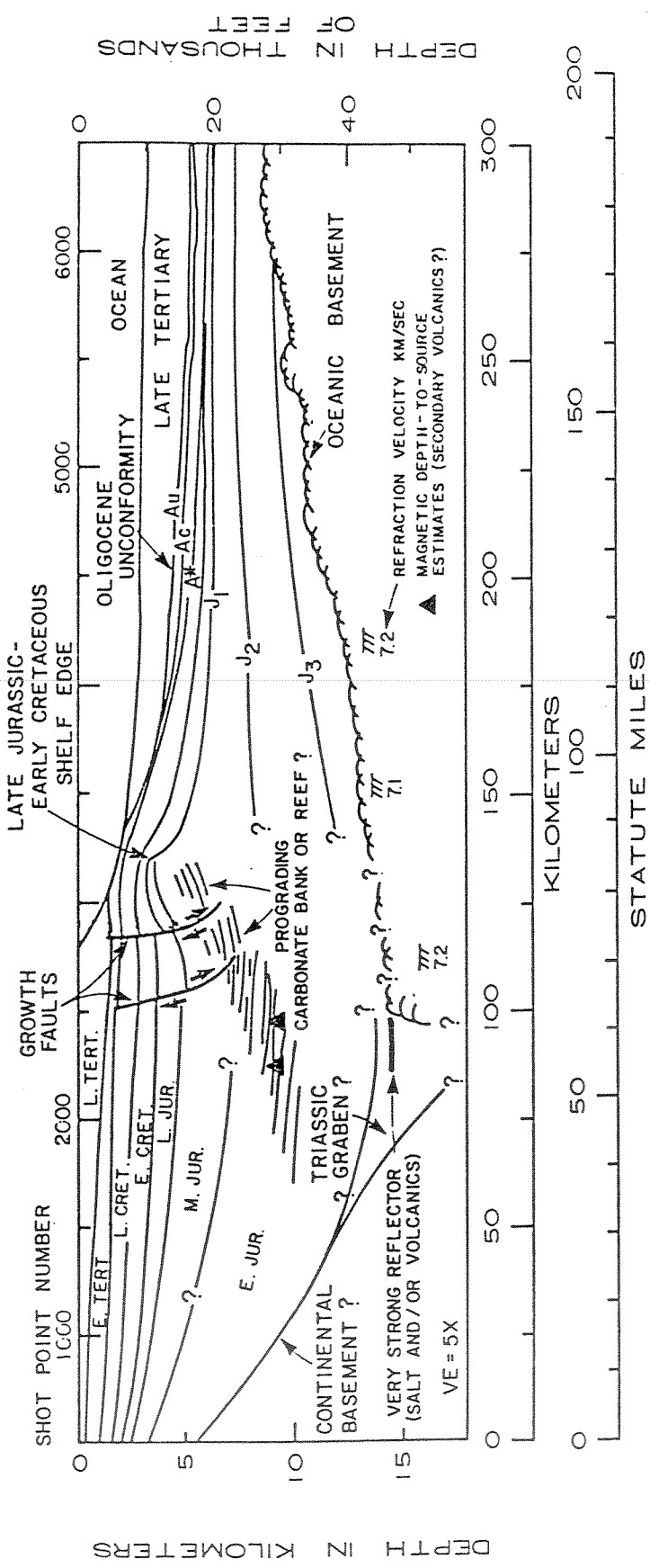


Figure 3: Line drawing interpretation of USGS seismic reflection profile 25 which is nearly parallel to the paleoslope line (from Grow, 1981).

its widest and structurally simplest area (Grow, 1981). The Baltimore Canyon is a basin filled with rapidly seaward-thickening sediments, lying under the present outer continental shelf from Virginia to New Jersey (figure 1). The trough reaches a maximum width of approximately 150km and a maximum sediment thickness of about 16km off New Jersey. Strata range in age from Jurassic to Recent (Grow, 1981). The formation of the Baltimore Canyon Trough was related to the rifting between North America and Africa, which began in Triassic time, and the initiation of sea floor spreading in the early Jurassic. Seismic reflection profiles indicate relatively undeformed post-rift sediments to a depth of about 13km, underlain by between three and five kilometers of synrift deposits (Grow, 1981).

The oceanic basins investigated (figure 2) represent a tectonically stable region dominated by thermal subsidence of the oceanic basement.

Biostratigraphy

Except in coastal plain wells, planktic foraminiferal biostratigraphic control is excellent. The zonation by Leckie (1984) proved most applicable to the present study. The ranges of the most useful species are provided in figure 4.

The middle Albian of the North Atlantic is characterized by common Ticinella primula and T. roberti

Figure 4: Principal planktic foraminiferal species employed in the study.

which also occur rarely in the lower upper Albian. Ticinella raynaudi and Rotalipora subticinensis are abundant in the lower upper Albian whereas the uppermost Albian is noted for abundant Planomalina buxtorfi. Rotalipora evoluta is the only index species encountered which is restricted to the lower Cenomanian where it is very rare in contrast to abundant Rotalipora appenninica, R. gandolfii, Praeglobotruncana delrioensis and Hedbergella portsdownensis. The upper Cenomanian contains dominant Rotalipora cushmani and R. greenhornensis and less common R. deeckei. The lower Turonian is characterized mainly by Marginotruncana imbricata, M. marginata and Whiteinella archaeocretacea whereas M. angusticarinata, M. coronata and M. renzi are abundant in the upper Turonian. Praeglobotruncana stefani, though rarely present in the Cenomanian, is abundant throughout Turonian sections.

The New Jersey coastal plain wells present a persistent problem in stratigraphic correlation. Most useful planktic indicators lived relatively deep in the water column and were largely excluded from nearshore regions. During the late Cretaceous, the globotruncanids and rotaliporids apparently possessed such a lifestyle whereas shallow-water areas were dominated by stratigraphically long-ranging species of hedbergellids, globigerinellids and heterohelicids (Olsson, 1977).

However, species of the benthic genus Epistomina were common in the coastal plain wells. These species have been useful in zonations in middle Cretaceous shallow-marine deposits (e.g., Ohm, 1967; Hart, 1984; Williamson and Stam, 1988) and are the primary indices used in the New Jersey coastal plain in this study.

Lithostratigraphy

Subsurface stratigraphy of the New Jersey coastal plain shows intergrading transgressive and regressive deposits (figure 5). Two major transgressive intervals are present. The youngest is represented by the extensive, dark gray, clayey silts of the Bass River Formation which attains a maximum thickness of 500 feet in the coastal plain wells. The older transgressive interval, an unnamed, upper Albian marine unit has a maximum thickness of 240 feet. It is composed of clayey silts and fine-grained sands which pinch out about 25km downdip of the farthest landward extent of the Bass River formation (Olsson et al., 1988).

The regressive sections are represented by fluvial and deltaic, medium- to coarse-grained, quartzitic sands of the Potomac and Raritan formations (figure 5). Stratigraphic correlation of these units is often difficult because they are similar in lithology. This similarity prevents definitive correlation of a relatively thin, non-marine

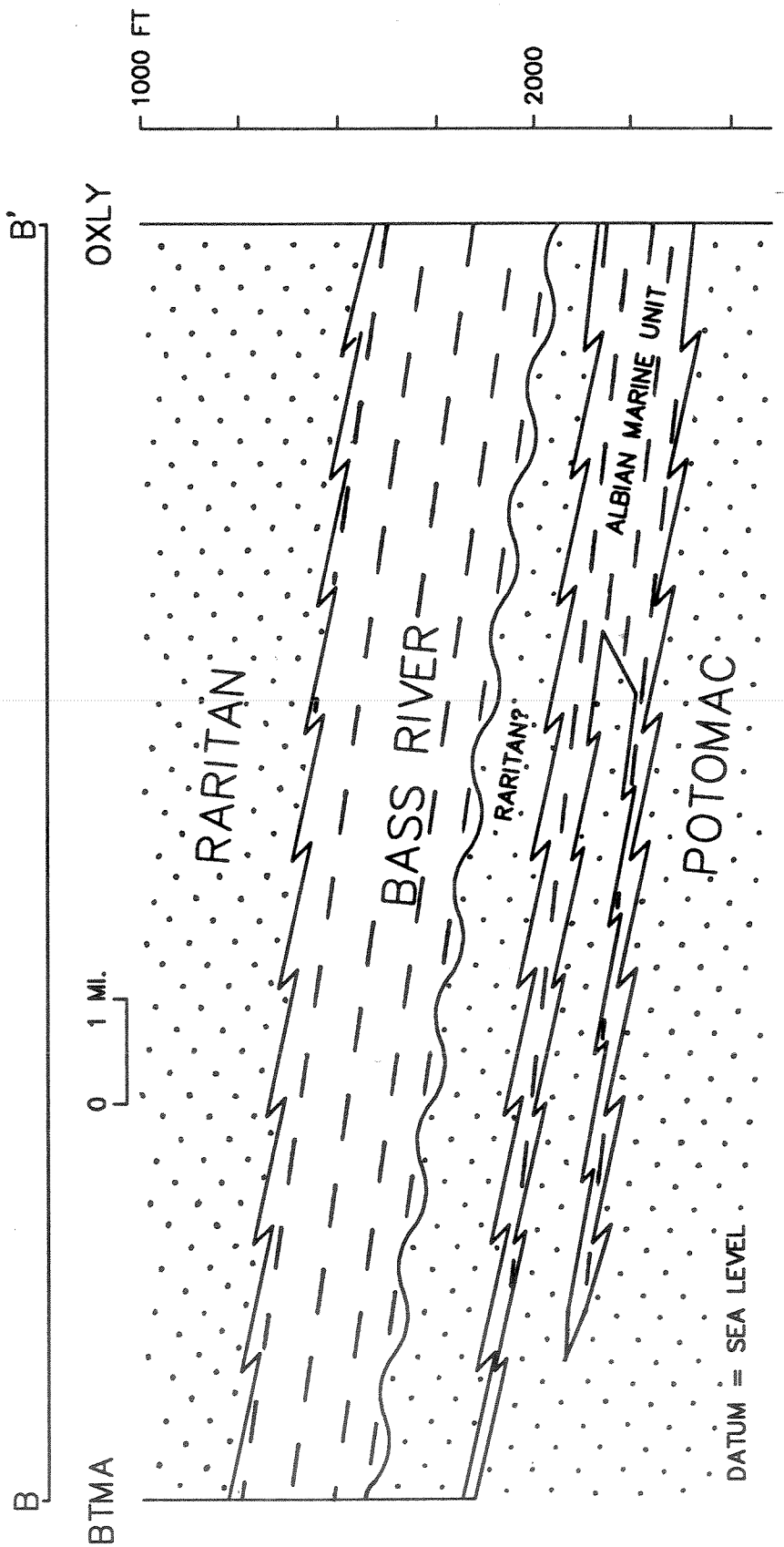


Figure 5: Lithostratigraphy of the coastal plain wells.

sand which separates the two transgressive sections (figure 5).

The wells of the Baltimore Canyon Trough show a marked change in lithology (figure 6). The sands and silts of the coastal plain are replaced by a more uniform lithology of fossiliferous calcareous claystones and shales. In the Baltimore Canyon wells, however, three major exceptions to this lithology are noted; a non-fossiliferous, medium-grained, quartzitic sand in the lower upper Albian of the COST B2 well, a non-fossiliferous, sandy silt separating Albian and upper Cenomanian sections in the Shell 272 well, and a lower Turonian pyritic, carbonaceous shale in the COST B2 well (figure 6).

Seaward of these wells the dominance of fine-grained sediments is much greater. Shell wells 586 and 587 show monotonous sequences of calcareous claystone interbedded with some thin limestone layers. The limestones are especially common near the Albian/Cenomanian and Cenomanian/Turonian boundaries. Stratigraphic thicknesses generally decrease from shelf to slope sites. For example, at least 400 feet of Vraconian (latest Albian) aged sediment is present in the COST B2 well whereas less than 30 feet is noted in the Shell 586 well. Presumably, the decrease in thickness represents lower but more continuous, sedimentation rates as the Shell 586 well has the most complete stratigraphic sequence examined. The nearby Shell

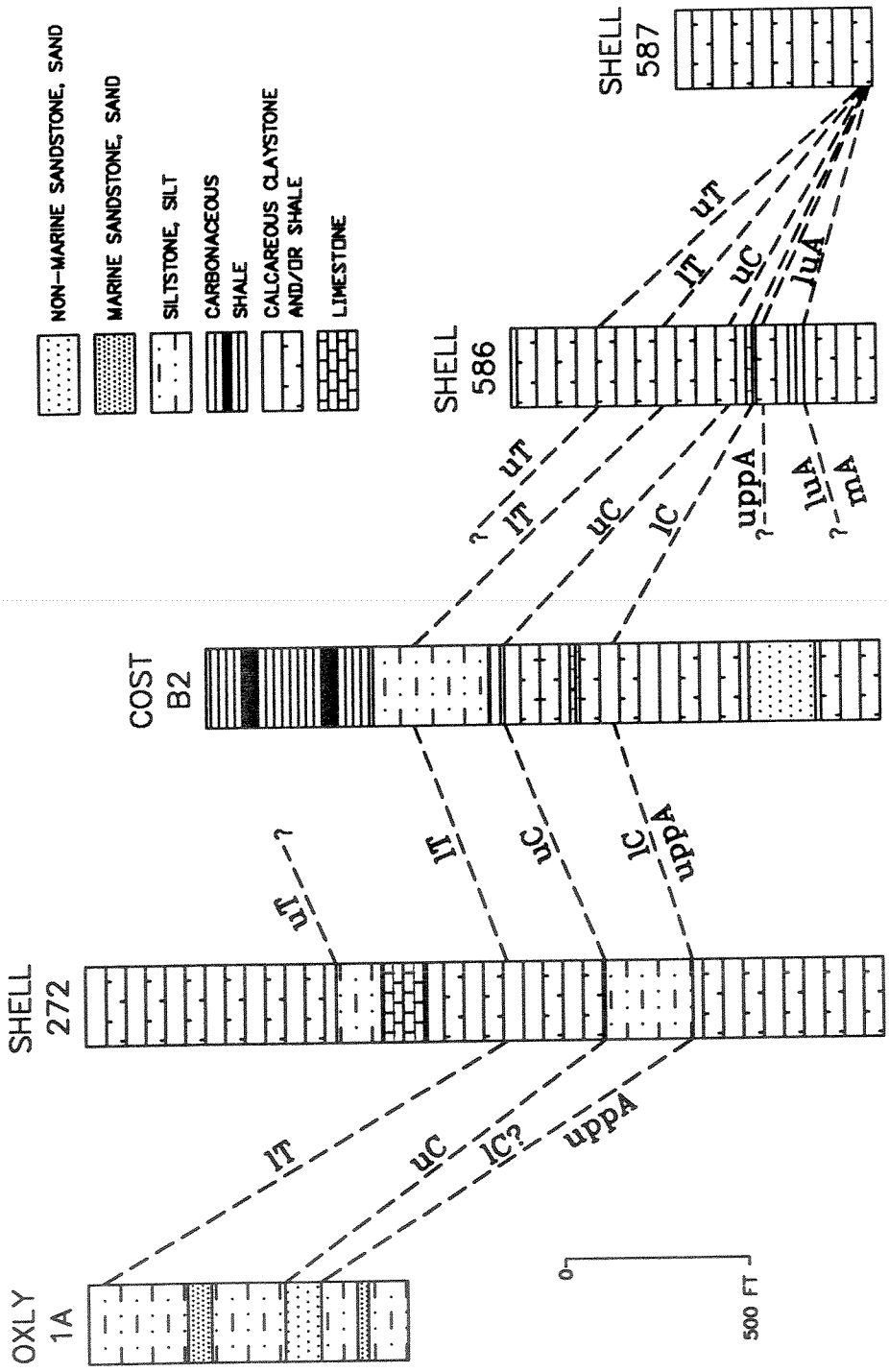


Figure 6: Diagram illustrating change in lithology from Oxly well downdip into the Baltimore Canyon Trough. Note: column thicknesses are proportional but relative position of columns is arbitrary (uT = upper Turonian, lT = lower Turonian, uC = upper Cenomanian, lC = lower Cenomanian uppA = uppermost Albian, luA = lower upper Albian, mA = middle Albian).

587 well shows only a Turonian section overlying a Barremian sand. Apparently, the Aptian-Cenomanian section was removed by a localized disturbance.

Carbonaceous clays dominate most North Atlantic DSDP Sites below the upper Albian. In the North American Basin, these carbonaceous sediments are defined as the Hatteras Formation and they are the predominant lithology up to the upper Cenomanian. The Hatteras Formation is overlain by non-calcareous, variegated clays of the Plantagenet Formation (Jansa et al., 1980).

In the eastern North Atlantic, however, upper Albian nannofossil oozes and marls are widely distributed (Arthur et al., 1979; Jansa et al., 1977). Calcareous sediments persist until the uppermost Cenomanian above which carbonaceous sediments are present at many localities (Cunningham and Gilbert, 1985).

Depositional Environments

The New Jersey coastal plain contains a middle Cretaceous alternation of shallow-marine and fluvial environments (Olsson et al., 1988; Petters, 1976). The transgressive deposits are indicative of two periods of middle Cretaceous sea level rise which may correlate with eustatic events postulated by Haq et al., 1987; a late Albian event which affected only the seaward margin of the coastal plain, and a late Cenomanian to early Turonian sea

level rise which flooded the entire area. The non-marine sand separating the two marine intervals (figure 5) most likely represents lower Cenomanian fluvial deposits known to underlie the Bass River south of New Jersey (Olsson et al., 1988).

The predominance of marine sediments in the Baltimore Canyon Trough resulted from the general rise in sea level which began in the late Albian. Abundant marine microfossils indicate middle- to outer-neritic environments (Poag, 1980) although intergradation with deltaic facies occurs along the landward margin (Sheridan et al., 1978). An example of these deltaic facies includes the sandy silt which separates Albian and upper Cenomanian calcareous clays in the Shell 272 well (Libby-French, 1984). The silt is tentatively correlated with the lower Cenomanian fluvial sand of the coastal plain (figure 6). This correlation suggests that the regressive interval corresponds to the relative sea level fall shown on the cycle chart of Haq et al. (1987) above the Albian/Cenomanian boundary. In response, fluvial and/or deltaic facies prograded out at least to the Shell 272 well. Conversely, during times of rapid sea level rise, a wide continental shelf would be created and may have acted as a trap for coarser sediment (Tucholke and Vogt, 1979). This trapping of sediment would result in fine-grained deposits and low sedimentation rates

in seaward areas such as the Shell 586 and 587 wells.

The widespread occurrence of organic-rich facies in the DSDP Sites indicates that anoxic bottom-water conditions persisted in the North Atlantic from the Barremian to the Cenomanian (Jansa et al, 1980). Likely causes of anoxia include barriers to deep-water exchange with the Pacific and Tethys, at such points as the Gibraltar and Panama straits (Arthur, 1979), coupled with considerable deposition of sediment and terrestrial organic detritus from surrounding land masses (Sheridan et al., 1978). Paleodepth estimates for more normal oceanic sediments found atop seamounts indicate that these poorly-oxygenated waters did not extend to depths shallower than about 2000m (Tucholke and Vogt, 1979). The late Albian resumption of carbonate deposition in the eastern Atlantic may have resulted from improved oceanic circulation, as the Atlantic continued to open, and from an end to input of terrestrial sediment and organic detritus as deltaic sources were flooded during sea level rises (Arthur, 1979).

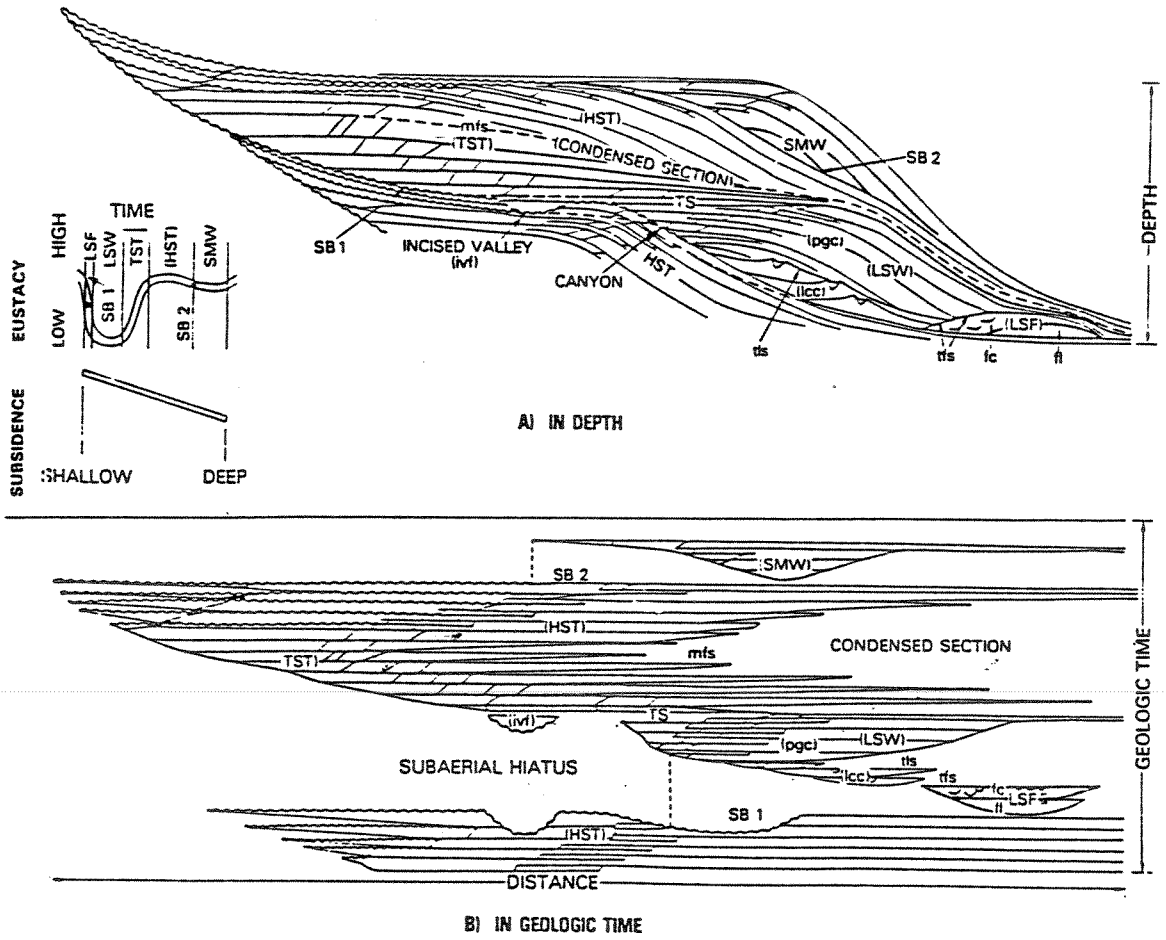
A return to low-oxygen environments occurred in late Cenomanian and early Turonian outer neritic and bathyal depths (Thiede and van Andel, 1977). These environments may reflect an expansion of the mid-depth oxygen minimum zone resulting from an increase in surface productivity over very wide continental shelves (Cunningham and Gilbert, 1985). In this study, organic-rich, bathyal sediments are

noted from eastern Atlantic DSDP Sites and from a lower Turonian section in the COST B2 well.

Depositional Sequence Stratigraphy

Eustatic change in sea level has occurred throughout Phanerozoic time. Similar patterns of coastal onlap from different continental margins partially reflect eustatic sea level changes (Vail et al., 1985). The succession of sediments which are deposited during one complete sea level cycle (i.e., from a sea level fall, through subsequent rise and ending with the next fall) is defined as a depositional sequence. Sequences are composed of different sections of genetically related strata (tracts) deposited during different phases of the sea level cycle (figure 7)(Haq et al., 1987).

Two types of lowstand tracts can occur depending on the rate of eustatic sea level fall. If the rate of sea level fall is rapid, it may exceed the rate of subsidence at the shelf edge. In this case, the shelf is exposed to erosion and a type 1 unconformity is produced. River valleys incise and feed sediment directly to the continental rise, producing turbidity currents and submarine fans (lowstand fan systems tract). If, however, the rate of eustatic sea level fall is slower than the rate of subsidence at the shelf edge, only landward portions of the shelf may be exposed (type 2 unconformity) as shelf



LEGEND

SURFACES

(SB) SEQUENCE BOUNDARIES
- (SB 1) = TYPE 1
- (SB 2) = TYPE 2

(DLS) DOWNLAP SURFACES
- (mfs) = maximum flooding surface
- (tfs) = top fan surface
- (tls) = top leveed channel surface

(TS) TRANSGRESSIVE SURFACE
- (First flooding surface above maximum regression)

SYSTEMS TRACTS

HST = HIGHSTAND SYSTEMS TRACT

TST = TRANSGRESSIVE SYSTEMS TRACT

LSW = LOWSTAND WEDGE SYSTEMS TRACT
- ivf = incised valley fill
- pgc = prograding complex
- lcc = leveed channel complex

LSF = LOWSTAND FAN SYSTEMS TRACT
- fc = fan channels
- fl = fan lobes

SMW = SHELF MARGIN WEDGE SYSTEMS TRACT

Figure 7: Concepts of sequence stratigraphy. Depositional model showing system tracts in relation to; A) depth, and B) time (from Haq et al., 1987).

margin facies prograde over the shelf edge onto the slope (shelf margin wedge systems tract).

When sea level rises at an increasing rate, transgressive facies (transgressive systems tract) migrate over the lowstand deposits. Transgression continues until the rate of sea level rise reaches a maximum value. At this time, maximum flooding occurs and depositional centers of terrigenous sediment have moved considerably landward. More seaward sites thus experience sediment "starvation" and the formation of condensed sections. As the rate of sea level rise decreases, however, progradation of highstand deposits result (the highstand systems tract) and continues until abruptly terminated by the next sea level fall.

The boundaries between the systems tracts provide three major surfaces useful in depositional sequence identification. The sequence boundary is a type 1 or 2 unconformity which separates older highstand deposits and younger lowstand tracts. The transgressive surface occurs above lowstand deposits and marks the onset of relatively rapid sea level rise. The maximum flooding surface, at the top of the transgressive systems tract, marks the point of maximum rate of eustatic sea level rise. It often correlates with condensed stratigraphic intervals in open marine sections.

A global cycle of sea level change is an interval in which relative rise and fall of sea level occurs on a global scale. Three orders of magnitude have been recognized (Haq et al., 1987) (figure 8). Two first order cycles characterize Phanerozoic time, the second beginning in the middle Triassic. Second order cycles (supercycles) are grouped together in supercycle sets ranging in duration from 10 to 80 million years. These, in turn, are divided into third order cycles which range from one to ten million years in duration. The studied interval is contained within the Upper Zuni A (UZA) supercycle set, supercycle UZA-2, third order cycles UZA 2.1 through 2.5 (figure 8). Haq et al. (1987) define stage boundaries at maximum flooding surfaces (indicated by dashed lines in figure 8) thus assuming these events are globally simultaneous. They define the Albian/Cenomanian boundary at the maximum flooding surface of UZA 2.2 whereas the Cenomanian/Turonian boundary is set at the surface of UZA 2.5 (figure 8). This method of defining stage boundaries sometimes provides results which are in disagreement with standard chronostratigraphy (see below, p. 37). Unless otherwise noted, stage boundaries are set in this study based upon planktic foraminiferal biostratigraphy.

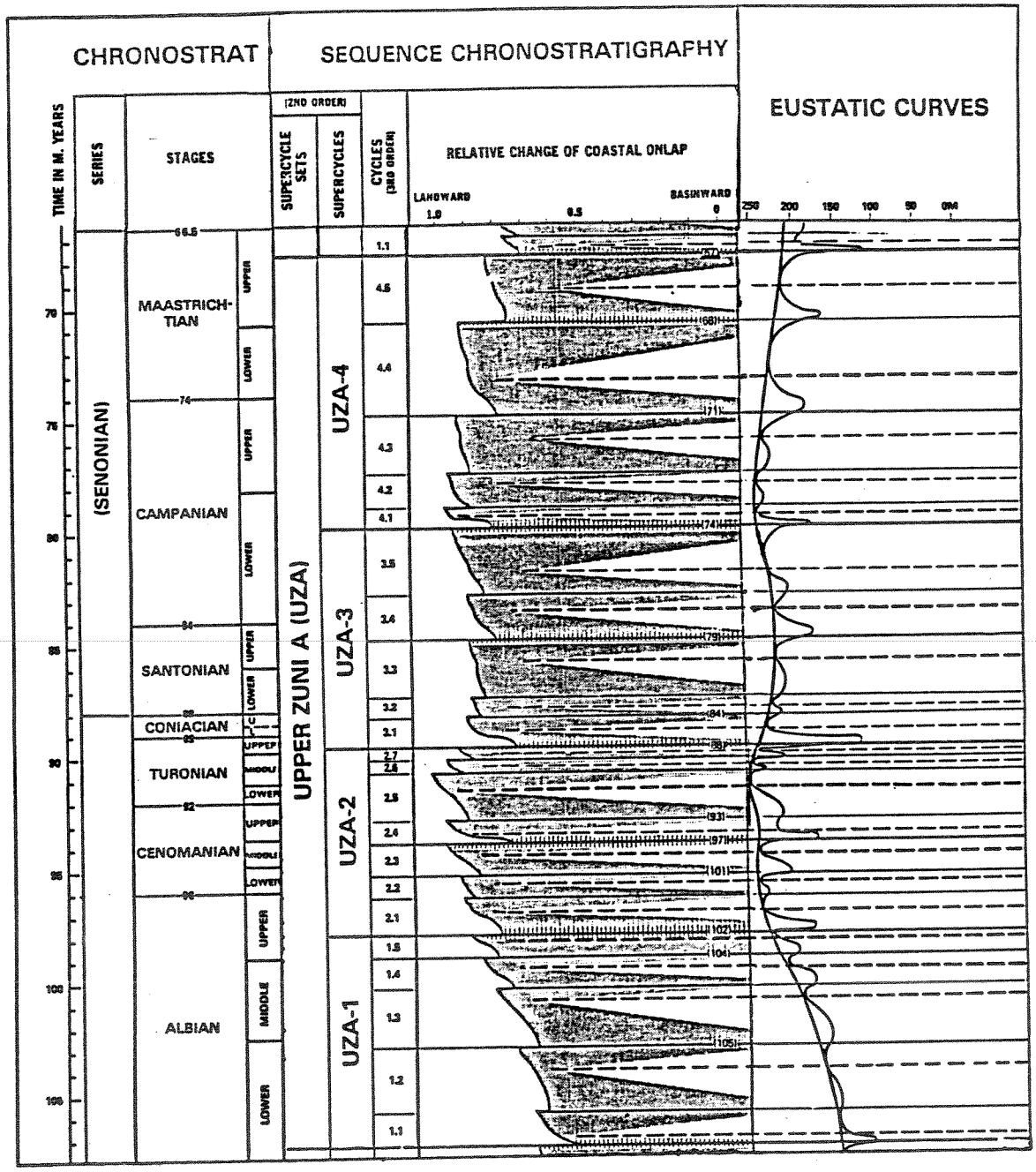


Figure 8: Middle and late Cretaceous chronostratigraphy and sea level fluctuation cycle chart (after Haq et al., 1987).

Methods and Techniques

Abundance counts of 300 specimens per sample were conducted when possible. A large majority of samples contained at least 200 specimens and no sample with fewer than 100 foraminifers was used. A total of 286 samples were analysed, the great majority showing no significant signs of dissolution. Relative abundance data is stored in the CHECKLIST II computer program (Phillips, 1985) and is available from the author upon request. Washed residue was available from the Baltimore Canyon Trough wells. DSDP core samples and unwashed residue from the Oxly and BTMA wells were treated and washed with sodium carbonate. When possible, the light fraction of the residue was then "floated", using tetrachloroethylene, a dense solvent.

Middle Cretaceous marine strata of the western Atlantic margin are absent in outcrop. Only rotary-cutting samples were available for study from coastal plain and Baltimore Canyon Trough wells. Downwell contamination in these samples was a persistent problem. In general, this problem can be minimized by eliminating rare and/or sporadic species from the analysis and by using only last appearance data as stratigraphic markers. This method also minimizes the effects of displaced species. However, downwell contaminants can be commonly and persistently present if they are extremely dominant, in situ components in an overlying section. Such a situation can be

recognized by a sharp break in relative abundance downwell from the in situ zone to the contaminated interval. Abundance then generally continues to decrease farther downwell. Figure 9 illustrates this effect in the Oxly well. The species Epistomina aff. ripleyensis and E. stelligera are abundant components of the Bass River formation as well as being common in the lower (Albian) marine unit. In the older section, their abundance is much lower and decreases markedly downwell, even though other species of Epistomina remain abundant. The occurrence of these two species in the lower marine unit most probably represents downwell contamination. Consequently, they were eliminated from the analysis of the section.

When planktic foraminiferal indices are abundant, the magnitude of contamination is obvious. Planktic indices are rare in the coastal plain wells but a few sidewall cores were available from the Toms River and Lavalette wells and serve as a reference of in situ benthic species with which to compare the Oxly and BTMA assemblages. Also a significant amount of downwell contamination results in an extremely heterogeneous fauna showing a mix of both abundant, but nonsynchronous biostratigraphic markers and biofacies elements indicative of different paleoenvironments. This thorough mixing of assemblages also often results in a nearly invariable relative

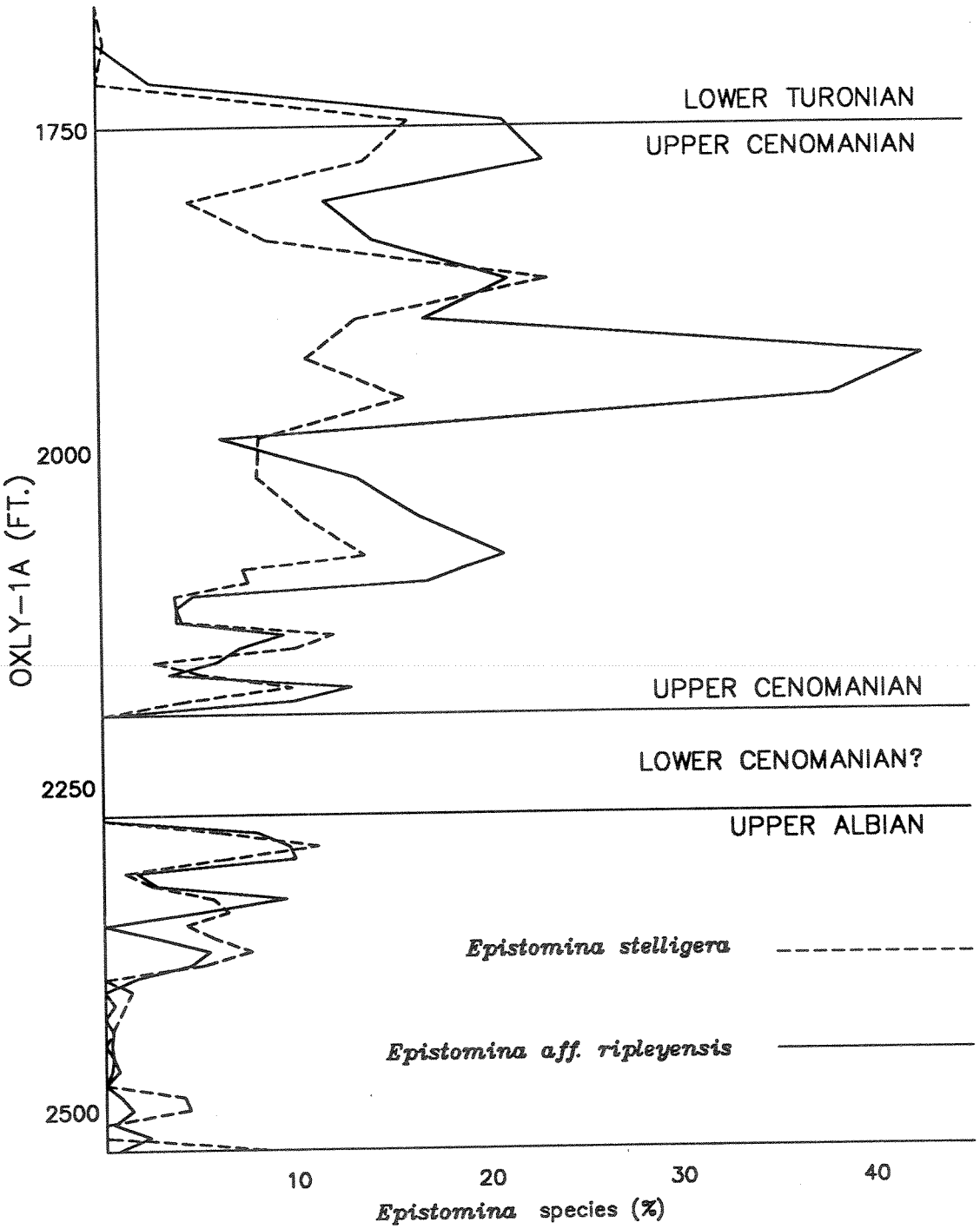


Figure 9: Relative abundance of E. aff. ripleyensis and E. stelligera, Oxly 1A, illustrating typical pattern of downwell contamination in the lower (Albian) marine unit.

abundance distribution among foraminifers recovered. Based on these criteria, highly contaminated samples were eliminated from the analysis. Examples include the Albian section of the BTMA well and certain COST B2 Albian samples from below a well depth of 8500 feet.

The relative abundance data of the most common in situ benthic species, occurring in not less than 30% of the samples examined, were subjected to quantitative analysis. Both R-mode cluster and factor analyses were performed on an IBM PC microcomputer utilizing the SYSTAT statistical system (Wilkinson, 1986). Because samples tended to be dominated by a small number of species, the Pearson correlation coefficient, which is insensitive to size displacement in the data matrix, was the similarity index used in the cluster process. Factor analysis (using VARIMAX rotation - Davis, 1986) was performed upon a correlation coefficient matrix generated from matrixes of the relative percent abundance of species.

Computation of a cophenetic correlation coefficient for the cluster dendrograms proved infeasible using the SYSTAT system. The validity of the clusters obtained was thus based upon more subjective criteria: clusters were observed to be well-formed, without any "chaining"; the combined relative abundance data of a group of species in a cluster characterized discrete sections of wells (e.g, see figures 16 and 19 below); similar species

groupings were defined in multidimensional factor space and when the derived factor loadings were run through cluster analysis, clusters similar to those obtained directly from the abundance data were derived, and; three different linkage methods (complete, average and single - Romesburg, 1984) resulted in the formation of the same clusters. Because of this similarity, complete linkage is used solely for its visual effect of producing globular, compact groupings.

Factor analyses were limited to three factors. This number was chosen because additional factors showed a marked decrease in variance. This is also indicated by a sharp break in the rate of eigenvalue decay. The values for the Oxly 1A well provide a typical example (figure 10).

However, an exception was the analysis of DSDP sites which involved a large number of species from many localities. Three factor R-mode analysis accounted for only 28% of the total variance. However, cumulative variance and eigenvalue decay show no obvious slope breaks beyond factor 2 and instead show an almost linear pattern (figure 11). Thus additional factors do not account for much more variance. Q-mode analysis gave similar results.

The factor analyses indicate that the data are too complex to be adequately pictured in one-dimensional

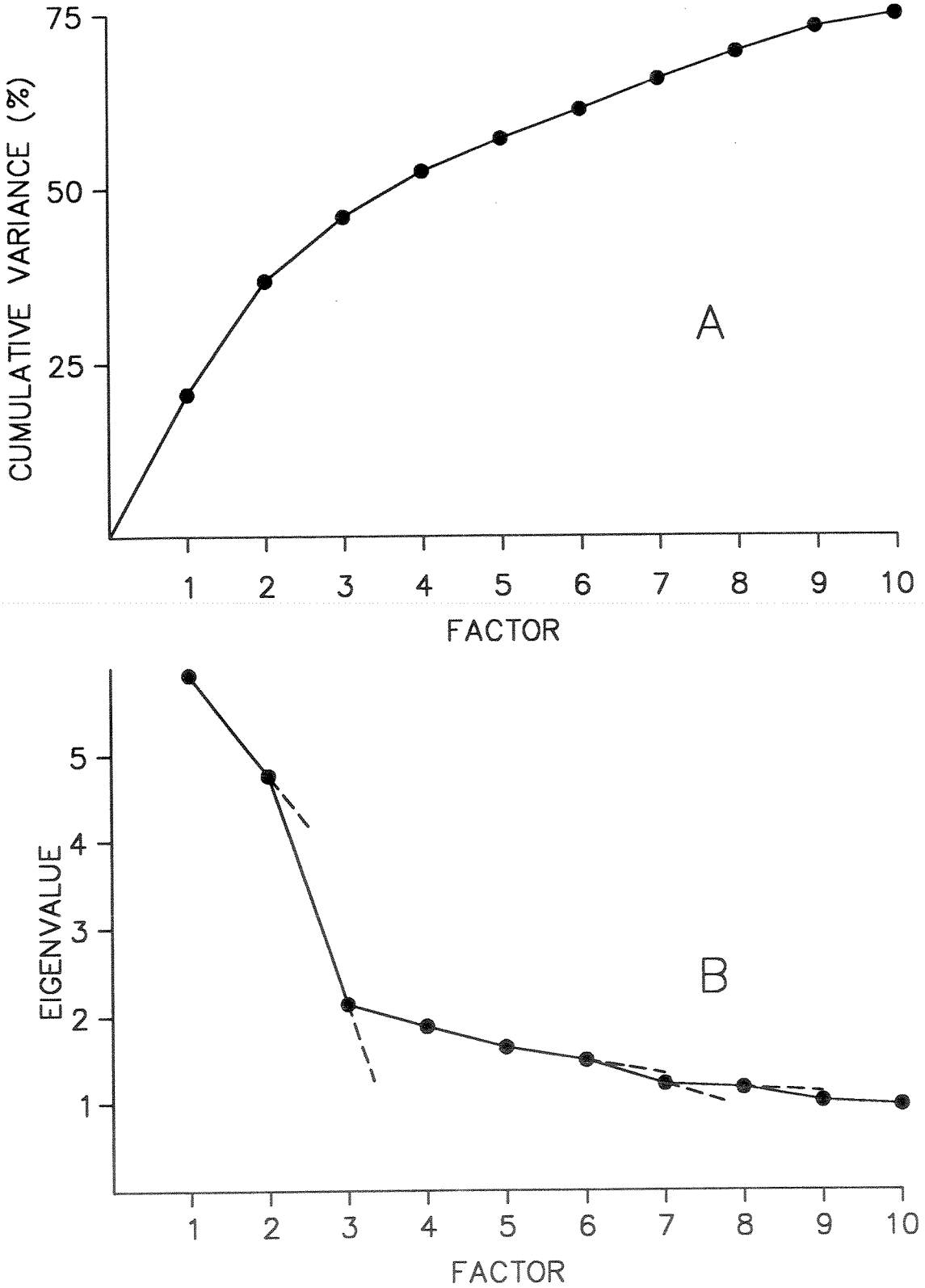


Figure 10: A) Cumulative variance, and, B) eigenvalue decay plots of first 10 factors of R–mode analysis of Oxly 1A data.

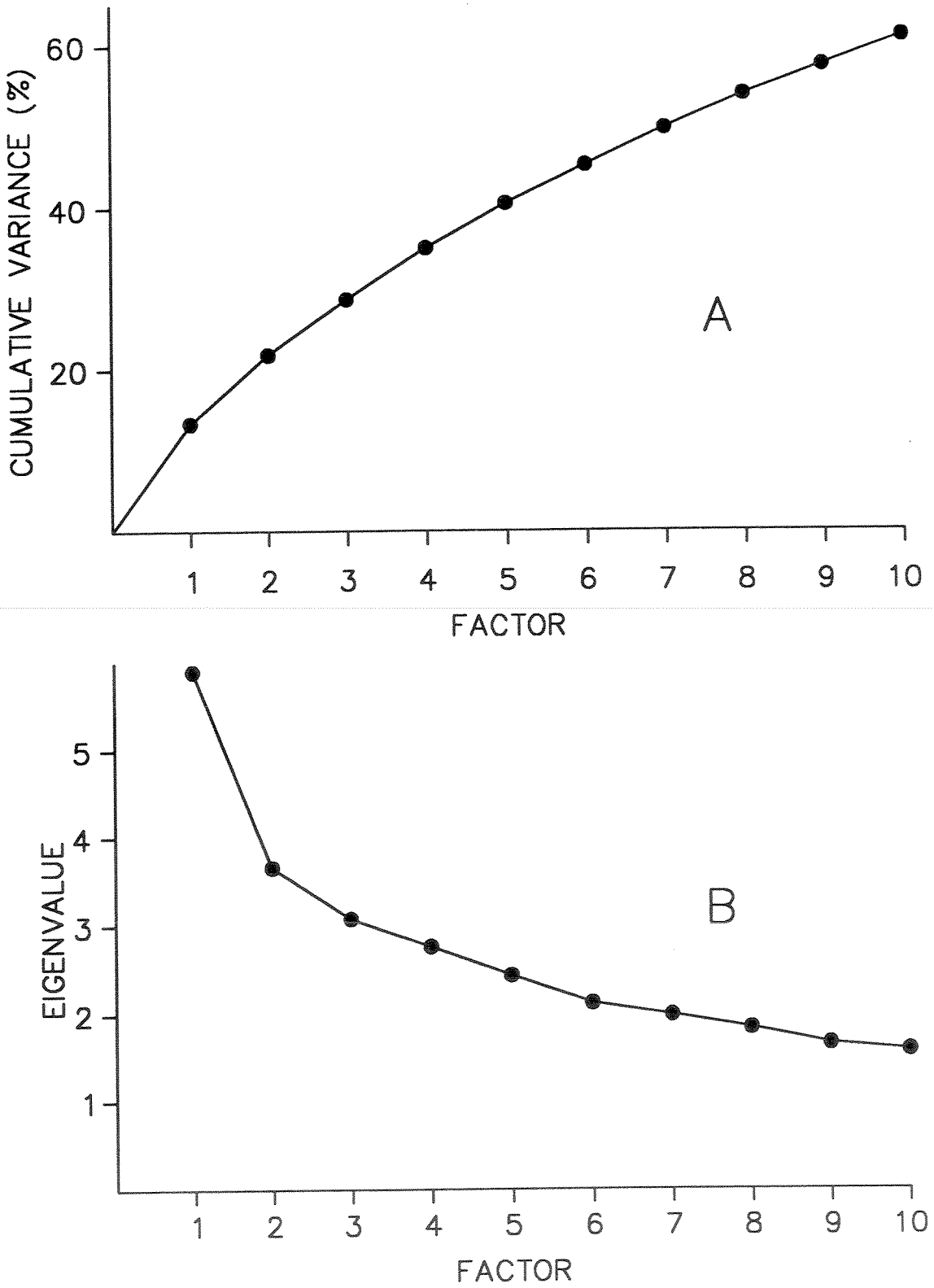


Figure 11: A) Cumulative variance and, B: eigenvalue decay plots of first 10 factors of R–mode analysis of DSDP data.

cluster analysis. When both R- and Q-mode cluster analyses were run, one large grouping and a few isolates of low similarity resulted. Rather than reduce the size of the data matrix, R- and Q-mode analyses were performed on matrices of factor loadings derived from a three-factor analysis and using the Euclidean Distance Coefficient. Although three factors account for a small amount of variance, it is presumably the most important part of the total variance. Cluster analysis then only needs to reduce three dimensions to one to obtain a representation of similarities in the original data matrix.

Recurrence of species clusters and factor groupings in different localities define biofacies. Inclusion within a biofacies requires that a species be a dominant constituent in similar assemblages from at least two different sites. Biofacies are then superimposed along strike onto the paleoslope transect. By assuming a paleogradient for the margin similar to that of today (1m/km), downdip distance of a biofacies along the paleoslope transect is directly related to paleodepth. Because the paleoslope is low, horizontal distance along the transect can be taken as a close approximation of downdip distance. In response to sea level changes which occurred during the middle Cretaceous, biofacies migrated up and down slope. Their horizontal distribution is repeated in their vertical stratigraphic distribution in

accordance with Walther's Law of Succession of Facies. As the relative paleodepth ranges of the biofacies will be known from the paleoslope model, the distance the assemblages migrate along slope can be used to estimate the absolute magnitude of paleodepth variation that occurred during sea level changes. The paleodepth of DSDP biofacies were estimated by backtracking the sites used, when possible. Backtracking was conducted using the empirical age-depth curve for the Atlantic of Tucholke and Vogt (1979) and the method of de Graciansky et al. (1985) for removal of the effects of sediment loading. The water depth zonation used is (after Sliter, 1977):

Neritic (shelf)	0-200 meters
Upper bathyal (slope)	200-500 meters
Middle bathyal (slope)	500-1500 meters
Lower bathyal (slope)	1500-2500 meters
Abyssal	>2500 meters

Additional paleodepth information is provided by benthic species diversity and the percentage of planktic foraminifers. Diversity trends have also been utilized to indicate major oceanographic boundaries (Olsson, 1984). However, heavy reliance on rotary cutting samples makes both values suspect. This is especially true for species diversity. It is believed that the effects of contamination on the limited number of species employed in the

analysis have been minimized. However, a similar statement cannot be made for the over three hundred total species collected which are the basis for diversity measurements. In calculating planktic percentage, stratigraphically-short-ranging index species allow easy recognition of downwell contamination. However, the much longer ranges of species of near-shore sections makes recognition of *in situ* taxa much more difficult. Therefore, detailed analysis based on either benthic diversity or planktic percentage is not considered warranted although relative increases in these indexes may still indicate increasing paleodepth.

A similar problem applies to Q-mode analysis. Sample inter-relationships based upon an analysis of total species data are suspect due to contamination. On the other hand, Q-mode analysis based only on the R-mode-analyzed species provides no information that is not reflected in the abundance distribution of those species. Therefore, except for DSDP material, Q-mode analysis was not conducted.

II. RESULTS

A. Depositional sequences of the New Jersey Coastal Plain

In this study, depositional sequences are identified in the coastal plain in the Oxly 1A and BTMA wells (figure 1). The relative abundance distribution of the benthic foraminiferal family Ceratobuliminidae is shown in each well (figures 12 and 13). The abundance is a gross indicator of relative paleodepth as ceratobuliminids are common only in shallow-water deposits (Williamson and Stam, 1988). In these near-shore deposits, lowstand tracts are not generally preserved and the sequence boundary is an erosional surface upon which the transgressive systems tract of the subsequent sea level rise is deposited. Thus the sequence boundary coincides with the transgressive surface. The transgressive systems tract represents a landward migration of facies as sea level is rapidly rising. Upwell within the tract, deeper marine facies are encountered and ceratobuliminid abundance declines. As the rate of sea level rise decreases, however, highstand deposits prograde over the trangressive section and the resulting tract represents progressively shallower facies upwell. Ceratobuliminid abundance consequently rises upsection. Integration of this abundance distribution with lithologic information and electric logs provides an

adequate means of depositional sequence identification. Planktic foraminiferal indices occur, albeit rarely, in some sections of the Oxly well and provide a means of correlating the sequences to the third-order cycle chart of Haq et al. (1987) (figure 8).

Oxly-1A well. In the Oxly well, a marked lithologic and paleontologic change occurs within the Bass River Formation at a depth of about 2000 feet (figure 12). A relatively coarse sand is abruptly overlain by a finer sequence, sandy at the base, but then composed of a thick interval of clayey silt. Ceratobuliminid abundance is low in the coarse sand layer, abruptly high at the base of the overlying finer sequence, and then declines upsection. The abrupt paleontologic and lithologic shift at the top of the major sand layer likely marks a sequence boundary. The coarser sand would then represent progradational highstand deposits of the older sequence, perhaps representing depths too shallow even for ceratobuliminids. Following a erosional event, the transgressive systems tract of the next sequence was deposited as sea level began to rise. Initially, relatively shallow water conditions prevailed and ceratobuliminid abundance was high but as sea level rapidly rose, abundance decreased sharply and sediments became finer grained (figure 12).

The rare occurrence of the planktic index Rotalipora cushmani indicates a late Cenomanian age for this interval

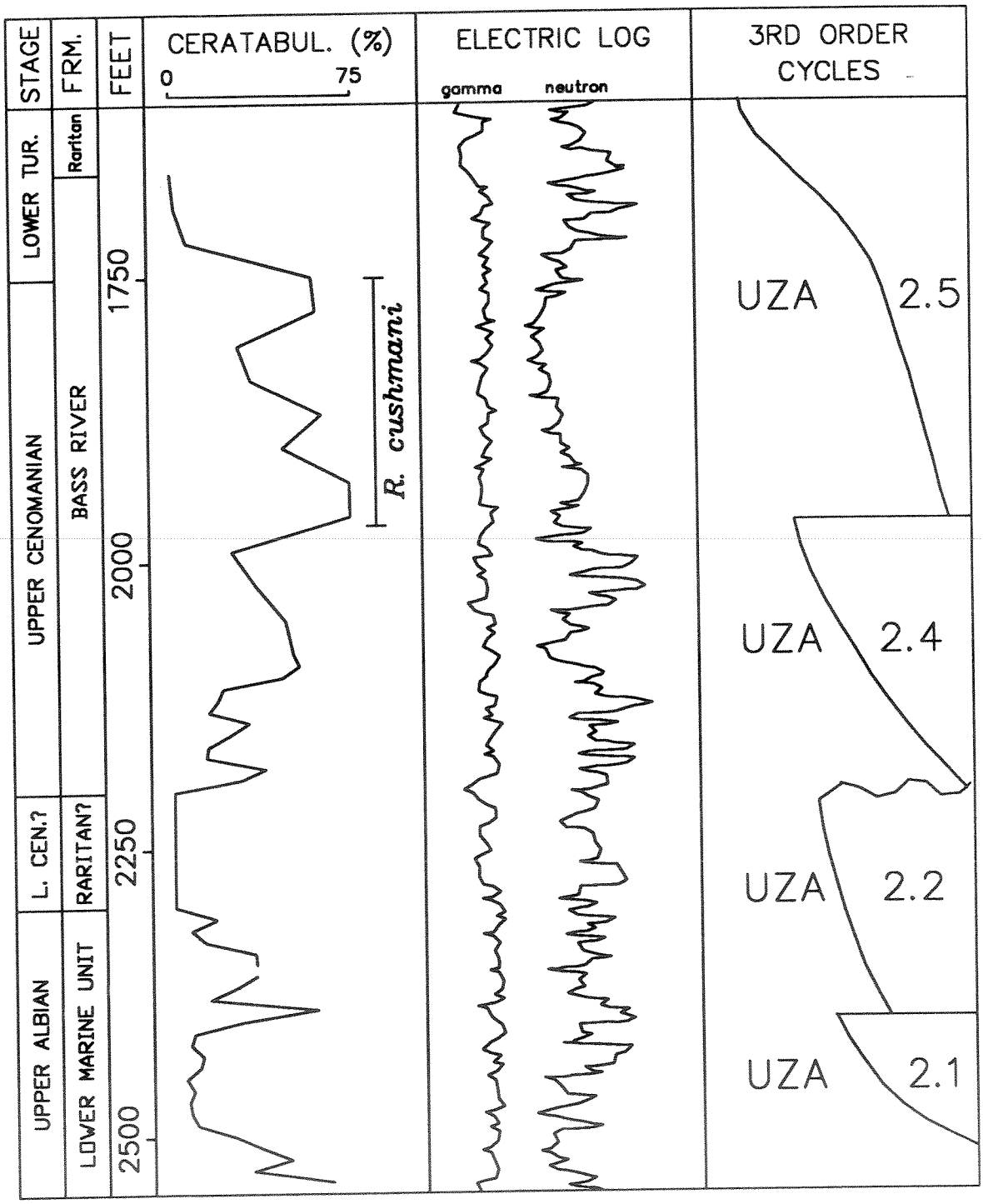


Figure 12: Correlation between depositional sequence stratigraphy, lithology and ceratobuliminid relative abundance – Oxly 1A.

and thus identifies the two sequences as third-order cycles UZA 2.4 and 2.5 (figure 8). The last appearance of R. cushmani is at a well depth of 1750 feet and it is succeeded by a greater relative abundance of early Turonian species of the genus Marginotruncana. Ceratobuliminids are very rare in this marine Turonian interval which thus appears to represent deeper-water conditions. The top of this interval, at a well depth of 1690 feet, marks the maximum flooding surface of UZA 2.5. It is overlain by highstand deposits of the fluvial Raritan formation. The Cenomanian/Turonian boundary was determined at a well depth of 1750 feet based on planktic foraminiferal biostratigraphy. Thus the maximum flooding surface of UZA 2.5 (1690 feet) occurs within the lower Turonian and does not indicate the Cenomanian/Turonian boundary.

A secondary ceratobulimind abundance peak occurs in the uppermost Cenomanian at a well depth of 1780 feet (figure 12). This increase in abundance suggests that a relative drop in sea level occurred during deposition of the transgressive systems tract. Relative sea level depends on the interaction of eustatic sea level, sediment input and margin subsidence. As subsidence rates are nearly constant over short time intervals (Pitman, 1978), this minor regressionary event during a period of eustatic sea level rise likely represents an increase in local sediment input.

In the lower, unnamed marine interval, a relatively coarse sand occurs at a well depth of 2400 feet (figure 12). Ceratobuliminid abundance distribution is similar to that of the Bass River formation. A sharp abundance peak occurs in, and immediately above the sand and then sharply decreases upsection. A duplicate pattern is noted in the interval underlying the sand. An abundance peak occurs at the base of the section (well depth - 2540 feet) and again rapidly decreases upwell.

Therefore two depositional sequences appear to be present in the Albian marine unit. In the older sequence, deposition of the transgressive systems tract began near the base of the section. Ceratobuliminid abundance decreases markedly upwell in these transgressive deposits but then strongly increases in the overlying highstand deposits represented by the sand layer at 2400 feet. The top of this sand marks the sequence boundary. Overlying this horizon is the trangressive systems tract of the next sequence in which ceratobuliminid abundance again drops off sharply. This transgressive section is overlain by highstand fluvial sands of the intermediate non-marine unit (2200-2300 feet well depth).

The lower marine unit of the Oxly well intergrades with Potomac sediments which have been palynologically dated as Albian in age (Doyle and Robbins, 1977). Prior to this time, sedimentation on the New Jersey coastal plain

was entirely nonmarine (Olsson et al., 1988). This major change in depositional environment was likely due to the two largest sea level rises to occur during the Albian; UZA 2.1 and 2.2 (figure 8). Because planktic indices are absent, the Albian/Cenomanian boundary is determined by the maximum flooding surface of UZA 2.2, at the base of the intermediate non-marine sand (2300 feet). No deposits from UZA 2.3 occur in the Oxly well. This hiatus is most likely due to erosion following the major sea level drop at the end of that cycle (type 1 unconformity).

BTMA well. In the Oxly well, one species of Epistomina, E. cf. hechti, is restricted to the Albian marine section. This species is used to identify the Albian/Cenomanian boundary in the BTMA well at a depth of about 1700 feet (figure 13). Below this level, thin Albian marine strata are interbedded with thicker, non-marine, Potomac sands. These marine layers presumably represent the maximum updip extent of flooding of UZA 2.2. A mixing of benthic foraminiferal assemblages within these beds indicates considerable downwell contamination has occurred. They were thus abandoned for quantitative analysis. However, foraminiferal content of the upper Cenomanian and lower Turonian sections of the BTMA well indicate only minor contamination.

A marked paleontologic and lithologic change occurs

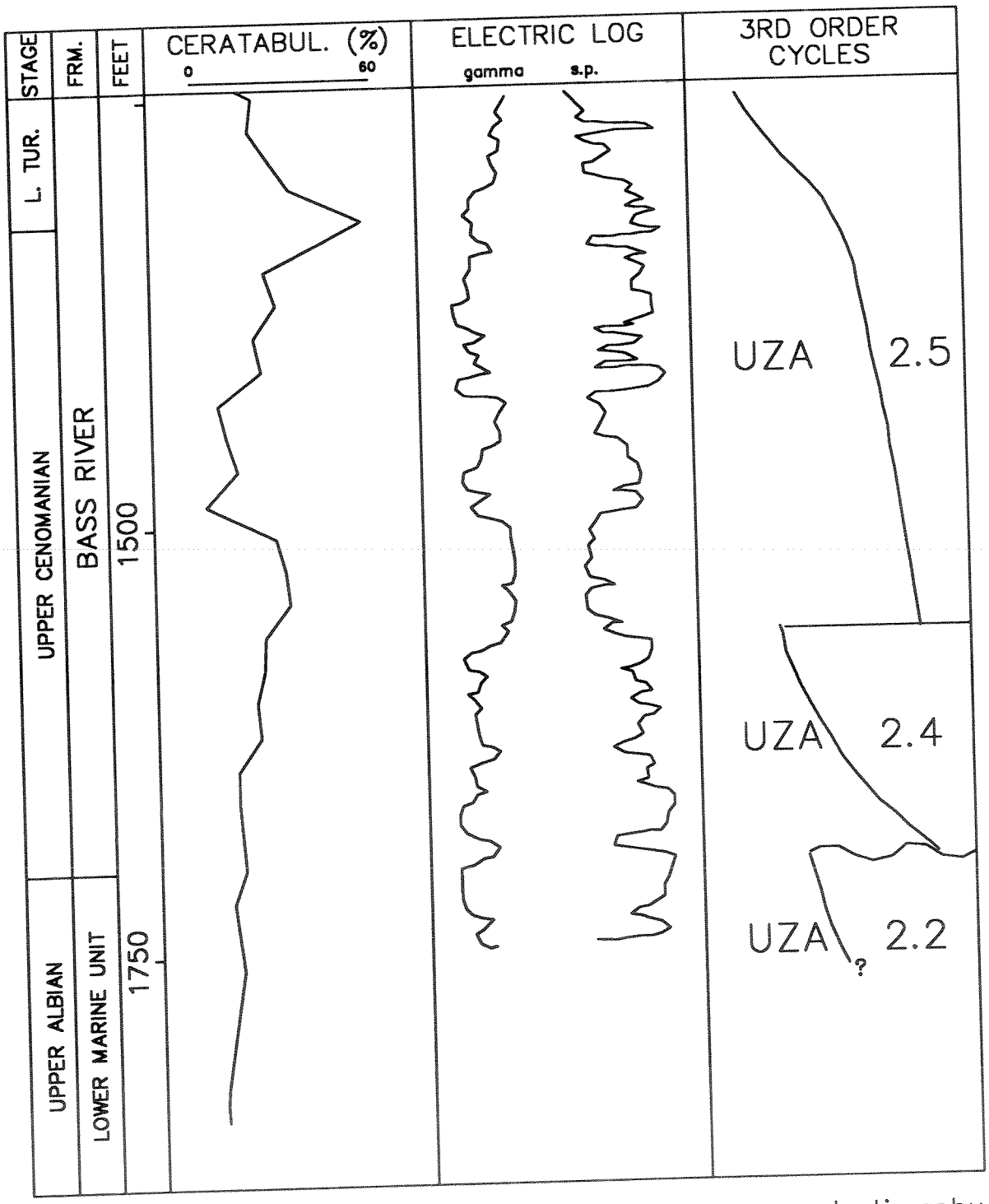


Figure 13: Correlation between depositional sequence stratigraphy, lithology and ceratobuliminid relative abundance – BTMA.

in the BTMA well at a depth of 1570 feet (figure 13). As in the Oxly well, a sandy interval is abruptly overlain by a thick silty section. Ceratobuliminid abundance shows a broad peak at the base of the silty interval and then decreases upwell. The sequence boundary between UZA 2.4 and 2.5 is then set at this well depth.

As in the Oxly well, ceratobuliminid abundance does not decline steadily upwell in the UZA 2.5 transgressive section but shows an abundance peak near the Cenomanian/ Turonian boundary (figure 13). Again, this peak is probably indicative of a local regression due to increased sediment input. However, because the BTMA well is farther updip of the Oxly well, the effects of this regression are greater. The lithology of the BTMA well is much sandier than at comparable levels in the Oxly well. The ceratobuliminid abundance peak in the BTMA well is broader than in the Oxly well and begins lower in the Cenomanian and continues into the lower Turonian. It also marks the greatest ceratobuliminid abundance in the BTMA well and therefore the shallowest paleodepths within the UZA 2.5 transgressive section (figure 13). In the Oxly well, however, the effects of the regression are more minor and concentrated within a narrower stratigraphic interval in the uppermost Cenomanian (figure 12).

Correlation of the two wells indicates the extent of the transgressive events (figure 14). Upper Albian marine

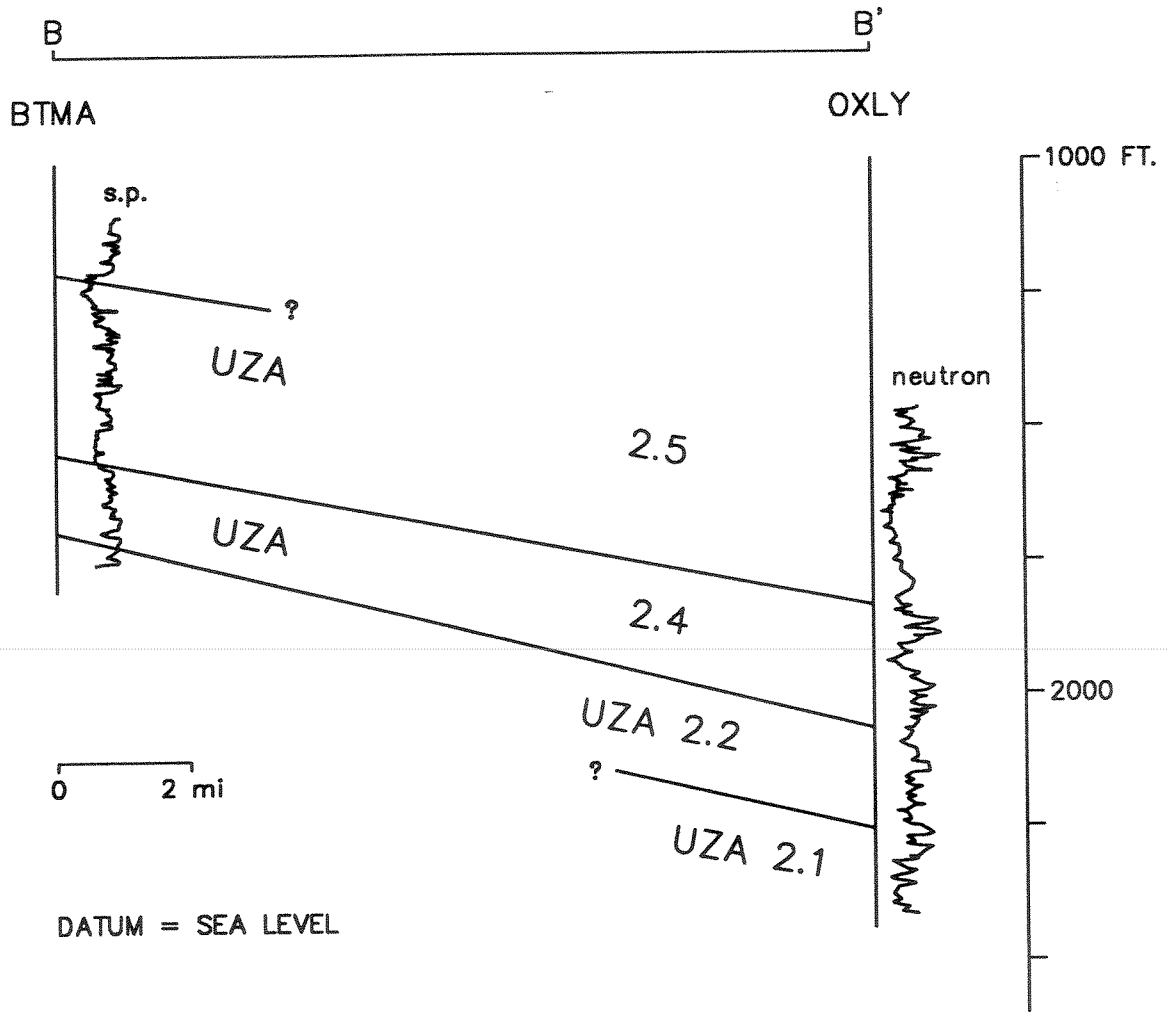


Figure 14: Correlation of depositional sequences of the studied interval – New Jersey Coastal Plain.

deposition has its greatest extent near the Albian/ Cenomanian boundary as marine deposits of UZA 2.2 extend to the BTMA well. However, the maximum flooding of the upper Cenomanian to lower Turonian was much more extensive. Almost 300 feet of UZA 2.5 transgressive systems tract is present in the BTMA well. The shoreline was about 45km further updip, likely situated near present outcrop of the transitional facies of the Woodbridge Clay member of the Raritan formation (Olsson et al., 1988).

Identification of sequence boundaries within the Baltimore Canyon Trough wells proved difficult. Sequence boundaries usually could not be identified due to the lack of both assemblage and lithologic control. As noted above, the lithology was dominated by monotonous sequences of calcareous shales and claystones and the foraminiferal assemblages of these greater paleodepths were less affected by eustatic changes and thus do not correlate as well with third order cycles.

B. Benthic Foraminiferal Distribution - New Jersey Continental Margin

Depth limits of benthic Foraminifera may vary geographically but studies have shown that the succession of modern faunas with increasing depth remains similar (e.g., Parker, 1954; Walton, 1964; Pflum and Frerichs, 1976).

Most biofacies of the Baltimore Canyon Trough represent outer neritic and upper bathyal paleoenvironments whereas New Jersey coastal plain sites predominantly contain inner neritic assemblages. Paleontologic similarity between these two regions is largely limited to eurybathic species of Gavelinella, Buliminella, Tritaxia and Valvulineria.

Biofacies of the New Jersey Atlantic margin are listed in table 5. Biofacies 1-6 form a downslope succession. Biofacies 1 is characteristic of shallowest inner neritic paleodepths and is mainly composed of species of Epistomina. Biofacies 2 represents relatively deeper inner neritic paleodepths and is composed of abundant species of Gavelinella. Biofacies 3 is the only assemblage common to both the coastal plain and Baltimore Canyon sites. It likely represents middle neritic paleodepths and is composed of species of Gavelinella, Globorotalites, Neobulimina and Eggerellina. Biofacies 4 is the most widespread assemblage of the Baltimore Canyon Trough, characterizing outer neritic to upper bathyal paleodepths. It primarily contains species of Gavelinella, Gaudryina and Gyroidinoides. Biofacies 5 is dominant in stage-boundary sections indicative of periods of maximum flooding and contains diverse species of Lingulogavelinella and Lenticulina. Elements of biofacies 6 occur only in

Table 1: Biofacies of the New Jersey Continental Margin.

	Defining Assemblages
Biofacies 1	
Ceratobulimina parva (post-Alb.) *Epistomina chapmani s.s.* (pre-Tur.) *E. cf. chapmani* (Hart) (pre-Tur.) *E. cf. hechti* (Albian) *E. aff. ripleyensis* (post-Alb.) *E. stelligera s.s.* (post-Alb.) *E. aff. stelligera* *Gavelinella dakotensis* (post-Alb.)	Clusters C,D,G,H
Biofacies 2	Clusters A,E
G. berthelini *Gavelinella* aff. *nelsoni*	
Biofacies 3	Clusters B,F,L,P
Eggerellina mariae *Gavelinella monterelensis* (post-Alb.) *G. plummerae* *Globorotalites rumanus* *Neobulimina* aff. *albertensis*	
Biofacies 4(ac) (pre-Turonian)	Clusters J,M Assemblage U'
Gaudryina cushmani *Gavelinella cenomanica* *Gyroidinoides* sp. 2 (Jannin) *Valvulineria parva*	
"Biofacies" 4(t) (Turonian)	Cluster K
Osangularia utaturensis *Dorothia oxycona* *Spiroplectinata capitosa*	

table 1 cont.

Biofacies 5	Clusters I,O,Q Factor Group T'
Lingulogavelinella globosa (Tur.) *L. frankei* *L. ciryi* *L. spinosa* *Lenticulina* species	
Biofacies 6(?)	Clusters X,Y
Hyperammina gaultina *?Lingulogavelinella newtoni* *Osangularia insigna* *O. utaturensis* *Praebulimina evexa*	
Biofacies DSA	Cluster R
Trochammina rainwateri *T. wickendeni* *Gavelinella minima* *G. tormarpensis*	
Biofacies DSB	Clusters W,Z,CC
Haplophragmoides menitens *Karreriella conversa* *Recurvoides subturbinatus* *R. deflexiformis* *Uvigerinammina jankoi*	
Biofacies DAA	Clusters AA,BB
Psammosphaera scruposa *Reophax guttifera* *R. pepperensis* *Verneuilinoides borealis*	

Turonian sections of the Shell slope wells 586 and 587 and include species of Praebulimina, Osangularia and Hyperammina.

In addition, three biofacies are recognized which are more restricted in stratigraphic distribution. Biofacies DSA and DSB (i.e, "dysaerobic assemblages A and B) are characteristic of Turonian organic-rich sediments whereas biofacies DAA (i.e., "disturbed agglutinated assemblage") occurs only in a thin interval immediately above a major unconformity in the Shell 587 well.

Inner and Middle Neritic Biofacies

Biofacies 1. In the Oxly well, R-mode clusters C and D define this assemblage in which epistominid species are most abundant (table 2; figure 15). The sums of the relative abundances of all species within each cluster are shown in figure 16. The abundance distributions of the two assemblages appear to correlate with the sequence tracts previously described. Cluster C assemblage is abundant in the lower (shallower) sections of the UZA 2.1 and 2.2 transgressive systems tracts. Upsection in both sequences, abundance of cluster C assemblage then sharply declines in progressively deeper-water facies. Cluster D assemblage is nearly absent in the lower (Albian) marine unit but is common in the Bass River Formation especially in the lower part of UZA 2.4 highstand deposits (well depth - 2100 ft.)

Table 2: Key to species abbreviations and symbols used in Oxly 1A cluster and factor analysis.

Species	Cluster	Factor
Buliminella fabilis	BULFAB	A
Ceratobulimina parva	CERPARV	B
Clavulina gaultina	CLAVGAUL	C
Eggerellina mariae	EGGMAR	D
Epistomina aff. caracolla	EPISCAR	E
E. chapmani s.s.	EPISCHAP	F
E. cf. chapmani (Hart)	EPISCFCH	G
E. cf. hechti	EPISHECH	H
E. aff. ripleyensis	EPISRIP	I
E. stelligera s.s.	EPISSTEL	J
E. aff. stelligera	EPISAFST	K
G. berthelini	GAVBERT	M
Gavelinella dakotensis	GAVDAK	L
G. minima	GAVMIN	N
G. monterelensis	GAVMONT	O
G. aff. nelsoni	GAVNEL	P
G. plummerae	GAVPLUM	Q
G. tormarpensis	GAVTOR	R
Globorotalites rumanus	GLOBRUM	S
Neobulimina aff. albertensis	NEOALB	T
Tritaxia plummerae	TRITPLUM	U
T. pyramidata	TRITPYR	V
T. tricarinata	TRITTRI	W
Valvulineria berthelini	VBERT	X
V. parva	VPARV	Y

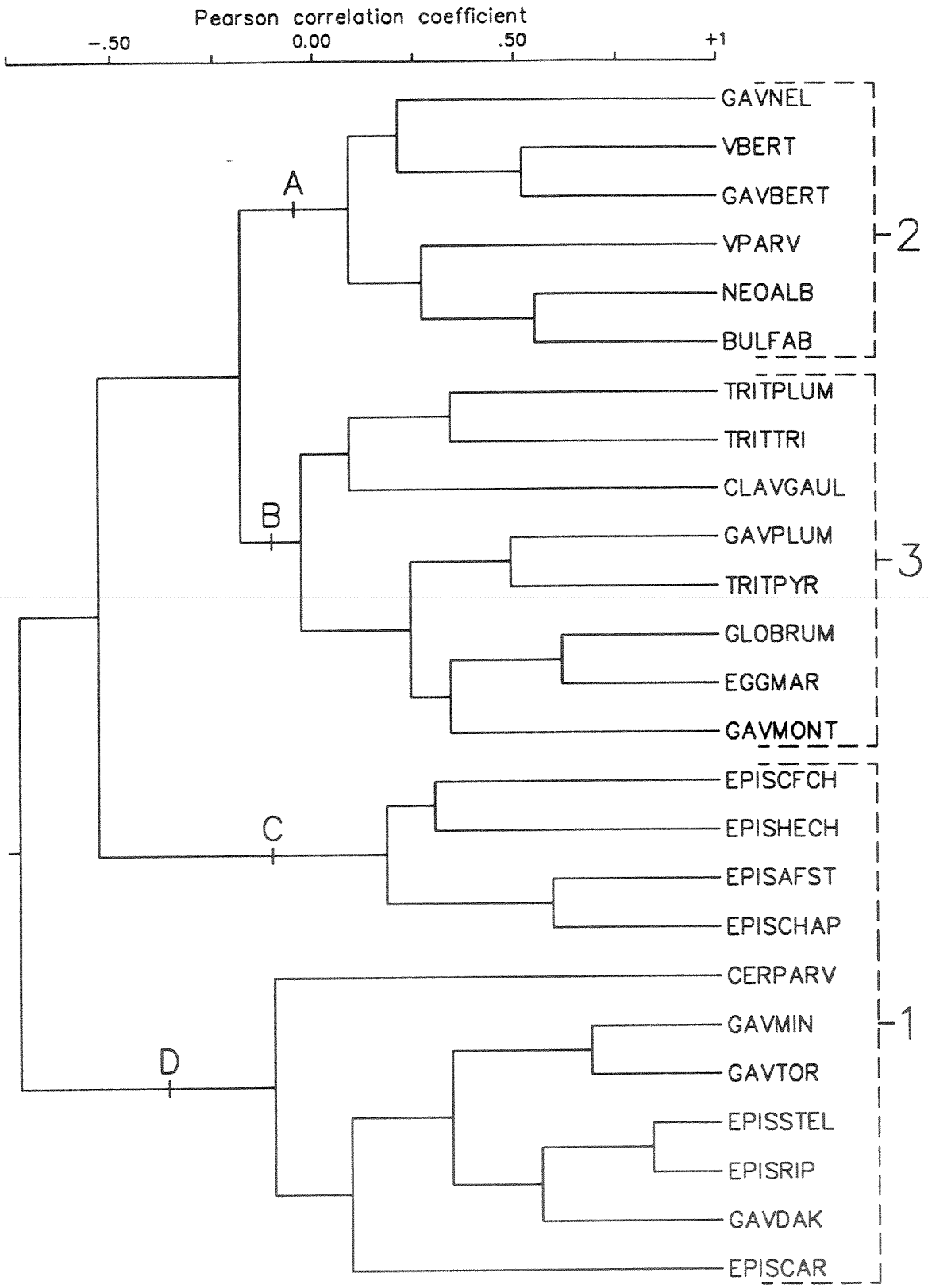


Figure 15: R-mode cluster analysis of Oxly 1A data with numbered biofacies.

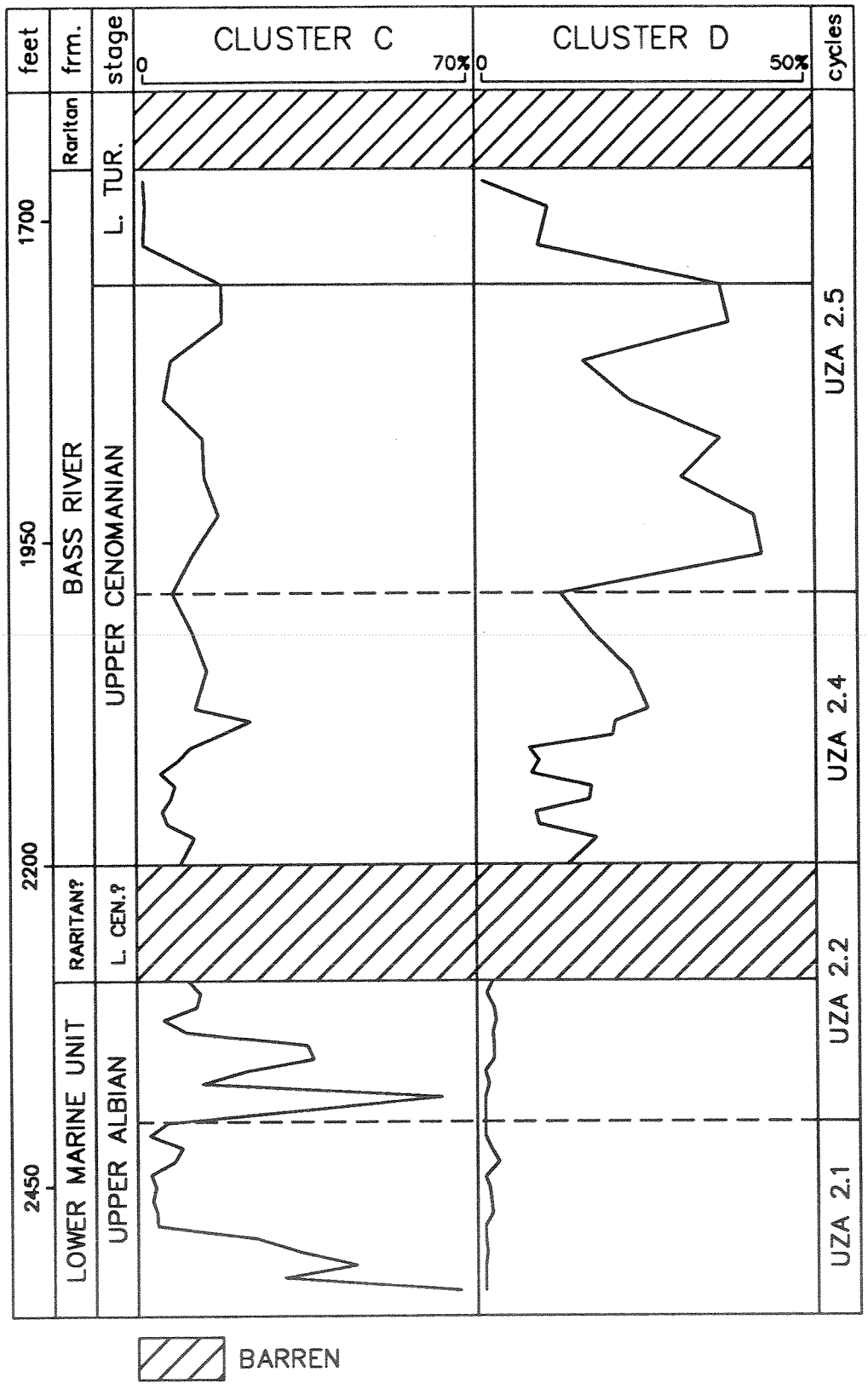


Figure 16: Sequence stratigraphy and relative abundance distribution of species composing clusters C and D, Oxly 1A.

and at the base of the UZA 2.5 transgressive section (figure 16). The assemblage becomes rarer upwell in deeper-water facies but then increases sharply in abundance in local regressionary deposits of the uppermost Cenomanian (well depth - 1780 ft.). Abundance of Cluster D assemblage sharply declines upsection to the maximum flooding surface of UZA 2.5 at the top of the lower-Turonian marine interval (1680 ft). Planktic foraminiferal abundance is low in the intervals dominated by these assemblages, ranging from 1 to 5%. Benthic species diversity in these same intervals, as measured by the Shannon-Wiener information function (H(S)), is the lowest of the examined section, ranging from 1.9 to 2.1 (maximum value = 3.0).

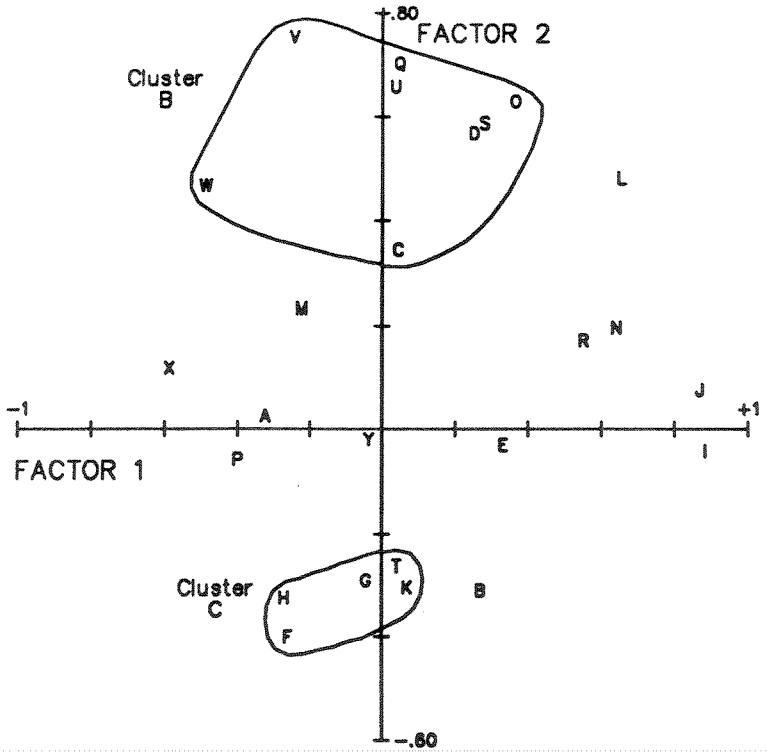
Though apparently indicative of similar paleoenvironments, cluster C and D assemblages show little similarity in cluster analysis (figure 15). The dissimilarity results because each assemblage characterizes a different stratigraphic interval. Cluster D assemblage is composed mainly of species which did not appear until the Cenomanian; Epistomina aff. ripleyensis, E. stelligera s.s., Ceratobulimina parva and Gavelinella dakotensis. Cluster C assemblage is most characteristic of the Albian marine unit (figure 16). Above the Albian, one of its most abundant species, Epistomina cf. hechti, does not occur and most of the other taxa become less common, including E. chapmani s.s., E. cf. chapmani (Hart), and E. aff.

stelligera.

R-mode factor analysis also defines the cluster C and D assemblages (figure 17). Cluster C assemblage occurs within a narrow range of negative values on factor 2 and as positive values on factor 3. Cluster D assemblage plots as positive loadings on factor 1 but is poorly defined by factor 2.

Cluster G and H assemblages of the BTMA well (table 3; figure 18) show strong similarity to the Oxly assemblages of biofacies 1. Cluster G assemblage contains abundant Epistomina aff. ripleyensis, E. stelligera s.s. and Ceratobulimina parva which also characterize Oxly cluster D (figure 15) whereas E. chapmani s.s. and E. aff. stelligera are abundant in both BTMA cluster H and Oxly cluster C.

As in the Oxly well, biofacies 1 is characteristic of the shallowest marine deposits (figure 19). Cluster H assemblage is most common at the base of the UZA 2.5 trangressive systems tract and then declines in abundance upsection. Its most common species, E. chapmani s.s., does not occur above the Cenomanian. Cluster G assemblage is dominant in local regressionary facies at the Cenomanian-Turonian boundary, an interval which yields the lowest values of planktic abundance (5%) and benthic diversity (H(S) = 2.3). Both assemblages are also well defined by factor analysis (figure 20). Cluster H assemblage occurs



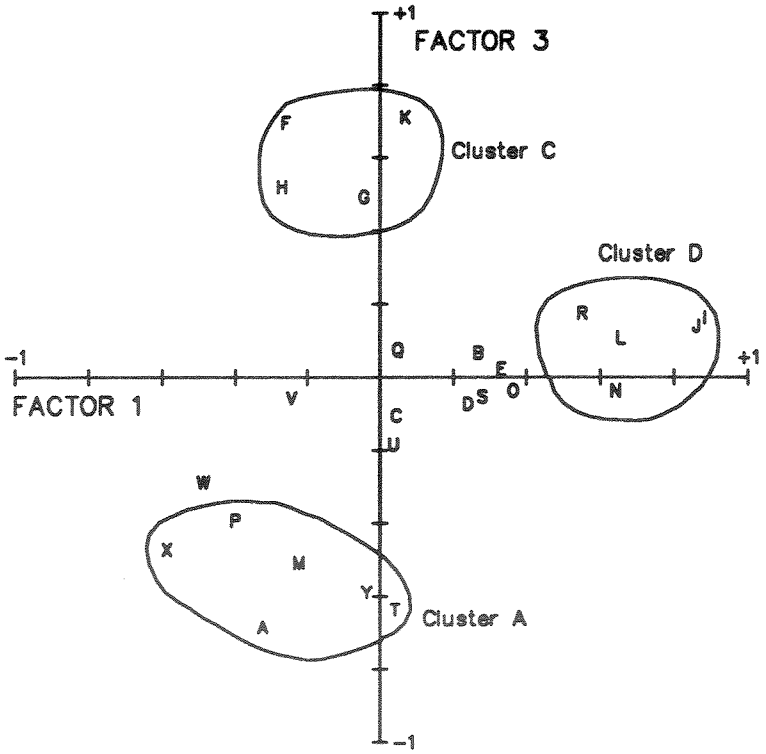


Figure 17: R−mode factor analysis, Oxly 1A, showing defined clusters in three dimensional factor space.

Table 3: Key to species abbreviation and symbols in BTMA cluster and factor analyses.

Species	Cluster	Factor
Buliminella fabilis	BULFAB	A
Ceratobulimina parva	CERPARV	B
Eggerellina mariae	EGGMAR	C
Epistomina chapmani s.s.	EPISCHAP	D
E. charlottae	EPISCHAR	E
E. aff. *ripleyensis*	EPISRIP	F
E. stelligera s.s.	EPISSTEL	G
E. aff. *stelligera*	EPISAFST	H
G. berthelini	GAVBERT	K
Gavelinella dakotensis	GAVDAK	I
G. intermedia	GAVINT	J
G. minima	GAVMIN	L
G. monterelensis	GAVMONT	M
G. aff. *nelsoni*	GAVNEL	N
G. plummerae	GAVPLUM	O
G. simionescui	GAVSIM	P
Tritaxia pyramidata	TRITPYR	Q
Valvulineria berthelini	VBERT	R
V. loetterlei	VLOET	S
V. parva	VPARV	T

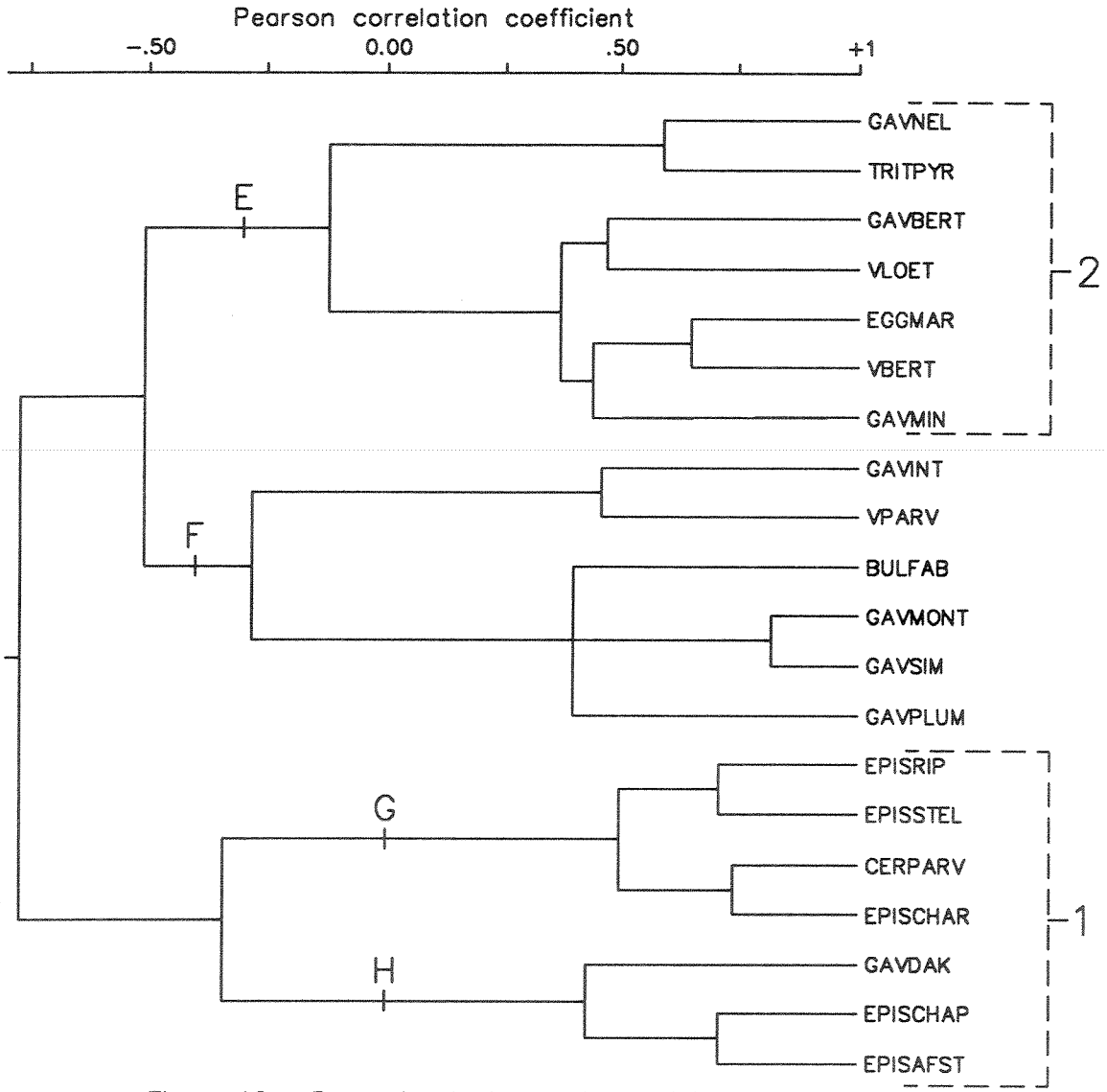


Figure 18: R-mode cluster analysis of BTMA data with numbered biofacies.

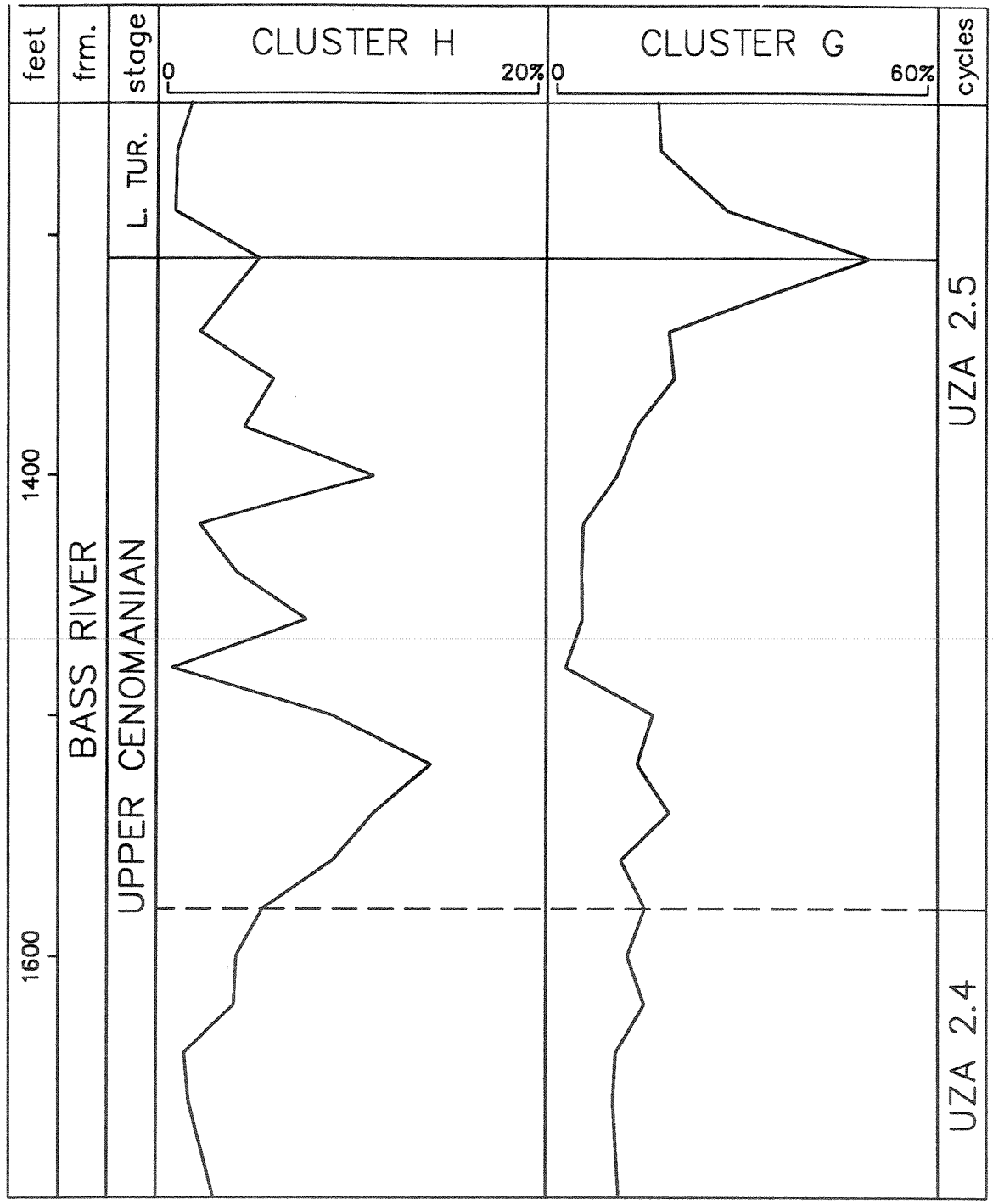
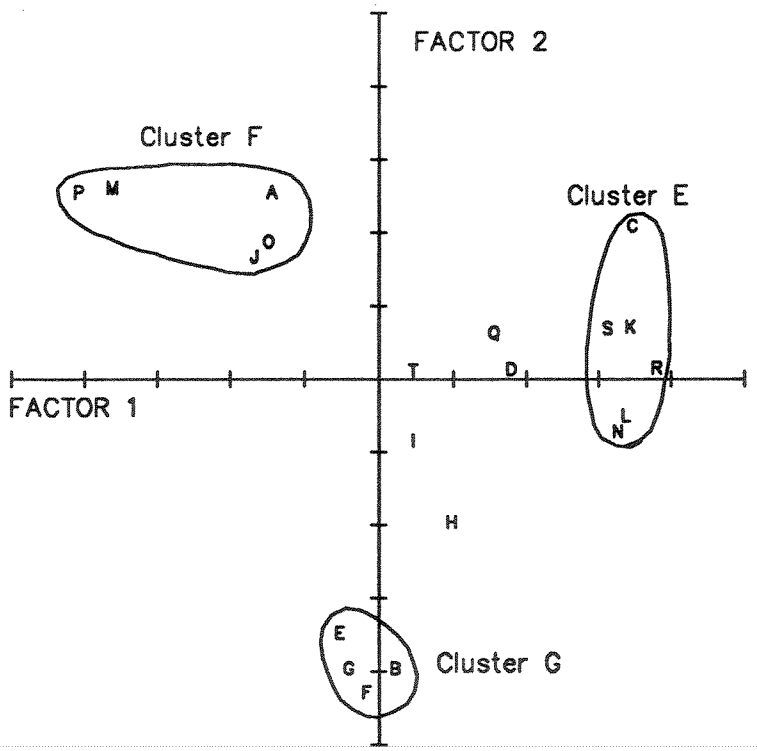


Figure 19: Sequence stratigraphy and relative abundance distribution of species composing clusters G and H, Cenomanian–Turonian sections of BTMA.



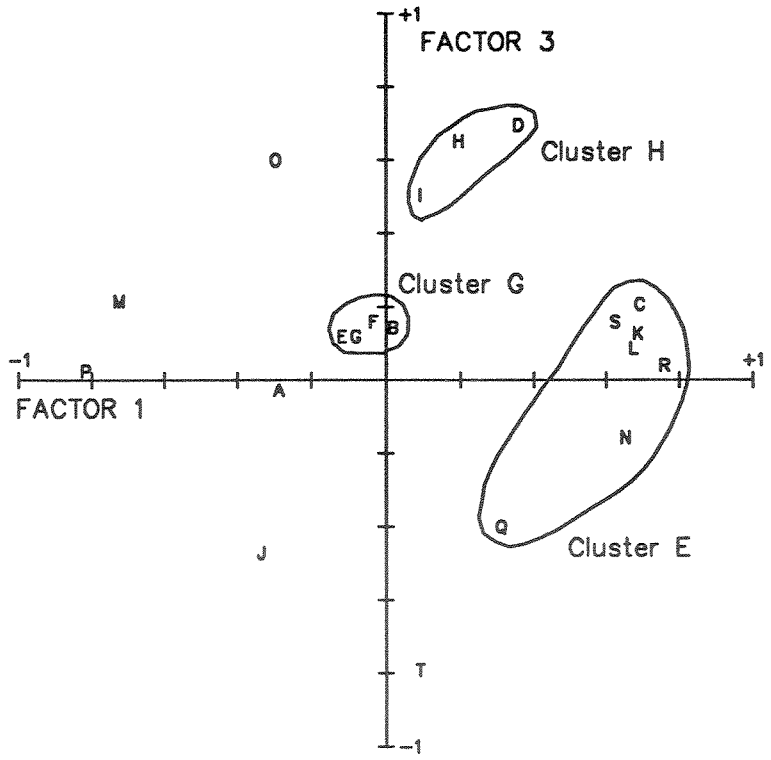


Figure 20: R-mode factor analysis showing defined clusters in three dimensional factor space, BTMA well.

as positive loadings on factor 3 whereas cluster G assemblage is best defined on the negative end of factor 2.

Overall, biofacies 1 is characteristic of shallow marine sediments including highstand deposits, basal intervals of transgressive sections and local regressionary sediments near the Cenomanian/Turonian boundary. Species composition changes to a greater degree than in any other biofacies. Cluster C and H assemblages are abundant in the Albian, less common in the Cenomanian and are largely absent in the Turonian. Cluster D and G assemblages first appear in the Cenomanian and progressively displace cluster C and H species upsection.

Biofacies 2. This assemblage is represented by R-mode cluster A in the Oxly well (figure 15). In the lower marine unit, cluster A assemblage shows an abundance distribution inverse to that of biofacies 1 (cluster C) (figures 16 and 21). Cluster A assemblage displaces cluster C species upsection in the transgressive systems tracts of both UZA 2.1 and 2.2. This displacement is accompanied by an increase in both planktic abundance and benthic diversity. Planktic percentage increases from about 1 to 25% whereas H(S) rises from 1.9 to 2.9.

Cluster A assemblage increases in abundance upsection in UZA 2.4 and 2.5 (figure 21). It is less common, however, in UZA 2.4 highstand sediments (well depth - 2100 ft.) and in the regressionary facies which characterize the

uppermost Cenomanian of UZA 2.5 (figure 21). Gavelinella aff. nelsoni and G. berthelini dominate the assemblage.

Factor analysis best defines cluster A assemblage on factor 3 (figure 17). Cluster A species plot as negative loadings and are well separated from cluster C species (biofacies 1) which occur as high positive values. Thus factor 3 apparently accounts for variance in species distribution due to Albian paleobathymetry; deeper-water Albian species plot as negative loadings whereas shallower-water taxa plot as positive values.

In the BTMA well, biofacies 2 is defined by cluster E. Species similarity to cluster A in the Oxly well is low but Gavelinella aff. nelsoni and G. berthelini are dominant in both assemblages (figures 15 and 18). As in the Oxly well, this biofacies appears to be indicative of deeper paleodepths than biofacies 1. The relative abundance distribution of cluster E assemblage increases upwell in transgressive deposits of UZA 2.5 and then steadily declines in overlying regressionary facies (figure 22). The greatest value of planktic abundance (16%) and H(S) (2.8) in the BTMA well occur at the level of maximum abundance of cluster E assemblage (well depth - 1450 ft.).

Cluster E species occur in a narrow range of loadings on factor 1 but factors 2 and 3 best separate it from cluster G and H assemblages of biofacies 1 (figure 20).

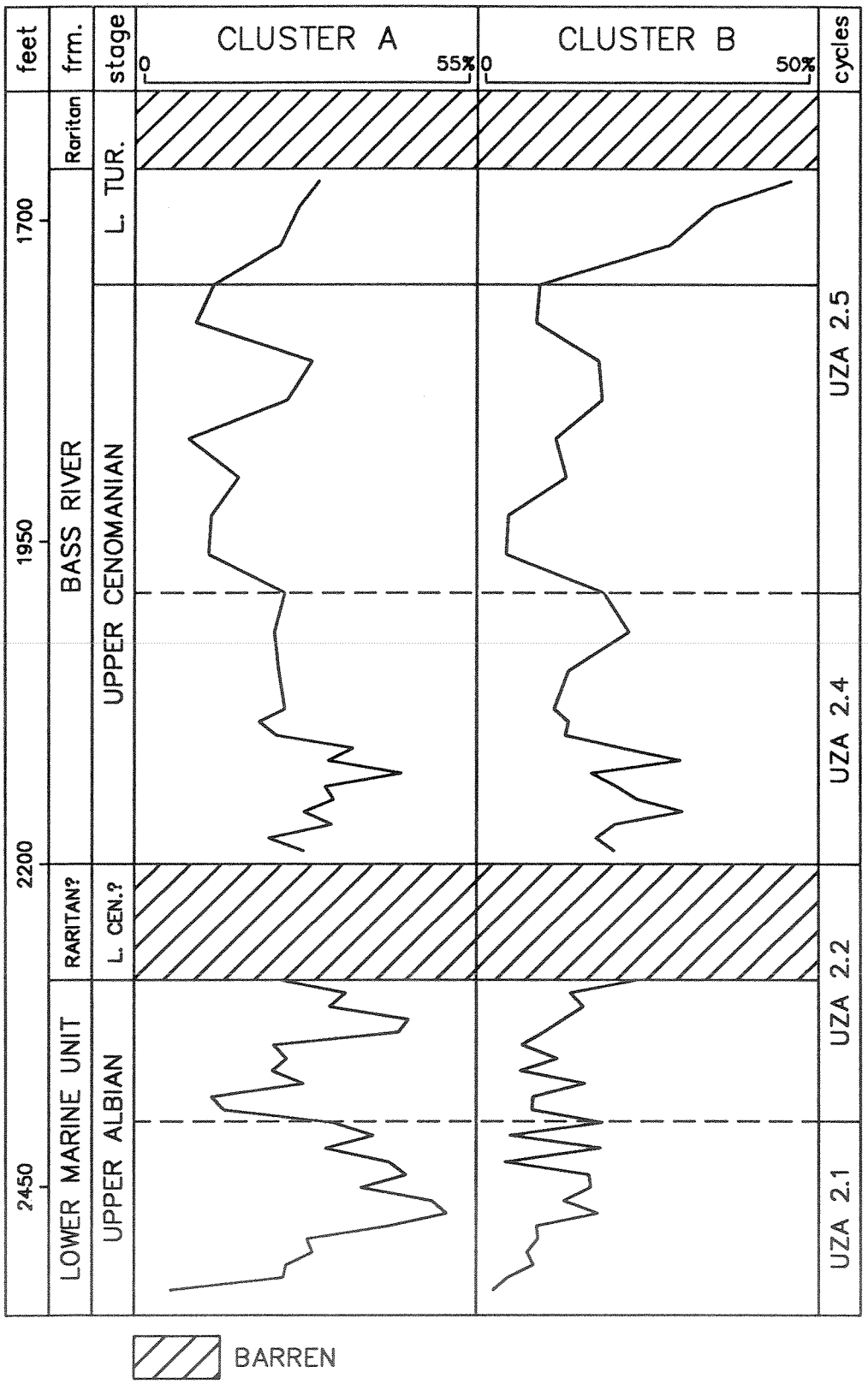


Figure 21: Sequence stratigraphy and relative abundance distribution of species composing clusters A and B, Oxly 1A.

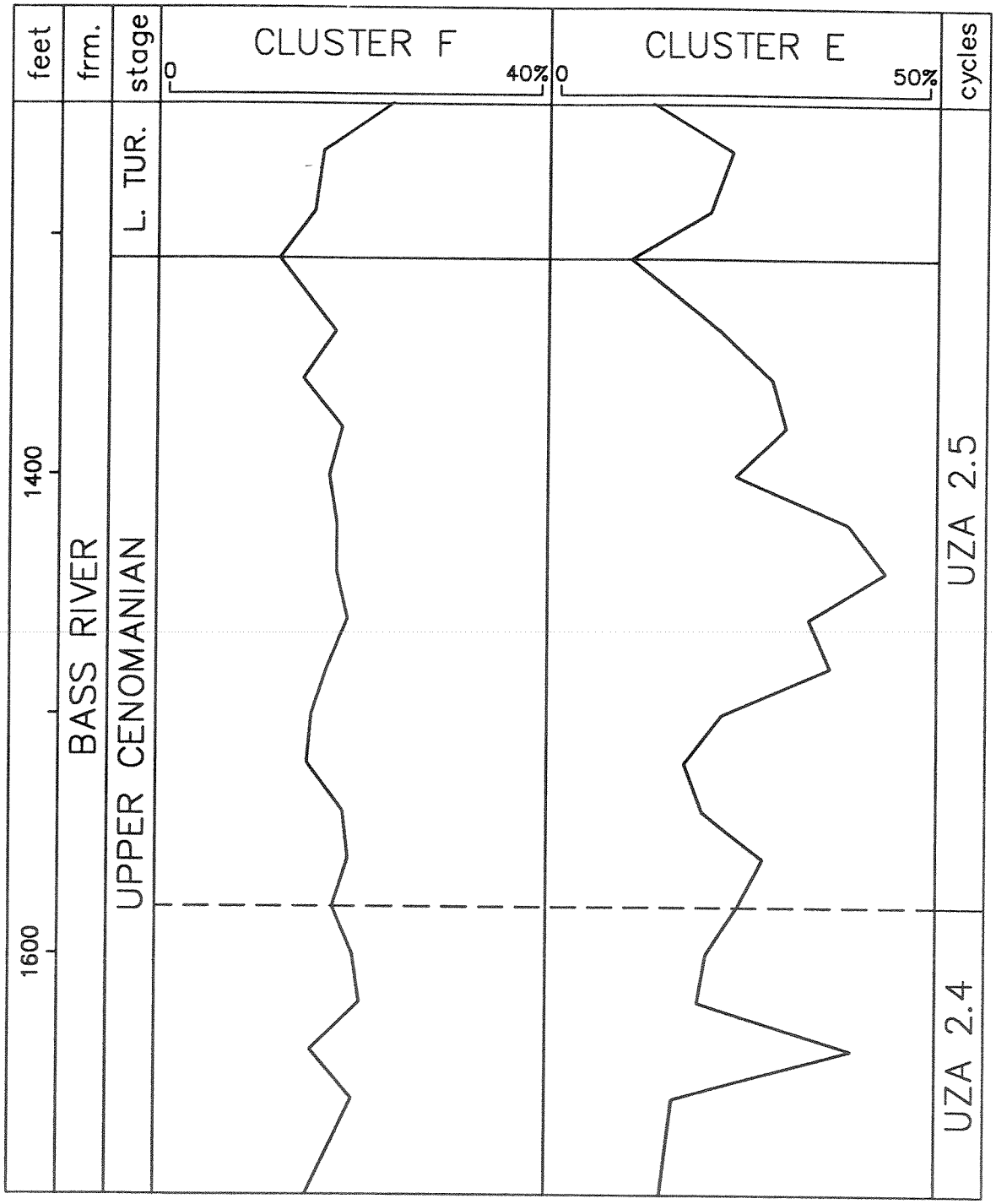


Figure 22: Sequence stratigraphy and relative abundance distribution of species composing clusters E and F, Cenomanian–Turonian sections of BTMA.

Factor 2 differentiates species of clusters E and G whereas factor 3 separates species of clusters E and H. Thus factors 2 and 3 at least partially reflect variance in species distribution due to alternation of biofacies 1 and 2 in response to paleodepth changes.

Overall, biofacies 2 is characteristic of deeper-water facies of the coastal plain, succeeding biofacies 1 upsection within the transgressive systems tracts of UZA 2.1, 2.2 and 2.5. Furthermore the assemblage shows a positive correlation with both planktic foraminiferal abundance and benthic diversity. Gavelinella aff. nelsoni and G. berthelini are the most abundant species of the assemblages defining biofacies 2. Cluster A and E assemblages are largely composed of eurybathic species of Tritaxia and Valvulineria.

Biofacies 3. The farthest updip extent of this biofacies is represented by cluster B assemblage in the Oxly well (figure 15). In the lower marine interval, the assemblage shows an erratic, low magnitude abundance distribution which shows no distinct pattern in relation to sequence stratigraphy (figure 21). In the Cenomanian, however, cluster B abundance distribution is similar to that of cluster A of biofacies 2 (figure 21). Greatest abundance occurs in deeper water sections of UZA 2.4 and 2.5 but cluster B species are always less common than those of cluster A. In the lower Turonian, cluster B assemblage

becomes dominant as abundance increases rapidly upsection to the maximum flooding surface of UZA 2.5 (figure 21). This lower Turonian section is marked by the greatest values of both planktic abundance (45%) and H(S) (3.0) in the Oxly well. This suggests that the Cluster B assemblage represents the deepest water biofacies present in the coastal plain. The most characteristic species include Gavelinella plummerae, G. monterelensis, Globorotalites rumanus and Eggerellina mariae.

R-mode factor analysis defines cluster B assemblage as as relatively high positive loadings on factor 2 (figure 17). Factor 2 widely separates cluster B assemblage from cluster C species of biofacies 1, reflecting the greatly dissimilar abundance distribution of these two assemblages. Cluster C species principally characterize shallow-water Albian sediments in which cluster B assemblage is rarest. Cluster B species are most common in the lower Turonian in which cluster C assemblage is absent (figures 16 and 21).

Two species of cluster B assemblage, Gavelinella plummerae and G. monterelensis, also occur in the BTMA well in cluster F (figure 18). However, cluster F assemblage is rare and uncharacteristic of any stratigraphic interval (figure 22). Paleodepths in the BTMA well apparently were deep enough to allow some defining species of biofacies 3 to extend updip to this site but not to occur commonly.

However, biofacies 3 is well defined by cluster L assemblage in the Shell 272 well (table 4; figure 23). All the characteristic species of cluster B assemblage in the Oxly well (figure 15) reoccur in cluster L. The most common are Gavelinella plummerae, G. monterelensis and Globorotalites rumanus. In addition, cluster L contains many eurybathic species of Tritaxia, Gavelinella and Buliminella as well as common Neobulimina aff. albertensis, a species only rarely present in the coastal plain. Cluster L assemblage rapidly increases in abundance upwell in an upper-Turonian calcareous clay (figure 24). This interval is a shallowing-upward section in which lithology becomes more silty upsection and planktic abundance decreases from 25 to 10%, the lowest value obtained in the Shell 272 well. Factor analysis defines cluster L assemblage as positive loadings on factor 2 (figure 25).

Biofacies 3 occurs in the COST B2 well as cluster P assemblage, defined by Gavelinella plummerae, Globorotalites rumanus and Neobulimina aff. albertensis (table 4; figure 26). Cluster P assemblage shows an abundance maximum in lower upper Albian silty clays which are interbedded with non-fossiliferous quartzitic sands (figure 27). The clays contain the lowest planktic abundance of the COST B2 well (25%). As in the Shell 272 well, biofacies 3 appears to represent relatively shallow water paleodepths and is abundant in stratigraphic

Table 4: Key to abbreviations used in cluster and factor analysis of Shell 272 and COST B2 species.

Species	Cluster	Factor
Ammobaculoides mosbyensis	AMMOMOS	A
Buliminella fabilis	BULFAB	B
Dorothia oxycona	DOROXY	C
Eggerellina mariae	EGGMAR	D
Epistomina spinulifera colomi	EPISCOL	E
Gaudryina cushmani	GAUDCUSH	F
G. pulvina	GAUDPUL	G
G. cf. quadrans	GAUDQUAD	H
Gavelinella baltica	GAVBAL	I
G. cenomanica	GAVCEN	J
G. intermedia	GAVINT	K
G. minima	GAVMIN	L
G. monterelensis	GAVMONT	M
G. plummerae	GAVPLUM	N
G. simionescui	GAVSIM	O
G. tormarpensis	GAVTOR	P
Globorotalites rumanus	GLOBRUM	Q
Guttulina vandenboldi	GUTVAN	R
Gyroidinoides infracretacea	GYRINFRA	S
G. primitiva	GYRPRIM	T
G. sp. 2 (Jannin)	GYRSP2	U
Lenticulina danubiana	LENTDAN	V
L. gaultina	LENTGAUL	W
L. munsteri	LENTMUN	X
L. secans	LENTSEC	Y
L. subangulata	LENTSUB	Z
Lingulogavelinella ciryi	LINGCIR	a
L. frankei	LINGFRAN	b
L. globosa	LINGGLOB	c
Neobulimina aff. albertensis	NEOALB	d
Osangularia insigna	OSANINS	e
O. utaturensis	OSANUTAT	f
Pseudopolymorphina ozawai	PSDOOZAW	g
Spirillina minima	SPIRMIN	h
Spiroplectinata capitosa	SPIROCAP	i
Tritaxia plummerae	TRITPLUM	j
T. pyramidata	TRITPYR	k
T. subrotunda	TRITSUB	l
T. tricarinata	TRITTRI	m
Trochammina rainwateri	TROCRAIN	n
T. wickendeni	TROCWICK	o
Valvulineria berthelini	VBERT	p
V. loetterlei	VLOET	q
V. parva	VPARV	r
Verneuilina cretacea	VERCRET	s

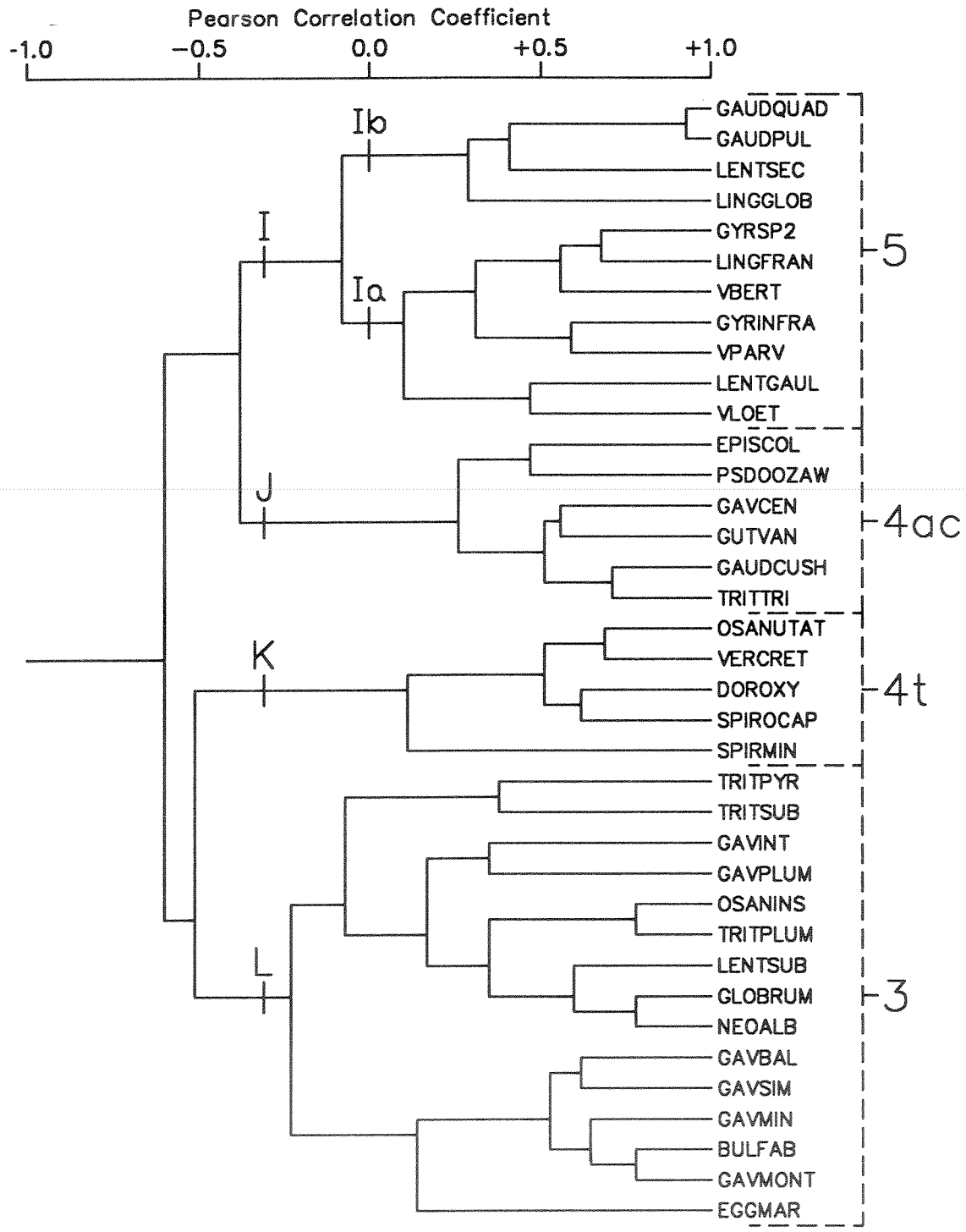


Figure 23: R-mode cluster analysis of Shell 272 species data with interpreted biofacies.

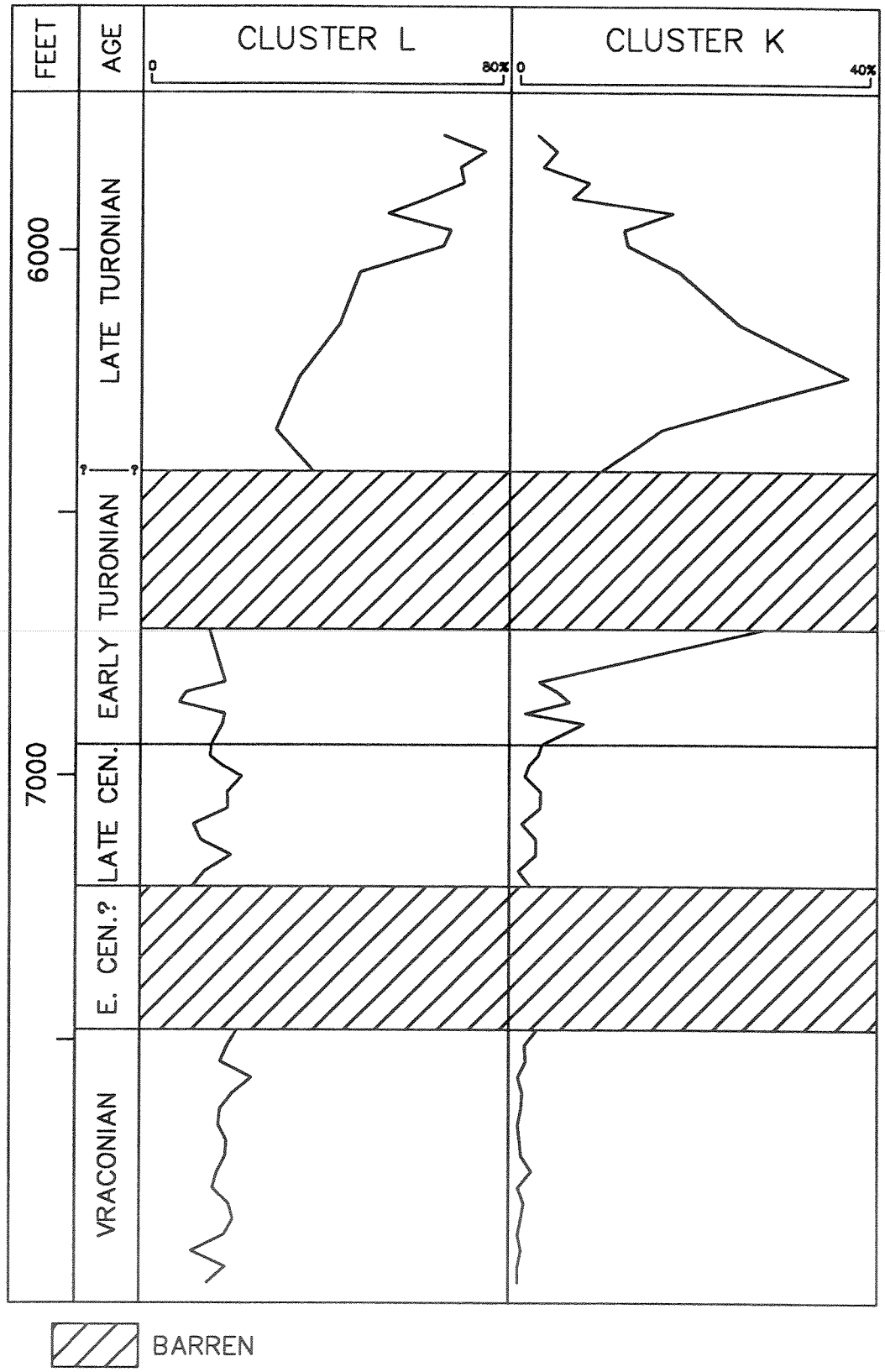
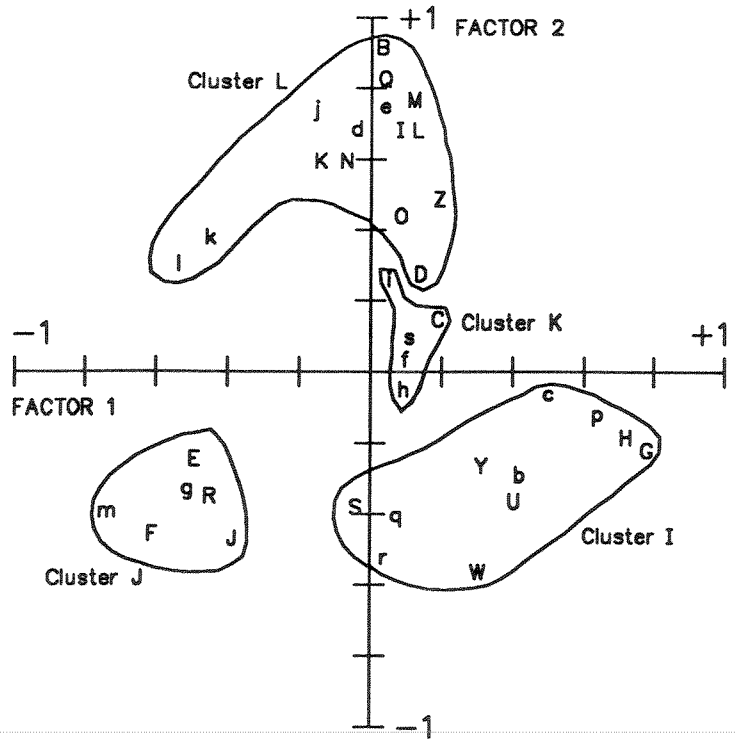


Figure 24: Relative abundance distribution of species comprising Shell 272 clusters K and L.



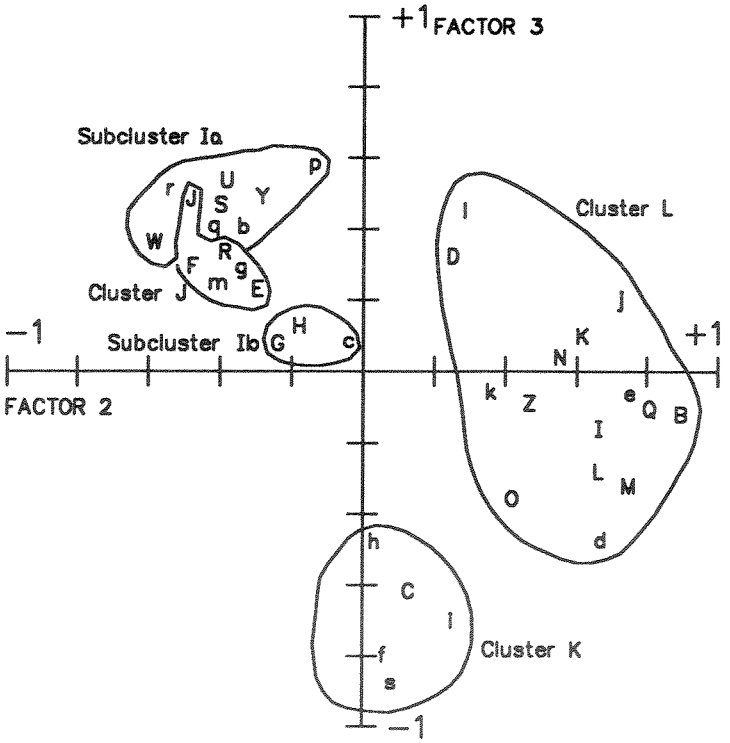


Figure 25: R-mode factor analysis showing Shell 272 clusters in three-dimensional factor space.

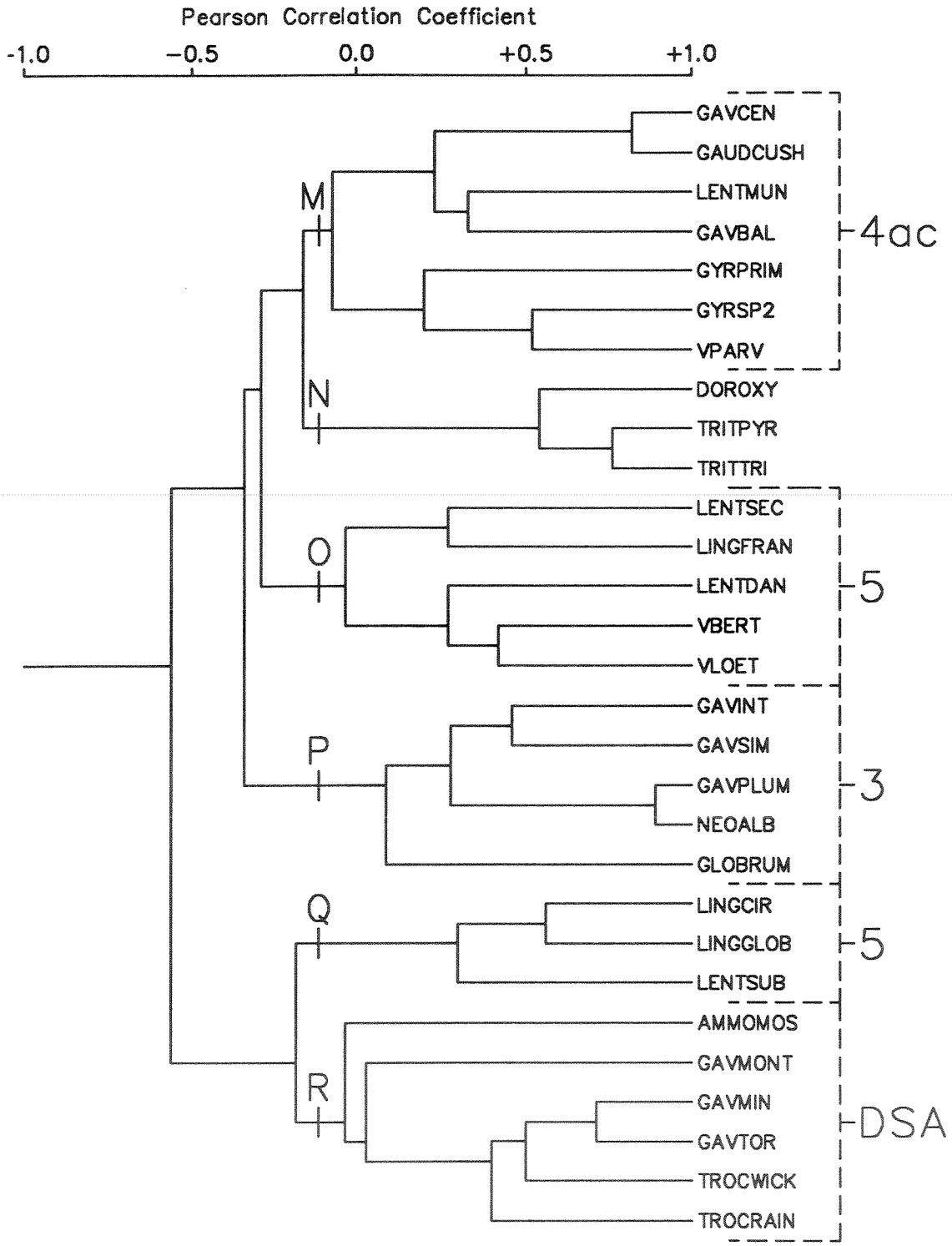


Figure 26: R-mode cluster analysis of COST B2 species data with interpreted biofacies.

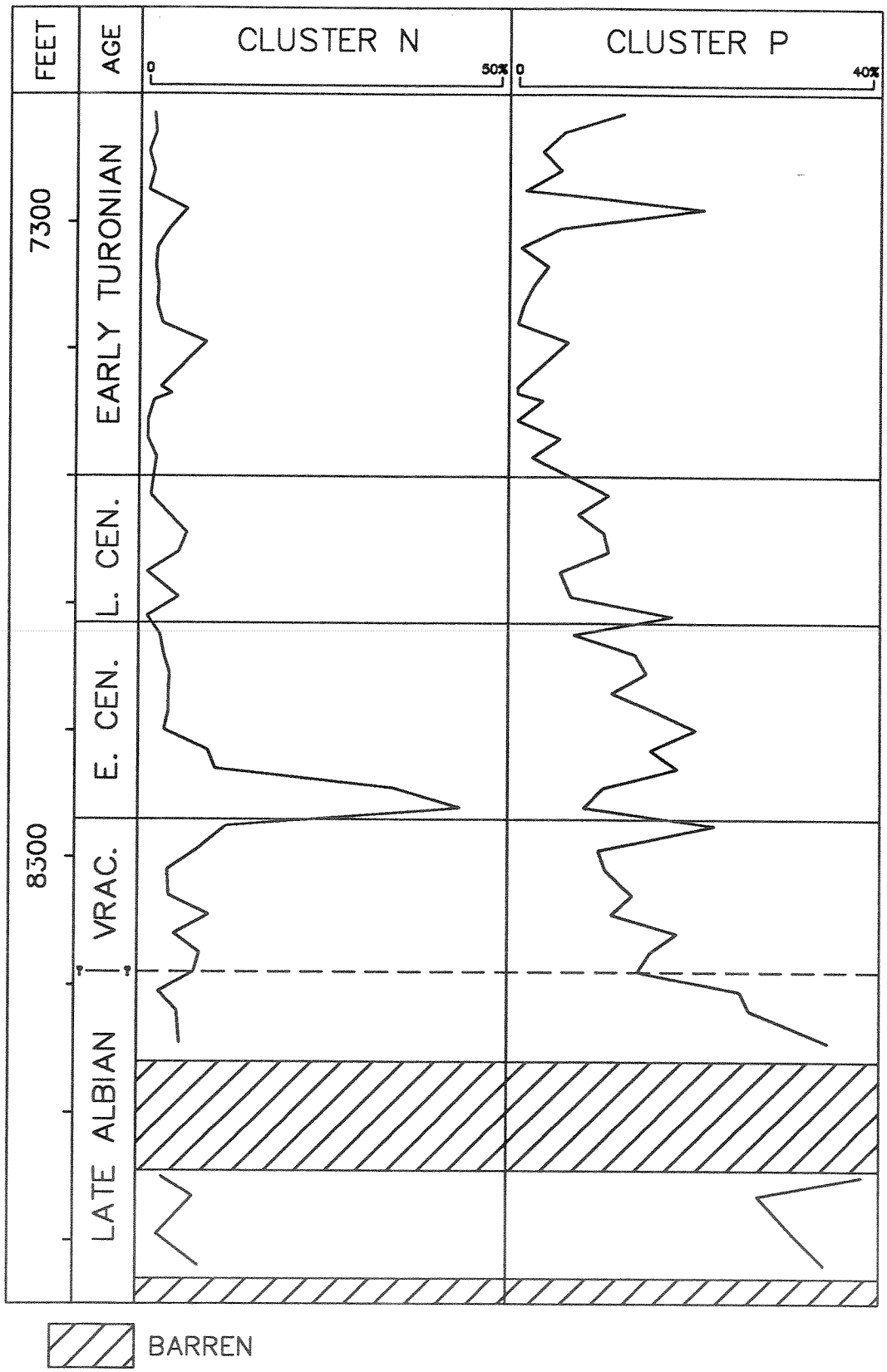


Figure 27: Relative abundance distribution of species comprising COST B2 clusters N and P.

intervals in which other assemblages are rare. This dissimilarity in abundance distribution is reflected by factor 2 on which cluster P assemblage is separated from all other analyzed species (figure 28).

Outer-Neritic and Upper-Bathyal Biofacies

Biofacies 4. In the Shell 272 well, clusters J and K define this biofacies (figure 23). Cluster J assemblage contains abundant Gavelinella cenomanica and Gaudryina cushmani as well as less common polymorphinids. The assemblage is most common in the uppermost Albian and in the lower part of the upper Cenomanian. It becomes much rarer upsection (figure 29). Most cluster J species disappear at the Cenomanian/Turonian boundary. The intervals dominated by cluster J assemblage show a planktic abundance of about 50%, indicating deeper paleodepths than sections characterized by biofacies 3 (cluster L).

Cluster K assemblage is representative of the lower upper-Turonian in the Shell 272 well (figure 24). It is replaced by cluster L assemblage of biofacies 3 in an overlying shallowing-upward section. Cluster K is primarily composed of species such as Osangularia utaturensis and Dorothia oxycona which are otherwise characteristic of deep-water DSDP sites. Spiroplectinata capitosa is also common and has its first appearance in the Turonian. Cluster K may represent species which

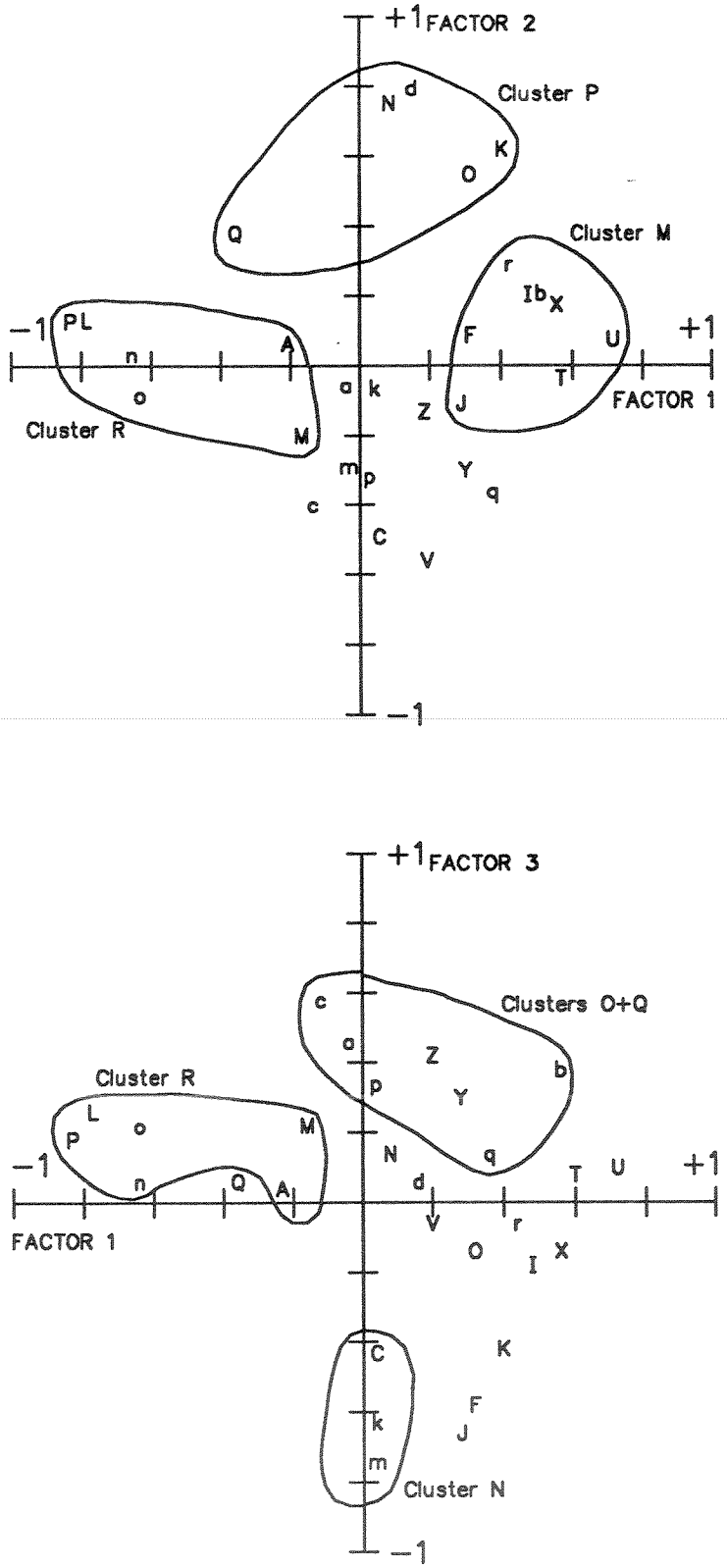


Figure 28: R-mode factor analysis showing COST B2 species clusters in three-dimensional factor space.

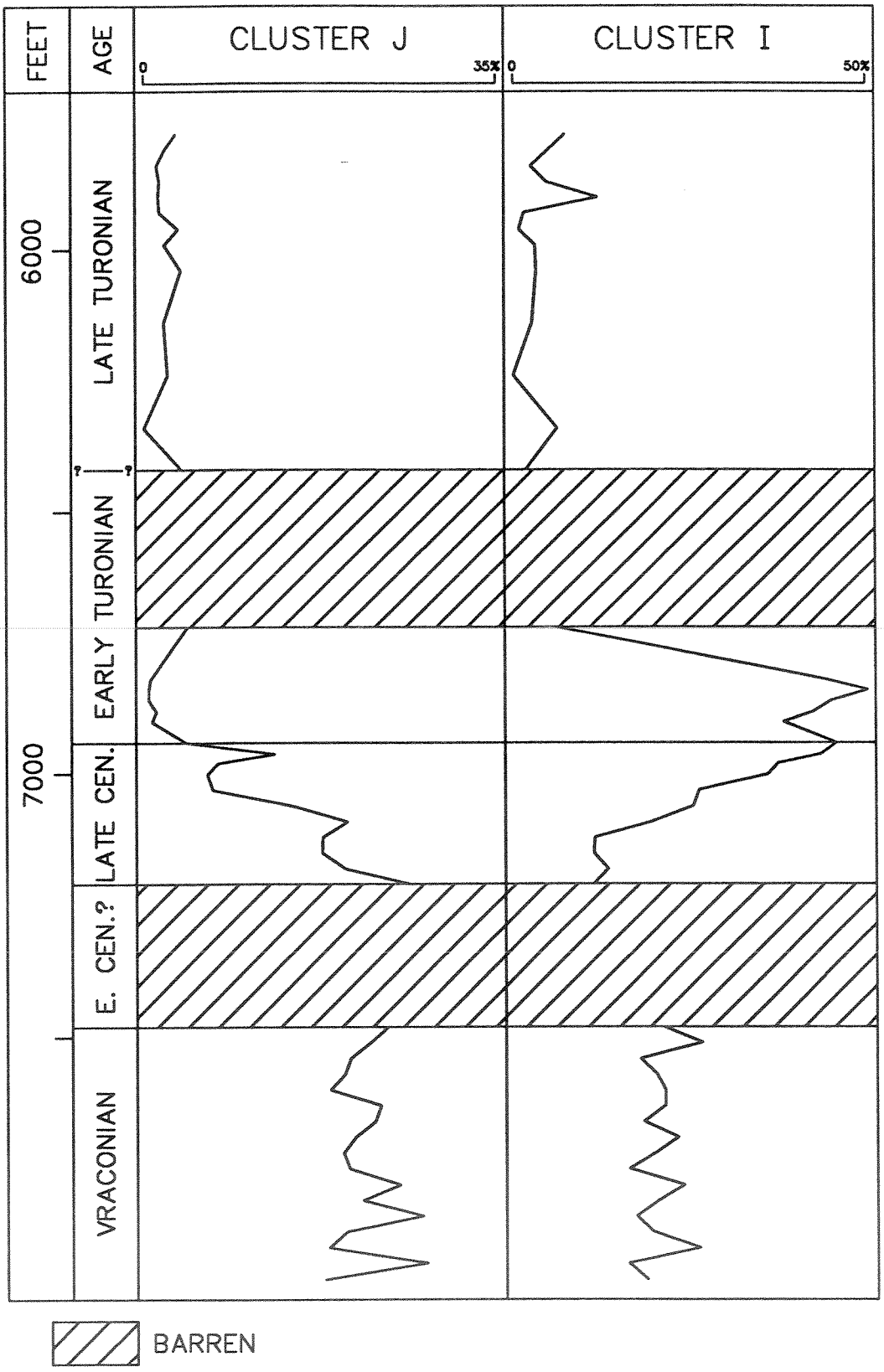


Figure 29: Relative abundance distribution of species comprising Shell 272 clusters I and J.

evolved or migrated from deeper paleodepths to fill a niche left vacant by the disappearance of cluster J assemblage. Both assemblages may represent a similar environment but at different times. Cluster J species, characteristic of the Albian and Cenomanian, are defined as biofacies 4(ac) whereas cluster K assemblage, characterizing the Turonian, is tentatively defined as "biofacies 4(t)" (found only in the Shell 272 well, the latter assemblage does not meet the stated requirements for biofacies definition). Both cluster assemblages are defined by factor analysis; cluster K species plot as negative loadings on factor 3 whereas cluster J species occur as negative loadings on factor 1 (figure 25).

In the COST B2 well, biofacies 4(ac) is represented by cluster M assemblage (figure 26), characteristic of Cenomanian and uppermost Albian sections (figure 30). As in cluster J of the Shell 272 well, Gavelinella cenomanica and Gaudryina cushmani are abundant but cluster M assemblage also contains common Gyroidinoides sp. 2 (Jannin) and Valvulineria parva. Though showing a somewhat different species composition than cluster J, nearly all the species composing cluster M assemblage nevertheless become extinct at the end of the Cenomanian (figure 30).

Cluster M species displace cluster P assemblage of biofacies 3 upsection in the COST B2 well in the Albian, and planktic abundance increases from 25 to 50%. Thus, as

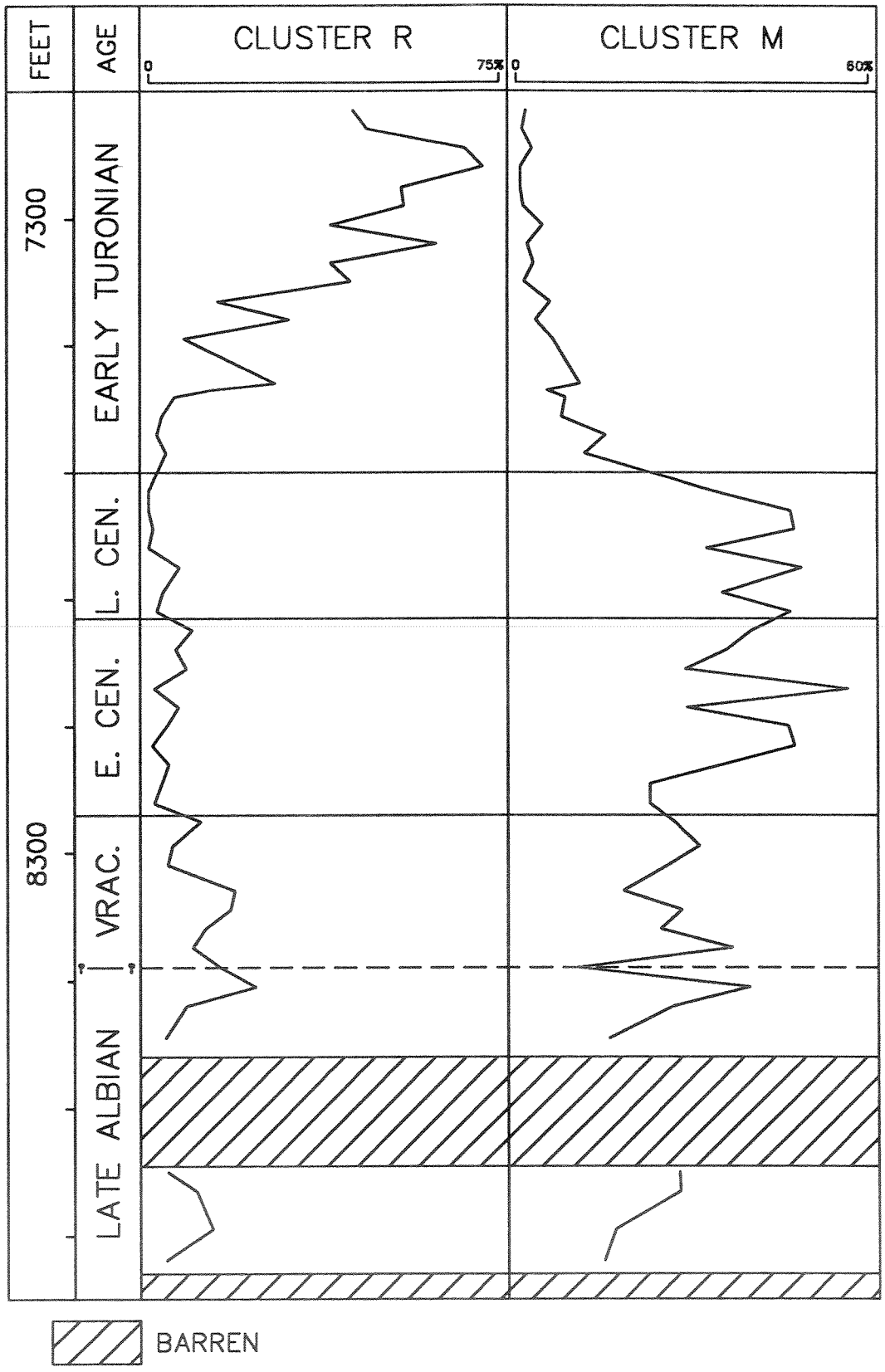


Figure 30: Relative abundance distribution of species comprising COST B2 clusters M and R.

in Shell 272, biofacies 4 apparently represents deeper paleodepths than biofacies 3. Factor analysis clearly defines cluster M assemblage as positive loadings on factor 1 (figure 28).

Cluster M assemblage dominates throughout deeper-water Albian and Cenomanian sections except in a relatively thin interval in the lowermost Cenomanian (figure 30). Here cluster N assemblage is very abundant (figure 27), a group which is essentially composed of two species of Tritaxia. These species are observed to be widespread, eurybathic forms which are dominant only in this interval. The cause of this abundance maximum cannot be ascertained based on the available evidence but presumably represents some local expression of the maximum flooding of UZA 2.2.

In the Shell 586 well, biofacies 4(ac) is poorly represented by cluster U assemblage (table 5; figure 31). As in cluster M assemblage of the COST B2 well, Gavelinella cenomanica, Gyroidinoides sp. 2 (Jannin) and Valvulineria parva are common. However, cluster U assemblage also contains common species of Lingulogavelinella which did not characterize biofacies 4(ac) in the Shell 272 or COST B2 wells. Also, the assemblage is indicative of a much thicker stratigraphic interval than any assemblage of biofacies 4(ac) in either well (figure 32).

Cluster U assemblage is poorly defined by factor

Table 5: Key to abbreviations used for Shell 586 and 587 species cluster and factor analyses.

Species	Cluster	Factor
Ammodiscus cretaceus	AMMOCRET	A
Astacolus grata	ASTGRAT	B
Buliminella fabilis	BULFAB	C
Dorothia oxycona	DOROXY	D
D. turris	DORTUR	E
??Flourensina sp.	FLOURSP	F
Gaudryina pulvina	GAUDPUL	G
Gavelinella baltica	GAVBAL	H
G. cenomanica	GAVCEN	I
G. complanata (Reuss)	GAVCOM	J
G. flandrini	GAVFLAN	K
G. intermedia	GAVINT	L
G. monterelensis	GAVMONT	M
G. pazdroae	GAVPAZ	N
G. plummerae	GAVPLUM	O
G. cf. baltica Price	GAVCFBAL	P
Globorotalites polonica	GLOBPOL	Q
Glomospira charoides	GLOMCHAR	R
Gyroidinoides infracretacea	GYRINFRA	S
G. primitiva	GYRPRIM	T
G. sp. 2 (Jannin)	GYRSP2	U
Haplophragmium lueckei	HAPLUEK	V
Haplophragmoides bulloides	HAPBUL	W
H. decussatus	HAPDEC	X
H. linki	HAPLINK	Y
H. menitens	HAPMEN	Z
Hyperammina gaultina	HYPGAUL	a
Karreriella conversa	KARCON	b
Lenticulina gaultina	LENTGAUL	c
L. munsteri	LENTMUN	d
L. rotulata	LENTROT	e
L. secans	LENTSEC	f
L. subangulata	LENTSUB	g
Lingulogavelinella albiensis	LINGALB	h
L. asterigerinoides	LINGAST	i
L. ciryi	LINGCIR	j
L. frankei s.s.	LINGFRAN	k
?L. newtoni	LINGNEWT	l
L. spinosa	LINGSPIN	m
L. aff. frankei	LINGAFFR	n
Neobulimina albertensis s.s.	NEOALB	o
Orthokarstenia cf. shastaensis	ORTHOSH	p
Osangularia insigna	OSANINS	q
O. occidentalis s.s.	OSANOCC	r
O. utaturensis	OSANUTAT	s

table 5 cont.

Species	Cluster	Factor
Osangularia aff. occidentalis	OSANAFOC	t
Pleurostomella obtusa	PLEUOB	u
Praebulimina evexa	PRAEEVEX	v
Psammosphaera scruposa	PSAMSCRU	w
Quadrimorphina allomorphinoides	QUADALLO	x
Ramulina aculeata	RAMACU	y
Recurvoides deflexiformis	RECDEF	z
R. pseudosymmetricus	RECPSEUD	A′
R. subturbinatus	RECSUB	B′
Reophax guttifera	REOGUT	C′
R. pepperensis	REOPEP	D′
??Saccimminoides sp.	SACSP	E′
Saracenaria navicula	SARNAV	F′
Spiroplectammina annectens	SPIRANN	G′
Textularia topagorukensis	TEXTOP	H′
Trochammina eilete	TROCEIL	I′
T. globigeriniformis	TROCGLOB	J′
Uvigerinammina jankoi	UVIGJAN	K′
Valvulineria berthelini	VBERT	L′
V. gracillima	VGRAC	M′
V. loetterlei	VLOET	N′
V. parva	VPARV	O′
Verneuilina cretacea	VERCRET	P′
Verneuilinoides borealis	VERBOR	Q′

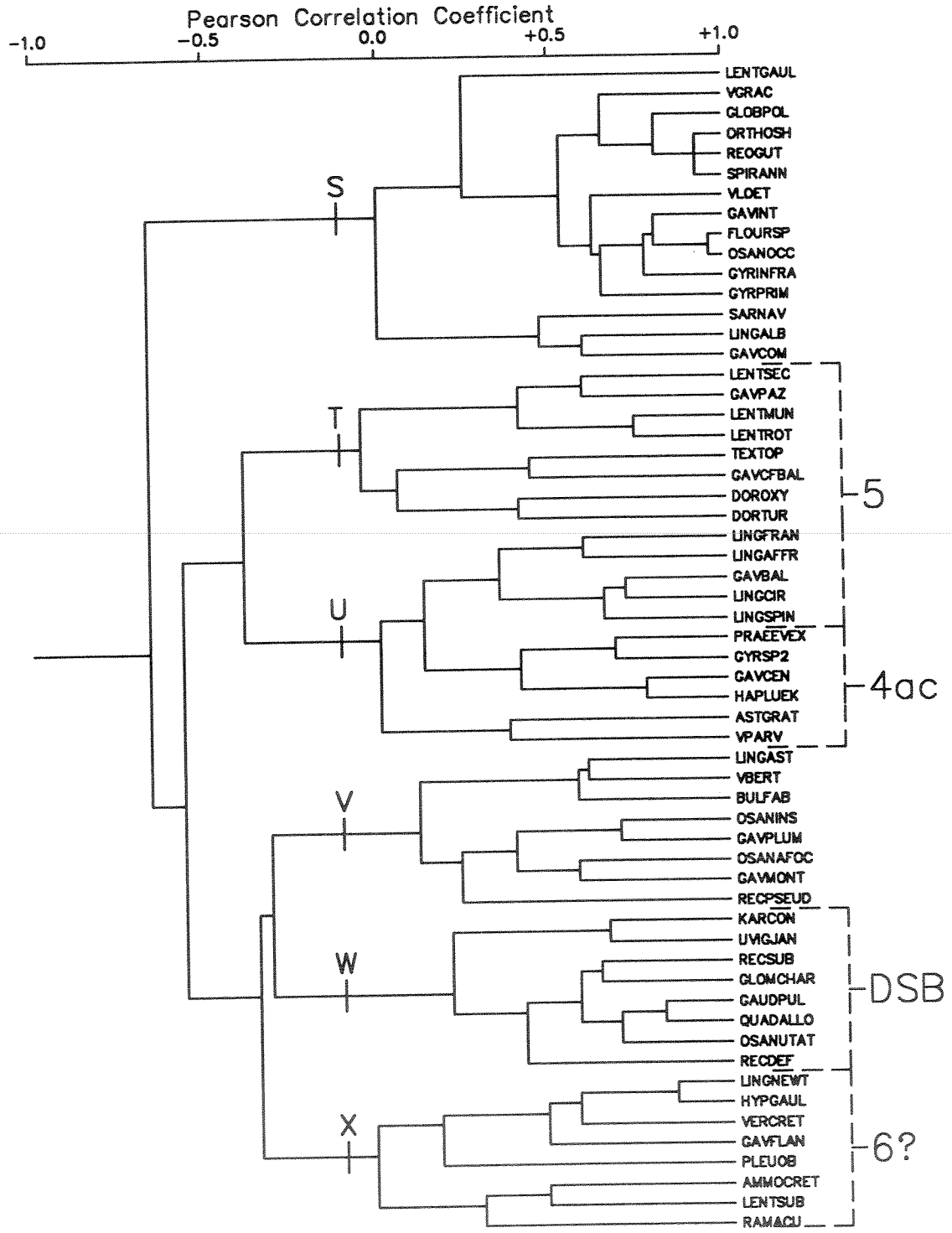


Figure 31: R-mode cluster analysis of Shell 586 species with interpreted biofacies (note: biofacies 5 is based upon factor T', figure 36, below).

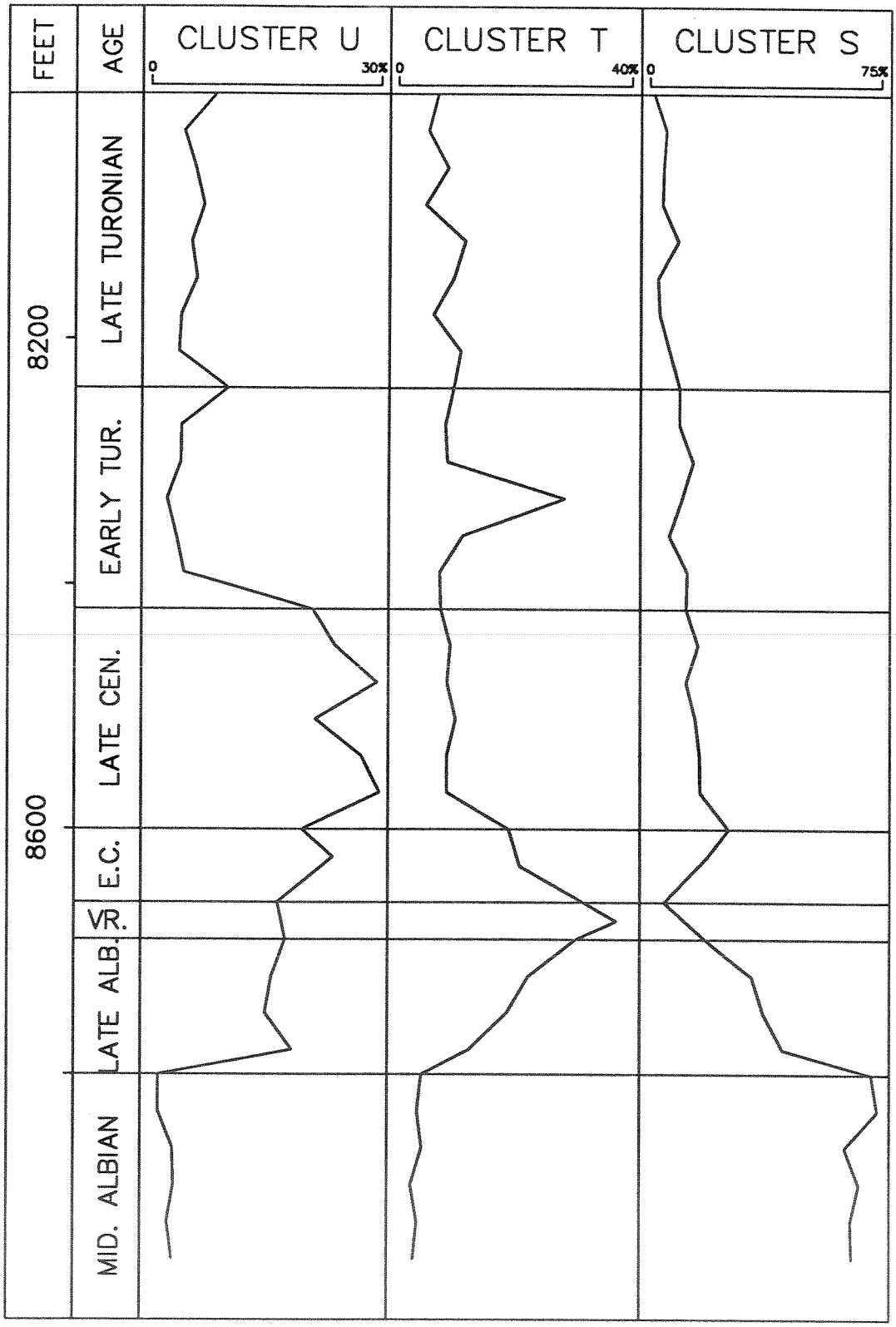
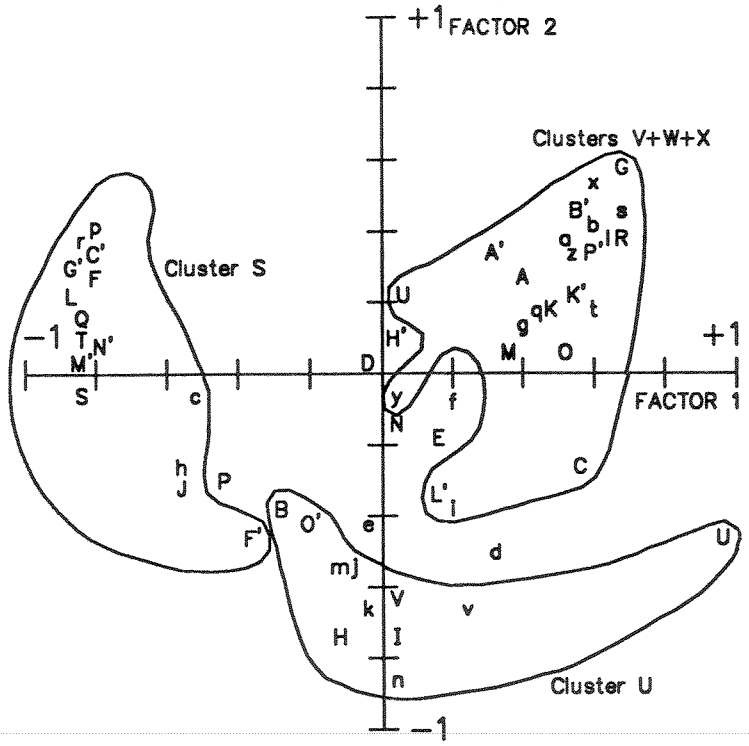


Figure 32: Relative abundance distribution of species comprising Shell 586 clusters S, T and U (E.C. = Early Cenomanian, VR. = Vraconian).

analysis, occurring within a relatively narrow range of negative loadings on factor 2 but not defined by either factor 1 or 3 (figure 33). However, factor 3 does appear to divide the assemblage into two parts; most species plotting as positive loadings whereas a smaller group of four species plot as negative values (figure 33). Three of these four taxa are Lingulogavelinella species which are uncharacteristic of biofacies 4(ac). Dropping these species from cluster U results in an assemblage (U') which much more closely resembles cluster M assemblage of biofacies 4(ac) in the COST B2 well. In both assemblages, Gavelinella cenomanica, Gyroidinoides sp. 2 (Jannin) and Valvulineria parva are the most abundant constituents. Assemblage U' characterizes a much narrower stratigraphic interval (upper Cenomanian) than does cluster U assemblage (figures 32 and 34). It should be noted, however, that assemblage U' is very poorly defined quantitatively (figures 31 and 33).

Thus the species composition of biofacies 4(ac) varies downslope from the Shell 272 well to the Shell 586 well. Only Gavelinella cenomanica is abundant in all defining assemblages. Biofacies 4 succeeds biofacies 3 downslope. It underlies biofacies 3 in a shallowing-upward section in the Shell 272 well and overlies biofacies 3 in a deepening-upward section of the COST B2 well. The wide distribution of biofacies 4 in shelf and slope sites likely indicates



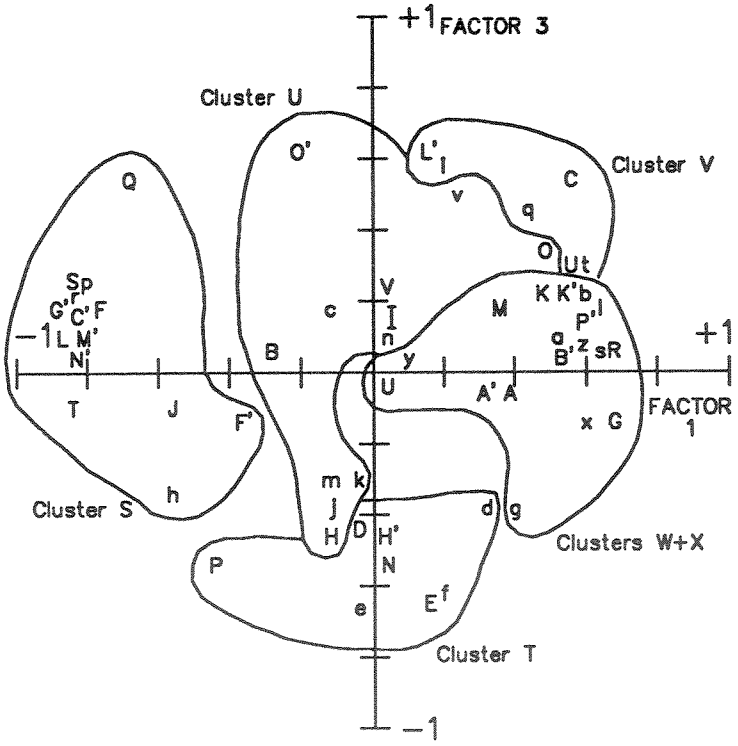


Figure 33: R-mode factor analysis showing Shell 586 species clusters in three-dimensional factor space.

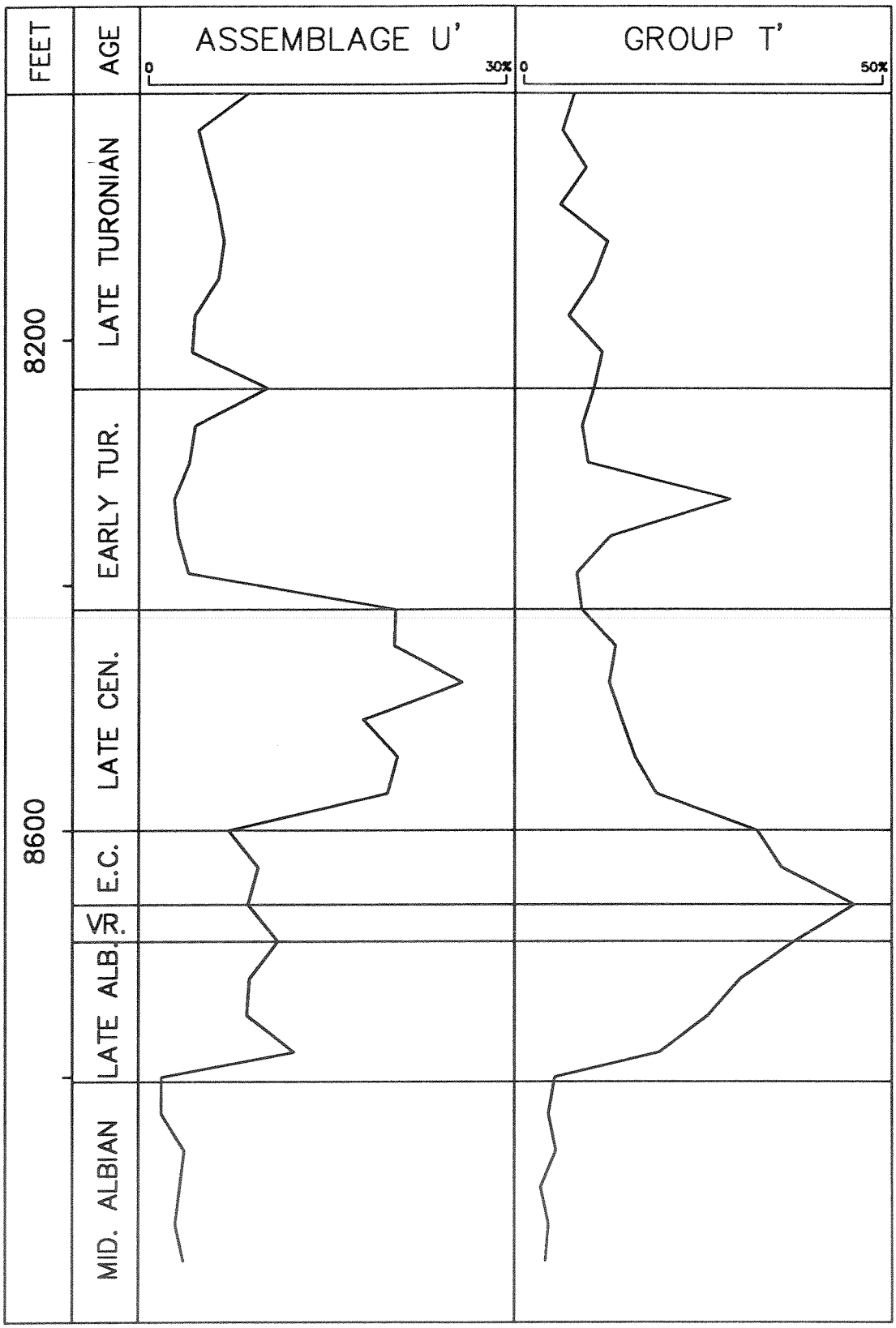


Figure 34: Relative abundance distribution of assemblage U' and factor group T', Shell 586.

that it represents outer neritic to bathyal paleodepths.

Biofacies 5. In the Shell 272 well, cluster I assemblage (figure 23) is very common in a narrow interval spanning the Cenomanian/Turonian boundary (figure 29). The boundary probably approximates the maximum flooding surface of UZA 2.5. Therefore, cluster I assemblage is indicative of the deepest paleodepths of the Shell 272 well and is defined as biofacies 5. Supporting paleobathymetric evidence is provided by planktic abundance which reaches maximum values of 75 to 80% in this interval. Cluster I assemblage is characterized by Lingulogavelinella frankei, L. globosa and species of Lenticulina.

Factor 1 best defines and separates the two deeper-water assemblages in the Shell 272 well (figure 25). Cluster I assemblage (biofacies 5) plots as positive loadings whereas cluster J assemblage (biofacies 4(ac)) plots as negative values. Factor 2 separates these two biofacies from shallow-water cluster L assemblage (biofacies 3). Negative loadings on factor 3 are assigned to species most characteristic of the upper Turonian (e.g., cluster K - "biofacies" 4(t)) (figure 25). However, those species common in the Albian to lower Turonian plot as positive loadings and the highest values tend to indicate specifically Albian and Cenomanian assemblages (e.g., cluster J - biofacies 4(ac)) (figure 25). Cluster I assemblage plots as positive values on factor 3 but appears

to be broken into two groups. Cluster analysis produces similar groupings as subclusters I-a and I-b (figure 23). Cluster I assemblage as a whole is characteristic of both the uppermost Cenomanian and lower Turonian (figure 29). However, species of subcluster I-a are abundant only in the lower Turonian whereas subcluster I-b assemblage is more indicative of the uppermost Cenomanian. Thus on factor 3 subcluster I-b and cluster J, both common in the Cenomanian, show considerable overlap whereas lower Turonian subcluster I-a plots as lower values.

This division of biofacies 5 into two assemblages is even more pronounced in the COST B2 well (figure 26). Cluster Q assemblage is common only in the lowermost Turonian whereas cluster O assemblage characterizes both upper-Cenomanian and lower-Turonian intervals (figure 35). The division may reflect a paleoenvironmental control. The maximum flooding surface of UZA 2.5 in the Oxly well occurs in the lower Turonian rather than at the Cenomanian/ Turonian boundary. Thus the assemblages of biofacies 5 which characterize the lowermost Turonian (subcluster I-a and cluster Q) may best define the time of most rapid sea level rise.

The "uppermost-Cenomanian" assemblages of biofacies 5 (subcluster I-b and cluster O) are also common in the lower Turonian (e.g., cluster O - figure 35). The sharp decrease

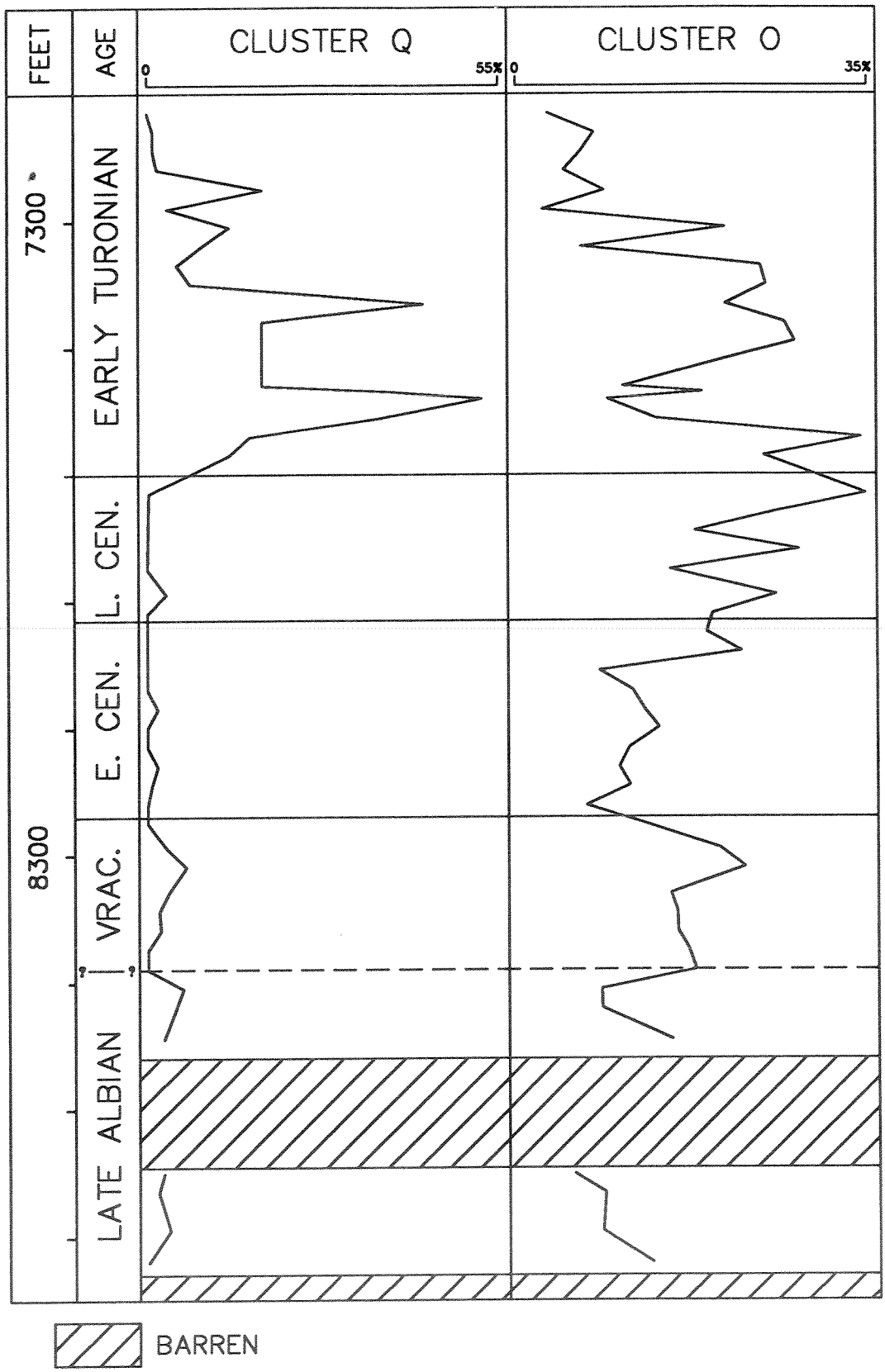


Figure 35: Relative abundance distribution of species comprising COST B2 clusters Q and O.

in abundance shown by the lower-Turonian assemblages downwell into the Cenomanian (e.g., cluster Q - figure 35) is mainly a reflection of the stratigraphic range of Lingulogavelinella globosa. This species is the most dominant component of both lower Turonian assemblages but does not occur in older sections. Its first appearance occurs in the Turonian as noted by Butt (1966) and Gawor-Biedowa (1972). The sudden appearance of abundant L. globosa upsection is likely the reason for the division of biofacies 5 by both factor and cluster analysis. The two assemblages thus probably do not represent different paleoenvironments. This assumption is supported by the COST B2 well factor analysis which fails to differentiate cluster Q and O assemblages. Species from both clusters plot as a single group of positive loadings on factor 3 (figure 28).

The Shell 586 well cluster analysis poorly differentiates biofacies 5 (figure 31). Most of the characteristic species of Lenticulina are contained in cluster T assemblage which is abundant only in the uppermost Albian and lower Cenomanian (figure 32). The species eliminated from cluster U assemblage to form assemblage U′ are also characteristic of biofacies 5, especially Lingulogavelinella frankei and L. ciryi (j and k in figures 33 and 36). Adding these species to cluster T assemblage forms factor group T′, defined as negative

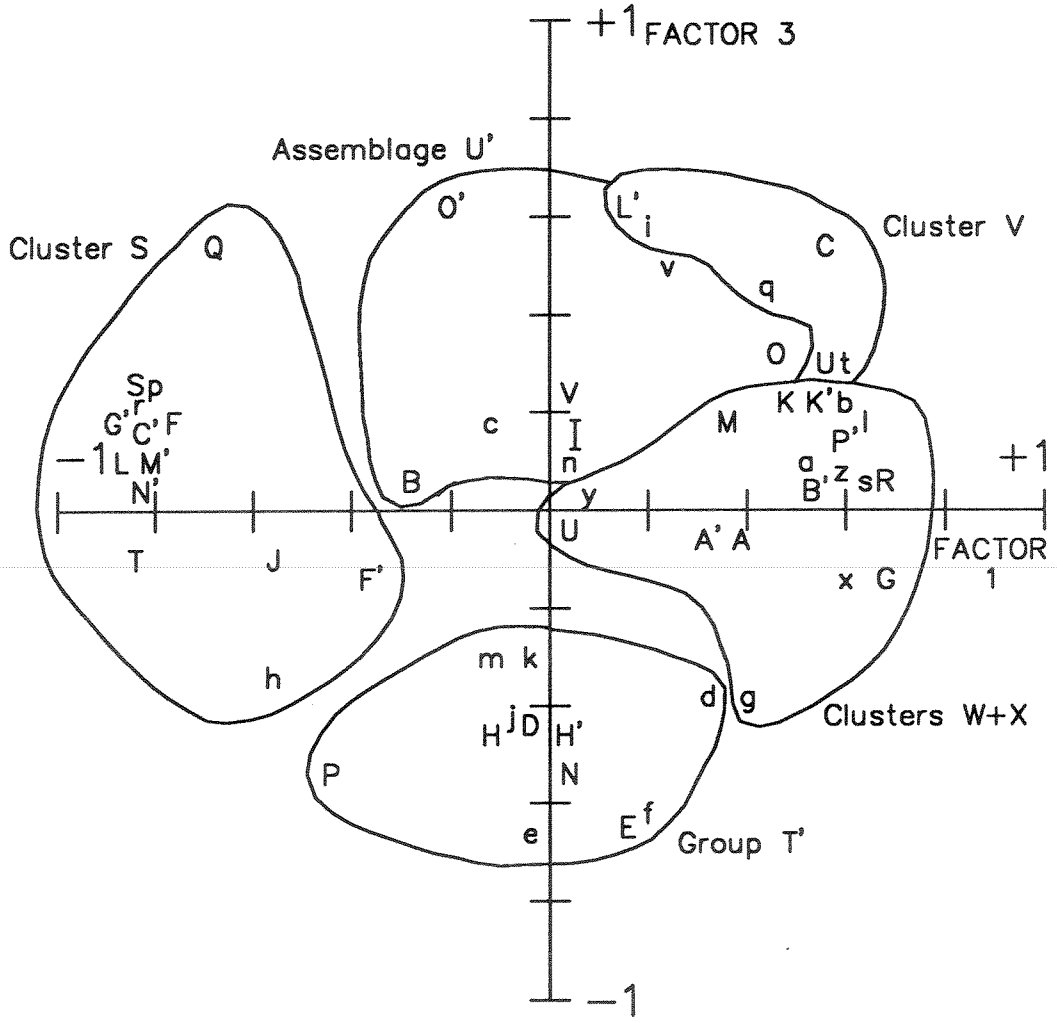


Figure 36: Factor 1 X 3 plot, Shell 586, indicating species factor group T'.

loadings on factor 3 (figure 36). Group T' assemblage is similar to biofacies 5 of the Shell 272 and COST B2 wells which contain common species of Lingulogavelinella and Lenticulina. The abundance distribution of factor group T' is nearly identical to that of cluster T assemblage. The addition of four species merely increases the magnitude of an abundance maximum at the Albian/Cenomanian boundary (figures 32 and 34). The boundary is contained within a condensed section indicated by thin stratigraphic intervals and common limestone beds. The condensed section marks maximum flooding of UZA 2.2.

Biofacies 5 is replaced downwell in the middle Albian by species of cluster S (figures 31 and 32). Other than a few depauperate DSDP assemblages, cluster S is the only middle Albian assemblage examined in this study. Cluster S assemblage existed prior to diversification of shelf and slope species accompanying middle Cretaceous sea level rises. Many cluster S species became extinct at the end of the middle Albian, including Orthokarstenia shastaensis, Osangularia occidentalis and Lingulogavelinella albiensis, whereas most species which define the described biofacies did not appear earlier than the late Albian. Because cluster S assemblage occurs only in this interval of the Shell 586 well, it cannot be related to any other biofacies.

Biofacies 6(?). Two assemblages which characterize

the upper Turonian of the Shell 586 and 587 wells show a species composition which is dissimilar to previously defined assemblages. Several of the species in these upper Turonian assemblages are common in middle bathyal to abyssal sediments of DSDP sites (see below).

In the Shell 586 well, cluster X assemblage (figure 31) is characterized by common deep-water species such as ?Lingulogavelinella newtoni, Praebulimina evexa, Pleurostomella obtusa and Hyperammina gaultina. Cluster X assemblage occurs commonly, though erratically in the upper Turonian but decreases in importance downwell (figure 37).

The Shell 587 well shows an upper-Turonian interval of near uniform lithology. Species content and abundance varies little and cluster and factor groupings are less well defined than those of previous wells. Cluster Y assemblage (table 5; figure 38) contains common deep-water species including Osangularia utaturensis, O. insigna, Quadrimorphina allomorphinoides and Praebulimina evexa. In addition, cluster Y contains Hyperammina gaultina and ?Lingulogavelinella newtoni which were also common in Cluster X assemblage in the Shell 586 well. Cluster Y assemblage steadily increases in abundance upwell, reaching a maximum at the top of the section (figure 39). In factor analysis, the Shell 587 well cluster assemblages are separated to some extent on factor 1 but are

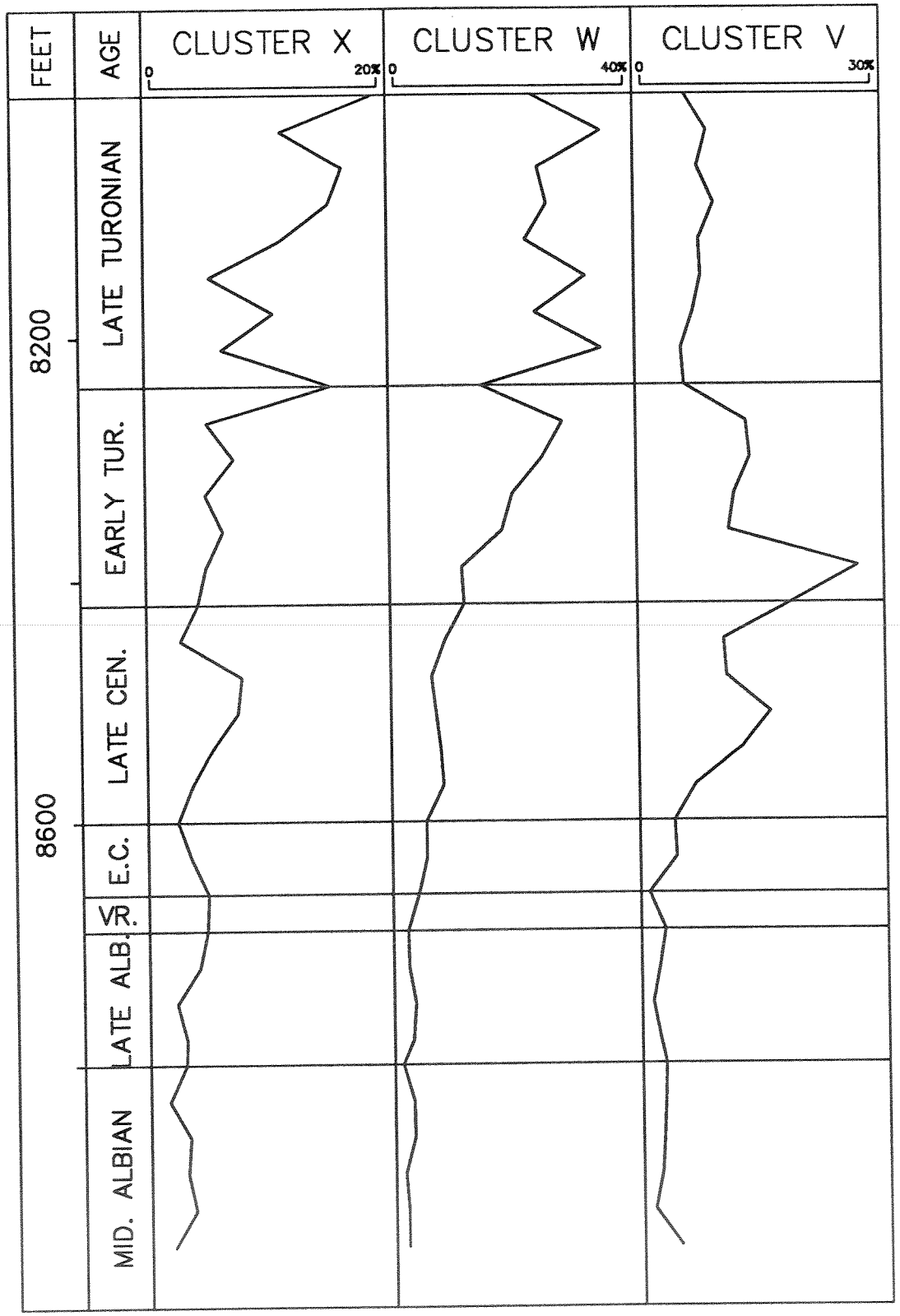


Figure 37: Relative abundance distribution of species comprising Shell 586 clusters V, X and W (E.C. = Early Cenomanian, VR. = Vraconian).

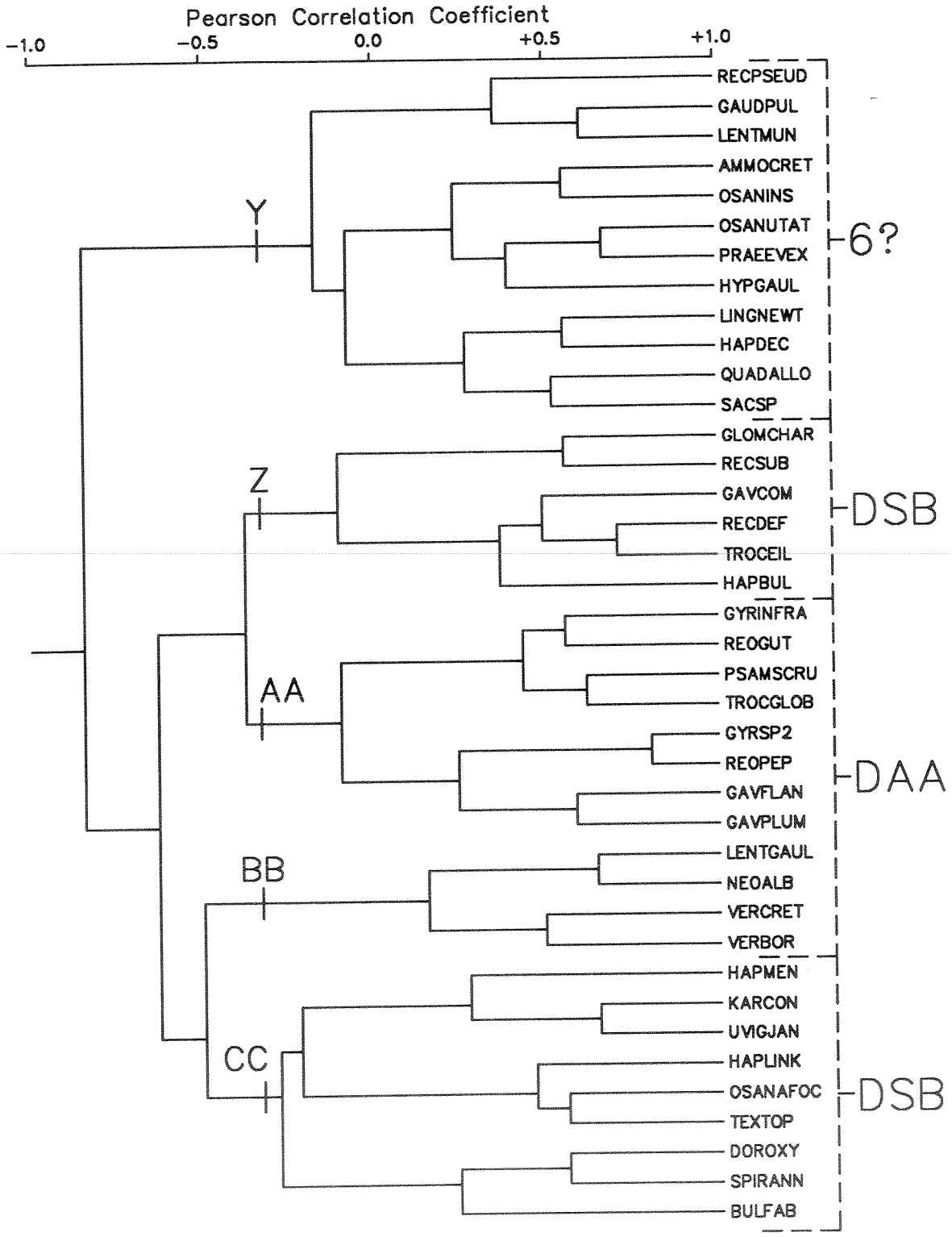


Figure 38: R-mode cluster analysis of Shell 587 species data with postulated biofacies.

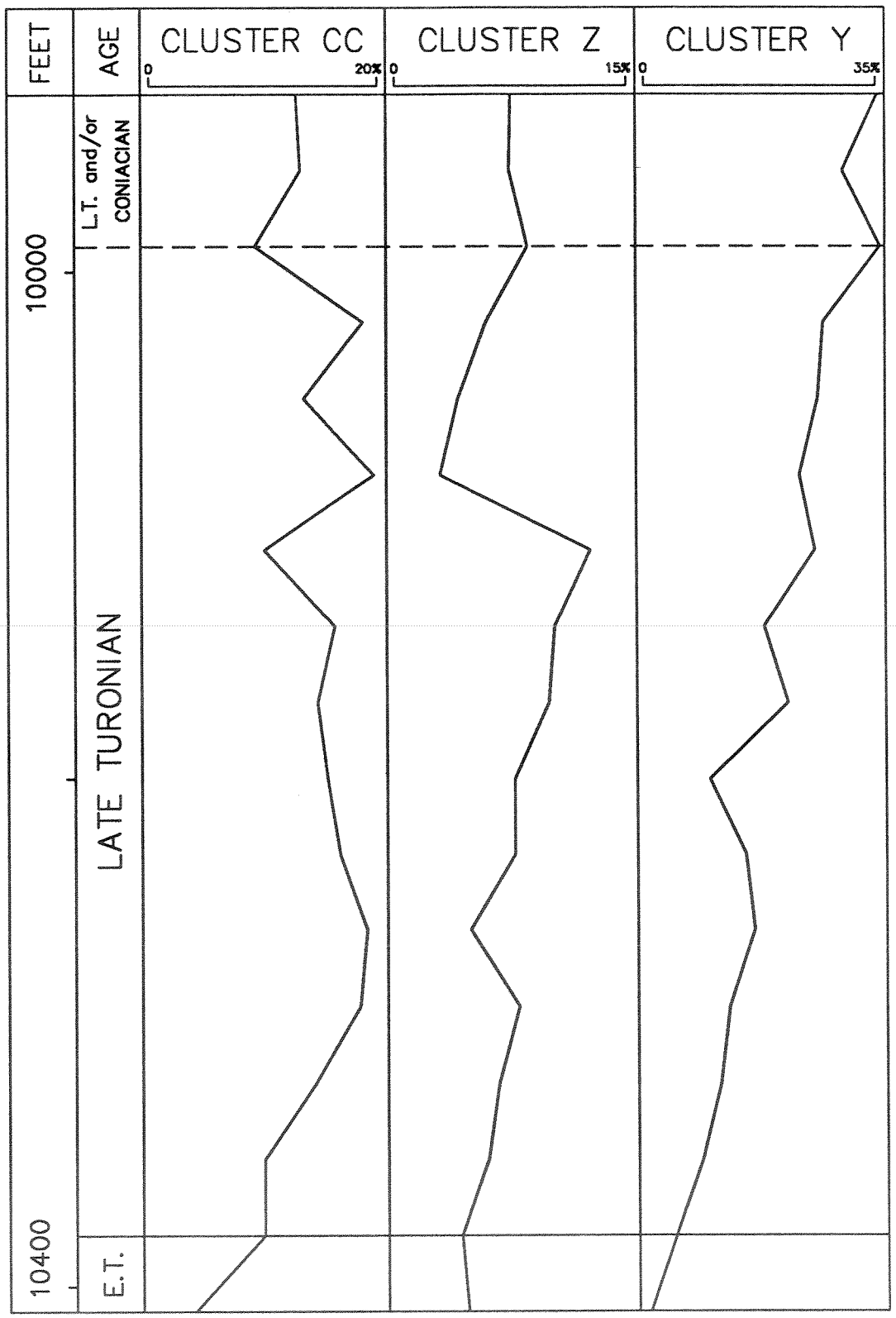


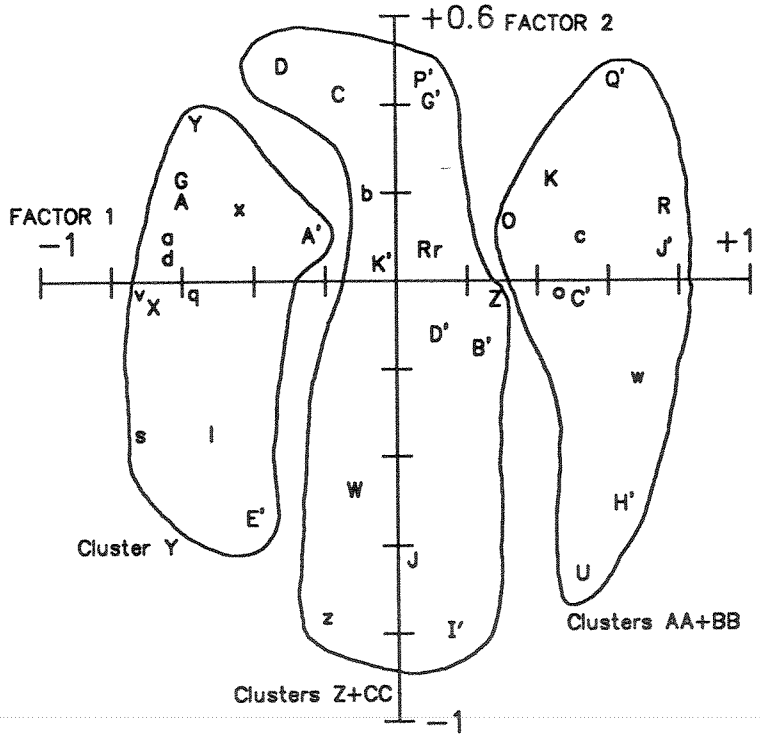
Figure 39: Relative abundance distribution of Shell 587 species clusters Y, Z, and CC (E.T. = Early Turonian; L.T. = Late Turonian).

undifferentiated by factors 2 or 3 (figure 40). Cluster Y assemblage plots as the most negative loadings on factor 1.

Cluster X and Y assemblages have many species in common with bathyal and abyssal biofacies 6 which will be defined in the next section based on DSDP data. Because these assemblages mark the only appearance of biofacies 6 elements in the New Jersey continental margin, they are referred to as biofacies 6(?).

Biofacies DSA and DSB. Two biofacies are defined which characterize organic-rich deposits. Biofacies DSA ("dysaerobic assemblage A") appears as cluster R assemblage in the COST B2 well (figure 26). It is characteristic of lower-Turonian, pyritic, carbonaceous shales which overlie calcareous clays dominated by biofacies 5. The highly compressed species Gavelinella tormarpensis and G. minima, together with poorly preserved Trochammina specimens, are extremely dominant. Cluster R assemblage is well defined by factor analysis as negative loadings on factor 1 (figure 28).

Biofacies DSB ("dysaerobic assemblage B") defines carbonaceous Turonian clays in the Shell slope wells. In the Shell 586 well, cluster W assemblage is indicative of this biofacies (figure 31) and is most common in the upper Turonian section which is also characterized by cluster X assemblage (containing species of biofacies 6). Though both cluster X and W assemblages are common in this



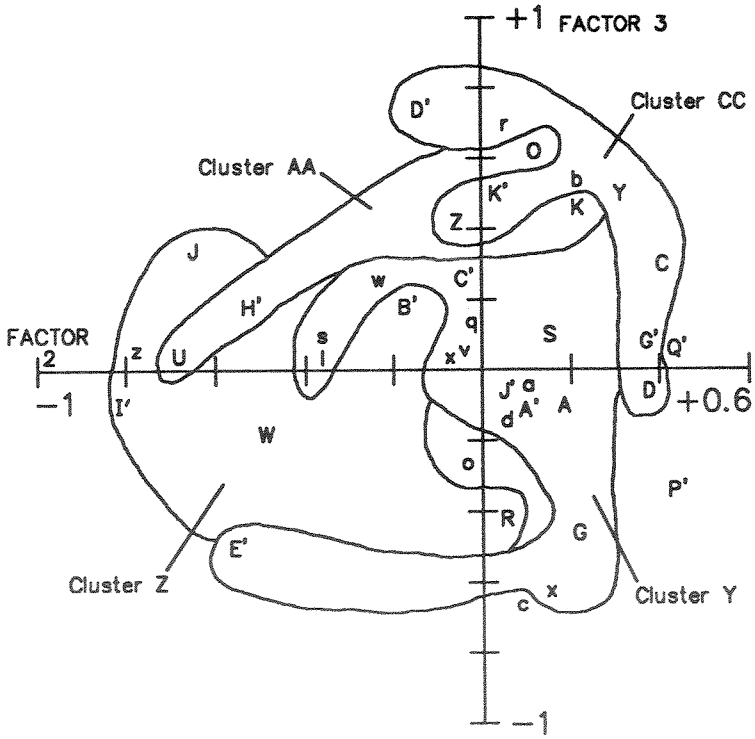


Figure 40: R−mode factor analysis showing Shell 587 species clusters in three−dimensional factor space.

interval, they show inverse abundance patterns which probably reflect different environmental tolerances (figure 37).

In the lowermost Turonian, cluster W species are largely replaced by cluster V assemblage (figures 31 and 37). Some cluster V species are characteristic of shallow-water biofacies (e.g., Gavelinella plummerae and G. monterelensis) and poorly preserved species of Epistomina are present. These species likely indicate downslope displacement and thus a significant portion of cluster V assemblage is not in situ.

Factor analysis fails to distinguish between the Turonian assemblages of the Shell 586 well (clusters V, W, X) which plot as a group of positive loadings on factors 1 and 2 (figure 33). Factor 1 separates Turonian species from Albian and Cenomanian assemblages whereas factor 3 partially separates cluster W and X assemblages from the displaced species of cluster V (figure 33).

In the Shell 587 well, biofacies DSB is defined by clusters Z and CC (figure 38). Both cluster assemblages show common, though erratic occurrence in most of the examined section, declining in abundance only near the top and bottom (figure 39). Factor analysis does not distinguish between clusters Z and CC which plot as a group within a relatively narrow range of loadings near zero on factor 1 (figure 40).

In both the Shell 586 and 587 wells, biofacies DSB is composed of agglutinated species such as Haplophragmoides cf. menitens, Karreriella conversa, Recurvoides subturbinatus, R. deflexiformis and Uvigerinammina jankoi, most of which have been previously reported from upper Cretaceous deep-sea sediments (Krashenninikov, 1974) as well as from Alpine and Carpathian flysch deposits.

Biofacies DAA. Cluster assemblages AA and BB of the Shell 587 well (figure 38) contain species which do not commonly occur in any other examined section. The assemblages characterize the lower 80 feet immediately overlying an Aptian-Cenomanian unconformity, and then generally decline in abundance upsection (figure 41). The assemblages are composed of agglutinated species which are similar to taxa previously described as indicative of disturbed benthic environments (Kaminski, 1985; Kaminski and Schroder, 1987; Kaminski et al., 1987). They include Psammosphaera scruposa and Reophax species as well as Verneuilinoides borealis which are here defined as biofacies DAA ("disturbed agglutinated assemblage"). Factor analysis defines clusters AA and BB as a single group of positive loadings on factor 1 (figure 40).

Biofacies Formation Summary

In each biofacies in table 1, the species listed are the most abundant components in the defining assemblages.

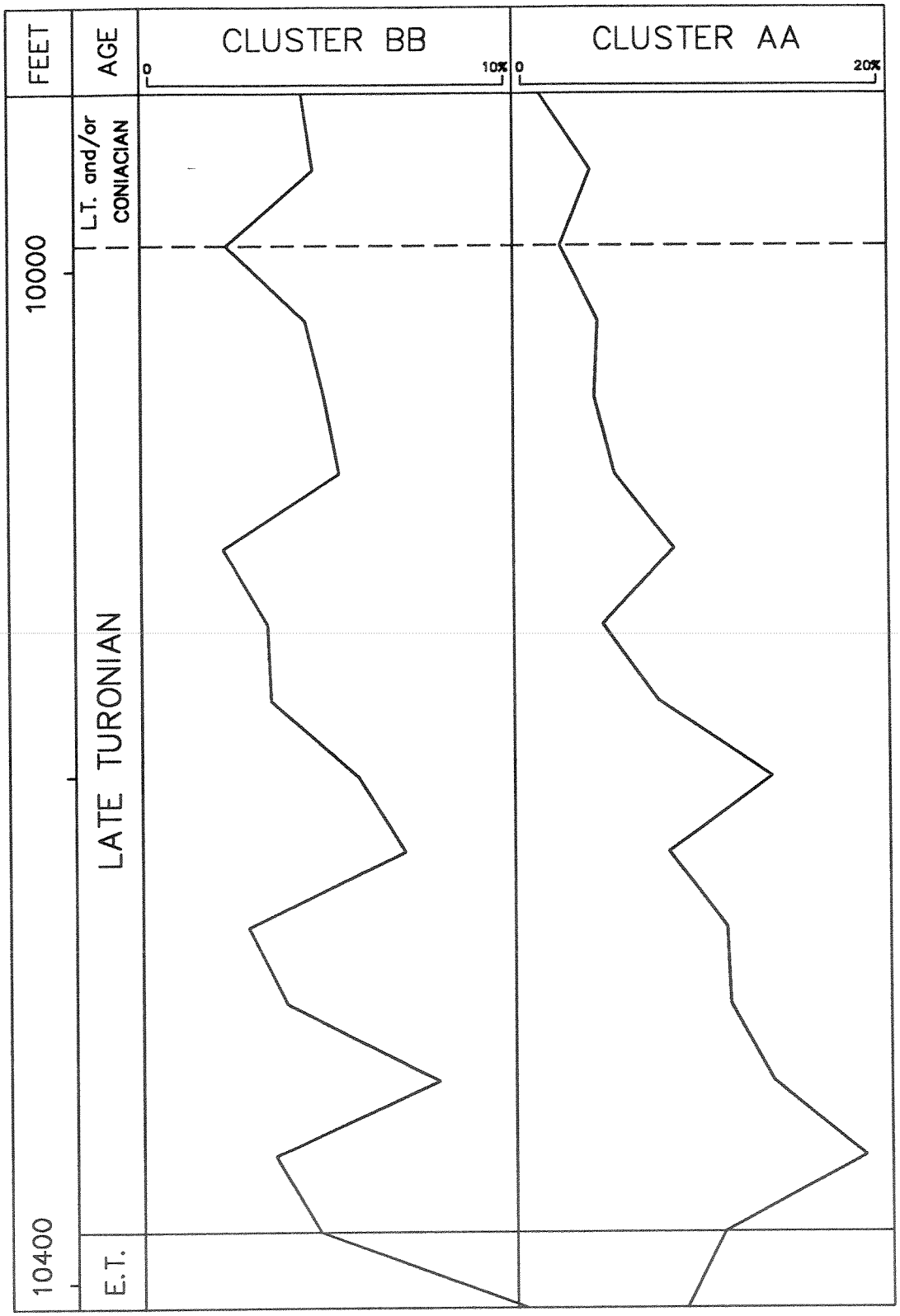


Figure 41: Relative abundance distribution of Shell 587 species clusters AA and BB (L.T. = Late Turonian; E.T. = Early Turonian).

Reoccurrence of these species in assemblages from different sites indicates similar paleoenvironments. This hypothesis is further supported by trends in planktic percentage, benthic diversity and lithology. The defining species also occur with less common, often eurybathic taxa which generally appear in different assemblages from site to site. Therefore, assemblage similarity based on total species content is often low (e.g., cluster A and E assemblages, biofacies 2 - figures 15 and 18). However, the author believes that reoccurrence of those species (table 1) most indicative of the observed paleoenvironments is a more meaningful measure of similarity. Based on this reoccurrence, all biofacies except 4 and 6 are well defined on the New Jersey Atlantic Margin.

Biofacies 4 is composed of two different stratigraphic assemblages. "Biofacies" 4(t) cannot be definitively recognized because of lack of upper Turonian data in the wells used. It is tentatively defined based on a single assemblage from the Shell 272 well (cluster K). Biofacies 4(ac) occurs in the Shell 272, COST B2 and Shell 586 wells. However, species composition is variable downslope and only Gavelinella cenomanica is abundant at all three sites. Upslope at the Shell 272 well, biofacies 4(ac) is characterized by Gaudryina cushmani and polymorphinids. Downslope at the Shell 586 well, the biofacies contains common Gyroidinoides sp. 2 (Jannin) and Valvulineria parva.

In between these points, all four defining species occur together in the COST B2 well. However, no matter what the species composition of the biofacies at any one point, the assemblage occupies the same slope position relative to the other biofacies and all four species go extinct at the end of the Cenomanian. Therefore, they appear to represent the same paleoenviroment and thus warrent formation as a biofacies. The variable species composition of biofacies 4(ac) probably reflects its broad geographic and bathymetric range to which only Gavelinella cenomanica had fully adapted by the end of the Cenomanian.

Cluster X and Y assemblages of the Shell 586 and 587 wells contain many species from bathyal and abyssal biofacies 6 defined below. However, the two assemblages show little similarity to each other and cannot meet the requirements of biofacies formation set by this study. Nevertheless, they are labeled as biofacies 6(?) because they represent the only occurrence of these deep-water species in the New Jersey continental margin.

C. Benthic Foraminiferal Distribution - North Atlantic DSDP Sites

Albian and Cenomanian benthic Foraminifera are indicative of neritic and lower bathyal to abyssal paleoenvironments at DSDP Sites in the North Atlantic.

Lower-bathyal and abyssal foraminifers characterize most sites and are represented by two biofacies (table 6). Biofacies 6 contains widely distributed species from both bathyal and abyssal paleoenvironments whereas biofacies 7 contains a relatively small number of species which are common only in abyssal deposits. However, neritic paleodepths are indicated at Sites 111 and 402 which are located on structural highs (Orphan Knoll and the Meriadzek Escarpment). The foraminiferal assemblages of these sites define biofacies 1* (table 6) which shows similarities to biofacies 1 of the New Jersey coastal plain.

R-mode cluster analysis of factor loadings derived from a three-factor analysis of the data matrix yields four well-defined species assemblages (table 7, figure 42). Q-mode cluster analysis was run on factor loadings derived from a factor analysis of samples based on total species content (178 species). The five groupings which result (figure 43), however, are seen to be chiefly characterized by the 44 species of the R-mode analysis.

Neritic Biofacies

Biofacies 1* is defined by R-mode (species) cluster A which contains species mainly collected from a small number of samples from Sites 111 and 402 (figures 44 and 45). These samples form most of Q-mode (sample) cluster 5 (figure 43). Site 111 is located off Newfoundland on a

Table 6: Biofacies of the DSDP Sites.

	Defining Clusters
Biofacies 1*	A
Ceratobulimina parva *Epistomina charlottae* *E. cf. chapmani* (Hart) *Patellina subcretacea* *Spirillina minima*	
Biofacies 6	B,C
Hyperammina gaultina *Pleurostomella obtusa* *Praebulimina evexa* *P. nannina* *Gavelinella pazdroae* *Osangularia insigna* *O. utaturensis* *Pleurostomella reussi*+ *Quadrimorphina allomorphinoides*+ *Quinqueloculina antiqua*+	
Biofacies 7	D
Eggerellina sp. 1 Moullade *Spiroplectammina anceps* *Pseudopatellinella rumana* *?Eponides* sp. *Osangularia brotzeni*	

+ predominate in low latitudes

Table 7: Abbreviations for DSDP species used in R-mode cluster analysis.

Buliminella fabilis	BULFAB
Ceratobulimina parva	CERPARV
Conorboides lamplughi	CONLAMP
Dorothia oxycona	DOROXY
Eggerellina sp. 1 Moullade	EGGSP
Epistomina chapmani	EPISCHAP
E. charlottae	EPISCHAR
E. cf. chapmani (Hart)	EPISCFCH
?Eponides sp.	?EPONSP
Gaudryina pulvina	GAUDPUL
Gavelinella baltica	GAVBAL
G. cenomanica	GAVCEN
G. flandrini	GAVFLAN
G. intermedia	GAVINT
G. pazdroae	GAVPAZ
Globorotalites sp.	GLOBSP
Glomospira charoides	GLOMCHAR
Gyroidinoides infracretacea	GYRINFRA
G. primitiva	GYRPRIM
G. sp. 2 (Jannin)	GYRSP2
Hyperammina gaultina	HYPGAUL
Neobulimina minima	NEOMIN
Osangularia brotzeni	OSANBROT
O. insigna	OSANINS
O. utaturensis	OSANUTAT
Patellina subcretacea	PATSUB
Pleurostomella obtusa	PLEUOB
P. reussi	PLEUREUS
Praebulimina evexa	PRAEEVEX
P. nannina	PRAENAN
Pseudonodosaria humilis	PSEUHUM
P. mutabilis	PSEUMUT
Pseudopatellinella cretacea	PSEUPCRE
P. rumana	PSEUPRUM
Quadrimorphina allomorphinoides	QUADALLO
Q. trochoides	QUADTROC
Quinqueloculina antiqua	QUINANT
Q. moremani	QUINMOR
Ramulina aculeata	RAMACU
Spirillina minima	SPIRMIN
Spiroplectammina anceps	SPIROANC
Valvulineria berthelini	VBERT
V. loetterlei	VLOET
V. parva	VPARV

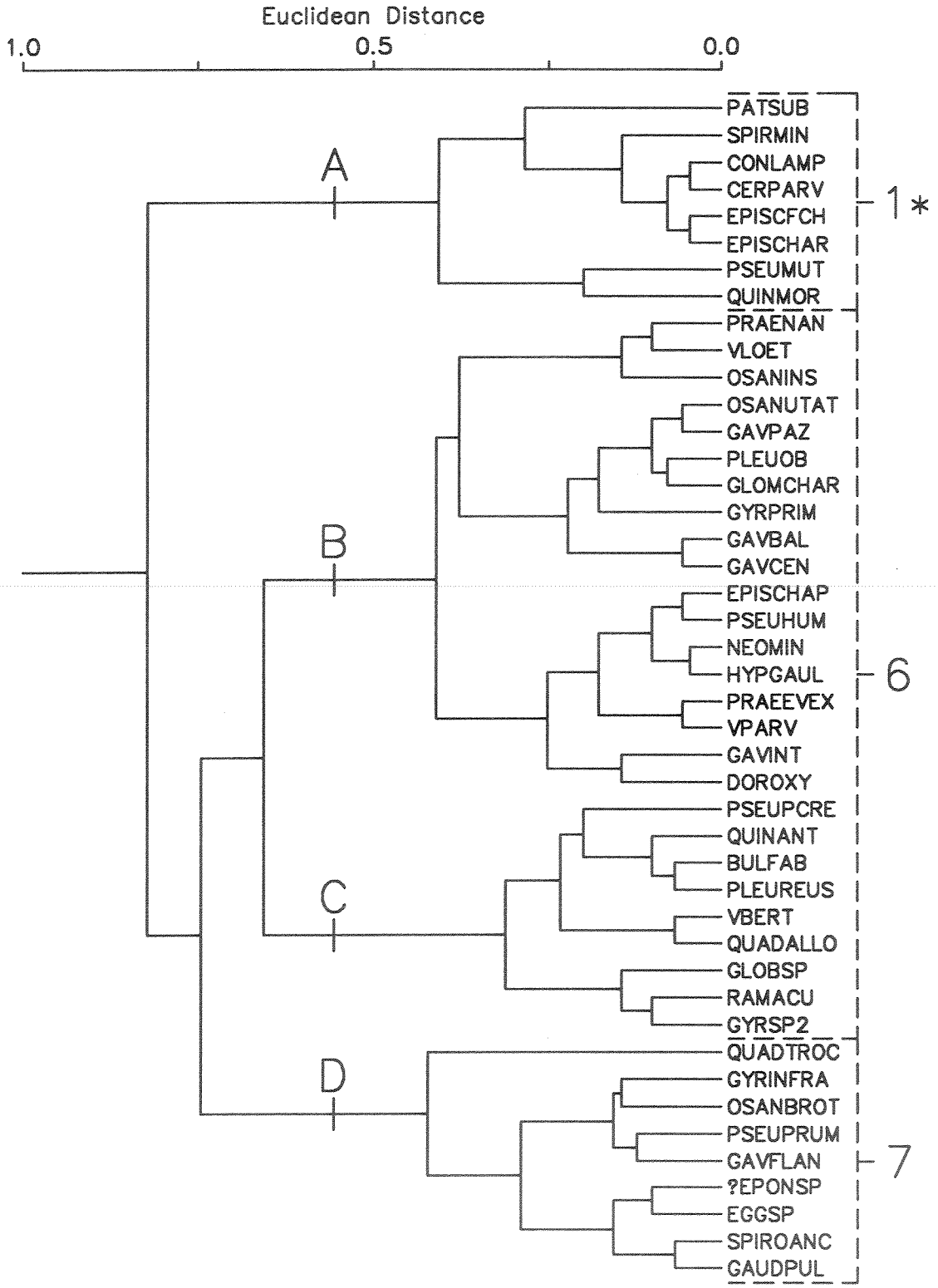


Figure 42: R-mode cluster analysis of DSDP data (based upon loadings from three-factor analysis) and proposed biofacies.

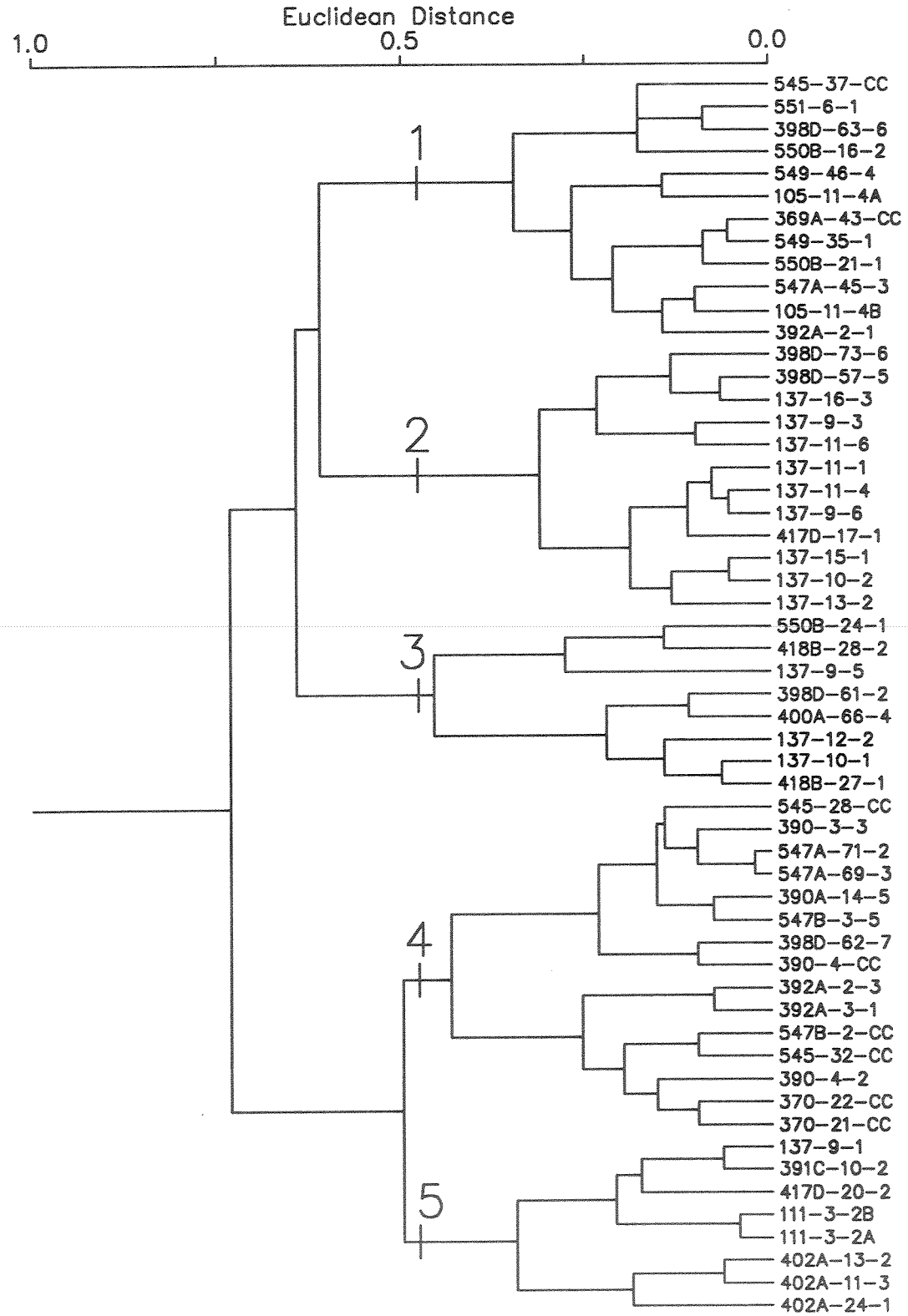


Figure 43: Q-mode cluster analysis of DSDP data (based upon loadings of three-factor analysis) and indicated sample groupings (137-9-1 = Hole 137, core 9, section 1; CC = core catcher).

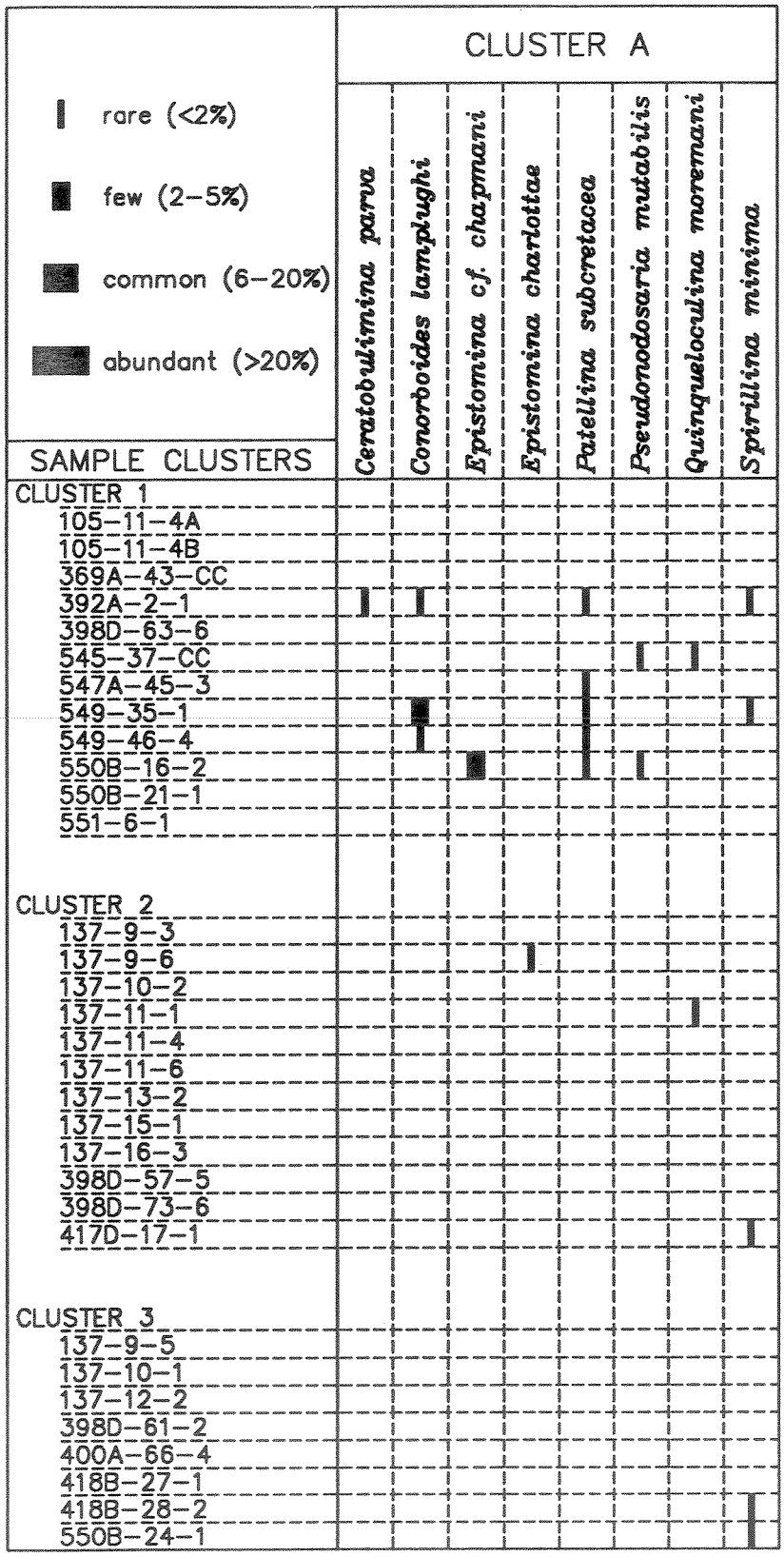


Figure 44: Relative abundance of DSDP species cluster A, showing greatest abundance in sample cluster 5.

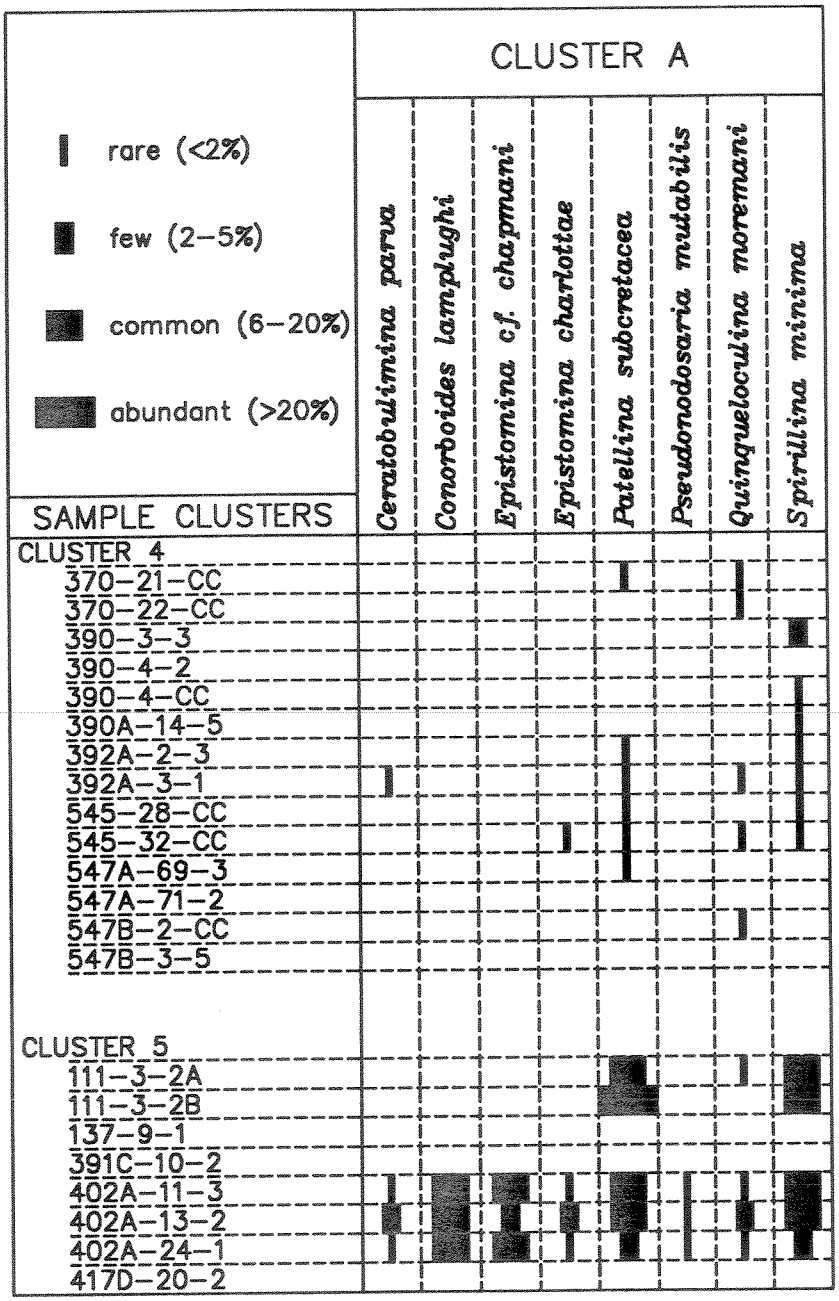


Figure 44 (cont.)

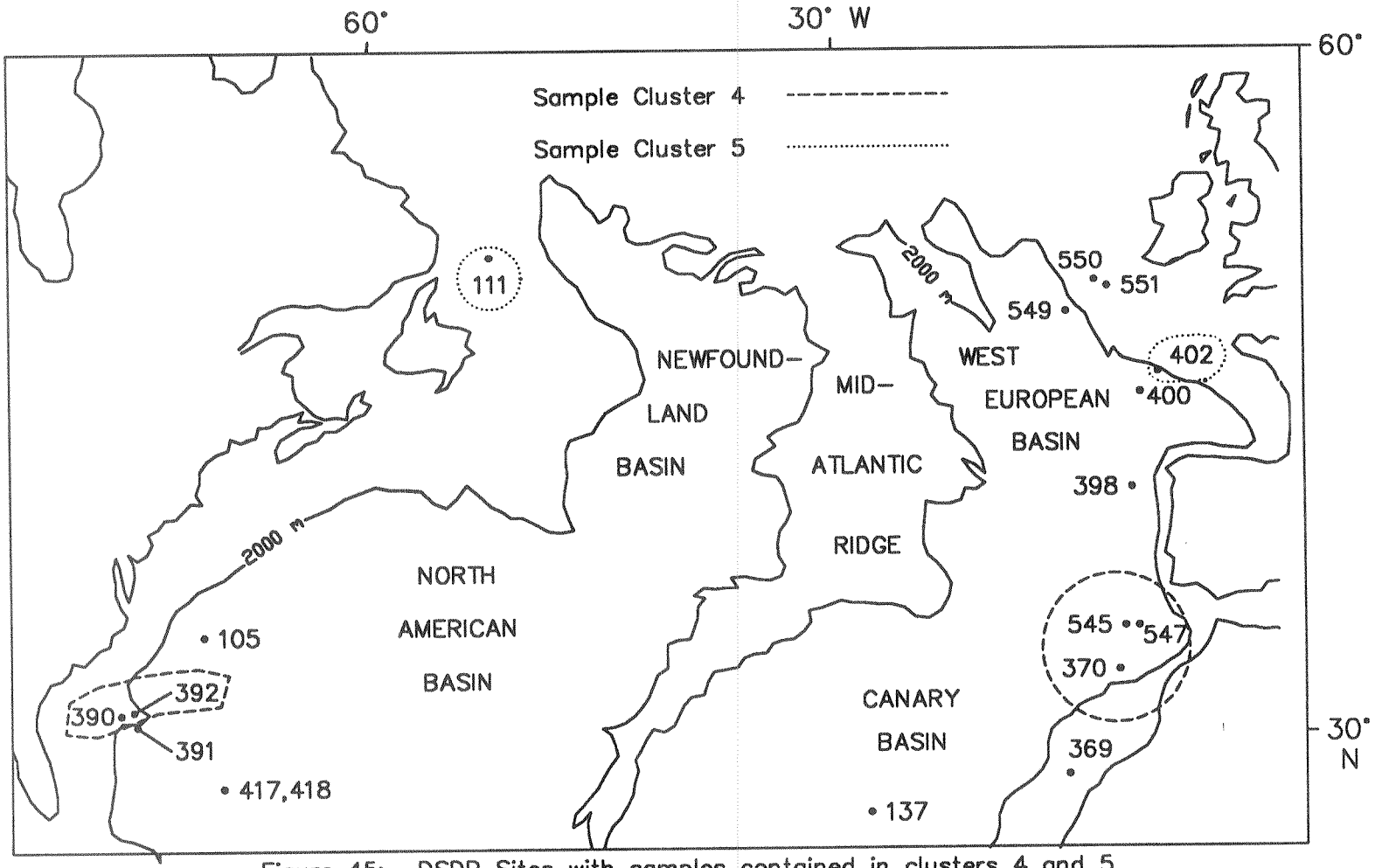


Figure 45: DSDP Sites with samples contained in clusters 4 and 5.

topographic and structural high (Orphan Knoll) and had a a paleodepth in the Albian and Cenomanian of less than 100m (Laughton et al., 1972). A similar estimate has been made for Site 402 on the upper Meriadzek Escarpment in the Bay of Biscay (Roberts and Montadert, 1979). The samples from these two sites have few benthic foraminifers in common with most other samples. This lack of similarity includes the three other samples with which they group in Q-mode cluster 5: hole 417D, core 20, section 2, containing a depauperate assemblage in pyritic, organic-rich clays, and samples 137-9-1 and 391C-10-2 which contain abyssal agglutinate species in variegated clays deposited below the CCD. These samples apparently group together with those of Sites 111 and 402 based solely on a shared absence of most of the R-mode analyzed species (figure 44).

Biofacies 1* shows some similarity to biofacies 1 of the New Jersey coastal plain in the common occurrence of the ceratobuliminid species Ceratobulimina parva, Epistomina charlottae and E. cf. chapmani (Hart). It differs strongly, however, in having an abundance of the spirillinid species Spirillina minima and Patellina subcretacea. These two taxa were the only components of biofacies 1* at Site 111 but the samples had been subjected to considerable dissolution. Most specimens were preserved as glauconitic casts. The aragonitic ceratobuliminids may have been present but dissolved before glauconite infilling

of their tests occurred.

The dominance of spirillinids in these shallow, but open sea sites and their absence from the New Jersey coastal plain, must reflect some environmental difference. A possible explanation would be a spirillinid preference for a carbonate substrate and/or lower sedimentation rates of Sites 111 and 402. In contrast, clayey-silts and higher rates of sedimentation characterize the New Jersey inner shelf environments. However, because biofacies 1* is based on a small sample size, any conclusions must be considered as tentative.

Bathyal and Abyssal Biofacies

Bathyal and abyssal foraminiferal species and genera of Albian and Cenomanian DSDP sites in the North Atlantic are broadly distributed. No major changes occur in either the geographic or stratigraphic distribution of the assemblages. Benthic species were generally common and diverse, yielding H(S) values between 2.5 and 3.0.

The most characteristic genera include Gavelinella, Gyroidinoides, Osangularia, Hyperammina, Glomospira and Pseudopatellinella. Species of the North Atlantic DSDP sites also occur in bathyal and abyssal middle Cretaceous deposits in many other regions of the Atlantic as well as in the Indian Ocean (e.g., Gradstein, 1978; Magniez and Sigal, 1985; Moullade, 1984; Scheibnerova, 1974; Sliter,

1977,1980). In this study, bathyal and abyssal foraminifers were recovered mainly from the eastern regions of the North Atlantic; the West European and Canary Basins, where deposition occurred above the CCD. In the western North Atlantic, preservation of middle Cretaceous foraminifers is poor due to deposition under corrosive, anaerobic bottom-water conditions.

Biofacies 6, defined by R-mode clusters B and C (figure 42), is a widely distributed assemblage which is common in all sample groupings except cluster 5. Most eurybathic species of the Atlantic Basin and the New Jersey margin are contained within either of these groups (e.g., Gavelinella intermedia, Buliminella fabilis). However, most species of R-mode clusters B and C do not occur in the New Jersey margin except for those few which indicate biofacies 6 in the Baltimore Canyon Trough. The assemblage represented by cluster B is the most widely distributed. It is absent only from the shallowest sites (111, 402) and from sediments deposited near of below the CCD (Sites 105, 369, 391)(figure 46).

The cluster C assemblage is also widespread and the species contained in it reach their greatest abundance in Q-mode cluster 4 (figure 47) at Sites 370, 390, 392, 545 and 547 (figure 45). None of these sites were suitable for backtracking but previous studies have all given

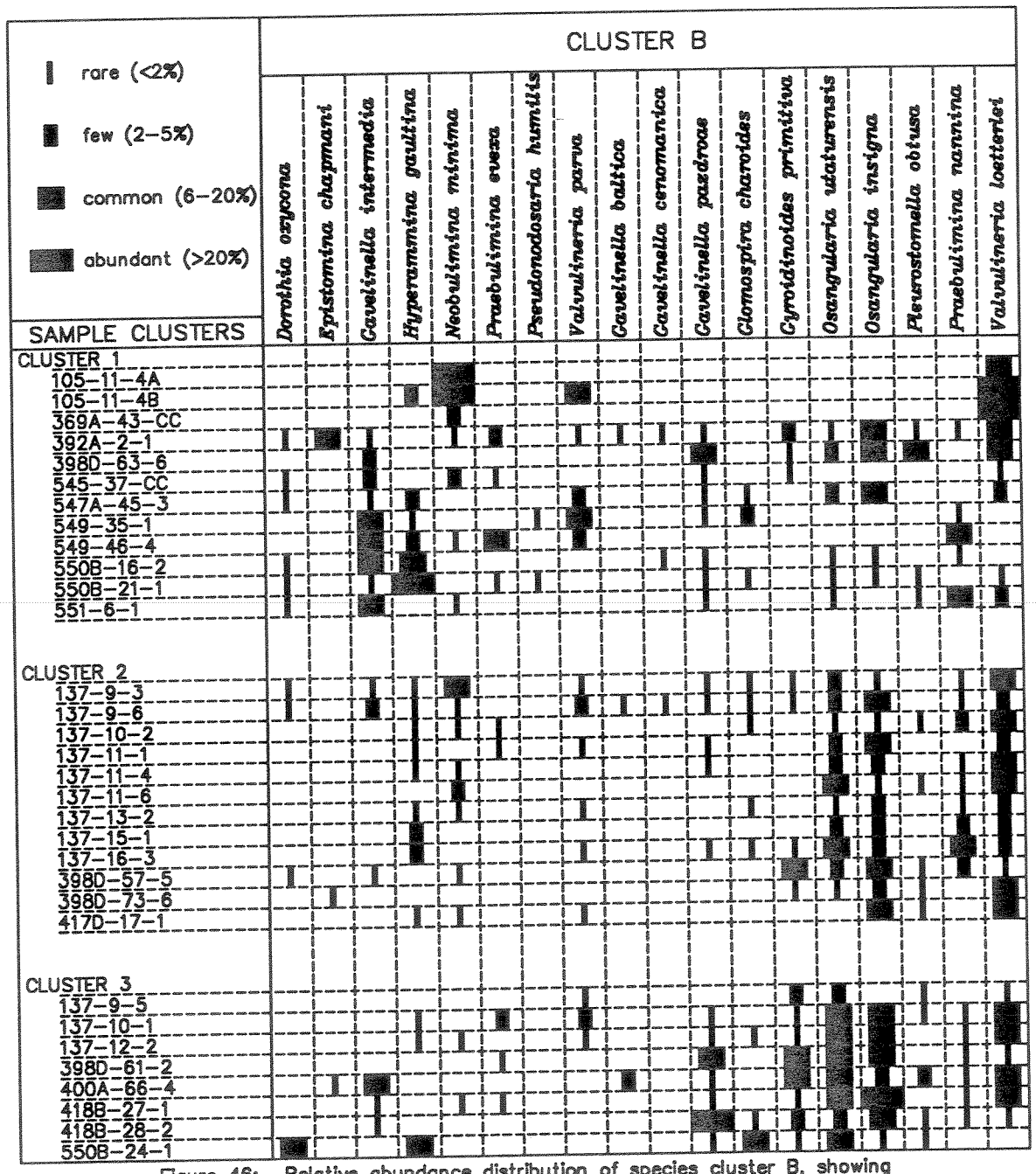


Figure 46: Relative abundance distribution of species cluster B, showing a pattern uncorrelative to any sample cluster.

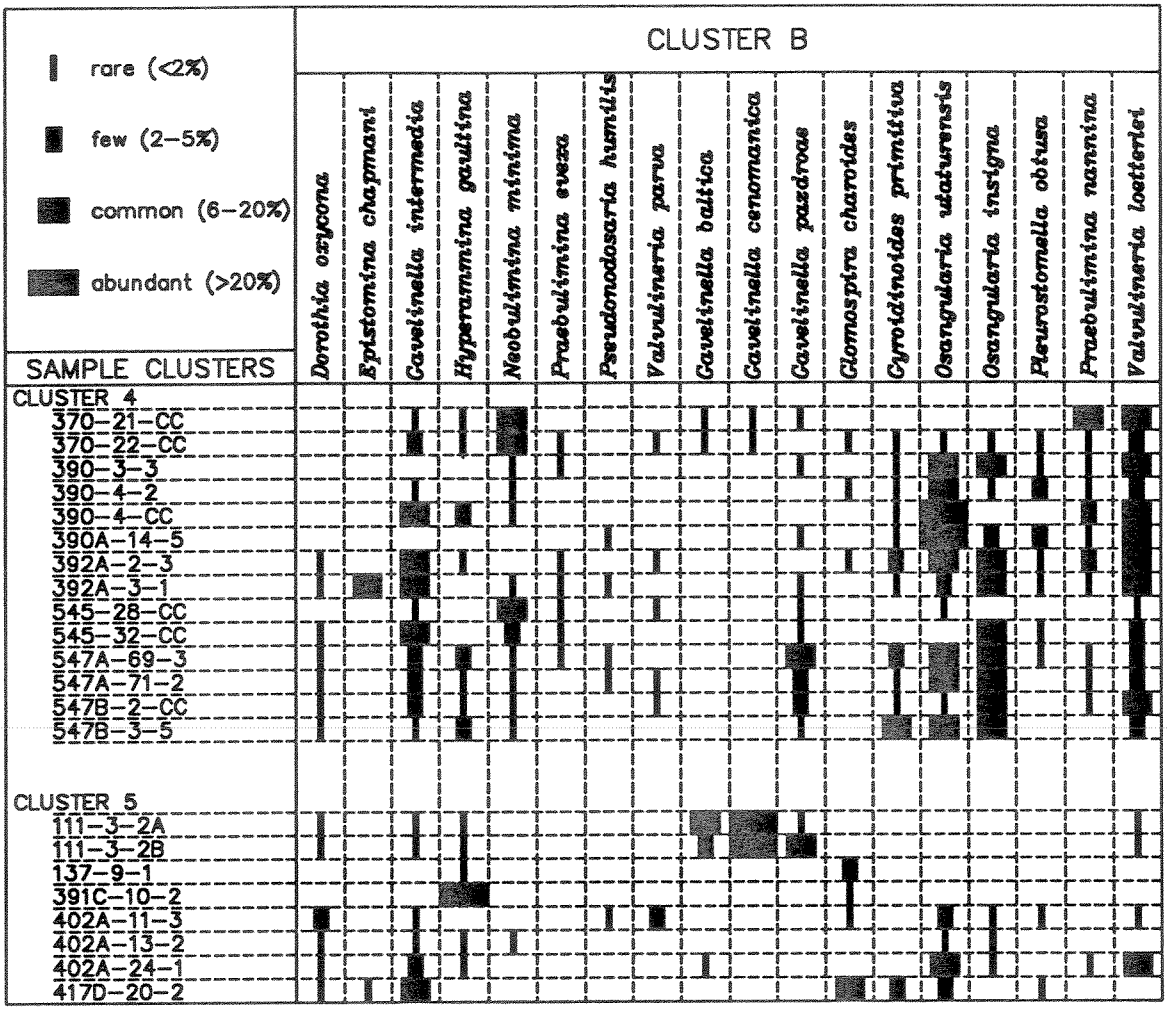


Figure 46 (cont.)

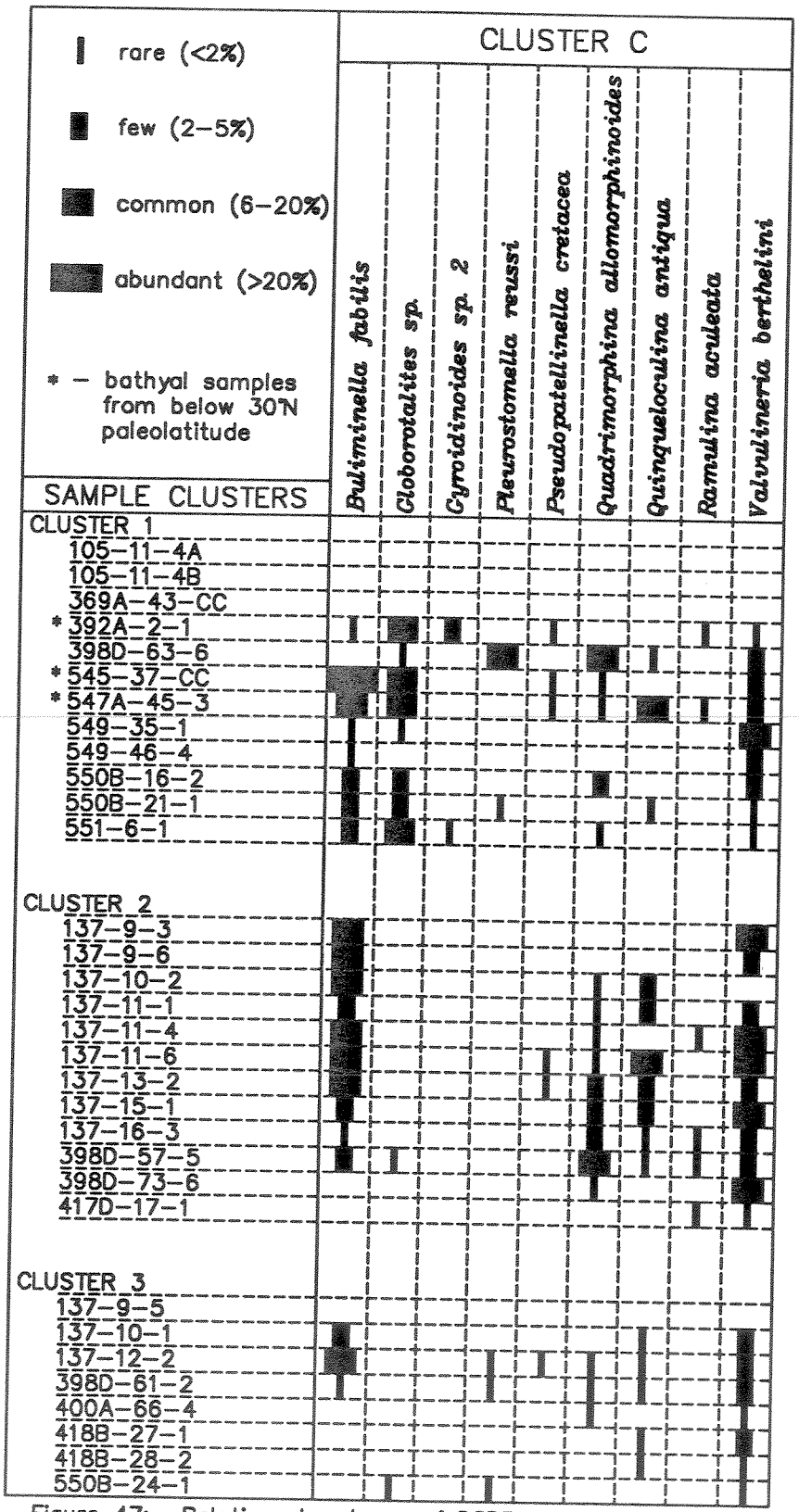


Figure 47: Relative abundance of DSDP species cluster C, showing no correlation to any sample cluster, but also showing a preference for lower–latitude, bathyal sites (see text for discussion).

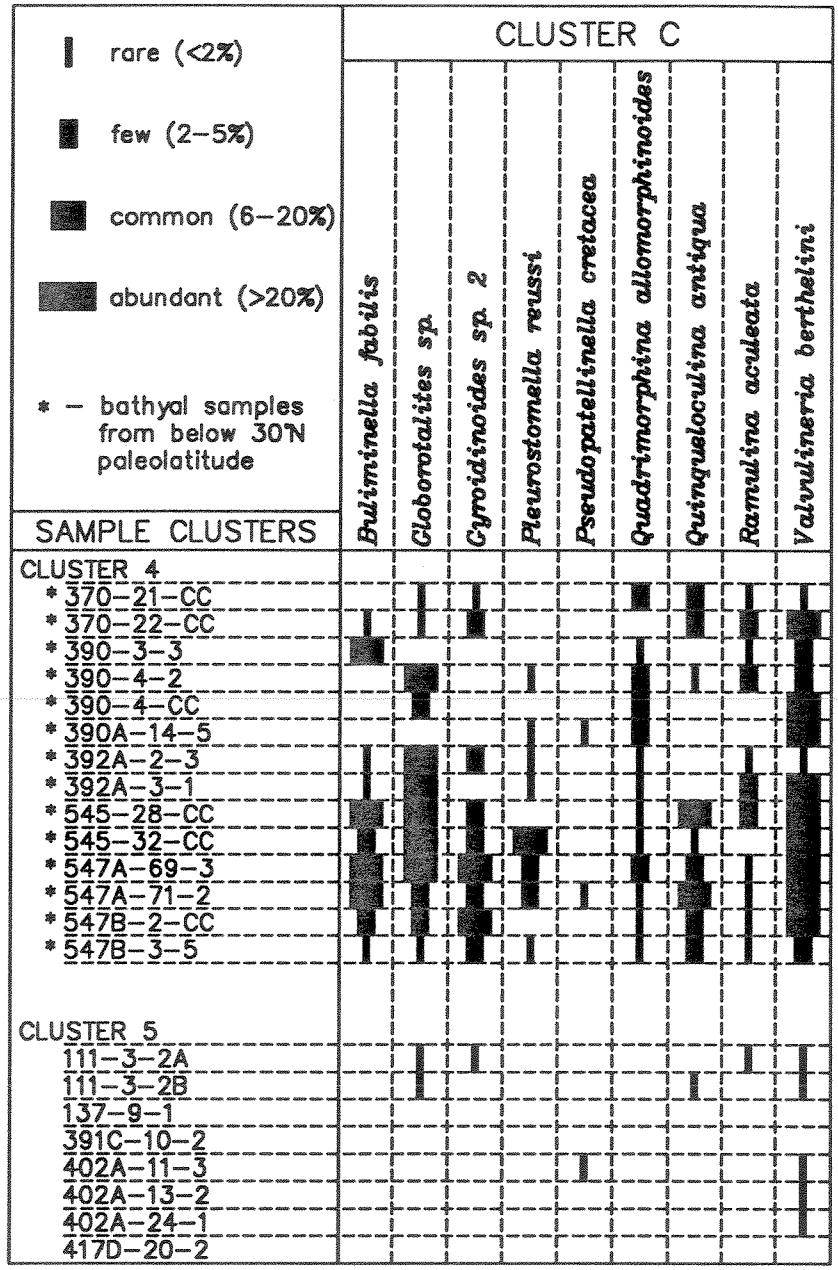


Figure 47 (cont.)

bathyal estimates of paleodepth based upon either assemblage and sedimentologic evidence (Site 370 - Jansa et al., 1977; Sites 390,392 - Benson et al., 1978) or geohistory analysis (Sites 545,547 - Winterer and Hinz, 1984). All the samples contained in Q-mode cluster 4 are from sites located below a modern latitude of 40°N and a middle Cretaceous latitude of 30°N. However, three samples from these southern sites group in cluster 1 rather than in cluster 4 (392A-2-1, 545-37-CC, and 547A-45-3). Cluster 1 is a group which otherwise contains samples from more northern bathyal sites such as 549, 550, and 551 (figure 48). Nevertheless, cluster C assemblage occurs more abundantly and consistently in the three southern sites than any other in cluster 1. This assemblage is less common in the northern sites where it chiefly contains eurybathyal elements such as Buliminella fabilis and Valvulineria berthelini (figure 47).

An explanation for the latitudinal preference of cluster C species is not clear. One possibility may have been differences in bottom-water chemistry. Middle Cretaceous bottom-water circulation was haline, apparently driven by excess evaporation of surface waters in low latitudes (Bass et al., 1982; Arthur et al., 1987). Dense, haline waters would form in such areas as low latitude shelves and then sink and flow northward. Thus northern bottom-waters would presumably be older, more

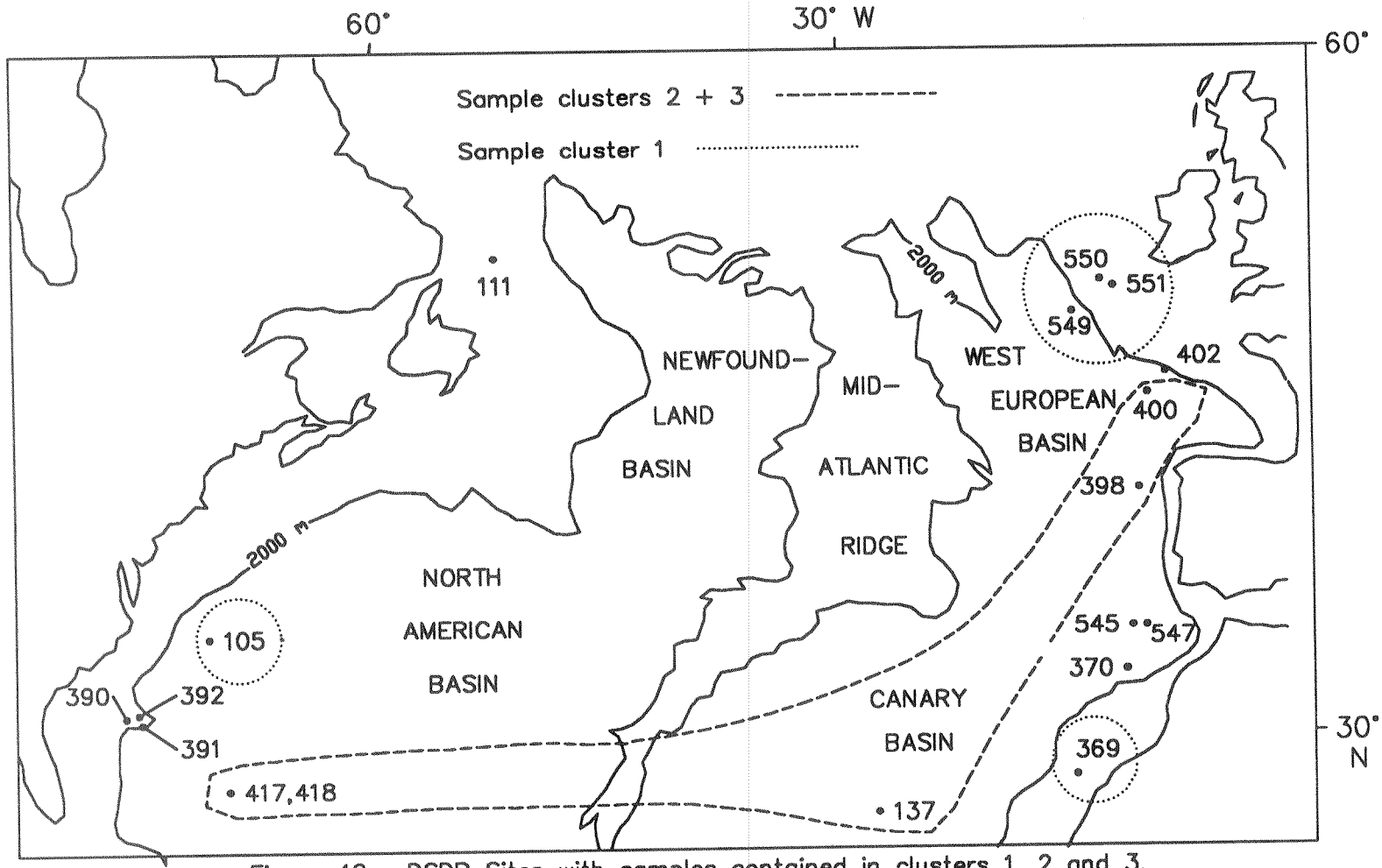


Figure 48: DSDP Sites with samples contained in clusters 1, 2 and 3.

corrosive, and less oxygenated than southern bottom-waters and the species of cluster C may have been unsuited to the less favorable northern environments. However, cluster C species are also present, though more rarely, in the northern sites of Q-mode cluster 1 (figure 48) and the distribution of R-mode clusters B and C both illustrate an overall fossil similarity in the North Atlantic (figures 46 and 47). Even if the distribution of cluster C reflects some latitudinal environmental gradient, of whatever cause, the overall difference was not considerable. Differentiation of cluster B and C assemblages into two biofacies is then not considered warrented.

Q-mode cluster 1 is composed mainly of samples from higher-latitude, bathyal sites (549, 550 and 551). Additional components include the three lower-latitude samples described above from Sites 392, 545 and 547 and a few abyssal samples from Sites 105 and 369 (figure 43). These abyssal samples (backtracked paleodepths of greater than 4000 m) contain organic-rich clays and a depauperate, largely pyritized assemblage which suggests low-oxygen environments near the CCD. The assemblages bear little resemblance to any other assemblage in this study, and group with the bathyal samples in cluster 1 based solely on a shared abundance of Valvulineria loetterlei and Neobulimina minima (figure 46). These two species compose

almost the entire assemblage in the abyssal samples of Sites 105 and 369 and, therefore they apparently were tolerant of low-oxygen environments.

Based on the distribution of the R-mode-analysed species, the bathyal samples of Q-mode cluster 1 can be generally characterized by a common to abundant occurrence of cluster B assemblage (figure 46) as well as rare occurrences of most of the abyssal assemblage of cluster D (see below). As noted above, the cluster C assemblage has a variable abundance. It is common in the southern bathyal sites (392, 545, 547) and rare in the northern sites (549, 550, 551) (figure 47). Thus these high- and low-latitude bathyal samples which group in cluster 1 must reflect some larger distributional pattern within the 178 total species used in the Q-mode analysis, a pattern not fully apparent in the distribution of only the R-mode-analyzed species.

Overall, R-mode clusters B and C define biofacies 6. The distribution of this biofacies (figures 46 and 47) shows it to be the most poorly defined of the seven biofacies recognized in this study. The number of defining species is large and shows a highly variable relative abundance distribution. In addition, the lower boundary of the assemblage is poorly defined. Biofacies 6 is most abundant in bathyal Q-mode clusters 1 and 4. However, it continues to be common in abyssal Q-mode clusters 2 and 3 which are dominated by biofacies 7. This

is especially true of cluster B assemblage (figure 46). Thus biofacies 6 and 7 show a greater degree of overlap than any other biofacies in this study.

However, biofacies 6 assemblage has a sharply defined upper boundary. The results from the New Jersey margin show that, with the exception of a few eurybathic species, the assemblage is absent from neritic paleodepths. The elements of biofacies 6 which occur in Shell wells 586 and 587 (biofacies (6?)) show little overlap with upper-bathyal biofacies 4 or 5.

Species of biofacies 6 which occur commonly in both DSDP Sites and the Shell slope wells include Hyperammina gaultina, Pleurostomella obtusa, Osangularia insigna, O. utaturensis and Praebulimina evexa. Other species are also common, including Gavelinella pazdroae and Praebulimina nannina. Of the cluster C species, indicative of low latitudes, the most abundant include Quinqueloculina antiqua, Pleurostomella reussi and Quadrimorphina allomorphinoides.

Biofacies 7 is defined by R-mode cluster D which is abundant only in Q-mode clusters 2 and 3 (figure 49). Biofacies 7 occurs in upper Albian to upper Cenomanian nannofossil oozes and marls at Sites 137, 398, 400, 417 and 418 (figure 48). Backtracking gives paleodepths of about 3500m for Site 137 and 3800m for Sites 417 and 418

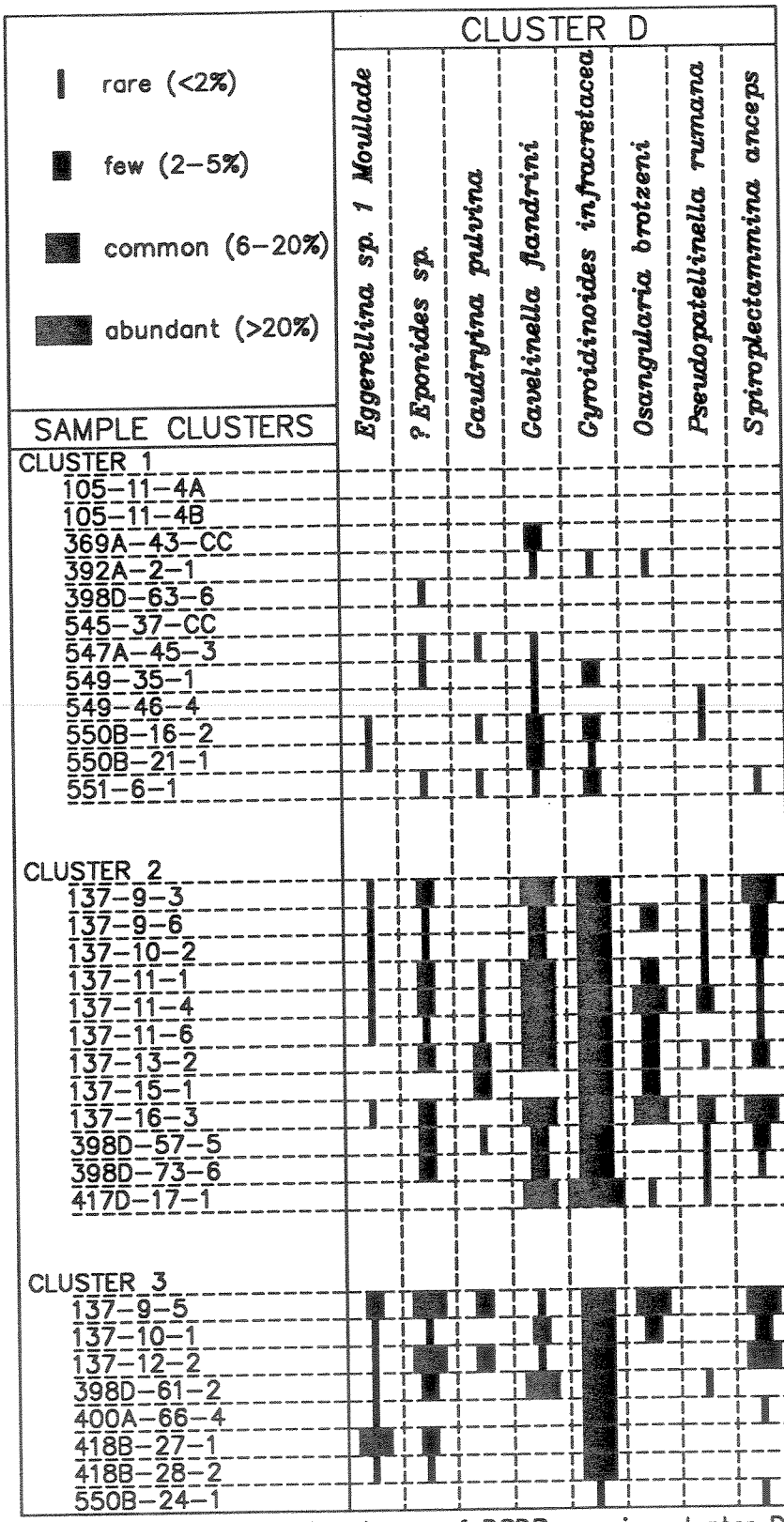


Figure 49: Relative abundance of DSDP species cluster D, plotted against sample clusters, showing greatest abundance in abyssal clusters 2 and 3.

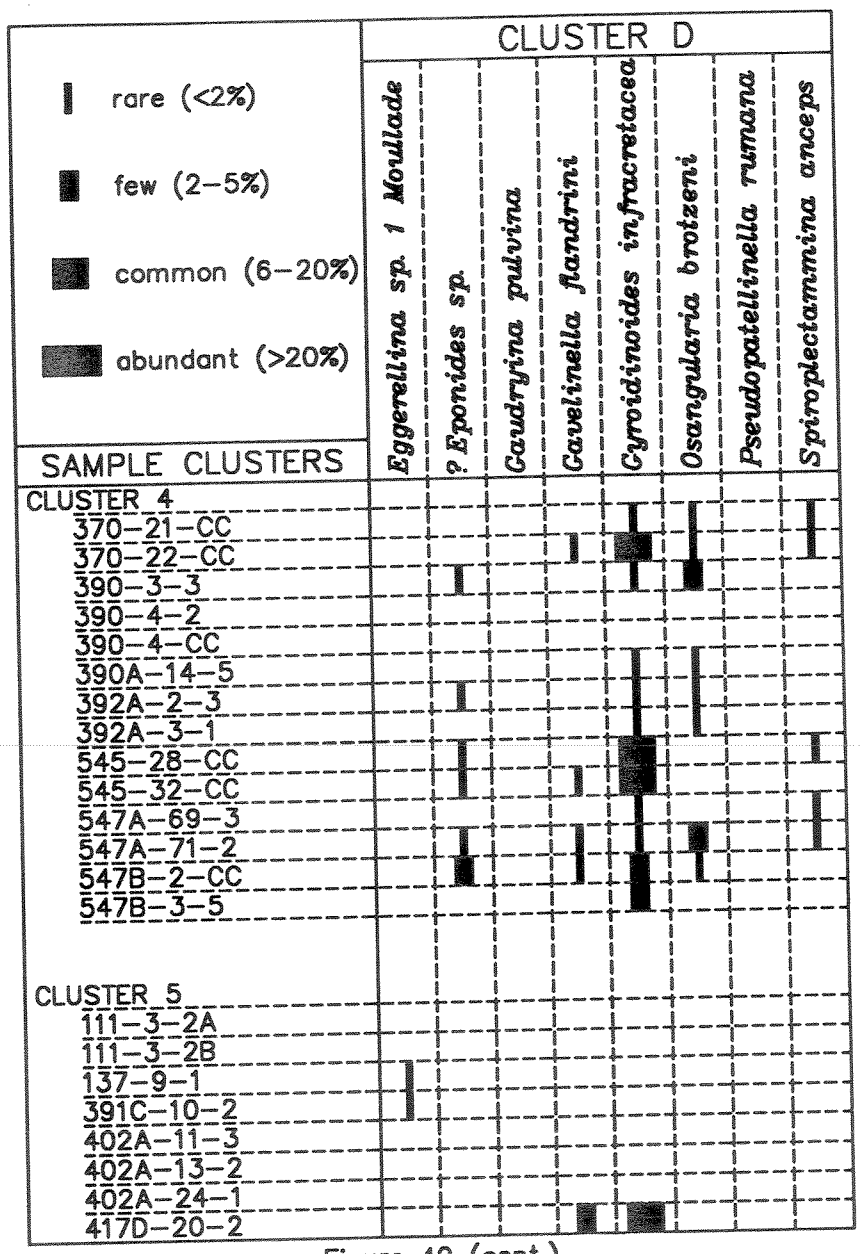


Figure 49 (cont.)

whereas a previous paleodepth estimate of 2500m was made made for Site 398 (Sibuet et al., 1979). Cluster D assemblage appears to be most characteristic of abyssal depths above the CCD in both the eastern and western Atlantic. Species most characteristic of biofacies 7 include Spiroplectammina anceps, Eggerellina sp. 1 Moullade, ?Eponides sp., Osangularia brotzeni and Pseudopatellinella rumana. Agglutinated species with tests constructed mostly of nannofossil plates compose 10-20% of this assemblage.

A non-calcareous agglutinate assemblage replaces biofacies 7 below the CCD. The assemblage was found in only two samples (137-9-1 and 391C-10-2) which group in Q-mode cluster 5 as described above. Crushing of most specimens prevented specific and often generic identification. Thus quantitative analysis of the assemblage was not possible.

III. DISCUSSION

A. Paleoslope Model and Paleoecologic Implications

Quantitative analysis of benthic foraminiferal abundance data from the New Jersey Continental margin identifies six biofacies which replace one another downdip in a regular pattern. Figure 50 shows the distribution of the assemblages in the wells used in this study. The biofacies also replace one another vertically in stratigraphic section, thus reflecting Walther's Law of succession of facies. As changes from deeper-water to shallower-water facies occur, or vice versa, the lateral succession of biofacies is repeated vertically in stratigraphic succession.

Planktic abundance and benthic diversity indices indicate that the succession of biofacies downdip positively correlates with increasing depth. Vertical succession of biofacies reflects water depth changes likely due to eustatic sea level fluctuations. A eustatic control on biofacies is further indicated by the correlation between biofacies and specific sections of depositional systems tracts.

However, these factors indicate only a relative distribution of the biofacies. Absolute depth ranges can be assigned by superimposing the biofacies onto the

AGE	COASTAL PLAIN		BALTIMORE CANYON TROUGH			
	BTMA	OXLY–1A	SHELL 272	COST B2	SHELL 586	SHELL 587
LATE TURONIAN	BARREN	BARREN	3	NOT STUDIED	6?, DSB	6? DSB
EARLY TURONIAN	1	3	5	DSA 5	DSB	DAA
LATE CENOMANIAN	1 2 1	1 2 1	4	4	4	
EARLY CENOMANIAN	BARREN	BARREN	BARREN	4	5	
VRACONIAN	NOT STUDIED	2 1	4	4	5	
LATE ALBIAN		2 1	NOT STUDIED	3	4,5	

Figure 50: Downslope distribution of biofacies of the New Jersey Continental Margin.

paleoslope transect, A-A' (figure 1). The gradient of the middle Cretaceous margin is assumed to be similar to that of today (1m/km). Then the absolute paleodepth of any locality on the baseline can be derived from the horizontal distance between the locality and the estimated position of the shoreline.

Figure 51 shows the integration of biofacies 1 through 5 on the paleoslope transect (A-A'). As middle Cretaceous outcrops largely represent fluvial deposits, the position of the shoreline was only approximately located for each age. For the early Turonian, the shoreline was set at outcrop of the Woodbridge Clay, a transitional facies of the Raritan formation. Late Cenomanian shoreline was located at about the point at which Bass River marine facies pinch out in the subsurface (Olsson et al., 1988). Similarly, Vraconian (latest Albian) shoreline was set at approximate pinch out of the Albian marine unit, at about the position of the BTMA well. No sediments of late Albian age were observed in the BTMA well, but sequence stratigraphy indicates 150 feet of late Albian marine sediments are present in the Oxly well (UZA 2.1). Late Albian shoreline is then set halfway along dip between these two wells. The BTMA, Oxly, Shell 272 and COST B2 wells are then integrated onto the paleoslope transect. For each age, the horizontal distance from the estimated shoreline position to the well is converted to the

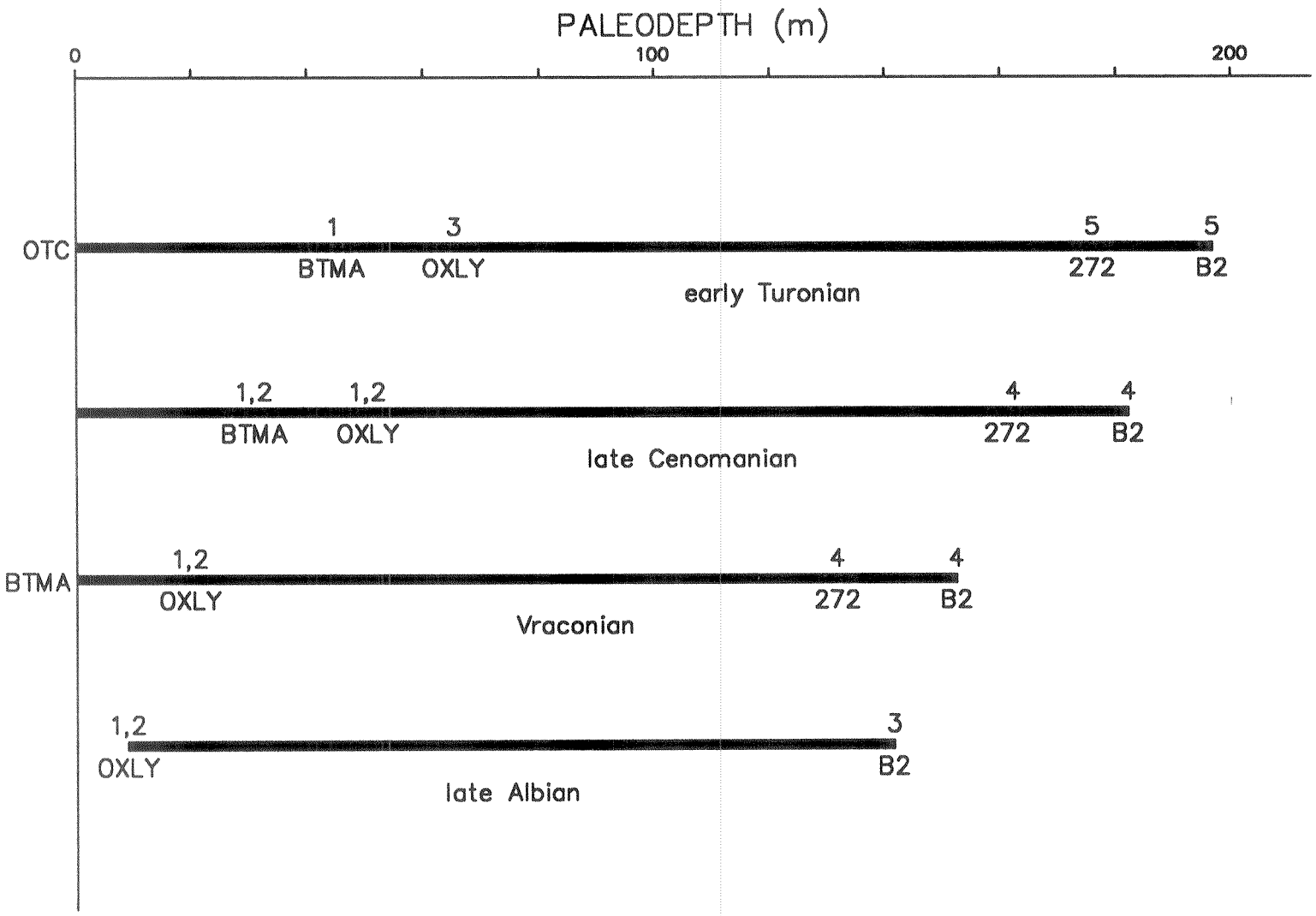


Figure 51: Integration of biofacies onto paleoslope baseline (A–A' – figure 1)(numbers refer to biofacies).

paleogradient (1m/km) and thus yields the increase in bathymetry between the two points. For example, for the Vraconian, downdip distance from the shoreline (BTMA) to the Oxly well is about 20km which converts to an Oxly well Vraconian water depth of 20m (figure 51). Additional data points are plotted in a similar manner thus providing a more precise paleobathymetric distribution of the defined biofacies.

In deeper-water sections, biofacies often dominate over large parts of one or more stages but in the coastal plain, biofacies 1 and 2 alternate over much shorter stratigraphic intervals (figure 50). These two biofacies cannot be differentiated on the stratigraphic scale used in figure 51. As a group, paleodepth limits of 10 to 50m are indicated but presumably, biofacies 1 would be most indicative of the shallower end of the range (10-30m) whereas biofacies 2 would represent the deeper half (30-50m). This assumption is contradicted by a depth estimate of about 45m for biofacies 1 in the lower Turonian of the BTMA well. However, this section contains local regressionary deposits probably resulting from an increase in sediment input from a source in the vicinity of the BTMA well, north of the paleoslope transect (figure 1). Lower Turonian paleodepths for this locality are anomalously shallow.

Biofacies 3 appears to occur between depth limits of 60m and 130m but is the least constrained of the biofacies. The bathymetric range is based on only two sections; the lower Turonian of the Oxly well and the lower upper Albian of the COST B2 well (figure 51). Most of the depth range of biofacies 3 was not analyzed in the present study due to a lack of information between the Oxly and Shell 272 wells, a downdip distance of nearly 100km.

Biofacies 4 and 5 show considerable overlap along the paleoslope transect. The upper depth limit of biofacies 4 is about 130m whereas that of biofacies 5 is 180 m. However, though biofacies 5 does not appear to dominate in paleodepths less that 180m, its constituent species remain common to the upper depth limit of biofacies 4.

The Shell 586 and 587 wells are not included on the paleoslope transect. The lithologic and paleontologic changes that characterize these wells indicates an increase in paleogradient which prevents integration onto the baseline. Presumably, the middle Cretaceous shelf break was situated somewhere along dip between sites of the COST B2 and Shell 586 wells. However, geohistory analysis (backstripping) can be used to generate paleodepths. Rifting and subsidence models of the margin can be constructed to yield values of tectonic subsidence (Steckler et al., 1988). By combining these values with sediment thicknesses and age control, paleodepth curves

through time can be calculated and margin reconstructions for various ages can be made. Steckler et al. (1988) reconstructed lower Cretaceous to lower upper Cretaceous margin profiles along USGS multichannel seismic line 25 (figure 52). Line 25 is located in the same area as paleoslope transect A-A' and the COST B2, Shell 272, 586 and 587 wells can be superimposed along strike onto these reconstructed margins (figure 52). The Albian profile yields a paleodepth of about 600m for the Shell 586 well whereas the Santonian-Coniacian profile is used to give a paleodepth estimate for the upper Turonian of the Shell 587 well of about 900m. In addition, figure 52 provides Albian paleodepth estimates of between 100m and 200m for the Shell 272 and COST B2 wells. These depths are comparable to the values of 130m to 160m provided by the paleoslope line and thus gives independent corroboration of the relative accuracy of the paleoslope method.

The paleodepth ranges calculated for each biofacies in figure 51 can be used to plot the paleoslope model, that is, the paleobathymetric distribution of the constituent species (figure 53). Two breaks in faunal distribution are noted. The upper break occurs at about 60m and coincides with the boundary of biofacies 2 and 3. The second break is noted at about 130m and approximates the boundary between biofacies 3 and 4 (figures 51 and 53). These faunal breaks probably reflect hydrographic conditions on

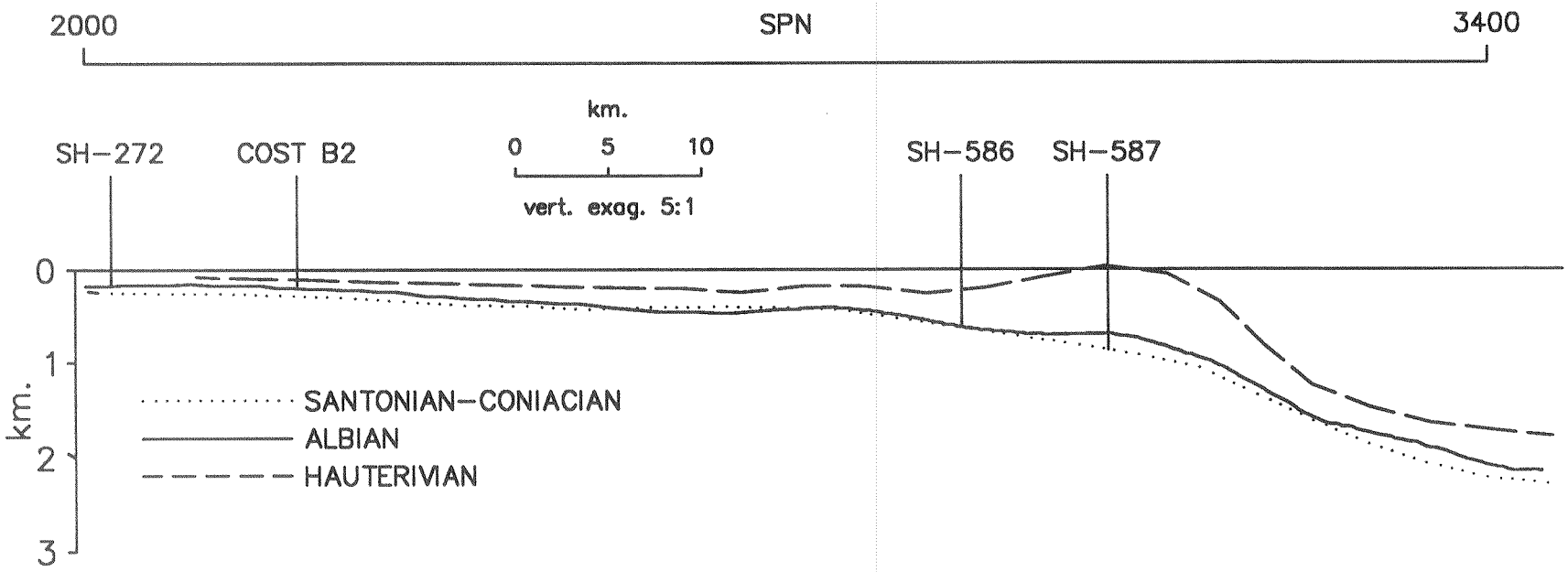


Figure 52: Superposition of Baltimore Canyon wells on reconstructed Cretaceous margin profiles along USGS multichannel seismic line 25 (after Steckler et al., 1988).

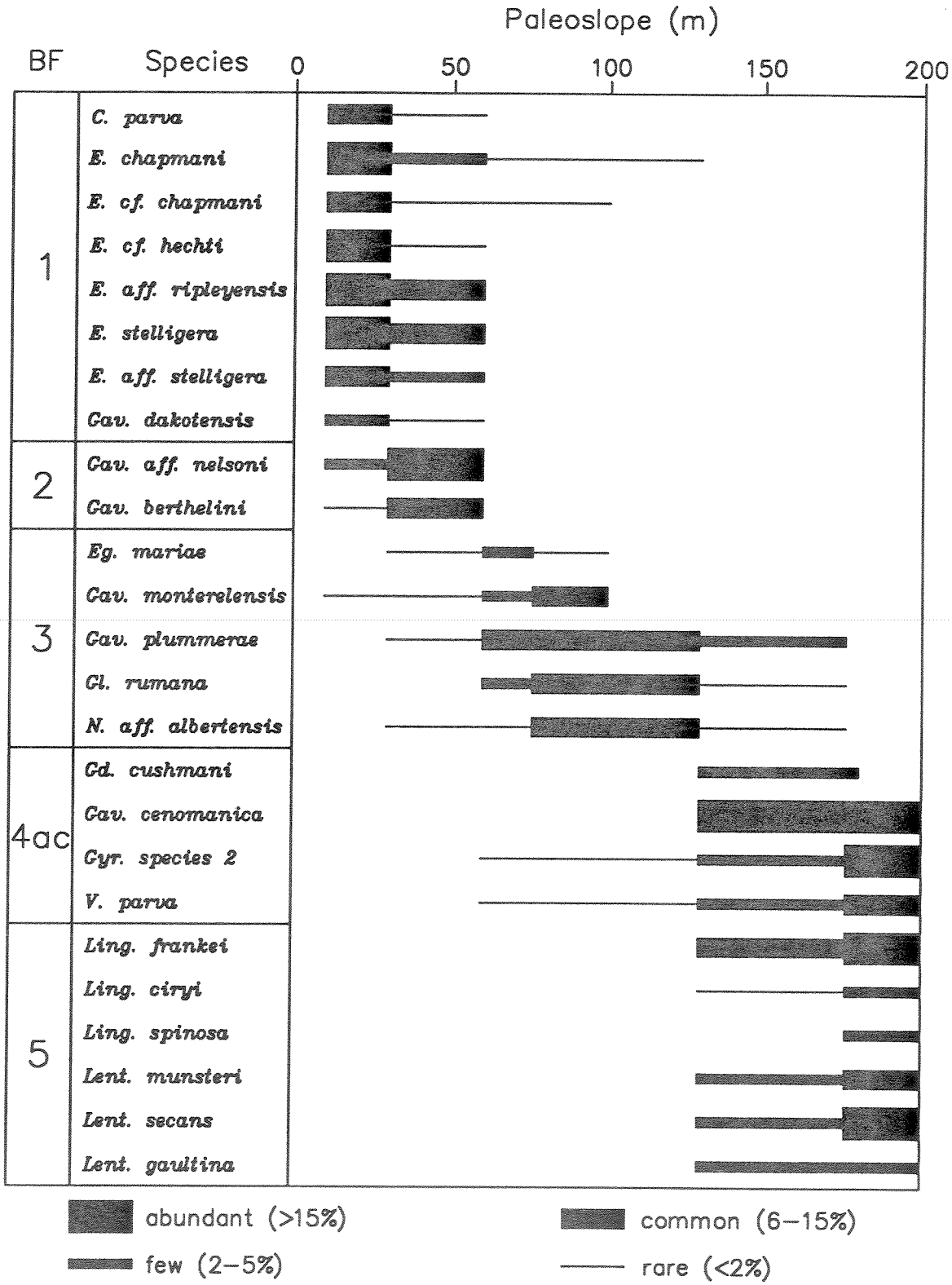


Figure 53: Upper Albian to lower Turonian paleslope model of benthic species from BTMA, Oxly, Shell 272 and COST B2. (Gav. = Gavelinella, Eg. = Eggerellina, Gl. = Globorotalites, Gd. = Gaudryina, Gy. = Gyroidinoides, Ling. = Lingulogavelinella, Lent. = Lenticulina)

the middle Cretaceous shelf. The 60m break most likely indicates effective wave base whereas 130m probably marks the limit of seasonably variable water masses (Culver and Buzas, 1983; Gibson and Buzas, 1973). Similar faunal breaks were reported in paleoslope models of the uppermost Cretaceous New Jersey continental margin (Nyong and Olsson, 1984; Olsson and Nyong, 1984).

Integration of paleodepth data from figures 51 and 52 with DSDP paleodepth estimates from backtracking and previous studies allows construction of an Albian-Cenomanian model for bathyal and abyssal foraminifera (figure 54). Outer-shelf biofacies 4 and 5 extend to the upper range of middle-bathyal depths (600 m). However, some components of biofacies 4, such as Gaudryina cushmani and polymorphinids, do not occur below a paleodepth of 200m. In previous studies, this paleodepth coincided with a major faunal break attributed to the effects of an oxygen-minumum zone (Gibson and Buzas, 1973; Nyong and Olsson, 1984). In the present study, no major faunal break is noted at this paleodepth (figure 54). Constituent species of biofacies 4 and 5 are absent from dark, organic-rich Turonian sediments, indicating low tolerance of dysaerobic conditions. The common occurrence of these biofacies in Albian and Cenomanian paleodepths of 130m to 600m indicates generally well-oxygenated environments.

A low-oxygen zone is likely represented by a

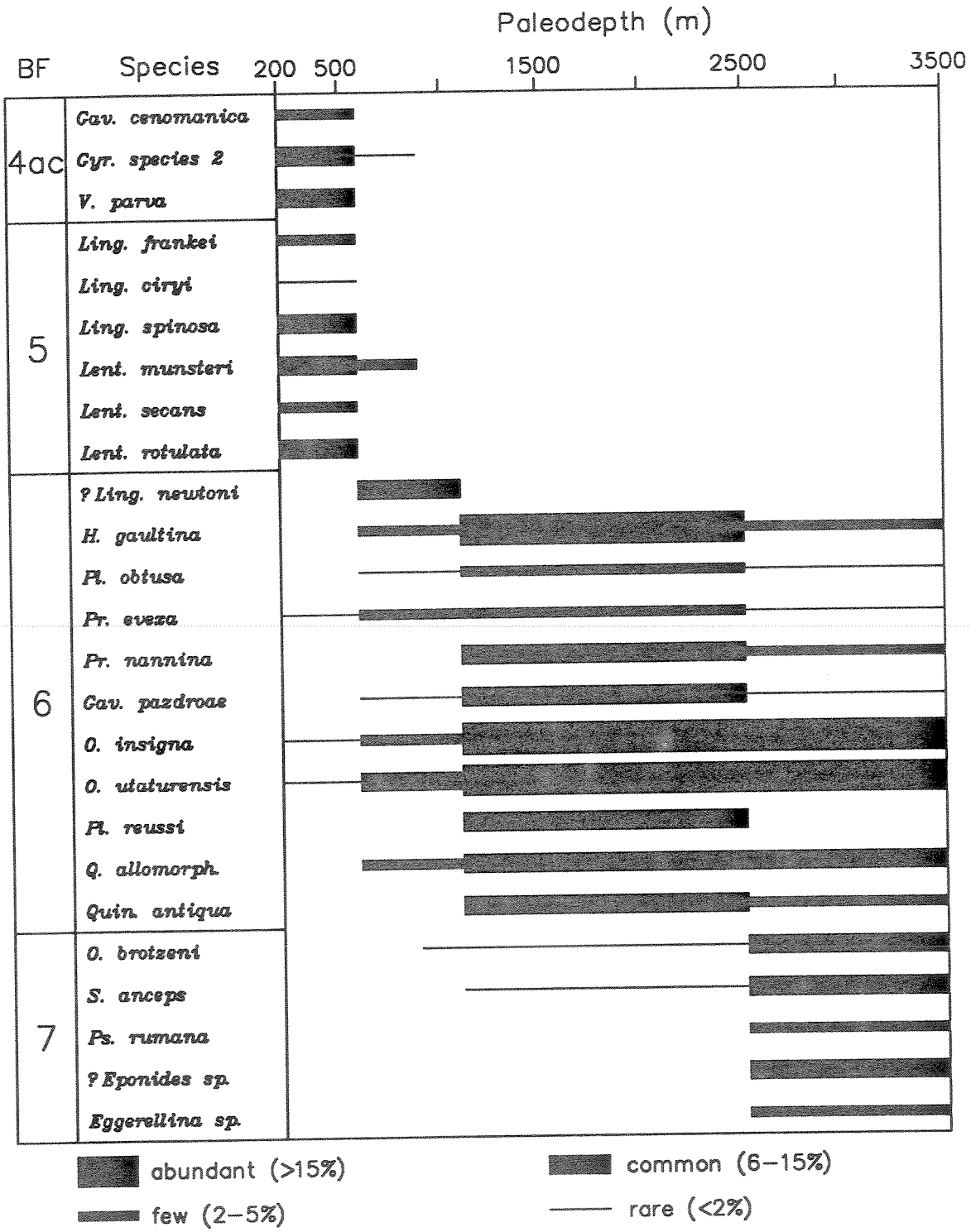


Figure 54: Upper Albian to upper Cenomanian paleoslope model of bathyal and abyssal benthic species (Pl. = Pleurostomella, Pr. = Praebulimina, Quin. = Quinqueloculina, Ps. = Pseudopatellinella).

faunal break at a paleodepth of 600m. The break roughly coincides with the lower limit of biofacies 4 and 5 and the upper boundary of biofacies 6. Some biofacies 6 species are relatively common in organic-rich DSDP sediments, indicating a tolerance for dysaerobic environments. Thus the 600m break probably represents the upper boundary of an Albian-Cenomanian oxygen-minumum zone.

A second, less well-defined break occurs at 2500m, coinciding with the upper boundary of biofacies 7 (figure 54). However, as biofacies 6 is common above and below this break, it likely does not represent a major environmental change. The 2500m paleodepth possibly marks the upper boundary of an abyssal mass of more saline water indicative of haline-driven Cretaceous deep-water circulation (Arthur et al., 1987).

In the early Turonian, species distribution changed in response to a worldwide expansion of the oxygen-minimum zone. The expansion was most likely caused by an increase in surface-water productivity in response to the large UZA 2.5 rise in sea level (Arthur et al., 1987; Cunningham and Gilbert, 1985; Schlanger et al., 1987). The resulting change in bathyal foraminiferal distribution is shown in figure 55. In the Turonian, lack of sampling prevented extension of the paleoslope model through upper bathyal paleodepths. Consequently, the lower boundaries of

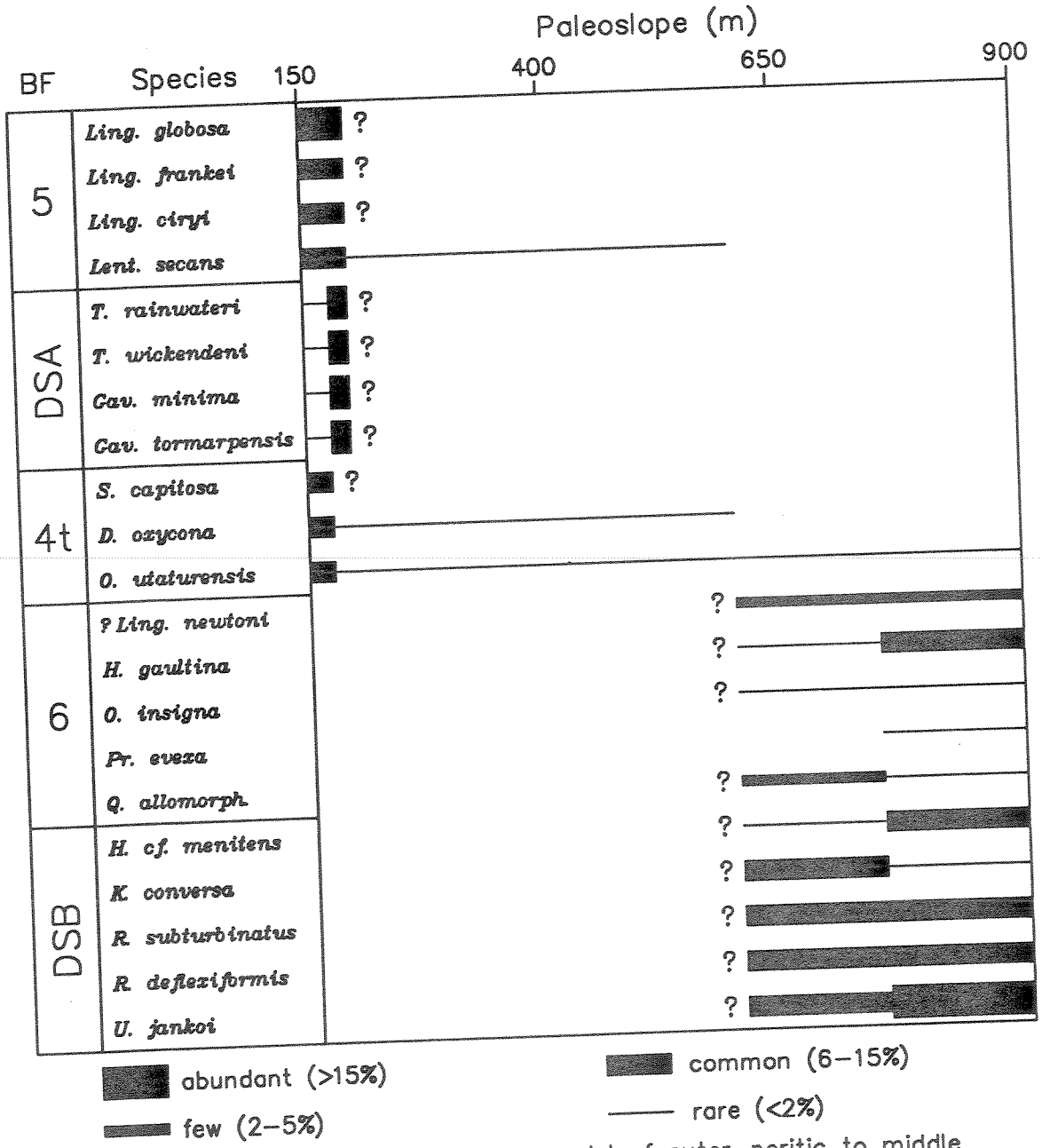


Figure 55: Turonian paleoslope model of outer–neritic to middle bathyal benthic species.

biofacies 4, 5 and DSA and the upper boundaries of biofacies 6 and DSB cannot be set definitively. However, a major depositional gap in the Shell 587 well and the evidence of displaced species in the Shell 586 well indicate that some form of downslope sediment transport was active on the middle Cretaceous slope. Nevertheless, species of biofacies 5 and DSA are absent from the slope wells. This absence, even as displaced species, may indicate that both biofacies were excluded from the slope. Therefore, the Turonian expansion of the oxygen-minimum zone apparently restricted biofacies 5 to outer shelf depths. On the slope, agglutinated biofacies DSB assemblage completely displaced biofacies 6. The boundary between well-oxygenated and dysaerobic waters thus retreated from a depth of 600m to 200m from the Cenomanian to the earliest Turonian.

Later in the early Turonian, low-oxygen conditions spread onto the outer shelf and biofacies 5 was replaced by biofacies DSA. The presence of calcareous species in biofacies DSA indicates an environment less corrosive and presumably better oxygenated than those slope regions dominated by non-calcareous biofacies DSB. A 200m faunal break remains, representing the boundary between low-oxygen outer-shelf waters and very low-oxygen slope environments. Biofacies DSB continued to dominate the slope into the late Turonian. A generalized model of the expansion of the

Turonian oxygen-minimum zone is given in figure 56.

In summary, in the Albian and Cenomanian, a 600m faunal break marks the boundary between two major faunal distributions (figure 57). Shallow depths are characterized by well-oxygenated sediments containing well defined biofacies composed of species with narrow bathymetric ranges. Biofacies migrated up and down slope in response to sea level change. Below 600m, biofacies 6 and 7 are more poorly defined and contain species of wide bathymetric range and variable abundance distribution. These deep-water environments were unaffected by sea level changes.

The earliest-Turonian expansion of the oxygen-minimum zone forced the retreat of shallower-water biofacies to depths of less than 200m. Later in the early Turonian, low-oxygen environments extended from the middle slope to the outer shelf and low diversity assemblages of primarily agglutinated species dominated. The continued abundance of biofacies DSB indicates that low-oxygen environments persisted into the late Turonian.

Paleoecologic overview

The implications of the paleoslope model and the general distribution of the defined biofacies results in the following paleoecologic conclusions.

Biofacies 1 characterizes innermost-neritic depths of

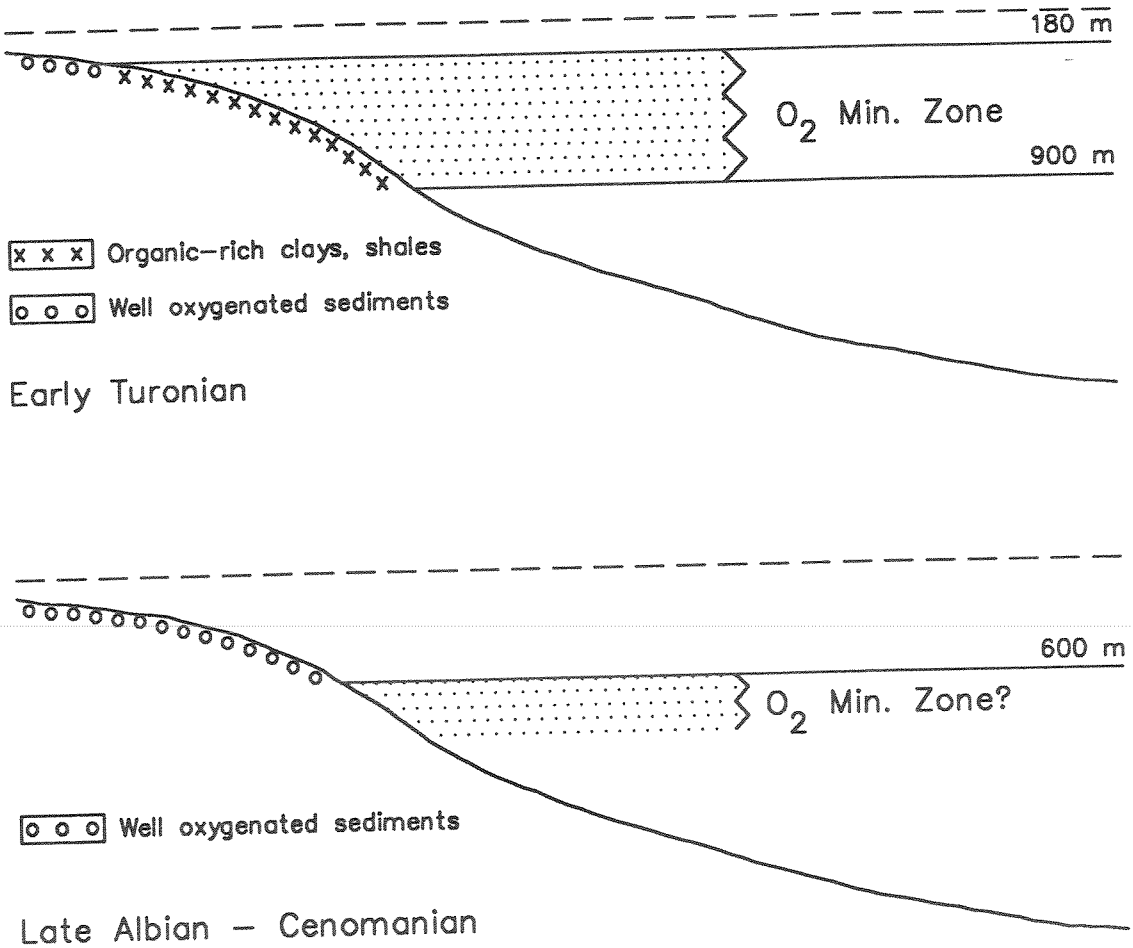


Figure 56: Diagram illustrating the position and expansion of the oxygen minumum zone from the Albian–Cenomanian to the early Turonian.

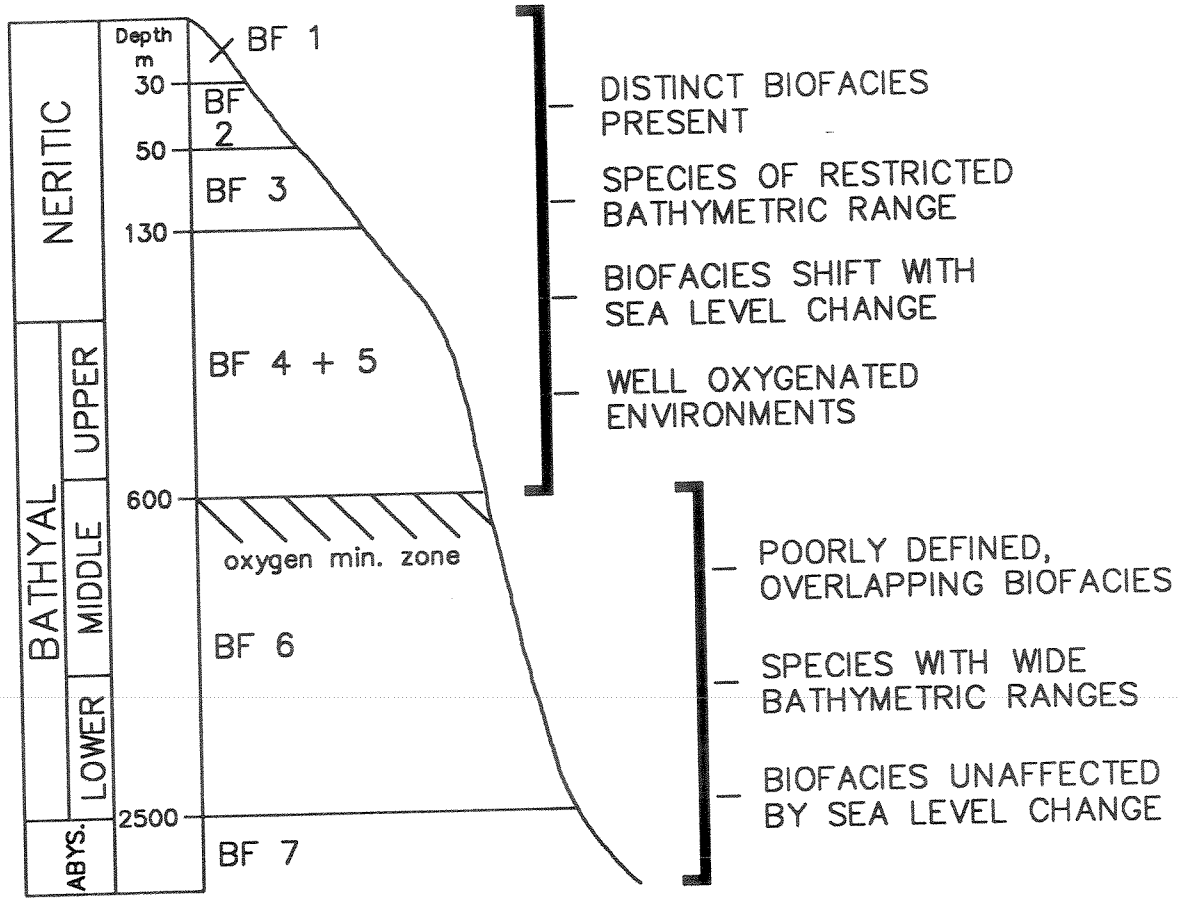


Figure 57: Summary of the major conclusions of the upper Albian to Cenomanian paleoslope model of the New Jersey Continental margin.

10m to 30m. The assemblage is dominated by species of Epistomina which, prior to the upper Albian, formed the predominant inner-neritic assemblages in clay-shale facies. Williamson and Stam (1988) performed a comprehensive study on Jurassic and Cretaceous epistominids in both Europe and Canada. They speculated that a rapid late Albian diversification in epistominids represented an attempt to compete with many new species of benthic Foraminifera which appeared at this time. The extinction of many epistominids at the end of the Albian was attributed to this increased competition as well as a progressive replacement of the epistominid-preferred clay-shale facies by limestones and marls. All ornamented species of Epistomina went extinct and only smooth-walled species of broad bathymetric distribution survived into the late Cretaceous.

This study presents evidence which contradicts this view on three points: 1) Though most ornamented forms are observed to disappear at the end of the Albian, three ornamented species survive at least until the late Cenomanian, i.e., Epistomina spinulifera polypiodes, E. cretosa and E. charlottae; 2) Unornamented species are not observed to possess wide bathymetric ranges. Most unornamented species of Epistomina are restricted to shallowest-neritic paleodepths including E. stelligera and

E. aff. ripleyensis. A few species, such as E. chapmani s.s., occur rarely in depths as great as 130m but are common to abundant only in inner-neritic depths (figure 55); 3) Epistominids are observed to have relatively wide substrate tolerances. Inner-neritic Epistomina species more often dominate in intervals of fine-grained quartz sand rather than in clayey intervals. In addition, the epistominid species of biofacies 1* (E. cf. chapmani (Hart) and E. charlottae) are very common in carbonate sediments of DSDP Site 402. Therefore, Epistomina species remained the dominant inner-neritic fauna in the Cenomanian and early Turonian and apparently were able to successfully compete with newly-evolved species of Gavelinella, Globorotalites and Valvulineria.

Biofacies 2 is indicative of paleodepths of 30m to 50m and is characterized by only two species; Gavelinella aff. nelsoni and G. berthelini. The remaining species defining the assemblages of this biofacies are eurybathic forms of Buliminella, Tritaxia and Valvulineria. Both Gavelinella species show a sharp lower bathymetric boundary and are absent from deeper-water facies (figure 53).

Biofacies 1 and 2 each characterize different phases of depositional sequences identified in the New Jersey coastal plain (figure 58). Biofacies 1 defines the lower (shallower) deposits of transgressive systems tracts of UZA 2.1, 2.2, and 2.5. In each sequence, it is succeeded

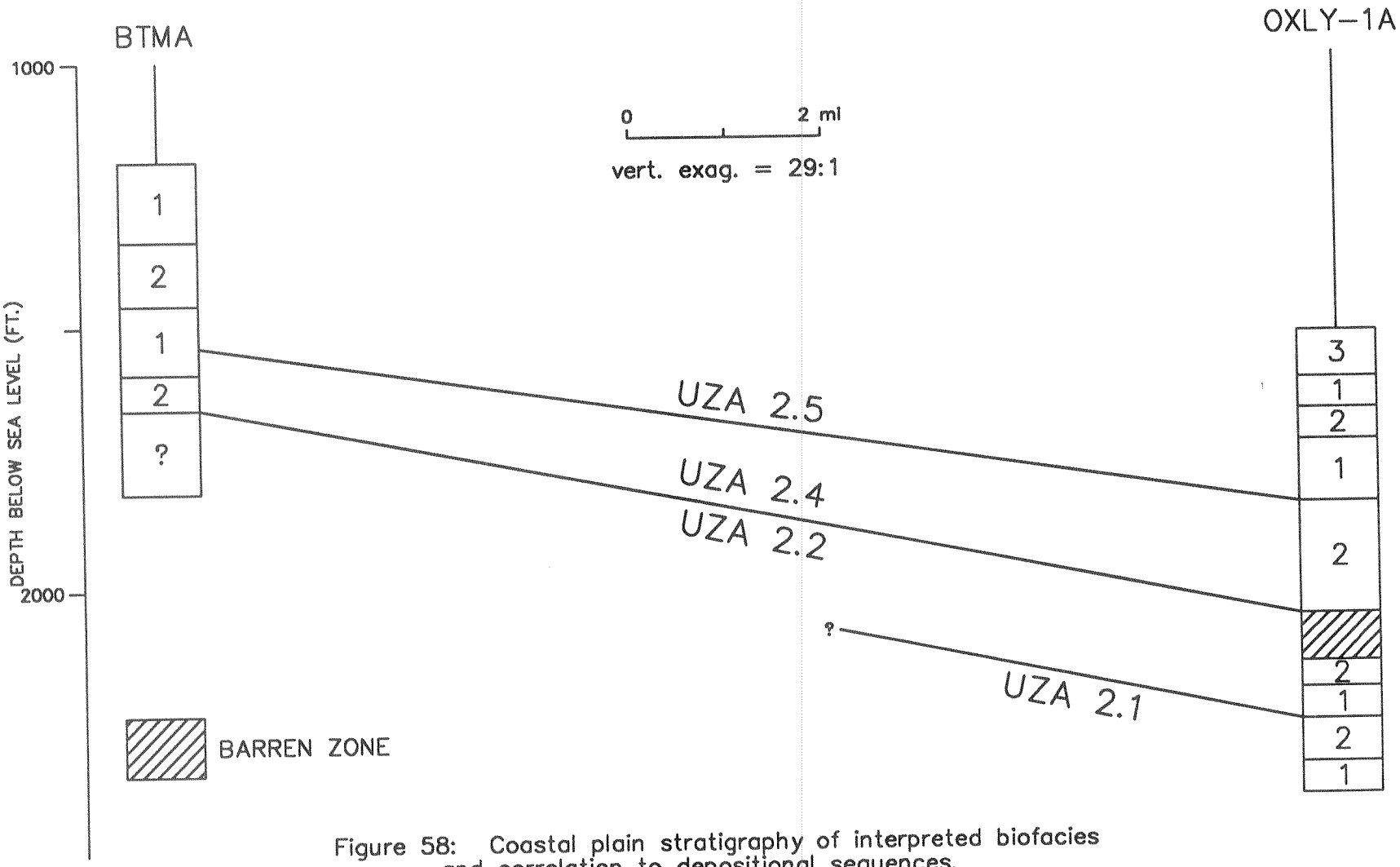


Figure 58: Coastal plain stratigraphy of interpreted biofacies and correlation to depositional sequences.

upwell by biofacies 2 which represents deeper-water facies. In UZA 2.5, biofacies 1 reappears in local regressionary deposits in the uppermost Cenomanian and then remains the dominant assemblage upwell in the BTMA well. Downdip in the Oxly well, however, biofacies 1 is abruptly succeeded in the lower Turonian by the only observed occurrence in the coastal plain of biofacies 3 (figure 58). The dominance of this assemblage marks the maximum flooding of UZA 2.5, the greatest sea level rise to occur during the middle Cretaceous.

Biofacies 3 is characteristic of middle-neritic depths of 60m to 130m (figure 51), likely a region below effective wave base but above the lower limit of seasonally variable water masses. It is the deepest biofacies observed in the coastal plain. In the Baltimore Canyon Trough, biofacies 3 is the shallowest-water biofacies present and characterizes silty intervals of the COST B2 and Shell 272 wells. Although the constituent species of this assemblage are common only within the bathymetric range of the biofacies, most rarely occur throughout inner- and outer-neritic paleodepths. Gavelinella plummerae is the most widespread species (figure 53).

Biofacies 4 and 5 dominated outer-neritic and upper-bathyal depths in the Albian and Cenomanian (figures 53 and 54). Biofacies 4 was most characteristic of outer-neritic

depths (130m-200m) whereas biofacies 5 was generally most dominant on the outermost shelf and upper slope (180m-600m) However, most constituent species of the two assemblages were common in both outer-neritic and upper-bathyal regions (figure 59). Thus biofacies 4 and 5 show considerable overlap and are composed of calcareous species with similar morphologies which, among modern benthic taxa, would indicate an epifaunal, foraging lifestyle (Corliss and Chen, 1988). Their absence in organic-rich facies indicates low tolerance of reduced oxygen environments.

The middle Cretaceous sea level rise created very wide continental shelves and increased surface productivity over outer-neritic and upper-bathyal regions (Arthur et al., 1987). The apparent lack of infaunal morphologies in biofacies 4 and 5 may indicate that burial of large amounts of organic carbon at this time (Schlanger et al., 1987) resulted in anoxic pore waters. Bottom waters, in contrast, remained fully oxygenated, at least until the early Turonian. During times of maximum flooding, variations in the physical parameters of outer-neritic and upper-bathyal environments would been have minimized. Concomitantly, the supply of organic detritus derived from surface productivity would have increased. Limiting environmental factors would have been largely competitive. Because biofacies 5 dominance correlates with maximum flooding, the assemblage must represent species adapted to

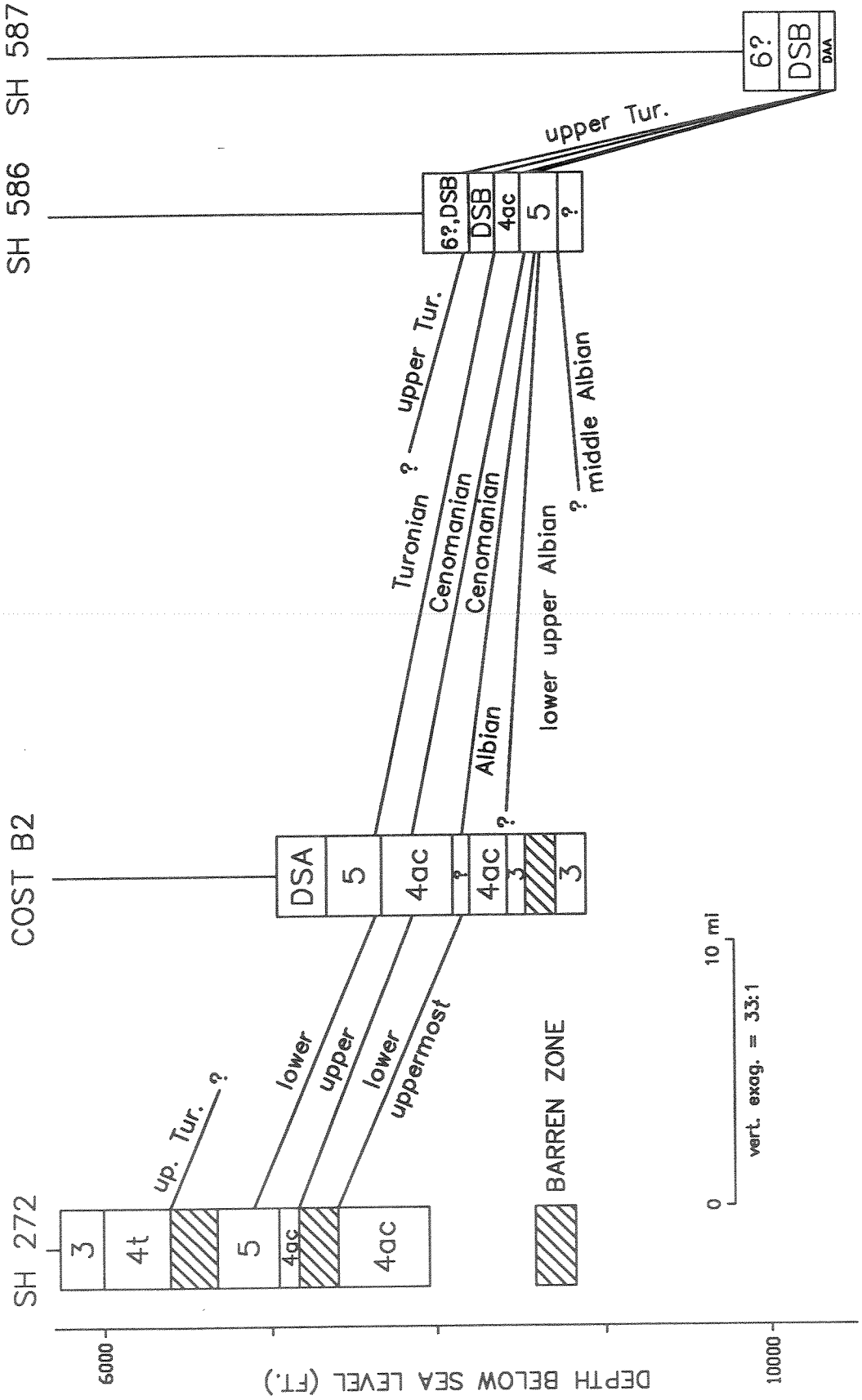


Figure 59: Stratigraphy of Baltimore Canyon Trough biofacies with biostratigraphic correlations.

these stable environments.

The late Cenomanian to early Turonian flooding (sequence UZA 2.5) was the greatest of Cretaceous time (figure 8). Consequently, the stable environment preferred by biofacies 5 extended farther onto the outer shelf than previously (figure 59). Biofacies 5 increased in abundance on the outer shelf and progressively displaced landward species of biofacies 4(ac). The ability of biofacies 4(ac) to migrate farther upslope was limited, however. Biofacies 4(ac) species are nearly absent from sections dominated by biofacies 3 which suggests poor tolerance for more physically-variable middle-neritic environments. As sea level continued to rise and biofacies 5 successfully competed for outer-neritic environments, biofacies 4(ac) disappeared at the end of the Cenomanian (figure 59).

In the early Turonian, biofacies 5 may have dominated the outer shelf to the lower boundary of biofacies 3 although this assumption cannot be corroborated due to lack of information between the Oxly and Shell 272 wells. The lower sea level of the late Turonian, however, may have resulted in the formation of "biofacies" 4(t). This assemblage contains some new taxa (e.g., Spiroplectinata capitosa) but is mainly composed of species such as Dorothia oxycona and Osangularia utaturensis which previously were characteristic of biofacies 6. Osangularia

utaturensis is most common. In the Albian and Cenomanian, it was a widespread and abundant component in middle bathyal to abyssal environments (figure 54). In the Turonian, however, O. utaturensis was rare in bathyal depths but appeared as a common component of neritic facies for the first time. This change in distribution likely represents migration of bathyal species such as Osangularia utaturensis and Dorothia oxycona to outer-neritic niches previously occupied by biofacies 4(ac). The migration was probably a response to the development of widespread dysaerobic conditions on the Turonian slope.

Biofacies 6 species are most characteristic of Albian and Cenomanian middle- and lower-bathyal paleodepths but are also common in abyssal regions (figure 54). However, most characteristic of abyssal sediments is biofacies 7, likely representing species best adapted to highly-saline, deep-water masses above the CCD.

Turonian biofacies DSA and DSB characterize dysaerobic sediments. Biofacies DSA was abundant in early Turonian outermost-neritic paleodepths (figure 59) and contains common species of Trochammina and Ammobaculoides. These agglutinated species were previously reported as indicative of middle Cretaceous carbonaceous shales of the Western Interior Seaway (Eicher and Worstell, 1970). The most abundant forms in biofacies DSA are extremely compressed species of Gavelinella. A compressed morphology increases

the surface area/volume ratio of the organism which aids in oxygen uptake and/or in the prevention of sinking into underlying anoxic sediments (Bernhard, 1986).

Biofacies DSB dominated the Turonian slope environment (figure 59). The assemblage is composed entirely of agglutinated species, many of which were previously reported from post-Turonian abyssal sediments deposited below the CCD (Krashenninikov, 1974). Migration of deep-water agglutinates to shallower depths in which oxygen levels diminished is not unknown (e.g., Hart and Biggs, 1981). However, most biofacies DSB species are absent in Albian and Cenomanian DSDP samples containing abyssal agglutinated assemblages from below the CCD. Biofacies DSB assemblage may thus have first originated in dysaerobic early Turonian slope environments and only later migrated to the abyssal plains.

The widespread dysaerobic conditions of the early Turonian were succeeded by late Turonian environments of fluctuating oxygen levels. Biofacies 6 reappears in upper Turonian middle bathyal sections and alternates in abundance with biofacies DSB (see figure 37 - p.91). A similar pattern of fluctuating faunal abundance, due to variable oxygen levels, was noted in Neogene deposits of the Mediterranean (Katz and Thunell, 1984).

Biofacies DAA bears strong resemblance to an infaunal

agglutinate assemblage characteristic of disturbed benthic environments (Kaminski, 1985). The biofacies occurs in the lower 80 feet of the Turonian of the Shell 587 well, above a major unconformity. However, the cause of this unconformity and the disturbed assemblage is unclear. High sea levels would have trapped sediment on very wide shelves (Wise and van Hinte, 1987) and it is thus unlikely that either major turbidite flows or submarine canyon development acted as the disturbing factor. In addition, the existence of a nearly complete stratigraphic section in the nearby Shell 586 well would seem to preclude any regional disturbance such as scour by bottom or surface currents. Whatever the cause, after resumption of deposition, the disturbance was shortlived and biofacies DAA was replaced by biofacies DSB.

Species diversification. Major speciation events are noted among the genera Gavelinella, Lingulogavelinella and Valvulineria. The evidence presented in this study supports previously published phylogenies (e.g., Jannin, 1967; Malapris-Bizouard, 1967; Price, 1977). The lower and middle Albian is characterized by one or two evolutionarily conservative species from which evolved many new forms in a rapid diversification in the upper Albian (figure 60). Many of these new species define neritic and upper-bathyal biofacies from the upper Albian to the lower Turonian. Some conservative ancestral species became extinct at the

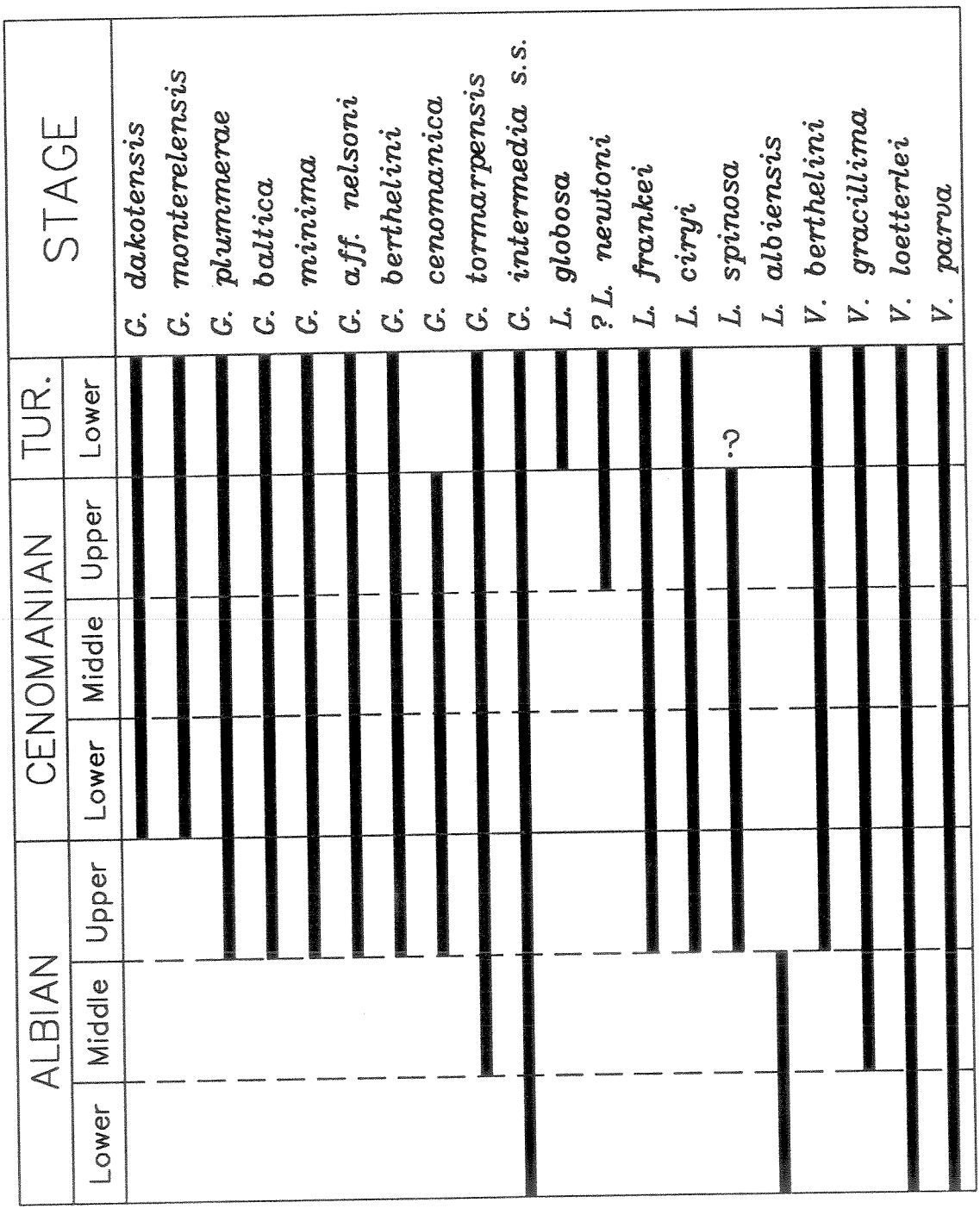


Figure 60: Stratigraphic ranges of examined species of Gavelinella, Lingulogavelinella and Valvulineria, illustrating late Albian diversification.

end of the middle Albian (e.g., Lingulogavelinella albiensis) whereas others continued into the Turonian as widespread eurybathic species (e.g., Gavelinella intermedia).

The only major exception to this pattern is shown by the genus Epistomina which also underwent an upper Albian diversification. However, many of the resulting species became extinct at the end of the Albian and further diversification and extinctions occurred in the Cenomanian. This relatively rapid turnover in species composition has been previously used to construct biostratigraphic zonations of shallow-water sediments in which planktic foraminifers are lacking (e.g., Hart, 1984; Ohm, 1967). However, the previous zonations are not fully applicable to the New Jersey coastal plain. Undescribed species are common including E. cf. hechti, E. aff. stelligera and E. aff. ripleyensis. Also the ranges of some species previously described as restricted to the Albian are extended into the upper Cenomanian (e.g., E. chapmani and E. cretosa). An independent zonation was formulated (figure 61). The upper Albian is characterized by abundant E. cf. hechti whereas E. aff. ripleyensis and E. stelligera s.s. first appear in the Cenomanian. The Cenomanian/ Turonian boundary is marked by the last occurrences of E. chapmani s.s. and E. cf. chapmani (Hart).

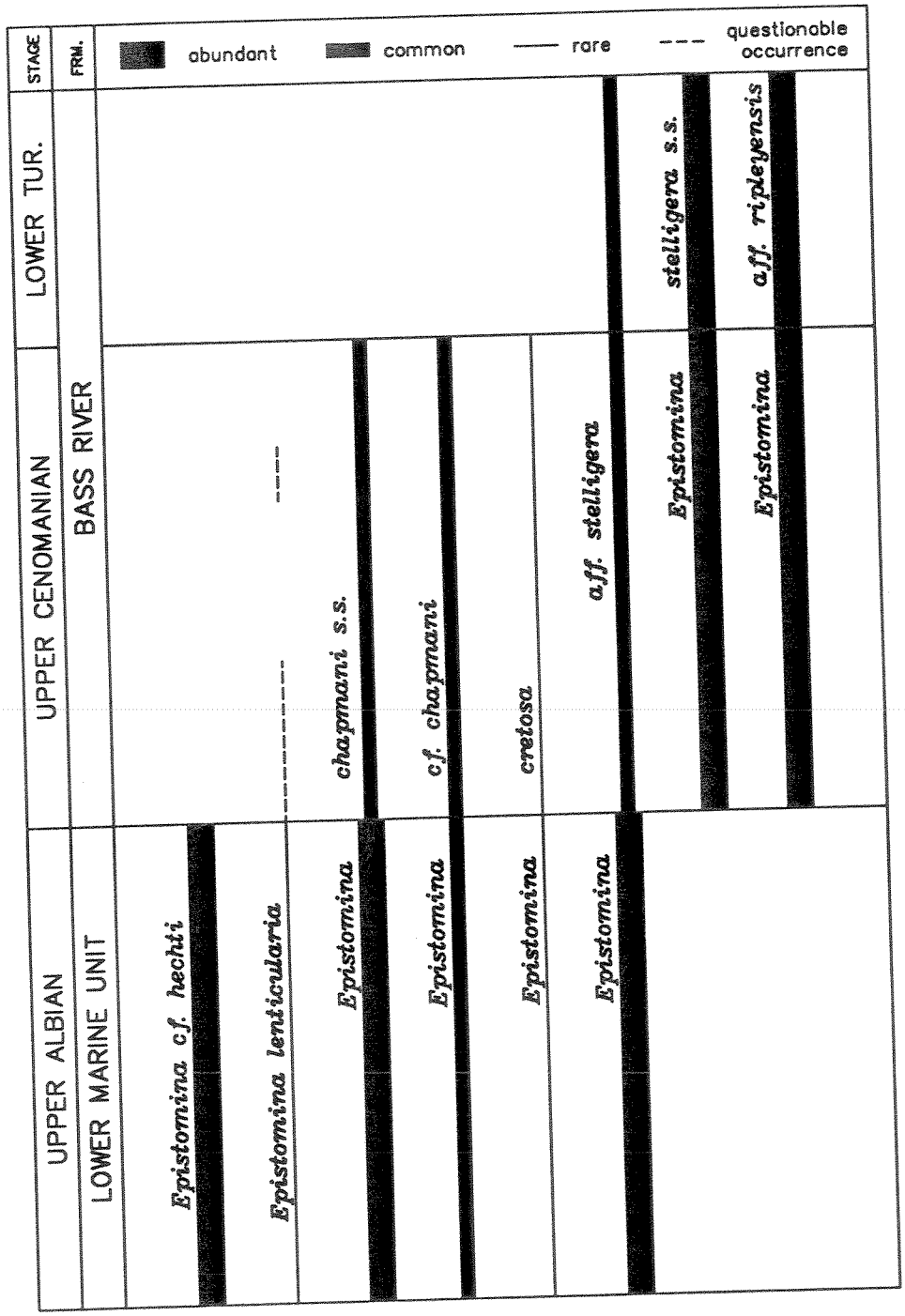


Figure 61: Biostratigraphic ranges of Epistomina species of the New Jersey Coastal Plain, based upon the BTMA and OXLY wells.

Overall, rapid species diversification occurred in the late Albian, concomitant with the first in a series of major middle Cretaceous sea level rises. Well defined neritic and upper slope biofacies appeared for the first time. The biofacies exhibited little variation in species composition from the upper Albian to the lower Turonian. No major extinction event marks the end of the Albian and no major diversification occurs in the Cenomanian. The end of the Cenomanian is characterized by the disappearance of biofacies 4(ac) but other assemblages show little change into the Turonian.

Biofacies 1, however, shows much more rapid species turnover, especially within the genus Epistomina. Major extinctions occurring at stage boundaries are followed by the appearance of numerous new species. Stage boundaries generally coincide with maximum flooding events which may have adversely affected this shallowest-water assemblage. Because of relatively rapid evolutionary rates, many Epistomina species serve as good biostratigraphic indices in inner-neritic deposits.

B. Depositional Sequences and Paleobathymetry of Sea Level Changes

Figure 62 shows the correlation of the Albian to Turonian depositional sequences of Haq et al. (1987) in the New Jersey coastal plain. Lithologic criteria alone proved

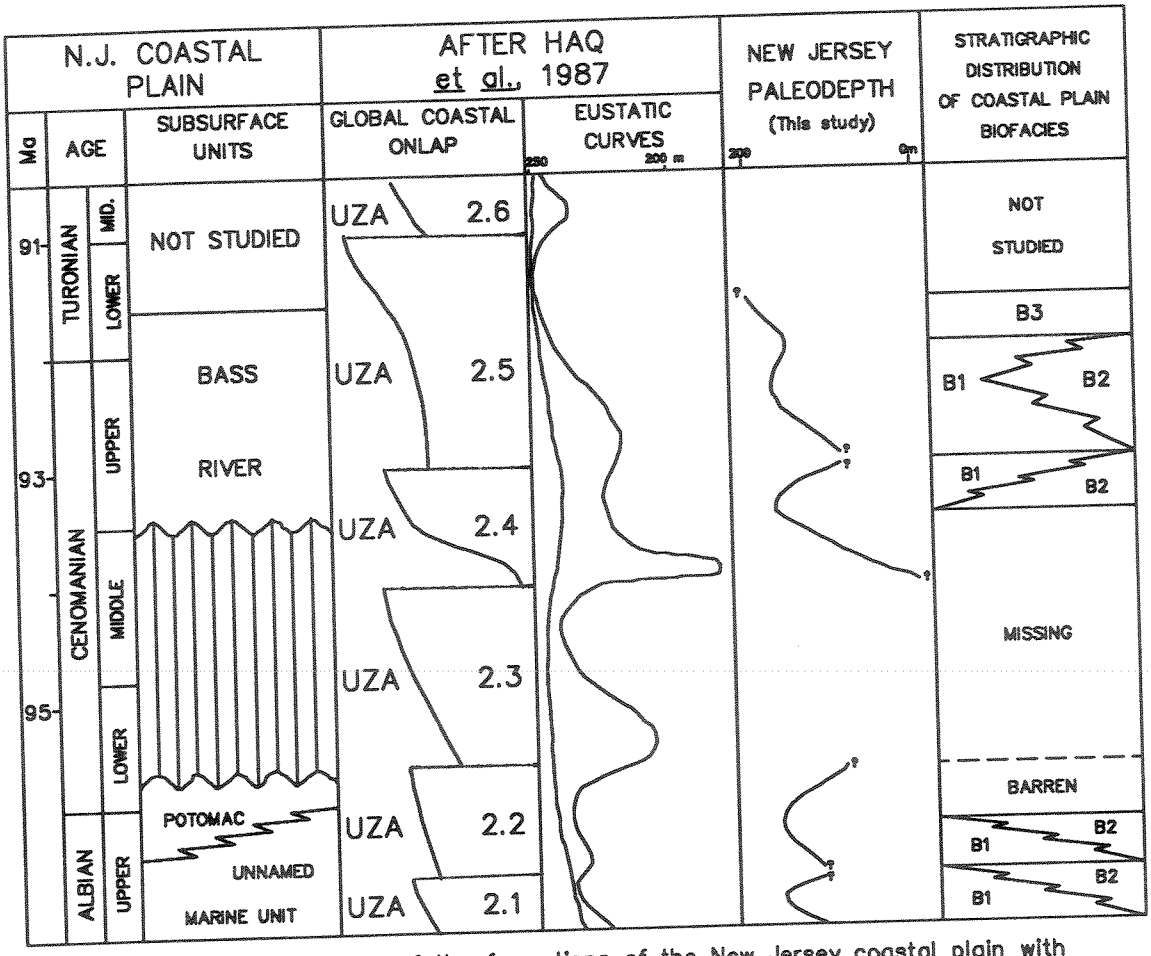


Figure 62: Correlation of the formations of the New Jersey coastal plain with third order cycles of Haq et al. (1987) and the distribution of biofacies. Also shown is comparison between eustatic curves of Haq et al. (1987) and paleodepth variations derived from paleoslope modeling.

inadequate in this study in the delineation of depositional sequences. However, rapid abundance fluctuation of biofacies 1 and 2 in response to sea level change considerably aids in sequence boundary recognition. Rare planktic markers in the Bass River Formation allowed the sequences to be correlated with the cycle chart of Haq et al. (1987). Late Cenomanian markers are Rotalipora cushmani and R. greenhornensis whereas early Turonian species include Marginotruncana marginata, M. imbricata and Whiteinella archaeocretacea. The base of the Bass River is marked by a type 1 unconformity which can be traced at least to the site of the COST B2 well. The unconformity resulted from a major drop in middle Cenomanian sea level (figure 8) after which deposition did not resume on the coastal plain until near maximum flooding of sequence UZA 2.4. Middle Cenomanian erosion removed the depositional record of sequence UZA 2.3 and possibly the upper highstand deposits of sequence UZA 2.2.

Underlying the unconformity in the Oxly well is a thin non-fossiliferous interval of medium-grained quartzitic sand which overlies a marine interval. The marine beds are characterized by the benthic species Epistomina cf. hechti. Planktic foraminifers are rare and non-diagnostic. The stratigraphic position of marine and nonmarine intervals below the unconformity suggests correlation with Albian sequences UZA 2.1 and 2.2 (figure 8). This correlation is

supported in the Shell 272 well.

In the Shell 272 well, upper Cenomanian and upper Albian marine sections are separated by a non-fossiliferous sandy silt. The sandy silt interval thus appears to be stratigraphically equivalent to the nonfossiliferous sand in the Oxly well (figure 63). The lower marine interval in the Oxly well would then correlate with a calcareous clay interval in the Shell 272 well. The calcareous clay contains Vraconian (latest Albian) planktic markers including Planomalina buxtorfi, P. praebuxtorfi and Rotalipora ticinensis. Thus the lower marine interval in the Oxly well correlates with upper Albian sequences UZA 2.1 and 2.2. The correlation establishes E. cf. hechti as an inner-neritic biostratigraphic index no younger than Vraconian in age.

Assuming flexural loading and local or Airy isostatic compensation, past sea level can be determined by quantitatively accounting for paleodepth, sediment loading, and tectonic subsidence (Bond and Kominz, 1984; Steckler and Watts, 1978):

$$SL = \frac{(Wd)(Dm - Dw) + (S^*)(Dm - Ds) - (Y(x))(Dm - Dw)}{Dm - 2Dw}$$

where SL is the difference between past and present sea level, Wd is paleodepth, S* is decompacted sediment thickness, Y(x) is tectonic subsidence as a function of distance along profile and Dm, Ds and Dw are mean

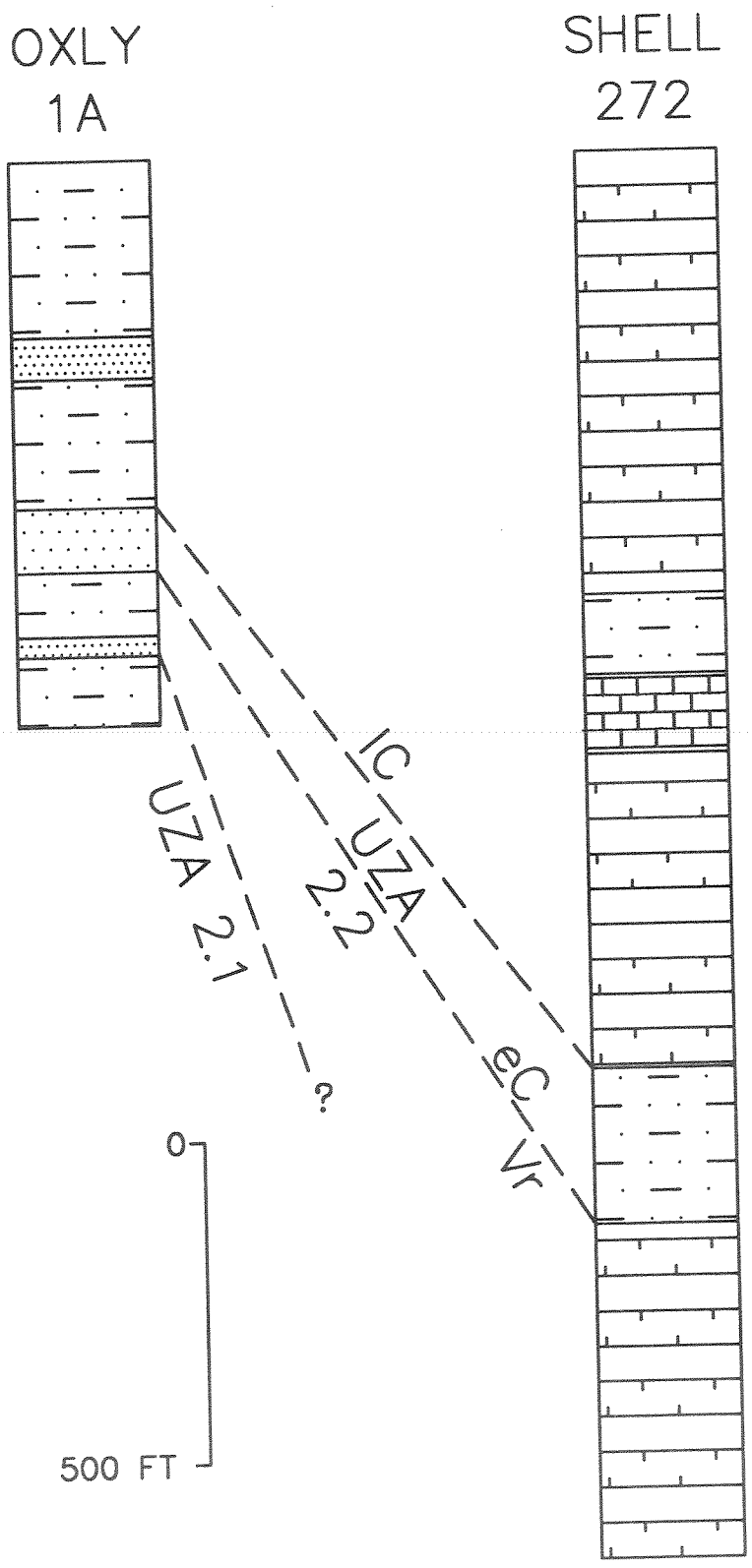


Figure 63: Depositional sequence correlation of Oxly–1A and Shell 272.

densities of the mantle, sediment and sea water, respectively. Thus variation in local water depth reflects changes in sea level if the effects of sediment loading and tectonic subsidence are taken into account.

Water depth and relative sea level can be directly related if one assumes a constant paleogradient maintained by a balance between sedimentation and subsidence rates. That is, if sediment input is just sufficient to fill the space provided by subsidence due to loading and tectonic effects, then any water depth changes would be a direct result of relative sea level variation.

Migration of biofacies along the paleoslope transect can be used to estimate paleodepth changes which occur during deposition of sequences (figure 62). For example, during the transgressive stage of UZA 2.5, the site of the Oxly well was intially occupied by biofacies 1, then by biofacies 2 and finally, during maximum flooding, by biofacies 3 (figure 50). The paleoslope model indicates a bathymetric range of 10m to 30m for biofacies 1 whereas the upper bathymetric limit of biofacies 3 is 60m (figure 53). Thus the UZA 2.5 cycle at the Oxly well site involved an increase in paleodepth of between 30m and 50m. Similarly, an increase in water depth of 20m to 30m is indicated during the late Albian and Vraconian to a paleodepth of 40m at maximum flooding.

During maximum lowstands of sequences UZA 2.2 and 2.5 (type 2 unconformities), sea level retreated from the coastal plain but did not reach the site of the Shell 272 well. Lack of data between the coastal plain wells and the Shell 272 well allows only a broad estimate of the magnitude of these sea level falls. The Shell 272 well is approximately 110km downdip of the Oxly well. Based on biofacies distribution, maximum paleodepth at the Oxly well site prior to UZA 2.2 and 2.5 lowstand was 40m. Therefore, lowstand for both sequences must have resulted in a decrease in local sea level of between 40m and 150m (assuming the same paleogradient (1m/km) for the erosional coastal plain surface as the continental shelf). Because the lower upper Albian was not examined in the Shell 272 well, a similar estimate cannot be made for UZA 2.1. Maximum lowstand of sequence UZA 2.4 is marked by a type 1 unconformity which can be traced at least to the COST B2 well. Haq et al. (1987) indicate that cycle UZA 2.3 involved a rise in sea level intermediate in magnitude between those of UZA 2.2 and 2.5 (figure 8). Therefore, a point half way between the estimated shoreline position for times of maximum flooding of sequences UZA 2.2 and 2.5 is taken to approximate the shoreline position of UZA 2.3. The COST B2 well is about 175km downdip of this position and thus a paleodepth decrease of about 175m is indicated from UZA 2.3 highstand to UZA 2.4 lowstand.

Paleoslope modeling indicates a maximum paleodepth of about 40m at the Oxly well site for sequence UZA 2.4. The Oxly well is 130km updip of the COST B2 well. Therefore, an increase in local sea level of 170m is indicated during cycle UZA 2.4, far in excess of the estimate of eustatic variation of Haq et al. (1987) (figure 62). However, the 170m estimate is excessive as it does not take into account margin subsidence during the lowstand period of nondeposition.

Nevertheless, it appears likely that New Jersey paleodepth variation exceeds the estimates of eustatic variation of Haq et al. (1987). Based on biofacies distribution, New Jersey paleodepth variation from the time of resumption of marine deposition on the coastal plain to maximum flooding is comparable to total eustatic variation (e.g., approximately a 40m increase for cycle UZA 2.5 - figure 62). Thus total local variation from lowstand to highstand much have been significantly larger than total eustatic variation as estimated by Haq et al. (1987).

Confident estimation of the magnitude of eustatic sea level can only result from a synthesis of regional studies of biofacies distribution from several continental margins combined with quantitative estimates of the effects of sediment loading and tectonic subsidence.

C. Conclusions

1. Seven benthic foraminiferal biofacies are established in the New Jersey continental margin and North Atlantic Basin. They are observed to regularly replace one another downdip as paleodepth increases. Four additional biofacies of much more limited distribution are also recognized: biofacies 1*, characterizing open marine, shallow-water environments; biofacies DSA and DSB, indicative of dysaerobic sediments; and biofacies DAA, resembling previously described assemblages of disturbed benthic environments.

2. Coastal plain depositional sequences are recognized based on lithologic criteria and the migration of biofacies along slope in response to sea level change. Correlation to the cycle chart of Haq et al. (1987) is provided in the upper Cenomanian and Turonian by the rare occurrence of planktic foraminiferal indices. Recognition of upper Albian coastal plain sequences is possible by correlation to equivalent Baltimore Canyon sections containing abundant planktic species. Deposits of UZA 2.1, 2.2, 2.4 and 2.5 are present in the coastal plain.

3. The upper boundary of an Albian-Cenomanian oxygen minimum zone existed at a paleodepth of 600m. The zone quickly expanded in the early Turonian to cover depths

between 180m and 900m. In response, agglutinate assemblages replaced calcareous biofacies on the slope and outermost shelf.

4. Backtracking of DSDP sites containing well preserved calcitic foraminiferal assemblages indicates a late Albian to Cenomanian CCD in excess of 4000m in the eastern North Atlantic. Benthic foraminiferal distribution shows a subtle latitudinal gradient in which some species are common only below a middle Cretaceous latitude of 30^{o} N. However, an overall species similarity throughout the North Atlantic suggests no great environmental change between northern and southern regions. The gradient may reflect decreasing oxygen levels from south to north related to relatively slow, haline-driven, deep-water circulation.

5. Neritic and bathyal benthic foraminifers are similar in composition to middle Cretaceous assemblages described from the South Atlantic and Europe. The stratigraphic distribution of species supports previously established phylogenies with the exception of the inner-neritic genus Epistomina. Several new species of this genus are encountered in the New Jersey coastal plain and the stratigraphic ranges of some previously described species are extended. The Epistomina species are good biostratigraphic indices in inner-neritic deposits of the

New Jersey coastal plain and are correlated by depositional sequence stratigraphy to planktic zonations best exhibited in the Baltimore Canyon.

6. A paleoslope model is presented which relates the foraminiferal biofacies to water depth of deposition from inner-shelf to abyssal environments. Migration of biofacies along paleoslope yields estimates of paleodepth change which likely reflects local sea level change occurring during UZA 2.1, 2.2, 2.4 and 2.5. Evidence indicates that these local variations significantly exceed the estimates of eustatic variations of Haq et al. (1987).

IV. SYSTEMATIC DESCRIPTIONS

Order	FORAMINIFERA	Eichwald, 1830
Suborder	TEXTULARIINA	Delage and Herouard, 1896
Superfamily	ASTRORHIZACEA	Brady, 1881
Family	PSAMMOSPHAERIDAE	Haeckel, 1894
Subfamily	PSAMMOSPHAERINAE	Haeckel, 1894
Genus	PSAMMOSPHAERA	Schulze, 1875

Psammosphaera scruposa (Berthelin), 1880

Plate 5 figure 20

Haplophragmium scruposum Berthelin 1880, Mem. Geol. France, v. 3, p. 21, pl. 1, fig. 1.

Psammosphaera scruposa (Berthelin) - Bartenstein and Bolli 1973, Ecl. Geol. Helv., v. 66, p. 392, pl. 1, figs. 24-26.

Psammosphaera scruposa (Berthelin) - Kaminski et al. 1988, Abh. Geol. B.-A., v. 41, p. 182,183, pl. 2, fig. 5.

Remarks. The test is spherical, composed of well-sorted, medium-grained quartz and occasionally some test fragments. No defined aperture is evident.

Occurrence. The species has been previously reported in lower and upper Cretaceous deep-water, terrigenous sediments of Europe, the North Atlantic and the Caribbean. In the present study, it occurs only in biofacies DAA in the Turonian of the Shell 587 well.

Superfamily	HIPPOCREPINACEA	Rhumbler, 1895
Family	HIPPOCREPINIDAE	Rhumbler, 1895
Subfamily	HYPERAMMININAE	Eimer and Fickert, 1899
Genus	HYPERAMMINA	Brady, 1878

Hyperammina gaultina Ten Dam, 1950

Plate 4 figures 1,2

Hyperammina gaultina Ten Dam 1950, Mem. Soc, Geol. France, no. 63, p. 5, pl.1, fig. 2.

Hyperammina gaultina Ten Dam - Bartenstein and Bolli 1973, Ecl. Geol. Helv., v. 66, p. 392, pl. 1, figs. 3-21.

Remarks. The species is usually found as simple, often irregular, tubular fragments. The wall is finely agglutinate with much cement. The proloculus is small, spherical and only slightly wider than the succeeding tubular chamber though specimens recovered with a proloculus are extremely rare.

Occurrence. H. gaultina was previously reported from deep-water facies of Europe, Trinidad and Australia. The species is abundant in biofacies 6 in middle bathyal to abyssal paleodepths as well as rarely occurring in outer neritic facies.

Superfamily	HORMOSINACEA	Haeckel, 1894
Family	HORMOSINIDAE	Haeckel, 1894
Subfamily	REOPHACINAE	Cushman, 1910
Genus	REOPHAX	de Montfort, 1808

Reophax guttifera Brady, 1884

Plate 5 figure 22

Reophax guttifera Brady - Bartenstein et al. 1957, Ecol. Geol. Helv., v. 50, p. 137, pl. 1, figs. 23-28.

Reophax guttifera Brady - Bartenstein and Bolli 1973, Ecol. Geol. Helv., v. 66, p. 28, pl. 1, figs. 27-33.

Remarks. The test is composed of one to three sub-

spherical, finely-agglutinate chambers, the last bearing a distinct apertural neck. Specimens recovered were often crushed.

Occurrence. R. guttifera has been recorded in lower Cretaceous deposits of the Caribbean and the North Atlantic. In the present study, it occurs rarely in abyssal deposits from below the CCD and in the middle Albian section of the Shell 586 well. However, the species is common only in biofacies DAA in the Turonian of the Shell 587 well.

Reophax pepperensis Loeblich, 1946

Plate 5 figure 21

Reophax pepperensis Loeblich 1946, J. Paleon., v. 20, p. 133, pl. 22, fig 1.

Reophax pepperensis Loeblich - Eicher 1965, J. Paleon., v. 39, p. 892, pl. 105, fig. 8.

Remarks. The test is small and very elongate with up to ten uniserial chambers, circular in section, greater in width than height. The wall is finely aggultinated but roughly textured.

Occurrence. The species has been reported in the Cenomanian and Turonian of Texas, Colorado, Wyoming and Alaska. Eicher (1965) theorized that R. pepperensis was characteristic of assemblages indicative of turbid water conditions. In the present study, the species is found only in biofacies DAA in the Shell 587 well.

Superfamily	LITUOLACEA	de Blainville, 1827
Family	HAPLOPHRAGMOIDIDAE	Maync, 1952
Genus	HAPLOPHRAGMOIDES	Cushman, 1910

Haplophragmoides cf. menitens

Plate 5 figure 19

Remarks. The species is similar to H. menitens Krasheninnikov. The test is involute, biumbilicate and sub-circular in outline. Chambers increase rapidly in size with 4 to 5 in the final whorl and the wall is smooth and finely-agglutinated. However, it differs by being somewhat coarser grained and larger in size. All individuals recovered are strongly crushed.

Occurrence. H. cf. menitens is restricted to biofacies DSB in the Shell 586 and 587 wells where it is common.

Superfamily	HAPLOPHRAGMIACEA	Eimer and Fickert, 1899
Family	AMMOSPHAEROIDINIDAE	Cushman, 1927
Subfamily	RECURVOIDINAE	Alekseychik-Mitskevich, 1973
Genus	RECURVOIDES	Earland, 1934

Recurvoides deflexiformis (Noth), 1912

Plate 5 figures 15,16

Recurvoides deflexiformis (Noth) - Geroch 1960, Biul. Inst. Geol., v. 153, p. 52, pl. 5, fig. 6.

Recurvoides deflexiformis (Noth) - Kaminski et al. 1988, Abh. Geol. B.-A., v. 41, p. 190, pl. 6, fig 3; pl. 10, fig. 15.

Remarks. The subspherical test has numerous chambers,

initially streptospiral with abrupt changes in coiling directions, then nearly planispiral in the last whorl of 7 to 9 chambers. The wall is finely finished and the sutures are nearly flush.

Occurrence. Widely reported from the upper Cretaceous and Paleogene of the Carpathians of Poland and the Soviet Union, the species has also been noted in deep-water facies of the North Atlantic and Caribbean. R. deflexiformis is one of the most abundant components of biofacies DSB in the Shell 586 and 587 wells.

Recurvoides subturbinatus (Grzybowski), 1898

Plate 5 figures 17,18

Haplophragmium subturbinatum Grzybowski 1898, Akad. Umiejet. Krakowie, v. 2, no. 30, p. 280, pl. 10, fig. 23.

cf. Thalmannammina subturbinata (Grzybowski) - Samuel 1977, Zapadne Karpaty, ser. Paleon., v. 2,3, pp. 43,44, pl. 27, fig.3.

Remarks. The test is nearly spherical, involute and finely agglutinate. The chambers are inflated, numerous and densely streptospiral, 7 to 9 in the final whorl. R. subturbinatus is distinguished from R. deflexiformis by its larger size, spherical shape and lack of a nearly planispiral final whorl.

Occurrence. The species is widespread in "flysch" facies of the upper Cretaceous and Paleogene of the Carpathian Mountains as well as noted from Trinidad. In the present study, it is common in biofacies DSB in the

Turonian in the Shell 586 and 587 wells, the oldest reported occurrence of the species.

Superfamily	SPIROPLECTAMMINACEA	Cushman, 1927
Family	SPIROPLECTAMMINIDAE	Cushman, 1927
Subfamily	SPIROPLECTAMMININAE	Cushman, 1927
Genus	SPIROPLECTAMMINA	Cushman, 1927

Spiroplectammina anceps (Reuss), 1845

Plate 4 figure 20

Textularia anceps Reuss 1845, Verst. Boehm. Kreide, pt. 1, p. 39, pl. 8, fig. 79; pl. 13, fig. 78.

Remarks. The test is composed of a small, bulbous, planispiral stage followed by a biserial segment of 4 to 6 chamber pairs. Chambers are much wider than high and somewhat overlapping with slightly depressed sutures. The wall is finely agglutinate, often composed of nannofossil plates.

Occurrence. Previously reported from the upper Cretaceous of central Europe, S. anceps has also been noted in abyssal sediments of the North Atlantic. An abundant component of biofacies 7, the species is restricted to abyssal, calcareous sediments of the North Atlantic in the present study.

Superfamily	TROCHAMMINACEA	Schwager, 1877
Family	TROCHAMMINIDAE	Schwager, 1877
Subfamily	TROCHAMMININAE	Schwager, 1877
Genus	TROCHAMMINA	Parker and Jones, 1859

Trochammina rainwateri Cushman and Applin, 1946

Plate 5 figure 5

Trochammina rainwateri Cushman and Applin 1946, Cush. Lab. Foram. Res., Contr., v. 22, pp 71-76, pl. 13.

Trochammina rainwateri Cushman and Applin - Eicher 1965, J. Paleon., v. 39, no. 5, pp. 898,899, pl. 105, fig. 16.

Remarks. The final whorl of the trochospiral test contains 6 to 8 ventrally-inflated chambers which increase slowly in size. Dorsal convexity varies from nearly flat to moderately convex. Sutures are moderately depressed ventrally but very slightly depressed dorsally and obscure. The wall is composed of medium-grained quartz and is commonly compressed.

Occurrence. T. rainwateri is a common species in Cenomanian and Turonian sediments of the Great Plains in the United States and Canada. Eicher (1965) and Eicher and Worstell (1970) reported the species as most characteristic of organic-rich shales. In the present study, it occurs rarely in the New Jersey coastal plain but is common only in biofacies DSA in the COST B2 well, indicative of outermost-neritic dysaerobic paleoenvironments.

Trochammina wickendeni Loeblich, 1946

Plate 5 figure 6

Trochammina wickendeni Loeblich 1946, J. Paleon., v. 20, p. 138, pl. 22, fig. 17.

Trochammina wickendeni Loeblich - Eicher 1965, J. Paleon., v. 39, p. 900, pl. 105, fig. 13.

Remarks. The species differs from T. rainwateri by having a very low trochoid test, a final whorl of only 4 to 5 chambers which increase rapidly in size, and more depressed, distinct dorsal sutures.

Occurrence. T. wickendeni often occurs with T. rainwateri in organic-rich facies of the Great Plains. In the present study, the species is common only in biofacies DSA in the COST B2 well.

Superfamily	VERNEUILINACEA	Cushman, 1911
Family	VERNEUILINIDAE	Cushman, 1911
Subfamily	VERNEUILINOIDINAE	Suleymanov, 1973
Genus	EGGERELLINA	Marie, 1941

Eggerellina mariae Ten Dam, 1950

Plate 2 figure 10

Eggerellina mariae Ten Dam 1950, Mem., Soc, Geol, France, no. 63, pp. 15,16, pl. 1, fig. 17.

Eggerellina mariae Ten Dam - Gawor-Biedowa 1972, Acta Paleontogr. Polonica, v. 17, pp. 33,34, pl. 3, figs. 1,2.

Remarks. The small test is finely agglutinate with much calcareous cement. Chambers are inflated, globular and arranged triserially, the last three composing over half the test.

Occurrence. Previously reported from the upper Albian and Cenomanian of the Netherlands and Poland, E. mariae in the present study is most characteristic of biofacies 3 in the Oxly and Shell 272 wells.

Eggerellina sp. 1 Moullade, 1984

Plate 4 figure 21

Eggerellina? sp. 1 Moullade 1984, 2nd Int. Symp. Benthic Foram. (Pau), p. 446, pl. 2, figs. 4,5.

Remarks. The species is small and composed of a single triad of chambers with subangular margins. The wall is made of very fine calcareous particles with much cement.

Occurrence. Moullade (1984) noted the species from the lower Cenomanian of DSDP Site 137. The present study recovered it from the uppermost Albian to upper Cenomanian of that site as well as at other abyssal localities of the North Atlantic. Though never very common, the species is one of the most characteristic components of biofacies 7.

Genus UVIGERINAMMINA Majzon, 1943

Uvigerinammina jankoi Majzon, 1943

Plate 5 figure 14

Uvigerinammina jankoi Majzon 1943, Mitteil. Jb. Kgl. Ung. Geol. Anst., Bd. 37, H. 1, p. 158, pl. 2, fig. 15.

Uvigerinammina jankoi Majzon - Krasheninnikov 1974, Init. Repts. DSDP, v. 27, pp. 642,643, pl. 6, figs. 9, 10.

Remarks. The high trochospiral test is finely agglutinated with a moderately rough surface. Early chambers are small and obscure whereas the last three are inflated and compose over half the test. A small round aperture occurs at the end of a very short neck.

Occurrence. U. jankoi has been described from

"flysch" facies of the Carpathian Mountains and from upper Cretaceous abyssal red clays of the Indian Ocean. The species is the most abundant component of biofacies DSB in the Shell 586 and 587 wells.

Genus VERNEUILINOIDES Loeblich and Tappan, 1949

Verneuilinoides borealis Tappan, 1957

Plate 5 figure 23

Verneuilinoides borealis Tappan 1957, U. S. Nat. Mus. Bull., no. 215, pp. 206,207, p. 66, figs 10-18.

Remarks. The elongate, triserial test has a slightly twisted axis. Early chambers are small and increase slowly in size but later chambers become rapidly larger and globular with very depressed sutures. The wall is generally fine to moderately agglutinated but varies in composition with substrate type. Most tests recovered are crushed.

Occurrence. Originally described from the Arctic coastal plain of Alaska, the species is rare in outer-neritic and bathyal facies of the New Jersey continental margin. However, it is common only in biofacies DAA in the Shell 587 well.

Genus SPIROPLECTINATA Cushman, 1927

Spiroplectinata capitosa (Cushman), 1933

Plate 2 figure 22

Gaudryinella capitosa Cushman 1933, Cush. Lab. Foram. Res., Contri., v. 9, p. 52, pl. 5, fig. 8.

Pseudogaudryinella capitosa (Cushman) - Cushman 1946, USGS Prof. Pap., no. 206, p. 40, pl. 10, figs. 15-19.

Remarks. The very large test has an early triserial stage, triangular in section with sharply angular margins. The intermediate stage is composed of two or three irregularly biserial pairs ending in one or two uniserial chambers which are circular in section. The wall is coarsely agglutinated but smoothly finished.

Occurrence. S. capitosa has been widely reported in Coniacian to Campanian neritic facies of the Gulf Coast. In the present study, in its oldest recorded occurrence, the species is common in "biofacies" 4(t) in the upper Turonian in the Shell 272 well.

Subfamily	VERNEUILININAE	Cushman, 1911
Genus	GAUDRYINA	d'Orbigny, 1839

Gaudryina cushmani Tappan, 1940

Plate 3 figure 7

Gaudryina cushmani Tappan 1940, J. Paleon., V. 14, no. 2, p. 99, pl. 15, fig. 6.

Gaudryina cushmani Tappan - Sliter 1977, Init. Repts. DSDP, v. 39, p. 677, p. 2, fig. 7.

Remarks. The early triserial stage is conical, rapidly increasing in width from a pointed base. The subsequent biserial stage is composed of two or three chamber pairs which increase very slightly in size.

Chambers are inflated with depressed sutures and the wall is moderately agglutinated and roughly finished.

Occurrence. Originally described from upper Albian neritic facies of Texas, Sliter (1977) reported the species from bathyal sediments of the South Atlantic. However, the present study finds G. cushmani to be restricted to the outer-neritic range of biofacies 4(ac).

Superfamily	TEXTULARIACEA	Ehrenberg, 1838
Family	EGGERELLIDAE	Cushman, 1937
Subfamily	DOROTHIINAE	Balakhmatova, 1972
Genus	DOROTHIA	Plummer, 1931

Dorothia oxycona (Reuss), 1860

Plate 2 figure 21

Gaudryina oxycona Reuss 1860, Akad. Wiss. Wien, Math.-naturwiss. Kl., Sitzungsber., v. 40, p. 229, pl. 12, fig. 3.

Marssonella oxycona (Reuss) - Cushman 1946, USGS Prof. Pap., no. 206, pp. 43,44, pl. 12, figs. 3-5.

Remarks. The specimens collected are typical of this widely described species. The test is conical and broadly flaring. Chambers are uninflated with flush sutures and a finely-agglutinated, smoothly-finished wall.

Occurrence. D. oxycona has been reported from lower- and upper-Cretaceous neritic to abyssal sediments of North America, Europe, Australia and the Atlantic, Pacific and Indian Oceans. In this study, it is widespread, though never common in Albian and Cenomanian bathyal and abyssal sediments of North Atlantic DSDP Sites and the Shell 586

and 587 wells. In the Turonian, the species is common in outer neritic "biofacies" 4(t) in the Shell 272 well.

Subfamily	EGGERELLINAE	Cushman, 1937
Genus	KARRERIELLA	Cushman, 1933

Karreriella conversa (Grzybowski), 1901

Plate 5 figure 13

Gaudryina conversa Grzybowski 1901, Akad., Umiejet. Katowie, ser. 2, v. 33, p. 224, pl. 8, figs. 15-16.

Plectina aff. conversa (Grzybowski) - Krasheninnikov 1974, Init. Repts. DSDP, v. 27, p. 643, pl. 7, figs. 3,4.

Karreriella conversa (Grzybowski) - Kaminski et al. 1988, Abh. Geol. B.-A., v. 41, p. 196, pl. 9, fig. 17,18.

Remarks. The chambers are initially trochospiral, then arranged in an elongate biserial stage with a twisted axis. Chambers are inflated with depressed sutures although specimens are commonly crushed. The aperture is round and very small, terminal in position at the apex of the final chamber.

Occurrence. The species has been reported in upper Cretaceous and Paleogene deep-water sediments of eastern Europe, the North Atlantic, Trinidad and New Zealand. It is a common component of biofacies DSB in the Shell 586 and 587 wells.

Suborder	SPIRILLININA	Hohenegger and Pillar, 1975
Family	SPIRILLINIDAE	Reuss and Fritsch, 1861
Genus	SPIRILLINA	Ehrenberg, 1843

Spirillina minima Schacko, 1892

Plate 2 figure 1

Spirillina minima Schacko - Bartenstein et al. 1957, Ecol. Geol. Helv., v. 50, p. 51, pl. 1, figs. 18-20.

Spirillina minima Schacko - Sliter 1980, Init. Repts. DSDP, v. 50, p. 400, pl. 15, figs. 3,4.

Remarks. The species is distinguished from others of the genus by the low number of whorls (4 to 5) of the ultimate tubular chamber.

Occurrence. S. minima has been widely reported in lower and upper Cretaceous neritic to abyssal sediments of the North Atlantic, the Caribbean and Europe. However, many of the deeper-water occurrences likely represent displacement from shallower depths (e.g., Sliter, 1980). In the present study, the species occurs very rarely from the New Jersey coastal plain to bathyal sites of the Baltimore Canyon and DSDP. It is abundant, however, only in biofacies 1* from neritic DSDP Sites 111 and 402.

Family	PATELLINIDAE	Rhumbler, 1906
Subfamily	PATELLININAE	Rhumbler, 1906
Genus	PATELLINA	Williamson, 1858

Patellina subcretacea Dieni and Massari, 1966

Plate 2 figures 2,3

Patellina subcretacea Dieni and Massari 1966, Palaeontogr. Italiana, v. 61, n. ser. 31, p. 121, pl. 2, fig. 3.

Patellina subcretacea Dieni and Massari - Sliter 1980, Init. Repts. DSDP, v. 50, p. 402, pl. 16, figs. 1-4.

Remarks. The ultimate tubular chamber forms 6 to 8

whorls in a regular, highly convex spire. The dorsal surface is coarsely perforate and has a raised spiral suture.

Occurrence. The species occurs in shallow- and deep-water facies of Europe and the North Atlantic. In the present study, P. subcretacea is restricted to biofacies 1* of DSDP Sites 111 and 402.

Suborder	MILIOLINA	Delage and Herouard, 1896
Superfamily	MILIOLACEA	Ehrenberg, 1839
Family	HAUERINIDAE	Schwager, 1876
Subfamily	SIPHONAPERTINAE	Saidova, 1975
Genus	QUINQUELOCULINA	d'Orbigny, 1826

Quinqueloculina antiqua Franke, 1928

Plate 4 figure 6

Miliolina (Quinqueloculina) antiqua Franke 1928, Abh. Preuss. Geol. Landesanst., v. 111, pp. 126,127, pl. 11, figs. 25,26.

Quinqueloculina antiqua Franke - Gawor-Biedowa 1972, Acta Paleontogr. Polonica, v. 17, pp. 35,36, pl. 3, fig. 6.

Remarks. The species is characterized by thick, robust chambers with very broadly rounded margins. The test is somewhat triangular in section and sutures are slightly depressed to somewhat raised.

Occurrence. Q. antiqua has been widely reported from the Albian to Turonian of both western and eastern Europe as well as from abyssal sediments of the North Atlantic. The species is most common in middle and lower bathyal sediments characterized by biofacies 6. It is also

widespread, though less common, in abyssal DSDP sites in the eastern North Atlantic.

Suborder	LAGENINA	Delage and Herouard, 1896
Superfamily	NODOSARIACEA	Ehrenberg, 1838
Family	VAGINULINIDAE	Reuss, 1860
Subfamily	LENTICULININAE	Chapman, Parr and Collins,
Genus	LENTICULINA	Lamarck, 1804

Lenticulina munsteri (Roemer), 1839

Plate 3 figures 14,15

Robulina munsteri Roemer 1839, Oolithengebirges, Nachtrag., p. 48, pl. 12, fig. 29.

Robulus munsteri (Roemer) - Cushman 1946, USGS Prof. Pap. no. 206, p. 53, pl. 17, figs. 3-9.

Lenticulina (Lenticulina) munsteri (Roemer) - Bartenstein et al. 1957, Ecol. Geol. Helv., v. 50, p. 22, pl. 3, fig. 54.

Lenticulina muensteri (Roemer) - Sliter 1980, Init. Repts. DSDP, v. 50, p. 368, pl. 9, figs. 3,4.

Remarks. Recovered specimens are typical of this widely described species, showing an involute, biumbonate, compressed test with a smooth surface. The last whorl is composed of 9 to 12 uninflated chambers with slightly limbate and curved sutures.

Occurrence. L. munsteri has been described from the lower and upper Cretaceous of Europe, North America, Australia, the Caribbean and the North and South Atlantic and Indian Oceans. In the present study, the species is very abundant in outer-neritic to upper-bathyal sediments dominated by biofacies 5.

Lenticulina secans (Reuss), 1863

Plate 3 figures 19,20

Cristellaria secans Reuss 1863, K. Akad. Wiss. Wien, Math.-Naturw. Cl., Sitzber., v. 46, p. 214, pl. 9, fig. 7.

Lenticulina (Lenticulina) secans (Reuss) - Neagu 1965, Micropaleon., v. 11, no. 1, p. 11, pl. 3, figs. 7,8.

Lenticulina (Lenticulina) secans (Reuss) - Moullade 1984, 2nd Int. Symp. Benthic Foram. (Pau), p.446, pl. 2, fig. 18.

Remarks. The species is characterized by its well defined umbonal bosses, large number of chambers in the final whorl (10-12), raised and strongly curved sutures and a wide and very thin keel. In the examined samples, L. secans commonly occurs with L. danubiana Neagu which it resembles but from which it can be distinguished by its larger size, larger bosses and much more highly developed keel.

Occurrence. L. secans has been commonly reported from the lower and lower upper Cretaceous of Europe as well as from deep-water sediments of the eastern North Atlantic. The species is a common component of biofacies 5 in outer-neritic and, especially upper- and middle-bathyal sediments. It also rarely occurs in lower bathyal DSDP sites of the eastern North Atlantic.

Suborder	ROBERTININA	Loeblich and Tappan, 1984
Superfamily	CERATOBULIMINACEA	Cushman, 1927
Family	CERATOBULIMINIDAE	Cushman, 1927
Subfamily	CERATOBULIMININAE	Cushman, 1927
Genus	CERATOBULIMINA	Toula, 1915

Ceratobulimina parva Eicher and Worstell, 1970

Plate 1 figures 1-3

Ceratobulimina parva Eicher and Worstell 1970, Micropaleon., v. 16, no. 3, p. 295, pl. 7, figs. 3,5.

Remarks. C. parva is distinguished by its small size, narrowly-rounded periphery and relatively large number of chambers in the final whorl (7 to 8).

Occurrence. The species was originally described from shallow-water deposits of the upper Cenomanian of the Western Interior Seaway. It is common in biofacies 1 in the Bass River formation of the New Jersey coastal plain as well as in biofacies 1* from neritic deposits of DSDP Site 402 in the Bay of Biscay.

Subfamily	EPISTOMININAE	Wedekind, 1937
Genus	EPISTOMINA	Terquem, 1883

Epistomina chapmani Ten Dam, 1948

Plate 1 figures 4-6

Epistomina chapmani Ten Dam 1948, Rev. Inst. Franc. Petr., v. 3, p. 166, pl. 1, fig. 5.

Epistomina chapmani Ten Dam - Gradstein 1978, Init. Repts. DSDP, v. 44, p. 673, pl. 8, fig. 5.

Hoeglundina chapmani (Ten Dam) - Hart 1984, 2nd Int. Symp. Benthic Foram. (Pau), p. 292, pl. 2, figs. 1-4.

Remarks. E. chapmani is characterized by a very smooth surface, acute periphery, lack of a well defined umbo and a highly convex ventral side.

Occurrence. The species has been widely reported

from Albian and lowermost Cenomanian neritic facies of Europe and the northern North Atlantic. In the New Jersey coastal plain, E. chapmani is common to abundant in biofacies 1 in the Albian marine unit and the upper Cenomanian section of the Bass River formation. It also occurs rarely in middle and outer neritic facies dominated by biofacies 3 and 4.

Epistomina charlottae Vieux, 1941

Plate 1 figures 22-24

Epistomina charlottae Vieux 1941, J. Paleon., v. 15, no. 6, p. 627, pl. 85, fig. 9.

Epistomina charlottae Vieux - Ten Dam 1948, Rev. Inst. Franc. Petr., v. 3,p. 165, pl. 1, figs. 9,10.

Remarks. The status of this species is questionable. The original description by Vieux (1941) was very incomplete and the holotypes have been lost. E. charlottae has been widely described in the literature but with a great amount of variability. Apparently, the species has often been used as a general repository for any unidentified middle Cretaceous epistominid. However, based on Vieux's holotype figures and the paratypes figured by Ten Dam (1948), the species can be distinguished by the following characters; a strongly convex ventral side culminating in a narrow, reticulate umbilical region, ventral sutures which are strongly raised near the umbilicus but decrease in elevation towards the periphery,

a much less convex dorsal side with a coarsely reticulate central region and raised and strongly curved dorsal sutures.

Occurrence. Originally described from the Albian of Texas, unquestionable specimens have also been described from the Albian and Cenomanian of north-west Europe. In the present study, E. charlottae is rarely but persistently present in biofacies 1 of the New Jersey coastal plain and common in biofacies 1* of DSDP Site 402 in the Bay of Biscay.

Epistomina stelligera (Reuss), 1854

Plate 1 figures 13-15

Rotalina stelligera Reuss 1854, Denkschr. K. Akad. Wiss., v. 7, p. 69, pl. 15.

Epistomina stelligera stelligera (Reuss) - Ohm 1967, Paleontogr., v. 127A, p. 151-153, pl. 20, fig. 3.

Remarks. The ventral side is very convex, culminating in a prominent umbo from which extend raised, radiate sutures in a distinctive astral pattern. The dorsal convexity varies from slightly convex to equally convex to the ventral side. Dorsal sutures can be nearly flush to moderately raised.

Occurrence. E. stelligera has been reported in Cenomanian to Coniacian shallow-water facies of Europe and northern North Atlantic margins. In the present study, it is restricted to the Bass River formation in which it is

extremely abundant in biofacies 1.

Epistomina cf. chapmani (Hart), 1984

Plate 1 figures 25-27

Hoeglundina sp. cf. chapmani (Ten Dam) - Hart 1984, 2nd Int. Symp. Benthic Foram. (Pau), p. 292, pl. 2, figs. 5-8.

Remarks. Dorsally identical to E. chapmani Ten Dam, the species differs ventrally by having depressed sutures between later chambers, a slightly lobate periphery, and a depressed umbilical region.

Occurrence. Hart (1984) described the species from upper Albian strata of the western Paris Basin. In the New Jersey coastal plain, it is a persistent, though never abundant component of biofacies 1 in the Albian marine unit and the upper Cenomanian section of the Bass River. It becomes common, however, only in biofacies 1* at DSDP Site 402 in the Bay of Biscay.

Epistomina cf. hechti

Plate 1 figures 7-9

Remarks. The species resembles E. hechti Bartenstein, Bettenstaedt and Bolli by having a sharply convex ventral side culminating in a large umbo. Ventral and dorsal sutures are raised and curved. However, it differs by lacking umbonal reticulate structures, instead showing a smooth, flattened, angular umbo.

Occurrence. E. cf. hechti is restricted to biofacies

1 in the upper Albian of the Oxly and BTMA wells.

Epistomina aff. ripleyensis

Plate 1 figures 10-12

Remarks. Specimens from the Bass River formation resemble E. ripleyensis (W. Berry) of the Coniacian to Campanian of the Gulf Coast. The test is equally biconvex with strongly raised ventral sutures merging in a small umbo. However, the Bass River specimens differ by having an extremely small umbo and much thinner ventral sutures which often merge before reaching the umbilicus (pl. 1, fig. 16).

Occurrence. E. aff. ripleyensis is dominant in biofacies 1 of the upper-Cenomanian to lower-Turonian Bass River Formation.

Epistomina aff. stelligera

Plate 1 figures 10-12

Remarks. The species differs from E. stelligera (Reuss) by having ventral sutures which abruptly curve near the periphery and more strongly raised dorsal sutures.

Occurrence. E. aff. stelligera is common throughout the middle Cretaceous of the New Jersey coastal plain though reaching greatest abundance in the Albian marine unit of Oxly-1A.

Suborder	ROTALIINA	Delage and Herouard, 1896
Superfamily	TURRILINACEA	Cushman, 1927
Family	TURRILINIDAE	Cushman, 1927
Genus	NEOBULIMINA	Cushman and Wickenden, 1928

Neobulimina aff. albertensis

Plate 2 figures 19,20

Remarks. The species resembles N. albertensis (Stelck and Wall) in having an elongate, mainly triserial test in which only the last two or four chambers become biserial. However, N. aff. albertensis has much less globular chambers, less depressed sutures and a distinctly papillose surface on the lower portion of the test (pl. 2, fig. 20).

Occurrence. The species is common in biofacies 3 in the Baltimore Canyon Trough as well as rarely occurring in the New Jersey coastal plain.

Genus PRAEBULIMINA Hofker, 1953

Praebulimina evexa (Loeblich and Tappan), 1949

Plate 4 figure 3

Bulimina evexa Loeblich and Tappan 1949, J. Paleon., v. 23, p. 263, pl. 51, fig. 5.

Praebulimina reussi (Morrow) - Marks 1967, Kon. Neder. Akad. Wetensch., ser. B, v. 70, no. 5, p. 439, pl. 3, fig. 1.

Praebulimina evexa (Loeblich and Tappan) - Gawor-Biedowa, Acta Paleontogr. Polonica, v. 17, p. 55, pl. 5, fig. 1.

Remarks. The test is very small, almost as wide as high, with three globular final chambers composing more than 75% of the test. The earlier chambers are indistinct

and form a rounded initial end.

Occurrence. P. evexa has been described from the Albian and Cenomanian of Texas, France and Poland. The species is common in biofacies 6, in middle and lower bathyal sediments, as well as occurring rarely in outer-neritic and abyssal facies.

Praebulimina nannina (Tappan), 1943

Plate 4 figures 4,5

Bulimina nannina Tappan 1943, J. Paleon., v. 17, no. 5, p. 482, pl.5, fig 1.

Praebulimina nannina (Tappan) - Moullade 1984, 2nd Int. Symp. Benthic Foram. (Pau), p. 448, pl. 3, figs. 25,26.

Remarks. The test is very small with three very globular chambers which compose over half the test. Many specimens collected in the present study differ from previous descriptions by having pores surrounded by mound-like structures (pl. 4, fig. 5). As the extent of this ornamentation on the test varies between localities, it presumably reflects some environmental adaptation. P. nannina is distinguished from P. evexa by its greater test height and more globular chambers.

Occurrence. The species was originally described from the Albian of Texas and Oklahoma and has subsequently been reported in Albian bathyal and abyssal deposits of the North Atlantic. P. nannina is a common species of biofacies 6 in Albian and Cenomanian lower bathyal to

abyssal facies.

Superfamily	PLEUROSTOMELLACEA	Reuss, 1860
Family	PLEUROSTOMELLIDAE	Reuss, 1860
Subfamily	PLEUROSTOMELLINAE	Reuss, 1860
Genus	PLEUROSTOMELLA	Reuss, 1860

Pleurostomella obtusa Berthelin, 1880

Plate 4 figure 7

Pleurostomella obtusa Berthelin 1880, Soc. Geol. France, Mem., ser. 3, v. 1, no. 5, p. 29, pl. 1, fig. 9.

Pleurostomella obtusa Berthelin - Neagu 1965, Micropaleon., v. 11, no. 1, p. 29, pl. 7, figs. 29-32.

Pleurostomella obtusa Berthelin - Scheibnerova 1974, Init. Repts. DSDP, v. 27, p. 713, pl. 11, fig. 2.

Remarks. The species is characterized by a large, bulbous initial chamber which is succeeded by 2 to 5, nearly uniserial chambers. Its relatively short test length distinguishes P. obtusa from other species of the genus.

Occurrence. The species has been widely reported in the Albian and Cenomanian of eastern and western Europe and in deep-water facies of the North and South Atlantic and Indian Oceans. It is a widespread and common component of biofacies 6 in Albian to Turonian bathyal and abyssal sediments.

Pleurostomella reussi Berthelin, 1880

Plate 4 figure 8

Pleurostomella reussi Berthelin 1880, Soc. Geol. France, Mem., ser. 3, v. 1, no. 5, pl. 1, figs. 10-12.

Pleurostomella reussi Berthelin - Neagu 1967, Micropaleon., V. 11, no. 1, p. 30, pl. 7, figs. 27-28.

Pleurostomella reussi Berthelin - Gawor-Biedowa 1972, Acta Paleontogr. Polonica, V. 17, p. 95, pl. 7, figs. 3,4.

Remarks. The test is very elongate. Chambers are initially irregularly biserial, then uniserial. Sutures are strongly depressed and the margin is lobate.

Occurrence. P. reussi has been widely reported from the Albian of eastern and western Europe. In the present study, it is one of the less common species of biofacies 6 in lower bathyal and abyssal DSDP sediments and is present only in oxygenated facies.

Superfamily	DISCORBACEA	Ehrenberg, 1838
Family	PLACENTULINIDAE	Kasimova, Poroshina and Geodakchan, 1980
Subfamily	ASHBROOKIINAE	Loeblich and Tappan, 1984
Genus	PSEUDOPATELLINELLA	Takayanagi, 1960

Pseudopatellinella rumana Neagu, 1975

Plate 7 figures 1,2

Pseudopatellinella rumana Neagu - Moullade 1984, 2nd Int. Symp. Benthic Foram. (Pau), p. 450, pl. 4, figs. 8,9.

Remarks. The small test is plano-convex. The dorsal side is evolute with 6 to 8 whorls of two chambers each whereas only the final two chambers are visible on the flat ventral side. The aperture is a narrow slit running along the base and then curving up the face of the final chamber.

Occurrence. The species has been described from

Albian and Cenomanian deep-water facies of Rumania and the South Atlantic. In the present study, it is restricted to biofacies 7 in abyssal facies of the North Atlantic.

Family	BAGGINIDAE	Cushman, 1927
Subfamily	BAGGININAE	Cushman, 1927
Genus	VALVULINERIA	Cushman, 1926

Valvulineria parva Khan, 1950

Plate 3 figures 1-3

Valvulineria parva Khan 1950, J. Royal Microscop. Soc., ser. 3, v. 3, p. 275, pl. 2, figs. 12-14, 19.

Valvulineria parva Khan - Jannin 1967, Rev. Micropal., v. 10, p. 156, pl. 1, figs. 1-5; pl. 3,figs 1-3; pl.4, fig. 1.

Remarks. The species is characterized by a nearly flat dorsal face with flush to slightly depressed sutures and chambers which are wider than high. V. parva commonly occurs with the eurybathic species V. loetterlei (Tappan) and V. berthelini Jannin. It can be distinguished from V. loetterlei by its much less convex dorsal face, much less depressed sutures, lack of a lobate periphery and by having much wider chambers in dorsal view. It differs from V. berthelini by having a much thicker test and lacking strongly depressed dorsal sutures.

Occurrence. V. parva has only been described from the Albian of northwest Europe. In the present study, however, it is common in biofacies 4(ac) in outer neritic to middle bathyal Albian and Cenomanian sediments of the New Jersey continental margin.

Family	EPONIDIDAE	Hofker, 1951
Subfamily	EPONIDINAE	Hofker, 1951
Genus	EPONIDES	de Montfort, 1808

?Eponides sp.

Plate 4 figures 22-24

Remarks. The small test has a slightly convex dorsal side with very limbate, slightly raised sutures, fusing into a low central callus which obscures the earlier whorls. The ventral side is very convex, culminating in a large umbilical boss and has radial and limbate sutures. The periphery is subangular with a thick keel. The aperture was not clearly observed but appears to be a moderately-high arch extending from the umbilical boss to the periphery. The lack of any specimens with a well preserved aperture leads to a tentative generic assignment.

Occurrence. The species is observed to be common in abyssal facies throughout the North Atlantic. It is restricted in occurrence to biofacies 7.

Superfamily	CHILOSTOMELLACEA	Brady, 1881
Family	QUADRIMORPHINIDAE	Saidova, 1981
Genus	QUADRIMORPHINA	Finlay, 1939

Quadrimorphina allomorphinoides (Reuss), 1860

Plate 4 figures 15,16

Valvulina allomorphinoides Reuss 1860, K. Akad. Wiss. Wien, Math.-Naturw. Cl., Sitzber., v. 40, p. 223, pl. 11, fig. 6.

Quadrimorphina allomorphinoides (Reuss) - Neagu 1965, Micropaleon., v. 11, no. 1, p. 30, pl. 8, fig. 9.

Remarks. The smooth oval test has a rounded periphery and is dorsally evolute with 4 to 6 chambers in the final whorl. The ventral side is characterized by slightly depressed, straight sutures and a low interiomarginal aperture covered by a large, plate-like lip extending from the final chamber.

Occurrence. Q. allomorphinoides has been described from the lower and upper Cretaceous of the Gulf Coast and western Atlantic margin, from Mexico, the Caribbean and South America and from eastern and western Europe and the North and South Atlantic. In the middle Cretaceous, it has been reported in Rumania and in bathyal deposits of the Atlantic Ocean. In the present study, the species is common in biofacies 6 in the Turonian in the Shell 586 and 587 wells and in lower bathyal Albian and Cenomanian DSDP sections, primarily from sites south of 30° N paleolatitude.

Family	GLOBOROTALITIDAE	Loeblich and Tappan, 1984
Genus	GLOBOROTALITES	Brotzen, 1942

Globorotalites rumanus Neagu, 1965

Plate 2 figures 16-18

Globortalites brotzeni rumanus Neagu 1965, Micropaleon., v. 11, no. 1, p. 37, pl. 10, figs. 7-9.

Remarks. The species is characterized by a relatively low ventral convexity, very depressed ventral sutures, a lobate periphery and a thick umbilical collar.

Occurrence. Originally described from the Wallachian

plain of southern Rumania, the species is characteristic of middle neritic biofacies 3 in the COST B2 and Shell 272 wells and also rarely occurs in the New Jersey coastal plain.

Family	OSANGULARIIDAE	Loeblich and Tappan, 1964
Genus	OSANGULARIA	Brotzen, 1940

Osangularia brotzeni (Gandolfi), 1942

Plate 5 figures 3,4

Conorbina brotzeni Gandolfi 1942, Riv. Ital. Paleont., v. 48, no.4, pp. 91,92, text-fig. 27a-c; text-fig. 28, 1a,b, 2a,b.

Conorbina brotzeni Gandolfi - Gawor-Biedowa 1972, Acta Paleontogr. Polonica, v. 17, pp. 58,59, pl. 6, fig. 4.

Osangularia brotzeni (Gandolfi) - Moullade 1984, 2nd Int. Symp. Benthic Foram. (Pau), p. 450, pl. 4, figs. 18-20.

Remarks. The dorsal side is very convex and evolute with raised, curved sutures and 5 to 6 chambers in the final whorl which rapidly increase in size. The ventral side is slightly convex to concave with curved, depressed sutures.

Occurrence. O. brotzeni has been reported from Albian "flysch" facies of Italy and Poland and from abyssal facies of the South Atlantic. The species is common in abyssal biofacies 7 in the North Atlantic as well as occurring rarely and sporadically in middle and lower bathyal facies.

Osangularia insigna Dailey, 1970

Plate 4 figures 9-11

Osangularia insigna Dailey 1970, Contr. Cush. Found. Foram. Res., v. 21, pt. 3, p. 109, pl. 13, fig. 5; pl. 14, fig. 1.

Osangularia insigna Dailey - Gradstein 1978, Init. Rept. DSDP, v. 44, p. 676, pl. 7, figs 1-4.

Remarks. The test is compressed, equally biconvex to slightly more convex ventrally. The last whorl is composed of 10 to 12 chambers with strongly raised sutures. A small umbilical boss is frequently present.

Occurrence. The species has been reported from the Albian and Cenomanian of California and from bathyal facies of the western Atlantic margin. In the present study, O. insigna is very abundant in biofacies 6 in middle bathyal to abyssal sediments of the North Atlantic and New Jersey continental margin.

Osangularia utaturensis (Sastri and Sastry), 1966

Plate 4 figures 12-14

Eponides utaturensis Sastri and Sastry 1966, Geol. Surv. India Rec., v. 94, p. 292, pl. 19, fig. 6.

Osangularia californica Dailey 1970, Contr. Cush. Found. Foram. Res., v. 21, pp. 108,109, pl. 12, figs. 3,4.

Osangularia utaturensis (Sastri and Sastry) - Scheibnernova 1974, Init. Repts. DSDP, v. 27, p. 714, pl. 5, figs. 1-9; pl. 11, figs 4,5.

Osangularia utaturensis (Sastri and Sastry) - Gradstein 1978, Init. Repts. DSDP, v. 44, p. 676, pl. 7, figs. 5-12.

Remarks. The test is circular in outline and strongly convex dorsally. The final whorl has 10 to 12 chambers with raised curved sutures dorsally and ventrally. O. utaturensis resembles O. brotzeni but differs by having a

greater number of chambers in the final whorl and raised ventral sutures.

Occurrence. The species has been reported in Albian and Cenomanian strata of India, Australia and California and from deep-water facies of the North and South Atlantic and Indian Oceans. It is very abundant in biofacies 6 in Albian and Cenomanian bathyal and abyssal sediments of the North Atlantic and New Jersey continental margin. In the Turonian in the Shell 272 well, it occurs as a common outer neritic species in "biofacies" 4(t).

Family	GAVELINELLIDAE	Hofker, 1956
Subfamily	GYROIDINOIDINAE	Saidova, 1981
Genus	GYROIDINOIDES	Brotzen, 1942

Gyroidinoides sp. 2 (Jannin), 1967

Plate 3 figures 4-6

Valvulineria (Gyroidinoides) sp. 2 Jannin 1967, Rev. Micropal., v. 10, pp. 160,161, pl. 1, figs. 7,8; pl. 3, figs. 16,17; pl.4, fig. 4.

Remarks. The test is plano-convex with 8 to 10 chambers in the final whorl increasing slowly in size. The ventral side is very convex, the last chamber rectangular in side view with a nearly flat upper margin. Dorsal sutures are curved, initially flush then becoming slightly depressed. Ventral sutures are radial, depressed near the umbilicus then becoming flush near the periphery. The aperture is an elongate slit running from the umbilicus to

the periphery and covered by a well-developed flap extending from the base of the final chamber. G. sp. 2 appears to be a homeomorph of the Santonian to Maastrichtian species, G. nitida (Reuss).

Occurrence. Originally described from the Vraconian of France, the species is abundant in biofacies 4(ac) in upper Albian and Cenomanian outer neritic to middle slope sediments of the Baltimore Canyon Trough. It also occurs rarely in deeper-water DSDP facies and in inner neritic sediments of the Oxly well.

Subfamily	GAVELINELLINAE	Hofker, 1956
Genus	GAVELINELLA	Brotzen, 1942

Gavelinella berthelini (Keller), 1935

Plate 2 figures 7-9

Anomalina berthelini Keller 1935, Bjul. Mosk. Obsc., Isp. Prip. Otd. Geol., v. 23, no.4, pp. 552,553, pl. 2, figs. 25,26.

Anomalina complanata Berthelin 1880 (non Reuss), Soc. Geol. Fr. Ser. 3, Mem., v. 1, no. 5, p. 66, pl. 4, figs. 12,13.

Anomalina berthelini Ten Dam 1947 (nomen nudum), Geol., Mijnbouw, v. 8, pp. 25-29.

Gavelinella intermedia var. A (Berthelin) - Price 1977, Paleon. v. 20, p. 516, pl. 60, figs. 9-11.

Remarks. The test is equally biconvex and compressed. The dorsal side is smooth, imperforate and has a small central boss of variable size which covers the earliest chambers. The last 2 or 3 chambers on the coarsely perforate ventral side have well-developed lamellar flaps

which partially cover a narrow umbilicus.

The species has had a very confused taxonomic development. Originally described by Berthelin (1880), it long remained a junior homonym of G. complanata (Reuss). Ten Dam (1947) renamed the species, G. berthelini, not realizing that Keller (1935) had done so previously. Malapris (1965) placed G. berthelini (Keller) in synonomy with G. intermedia (Berthelin). Price (1977) agreed but defined it as G. intermedia var. A which he claimed to be totally intergradational with G. intermedia s.s. However, the author believes that the spiral boss and a greater test compression serve to effectively distinguish G. berthelini from G. intermedia. Though the size of the boss is variable, the present study shows no evidence of total intergradation between the two species. G. berthelini differs from G. complanata (Reuss) by its spiral boss and lack of strongly raised dorsal and ventral sutures. It differs from G. simionescui (Neagu) by its smaller size and smaller dorsal boss.

Occurrence. G. berthelini has been widely described from the Albian to Turonian of eastern and western Europe. In the present study, the species is abundant in biofacies 2 of the New Jersey coastal plain.

Gavelinella cenomanica (Brotzen), 1945

Plate 2 figures 23-25

Cibicidoides cenomanica Brotzen 1945, Sver. Geol. Unders., ser. C, v. 396, no. 30, p. 54, pl. 2.

Gavelinella (Gavelinella) cenomanica (Brotzen) - Gawor-Biedowa 1972, Acta Paleontogr. Polonica, v. 17, pp. 126-128, pl. 17, fig 4.

Gavelinella cenomanica (Brotzen) - Price 1977, Palaeont., v. 20, p. 516, pl. 60, figs. 5,6.

Remarks. The species is easily identified by a thick, high dorsal ridge which parallels the early part of the spiral suture. Ventrally, chambers are triangular, with well-developed lamellar flaps which intersect at a very narrow umbilicus.

Occurrence. G. cenomanica has been widely reported in the upper Albian and Cenomanian of eastern and western Europe. It is the most abundant and characteristic species of biofacies 4(ac) in the Albian and Cenomanian of the Baltimore Canyon Trough.

Gavelinella dakotensis (Fox), 1954

Plate 1 figures 19-21

Planulina dakotensis Fox, 1954, USGS Prof. Pap., no. 254-E, p. 119, pl. 26, figs. 19-21.

Gavelinella dakotensis (Fox) - Eicher and Worstell 1970, Micropal. v. 16, no. 3, p. 293, pl. 5, fig. 5.

Remarks. The test is very compressed, equally biconvex and coarsely perforate. The dorsal side is evolute with initially limbate and slightly raised sutures which later become depressed. Ventral chambers are triangular, the last 3 or 4 having well-developed lamellar

flaps.

Occurrence. The species has been reported in Cenomanian and Turonian shallow-water deposits of the Western Interior Seaway and the western Atlantic margin. It is a consistent, though never abundant component of biofacies 1 in the New Jersey coastal plain.

Gavelinella minima (Vieux), 1941

Plate 5 figures 10-12

Discorbis minima Vieux 1941, J. Paleon., v. 15, no. 6, p. 627, pl. 85, fig. 10.

Gavelinella aff. tormarpensis Brotzen - Malapris 1965, Rev. Micropal., v. 8, pp. 146-148, pl. 3, figs. 5,6.

Remarks. The test is very compressed. The slightly convex dorsal side is evolute and imperforate with sutures which are initially flush, then depressed. The ventral side is moderately concave and perforate.

Occurrence. G. minima was originally described from Albian carbonaceous shales of Texas. It is abundant in biofacies DSA in the COST B2 well, indicative of early Turonian dysaerobic environments. The species is also rarely present in the New Jersey coastal plain.

Gavelinella monterelensis (Marie), 1941

Plate 2 figures 14,15

Anomalina monterelensis Marie 1941, C.R. Somm. Soc. Geol. France, v. 8, p. 43, pl. 37, figs. 3,4.

Gavelinella monterelensis (Marie) - Hofker 1956, Copenh.

Univ. Zool. Mus. Spolia (Skrift.), v. 15, p. 29, pl. 3, fig. 60.

Remarks. The species is chiefly characterized by a large umbilical plug, part of thickened umbilical border from which extend strongly curved, limbate sutures. The dorsal side is marked by a central boss of variable size.

Occurrence. G. monterelensis has been described from the Cenomanian and Turonian of north west Europe, the Caribbean and western Atlantic margin. It is common in middle neritic biofacies 3 as well as rarely occurring in inner neritic facies of the New Jersey coastal plain.

Gavelinella pazdroae (Gawor-Biedowa), 1972

Plate 4 figures 17-19

Lingulogavelinella pazdroae Gawor-Biedowa 1972, Acta Palaeontogr. Polonica, v. 17, pp. 112-114, pl. 14, fig. 6.

Gavelinella sp. C Gradstein 1978, Init. Repts. DSDP, v. 44, p. 674, pl. 7, figs. 14-16.

Gavelinella pazdroae (Gawor-Biedowa) - Moullade 1984, 2nd Int. Symp. Benthic Foram. (Pau), p. 452, pl. 5, figs. 14-16.

Remarks. The test is plano-convex, the flat, perforate ventral side marked by a large, flat umbilical node. The highly convex dorsal side is imperforate and nearly involute, commonly with a small central boss.

Gawor-Biedowa (1972) originally placed the species in Lingulogavelinella because most of the chambers possess well-developed umbilical flaps. However, as these flaps do not cover the umbilicus, the species should be assigned to

the genus Gavelinella. G. pazdroae somewhat resembles G. monterelensis but can be distinguished by its plano-convex shape, flat umbilical node and imperforate dorsal side.

Occurrence. The species was originally described from Albian to Turonian deep-water sediments of the Carpathian Mountains. It was subsequently reported from bathyal and abyssal DSDP sites of the North and South Atlantic. In the present study, G. pazdroae is highly characteristic of bathyal paleodepths in biofacies 6 as well as rarely occurring in abyssal sediments.

Gavelinella plummerae (Tappan), 1940

Plate 2 figures 11-13

Anomalina plummerae Tappan 1940, J. Paleon., v. 14, no.2, p. 124, p. 14, fig. 15.

Gavelinella plummerae (Tappan) - Eicher and Worstell 1970, Micropal. v. 16, no.3, p. 293, p..6, figs. 4,5.

Remarks. The most characteristic feature of the species is a very large spiral boss which covers all earlier whorls. Ventrally, G. plummerae resembles G. monterelensis (Marie) but shows a much smaller umbilical node. G. simionescui (Neagu) differs by having a larger test and a smaller spiral boss which does not completely cover earlier whorls.

Occurrence. G. plummerae has been reported from Albian to Turonian neritic facies of the Western Interior Seaway, the western Atlantic margin and western Europe. In

the present study, the species consistently occurs from inner to outer neritic paleodepths but is common only in middle neritic biofacies 3 in the Oxly, Shell 272 and COST B2 wells.

Gavelinella tormarpensis Brotzen, 1942

Plate 5 figures 7-9

Gavelinella tormarpensis Brotzen 1942, Sver. Geol. Unders., ser. C, v. 396, p. 52, pl. 1, fig. 6.

Gavelinella tormarpensis Brotzen - Malapris 1965, Rev. Micropal., v. 8, no. 3, p. 148, pl. 4. figs. 1-4.

Remarks. The species is very similar to G. minima (Vieux) but differs by having fewer chambers in the final whorl (5-7) which rapidly increase in size, a more strongly concave ventral side, and a coarsely perforate dorsal surface.

Occurrence. G. tormarpensis has been previously reported only from the Albian of north-west Europe. On the New Jersey continental margin, it is extremely abundant in biofacies DSA in lower-Turonian carbonaceous shales of the COST B2 well and also occurs rarely in the New Jersey coastal plain.

Gavelinella aff. nelsoni

Plate 2 figures 4-6

Remarks. Specimens assigned to this species are near homeomorphs to G. nelsoni (W. Berry) of the Campanian and

Maastrichtian. It differs slightly by having a lower ventral convexity, a more angular early periphery and only slightly depressed ventral sutures.

Occurrence. G. aff. nelsoni is one of the most abundant species of the Albian and Cenomanian of the New Jersey coastal plain and is the most characteristic species of biofacies 2.

Genus LINGULOGAVELINELLA Malapris, 1965

Lingulogavelinella ciryi Malapris, 1968

Plates 3 figures 8-10

Lingulogavelinella ciryi Malapris 1968, Rev. Micropal. v. 10, no. 2, p. 137, pl. 1, fig. 16-19; pl. 1, figs. 16-20.

Remarks. The species can easily be distinguished from all others of the genus by its very compressed test, numerous globular chambers which increase slowly in size and completely evolute dorsal side.

Occurrence. Originally described in neritic deposits of the Paris Basin, L. ciryi is a consistent, though never abundant component of biofacies 5 in the COST B2 and Shell 586 wells.

Lingulogavelinella frankei (Bykova), 1953

Plate 3 figures 8-10

Valvulineria frankei Bykova 1953, VNIGAZ, Trudy, pp. 81,82, pl. 9, fig. 6.

Lingulogavelinella albiensis Malapris forme annoncant l'espece frankei (Bykova) - Malapris 1968, Rev. Micropal.,

v. 10, no. 2, pp. 133,124, pl. 1, figs. 10-13; pl. 2, figs.11-13.

Lingulogavelinella frankei (Bykova) - Scheibnerova 1971, Micropal. v. 17, no. 1, pp. 111,112, text-figs. 2,3; pl. 1, figs. 1-11.

Remarks. The dorsal side is concave and involute with curved, strongly depressed sutures. The ventral side is convex with large, well-developed lamellar flaps which entirely cover the umbilicus. The periphery is rounded and lobate.

Occurrence. L. frankei has been reported from the Albian of western and eastern Europe and the eastern North Atlantic and the Albian and Cenomanian of Australia. It is abundant in biofacies 5, especially in outer-neritic deposits in the Shell 272 and COST B2 wells.

Lingulogavelinella globosa (Brotzen), 1945

Plate 3 figures 11-13

Anomalinoides globosa Brotzen 1945, Sver. Geol. Unders., ser. C., v. 471, no. 38, pp 55,56, pl. 2, fig. 6.

Orostella turonica Butt 1966, Micropal., v. 12, p. 180, pl. 3, fig. 6; pl. 4, fig. 4.

Remarks. L. globosa is similar to L. frankei (Bykova) but can be distinguished by its biumbilicate test and semi-evolute dorsal side.

Occurrence. Very widely reported from eastern and western Europe, L. globosa is also very abundant in biofacies 5 in the lower Turonian in the COST B2 and Shell 272 wells.

?Lingulogavelinella newtoni Eicher and Worstell, 1970

Plate 3 figures 24-26

Lingulogavelinella newtoni Eicher and Worstell 1970, Micropal., v. 16, no. 3, p. 294, pl. 5, figs 2-4.

?Conorbina newtoni (Eicher and Worstell) - McNulty 1984, Init. Repts. DSDP, v. 75, p. 556, pl. 2, figs. 4,5; pl. 3, figs. 18-20.

Remarks. Lamellar umbilical flaps are present but do not completely cover the narrow umbilicus. Eicher and Worstell (1970) did not believe the lack of a closed umbilicus was sufficient reason to exclude the species from Lingulogavelinella. However, in addition, ?L. newtoni is extremely convex dorsally whereas all other lingulogavelinellids have very low trochospires. Therefore the author believes the generic assignment to be questionable but the small number of specimens recovered prevents any definite conclusions.

Occurrence. The species has been described from relatively deep-water facies of the Western Interior Seaway and bathyal sediments of the eastern North Atlantic. In the present study, ?L. newtoni is relatively rare but persistent in biofacies 6 in the Turonian in the Shell 586 and 587 wells.

Lingulogavelinella spinosa (Plotnikova), 1962

Plate 3 figures 21-23

Cibicides (Cibicides) spinosus Plotnikova, Geol. Zurnal, v. 22, p. 54, pl. 2, fig. 4.

Lingulogavelinella spinosa (Plotnikova) - Gawor-Biedowa 1972, Acta Palaeontogr. Polonica, v. 17, pp. 114,115, pl. 18, fig. 1.

Remarks. The ventral side is flat with closely-spaced, pointed lamellar flaps. The dorsal side is convex and involute. Sutures on both sides of the test are highly raised and limbate and the surface is coarsely perforate.

Occurrence. L. spinosa has previously been reported only from the Albian and Cenomanian of Poland and the Soviet Union. It is common in biofacies 5 in the Shell 586 well but becomes rarer in the COST B2 and Shell 272 wells. It thus apparently is most characteristic of well oxygenated environments of the upper slope.

REFERENCES

Arthur, M. A., 1979, North Atlantic Cretaceous black shales: The record at Site 398 and a brief comparison with other occurrences; in Sibuet, J. C., Ryan, W. B. F. et al., Init. Repts. DSDP, v. 47, pt. 2: Washington (U. S. Govt. Printing Office) p. 729-751.

_____, Schlanger, S. O., and Jenkyns, H. C., 1987, The Cenomanian-Turonian oceanic anoxic event, II. Palaeoceanographic controls on organic-matter production and preservation; in Brooks, J. and Fleet, A. J., Marine petroleum source rocks, Geol. Soc. Spec. Pub. no. 26, p. 401-420.

Bandy, O. L., 1960, General correlation of foraminiferal structure with environment, Int. Geol. Congr., Copenhagen, 21st Sess., Rep. 22, p. 7-19.

Benson, R. N., 1984, Structure contour map of pre-Mesozoic basement, landward margin of Baltimore Canyon Trough, Delaware Geol. Survey, miscellan. map series, no. 2.

Bernhard, J. M., 1986, Characteristic assemblages and morphologies of benthic foraminifera from anoxic, organic-rich deposits: Jurassic through Holocene, J. Foram. Res., v. 16, no. 3, p. 207-215.

Bond, G.C., and Kominz, M.A., 1984, Construction of tectonic subsidence curves for the early Paleozoic miogeocline, southern Canadian Rocky Mountains: Implications for subsidence mechanisms, age of breakup, and crustal thinning, GSA Bulletin, v. 95, p. 155-173.

Brass, G. W., Southan, J. R., and Peterson, W. H., 1982, Warm saline bottom water in the ancient ocean, Nature, v. 296, p. 620-623.

Butt, A. A., 1966, Foraminifera from the type Turonian, Micropal., v. 12, no. 2, p.168-182.

Corliss, B. H. and Chen, C., 1988, Morphotype patterns of Norwegian Sea deep-sea benthic foraminifera and ecological implications, Geology, v. 16, no. 8, p. 716-710.

Culver, S. J., and Buzas, M. A., 1973, Benthic Foraminifera at the shelfbreak: North American Atlantic and Gulf margins; in Stanley, D. J. and Moore, G. T., The

Shelfbreak: Critical Interface on Continental Margins, S.E.P.M. Spec. Pub. no. 33, p. 359-371.

Cunningham, R. and Gilbert, D., 1985, Organic facies of Cenozoic and Cretaceous sediments from DSDP Sites 548 to 551, northern North Atlantic; in Graciansky, P. C. de, Poag, C. W., et al., Init. Repts. DSDP, v. 80: Washington (U. S. Govt. Print. Off.), p. 969-982.

Davis, J. C., 1986, Statistics and data analysis in geology, John Wiley and Sons: New York, 646 pp.

Doyle, J. A., and Robbins, E. I., 1977, Angiosperm pollen zonation of the continental Cretaceous of the Atlantic coastal plain and its application to deep wells in the Salisbury embayment, Palynology, v.1, p. 43-78.

Dow, W. G., 1978, Geochemical analysis of samples from Holes 391A and 391C, Leg 44: Blake Bahama Basin; in Benson, W. E., Sheriden, R. E., et al., Init. Repts. DSDP, v. 44: Washington (U. S. Govt. Print. Off.), p. 625-634.

Eicher, D. L. and Worstell, P., 1970, Cenomanian and Turonian foraminifera from the Great Plains, United States, Micropal., v. 16, no. 3, p. 269-324.

Gawor-Biedowa, E., 1972, The Albian, Cenomanian and Turonian foraminifera of Poland and their stratigraphic importance, Acta Paleontogr. Polon., v. 17, p. 1-155.

Gibson, T. G., and Buzas, M. A., 1973, Species diversity patterns in modern and Miocene foraminifera of the eastern margin of North America, G.S.A. Bull., v. 84, p. 217-238.

Graciansky, P. C. de, Poag, C. W., et al., 1985, Site 550, Init. Repts. DSDP, v. 80: Washington (U. S. Govt. Print. Off.), p. 288-289.

Gradstein, F. M., 1978, Biostratigraphy of Lower Cretaceous Blake Nose and Blake-Bahama Basin foraminifers, DSDP Leg 44, Western North Atlantic Ocean; in Benson, W. E., Sheridan, R. E., et al., Init. Repts. DSDP, v. 44: Washington (U. S. Govt. Print. Off.), p. 663-701.

Grow, J. A., 1981, Structure of the Atlantic Margin of the United States; in Geology of passive continental margins: history, structure and sedimentologic record (with special emphasis on the Atlantic margin),

A.A.P.G. Education Course Note Series, no. 19, p. 3-1 to 3-41.

Haq, B.U., Hardenbol, J., and Vail, P. R., 1987, Chronology of fluctuating sea levels since the Triassic, Science, v. 235, p. 1156-1167

Hart, M., 1984, The Superfamily Robertinacea in the Lower Cretaceous of the United Kingdom and adjacent areas of north-west Europe; in Oertli, H. J., (ed.), Benthos '83 - 2nd Int. Symp. Benthic Foram., Esso REP and Total CFP: Pau and Bordeaux, p. 289-298.

_____, and Bigg, P. J., 1981, Arenaceous foraminifera from Late Cretaceous "anoxic events" in north-west Europe; in Verdenius, J. G., van Hinte, J. E., and Fortuin, A. R. (eds.), Proc. 1st Workshop Aren. Foram., Cont. Shelf Inst.: Trondheim, Norway, p. 89-90.

Jannin, F., 1967, Les Valvulineria des l'Albien de l'Aube, Rev. Micropal., v. 10, p. 153-178.

Jansa, L., Gardner, J. F., and Dean, W. E., 1977, Mesozoic sequences of the central North Atlantic; in Lancelot, Y., Seibold, E., et al., Init. Repts DSDP, v. 41: Washington (U. S. Govt. Print. Off.), p. 991-1032.

_____, Enos, P., Tucholke, B. E., Gradstein, F. M., and Sheridan, R. E., 1980, Mesozoic-Cenozoic sedimentary formations of the North American Basin; western North Atlantic, Amer. Geophys. Union; Maurice Ewing Series, v. 3, p. 1-57.

Kaminski, M. A., 1985, Evidence for control of abyssal agglutinated foraminiferal structure by substrate disturbance: results from the HEBBLE Area, Mar. Geol., v. 66, p. 113-131.

_____, and Schroder, C. J., 1987, Environmental analysis of deep-sea agglutinated foraminifera: can we distinguish tranquil from disturbed enviroments?, in Innovative biostratigraphic approaches to sequence analysis: new exploration opportunities, G.C.S.S.E.P.M. Found. 8th Ann. Res. Conf., p. 90-93.

_____, Grassle, J. F., and Whitlatch, R. D., 1987, Life history and recolonization among agglutinated foraminifera in the Panama Basin, Proc. 2nd Int. Workshop Agglut. Foram., Vienna, Austria, p. 113-123.

Katz, M. E., and Thunell, R. C., 1984, Benthic foraminiferal biofacies associated with middle Miocene to early Pliocene oxygen-deficient conditions in the eastern Mediterranean, J. Foram. Res., v. 14, no. 3, p. 187-202.

Krashenninikov, V. A., 1974, Upper Cretaceous benthonic agglutinated foraminifera, Leg 27, DSDP; in Veevers, J. J., Heirtzler, J. R., et al., Init. Repts. DSDP, v. 27: Washington (U. S. Govt. Print. Off.), p. 631-662.

Laughton, A. S., Berggren, W. A., 1972, Site 111, Init. Repts. DSDP, v. 12: Washington (U. S. Govt. Print. Off.), p. 77-78.

Leckie, R. M., 1984, Mid-Cretaceous planktonic foraminiferal biostratigraphy off central Morocco, Deep Sea Drilling Project Leg 79, Sites 545 and 547; in Hinz, K., Winterer, E. L., et al., Init. Repts. DSDP, v. 79: Washington (U. S. Govt. Print. Off), p. 579-620.

Libby-French, J., 1984, Lithostratigraphy of Shell 272-1 and 273-1 wells: implications as to depositional history of Baltimore Canyon Trough, Mid-Atlantic OCS, A.A.P.G. Bull., v. 65, p. 1476-1484.

Magniez, F., and Sigal, J., 1985, Barremian and Albian Foraminifera, Site 549, Leg 80; in Graciansky, P. C., de, Poag, C. W., et al., Init. Repts. DSDP, v. 80, pt. 1: Washington (U. S. Govt. Print. Off.), p. 601-628.

Malapris, M., 1965, Les Gavelinellidae et formes affines du gisement Albien de Courcelles (Aube), Rev. Micropal., v. 8, no. 3, p. 132-150.

Malapris-Bizouard, M., 1967, Les Lingulogavelinelles de l'Albien inferieur et mogen de l'Aube, Rev. Micropal., v. 10, p. 128-150.

Moullade, M., 1984, Interet des petits foraminiferes benthiques "profounds" pour la biostratigraphie et l'analyse des paleoenvironments oceaniques Mesozoiques, Benthos '83, 2nd Int. Symp. Benthic Foram, Esso REP and Total CFP: Pau and Bordeaux, p. 429-464.

Nyong, E. E., and Olsson, R. K., 1984, A paleoslope model of Campanian to lower Maestrichtian Foraminifera in the North American Basin and adjacent continental margin, Marine Micropal., v.8, p. 437-477.

Ohm, U., 1967, Zur kenntnis der Gottungen Reinholdella, Garantella, und Epistomina (Foraminifera), Paleontogr., Abt. A., v. 127, p. 103-188.

Olsson, R. K., 1977, Mesozoic Foraminifera - western Atlantic, in Swain, F. M. (ed.), Stratigraphic micropaleontology of the Atlantic Basin and Borderlands, Elsevier: Amsterdam, p. 205-229.

_____, 1984, Paleoslope models of Foraminiferans, 27th Int. Geol. Congr., Moscow, U.S.S.R., abstr. with progr., p. 188.

_____, and Nyong, E. E., 1984, A paleoslope model for Campanian-lower Maestrichtian Foraminifera of New Jersey and Delaware, J. Foram. Res, v. 14, no. 1, p. 50-68.

_____, Melillo, A. J. and Schreiber, B. L., 1987, Miocene sea level events in the Maryland coastal plain and the offshore Baltimore Canyon Trough, Cush. Found. Foram. Res. Spec. Pub., no. 24, p. 85-97.

_____, and Wise, Jr., S. W., 1987, Upper Paleocene to middle Eocene depositional sequences and hiatuses in the New Jersey Atlantic margin, Cush. found. Foram. Res. Spec. Pub., no. 24, p. 99-111.

_____, Gibson, T. G., Hansen, H. J., and Owens, J. P., 1988, Geology of the northern Atlantic coastal plain: Long Island to Virginia; in Sheridan, R. E., and Grow, J. A., (eds.), The Geology of North America, the Atlantic Cont. Margin, U. S., v. I-2, G.S.A.: Boulder, Co., p. 87-105.

Parker, F. L., 1954, Distribution of the foraminifera in the northeastern Gulf of Mexico, Bull. Mus. Comp. Zool., Harvard, v. 111, p. 454-547.

Pessagno, Jr., E. A., 1967, Upper Cretaceous planktonic Foraminifera from the western Gulf Coastal Plain, Palaeontogr. Amer., v. 5, no. 37, p. 243-445.

Petters, S. W., 1976, Upper Cretaceous subsurface stratigraphy of the Atlantic coastal plain of New Jersey, A.A.P.G. Bull., v. 60, p. 87-107.

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

Phillips, F.J., 1985, CHECKLIST II - For Entry and Presentation of Population Data, F.J. Phillips: Golden, Co.

Phleger, F. G., 1956, Significance of living foraminiferal populations along the central Texas coast, Cush. Found. Foram. Res. Spec. Pub, no. 7, p. 106-151.

Pitman, W. C., III, 1978, Relationship between eustacy and stratigraphic sequences of passive margins, G.S.A. Bull., v. 89, p. 1389-1403.

Price, R. J., 1977, The evolutionary interpretation of the Foraminiferida Arenobulimina, Gavelinella, and Hedbergella in the Albian of north-west Europe, Paleontology, v. 20, p. 503-527.

Roberts, D. G., and Montadert, L., 1979, Margin paleoenvironments of the northeast Atlantic; in Montadert, L., Roberts, D. G., et al., Init. Repts. DSDP, v. 48: Washington, (U. S. Govt. Print. Off.), p. 1099-1118.

Romesburg, H. C., 1984, Cluster Analysis for Researchers, Lifetime Learning Pub.: Belmont, Ca., 334 pp.

Scheibnerova, V., 1974, Aptian-Albian benthonic foraminifera from DSDP Leg 27, Sites 259, 269 and 263, eastern Indian Ocean; in Veevers, J. J., Heirtzler, J. R., et al., Init. Repts. DSDP, v. 27: Washington (U. S. Govt. Print. Off.), p. 697-741.

Schlanger, S. O., Arthur, M. A., Jenkyns, H. C., and Scholle, P. A., 1987, The Cenomanian-Turonian oceanic anoxic event, I. Stratigraphy and distribution of organic carbon-rich beds and the marine delta carbon-13 excursion, in Brooks, J., and Fleet, A. J., Marine Petroleum Source Rocks, Geol Soc. Spec. Pub. no. 26, p. 371-399.

Sheridan, R. E., Enos, P. and Gradstein, F., 1978, Mesozoic and Cenozoic sedimentary environments of the western North Atlantic; in Benson, W. E., Sheridan, R. E., et al., Init. Repts. DSDP, v. 44: Washington (U. S. Govt. Print. Off.), p. 971-980.

Sibuet, J. C., Ryan, W. B. F., et al., 1979, Site 398, Init. Repts. DSDP, v. 47, pt. 2: Washington (U. S. Govt. Print. Off.), p. 579-583.

Sliter, W. V., 1977, Cretaceous benthic foraminifers from the western South Atlantic Leg 39, Deep Sea Drilling Project; in Supko, P. R., Perch-Nielsen, K., et al., Init. Repts. DSDP, v. 39: Washington, (U. S. Govt. Print. Off.), p. 657-697.

_____, 1980, Mesozoic foraminifers and deep-sea benthic environments from Deep Sea Drilling Project Sites 415 and 416, eastern North Atlantic; in Lancelot, Y., Winterer, E. L., et al., Init. Repts. DSDP, v. 50: Washington (U. S. Govt. Print. Off.), p. 353-428.

Steckler, M.S., and Watts, A.B., 1978, Subsidence of the Atlantic-type continental margin off New York., Earth Planet. Sci. Letters, v. 41, p. 1-13.

_____, Watts, A.B., and Thorne, J.A., 1988, Subsidence and basin modeling at the U.S. Atlantic passive margin; in Sheridan, R.E., and Grow, J.A., eds., The Atlantic Continental Margin, U.S.: GSA, The Geology of North America, v. I-2., pp. 399-416.

Tappan, H., 1957, New Cretaceous index foraminifera from northern Alaska, U. S. Nat. Mus. Bull., no. 215, p. 201-222.

Thiede, J., and van Andel, T. H., 1977, The paleoenvironment of anaerobic sediments in the late Mesozoic South Atlantic Ocean, Earth Planet. Sci. Letters, v. 33, p. 301-309.

Tucholke, B. E. and Vogt, P. R., 1979, Western North Atlantic: Sedimentary evolution and aspects of tectonic history; in Tucholke, B. E. and Vogt, P. R., et al., Init. Repts DSDP, v. 43: Washington (U. S. Govt. Print. Off.), p. 791-826.

Vail, P. R., Mitchum, R. M., Jr., and Thompson, S., III, 1977, Seismic stratigraphy and global changes of sea level, part 4: global cycles of relative changes of sea level, A.A.P.G. Mem., no. 26, p. 83-97.

_____, Hardenbol, J., and Todd, R.G., 1985, Jurassic unconformities, chronostratigraphy and sea level changes from seismic stratigraphy and biostratigraphy; in Schlee, J.S., ed., Interregional unconformities and hydrocarbon accumulation, AAPG Memoir 36, p. 129-144.

Walton, W. R., 1964, Recent foraminiferal ecology and paleoecology; in Imbrie, J., and Newell, N. D.,

(eds.), Approaches to Paleoecology, John Wiley and Sons: New York, p. 93-114.

Watts, A. B., 1981, The U. S. Atlantic continental margin: subsidence history, crustal structure and thermal evolution; in Bally, A. W., (ed.), Geology of passive continental margins, A.A.P.G. Ed. Course Note Series, no. 19, p. 2-1 to 2-75.

_____, 1982, Tectonic subsidence, flexure and global changes of sea level, Nature, v. 297, p. 469-474.

Wilkinson, L., 1986, SYSTAT: The system for statistics, SYSTAT Inc.: Evanston, Il.

Winterer, E. L., and Hinz, K., 1984, The evolution of the Mazagan continental margin: a synthesis of geophysical and geological data with results of drilling during Deep Sea Drilling Project Leg 79; in Hinz, K., Winterer, E. L., et al., Init. Repts. DSDP, v. 79: Washington (U. S. Govt. Print. Off.), p. 893-922.

Wise, S. W., Jr., and van Hinte, J. E., 1987, Mesozoic-Cenozoic depositional environments revealed by Deep Sea Drilling Project Leg 93 drilling on the continental rise off the eastern United States: cruise summary; in van Hinte, J. E., Wise, S. W., Jr., et al., Init. Repts. DSDP, v. 93, pt. 2: Washington (U. S. Govt. Print. Off.), p. 1367-1423.

PLATE 1
(all figures magnified X90
unless otherwise noted)

Figures		Page
	Biofacies 1 and 1*	
1-3	Ceratobulimina parva Eicher and Worstell - X120 - 1) dorsal view; 2) side view; 3) ventral view - Oxly (1780-1810).	182
4-6	Epistomina chapmani Ten Dam - 4) dorsal view, Oxly (2380-2390); 5) ventral view, Oxly (2360-2370); 6) side view, BTMA (1400-10).	182
7-9	Epistomina cf. hechti - 7) dorsal view, Oxly (2510-20); 8) side view, BTMA (1760-70); 9) ventral view, BTMA (1840-50).	185
10-12	Epistomina aff. stelligera - 10) dorsal view, Oxly (1870-1900); 11) ventral view, Oxly (2020-50); 12) side view, Oxly (2120-30).	186
13-15	Epistomina stelligera s.s. (Reuss) - 13) dorsal view, Oxly (1870-1900); 14) side view, Oxly (1930-60); 15) ventral view, Oxly (1750-80).	184
16-18	Epistomina aff. ripleyensis - 16) ventral view; 17) dorsal view; 18) side view - Oxly (1930-60).	186
19-21	Gavelinella dakotensis (Fox) - X120 - 19) dorsal view, Oxly (2080-90); 20) side view, Oxly (1840-70); 21) ventral view, Oxly (1690-1720).	199
22-24	Epistomina charlottae Vieux - X120 - 22) dorsal view; 23) side view; 24) ventral view - DSDP 402A-13-2.	183
25-27	Epistomina cf. chapmani (Hart) - 25) dorsal view; 26) side view; 27) ventral view - Oxly (2190-2200).	185

PLATE 2
(all figures magnified X120
unless otherwise noted)

Figures		Page
	Biofacies 1* cont.	
1	Spirillina minima Schacko - X180 - DSDP 402A-13-2.	178
2,3	Patellina subcretacea Dieni and Massari - X180- 2) dorsal view; 3) ventral view - DSDP 402A-13-2.	178
	Biofacies 2	
4-6	Gavelinella aff. nelsoni - 4) dorsal view; 5) ventral view; 6) side view - BTMA (1400-10).	203
7-9	Gavelinella berthelini (Keller) - 7) dorsal view, Oxly (2350-60); 8) side view, Oxly (2110-20); 9) ventral view, Oxly (2130-40).	197
	Biofacies 3	
10	Eggerellina mariae Ten Dam - X180 - Oxly (1690-1720).	172
11-13	Gavelinella plummerae (Tappan) - 11) dorsal view, Oxly (1810-20); 12) side view, Shell 586 (8420-50); 13) ventral view, BTMA (1840-50).	202
14,15	Gavelinella monterelensis (Marie) - 14) side view; 15) ventral view - BTMA (1300-10).	200
16-18	Globorotalites rumanus Neagu - 16) ventral view, X90; 17) apertural view; 18) side view - Shell 272 (6860-80).	193
19,20	Neobulimina aff. albertensis - 19) serial view; 20) closeup of early chambers showing papillose wall ornamentation, X480 - Oxly (2430-40).	187

Plate 2 cont.

Biofacies 4t (also includes O. utaturensis - plate 4)

21	Dorothia oxycona (Reuss) - DSDP 547B-3-5.	176
22	Spiroplectinata capitosa (Cushman) - X42 - Shell 272 6840-60).	174

Biofacies 4ac

23-25	Gavelinella cenomanica (Brotzen) - X90 - 23) ventral view; 24) side view; 25) dorsal view - COST B2 (7730-40).	198

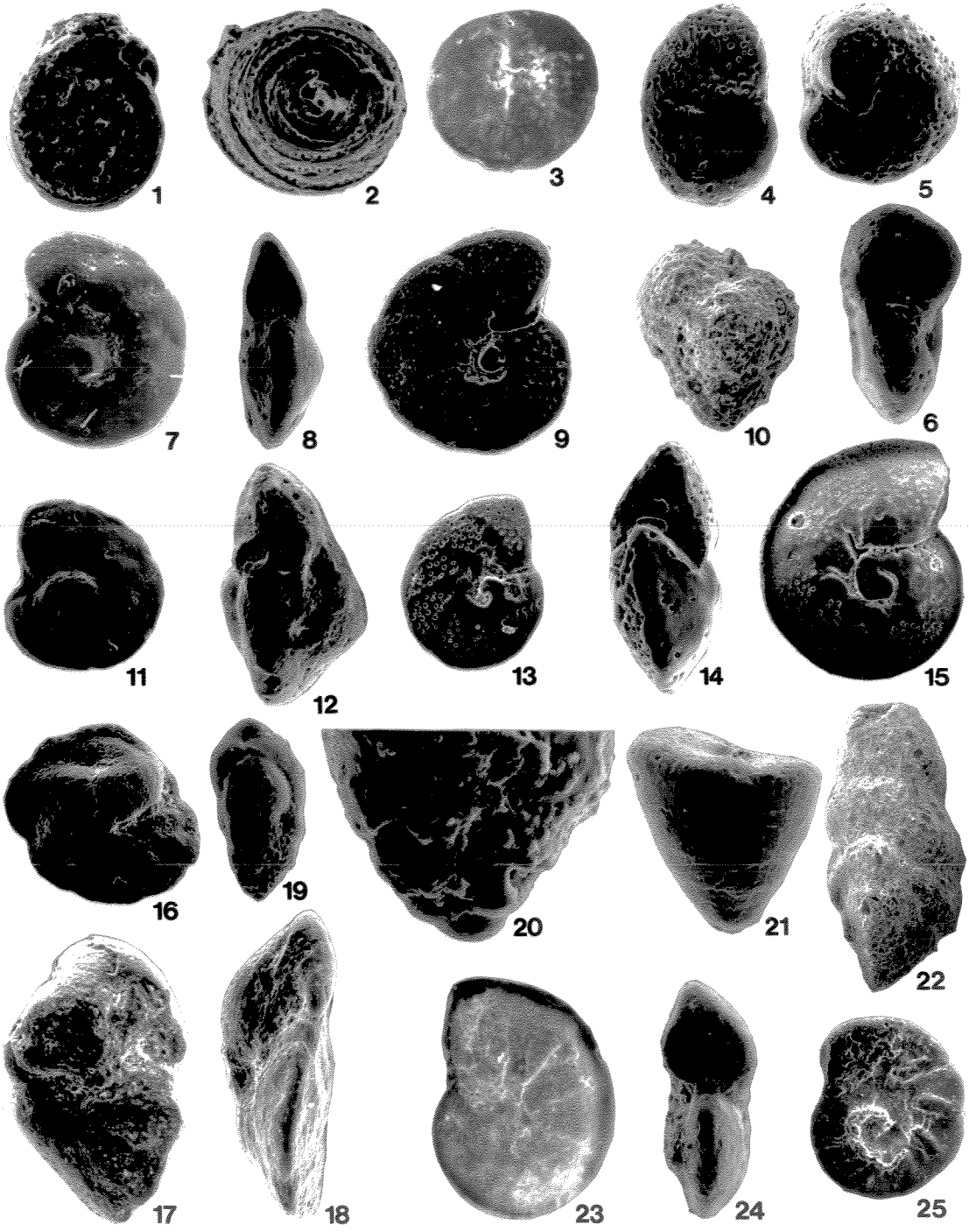

1
2
3
4
5
7
8
9
10
6
11
12
13
14
15
16
19
20
21
22
17
18
23
24
25

PLATE 3
(all figures magnified X120
unless otherwise noted)

Figures		Page
	Biofacies 4ac cont.	
1-3	Valvulineria parva Khan - 1) dorsal view, Oxly (2120-30); 2) side view, Oxly (2130-40); 3) ventral view, Oxly (2310-20).	191
4-6	Gyroidinoides sp. 2 (Jannin) - 4) dorsal view; 5) side view; 6) ventral view - Oxly (1690-1720).	196
7	Gaudryina cushmani Tappan - X60 - Shell 272 (7090-7120).	175
	Biofacies 5	
8-10	Lingulogavelinella frankei (Bykova) - 8) ventral view, Shell 586 (8480-8510); 9) side view, Shell 586 (8630-60); 10) dorsal view, Shell 586 (8780-8800).	204
11-13	Lingulogavelinella globosa (Brotzen) - 11) dorsal view, COST B2 (7610-20); 12) side view, Shell 272 (6860-80); 13) ventral view, BTMA (1460-70).	205
14,15	Lenticulina munsteri (Roemer) - X30 - 20) planispiral view, COST B2 (8250-60); 21) side view, Oxly (1810-40).	180
16-18	Lingulogavelinella ciryi Malapris - 16) dorsal view, Shell 272 (7180-7210); 17) side view, Shell 272 (7030-60); 18) ventral view, Shell 586 (8570-8600).	204
19,20	Lenticulina secans (Reuss) - X24 - 22) planispiral view, Oxly (2390-2400); 23) side view, Oxly (2360-70).	181
21-23	Lingulogavelinella spinosa (Plotikova) - 21) dorsal view; 22) side view; 23) ventral view - Shell 586 (8630-60).	206

Plate 3 cont.

Biofacies 6

24-26 ?Lingulogavelinella newtoni Eicher and Worstell - 24) dorsal view, Shell 586 (8060-90); 25) side view, Shell 586 (8030-60); ventral view, Shell 586 (8090-8210). 206

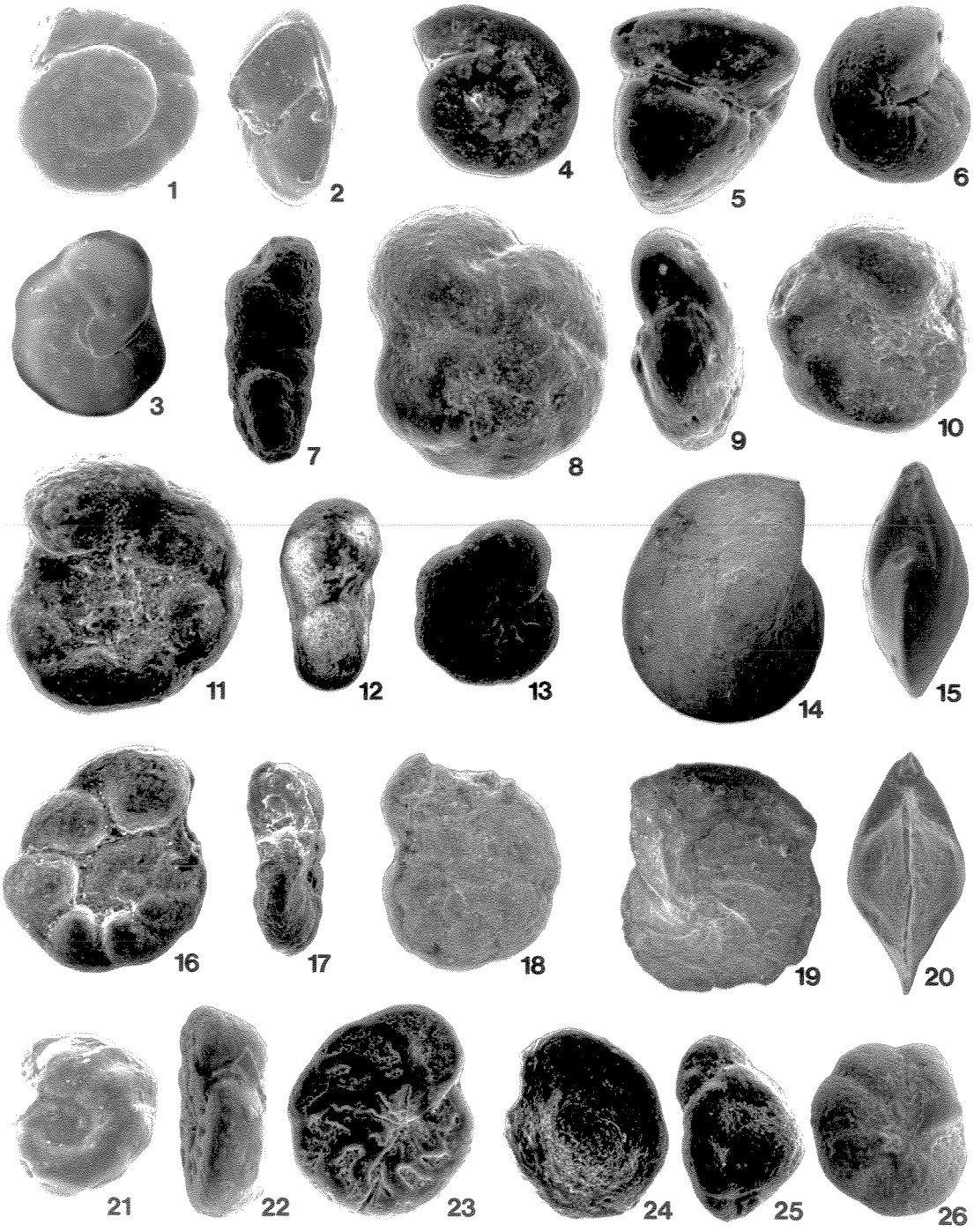

1
2
4
5
6
3
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

PLATE 4
(all figures magnified X120
unless otherwise noted)

Figures		Page
	Biofacies 6 cont.	
1,2	Hyperammina gaultina Ten Dam - 1) fragment of irregular tubular chamber, X90, DSDP 550B-21-1; 2) fragment with intact proloculus, Shell 587 (9990-10020).	166
3	Praebulimina evexa (Loeblich and Tappan) - X150 - Shell 586 (8450-60).	187
4,5	Praebulimina nannina (Tappan) - 4) triserial view, X360; 5) closeup of mound-like pore structures, X1620 - Shell 586 (8090-8120).	188
6	Quinqueloculina antiqua Franke - DSDP 547A-45-3.	179
7	Pleurostomella obtusa Berthelin - DSDP 390-4-2.	189
8	Pleurostomella reussi Berthelin - DSDP 390-4-2.	189
9-11	Osangularia insigna Dailey - 9) dorsal view, Shell 586 (8080-8120); 10) side view, Shell 586 (8120-50); 11) ventral view, Shell 586 (8270-8300).	194
12-14	Osangularia utaturensis (Sastri and Sastry) - 12) dorsal view, DSDP 137-9-5; 13) side view, DSDP 390-3-3; 14) ventral view, DSDP 390-3-3.	195
15,16	Quadrimorphina allomorphinoides (Reuss) - 15) dorsal view, Shell 586 (8180-8210); 16) ventral view, Shell 586 (8210-40).	192
17-19	Gavelinella pazdroae (Gawor-Biedowa) - 17) dorsal view, DSDP 137-16-3; 18) side view, DSDP 398D-61-2; 19) ventral view, DSDP 137-16-3.	201

Plate 4 cont.

	Biofacies 7	
20	Spiroplectammina anceps (Reuss) - DSDP 137-11-4.	170
21	Eggerellina sp. 1 Moullade - DSDP 137-16-3.	173
22-24	?Eponides sp. - 22) dorsal view; 23) side view; 24) ventral view - DSDP 137-16-3.	192
25-26	Gaudryina pulvina Belford - 25) specimen illustrating tendency of abyssal agglutinate species in calcareous sediments to construct tests composed of coccolith plates, X90; 26) closeup of wall structure, X3000 - DSDP 137-9-5.	____

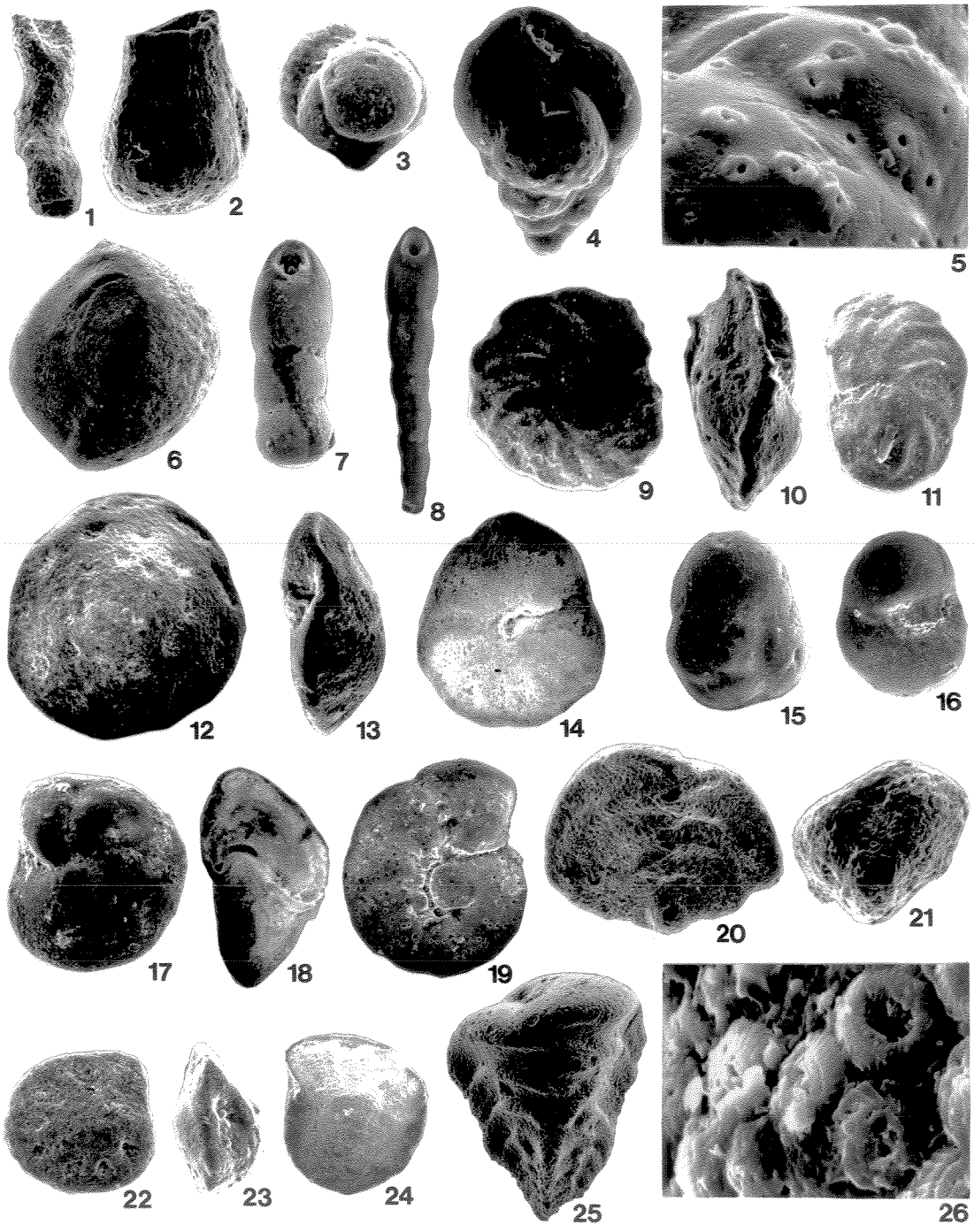

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

PLATE 5
(all figures magnified X120
unless otherwise noted)

Figures		Page
	Biofacies 7 cont.	
1,2	Pseudopatellinella rumana Neagu - X300 - 1) dorsal view; 2) ventral view - DSDP 137-10-2.	190
3,4	Osangularia brotzeni (Gandolfi) - 3) ventral view; 4) side view - DSDP 137-9-5.	194
	Biofacies DSA	
5	Trochammina rainwateri Cushman and Applin - dorsal view - Shell 272 (6880-6900).	171
6	Trochammina wickendeni Loeblich - dorsal view - COST B2 (8130-40).	171
7-9	Gavelinella tormarpensis Brotzen - 7) dorsal view; 8) side view; 9) ventral view - Oxly (1750-80).	203
10-12	Gavelinella minima (Vieux) - 10) dorsal view; 11) side view; 12) ventral view - Oxly (1750-80).	200
	Biofacies DSB	
13	Karreriella conversa (Grzybowski) - X90 - Shell 586 (8240-70).	177
14	Uvigerinammina jankoi Majzon - Shell 586 (8060-90).	173
15,16	Recurvoides deflexiformis (Noth) - 15) streptospiral view showing nearly planispiral last whorl; 16) apertural view - Shell 587 (10080-110).	168
17,18	Recurvoides subturbinatus (Grzybowski) - 17) apertural view; 18) streptospiral view - Shell 586 (8060-90).	169

Plate 5 cont.

19 Haplophragmoides cf. menitens Krasheninnikov - Shell 586 (8060-90). 168

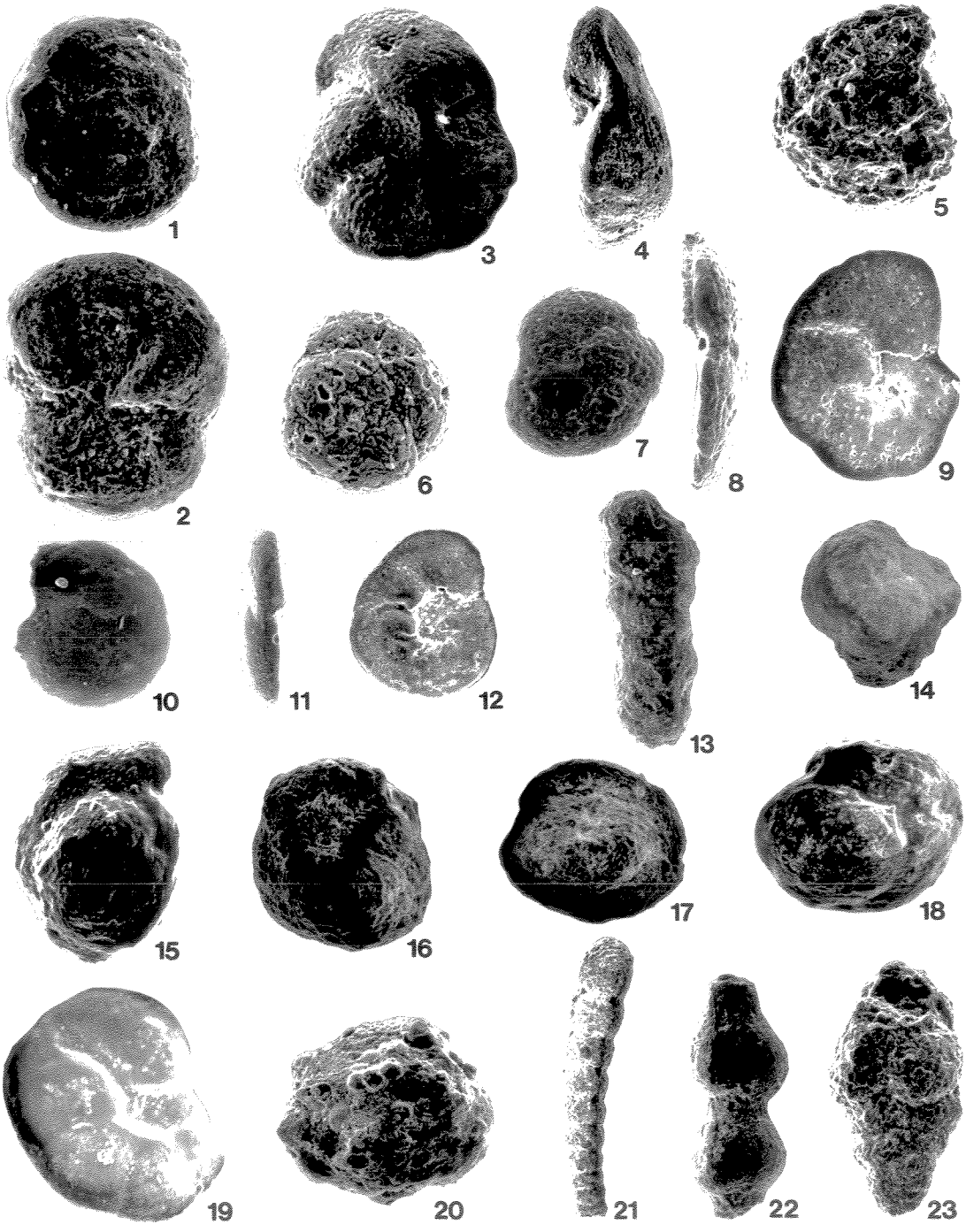
Biofacies DAA

20 Psammosphaera scruposa (Berthelin) - Shell 587 (10410-40). 165

21 Reophax pepperensis Loeblich - X48 - Shell 587 (10320-50). 167

22 Reophax guttifera Brady - Shell 587 (10410-40). 166

23 Verneuilinoides borealis Tappan - X90 - Shell 587 (10230-60). 174


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

VITA

1958	Born February 23 in Pottsville, Pennsylvania
1976	Graduated from Nativity B.V.M. Senior High School, Pottsville, Pennsylvania
1976-81	Attended Pennsylvania State University, University Park, Pennsylvania
1981	B.S., Earth Science; B.A., History, Pennsylvania State University
1981-84	Graduate work in Geological Sciences, University of Texas at Austin
1981-83	Teaching Assistant, Department of Geological Sciences, University of Texas at Austin
1984	M.A., Geological Sciences, University of Texas at Austin
1985	Attended University of Wyoming, Laramie, Wyoming
1985	Micropaleontologic consultant, Biostrat Inc., Laramie, Wyoming
1985-89	Graduate work in Geological Sciences, Rutgers University, New Brunswick, New Jersey
1985-89	Graduate Assistant, Department of Geological Sciences, Rutgers University
1989	Ph.D., Geological Sciences, Rutgers University