Environmental distribution of Recent benthic foraminifera on the northeast United States continental slope

KENNETH G. MILLER *Woods Hole Oceanographic Institution/Massachusetts Institute of Technology Joint Program in Oceanography, Woods Hole, Massachusetts 02543*
G. P. LOHMANN *Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543*

ABSTRACT

Several bathymetrically consistent Recent benthic foraminiferal biofacies have been recognized from the continental slope southeast of Cape Cod. Faunal assemblages are dominated by *Globobulimina/Bulimina* (upper slope; less than 1,000 m) and *Uvigerina peregrina* (lower slope–uppermost rise; water depths between 1,000 and 2,500 m). The *Globobulimina/Bulimina* assemblage coincides with the oxygen minimum zone; this agrees with the occurrence of *Globobulimina* in Mediterranean sapropels, organic-rich sediments deposited under anoxic conditions. Previous studies have noted the association of *U. peregrina* with bathyal water depths, deep-water temperatures of 3 to 4 °C, and water of low oxygen content. However, correlations between abundance of *U. peregrina* and water depth or temperature are not the same everywhere, and no correlation with dissolved oxygen in the water column is seen on the United States continental slope and rise. The highest abundances of *U. peregrina* coincide with maxima of organic carbon and silt within the slope sediments. This suggests that the distribution of *U. peregrina* in this region may be influenced more by low oxygen in the sediments, rather than by low oxygen content of the overlying water.

INTRODUCTION

Benthic foraminifera have been used widely to typify water depths of modern marine environments and to derive paleodepths which are useful in understanding eustatic sea-level changes, paleobiogeography, and other geologic problems. Recent studies, however, correlate abundances of deep-sea benthic foraminifera with physical and chemical properties of water masses (T, S, O_2), properties that may vary spatially and temporally independently of water depth (Streeter, 1973; Streeter and Shackleton, 1979; Schnitker, 1974, 1979, 1980; Lohmann, 1978; Corliss, 1979). We examined benthic foraminifera from the northeast United States continental margin southeast of Cape Cod and compared their distribution with hydrographic and substrate data in order to evaluate correlations between water mass and benthic foraminifera.

Two distinct biofacies occur on the continental slope: a *Globobulimina/Bulimina* assemblage and an *Uvigerina peregrina* Cushman assemblage. Prior to this study, the species *U. peregrina* has been used both as a depth and a water-mass marker (Streeter, 1973; Lohmann, 1978; Streeter and Shackleton, 1979; Schnitker, 1979, 1980). Our faunal, hydrographic, and sedimentary substrate analyses from the northeast continental margin of the United States show that the *Globobulimina/Bulimina* assemblage is associated locally with low oxygen in the water column, but that abundant *U. peregrina* is not correlated with water-mass distribution or bathymetry. Instead, we find evidence that *U. peregrina* is correlated with maxima of organic carbon and silt in the substrate.

PREVIOUS WORK

Cushman's (1918–1923) early study of Atlantic foraminifera contained samples from the northeast United States continental slope. Subsequently, Phleger (1942), Parker (1948), Streeter (1973), and Schnitker (1974, 1979) have examined Recent benthic foraminifera from this region. These studies have established that *Globobulimina* spp. and *U. peregrina* are abundant in the slope sediments.

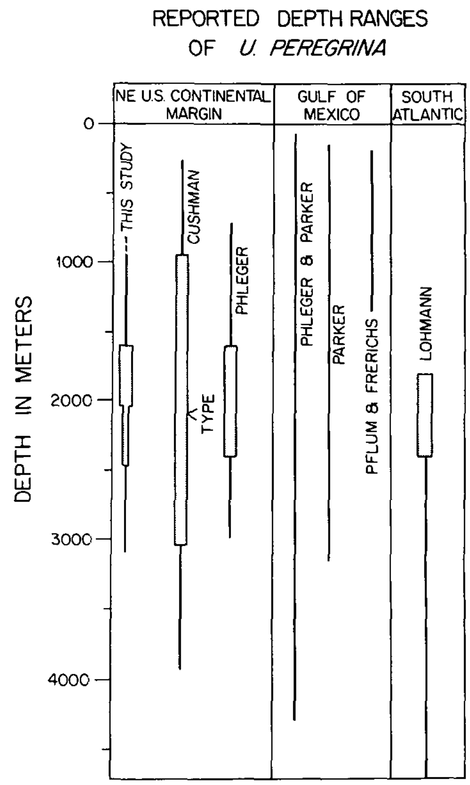


Figure 1. Comparison of reported depth ranges of *Uvigerina peregrina* for various regions; stippled areas represent greatest abundances (data from Cushman, 1918–1931; Phleger, 1942; Phleger and Parker, 1951; Parker, 1954; Pflum and Frerichs, 1976; Lohmann, 1978). The depth of occurrence of Cushman's type specimen from northeastern United States continental slope is indicated with an arrow.

This article is based on a paper that was presented at a symposium entitled "Quaternary Benthic Foraminifera of North American Continental Margins," held in November 1980.

Geological Society of America Bulletin, v. 93, p. 200–206, 1 pl., 6 figs., 1 table, March 1982.

Globobulimina has been reported from low-oxygen environments. Mullineaux and Lohmann (1981) have shown that *Globobulimina affinis* (d'Orbigny) occurs immediately below, above, and occasionally within Mediterranean Quaternary sapropels, black organic-rich sediments inferred to have been deposited under anoxic conditions.

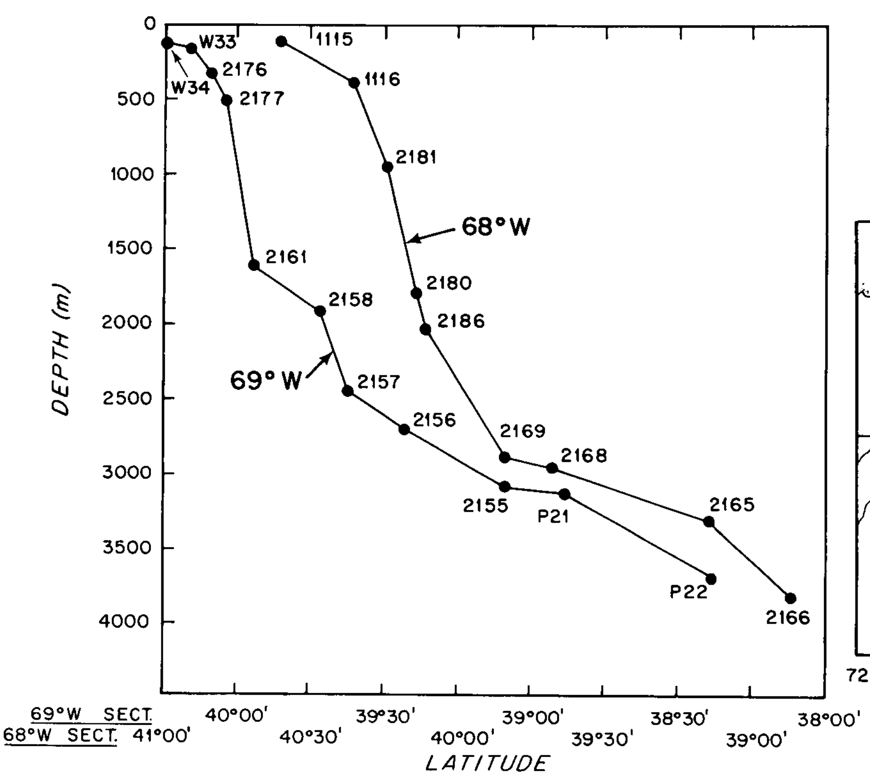
U. peregrina was first described from the northeast continental slope of the United States (Cushman, 1918–1923); its abundance has been correlated with depth zones in this region and in the Gulf of Mexico (Phleger, 1942, 1960; Parker, 1948, 1954; Phleger and Parker, 1951; Pflum and Frerichs, 1976). In general, the presence of *U. peregrina* has been used as an indicator of bathyal depths (Bandy, 1960). Within the northeast continental margin, the range of *U. peregrina* has been reported from a consistent depth interval (~ 1,000 to 3,000 m; Cushman, 1923; Phleger, 1942; Streeter and Lavery, 1979; this study). Studies from other regions, however, have shown that interregional correlations of this species with depth are not maintained (Fig. 1).

TABLE 1. SAMPLE LOCATIONS, PERCENT *U. PEREGRINA*, AND PERCENT ORGANIC CARBON

Sample	Designation	Depth	Location	Relative percent *U. peregrina*	Total no. benthic foraminifera counted
	69° W section				
1	W-34	111m	40° 15′N 68° 50′W	0	291
2	W-33	154	40° 09′N 68° 50′W	0	111
3	2176	320	40° 05′N 68° 44′W	0	97
4	2177	505	40° 01′N 68° 56′W	0	99
5	2161	1625	39° 56′N 68° 51′W	86	126
6	2158	1925	39° 43′N 69° 06′W	90	182
7	2157	2460	39° 37′N 68° 54′W	53	127
8	2156	2695	39° 25′N 69° 00′W	7	96
9	2155	3080	39° 05′N 68° 59′W	1	161
10	P-21	3128	38° 53′N 68° 59′W	0	102
11	P-22	3687	38° 23′N 68° 56′W	0	133
	68° W section				
12	1115	124m	40° 31′N 67° 46′W	0	152
13	1116	382	40° 21′N 67° 48′W	0	104
14	2181	940	40° 14′N 67° 46′W	31	173
15	2180	1813	40° 08′N 67° 45′W	81	233
16	2186	2035	40° 06′N 67° 30′W	80	142
17	2169	2870	39° 50′N 67° 41′W	2	100
18	2168	2950	39° 41′N 67° 59′W	2	114
19	2165	3300	39° 09′N 68° 09′W	0	106
20	2166	3820	38° 52′N 67° 52′W	0	100

Note: Designation refers to WHOI/USGS Continental Margin Program sample number (Hathaway, 1971).

In the North Atlantic, previous investigators reported the restriction of *U. peregrina* to temperatures from ~ 3 to 4 °C and used the record of this species in deep-sea cores to infer that bottom waters warmed during Pleistocene ice ages (Streeter, 1973; Schnitker, 1974). *U. peregrina* in the South Atlantic, however, is associated with water temperature < 3 °C (Lohmann, 1978), showing that, as with its correlation with water depth, the *U. peregrina*-temperature correlation is also not maintained from region to region. Lohmann, however, noted a close coincidence of maximum relative abundances of *U. peregrina* (~ 20%) with low dissolved oxygen in the overlying water (< 5 ml/l). Streeter and Shackleton (1979) sub-



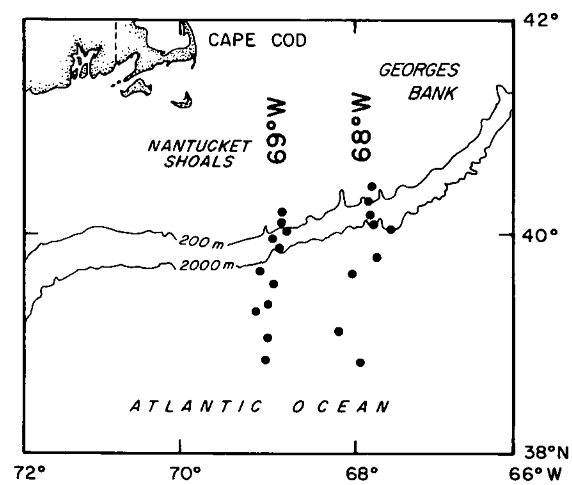


Figure 2. Locations of samples used in this study. The samples were from two traverses across the continental margin. Sample numbers refer to Hathaway (1971) and Table 1.

sequently showed a correlation of *U. peregrina* with similar low values of dissolved oxygen between 2,000 and 4,000 m in the North and South Atlantic. Schnitker (1979, 1980) also suggested that this species prefers waters low in dissolved oxygen. In the Gulf of Mexico, *U. peregrina* is found in the oxygen minimum zone, supporting the correlation between low oxygen in the water column and abundant *U. peregrina* in the sediments (Pflum and Frerichs, 1976). The correlation of this species with low oxygen was used to infer lowered oxygen content of glacial deep waters in the Pleistocene North Atlantic (Streeter and Shackleton, 1979).

METHOD

Twenty grab samples from two meridional sections off the continental margin southeast of Cape Cod were selected from the collection of the Woods Hole Oceanographic Institution–United States Geological Survey Continental Margin Program (68° W, 69° W; water depths between 111 and 3,820 m; Fig. 2). Sediment descriptions (Hathaway, 1971) and hydrographic data (R/V *Crawford,* 128, June 1965; unpub. data, Woods Hole Oceanographic Institution) from this region were compared with the benthic foraminiferal distributions.

Approximately 100 benthic foraminifera (> 250 μm) were counted from aliquots of the 20 surface grab samples. Although there is indication of downslope movement of some material, displaced shallow-water contaminants form a very small fraction (< 2%) of each sample. The faunal trends are nearly identical between our two transects.

Plate 1.

Upper row: Neritic assemblage

Figure 1. *Cibicidoides mediocris* (Finlay)
Sample 1115 ×105

Figure 2. *Islandiella californica* (Cushman and Hughes)
Sample 2176 ×125

Figure 3. *Bulimina marginata* (d'Orbigny)
Sample W-34 ×90

Figure 4. *Cibicides lobatulus* (Walker and Jacob)
Sample 2166 ×40

Middle row: Upper bathyal *Globobulimina/Bulimina* assemblage

Figure 5. *Globobulimina* sp.
Sample 2157 ×80

Figure 6. *Bulimina aculeata* (d'Orbigny)
Sample 2177 ×85

Figure 7. *Martinottiella nodulosus* (Cushman)
Sample 2177 ×20

Figure 8. *Globobulimina* sp.
Sample 2157 ×80

Lower row: *Uvigerina*:

Neritic:

Figures 9, 10. *Uvigerina juncea* (Cushman and Todd)
9. Sample W-34 ×80
10. Sample W-34 ×145

Bathyal:

Figures 11, 12. *Uvigerina peregrina* (Cushman)
11. Sample 2180 ×125
12. Sample 2180 ×85

Abyssal:

Figures 13, 14 *Uvigerina* sp.
13. Sample 2166 ×60
14. Sample 2166 ×65

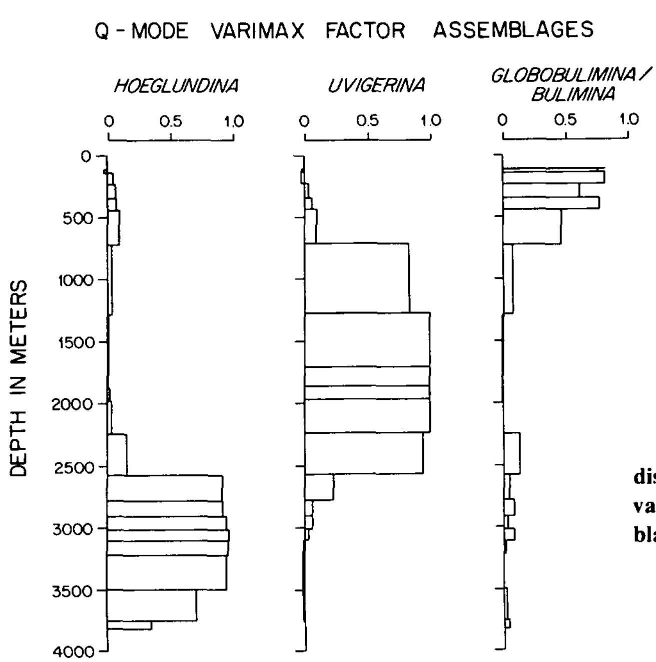
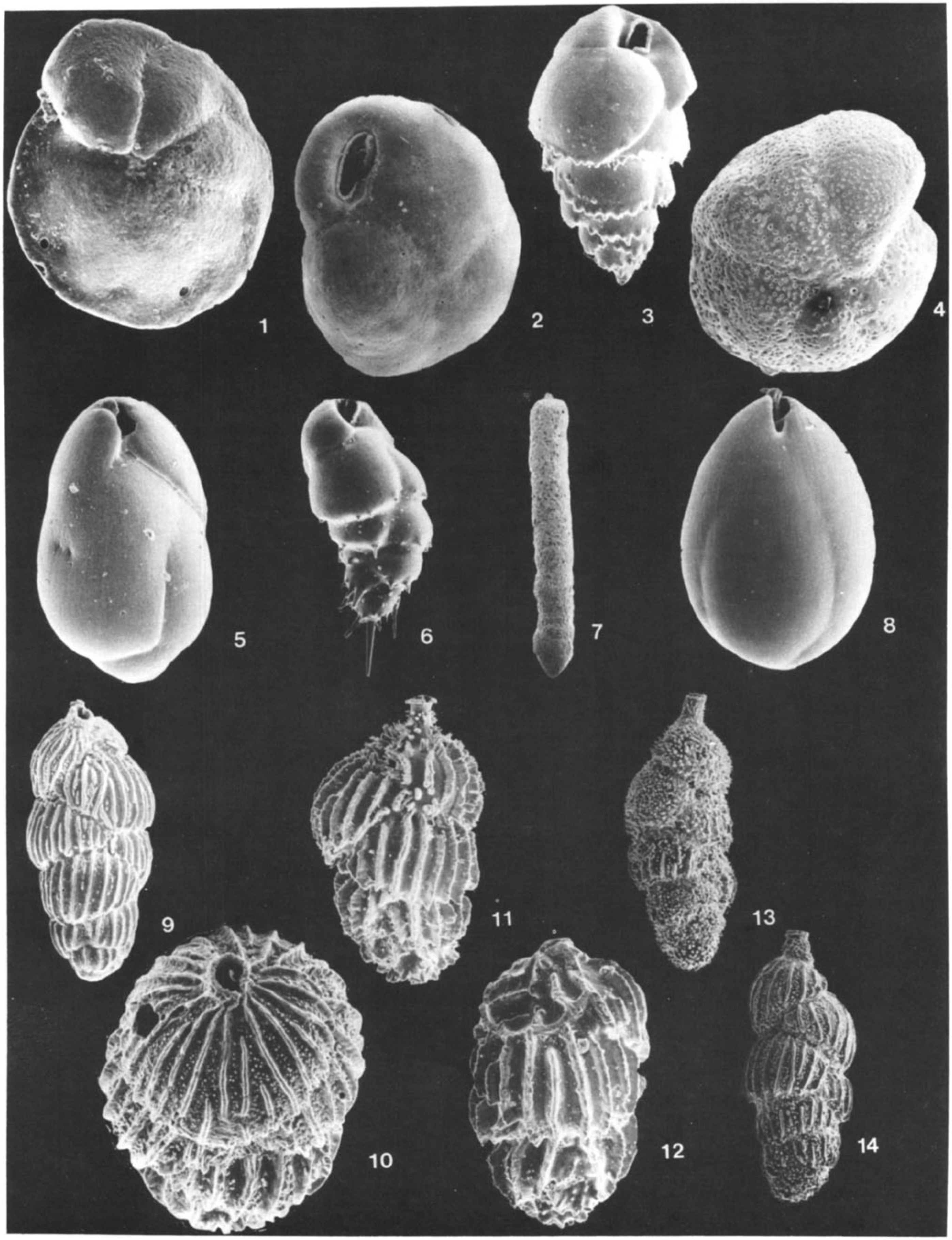


Figure 3. Bathymetric distributions of Q-mode varimax factor assemblages.

In addition, the core-top studies of Phleger (1942) and Streeter and Lavery (1979) have shown that the same regionally depth-consistent benthic foraminiferal assemblages occur in the continental margin from Cape Hatteras to Cape Cod. This consistency of faunal distribution within and between studies in this region suggests that reworking does not obscure a widespread faunal pattern. (See Table 1.)

The consistency of the faunal patterns within and between studies suggests that the samples are of the same age. Downcore glacial-interglacial changes occur in benthic foraminifera in the North Atlantic, including the northeast United States continental slope (Streeter, 1979; Schnitker, 1974, 1979; Streeter and Lavery, 1980). If glacial sediments were locally reworked, a mixed pattern of benthic foraminifera could be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expected. In addition, we note the presence of "warm-water" planktonic foraminifera in our samples (including abundant *Globorotalia menardii* complex and rare pink *Globigerinoides ruber*). As the region of our study was dominated by subpolar planktonic foraminifera during the last glaciation (McIntyre and others, 1976), these "warm-water" forms indicate that our samples are of an interglacial age. Although we acknowledge the possibility that the faunal patterns are relict, we regard this as unlikely.

RESULTS

Both principal component and factor analyses were used to help delineate the benthic foraminiferal biofacies in our samples. Q-mode varimax factor 1 is dominated by *Hoeglundina elegans* (d'Orbigny) and is restricted to the continental rise (Fig. 3). Factor 2 is dominated by *Uvigerina peregrina* and is found on the middle to lower slope and uppermost rise. Factor 3 is dominated by *Globobulimina* spp. and *Bulimina* spp.; it may be subdivided into an outer-shelf *Bulimina marginata* (d'Obigny)/*Cibicidoides mediocris* (Finlay) assemblage and an upper-slope *Globobulimina* spp./*Bulimina aculeata* d'Orbigny assemblage (Pl. 1.)

Globobulimina spp. (including *G. affinis*) and *Bulimina aculeata* dominate the benthic foraminiferal fauna in samples ranging in water depth from 352 to 505 m. This interval coincides with the oxygen minimum zone, supporting Mullineaux and Lohmann's (1981) postulated association of *G. affinis* with low oxygen or anoxic sediments. *B. aculeata* is restricted to these upper bathyal water depths; however, abundant *Globobulimina* spp. also occur in several samples from the continental rise (in the *Hoeglundina* assemblage; ~ 2,500 to 3,500 m). Unfortunately, our sample coverage is insufficient to precisely determine the bathymetric range of the *Globobulimina*/*Bulimina* assemblage and its transition to the *U. peregrina* assemblage (no samples obtained between 505 and 940 m).

Uvigerina peregrina dominates the benthic foraminiferal fauna in samples from both transects between water depths of 940 and 2,460 m (25% to 90% of benthic foraminifera; Fig. 4). Although we examined a larger size-fraction, these observations are similar to those of Phleger (1942) and Streeter and Lavery (1979), who reported abundances of *U. peregrina* greater than 60% at water depths between 1,000 and 2,500 m from Cape Cod to Cape Hatteras.

Water temperatures over this depth interval agree with those in which *U. peregrina* is found in other areas of the North Atlantic (Streeter, 1973). Potential temperatures are 3 to 3.5 °C, salinities are 34.95 to 34.97 ‰, dissolved oxygen is 6.1 to 6.2 ml/l, and silicate is between 12.5 and 20 μg-atom/l.

Samples with the highest percentages (> 80%) of *U. peregrina* come from relatively isohaline (34.95 ± .01%) water between 1,625 and 2,035 m, where dissolved oxygen content is also nearly constant (6.1 to 6.2 ml/l). This depth interval is below the secondary silicate minimum (13.5 to 18 μg-atom/l; 500 to 1,500 m) and the oxygen minimum (~ 3 ml/l; 150 to 425 m). For our data, peak abundances of *U. peregrina* correlate only with maximum organic carbon (> 1.0%) and silt content (> 60%) of the sediments (Fig. 4).

DISCUSSION

The depth distribution of *Uvigerina peregrina* on the northeast continental margin differs from previously reported distributions in the South Atlantic, Gulf of Mexico, and the North Atlantic (Fig. 1). Thus, although this species may have a depth-consistent distribution regionally, it occurs at different depths in different regions.

We agree with Streeter's (1973) observation that in the North Atlantic *U. peregrina* is most abundant in waters with potential temperatures of 3 to 4 °C. However, Lohmann (1978) documented high relative abundances of *U. peregrina* in waters colder than 3 °C from the South Atlantic, and Streeter and Shackleton (1979) suggested that this species was associated with glacial bottom waters colder than 3 °C. These observations show that the correlation between water depth or temperature and relative abundances of *U. peregrina* is not

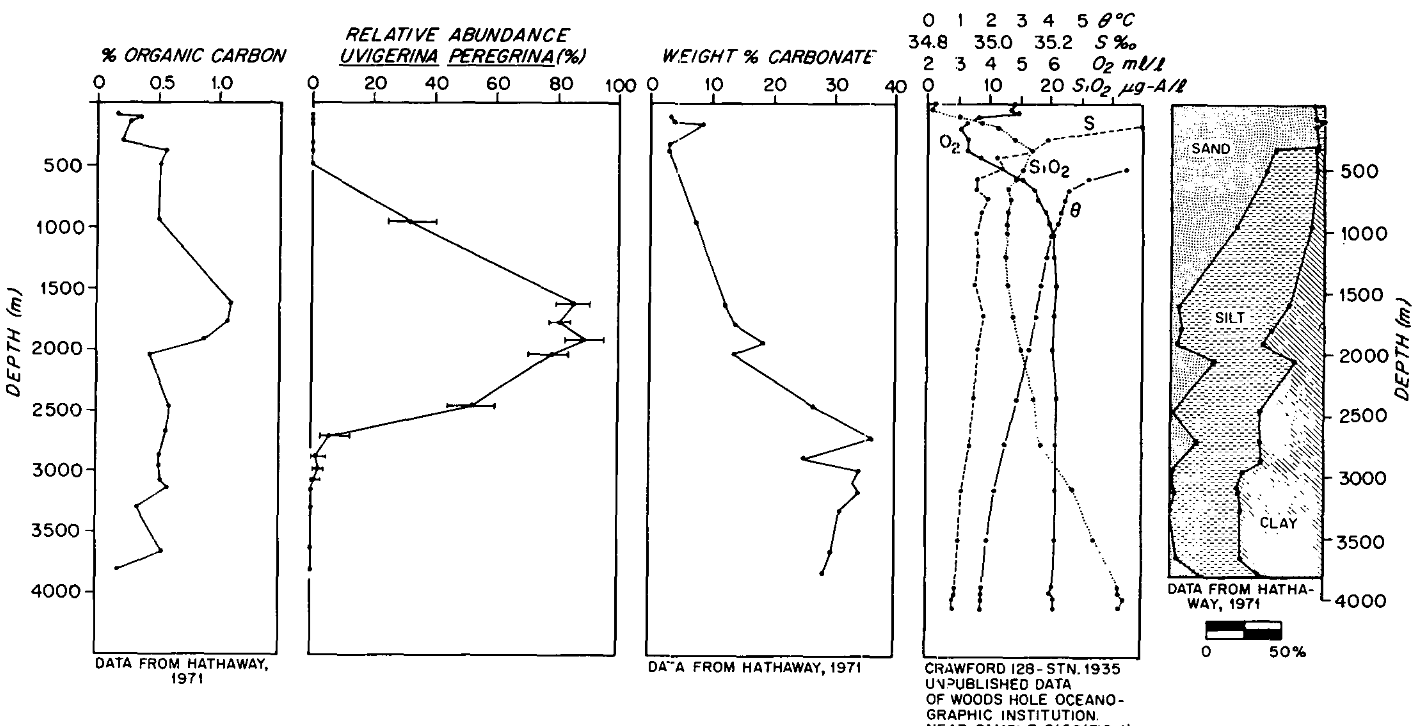

Figure 4. Comparison of distribution of *U. peregrina* with sedimentary substrate and hydrographic data. 95% confidence limits for percentage of *U. peregrina* are shown.

consistent either spatially or temporally, and suggest that the distribution of *U. peregrina* is controlled by some property other than, but sometimes locally correlated with, temperature.

The reported correlation of *U. peregrina* with low oxygen is not unique, for other environmental properties covary with oxygen. Dissolved phosphate and nitrate are generally inversely correlated with oxygen (Sverdrup and others, 1942). Also, low-oxygen values in the water column are often associated with high organic carbon in the substrate (Calvert, 1964; Fischer and Arthur, 1977). However, southeast of Cape Cod, organic carbon in the sediment does not covary with oxygen in the water column. This allows us to independently compare variations in sediment organic carbon and oxygen of overlying waters with abundance of *U. peregrina.*

Comparison of the relative abundance of *U. peregrina* with measured carbon, carbonate, and silt content of the sediment, and with salinity, oxygen, silicate, and potential temperature measured in the water column (Fig. 4), shows that high (> 80%) relative abundances of *U. peregrina* correspond only to high percentages of organic carbon and silt. No correlation is found between low oxygen and abundance of *U. peregrina.* This is not attributable to regional or seasonal variations in oxygen content in the water column, for the depth of the oxygen minimum (between 150 and 425 m) and the constant, high values below are regionally and seasonally consistent (comparison of 20 R/V *Crawford* 128 hydrographic stations made southeast of Cape Cod, June 1965, and nearby stations made August 1969, October 1969, and February 1967, at 39° N, 70° W; unpub. data, Woods Hole Oceanographic Institution; see also Emery and Uchupi, 1972, p. 303). This is consistent with the weak correlation between this species and oxygen found in the Indian Ocean (Corliss, 1979).

Previous studies have shown that the continental slope sediments north of Cape Hatteras have high silt (> 50%) content (Hollister, 1973; Doyle and others, 1979) and that the middle to lower continental slope sediments have abundant organic carbon content (> 1.0%; Doyle and others, 1979; Rowe and Haedrich, 1979; Premuzic, 1980). We note similar high values of carbon and silt on the continental slope (Figs. 4 and 6). Our samples show a strong correlation between abundance of *U. peregrina* and organic carbon and silt (Figs. 5 and 6).

In our study, therefore, abundance of *U. peregrina* correlates with organic carbon in the sediments and not with dissolved oxygen in the water column. However, this does not completely rule out the suggestion that high abundances of *U. peregrina* in the study area may result from low dissolved oxygen. The high organic content of the sediments may result in low-oxygen interstitial waters or waters directly overlying sediments. The low oxygen levels could thus be attributable to the high organic carbon rather than to a reflection of regional hydrography.

Globobulimina spp. occurs predominantly on the upper slope associated with the oxygen minimum. Together with the reported association of *G. affinis* with sapropels (Mullineaux and Lohmann, 1981), this suggests that *Globobulimina* is tolerant of low-oxygen conditions. How-

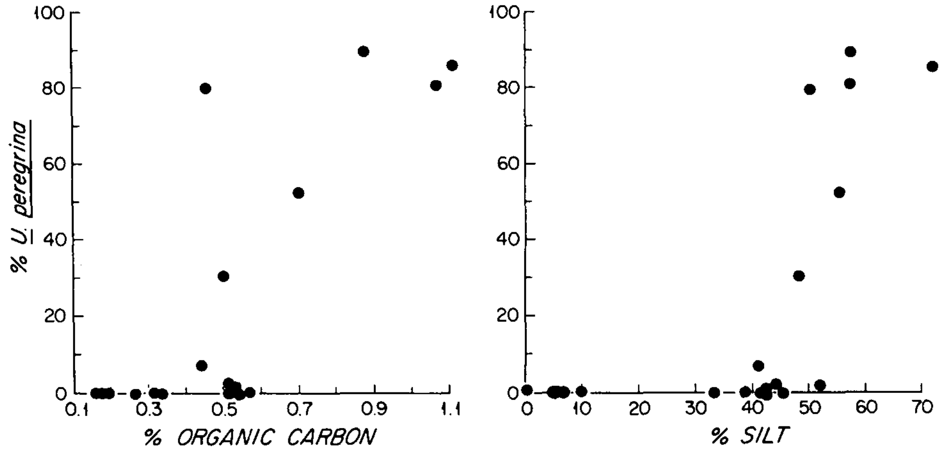

Figure 5. Percentage of *U. peregrina* versus percentage of organic carbon and percentage of silt for the samples studied. Carbon and silt values for samples are from Hathaway, 1971.

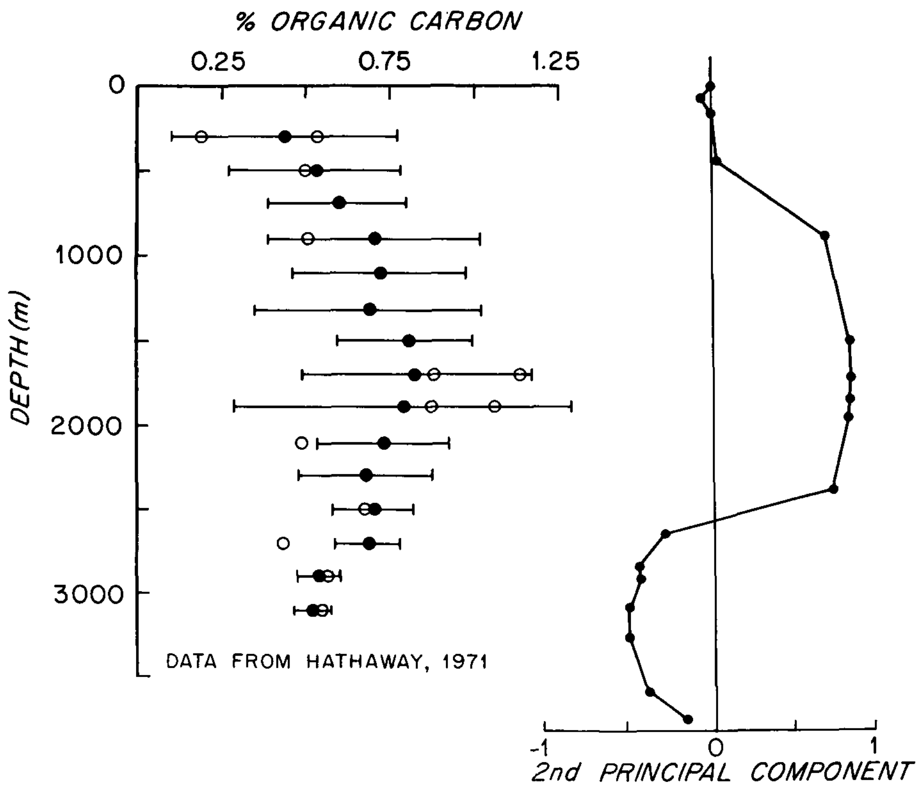

Figure 6. Percentage of organic carbon averaged in 200-m depth increments for the continental margin from New Jersey to southeast of Cape Cod (143 data points taken from Hathaway, 1971). Black dots represent mean values; open dots represent values for the samples used in this study; bar is one standard deviation. Loadings on the second principal component are plotted against the same depth scale; positive loadings correspond to higher than average abundances of *Uvigerina peregrina;* negative loadings to *Hoeglundina.*

ever, we find that a secondary maximum of this genus occurs on the continental rise and is associated with higher oxygen in the water column (>6 ml/l) and lower organic carbon in the sediments (~ 0.5%). This indicates that factors other than dissolved oxygen content of deep waters may influence the distribution of this genus. In contrast, high abundances of *Bulimina aculeata* are restricted to the oxygen minimum zones.

CONCLUSIONS

Previous studies show that the abundance of *Uvigerina peregrina* is related to depths and temperatures that differ from place to place. The reported association of relatively abundant *U. peregrina* with low oxygen (<5 ml/l) water masses is not found in the northeast continental margin from Cape Cod to Cape Hatteras. Among the seven environmental properties considered, abundant *U. peregrina* is correlated only with maximum organic carbon and silt. In such organic-rich areas, the oxygen content of the interstitial waters of the sediments and of the waters immediately overlying the sediments may be reduced. The distribution of *U. peregrina* therefore may be associated with low oxygen, but we show that it is not always related to the level of dissolved oxygen in the water column. *Globobulimina* spp. and *Bulimina acualeata* correlate with the oxygen minimum in the study area.

ACKNOWLEDGMENTS

We thank C. W. Poag, B. H. Corliss, M. L. Bremer, W. A. Berggren, and J. D. Milliman for discussions and criticisms of the manuscript. C. T. Shafer and B. K. Sen Gupta reviewed the final manuscript. Discussions with S. S. Streeter were especially useful. Ruth Todd helped us with the taxonomy of *Uvigerina.*

This work was supported by a Graduate Student Research Fellowship through the Woods Hole Oceanographic Institution Education Department and by National Science Foundation Grant OCE78-19768. Curation of the material for this study is supported by grants from both the National Science Foundation and the Office of Naval Research.

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MANUSCRIPT RECEIVED BY THE SOCIETY APRIL 15, 1981
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