

SUBSURFACE PRESERVATION OF AGGLUTINATED FORAMINIFERA IN THE NORTHWEST ATLANTIC OCEAN

by

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With 10 figures and 1 table

ZUSAMMENFASSUNG

Die sandschalige Foraminiferenfauna von den oberen 30 cm in 6 Kastengreifern, die vom Kontinentalhang vor Nova Scotia und der Nares Tiefsee-Ebene stammen, wurde qualitativ und quantitativ ausgewertet. Schwankungen in der Häufigkeit der Sandschaler stehen in einem gewissen Zusammenhang mit sedimentologischen Veränderungen. Es wird deutlich, daß sich die verschiedenen Erhaltungspotentiale der einzelnen Arten und die Verschiebungen durch Transport- und Aufarbeitungsvorgänge von Sedimenten in der Verteilung der sandschaligen Foraminiferen bemerkbar machen. Der Übergang zwischen oxydierendem und reduzierendem Milieu im Sediment ist durch einen starken Rückgang in der Anzahl der Arten, deren Gehäuse eisenhaltigen Zement besitzen, gekennzeichnet. Die gefundenen Arten wurden aufgrund ihrer Gehäusekonstruktion, Stabilität und Häufigkeit in verschiedenen Kerntiefen in 3 Gruppen eingeteilt. Diese geben ein Maß für die Wahrscheinlichkeit ihrer Erhaltung in fossilen Ablagerungen.

ABSTRACT

The vertical changes in sediment in the upper 30 cm of two box-cores from the Continental Rise off Nova Scotia and 4 box-cores from the Nares Abyssal Plain are compared with changes in the agglutinated foraminifera fauna. The effects of selective preservation of various species and shifts through transport and reworking processes are reflected in the vertical distribution of the agglutinated assemblages. A significant decrease in the abundance of species with a ferruginous cement is correlated with the transition downcore from an oxidizing to a reducing sediment. Based on test construction and depth distribution pattern, agglutinated species are ranked into three major classes reflecting fossilization potential.

INTRODUCTION

In this paper I will discuss the transition from live to dead to buried and fossilized assemblages of agglutinated foraminifera. The agglutinated component has often been ignored in studies dealing with Recent benthic deep-sea foraminifera (e.g. Streeter 1973; Lohmann 1978). The disappearance of various species below the sediment surface has been interpreted as an indication that no agglutinated forms are preserved in the fossil

record. The geological record contradicts this interpretation and as a consequence the following questions are raised:

- 1) Which factors modify the assemblage during the life stage, after death, and after burial?
- 2) How is the diversity and abundance of species influenced by these factors? and
- 3) Which specific components of the modern fauna will survive fossilization?

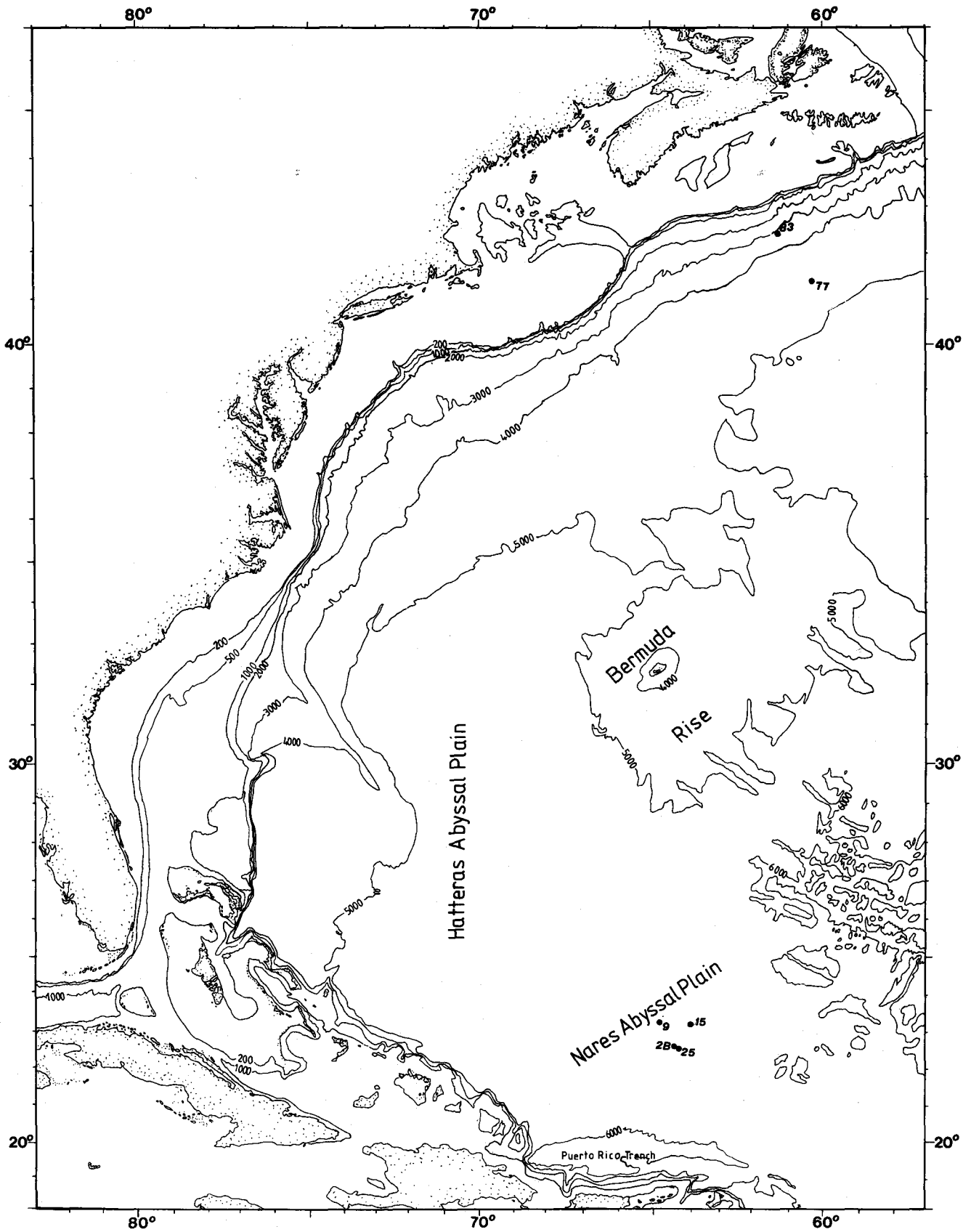


Fig. 1.
Index map of stations investigated.
Numbers refer to stations of two cruises (see table 1). Depth contours in meters. Bathymetry after "General Bathymetric Chart of the Oceans" (GEBCO), Canadian Hydrographic Service, Ottawa.

The suggested factors involved in modification acting on the living population are (after Hart 1983): a) life span of taxa; b) growth rate of taxa; c) reproduction rate of taxa; d) intra- and interspecific competition; and e) predation.

The modification factors initiated after death are: a) attack of bacteria or scavengers; and b) post-mortem movement by currents or bioturbation.

The modification factors activated after burial are: a) compressional effects, especially for species with flexible tests; b) attack by geochemical processes in the pore-water; c) surface overgrowth through diagenesis; and d) decalcification of a mixed calcareous/agglutinated assemblage, producing an entirely agglutinated assemblage or affecting the calcareous cement of some agglutinated forms.

For this study the upper 25 to 35 cm of sediment in 4 box-cores from the Nares Abyssal Plain (5775 m) and 2 box-cores from the continental rise off Nova Scotia (2750 m and 4499 m) were examined (table 1 and figure 1). Both areas form deep-sea environments with different benthic habitats which contain distinct faunal assemblages. The Nares Abyssal Plain is relatively undisturbed by bottom currents and inhabited by a foraminiferal fauna with delicate tests. The surface sediment is dominated by pelagic brown clays, which contain about 5% coarse fraction ($>63\mu\text{m}$), (Shiple 1978). The scarcity of carbonate in the surface sediment layer attests to the overlying position of the CCD and the low productivity in the overlying Sargasso Sea surface water. Pre-Holocene sequences contain gray clay and are interpreted as distal turbidites. These layers have an increased silt and organic carbon content and are enriched in calcium carbonate (Kuijpers 1985).

The continental rise off Nova Scotia is strongly influenced by the Western Boundary Undercurrent (WBUC) (Bulfinch and Ledbetter 1983, 1984). This

contour current modifies the substrate which in turn influences the composition of the agglutinated assemblage. The sample on the middle rise represents a region with increased current velocity (Lively 1984) and therefore is subject to winnowing processes. The resulting coarse-grained surface layer is characterized by an increased number of species with coarse-grained tests. The lower rise in the sampled area displays a finer surface sediment. Here a deep component of the current system caused periods of strong erosion and rapid deposition (Hollister and McCave 1984) which influence the benthic foraminiferal fauna. The described environmental setting could have been subject to changes during Pre-Holocene time. For more detailed ecological observations of the Recent assemblages the reader is referred to Schröder (1986).

METHODS

From each box-core, one core (usually 25-35 cm) was taken in the middle, using plastic coring tubes. The cores were split, described, X-rayed and sampled continuously at intervals of 1 to 1.5 cm. All samples were washed with a fine water spray over a $63\mu\text{m}$ (230 mesh) sieve to retain the foraminifera. The surface material was preserved with formalin after collection and later stained with Rose Bengal for at least 24 hours to detect individuals living at the time of collection. All samples were kept in a bath of alcohol. Only the total agglutinated assemblage was counted quantitatively.

SEDIMENTOLOGICAL CHANGES AND FAUNAL TRANSITIONS

The upper sediment sequence of the Nares Abyssal Plain samples is a brown mud, characterized by mottling and bioturbation down to 10-14 cm (figure 2) with the exception of core 84-BC-2B/5, where the

Table 1.
List of samples.

Nova Scotia Rise:

Box-core	Depth (m)	Latitude	Longitude
82-022-83/E	2750	42°31.80	61°17.26
82-022-77/E	4499	41°37.96	60°19.15

Nares Abyssal Plain:

84-BC-9/5	5775	23°12.00	64°45.24
84-BC-25/5	5775	22°57.42	64°10.36
84-BC-2B/5	5775	22°42.42	64°20.12
84-BC-15/5	5779	23°16.42	63°53.36

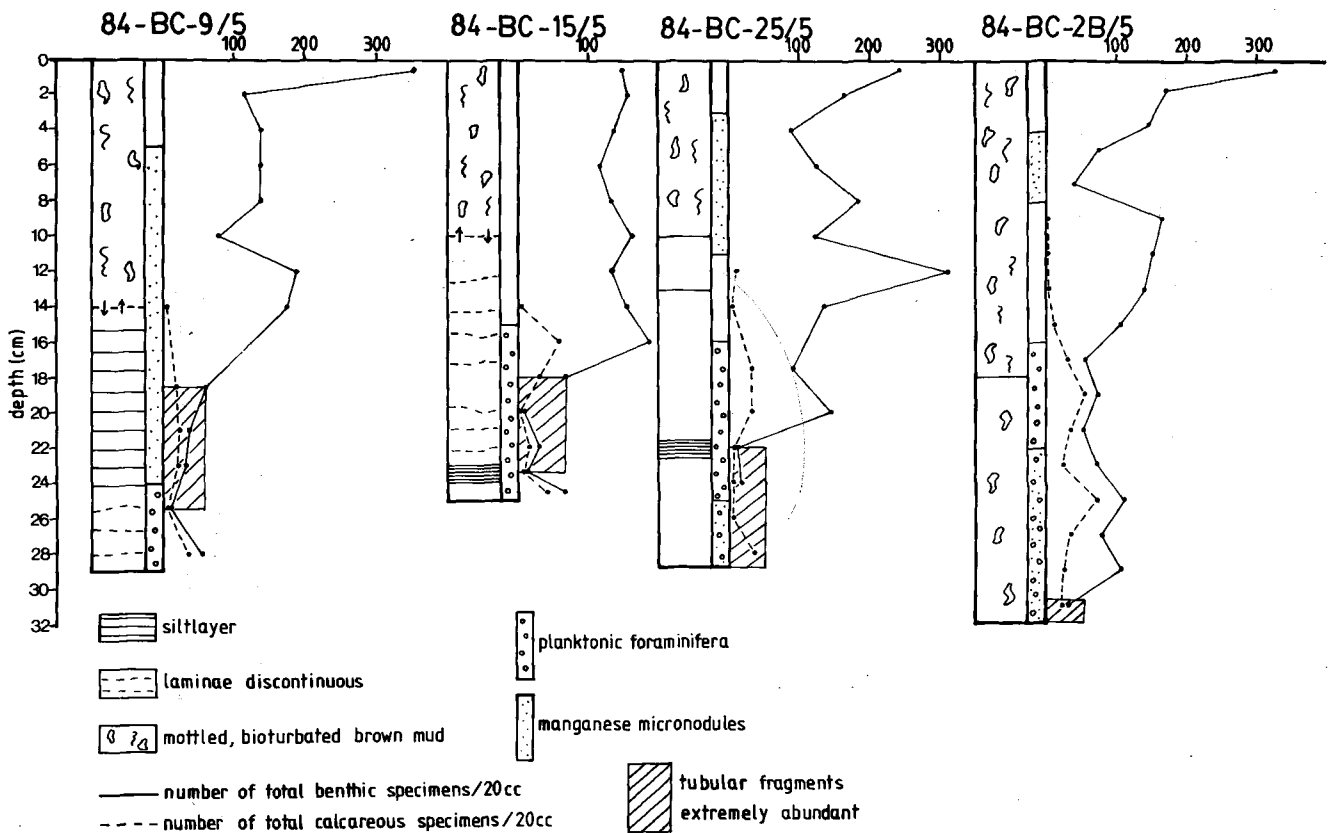


Fig. 2. Sedimentological observations, changes in number of total benthic specimens, and changes in the number of total calcareous specimens per 20 cc wet sediment in four short cores from the Nares Abyssal Plain. The hatched areas indicate sequences with abundant short, tubular agglutinated fragments which were not recorded quantitatively.

entire sequence is bioturbated. The lower parts of the Nares cores show thin lamination, occasional silt layers and a slightly more grayish color. In these sequences the carbonate content is increased because of the occurrence of planktonic foraminifera, mainly fragmented or corroded specimens, and benthic calcareous species. High percentages of these calcareous components below the usual 5000 m depth limit of the CCD appear to be the result of sudden major depositional events that allow no opportunity for long periods of solution by sea water undersaturated with respect to calcium carbonate.

The number of agglutinated specimens per 20 cc of wet sediment fluctuates throughout the upper sequence of the cores. The surface assemblage has the highest number, varying between 200 and 350 specimens, with the exception of core 84-BC-25/5, where the sample 12 cm below the surface exceeds the surface sample in terms of the foraminiferal number. In the upper 4 cm a drastic decrease from about 300 to 100 specimens per 20 cc occurs in three of the studied cores. A second major decrease in the number of agglutinated specimens parallels the sedimentological change from the brown bioturbated mud to the grayish turbiditic sediment. In specific layers of the turbiditic sequence, the agglutinated fauna is impoverished in diversity, but

represented by countless number of small tubular fragments, which are difficult to identify. They may be related to *Saccorhiza ramosa* or *Rhabdammina* sp. The concentration of these short fragments in specific layers, which are more or less all the same size, may result from hydrodynamic sorting during turbiditic processes. The same phenomenon was encountered in turbiditic sequences in deeper layers of piston-cores from the Nares Abyssal Plain, and has been noted in known turbiditic areas of the Arctic Ocean (D. Scott, personal communication, 1985).

The number of specimens per 20 cc of wet sediment of various abundant species of the Nares Abyssal Plain is illustrated in figures 3 and 4. The most dominant species is *Adercotryma glomerata*, a form which has been found in Pleistocene sediments up to 20,000 years old on the continental margin of Eastern Canada (Scott *et al.* 1984). The vertical changes in abundance of *A. glomerata* in all four cores are plotted for comparison in figure 5. Downcore fluctuations cannot be correlated between localities. However, the zone between 16 and 20 cm is marked by drastic decrease from about 40 to 10 or less specimens per 20 cc in all four cores. Less common agglutinated species like *Nodellum membranaceum*, *Ammobaculites filiformis*, *Haplophragmoides rotulatum*, *Ammomarginulina*

foliacea, *Reophax dentaliniformis*, and *Cyclammina trullissata* fluctuate randomly downcore and diminish at the upper boundary of the turbidite sequence. At this boundary, the calcareous foraminiferal component increases and is dominated by *Epistominella umbonifera*. This species forms the most abundant taxa of the adjacent deep-sea areas above the CCD, where turbidity currents pick up material and spread it over the Nares Abyssal Plain. Additional, less common species are related to the genera *Cibicidoides*, *Pullenia* and *Eponides*. The observed disappearance of the diversified agglutinated assemblage at the turbiditic level and the appearance in this sequence of countless tubular fragments and a calcareous component in this case clearly relates to changes in sedimentation regime and the substrate.

The localities examined represent a relatively restricted area of the Nares Abyssal Plain. It can be assumed therefore that water mass characteristics and sediment distribution are uniform over the study area as factors influencing the distribution of agglutinated foraminifera. However, the changing vertical abundance of the illustrated species (figures

3 and 4) does not indicate a uniform pattern within the investigated localities. The differences may have to be explained by factors operating on a small regional scale. Fluctuations in abundance may be due to changes in biological productivity or to the dilution effects resulting from an increased sedimentation rate, which becomes an important factor in the turbiditic sequence.

Corliss (1985) studied the depth distribution of living deep-sea calcareous species in response to different physico-chemical conditions within the sediment. Some taxa prefer microhabitats 10 cm below the surface. This preference may also be valid for certain agglutinated species. However, such cannot be corroborated by the present study because the subsurface samples were not stained.

Another important explanation for the decrease of agglutinated foraminifera with depth below the sediment/water interface is the great fragility of many taxa. Selective preservation decreases species diversity and creates shifts in species dominance. Many agglutinated species have an iron compound, stabilizing the organic cement which binds the

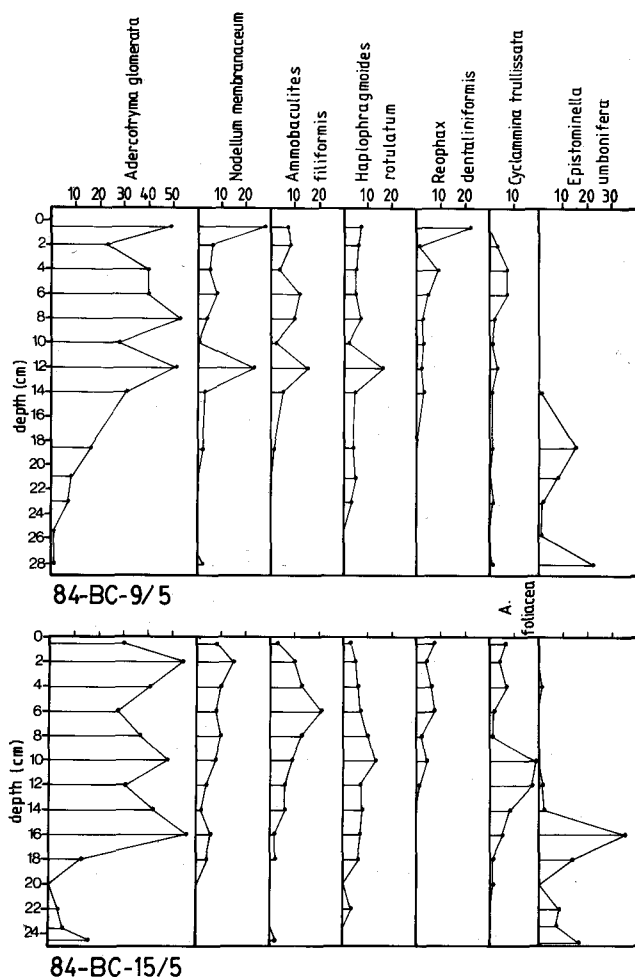


Fig. 3. Vertical changes in actual number of selected species per 20 cc wet sediment in cores 84-BC-9/5 and 84-BC-15/5 from the Nares Abyssal Plain.

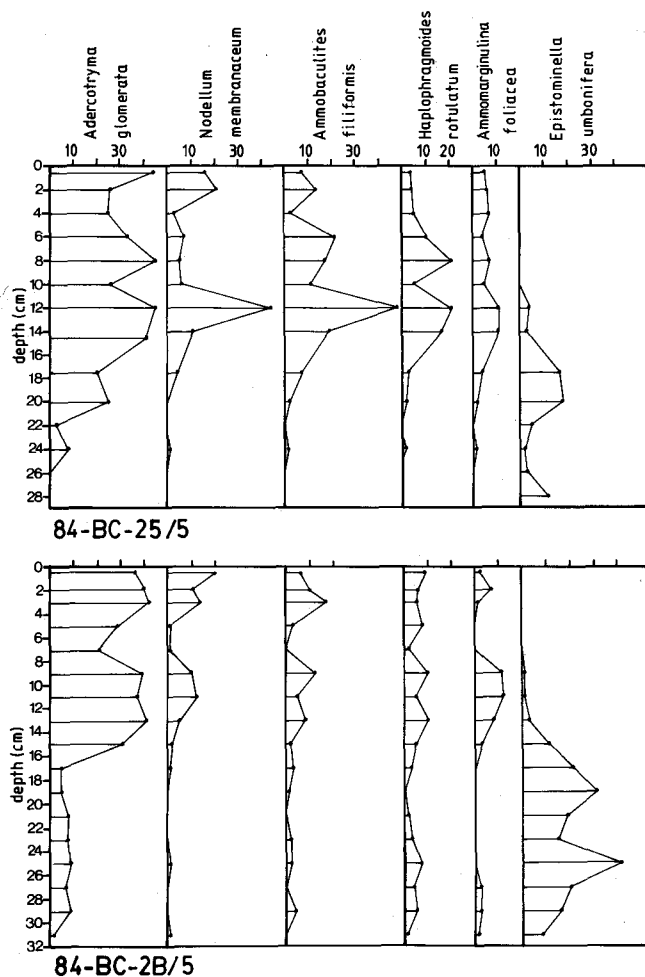


Fig. 4. Vertical changes in actual number of selected species per 20 cc wet sediment in cores 84-BC-25/5 and 84-BC-2B/5 from the Nares Abyssal Plain.

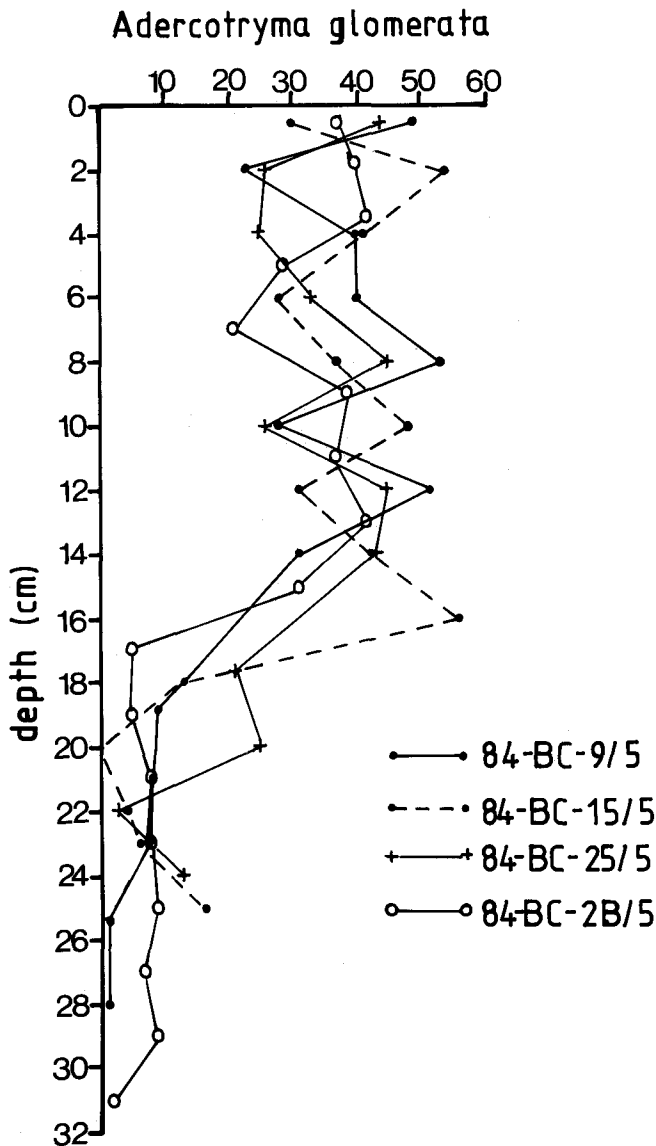


Fig. 5. Comparison of the vertical changes in actual number per 20 cc wet sediment of *Adercotryma glomerata* in four cores of the Nares Abyssal Plain.

individual detrital grains in the test (Hedley 1963; Towe 1967). This iron can be attacked by chemical agents. The vertical distribution of iron-rich agglutinated foraminifera in the Late Quaternary has been studied by Sidner and McKee (1976). Their results indicate that the distribution is controlled more by geochemical factors rather than ecological ones. Agglutinated foraminifera with a ferruginous cement occur abundantly in the upper oxidized layer which is characterized by a positive redox potential. In the underlying reduced sediment, the iron in the organic cement is reduced from the ferric to the ferrous state and subsequently mobilized. This process causes bleaching and the ultimate destruction of the test (Sidner and McKee 1976).

Geochemical analyses have been carried out on piston-cores of the southern Sohm Abyssal Plain (Winters and Buckley 1986). Measurements of the iron content in the pore water indicate an increase

several centimeters below the surface at the transition from an oxidizing zone to a reducing sediment. Where agglutinated specimens have an iron compound in their cement, they may be affected by the geochemistry of the pore water. Consequently, this change may be reflected partly in the drastic decrease of the number of agglutinated species below the surface (figure 2). Core 84-BC-2B/5 shows a slightly higher number of agglutinated specimens per 20 cc throughout the entire column. This occurrence may be the result of a more oxidized sediment, an observation that is supported by visible bioturbation features that extend down to 30 cm below the sediment surface.

From the continental rise off Nova Scotia, two box-cores were selected to study the vertical change in agglutinated foraminifera. A change in the sedimentological regime in the cores of the continental rise can be recognized (figure 6). Both sites are under the influence of contour currents influencing the substrate. A hard surface layer, more grayish in color, is well developed at 2750 m, where most of the fine particles have been removed

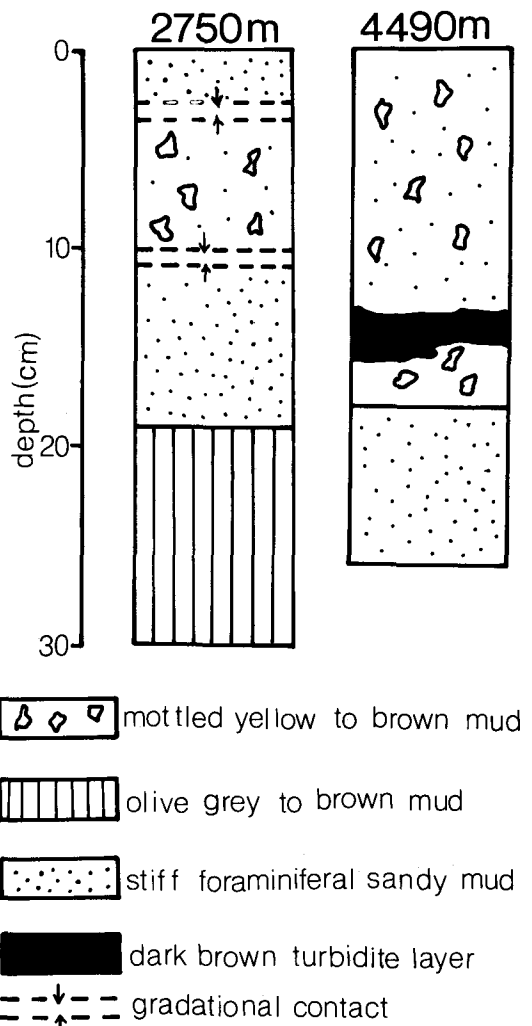


Fig. 6. Sedimentological changes in two short cores from the continental rise off Nova Scotia.

by winnowing processes. These two zones represent environments that are exposed to changing sedimentological processes such as turbidity current activity and bottom current sediment surface interactions. Conversely, the Nares Abyssal Plain is an example of a more stable substrate. Shifts in the intensity of factors influencing the sea bottom take place through time and may be reflected in the foraminiferal content. The agglutinated component was studied quantitatively. For an evaluation of the vertical changes of calcareous species from live to dead to fossil assemblages, the interested reader is referred to Douglas *et al.* (1980), who studied samples from the Southern California borderland.

A visual estimation of the quartz component in the sand fraction suggest a downcore increase at both localities. The average grain size is larger on the upper rise where the sediment also includes many pebbles. This indicates a more active downslope transportation of terrigenous sediments in the Early Holocene. Such allocthonous input in the lower sequence of core 82-022-77/E is reflected in the occurrence of calcareous species usually found on the slope such as *Elphidium excavatum*, *Rutherfordoides tenuis*, *Nonionella* sp., and *Globobulimina* sp. In the Monterey deep-sea fan off Central California, the proportion of shallow-water species in deep-sea sediments has been used to distinguish turbidite sequences from hemipelagic muds (Brunner and Normark 1985). In my material, significant differences between both core localities exist in the general trends of number of species and number of specimens per 10 cc of wet sediment (figures 7 and 8). The surface assemblage of core 82-022-83/E has a rich agglutinated fauna showing a

high diversity of 50 species due to a concentration of robust forms, which are resistant to the erosive forces that occur below the WBUC axis. Below the upper centimetre of sediment, the agglutinated fauna decreases drastically from over 1000 to 380 specimens per 10 cc. This drop is also reflected in the vertical distribution of all dominant species. The decrease in the agglutinated fauna directly below the surface might be caused by compaction which does not favor the preservation of fragile tests. The agglutinated component disappears almost completely between 12 and 14 cm. Slightly bleached specimens occur below 12 cm where the sediment color changes to light gray (figure 6). In this sequence, the remaining taxa are *Eggerella bradyi*, *Karreriella bradyi*, *Karreriella novangliae*, and *Reophax bacillaris* species, which have a calcareous or an organic matrix and therefore are not affected by the solubility of iron in a reducing environment.

Core 82-022-77/E is characterized by a sparse agglutinated fauna of low diversity at the surface, which increases significantly in number of species and specimens towards the 4 cm level downcore. The foraminiferal number changes from 20 to 150 specimens and the species number from 10 to 30 species per 10 cc. The impoverished surface population is here interpreted as a residual assemblage after erosion of the substrate by bottom currents, described as a deep-sea storm event (Hollister *et al.* 1984). This current occurs episodically and influences the substrate with varying intensity. These changes may explain some of the vertical differences in species richness of the benthic foraminiferal populations. The dominant species fluctuate in the upper 10 cm. Among these

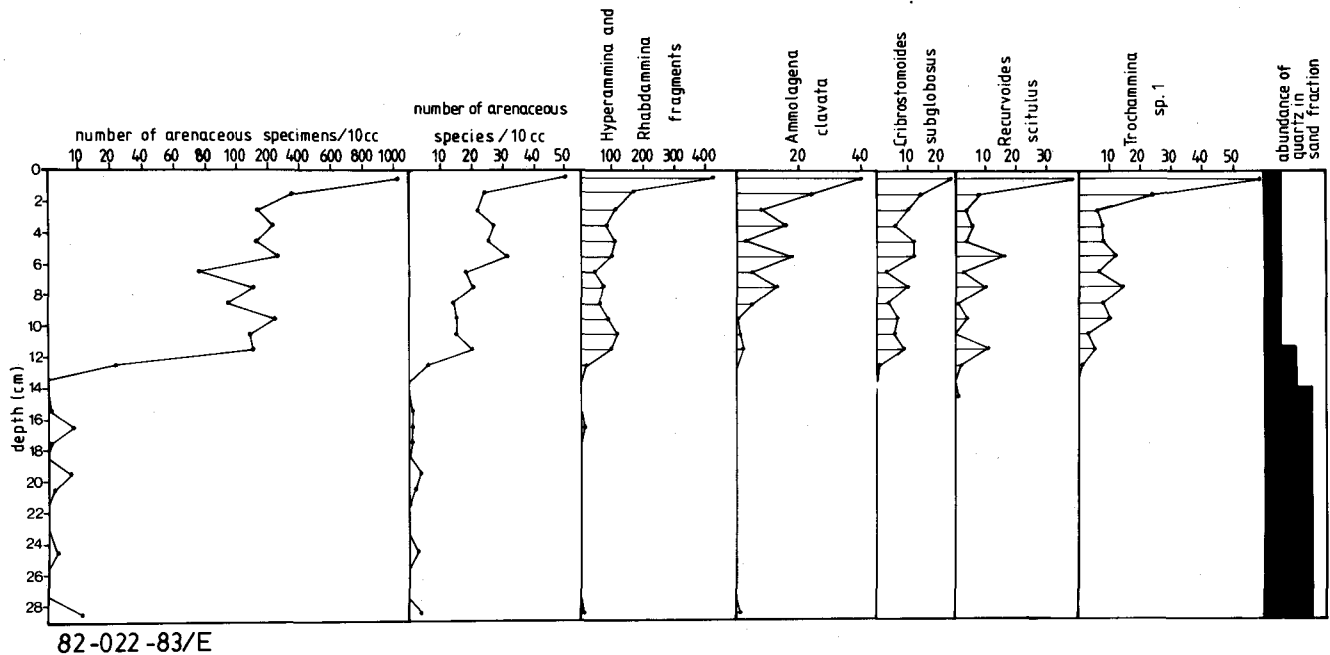


Fig. 7. Vertical changes in number of agglutinated specimens, number of agglutinated species and actual number of selected dominant species per 10 cc wet sediment in core 82-022-83/E of the middle continental rise off Nova Scotia.

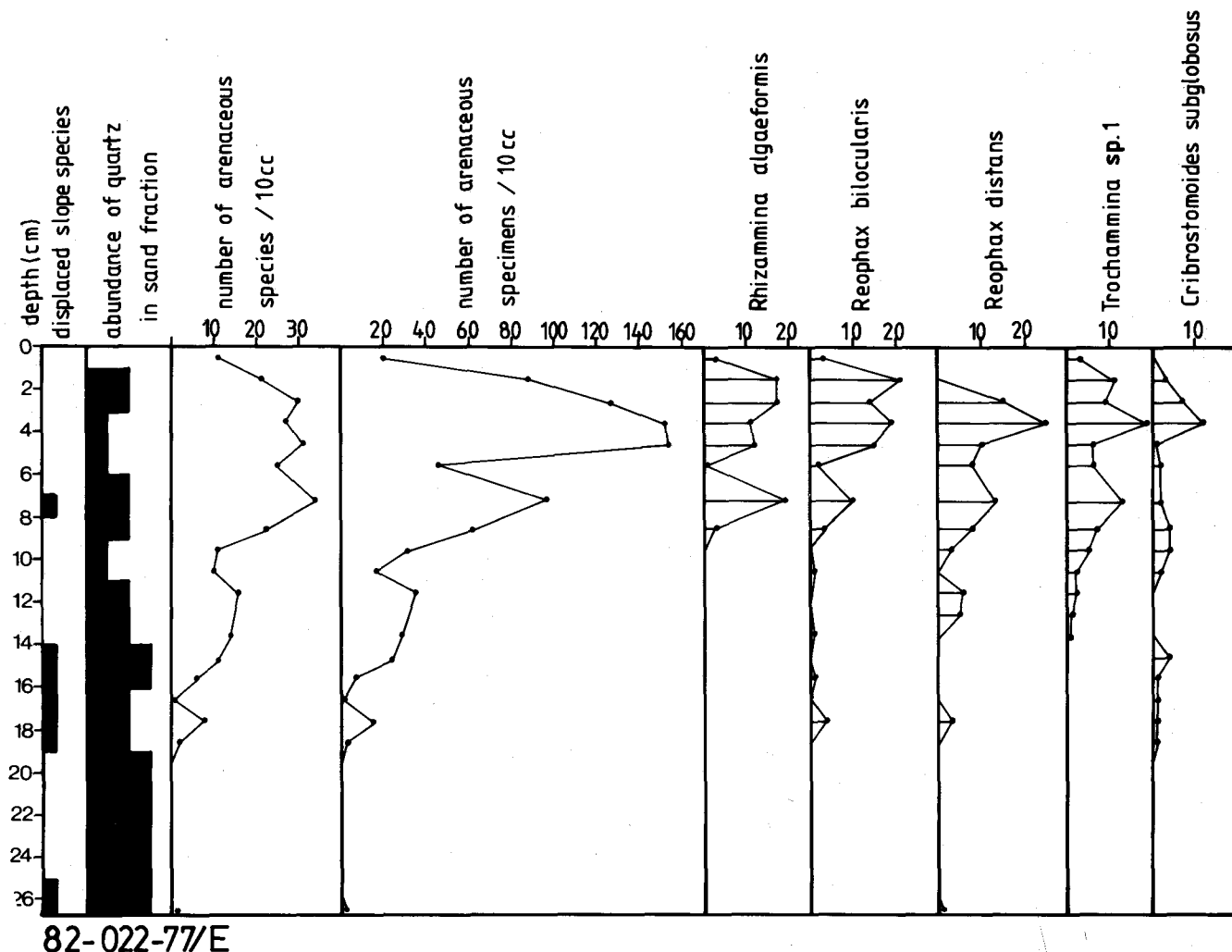


Fig. 8

Vertical changes in number of agglutinated specimens, number of agglutinated species and actual number of selected dominant species per 10 cc wet sediment in core 82-022-77/E of the lower continental rise off Nova Scotia. Note the increase in the terrigenous component downcore.

species, *Rhizammina algaiformis* has the most fragile test and does not remain below 9 cm. The occurrence of *Reophax distans*, *Trochammina cf. globigeriniformis*, and *Cribrostomoides subglobosus* is unusual at this water depth. These species represent, in the modern assemblage, the middle continental rise (Schröder 1986). The presence of relatively coarse-grained tests of these species in a core which represents a relatively fine-grained sediment, may imply downslope transportation of the tests. No distinct oxidized zone is developed in core 82-022-77/E. In contrast to the Nares Abyssal Plain, bleached agglutinated specimens were found in the upper three samples of the core. The transition to non-bleached specimens occurs gradually with tests showing only a bleached final chamber.

The mentioned differences in the vertical distribution of agglutinated foraminifera seem to be controlled by various factors such as a changing substrate through time, a variable input of displaced faunal components or by preference for an infaunal

microhabitat. However, chemical and mechanical destruction of tests blur, through selective removal, the natural changes in the abundance of agglutinated species. Unfortunately, the penetration depth of the box-cores does not extend to a depth that allows a study of the faunal changes below the turbidite sequence. A piston-core on the Nova Scotia rise, however, indicates a short Holocene with no repeat of the agglutinated fauna below the turbidite layer (Thomas 1985).

IMPLICATION OF BURIAL MODIFICATION FOR PALEOECOLOGY USING FOSSIL FORAMINIFERAL ASSEMBLAGES

The importance of agglutinated foraminifera in paleoenvironmental interpretations in the fossil record has been realized for some time. In so-called "flich-type" faunas, agglutinated species form the entire foraminiferal assemblage (Pflaumann 1964; Simpson 1969; Gradstein and Berggren 1981). However, only limited use had been made of the

distributional data on modern agglutinated species as depth and environmental indicators to produce valuable information for the interpretation of the past. For such an attempt, it is of interest to know which component of the modern fauna remains through geological time.

The Recent deep-sea agglutinated fauna consists to a large extent of fragile species, such as found in the family *Komokiacea* on the abyssal plains. This component has no potential to survive the fossilization process. The loss of these taxa confronts us with a residual fauna in the fossil record of deep-sea sediments. As a result, the fossil assemblage may lack the most dominant or indicative species for the environment at that time. The study of the vertical changes of the agglutinated composition over the upper 30 cm of sediment allows some estimation of which taxa may survive processes such as transportation, burial, compaction and dissolution.

the species within each group in vertical order with respect to increasing test stability.

Group A comprises species with a flexible test and with delicate branches of agglutinated clay particles. These forms often collapse if the test dries out, such as the species related to the family of *Komokiacea*. These taxa are most susceptible to mechanical destruction and slight compaction and therefore have no potential to survive in the fossil record. They were never found below 4 to 5 cm in the cores.

Group B includes species with relatively fragile tests, thin walls, and often loosely cemented wall material like the genus *Rhizammina*. These taxa have only a small chance to survive compaction and show, therefore, a low potential to remain in the fossil record.

Group C is formed by those species which have a firmly cemented agglutinated test and consequently have a high potential to survive fossilization.

Figures 9 to 10 group deep-sea agglutinated species into three categories. I have attempted to arrange

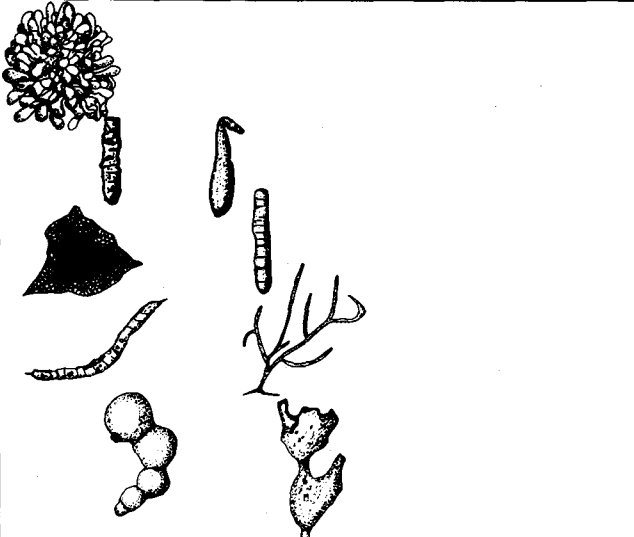
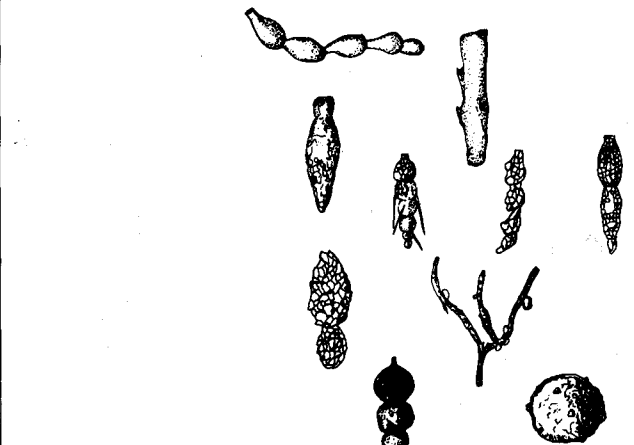
<p>GROUP A</p> <p>species with flexible tests, most susceptible to mechanical destruction and slight compaction</p> <p>no fossilization potential</p>		<p>KOMOKIACEA</p> <p><i>Pelosina cylindrica</i></p> <p><i>Pelosina variabilis</i></p> <p><i>Vanhoeffenella gaussi</i></p> <p><i>Bathysiphon hirundinea</i></p> <p><i>Rhizammina indivisa</i></p> <p><i>Dendrophrya arborescens</i></p> <p><i>Hormosina normani</i></p> <p><i>Aschemonella scabra</i></p>
<p>GROUP B</p> <p>species with loosely cemented wall material, susceptible to compaction</p> <p>low fossilization potential</p>		<p><i>Hormosina carpenteri</i></p> <p><i>Aschemonella ramulifera</i></p> <p><i>Reophax heleneae</i></p> <p><i>Reophax horrida</i></p> <p><i>Reophax scorpiurus</i></p> <p><i>Reophax dentaliniformis</i></p> <p><i>Reophax bilocularis</i></p> <p><i>Rhizammina algaeformis</i></p> <p><i>Hormosina globulifera</i></p> <p><i>Thurammina papillata</i></p>

Fig. 9. Potential for fossilization of selected Recent agglutinated foraminifera, coordinated in 3 groups. The species are arranged in each category in vertical order of increased test stability with respect to destructive agents.

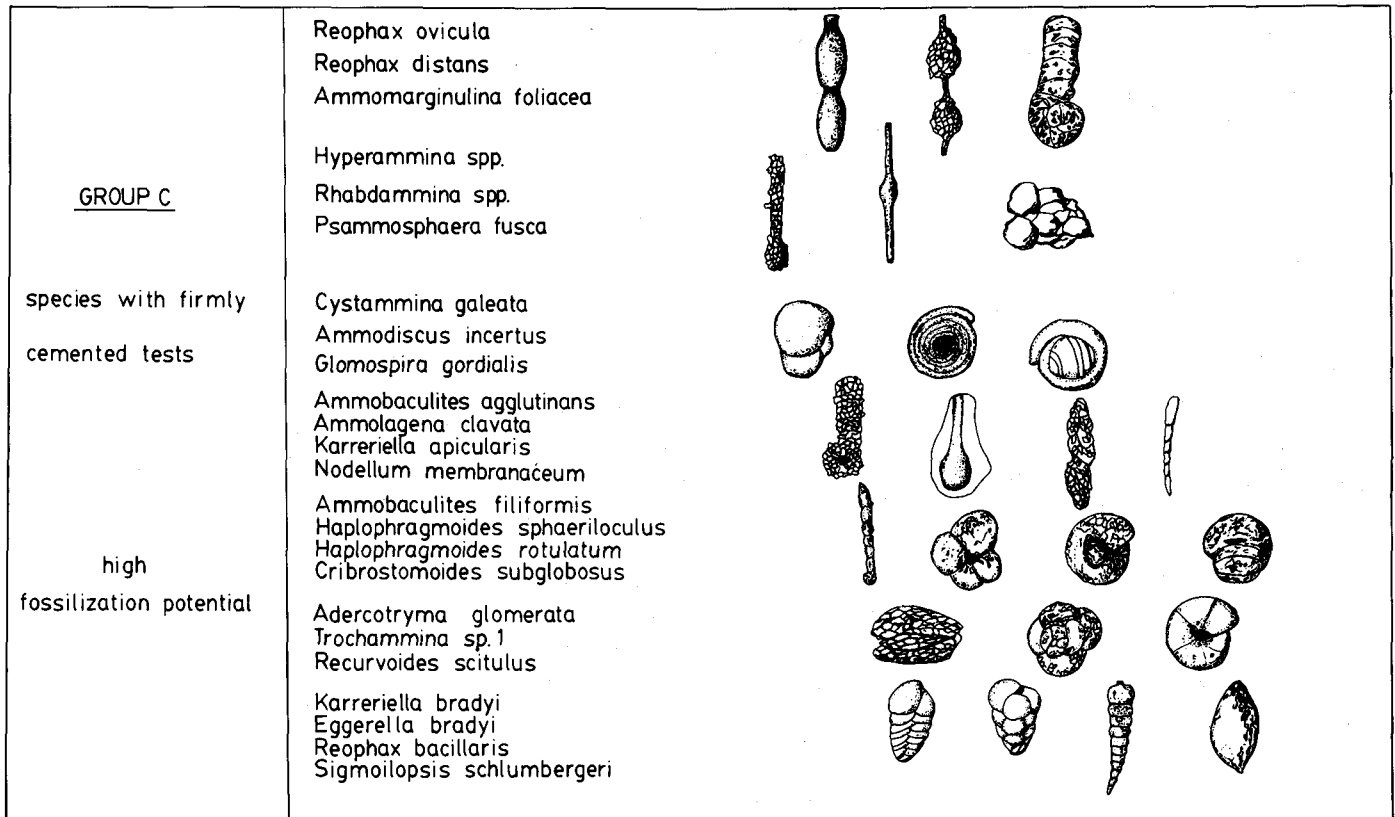


Fig. 10.

Potential for fossilization of selected Recent agglutinated foraminifera, coordinated in 3 groups. The species are arranged in each category in vertical order of increased test stability with respect to destructive agents.

The influence of geochemical processes in the sediment column on the various types of cement has not been considered in this classification. Destruction through chemical solution may be a localized effect which is difficult to generalize without quantitative chemical studies.

Species related to *Rhizammina* were described from Late Cretaceous and Early Tertiary assemblages (Pflaumann 1964; Gradstein and Berggren 1981; Miller *et al.* 1982). From comparison with the fragile tests of the recent species, fossilization of this genus appears to be questionable. The majority of the species of *Reophax* show a tendency to disintegrate rapidly after burial. Exceptions are *Reophax bacillaris*, *R. distans*, and *R. ovicula*. Vilks and Mudie (1983) found *Reophax fusiformis* together with *Saccammina atlantica* and *Spiroplectammina biformis* abundantly preserved in cores of Lake Melville, Labrador, down to 7 m below surface. Scott *et al.* (1984) found *Reophax arctica* (a small fragile test) in sediments of Late Pleistocene age (10 m below the surface). Miller *et al.* (1982) observed *Reophax scottii* (a very delicate form) fossilized in a fjord at depths up to 4 m below the surface. These types of observations make generalized groupings difficult.

As mentioned earlier, in the Early Holocene and Pleistocene turbiditic sequences of the Nares

Abyssal Plain, some layers are characterized by abundant tubular fragments as the only agglutinated component (figure 2). The concentration of primitive taxa in restricted zones was also observed in the fossil record. Pflaumann (1964) described from the Late Cretaceous flysch faunas of Bavaria an alternation of layers dominated by primitive tubular forms and layers with higher developed taxa. Simpson (1969) reported, from the Carpathian flysch, assemblages which mainly consist of *Bathysiphon* and *Hyperammina* species. In turbidite sequences of the Tertiary sediments in the Norwegian-Greenland Sea, two subfaunas were distinguished by Verdenius and Van Hinte (1983): (1) a frontier-area subfauna, consisting of more primitive forms, which quickly repopulate a substrate affected by a turbidite and (2) a species-rich subfauna of sophisticated forms that fit into narrow ecological niches in the environment.

Since on the Nares Abyssal Plain the assemblage of tubular forms occur together with a calcareous component, which clearly indicates the allochthonous nature of the sediment, I assume that these agglutinated specimens are transported and have been concentrated through hydraulic sorting during a turbidity current event.

CONCLUSIONS

The vertical change with depth in the sediment and in the abundance of agglutinated foraminifera illustrates how effects of selective preservation, transport and reworking influence the fossil assemblages. Results also show that significant numbers of modern agglutinated species do fossilize and can be used as paleoceanographic indicators. A significant decrease in the abundance of species with a ferruginous cement such as *Adercotryma glomerata*, *Cribrostomoides subglobosus* and *Trochammina* spp. is correlated with the transition downcore from an oxidizing to a reducing sediment.

The decrease of agglutinated species in the North Atlantic in subsurface sediments is related to a major change in sedimentation, not simply non-fossilization of agglutinated species.

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