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ON THE POTENTIAL OF SMALL BENTHIC FORAMINIFERA AS PALEOECOLOGICAL INDICATORS: RECENT ADVANCES

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ABSTRACT
The present article aims to introduce some of the possible ways of paleoecological interpretation of data obtained from the study of foraminiferal assemblages. Six criteria are first introduced in Bulgaria: diversity index α (*Fisher*-index), triangular plot for the foraminiferal assemblage structure (based on three types wall texture - agglutinated, porcelaneous, hyaline), planktic/benthic ratio, tau-index as bathymetrical indicator, the tolerance of the taxa (mainly at generic level) with respect to some environmental parameters (bathymetry, temperature, salinity levels, calcium carbonate availability, dissolved oxygen levels, substrate conditions, water energy), occurrence of dominant species in relation to species diversity.
Key words: benthic foraminifera, paleoecological interpretation, criteria, parameters.

INTRODUCTION

During the last four decades foraminifers have turned into one of the most useful groups for ancient sea environment interpretation. With the renewal of the foraminiferal fauna during the Paleogene, Tethyan assemblages have closer approximation to modern ones (mainly at generic level), which allows applying the recent distribution patterns for reconstruction of paleoenvironmental parameters from distant time intervals. The interpretations will be more precise if analogues are made between forms at the lower taxonomical level. However, this possibility decreases as the time distance increases because of the decrease of the resemblance between the species composition of modern and fossil assemblages.

The recent advances in paleoecological investigations of foraminiferal assemblages made us reassess the significance of small benthic foraminifera in Bulgarian micropaleontology and direct the investigations in a paleoecological apect, because till now in Bulgaria this group has been used for biostratigraphical and taxonomical purposes only. The present article aims to introduce some of the possible ways of paleoecological interpretation of data obtained from the study of taxonomical composition and structure of small benthic foraminiferal assemblages. Six criteria are first introduced in Bulgaria.

CRITETIA

The following criteria are usually used in the paleoecological interpretations: diversity index α (*Fisher*-index), triangular plot for the foraminiferal assemblage structure, planktic/benthic (P/B) ratio, *tau*-index as bathymetrical indicator, the tolerance of the taxa (mainly at generic level) with respect to some environmental parameters (bathymetry, temperature, salinity levels, calcium carbonate availability, dissolved oxygen levels, substrate conditions, water energy), occurrence of dominant species in relation to species diversity.

Diversity Index α (Fisher-index)

Diversity index was introduced by Fisher et al. (1943, in Murray, 1991). It takes in account the number of species among a certain number of specimens:

$$\alpha = n_1 : x \qquad (1)$$

where x is a constant having values <1, $n_1=N(1-x)$, N being the number of individuals. To facilitate the calculations the graph shown on Fig. 1 is usually used. Low values of α suggest some deviation from the norm of some of the paleoenvironmental parameters. It has to be borne in mind the fact that the species diversity in fossil assemblages could be influenced by taphonomical factors.

Triangular Plot for the Foraminiferal Assemblage Structure

It is based on three types wall textures: agglutinated, porcellaneous and hyaline, corresponding with three suborders - Textulariina, Miliolina, Rotaliina from the Loeblich&Tappan's (1964) classification. In the revised classification (Loeblich&Tappan, 1988) suborder Rotaliina was divided into four suborders - Spirilinina, Lagenina, Robertinina, Rotaliina (Fig. 2);

Planktic/Benthic Ratio

With the increase of the depth the percent abundance of planktic individuals in the samples increases. However there are exeptions –very wide shelves and enclosed epicontinental seas are characterized by low abundance of planktic forms despite the depth. With the approach of *carbonate compensation depth* (*CCD* – 3500-4000 m) a gradual dissolution of the calcareous tests is observed, and under this level planktic forms are not available.

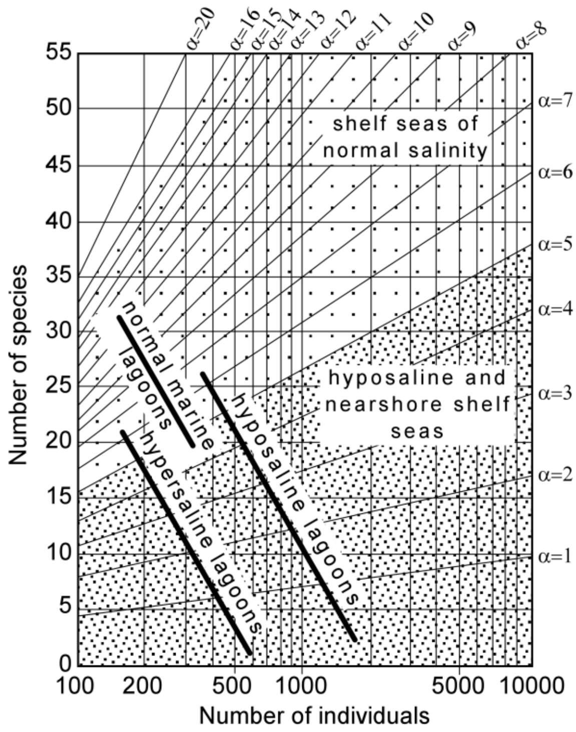

Figure 1. Graph illustrating the calculation of the diversity index α (after Wright, 1972)

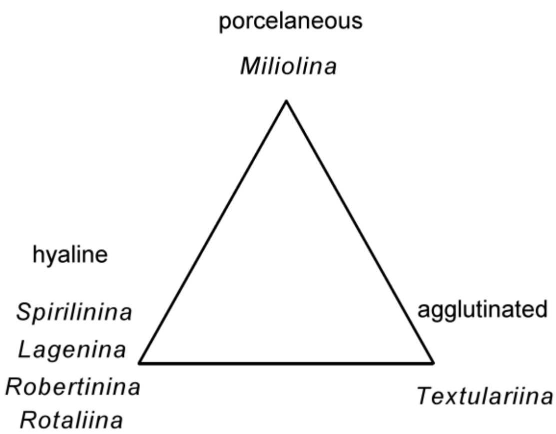

Figure 2. Triangular plot about foraminiferal assemblage structure based on three types wall texture (after Murray, 1991)

Tau-index

It was introduced as bathymetrical indicator by Gibson (1988) based on data obtained from the Gulf of Mexico. It could be calculated using the formula:

$$tau = b \cdot \%p \qquad (2)$$

where *b* is the number of benthic species, and *p* – the number of planktic individuals in a sample. With the increase of the depth the values of *tau* increase.

Tolerance of the Taxa with Respect to Some Environmental Parameters

Particular taxa demonstrate different tolerance of depth, temperature, salinity, aeration, calcium carbonate and silica availability, water energy, substrate conditions. Of grate importance are taxa with minimal tolerance of changes in the above mentioned parameters. Data from modern assemblages, as well as data, obtained during the deep sea drilling in the Atlantic, Pacific and Indian Ocean are used in the interpretations.

Occurrence of Dominant Species in Relation to Species Diversity

The availability of strong dominance of some species in relation to low species diversity suggests deviation from the norm of some of the parameters. The absence of dominant species in relation to high species diversity indicates stable environmental parameters.

PARAMETERS

The parameters that are interpreted in the majority of the investigations are bathymetry, temperature, salinity levels, dissolved oxygen levels, calcium carbonate availability, water energy, substrate conditions.

Bathymetry

Bathymetry is a part of three dimensional space and the parameters related with it – temperature, pressure, light, salinity, etc. (Gibson, 1988). Its interpretation is based on the comparison of upper and lower tolerance depth limits of modern foraminiferal genera, analogous to fossil ones. The depth limits of particular genera are shown on Fig. 3. Of grate importance are taxa showing narrow bathymetrical range.

Species diversity is also informative for bathymetry. The values of *Fisher*-index increase as the depth increases. Outer shelf is characterized by α=5-19, the slope – by α=5-25. The highest values of α demonstrates the lowermost slope (Murray, 1976).

Planktic/benthic (*P/B*) ratio depends also on the depth. According to Murray (1976) inner shelf is characterized by up to 20% planktic individuals, the middle shelf – 10-60 %, the outer shelf – 40-70%, and the upper slope - >70%. The highest values are established in the lowermost slope (about 90% - Boersma, 1983).

Gibson (1988) introduced *tau*-index as bathymetrical indicator. Depths up to 40 m are characterized by *tau* <100, depths between 40 and 1000 m are marked by values between 100-1000, and depths up to 2000 m – by values between 1000-10000.

Wall texture of the foraminiferal tests is connected with the bathymetry (Fig. 4). Porcelaneous tests as a rule are typical for the inner shelf. As an exception the genera *Pyrgo* and *Biloculinella* have been established in abyssal depths (Haynes, 1981). The percent abundance of hyaline forms increase as the depth increases. In the abyssal depths below the *CCD* only agglutinated forms are presented.

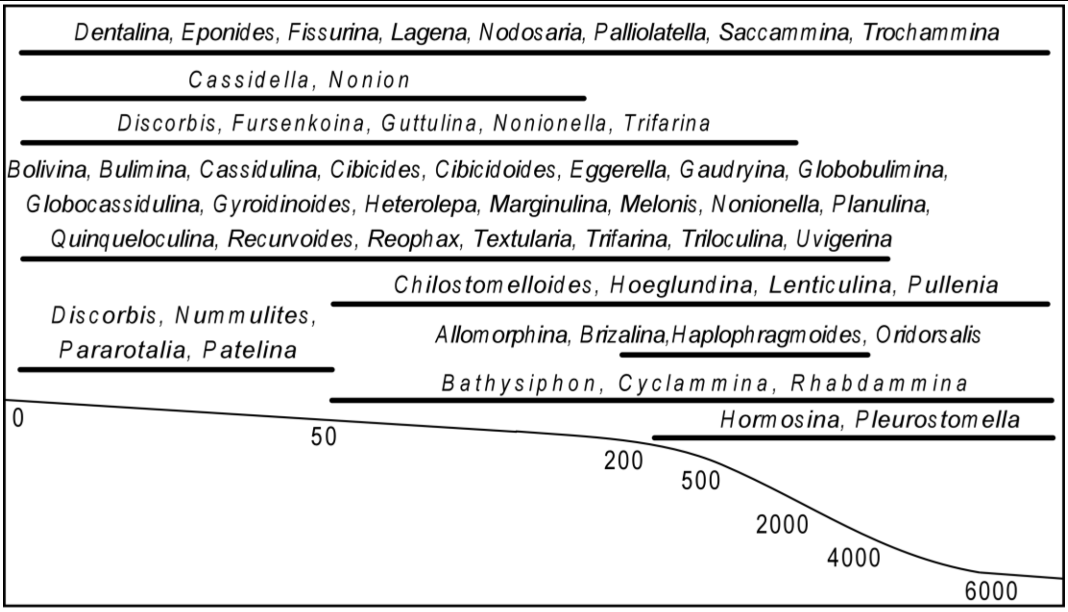

Figure 3. Bathymetrical distribution of modern foraminiferal genera (after Ujetz, 1996)

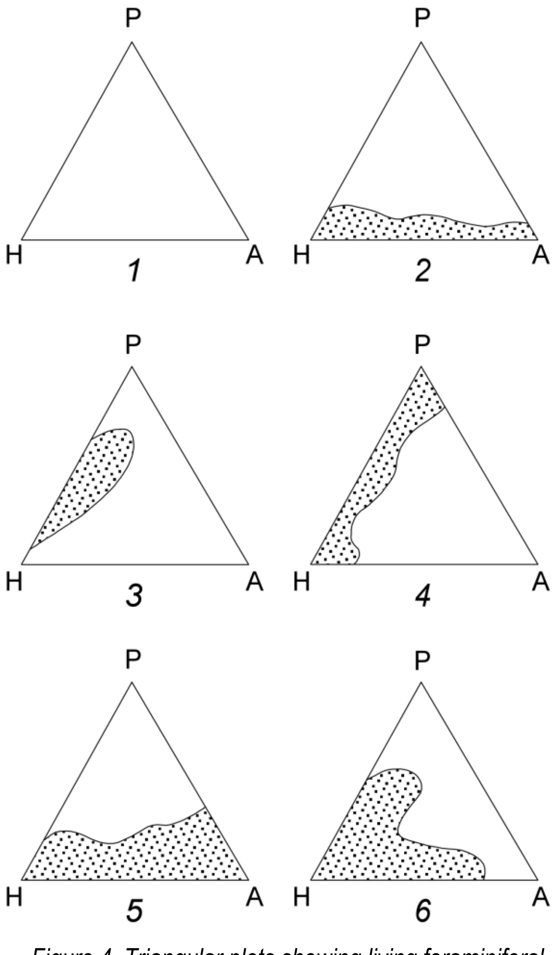

Figure 4. Triangular plots showing living foraminiferal assemblage structures from different environments (after Brasier, 1980)
1 - fresh waters; 2 - hyposaline lagoons; 3 - normal marine lagoons and carbonate platforms; 4 - hypersaline lagoons; 5 - shelf seas; 6 - normal marine continental slope waters; types of tests: P - porcelaneous; X - hyaline; A - agglutinated

The composition of the cement of agglutinated foraminifers indicates the deposition depth in relation to *CCD*. Assemblages composed of agglutinants with calcareous cement *(Gaudryina, Dorothia, Arenobulimina, Textularia, Vulvulina, Remesella, Marssonella, Karreriella* - King et al., 1989) indicates deposition above *CCD*, while assemblage comprised of taxa with noncalcareous cement (*Bathysiphon, Glomospira, Haplophragmoides, Ammosphaeroidina, Trochammina*) is a marker for sedimentation below *CCD*.

Agglutinated foraminifers change their test morphology with the depth changes. Their most deep-water representatives, comprising the so called "*Rhabdammina*-fauna" show simple test morphology (Brower, 1965, in Winkler, 1984) – unicellular, tube-like fragments, or multicellular uniserial (*Bathysiphon, Rhizammina, Saccammina, Hyperammina, Hormosina*). Bathyal agglutinants demonstrate higher morphological diversity. The assemblage is dominated by taxa with simple morphology, but there could be observed forms with biserial (*Textularia*), multiserial (*Gaudryina, Dorothia*), planispiral (*Cribrostomoides, Haplophragmoides*), trochospiral (*Trochammina, Recurvoides*), heteromorphous (*Spiroplectammina, Clavulinoides*) tests (Berggren, 1984).

During the investigations on the so-called "flysh-type" agglutinated foraminifera from the Paleocene of the North Sea, Jones (1988) established that the depth changes influence not only the test size and morphology, but the test colour. In the uppermost slope (200-500 m) finely to middle agglutinated middle sized white tests were observed. With the increase of the depth (500-1000 m) the tests become more coarsely agglutinated, large-sized and brownish-green in colour. At depths between 1000 and 1500 m middle to finely agglutinated, small-sized, dark green forms were established.

The morphology of some hyaline genera also demonstrate dependance on the depth. Typical examples are *Pullenia, Bolivina, Bulimina, Chilostomelloides*. The most changeable features are the test size and the oramentation. *Bolivina* loses its ornamentation as the depth increases, while *Bulimina* become more ornamented. Both genera increase their test size (Bandy, 1960, in Boltovskoy et al., 1991). With the increase of the depth the degree of inflation of *Pullenia* increases (Haynes, 1981),while *Chilostomelloides* increases its test size (Bandy, 1963). *Cibicidoides, Cibicides* develop inflected sutures (Bandy, 1960, in Ujetz, 1996).

Temperature

The tolerance of selected taxa of the changes of temperature is shown on Fig. 5 .

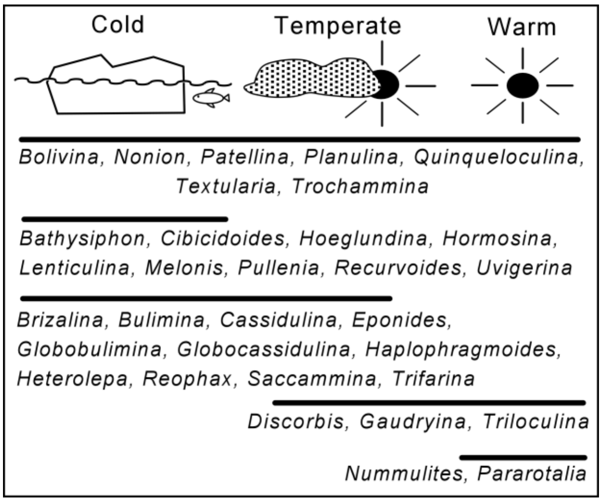

Figure 5. Distribution of living foraminiferal genera according to temperature (after Ujetz, 1996)

Temperature influences the test size and test morphology (Boltovskoy et al., 1991). The trends are towards an increase of the test size and the test porosity with the increase of temperature (Frerichs et al., 1963, in Ujetz, 1996).

Assemblages with high species diversity are typical for basins with constant high temperature (Boggs, 1987, in Ujetz, 1996).

Temperature influences also calcium carbonate availability in the water column. It values decrease as the temperature decreases. Such an environment is characterized mainly by calcareous thick-walled foraminifers (Boltovskoy, Wright, 1976 в Ujetz, 1996). The presence of large-sized agglutinants and low species diversity indicates constant temperature and stagnant water conditions (Haynes, 1981).

Salinity Levels

The vast majority of foraminifers is adapted to normal marine conditions – about $35^{0}/_{00}$ (Brasier, 1980). Genera flourishing in normalsalihe waters are the following: *Alabamina, Anomalinoides, Bathysiphon, Bolivina, Bulimina, Chilostomelloides, Cibicides, Cibicidoides, Cyclammina, Fursenkoina, Gaudryina, Globobulimina, Haplophragmoides, Heterolepa, Lagena, Lenticulina, Nonion, Paliolatella, Pullenia, Recurvoides, Reophax, Saccammina, Textularia, Trochammina* (Bolyovskoy et al., 1991; Murray, 1991; Murray et al., 1989). *Bolivina, Bulimina, Cibicides, Globobulimina, Nonion* are tolerant of both normalsaline and hyposaline environments (Murray et al., 1989).

The presence of planktic individuals as well as thick-walled calcareous forms in the samples also indicates normal marine environment (Boltovskoy, Wright, 1976, in Ujetz, 1996).

Salinity levels influence the species diversity. Values of α>5 suggest normal salinity (Murray, 1991). Hyposaline and hypersaline conditions are marked by low species diversity (α<5 – Fig. 1).

Additional data about the salinity provide triangular plots. Normal marine environments are dominated by hyaline-test foraminifers. Hyposaline realms (<$32^{o}/_{oo}$) are marked by abundant agglutinants, while hypersaline ones (>$40^{o}/_{oo}$) – by abundant porcelaneous tests. On Fig. 5 are shown triangular plots demonstrating assemblage structures from different environments (after Brasier, 1980).

The presence of agglutinated forms with noncalcareous cement could suggests shallow-water environment with low salinity (Haynes, 1981).

Dissolved Oxygen Levels

Well aerated environment is characterized by diverse calcareous foraminiferal fauna (α>5), thick-walled large-sized and ornamented tests (Murray, 1991; Boltovskoy, Wright, 1976, in Ujetz, 1996). High oxygenated realm is also marked by the presence of infauna. For example genera like *Lenticulina* and *Vaginulinopsis* are characterized by compressed tests with angulate periphery (often keeled) which are adapted to “slice” through well aerated substrate. According to Kaminski et al. (1988) elongate uniserial agglutinants are typical for the infauna. Such tests have genera like *Hormosina, Reophax, Subreophax*. Elongate tube-like and branched tests are characteristic for attached forms (*Bathysiphon, Rhizammina, Dendrophrya*). The absence of infauna could indicate anaerobic environment. Assemblages flourishing in well aerated realm are characterized by spherical and lenticular forms while low oxygenated realm are dominated by elongate and flattened forms (Bernhard, 1986).

The dissolved oxygen level could be established by the presence of definite genera in the assemblage. For example *Bolivina, Bulimina, Cyclammina, Haplophragmoides, Bathysiphon* flourish in low oxygenated environment (Boltovskoy, Wright, 1976 in Ujetz, 1996).

The presence or absence of ornamentation is also influenced by the oxygen levels. For example the presence of ornamented individuals of *Bulimina, Globobulimina, Chilostomelloides* suggests low dissolve oxygen levels. Foraminiferal tests with large-sized pores are adapted to low oxygenated environment (Perez-Cruz, Machain-Castillo, 1990).

Species diversity is also informative for the dissolved oxygen levels. Assemblages, characteristic for low oxygenated environment demonstrate low species diversity (α<7) and they are dominated by 2-3 species comprising over 80% of the total number of individuals in the samples.

Calcium carbonate Availability

In recent seas assemblages dominantly composed of agglutinated foraminifers are characteristic of low salinity levels or deep-sea bottoms undersaturated in calcium carbonate

(Haynes, 1981). The occurrence of microfaunas comprised of calcareous forms and characterized by high species diversity indicates high level of calcium carbonate-availability. Corliss (1979) suggested that the high solubility of calcium carbonate at great depths is one of the reasons responsible for the prevalence of small-sized specimens.

Substrate conditions

The influence of substrate on the test morphology is particularly important in agglutinated and sedentary forms. The wall texture in agglutinated foraminifers is characteristic feature for the substrate conditions. Finely agglutinated forms indicate fine grained substrate, while the coarsely agglutinated tests are typical for coarse grained sediments (Hada, 1957 в Boltovskoy et al., 1991). The differences in wall texture lead to differences in the test-shape in one and the same taxon (Boltovskoy et al., 1991).

The occurrence of infauna – lenticular or elongate compressed forms indicates a soft substrate allowing these forms to "slice" through sediment to obtain nutrients. Silty and muddy substrates are rich in organic debris and therefore attractive to foraminifers. Such conditions support large populations. Many of their species are thin-walled, delicate and elongate forms (Brasier, 1980). The hard substrate support sparcer populations and foraminifers from these conditions are thick-walled and heavily ornamented.

The occurrence of attached forms also suggests hard substrate (Murray, 1991). Characteristic genera of attached foraminifers are *Planulina, Patelina, Textularia, Cibicides, Cibicidoides, Gaudryina, Heterolepa, Bathysiphon*. Trochospiral attached forms have flat or slightly concave spiral side.

Water Energy

The study of modern agglutinated foraminifers of the so-called "flyh-type" or "A-type" from the Northwestern Atlantic showed that finely agglutinated small-sized and delicate tests are characteristic for low energy conditions and fine grained substrate. Conversely, coarse grained robust forms occur in high energy conditions (Schroeder, 1986, в Jones, 1988). Jones (1988) used this pattern in the paleoecological interpretation of the Upper Paleocene agglutinated assemblages from the North Sea. The results revealed that finely agglutinated small-sized forms (*Rzehakina, Rhizammina*) are characteristic for low energy conditions, which in this case were established at 1000-1500 m depth. Coarsely agglutinated robust forms (*Recurvoides, Psammosphaera, Bathysiphon, Hyperammina*) were established at 500-1000 m depth and they indicate highly energy environment.

Species diversity is another one indicator for the water energy. The occurrence of high species diversity suggests deep-water environment with stable low energy (Murray, 1979).

CONCLUSIONS

The presentation of the criteria and the possible ways of interpretation of the environmental parameters showed that small benthic foraminifera have considerable potential for paleoecological interpretation of data obtained from the study of the taxonomical composition and structure of foraminiferal assemblages. The significance of the interpretations increases in case of integration with paleoecological data from other groups benthic organisms, ichnofossils, as well as data from sequence and event stratigraphy, facies analysis, geochemical and mineralogical data.

The possible ways of paleoecological interpretations introduced in the present article come across some restrictions: 1) the precision of the interpretations decreases as the time distance increases because of the decrease of the resemblance between the species composition of modern and fossil assemblages; 2) the above mentioned criteria are based on quantitative methods which are not applicable in foraminiferal investigations in thin sections.

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