

MULTI-FACTOR ANALYSIS OF THE MARINE ENVIRONMENTAL INFLUENCE ON BENTHIC FORAMINIFERA, NORTHWESTERN BLACK SEA SHELF

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The geocological state of the continental shelf is often analyzed using the changes in geochemical characteristics of the water column and bulk chemical or xenobiotic composition of bottom sediments. No single indicator reflects the complex ecosystem interrelationships if it is not considered together with other attributes. Biotic components of the shelf control the physico-chemical environment and the concentration of substances in bottom sediments. The effect of toxic compounds on organisms is most evident in a disruption of biomineralization functions, so that the resulting morphogenetic indicators become the product of the effects of toxins on an active protein matrix. Therefore, areas of the NW Black Sea shelf (Fig. 1) that are under natural and anthropogenic stress exhibit a variety of morphological changes in foraminiferal tests. Morphogenetic attributes serve as objective evidence of the disruption in biomineralization functions of organisms and become integral indicators of the quality of the marine environment.

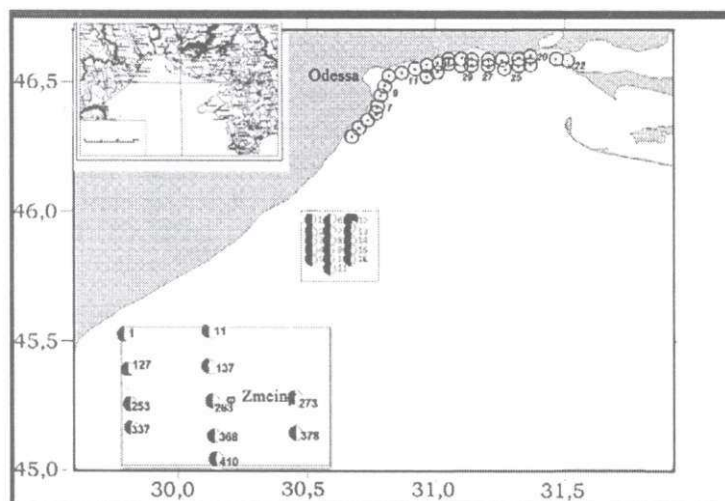


Figure 1. Studied area.

Methodology

The evaluation of the geocological setting of the shelf based on a unified methodology is provided by litho-geochemical and micropaleontological methods for determining the pollution and toxicity of bottom sediments. Seasonal changes in the distribution of heavy metals in bottom sediments and indicative attributes of benthic foraminifera in modern sediments of the Black Sea shelf have been investigated in the Dniester liman region, near Zmeinyi Island and the Danube River delta, and between Ilyichevsk Port and Dnieper-Bug liman during the 1997-1999 cruises of the R/V Argon and R/V Sprut. The dependence of the

development of marine organisms on the changing geoecological state was considered, from the general evaluation of the foraminiferal community state to fluctuations of various attributes within individual organisms. The distribution parameters, as well as correlative links between the attributes, were determined using primary statistical analysis. The second stage focused on the results of factor and cluster analysis.

Factor analysis was applied to assess multiple dependencies between random values which reflect the chemical environment and distribution of foraminifera. This method is based on the transformation of initial data into primary components, which are independent from one another and contain specific information. Cluster analysis relates to mathematical methods of classifying geological objects (Kogan *et al.* 1983). The primary goal is to group objects or observations according to the most substantive properties. The classification procedure includes derivation of coefficients of similarity or contrast between all possible pairs of multivariate observations. Grouping of the objects into clusters is presented by hierarchical trees (dendrograms).

Results

Factor analysis was used to investigate multivariate links of the community state of benthic foraminifera with various parameters of bottom waters and sediments. The grouping of attributes is obtained in two variants, which differ by the number of active factors along the Dniester-Danube shelf. The interconnections between measured attributes is most fully characterized by four factors that control the ecological setting of the two areas.

The first group is strongly influenced by the factor controlling the accumulation of the terrigenous sediment fraction. Its contribution is corroborated by high positive loading of Fe (0.99), Cr (0.96), Ni (0.95), Co (0.95), Zn (0.86), and Mn (0.94). These elements form a stable geochemical association in the solid phase of bottom sediments. Similar conditions lead to accumulation of organic carbon (0.74) and liquid carbohydrates (0.79) in sediments. In addition, Factor 1 is distinguished by a strong negative correlation with the presence CaCO₃ (-0.80) in the sediment and oxygen content (-0.75) of bottom waters. The observed correspondence fully reflects the role of solid discharge in sedimentation processes when oxygen consumption increases with increasing organic content, whereas biogenic carbonates cause a dilution in the bulk content of terrigenous components. При выборе трех факторов положительная нагрузка повышается до значимых величин. The influence of the first factor on the survival of foraminifera (0.36) increases by using three factors (0.49), which indicates the lack of negative influence of terrigenous discharge on the development of foraminiferal communities.

Factor 2 combines the next most influential group of attributes related to the development of sulfidization and morphological disruption of foraminiferal tests. The high positive loading is attributed to the indicators of the degree of sulfidization (0.80), the degree of morphological changes in organisms (0.50), as well as the content of phosphates (0.86), nitrates (0.86), and nitrites (0.85) in the bottom waters. The direct influence of abiotic environmental attributes on the disruption of physiological functions of organisms is conditioned by the peculiarities of the shelf evolution (Kravchuk 2002). The activity of Factor 2, which is linked to increased nitrogen and phosphorus content in the bottom waters, is related to the manifestations of the syndrome of anthropogenic or cultural eutrophication. The consequences of such events are reflected in the instability of development of benthic foraminiferal communities (sulfidization and higher frequency of phenodeviants).

Factor 3 combines three parameters of the water column, which lack meaningful correspondence with other properties. The similarity of the factor loading values reflects a direct dependence of bottom water salinity (-0.93) on water depth (-0.79). The pH values of bottom waters are characterized by positive factor loading (0.75), which signifies the decrease in hydrogen markers with increasing water depth or salinity. A possible reason for low ecological informational value of Factor 3 is the insufficient environmental stability during the investigation of the water column.

Factor 4 reflects the most interesting group of interconnections of the analyzed attributes. Loading of the same sign combines the degree of foraminifera survival (-0.48) and the organic carbon content of vegetative origin in sediments (-0.85). The presence of accessible nutrients in the form of non-mineralized organic matter (chlorophyll and other products of the breakdown of plant matter) is the favorable condition for the preservation of species diversity of benthic foraminifera. An important role in the analysis of the geoecological setting is the assessment of the biogeochemical role of specific chemical elements. Multiple links between sedimentary components were characterized on the basis of cluster analysis (Fig. 1).

Paragenetic relationships between chemical elements prior to the start of the summer season are complicated by the influence of a complete settling of suspended river load in the geochemical barrier zone of the Danube. The absence of a clear grouping of geochemical associations on the dendrogram (Fig. 2A) confirms the phenomenon of "homogenation" of the matter during the composite accumulation on the fluvial-marine barrier.

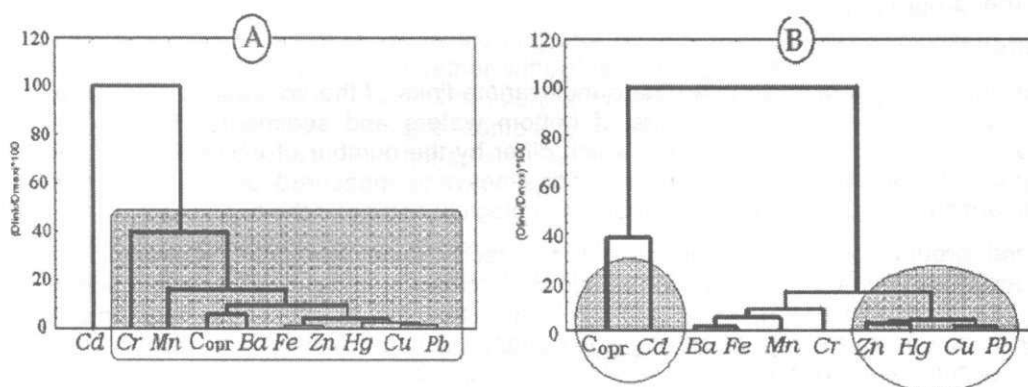


Figure 2. Rearrangement of paragenetic links of chemical elements in the bottom sediments of Danube delta as a result of season activation of geochemical processes (R/V Argon cruises: A – May 1997; B – September 1997).

The increased dynamics of migration at the end of the summer season are accompanied by structuring of geochemical associations in the bottom sediments. On the dendrogram in Fig. 2B, two clusters with the strongest multiple links can be distinguished. One of them includes the group of chalcophylic elements (*Zn, Hg, Cu, Pb*) and another combines a less uniform group of elements (*Ba, Fe, Mn, Cr*). The third cluster (*C_{org}* and *Cd*) occupies an independent position indicative of a limited coupled concentration with other sedimentary components.

The peculiarities of the cadmium behavior are explained by the conditions of its migration with the preponderance of reactive forms. The paragenetic link of cadmium with biogenic carbonates is most apparent within the Mussel field of the Danube delta (Kravchuk 1999; Svertilov *et al.*, 1999). Therefore, the most mobile and toxic forms of cadmium, which are unrelated to suspended river load, freely penetrate the geochemical "river-sea" barrier contour and undergo active biological consumption along the entire food chain from phytoplankton to benthic filter-feeders.

The assessment of indicator properties of benthic foraminifera on an ecosystem and population level includes the signatures of the degree of preservation of species diversity (survival), sulphidization, and morphological alteration of the tests. Anomalous deviations in test morphology can be traced in different parts of the shelf, which demonstrates the non-specificity of organism reactions to detrimental stresses.

Conclusions

The occurrence of benthic foraminifera along different sectors of the shelf is controlled by a complex interaction of natural and technogenic factors. Typically, the multiple links between the investigated parameters reflect the patterns within the ecological setting on the shelf, the most important being the following:

- 1) The geochemical setting on the continental shelf is characterized by a distinct partitioning of migration pathways of chemical elements. Along with element associations, which are localized in the terrigenous sediment fraction, there is a marked separation of metal groups, the mobile forms of which influence the state of benthic communities.
- 2) An integral indicator of the degree of survival in foraminifera characterizes the preservation of species diversity in benthic communities. The most prominent influence of toxic effects on benthic organisms during the summer reactivation of geochemical processes is related to accumulation of heavy metals in bottom sediments. This argument is based on the fact that accumulation of lead in sediments is unfavorable for the preservation of foraminiferal species diversity.

The leading limiting factor in the migration of dissolved matter is the process of bio-consumption. In the case of cadmium, we demonstrate the tendency of the most mobile toxic components to accumulate in carbonate shelf sediments. For the most part, benthic foraminifera serve their role in documenting short-term events related to seasonal changes in geochemical status and technogenic accidents on the shelf.

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