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Original Articles

Benthic foraminifera in a coastal marine area of the eastern Ligurian Sea (Italy): Response to environmental stress

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ABSTRACT

Benthic foraminiferal assemblages from 19 superficial marine sediment samples of a coastal area in the Ligurian Sea were analysed for benthic foraminifera in order to recognize changes in assemblage composition and structure, decrease of faunal density, increased morphological abnormalities and inclusion of heavy metals in carbonate tests as possible evidences of environmental stress. Also grain size was determined as a main factor conditioning foraminifer's distribution.

The generalized low faunal density was considered as indicative of environmental stress, attributable to the well-known natural Cr and Ni enrichment, which characterizes marine sediments of the region. The cluster analysis highlighted distinct foraminiferal assemblages with decreasing species diversity approaching to the coast. This distribution was interpreted as the result of local source of environmental stress, probably due to the stream contribution. Deformed foraminifera more abundant than background levels of unstressed environments were also recorded in 39% of samples.

Energy Dispersive Spectroscopy (EDS) analyses were carried out on carbonate tests of 55 specimens to investigate the role of the incorporation of heavy metals in the development of morphological abnormalities. Foraminifera showed the inclusion of heavy metals, not present in control specimens, indicating that environmental stress, due to metal sediment enrichment, plays a role in this phenomenon. Although anomalous elements were detected both in normal and deformed specimens and chambers, it was supposed that deformities develop as a result of the toxic effect of heavy metals on cytological activities because, contrarily to the normal specimens, all the deformed ones included anomalous elements. Higher occurrence of deformities in porcelaneous tests, typically enriched in Mg, is associated to the higher number of incorporated elements (Mn, Fe, Cu and Zn).

1. Introduction

Benthic foraminifera have been used since the 1960s as ecological indicators in marine environments (reviews in Nigam et al., 2006; Frontalini and Coccioni, 2011) due to their high density and species diversity, short life cycle and good preservation potential in marine sediments, which make them an ideal tool for characterization and monitoring of marine ecosystems (Gooday, 2003; Jorissen et al., 2007; Schönfeld et al., 2012). The response of benthic foraminifera to environmental stress, both under natural and anthropogenically-impacted conditions, has been deeply studied in the last decades. In particular, the response to trace element enrichment in marine sediments has been highlighted in study areas with different concentration levels; the change of taxonomic structure and composition, reduction of species diversity and abundance, increased development of abnormalities and change of test geochemistry were observed (Alve, 1991; Bergin et al., 2006; Frontalini and Coccioni, 2008; Cherchi et al., 2009; Martins et al., 2013; Li et al., 2014; Youssef, 2015, among the others). Besides, the anomalous inclusion of some trace elements, like as Cu, Fe, Pb and Zn, in the crystal lattice of deformed specimens from contaminated areas was recorded by several authors (Samir and El-Din, 2001; Frontalini et al., 2009; Romano et al., 2009).

Experimental and mesocosm studies considered the effects of a single metal, mainly Cu, Hg and Zn, on foraminiferal assemblages, demonstrating the causal effect of increasing metal concentrations on changes of community structure, lowering of foraminiferal density and

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diversity and increasing of abnormalities (Alve and Olsgard, 1999; Frontalini and Coccioni, 2012; Frontalini et al., 2018). In some cases, studies carried out on single species highlighted apparently contradictory results: *Rosalina leei* showed an increased number of morphological anomalies in treatments under higher Hg concentrations (Saraswat et al., 2004; Nigam et al., 2009), while *Pseudotriloculina rotunda* did not show deformations at the highest Zn concentrations (Nardelli et al., 2013, 2016). On the other hand, analyses of calcareous tests of benthic foraminifera exposed to increasing heavy metal (single or multi-element) concentrations recognized their linear uptake from the culture solutions to the carbonate test, but they did not record the presence of deformed specimens (de Nooijer et al., 2007; Munsel et al., 2010). For these reasons, the relationship between anomalous test geochemistry and development of abnormalities is still matter of debate.

The present study represents the first characterization of living and dead benthic foraminiferal faunas from the coastal zone of the East Ligurian Sea. It considers marine sediments characterized by natural trace metals enrichment, mainly for Cr and Ni, due to the presence in the mainland of ophiolitic sequences (Cosma et al., 1982). The research is finalized to highlight potential evidences of environmental stress in the foraminiferal assemblages attributable to sediment metal enrichment, pointing out the effect of the terrestrial contribution to the marine environment and its effect on biota. Species diversity and foraminiferal density were considered as potential indicators of environmental stress and reliable ecological proxies. Moreover, the investigation of carbonate geochemistry, by means of Energy Dispersive Spectrometry (EDS), was applied to detect the presence of trace metals in the test structure and to recognize their possible role in the development of morphological abnormalities. The improvement of knowledge about the abnormalities affecting foraminifera may be useful in the environmental assessment of trace metal enriched environments.

2. Study area

2.1. Geological setting

The Ligurian region is characterized by a complex geological framework due to the joining, in correspondence of the Sestri-Voltaggio zone, of Alpine (to the West) and Apennine domains (to the East). In the mainland of the study area, belonging to the Apennine domain, Jurassic ophiolitic sequence, covered by thick sedimentary units, outcrops (Elter and Marroni, 1991).

The studied marine area receives sedimentary contribution from the hydrographic basins of Entella and Gromolo streams (Fig. 1). The first one, flowing between Chiavari and Lavagna, drains extremely different lithologies, mainly constituted by flysch, alluvial, colluvial and eluvial debris deposits, ophiolitic lithotypes (peridotites, gabbro, jasper) and carbonate formation (Barsanti et al., 2003 and references therein). The second one drains ophiolitic units (serpentinites, gabbro, basalts), jasper, limestone and pelitic arenaceous turbidites (Dinelli et al., 2001). The diffuse presence of ophiolites has strong influence on the geochemistry of the territory, which is characterized by geochemical anomalies for Cr and Ni, very abundant elements in ultrafemic rocks such as peridotites and serpentinites (Ottonello, 2008). In the mainland facing the study area basin, waste materials produced by an iron/copper mine, which worked from 1864 to 1962, are partially crossed by two tributaries of the Gromolo stream, supplying contaminants in the water and river sediments (Dinelli and Tateo, 2002).

2.2. Marine coastal area

The littoral zone of the study area is mainly fed by sedimentary supply of the Entella stream and, only close to Sestri Levante, of the Gromolo stream. It is influenced by a permanent NW current flowing roughly along the coast and following the narrow shelf, with only short inversion time periods, while a SE gyre is generated by the presence of the headland; moreover, an eastward counter-current is present along the north coast with a resulting drift of the coastal materials from Entella stream to Sestri Levante area (Barsanti et al., 2003; Corradi et al., 2003; Doglioli et al., 2004). Along the coast, between the Entella mouth and Sestri Levante, several authors recognized a sedimentary deficit responsible for to the present erosive trend, mainly due to the building of the Chiavari and Lavagna harbours. A sedimentological study showed that coarse to very coarse sands are confined to the coast, with a seaward gradient, as a result of erosion and suspension by the rip-currents on the seabed, while the finer fractions settle in a more distal position, below 30 m water depth (Corradi et al., 2003). The main mineralogical components of marine sediments are calcite, plagioclase, potassium feldspar, quartz, chlorite, serpentine and mica/illite. The highest concentrations of serpentine were found close to the coast, identifying the transport by traction directed toward south-east, from the mouth of the Entella towards Sestri Levante, in agreement with the direction of the coastal drift (Barsanti et al., 2003).

At a regional scale, natural geochemical anomalies of Cr and Ni in marine sediments were attributed to the outcropping of ophiolitic sequences (Cosma et al., 1979). The geochemical study of marine sediments from sectors close to the studied one revealed natural enrichment mainly for Cr and Ni and, at a lesser extent, Cu and Mn, which is higher close to the mouths of streams crossing areas affected by the presence of ophiolitic lithotypes, as well as for Entella and Gromolo streams (Cosma et al., 1982). In particular, Cr and Ni showed concentrations up to 195 mg kg^{-1} and 154 mg kg^{-1}, respectively, at the mouth of Entella stream, where Bertolotto et al. (2005) recorded Cr concentrations up to 230 mg kg^{-1} in marine sediments. Capello et al. (2016), who investigated part of the study area, considered the high Cr and Ni concentrations (up to 384 mg kg^{-1} and 342 mg kg^{-1}, respectively) in agreement with the bulk chemistry composition of the rocks outcropping in the area.

3. Materials and methods

3.1. Sampling

A total of 19 surface sediment samples were collected in July 2015 by van Veen grab, at depth ranging between 2 and 28 m (Fig. 1; Table 1), because of the textural sediment characteristic. A volume of 50 cm^3, from the upper 2 cm layer of the undisturbed sediment, was collected directly from the upper windows of the grab and immediately stained with ethanol/rose Bengal solution (2 g l^{-1}) for the identification of living benthic foraminifera (Walton, 1952). An aliquot of 50 cm^3 was also collected for the analysis of grain size and the qualitative study of sediment mineralogy.

3.2. Sediment analysis

Samples were pre-treated with a solution of hydrogen peroxide (30%) and distilled water (1:3) to remove salts and organic matter, wet-separated into two fractions using a sieve with a 63 μm mesh and then oven dried at 40 °C. The coarse fraction (> 63 μm) was sieved using ASTM series sieves, with meshes ranging from −1 to +4 ϕ, while 2.5 g of fine fraction (< 63 μm) was analysed by means of laser diffraction granulometer (Sympatec Helos, FKV) after dispersion in a solution of sodium hexametaphosphate (0.05%). The sandy fraction was also observed under stereomicroscope in order to recognize the main components of biotic and abiotic fractions, useful to recognize sedimentary sources (Romano et al., 2009, 2016).

3.3. Benthic foraminiferal analysis

Samples were washed over a 63 μm sieve to remove staining solution and mud particles and then oven dried at 40 °C. Microfaunal