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Benthic foraminifera and trace element distribution: A case-study from the heavily polluted lagoon of Venice (Italy)

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ABSTRACT

Living benthic foraminiferal assemblages were studied in surface samples collected from the lagoon of Venice (Italy) in order to investigate the relationship between these sensitive microorganisms and trace element pollution. Geochemical analysis of sediments shows that the lagoon is affected by trace element pollution (Cd, Cu, Ni, Pb, Zn and Hg) with the highest concentrations in its inner part, which corresponds to the Porto Marghera industrial area. The biocenosis are largely dominated by *Ammonia tepida*, *Haynesina germanica* and *Cribroelphidium oceanensis* and, subordinately, by *Aubignyna perlucida*, *Ammonia parkinsoniana* and *Bolivina striatula*. Biotic and abiotic factors were statistically analyzed with multivariate technique of cluster analysis and principal component analysis. The statistical analysis reveals a strong relationship between trace elements (in particular Mn, Pb and Hg) and the occurrence of abnormalities in foraminiferal tests. Remarkably, greater proportions of abnormal specimens are usually found at stations located close to the heaviest polluted industrial zone of Porto Marghera. This paper shows that benthic foraminifera can be used as useful and relatively speedy and inexpensive bio-indicators in monitoring the health quality of the lagoon of Venice. It also provides a basis for future investigations aimed at unraveling the benthic foraminiferal response to human-induced pollution in marine and transitional marine environments.

1. Introduction

Over the last few years, many studies of benthic foraminiferal assemblages have been carried out in different parts of the world, in areas exposed to different kinds of marine pollution. Through these studies, a considerable effort has been made to develop new methodologies for the biological monitoring of different contaminants. Moreover, because of increased knowledge of the biology of foraminifera, these studies have revealed that benthic foraminifera have great potential as indicators of pollution, thereby providing one of the most sensitive and inexpensive markers of environmental stress in both naturally and anthropogenically stressed locations (Murray and Alve, 2002). More recently, a number of studies from different environmental settings have focused on the benthic foraminiferal response to trace element pollution, which has markedly increased over the last few decades, with deleterious effects on ecosystems (e.g. Alve, 1991; Yanko et al., 1994, 1999; Stouff et al., 1999; Coccioni, 2000; Samir and El-Din, 2001; Elberling et al., 2003; Armynot du Châtelet et al., 2004; Coccioni et al., 2003, 2005; Ferraro et al., 2006; Frontalini and Coccioni, 2008; Frontalini et al., 2009). These investigations have documented the fact that such contamination, which may result in pathological processes in the foraminiferal cell, plays an important role in the development of abnormal (teratological) tests, as well as in changes in foraminiferal abundance and taxonomic composition, size variation, and structural modification.

This study aims to document the living benthic foraminiferal assemblages in the affected lagoon of Venice, and relate these to the trace element pollution thereof.

2. The lagoon of Venice

2.1. An overview

The lagoon of Venice which is located at the northern extremity of the Adriatic Sea, is a marginal system with a surface area of about 549 km^2, an average depth of 0.6 m, and a tidal excursion of less than 1 m. It is connected to the Adriatic Sea by three inlets (Lido, Malamocco and Chioggia), thereby permitting water and sediment exchanges that are driven by the tidal cycle (Fig. 1).

The semidiurnal tidal cycle exchanges about 50% of the lagoon water with the sea during spring tides, and this is further reduced to 25% during neap tides (Silvestri et al., 2000). The annual average

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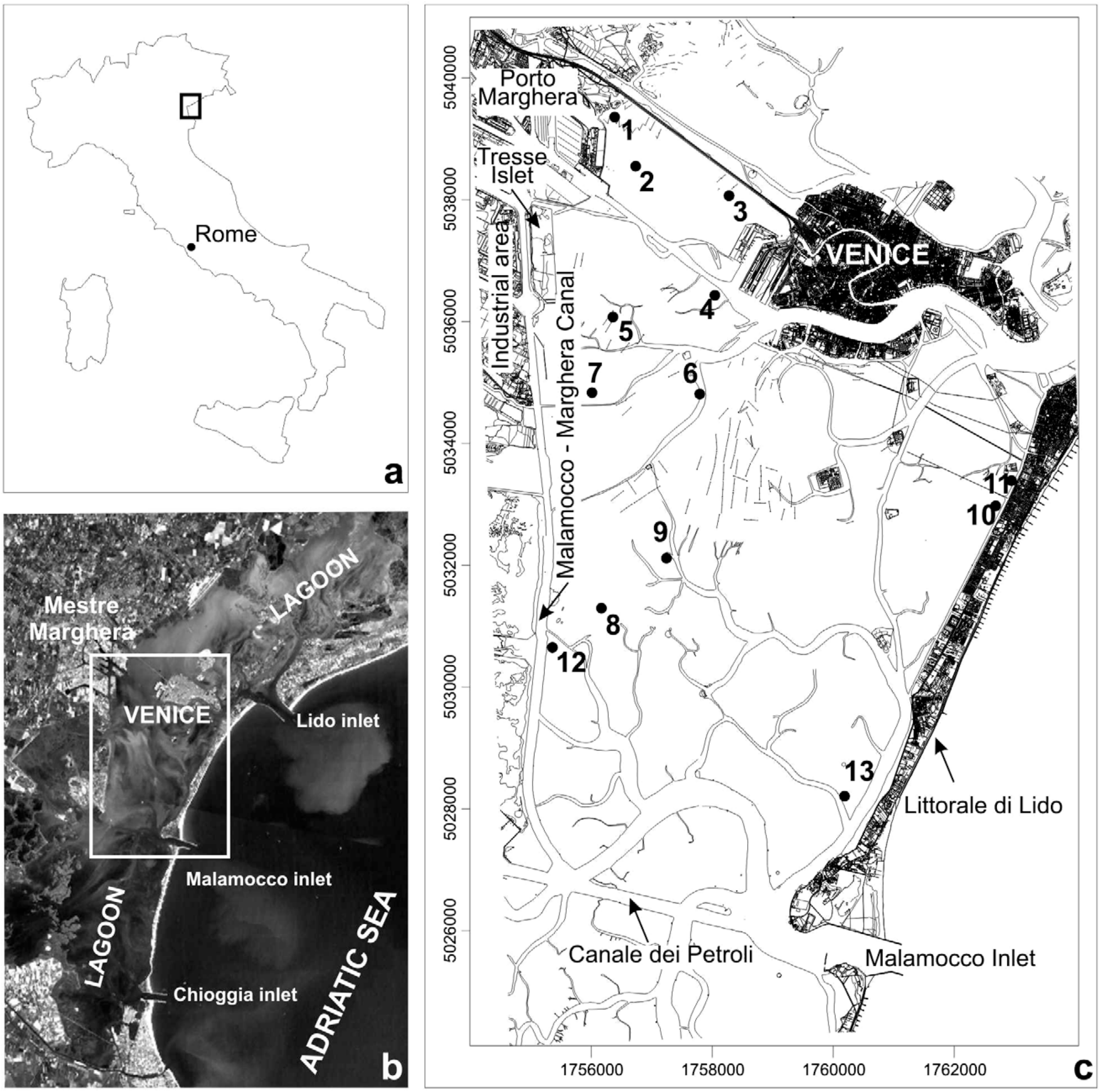

Fig. 1. Location map showing: (a) the location of the Venice lagoon; (b) satellite map of the Venice lagoon; (c) sampling stations (coordinates are reported in Gauss–Boaga).

temperature in the study area is 13.0–14.1 °C, reaching a maximum of 23.5–25 °C in the summer, and a minimum of 6.1 °C in the winter, with values sometimes approaching 0 °C, particularly in areas with minimum tidal flow. According to Marcello (1967), and Albani and Serandrei Barbero (1982), the salinity varies between 34.4–34.9‰ at high tide and 32.8–33.6‰ at low tide. The water dynamics are at their maximum at the inlets and within the main channels, and at their lowest close to the mainland. The complex morphology and hydrodynamics of the lagoon are determined by natural and artificial channels of varying depths, salt marshes, mud flats and small estuaries.

2.2. Pollution history

The lagoon is affected by inorganic and organic micro-pollutants from industrial sources (the Porto Marghera industrial centre, one of the key chemical districts in Italy and a well-known site of terrible human and environmental tragedy: e.g. Benatelli et al., 2002; Casson, 2007), municipal wastewater discharges (the urban areas of Venice and Mestre), agricultural drainage, atmospheric deposition and illegal dumping. The high organic matter productivity and the shallow and low water exchanges, especially in the inner part of the system, ensure that the sediment is the major and final host of many toxic substances. The frequent man-made sediment resuspensions (e.g. dredging operations, fishing gear used in clam harvesting and boating) may affect benthic and water column organisms. The contamination of the lagoon waters and sediments began in 1920 when at its border, and through the infilling in of 550 ha of marshes, the first industrial district of Porto Marghera was built. Industrial development accelerated in the 1930s with the construction of a second industrial area. The excavation of several channels has also deeply modified the hydrography of the central lagoon, thereby expanding the influence of the Adriatic Sea. Porto Marghera was one of the most important indus-