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Impact evaluation of the industrial activities in the Bay of Bakar (Adriatic Sea, Croatia): Recent benthic foraminifera and heavy metals

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ABSTRACT

The Bay of Bakar is one of the most heavily polluted bays at the Eastern Adriatic. Three major industrial companies potentially endanger the bay. The concentration of major, minor and trace elements in surface sediments from thirteen stations was discussed in relation to the sediment type and foraminiferal assemblages. The distribution of major elements in the bay is influenced by geological nature of surroundings. Heavy metal distribution depends on pollution sources and on amount of mud fraction: fine-grained sediments are enriched by them in comparison with coarse-grained ones. Different sediment quality criteria complicate the pollution assessment in the bay. Heavy metal concentrations generally fall into allowed depositional values for marine environments; only area in front of the coke plant and the City of Bakar harbor is heavily polluted. Stress-tolerant foraminiferal species dominate at stations with higher concentrations of heavy metals and coarse-grained sediments consist of larger number of epifaunal taxa.

1. Introduction

Anthropogenic activities like industry threaten the environment with the possibility of emission of various heavy metals, whose distinctive feature is their non-biodegradability. After the discharge, they redistribute in water in particulate and dissolved phases, precipitate or settle down in the sediment, accumulate in the organisms and are consumed by them (Fichet et al., 1998). Through biogeochemical processes of desorption and resuspension, they can be removed from the sediment and accordingly become the long-term source of the contamination (Fichet et al., 1998; Ouyang et al., 2006). The research on the Adriatic shelf revealed that the highest concentration of heavy metals is in the southern Adriatic and along the Italian coastal area, following the highest concentrations of clay minerals (Vdović et al., 1991). Contrary to this, the Eastern Adriatic sediments have very high concentration of carbonates and consequently low heavy metal content (Dolenec et al., 1998; De Lazzari et al., 2004), with local anomalies related to different types of anthropogenic activities (Ujević et al., 2000; Mikulić et al., 2004, 2008; Lovrenčić et al., 2005; Vreca and Dolenec, 2005; Valković et al., 2007; Obhođaš and Valković, 2010; Castelli and Kljajić, 2010; Cukrov et al., 2011; Obhođaš et al., 2006, 2012).

The distribution of benthic foraminifera in polluted marine environments has been the object of scientific interest for the last 50 years (Resig, 1960; Watkins, 1961; Botlovskoy, 1965), often emphasizing that foraminifera are one of the most responsive indicators available for the environmental monitoring of the pollution in the marine environments (Kramer and Botterweg, 1991). Numerous studies have been published in recent decades, focusing on the effect of different sources of pollution (urban organic waste, aquacultures, agricultural and industrial activities) on living foraminiferal communities (e.g. Alve, 1995; Yanko et al., 1998; McGann et al., 2003; Armynot du Châtelet et al., 2004; Bergin et al., 2006; Nigam et al., 2006; Bouchet et al., 2007; Carnahan et al., 2009). The majority of studies in the Adriatic Sea dealing with foraminifera as bioindicators of various anthropogenic activities are from the Italian coast (e.g. Donnici et al., 1997; Coccioni, 2000; Ferraro et al., 2006; Albani et al., 2007; Frontalini and Coccioni, 2008, 2012; Coccioni et al., 1997, 2009). There is only one study in the Eastern Adriatic that concerns the effect of pollution on foraminiferal communities, investigating the impact of organic pollution coming from fish farming (Vidović et al., 2009), followed by the updated and annotated list of determined foraminifera from the sea-bottom sediments (Ćosović et al., 2011). To the present day, there is no documented study dealing with the effect of industrial activities and associated heavy metals on foraminiferal communities in the Eastern Adriatic, which draw our attention to the need of carrying out such study.

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The aim of this research is to identify benthic foraminiferal community in the broader area of the Bay of Bakar and to study their abundance in relation with heavy metal concentrations in the sediments. For that purpose we analysed: (1) the abundance of major, minor and trace elements in polluted sediments, with a special regard to the trace elements, which are potentially toxic contaminants ("heavy metals"); (2) the distribution and concentration of heavy metals coming from anthropogenic sources; (3) the composition, diversity and distribution of total foraminiferal assemblages in the surface sediments; (4) the correlation (if any) among fauna and chemical properties of the sediment, all with the intention to make the assessment of industrial activities in the bay and to contribute to present cognition of environmental monitoring tools and practice procedures.

2. Study area

The Bay of Bakar is located in the northern part of the Eastern Adriatic coastal area, and is considered as one of the most heavily polluted bays along the Croatian part of the coast. Geological features of the broader area around the Bay of Bakar include deposits ranging from the lower Cretaceous to the top of the Quaternary: lower Cretaceous Limestone and breccias, upper Cretaceous limestones, dolomites and dolomite breccias, Eocene foraminiferal limestones and flysch deposits, Eocene–Oligocene limestone breccias and Quaternary diluvia deposits (Grimani et al., 1963; Šušnjar et al., 1970; Fig. 1). There are three major industrial companies with associated facilities located in the broader area of the bay: Oil refinery INA Urinj, Bulk cargo terminal of the Port of Rijeka and the area of the former Coke plant Bakar. Besides mentioned industries, the bay may be contaminated by discharges coming from small harbor and from domestic sewage.

The coastline of the City of Urinj due to its water depth is suitable for tankers up to 200,000 dwt. Oil refinery does not produce wastewaters, but possible oil spills represent potential danger for the environment (Đekić, 2005).

Bulk cargo terminal of the Port of Rijeka is intended for the transshipment of iron ores and coal. The terminal is modernized with novel transshipment equipment that reduces the emission of the dust (Dubrović, 2001).

The coke plant in the City of Bakar began with the work in 1978 and was closed in 1994. Within the coke plant 15 millions tones of coal had been processed, 11 tones of coke and 440,000 t of raw coal tar had been produced. During the activity of the coal plant, there had been unchartered emissions of raw coal, oil and naphthalene. The degradation of the equipment and the parts of the coke plant lasted from 1994 to 2001, while the chimney was torn down in 2005 (Nadilo and Sojčić, 2005).

Water well Dobrica is located near submarine spring which causes lower salinity in the neighbouring area. Similar environmental conditions are found at the rainfall drain and fresh water spring in the City of Bakar.

Thirteen localities in the broader area of the Bay were selected for the study (Fig. 1, Table 1): two stations in the area of the Oil refinery INA Urinj, the harbor of the City of Bakarac, the site with the rainfall accumulation in the City of Bakarac, water well Dobrica, the site of INA Urinj Petroleum decanter, two stations in the area of the coke plant, two stations at the Bulk cargo terminal, the rainfall drain in the City of Bakar and fresh water spring and sewage disposal in the City of Bakar. The reference station is located outside the bay.

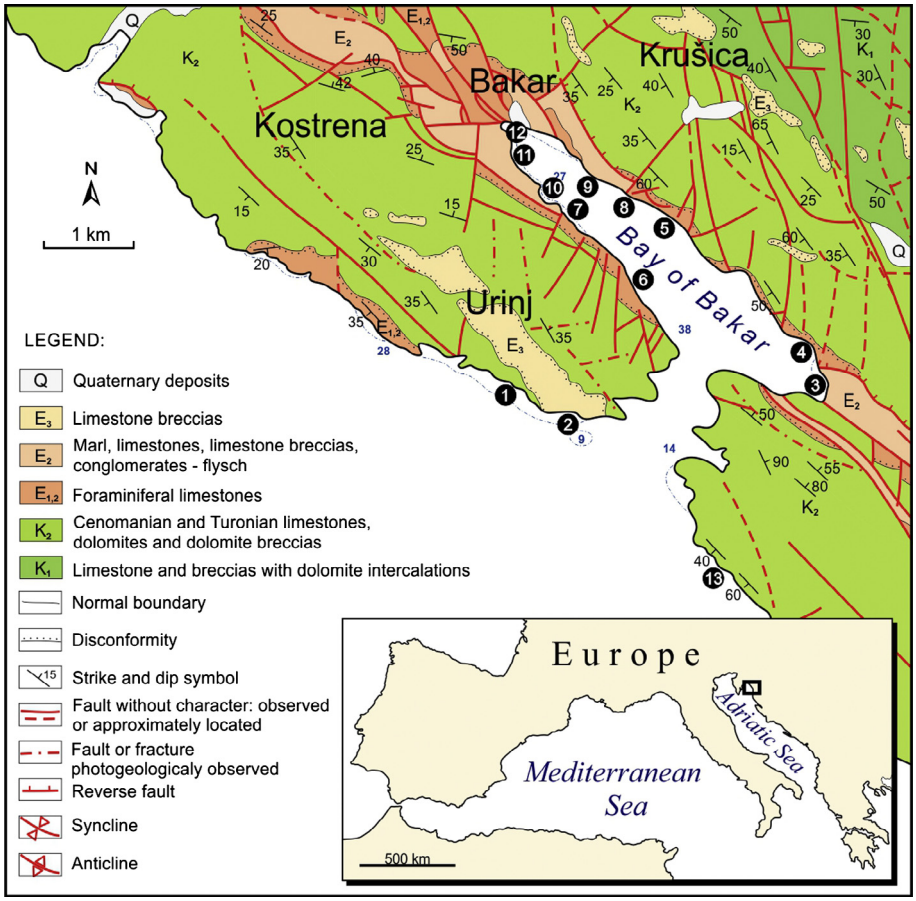

Fig. 1. Geological map of the study area with the positions of sampling locations.