Marine Pollution Bulletin 75 (2013) 114–125

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Benthic foraminiferal assemblages and trace metals reveal the environment outside the Pearl River Estuary

Tao Li[a,b,*], Rong Xiang[c], Tuanjie Li[b]

[a] Guangzhou Marine Geological Survey, Guangzhou 510760, People's Republic of China
[b] South China Sea Marine Engineering Surveying Center, State Oceanic Administration, Guangzhou 510300, People's Republic of China
[c] South China Sea Institute of Oceanology, Chinese Academy of Science, Guangzhou 510301, People's Republic of China

ARTICLE INFO

Keywords:
Benthic foraminifera
Population characteristics
Trace metal
Statistical analysis
Pearl River Estuary

ABSTRACT

We investigated the distribution patterns of the benthic foraminiferal assemblages outside the Pearl River Estuary in relation to trace metals, organic carbon and sedimentary particle fractions. The study area is unpolluted to moderately polluted by Cr, Cu, Pb and Zn and is completely polluted by Ni. The highest levels are found in the western coastal zone. Spatial distributions of the measured elements are strongly related to the behavior of the sedimentary clay fraction. The analyses of species abundance and community diversity as well as subsequent canonical correspondence analysis were used to reveal the relationship between foraminifera data and environmental parameters. Four sampling site groups established by factor analysis were distributed from the coastal area to the inner shelf. Their distribution patterns have a strong correlation with Cu, Pb and Ba. This research shows that benthic foraminifera can be used as bioindicators of trace metal pollutants outside the Pearl River Estuary.

1. Introduction

Sediment contamination by trace metals in estuaries and adjacent coastal areas has become an issue of increasing environmental concern. Such pollution is mainly caused by nonpoint source runoff and human activities, including industrial, domestic, agricultural, mining, fishing, shipping and other activities that produce waste containing metal residues. The massive amount of pollution has adverse effects on the marine ecosystem, is toxic to living resources and is hazardous to human health.

Benthic foraminifera are a powerful tool for the analysis and assessment of recent and ancient marine environments owing to their small size, abundance and well preserved shells (Murray, 2000). The distribution, abundance, and diversity of benthic forams depend on water depth, sediment texture and the physicochemical characteristics of sediments (Murray, 2006). Variation in any attribute can lead to a modification of the behavior and metabolism of individual species as well as the whole community. Previous syntheses of the foraminiferal community in polluted ecosystems have demonstrated that benthic foraminifera provide one of the most sensitive markers available for detecting coastal sediment contamination (Frontalini and Coccioni, 2011). These studies are mainly based on the attribution of different foraminiferal features to particular polluted sites by comparison with foraminifera detected in clean environments. Trace metals, which pollute the aquatic environment, are ultimately deposited on coastal marine sediments and impact foraminifera by modifying their community structure (Pati and Patra, 2012). In the majority of studies, a trace metal-induced environmental stress on benthic foraminiferal communities is measured via a correlation between biotic and abiotic data (Alve et al., 2009; Frontalini et al., 2009; Frontalini and Coccioni, 2008). The Pearson correlation coefficient, which is sensitive only to a linear relationship between two variables, is the most common tool for measuring the degree of correlation. However, the significance of such correlations is questionable if synergistic effects exist (Alve et al., 2009). Subsequently, multivariate approaches are used to distinguish the effect of the available pollutants from mixed influencing factors and allow for a quantitative evaluation (Eichler et al., 2012; Frontalini and Coccioni, 2008; Martins et al., 2010, 2013; Romano et al., 2008; Teodoro et al., 2010). Most studies have shown that foraminiferal assemblages in polluted areas have extremely low species numbers and diversity compared with those in non-polluted areas (Bergamin et al., 2009, 2005; Debenay and Fernandez, 2009; Elberling et al., 2003; Ferraroa et al., 2006; Samir, 2000; Schafer, 1973; Yanko et al., 1998). Nevertheless, an increased pollution level was reportedly the cause of an increased abundance of certain species, which is typical when species become tolerant to special trace metals (Alve and Olsgard, 1999; Armynot du Châtelet

* Corresponding author. Address: Room 412, Jidi Building, No. 188 Guanghai Road, HuangPu District, Guangzhou, People's Republic of China. Tel.: +86 020 82030197.
E-mail address: lukelitao80@163.com (T. Li).

0025-326X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2013.07.055

et al., 2004, 2011; Bergamin et al., 2009, 2003; Debenay et al., 2001; Foster et al., 2012; Frontalini and Coccioni, 2008; Le Cadre and Debenay, 2006; Romano et al., 2009, 2008).

This work aims to (1) identify the distribution patterns of benthic foraminiferal assemblages outside the Pearl River Estuary, (2) reveal the relationship between the spatial distribution of trace metals and the dispersion of sedimentary material, and (3) examine the variance of foraminiferal assemblages in relation to available environmental variables.

2. Study area

The Pearl River Estuary is located on the south coast of China and connects to the northern continental shelf of the South China Sea. Three principal tributaries, namely, West River, North River and East River, flow into the Pearl River (see Fig. 1a). The Pearl River is the largest river system of the South China Sea, and the annual water flow rate of this river is approximately 11,100 m^3/s (Wong et al., 1995).

The study area is located outside of the Pearl River Estuary and its surrounding coastal area. It extends from the offshore area of Shangchuan Island to Honghai Bay, covering an approximate area of 2×10^4 km^2, and the water depths range from 2 m to 100 m (Fig. 1b). Bathymetrically, this area can be divided into two parts: (1) the coastal marine area, which is shallower than 20 m, and (2) the inner shelf, which is deeper than 20 m.

The entire study area is mainly influenced by three different hydrodynamic systems: the Pearl River discharge, oceanic waters from the South China Sea and coastal waters from the South China Coastal Current (Yin et al., 2000). In winter, the northeast monsoon prevails, and the South China Coastal Current controls the coastal currents. In summer, the southwest monsoon dominates, and the interaction between the estuarine plume and the oceanic waters plays a leading role.

3. Materials and methods

3.1. Sediment sampling

Surface sediment samples were collected with a grab using a boat at 246 sites during the summer of 2005. The boat's sonar was used to measure the water depth, and a differential global positioning system (DGPS) was used to locate the sites (Appendix A). The surface sediment samples were collected at the selected locations. Only the top ~5 cm of sediment was retained for analysis. The bathymetry of the study area is shown in Fig. 1b along with the location of the sites selected.

3.2. Foraminiferal analysis

All samples were dried at 50 °C and weighed. Subsequently, the samples were gently washed through a 63-μm sieve with tap water to remove clay and silt. The residual fractions were re-dried at 50 °C and weighed to determine the mass of the mud fraction. Quantitative analyses on benthic foraminifera were performed on the fraction larger than 150 μm, and total foraminiferal assemblages were counted. The minimum number of specimens used in statistical analysis was approximately 100 for each sample. The counts were standardized as percentages.

Several parameters linked to the assemblages were calculated, including the species abundance (defined as the total number of individuals per 50 g of dried sediment), the species richness (number of species per sample), the Shannon–Weaver index $H(S)$ (describes the species diversity in a community) (Shannon, 1948), and the Fisher α index (measures the mean species diversity) (Fisher et al., 1943). The multivariate statistic software PRIMER v5 (Plymouth Routines In Multivariate Ecological Research) was used in the calculation of the $H(S)$ and the Fisher α index (Clarke and Gorley, 2001).

3.3. Trace metal and organic carbon analysis

The second set of samples was dried, reduced to a fine powder and used to determine trace metal contents in sediments. Wuhan Mineral Resources Supervision and Inspection Center (Ministry of Land and Resources, P.R.C.) analyzed a fraction of each sample (0.4–4 g) to determine the levels of 20 elements using an X-ray fluorescence spectrometer (PW2440 (MagiX Pro), Panalytical company, Holland). A series of geochemical standards were used as controls. In this work, only the concentrations of Ba, Co, Cr, Cu, Ni, Pb, Sr, V, Zn and Zr were evaluated. The detection limits for trace metals were Ba: 7.2 mg kg^{-1}, Co: 0.7 mg kg^{-1}, Cr: 2 mg kg^{-1}, Cu: 1 mg kg^{-1}, Ni: 0.7 mg kg^{-1}, Pb: 2 mg kg^{-1}, Sr: 0.8 mg kg^{-1}, V: 5 mg kg^{-1}, Zn: 2 mg kg^{-1}, and Zr: 1 mg kg^{-1}.

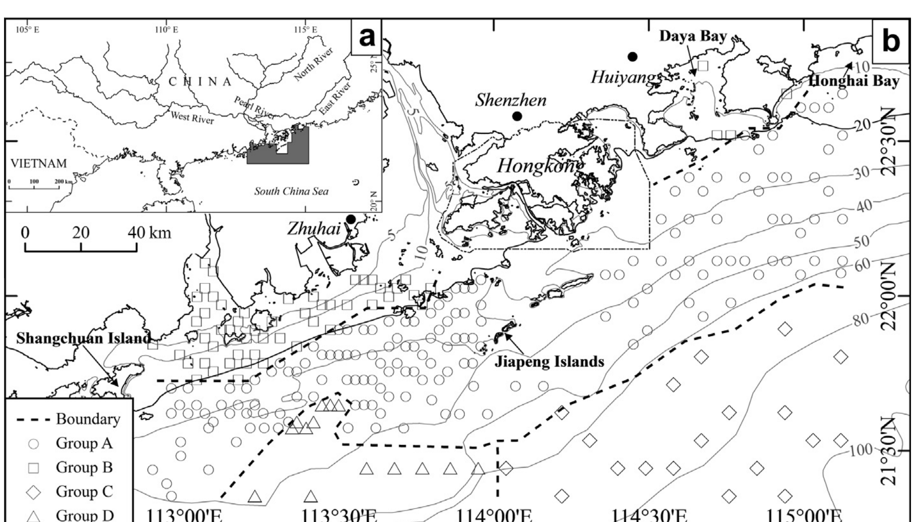

Fig. 1. Maps showing the study area (a) and the sampling locations (b). Site coordinates are included in Appendix 1. Samples are grouped based on the results of factor analysis.