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Research paper

Influence of trace metals in recent benthic foraminifera distribution in the Pearl River Estuary

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ABSTRACT

This work analyzed the distribution of trace metals and benthic foraminifera in the Pearl River Estuary and studied the influence of environmental parameters (i.e., trace metals, organic matter and sediment grain size) on the total (living plus dead) benthic foraminiferal assemblages. The results indicate that the distribution patterns of Co, Cr, Cu, Ni, Pb and Zn are strongly related to the behavior of the sedimentary clay fraction (kaolinite and illite) and are dispersed with sedimentary material, whereas Ba, Sr, V and Zr follow different trends. The study area is moderately to severely polluted with Co, Cr, Cu, Ni, Pb and Zn, and maximum values were found in the upstream and on the western side of the estuary, where the lowest levels of $H(S)$, Fisher α index and number of species are situated. Analyses of species abundance and community diversity, as well as the subsequent canonical redundancy analysis, were conducted to reveal the relationship between the foraminifera data and environmental parameters. Two assemblages were established by cluster analysis and were distributed in relation to bathymetry. The distribution of foraminiferal assemblages was mainly determined by Cu, Zn and Pb; while sand may exert an influence on particular species. *Ammonia tepida*, *Haplophragmoides canariensis* and *Elphidium nakanokawaense* are tolerant to the metal enrichment; while the abundances of the other species decline and are prejudiced. This study indicates that benthic foraminifera can be used as a bio-indicator of trace metal pollutants in the Pearl River Estuary and the results promote a better understanding of the response of benthic foraminifera to human-induced pollution in estuaries.

1. Introduction

Trace metals are among the most common environmental pollutants. Once released, these elements enter the hydrological circulation and are finally deposited in marine sediments. The accumulation of metal contaminants in sediments can pose serious environmental problems to the surrounding areas, as well as bio-assimilation and bio-accumulation of metals in benthic organisms, resulting in potential long-term implications on human health and local ecosystems.

Benthic foraminifera are a powerful tool for the analysis and assessment of recent and ancient marine environments due to their small size, abundance and well preserved tests (Murray, 2000). The distribution of benthic foraminifera is controlled by environmental gradients, and thus can be used to assess the level of environmental stress and pollution (Albani et al., 1995; Sen Gupta, 1999; Samir, 2000). Numerous studies have revealed that benthic foraminifera are particularly sensitive to trace metal contamination and are increasingly used in the monitoring of human-related trace metal contamination in coastal and marginal marine settings (Samir, 2000; Bergin et al., 2006; Ferraro et al., 2006; Carnahan et al., 2008; Frontalini and Coccioni, 2008; Romano et al., 2008; Bergamin et al., 2009; Coccioni et al., 2009; Frontalini et al., 2009, 2010; Martins et al., 2010, 2013).

The Pearl River Estuary (PRE) and vicinity are one of the most rapidly developing regions in China. With massive economic growth and urban development in the region since the 1970s (Huang, 1995; Wen et al., 1995), the discharge of waste into the estuarine and adjacent coastal environments has become a serious problem and has led to a significant increase in trace metal contamination (Lin and Liang, 1995; Li et al., 2000). The main sources of trace metal pollutants in the PRE include industrial wastewater, domestic sewage, marine traffic, and inflow from upstream mining sites (Chen and Zhou, 1992; Li et al., 2000). Earlier investigations demonstrated the spatial distribution patterns of trace elements in the modern sedimentary environment (Wen and He, 1987; Lin and Liang, 1995; Li and Zhu, 1996; Li et al., 2000; Zhou et al., 2004; Ip et al., 2007; Heise et al., 2010; Yu et al., 2010).

The earliest description of benthic foraminifera in the PRE dates back to the 1980s when researchers found that the western region of the PRE was characterized by the *Ammonia tepida* (reported as *Ammonia beccarii*)–*Elphidium nakanokawaense* assemblage (Wang et al., 1980).

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The most detailed analysis of benthic foraminifera in the PRE was reported by Li (1985) in a study that involved the examination of 209 grab samples and resulted in the establishment of three main assemblages. The descriptions of recent foraminifera in the PRE (also referred to as the Lingdingyang estuary) are also provided by Wang (1985), Li (1988), Chen (1989), Huang and Yim (1998), Luo et al. (2001) and Li et al. (2011). These previous studies assume that the assemblages are controlled by the water depth, salinity and sea-floor sediment type (Huang and Yim, 1998). Recently, Garrett (2010) linked the faunal data to selected environmental variables (i.e., salinity, water depth, total organic carbon, total nitrogen, $\delta^{13}C$, sand, clay and silt) and highlighted salinity as the most important factor in controlling foraminiferal distributions.

The current research aims to (1) identify the distribution patterns of benthic foraminiferal assemblages in the PRE, (2) reveal the relationship between the spatial distribution of trace metals and the dispersion of sedimentary material, (3) examine the variance of foraminiferal assemblages with respect to the available environmental variables (i.e., trace metals, organic matter and sediment grain size), and (4) improve our understanding of the influence of trace metals in benthic foraminiferal species and assemblage distribution in the PRE.

2. Study area

The Pearl River is the largest river system flowing into the South China Sea and consists of three principal tributaries: West River, North River and East River (Fig. 1a). The main PRE appears as an inverted funnel-shaped area with an N–S distance covering approximately 49 km and an E–W width varying from 4 km to 58 km. The sediment transported into the Pearl River Estuary primarily accumulates at the four river outlets (Hu Men, Jiao Men, Hongqi Men and Heng Men).

The study area is located in the PRE and its adjacent continental shelf. This area extends from Longxue Island to the Jiapeng Islands, covering an area of approximately 5×10^3 km^2, and the water depths range from 2 m to 50 m (Fig. 1b). Bathymetrically, this area can be divided into two parts: (1) an estuary with water depths <20 m, (2) a continental shelf with water depths >20 m.

The interactions of the river flow, tidal currents, and basin morphology determine the type of circulation in the estuary area. The distribution pattern of the mean current in the PRE occurs in the form of an anti-clockwise circulation, and seawater intrusion dominates the eastern side, whereas river outflow prevails in the western half (Mao et al., 2004).

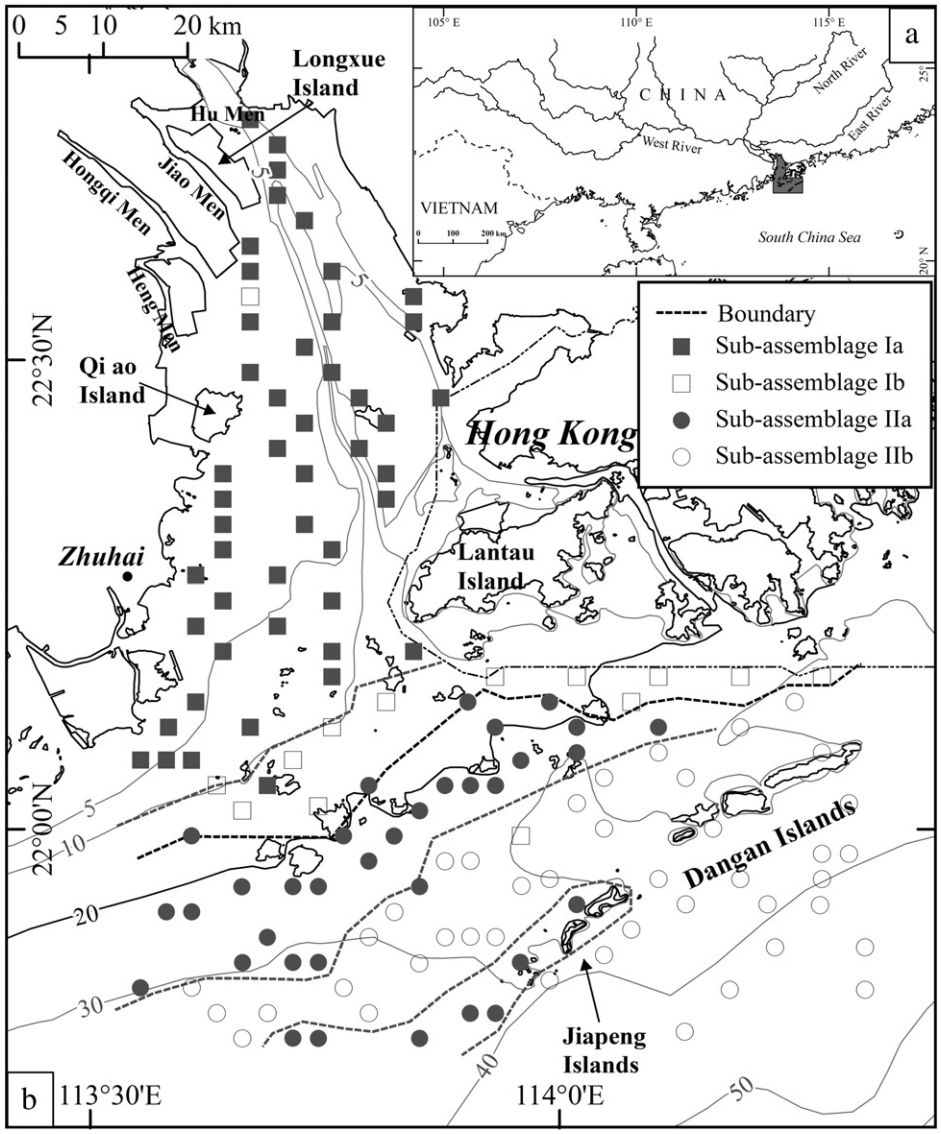

Fig. 1. Maps showing the studied area (a), and sampling locations (b). Site coordinates are included in Appendix 1. Samples are classified on the basis of Q-mode cluster analysis.