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Geochemical constraints on the provenance of surface sediments of radial sand ridges off the Jiangsu coastal zone, East China

Wenbo Rao [a], Changping Mao [a,*], Yigang Wang [b], Jinbao Su [a], William Balsam [c], Junfeng Ji [d]

[a] School of Earth Sciences and Engineering, Hohai University, No.1 Xikang Road, Nanjing 210098, China
[b] College of Harbour, Coastal and Offshore Engineering, Hohai University, No.1 Xikang Road, Nanjing 210098, China
[c] Department of Earth Sciences, Dartmouth College, Hanover, NH 03755, USA
[d] Key Laboratory of Surficial Geochemistry, Ministry of Education, School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China

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ABSTRACT

The Jiang harbor-centered radial sand ranges (RSRs) off the Jiangsu coast are the largest in the Yellow Sea. However, the provenance of the RSRs remains controversial. In this study, we compare major and trace element geochemistry together with grain size and main mineral composition in carbonate-free sediments from RSRs and potential sources. Onshore and offshore RSR sediments have different grain size characteristics: onshore RSR sediments have mean grain-sizes of <50 μm whereas offshore RSR sediments are between 50 and 160 μm in mean grain size. Despite these differences in grain size onshore and offshore RSRs have similar mineral compositions. Relative to upper continental crust (UCC), onshore RSR sediments are enriched in SiO_2, TiO_2, Li and partly in Cs, Zn and some high field strength elements (Y, Zr, Nb, Pb and Th) while depleted in other elements. Offshore RSR sediments are complicated in geochemical compositions. Some of them have very high contents of high field strength elements, and others are similar to onshore RSR sediments. Onshore and offshore RSR sediments have different controlling factors of geochemical compositions: onshore RSR sediments are influenced by clay-size minerals whereas offshore sediments are controlled by heavy minerals. The identification of Zr/Nb and Ti/Zr vs. K/Rb shows that onshore and offshore RSRs seem to have similar sources. Their differences in grain size are a result of hydrodynamic sorting. The identification of elemental ratios reveals that sources of RSR sediments are variable in space and time and the inputs of the Chinese Rivers, especially the old Yellow River and the Yangtze River are still dominant but the effect of the Korean field cannot be neglected. Our findings also demonstrate the potential of elemental ratios such as Zr/Nb and K/Rb as tracer pairs for provenance of sediments in the Yellow Sea.

1. Introduction

Sand ridges are found in many coastal zones including Australia, America, Europe and Asia (Thom, 1983; Collins et al., 1995; Fitzgerald and Heteren, 1999; Wang et al., 1999). They usually develop as a response to sea–land interactions in continental shelf shallow seas, originating either from erosion of the sea bed, coastal erosion or fluvial input through bedload or suspended load transport. Their magnitude and dimensions are closely related to sea-level changes and hydrodynamic and sedimentary regimes (Dyer and Huntley, 1999). Sand ridges may be utilized not only as good archives to reveal coastline evolutions and related climate changes, but also as storm barriers reducing coastal hazards and even as a potential land resources to relieve the pressure of population. Because of the above-mentioned importance, sand ridges and particularly their provenance, have received considerable attention from scientists, engineers and governmental officials in recent years (Anthony, 1995, 2013; Li et al., 1999; Wang et al., 1999, 2012a, b; Yang et al., 2003a; Zhang and Wang, 2009; Wang and Wall, 2010; Martinelli et al., 2011; Xing et al., 2012; Arens et al., 2013; Jackson et al., 2013; Rosenbauer et al., 2013).

The Jiang Harbor-centered radial sand ridges off the Jiangsu coastal zone (Fig. 1), which are located between the old Yellow River and modern Yangtze River, trend north–south with a length of 200 km and a west–east width of 140 km. They are a unique geomorphological feature in the Yellow Sea and also one of the largest marine sand complexes in the world (Wang and Wall, 2010; Wang et al., 2012a, b). A few studies have been carried out on the provenance of the sand ridges off the Jiangsu coastal zone in the past several decades with the purpose of thoroughly understanding land–sea interactions and scientifically guiding land reclamation (Yang, 1989; Wang and Ke, 1997; Wang et al., 1999, 2012a; Li et al., 2001). For instance, Wang and Ke (1997) speculated that sediments were supplied to radial sand ridges mainly by the reworking of older delta sediments under the present hydrodynamics; Li et al. (2001) pointed out that sediments of the sand ridges initially came from the Yangtze River (Changjiang) and later mainly from the Yellow River (Huanghe) and partly from sea-floor

* Corresponding author at: Institute of Isotope Hydrology, School of Earth Sciences and Engineering, Hohai University, 1#, Xikang Road, Nanjing, Jiangsu, China.
E-mail address: maochangping@hhu.edu.cn (C. Mao).

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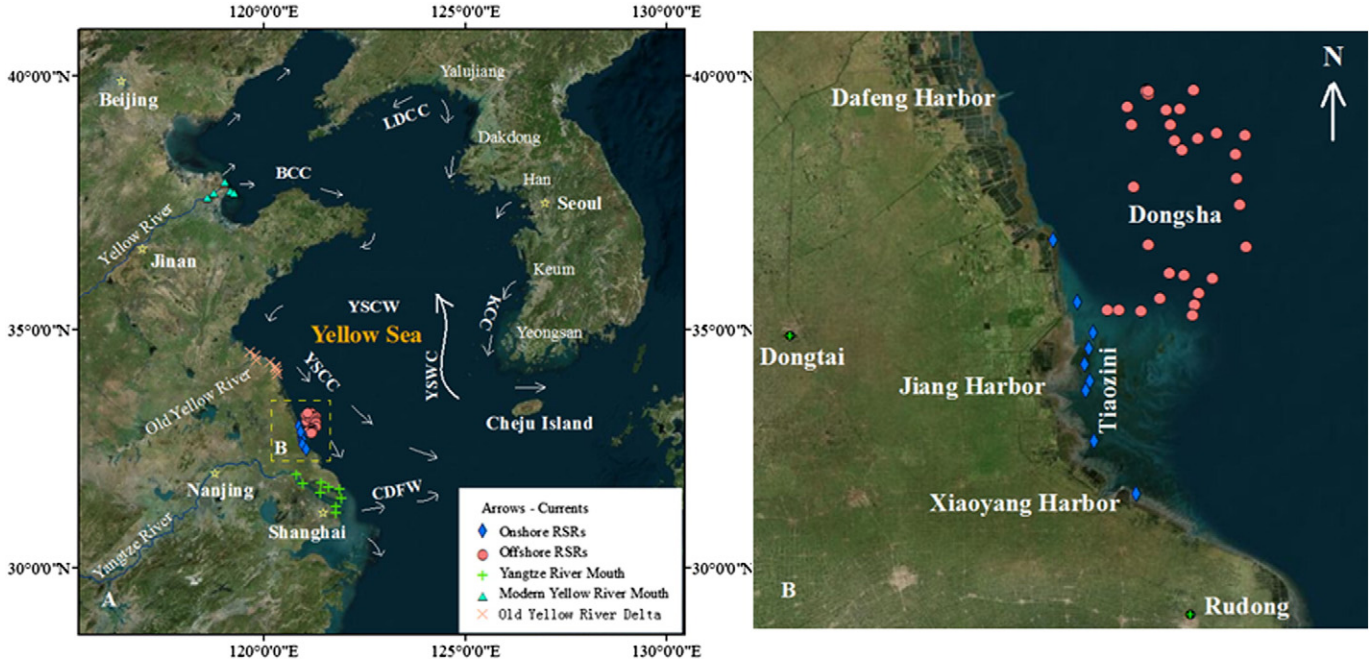

Fig. 1. Map showing study area and sampling locations. The modern current systems include Bohai Coastal Current (BBC), Liaodong Coastal Current (LDCC), Korea Coastal Current (KCC), Yellow Sea Coastal Current (YSCC), Yellow Sea Warm Current (YSWC), Changjiang diluted Freshwater (CDFW) and Yellow Sea Cold Water (YSCW) in the Yellow Sea (Ichikawa and Beardsley, 2002).

erosion; Wang et al. (1999, 2012a) suggested radial sand ridges originated from the old Yangtze River sediment during the late Pleistocene period and later were affected by the input of the Yellow River during the late Holocene and fine sand came more from the Yangtze River whereas clay material came more from the Yellow River. However, previous conclusions from various authors are not uniform and some conflict with each other on the provenance of RSRs, which is probably caused by (1) different study areas and objectives of different authors and/or (2) the large uncertainties of the methods used (Barnard et al., 2013). In addition, there are few published articles on the geochemical composition and the provenance of radial sand ridges off the Jiangsu coastal zone (Yang et al., 2002b) although geochemical methods, particularly elemental ratios, have more potential for tracing the sediment provenance and have been applied in the studied of marine sediments (Cho et al., 1999; Yang et al., 2004b, c, 2007; Youn and Kim, 2011; Lim et al., 2013).

The Yellow Sea is a typical epicontinental marginal sea surrounded by Korea and China and receives about 10% of the world's riverine sediment discharge from surrounding rivers (Milliman and Meade, 1983). Sediments of submarine (paleo)river deltas have been remobilized and transported by current systems in the Yellow Sea (Yang et al., 2003a). The semidiurnal tides of the Southern Yellow Sea cause tidal currents flow from north, northeast, east and southeast to the west coast of the Yellow Sea, eventually converging around Jiang Harbor. The most recent studies indicate that sand ridges are actively accreting (Wang et al., 2012a, b; Xing et al., 2012) and Jiang Harbor is a sediment sink. However, source variations of sediments of the sand ridges are impacted by changes in sediment flux and the pathways of rivers flowing in the Yellow Sea (Yang et al., 2005; Wang and Wall, 2010). The geochemical characteristics of sediments of radial sand ridges (RSRs) off the Jiangsu coastal zone are poorly known. In this study, we examine the geochemical composition of surface sediments of radial sand ridges off the Jiangsu coastal zone, explore the influences on sediment geochemistry, compare RSR geochemistry to that of potential sources and, using pairs of elemental ratios, attempt to identify the sources of RSR sediments.

2. Regional setting

The Jiangsu coastline is 954 km long from the mouth of the Xiuzhen River at the boundary with Shandong Province to the north bank of the Yangtze River. The coast is classified into three types by sediment composition: sandy coast, bedrock coast and silt-muddy coast (Zhang and Wang, 2009). Among these types of coasts, the silt-muddy coast is 884 km long and comprises about 93% of the Jiangsu coastline. Jiang Harbor-centered RSRs lie between the old Yellow River submerged delta and Yangtze River submerged delta and are typically muddy and silty (Fig. 1). The RSRs extend radially 200 km long in the north and south directions and are 140 km wide in the east and west directions with the water depth of 0–25 m; they cover an area of >20,000 km^2 (Wang and Wall, 2010; Wang et al., 2012a). The Jiangsu coast, which is located in a transitional belt from northern subtropical to warm temperate zones, is controlled by a monsoonal climate. The annual average temperature and the annual precipitation ranges from 9 °C to 15 °C and from 562 mm to 1100 mm, respectively. Northerly winds prevail in winter whereas southerly winds dominate in summer. Semidiurnal tides are predominant along the Jiangsu coast. The tidal wave is generally progressive in the southern part of the Jiangsu coast area when it moves into the Yellow Sea from the Eastern Sea whereas it forms an anti-clockwise rotating wave and continues northward due to blocking of Shandong Peninsula. Suspended sediment concentration of sea water is as high as 1.5 kg/m^3–3.0 kg/m^3 in the RSR area but is very low north and south of this area (Zhang and Wang, 2009). RSRs in some places of the Jiangsu coast zone were reclaimed for farming, fishery, salt production, wind plants, and harbor construction. The economic budget of tidal flat-developed resources increased by more than 9 billion RMB from 2001 to 2005 in Jiangsu alone. Along the Jiangsu coast there are plans to reclaim 260 km^2 of RSRs over the next several years from the onshore district (Tiaozini) and 400 km^2 from the offshore district (Dongsha) (Zhang and Wang, 2009).

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