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Magnetic and geochemical evidence of Yellow and Yangtze River influence on tidal flat deposits in northern Jiangsu Plain, China

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ABSTRACT

The formation of a broad tidal flat along the coast of the northern Jiangsu Province of China depends largely on the sediment supply from the Yellow and Yangtze Rivers although the relative contributions from each of these two large rivers remain uncertain. Knowledge of sediment sources to the tidal flat is critical for understanding the evolution of this muddy coast impacted by the large rivers. The present study focuses on tracking the sediment source of the tidal flat deposits based on sediment magnetic properties and geochemical analyses as well as statistical analysis. The study shows that sediments to the north of Yangkougang (site 9) have lower values of saturation isothermal remanence magnetization (SIRM), magnetic susceptibility (χ), demagnetization parameter S_{-100} ratios, lower Fe/Al values and higher Ca concentrations, while the opposite is true for samples south to Haozhigang (site 18). In addition, SIRM values of the <16 μm and >63 μm fractions generally display increasing trend from north to south. These results suggest that sediment sources rather than particle size variation are the dominant factors influencing the bulk magnetic properties. In light of the sediment composition comparison between the Yellow River and Yangtze River, factor analysis is used to identify sediment source of the tidal flat sediments. It is indicated that the Yellow River in its former course is the dominant supplier for sites to the north of Yangkougang (site 9), while the Yangtze River is the dominant supplier for sites to the south of Haozhigang (site 18). The coast between Yangkougang (site 9) and Haozhigang (site 18) is a transition zone influenced by both rivers. The inferred provenance contrasts are consistent with the pattern of coastal geomorphological evolution. Our data also suggest that sediments eroded from the former Yellow River delta have contributed to the evolution of the Yangtze Estuary in historical time. This study demonstrates that a combined magnetic and geochemical fingerprinting techniques in couple with statistical analysis is valuable for identifying sediment sources of tidal flats and deltas influenced by large rivers in the world.

1. Introduction

Tidal flats act as an effective barrier for coastal protection besides providing a basis for land reclamation, habitats and nutrient sources for wildlife, pollutant attenuation and attractions for tourism (Jickells and Rae, 1997). The progradation and/or accretion of tidal flats, and hence the multiple services they provide, are dependent on sediment influx and deposition. This becomes especially important under a setting of reduced fluvial sediment delivery and possibly continuing sea level rise (Syvitski et al., 2005, 2009; Walling, 2006). Where there are multiple sources of sediment supply, knowledge of sediment sources is critical for proper coastal management and sustainable development.

Along the coast of Jiangsu Province in China, a 884 km long, continuous stretch of tidal flat is well developed between Lianyungang in the north and Qidongzui in the south (Fig. 1), with the width ranging from several kilometers to tens of kilometers (Ren, 1986; Wang and Ke, 1997). A 4530 km^2 of United Nations Educational, Scientific and Cultural Organization (UNESCO) biosphere reserve was designated in the northern part of the coast in 1992. The middle section of the tidal flat is sheltered by extensive offshore radial sand ridges (Fig. 1). The sources of sediment for such a huge depositional system have attracted much attention in the past several decades (Ren, 1986; Li et al., 2001; Wang, 2002). It is generally agreed that a large amount of sediment to the Jiangsu coast is supplied by the Yellow River in the north and the Yangtze River in the south because these two largest rivers in China deliver an annual average load of 10.8×10^8 and 4.78×10^8 metric tonnes of sediments into the sea, respectively (Milliman and Meade, 1983). Although the Yellow River currently discharges into the Bohai Sea in the north, it followed a more southerly course from 1128 to 1855 AD, resulting in rapid progradation of the coastline by as much as 90 km beyond the sea dyke built in the 11th century (Zhang, 1984). With the northern shift of the Yellow River, the tip of the delta was eroded, but the coast to the south of the delta still prograded due to the southward

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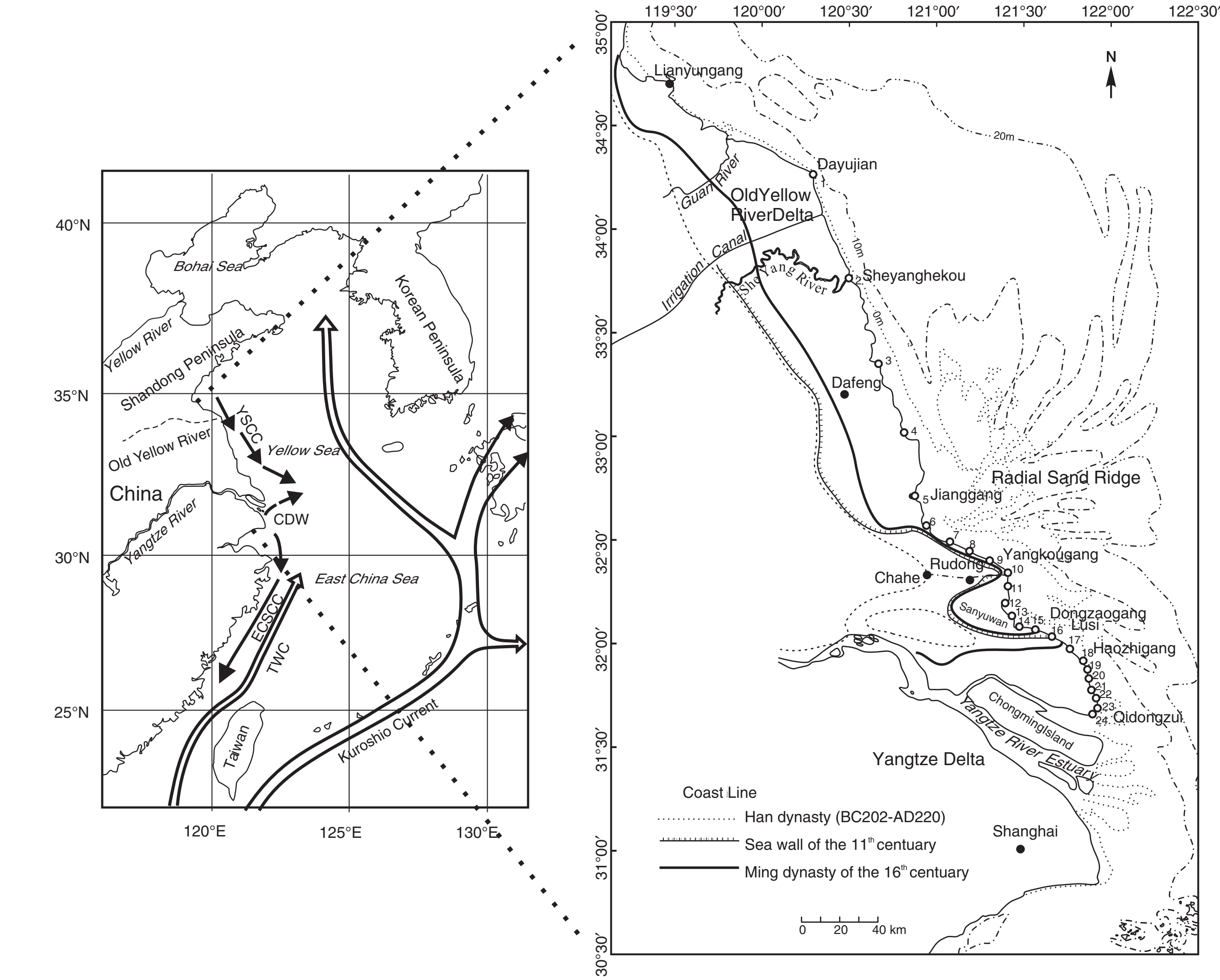

Fig. 1. Study area and sampling sites. The left panel indicates regional surface currents (modified after Yang et al., 2003), which are Yellow Sea Coastal Current (YSCC), Taiwan Warm Current (TWC), Changjiang (Yangtze) Diluted Water (CDW), and East China Sea Coastal Current (ECSCC). The historical shift of shorelines in the right panel is after Zhang (1984), and the northern boundary of paleo-Yangtze Estuary 2000 years ago is after Chen (1957). The open circles mark the 24 sampling sites.

transport of eroded deltaic material. The southern part of the coast (south of Yangkougang, Fig. 1) was formed through the infilling of the paleo-Yangtze River incised valley during the Holocene (Yan and Xu, 1993; Li and Wang, 1998), and therefore comprised a northern arm of the present Yangtze River delta. It has been suggested that the tip of the northern bank of the Yangtze Estuary was located at Chahe approximately 2000 years ago, migrating southward to Lüsi during the 11th century, and to the present position at Qidongzui in the early 20th century (Fig. 1; Chen, 1957). Although the sequence of changes in the coastline since the 11th century has been well established, the question about sediment sources remains the subject of much debate and interest. For example, Wang (2002) suggested that the sand ridge neighboring Jianggang might be primarily composed of sediments from the Yangtze River in late Pleistocene age when the Yangtze River entered the sea at Jianggang (Fig. 1). However, Li et al. (2001) suggested that the sediments north of Dafeng could be dominated by the Yellow River, whereas sediments south of Rudong by the Yangtze River, with sediments between Dafeng and Rudong comprising a mixture of the two (Fig. 1). Based on clay mineral assemblages, it is suggested that sediments north of Rudong are dominated by inputs from the Yellow River whereas those south of Rudong by the Yangtze River (Yi et al., 1988). However, Eisma et al. (1995) suggested that clay minerals from the Yellow River might pass southward as far as Qidongzui. Nevertheless, it should be noted that clay mineral analysis provides information only on the finest fraction (i.e., <2 μm) of the sediments.

Magnetic minerals are ubiquitous components in sediments (Thompson and Oldfield, 1986; Verosub and Roberts, 1995; Dekkers, 1997; Maher and Thompson, 1999; Evans and Heller, 2003). The environmental magnetic method, which includes the characterization of the mineralogy, concentration, and grain size of magnetic minerals, has been widely applied to establish sediment provenance in diverse environmental settings (e.g., Thompson and Oldfield, 1986; Robinson et al., 1995; Yamazaki and Ioka, 1997; Jenkins et al., 2002; Hounslow and Morton, 2004; Watkins et al., 2007; Peters et al., 2008; Maher et al., 2009; Liu et al., 2010). In this study, building upon our previously published magnetic criteria for distinguishing the Yangtze and Yellow River sediments (Zhang et al., 2008), we aim to investigate the sediment sources to the tidal flats influenced by the world largest rivers — Yangtze River and Yellow River, using a combined magnetic and geochemical methodology, and provide insights into the evolution of intertidal zone and