Geomorphology 226 (2014) 300–311

Contents lists available at ScienceDirect

Geomorphology

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

Magnetic fingerprinting of hydrodynamic variations and channel erosion across the turbidity maximum zone of the Yangtze Estuary, China

Chenyin Dong [a,**], Weiguo Zhang [a,*], Qing He [a], Yan Dong [a,b], Lizhong Yu [a]

[a] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China
[b] Institute of Geographic Engineering Technology, School of Geographical Science, Nantong University, Nantong 226007, China

ARTICLE INFO

Article history:
Received 31 July 2013
Received in revised form 20 July 2014
Accepted 6 August 2014
Available online 15 August 2014

Keywords:
Magnetic properties
Particle size
Hydrodynamics
Diagenesis
Erosion
Yangtze Estuary

ABSTRACT

Magnetic measurements were conducted on surface sediments and suspended particles collected across the turbidity maximum zone of the Yangtze Estuary, in order to examine the spatial distribution of magnetic mineral assemblages and the factors responsible for this distribution. The results indicate that magnetic properties are dominated by ferrimagnetic grains. Bulk magnetic susceptibility (χ) and saturation isothermal remanent magnetization (SIRM) values show positive correlations with the proportion of the >63 μm fraction in the North Channel, while anhysteretic remanent magnetization (χ_{ARM}) is significantly correlated with the proportion of the <16 μm fraction in both surface sediments and suspended particles. Such a bimodal distribution of ferrimagnetic minerals in the sand and finer fractions is confirmed by particle size-specific measurements. Sediments in the North Channel have the highest χ and SIRM values but lowest χ_{ARM}/SIRM ratios, which is consistent with the coarsest particle size due to strong hydrodynamics, i.e. currents. Within each channel, χ and SIRM values are higher in sediments from shallower water depth due to energetic conditions resulting from waves. Compared with surface sediments, suspended particles have lower χ and SIRM values but higher χ_{ARM}/SIRM ratios due to lower sand fractions. The increasing trend of χ_{ARM}/SIRM of suspended particles along the pathway of sediment transport indicates weakening hydrodynamics from the inner estuary to the outer estuary. Diagenesis is another factor influencing magnetic properties in addition to particle size. Channel erosion leads to local exposure of buried sediments on the channel bed. As a result of a stronger diagenetic imprint, they show magnetic properties different from the recently deposited sediments. Our results indicate that magnetic properties cannot only indicate spatial variations in hydrodynamics, but also provide insight into sediment erosion/deposition processes. Combined granulometric and magnetic methods can therefore be used to interpret hydrodynamics and track changes in estuary morphology.

1. Introduction

An estuary, located at the interface between river and sea, is strongly influenced by the interaction of fluvial and marine processes (Uncles, 2002). Because of their geographical advantages and abundant resources, estuaries have been exploited extensively by human society for use, such as navigation channels, harbors, waste disposal and land reclamation. The erosional/depositional processes shape the morphology of estuary and its evolution, which is critical to sustainable resource use, environmental protection and coastal hazard remediation. Hence the study of hydrodynamics, sediment transport and morphological change of estuary has drawn considerable attention (e.g., Chen et al., 1988; FitzGerald and Knight, 2005).

It has been well documented that sediment particle size is sensitive to prevailing hydrodynamics (Visher, 1969), and analysis of particle size has been widely used to infer information about sedimentary environments and sediment dynamics (e.g., Gao and Collins, 1992; H. Liu et al., 2010; Rahman and Plater, 2014; Wang et al., 2014). Magnetic minerals, which can be sensitively characterized by magnetic measurements, are widespread in sediments. Therefore, magnetic properties of sediments have been used in the study of environmental processes, such as sediment tracing, hydrodynamic sorting and early diagenesis in a variety of environments (e.g., Bloemendal et al., 1988; Yu et al., 1990; Deng et al., 2004; Hatfield and Maher, 2008; Maher et al., 2009; Rowan et al., 2009; Ao et al., 2010; Hatfield et al., 2010; Mohamed et al., 2011; Dewangan et al., 2013). Among these studies, it has been found that particle size is an important factor affecting magnetic properties, even if the sediment source does not vary (Oldfield et al., 1985, 2009; Oldfield and Yu, 1994; Zhang and Yu, 2003). This is due to the fact that magnetic minerals span a wide range of size. The individual magnetic component with a specific size preferentially resides in the corresponding particle size fraction (Oldfield et al., 2009). Therefore different particle size fractions contain magnetic minerals of different sizes and amounts.

In aquatic environments, hydrodynamic variation can result in particle size sorting during the course of sediment transport and deposition (e.g., Friedman, 1967; Reading, 1996; Rahman and Plater, 2014).

* Corresponding author. Tel.: +86 21 62233406; fax: +86 21 62546441.
** Corresponding author at Chenyin Dong is studying at Department of Environment and Geography, Macquarie University, Sydney, NSW 2109, Australia.
E-mail address: wgzhang@sklec.ecnu.edu.cn (W. Zhang).

http://dx.doi.org/10.1016/j.geomorph.2014.08.008
0169-555X/

As a result, the dependence of magnetic properties on particle size has been used to infer sediment sources and hydrodynamics (e.g., waves, currents) in coastal and estuarine environments (Hatfield et al., 2010; Holden et al., 2011; Badesab et al., 2012; Gallaway et al., 2012). In the study of coastal deposits of the Point Pelee National Park, energetic waves and winds lead to the concentration of coarse ferrimagnetic minerals in the beach placer deposits (Hatfield et al., 2010). The selective concentration of magnetic minerals, due to tide-induced residual currents, was also observed in tidal channels of New Zealand (Badesab et al., 2012).

The Yangtze River is the third largest river in the world, and about half of the sediments are deposited in the Yangtze Estuary (Chen et al., 1988). Annual mean water discharge and sediment load from 1950 to 2000 was approximately 9.05×10^{11} m^3 and 4.33×10^8 t, respectively (Hu et al., 2009). However, the sediment load from the Yangtze River has decreased significantly since the late 1980s (Z. Yang et al., 2006; Wang et al., 2007; Xu and Milliman, 2009). Meanwhile, engineering works, such as the Deep Waterway Project (1998–2011), have significantly modified estuarine morphology, with the water depth of the North Passage (Fig. 1) increasing from 7 m to 12.5 m (Jiang et al., 2012). Sediment dynamics and morphodynamics within the estuary in response to the reduced fluvial input and estuarine works have thus attracted great attention in recent years (S. Yang et al., 2006, 2007, 2011; Li et al., 2012; Wang et al., 2013). Particle size analysis has been used to infer hydrodynamic variations and sediment transport in the estuary and its exchange with the neighboring continental shelf (e.g., H. Liu et al., 2010). In our previous works, we have studied magnetic properties of tidal flats in the Yangtze Estuary and continental shelf sediments off the estuary (Zhang and Yu, 2003; Zhang et al., 2007; S. Liu et al., 2010). These studies confirm that magnetic properties are strongly influenced by particle size. However, no studies have been carried out on magnetic properties of sediments in the estuarine channels.

Here we report on the magnetic properties of channel surface bed sediments across the turbidity maximum zone of the Yangtze Estuary. For better understanding of sedimentation dynamics in the estuary, suspended particles were also studied for comparison. The purpose is to explore the potential role of magnetic measurements in fingerprinting hydrodynamics (e.g., currents and waves) and sedimentation dynamics in estuarine environments, and therefore tracking changes in estuary geomorphology.

2. Study area and method

2.1. Study area

The Yangtze Estuary is a multi-channeled estuary with a three-level bifurcation. Four outlets, which are separated by islands or shoals, are present at the river mouth (Fig. 1; Chen et al., 1988). At present, about 95% of the water and sediment discharge is through the three outlets in the South Branch (Chen et al., 1985). In the South Branch, freshwater is almost equally discharged through the North Channel and South Channel (Mao et al., 2008).

Tides in the Yangtze Estuary are semi-diurnal, varying from 2 to 4 m in range (Chen et al., 1988). The flow pattern is almost rectilinear within the channels, and transformed into rotary currents at the seaward side of river mouth. Due to the larger freshwater discharge volume, the North Channel has a stronger fluvial flow influence than the South Passage and North Passage. Such a spatial variation of currents largely determines the particle size distribution of sediments (H. Liu et al.,

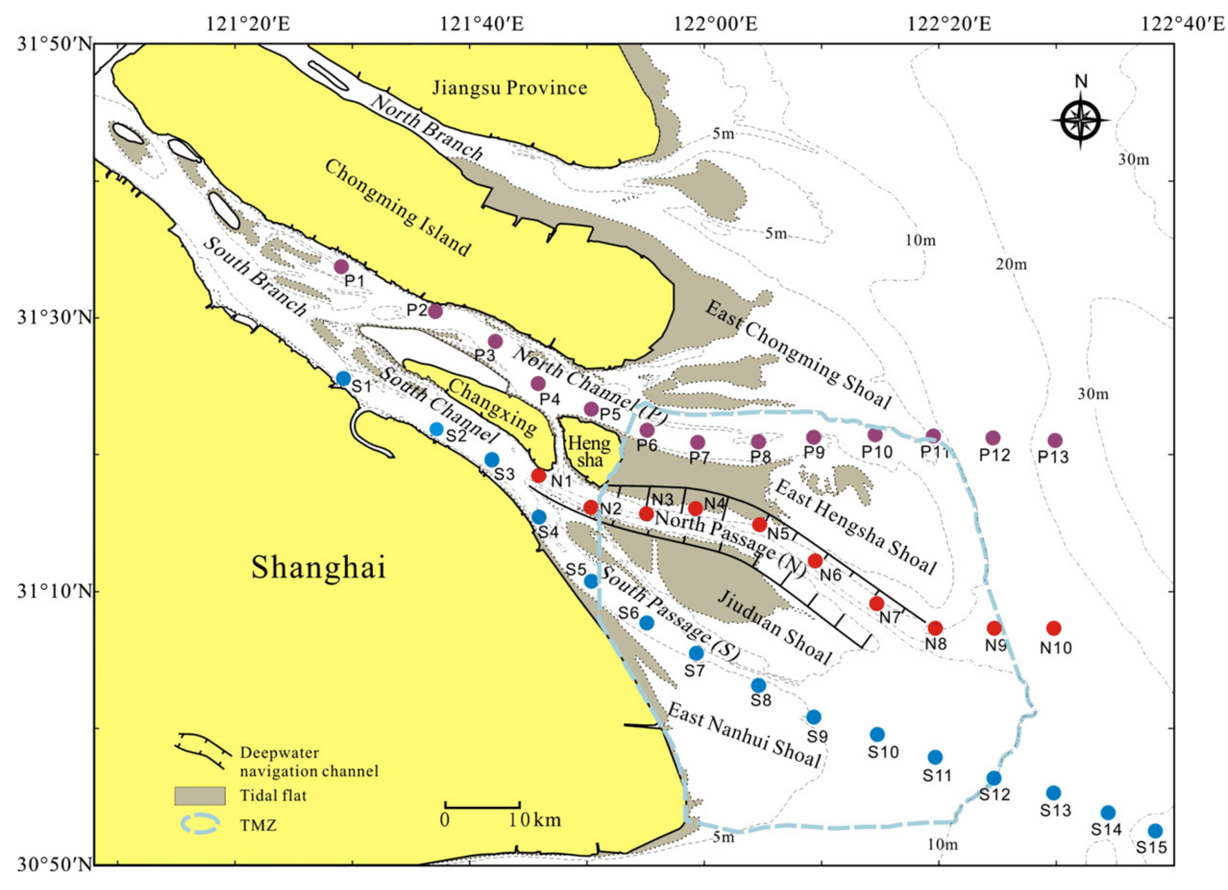

Fig. 1. Study area and sampling sites of surface sediments and suspended particles. The Yangtze Estuary is split into two branches (the North Branch and South Branch) by Chongming Island. The South Branch is further divided into the North (P) and South Channels by the Changxing Island and Hengsha Island. The South Channel has two outlets: the North Passage (N) and South Passage (S), which are separated by the Jiuduansha Shoal. The bold dotted line marks the boundary of turbidity maximum zone (after Shen and Pan, 2001).