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Magnetic properties of surface sediments from the Pearl River Estuary and its adjacent waters: Implication for provenance

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ABSTRACT

Environmental magnetism has been widely used as a rapid, cost-effective, and non-destructive method in various fields including sediment source identification. Nineteen surface sediments from ten transects in the Pearl River Estuary (PRE) and its adjacent seas were studied for magnetic measurements. Combined with mineral analysis for representative samples, magnetic implications for provenance are discussed. The results indicate that concentration-dependent magnetic parameters decrease gradually and change sharply between the PRE and its adjacent waters. The magnetic mineral assemblage is basically consistent at all sites, i.e. consisting of magnetite and hematite. However, the grain size of magnetite particles is clearly different probably due to different material sources. Magnetic parameters allow separating the sediments from the PRE and its adjacent seas into three groups, more distinctively than deduced from clay mineral analysis. These new findings indicate that magnetic properties of surface sediments bring complementary information of material source as well as marine geology.

1. Introduction

The study on provenance in the estuary-ocean area is not only an important field of sedimentology, but also directly related with the marine geological problems such as characteristics of seabed, marine evolution, ocean currents, etc. The South China Sea (SCS) is one of the typical largest margin seas. Its northern part receives sediments from various sources including the Pearl River (PR), the Red River, the Taiwan Island, and the Luzon Island (Liu et al., 2008). The contribution of these different sources to the sediments in the SCS has attracted much attention. Many researchers have attempted to identify the sediment provenances of the northern SCS using sedimentological, geochemical, and mineralogical methods (Shao et al., 2000; Zhang et al., 2002; Tang et al., 2009; Cai et al., 2010; Li et al., 2011; Yan et al., 2012; X.F. Zhang et al., 2012). Shao et al. (2009) analyzed Nd isotopic compositions of recent sediments in the northern SCS and found that materials from the PR mainly influence the southwestern area of the Lingdingyang to Dongsha Island. Ge et al. (2010) suggested that kaolinite within the northern SCS sediments mostly came from the PR, while illite and chlorite are sourced from the Changjiang River and the Taiwan Island. Z.F. Liu et al. (2007) analyzed clay minerals of surface sediments from the PR drainage basin and discussed their contribution to the SCS. They found that the clay mineral assemblage of the PR sediments dominantly consists of kaolinite, with less chlorite and illite, and very scarce smectite. They concluded that "the maximum contribution of clay minerals from the PR is 72% in the northern margin and only 15% in the northern slope of the South China Sea". Liu et al. (2010a) confirmed the clay mineral assemblage as an indicator of the PR input and suggested that materials from the PR were predominantly distributed in the area between the PR estuary and northeast of Hainan Island.

Magnetic methods have been widely used for researching paleoenvironmental evolution as well as modern environmental pollution due to its fast, economical and non-destructive application (Thompson and Oldfield, 1986; Evans et al., 1997; Maher, 2007; Su et al., 2015). Magnetic properties of marine sediments often provide reliable information on environmental change (Kumar et al., 2005; Sangode et al., 2007; Yang et al., 2008; Zheng et al., 2010). In particular magnetic concentration parameters such as magnetic susceptibility (MS) have become a kind of basic data for marine sediment research (Evans and

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Heller, 2003; Yim et al., 2004; Ghilardi et al., 2008; Mohamed et al., 2011). Identifying sediment provenances is one important application of magnetic measurements (Yu and Oldfield, 1989; Hatfield and Maher, 2009; Lyons et al., 2012; Larrasoaña et al., 2015). Though interpretation of magnetic features of marine sediments is complex due to various influencing factors such as terrigenous input and diagenesis of magnetic minerals, magnetic characteristics of marine surface sediments can be regarded as an effective means for identification of sediment provenance (Walden et al., 1997; Rotman et al., 2008; Nguyen et al., 2016).

Recently, magnetic data has been used to identify the origin of surface sediments in the SCS (Liu et al., 2010b). Many previous researches indicated that magnetic response to climate differed at different region of the SCS due to difference in magnetic properties of different sources and transportation pathways (Liu et al., 2003; Wang et al., 2009, 2010; Liu et al., 2010c). However, investigation of magnetic property and its provenance implication for estuary-ocean area along the SCS margin has not yet been reported but is clearly important for the magnetic-based paleo-environmental reconstruction and geological evolution of the SCS. The main purpose of our study is to investigate the similarities and differences of magnetic characteristics of surface sediments collected from the Pearl River Estuary (PRE) and its adjacent seas. Combing magnetic characteristics and mineral analysis, we aim to discuss the significance and effectiveness of magnetic methods to trace provenance features in the study area and thus provide a valuable tool for sediment source tracing of estuary-ocean elsewhere.

2. Materials and methods

2.1. Site characteristics

The Pearl River estuary (PRE) and its adjacent sea waters were selected as the study area of the present study. The PRE is in the warm and humid subtropical area of South China. The average annual rainfall and total runoff of the PR drainage area are 1600 to 2300 mm and 345.78 billion m^3, respectively. Though the suspended sand concentration of the PR is relatively low, the PRE annually discharges about 64 million tons of suspended sediments and more than 0.1 billion tons of total sediments into the SCS from its eight outlets. The PR suspended sediments are the main material source of the study area (Mo and Chen, 1986; Lan, 1996; Long, 1997). However, recent studies indicated that the sediment source of the study area differs at different water depths (Zhou et al., 1991). The eastern four outlets named Humen, Jiaomen, Hongqimen and Hengmen pour waters into a trumpet-shaped estuary called Lingdingyang, which is referred to the PRE in the present study (Fig. 1). The unique topographic features of the PRE are formed under the interaction of river runoff, tidal current, geological structure and geographical factors (Song and Ruan, 1986). The runoff from the East River and North River and part of the runoff from the West River discharge into the SCS through the mentioned four gates. Meanwhile, the Pacific Ocean tidal wave enters into the SCS through the Bashi strait and then spreads across each entrance of the PR. Naturally, two deep grooves in the East and West and three shoals in the East, middle and west were formed within the Lingdingyang waters. Due to the effects of differences in sediment source amount and dynamic conditions, a development pattern characterized with rapid expansion of Western shoal, constriction of the west groove, northwest-southeast elongation of the central shoal, little water depth changes and slight constriction of the East groove, and basically stable of the eastern shoal has been formed (Dong, 1986).

According to the results of hydrological survey of the PRE coastal area, the hydrological characteristics of this area is the result of the two main dynamic factors of runoff and tidal current as well as the influence of other factors, such as the outlet flow system and the wind field. The east wind and east or north wind dominates the PRE coastal area during flood and dry seasons, respectively. The maximum wind speed of this area is 4.0 to 9.9 m/s (Mo and Yan, 1986). The reciprocating flow dominates the thalassic area and coastal current and rotational flow interacts at the waters between the bay mouth and the 20 m water depth isobaths. At the Lingdingyang waters, a strong tidal current and a significant influence of runoff affects the eastern and western areas, respectively (Department of Coastal Hydrology, 1986). According to the result s of sediment test of the Lingdingyang closed area, total deposition dominates this area at both flood and dry seasons (Yang, 1986). Mo and Chen (1986) suggested that the main sedimentary characteristics of the PRE was that the particles ranged from relatively coarse, fine, and gradually coarse from estuary, coastal shallow water area, to the outer waters.

2.2. Sampling

Nineteen surface sampling stations with 14 in the estuary and 5 in the shelf were selected for the present study (Fig. 1). According to previous mineral analysis performed by Z.F. Liu et al. (2007, 2008), sediments at sampling sites A9 and A8 mostly come from the Pearl River (52%), and some smaller fractions from Taiwan (29%) and Luzon (19%). The contribution of the PR, Taiwan, and Luzon to the area of sampling sites A7, A6, and A5 are 31%, 23%, and 46%, respectively. The samples from the PRE were collected in autumn 2010 by using grabbers. Sediments from the adjacent sea were collected in summer 2009, using a box corer. The samples are distributed from the shallow estuary with 2 m water depth to the outer shelf with water depth up to 102 m. All samples were freeze dried before performing measurements.

2.3. Mineral and magnetic analysis

Mineral analysis is a widely used method for provenance identification in the study area. In our study, mineral composition analysis was performed for nine representative samples using a BRUKER D8 ADVANCE X-ray diffractometer (XRD), Cu (monochrome).

A suite of mineral magnetic analyses were performed for all samples in order to determine magnetic concentration and magnetic grain size (i.e. magnetic domain state). Magnetic susceptibility (MS) and temperature variation of MS (κ-T curves) were measured at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. All other magnetic measurements were performed at the Department of Geosciences, University of Tuebingen.

Low (976 Hz) and high (15,616 Hz) frequency MS (mass-specific χ_{lf} and χ_{hf}, respectively) were measured using a Kappabridge MFK1-FA (AGICO). Frequency dependent MS was calculated from the expression χ_{fd} (%) = $[(\chi_{lf} - \chi_{hf}) / \chi_{lf}] \times 100$. Variation of MS with temperature (κ-T curves) was measured using CS4/CSL high and low temperature units attached to the MFK1-FA for both bulk samples and magnetic extracts of representative samples. Anhysteretic remanent magnetization (ARM), expressed as susceptibility of ARM (χ_{ARM}) in this paper, was imparted with an AF peak field of 100 mT and a DC biasing field of 0.1 mT using a 2G Enterprises 755 cryogenic magnetometer with attached degausser system. Stepwise thermal demagnetization of triaxial isothermal remanent magnetization (IRM) (applied fields 1.0 T, 0.3 T, and 0.1 T) and alternating field (AF) demagnetization were performed using the 2G magnetometer with the degausser. Hysteresis parameters, which are helpful to identify the type and particle size of magnetic minerals (Day et al., 1977; Dunlop 2002; Zang et al., 2010), were measured using a MicroMag 2900 AGM, with a maximum applied field of 0.6 T. Isothermal remanent magnetization (IRM) acquisition curves with twenty-five steps up to 2500 mT were acquired using a MMPM9 pulse magnetizer and a Molspin Minispin magnetometer. Then IRM was measured at backfields of 100 mT and 300 mT, respectively. The IRM at an applied field of 2500 mT was regarded as saturation IRM (SIRM).