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Mineral magnetic properties of Holocene sediments in the subaqueous Yangtze delta and the implications for human activity and early diagenesis

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A B S T R A C T

This study examines the temporal and spatial distribution of magnetic properties in Holocene sediment cores taken from the subaqueous Yangtze delta, China, to evaluate depositional environmental changes including the sediment with an anthropogenic provenance and changes in the bottom-water chemistry. Our approach is to compare the magnetic properties in Holocene cores with those from a suite of surficial sediment samples taken at various locations from the Yangtze delta and the adjacent continental shelf. The results indicate that the magnetic properties in sediment cores change generally with sedimentary facies, mainly due to their in-phase changes with sediment grain size and redox conditions, but that they have also been significantly altered by effects of human activity and early diagenesis. Magnetic parameters that exhibit soil erosion associations show remarkable increases over the past ~800 years, reflecting an increase in the terrestrial supply of fine-grained magnetic minerals induced by the intensification of human activity in the Yangtze River catchment. Early diagenesis was strong in core HZK8, located at the depocenter of the subaqueous Yangtze delta, including dissolution of fine-grained ferrimagnetic minerals and the precipitation of authigenic greigite and pyrite, as evidenced by both room-temperature and thermo-magnetic analyses. The dissolution of ferrimagnetic minerals coincides with changes in sedimentation rate at different sites and time periods, suggesting that this factor is important for controlling the rate of early diagenesis. Authigenic iron sulfides suggest the function of sulfate-reducing bacteria, which implies a hypoxic environment at this site from ~6000 cal. yr BP.

1. Introduction

Sedimentary magnetic properties reflect the content, species and grain size of magnetic minerals and are useful for identifying depositional environments (Oldfield, 1991). In our previous work (Pan et al., 2015) we investigated the magnetic properties of surficial sediments from the modern Yangtze River mouth and adjacent continental shelf (Figs. 1 and 2). The magnetic parameters measured and calculated include magnetic susceptibility (χ), frequency-dependent magnetic susceptibility (χ_{FD}%), susceptibility of anhysteretic remanent magnetization (χ_{ARM}), isothermal remanent magnetization (IRM), 'hard' isothermal remanence (HIRM) and S ratio (S_{-kmT}). We demonstrated that various depositional environments, including tidal flats, distributary channels, river mouth sandbars, the delta front slope, prodelta, delta-shelf transitional zone and relict sand (Emery, 1968), exhibit significantly different magnetic properties (Fig. 2; Table 1). The most distinctive magnetic characteristics include high values of χ and SIRM in distributary channel sediments and high values of χ_{FD}%, χ_{ARM}, χ_{ARM}/χ, χ_{ARM}/SIRM and HIRM in delta front slope and prodelta sediments. These findings raise the question of whether or not magnetic properties can be used to help analyze the depositional environment in sediment cores.

However, magnetic properties of sediments in various depositional environments are often affected by early diagenesis and the reductive dissolution of fine-grained ferrimagnetic minerals is especially common (Karlin and Levi, 1983; Snowball, 1993; Evans et al., 1997; Robinson et al., 2000; Chen et al., 2015). This is often characterized by an initial reduction in χ_{FD}%, followed by a

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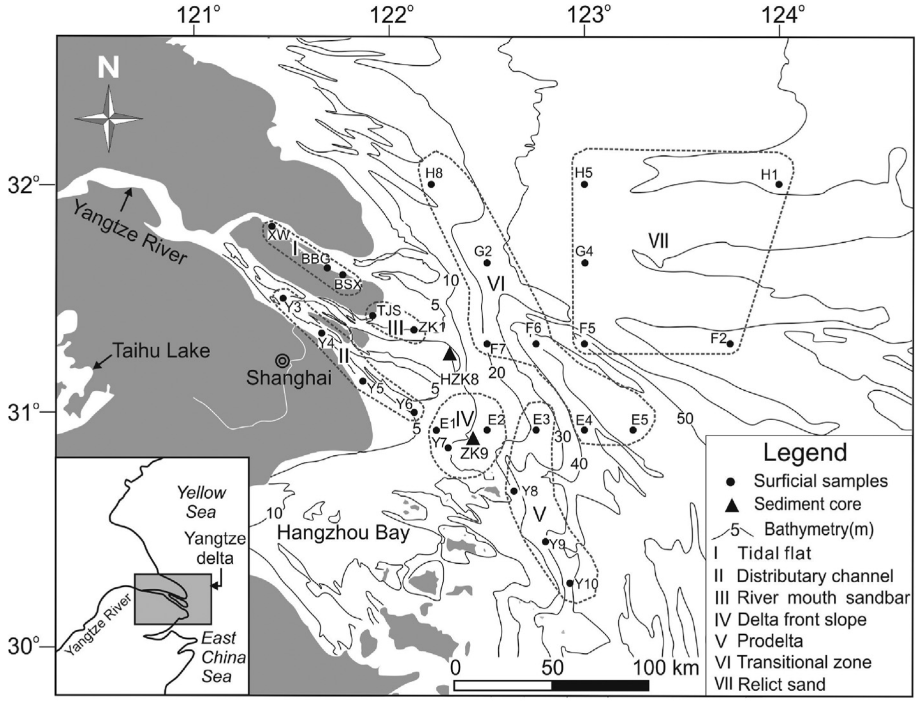

Fig. 1. The location of study area, sediment cores HZK8 and ZK9 (Liu et al., 2013), and the sites of surficial sediment samples (Pan et al., 2015). The type of sedimentary environment from which the surface sediment samples were collected is indicated by the numbers I-VII.

reduction in χ_{ARM}. For the anoxic marine sediments, abundant organic matter and a high concentration of dissolved sulfide in pore water favor dissolution of magnetite and formation of iron sulfides (e.g. phyrite and greigite) (Jorgensen, 1977; Westrich, 1983; Canfield and Berner, 1987; Karlin, 1990a, 1990b; Leslie et al., 1990; Bloemendal et al., 1992; Chen et al., 2015). In addition, the magnetic properties of river mouth sediments are often significantly influenced by human activity in the catchment. Wang et al. (2011) showed that soil-derived superparamagnetic (SP) minerals dominate the recent fine-grained sediments of the Yangtze delta and were related to major deforestation in the drainage basin starting at ca. 1.7 cal. ka BP. They also revealed that rock and soil erosion intensified after ca. 0.8 cal. ka BP, which are the times when both χ_{LF} and χ_{FD}% exhibit their highest values.

Liu et al. (2013) examined the magnetic properties of sediment core ZK9 from the subaqueous Yangtze delta and assumed that χ_{ARM} and HIRM were much less affected by early diagenesis and exhibited significantly higher values above the maximum flooding surface (MFS). Chen et al. (2015) also reported that HIRM in a Holocene core of tidal flat and saltmarsh deposition from the Yangtze coastal plain preserved the primary magnetic signals and its temporal variation reflected the fluctuations in detrital mineral input, although early diagenesis also prevailed and authigenic greigite was formed. Their findings encouraged us to examine more sediment cores from the Yangtze River mouth.

In this study, we measured the magnetic properties of sediment core HZK8 taken from a sandy shoal at the Yangtze River mouth. We then compared the results with those of surficial sediments from the river mouth and adjacent continental shelf and sediments from core ZK9, taken from further offshore (Liu et al., 2013). We intend to characterize temporal and spatial variations in magnetic properties and early diagenesis and their implications for characterizing environmental changes including anthropogenic effects on sediment provenance, and discuss the possible mechanisms for the variability in processes of early diagenesis.

2. Material and methods

The sediment core HZK8 (31°14′2.5″ N, 122°18′51.3″ E), 60.9 m long, was obtained in 2012 from the Heng-Sha shoal of the Yangtze River mouth. The core was drilled with a rotary drill 10.8 cm in diameter in 5.3 m of water depth and the recovery was 97%. This core is located in the incised Yangtze paleo-valley (Wang et al., 2012), where fluvial, estuarine and deltaic sedimentary settings have developed since the last deglaciation. The core was split, described, and photographed in the laboratory immediately after drilling. Four ^{14}C ages of mollusk shells were measured by Beta Analytic using accelerator mass spectrometry (AMS) (Table 2). All conventional dates were calibrated (cal yr BP) using the Calib Rev 5.1 (Beta) program (Stuiver and Reimer, 1993). Calibration dataset Marine04 was used for all dates. In order to correct for the marine reservoir effect, for samples with δ^{13}C values from 2‰ to −2‰ we used the ΔR value 71 ± 31, which was averaged from marine samples from the north-western coast of Taiwan and the Okinawa trough (Yoneda et al., 2007), and for the one lower than −2‰ we use −1 ± 143, which was averaged from coastal samples from the east China marginal sea (Southon et al., 2002; Kong and Lee, 2005; Yoneda et al., 2007).

Lithology, sedimentary facies and sequence stratigraphic comparison with other sediment cores from the Yangtze delta has been described in Wang et al. (in preparation). The stratigraphy is composed of a transgressive system tract (estuarine setting) at 60.9–40.3 m and a highstand system tract (deltaic setting) at 40.3–0 m. Here we summarize the lithology as follows: 60.9–56.5 m, fine gray sand with several mud clasts and laminae in the lower and upper parts (Fig. 3-1, 2); 56.5–49.7 m, sand-mud couplets with sharp boundaries between sand and mud layers at the base (Fig. 3-3), wavy bedding from 55.6 to 52.1 m (Fig. 3-4) and flaser bedding from 51 to 49.7 m (Fig. 3-5); 49.7–40.3 m, interbedding of sand and mud layers with a sharp contact with underlying layer (Fig. 3-6, 7, 8 and 9); 40.3–39.2 m, mixture of sand and

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