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Heavy mineral compositions of the Changjiang (Yangtze River) sediments and their provenance-tracing implication

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ABSTRACT

A total of 71 floodplain sediments were collected from the mainstream and major tributaries of the Changjiang for heavy mineral examinations. The upper Changjiang samples contain more heavy minerals in the very fine sand fraction than the middle-lower samples which are relatively enriched in polygenetic heavy minerals. The heavy mineral assemblages are characterized by Fe–Ti oxide minerals, calcic amphibole, epidote, garnet, biotite, and zircon, which exhibit large variations in percent between different tributaries and the mainstream. The widely distributed granitoids and Permian Emeishan Basalt in the drainage basins account for the high contents of zircon and hypersthene in the Xiangjiang and Daduhe samples, respectively. Most of the detrital magnetite grains are homogeneous in typomorphic feature and almost stoichiometric in chemical composition. The discrimination plot of $TiO_2 + V_2O_3$ versus $MgO/(MgO + Al_2O_3)$ suggests that most of the detrital magnetite grains are sourced from felsic plutonic/volcanic and metamorphic parent rocks, and those from different tributaries have distinct chemical compositions. Our study suggests that the combination of transparent heavy mineral assemblages and varietal study of individual heavy minerals sheds new light on the provenance discrimination of the Changjiang sediments and contributes to the mineralogical determination of ancient source rocks within a large drainage basin, despite the sediment recycling and complex source rock types.

1. Introduction

Although sedimentary processes such as weathering, physical abrasion and hydrodynamic sorting during transport, alluvial storage, and diagenesis may obscure or overprint the original provenance signal (Morton and Hallsworth, 1994, 1999; Svendsen and Hartley, 2002; Morton et al., 2005), heavy mineral assemblages has long been regarded as sensitive indicators of sediment source (Rubey, 1933; Pettijohn et al., 1987; Nechaev and Isphording, 1993; Heroy et al., 2003; Garzanti et al., 2005, 2006, 2007, 2008; Garzanti and Andó, 2007). Certain features of heavy mineral suites, especially the varietal characteristics including chemical compositions of individual mineral species, can directly indicate the source rock characteristics, because these varietal characteristics are mostly inherited from source rocks and are not likely to change with weathering and transportation. Over the last two decades, specific heavy minerals including zircon, monazite, garnet, tourmaline, apatite, rutile, and Ti–Fe oxide minerals have been widely used to decipher the provenances of marine and riverine sediments in terms of their unique varietal characteristics (Darby and Tsang, 1987; Grigsby, 1990, 1992; Razjgaeva and Naumova, 1992; Morton and Hallsworth, 1994; Datta and Subramanian, 1997; Dill, 1998; Sabeen et al., 2002; Svendsen and Hartley, 2002; Heroy et al., 2003; Lin et al., 2003; Zack et al., 2004; Mange and Otvos, 2005; Poulton and Raiswell, 2005). Among these heavy minerals, opaque Ti–Fe oxide minerals, especially magnetite, are more suitable for single-grain mineral chemical analysis than many other heavy minerals because they are relatively stable, easily separated from the bulk minerals and have unique typomorphic features and mineral chemistry diagnostic of provenance rocks (Darby and Tsang, 1987; Pettijohn et al., 1987; Basu and Molinaroli, 1989; Grigsby, 1990, 1992; Razjgaeva and Naumova, 1992; Yang et al., 2000; Hounslow and Morton, 2004).

The Changjiang as the longest river in Asia, delivers a large volume of sediment into the estuary, which exerts a significant influence on sediment budget, formation of sedimentary systems and environmental changes in East Asian marginal seas. Recognition of the source to sink transport pattern of the Changjiang sediments, therefore, allows us to better understand the above research topics. In recent years, sediment source discriminations of the Changjiang were performed primarily using elemental geochemical and clay mineralogical methods (Li et al., 1984; Yang, 1988; Qin et al., 1987; Yang et al., 2004; Yang et al., 2006; Lim et al., 2006), whereas heavy mineralogy of the Changjiang sediments has rarely been

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investigated, mainly due to the complicated river system and source rock types in the Changjiang drainage basins. Previous studies on heavy mineral assemblages of the Changjiang-derived sediments gave emphasis to the Changjiang estuarine and inner shelf area (Chen et al., 1980; Qin et al., 1987; Sun, 1990; Jin, 1992; Lu, 1992; Wang et al., 1997; Wang et al., 2007), and did not extend to the whole drainage system including the major tributaries of the Changjiang. Recent studies by Yang et al. (2000, 2006) show that single-grain mineral chemistry (magnetite and monazite) is useful in determining sediment provenance and deciphering the river evolution history of the Changjiang. Nevertheless, the heavy mineral investigations of the whole Changjiang and its major tributaries still remain incomplete.

In this contribution, we examine the transparent heavy mineral assemblages and chemistry of single-grain magnetic minerals in the Changjiang sediments. The principal research objectives are to characterize and differentiate the typical heavy mineral assemblages and chemical compositions of detrital magnetite grains between the Changjiang mainstream and its major tributaries, and further to relate them to sediment provenances and source rock types in the drainage basins.

2. River setting

The Changjiang is one of the largest rivers in the world in terms of its huge water and sediment discharges of about 900×10^9 and 480×10^6 ton/yr, respectively. The tributary system of the Changjiang is extensively developed in the drainage basin which fosters 49 tributaries with each catchment area above 10,000 km^2 (Fig. 1). Among them, the four largest tributaries, the Jialingjiang, Hanjiang, Minjiang, and Yalongjiang Rivers, all are located in the upper-middle valley of the Changjiang, with each occupying 100,000 km^2 in drainage area and yielding the sediment load >40×10^6 ton/yr based on fifty-year (1950–2000) hydrologic observations. The annual sediment loads average 501×10^6 ton at Yichang hydrologic station (about 1800 km away from the river mouth) and 433×10^6 ton at Datong hydrologic station (the tidal limit of the Changjiang, about 650 km away from the estuary), respectively. Nevertheless, the construction of the world's largest dam, the Three Gorges Dam, has greatly altered the sediment budget in the middle-lower reaches and the flux of suspended sediment into the Changjiang Estuary (Yang et al., 2007).

The Changjiang drainage basin spans the typical topography of China with three-grade relief terraces, which have the average elevations of 3500–5000 m, 500–2000 m and less than 500 m, respectively. The several large catchment basins including the Sichuan Basin, Jianghan Basin, Dongting Lake, Poyang Lake and Taihu Lake from west to east towards the river mouth, complicate the transport and deposition patterns of the Changjiang-derived sediments (Fig. 1). The upper Changjiang valley, especially the mountainous region in the Jinshajiang and Jialingjiang river basins, experiences the strongest soil erosion and has the highest sediment yield, up to 1000–5000 ton/km^2·a (Changjiang Water Resources Commission, 2005).

Geologically, the Changjiang drainage basin is primarily situated in the Yangtze Craton framed by the Mesozoic Yanshanian orogenic belt, and the westernmost upper part, the Jinshajiang valley, has been extensively influenced by the Tibetan uplift during the Cenozoic. The complicated source rock types in the drainage basin primarily comprise Archean metamorphic rocks, Paleozoic carbonate and sedimentary rocks, Mesozoic–Cenozoic igneous and clastic rocks, and Quaternary detrital sediments (Fig. 1; Changchun Institute of Geography, 1998; China Geological Survey, 2004). Different drainage basins in the Changjiang and its major tributaries consist of distinct tectonics and source rock types. The upper Jinshajiang valley comprises metapsammite and metapelite, carbonate rocks and acidic igneous rocks, and especially the intermediate-acidic rocks formed during the Himalayan Stage. The drainage basins of the Jinshajiang, Wujiang and Jialingjiang Rivers are characterized by Paleozoic carbonate rocks, Permian Emeishan

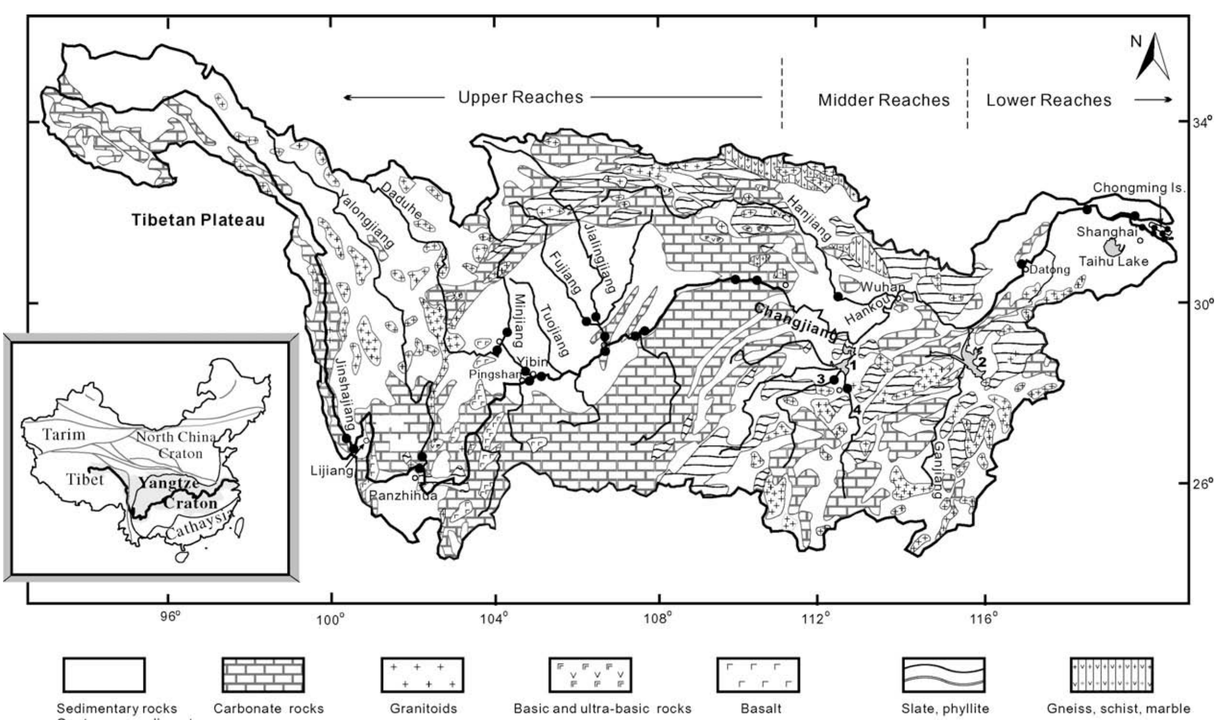

Fig. 1. A sketch map showing the Changjiang drainage basins, major tributaries, sampling locations and main provenance rock types. 1 Poyang Lake; 2 Dongting Lake; 3 Yuanjiang River; 4 Xiangjiang River. The geology of the Changjiang drainage basins is modified from Geological Map of China (1:2,500,000, CGS, 2004).