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Review

Provenance discrimination of sediments in the Zhejiang-Fujian mud belt, East China Sea: Implications for the development of the mud depocenter

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ABSTRACT

In the past decade, the 800 km elongated mud belt off Zhejiang-Fujian coast, East China Sea (ECS), has been extensively studied for understanding the source to sink processes on the East Asian continental margin in the context of the Asian monsoon. However, to better understand the sediment source and dispersal pattern, the existing mineralogical and geochemical data of adjacent river systems, including the Changjiang River (CJR) and local rivers in Zhejiang, Fujian and Taiwan, need to be systematically reviewed. Therefore, various indicators from published literatures for the provenance discrimination in the mud belt have been summarised in this article. The results show that high diversity of clay mineral assemblages in fluvial sediments being supplied into the mud belt, e.g., dominant illite and chlorite in the CJR, absence of smectite in Taiwan rivers, similar amounts of the four clay mineral species in Zhejiang rivers, and dominant kaolinite in Fujian rivers. On heavy mineralogy, the CJR is dominated by dolomite, hornblende, and flaky minerals; and among of them, dolomite is distinctive for the CJR. For geochemical approaches, elemental compositions, combined with strontium and neodymium isotopes, reflect strong provenance control. However, geochemical and mineralogical compositions are found to vary with grain size, and thus extra caution should be taken when using these parameters as provenance indicator to discriminate the marine sediments with variety of grain-size fractions. In addition, pyrrhotite, occurred in fluvial sediments from western Taiwan, has not been found in sediments derived from mainland China, indicating that magnetic parameters could be used to discriminate sediment provenance. The mud belt formed during sea-level highstand, when modern current system in the ECS has been established, resulting in sediments derived from the CJR have been transported southward since 8 ka. In addition, sediment provenances have not been constant since initiation of the mud belt in response to climatic and oceanographic changes during the Holocene, which has been documented by mineral and geochemical signals. Nevertheless significant studies have been carried out, to better understand the formation mechanism for the mud belt and its implications for environmental changes, further studies on sediment provenance throughout the Holocene, in situ observation, and sedimentation dynamical modelling are required.

1. Introduction

Continental margin is the most critical interaction of land and sea, where information on climate and sea level in the past has been archived (Walsh et al., 2016), thus study of flux and fate of terrestrial sediment in marginal seas is of great significance for understanding global climatic change and biogeochemical circulation (McKee et al., 2004; Aller et al., 2010; Hanebuth et al., 2011; Gao and Collins, 2014). The East Asian marginal seas, linking the largest continent (Eurasia) with the largest ocean (the Pacific Ocean), are characterized by river-dominated marginal sedimentation (Yang et al., 2015a, 2015b). Terrigenous sediments eroded from the drainage basin are transported and deposited on the marginal seas, which formed the natural laboratory to study the sediment source-to-sink process in the context of the Asian monsoon (Shi et al., 2015; Liu et al., 2016).

The East Asian continental margin is characterized by a broad continental shelf, where variety of sedimentary systems occurred during the Holocene, such as, river deltas, tidal flats, tidal ridges, and coastal and shelf mud deposits (Gao, 2013; Li et al., 2014; Gao et al., 2015). As pointed out by Gao and Collins (2014), these high temporal resolution sedimentary records may form a complete archive for environmental change if they are connected together. Among these

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sediment systems, the mud belt off the Zhejiang-Fujian coast (ZFMB), deposited on the inner shelf of the East China Sea (ECS), were formed in response to low-energy depositional environments constrained by coastal currents and Holocene sea-level highstand (Liu et al., 2006; Liu et al., 2007; Xu et al., 2012). Due to continuous deposition and high sedimentary rates, abundant paleoclimatic and paleoceanographic studies have been carried out on these muddy deposits in the past decade since Xiao et al. (2006) proposed that the high resolution mean grain-size variation could be indicative for East Asian winter monsoon (EAWM). In spite of the grain size, large number of proxies have been proposed to link the physical and chemical signals of muddy sediments to global climatic changes (Liu et al., 2014; Tu et al., 2017), such as environmental magnetism (Zheng et al., 2010a), geochemical composition (Liu et al., 2013b), clay mineral assemblages (Liu et al., 2014), heavy mineral assemblages (Dong et al., 2015), and isotopes of oxygen carbon and nitrogen (Hu et al., 2014; Li et al., 2015b). It seems that the ZFMB have been studied completely for paleoclimatic and paleoceanographic reconstruction, however many aspects to these fine-grained sediments are still not well understood so far.

The ZFMB receives huge fluvial sediments from the adjacent land (Xu et al., 2012; Bi et al., 2015; Yang et al., 2015a), including the Changjiang River (CJR) originating from the Tibetan Plateau, small mountainous rivers in Taiwan, and the rivers in Zhejiang and Fujian Provinces draining Southeast China (Fig. 1). At present time, most terrigenous sediments of the ZFMB have been considered to be derived primarily from the CJR, transported southward by coastal currents in winter (Liu et al., 2006; Liu et al., 2007; Xu et al., 2009c; Xu et al., 2012). However, Holocene sedimentary records from the Hangzhou Bay indicated that there was not a large amount of sediment from the CJR being transported southward until the later part of the Holocene (Wang et al., 2015; Zhang et al., 2015a). Therefore, Gao et al. (2015) proposed that there might have been a significant hiatus in the sediment sequence of the ZFMB between 6 and 2 ka. On the contrary, REE results from core EC2005 suggested that sediments in the ZFMB are continuously supplied from the CJR since 10–9.8 ka (Xu et al., 2011). Further, clay mineral record from core MZ02 demonstrated that more than 60% sediments were transported from Taiwan rivers between 6.2 a d 2.4 ka (Liu et al., 2014). As well as, geochemical proxies from core MD06-3040 indicated that there was a sudden increase in sediment contribution from small local rivers in Zhejiang and Fujian Provinces since 1.5 ka (Yang et al., 2015a). These debates on the provenance discrimination will influence our interpretation on the paleoclimatic signals recorded in the ZFMB, thus a comprehensive review on sediment provenance discrimination is necessary.

This article thus aims to integrate existing documentation on the provenance discrimination of the muddy sediments, so that effective indicative proxies could be extracted. For this aim, a large number of published data have been examined thoroughly, involving mineral, geochemical and geophysical records. The goals of this work are: (i) to evaluate the effectiveness of the modern proxies for provenance discrimination, (ii) to demonstrate the change in sediment provenance during the Holocene and its implications for the formation of the ZFMB, and (iii) to provide new perspective on the further research on the muddy sediments on the shelf.

2. Regional setting

2.1. The East China Sea (ECS)

The ECS covers an area approximately $0.77 \times 10^6\,km^2$, with most of water depth less than 200 m, which deepens eastward and southward to a maximum depth of 2300 m in the Okinawa Trough (Deng et al., 2006). The major currents in the ECS include the Kuroshio Current (KC), the Tsushima Warm Current (TSWC) and the Taiwan Warm Current (TWC), and the Zhenjiang-Fujian Coastal Current (ZFCC; Fig. 2). The ECS current circulation pattern is largely controlled by the KC, which flows north-eastward along the shelf break of the ECS (Ren et al., 2015). The intruding Kuroshio water along with the warm water from the Taiwan Strait (TS) forms the TWC, which provides warm and saline waters to the sea area off the Zhejiang and Fujian coasts and the Changjiang estuary (Yang et al., 2011; Yang et al., 2012; Zhou et al., 2015; Lian et al., 2016). The buoyant ZFCC flows southward from the Changjiang Delta with a width of about 30–50 km (Wang et al., 2016), which has a higher flow potential in winter (velocity of $50\ cm\ s^{-1}$) than that in summer due to the monsoon climate (Wu et al., 2015). The behaviour of the CDW also shows a remarkable seasonal variation, which can extend to the northeast toward the Cheju Island during the summer, while it hugs the Chinese coast to the southwest within a narrow band in the winter (Chang and Isobe, 2003). These current systems play a significant role in transporting the fluvial sediments to the outer seas (Pang et al., 2016).

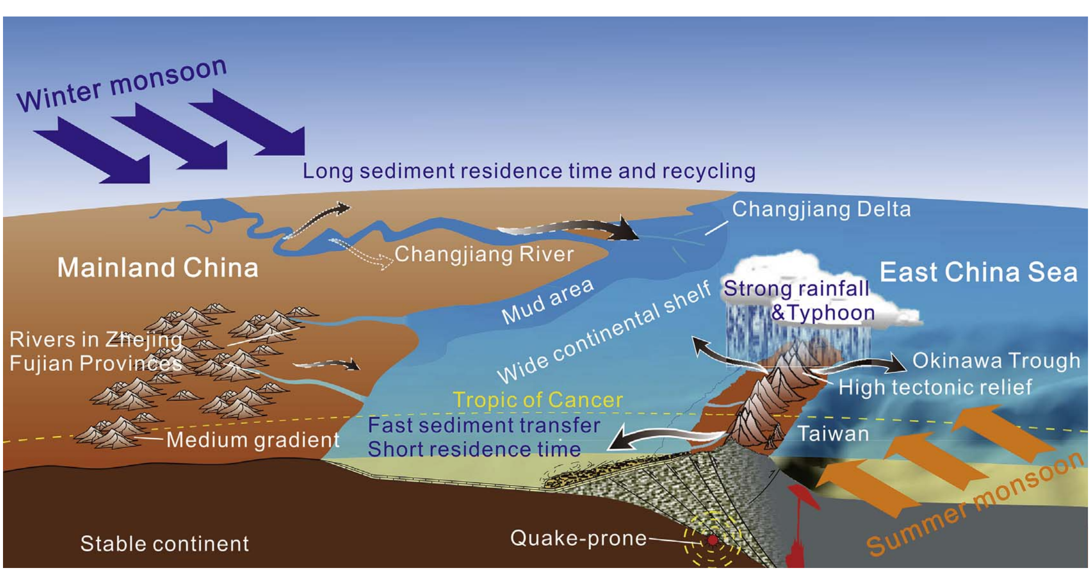

Fig. 1. A schematic model of potential sediment provenances for the muddy deposits on the inner shelf of the East China Sea in the context of the Asian monsoon, modified from Bi et al. (2015). The source areas include tectonically stable rivers (the Changjiang River and rivers in Zhejiang-Fujian Provinces), and tectonically active mountainous rivers in Taiwan.