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Provenance discrimination of last deglacial and Holocene sediments in the southwest of Cheju Island, East China Sea

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ABSTRACT

The ultimate provenance of muddy sediment in the southwest of Cheju Island, East China Sea, remains enigmatic thus far. In this study, rare earth elements (REEs) were used to investigate sediment provenances of cores E03-6, E03-10 and E03-11 taken from the mud patch. Discrimination plots based on REE fractionation parameters and trace elements suggest that the sediments deposited during the last deglacial period (>15 ka) were derived predominantly from the paleo-Huanghe (Yellow River) which might have delivered sediments directly into the northeastern East China Sea during the lowstand of sea level. The coarse-grained sediments deposited at transgressive stage (15–6 ka) were primarily sourced from the Changjiang (Yangtze River) and partly from the Korean Peninsula, probably transported by tidal currents. In comparison, the clayey sediments deposited at highstand stage (<6 ka) were mostly derived from the modern and old Huanghe. In particular, the fine-grained sediments eroded from the old Huanghe Delta in the southwestern Yellow Sea can be transported to the northeast of the East China Sea by the coastal current and the Changjiang Freshwater Plume as well, and finally trapped within a cyclonic upwelling gyre. The dispersal and deposition of terrigenous sediments in the northeast of the East China Sea are remarkably controlled by the oceanic circulation related to sea level variability. The variable depositional rates and drastic river–sea interaction during the late Quaternary make it difficult to reliably reconstruct a high-resolution paleoenvironmental change in the river-dominated shelf sea. Nevertheless, geochemical approach can provide important constraints on sediment source-to-sink transport patterns in this typical pericontinental sea.

1. Introduction

The East China Sea, as a typical marginal sea in the West Pacific, has increasingly received research attention over the past two decades. It is characterized by complicated oceanic circulation and sediment dispersal patterns, remarkable sea level change, huge input of terrigenous sediment and strong land–sea interactions during the late Quaternary. The provenances of terrigenous sediments on the East China Sea shelf thus become the foci of Asian marine geological study, and especially, the influence of large rivers including the Changjiang (Yangtze River) and Huanghe (Yellow River) on the shelf sedimentation has been widely investigated (Xu and Oda, 1999; Liu et al., 2003; Yang et al., 2003a; Jung et al., 2006; Lim et al., 2007; Xu et al., 2011; Youn and Kim, 2011; Xu et al., 2012; Kim et al., 2013; Um et al., 2013).

The mud patch in the southwest of Cheju Island (SWCIM, Yang et al., 2003a), the northern margin of the East China Sea, attracted many research attempts in terms of its sediment provenance and depositional mechanism. It was once regarded as the distal end of the dispersal system of the modern Huanghe in the East China Sea (DeMaster et al., 1985; Alexander et al., 1991), and was formed in a counterclockwise cyclonic eddy (Hu and Li, 1993). The muddy surface deposits of the SWCIM were considered to be derived primarily from the modern Huanghe based on clay mineral and detrital calcite compositions (Milliman et al., 1985; Lee and Chough, 1989), or jointly from the old Huanghe and modern Changjiang sediments based on remote sensing observation, sediment budget calculation, and sediment geochemical and environmental magnetic studies (Saito, 1998; Sun et al., 2000; Liu et al., 2003; Yang et al., 2003a; Xiang et al., 2006; Yang et al., 2009). The suspended sediments from Korean rivers are transported southward and may also contribute to the sedimentation of the southeastern Yellow Sea and northern margin of the East China Sea (Park and Khim, 1992; Lee and Chu, 2001; Lim et al., 2007). Despite these previous research attempts, the ultimate sediment provenance and depositional mechanism of the SWCIM are still open questions mainly because of the lack of high quality data from bore holes.

Recent finding of large ore deposit of rare earth elements (REEs) around Japan Islands in the West Pacific has received global attentions.

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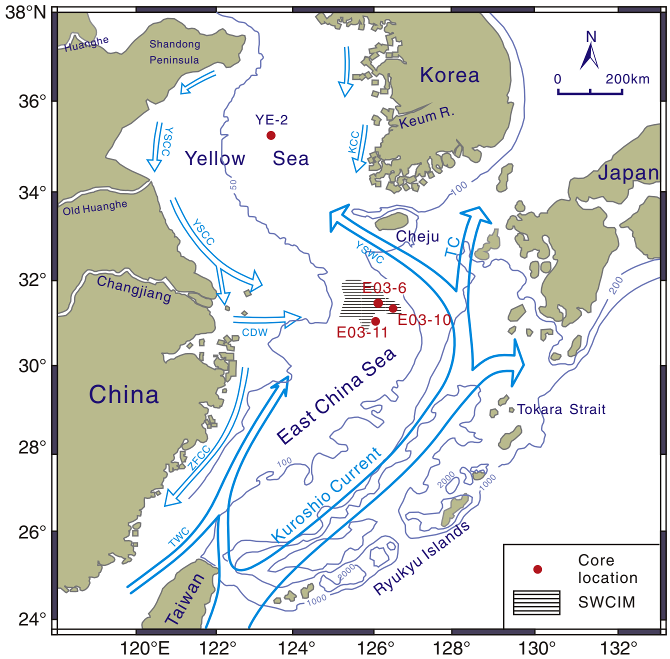

Fig. 1. Sketch map of the East China Sea and the Yellow Sea showing bathymetric contour in meter, the core locations, and oceanic circulation (modified after Yang et al., 2003a). KCC: Korea Coastal Current; YSCC: Yellow Sea Coastal Current; ZFCC: Zhejiang–Fujian Coastal Current; YSWC: Yellow Sea Warm Current; CDW: Changjiang Diluted Freshwater Plume; TWC: Taiwan Warm Current; TC: Tsushima Current; SWCIM: Southwest Cheju Island Mud. Data of core YE-2 was from Xiang et al. (2008).

Scientifically, REEs have been widely accepted as reliable provenance tracers because they are largely water-immobile and thus behave conservatively during sedimentary processes (Taylor and McLennan, 1985; Rollinson, 1993). The clear difference in REE compositions between the major rivers from China and Korea has been well established and successfully applied for identifying the origins of these river sediments in the Yellow Sea and the East China Sea (Yang et al., 2002a,b, 2003a,b, 2004; Jung et al., 2006; Liu et al., 2009; Song and Choi, 2009; Dou et al., 2010). In this study, REE geochemical method will be applied for identifying the sediment sources of cores E03-6, E03-10 and E03-11 taken from the SWCIM and surrounding area, i.e. the northeastern East China Sea. The main research objectives of this paper are to 1) examine the variations of REE compositions in the core sediments; 2) decipher the sediment provenances since the last deglacial period; and 3) discuss the variability of terrigenous sediments into the northeastern East China Sea in response to the changes of sea level, fluvial runoff and oceanic circulation.

2. Sample sources and methods

Three gravity cores E03-6, E03-10 and E03-11 were taken from the northeastern East China Sea in 2003, with seawater depth from 65 to 80 m, among which E03-6 and E03-10 were drilled directly from the SWCIM, and core E03-11 was located in the south of the SWCIM (Fig. 1). Core E03-6 is 305 cm long and the upper unit (Unit 1) is mainly composed of silt clay, while the lower unit (Unit 2) is predominately sand. Core E03-10 is 370 cm long and composed of silt clay without apparent sand layers. Core E03-11 is also 370 cm long and consists of mixture of sand, silt and clay. The detailed locations of these cores and AMS^{14}C ages of selected benthic foraminifera and peaty sediment samples were given in Table 1. The AMS^{14}C dates reveal different basal ages of the three cores, albeit with similar core lengths. Core E03-11 sediments were deposited during the last deglacial to middle Holocene period, while the other two cores have the depositional ages of the mid–late Holocene. The linear sedimentation rate is of the lowest value in core E03-11 whereas it reaches the highest in core E03-10.

A total of 106 bulk samples were selected from the cores for elemental analysis. For removing the mobile, authigenic and biogenic fractions from the bulk sediments, 65 bulk samples were pretreated by acid to get the residual fractions, i.e. about 0.2 g bulk sediment samples being leached with 20 ml 1 N hydrochloric acid (HCl) for 24 h at 50 °C. In this study, we followed the 1 N HCl-leaching method by Choi et al. (2007). Yang et al. (2004) and Song and Choi (2009) also used this method to leach the river sediments for separating leachable and residual phases. All the samples were combusted in the muffle furnace for 2 h at 600 °C before the acid digestion. About 50 mg powdered samples were digested with 4 ml HNO_3 and 1 ml $HClO_4$ for 24 h in a tightly closed Teflon vessel on a hot plate at less than 150 °C, heated to dryness, and then digested with a mixture of 4 ml HF and 1 ml $HClO_4$. Afterwards, the solution was evaporated to dryness, and extracted with 10 ml 1% HNO_3. Concentrations of rare earth elements and other trace elements in the bulk samples were measured by an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) at the University of London, while the REE concentrations of the residues were measured at the State Key Laboratory of Marine Geology at Tongji University, China. The analytic errors monitored by the international geostandard MAG-1 and Chinese Geostandard GSD-9 are below 5%. The sediment grain size compositions were measured by laser grain-size analyzer (Coulter LS 230) with the analytic precision of about 1%.

3. Results and discussions

3.1. Sediment grain size and REE compositions of the core sediments

The mean grain size (Mz) and REE concentrations as well as the REE fractionation parameters including $(La/Yb)_{UCC}$, $(Sm/Nd)_{UCC}$, and cerium (δCe) and europium (δEu) anomalies in the bulk samples are given in Fig. 2 and Table 2. $(La/Yb)_{UCC}$ indicates the degree of fractionation between light (La to Eu) and heavy (Gd to Lu) REEs while $(Sm/Nd)_{UCC}$ indicates the fractionation degree of middle (Sm to Dy) REE relative to light REE. In this study, the average composition of the Upper Continental Crust (UCC, Taylor and McLennan, 1985) was used to normalize the REE concentrations in the core sediments.

The compositions of Mz and REE in the three cores exhibit different downcore variations, with larger variations occurring in cores E03-06

Table 1
Core locations and radiocarbon AMS^{14}C ages of the selected sediments.

Cores	Latitude	Longitude	Water depth (m)	Core length (cm)	Depth (cm)	Conventional AMS^{14}C age (yr BP)	Calendar age (yr BP)	Materials
E03-6	31°56.168′N	126°05.267′E	80	305	36	1540 ± 40	1930 ± 40	Benthic foram.
					267	6650 ± 40	7050 ± 40	Benthic foram.
E03-10	31°37.618′N	126°53.176′E	65	370	20	500 ± 40	890 ± 40	Benthic foram.
					150	650 ± 40	1030 ± 40	Benthic foram.
					298	2070 ± 40	2470 ± 40	Benthic foram.
E03-11	31°04.295′N	126°08.164′E	75	370	15	4870 ± 40	5260 ± 40	Benthic foram.
					120	15,740 ± 80	15,770 ± 80	Organic sediment
					220	16,660 ± 60	16,700 ± 60	Organic sediment

Note: The AMS^{14}C ages did not make a correction of marine reservoir effect.