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Spatial and temporal distributions of clay minerals in mud deposits on the inner shelf of the East China Sea: Implications for paleoenvironmental changes in the Holocene

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We present a paleoclimatic reconstruction for the Holocene by clay mineral analyses of sediments from core MZ02 retrieved from the mud area of the inner continental shelf of the East China Sea (ECS). The clay minerals mainly consist of illite (66%–79%) and chlorite (12%–19%), with minor kaolinite (7%–13%) and smectite (0–6%). Provenance analysis suggests that the illite-dominated clay minerals were derived mainly from the detrital outputs of the Changjiang, Minjiang, and small rivers from Taiwan Island. Our study indicates that the sea level rise since the last glacial, the strength of the Taiwan Warm Current (TWC) and Chinese Coastal Current (CCC) have controlled the dispersal and deposition of clay minerals on the ECS, that in turn determined the clay mineral compositions in the core sediments. During 13,000–9500 BP, due to the lower sea level and shorter distance between these three estuaries and core MZ02, fine sediments on the inner shelf of the ECS were primarily supplied by mixed provenances from the Changjiang, Taiwanese, and Minjiang rivers. During the early Holocene (9500–6200 BP), stronger sediment reworking and erosion at the shelf edge was responsible for the increased lateral transport of fine sediments in the ECS, which lead to a dominance of the sediment source from the Changjiang, while the Taiwanese and Minjiang rivers only provided minor components of detrital sediment to the shelf. Increased strength of TWC might have played an important role in the sediment dispersal and deposition on the inner shelf of the ECS during 6200–2400 BP, with a dominance of more than 60% sediments transported from Taiwanese rivers. Furthermore, our study implies that the Asian monsoon and the weakening of TWC were linked to the abrupt increase of Changjiang and Minjiang derived terrigenous detritus materials since 2400 BP.

1. Introduction

Holocene mud deposits are commonly found in estuaries and continental shelves (Milliman et al., 1985; Nittrouer et al., 1986; Díaz et al., 1990; Alexander et al., 1991; Díaz and Ercilla, 1993; Park et al., 1999; Chough et al., 2002; Milliman and Kao, 2005; Liu et al., 2007). The depositional patterns of these mud deposits are mainly determined by the supply of suspended sediments, and also by sediment dispersal processes such as tides, waves, and coastal currents (Nittrouer et al., 1986; Wright and Nittrouer, 1995; Díaz et al., 1996; Jin and Chough, 1998; Cattaneo et al., 2003). These mud deposits generally have been developed as pervasive blankets across the shelf or as a belt along the coast in parallel with the dominant direction of sediment transport (Milliman et al., 1985; Nittrouer et al., 1986; Díaz et al., 1990, 1996; Jin and Chough, 1998; Cattaneo et al., 2003). During the Holocene, the mud deposits have been formed on the shelves of the ECS in response to low-energy, shelf depositional environments dominated by the coastal currents and a condition of higher sea levels after transgression since the last glacial period (Xu et al., 2009a,b; Liu et al., 2011a,b).

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Geological and geophysical investigations have demonstrated that the mud deposits in the ECS are continuous and exhibit high sedimentary rates (Satio et al., 2001; Hori et al., 2002; Xiao et al., 2006; Zheng et al., 2010; Liu et al., 2010a,b) and could be ideal materials for high-resolution reconstructions of paleoclimate at millennial to possibly multi-decadal scales (Dierk et al., 2003; Yasuhiro et al., 2011). In these studies, indicators such as grain size (Xiang et al., 2006; Xiao et al., 2006; Sun et al., 2011), element geochemistry (Su and Huh, 2002; Liu et al., 2013a,b), magnetic susceptibility (Ge et al., 2003), biogenic silica (Fan et al., 2009; Liu et al., 2011a,b), Bio-markers (Li et al., 2009, 2012a,b) and color reflectance (Wang et al., 2006; Xu et al., 2012; Liu et al., 2013a,b) had been widely used as environment proxies revealing the changes in fluvial processes, sea levels, and temperature/precipitation conditions. Moreover, clay minerals had been demonstrated indicative of oceanic current and climatic changes prevailing in continental source areas (Colin et al., 1999; Gingele et al., 2001), and useful in sedimentation and paleoenvironmental studies (Liu et al., 2010a,b), especially those deposited on continental margins where are dominated by terrigenous sediments (Biscaye, 1965; Griffin et al., 1968). As an important component in terrigenous sediments, clay mineral could provide valuable information on sediment provenances, such as relative contributions of river and aeolian inputs (Dou et al., 2010). The clay mineral could also offer critical constrains on sediment transport patterns and depositional processes, which are relevant to the weathering regimes within the continental interior where the clay mineral had been formed (Petschick et al., 1996; Thiry, 2000). Most previous studies based on the analysis of the clay minerals in sediment cores from western Pacific margin seas show clear variations during the past glacial–interglacial cycles (Liu et al., 2010a,b; Wan et al., 2012). These studies demonstrated that during the Quaternary and Neogene, the fluxes of clay minerals into the Pacific marginal seas were mostly controlled by the changes of sea level, ocean circulation, and the intensity of physical erosion and chemical weathering in the source areas. However, over shorter time scales, such as the Holocene, clay mineral assemblages appear to be indicative of different sediment sources, together with partitioning processes during transportations (Diekmann et al., 2008; Steinke et al., 2008). Therefore, to fully understand the changes in clay mineral compositions during the Holocene on the ESC shelf with possibly different provenances and their climate controls, a high-resolution study of sediment cores is needed.

The clay mineral assemblages in the ECS primarily consist of illite, which constitutes average contents of about 60–70%, while smectite, kaolinite and chlorite are subordinate (Fan et al., 2001; Yang et al., 2003). Generally, most studies on clay mineral assemblages in the ECS focused on the estuarine areas (Lü and Wang, 1985; Fan et al., 2001; Fang et al., 2007; Lan et al., 2011) and Okinawa Trough (Diekmann et al., 2008; Yu et al., 2008; Dou et al., 2010), while the mud area on the inner shelf of the ECS was less investigated. With more and more information obtained about the clay minerals in modern riverine sediments around the ECS, such as from the Changjiang (Fan et al., 2001; Yang et al., 2003), Taiwan rivers (Liu et al., 2008; Xu et al., 2009a,b; Li et al., 2012a,b), and the Minjiang and Oujiang rivers (Xu et al., 2009a,b; Shi et al., 2010), further investigations on any possible changing provenances and their paleoclimatic implications around the core sediments from the mud area on the inner shelf of the ECS become possible.

In this study, we present millennial to possibly multi-decadal scale paleoclimatic records based on a core retrieved from the mud deposit area on the inner shelf of the ECS. The aims of this study are to quantitatively estimate the relative contributions of fine-grained terrigenous sediments from different provenances, and further explore the links between clay mineral assemblages and paleoclimate changes in the sea and proximal land areas during the Holocene.

2. Regional setting

The continental shelf of the ECS adjacent to the Okinawa Trough is one of the widest continental shelves in the world, with an average width of 500 km. The shelf is characterized by high terrestrial material discharge that results in high sedimentation flux (Qin et al., 1987), with an average sediment accumulation rate of ~2 cm/year in the past one hundred years (Huh and Su, 1999).

In the ECS, rivers provide the major route for transporting terrigeneous sediments to the ocean (Xu et al., 2009a,b). The Changjiang, one of the largest rivers in the world, drains into the northern ECS. With a sediment discharge rate of 4.8×10^8 t/a, a huge amount of sediments have accumulated in the estuaries and offshore areas of the Changjiang, especially on its southern margin (Milliman and Meade, 1983). Smaller rivers such as Minjiang, Oujiang, and Qiantangjiang could also discharge more than 2.0×10^7 t/a sediments to the ECS annually (Jin, 1988). In addition, there are more than twenty mountainous rivers in Taiwan Island. Some, such as the Choshui, Taan, Wu, and Danshui rivers have also provided significant loads of terrigenous sediments to the ECS shelf (Li et al., 2012a,b).

The modern currents in the ECS developed with the rising of sea level to about its present level at about 6400–7500 BP, which submerged large parts of the shelf (Qin et al., 1987; Liu et al., 2004). The Coast Current (CC) in the ECS is stronger in the winter, carrying fresh water and sediment discharge from the Changjiang southwardly along the inner shelf (Milliman et al., 1985; Qin et al., 1987; Su, 2001). In contrast, the Taiwan Warm Current (TWC), that flows northwardly offshore in summer, plays a key role in keeping Changjiang-discharged sediments on the inner shelf (Gu et al., 1997; Hu and Yang, 2001; Xiao et al., 2006; Liu et al., 2007) and taking the Taiwan-derived material to the ECS (Fig. 1). Both

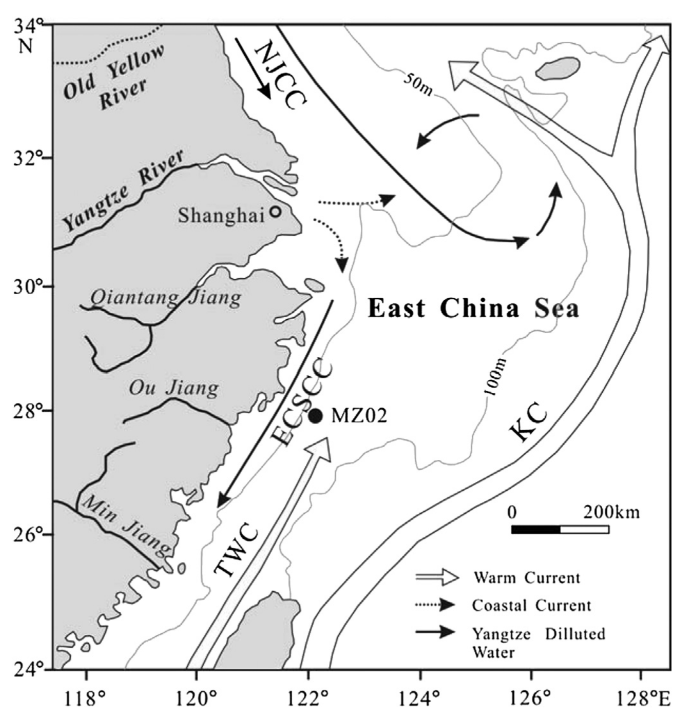

Fig. 1. Core MZ02 and schematic current system of the study area (modified from Qin et al., 1987; Hu and Yang, 2001).