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Late Quaternary sedimentary evolution of the outer shelf of the East China Sea

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ABSTRACT

This study investigated the late Quaternary sedimentary evolution of the outer shelf of the East China Sea (ECS) using borehole core data (DH02). Three unconformity-bounded sedimentary facies, namely, prodelta facies of marine isotopic stage (MIS) 3, intertidal to subtidal flat facies of the deglacial period, and offshore tidal sand ridge facies of the Holocene, were identified from the base upward according to combined evidence of lithology, microfossil assemblages, and geochronology. Through comparative analysis with other neighboring borehole cores, these three facies, along with the MIS 3 nearshore facies and the last glacial maximum (LGM) river facies, were found to constitute the late Quaternary sediment strata. Sedimentary processes of these five facies were interpreted based on a synthetic consideration of sea-level change, climate variation, paleotopographic setting, and paleoriver-sea interactions. In particular, the development of the delta was attributable to integration of the slow sea-level decline during the later stage of the MIS 3 and abundant sediment supply resulting from the warm-wet climate. The gentle shelf topography suggests the presence of shallow and wide rivers in the delta, and the lateral shift of river channels might have induced the local formation of nearshore facies at the abandoned river mouth. The LGM river facies, which was rarely observed (presumably due to marine erosion with deglacial transgression), was inferred to have been deposited during the latter half of the LGM in response to the rise in river base level. Occurrences of tidal flat facies imply the formation of a tide-dominated estuary with the deglacial transgression. Furthermore, tidal flat sediments were reworked by enhanced tidal currents in the estuary front environment, forming mud ridges during subsequent deglacial transgression. Formation of tidal sand ridges in offshore environments of the Holocene was attributable to the uneven base caused by the underlying estuarine erosion mud ridges, and this promoted the occurrence of tidal depositional processes. The sedimentary evolution in association with sea-level change was constructed using the above-mentioned results. Overall, this study systematically elucidates the late Quaternary sedimentary processes and evolution of the outer ECS shelf, and provides an insight into the sedimentary development of analogous shelves around the world.

1. Introduction

The sea level has primarily controlled the late Quaternary sedimentary evolution of global shelves (Fairbanks, 1989; Lambeck and Chappell, 2001; Mix et al., 2001). Distinct sedimentary environments, such as rivers, estuaries, deltas, and littoral and neritic facies, prevailed due to different sea-level changes. Numerous studies have been conducted on modern continental shelves to clarify the occurrence and formation processes of sedimentary facies of different periods, and reenact the sedimentary history accompanied by sea-level fluctuations (Stanley and Warne, 1994; Wellner and Bartek, 2003; Hanebuth and Stattegger, 2004; Dittmers et al., 2008; Green, 2009; Maia et al., 2010; Li et al., 2014; Thieler et al., 2014).

The East China Sea (ECS), which connects Eurasia—the largest continent on earth—and the west Pacific Ocean, has one of the broadest continental shelves in the world (Fig. 1). During the last glacial maximum (LGM), the Changjiang river, one of the largest rivers in the world, cut across the shelf (Wellner and Bartek, 2003; Li et al., 2014),

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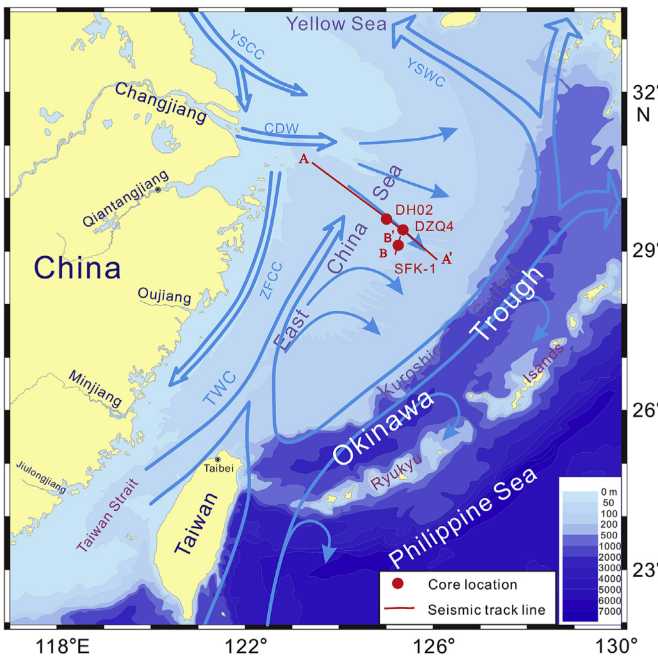

Fig. 1. Sketch map of the East China Sea and Yellow Sea showing bathymetric contours in meter, core locations, seismic track lines, and oceanic circulation (modified after Dou et al., 2015). Yellow Sea Coastal Current; ZFCC: Zhejiang–Fujian Coastal Current; YSWC: Yellow Sea Warm Current; CDW: Changjiang Diluted Freshwater Plume; TWC: Taiwan Warm Curren. The seismic profile A–A′ is from the joint Chinese-French cruise in 1996 (Berné et al., 2002) and B–B′ is modified after Wang et al. (2014). Data for cores DZQ4, and SFK-1 are sourced from Berné et al. (2002), and Wang et al. (2014), respectively.

dominantly contributing to modern shelf sediments (Liu et al., 2006). Over the past ~7 ka, most Changjiang-derived sediments were captured near modern estuaries, forming the mega river delta and a mud belt elongated along the inner shelf of the ECS (Fig. 1; Liu et al., 2006). In contrast, the mid-outer shelf, which was widely covered by sand ridges, received few river-derived sediments, and existing sand ridges are considered as relicts formed during the transgression after the LGM (Fig. 1; Liu et al., 2007a; Li et al., 2014). Numerous geological and geophysical studies have been conducted on the ECS shelf to investigate the late Quaternary sedimentary evolution. Most of these studies focused on delta and inner-shelf mud belts using a large number of high-quality borehole cores and seismic profiles (Chen et al., 2000, 2003; Li et al., 2000, 2002; Hori et al., 2001a, 2001b, 2002a, 2002b; Liu et al., 2006, 2010; Wang et al., 2010; Song, 2012; Xu et al., 2012, 2016). However, the mid-outer shelf has received much less attention because of the scarcity of chronologically constrained borehole core data (Saito et al., 1998; Liu et al., 2000, 2007a; Berné et al., 2002; Wellner and Bartek, 2003; Wang et al., 2013, 2014).

Considering the lack of information on this area, this study was conducted to reveal the late Quaternary sedimentary evolution of the outer ECS shelf. Accordingly, the lithology, sedimentology, micropaleontology, and chronology of borehole core DH02, which was recovered from the outer ECS shelf recently, were documented in detail, and sedimentary facies of the core were interpreted. Then, sedimentary processes at different geological periods were discussed based on data from DH02 and other neighboring boreholes and seismic profiles.

2. Regional setting

2.1. Physiography and sediment distribution of the ECS

The ECS is located in the East Asian continental margin and has one of the broadest and gentlest continental shelves in the world (Fig. 1). It is more than 600 km wide, with a slope angle of less than 0.28‰ (on average) (Wang and Sun, 1994; Wang et al., 2014). As a typical river-dominated marginal sea in Asia, the ECS receives a large amount of terrigenous material mainly from the Changjiang river (Xu et al., 2012). The annual sediment load of the modern Changjiang river has been ~480 million tons historically, although 70% of these sediments are trapped near the river mouth to form a delta (Milliman and Meade, 1983; Liu et al., 2007b). The Huanghe river and small rivers, such as the Qiantang Jiang, Ou Jiang, Min Jiang, and other rivers from Taiwan Island, make relatively small contributions to the ECS (Liu et al., 2007b; Xu et al., 2012).

The oceanic current system of the ECS mainly consists of the northward intrusion of the Kuroshio Current and its branch, the Taiwan Warm Current (TWC), and the southward Zhejiang-Fujian Coastal Current (ZFCC) (Fig. 1). The complicated oceanic circulation primarily determines the distribution and dispersal patterns of muddy and sandy sediments in the ECS (Yang et al., 2015). Several muddy deposits were formed off the Changjiang estuary, on the southwest shelf of Cheju Island, the inner shelf along the Zhejiang-Fujian coastal area, and the west slope of the Okinawa Trough (Fig. 1). Sands covering the mid-outer shelf are considered as transgressive relict deposits formed during transgression after the LGM (Fig. 1; Li et al., 2014; Wu et al., 2017).

2.2. Sedimentary studies of the late Quaternary

Around the 1990s, attempts were made to investigate the late Quaternary sedimentary evolution of the mid-outer ECS shelf in order to reveal the formation and development of tidal sand ridges extensively exposed on the sea floor. Using a gravity core (YQ1), Yang (1989) interpreted the sand ridges as relicts of paleo-Changjiang estuarine sediments formed during the deglacial sea-level transgression. In contrast, based on four gravity cores on a cross-shelf transect, Saito et al. (1998) suggested that the sand ridges are relicts of the paleo-Changjiang delta of marine isotopic stage (MIS) 3. Based on constriction by sufficient accelerator mass spectrometry (AMS) ^{14}C dates, they emphasized that ridge formation occurred in offshore shallow marine environments during the postglacial (Holocene) period. Some other studies correlated sand ridge formation to several decelerated sea-level rising periods among melt-water pulses (Li et al., 2014; Wu et al., 2017). However, according to core SFK-1, Wang et al. (2014) attributed the ridge formation to two accelerated sea-level rising stages of the Holocene.

Berné et al. (2002) carried out a study on synthetic sediments based on a long drilling core (DZQ4) constrained by thermoluminescence (TL) dates, building up a representative facies succession comprising prodelta facies of MIS 3, estuary to river facies of the LGM, and the deglacial to Holocene sand ridges. Recently, Wang et al. (2014) performed a similar study based on a new core (SFK-1) constrained by radiocarbon and optically stimulated luminescence (OSL)-derived dates. In contrast to the former study, the latter suggested that the delta did not form on the ECS shelf during MIS 3, but the river environment prevailed at that time, as indicated by the recognition of nearshore facies. Regarding the paleo-valley of the LGM, Wellner and Bartek (2003) outlined a wide but shallow valley system using a 3-D seismic framework. Contrary to the common interpretation that the valley formation was primarily caused by river downward incision (Saito et al., 1998; Li et al., 2014), Berné et al. (2002) proposed that the extremely gentle shelf topography largely determined the river incision ability and tidal current erosion processes, which prevailed during the deglacial sea-level rise, thus dominantly contributing to the valley formation. Recently, Wang et al. (2013) verified the occurrence of river deposition with the sea-level lowstand based on the identification of LGM river facies in SFK-1.

Although these studies have contributed towards the understanding of sedimentary facies and processes, knowledge of the late Quaternary sedimentary evolution of the mid-outer ECS shelf remains limited due to the scarcity of chronologically constrained borehole core data. In