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Late Quaternary stratigraphic evolution on the outer shelf of the East China Sea

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ABSTRACT

The East China Sea is a typical marginal sea and is characterized by strong land–sea interaction and paleoenvironmental changes during the late Quaternary with sea-level fluctuations. In this study, late Quaternary sedimentary stratigraphy and facies on the outer shelf of the East China Sea were reconstructed by using high-resolution seismic reflections and combining evidences from lithology, microfossil assemblages, element geochemistry and geochronology of borehole SFK-1. Sedimentary sequence consists of nearshore facies of forced regression formed during the late marine isotopic stage 3, tide-influenced fluvial and estuarine facies during the last glacial maximum, incised-valley fill and estuarine-tidal flat facies during the deglacial transgression, buried and quasi-active tidal sand ridge facies during the postglacial and Holocene periods.

The sea-level fluctuation and paleo-river and sea interaction primarily controlled the stratigraphic framework and sedimentary facies on the outer shelf during the late Quaternary. This study confirms the occurrence of paleo-river channels and relating deposits on the outer shelf. Paleo-fluvial deposits accumulated during the last glacial maximum albeit with strong tidal reworking, and tide-dominated estuarine facies are recognized during the early deglacial transgression. The previously-recognized delta facies might not have formed on the outer shelf because of the low sediment supply and/or strong tidal reworking.

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1. Introduction

As a link between land and deep ocean, the continental shelf plays an important role in land–sea interaction, sediment transfer and accumulation, and paleoenvironmental changes of continental margin over the geologic past (Berné et al., 2002; Dittmers et al., 2008; Green, 2009; Hanebuth et al., 2009; Lericolais et al., 2009; Nordfjord et al., 2009; Gerber et al., 2010; Schattner et al., 2010). In particular, the continental shelves on the earth were largely exposed to land during the Last Glacial Maximum (LGM, ca. 22–18 ka), with a significant drop of sea level (Bard et al., 1990). Terrestrial material was thus more easily transported across continental shelf to the deep ocean during the LGM than in the present day, mostly via river channels or incised valleys. Consequently, the lowstand systems tract on the shelf is characterized by a depositional hiatus atop of Pleistocene sediments and by some dendritic incised paleo-river networks (Li et al., 2002; Dittmers et al., 2008; Green, 2009). In other words, the terrigenous sediments mostly bypassed continental shelf and were directly delivered to the outer shelf or continental slope during the lowstand of sea level.

During the deglacial period, sea level began to rise and the transgressive deposits accumulated on the shelf. The incise valleys and channels were firstly filled and the shelf sediments deposited at the lowstand of sea level were largely eroded or reworked. Meanwhile, delta–estuary complexes, littoral and neritic sedimentation developed while the coastal line and estuaries retreated landward, and depositional environments gradually changed from fluvial-dominated to marine-dominated (Liu et al., 1998, 2000; Saito, 1998; Saito et al., 1998; Berné et al., 2002; Hori et al., 2002; Wellner and Bartek, 2003; Dittmers et al., 2008; Green, 2009).

The East China Sea (ECS) fosters one of the broadest continental shelves in the world, which connects the largest Eurasia continent and the west Pacific Ocean. The ECS is a typical river-dominated marginal sea in terms of its enormous sediment influx from large rivers such as the Changjiang (Yangtze River), Huanghe

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(Yellow River) and some small mountainous rivers in Taiwan Island during the Late Quaternary (Milliman et al., 1985; Chen et al., 2000; Liu et al., 2004, 2007; Xu et al., 2012). These terrigenous sediments formed large deltas and unique depositional systems on the shelf (Chen and Stanley, 1993; Li et al., 2000; Hori et al., 2001; Liu et al., 2004; Yang and Liu, 2007). Because of its unique geographic location and striking land–sea interaction, the Quaternary sedimentation and paleoenvironmental changes in the ECS have increasingly attracted research attentions over the last half century. Early in 1961, Niino and Emery used echosounder reflection amplitude notations on nautical charts to map the surficial sediments in the ECS, and defined modern detrital, residual and relict sediment origins (Niino and Emery, 1961). Since their pioneering work, numerous studies have been carried out on marine sedimentology of the ECS, with special emphases on sedimentary stratigraphy, sediment sources and environmental changes of the estuarine-deltaic and inner shelf areas (Chen et al., 2000; Li et al., 2000, 2002; Hori et al., 2001; Liu et al., 2007; Liu et al., 2010a, 2010b), but few focused on the mid-outer shelf (Saito et al., 1998; Liu et al., 2000; Berné et al., 2002; Yang, 2002; Yoo et al., 2002; Wellner and Bartek, 2003; Li et al., 2005a; Liu et al., 2009; Wang et al., 2013).

Regarding the late Quaternary stratigraphy and paleoenvironment of the ECS shelf, many fundamental questions are still open to discussion. One of them is the sequence stratigraphy and sedimentary facies formed on the outer shelf during the late Quaternary and its relationship with sea-level fluctuation. Another one is the recognition of the paleo-river channel on the exposed shelf and its sedimentation during the LGM. In this study, we first review the state-of-the-art researches on these key questions, and then reconstruct the later Quaternary sedimentary stratigraphy and its paleoenvironment on the outer shelf of the ECS based on data from borehole SFK-1 and neighboring boreholes.

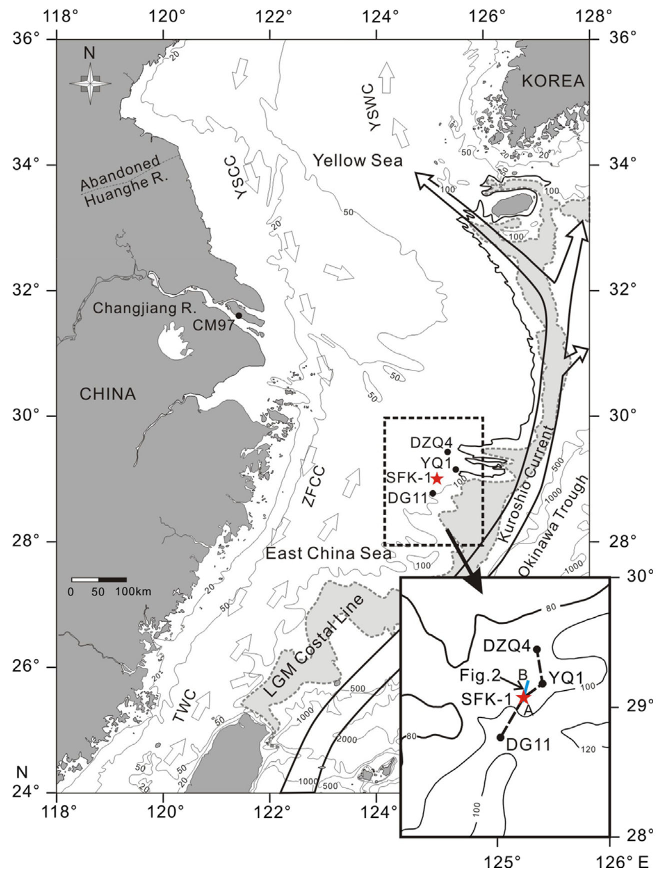

Fig. 1. A sketch map of the East China Sea with the locations of core SFK-1 and other boreholes. The index map shows the seismic trackline A–B (the blue solid line) across the studied core (the red star; see Fig. 2 for the details). The coastal line (the grayish shade area) at the last glacial maximum (LGM) is modified after Saito et al. (1998b), and the oceanic circulation is modified after Guan and Mao (1982) and Su (2001). ZFCC: Zhenjiang and Fujian Coastal Current; TWC: Taiwan Warm Current; YSCC: Yellow Sea Coastal Current; YSWC: Yellow Sea Warm Current. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Regional setting and marine sedimentation on the ECS shelf

2.1. Physiography and sedimentation of the ECS

The East China Sea as a typical marginal sea in Asia, has one of the broadest continental shelves in the world, linking the Eurasia continent and the west Pacific Ocean (Fig. 1). The shelf is more than 600 km wide and has an area of $>77\times10^4$ km^2, and a very low gradient (<0.28‰ on average) (Wang and Sun, 1994). The oceanic circulation of the ECS primarily consists of two different water masses (Fig. 1): the high-temperature and saline Kuroshio Current and Taiwan Warm Current flowing northward, while the costal currents with low temperature and salinity flowing southward along China's coast. These two main current systems basically control the distribution and dispersal of detrital sediments in the ECS, although both show large temporal and spatial variability in strength and pathways (Beardsley et al., 1985; Su, 2001; Lee and Chao, 2003).

The Changjiang River as the largest one in Asia, delivers a huge volume of sediments (about 4.8×10^8 ton/yr on multi-year average) into the estuary and shelf. Though about 70% of the Changjiang sediment is trapped in the river mouth to build a large delta, the remainder is dispersed southeastward, forming a muddy belt in the inner shelf off the Zhejiang and Fujian coast over the last 7000 years (Milliman et al., 1985; Li et al., 2001; Liu et al., 2007; Xu et al., 2012). In addition, the Huanghe River once flowed into the southern Yellow Sea during the late Quaternary, and its huge sediment input exerted a clear influence on the ECS (Li et al., 2001; Saito et al., 2001; Liu et al., 2010a, b).

Except the muddy sediments in the estuarine and inner shelf areas, the major part of the ECS shelf is blanketed by medium- to fine-grained sands (Qin et al., 1996). The distribution pattern and characters of detrital sediments on the shelf suggests that the modern Changjiang dominates the sedimentation on the inner shelf, while the relict sand sheets and ridges on the mid-outer shelf formed during the last transgression were also primarily derived from the paleo-Changjiang and/or the paleo-Huanghe (Milliman et al., 1985; Berné et al., 2002; Li et al., 2002, 2005a, b; Wellner and Bartek, 2003; Liu et al., 2003, 2007; Liu et al., 2010a, 2010b; Wang et al., 2013).

2.2. Sedimentation and river–sea interaction during the LGM

Sea level fluctuations in the ECS during the late Quaternary have been widely documented based on radiocarbon ^{14}C dates of various dating materials including peat, organic mud, molluscan shells and shell fragments (Zhao et al., 1979; Zhu et al., 1979; Chen et al., 1985; Saito et al., 1998; Liu and Milliman, 2004; Wang et al., 2013). The lowest sea level at the LGM (ca. 21–18 ka) was estimated to be from 110 m to 160 m below the present one, and then, a rapid rise of sea level at 15–18 ka and a highest level reached at ca. 6–7 ka were well accepted. The shelf was largely exposed during the LGM, accompanied with the ubiquitous incised valleys of paleo-rivers (Emery et al., 1971; Zhu et al., 1979; Qin et al., 1996; Saito, 1998; Chen et al., 2000; Berné et al., 2002; Liu and Milliman, 2004; Li et al., 2005a; Wang et al., 2013). During the deglacial sea-level rise, the subaerially exposed shelf was rapidly submerged and the incised valleys were filled. Paleo-estuarine/deltaic complex, transgressive sand ridges, and transgressive to

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