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Holocene evolution of bottom sediment distribution on the continental shelves of the Bohai Sea, Yellow Sea and East China Sea

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ABSTRACT

Coastline shifts due to transgression and regression can remodel tidal fields of continental shelves, and this can control transport of sediments and modulate sediment distribution accordingly. Tidal currents have become the dominant hydrodynamic processes on the continental shelves of the Bohai Sea, Yellow Sea and East China Sea (BYECS) since the transgression after the Last Glacial Maximum (LGM). To examine the evolution of the bottom sediment distributions on the continental shelves of the BYECS, we simulated patterns of tides and tidal currents, sediment transport, and bottom sediment types (sand, mud and mixed sediments) for five periods, corresponding to sea level lowstands of 80 m, 52 m and 30 m below present, the Holocene transgression maximum (HTM), and the present. The simulation shows that both sediment transport and shelf sediment distribution patterns were controlled by the strength, type and asymmetry of tidal currents in the BYECS since the LGM. Evolution of shelf sediment distribution patterns occurred in two stages: (1) sediment emplacement and formation stage before the HTM, and (2) local adjustment after the HTM. The marked changes in coastline configuration since the LGM are the dominant factor controlling tide and tidal current evolution. Distribution of shelf sediment types in the BYECS is closely related to tidal current fields during transgression after the LGM.

1. Introduction

Sandy and muddy sediments are typical deposits on global continental shelves, of which about 70% are occupied by sandy sediments in the forms of sand ridges and sheets (Swift, 1975). Many advances have been made on the origin of sandy shelf sediments since Off (1963) identified 14 types of sandy shelf sediment accumulations (e.g., Caston and Stride, 1970; Swift and Field, 1981; McBride and Moslow, 1991; Harris et al., 1992; Liu and Xia, 2004). The study of muddy shelf sediments, however, has comparatively lagged behind. More recently, explanations of their distributions on shelves (e.g., Harris et al., 2008; Xu et al., 2012) and in local bays (e.g., Warner et al., 2008) have been made.

Early studies on the distributions of sandy and muddy shelf sediments are mainly based on qualitative and comparative geological analysis (e.g., Caston and Stride, 1970; Parker et al., 1982; Liu et al., 1989; Harris et al., 1992). Numerical simulation of sediment dynamics has been used in some local studies (e.g., Huthnance, 1982a, 1982b; Zhu and Chang, 2000; Harris et al., 2008). However, numerical simulation of sediment dynamics is less commonly used to study sediment transport, deposition, and bottom sediment distribution across large-scale shelves, under single or multiple hydrodynamic conditions. Few studies also integrate sandy and muddy sediment transport together over long time periods, although numerical simulations of paleo-tide and tidal currents in different areas and for different periods since the Last Glacial Maximum (LGM) have been reported (e.g., Gehrels et al., 1995; Hall and Davies, 2004; Yoshida et al., 2007; Neill et al., 2010).

Surveys of shelf deposits in the Bohai Sea, Yellow Sea, and East China Sea (BYECS) show that there are three main bottom sediment types (Zhu and Chang, 2000): sand (mainly composed of fine sand), mud (including the full size range from clayey silt to clay) and mixed sediments (composed of sand–silt–clay). The origins of these sediments have been studied based on field data (e.g., Hu, 1984; Qin et al., 1987; Jin, 1992; Shen et al., 1996; Liu, 1997). However, there are still different opinions about their hydrodynamic conditions, sources and evolution.

Emery (1968) suggested that most of the sandy shelf sediments in the BYECS are relicts deposited during Late Pleistocene sea level lowstands. Other views are that most sandy sediments are tidal deposits (e.g., Liu et al., 1998a; Zhu and Chen, 2005). Hu (1984) suggested that upwelling in the Yellow Sea would result in mud deposition. Qu and Hu (1993) ascribed the mud deposition south of Cheju Island, East China Sea, to barotropic anticlockwise circulation; however, Yanagi et al. (1996) suggested that the circulation had nothing to do with mud deposition.

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Tidal currents, sea currents, and waves all contribute to hydrodynamic conditions in the BYECS (Fig. 1). Tidal currents, particularly the M_2 constituent, are a permanent feature and have dominated shelf dynamics since the post-LGM transgression (Sternberg et al., 1985; Dong et al., 1989). M_2 tides have been considered as the main dynamical forcing in sediment transport and deposition, especially in the formation and evolution of tidal current ridges (e.g., Liu et al., 1998a; Zhu and Chang, 2000; Uehara et al., 2002).

Wave forcing can also initiate sediment motion when water depth is less than one half of the wavelength, but deposition of these sediments is eventually controlled by tidal current patterns (Dong et al., 1989; Zhu and Chang, 2000). Ocean currents have marked seasonal patterns, and M_4 tides are weaker than M_2 tides in the BYECS. These non-tidal hydrodynamic factors are less effective for sediment dynamics, compared to M_2 tides, in both strength and duration (Dong et al., 1989; Liu et al., 1998b). Sediments on shelves of the BYECS are also influenced by the Changjiang River and the Huanghe River. River plumes can bring fine sediments to the shelf, but the seabed distributions of sediments are controlled by tidal currents (Liu et al., 1998a; Zhu and Chang, 2000). The non-linear model used in this paper can reproduce M_4 tides through non-linear processes in the shelf region, even though the model was forced solely by M_2 tides offshore. For simplification, waves, ocean currents, M_4 tides, and river plumes are not considered, and we focus on M_2 tidal patterns in this paper.

This paper aims to use numerical simulation to reproduce the M_2 tide and tidal currents, associated sediment transport, and bottom sediment distribution for five time periods since the LGM, corresponding to sea level lowstands at 80 m, 52 m, and 30 m below present, the Holocene transgression maximum (HTM), and the present day. The aim is to elucidate mechanisms of sediment distribution of the three main bottom sediment types (sand, mud and mixed sediment) on the shelves of the BYECS.

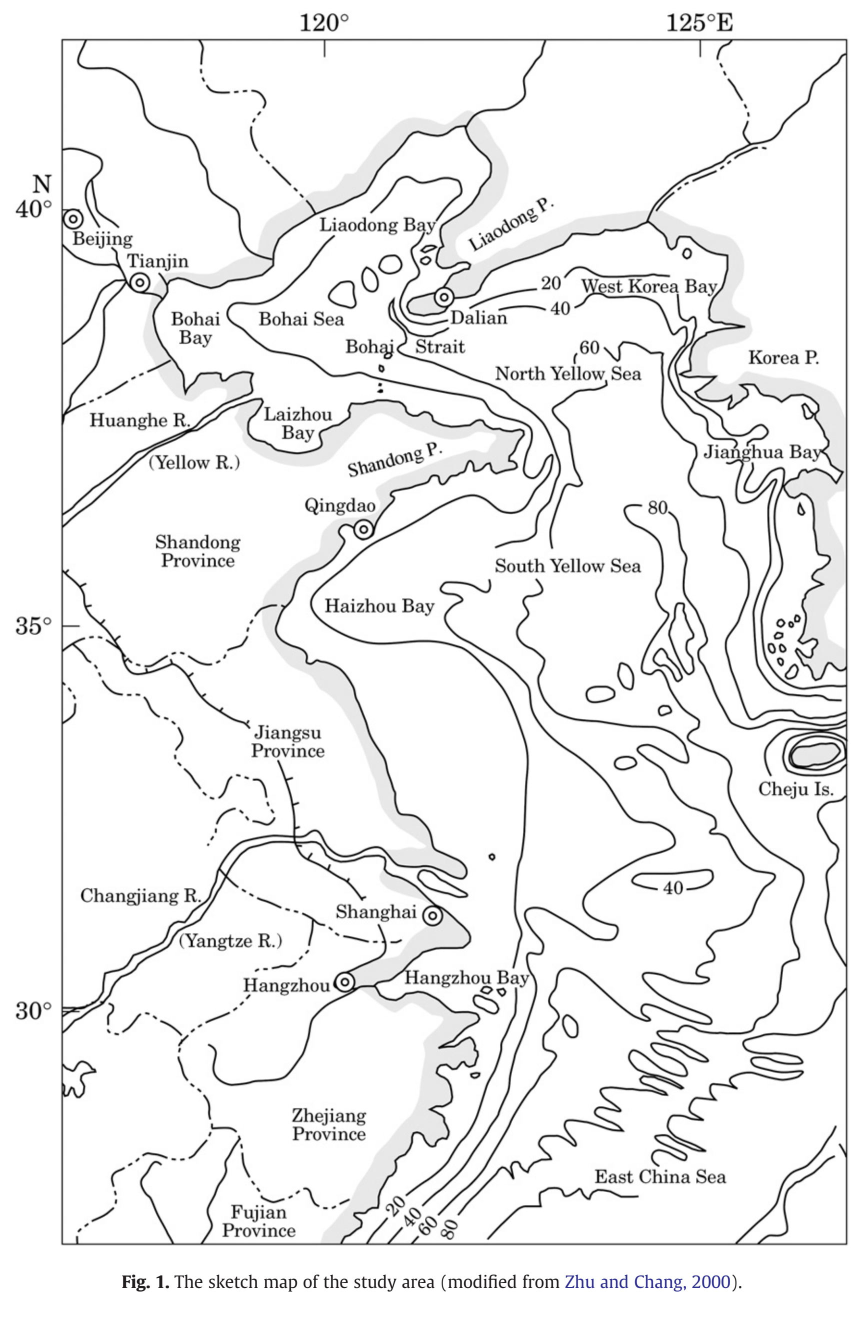

Fig. 1. The sketch map of the study area (modified from Zhu and Chang, 2000).