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Distal mud deposits associated with the Pearl River over the northwestern continental shelf of the South China Sea

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ABSTRACT

Continental shelf mud deposits represent an important archive of the Holocene earth history. Such deposits are usually associated with large rivers that transport a large quantity of suspended sediment. The Pearl River has formed a distal, shore-parallel Holocene mud deposit on the northwestern continental shelf of the South China Sea; investigations into its spatial distribution and evolutionary history are necessary for an improved understanding of such sedimentary systems. Seabed sediment sampling, in situ tidal cycle measurements, seismic survey and the associated data analyses reveal that the distal mud deposit associated with the Pearl River occupies an area of approximately 8.87×10^3 km^2, with a modern deposition rate of 1.27 to 5.66 mm yr^{-1}. Evidence from sediment balance, environmentally sensitive components, sediment transport processes and regional shelf circulation patterns indicates that the Pearl River is a major sediment source for the mud deposit. This distal mud deposit represents an initial stage of its development. The fining upward pattern and the negative skewness values in the layer are indicative of the Pearl River influence, and the ^{210}Pb age is younger than 10^2 yr. The main body of the Holocene deposit of the region is not related directly to the modern Pearl River sediment. For most of the Holocene periods the Pearl River has been trapping the sediment to fill its extensive estuarine waters and, therefore, the formation of the distal mud is a recent event. A regional characteristic is that the timing of the formation of distal muds associated with large rivers depends on the estuarine morphological evolution and the quantity of sediment discharge.

1. Introduction

Annually, a large quantity of approximately 12.6 BT terrestrial sediments is delivered to the global coastal ocean (Syvitski et al., 2003). Continental shelves represent a major sink of terrestrial materials on the sediment pathway from the catchment to the continental slope (Lantzsch et al., 2009). Sedimentary rocks, including the topmost parts of unconsolidated sediments, formed on shelves may bear a major portion of the stratigraphic record that reflects a diverse range of the past tectonic, climatic and hydrodynamic conditions (Hill et al., 2007). Further, the analysis of the stratigraphic record will enhance our ability to predict future flux and fate of fluvial sediment delivered to coastal waters (Sommerfield et al., 2007).

During the Holocene period the shelf deposits tend to occur in the form of mud patches or belts, in both high and/or low energy depositional environments (Lantzsch et al., 2009). Three conditions are favorable for the formation of large scale mud deposits: (1) sufficient accommodation space, which may be created by the tectonics and/or the eustasy; (2) abundant terrestrial sediment supply; and (3) suitable hydrodynamic and sediment dynamic processes for the transport and accumulation of the sedimentary materials. For instance, on the broad continental shelf of the northern and eastern China, large quantities of river input from, e.g., the Yellow and Changjiang Rivers (Milliman and Farnsworth, 2011) are coupled with intense tidal currents, shelf circulations and sediment gravity flow (Gao, 2013); as a result, large volumes of Holocene mud deposits have been formed on the inner shelf, far away from the river mouths (Cheng et al., 2004; Liu et al., 2004, 2006; Yang and Liu, 2007). Moreover, here mud patches are also formed on the middle-outer shelf, where tidal currents are relatively weak but vertical circulations causing seaward dispersion of fine-grained sediment are active (Kwan, 1963; Dong et al., 1989; Gao and Jia, 2003). In the case of the Po River, which discharges into the Adriatic Sea, although the tidal action is weak shelf residual currents are able to transport the fine-grained sediment for a long distance; hence, remotely distributed med belts are formed along the transport pathway (Cattaneo et al., 2003). Elsewhere, on relatively narrow shelves, the dispersal of fine-grained sediment is controlled by gravity-induced transport, with mud belts being formed on the middle shelf (Nittrouer et al., 2007).

The Pearl River, which is the third largest river in China, discharges into the northern part of the South China Sea (SCS); here, a mud belt has been found over the inner shelf, along the coastlines to the west of the Pearl River mouth (Qin, 1963; Owen, 2005). The geographic location of the mud belt has a similarity to the Yellow, Changjiang, Po and Eel

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Rivers, i.e., to the right side of the river mouth as viewed from the river flow direction. However, it is still poorly understood how the Pearl River-derived fine-grained sediments affect the mud deposition over the northwestern inner shelf of the South China Sea. A systematic study can not only increase our knowledge about the characteristics of the distal river-induced subaqueous deltas with different types of river mouth, infilling history, and sediment flux conditions, but also can stimulate quantitative, process-based research of the formation of Holocene shelf deposits.

Hence, the present study aims to provide the results of recent investigations into the shelf mud deposits on the northwestern shelf of the SCS and to discuss the underlying processes and mechanisms. In detail, we present: (1) the spatial distribution patterns of the fine-grained sediments; (2) the transport and accumulation processes responsible for the formation of this sedimentary system; and (3) the development history of the Holocene mud deposits in relation to the shelf environment and the Pearl River sediment input.

2. The study area

The South China Sea is the largest marginal sea of the western Pacific Ocean. Its northern continental shelf is 200–220 km in width (Liu et al., 2002). The inner continental shelf (water depth < 60 m) has a bed slope of around 0.08°, which is slightly steeper than the outer shelf (i.e., 0°03′–0°04′) (Feng and Zheng, 1982).

The study area is located within the coastal waters to the west of the Pearl estuary, on the northwestern inner shelf of the SCS (Fig. 1a). This region is under the influence of the East Asian monsoon (Liang, 1991): in winter northeasterly winds prevail over the entire SCS with an average magnitude of 9 m s^{-1} (Hu et al., 2000), while in summer weaker southwesterly winds of 6 m s^{-1} dominate over most parts of the SCS. Due to the effect of the seasonal reversing of summer- and winter-monsoon winds, rainfall over this area is concentrated mainly in the wet season (April to September), while less than 30% of precipitation occurs in the dry season (Wang, 2007).

The ocean circulation in the entire SCS is complex, characterized by seasonal variations which are driven primarily by the monsoon winds, accompanied by the impact of the Kuroshio Current (Su, 2004; Xiu et al., 2010). In the study area, the shelf circulation is dominated by currents towards the west in winter, but in summer the currents are directed towards the east (Fig. 2). The average current speed in winter is larger than in summer, with a magnitude of around 0.26 m s^{-1} (Wang, 2007).

More than 20 rivers in southern China (e.g., the Pearl and Moyang Rivers) discharge into the SCS, most of which have a drainage basin of

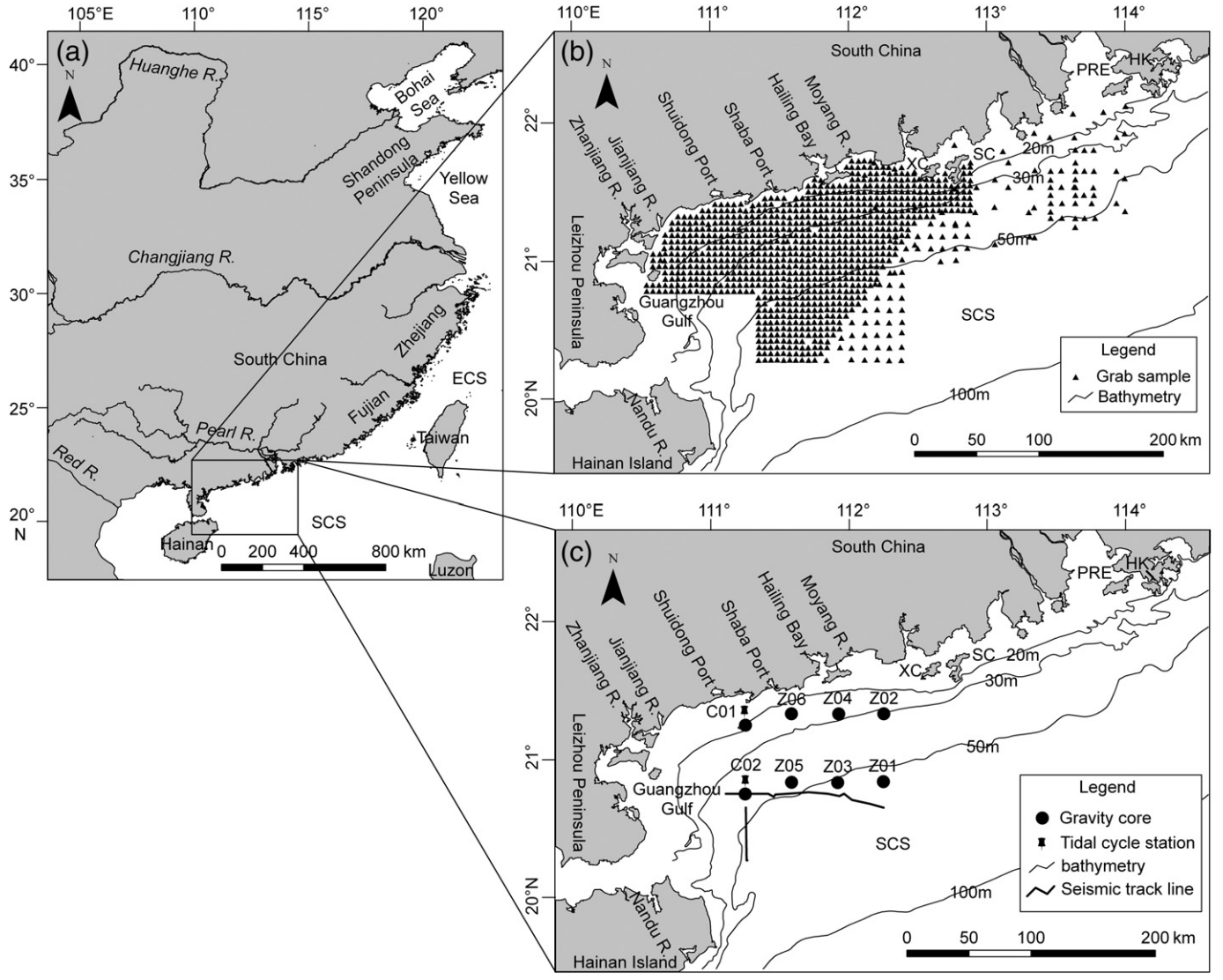

Fig. 1. The study area and the sites for sediment sampling and sediment dynamic measurements: (a) geographic map showing the study area in the northern South China Sea; (b) location of grab samples, PRE = Pearl River Estuary, SC = Shangchuan Island, XC = Xiachuan Island, HK = Hong Kong; and (c) the sites of tidal cycle measurements, gravity core sampling and seismic profiles.