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Lithological and palynological evidence of late Quaternary depositional environments in the subaqueous Yangtze delta, China

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ABSTRACT

AMS ^{14}C ages of post-glacial core sediments from the subaqueous Yangtze delta, along with sedimentary structures and distributions of grain size, pollen spores, and dinoflagellate cysts, show an estuarine depositional system from 13 to 8.4 cal ka BP and a deltaic system from 5.9 cal ka BP to the present. The estuarine system consists of intertidal to subtidal flat, estuarine, and estuarine-front facies, characterized by sand–mud couplets and a high sedimentation rate. The deltaic system includes nearshore shelf and prodelta mud featured by lower sedimentation rate, markedly fewer coastal wetland herbaceous pollens, and more dinoflagellate cysts. We explain the extremely high sedimentation rate during 9.2–8.4 cal ka BP at the study site as a result of rapid sea-level rise, high sediment load due to the unstable monsoonal climate, and subaqueous decrease of elevation from inner to outer estuary. A depositional hiatus occurred during 8.2–5.9 cal ka BP, the transition from estuarine to deltaic system, caused possibly by a shortage of sediment supply resulting from delta initiation in paleo-incised Yangtze valley and strong tidal or storm-related reworking in offshore areas. The subsequent development of deltaic system at the study site indicates accelerated progradation of Yangtze delta post-5.9 cal ka BP.

Introduction

The subaqueous Yangtze River delta is one of the most dynamic geomorphologic units in the marginal seas of the western Pacific Ocean. The huge catchment of the Yangtze River rises to an altitude of over 5000 m and has supplied plentiful sediments to the estuary to form a mega-delta on the eastern China coast during the Holocene (Fig. 1). In recent decades, numerous studies have investigated environmental changes during the Holocene deposition of the Yangtze delta. These have included studies of the climate- and sea-level-controlled geomorphologic and sedimentary evolution of the delta plain (Stanley and Chen, 1996; Stanley et al., 1999; Chen et al., 2005; Wang et al., 2006; Atahan et al., 2007; Itzstein-Davey et al., 2007; Chen et al., 2008), changes in the sedimentary environment and stratigraphy of the paleo-incised Yangtze valley (Li et al., 2000; Hori et al., 2001a,b; Hori et al., 2002a,b), and changes in the vegetation and climate (Liu et al., 1992; Yi et al., 2003; Yi and Saito, 2004; Yi et al., 2006).

Previous work has revealed only a thin early Holocene sequence on the delta plain and has shown that the major accumulation of sediments there occurred after ca. 8 cal ka BP (Stanley et al., 1999). The Holocene sedimentary sequence is more complete (~50 m thick) in the paleo-incised Yangtze valley than on the delta plain (Li et al., 2000; Hori et al., 2001a). The evolution of the depositional environment in the paleo-incised valley was closely related to sea-level changes (Hori et al., 2001a, 2002a,b; Hori and Saito, 2007). A large decrease of the sediment accumulation rate in the paleo-incised valley at ca. 8.5–9.0 cal ka BP is attributed to a sea-level jump at that time (Hori and Saito, 2007). Comparison of borehole data from the delta plain and the paleo-incised valley shows some differences in the sedimentary record. For example, the early Holocene climate optimum evident in borehole ZX-1 from the delta plain (Chen et al., 2005) was not reported in boreholes HQ98 or CM97 from the paleo-incised valley (Yi et al., 2006).

To date, studies of the subaqueous Yangtze delta are few compared to those of the paleo-incised Yangtze River valley. Only a few boreholes were drilled into late Quaternary sediments during the 1980s, and few dating results have been reported in previous work (Chen et al., 2000). Some recent, better age-controlled boreholes have been drilled in the distal area of the delta where Holocene sediment thickness is generally less than 10 m (Chen et al., 2003; Wang et al., 2005a). Seismic profiling has revealed that the Holocene sequence in the subaqueous delta is thick, but it failed to define the complete Holocene sequence because of strong attenuation of seismic signals by natural gas reservoirs in the sequence (Liu et al., 2007).

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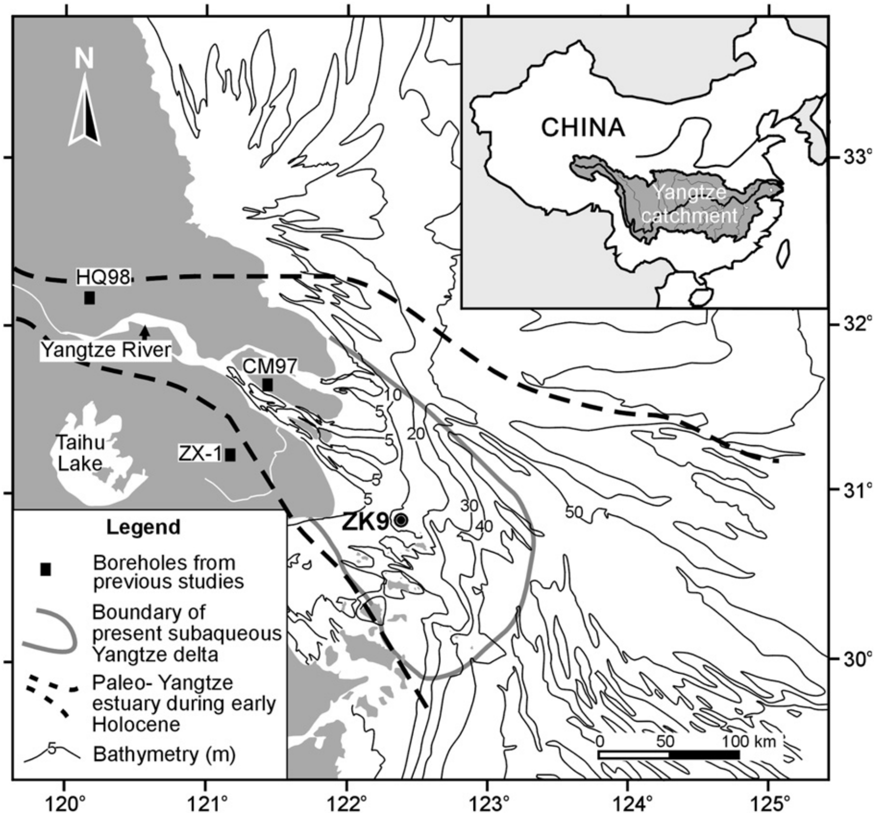

Figure 1. Map of the study area showing borehole locations and outlines of the present-day subaqueous delta and the Holocene Yangtze River estuary. The water depth at the ZK9 borehole site was 12.5 m. Data from boreholes HQ98 and CM97 are from Hori et al. (2001a). Data from borehole ZX-1 are from Stanley et al. (1999).

In 2007, we obtained a 50-m-long core (ZK9) from the subaqueous Yangtze delta from a water depth of 12.5 m (Fig. 1). Core recovery was 96%, and fine-grained sediments were dominant in the core (Fig. 2). The results of this study revealed changes of the lithology and palynology of Holocene sediments that allowed us to examine sedimentary environments and their relationship with climate-controlled sea-level fluctuations. The data from this core also provide an opportunity to correlate the depositional systems of the offshore area with those of the paleo-incised valley and a broad view of the evolution of the Yangtze estuary during the Holocene.

Methods

Twelve shell and plant fragment samples were obtained from the borehole core and used for AMS ^{14}C dating (Table 1). Specimens for dating were prepared at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, and age determinations were completed at the State Key Laboratory of Nuclear Physics and Technology, Peking University. $^{14}C/^{12}C$ ratios were measured for the age determination, and $\delta^{13}C$ was assumed to be $-2‰$ for shell samples and $-25‰$ for plant samples, because it was not measured in each sample. After $\delta^{13}C$ corrections for isotope fractionation, all conventional dates were calibrated (cal yr BP) by using the Calib Rev 5.1 (beta) program (Stuiver and Reimer, 1993; Table 1). Calibration datasets Marine04 and IntCal04 were used for shell and plant samples, respectively. The marine reservoir effect (ΔR) was corrected for according to the method of Southon et al. (2002) and Kong and Lee (2005). Final calibrated ages at 1σ with probabilities >0.8 were used in this study. We also collected AMS ^{14}C dates previously determined from borehole ZX-1 (Stanley et al., 1999) and converted them to calibrated ages (Table 1).

Grain-size analysis of 95 samples was done with a Beckman Coulter Laser Diffraction Particle Size Analyzer (LS13320). Samples 5–10 cm thick were taken at ~50-cm depth intervals along the core. The samples were allowed to dry naturally and then mixed before specimens of around 3 g were oven dried in preparation for grain-size analysis.

Forty-three samples were taken at core intervals of ~1 m for analysis of pollen spores and dinoflagellate cysts. Between 200 and 500 fossils grains were identified in most samples. Samples with fewer pollen-spore fossils (<100 grains) were not included in the statistical analysis. The absolute pollen-spore concentration (grains/g) was calculated by adding Lycopodiaceae as a tracer.

Results

Lithology, palynology, and radiocarbon ages

According to the lithology, concentrations of pollen spores and dinoflagellate cysts, and radiocarbon ages, we divided the borehole sediments into sections in ascending order as follows:

Sediments from the last glaciation (43–50 m)

45.5–50 m

Greenish gray and dark gray sand or silt is prevalent in this section (Fig. 2). The sand content is 26.6–56.3%; silt 30.5–63.7%, and clay 9.7–16.2%. Silt content increases with depth. The mean grain size is between 47.3 and 87.2 μm. Only a few pollen spores were found, with a concentration of <250 grains/g. No dinoflagellate cysts were observed.

43–45.5 m

This section comprises mainly homogeneous gray and hard mud (Fig. 3-1). The lithology is similar to that of the first hard mud layer of the Yangtze delta plain, which formed during the last glacial maximum (Qin et al., 2008). Silt (59–68.9%) is dominant in this section, followed by clay (23.2–31%), and sand (0.1–17.8%). Mean