Journal of Asian Earth Sciences 128 (2016) 158–180

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Full length Article

Seismic and core investigation on the modern Yellow River Delta reveals the development of the uppermost fluvial deposits and the subsequent transgression system since the postglacial period

Shihao Liu [a,b,*], Peiying Li [b], Aiping Feng [b], Jun Du [b], Wei Gao [b], Yuanqin Xu [b], Xiaoxiao Yu [b], Ping Li [b], Xueliang Nan [b]

[a] College of Environmental Science and Engineering, Ocean University of China, Qingdao 266100, PR China
[b] The First Institute of Oceanography, State Oceanic Administration, Qingdao 266061, PR China

ARTICLE INFO

Article history:
Received 4 February 2016
Received in revised form 2 June 2016
Accepted 11 July 2016
Available online 11 July 2016

Keywords:
High-resolution seismic profiles
Borehole cores
Stratigraphic sequence
Late Quaternary
Environmental evolution
Modern Yellow River Delta

ABSTRACT

Postglacial stratigraphy and environmental evolution onshore and offshore the modern Yellow River Delta were investigated and analyzed through ~1200-km high-resolution seismic profiles and four boreholes together with previous publications. Four seismic units (SU 1–4, top-to-bottom) that are bounded by seismic surfaces (T_1-T_4) were identified in seismic profiles, while four depositional units (DU 1–4, top-to-bottom) were recognized in representative boreholes. These seismic units and depositional units exhibit good correlation. We interpreted SU 1/DU 1 as the modern Yellow River Deltaic deposits, SU 2/DU 2 as the Holocene neritic sediments, SU 3/DU 3 as a Pleistocene-Holocene transitional layer, and SU 4/DU 4 as the lowstand fluvial sediments. Apart from T_1 (seafloor), T_2 (deltaic base), T_3 (shoreface ravinement) and T_4 (transgressive surface) all dip seaward, but their dipping gradients reduced from T_4 to T_2. Therefore, the thicknesses of SU 2–3 were observed seaward-thicker trends presumably in relationship with different spatial sedimentation rates. Additionally, down-core distributions of environmental proxies (e.g. grain size, microfossils and geochemical characteristics) reveal the transgression system (DU 2 and 3) can be further subdivided into 5 intervals associated with sharp environmental changes.

Based on above evidences, we raised an evolutionary model of the postglacial depositional environment at the modern Yellow River Delta and adjacent marine areas, suggesting the study area evolved from riverine, estuarine, coastal, shoreface, neritic to final prodeltaic/deltaic environment since the Post-Last Glacial Maximum (LGM) in relationship with eustatic and climatic events as well as sediment input. In the model, we redefined the two-phase channel systems that exhibited in our previous study (Liu et al., 2014) as the tributaries of the LGM paleo-Yellow River and the tidal/estuarine tidal channels that formed at the early Holocene. Besides, we speculated that two hiatuses/erosions occurred at Younger Dryas and ~4–3 cal. kyr BP, and further divided the study area into three depositional zones based on their different sedimentation rates of the transgression system.

1. Introduction

High-resolution stratigraphic studies of the upper continental deposits and subsequent transgressive deposits that were accumulated between the latest Pleistocene and the Holocene are of importance to recognize the Late Quaternary evolutionary history of the depositional environment in eastern China (e.g. Li et al., 2014; Xu et al., 2016). They also provide information for eustatic event and environmental evolution in the glacial/interglacial cycles. During this period, Chinese continental shelves and coastal areas experienced a complex environmental change under sea-level change and climatic variation, and thereby attracted widespread interests and researches (e.g. Saito et al., 1998; Berne et al., 2002; Zhao et al., 2008; Xie et al., 2008; Yi et al., 2012a,b).

Historic evolution of the Yellow River Delta is one of the topic that has received large amount of researches but remains controversial. For example, Zhu (1989) argued the origin of the Yellow River during the Last Glacial Period happened in Early Pleistocene rather than widely accepted Latest Pleistocene (Zhang, 1989). Besides, Xia et al. (1996) proposed that the water and sediment

* Corresponding author at: First Institute of Oceanography, State Oceanic Administration, No. 6 Xianxialing Rd., High Science and Technology Industrial District, Qingdao 266061, PR China.

E-mail address: liushihao@fio.org.cn (S. Liu).

http://dx.doi.org/10.1016/j.jseaes.2016.07.009
1367-9120/

flux of Yellow River were very low and the downstream course was nearly disintegrated during the Last Glacial Maximum (LGM, ~23–19 cal. kyr BP) in relation with arid climate. On the contrary, Liu et al. (2010) suggested the Yellow River discharged into the shelf of the South Yellow Sea during Marine Isotope Stage 3 (MIS 3, ~40 cal. kyr BP) and MIS 2. Apart from these debates, development of the Yellow River course since mid-Holocene (~7 kyr BP) was well documented since a series of investigations were conducted through lithology, sedimentary facies, radiocarbon ages, pollen assemblages, foraminifera/ostracoda assemblages and high-resolution seismic profiles for discussing the Post-LGM evolutionary history of the Yellow River mouth shifting as well as the evolution of the stratigtaphic successions among the South Yellow Sea (e.g. Liu, 2001; Liu et al., 2010, 2013), off the Shandong Peninsula at the North Yellow Sea (e.g. Liu, 2001; Liu et al., 2002, 2004, 2007, 2009b; Yang and Liu, 2007) and the western Bohai Sea (e.g. Saito et al., 2000, 2001; Yi et al., 2003; Shi et al., 2003; Liu et al., 2009a, 2014; Zhou et al., 2014; Qiao et al., 2011).

Nevertheless, they did not provide sufficient materials to fully understand the subfacies of the Latest Pleistocene and the Holocene stratigraphy as well as the environmental evolution at the modern Yellow River delta, probably because of the stratigraphic complexity which was driven presumably by the complicated stepwise Post-LGM sea-level rise (Liu, 2001; Liu et al., 2004). The sedimentation and paleoenvironmental evolution during this time span remain controversial, which can be primarily summarized as the following three issues.

Issue (1): How and in what paleo-environment did the sedimentation take place during the period between the LGM and ~18.9 kyr BP? For the issue, Xia et al. (1991) proposed that the continental shelf of Bohai Sea was dominated by desert owning to the prevailing arid cold climate according to a set of seismic and borehole core surveys at central and eastern Bohai Sea. On the basis of their proposal, a presumed theory that desertification and disintegration of previous transgressive deposit was widely occurred among Chinese continental shelves was presented (Zhao, 1991; Zhao et al., 1996; Yu and Han, 1999). On contrary, several other investigations suggested the LGM deposits at modern western coastal area were formed from fluvial or lacustrine origin (e.g. Starkel, 1983; Liu et al., 2009a; Zhou et al., 2014). Nevertheless, since typical environmental indicators (e.g. micro-fossil assemblages and geochemical distributions) exhibited very limited composition at samples from this layer, they were not sufficient to support either of the above views (Liu et al., 2014).

Issue (2): How and in what sedimentary environment were sediments preserved during the period from ~11 to 8.5 kyr BP? For this issue, Zhou et al. (2014) summarized Yi et al. (2003)'s study, and suggested the fluvial activity diminished gradually after the Younger Dryas (~12.9–11 cal. kyr BP). In contrast to them, Liu et al. (2004) identified a flooding event occurred ~9.8–9.2 cal. kyr BP offshore of the Shandong Peninsula at the North Yellow Sea and demonstrated that it was an extreme flood of the Yellow River (Yang et al., 2000). Additionally, Saito et al. (2000) and Yi et al. (2003) identified a transitional (estuarine) unit formed during this period, but which loss focus at latter studies.

Issue (3): How to subdivide the deposits formed between ~6 kyr BP and 1 kyr BP and subsequently point out the corresponding depositional environment? During this period, the modern Yellow River subaqueous delta was stably covered by seawater. Marine deposits were discovered widely in representative borehole cores which were derived from the modern western coast of the Bohai Sea (e.g. Qin et al., 1990; Yi et al., 2003; Liu et al., 2009a), yet they are among the insufficient understood. Owing to the sedimentation rate was as low as less 1 mm/yr at the modern Yellow River subaqueous delta, a thin neritic layer (usually less than 5 m, e.g. Liu et al., 2009a, 2014) was deposited there. Previous studies failed in providing sufficient high-resolution stratigraphic and seismic materials for fully understand the evolution of the neritic system.

To further explore the issue (1), additional investigations were conducted through mineralogy (Liu et al., 2009a), phytolith analysis (Nan et al., 2015), paleo-topography (Zhou et al., 2014), and geo-hazard assessment (Zhou et al., 2004; Li et al., 2013; Liu et al., 2014). However, some of the interpretations also remained conflicting. For example, mica concentration indicated that the Yellow River did neither discharge nor influence the Bohai Sea during the MIS 2 (Liu et al., 2009a), but seismic, chronological (Liu et al., 2014) and geochemical (Zhou et al., 2014) materials revealed a buried channel system as well as the fluvial layer was formed during the last deglaciation from a Yellow River origin. Nevertheless, these investigations provide high-resolution seismic and core materials for the above three issues.

Although we have published an article describing the morphology and evolution of the buried channel system beneath the modern Yellow River subaqueous delta (Liu et al., 2014), we suggest the stratigraphic sequence and environmental evolution exhibited in that paper were partly wrong after analyzing complementary materials, including ~550 km offshore seismic profiles, three onshore borehole cores as well as data from literatures. Mistakes in that paper occurred primarily when (1) calibrate the radiocarbon ages, (2) strictly correlate the seismic units with sedimentary facies (0.5–2 m error existed in both seismic and lithological boundaries), and (3) some interpretations of the evolutionary history. Compare to previous high-resolution stratigraphic studies there (e.g. Liu et al., 2009a; Zhou et al., 2014) which usually focused on a large time scale (e.g. from MIS 5 to MIS 1) and highlighted less on the Pleistocene-Holocene transgressive system and Holocene highstand system (e.g. the bounding surfaces and ravinements in stratigraphic sequence category within these systems have not been reported before), in this study, we interpreted/reinterpreted approximate 1200-km high-resolution seismic profiles for seismic structure, and analyzed four borehole cores onshore and offshore the modern Yellow River Delta complemented with previously published representative cores with rigorous measured ages for sedimentary stratigraphy, to enhance the stratigraphic recognition of the fluvial system and subsequent transgression system which deposited during the postglacial period. We also attempted to discuss the environmental evolution and its response to major environmental/sedimentary events on the basis of recognition of primary bounding surfaces, ravinements and restrict correlation between seismic and borehole materials, and tried to explore the less understood issues (2) and (3), i.e. the coastal process and sedimentation at the study area during the Pleistocene-Holocene transgression.

2. Geological setting

As a semi-enclosed interior continental shelf sea of China, the Bohai Sea is connected to the northern Yellow Sea via the Bohai Strait (Fig. 1) with a mean depth <30 m (Qin et al., 1990). It is a rift sedimentary basin where block-faulting activities are primarily controlled by NE- and NNE- trending faults. Nevertheless, most of the faulting activities have diminished since Neogene (Cai et al., 2001; Guo et al., 2007). As a result of the regional tectonism, the Bohai basin become a depocenter and sea-level variation which was driven by the glacial/interglacial climatic cycles contributed to the interbedded marine and continental subsequences (Qin et al., 1990).

The selected research area lies at the subaqueous modern Yellow River delta and the adjacent sea regions in and around the modern western Bohai Sea coast (Fig. 1). The modern Yellow River delta covers a land area of 5500 km^2. It formed after 1855