Quaternary Science Reviews 189 (2018) 91–104

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Early to Middle Holocene sea level fluctuation, coastal progradation and the Neolithic occupation in the Yaojiang Valley of southern Hangzhou Bay, Eastern China

Yan Liu [a], Qianli Sun [a, *], Daidu Fan [b], Bin Dai [a], Fuwei Ma [a], Lichen Xu [a], Jing Chen [a], Zhongyuan Chen [a]

[a] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, 200062, China
[b] State Key Laboratory of Marine Geology, Tongji University, Shanghai, 200092, China

ARTICLE INFO

Article history:
Received 8 September 2017
Received in revised form
5 March 2018
Accepted 11 April 2018

Keywords:
Yaojiang Valley
Sea level
Foraminifera
Transgression and regression
Hemudu culture
Neolithic occupation
Waterlogging

ABSTRACT

The Yaojiang Valley (YJV) of southern Hangzhou Bay was the birthplace of the well-known Hemudu Culture (HC), one of the representatives of Neolithic civilization in eastern China. To explore the magnitude of natural environmental effects on the HC trajectory, the palaeo-embayment setting of the YJV was studied in detail for the first time in terms of 3D Holocene strata supported by a series of new radiocarbon-dated cores. The results indicated that the local relative sea level rose rapidly during the Early Holocene in the YJV, reached its maximum flooding surface *ca.* 7900 cal yr BP, and then remained stable *ca.* 7900-7600 cal yr BP. Thereupon, an estuary stretching inland was first formed by marine transgression, and then, it was transformed to an alluvial-coastal plain by regressive progradation. The alluvial plain was initiated in the foothills and then spread towards the valley centre after sea level stabilization *ca.* 7600 cal yr BP. Accompanying these natural environmental changes, the earliest arrivals of foragers in the valley occurred no later than *ca.* 7000 cal yr BP. They engaged in rice farming and fostered the HC for approximately two millennia from *ca.* 7000-5000 cal yr BP as more lands developed from coastal progradation. The rise and development of the HC are closely associated with the sea level-induced landscape changes in the YJV in the Early-Middle Holocene, but the enigmatic exodus of the HC people after *ca.* 5000 cal yr BP is still contentious and possibly linked with the rapid waterlogging and deterioration of this setting in such a low-lying coastal plain as well as with associated social reasons.

1. Introduction

The evolution of coastal environments in the Holocene was greatly affected by post-glacial sea level changes. The deceleration of sea level rise since the Middle Holocene, in combination with high sediment discharge from large rivers, resulted in the formation of immense deltas and adjacent coastal plains (Chen and Stanley, 1993; Stanley and Warne, 1994; Li et al., 2000; Fan et al., 2017). These new coastlands, rich in multiple living resources, attracted ancient foragers to settle, promoting the development of Neolithic civilizations (Chen and Stanley, 1998; Higham, 2002; Funabiki et al., 2012). The linkage between coastal evolution and Neolithic occupations has therefore attracted considerable attention from both geomorphological and geo-archaeological communities in the past decades (Stanley and Warne, 1993; Blake and Knapp, 2008; Chen et al., 2008).

The Neolithic culture in the Yangtze Delta of eastern China was highly developed, as represented by three major consecutive cultures: the Majiabang Culture (*ca.* 7000-5900 cal yr BP), the Songze Culture (*ca.* 5900-5200 cal yr BP) and the Liangzhu Culture (*ca.* 5200-4000 cal yr BP) (SMCPAM, 2002; Liu, 2005; Liu and Chen, 2012) (Fig. 1A and B). Their development histories from beginning through culmination to decay have been intensively discussed in the context of archaeological and geological perspectives (Chen and Stanley, 1998; Yu et al., 2000; Zhu et al., 2003; Liu et al., 2015). In comparison, on the southern bank of Hangzhou Bay, the earliest Neolithic sites of the Shangshan Culture (*ca.* 11,000–8600 cal yr BP) are found in the upper catchments. Coastal Neolithic occupations can be traced back to the Kuahuqiao Culture of *ca.* 7800 years ago, even earlier than those in the Yangtze Delta plain of northern

* Corresponding author.
E-mail address: qlsun@sklec.ecnu.edu.cn (Q. Sun).

https://doi.org/10.1016/j.quascirev.2018.04.010
0277-3791/

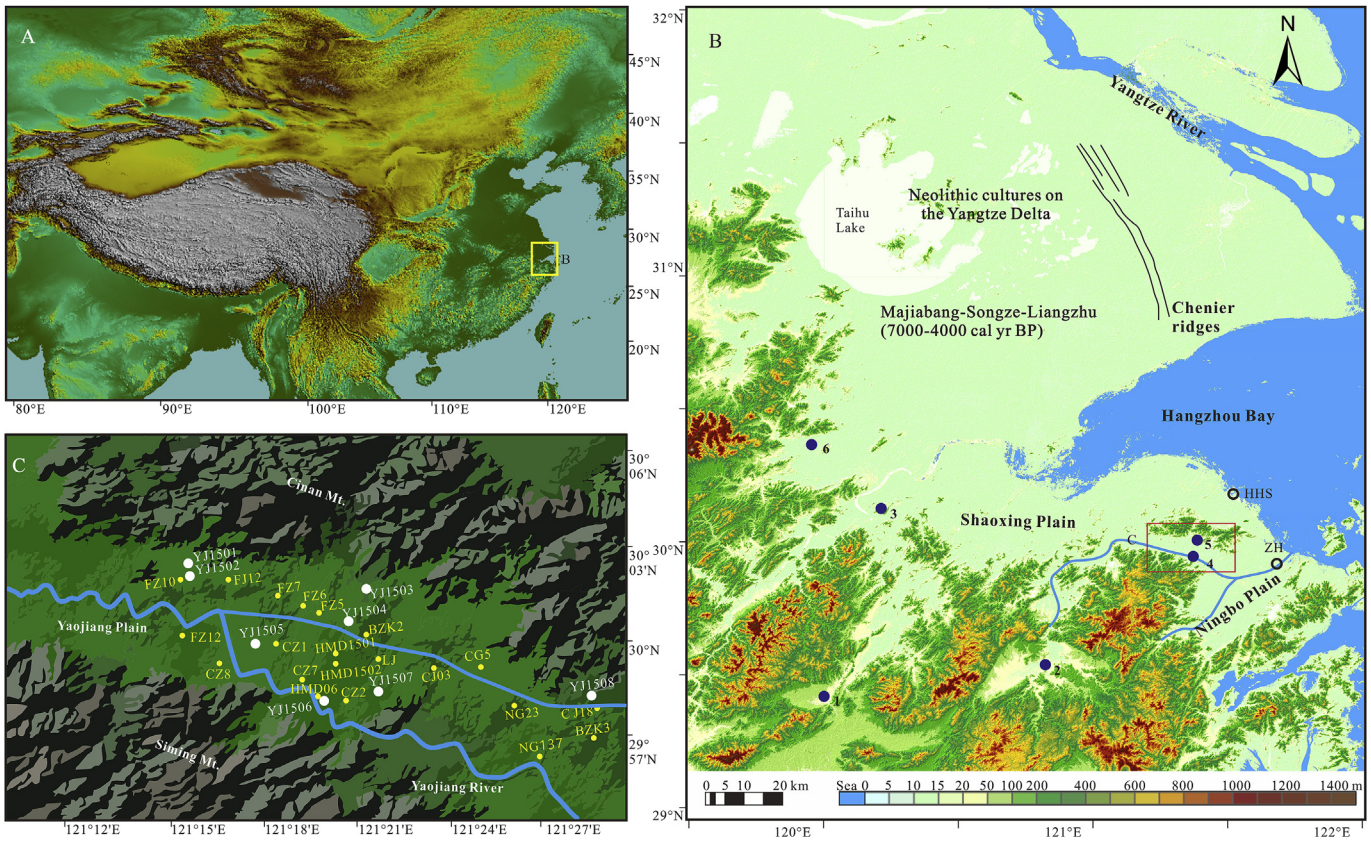

Fig. 1. A) Geographic location of the study area, B) Neolithic occupations in the Yangtze Delta and the coastal region of Southern Hangzhou Bay, including some representative sites: 1, 2-(sites of Shangshan Culture), 3-Kuahuqiao site, 4-Hemudu site, 5-Tianluoshan site, and 6-Liangzhu site, C) An enlarged map of the Yaojiang Valley, white and yellow dots indicate sediment core sites of the present study and from previous publications, respectively (Sun, 2013a; b; Liu et al., 2014; Zheng et al., 2016). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Hangzhou Bay (Zong et al., 2007; ZPICRA, 2016a, b; Zuo et al., 2017, Fig. 1B). This occupation was then followed by the Hemudu Culture (HC) during *ca.* 7000-5000 cal yr BP, whose settlements were mostly concentrated in the Yaojiang Valley (YJV) (ZPICRA, 2003; Wang and Liu, 2005; Liu et al., 2016, Fig. 1C).

The HC is notable for its cultural continuity over 2000 years, almost covering the three phases of Neolithic culture on the Yangtze Delta. From an archaeological view, the HC shows a relatively independent development trajectory compared with its counterparts in the northern Hangzhou Bay. What caused such a difference in cultural trajectories on the two flanks of Hangzhou Bay has become a popular topic for the geo-archaeological community. Thus, a detailed study of Neolithic human-environment interactions in the YJV may elucidate the comparative study of prehistoric cultures in East China coastal regions.

In the past decades, a number of individual sediment cores and archaeological excavations have preliminarily outlined the Holocene environmental changes and Neolithic human activities in the YJV (e.g., Wu, 1983; Lang, 1987; Lian et al., 2014). For instance, some geological surveys have explored the Holocene basal relief from the perspective of engineering geology (Fig. 1C) (Sun, 2013a; b; Peng et al., 2016). Others have discussed the Holocene transgressive and regressive history from individual sediment cores (Qin et al., 2011; Liu et al., 2014; Zheng et al., 2016). Neolithic human subsistence has also been revealed with respect to early rice farming and environmental changes (Fuller et al., 2009; Zheng et al., 2009; Li et al., 2010). However, the detailed landscape changes in the YJV in response to local sea level fluctuations and coastal sedimentation processes have not been systematically investigated. This lack hinders a comprehensive understanding of the relationship between the HC development and natural environmental changes in the YJV.

In this study, a series of sediment cores was retrieved from the YJV (Fig. 1C). Multi-proxy indicators including grain size, foraminifera and sedimentary facies were employed to decode the environmental processes in response to relative sea level and climate change during the Early to Middle Holocene based on radiocarbon chronology. Combining these results with those of previous studies, the landscape changes in the YJV during the Early to Middle Holocene were displayed. The archaeological findings and geological evidence were finally integrated to illustrate the pattern of the Neolithic adaptations to landscape changes in the YJV, which is a miniature of Neolithic culture development on the eastern China coast.

2. Geographic background

The YJV is situated in the central west part of the Ningshao coastal plain, which is separated from the Yangtze Delta by the Qiantang Estuary and Hangzhou Bay (Fig. 1B). The west-east trending valley is approximately 40 km in length and 6 km in width, with a general elevation of <5 m (Fig. 1). It is constrained by hills (*ca.* 100–500 m in elevation) of Jurassic and Cretaceous igneous rocks on both sides. The Yaojiang River runs through the valley along its axis from the west, joins the Yongjiang River, and then discharges into Hangzhou Bay. According to gauge stations Haihuangshan (HHS) and Zhenhai (ZH), the annual averaged tide ranges adjacent to the YJV are 3.34, 1.28, −0.87 and −2.08 m for the