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Phytolith and diatom evidence for rice exploitation and environmental changes during the early mid-Holocene in the Yangtze Delta

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ABSTRACT

Using phytolith analysis from a well-dated and high-resolution sediment sequence in the apex of northern Yangtze Delta, we investigate environmental changes, the rise and decline of rice exploitation and possible impacts of environment on rice exploitation during the early mid-Holocene. The phytolith sequence documents a relatively warm and dry interval during ca.9000 to 8200 cal yr BP, followed by climatic amelioration before 7200 cal yr BP. Phytolith evidence indicates that rice exploitation at the apex of northern Yangtze Delta began at 8200 cal yr BP, flourished by 7700 cal yr BP and ceased after 7400 cal yr BP. The first emergence of marine diatom species approximately 7300 cal yr BP likely indicates an accelerated sea-level rise. The apparent correlation of the initiation of rice exploitation with climatic amelioration during the early mid-Holocene suggests that climatic changes may have played an important role in facilitating rice exploitation. Both the ideal climatic conditions and stable sea level enabled flourishing rice exploitation during 8200 to 7400 cal yr BP. Although the climate remained warm and wet after 7400 cal yr BP, local sea-level rise possibly led to the termination of earlier rice exploitation at this site of the northern Yangtze Delta.

Introduction

The Yangtze Delta was a core area for the early development of rice agriculture (Zhao, 2010). The influences of early Holocene sea-level rise, delta evolution, and climatic warming on agricultural development have long been a focus of research (Stanley and Chen, 1996; Hori and Saito, 2007; Long et al., 2014). Variations in the rate of sea-level rise (Lambeck et al., 2014) may have threatened or destroyed agricultural development (Zong et al., 2007; Chen et al., 2008; Shu et al., 2010), while enabling formation of the Yangtze Delta (Bird et al., 2010), which facilitated the establishment and development of agriculture (Zong et al., 2012, 2013). Following the end of the last glacial, the period of climatic amelioration until the mid-Holocene provided ideal environmental conditions for the establishment of permanent settlements and the domestication of rice in the Yangtze Delta (Yi et al., 2003; Wang et al., 2010a). The archaeological record indicates that rice exploitation first emerged around the Majiabang Culture (7200–5200 cal yr BP) in the Yangtze Delta. This was followed by improved rice exploitation during the Songze (5700–5200 cal yr BP) and Liangzhu (5500–4000 cal yr BP) periods (Long and Taylor, 2015).

Rice exploitation appears to have commenced later in the Yangtze Delta region than elsewhere. Early exploitation of rice was discovered at Yuchanyan, in the middle reaches of the Yangtze River (Zhao and Piperno, 2000). Subsequently, rice was more extensively exploited at Pengtoushan and Bashidang sites (Fig. 1). Even in northern China, newly recovered records indicate that exploitation of rice occurred no later than 8000 cal yr BP (Jin et al.,

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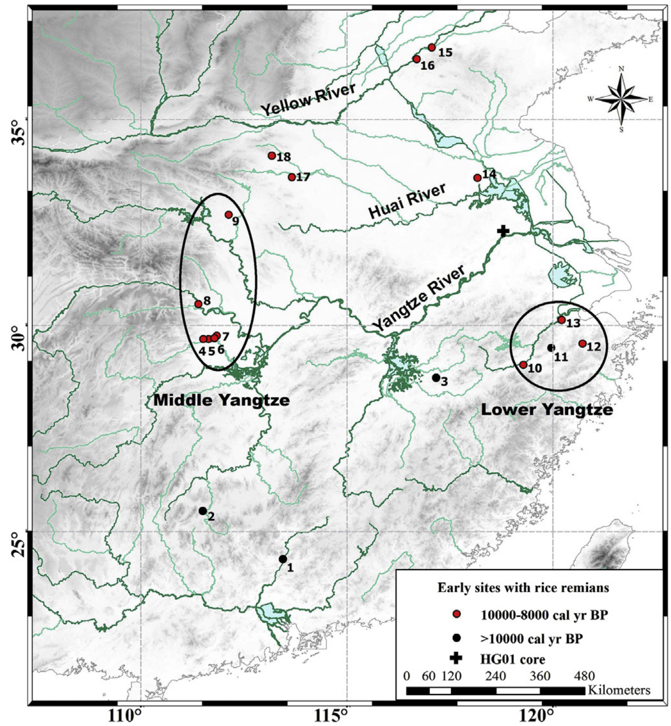

Figure 1. The main archaeological sites with rice remains in China cited in this study. 1 Niulandong. 2 Yuchanyan. 3 Diaotonghuan. 4 Shanlonggang. 5 Pengtoushan. 6 Shiligang. 7 Bashidang. 8 Chengbeixi. 9 Baligang. 10 Hehuashan. 11 Shangshan. 12 Xiaohuangshan. 13 Kuahuqiao. 14 Shunshanji. 15 Xihe. 16 Yuezhuang. 17 Jiahu. 18 Tanghu. The black cross represents our research area.

2014). The Ningshao Plain, south of the main Yangtze Delta, experienced similar sea-level rise and climate changes during the early to mid-Holocene, and rice in this area developed in the early stage of domestication before 8000 cal yr BP, during the Kuahuqiao Culture (Zheng et al., 2004).

The Yangtze Delta shares a similar environmental background with the Ningshao Plain. Its climate condition is more favorable for rice exploitation than that in northern China. Why did rice exploitation emerge here much later than that in the other regions mentioned above? Many studies have examined this issue (Stanley and Chen, 1996; Zhu et al., 2003; Atahan et al., 2007, 2008; Chen et al., 2008; Wang et al., 2012; Wu et al., 2014a), but the reasons remain unclear. Catastrophic events (flooding, marine transgression, or storm tides) (Zhu, 2005; Wu et al., 2012), development of sterile soil on stiff muds, low temperature (Chen et al., 2008), and brackish water (Wang et al., 2012) have been suggested as reasons for the non-favorable conditions for rice exploitation in the Yangtze Delta area during the early Holocene. The main questions are therefore as follows: (1) Did rice exploitation exist in the Yangtze Delta before 8000 cal yr BP? (2) If so, what reasons forced the emergence, development, and termination of rice exploitation at this site, climatic or hydrological background, or both? A more detailed insight into the environmental background is central to understanding the complexities of human occupation and agriculture in the Yangtze Delta area (Crawford, 2012).

Although many previous studies have reconstructed detailed environmental changes and climatic variability, especially in the southern parts of the delta (Liu et al., 1992; Zhang et al., 2004, 2005; Chen et al., 2005; Tao et al., 2006; Wang et al., 2010b; Wang et al., 2010c, 2012; Qin et al., 2011; Wang and Yang, 2013), reliable reconstruction is hampered by comparatively low temporal resolution in the middle and lower delta regions during the early mid-Holocene. Archaeological sites faithfully recorded the development of rice exploitation (Stanley and Chen, 1996; Atahan et al., 2007, 2008; Itzstein-Davey et al., 2007; Innes et al., 2009; Zong et al., 2011, 2012; Innes et al., 2014; Long et al., 2014; Patalano et al., 2015); however, these records may lack the details necessary for the reconstruction of climate changes due to low temporal resolution, sedimental hiatuses, and extensive human influences. Consequently, the use of high-resolution sedimentary records, which are free of the effects of accelerated sea-level rise, is key to resolving the above issues.

In this paper, we present detailed phytolith and diatom records from the apex region of the northern Yangtze Delta in order to constrain the initiation of rice exploitation and reconstruct environmental changes during the early mid-Holocene.

Regional setting

The Yangtze Delta lies on the east coast of China, which occupies an area of approximately 5.2×10^4 km^2. It is divided into three major sections: 1) the main delta body, 2) the southern flank, and 3) the northern flank (Li et al., 2002). It is located in a transitional zone between temperate and subtropical climates, with an annual mean temperature of ca.15.5 °C and a mean precipitation of ca. 1100 mm (Jiang, 1991). HG01 core was retrieved from the upper region of the Yangtze Delta in 2010 (at 32°17′21″ N, 118°48′09″ E, 7.5 m a.s.l.). It is located to the northeast of Nanjing, an apex area of the Yangtze Delta, between Nanjing and Yizheng (Fig. 2).

Several previous studies indicated that the formation of the Yangtze Delta plain was initiated at about 8000 cal yr BP (Stanley and Chen, 1996; Hori and Saito, 2007), and that it spread from the area between Nanjing and Yizheng (Song et al., 2013). Meanwhile, the depocenter moved landward as a result of sea-level rise during the early Holocene (Hori and Saito, 2007). The upper region of the present Yangtze Delta (the delta apex region) received large amounts of sediment materials and formed a relatively continuous sediment sequence during the early mid-Holocene (Song et al., 2013).

Materials and method

Sedimentary facies

The 23.2-m-long sediment core consists of two main sections (Fig. 3). The lower section (below 17.16 m depth) consists of late Pleistocene sediments in the Low Yangtze region, and it is categorized as “hard clay”. The section above 17.16 m depth is composed of Holocene sediments and comprises three divisions of facies: (1) flood plain facies (17.16–5.38 m depth), (2) channel fill facies (5.38–3.50 m depth), and (3) flood plain to surface soil facies (3.50–0 m depth).

The sediments of 17.16–5.38 m depth in the HG01 core consists of heavily bioturbated gray clay to silt, containing abundant plant fragments and gastropods. The mud content accounts for >87% of the sediments. The overall median grain size is about 7-6φ. There are some granules in the lower part. Freshwater gastropods of *Parafossarulus striatulus* and *Gyraulusalbus* are scattered in most sediments of this unit. The brackish water type, *Assiminea cf. sculpta*, can be observed only at 10.8 m depth. A 5-mm-diameter calcareous concretion occurs at 14.33 m. Partial silt–clay couplets are observed at depths of 12.70–12.40 m, 11.37–11.00 m, and 7.60–7.40 m. It should be noted that abundant plant fragments, freshwater gastropods, and other organic materials were found in the floodplain section, indicating terrestrial sediment source. The muddy sediments and weak couplets indicate weak flow conditions. The most floodplain sedimentation occurs during floods and that it is mostly due to suspension (Miall, 1992; Collinson, 1996).

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