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Changes in sea level, water salinity and wetland habitat linked to the late agricultural development in the Pearl River delta plain of China

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ABSTRACT

Environmental change plays a significant role in the development of agriculture worldwide. The availability of wetland habitats and freshwater supply has been particularly important to the expansion and sustainability of rice-based economies. Some studies have emphasized the connections between societal changes and climatic fluctuations. However, recently emerged evidence has indicated the prevalence of human's initiatives. To tackle this complex issue, we employ a multi-proxy approach applying microfossil diatom/pollen and organic carbon isotopes collected from sediment cores of multiple locations to the reconstructions of palaeo-environment and identification of agricultural activity in the northern part of the Pearl River delta. Our study confirms the importance of environmental conditions, but also reveals initiatives taken by the agricultural communities in site selection for cultivation and settlements. Our results also show that freshwater wetland conditions became available in the most landward part of the deltaic plain along the West/North Rivers as early as 7000 years ago, since which wetland habitats expanded seawards as the deltaic shoreline advanced. By 2500 years ago, extensive freshwater wetlands already emerged in northwest part of the deltaic plain. However, before this time, economic activity within the deltaic basin was still predominantly based on fishing and gathering. This is possibly because the Neolithic communities did not need to adapt the labour-intensive cultivation due to the abundance of natural resources in the deltaic region, a strong contrast to what the communities in the Yangtze valley did 5000 years earlier. The agriculture was finally expanded about 2500–2200 years ago in a small area of marsh wetlands along a small river on the northern edge of the deltaic plain by a community migrated from the Yangtze basin. The agricultural activity was spread across the deltaic plain by about 1000 years ago, again as a result of the influx of migrants from the Yangtze basin. This study highlights the usefulness of the multi-proxy, multiple location approach that has helped pin-pointing the location where agriculture in the study area was originated.

1. Introduction

Postglacial sea-level rise has created an accommodation space in previously incised river valleys and transformed these landscapes into deltaic or estuarine environments. The subsequent sedimentation gradually filled up these spaces and formed extensive coastal wetlands with rich biological resources (e.g. Woodroffe, 2000). Many such coastal wetlands were exploited by pre-historic communities for food collection initially, and later, for food production through agriculture (e.g. Zong et al., 2012a). However, when these cases are closely examined and compared, differences between them appear. For instance, recent research indicated that the rise of sea level during the early Holocene created freshwater wetlands around the head of the Hangzhou Bay, a habitat suitable for rice cultivation, which was exploited by an early Neolithic community about 7700 years ago (Zong et al., 2007; Innes et al., 2009; Shu et al., 2010). The subsequent expansion of coastal wetlands in the Lower Yangtze region during the middle Holocene (Zong et al., 2011) had certainly encouraged other Neolithic communities to develop and expand their rice-based agriculture (Atahan et al., 2008; Chen et al., 2008; Zong et al., 2012b). This development was supported by a sustained freshwater supply (Qin et al., 2011) and human's ability to manipulate the wetland landscape and manage water conservation (Zong et al., 2012c).

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However, the Neolithic rice agriculture in many estuarine wetlands of southeast and south China and across the Southeast Asia (e.g. Higham, 1996a, 1996b) lagged significantly behind in time from that of the Yangtze region. In the Min River estuary of Fujian coast, the Neolithic remained maritime nature during the middle Holocene (Rollett et al., 2011), and rice cultivation only started about 4000 years ago (Jiao, 2004). Such a late start of agriculture in the Fujian coast was attributed to the saline conditions which persisted till the late Holocene (Rollett et al., 2011).

In the Pearl River delta and nearby coastal areas, food acquisition during the Neolithic period was largely through fishing-hunting and collecting shellfish (Huang, 1996). Rice agriculture emerged in the area around 4000–3000 years ago (Li et al., 1991; Zheng et al., 2004; Liu et al., 2010), followed by a phase of expansion shortly before 2000 years ago (Anon, 1999; Zong et al., 2010a). The reason for such late start of agriculture in southern China is still unclear, despite the fact that extensive deltaic plain might have already emerged by this time (Zong et al., 2009a). Some studies have focused on the causes of this transition. For instance, Zheng et al. (2004) and Wang et al. (2009) suggested that a phase of climate cooling from 4000 to 3000 years ago may have caused the decline of Neolithic and the rise of agriculture in this region. Huang (1996) however, considered the transition to be triggered possibly by a phase of sea-level rise from 4000 to 3000 years ago. Further a field in the Song Hong delta, natural levee development and rapid deltaic progradation during the middle Holocene had created back-swamp wetlands (Funabiki et al., 2012) which became available for agricultural exploitation. Consequently, human activity in the form of agriculture emerged around 3340 years ago and intensified 1000 years later (Li et al., 2006). All these cases suggest that the availability of freshwater wetland landscape was one of the factors for the inception of agriculture. But, the timing for such wetlands to be exploited for agriculture seems depending on circumstances and human's initiatives (e.g. Zong et al., 2012c).

To test the environmental hypothesis, we conducted an investigation into environmental conditions and human history in the Pearl River delta, and employed a multiple-proxy approach applying microfossil diatom/pollen and organic carbon isotope ratios along with sedimentary analysis to the reconstructions of palaeo-environment and identification of agricultural activity. The sedimentary data are compared with archaeological and historical records, in order to determine the main reasons for the late start of agriculture in the study area, being either the unfavourable environmental conditions to agriculture, human's own initiatives, any climatic and historic events, or a combination of some or all of these factors.

2. Materials and methods

The area selected for this investigation lies across the northern part of the Pearl River deltaic plain and its adjacent areas (Fig. 1a). Newly drilled boreholes using a push-corer provide sedimentary records for a number of locations. Subsamples from these cores were analysed for microfossil diatoms to infer the palaeo-salinity (e.g. Zong et al., 2009b). For each subsample, we counted a minimum of 300 diatoms which were classified into species according to Van der Worff and Huls (1958–1966) and presented as marine-brackish water and freshwater types (Zong et al., 2006). Palaeo-salinity for each subsample was reconstructed using the diatom-based water salinity transfer functions developed based on the modern diatom–salinity relationship existed in the present Pearl River estuary (e.g. Zong et al., 2010c). Pollen and spores were also counted from the sediment samples. Pollen results are presented as percentages of total land pollen. Spores are plotted as percentages of total pollen and spores. Some indicative taxa are highlighted, and they include mangroves (*Rhizophoraceae*, *Aegicera*, *Bruguiera* and *Excoecaria*), water pines (*Glyptostrobus pensilis,* known as Chinese swamp Cypress which tends to live in river banks, ponds and swamps), sedges (*Cyperaceae*) and grasses (*Poaceae*), and ferns (*Dicranopteris* sp. as it is a pioneer fern that tends to colonise cleared landscape). To some extent the abundance of *Poaceae* can be used to indicate the fact that some of them may come from cultivated rice (Atahan et al., 2008). In order to detect input of C4 plant material as it can be related to agricultural activity in the study area (e.g. Zong et al., 2010a), stable organic carbon isotope ratios ($\delta^{13}C$) were measured from sediment samples using an Elemental Analyser connected to an Isotopic Ratio Mass Spectrometer. In order to confirm some agricultural activity revealed by the sedimentary data as rice-based, archaeological and historical records were consulted. The archaeological and historical records reviewed in this paper are from published literature, archives from the local annals office of Guangzhou City and materials from Guangzhou City Museum and Guangdong Provincial Museum. Radiocarbon dates using AMS method were obtained from sediment sequences to determine the timing of changes. Materials for dating are all terrestrial organic matter. All the dates are calibrated using the CALIB 5.10 software (Stuiver et al., 1998) with the Intcal04 programme.

3. Results

For the palaeo-environmental reconstructions, seven sites in the northern part of the Pearl River deltaic plain are investigated (Fig. 1a). Among them, three sites (Longpu, SS0901, SS0904) are selected along the North River (an area with a large number of Neolithic settlements), two (H24 and JT81) along the Liu-Xi River and two (SDZK01 and GZ-2) from the central part of the Pearl River delta plain. All these sites link up to the previously published record of HKUV1 at the estuarine mouth (Zong et al., 2010a).

3.1. The Longpu site

This site lies in a valley floor linked through a small tributary to the North River, c. 35 km northwest from the most inland area of the deltaic plain. This site provides evidence of human activity in the area immediately beyond the deltaic environment. The sediment record from this site shows a sharp change at the depth of 2.02 m from a wetland swamp sequence with abundant remains of water pine to silt and clay (Table 1). This change is also reflected in the pollen result (Fig. 2), which indicates a sharp decline in water pine and a change from a swamp to a marsh environment with vegetation dominated by sedges and grasses. Ferns (such as *Osmunda* sp., triplete and monolete types) also increase from 2.0 m upwards. At this sedimentary horizon, the $\delta^{13}C$ value shows a sharp shift from −29.4‰ below 2 m to −25.6‰ immediately above 2 m (Fig. 2), a clear indication of the input of C4 plant material. The above data also suggest a phase of land clearance at the site and soil erosion from the surrounding area (e.g. Zheng, 1998), which may be linked to a widespread cultivation. The timing for this event is unclear, but most likely shortly before 1160 years ago.

3.2. Core SS0901

This core is obtained at a site sheltered from the North River in the landward end of the deltaic plain. The lithostratigraphy shows a sequence of clay with shell fragments in the lower part of the core (Table 1). Shell fragments gradually disappear whilst organic matter increases from c. 4.0 m upwards, indicating a change from tidal sedimentation to a wetland environment. Organic matter increases markedly in 1.67–1.41 m, and here, large fragments of water pine are found. Clay content increases from 1.41 m upwards suggesting land clearance and an increase in soil erosion. The increase of