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ORIGINAL ARTICLE

New evidence for Neolithic rice cultivation and Holocene environmental change in the Fuzhou Basin, southeast China

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Abstract A stratified profile of the Zhuangbianshan (ZBS) archaeological site (Fuzhou Basin, Fujian) was studied to investigate Neolithic era anthropogenic influence and associated environmental changes. Analysis of the archaeological sediments focused on phytoliths, palynomorphs and microcharcoal. Until now, a lack of direct evidence for agriculture has made it difficult to know if Neolithic cultures of this area relied on the exploitation of wild plants such as nuts and sago palm, or a combination of farming and foraging. Three types of rice phytoliths were found in ZBS archaeological deposits, providing robust evidence for rice farming as part of a broad-spectrum Neolithic subsistence economy centered on fishing and hunting. Chronologies based on AMS ^{14}C dates and artifact typology place the earliest rice during the Tanshishan (TSS) Period (5,000–4,300 cal BP) followed by a shift to economic dependency on rice in the Huangguashan (HGS) Period (4,300–3,500 cal BP). The ZBS phytolith assemblage contains high frequencies of rice husk (peaked-shape glume cells) phytoliths, with far fewer leaf and stem types. This indicates late stage processing activities such as dehusking, implying a focus on consumption rather than rice production. High concentrations of charcoal in the Neolithic ZBS deposits indicate local human settlement and peaks in fire use. The ZBS pollen record also reflects human settlement and peaks in local forest clearance during the Neolithic. Forest cover was renewed when the site was temporarily abandoned following the Neolithic. Rapid formation of the Min River floodplain began ~2,000 cal BP in association with retreating sea level and intensifying anthropogenic influence. Prior to that, rice farming in the Fuzhou Basin was limited by the scarcity of wetlands suitable for agriculture.

Keywords Neolithic · Phytolith · Archaeology · China · Fuzhou Basin · Rice agriculture

Introduction

The Fuzhou Basin lies opposite Taiwan on the coast of southeast China. Neolithic cultures of this area flourished between 5,500 and 3,000 cal BP and are significant for understanding the spread of rice agriculture and the origins of the Austronesian seafarers (Chang and Goodenough 1996; Bellwood 2005; Rolett et al. 2011; Hung and Carson 2014). Although it is widely believed that early food production, especially agriculture, supported the global transition to sedentary village life (Bocquet-Appel 2011), Neolithic economies of coastal Fujian were maritime-oriented and the role of rice farming is poorly understood (Bellwood 2011; Jiao 2013). Currently, the only direct evidence suggesting agriculture consists of a small number of carbonized rice grains recovered from difficult to interpret contexts (Lin 2008a). The history of rice is better known for the Yangtze Delta region, where rice was domesticated around

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7,000–8,000 years ago in wetland environmental contexts (Zong et al. 2007; Fuller et al. 2009). In the Yangtze Delta area, economic dependency on rice was preceded by a long period of low intensity rice cultivation during which early farmers also collected and relied heavily on acorns, chestnuts and other wild plants (Zhao and Piperno 2000; Fuller and Qin 2010). By contrast, palaeobotanical evidence suggests that early Neolithic cultures in the Pearl River area depended on the exploitation of wild plants including sago palm, banana, and lotus roots, not rice (Yang et al. 2012; Yang et al. 2013).

When did rice agriculture and the development of rice-dependent cultures appear on the Fujian coast? A lack of evidence for dating the development of rice agriculture in Fujian has clouded efforts to integrate southeast China into models explaining human migration and the spread of rice (e.g. Bellwood 2011). Rice grows best in semi-aquatic conditions. Ancient wetland rice fields, most of which were engineered through human intervention, were a major non-industrial source of methane (Neue et al. 1997). Dating the onset and subsequent intensification of irrigated rice agriculture is therefore important for estimating anthropogenic greenhouse emissions in models simulating climate change (Ruddiman et al. 2008; Fuller et al. 2011).

This paper addresses questions concerning early rice agriculture in the Fuzhou Basin by using phytolith, pollen and micro-charcoal analyses to investigate the Zhuangbianshan (ZBS) archaeological site. Our study focuses on ZBS, the largest known Neolithic site in Fujian. The ZBS stratigraphy, chronology and cultural content are similar to that of the nearby Tanshishan (TSS) site, for which the TSS Neolithic culture (5,000–4,300 cal BP) is named (Fujian Provincial Museum 1976). The ZBS site covers an area of about 20,000 m^2 and was excavated mainly from 1982 to 1984 (Fujian Provincial Museum 1998). The site is situated on the summit and slopes of a small hill rising above the floodplain of the Min River, nearly 80 km from the ocean and upstream from Fuzhou City. We collected a series of sediment samples from a ZBS profile exposed by recent farming near the 1982–1984 excavation area. We investigated phytoliths, pollen and micro-charcoal particles from these sediments to document early evidence for Neolithic rice. We also situate the evidence for Neolithic rice within the broader context of regional vegetation history and anthropogenic influence on the landscape.

Site description

Environmental setting

The ZBS site covers a small hill rising 25–30 m above the Min River floodplain about 75 km from the modern coast and 20 km upstream from Fuzhou City (Fig. 1). The surface area of the hill is ca. 50,000 m^2 (Fujian Provincial Museum 1998). The present vegetation cover consists mainly of tea plantations, fruit trees and other economic crops growing on terraces. ZBS lies directly across the Min River from the TSS site in Minhou County. The Min River—the largest in Fujian—is 577 km in length with a drainage area of nearly 61,000 km^2 (Lu 2004). It flows through the Fuzhou Basin, a fault-depression formed during the Pleistocene. The Fuzhou Basin and Min estuary open on to a rugged coastline backed by low mountains which also surround the basin as they extend inland.

Sediments in the lower Fuzhou Basin are up to 70 m thick. Palaeoenvironmental models based on a series of sediment cores record a late Holocene change from marine to terrestrial deposits (Zheng et al. 2005; Rolett et al. 2011). One core (FZ5) was collected from the vicinity of the ZBS site and is particularly valuable for explaining evolution of the local environmental setting (Rolett et al. 2011). Results for FZ5 and related cores indicate local marine inundation began by 9,000 cal BP with the deepest marine transgression at about 6,000–7,000 cal BP, followed by a period of relative stability. The onset of a marine regression is recorded after ca. 2,000 cal BP, coinciding with intensifying anthropogenic influence as characterized by sharp rises in pioneer plants (Yue et al. 2015). The floodplain and extensive lowlands suitable for rice paddy field systems did not exist until after 2,000 cal BP. Although today ZBS hill rises above the floodplain, ZBS was a small island in the upper reaches of a vast palaeoestuary when it was first settled by Neolithic peoples during the mid-Holocene sea level highstand (Rolett et al. 2011).

This region is strongly affected by the East Asian summer monsoon, characterized by a humid, subtropical monsoon climate. Average annual temperatures range from 15 to 21 °C, with minimum winter temperatures averaging from 7 to 10 °C, and maximum summer temperatures averaging around 28 °C. Annual precipitation ranges from 1,000 to 1,700 mm, with heaviest rainfall during the spring and summer. The zonal vegetation is monsoonal broad-leaved evergreen forest (Lu 2004).

Recent pollen studies from the lower Fuzhou Basin floodplain (Yue et al. 2015) and from a peatland in the nearby mountainous region (Yue et al. 2012) correspond closely. They show: (1) a dense subtropical forest during the Holocene thermal maximum between ca. 9,000 and 7,000 cal BP, and (2) retreat of the *Castanopsis*-dominated thermophilous woodland and expansion of coniferous woodland between ca. 5,500 and 2,000 cal BP, reflecting moderate climatic cooling. The Fuzhou Basin pollen record (Yue et al. 2015) further shows that (1) human induced vegetation change was negligible during the time of Neolithic sedentary village life ca. 5,500–3,500 cal BP, and (2)

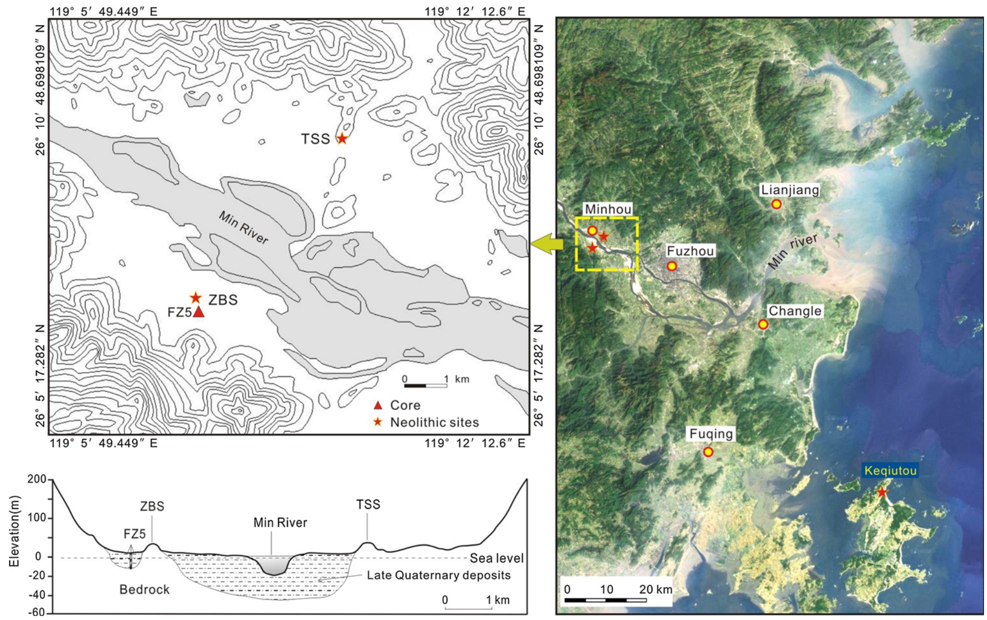

Fig. 1 Locations of the ZBS and TSS archaeological sites and the FZ5 sediment core in the Fuzhou Basin, with a schematic topographical cross-section (modified after Rolett et al. 2011) of the Min River

rising frequencies of Poaceae and taxa (including Cyperaceae and *Artemisia*) associated with agriculture at ca. 3,000–1,500 cal BP indicating farming of lowlands in the emerging Min River floodplain.

After 2,000 cal BP, we observe the onset of a marine regression followed by evidence for an intensely human-impacted environment characterized by sharp rises in pioneer plants such as Poaceae and *Dicranopteris*. This transition coincides with a rapid retreat of coastline and emergence of the Fuzhou Basin floodplain.

Cultural setting

Like TSS, the ZBS site is characterized by rich shell midden deposits containing pottery, stone tools, burials and faunal assemblages that reflect complex Neolithic societies. The palaeoenvironmental context is consistent with a maritime-oriented culture; both TSS and ZBS were first settled during the time of the mid-Holocene sea level highstand, when they were small islands in a vast estuary filling the Fuzhou Basin (Rolett et al. 2011).

The coastal Fujian Neolithic cultural sequence consists of three main phases spanning the time period around 6,500–3,500 cal BP (Jiao 2007; Lin 2008b). Keqiutou (6,500–5,500 cal BP), the oldest Neolithic phase, is known for coastal settlements on nearshore islands. The TSS phase (5,000–4,300 cal BP), defined by the TSS type site, is characterized by evidence for a sedentary village with defensive trenches. Aspects of the material culture, including red-slipped and cord-marked pottery, display a distinct affinity with the earliest Neolithic cultures of Taiwan (Chang and Goodenough 1996; Rolett et al. 2002; Bellwood 2005; Jiao 2007; Hung and Carson 2014). The TSS subsistence economy was dominated by a reliance on marine resources and hunting (Chen 2004; Jiao 2013; Hung and Carson 2014). Until now, the absence of direct evidence for agriculture has made it difficult to know if the TSS culture relied on the exploitation of wild plants such as nuts and sago palm, or a combination of farming and foraging.

The Huangguashan (HGS) phase (4,300–3,500 cal BP), the final stage of the local Neolithic sequence, displays decreased reliance on marine resources, as shown by lower density shell middens. It is assumed this period coincides with the expansion and intensification of agriculture and food production, although again, the direct evidence supporting this inference is scarce (Lin 2008a; Jiao 2013).

The ZBS site is known especially for its rich TSS Culture deposits. Extensive excavations, mostly from 1982 to 1984, covered an area of 2,804 m^2. The ZBS stratigraphic sequence consists of Neolithic TSS and HGS phase deposits overlain by layers representing an occupation hiatus, followed by an upper series of comparatively recent, early historic deposits. Archaeological deposits are thicker on the slopes than at the top of the hill. The TSS phase deposits are characterized by dense concentrations of shell, with numerous shell-filled trash pits and human burials containing grave goods consisting mainly of pottery vessels (Fujian Provincial Museum 1998).

Materials and methods

Stratigraphy and chronology of the ZBS site

The ZBS site stratigraphy consists of six layers identified during the 1982–1984 excavations (Fujian Provincial

Museum 1998). From ground surface to the substrate, the layers are (Fig. 2):

Layer 1 Modern cultivated soil, 15–25 cm thick.
Layer 2A. Black-brown silty clay sediment containing moderate quantities of crushed shell, up to 50 cm thick. Diagnostic artifacts include blue and white proto-porcelain.
Layer 2B Yellow–brown silty clay sediment containing moderate quantities of crushed shell, up to 60 cm thick. Diagnostic artifacts include blue and white proto-porcelain. Numerous tombs dating to the late Zhou/early Han Dynasty, roughly 2,300 cal BP.
Layer 3 Shell midden with black-gray clay sediment up to 50 cm thick. Diagnostic artifacts include red-slipped and typical HGS painted pottery. Age is roughly 4,300–3,500 cal BP based on radiocarbon dates for the HGS culture.
Layer 4 Shell midden with yellow–brown clay sediment up to 75 cm thick. Diagnostic artifacts include typical TSS cord-marked and red-slipped pottery, in addition to shell, bone and stone tools. Numerous human burials and trash pits. Age is roughly 5,000–4,300 cal BP based on radiocarbon dates for the TSS culture.
Substrate Yellow–red clay substrate underlying the archaeological layers. No artifacts or other cultural remains.

The ZBS profile and sample collection

Samples for this study derive from an exposed stratigraphic profile on a terraced slope near the southern part of the 1982–1984 ZBS excavation zone. Stratigraphy in this area is as recorded by the Fujian Provincial Museum (1998) (Fig. 2). In 2011 a series of 34 sediment samples was collected consisting of five samples taken at 10 cm intervals for the upper levels of the 125 cm wall profile and 29 samples from 5 cm intervals for the lower deposits. We used a Russian corer to collect a sediment core extending 70 cm below the base of the profile into the clay substrate (Fig. 2). A single shell collected at 112 cm was selected for AMS radiocarbon dating. It yielded a conventional radiocarbon age of 4,350 ± 30 BP, calibrated to 4,500–4,230 cal BP (Table 1). This age estimate is consistent with other radiocarbon dates for the TSS site (Fujian Provincial Museum 2010).

Phytoliths and pollen grains were extracted and concentrated using two different chemical preparation processes. For phytoliths, 10 g of sediment from each sample was taken and H_2O_2 was first used to remove the organic material, followed by a heavy liquid (density 2.3 g/cm^3) treatment for elimination of the mineral remains (Wang and Lu 1993). For pollen samples, sediments were treated with HCl, KOH and a heavy liquid (density 1.8 g/cm^3) (Nakagawa et al. 1998). All specimens were identified using a Nikon E200 optical microscope. At least 200 pollen grains and spores were counted per sample at magnification of ×400, and with ×1000 oil immersion lenses as needed. Phytolith analysis was a two-stage process. The first step involved counting at least 300 phytoliths per sample in order to quantify the overall phytolith assemblage. The second step involved identifying and counting all diagnostic *Oryza* phytoliths present in each slide. Phytoliths were identified following Wang and Lu (1993) and named and classified according to the International Code for Phytolith Nomenclature (Madella et al. 2005). Micro-charcoal was obtained during the pollen preparation process. *Lycopodium* marker spores were added to each sample to estimate the concentrations of pollen grains, phytoliths and micro-charcoal particles per gram of sediment. Micro-charcoal particles were measured and sorted into three size classes 10–50, 50–100 and >100 µm. Particles smaller than 10 µm were not counted, because they were probably broken fragments.

Phytoliths preserve well in most environments, even in strong weathering conditions and are often abundant in archaeological sites. In general, phytolith assemblages collected from archaeological sites are not good indicators

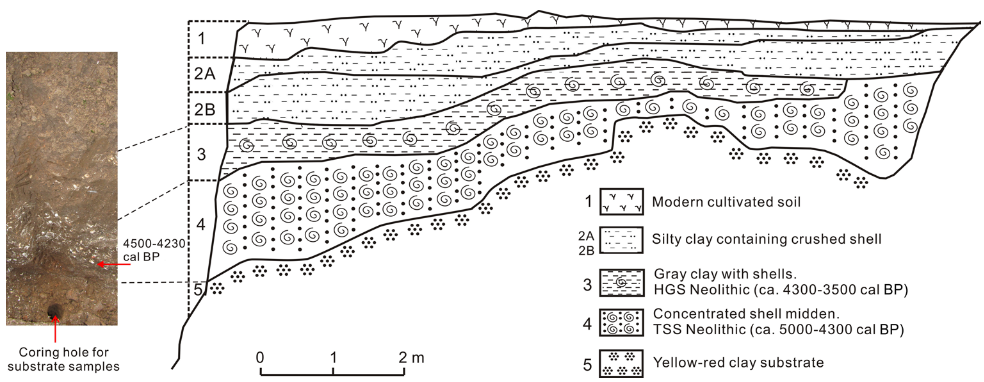

Fig. 2 Representative stratigraphic profile of the ZBS site (modified after Fujian Provincial Museum 1998) juxtaposed with a photograph of the ZBS profile sampled for this study

Table 1 Accelerator mass spectrometry (AMS) dates for the TSS Neolithic Culture of the Tanshishan (TSS) and Zhuangbianshan (ZBS) excavation sites; Radiocarbon dates for the site TSS are from Fujian Provincial Museum (2010)

Site	Excavation area	Lab. code[a]	Dated material	^{14}C-age (BP)	$^{13}C/^{12}C$ ratio	Calibrated age, 2σ-range (cal BP)[b]
TSS	HI44(2)	BA 04289	Charcoal	3,965 ± 30	–	4,450–4,350
TSS	HI44(2)	BA 04290	Charcoal	3,975 ± 30	–	4,530–4,350
TSS	GI04(1)	BA 04292	Charcoal	4,055 ± 30	–	4,620–4,420
TSS	GI04(5)	BA 04293	Charcoal	4,025 ± 30	–	4,570–4,410
TSS	GI04(5)	BA 04294	Charcoal	4,120 ± 30	–	4,740–4,520
TSS	GI04(5)	BA 04295	Charcoal	4,095 ± 30	–	4,660–4,510
TSS	H145	BA 04298	Charcoal	3,970 ± 40	–	4,530–4,290
TSS	H146	BA 04299	Charcoal	4,095 ± 40	–	4,730–4,500
ZBS	Profile (Fig. 2)	Beta 347604	Shell	4,350 ± 30	−9.3	4,500–4,230

[a] BA, Beijing University; Beta, Beta Analytic

[b] BA dates were calibrated using the calibration dataset INTCAL98 (Stuiver et al. 1998), the Beta date was calibrated using the calibration dataset MARINE09 (Reimer et al. 2009) with Delta-R = 92 ± 40

of regional vegetation cover, but they can be valuable for identifying activity areas in archaeological sites and reconstructing ancient cultural activities (Pearsall 1989). Poaceae (grasses) are particularly well represented by phytoliths. Tropical plants of East Asia that produce diagnostic phytoliths include *Oryza* (rice), *Musa* (banana), Cyperaceae (sedges), and Palmae (palms) (Pearsall 1989; Weisskopf et al. 2014). Over the past two decades, phytoliths have played an important role in investigating early rice agriculture in China (e.g. Zhao et al. 1998; Lu et al. 2002; Fuller et al. 2007; Itzstein-Davey et al. 2007; Jin et al. 2014; Wu et al. 2014). Three morphological types are diagnostic for identifying rice: scooped bilobates and *Oryza*-type cuneiform bulliforms from the leaves and stems of rice; and *Oryza*-type peaked-shape glume cells from the rice husk (Fig. 3). The *Oryza*-type peaked-shape glume cells are characterized by single or double peaks. Double peaked glume cells can be used for identification of domesticated rice based on discriminant function analysis (Pearsall et al. 1995; Zhao et al. 1998, 2000). *Oryza*-type cuneiform bulliform cells can be recognized by fish-scale ornaments on the top and two lateral protrusions (Fujiwara 1993; Lu et al. 2002). The scooped bilobate arranged in parallel is typical of tribe Oryzeae (Wang and Lu 1993; Jiang 1995).

Results

ZBS phytoliths

Palaeobotanical and vegetation history data from phytolith and pollen studies are complementary. While pollen rain is wind-blown and highly mobile, phytoliths found in archaeological sediments derive mostly from decayed and burned vegetation growing in situ or introduced plant materials (Pearsall 1989). Thus, archaeological phytoliths mainly represent localized deposition, whether from ground cover or such human activities as making thatched roofs and processing cereal grains. As with pollen data, certain taxa may be over or under-represented in phytolith assemblages. Grasses (abundant producers of silica bodies) tend to be over-represented, while other plants may be nearly invisible in the phytolith record.

For this study, it is significant that the Neolithic archaeological context is a shell midden waste heap. Many well-defined trash pits were identified during the ZBS excavation (Fujian Provincial Museum 1998). Phytoliths in the ZBS assemblage derive mainly from silica producing plants such as grasses which grew on site, as well as materials introduced to the site by humans (e.g. bamboo and unprocessed rice). Most common among the ZBS phytoliths are square and rectangular short cells, cuneiform bulliform cells and elongate psilate long cells. Saddle, bilobate short cell, unciform hair cell, elongate echinate long cell, cylindric sulcate tracheid, rondel and crenate types are also represented. These phytolith types are produced mainly by grasses (Poaceae) (Wang and Lu 1993).

Analytic zones for the ZBS archaeological profile are mainly based on frequencies and distributions of phytoliths, palynomorphs and micro-charcoal. Five analytic zones can be distinguished (Figs. 4, 5).

Zone V (124–195 cm). This is a culturally-sterile, clay substrate underlying the archaeological layers. Rectangular and square short cells, elongate psilate long cells, unciform hair cells and non-rice cuneiform bulliform phytoliths are the most common types.

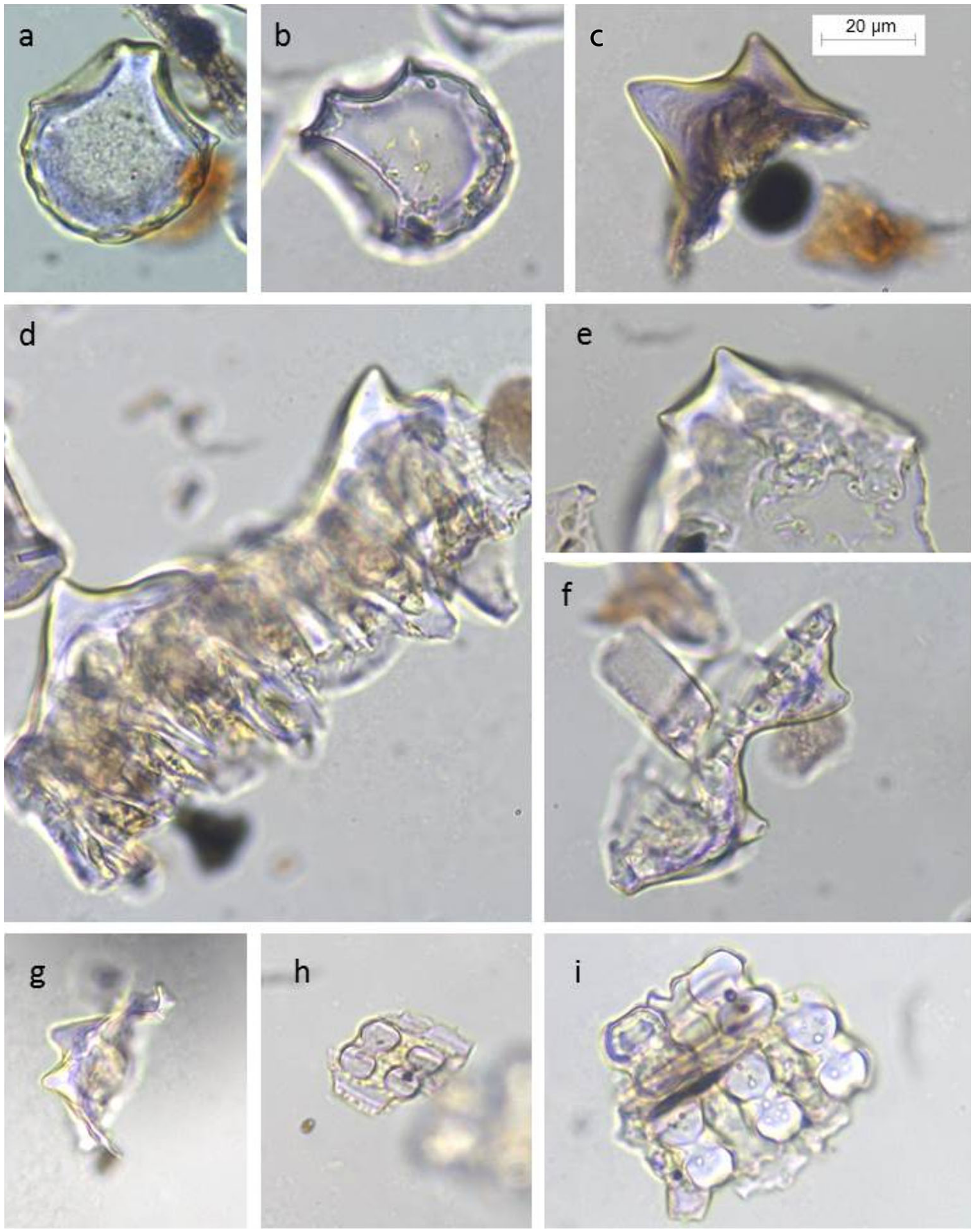

Fig. 3 Morphology of diagnostic rice phytoliths from the ZBS profile: *Oryza*-type cuneiform bulliform, **a** 50–55 cm; **b** 55–60 cm; *Oryza*-type peaked-shape glume cell, **c** 50–55 cm; **d** 55–60 cm; **e** 60–65 cm; **f** 55–60 cm; **g** 65–70 cm; scooped bilobate, **h** 70–75 cm; **i** 50–55 cm

Zone IV (124–105 cm). This zone is the lower shell midden, dating to the TSS Neolithic occupation (5,000–4,300 cal BP). The phytolith assemblage is dominated by elongate psilate long cells, with lower percentages of rectangle and square short cells. Bilobate short cells increase in frequency.

Zone III (105–75 cm). This zone, the upper shell midden, dates to the HGS Neolithic occupation (ca. 4,200–3,500 cal BP). Sharply rising frequencies of *Oryza*-type peaked-shape glume cells reach a peak of 20 % at 105 cm. Scooped bilobate and *Oryza*-type cuneiform bulliforms are present in lower frequencies. Square and rectangular short cells increase, while elongate psilate long cells decline in frequency.

Zone II (75–25 cm). This is a bronze age/early historic era (ca. 3,000–2,000 cal BP) deposit lying above the shell midden. It reveals sharp falloffs in the frequency and concentration of *Oryza*-type peaked-shape glume cells. Square and rectangular short cells increase moderately, as elongate psilate long cells decline in frequency.

Zone I (25–0 cm). This, the modern surface deposit, is notable for increasing frequencies of elongate psilate long

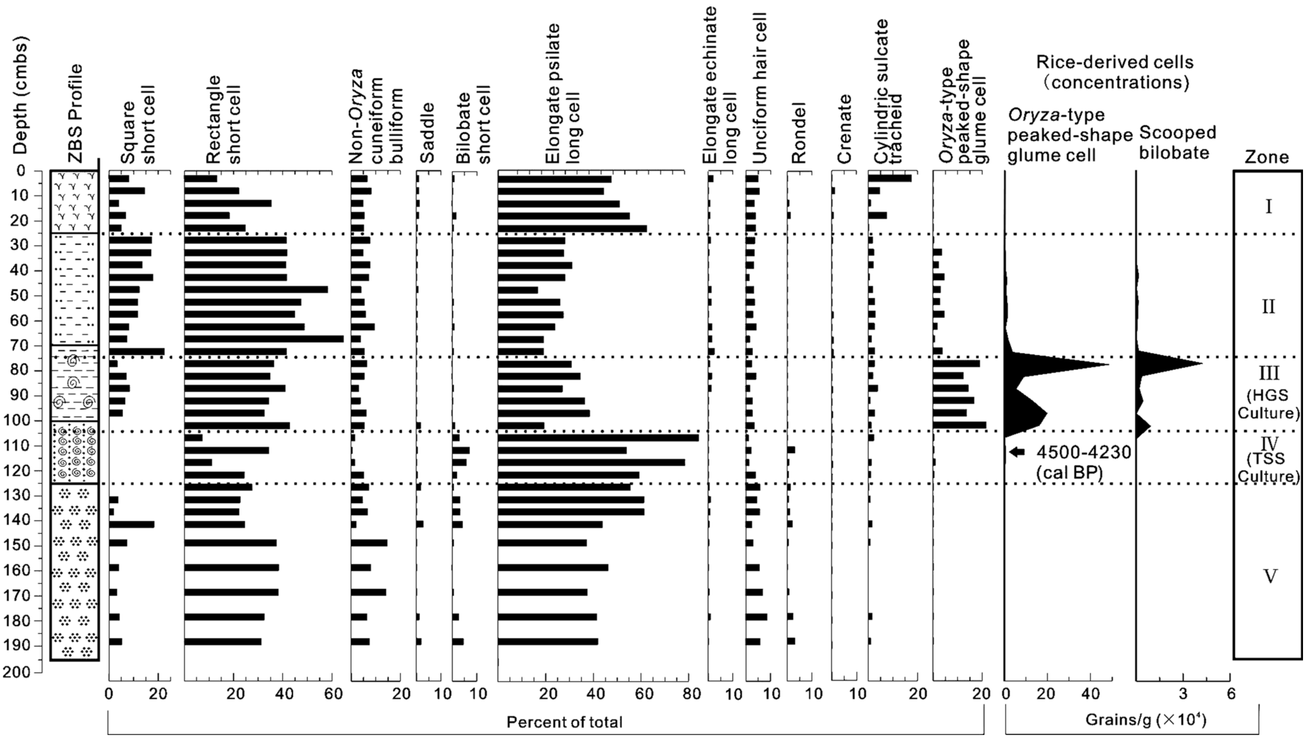

Fig. 4 Major phytolith types from the ZBS profile

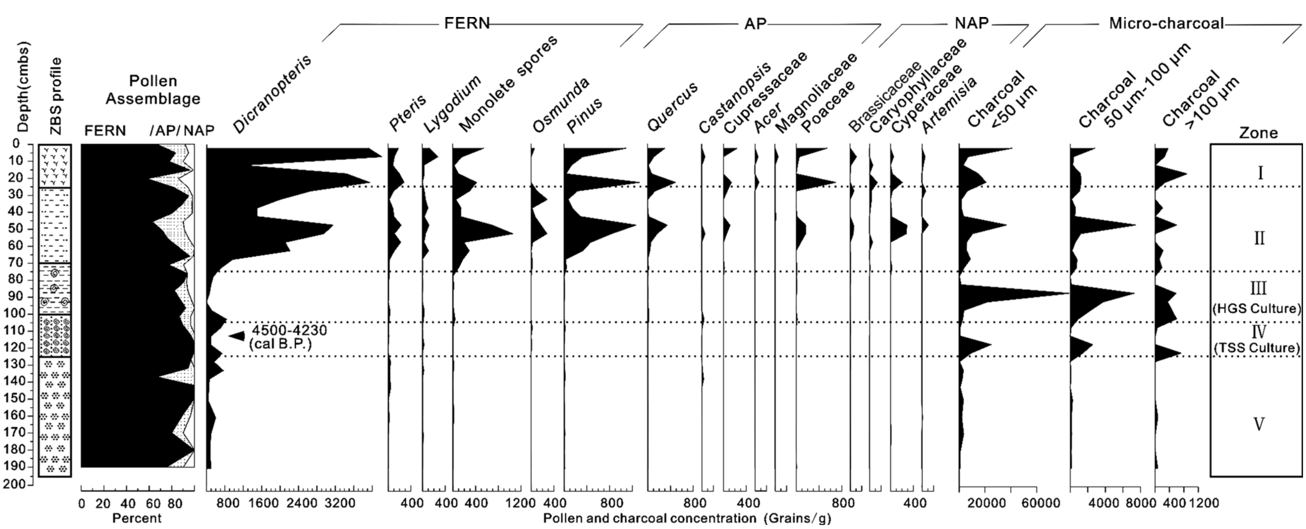

Fig. 5 Pollen, spore and micro-charcoal assemblages from the ZBS profile

cells, together with declines in square and rectangular short cells. *Oryza*-type peaked-shape glume cells disappear.

The low abundances of palynomorphs in Zone V may be related to erosion of the paleo-soil horizon, as would be consistent with intense anthropogenically-induced land cover change during the first years of Neolithic settlement. The shell midden deposits (Zones III and IV) above the Zone V substrate contain dense accumulations of rice phytoliths.

Among the morphological types of phytoliths diagnostic for identifying rice, *Oryza*-type peaked-shape glume cells derive from the rice husk, while scooped bilobate and *Oryza*-type cuneiform bulliforms are produced by stems and leaves. Quantifying the frequencies of these phytolith types helps reconstruct crop processing stages (Harvey and Fuller 2005). For example, an archaeological deposit with high frequencies of leaf and stem phytoliths, but low frequencies of husk phytoliths likely represents threshing and winnowing when grain is separated from the straw and leaves. By contrast, the ZBS assemblage contains high frequencies of rice husk (*Oryza*-type peaked-shape glume cells) phytoliths, with far fewer leaf and stem types (Table 2; Fig. 6). This indicates late stage processing activities such as dehusking, implying a focus on consumption rather than rice production.

ZBS pollen and charcoal

Concentrations of pollen and charcoal are low throughout Zone V. The most common palynomorphs are trilete type spores. Certain fern spores easily permeate the soil layer in rainy monsoon areas; this may explain why pteridophyte spores are more abundant than pollen in the basal deposit. Pollen concentrations are also notably low in the Zone III and IV shell midden deposits, but charcoal concentrations increase dramatically. A first charcoal peak is marked by particle concentrations of 28,000/g at 117 cm (Zone IV). An even higher peak occurs at 87 cm in Zone III, where concentrations reach up to 93,000 grains/g.

Controlled studies of micro-charcoal assemblages collected from burned and unburned areas show that large particles (>100 µm) mostly fall close to the fire, while smaller ones fall close but can also be carried by wind over much greater distances (Clark 1988; Blackford 2000; Whitlock and Larsen 2001). For the ZBS micro-charcoal record, although large particles are present in much lower quantities than small ones, trends among the different particle sizes are synchronized; all of the size groups have peak concentrations at the same depths. This suggests that fires producing the charcoal were mainly local. These synchronized peak concentrations of large and small particles are consistent with intense, local anthropogenic burning beginning with Neolithic settlement of the site. However, in contrast to the local ZBS evidence, pollen data from a downstream sediment core (FZ4) indicates that regional anthropogenic influence was still quite low during the Neolithic era (Yue et al. 2015).

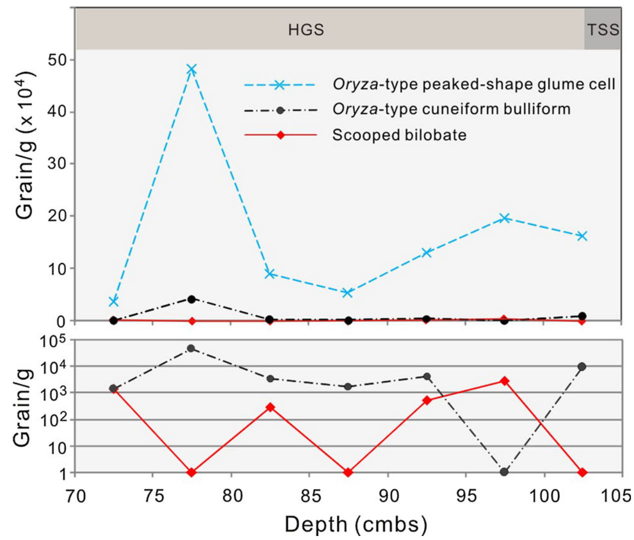

Fig. 6 Diagnostic rice phytoliths from Zone III (HGS Neolithic era) of the ZBS profile. Lower diagram shows *Oryza*-type cuneiform bulliforms and scooped bilobates on a logarithmic scale

Pollen and spore concentrations rise sharply in Zone II, the post-Neolithic phase. Pioneer plants, especially *Pinus, Dicranopteris* and Monoletes (mainly Polypodiaceae) are prominent. Poaceae, Cyperaceae and *Quercus* are also common. The abrupt and dramatic increases in conifers suggest forest restoration in the ZBS area. Other pioneer plants such as *Dicranopteris* ferns also point to the formation of secondary vegetation cover, while accompanying increases in Poaceae pollen reflect the local expansion of grasses. The end of Zone II dates to the founding of nearby Fuzhou City around 2,000 years ago. This coincided with emergence of the Fuzhou Basin floodplain during a period of rapid population growth and intensifying anthropogenic impact (Rolett 2012), as reflected by the charcoal record. Zone I shows a modern era continuing trend of secondary vegetation dominated by *Dicranopteris* and *Pinus.*

Table 2 Diagnostic rice phytoliths from Zone III (HGS Neolithic era) of the ZBS profile (concentrations in numbers/g)

Depth (cm)	*Oryza*-type peaked-shape glume cell	*Oryza*-type cuneiform bulliform	Scooped bilobate
70–75	37,564	1,341	1341
75–80	481,673		42,113
80–85	89,024	281	3,380
85–90	53,546		1,727
90–95	13,088	521	4,171
95–100	197,016	2,736	
100–105	161,431		9,040

Discussion and conclusion

Neolithic rice farming in the Fuzhou Basin

Our phytolith study offers the first robust evidence for dating early rice farming in the Fuzhou Basin area. Previous reports of Neolithic-era rice derive from the nearby TSS site, but the finds consist of only a handful of carbonized rice grains from uncertain stratigraphic contexts (Lin 2008a). Zone III of the ZBS profile, which contains the densest accumulation of rice phytoliths, yielded painted pottery chronologically diagnostic of the HGS Period, dated to around 4,300–3,500 cal BP (Lin 2008b). This chronological estimate for Zone III agrees with results for the single AMS date from our profile. In sum, our data suggest that local rice cultivation began during the TSS Neolithic period and the transition to a rice dependent agricultural economy was fully underway in the subsequent HGS Period, around 4,300–3,500 cal BP.

In comparison with the development of rice agriculture in the lower Yangtze area, our Fuzhou Basin study reveals both similarities and differences. In both regions economic dependency on rice was preceded by a period of low intensity rice cultivation. However, in the lower Yangtze area where rice was domesticated, the developmental sequence from initial cultivation to economic dependency clearly centered on rice as a wetland crop. In the lower Yangtze region, early rice was first cultivated in slightly brackish coastal wetlands, using artificial bunding to retain seasonal flood water while preventing marine inundation (Zong et al. 2007). Rice may have been cultivated in a similar fashion on the edge of the estuarine ZBS island, but any local wetlands were highly constrained in surface area. Small natural wetlands would also have been found along the estuary coastline but land suitable for irrigated rice agriculture was highly limited prior to emergence of the vast Min River floodplain during the last two millennia (Rolett et al. 2011). Instead, during the Neolithic era, it seems more likely that rice was grown in rainfed gardens on nearby slopes of the Fuzhou Basin area.

Rainfed gardens produce rice yields much lower than those attained when rice is grown in wetland settings. Thus, the hypothesis that most Neolithic rice grown in the Fuzhou Basin was rainfed or "dry" leads to two further observations. First, it seems likely that rice played a comparatively smaller role in the TSS and HGS era subsistence regimes than it did in Neolithic subsistence regimes of the lower Yangtze area. This is consistent with results of recent studies indicating the dietary importance of wild plants in Neolithic cultures further south in the Pearl River area (Yang et al. 2013). Extrapolating from our landscape reconstruction of the Fuzhou Basin leads to the inference that lowlands across the Fujian coastline formed mainly during the last two millennia. If this is correct, rainfed gardens may have been the dominant form of rice agriculture across coastal Fujian throughout the Neolithic, due to the scarcity of land suitable for wetland rice. Finally, the hypothesis that Neolithic rice farming in the Fuzhou Basin focused on rainfed rather than wetland agricultural systems is significant for estimating early human contributions to methane gas emissions. Previous efforts to estimate anthropogenic methane emissions (e.g. Ruddiman et al. 2008; Fuller et al. 2011) tended to assume that Neolithic rice farming on the Fujian and Guangdong coastlines represented wetland agriculture, although there was no empirical basis for ruling out the possibility of rainfed agriculture. Thus our findings suggesting the Neolithic dominance of rainfed agriculture in the Fuzhou Basin, and likely across the Fujian coast, should help in revising estimates of anthropogenic greenhouse emissions for climate change simulations.

Neolithic shell midden deposits of the ZBS site consist of heaps of ancient shellfish waste. Rice phytoliths were found in these same deposits, indicating that rice plant remains were discarded in the same location as the shellfish. Rice phytoliths are profusely abundant in upper levels of the shell midden deposit (Zone III) but scarce in the deeper midden layer (Zone IV) (Fig. 4). *Oryza*-type peaked-shape glume cells from the rice glume, which attaches the grain to the husk, are by far the most common in Zone III (Fig. 6). This abundance of glume phytoliths, and very low quantities of ones indicative of rice leaves and stalks (scooped bilobates and *Oryza*-type cuneiform bulliforms), suggests that separation of the rice grains from the straw occurred mostly off site. Taken together, our results support the hypothesis that rice was not grown in situ. Rather, it appears that partially processed rice was transported to the site.

Environmental change and anthropogenic influence

The environmental reconstruction is based on a complementary set of three palaeobotanical indicators: palynomorphs, phytoliths and charcoal (Fig. 7). The ZBS pollen assemblages are supplemented by high resolution pollen records for two sediment cores collected in nearby areas (Yue et al. 2012, 2015). The charcoal record provides a basis for dating and understanding land clearing associated with the Neolithic occupation of ZBS, as well as the later period of reforestation. Finally, phytoliths are the key indicator in this study for rice agriculture, making it possible to date the beginning of Neolithic rice farming in this region.

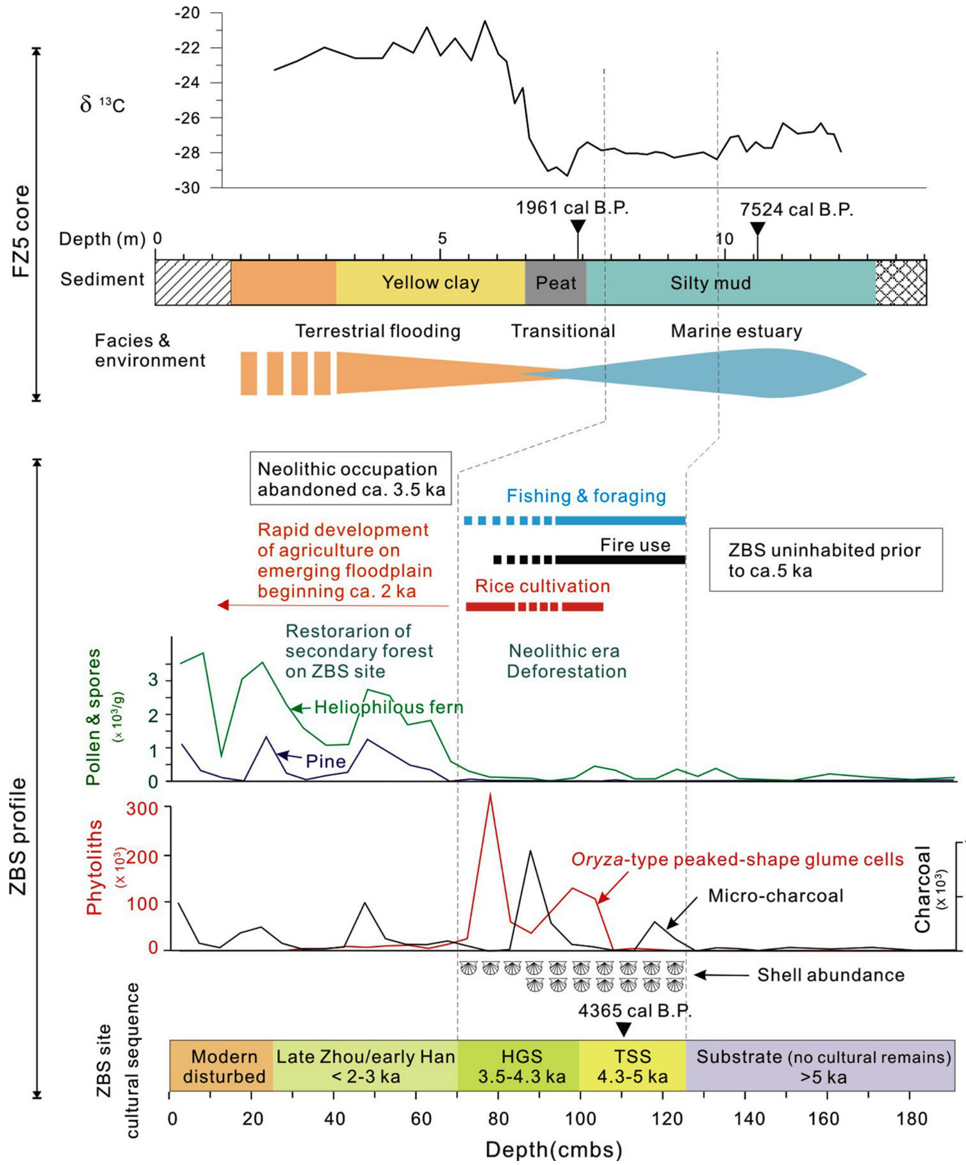

Fig. 7 Key environmental proxies for vegetation, agriculture and fire-use from the ZBS archaeological profile, correlated with the nearby FZ5 sediment core record (Rolett et al. 2011)

The abundance of palynomorphs and phytoliths is unusually low in the basal ZBS deposit, Zone V. This may be related to erosion of the pollen and phytolith bearing palaeo-soil horizon. The profile we sampled is situated on slopes below the hilltop main settlement area. Apparently, after early deforestation and erosion denuded this area it was selected for disposal of shellfish and other waste. In any case, given the absence of in situ evidence, we must rely on the nearby sediment cores for reconstruction of the pre-Neolithic regional vegetation (Yue et al. 2012, 2015). The results indicate a heavily forested early-mid Holocene landscape dominated by subtropical broadleaved evergreen taxa associated with grasses, ferns and conifers. There is no pollen/spore evidence for regional-scale human-induced land cover change until around 2,000 cal BP. Low charcoal concentrations throughout Zone V are consistent with this interpretation of minimal regional scale human impact on the landscape during the pre-Neolithic era.

Zone IV, the TSS period shell midden deposit and earliest human occupation layer, is marked by significant increases in charcoal, although the palynomorph concentrations remain very low, as in Zone V. The increased charcoal, with a pronounced peak at 115 cm likely records fires used to clear local vegetation during a period when the ZBS landscape was highly circumscribed. Low Zone IV palynomorph concentrations also suggest limited vegetation on the Neolithic-era island, which lay some hundreds of metres from hilly slopes rising above the palaeoestuary coastline.

Because regional pollen records show no evidence for widespread human-induced deforestation during the Neolithic, we interpret the Zone IV charcoal increases as localized human impact on a micro-island landscape. Anthropogenic influence intensified during the following HGS period as evidenced by sharply higher Zone III charcoal concentrations. Thus we conclude that during this time period there was deforestation, land clearing and heavy burning in a localized setting even though regional vegetation reconstructions still reveal no evidence for large-scale human transformation of the landscape.

The upper shell midden deposit (Zone III) is distinguished by much higher concentrations of rice phytoliths than found in Zone IV. This signals the transition to a rice dependent economy during the HGS culture period. Yet at that time, rice farming was constrained by the scarcity of land suitable for irrigated rice—an ongoing consequence of the mid-Holocene palaeoestuary landscape. Low demographic estimates for the Neolithic population size of coastal Fujian (Jiao 2013) are consistent with the interpretation that intensive rice farming was not widespread.

The pollen/spore and charcoal proxies denote forest regeneration in Zone II, suggesting that ZBS was abandoned after the HGS Neolithic period occupation. This finding agrees with archaeological evidence for a hiatus in the ZBS settlement chronology; there is no record of human occupation from the end of the HGS Neolithic period until the late Zhou/early Han Dynasty (Fujian Provincial Museum 1998). Environmental factors, including landscape changes linked with anthropogenic influence and falling sea level, likely contributed to human abandonment of the ZBS site during that time (ca. 3,500–2,200 cal BP).

A sediment core (FZ5) collected in the immediate vicinity of ZBS shows that the local environment evolved into a marshland setting around 2,000 years ago (Rolett et al. 2011). In our view, shoreline advance associated with this change is related to both a fall in sea-level from the mid-Holocene highstand and intensified erosion caused by land clearing and other human activities. As the local environment changed from an estuary to marshland, marine resources disappeared from the upper Fuzhou Basin. Concomitantly, emergence of the floodplain in this area created freshwater marshes that would have allowed the beginning of widespread intensive irrigated rice agriculture. Taken together, these suggest that ZBS was abandoned in part because environmental changes disrupted maritime-oriented subsistence strategies that supported the mid-Holocene Neolithic population, even as nearby areas became increasingly attractive for the development of a food production economy.

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