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Phytolith evidence suggests early domesticated rice since 5600 cal a BP on Hainan Island of South China

Yan Wu [a, *], Limi Mao [b, **], Can Wang [c, d], Jianping Zhang [c], Zhijun Zhao [e]

[a] Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China
[b] Nanjing Institute of Geology and Palaeontology, CAS, Nanjing 210008, China
[c] Institute of Geology and Geophysics, Chinese, Academy of Sciences, Beijing 100029, China
[d] University of Chinese Academy of Sciences, Beijing 100049, China
[e] Institute of Archaeology, Chinese Academy of Social Sciences, Beijing 100710, China

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ABSTRACT

The prehistory of the domestication of rice in the tropical areas of South China is poorly understood. Here we present phytolith evidence recovered from a sediment core from the central-east coast of Hainan Island, China. The result of this study indicates that domesticated rice might grow on the Hainan Island in 5600 cal a BP. The early timing of rice domestication on Hainan Island supports the hypothesis of the spread rice agriculture from its origins in the Middle and Lower Yangtze River and its tributaries. Our results also highlight the practice of growing rice since 2000 years ago in the Lingnan region of the Nanyue Kingdom. The discovery of microfossil evidence such as phytoliths and starch grains should inspire more archaeological research that focuses on the origins and consequences of the spread of domestic rice agriculture to Hainan Island.

1. Introduction

Rice is one of the most important crops used to feed our global population. In China, rice has a long history of cultivation. According to archaeobotanical studies in the last decade, the Middle and Lower Yangtze River regions have been identified as the areas where rice was domesticated first (Crawford, 2006; Fuller, 2007; Fuller et al., 2007, 2008, 2009; Liu et al., 2007; Zhao, 2010, 2011; Cohen, 2011). Based on archaeological evidence rice agriculture is believed to have spread gradually northwards and southwards. It also has been suggested that the Neolithic archeological cultures found in the provinces of Guangxi, Guangdong and Hainan Island, were connected with Neolithic cultures of the Yangtze River (Zhang and Hung, 2010).

More importantly the southward dispersal of rice agriculture from the Yangtze River may be related to the expansion of Austroasiatic- and Austronesian-speaking populations into Mainland and Island Southeast Asia (Higham and Lu, 1998; Higham, 2002; Diamond and Bellwood, 2003). Thus the Lingnan region including Hainan Island should play a very important role in the process of the spread of rice agriculture in southern China and its adoption by different cultural groups.

Over the past two decades, phytolith analysis has rapidly developed as an approach yielding convincing supportive evidence in many aspects of archaeological research. Due to their resistance to decay and mechanical decomposition, phytoliths can be preserved for long time under a wide range of environmental conditions. Some phytoliths can be distinguished to genus or even species level according to their distinctive morphological characteristics (e.g., Lu et al., 2002; Piperno, 2006). Therefore the analysis and identification of plant phytoliths can be used as a reliable method for the study of plant remains.

Phytoliths are frequently used in vegetation reconstruction and archaeology in tropical area since soils in tropical areas generally contain larger concentrations of phytoliths. Piperno etc. have made significant progress in the origins (Piperno, 2003, 2006) and domestication of wild plants (Piperno et al., 2007) based on phytoliths from tropical areas of Central America. However, no

* Corresponding author. Institute of Vertebrate Paleontology and Paleoanthropology, CAS, Beijing 100044, China.
** Corresponding author. Nanjing Institute of Geology and Palaeontology, CAS, Nanjing 210008, China.
E-mail addresses: wuyan@ivpp.ac.cn (Y. Wu), lmmao@nigpas.ac.cn (L. Mao).

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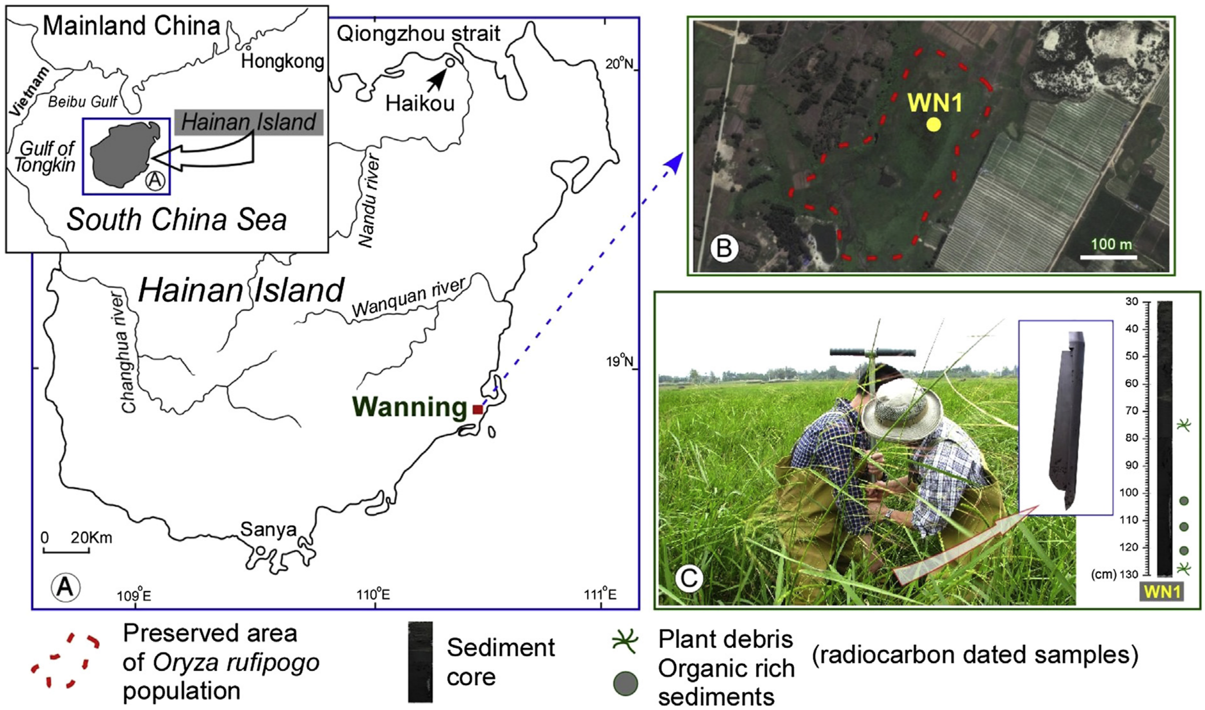

Fig. 1. Diagrams showing the study area in Wanning, Hainan Island, China (A), aero view of the sampling site (B), the preserved population of *Oryza rufipogon* (C), also showing the peat sampler, the sediment core WN1 and the levels of the radiocarbon dated samples, as well as materials.

phytolith research work has so far been published from the tropical areas of China.

The use of multivariate statistical analysis has been recently used to distinguish wild from domestic rice based on three-dimensional measurements of double-peaked glume cells from the husks of rice, and the number of scale-like of decorations occurring on cuneiform bulliform cells from the leaves of rice (Pearsall et al., 1995; Zhao, 1998; Zhao et al., 1998, 2000; Lu et al., 2002; Gu et al., 2012; Wu, 2014). Our previous research has proved that the trends of morphological changes in double-peaked glume cells and the increase in the number of scale-like decorations present on the margins of cuneiform bulliform cells indicates that the percentage of wild rice phytoliths decreases while the percentage of domestic rice phytoliths increases through time in archaeological contexts (Wu et al., 2014). Therefore, the unique morphological features of rice phytoliths can be used to distinguish wild from domestic rice remains recovered from archaeological contexts. By using this technique we can identify trends of morphological change in rice phytoliths from Hainan Island, South China. We also discuss early agricultural practice of domesticated rice based on phytolith evidence under the chronological control of a suite of AMS radiocarbon dates from a sediment core.

2. Geological background

Our study area is located in the central-east coast of Hainan Island, China. Quaternary silt deposits cover the area normally 10–15 m in depth. Rapid sea-level rise during the late Pleistocene and early Holocene shaped the coastal depositional basin (Liu et al., 1997). Holocene high sea level stands were traced by comparative sedimentological studies on coal-forming environments from northeast area of the island around 6000 cal a BP, followed by fluctuation lowering between 6000 and 4000 cal a BP, and since 4000 cal a BP, sea-level fluctuated with a slight rising trend (Liu et al., 1997). The relatively stable coastal plain favored early settlement by rice horticulturalists.

3. Materials and methods

3.1. Sampling and phytolith extraction

A sediment core (WN1) was drilled by a peat sampler (Russian type) in Wanning (18°44′26.22″N, 110°24′35.67″E, 3 m a. s. l.), which is located on the central-east of coast of Hainan Island (Fig. 1). This study site is open for researchers from Chinese Academy of Science to collect soil samples and we also confirm that the field survey did not affect any endangered or protected species.

The core was subsampled in 5 cm intervals for phytolith analysis, following standard analysis procedures (Pearsall, 2000). The brief descriptions of the core sediments are as followings: 30–40 cm, mud with herb roots/debris; 40–66 cm, silt with gray laminated mud; 66–130 cm, black silt.

The process of phytolith extraction followed the slightly modified methods outlined by several authors (Pearsall, 2000; Wu, 2014). The soil samples were dried and ground into powder. Ten percent hydrochloric acid and thirty percent hydrogen peroxide were added to each sample to remove carbonates and organic matter. A tablet of *Lycopodium* maker (ca. 18,583 spores per tablet) was added to each sample in order to estimate the concentrations of phytoliths (grains per gram dry sample). To concentrate phytoliths, heavy liquid flotation is carried out using a $ZnBr_2$ at a density of 2.4 by centrifuging at 3000 rpm for 10 min. Identification of phytoliths was performed through the examination of least 500 grains using a light microscope. The data of phytoliths are expressed in percentage and total concentration for each sample, and the percentage diagram is made by Tilia program (Grimm, 1991 and afterward updated version).

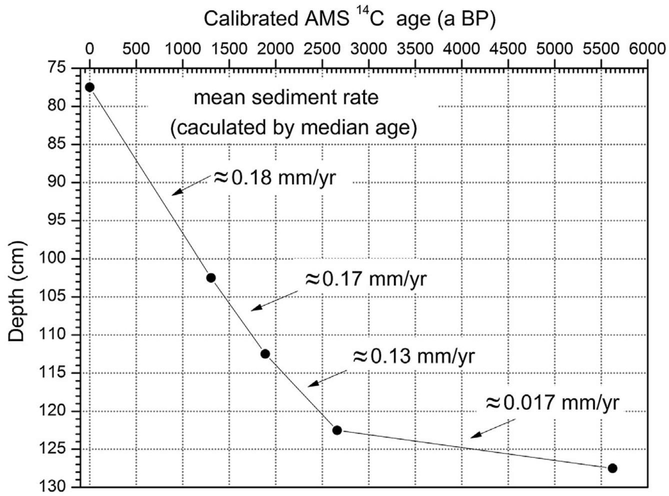

Fig. 2. Age-depth model based on the measured radiocarbon dates, also showing the sedimentation rates for different stages.

3.2. Dating

In this study, five AMS ^{14}C samples were dated by Beta Analytic Radiocarbon Dating Laboratory including one sample (younger than AD 1950) was measured by PMC (percent Modern Carbon). Four measured ^{14}C ages were calibrated based on the dataset INTCAL13 (Reimer et al., 2013).

4. Results and discussion

4.1. Dating and frequency of phytolith types in the Hainan core

Detailed information on the dated materials, measured results and calibrated ages (2 Sigma) are presented in Table 1. To facilitate a description of the results and discussion, age-depth model was illustrated based on the measured AMS radiocarbon age (Fig. 2).

Table 1
AMS ^{14}C radiocarbon ages for the samples of the core WN1 from the wild habitat of *Oryza rufipogon* in Wanning, Hainan Islan, China.

Depth (cm)	Sample code	Laboratory number	Dated material	Measured radiocarbon age	^{13}C/^{12}C δ^{13}C(‰)	Conventional radiocarbon age	2 Sigma calibration[b]
75–80	WN1-10	Beta – 381843	Plant material	119.6 ± 0.3 pMC[a]	−28.3	120.4 ± 0.3 pMC[a]	Modern carbon(younger than AD 1950)
100–105	WN1-15	Beta – 392751	Organic sediment	1390 ± 30 a BP	−25.5	1380 ± 30 a BP	Cal AD 620–671 (Cal a BP 1330–1279)
110–115	WN1-17	Beta – 381844	Organic sediment	2000 ± 30 a BP	−25.7	1990 ± 30 a BP	Cal BC 45 to AD 70 (Cal a BP 1995–1880)
120–125	WN1-19	Beta – 389111	Organic sediment	2420 ± 30 a BP	−26.3	2400 ± 30 a BP	Cal BC 730–690 (Cal a BP 2680–2640)
125–130	WN1-20	Beta – 381845	Plant material	4930 ± 30 a BP	−27.7	4890 ± 30 a BP	Cal BC 3705–3640 (Cal a BP 5655–5590)

[a] pMC: (percent Modern Carbon, younger than AD 1950).
[b] Database used: INTCAL13 (Reimer et al., 2013).

The identify forms of phytoliths from the core WN1 are elongate psilate, elongate echinate, elongate dendritic long cells, bulliform, rondel, bilobate, rectangular short cells, acicular hair cell, saddle, short-saddle, echinate spheroid, double peaked glume cells and cuneiform bulliform cells. Frequent phytoliths are illustrated in Fig. 3. The detailed phytolith percentage diagram is illustrated in Fig. 4.

4.2. Overall occurrence of rice phytoliths (Oryza)

By analyzing rice phytoliths from 30 to 130 cm, we only found a few double peaked glume cells in the samples. Fortunately, cuneiform bulliform cells are more commonly present than double peaked glume cells. In this study, we focus on the identification of cuneiform bulliform cells with scale-like decorations through the time of WN1core (Figs. 4 and 5). Each sample was scanned until fifty individual cuneiform bulliform cells were examined.

4.3. Predictions of domestic rice based on the number of scale-like decorations located on cuneiform bulliform cells

Fujiwara (1993) reported that there is a distinct difference in cuneiform bulliform cells between cultivated and wild *Oryza* species (Fujiwara, 1993). Moreover, Lu et al. (2002) indicated that there is a great diversity in numbers of decorations and scale-like decorations with wild rice commonly less than 9 while those of cultivated rice show generally 8 to 14 (Lu et al., 2002). Therefore, the number of decorations of nine or greater indicates that the rice belongs to the domesticated species.

To further validate the observation, we tested each sampled context with almost fifty individual cuneiform bulliform cells by counting number of scale-like decorations from modern wild and domesticated rice from Jiangxi province. We found that ninety percent of modern wild cuneiform bulliform cells from the rice samples from Jiangxi province are classified into the wild group and seventy-nine percent of domesticated cuneiform bulliform cells from Jiangxi province are classified into domesticated group (Fig. 5). The results indicate that the characteristic of cuneiform bulliform cells appear to provide a satisfactory method to statistically identify phytoliths from wild or domesticated rice.

To verify the statistical significance, treating each sampled context with almost 50 cuneiform bulliform cells were encountered through the WN1 core (Fig. 6). It is clear that a distinct difference in decorations occurs among the 20 samples. We found that almost ninety percent of cuneiform bulliform cells from 80 cm (younger than AD 1950) and above are classified into the wild group on the basis of direct radiocarbon dating. The result of this analysis also matches the environment which have the preserved a relict population of *Oryza rufipogon*. Meanwhile it also observed that the characteristics of cuneiform bulliform cells appear to provide a satisfactory method for distinguishing phytoliths from wild rice.

The phytolith record from the WN1 core reveals the presence of rice phytoliths is low in samples dating between from 5655 to 2640 cal a BP (depth125–130 cm). This low percentage of rice phytoliths in the core sample indicates that domesticated rice did not appear to have been the dominant food crop of the people in this time.

There is a dramatic increase in the amount of rice phytoliths found in samples from dating between 2640 and 1880 cal a BP, which may suggest the increasing importance of domesticated rice during this period. According to the historical documents (Loewe, 1986, 1994, 2000), there was a significant increase in population, agriculture production and economic growth around 2000 cal a BP in the Lingnan region associated with a short but prosperous Nanyue Kingdom.

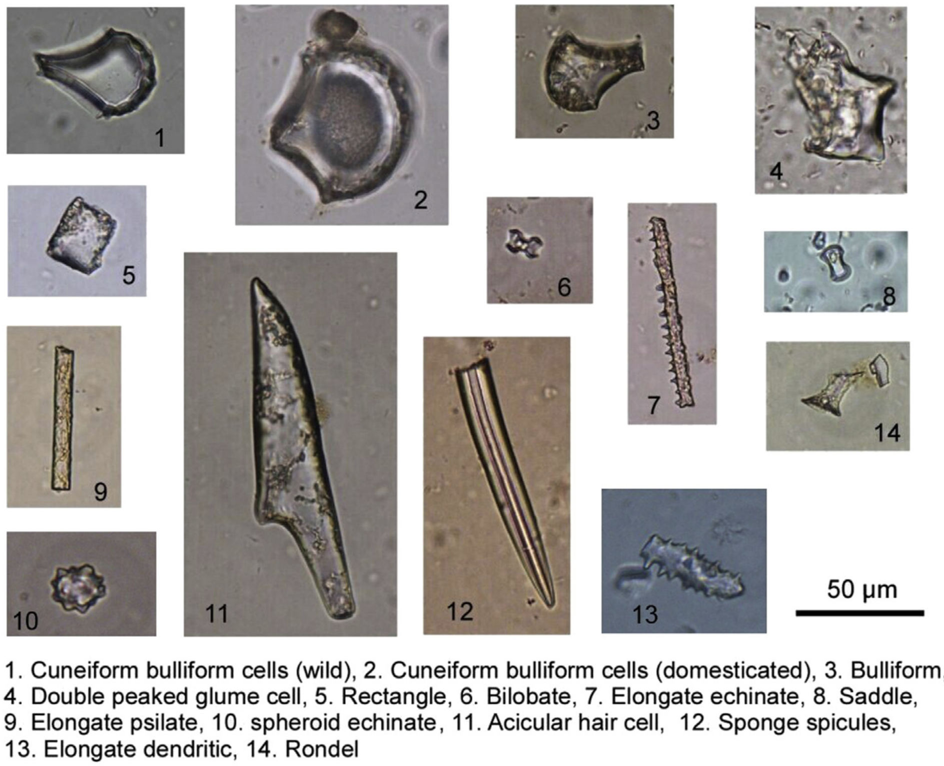

Fig. 3. Frequent phytoliths from the core WN1.

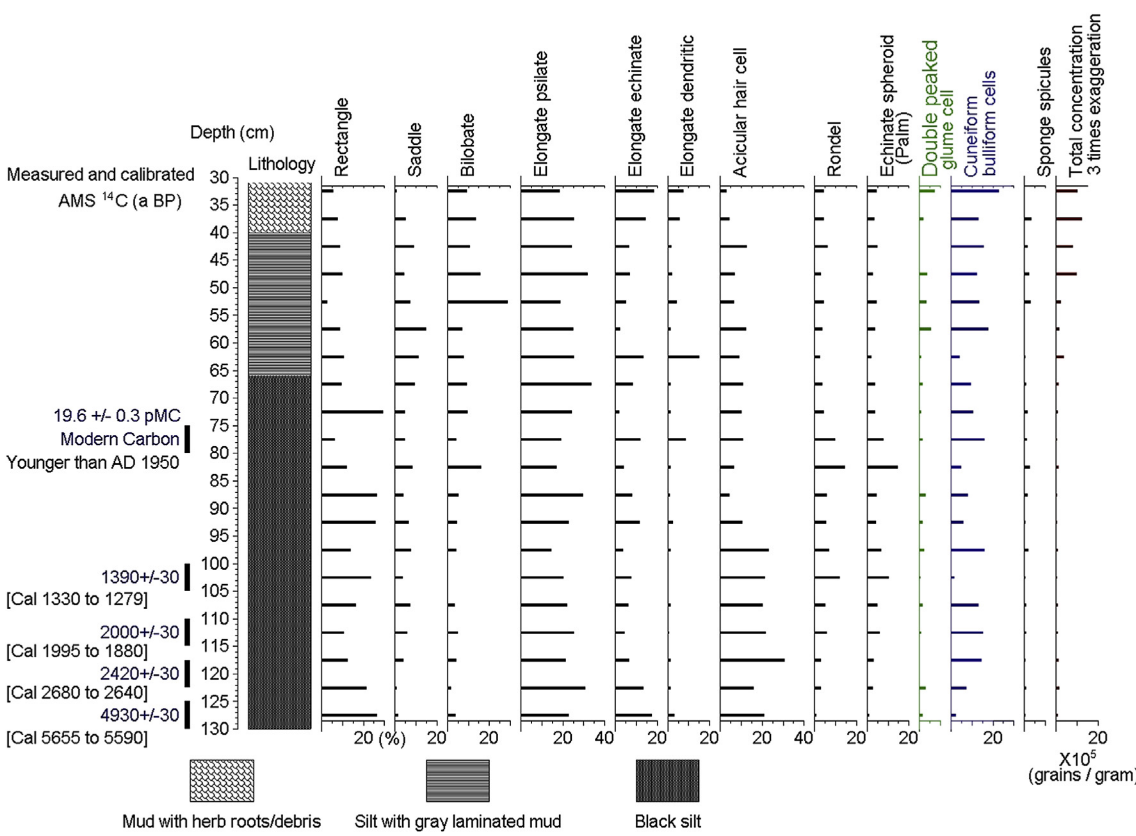

Fig. 4. Phytoliths percentage diagram of core WN1 from central east coast of Hainan Island, China.

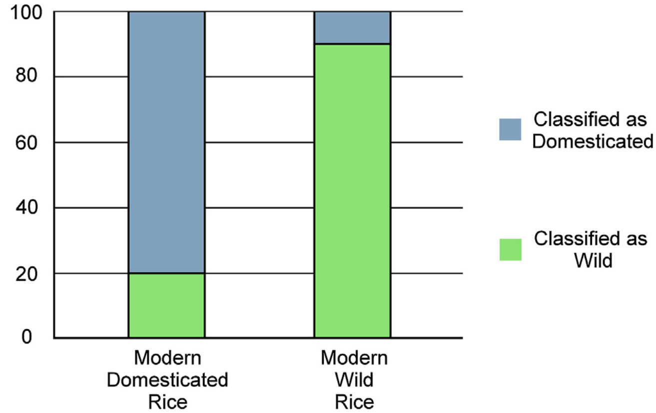

Fig. 5. *Oryza* phytolith variation of wild type vs domesticated type in modern reference.

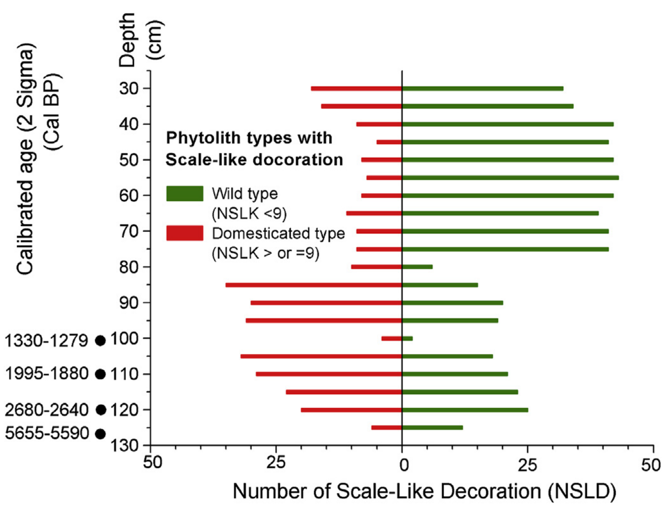

Fig. 6. *Oryza* phytolith variation of wild type vs domesticated type through the time from the core WN1.

However, there is an obvious decrease of rice phytoliths together with an increase of spheroid echinate phytoliths possibility come from economically important palm species on the basis of morphological characteristics (Fenwick et al., 2007) in sample fifteen dating between 1330 and 1279 cal a BP (depth100–105 cm) (Fig. 4), which indicates that domesticated rice did not appear to have been the dominant food crop at that time. This phenomenon might be linked with the local political turmoil from the Han dynasty to Tang dynasty (Chen, 2003).

From the results shown in Figs. 4 and 6, eighteen grains of cuneiform bulliform cells were identified in sample 20 (depth125–130 cm, 5655–5590 cal a BP). We found that thirty percent of cuneiform bulliform cells are classified into the domesticated group and seventy percent of cuneiform bulliform cells are classified into the wild group. Domesticated rice begins to appear on Hainan Island at about 5655–5590 cal a BP. Moreover, the proportion changes over time in favor of domesticated types of rice phytoliths, which increase from thirty to sixty-four percent between 5650 and 2000 cal a BP (depth125–130 cm). Archaeological evidence from sites in the Lingnan region reveals that domesticated rice was present around 6000 cal a BP as the result of human population movement (Zhang and Hung, 2010). According to Bellwood's paper (Bellwood, 2011), the core developmental sequence in the Yangzi Basin and adjacent areas, from wild rice management to intensive wet field construction, occupied the millennia from about 7000 to 4000 BC. At 3000 to 2000 BC, rice cultivation was spreading into regions such as Vietnam and Taiwan. The spreading to Hainan may have happened at the same time as its spread to Taiwan. Sagart also favors a dual origin for rice vocabularies, one within Austroasiatic and another within Tai and Austronesian. Allowing that rice cultivation was first developed in a generalized Yangzi source region, this could suggest a dual expansion of rice vocabulary, on the one hand involving coastal China from southern Shandong southwards to Hainan and Taiwan [Austronesian and Tai, with (Sagart, 2005, 2008) suggested links to Sino-Tibetan] and on the other hand an inland riverine Austroasiatic dispersal (Sidwell, 2010). Our findings support Bellwood and Sagart's suggestions of expansion of rice vocabulary involving coastal China from southern Shandong southwards to Hainan and Taiwan.

Based on the phytolith record from the WN1core, we propose that domesticated rice was grown on Hainan Island by 5655–5590 cal a BP. This study indicates that Hainan Island should play a very important role in the process of the spread of domestic rice agriculture into southern China and Southeast Asia.

5. Conclusion

The characteristics of cuneiform bulliform cells of phytoliths derived from rice leaves provide an effective method for distinguishing wild from domesticated types in *Oryza*.

The phytolith data from the sediment core indicate the earliest occurrence of domesticated rice on Hainan Island dates to at least 5655–5590 cal a BP. However, low abundance of rice phytoliths from 5650 to 2640 cal a BP suggests that domesticated rice did not appear to have been the dominant food crop during this period. The production of domesticated rice shows increases between 2640 and 1880 cal a BP as inferred from the increased amount of phytoliths of domesticated rice. Historical records of the Han dynasty also document a significant increase in population, agriculture production and economic expansion around 2000 cal a BP in Lingnan region associated with the presence of the ancient Nanyue Kingdom.

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