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Implications of phytolith and diatom assemblages in the cultural layers of prehistoric archaeological sites of Ban Non Wat and Nong Hua Raet in Northeast Thailand

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Introduction

The Mun River valley is an important prehistoric archaeological region in Northeast Thailand and represents a rich and long period of occupation spanning two millennia during the Neolithic, Bronze and Iron Ages (Boyd 2008; Boyd and Chang 2010; Higham and Higham 2009). Extensive archaeological investigation provides a rich picture of the day-to-day life of the inhabitants of the many sites scattered throughout the region. Evidence has been found related to past human behaviour and activities, such as rice-based agriculture, farming activities, industrial activities, trading and exchange, and ritual activity (Chang 2002; Domett *et al.* 2016; Grant and Higham 1991; Higham 2004, 2011; Higham and Rispoli 2014). While it is well established that prehistoric societies in the region were supported, in part, by rice-based agriculture (Castillo 2011; Higham 2002; Higham and Rispoli 2014; Higham *et al.* 2010; King *et al.* 2013), little effort has been made to identify the details of the form of that agriculture; archaeology has been content to state that rice was present, but details such as the focus of processing, storage etc. – for example, was rice being processed before being brought onto the sites or was such work being done in the settlements? – have not been examined previously. Likewise, previous studies have identified that the site sediments are derived from the neighbouring floodplain (Boyd *et al.* 1999; Habberfield-Short and Boyd 2007; McGrath *et al.* 2008), but little more detail has been examined. Was, for example, the clay used to build working surfaces and domestic floors brought from nearby ditches and channels or from further afield on the floodplain? Such questions address matters of the daily lives of the prehistoric inhabitants, and provide a human and behavioural richness to the larger archaeological picture (Domett *et al.* 2016; Gebhardt and Langohr 1999; Karkanas and Moortel 2014; Parkinson *et al.* 2010; Salisbury *et al.* 2013).

Environmental context

In order to examine such issues, palaoenvironmental evidence – sediments, plant fossils etc. – provides useful indicators of human activities, reflecting people's use of natural resources; evidence for daily activity, however, needs to be balanced against equivalent evidence for the environmental context (e.g. Boyd 1988). In this respect, it is already understood that the environmental condition of the valley has undergone significant change throughout the late Holocene epoch (Boyd and McGrath 2001a; Higham 2011). The area is presently dominated by semi-arid scrub and woodland and low-productivity rice cultivation. Boyd and McGrath (2001b) conducted the first palynological study in the area. They examined six locations by excavating trenches from the edges of prehistoric mound sites into the surrounding floodplain and concluded that the area around the sites was initially dominated by forest (at the time of first sedentary human occupation, approximately 4000 years ago) that then underwent three phases of replacement occurring at 2500 BC to AD 600. The result was a mosaic of grassland, probably due to the introduction of rice cultivation, and arboriculture

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marking the effects of intense human settlement (Boyd 2008; Boyd and McGrath 2001a). By the Iron Age (approximately 400 BC to AD 500), the Mun River valley appears to have been an area of dense occupation with, many researchers argue, wealthy and hierarchically structured communities (Boyd and McGrath 2001a). Iron Age communities appear to have abandoned the site of Ban Non Wat about 1400 years ago, or at least any continued occupation has left a very limited archaeological signature, and the reason for this may relate to changing environmental conditions (Boyd 2008).

Pollen representing a great variety of species were identified from Iron Age contexts and indicated a wide range of growth forms and ecological preferences. Boyd and McGrath (2001b) categorised the pollens recovered into different plant groups including; forest trees, regeneration/disturbance species, significant arboriculture species and open-land plants. The possible human use of these plants in prehistory was discussed. Based on ethnographic comparisons they noted that forest trees likely provided economic materials such as wood, oil, varnish and timber while regeneration/disturbance species may have been used as ornamental plants and arboricultural plants possibly provided important starchy foods, edible seeds and fruits, as well as potentially being used for medicine, dye, tanning and timber. Some *Ficus* species (*Ficus religiosa*) are important in religious contexts, although this more clearly relates to the Buddhist and Hindu traditions that do not appear until the end of the Iron Age in the area. Open-land grasses and shrubs are used as herbs and edible plants. Among the grass pollens, rice might be found in large quantities based on the assumption that the inhabitants had a strong rice-based society at that time (Boyd and McGrath 2001b, Castillo 2011).

The present study examines the archaeological implications of phytoliths and diatoms observed in the different cultural layers at the Ban Non Wat and Nong Hua Raet prehistoric sites. Comparative samples were taken for siliceous microfossil analysis with an aim to provide a more generalised view of the on-site context. Iron Age, Bronze Age and Neolithic occupation layers were represented in the samples from excavated spits and hard floor (HF) surfaces. The HF surfaces have previously been demonstrated to be domestic surfaces, used, at least in part, as locations for processing meat (Kanthilatha *et al.* 2014); further study has demonstrated the presence of *in situ* burning and anthropogenic waste (Kanthilatha *et al.* in press), thus filling out the picture of domestic use of the floors. It is unknown, however, whether rice, which is ubiquitous throughout the period of occupation, was also processed in these areas, rather than being processed off-site. Phytolith analysis provides an opportunity to test this. While analysis of the siliceous fossils initially focussed on these plant remains, it also yields evidence for other classes of siliceous fossils, namely diatoms and sponge spicules. These are relatively uncommon, and confirmed to be associated with the floors, and thus provide opportunity to revisit the construction techniques of the floors.

Phytolith research in archaeology

Phytolith analysis has become an increasingly more important research tool in environmental archaeology during the last decade used in reconstructing past environments particularly in situations where pollen preservation is poor (Boyd 1998; Huang and Zhang 2000; Parr *et al.* 2001). Phytoliths were initially discovered in the 1830s and saw their first use in paleoecological work only after the mid-1950s (Piperno 1988). Phytolith analysis of different soil samples provides data relevant to the type of vegetation cover in relation to the chronology of a particular site. Phytolith analysis is therefore fundamental to any research in the areas of palaeoenvironmental reconstruction and archaeological applications (Parr *et al.* 2001).

Phytolith studies have been used to identify rice domestication and to identify ancient rice cultivation sites (Fuller *et al.* 2010; Harvey and Fuller 2005; Huang and Zhang 2000; Kealhofer and Penny 1998; Lu *et al.* 2002; Zhao 2010; Zhao and Piperno 2000). Double-peaked, bulliform and parallel-bilobate (scooped bilobate) are the three main types of phytoliths that are produced by the rice plants (Lu *et al.* 1996, 2002; Pearsall *et al.* 1995). Phytoliths can be used to identify farming techniques and harvesting methods of rice by investigating the remaining phytolith types in the sediments. Parallel-bilobates and fan-shaped bulliforms are produced from rice leaves and stem, and the double-peaked bulliforms are produced by rice husk cells (Harvey and Fuller 2005; Zhao 2010).

Diatoms

Diatoms are effective bio-indicators that occur in almost all aquatic environments and changes in diatom communities represent rapid response to the environmental change (Gell *et al.* 2005; Jüttner *et al.* 2003; Kupe *et al.* 2008; Li *et al.* 2012). Water quality conditions can be reconstructed from fossil diatom assemblages because they are highly sensitive to water pH (Reid *et al.* 1995). Diatoms exist in fresh water, salt water or any conditions where moisture is present (Coil *et al.* 2003). The presence of diatoms in archaeological soils indicates the presence of water source nearby to the site.

Materials and methods

This study was structured to provide a broad review of the distribution of siliceous microscopic biological remains across the range of samples representative of the archaeology of the related sites of Ban Non Wat and Nong Hua Raet. The sampling strategy included samples from cultural layers and specific features, notably floors, allowing comparison and, especially, a focus on further questions of human activity associated with the floors. Furthermore, sampling was designed to span five excavation pits, since these have been shown to demonstrate a range of archaeological facets of the prehistoric occupation of the sites.

Study area

Two prehistoric archaeological sites at the upper Mun River valley were selected for the analysis of sediment samples for both phytoliths and diatoms. The origins of Angkor archaeological project and the subsequent society and environment before Angkor archaeological project have been excavating in northeast Thailand over almost two decades. A major focus has been on occupation mounds in the upper Mun River valley to reveal the geoarchaeological evolution of the sites (Boyd and McGrath 2001a, 2001b; Boyd and Chang 2010; Boyd *et al.* 1999; Duke *et al.* 2010; Higham 2002, 2004; Higham and Higham 2009; Higham and Rispoli 2014). Human settlements in the Khorat Basin spanned the Neolithic, through Bronze Age and Iron Age communities up to the Khmer era. The Iron Age is generally accepted as a critical period in the development of socio-economic and demographic complexity in the region (Habberfield-Short 2006). Chang (2002) suggests that the technological and social changes from low-density Bronze Age to the high-density Iron Age were a gradual process. Ban Non Wat is the most recent and most significant excavation site, certainly in terms of the longevity and amount of excavation at a single site and has been excavated from 2002 to 2007 (Series 1 excavations, origins of Angkor team) and from 2007 to 2011 (Series 2 excavations, society and environment before Angkor team). At Ban Non Wat, evidence has been found for repeated, possibly continuous occupation starting with occupation by hunter–gathers prior to the Neolithic (Boyd and Chang 2010; Higham 2002, 2004). The sediments studied here are from the Series 2 excavation pits at the Ban Non Wat and nearby Nong Hua Raet (Fig. 1).

This study focused on four excavation pits at the moated-mound site of Ban Non Wat, described as P300, S400, G104 and N96, and one, HI100 at the simple mound site of Nong Hua Raet (Fig. 1). Cultural layers were identified in the excavations, up to 5-m deep, based on the characteristic features of the soil colour, texture and associated archaeological artefacts. Excavation followed site stratigraphy, revealing and removing floors and other features in sequence. Where this was not appropriate, sediments were removed in 10 cm spits to maintain vertical control over finds and samples. Excavation continued until culturally sterile sediments were reached. Identified cultural

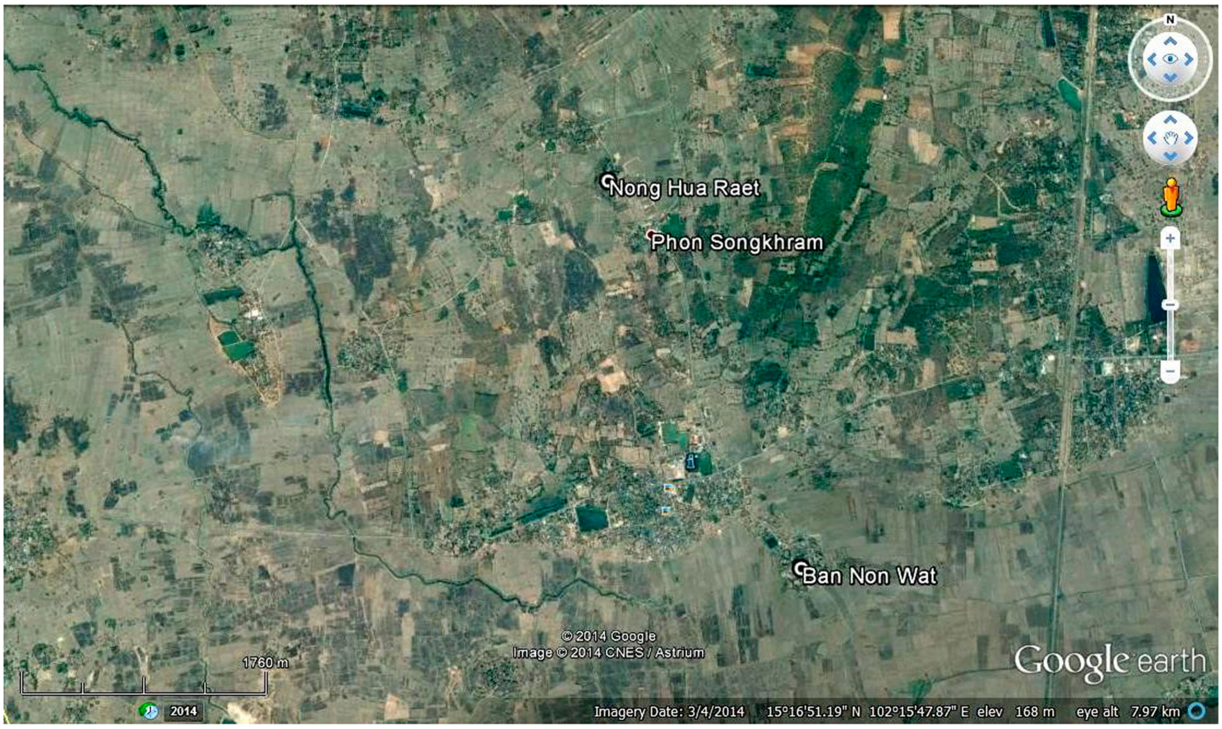

Figure 1 Location map showing the study sites of Ban Non Wat and Nong Hua Raet within the 'Origins of civilisation of Angkor' archaeological project study area (Google Earth 2014).

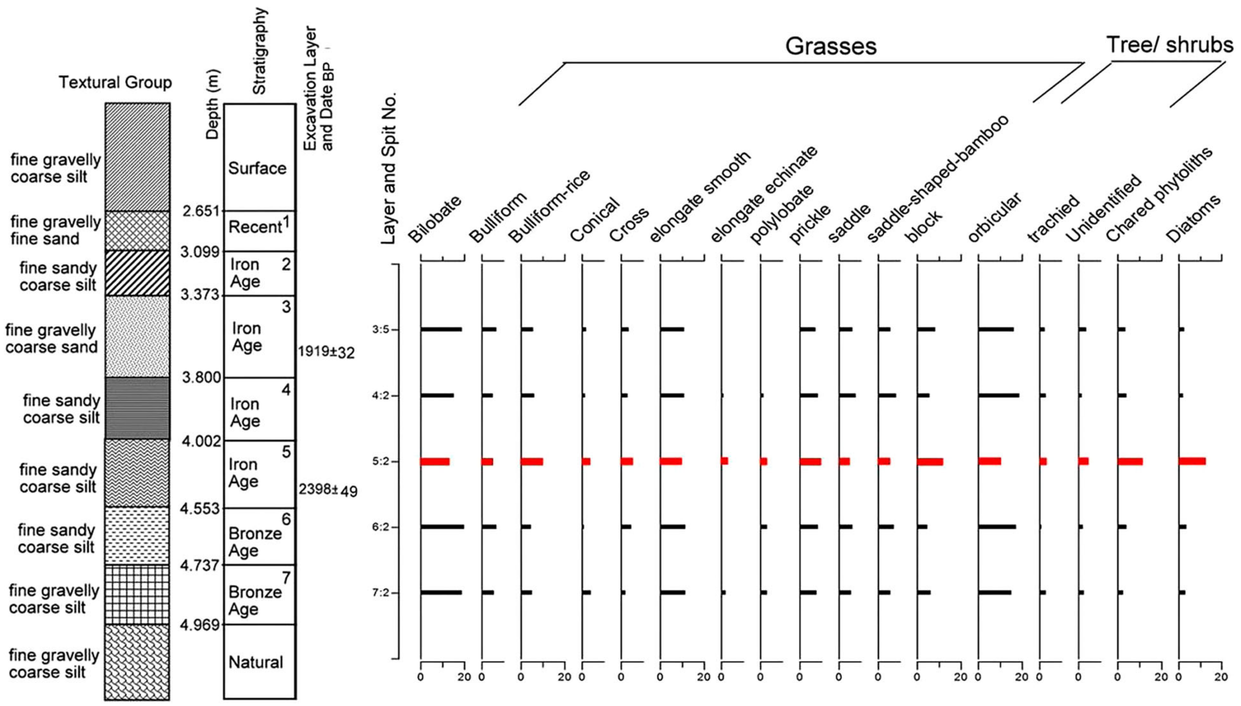

Figure 2 Diagram showing textural groups, stratigraphy and abundance of phytolith types (% of the sum) in different cultural layers of P300 excavation pit. Identified phytolith types in HF surface is shown in red colour.

layers, their textural groups and available radiocarbon dates are provided in Figs. 2–6. Details of silicious microfossils are included in studied layers (Figs. 2–6).

Extraction, analysis and presentation of siliceous microfossils

Phytoliths and diatoms were extracted from the samples using a modified version of the rapid microwave digestion method described in Parr (2002) and Parr *et al.* (2004). About 0.25 g of dry sediments was used in a CEM MARSXpress biological microwave digester with 1:1 HNO_3 and HCl. The in-built computer on the CEM MARSXpress biological microwave digester was programmed as per outlined in Parr and Sullivan (2014). Microscope slides were mounted using benzyl benzoate (Parr 2002). The

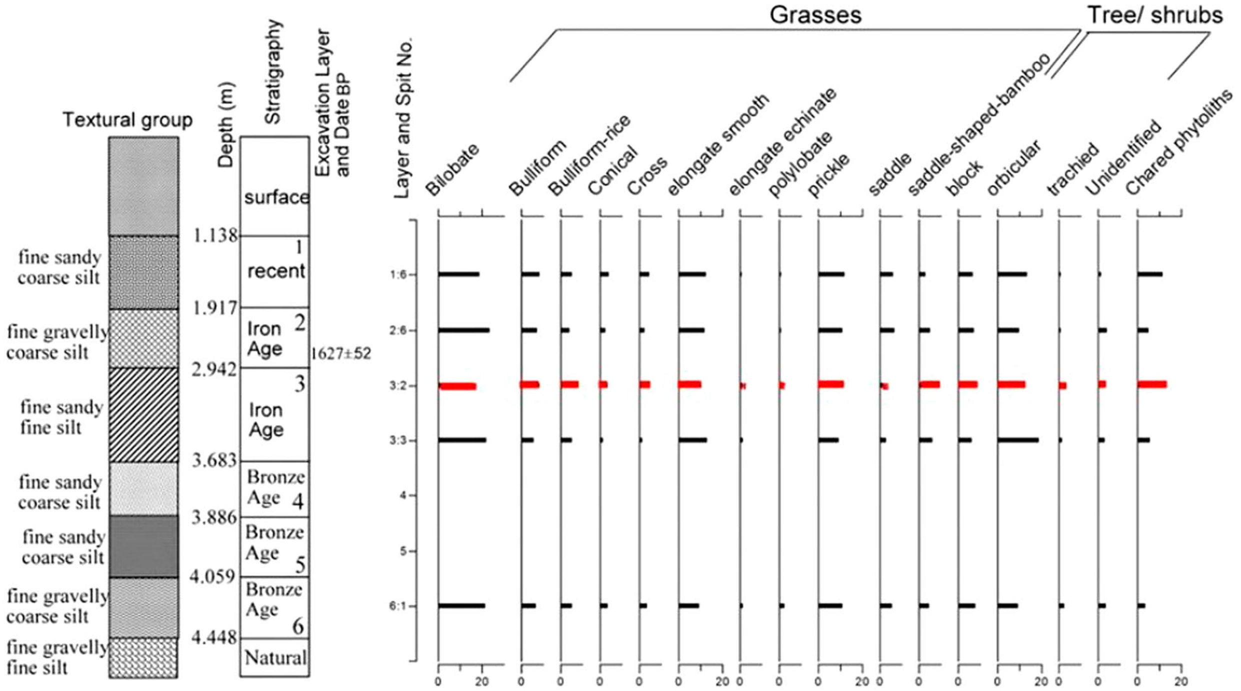

Figure 3 Diagram showing textural groups, stratigraphy and abundance of phytolith types (% of the sum) in different cultural layers of S400 excavation pit. Identified phytolith types in HF surface is shown in red colour.

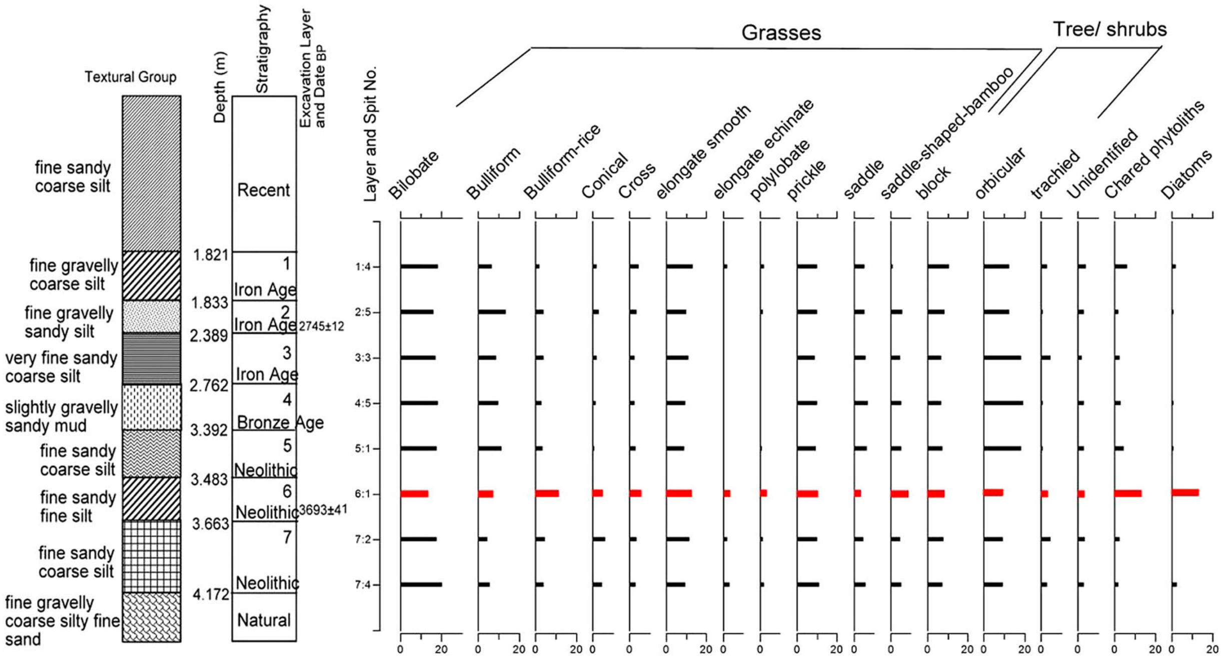

Figure 4 Diagram showing textural groups, stratigraphy and abundance of phytolith types (% of the sum) in different cultural layers of G104 excavation pit. Identified phytolith types in HF surface is shown in red colour.

microscope was fitted with polarising filters and a cooled head Micropublisher 5 mega-pixel digital camera driven by Q-capture software for recording digital images. A count of at least 200 phytoliths and other microfossils such as diatoms and sponge spicules was attempted for each slide. Phytoliths were counted and classified according to the International Code for Phytolith Nomenclature (Madella *et al.* 2005) and using various taxonomic guides (Boyd 1998; Piperno 1988; Pearsall 2000). Chronology of the excavation layers was attained by AMS radiocarbon dating of charcoal samples at the Australian Nuclear Science and Technology Organisation (Kanthilatha *et al.* in press). Phytoliths can be used to identify a certain genus or in some cases species according to its shape, size, ornamentation, cell orientation and other anatomical features (Twiss 1987; Piperno 1988). At this stage, the research was mainly focused to the identification of phytoliths in the different occupation layers of each site and was not overly concerned with

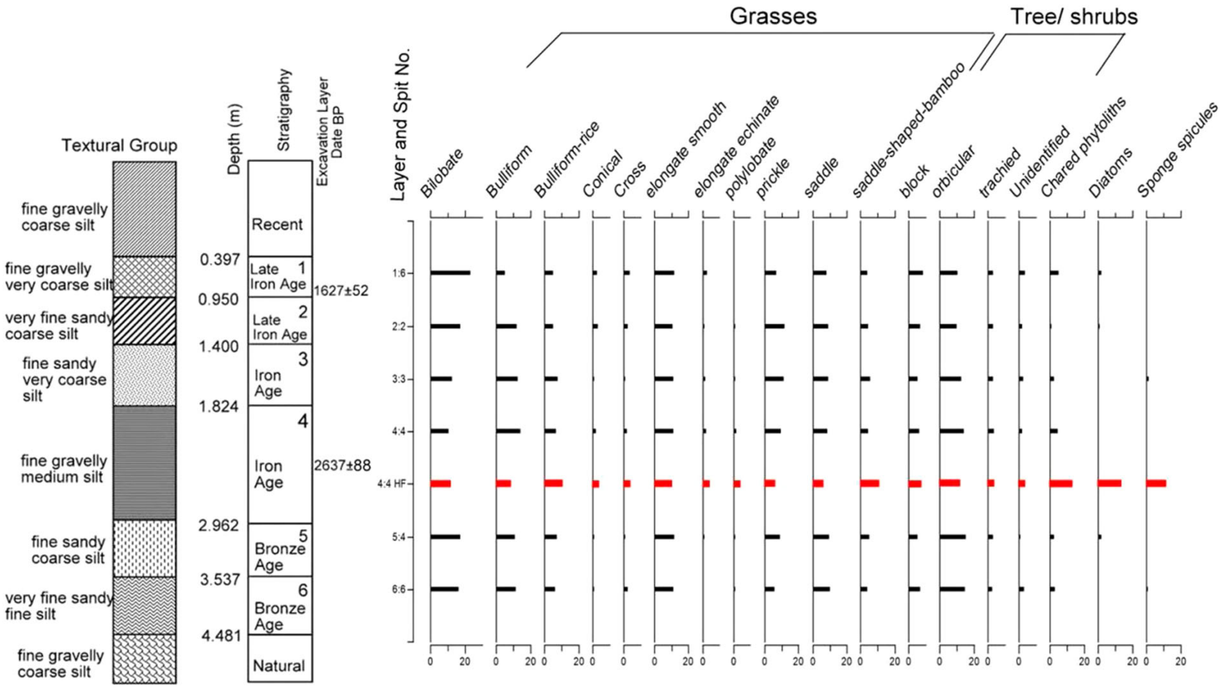

Figure 5 Diagram showing textural groups, stratigraphy and abundance of phytolith types (% of the sum) in different cultural layers of N96 excavation pit. Identified phytolith types in HF surface is shown in red colour.

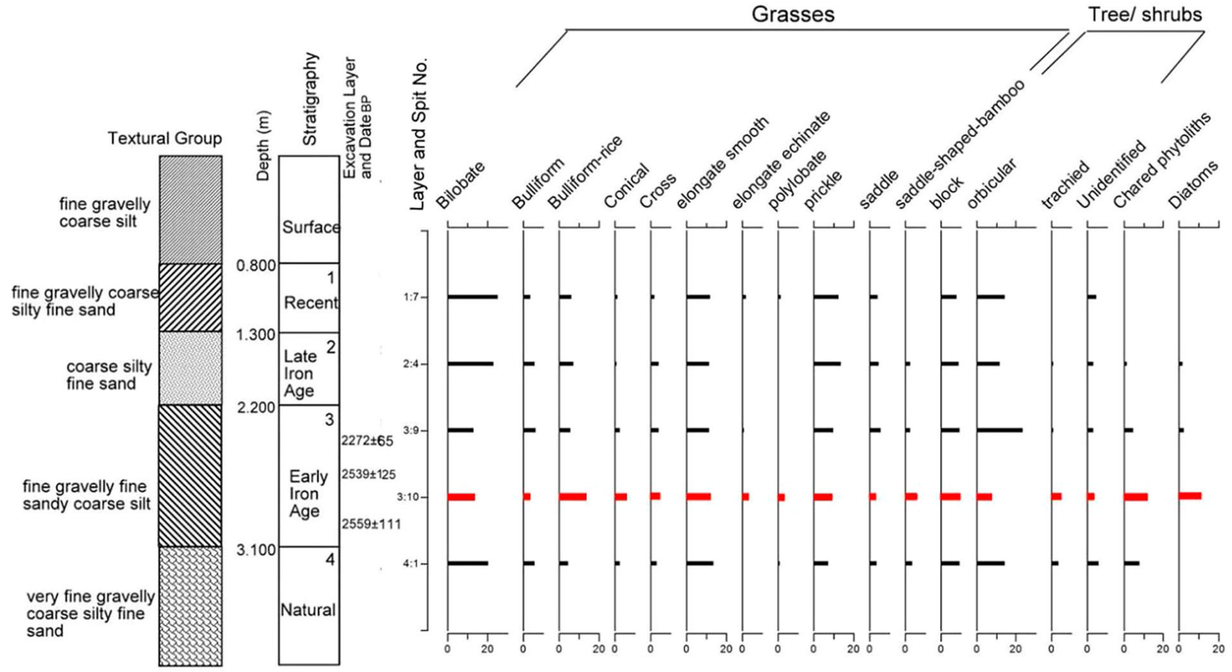

Figure 6 Diagram showing textural groups, stratigraphy and abundance of phytolith types (% of the sum) in different cultural layers of HI100 excavation pit. Identified phytolith types in HF surface is shown in red colour.

identified to genus or species level. Diatoms and sponge spicules were identified in some samples.

The C2 software at the Newcastle University developed by Juggins (2007) was used to produce the phytolith diagrams of each of the proxies and plotted against the depth of each excavation pit. C2 is software developed for ecological and palaeoecological data analysis and visualisation (Juggins 2007).

Results

All of the studied occupation layers yielded abundant, well-preserved phytoliths. The identified major phytolith forms, diatoms and sponge spicules of each excavation pit were plotted with the relevant stratigraphic layer of the occupation (Figs. 2–6). The most abundant types of phytoliths in the sediment samples were from grasses (about 75%). Abundant phytolith forms were identified as bilobate, bulliform, conical, cross, elongate, polylobate, prickle, saddle, block, orbicular and tracheid types (Fig. 7). The excavation pit of P300 has seven identified layers of occupation beginning from the Bronze Age and sediments from layer 3 to layer 7 were used for the present study. The major HF studied here occurred in layer 5 which belongs to the early Iron Age period. Charred phytoliths, diatoms and rice bulliforms were present in the HF surface more prominently than that of the other layers (Fig. 2). The excavation pit S400 identified six layers of occupation beginning from the Bronze Age and all the layers except 4 and 5 were examined in the study. Charred phytoliths and rice bulliforms were present in the HF layer; however, there were no visible diatoms (Fig. 3). For excavation pit G104 seven layers of human occupation beginning from the Neolithic period were identified and all the cultural layers were studied. A HF was found in layer 6 which was associated with Neolithic occupation. Charred phytoliths, diatoms and rice bulliforms were prominent in this HF layer. Relatively higher numbers of tree/shrubs phytolith counts were observed in the layers 3–5 (Fig. 4). The excavation pit N96 had six layers beginning from the Bronze Age occupation and sediments from all the layers were examined. A HF was encountered in layer 4 and which contained relatively high levels of charred phytoliths, diatoms, sponge spicules and rice bulliforms. This is the only HF, where sponge spicules were identified (Fig. 5). The excavation pit of HI100 had only three major layers of occupation identified which relate to the Iron Age period, although the very lowest cultural layers may have accumulated in the Bronze Age. The studied HF at this site was found in layer 3 and contained prominent numbers of charred phytoliths, diatoms and rice bulliforms. Layer 4 was identified as a culturally sterile layer, with relatively small numbers of phytoliths (Fig. 6).

Bulliform type phytoliths (Fig. 7) that originated from rice (*Oryza*) were abundantly present in the studied sediments, especially in the HF surfaces. *Oryza* is essentially a tropical plant of semi-aquatic habitats (Zhao and Piperno 2000). Phytoliths from Bambusoideae plants were also observed, they are adapted to warm and humid climates and their presence can be confirmed by the macro-evidences of bamboo use in hearth structures. Charred phytoliths were identified in the sediment samples and they are also a good

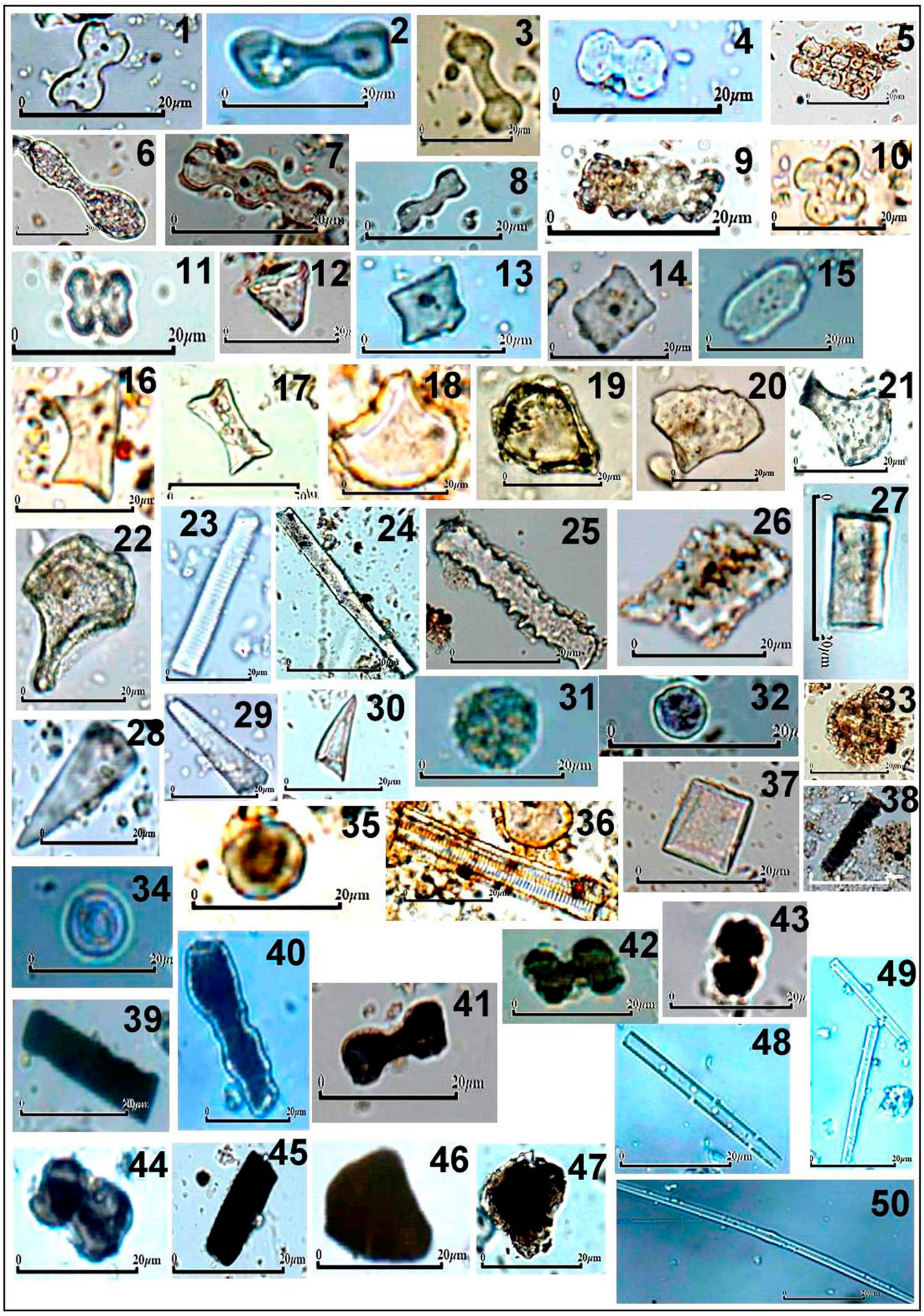

Figure 7 Photographs of phytoliths identified in the studied areas of Ban Non Wat and Nong Hua Reat: 1, 2, 3, 4, 5, 6 – bilobate; 7, 8, 9 – polylobate; 10, 11 – cross, 12 – conical; 13, 14, 15 – saddle; 16, 17 – saddle-bamboo; 18, 19, 20, 21, 22 – bulliform; 23, 24, 25, 26, 27 – elongate; 28, 29, 30 – prickle; 31, 32, 33, 34, 35 – orbicular; 36 – trachied; 37 – block; 38, 39, 40, 41, 42, 43, 44, 45, 46, 47 – charred phytoliths; 48, 49, 50 – sponge spicules.

indicator of using fire (Parr 2006). Diatoms were present especially in the HF s which is an indication of a damp habitat within the sites and/or that water was transported and used on site. Nine species of diatoms were identified in the studied sediments (Table 1). Identification was mainly based on the Foged (1971) and the identified species are *Diploneis smithi*, *Eunotia* sp., *Navicula* sp., *Frustulia rhomboids*, *Mastogloia* sp., *Nitzschia palea*, *Achnanthes hungarica*, *Navicula cuspidate* and *Gomphonema* sp. (Fig. 8).

Discussion

Rice cultivation

The most abundant types of phytoliths originated from grasses (Zhao and Piperno 2000). Current analysis also supports this statement. Grasses are probably the most widely distributed plants on Earth and produce many and varied phytoliths (Carter 2007). Palynological analysis previously undertaken on the same study site, including along the moat complexes of a total of six moated sites, indicates that the

Table 1 Identified diatom species on different stratigraphic layers. Presence of diatoms indicate by a tick. HF surfaces were identified more species.

Sample	*Diploneis smithi*	*Eunotia* sp	*Navicula* sp	*Frustulia rhomboides*	*Mastogloia* sp	*Nitzschia palea*	*Achnanthes hungarica*	*Navicula cuspidata*	*Gomphonema*
P300 3:5			√			√	√		
P300 4:2			√						√
P300 5:2 HF	√	√	√	√	√	√		√	
P300 6:2			√			√	√		√
P300 7:2			√		√		√		
G104 1:4	√	√	√			√			
G104 2:5			√			√			
G104 4:5	√			√	√		√		
G104 5:1	√			√	√				
G104 6:1 HF	√	√	√	√	√	√	√	√	√
G104 7:4	√		√		√		√		
N96 1:6	√	√	√						√
N96 2:2			√						
N96 4:4 HF	√	√	√	√	√	√	√	√	
N96 5:4			√				√		√
HI100 2:4			√				√		
HI100 3:9			√				√		
HI100 3:10 HF			√			√	√		√

floodplain was initially dominated by forest before the replacement by mosaics of grassland (Boyd and McGrath 2001a). Boyd and Chang (2010) suggest a model of vegetation change during the Mun valley Iron Age encompassing three phases of change: a gradual early prehistoric forest change during the Neolithic and Bronze Ages into the early Iron Age (ca. 2500 BC to 200 BC); a more rapid period of Iron Age landscape management producing phased and sequential change from ca. 200 BC to AD 500; and a rapid immediately post-Iron Age transition at ca. AD 500 to AD 600, where the Iron Age agricultural landscapes were replaced by the dry woodland and grasslands of the late Holocene. Radiocarbon dates for layer 6 of G104, layers 2 and 3 of HI100, layer 4 of N96 and layer 5 of P300 excavation pits support the above characterisation of phase 1, a gradual vegetation change. Layer 2 of S400 and layer 3 of P300 are associated with phase 2 and indicate a rapid vegetation change in the Iron Age (Figs. 2–6). The total phytolith count in different occupation times is consistent with existing knowledge of vegetation change from Neolithic to the Iron Age (Boyd 2008; Boyd and Chang 2010; Boyd and McGrath 2001a, 2001b).

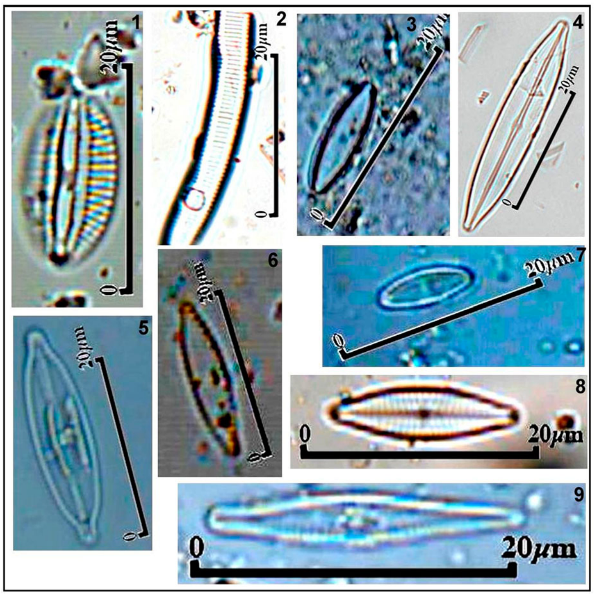

Figure 8 Photographs of the identified diatoms in the study area mainly based on Niels Foged's (1971): 1 – *Diploneis smithi*; 2 – *Eunotia* sp.; 3 – *Navicula* sp.; 4 – *Frustulia rhomboides*; 5 – *Mastogloia* sp.; 6 – *Nitzschia palea*; 7 – *Achnanthes hungarica*; 8 – *Navicula cuspidata*; 9 – *Gomphonema* sp.

Phytoliths coming from rice were found throughout the stratigraphic sequences in a wide variety of forms. Plenty of evidence is available from these and neighbouring prehistoric sites to confirm the presence of a long-established a rice-based society; rice remains, for example, appear as grave offerings, husks preserved as ash within the soil and pottery, imprints on pottery sherds, charred rice grains and rice chaff as ceramic temper (Castillo 2011; Higham 2002; Higham *et al.* 2010; Higham and Rispoli 2014). The typical habitat of perennial rice can be found throughout this period in neighbouring wetlands, and this archaeological evidence provides support and validation for the continuing role of rice in the region's prehistoric society. However, little attention has been previously paid to questions of the domestic processing of rice at these sites, other than that it was probably cultivated close to the sites. According to the traditional system, harvesting and processing of rice can be subdivided into several stages; crops harvested from the field, threshing and winnowing to separate the spikelets, storing of the whole spikelets, pounding, de-husking and winnowing of spikelets again to separate prime grain from the waste fraction prior to the consumption (Thompson 1996). While the origins of *Oryza sativa* cultivation may be more than 8000 years old, (Fuller and Qin 2009; Gu *et al.* 2012; Lu *et al.* 2002; Wu *et al.* 2014) it was introduced into this region most likely around 3500 BP from China (Bellwood 2001; Castillo 2011; Higham 1989). Carbonised *Oryza sativa* samples found in central Thailand have been dated to the Iron Age (Weber *et al.* 2010), while pollen analysis at Khok Phanom Di (central Thailand) revealed rice cultivation around 2000 BC (Maloney 1991). The morphology of the abscission scar is a good indicator of rice domestication and the records of Khok Phanom Di specimens confirm that they were from a domestic crop (Thompson 1997). Sub species of rice *japonica* was being consumed and cultivated in mainland Southeast Asia in the Bronze and Iron Ages and the *indica* have been brought into Thailand only after the initial period of Indian contact (Castillo *et al.* in press). Archaeological evidence suggests rice consumption by the prehistoric people of northeast Thailand since the onset of Neolithic occupation through to the Iron Age (Castillo 2011; Higham 2002; Higham and Rispoli 2014; Higham *et al.* 2010; Maloney 1991, 1992; Weber *et al.* 2010).

Better understanding of the floors

At Ban Non Wat and Nong Hua Raet, rice is associated with a range of contexts. Importantly, rice is associated with identified floors, linking, for the first time in this region, rice with specific human domestic activity. The oldest such floor (excavation site G104) is dated to 3693 ± 41 cal BP, with dates from pit N96 of 2637 ± 88 cal BP, P300 of 2398 ± 49 cal BP and HI110 of 2559 ± 111 cal BP. There are three aspects of the floors, especially in relation to people's construction and use of them, that the current evidence provides further insight on: mode of construction; association with hearths; and relationship with rice.

Mode of floor construction

An unexpected finding in the analyses was that of the presence of diatoms and sponge spicules. These are tropically aquatic organisms, commonly found in sediments deposited in flowing or standing water, swampy conditions or damp soils. The significance in the diatom and sponge spicule assemblage being associated with specific archaeological sediments – i.e. not associated with evidence for primary deposition under (natural) conditions, but with sediments that represent secondary (archaeological) deposition – is that they may provide potential evidence for either the aquatic conditions at the sample site or for conditions at the source of materials brought onto the site. Diatoms occur in almost all aquatic environments (Reid *et al.* 1995), are frequently dominant in freshwater bodies, may be associated variously with aquatic sediments and aquatic plants, and have a direct relationship with pH of the water (Bradshaw *et al.* 2000); they are useful indicators of environmental conditions in aquatic ecosystems (Bere and Tundisi 2011; Delgado *et al.* 2012; Leira and Sabater 2005; Reid *et al.* 1995). The assemblage, therefore, has the potential to describe the environmental conditions at source or on the archaeological site. The presence of diatoms and sponge spicules in archaeological soil may provide evidence of several characteristics of the site (Coil *et al.* 2003; Maloney and Rovner 1991). In this case, possible characteristics include: (i) locally damp soil; (ii) local standing or flowing water at the site; (iii) flooding of the site; (iv) water quality at the source of water brought onto the site; (v) environmental conditions at the source of the clays, other sediments or materials brought onto the site. The assemblage of diatom species is predominantly benthic. Given, therefore, both the lack of sedimentary evidence for standing water sediments, and the demonstrable function of the floors, the three most likely explanations for these assemblages are that they represent the conditions of source locations for materials brought onto the site: (a) water brought from the neighbouring floodplain or channels into the settlement for domestic consumption; (b) the clay, also derived from the neighbouring floodplain used to construct the floors; and (c) with pond weeds brought into the occupations sites as animal fodder or bedding or as human food.

Nine species of diatoms were identified in the sediment samples (Table 1) and most of them belong to *Navicula* species (Fig. 8; Foged 1971). Two of the species, *Navicular mutica* and *Nitzschi palea,* are tolerant of polluted water. *Navicula confervacea* and *Navicula radiosa* are a less pollution-tolerant group (Kobayasi and Mayama 1989; Michels 1998). As pollution increases, low pollution-tolerant species are replaced by pollution-tolerant species, and have been frequently recorded in waters that are nutrient rich and poorly oxygenated (Bere and Tundisi 2011; Round 1991). Presence of the more tolerant species may suggest stagnant or polluted water in the study area, although they can occur in non-polluted water, while more sensitive species may suggest the presence of fresh water with no (or low) pollution (Lange-Bertalot 1979). It is thus difficult to determine water quality in the study areas.

Importantly, however, the identified species are mainly benthic diatoms; this means that they are associated with the sediments of water bodies rather than being free swimming. Benthic diatoms found in the sediments of the floors are, therefore, more likely associated with the clay from which the floors are constructed. Clay has been used for the formation of hearth structures and daubs (Parr and Boyd 2002), and the floors were constructed by layered plastering of clay (Kanthilatha *et al.* 2014, in press; O'Reilly 1997). Multiple re-plastered floor sequences have also been found in different archaeological sites for the same time period (Karkanas and Moortel 2014; Macphail and Crowther 2007; Milek 2012). This evidence indicates that the clay has been used for the construction of hearth, daubs and plastering/re-plastering of floors etc., but no research has identified the exact clay source. They are certainly very hard to infer from the archaeological evidence. The HFs discussed here are thus doubly important. It is only at the very end of the Iron Age with sites such as Non Ban Jak (Higham and Rispoli 2014) and Non Muang Kao (O'Reilly 1997) that we see clear evidence of likely domestic structures. These take the form of much more finely plastered floors. However, the interpretation of these structures remains difficult due to their close proximity to graves. Are they really domestic structures? Or, cemetery structures? The same issue can be mentioned for Khok Phanom Di where early clay floor features also seem to be closely associated with the cemetery (Maloney 1991). The diatom evidence in the present study thus suggests that the floors were constructed using nearby channel and floodplain sediments. The sponge spicule evidence may support thus, although inconclusively. They were identified in the floor sediments of the N96 pit, and imply a damp habitat (Clarke 2003; Coil *et al.* 2003). The value of the diatom evidence is in identifying the likely source of material used to construct the floors. Elsewhere, we have used evidence from the macroscopic remains and geochemistry to explore the construction of these surfaces more fully (Kanthilatha *et al.* 2014, in press).

While the sedimentary and geochemical evidence indicate that the floors were deliberate constructions used for domestic activity in the past, and now are known to be constructed using clays probably derived from off site, the phytolith evidence provides further detail. The relatively high percentages of charred phytoliths found in the floor samples are important. The presence of charred phytoliths is a good indicator of the use of fire in prehistoric locations and landscapes (Parr 2006). The floors are associated with the remains of hearths (e.g. pit HI100 at Nong Hua Raet; Kanthilatha *et al.* 2014), while Parr and Boyd (2002) record daub containing charred phyoliths as evidence for industrial kilns at nearby Iron Age Noen U-Loke. Moreover, it is likely this fire was used for domestic or industrial purposes on these living or activity areas. The presence of charred phytoliths along with enhanced concentrations of potassium (Kanthilatha *et al.* in press) in the floors indicates the presence of fireplaces, possibly for food cooking on these living surfaces.

Relationship between rice and the floors

The more important finding, however, concerns the relationship between rice and the floors. Bulliform type phytoliths that originated from rice (*Oryza*) were abundantly present in the studied sediments, especially in the HF surfaces (Fig. 7). To identify specific human activities and stages in the processing of plant foodstuffs, from growth, through harvesting, transport, storage and processing, to preparation for eating, attention must be paid to the composition of plant parts and, if available, related species, represented by the fossils; these compositions form distinctive signatures for each stage of the plant and food processing (Hillman 1981; Harvey and Fuller 2005). In this study, therefore, attention has been paid to the different morphological types of phytoliths produced by the rice plant. After harvesting, a rice crop is processed using methods such as threshing, winnowing and cleaning before being stored or prepared for eating (Dennell 1974; Harvey and Fuller 2005). Phytoliths can be identified as originating from different plant parts (e.g. the chaff, straw, leaves, grain). Bormann (2012) studied phytoliths in modern rice cultivars in Yangtze River Delta in China, identifying bilobate and short-cell phytoliths as the largest contributors to the overall phytolith content, while long-cell phytolith projections, hair phytoliths, cross-shaped phytoliths and bulliform cells were only found to be minor contributors to phytolith assemblages. Bulliform phytoliths are mainly found in the rice leaves and long cells are the main type found in rice sheath, stem and roots (Bormann 2012). In the current study, the phytolith assemblages contain a notably high proportion of rice bulliforms, although a range of forms of rice phytoliths were identified, bilobates, short-cell phytoliths, long-cell projections, hair cells, cross-shaped phytoliths and bulliforms. Cuneiform bulliform phytoliths were found in almost all occupation layers, and, notably in greater concentrations, in the HF sediments. This implies the presence of rice leaves associated with the floors, double-peaked cells from rice husks, and some parallel-bilobates possibly from rice stems and leaves, were also present (cf. Gu *et al.* 2012; Harvey and Fuller 2005).

Evidence is thus available for the presence of the rice leaves, husks and stems (Fig. 9). This implies that the whole rice plant was present in the occupation surfaces, indicating that whole rice plants were transported to the occupation areas without prior processing. At present, much of the rice harvested is

Figure 9 Carbonised rice grains from layer uncovered in the excavation pit of K500 in the Ban Non Wat (spit3, feature1) (photograph: Nigel Chang).

threshed outside the villages, close to the fields in which they were grown; in such a situation, it would not be expected to find evidence for leaves and stems on site, except where straw is brought on site; the latter situation would preclude evidence for husks. It is hard, however, to confirm the exact process of prehistoric harvesting based on the current phytolith evidence. There may be several possibilities: the whole rice plant may have been stored in living areas until processing; some plant parts may be deposited in distinct areas accidently or deliberately during nearby processing of rice; or rice straw was used on site. Leaf impressions have also been found in the compacted clays of the floors. This observation is consistent with previous observations of rice imprints in daub samples from Noen U-Loke (Parr and Boyd 2002). Rice leaves might have been used for various purposes, including roof thatching or animal fodder. The phytolith results therefore strongly suggest that the whole rice plant was brought to the sites after harvesting. This is an insight to the occupants' behaviour that has been previously unavailable to the archaeological understanding of these sites. Concentrations of rice phytoliths on the floors suggest that these living areas were used to store whole rice plants, or at least all harvested parts of the rice plants and, possibly, process the rice, rather than merely rice grain that had been separated and stored elsewhere.

Conclusion

Our results demonstrate that siliceous microfossil analysis is a useful tool for elaborating past agricultural patterns, identifying plant processing associated with ancient settlements, and considering construction and use of archaeological features. This research presents the results of phytolith and diatom analysis for cultural layers at the prehistoric sites of Ban Non Wat and Nong Hua Raet, with a particular focus on identified domestic floors. The palaeovegetation is represented by a significant proportion of grasses. Bilobates, bulliforms and hair cells were the most prominent types among grasses. Rice bulliform records indicate that *Oryza* was present from the beginning of the occupation. Harvested whole rice plants had been transported to the living areas, while charred phytoliths suggest the use of fire for (probably) food processing. The presence of diatoms and sponge spicules most likely represents floor construction using channel or floodplain clay. These results support the suggestion that the floors uncovered in the archaeological excavations were indeed occupation surfaces built and used by the ancient inhabitants. In particular, they provide new insight into patterns of rice processing, handling and storage at these sites adding to a growing body of data on the day-to-day lives of people in prehistoric Thailand.

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