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Late Pleistocene Humans used Rice in Sri Lanka: Phytolith Investigation of the Deposits at Fahien Rock Shelter

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Abstract
Phytolith (microscopic plant silicate bodies) evidence suggests that anatomically modern humans lived at Fahien rock shelter in the south-western Sri Lanka intensively used wild rice species (e.g. Oryza cf. nivara) in association with lowland rain forests from 48.35ka (48,350 calyrs BP). The intensive use of wild rice could be a local innovation.

Keywords: fahien rock shelter; sediment; stratigraphy; phytoliths; rice; Sri Lanka.

Introduction
Domesticated rice (*Oryza sativa*) is one of the world's most important crops today. It is believed that early humans associated ancestors of domesticated rice (wild rice) before the appearance of domesticated rice in human cultures of South Asia from the early Pleistocene onwards (1). But, understanding the antiquity of the human usage of wild rice in the archaeological context remains in dispute due to lack of studies (1, 2-6). The available rice data indicate that several independent geographical origins of rice domestication from their wild ancestors appear to have occurred in East and/or Southern Asia (7-13). Currently, the Yangtze valley in China has yielded the earliest evidence for the intensive use of wild rice during the Late Glacial (20 ka), with a transition to domestication early in the Holocene, around 9 ka (11), and evidence from the Ganges plains in North India in dictates the use of wild rice from the post glacial time (15 ka), with a transition to domestication around 8 ka (12). In this paper, we report well-preserved rice phytolith evidence from the late Pleistocene archaeological context at the Fahien rock shelter in Sri Lanka which is indicative of the intensive use of wild rice species.

Fahien Rock Shelter
Fahien rock shelter, one of the largest rock sheltersin Sri Lanka, is situated at E80° 12' 55" N6° 38' 55" at 130 m asl in Yatagampitiya village, near Bulathsinhala in the Kalutara District, southwest Sri Lanka (Fig. 1). The rock

shelter hasgreat potential for understanding the late Pleistocene humans and environment. It is a complex of interconnected rock shelters developed in coarse crystalline gneiss rock faces (14). The mouth has a width of 30 m and average height of 20 m above the floor. The interior is about 10 m in depth and slopes down from west to east. The present day climate is warm-humid monsoonal, with an average rainfall around 3000-4000 mm/yr and a mean annual temperature at sea level about 26-27°C(15). The landscape around the rock shelter is characterized
by disturbed lowland rainforest with paddy fields present in the slightly incised valley below the rock shelter.

Material and Methods

Site Stratigraphy

In 1968, Siran Deraniyagala, the former Director General in the Department of Archaeological Survey of Sri Lanka (DAS) first examined Fahien and excavated over several seasons between 1986 and 2012 under the direction of the DAS. The depiction of lithological succession with archaeological contexts at Fahien was made according to the standard tool, Harris Matrix. Excavation (4 x 5 m) located in the east of the main chamber of the Fahien rock shelter has indicated the potential for understanding of the archaeological stratigraphies (16-20). The excavation penetrated ca.2.40 m of heterogeneous clast-rich loam sediments showing 5 major layers, 10 archaeological phases and approximately 250 archaeological contexts (Table 1). The bio-stratigraphy comprises of human bones, animal remains, burnt and unburnt shells, shell beads, charcoal, plant remains and coprolites. Human remains include several internments; some coated with red ochre and are associated with the first microlith and osseous technologies anywhere in South Asia. The stratigraphy also contains palaeo-floors, postholes, excavated pits and preserved hearths.

Renewed excavation at the rock shelter yielded a secure chrono-stratigraphy for the earliest modern human habitation deposits (18-21). This work led to the site being recognized as having, to date, the oldest archaeological sequence in Sri Lanka. Well preserved, in situ charcoal, charred wood, shells and sediment samples were taken from the sections for 14C and OSL dating. Twenty six (26) radiocarbon dates were produced using Accelerator Mass Spectrometry at the CHRONO centre, Queens University, Belfast and the Beta Analytic Laboratory in USA. They were calibrated using Calib 6.11 (22). Two sediment samples from the context 92 were processed using OSL and indicate that the base of the sequence is between 39.9 ± 2.5 ka (SUTL2327) and 22.0 ± 1.3 ka (SUTL2326) in age.

Twenty six AMS dates obtained from charred seeds, charred wood, charcoal, Canarium cf. zylanicum nut and freshwater shells indicate that the period of sequence formation was between 48.35 ka and 3.85 ka. The most significant late Pleistocene archaeological evidence, which includes the oldest microlith toolkits known to South Asia associated with the contexts from 87 to 92 are dated to between 48.35 ka and 28.5 ka (Fig. 2).

Sediment processing for phytolith extraction

Twelve 30x10x8 cm monoliths were taken from the southern profile of the excavated area (Fig. 2). These covered five major layers (L1-L5) including the described archaeological phases (I-X) (Table 1, 18-19). From these monoliths, seventeen subsamples were selected. Eleven subsamples (C-44 to C-86) of early to late Holocene age were taken from L2 and L3. Six of the subsamples (C-81 to C-92) were taken from L3/L4, L5 covering the late Pleistocene age (Fig. 2).The current work considers the late Pleistocene sample only. Phytolith extraction was made according the standard procedure (23).

Phytolith taxonomy and taphonomy

Classifications and taxonomic identification of phytoliths from archaeological samples were made using a modern and archaeological phytolith collections housed at the Laboratory for Palaeoecology, Postgraduate Institute of Archaeology, University of Kelaniya, Sri Lanka and at the French Institute of Pondicherry(IFP), India. In order to precisely identify rice taxa from the archaeological samples, comparative knowledge from multiple reference samples of phytoliths from a wide range of the parts (e.g. seeds/husks and leaves) of rice plants growing in different ecological and environmental contexts, both in Sri Lanka and Southern India was used. In this procedure, the most common morphological characteristics, general occurrence and appearance of key archaeological phytoliths were comparatively studied (1, 8-9, 13, 24-27).

Results

a) Phytoliths from the Late Pleistocene samples (48.35-12.15 ka)

In this paper, we mainly highlight the rice phytolith records from late Pleistocene samples, while the detailed phytolith records from the sequence studied will be published elsewhere. The summary of the phytolith assemblages are shown in Fig.3.All samples contained high counts of well-preserved phytoliths.A few samples yielded pitted, displayed a few relatively large micro-channels, mineralized micro-structures and broken phytoliths. More than 54 phytolith morphotypes (monocot and dicots) were identified. In this composition, wild rice(*Oryza* spp) and banana phytoliths are extremely abundant in the samples. Phytoliths from rice leaves (e.g. bulliforms and elongates) and seeds/husks/glumes (e.g. double and single peaked morphotypes) are closely comparable with modern material from the leaves and seeds/husks/glumes of modern wild rice, *Oryza rufipogon* and *O. nivara* collected from Sri Lanka and South India. In addition, phytoliths from several other economic plants, e.g. Palmae, *Artocarpus* cf. *nobilis* (wild breadfruit), *Durio* sp and Poaceae (wild grasses) are found in all samples. Burseraceae (*Canarium* sp. nut) and Cyperaceae phytoliths are found in several samples. Freshwater diatoms are common in many samples. Few brackish/marine diatomsare limited to few samples.

Discussion

Reliability of the late Pleistocene samples and phytoliths evidence

Fahien rock shelter sediments are heterogeneous and the archaeological analysis of the ca. 250 contexts

indicates complex sedimentary processes (18-20, 28). All dates of the late Pleistocene samples are in good strait graphic order. The chronology indicates that a significant depositional hiatuses occur within the excavated sequence between the late Pleistocene and early Holocene. Multiple hiatuses extended only from 29.9ka (C-87) to 12.5 ka, marked by the reduction of phytolith sum (Fig. 2).These hiatuses can be explained by alternating periods of desiccation and erosion of the rock shelter sediments. The condition of the desiccation corresponds to the number of severe millennial to multi century-scale dry climatic cycles (e.g. arid/semi-arid) due to monsoon failures identified from the peat and sedimentary archives in Southern Asia between 24 ka and 8.1 ka (29- 35). The records suggest that the impact of climate, environmental conditions including humans was the dominant factor for forming the litho-stratigraphy through the late Pleistocene.
Understanding phytolith taphonomy (a-e, described below) is essential for interpreting therock shelter phytoliths. The presence of phytoliths in the rock shelter sediments provides information about the depositional processes in several ways (a) in situ plant decay leading to phytoliths deposition on surfaces (b) alluvial or colluvial re-deposition of phytoliths along with their associated sediments (c) wind deposition (d) cultural deposition of phytoliths through plant materials used by the occupants of the rockshelter for food and other cultural purposes and (e) fossilization. The lack of living plants taxa such as rice, banana and Palmaein the rock shelter suggests a minimal input of in situ deposition of phytoliths. Abundant phytoliths from these taxa in the samples suggest that alluvial and/or colluvial processes (effect of horizontal and vertical movements) may have played a limited role in the phytolith re- deposition. Due to the presence of drip line, the impact of rain water penetration into the rock shelter is minimal. Wind deposition is rare due to the particular geomorphology of the rock shelter in the humid tropical environment. This is clearly confirmed by the highly variable phytolith counts/sum in all the samples (Fig. 3). Except for very uppermost parts of the sequence (e.g. Holocene samples), a lack of the post-depositional disruptions through roof falling, vertical cracks and animal burrows indicate limited vertical movement of phytoliths in the late Pleistocene samples (18-19). Indeed, the lack of evidence of root penetration from plants and the lack of organic litter deposits within the clay- and silt-rich, highly-compacted and multi-layered sediments do not interfere with phytoliths buried at much deeper stratigraphic levels through multiple re- working events and bioturbation. More homogeneous distribution of the smallest phytoliths (3-10 µm) from wild banana seeds and from Bombacaceae and fine-grained sediments in all the samples suggest the minimal impact of illuviation of clay minerals as common process in the rock shelter stratigraphy (28, 36-37). All these minimized sources of biases indicate that spatial and temporal fidelity ishigh in the late Pleistocene samples (38).
The main process, therefore, of phytolith deposition in the rock shelter is most likely to have been through human or animal vectors. However, animals such as bats, birds, and insects in the vicinity of the rock shelter environment are very unlikely to play a role in the phytolith deposition reported. This agrees with highly variable phytolith counts through the sequence studied (39). It is inferred that humans are the most likely agents for phytolith deposition in the rock shelter, - the materials from economic/anthropic plants such as rice

and banana and breadfruit brought into the rock shelter are from the plants commonly grown in disturbed lowland rainforest near to the rock shelter (most possibly within a few kilometers at most). Abundant phytoliths from monocotyledonous taxa (e.g. Poaceae/grasses and Cyperaceae/sedges) identified as anthropic taxa in this context, probably associated the rice plants brought by humans. The significant occurrence of freshwater and brackish-marine diatom species throughout is not surprising in habitation deposits and is consistent with a number of human activities. In the majority of samples, abundantwith rice seeds/husks and leaf phytoliths together with the lack of taphonomic markers (e.g. breakage, corrosion, microchannels, regulation, dissolution pits, mineralized microstructures, cut marks and pitted patterns) indicate excellent preservation conditions and selective distribution of phytoliths from rice used by rockshelter occupants. This suggests high phytolith compositional fidelity in the samples.

The well-preserved phytoliths suggest that they were directly subjected to the processes of diagenesis, i.e., physical and chemical impact on phytoliths due to the long-time environmental burial (or buried for a long time) and permanent incorporation into the rock shelter sediments (37, 40, 41-54). Alkaline conditions are also thought to contribute to phytolith dissolution processes (47, 53, 55-56) due to the increase in solubility of silica at pH > 7.8. This impact on the iron (Fe) rich fine- grained Fahienrock shelter sediments is limited as indicated by pH measurements (6.5-7.3) in all the sediment samples studied (57). Facetate and sclereidsphytoliths from woody dicotyledonous (e.g. forest taxa) are rare in the Late Pleistocene, possibly due to dissolution (44), and/or less incorporation of phytoliths from woody materials. We report that facetate and sclereidsare very unlikely to be preserved in much older samples (1).

Late Pleistocene wild rice exploitation

Late Pleistocene deposits yielded archaeological records (Table 1) and high amounts of phytoliths from economic plants. Phytolith records from the wild rice species, together with number of other economic plants (e.g. wild banana and breadfruit) suggests thatrock shelter occupants have usedwild rice plants, most probably for food and also for various other purposes, e.g. fuel, rituals medicines and artifacts. The methodological constrains used for rice identification confirm that phytoliths were from *Oryza nivara* and/or *O. rufipogon*, but the criteria used herewith, cannot fully separate the *rufipogon*, perennial from *nivara* annual ecotype.

Ecology of wild rice

Understanding the evidence related to ecology of wild rice provides an opportunity to explore the relationship between human activity and the presence of wild rice in the late Pleistocene. The ecology of the wild rice species clearly indicates differing modes of human exploitation of wild rice for food from the prehistoric period in South Asia (58-61). The latter works suggest that *O. nivara*, which commonly grows in drylands and has a large-scale seed production could have been easily used by prehistoric hunter-gatherers without any serious cultivation whereas *O. rufipogon*, which is prominently grown in aquatic habitats has a much lower seed production during the very early stage of plant domestication, i.e. late Pleistocene (59-60, 62-64). *O. nivara* rice tends to grow in relatively small isolated patches and not in stands of genetically uniform populations. Prior to the Toba volcanic event ca. 74 ka years ago, humans at Jwalapuram, Locality 22, Southern Asia lived in a mixed woodland and grassland mosaic. This was followed by cooler and possibly drier conditions after the eruption (65). The elevated δ13C and δ18O from Batadomba-lenarock shelter (Fig. 1) faunal remains (66) and Himalayan ice cores(67) indicate that lowland rainforest of Southern Asia were more open with decreased canopy cover during the period 36-29 ka. This has been linked to decreased rainfall and temperature (68). Prior to the Last Glacial maximum (LGM), humid environments appear to have prevailed in the Indian subcontinent (69-71). Paleoclimatic records suggest that atmospheric cooling by 3-4 °C occurred in the Tropics (72), with a remarkable drop in precipitation during the LGM much greater than during any of the earlier (middle Pleistocene) glaciations (66). Palaeoclimate data from Sri Lanka suggest a drier LGM punctuated by climatic ameliorations in short bursts (73- 74).It is obvious that climatic fluctuations that includes prevailing prominent dry conditions in the Late Quaternary may have resulted in a number of climatically adapted wild rice populations (61,75-76). Rock shelter occupants could have easily modified O. nivara populations leading to more reliable wild grains for human use, especially when they were already widely growing in ideal habitats associated with prolonged dry conditions long before the domesticated forms arose (1, 60, 77-79). During early rice exploitation, it is worth noting that high micro charcoal, phytolith and poll encore records indicate regular anthropogenic burning from the Terminal (14.5-13 ka) and end of the Pleistocene through early-middle Holocene in the archaeological sites from Ganges plains in north India (80-81). Several sites in the Yangzte valley in China, dating from 17 ka through the Terminal Pleistocene yielded O. nivara phytolithsin association with humans (11, 82-85). Similarly, multi-proxy investigations (e.g. pollen, phytolith, charcoal, mineral magnetics, stable carbon and diatom) in the Horton Plains, Sri Lanka, suggest anthropogenic burning and disturbance in association with south west monsoon fluctuations from 17.5 ka through the late glacial time (31,35,75). In this ecological regime, phytoliths from Oryzasppwere reported in association with dry climate between 15.9-13.8 ka. All those records indicate that wild rice was present in human economies through the late Pleistocene to the Holocene in South and East Asia. This indicates that the rice species exploited by Fahien rock shelter occupants (i.e. late Pleistocene hunter- gatherers) was more likely O. nivara than O. rufipogon, adopting to the ecological/habitant, e.g. dry and mixed woodland and grassland conditions prevailed in the late Pleistocene (Fig. 4). The antiquity of human use of wild rice species, O. nivara at Fahien is remarkably as early as 48 ka, compared to the tradition of rice foraging in known Asian sites (77,86).

Conclusion

Little is known of the use of wild rice in prehistoric Sri Lanka. Investigations from the archaeological sequence at Fahien rock shelter in south western Sri Lanka, dated to 48.35-3.9 ka provide phytolith evidence suggesting the use of wild rice, most possibly Oryza cf.nivara, with several other wild plant resources, e.g. banana, breadfruit and a number of species from Palmae. The rock shelter provides the oldest evidence for the wild rice associated late Pleistocene human rainforest occupation among the archaeological sites in Southeast Asia, Melanesia and South Asia.

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Fig. 1: Location of the Fahien rock shelter in the southwestern Sri Lanka. Beli-lena and Batadomba-lena are excavated prehistoric rock shelters.

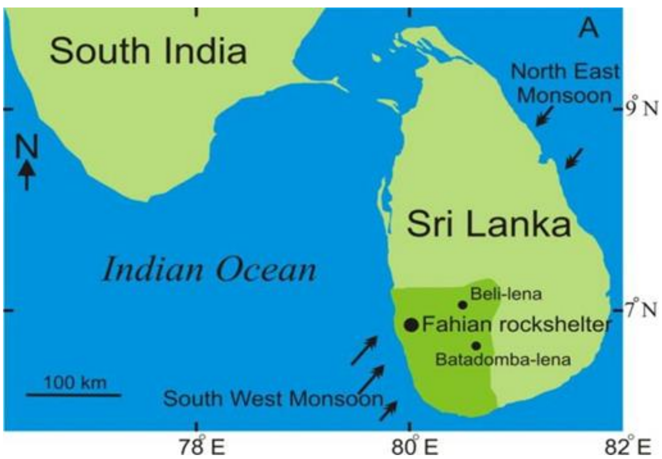


Fig. 2: Late Pleistocene stratigraphy of the rock shelter (Y). Excavated area is marked (X)

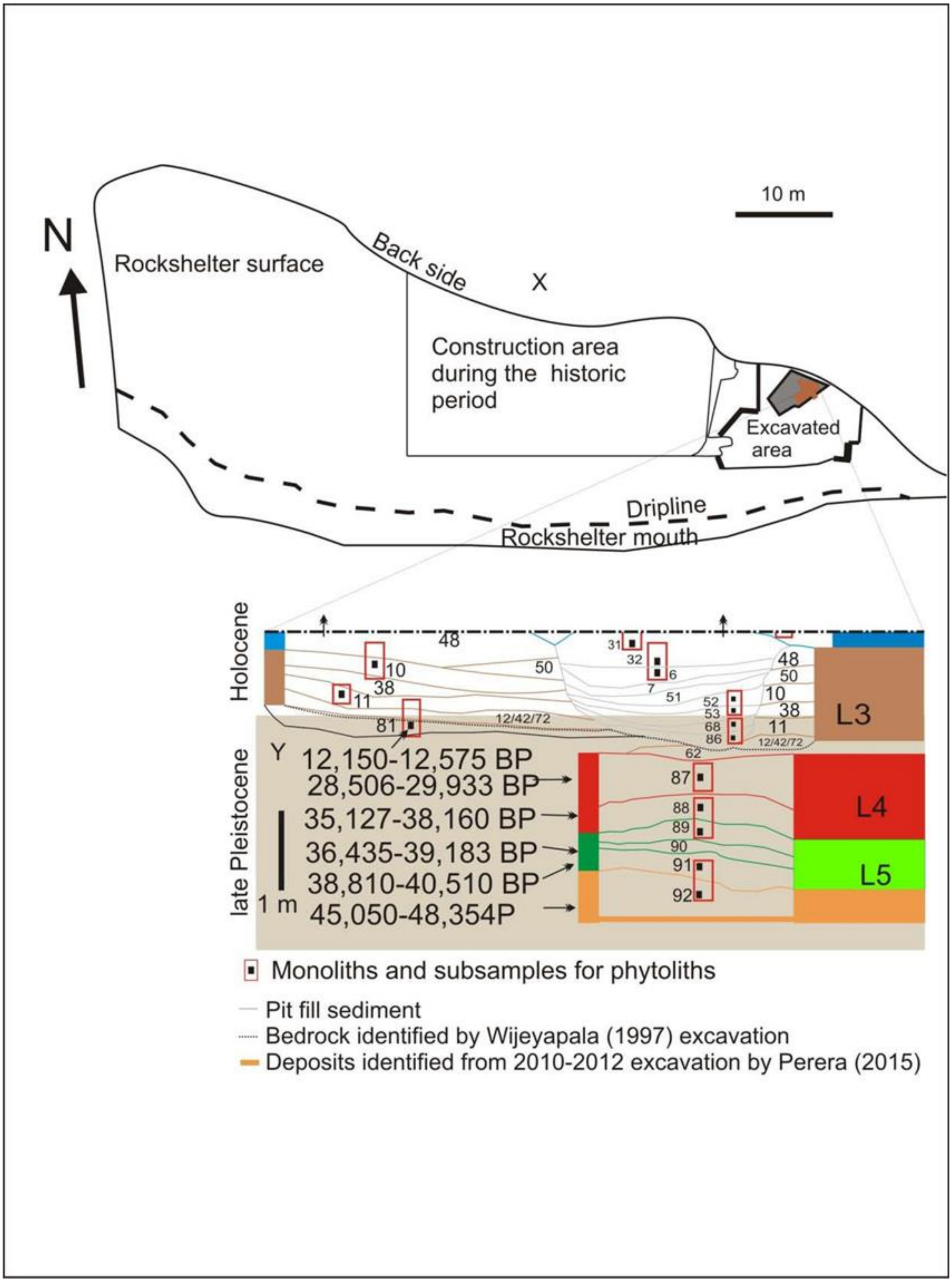
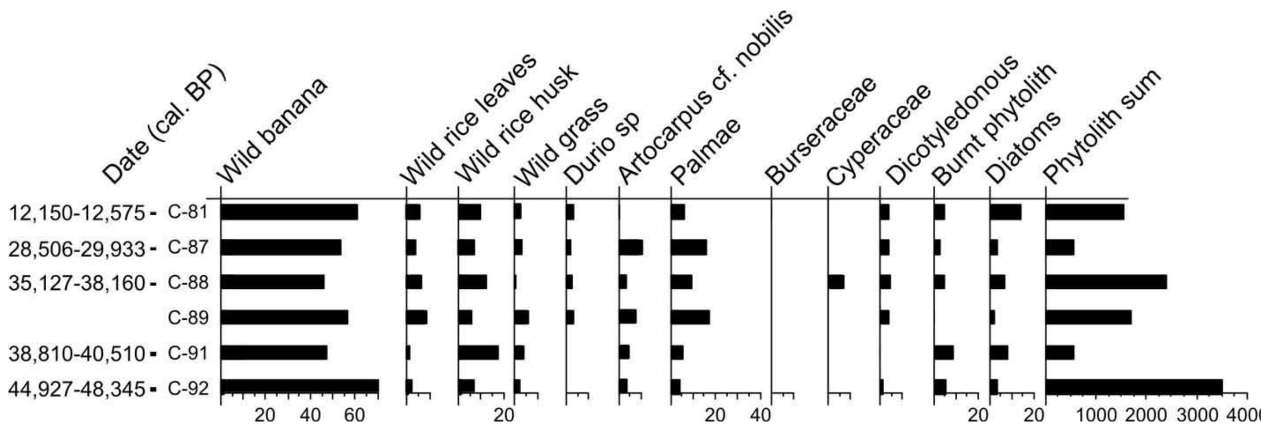


Fig. 3: Phytolith records (%) of the selected taxa from the late Pleistocene samples at the Fahien rock shelter



Note that C-81 sample contained a few phytolith finds of Bursercaeae.

Fig. 4. Wild rice phytolith morphotypes. A: Bulliforms from rice leaf. B: Black color coat on bulliform indicates that it was released from burnt rice leaf. C-E: Glume cells with small projections arising deeply serrated cells from rice husk. F-G: Double and single peak phytoliths from rice husk (reference: 1, 27), scale bar = 10 micron.

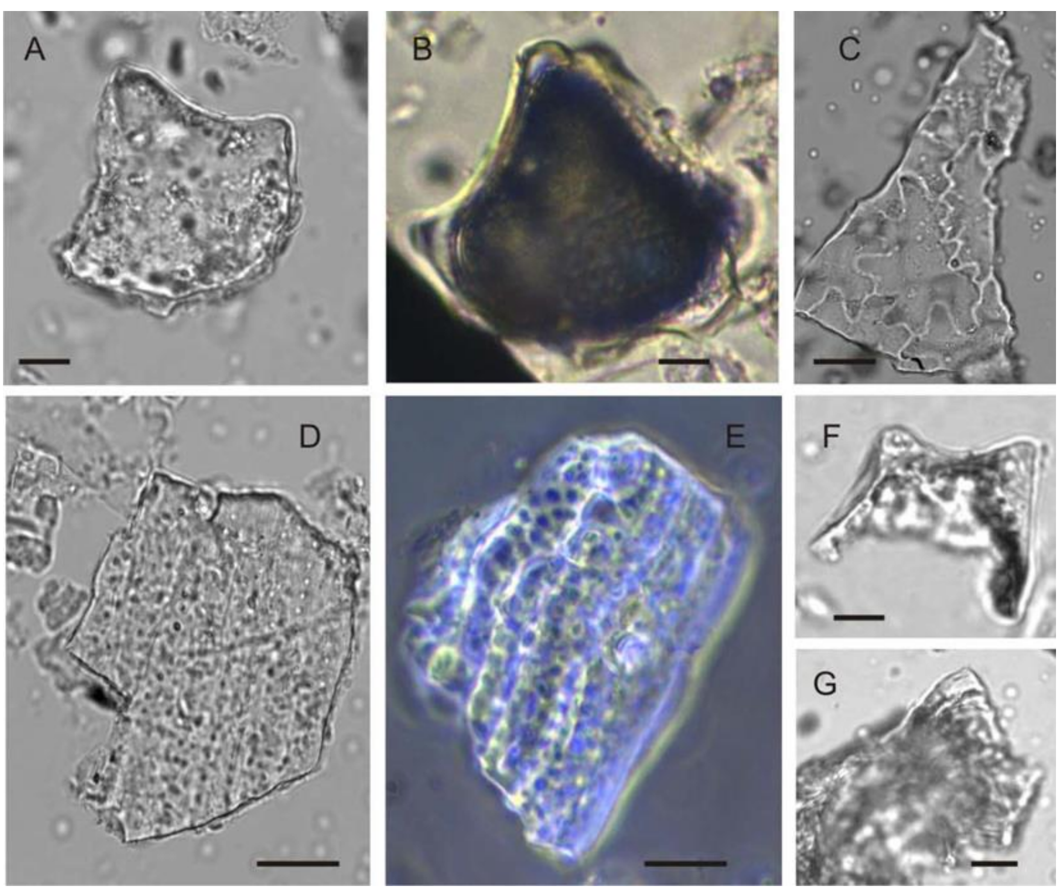


Table 1: Summary of archaeology and stratigraphy described from the Fahien rock shelter. Bold font indicates the contexts sampled for Phytolith analysis

Layers (Wijeyapala (1997)	Thickness (m)	Contexts	Archaeogical phases	Litho-stratigraphy	Colour	Bio-stratigraphy	Cultural density
Bedrock	NA	95	I	NA	NA	NA	NA
NA	0.40	92	II	Consolidated clast-rich loam	Yellowish brown	Ashy habitation deposits, human bone	Relatively low
L5	0.15	90, 91, 89	III	Moderately unconsolidated clast-rich loam	Pinkish grey to greyish brown	Ashy habitation deposits, charcoal, fragment of small mammals and human bones,burnt shells, hearths, microliths	Relatively high
L4 NA	1.00	89, 88, 87 70	IV V	Moderately unconsolidated clast-rich loam	Dark grey to brown	Ashy habitation deposits, charcoal, burnt shells, unburnt shell, human bones, *Canarium* nuts, microliths, red ochre, grindstones, postholes	High
L3 L3 NA Pit fill Re-worked	0.25	12/42/72 10, 11, 38, 48, 50, 62, 81 6, 7, 51, 52,53, 68, 86 5, 26, 31, 32	VI VI VI /II VIII	Moderately unconsolidated loam	Brown	Charcoal rich habitation deposits, ashy, *Canarium* nuts, carnivore coprolites,bones, shells, unburnt shells, carnivores coprolites, wood, microliths. Fragmentary human skeleton found from the context 81, which has beendirectlydatedto around12,000BP.	Relatively high
L2	1.10	3, 4, 33, 44, 49	IX	Moderately unconsolidated loam	Yellowish light brown to grey	Ashyhabitationdeposits, Charcoal,ash and shell rich habitation deposits, shell ash, red ochre coated human skull, red ochre, bones, unburnt shells, burnt shells, *Canarium* nuts, *Artocarpus* epicarps, graphite,microliths	High
L1	1.25	1, 2/8/9, 17, 18, 19, 20, 40	X	Moderately unconsolidated loam	Brown to reddish brown	Disturbed deposits, prehistoric occupation debris mixed with historical artefacts, animal burrows, shells, bones, *Canarium* nut	Low