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On the Holocene record of phytoliths of wild and cultivated rice from Ganga Plain: evidence for rice-based agriculture

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Evidence of rice-based agriculture is recorded in the form of phytoliths from about 10 kyrs BP to present succession of Lahuradewa lake deposits, Sant Kabir Nagar district, Ganga Plain. Bulliform phytoliths are considered to be of rice, where distinction between wild rice (*Oryza rufipogon*) and cultivated rice (*Oryza sativa*) has been made using the criterion of number of scale-like ornamentation on the edges of fan-shaped phytoliths. The wild rice phytoliths are present since about 10300 cal. yrs BP, while cultivated rice phytoliths appear 8350 cal. yrs BP. Upward in the profile, cultivated rice phytoliths increase with a simultaneous decrease in the wild rice phytoliths. This indicates the beginning of rice cultivation in the Ganga Plain around 8350 cal. yrs, which supports the presence of cultivated rice at Lahuradewa archaeological site, dated 8360 cal. yrs BP.

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IN this study, we describe the phytoliths in a Holocene lake fill succession of Ganga Plain, where identification of phytoliths of Oryzeae tribe of Oryzoideae subfamily and distinction between wild and domesticated rice have been done. Lahuradewa lake is located adjacent to the Lahuradewa archaeological site where archaeological excavation is being carried out by the Uttar Pradesh State Department of Archaeology[1]. The study of rice phytoliths in lake deposits and archaeological sites can be useful in understanding the anthropogenic activity and the beginning of agriculture in the Ganga Plain.

The Ganga Plain occupies a central position in the Indo-Gangetic plains. It exhibits many fluvial landforms, namely abandoned channels, meander cut-offs, lakes and ponds. The present-day highly diversified fluvial geomorphology of the Ganga Plain is a consequence of climate changes, tectonic activity and base-level changes during Late Quaternary[2–4]. The lakes and ponds have been mostly formed during Late Pleistocene–Early Holocene due to channel abandonment, in response to tectonics and changing climatic conditions[3–5].

The vegetation of the Ganga Plain must have witnessed changes in the last few millennia under climate change and anthropogenic influence. Information on changing palaeovegetation pattern in the Ganga Plain is scanty. Only recently, attempts have been made to reconstruct the palaeovegetation in the Ganga Plain using mainly pollen studies in lake deposits[6–8]. These studies demonstrate that for the last 15,000 yrs, the Ganga Plain was a grassland with few thickets[9–11].

Lahuradewa lake (lat. 26°46′N; long. 82°57′E) (Figure 1) and Lahuradewa archaeological site are located in the vicinity of Lahuradewa village, Sant Kabir Nagar district, UP[1]. The mean annual rainfall of this area is about 1400 mm. The lake is situated on the upland interfluve surface and receives its water budget mainly from the monsoon. Generally the lake holds water throughout the year; but in the extremely dry years it may dry out completely. The northern and eastern parts of the lake are shallow due to high siltation, mainly as a consequence of intense agricultural activity. The western portion of the lake holds sufficient water during all the seasons. The region of Lahuradewa is characterized by shrubs and grasses with scattered trees. At present, the surrounding area of the lake is influenced by intense agricultural activity and large inhabitation.

A 2.80 m deep trench was dug on the eastern dried flank of the lake, about 150 m north of the Lahuradewa archeological site. Twenty-eight samples were collected from this profile at 10 cm interval. All the samples were analysed for grain size and phytolith assemblage. Samples were also collected from the same trench at larger intervals for radiocarbon dating.

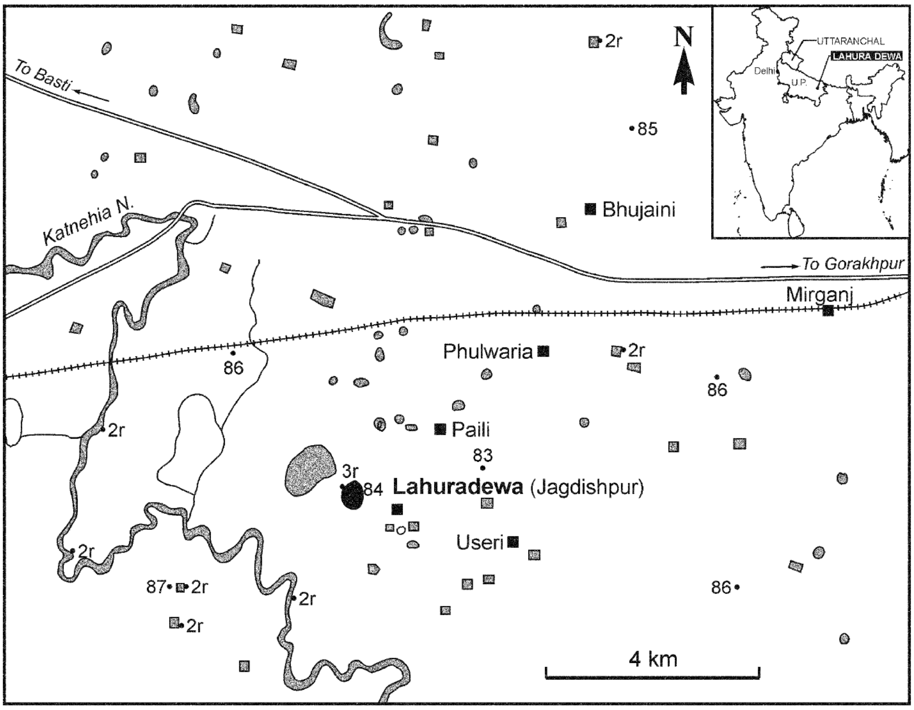

Figure 1. Location map of Lahuradewa area. Lakes and ponds of the region are emphasized. Lahuradewa lake and adjoining Lahuradewa archaeological site are shown.

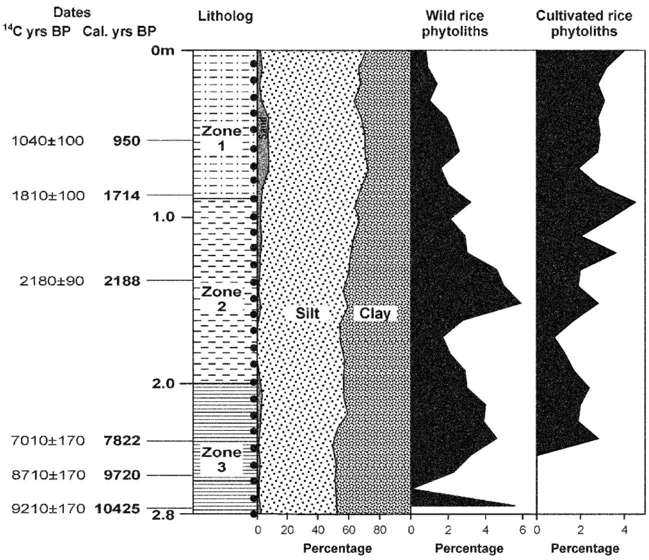

Figure 2. Distribution of sand–silt–clay fractions, wild rice phytoliths and cultivated rice phytoliths in Lahuradewa lake profile. ^{14}C ages and calibrated ages are given. There is distinct increase in cultivated rice phytoliths in the profile.

The grain-size analysis was done by normal sieving method, followed by pipette method to determine silt and clay fractions[12]. For phytolith studies, 10 g of dry sediment of each sample was treated with HCl (3%) for dissolution of carbonates, followed by oxidation of organic matter using 30% hydrogen peroxide heated at 90°C until the reaction subsided. The samples were passed through a 37 μm (60 mesh) sieve to remove the coarser material and through a 149 μm (500 mesh) sieve for removal of silt and clay. Slides were prepared using a few drops of maceral, and mounted in canada balsam for counting and in glycerine for 3D observation of shapes. The phytoliths were diagnosed and counted.

The lake profile does not show any marked variation in sediment grain size. The succession mainly consists of silt and clay with minor amount of sand (Figure 2). However, depending upon the colour and sand content, the whole profile is divided into three distinct lithological units. From top to bottom the zones are:

Zone 1 (0.0–0.90 m): dark mud with rootlets;
Zone 2 (0.90–2.0 m): dark mud;
Zone 3 (2.0–2.80 m): black organic mud (peat).

Six radiocarbon dates of total organic matter are available for the succession (Figure 2). The sedimentation rate is variable throughout the profile. The sample at a depth of 2.75 m is dated 10425 cal. yrs BP. There is a sediment thickness of 5 cm below this sample date. The rate of deposition was 2.8 mm/100 yrs, during the time period 10425–9720 cal. yrs BP. Assuming the same sedimentation rate, the age of the base of the profile at 2.80 m depth is estimated about ~10600 cal. yrs BP. The rate of sedimentation for the time period 9720–7822 cal. yrs BP is about 1.0 mm/100 yrs. Assuming the rate of sedimentation to be constant for this part, the age for the samples LRD-21 at the top of zone-3 can be assigned as 5800 cal.

yrs BP. During the deposition of peat horizon (zone 3), the rate of sedimentation was rather slow, covering a time span of Early to Middle Holocene (10600–5800 cal. yrs BP). During the time period 5800–2188 cal. yrs BP, the rate of sedimentation increased to 1.7 mm/100 yrs. Later, deposition took place at a fast rate of 7.0 mm/100 yrs in the time range 2188–1714 cal. yrs BP, probably due to increased sediment supply. During the period of 1714–950 cal. yrs BP, sedimentation rate reduced to 4.2 mm/100 yrs. The topmost 55 cm thick succession (950 cal. yrs BP–Present) was deposited at a faster rate of 5.8 mm/100 yrs.

Reconstruction of palaeoclimate and palaeovegetation on the continents is an important aspect of Quaternary studies. It is usually inferred from one of the several proxies such as pollen, soil organic matter, microfaunal assemblage, carbon isotope data, geochemistry, magnetic minerals and phytoliths. Lacustrine sediments are important repositories for climate change and various investigations are being carried out in lake deposits[13,14]. Palynological studies provide direct information on the palaeovegetation. In subtropical–tropical climate with prolonged seasonal droughts, preservation of organic matter and pollen spores is usually poor[15]. However, in such areas, phytoliths (microscopic silica particles precipitated in living plant tissues) are preserved as discrete particles. The morphological shapes of phytoliths are distinctive, and can be used to identify plant families or even plant species[16]. Phytoliths are now being increasingly used to reconstruct the palaeovegetation[17–19]. Most of the work regarding phytoliths has been done in the temperate and inter-tropical areas of the world[20–23]. In India, the use of phytoliths in palaeovegetation reconstruction is still in its infancy; however, few studies are available[24–28].

Phytoliths are microscopic opal-A particles that are known to occur in many plants, when monosilicic acid, carried into the plants with groundwater, gets precipitated in the cells and between cells of living plant tissues[29]. They reflect the shape and size of the cell in or around which they are formed[23]. The distribution and concentration of silicic acid is not uniform in the whole plant, rather its concentration varies from one particular cell type to another[30]. After the decay of the plants, phytoliths remain in the soil and sediment as a relict of earlier existing ecosystems[31], making them useful for the study of vegetation changes[32]. Based on phytolith studies, it is possible to distinguish various subfamilies of grasses, namely Arundonoideae, Oryzoideae, Panicoideae, Pooideae, etc. which cannot be achieved by pollen studies. Phytoliths have an advantage over the grass pollen records, as they can be identified to a more precise taxonomic level than grass pollen, sometimes indicating environmental preferences. It is possible to draw the discrimination at the generic and species level with the phytoliths[15].

All the samples of the profile have yielded sufficient amount of phytoliths, their number ranges from 18 to 306. Throughout the profile, the phytoliths of Poaceae dominate and account for about 70–80% of the total. However, phytoliths of Cyperaceae (sedges) rectangular along with cone-shape depression, and hat-shaped morphotypes; palmate, spherical and spiked phytoliths, and zigsaw, polygonal morphotypes of dicots, namely Asteraceae, Malvaceae and Chenopodiaceae/Amaranthaceae are also recorded. They show considerable variation in shape and size. Here we describe only the phytoliths ascribed to rice.

Rice leaves produce mainly two types of phytoliths, the bulliform (motor cell) phytoliths and grass silica short cell phytoliths, which are mainly dumb-bells and crosses with intermediate shapes. The bulliform phytoliths are produced in the motor cells of rice leaves. They are supposed to provide mechanical strength for the rolling movement of the leaf[30]. Many taxa of Poaceae such as *Phragmites*, *Paspalum, Indocalamus* and *Miscanthus* produce fan-shaped phytoliths, but their characteristics vary considerably and are diagnostic of the particular genera and species. Phytoliths of rice are unique in nature because of the presence of scale-like ornamentation on the edges of the fan. Moreover, there are other distinctive morphological traits and qualitative features such as shape, size and ornamentation by which rice phytoliths can be distinguished[33]. On the basis of these morphological characteristics, the rice (*Oryza*) phytoliths can be identified in genera and species[34].

The discrimination between phytoliths of wild and cultivated rice is based on the number of scales on the edges of the fan (the bulliform phytoliths). The cultivated rice phytoliths show larger number of scales[35] and have more than nine scales, while the wild rice phytoliths have less than or equal to nine scales (Figure 3). So the distinction can be drawn statistically between cultivated and wild varieties. Moreover, the scaly ornamentation in the wild rice phytoliths is not so smooth and regular compared to the cultivated ones[35]. Further, two wild varieties of rice and one cultivated variety along with the foxtail grass (*Setaria* sp.) were collected from the area adjoining the Lahuradewa lake and used for comparative study. These investigations support the above criteria used for distinction between wild and cultivated rice. The wild varieties of rice among themselves cannot be distinguished using the same criteria because of the overlapping of the number of scales. Discrimination of *Oryza rufipogon* from other wild varieties is made on the basis of morphometry of the fan-shaped phytoliths. Handle length, fan width, fan length and arc length are measured from different morphotypes and the ratio between the fan width and fan length is taken[36]. The shape coefficient, b/a (ratio of handle length and fan length) is taken into account and it ranges between 0.9 and 1.3 for *O. rufipogon*. These observations are based on the comparison between the modern wild rice variety and that obtained from lake samples. Though other wild rice morphotypes are also present, the species cannot be ascertained due to lack of modern comparison. Thus, emphasis has been given to *O. rufipogon* only. A few workers argue that distinction between wild and domesticated rice phytoliths is difficult[37].

Rice phytoliths are recorded throughout the Lahuradewa lake profile. The wild rice phytoliths are present from a depth of 2.70 m of the profile, dated about 10300 cal. yrs BP. In the lower part of the profile, the frequency of phytoliths is low. Upward in the profile, their count increases gradually. The cultivated rice (*Oryza sativa*) phytoliths make their appearance at about 2.40 m depth dated about 8300 cal. yrs BP (Figure 2). Up to a depth of 1.6 m (~ 3500 cal. yrs BP), the percentage of wild rice increases; the cultivated ones also show rising tendency. Above this depth, upward in the profile, the wild rice phytoliths start diminishing, while the cultivated rice phytoliths gradually become more abundant. In the topmost part (top 50 cm, from ~ 850 cal. yrs BP to the present) the cultivated rice phytoliths are plentiful, indicating the intense rice-farming practices in the recent past.

Another evidence of rice cultivation in the area is the presence of paddy field diatoms. These diatoms can withstand the highly fluctuating water levels of paddy fields and are considered as indicators of rice cultivation in the past when present in the fossil assemblages[38]. Diatoms survive in paddy fields because they grow in waterlogged condition. Most paddy-field diatoms belong to the benthic and tychoplanktonic community which is tolerant to highly fluctuating water level. They bloom in large amount in the paddy fields during summer and can survive acute water deficiency during autumn by forming resting spores, which bloom in the next season, surviving through unfavourable conditions of water exhaustion[39]. The three basal samples are relatively poor in diatoms. There is increase in diatoms from at about 9720 cal. yrs BP, indicating rice cultivation. These studies along with phytoliths suggest the anthropogenic activity.

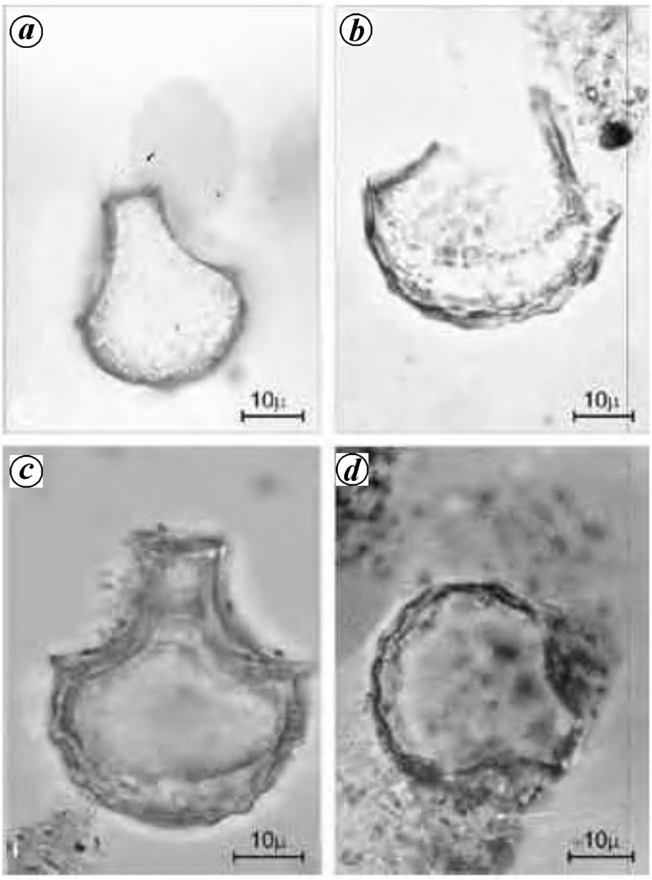

Figure 3. Photomicrographs of fan-shaped rice phytoliths showing scales on the edges. ***a***, ***b***, Wild rice phytoliths showing few poorly developed scales along the edges of the fan. ***c***, ***d***, Cultivated rice phytoliths showing a large number of well-developed scales along the edges of the fan.

Evidence of anthropogenic activity in the area is also available in the form of Cheno/Am pollens since 7822 cal. yrs BP and cerealia pollen since ~ 7500 cal. yrs BP. In the upper part of the profile, increased human activity is indicated by the appearance of *Trapa*, *Cannabis sativa* and a large number of tree pollen[8].

Significant evidence for rice cultivation in the area comes from the Lahuradewa archaeological site, wherein the bottom layers have yielded remains of domesticated rice (*O. sativa*), wild rice (*O. rufipogon*) and foxtail millet (*Setaria* sp.). The associated charcoal of this layer provides a radiocarbon date of 6290 ± 160 (7247 cal. yrs BP)[1]. Dating of a glume piece (husk) of domesticated rice, *O. sativa* by AMS method gives an age of 7532 ± 58 yrs BP (8360 cal. yrs. BP). Identification of domesticated rice (*O. sativa*) is based on ornamentation on the surface of the glume[40–42]. The identification was done by K. S. Saraswat, BSIP, while AMS dating[43] was done at the University of Erlangen-Nuremberg, Germany (K. S. Saraswat, pers. commun.).

The date of cultivated rice from the Lahuradewa archaeological site broadly corresponds to the date of appearance of cultivated rice phytoliths in the adjacent lake profile. The appearance of cultivated rice is the culmination of the effects of hybridization among the wild species and selection of the better ones, as a consequence of transformation of early humans from hunter–gatherers to cultivators. It indicates that wild rice was grown in the area during Holocene and cultivated rice is present since the ninth millennium BP.

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Lichenometry of yellow *Rhizocarpon geographicum* as database for the recent geological activities in Himachal Pradesh

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In the present study, the growth rate and colonization delay of yellow *Rhizocarpon geographicum* species of lichen are recorded to date recent geological activities at four different localities in Himachal Pradesh. The study involved the measurement of the largest sized specimen growing on the well-dated monuments. Correlation of size with age, by plotting the measurements on a graph and finding the best fit line, gives the rate of growth of lichens (per year) and colonization delay, the time taken by the lichen to grow on a surface after its exposure to the atmosphere. It has been found that colonization delay and growth rate in the four localities namely Sanjoli, Kanlog (both in Shimla), Dharamshala and Dalhousie are 24, 68, 50, 86 yrs and 0.73, 0.79, 0.56, and 0.54 mm/yr respectively. Colonization period was also confirmed by the absence of lichens on the recent monuments prior to the calculated dates. The database will be useful to date the recent geological activities in the region.

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LICHENS are made up of algae and fungi, where the algae perform photosynthesis and supply the community with nutrients, and fungi take up water and minerals and shelter the algae in a greenhouse. In the present study an attempt has been made to find the growth rate and colonization delay of lichens in the Himalaya. Colonization delay is the time taken by the lichen to grow on a surface after its exposure to the atmosphere. Four different localities in Himachal Pradesh (HP) namely Sanjoli and Kanlog (in Shimla), Dharamshala and Dalhousie were selected to date various geological activities in the region. Shimla is situated at lat. 31°4′30″ and long. 77°10″, at a height 2205 masl. Lichens with known dates found in the Kanlog area (south of Shimla, at a height of 1980 m, is studded with dense deodar forest) and Sanjoli area (north of Shimla, at a height of 2360 m, studded with open deodar forest in the surrounding area). Dalhousie is situated at a height of 2039 m in the outer slopes of Dhauladhar range at long. 75°47′51″ and lat. 32°32′24″. Dharamshala is situated around lat. 32°12′ and long. 76°18′35″.

Growth rate and colonization delay will help in finding the dates of lichens on a rock surface that is exposed to the atmosphere in the surrounding regions. This will directly give the age of the activity that has exposed that surface/boulder. Further, the database will help in dating the old landslides by measuring the biggest lichen on the exposed surface of boulders; finding history of landslides – reported or unreported[1] in a particular area; dating structures generated by prehistoric earthquakes[2,3] and assessing the influence of climate[4] and local microenvironment on lichen growth rate.

The study is based on lichen size/age correlation and lichen population distribution using approaches described by Winchester and Harrison[5,6]. Lichenometry is a technique used to find relative or absolute date of rock-surface exposure. Details of the technique and criticisms have been published earlier[7–9]. The dating range depends on specific species and environmental factors; in temperate environments some foliose forms might survive about 150 years, minute crustose forms can provide dating over 400 to 600 years; and at high latitudes, dating may exceed 1000 years[10]. Absolute dating is based on the size of the largest surviving lichen. Therefore, reference to their specific details should be taken as minimum approximations only. Other factors leading to lichen mortality and renewed colonization are: competition for growing space on the rock surface, vegetation growth, animal or human interference, weathering or other geomorphologic processes.

The most common lichen growing on the slope boulders is *Rhizocarpon geographicum* (Figure 1 *a*). It belongs to