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Application of Phytolith Analysis to Reconstruction of Past Environments and Subsistence: Recent Research in the Pacific

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Abstract—Study of phytoliths, plant opaline silica bodies, extracted from archaeological and geological sediments, is a valuable source of information on past subsistence and vegetation. Applications of the technique in the Pacific region are recent but have already contributed to vegetation reconstruction or identification of crops and agricultural activity in Hawaii, Micronesia, and the Philippines. Phytoliths are extracted from soil by heavy liquid flotation and identified by comparison with modern plant specimens. The relative abundance of different phytoliths in archaeological sediments is compared to their occurrence in soil from known vegetation formations to reconstruct past environments. While many cultivated and useful wild plants remain to be tested for phytolith production, progress has been made on identifying rice, millet, banana, and gourd. With the continued support of archaeologists, phytolith analysis will contribute significantly to our understanding of land use, cultivation practices, and vegetation change in the Pacific region.

Introduction

Application of phytolith analysis in archaeology has increased rapidly in the past ten years. The potential and limitations of the technique are becoming more clearly defined. This paper addresses the potential of the phytolith technique for archaeological research in the Pacific by reporting on recent analyses carried out at sites in Hawaii, Micronesia, and the Philippines.

The goals of this paper are three-fold: 1) to give a brief introduction to phytolith analysis, its applications in archaeology, and its potential and limitations, 2) to summarize results of recent research in the Pacific region, and 3) to propose directions for future research.

Phytolith Analysis in Archaeology

Study of phytoliths, or plant opaline silica bodies, to identify archaeological plant material began early in this century in the Old World. Application of phytolith analysis in the New World dates from the 1960's with investigations at the Kotosh site in Peru (Matsutani 1972) but it was not until the mid-1970's that interest in the technique began to grow (for reviews of recent work see Pearsall 1982, 1989, Piperno 1988, Rovner 1983).

Phytoliths are microscopic silica bodies, ranging in size from about 5 to 250 microns, which occur in stems, leaves, and inflorescenses of plants. Silica that forms phytoliths is carried up from ground water as monosilicic acid (Jones & Handreck 1967) and is deposited in cells. In some taxa, distinctively shaped bodies are formed when silica completely fills the cell, solidifies, and retains cell shape after organic material has decayed or burned (Blackman 1971). Taxonomic value of phytoliths produced by grasses, other

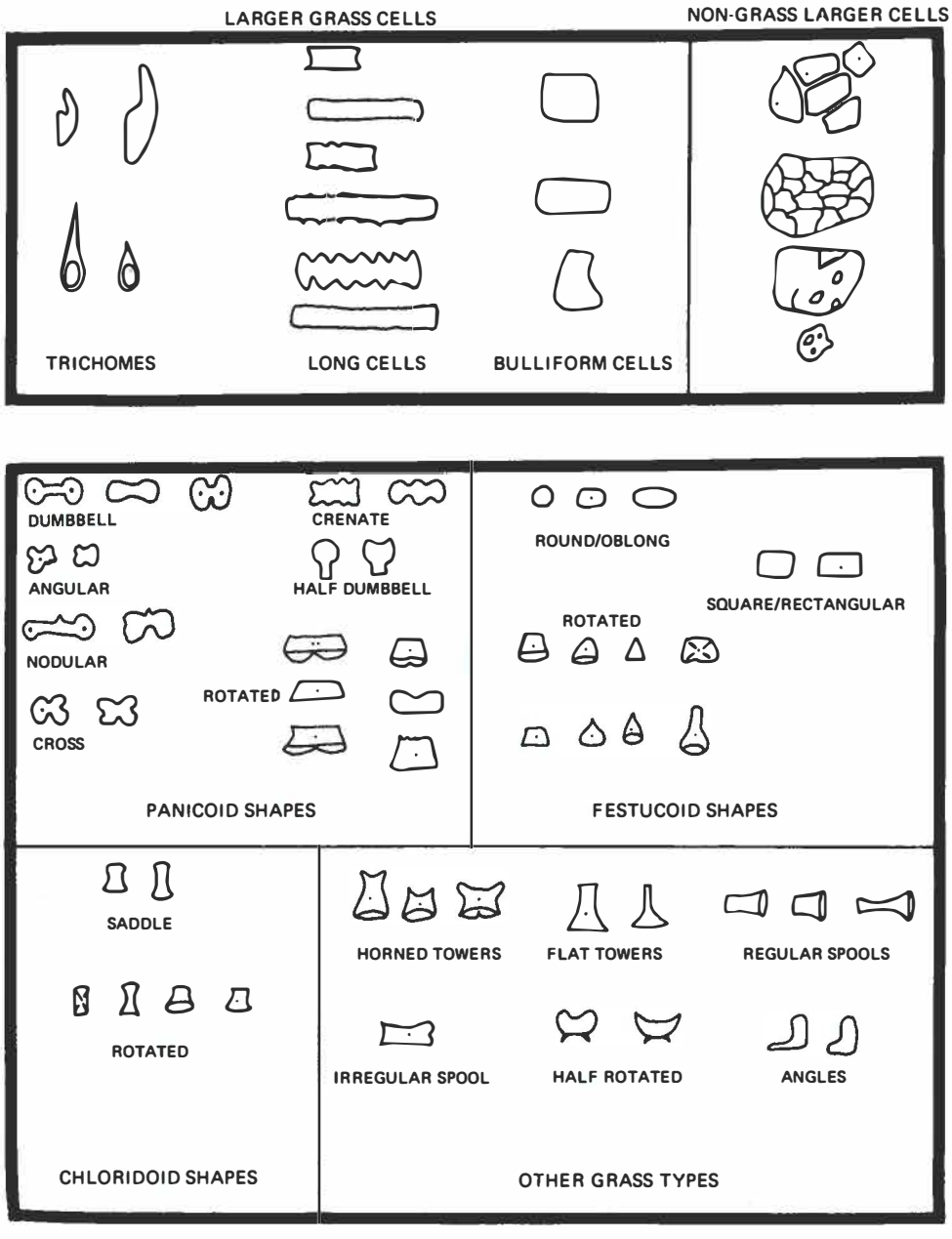

Figure 1. Modified Twiss *et al.* (1969) phytolith classification system: top, long-cell silica bodies; bottom, short-cell silica bodies (from Pearsall & Trimble 1983: 476).

monocotyledons, and dicotyledons varies. Phytoliths occurring in the Gramineae, or grasses, one of the highest silica-producing groups, can be divided into two broad morphological classes: bodies in long cells and bodies in short cells (Metcalfe 1960) (Fig. 1). Short cells are used to identify grasses at the sub-family level. Some phytoliths produced by forbs and woody plants are of limited taxonomic value. However, as recent research has shown (i.e., Bozarth 1986, 1987, Piperno 1985, 1988, Wilson 1985), many plants outside the Gramineae do produce distinctive phytoliths, including types diagnostic at the genus or family level (Fig. 2).

Identification of phytoliths is done by comparing them to samples extracted from modern plant material. Two sources of comparative materials aid in the process of identification and interpretation: 1) modern surface soil samples, collected from distinctive vegetation zones in the study area, and 2) plant specimens collected in those zones. Only plants which are securely identified, such as herbarium voucher specimens, should be used as comparative specimens. Duplicate specimens should be deposited for future researchers to consult.

Recovering phytoliths from soil samples is achieved by a flotation process. Phytoliths vary in specific gravity between 1.5 and 2.3. By using a heavy liquid of specific gravity of 2.3, phytoliths can be separated from denser soil constitutents. Phytoliths are extracted from modern leaf specimens by oxidation (chemical or by ashing). Detailed descriptions of processing procedures may be found in Pearsall (1989) and Piperno (1988).

Following processing, phytolith extract is slide-mounted in Canada Balsam or Permount. A standard amount of phytolith material is mounted on each slide (0.001 g dried weight) to allow precise comparisons of phytolith occurrence among samples.

Archaeological soil phytolith analysis generally involves quantification of occurrence of all identifiable phytolith types. The total range of phytoliths occurring in a sample expressed quantitatively is the soil phytolith assemblage. This is analogous to the pollen sum (Pearsall 1989). Simple presence of diagnostic phytoliths may also yield useful information, however. Quantitative scanning is carried out to maximize recovery of data from archaeological or comparative samples.

Slide scanning is a two-part procedure. First, slides are scanned in non-overlapping rows to obtain a minimum count of grass short cells, generally 200, or until the entire slide is scanned. Short cell phytoliths are classified into three distinctive classes, festucoid, panicoid, and chloridoid (Pearsall 1979, 1989, Twiss *et al.* 1969). The relative quantity of short cells of these classes in samples reflects the mixture of grasses deposited at the site.

Figure 2. Examples of diagnostic phytoliths: (a) long cells with conical projections from leaf epidermis of rice, *Oryza sativa;* (b) glume epidermal cells from rice; (c) trough-shaped phytoliths from banana leaf, *Musa* sp. Scale bar: 20 micrometers.

Such data may be interpreted in terms of available moisture and the general vegetation profile of an area and to identify presence of cultivated grasses.

A second tabulation is usually made of other distinctive phytoliths present in the assemblage. These may include epidermal cells from the leaf or seed, bulliform cells, dermal appendages, hair-bases, spheres, and other biosilica bodies, such as diatoms and sponge spicules. A number of different methods of quantifying and classifying the occurrence of these distinctive types has been used at the Missouri lab. For the Waimea-Kawaihae study, Hawaii, epidermal cells from grasses and other plants were counted for as many rows as scanned for short cells, or up to five rows or a 100-count (Pearsall & Trimble 1983, 1984). For work in Mountain Province, Philippines, and on Rota in the Marianas, a given number of microscopic fields, chosen randomly, were scanned for each slide (Pearsall 1986, 1987a). Phytoliths observed in each field were noted, along with an estimate of their abundance, quantified as the area of the microscope field covered by each type (area expressed as percentage cover). This technique is known as visual estimation (Terry & Chilingar 1955) and can be useful for quantifying the occurrence of material which cannot be easily counted. A third technique, "quick-scanning", was utilized for samples from Guam and Yap, Western Carolines (Pearsall 1987, unpub.) In this procedure, each slide is examined and a list made of all phytolith types present on it. Abundance of each type is then assessed on the basis of its presence or absence in each field of vision. Other researchers, such as Piperno (1988), incorporate all diagnostic phytoliths into one count. Whatever the method utilized, the goal of quantitative analysis of phytolith assemblages is to determine the relative abundance of types in the assemblage and to reconstruct past vegetation by comparing the unknown assemblage to phytolith assemblages from known vegetation formations. This approach, the comparative or analogue approach, is widely used by palynologists (Pearsall 1989).

The phytolith technique has considerable potential for research in the Pacific. One area of application is in identification of the appearance and spread of cultivated plants. A number of cultivated plants of the Far East and Pacific are grasses, i.e., rice, the millets, sugar cane, and Job's Tears. Because grasses are silica-accumulators, this enhances the possibility of their identification using the phytolith technique. Edman & Soderberg (1929) and Watanabe (1968), for example, identified rice and millet (Watanabe 1970) by reference to spodograms, or multicelled epidermal silica "skeletons." Rice produces very distinctive silicified epidermal cells, both in the leaf and glume, which make spodograms easily recognized. These diagnostic phytoliths are sometimes lightly silicified, however (Pearsall 1986), and may not always survive in soil, where disarticulated phytoliths, rather than spodograms, are the rule. "Motor cells" are being used to identify rice in archaeological deposits in Japan by Fujiwara and colleagues (Fujiwara *et al.* 1985). Identification of cultivated grasses using short cell characteristics also has considerable potential as work in the New World on maize has shown (Pearsall 1978, 1979, 1982, 1889, Piperno 1983, 1984, 1988).

Wilson (1985) reports presence of diagnostic phytoliths in the genus *Musa*, the banana group. Although it may prove impossible to separate the three sections of the genus (*Eumusa, Australimusa,* and *Ingentimusa*), making it difficult to distinguish cultivated species from disturbance species, Wilson's work has clear application for identifying agricultural activity and for documenting the spread of bananas outside their native range.

Bozarth (1987) had identified diagnostic phytoliths in the bottle gourd (*Lagenaria*

siceraria) and in the New World squashes (*Cucurbita* spp.). It should be possible to document the spread of bottle gourd into the Pacific region using the phytolith technique, and it may be possible to develop a method of identifying Old World cultivars of the Cucurbitaceae (i.e., watermelon, cucumber, and muskmelon).

Many other cultivated and useful wild plants of the Pacific remain to be examined for phytolith production. Tests of tubers and leaves from the edible aroids (*Alocasia, Colocasia,* and *Cyrtosperma*) have proven negative, unfortunately (Pearsall 1986, Wilson 1985).

Another area of application of phytolith analysis in the Pacific has already been mentioned: identification of agricultural activity. Even if specific cultivars cannot be identified, it is often possible to document human-induced environmental disturbance associated with agriculture. This is done by certifying the presence of plant taxa adapted to disturbed habitats or by showing shifts in soil phytolith assemblages away from those reflecting "pristine" vegetation. The latter approach was utilized in the Waimea-Kawaihae study (Pearsall & Trimble 1983, 1984). Phytolith analysis can also be applied to more general questions of vegetation reconstruction, as will be illustrated by discussing an analysis of samples from Yap (Pearsall, unpub.).

Recent Phytolith Research in the Pacific

HAWAII

Two archaeological phytolith projects have been completed from Hawaii Island (Pearsall & Trimble 1983, 1984, Pearsall 1984). Both were components of highway road corridor site mitigation. During the Waimea-Kawaihae project (Clark & Kirch 1983), a series of sites, thought to be agricultural fields, were investigated using phytolith, pollen, and snail analysis of soil columns (Bennet 1983, Christensen 1983, Pearsall & Trimble 1983). The road corridor, running on the island's leeward side from the coast inland to 870 m elevation, provided an almost ideal environmental sampling transect through the leeward zone, from dry coastal habitat to moist upland zones. Thirteen archaeological sites, two control columns, and six surface samples were analyzed for phytoliths. Similar biological analyses were carried out for the Kuakini project sites in a short road corridor paralleling the leeward coast (Schilt 1984). Phytolith samples came from two agricultural sites in the Kona field system (Pearsall 1984).

The objective in both of these studies was to identify agricultural use horizons in tested field areas. The method employed was to determine the nature of phytolith assemblages of "pristine" vegetation occupying site areas, to identify where in test columns these assemblages changed, and to document the transition to modern surface vegetation. In practice, this approach was complicated by 1) difficulty in obtaining comparative soil samples from native vegetation zones now severely or completely altered, 2) erosion of surface soil layers in some locations, and 3) problems in quantifying the occurrence of phytoliths characterizing forest-dominated vegetation. In spite of these problems, it was possible to identify agricultural use horizons in a number of fields in the Waimea-Kawaihae area by the occurrence of grass phytoliths and to observe the trend of vegetation change after field abandonment. No evidence for major vegetation shifts was found for sites tested in the Kuakini area.

The Hawaiian phytolith research demonstrated the potential of directly testing sus-

pected agricultural features for data on the antiquity of altering native vegetation for agriculture. Even if specific cultivated plants, such as root crops, cannot be identified, the process of clearing land, forested or open, and planting crops alters soil phytolith assemblages, reducing occurrence of phytoliths from mature vegetation and increasing occurrence of silica from disturbed habitat species and exotics.

MICRONESIA

Phytolith analysis has recently been completed as part of archaeological investigations on the north coast of Rota, Mariana Islands (Butler 1987, Pearsall 1987). Research for the Airport Road Project had two goals: 1) to assess preservation of phytoliths in coarse coralline sands of the study area, and 2) to describe, and possibly identify, types of phytoliths present (Pearsall 1987). One additional issue of special interest was whether evidence for rice cultivation could be obtained. Five archaeological soil samples and one surface control sample were analyzed. Occurrence of grass phytoliths was very low in all samples. Most phytoliths recovered were broken pieces of honey-comb or plate-like silica, which are produced in leaves of many plant taxa, including forbs and woody plants. Abundance of such forms, coupled with the virtual absence of grass phytoliths, may indicate that vegetation which decayed or burned in areas sampled was dominated by non-grass forbs or woody vegetation. It is also possible that phytolith diversity was reduced by loss of smaller silica bodies, such as grass short cells, through breakage or dissolution in the sandy deposits. No indication of rice was found.

Work has also been completed on an analysis of soil samples from the village site of Asan on the west-central coast of Guam, investigated by Michael Graves and colleagues (Pearsall, unpub.). Nine archaeological soil samples, one comparative surface sample, and seventeen comparative plant specimens were analyzed. Soil samples from all contexts studied produced very similar phytolith assemblages. These were characterized by 1) low occurrence of grass phytoliths, 2) moderately abundant occurrence of highly redundant phytoliths produced by forbs or woody plants, and 3) low overall diversity of phytolith types. No evidence for rice or banana was found. Palm phytoliths were observed in two samples. These results are very similar to those obtained from sites tested on Rota.

Testing of the phytolith technique for distinguishing among vegetation formations on Map Island, Yap, shows considerable promise (Pearsall unpub.). The objective of the pilot study, conceived by Rosalind Hunter-Anderson, was to determine if phytolith analysis could be used to distinguish present-day grasslands (*Pandanus* and fern communities) from forested lands (agroforest in long-fallow yam cultivation). If the technique proved successful, Hunter-Anderson (pers. comm.) hoped to clarify whether presently grass-dominated areas on the islands were once forest-covered. A number of diagnostic phytoliths were identified from modern leaf samples, allowing the leaf litter deposited in grassland, forest, and fernland vegetation formations to be distinguished. Not all diagnostics were sufficiently silicified to preserve in soil samples, however. It was possible to classify correctly all three fernland soil samples and two of three grassland soil samples. An analysis of agroforest samples and a study of unknown phytolith types is planned.

Results of the Micronesian phytolith projects briefly described here demonstrate that phytoliths are deposited and preserved in a number of depositional contexts in high islands

in this region. Limited comparative work has revealed presence of diagnostic phytoliths in a number of local and exotic plants. Phytolith analysis appears to have some potential for addressing questions of subsistence and land use in the Micronesian area.

PHILIPPINES

Phytolith analysis was carried out as part of Bodner's (1986) research into intensification of agricultural systems in central Bontoc, Mountain Province, Philippines (Pearsall 1986). Goals of the phytolith analysis were 1) to identify plants used at tested archaeological sites and to determine if variation over time in use occurred, and, 2) to detect changes in land use which might relate to agricultural intensification. Archaeological soil samples from the Lubok and Bekes sites were analyzed, and comparative surface soil samples and plant specimens were studied.

Phytolith analysis revealed several interesting patterns of variation among archaeological samples which suggested differential plant use among different use contexts and between sites. Phytolith assemblages from both sites showed occurrence of non-grass taxa, which probably included both low, open area growth (weedy herbs and small shrubs) and trees. It is unlikely that such assemblages were produced if sites were located in a grassland environment, more likely if a mixed vegetation formation was present.

No archaeological samples contained the distinctive epidermal phytoliths unique to rice. Analysis of comparative soil samples from areas of known modern rice occurrence (i.e., rice field, granary, and processing area) indicated presence of panicoid grass (the correct group for rice) but an absence of the distinctive, but lightly silicified rice epidermal cells. Apparently insufficient deposition of rice straw and chaff occurred in those depositional contexts to permit recovery of the diagnostic phytoliths.

Directions for Future Research

There are several directions for future research in applying phytolith analysis to archaeology in the Pacific region. These are 1) development of a method of identifying the cultivated grasses of the region, 2) systematic study of phytolith production patterns in the major vegetation formations, and 3) investigation of phytolith preservation in sandy soils. Progress in these areas depends on the interest and support of archaeologists working in the Pacific.

One result of the analysis of archaeological samples from Central Bontoc, Philippines, was to illustrate that more research on identifying rice using the phytolith technique is needed. Relying solely on the presence/absence of the distinctive epidermal cells of the leaf and glume as a test for rice could lead to incorrect conclusions if the cells were lightly silicified. Any identification method for rice which used more redundant phytolith forms, such as short cells, must also be capable of distinguishing rice from other cultivated panicoid grasses (Job's Tears, millets, sugar cane) and from local wild/weedy grasses, however. Success in using short cell assemblages for identifying maize suggests that this approach may be ultimately successful. Intensive study of rice and its related weedy and wild relatives and of the millets is currently underway at the University of Missouri.

As recent research by Bozarth (1987), Piperno (1985, 1988), and Wilson (1985)

have shown, many plant families outside the Gramineae also produce diagnostic phytoliths useful for identifying the presence of those groups archaeologically. Many cultivated plants and utilized wild taxa of the Pacific remain to be investigated. Although study of modern plant materials is important, it is also necessary to understand how phytoliths from individual plants are combined to produce soil phytolith assemblages. Study of surface soil from distinctive vegetation formations ("pristine" as well as human-influenced) not only reveals which phytoliths are preserved in soil but shows how such formations may be distinguished from one another. This approach has many applications in archaeological phytolith analysis.

The quality of preservation of phytoliths in coarse soils, such as coralline sand, is an issue of some importance in the Pacific region. Analysis of such samples from Rota and Guam revealed that while phytoliths were present, fewer occurred in archaeological samples than in surface control samples, and less diversity of forms was present (Pearsall 1987, unpub.). It is possible that phytolith loss occurred.

Phytoliths do not tend to move in a soil profile, being contained largely within the surface (A) horizon in which they were deposited. The possibility of downward movement in sandy soils could be tested, however, by exposing a complete soil profile in an area where current surface vegetation (and surface soil phytolith assemblages) is known to be distinctive from previous vegetation (and paleosol phytolith assemblages) and examining the depth to which the present surface phytoliths penetrate. Loss of phytoliths might also be attributed to dissolution, which can occur under conditions of very high pH (approaching 9). There is no simple relationship between pH and phytolith preservation, however; I have recovered good phytolith assemblages from soils with pH values well over 9. The relationship of pH, water percolation rate, temperature, and soil texture to phytolith assemblage integrity needs to be investigated systematically.

From the viewpoint of sampling archaeological sites on sandy substrate for phytolith analysis, focusing on areas where cultural deposition is densest or where finer soil has accumulated may enhance recovery. Another strategy is to sample in accumulating soil horizons away from the site. A sequence of phytolith assemblages reflecting changes in land use, cultivation practices, and vegetation may be recovered from such settings, enhancing interpretation of archaeological samples.

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