# Opal Phytoliths, Inorganic, Biogenic Particles in Plants and Soils


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Major cultivated plants such as rice, wheat, barley, oats, corn, etc. are members of grass families. They contain a large amount of hydrated amorphous silicate ($SiO_2 \cdot nH_2O$), which is similar to opal in physico-chemical and optical properties, in leaf blades, leaf sheaths, stems, and parts of inflorescence.

Botanists discovered silica deposits on lumen and wall of epidermal cells and called these plant tissue silica skeltons as silicified cell or silica body. On the other hand, soil scientists gave the names such as plant opal, opal phytolith, grass opal, or opaline silica, etc. to the silicified cells released to the soil by decomposition or burning of plants or through animal excrements[1,2].

These opal phytoliths are greatly diversified in their shape, quantity, and in the locational distribution in leaves depending upon kinds of plant. Particularly the morphology of opal phytolith is characteristic with grasses, so that it has been used for taxonomic studies and for identifying epidermis fragments and grass plants remaining in soils[2-6].

Recently, it has been known that silica bodies with characteristic shapes are contained not only in *Graminae* but also many other herbaceous plants like *Cyperaceae, Commelinaceae, Boraginaceae* etc. as well as trees including Palmae. As a result, the possible usefulness of opal phytoliths in paleoecological reconstruction comes to attract attentions of soil scientists, ecologists and archaeologists[4,7,8,9].

In the present paper, a brief description of opal phytoliths will be made by comparing that of grass origin with that of tree origin, and some of the interesting recent findings will be introduced.

## Silica in grasses and trees

In general, silica deposition occurrs indiscriminately in all parts of plant of grasses and trees although to varying extent with different plants, but the remarkable concentration takes place in leaves and leaf sheaths of mature plants. Though the degree of leaf silicification varys with kinds of plant, the silicification of epidermal cells is highest with grasses, On the contrary, the highest silicification occurrs in vascular cells, epidermal cells, epidermal hairs and hair bases with trees[8,9].

Silica content of grasses is commonly 3 to 6% on dry weight basis, and it is about 10 to 20 times that of many dicotyledons. On the contrary, silica content of many trees is very low, i.e., less than 1%, and particularly low with coniferous woods[7,8]. However, some deciduous woods, for example *Magnoliaceae, Ulmaceae, Moraceae,* etc. show fairly high silica content which is comparable to that of grasses[8]. Trees in tropical and subtropical regions have generally higher silica content than that of trees in temperate regions.

## Morphological features of grass and tree phytoliths

Morphology of phytoliths of grasses and forest trees depends mostly on the shape of tissue cells in which they originated. Leaf epidermal cells of grasses are classified basically into the following 3 groups: 1) long or fundamental cells, 2) short or specialized cells (silica, cork, stomata, trichomes) and 3) bulliform cells (or motor cells). Among these cells, the shape, frequency of occurrence and distribution of silica bodies in the short cells, in particular, are closely related to taxonomic groups of grasses.

Twiss et al.[3] classified the silica body in leaves of grasses into 4 major groups: Chloridoid class (Plate 1-2), panicoid class (Plate 1-3), festucoid class (Plate 1-4), and elongate class (Plate 1-5), based on the research results obtained so far by botanists.

Sase and Kondo[6] proposed to establish the following 3 groups in addition to the above 4 groups: fan-shape silica body (Plate 1-6) from bulliform cells, point-shape silica body (Plate 1-7) from prickle hairs, and sasoid (Plate 1-1) from the short cells of the genera *Sasa*. With wild grasses growing in Japan, they proved that sasoid, chloridoid, panicoid and festucoid silica bodies are closely related to the taxonomic groups of grasses[5,6].

To-day, most of the grass phytoliths can be identified at the sub-family and genus level from their morphological characteristics. However, the phytolith from branched cells in leaves of *Nardus strica* and that from bulliform cells in leaves of *Oryza stativa* L. can be identified at the species level due to morphological characteristics specific to each species[2,10].

Most of the phytoliths originated from trees, except some of the conifers, are different morphologically from the grass phytoliths[8]. Scanning electron micrographs of some typical tree phytoliths are given in Plate 2. Phytoliths of conifers show rather simple rectangular prism or irregularly shaped polyhedron, whereas those of broad leaf trees are widely diversified in shape. For example, *Fagaceae* trees contain branched or Y-shaped phytoliths (Plate 2-3) in vascular bundle cells, while

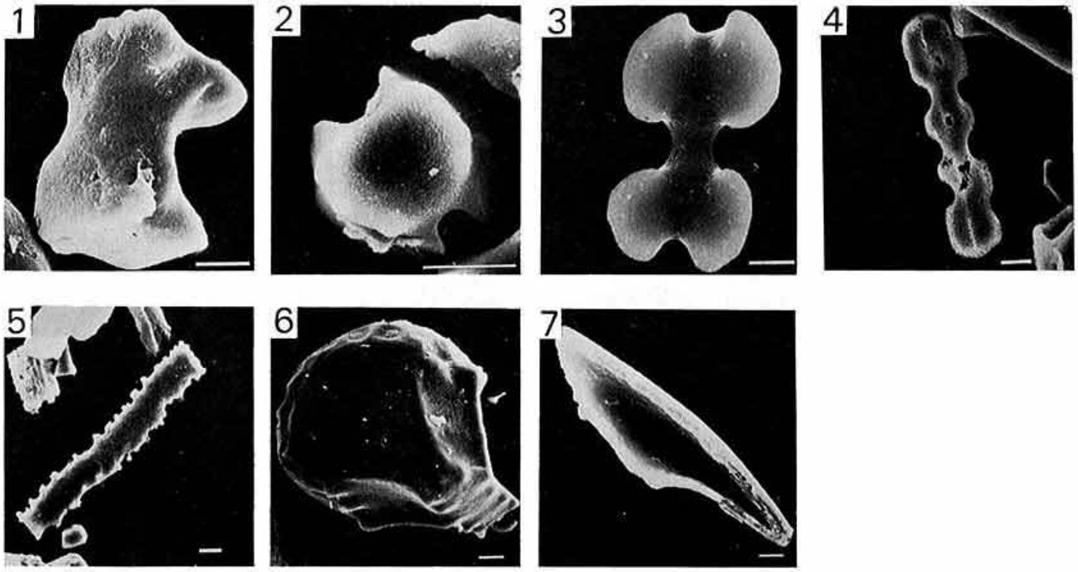

Plate 1. Comparision of graminous phytoliths separated from grass leaves (2, 6 and 7) and soils (1, 3, 4 and 5). Scale bars : 5$\mu$.
1: Sasoid from brown forest soil in Chichibu, 2: Chloridoid from short cell of *Zoysia japonica* Steudel, 3: Panicoid from humic latosol in Brazil, 4: Festucoid from buried parabraun erde-like soil in Obihiro, 5: Elongate from volcanic ash soil in Hirō, 6: Fan-shape from bulliform cell of *Oryza stative* L., 7: Point-shape from prickle hair of *Lolium multiflorum* Lamark.

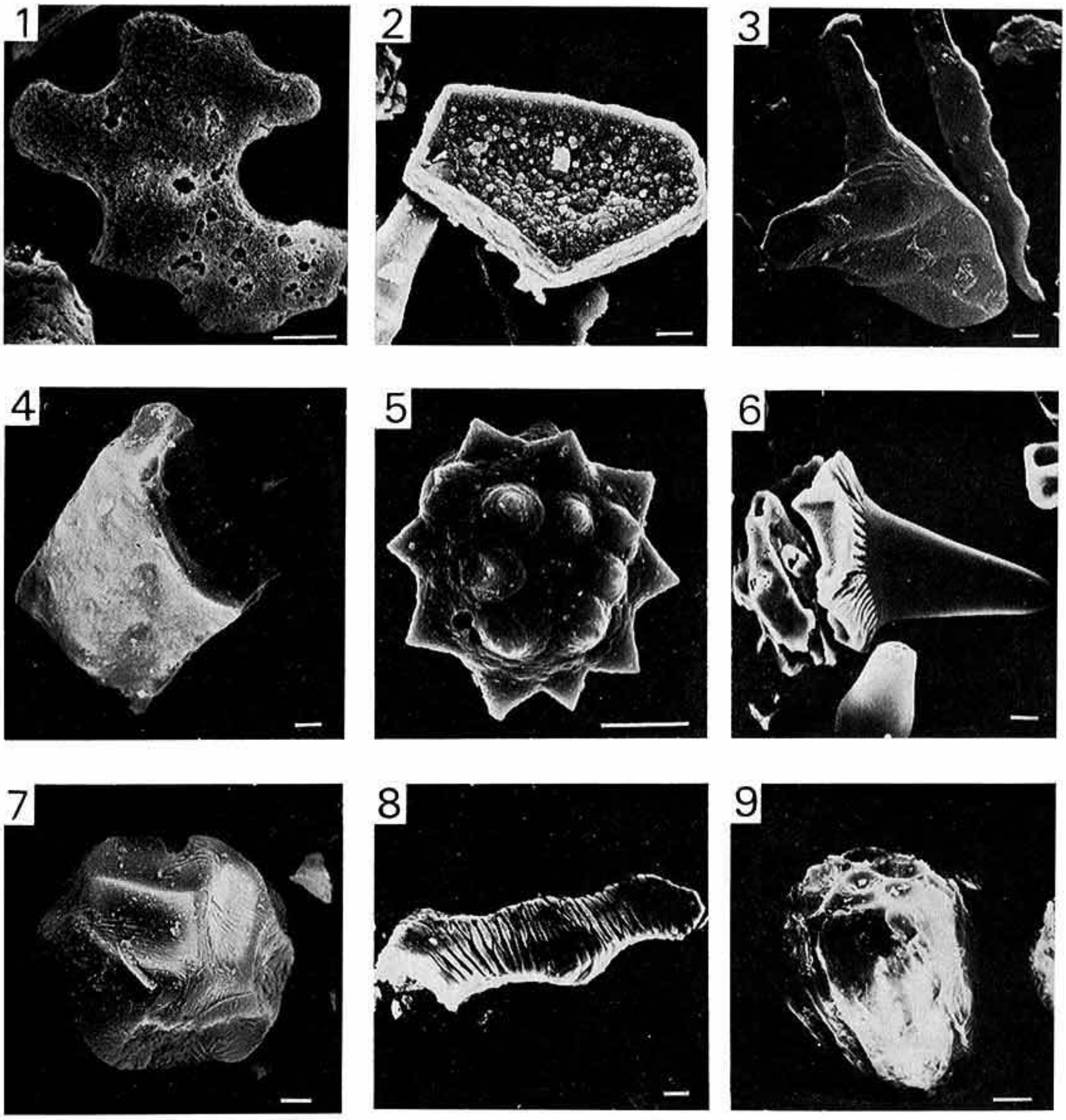


Plate 2. Scanning electron micrographs of forest phytoliths separated from selected tree leaves. Scale bars : 5$\mu$.
1 : Jigsaw shaped form from epidermal cell of *Fagus crentata* Bl., 2 : Pentagonal form from epidermal cell of *Quercus dentata* Thunb., 3 : Y shaped (branched rod) form from phloem cell of *Quercus sessilifolia* Bl., 4 : Rectangular form from *Picea jezoensis* Carr., 5 : Spiky star shaped from *Palmae.*, 6 : Hollow-socketed form from epidermal hair of *Ulmus laciniata* Mayr., 7 : Round globular form from *Castanopsis cuspidata* Schottky, 8 : Straited oblong form from xylem cell of *Lindera umbellata Thunb.*, 9 : Oval casular form from *Lindera umbellata* Thunb.

*Ulmaceae*, *Moraceae* and *Weigela hortensis* of *Caprifoliaceae* contain a large number of hollow-socketed phytoliths (Plate 2-6). And, many of broad leaf trees contain jigsaw-shaped, and pentagonal phytoliths (Plate 2-1 and 2) in epidermal cells.

It is said that these tree phytoliths can be identified based on their morphological characteristics at the family or genus level[8,9]. It is expected that a more accurate system of classifying tree phytoliths will be developed if further morphological comparisons are made within a family and genus, and among species.

## Nature of phytoliths

Phytoliths give colorless (or light brown) to opaque black appearance under the transmitted light. Light refraction index is 1.41–1.48, and specific gravity ranges from 1.5 to 2.3. Diameter is approximately <2–1000$\mu$, showing big differences between species. In the chemical composition, silica is predominant (80–95%) with a few % of water and a number of elemental impurities which occluded organic carbon[1,4,7].

X-ray diffraction analysis and infrared absorption spectra indicate that phytoliths in general have a character of amorphous silica, but there are X-ray studies showing a partial change to quartz, cristobalite and tridemite[1].

By the scanning electron microscopy of fracture surface of phytoliths, a structure closely packed with spherical particles (0.2–1$\mu$) of amorphous silica is observed, and this structure is similar to that of natural "potch" opal.

Phytoliths are relatively tolerant against weathering, so that they are found in pleistocene sediment and geological sediments of tertiary age[1,4,7].

## Distribution of phytoliths in soils

Although many researchers mentioned that phytoliths can be a promising new tool for reconstructing vegetative history, the case in which vegetative history was clearly reconstructed by using phytoliths in soils is extremely rare.

In Table 1, the distribution of 7 groups of phytoliths separated from the humus horizons of present and buried volcanic ash soils is shown. From the morphological grouping of these phytoliths, it was ascertained that the source of humus of volcanic ash soils in Japan was supplied by grassland vegetation grown since about 6,000 years ago in each regions, that is similar to the present vegetation (*Miscanthus-Sasa* type, *Miscanthus* type, and *Miscanthus-Pleioblastus* type)[5,6]. It was also ascertained that in the eastern part of

**Table 1. Distribution of phytoliths separated from the humus horizons of present and buried volcanic ash soils in Japan[1]**

| Sample[2] | Location | Groups of phytolith[3] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sas. | Chlorid. | Pani. | Festuc. | Fan. | Elong. | Point. | Others |
| | | % | % | % | % | % | % | % | % |
| Obihiro | Hokkaido | 22 | | 1 | 4 | 11 | 16 | 18 | 28 |
| Obihiro* | Hokkaido | 19 | | | 1 | 10 | 24 | 8 | 38 |
| Abashiri | Hokkaido | 3 | tr. | 1 | 11 | 20 | 20 | 21 | 24 |
| Abashiri* | Hokkaido | | | 1 | 19 | 6 | 26 | 13 | 35 |
| Takko | Tohoku | 1 | | 4 | 1 | 43 | 18 | 4 | 29 |
| Kawatabi | Tohoku | 2 | | 9 | 5 | 16 | 11 | 1 | 55 |
| Numazu | Tokai | 27 | tr. | 6 | 1 | 16 | 14 | 1 | 35 |
| Takasakishinden* | Kyushu | 22 | | 1 | | 25 | 11 | tr. | 41 |
| Miyakonojo | Kyushu | 29 | tr. | 1 | 1 | 13 | 8 | 1 | 47 |
| Fukuyama | Kyushu | | tr. | 24 | tr. | 21 | 9 | 1 | 45 |

1) Sase & Kondo; 1974, Sase & Kato; 1976
2) *: buried humus horizon
3) Abbreviation: Sas.=Sasoid, Chlorid.=Chloridoid, Pani.=Panicoid, Fan.=Fan-shape, Elong.=Elongate, Point.=Point-shape, Others=Nondescription, %: grain percent in size from 10 to 100$\mu$, tr.: <1%

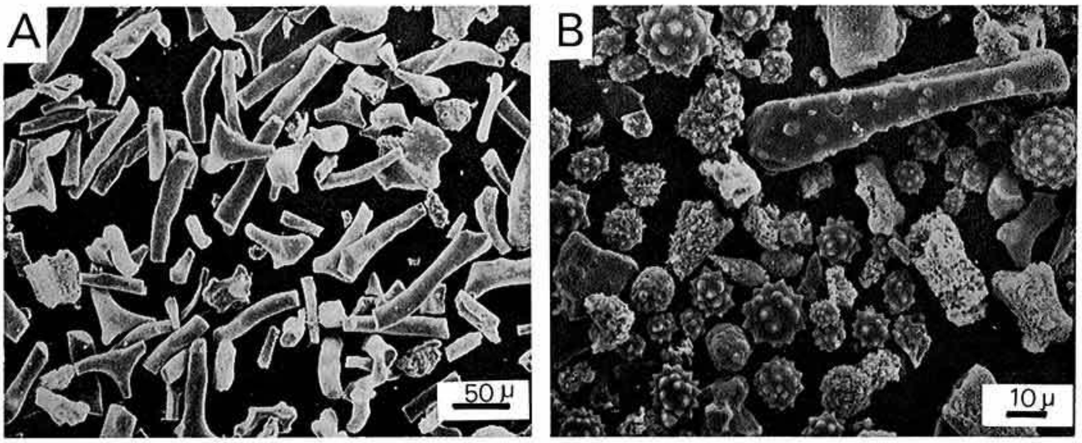


Plate 3. Scanning electron micrographs of non-grass phytoliths separated from the humus horizon of volcanic ash soil in Japan (A) and from humic latosol in Brazilian Amazonia (B).

Hokkaido no vegetation of the genera *Sasa* existed 6,000 years ago but the tribes of *Festuceae* were dominant[5].

Fujiwara[10] detected phytoliths originated from motor cells of rice plants from the soil and pottery in the ruins of final Jomon age, furnishing an evidence for the rice farming in the Jomon age.

Recently, the present author found out the phytoliths originated from the leaf vascular bundle cells of *Distylium racemosum* occurring with a high frequency in volcanic ash soils of Kyushu, Red-yellow podzonic soil of the Okinawa-Honto, and surface layer of Red soil as well as buried humus layer of the Bonin Islands, and suggested that grasses were not the only source of humus for these soils (Plate 3-A)[8].

Soils under the tropical and subtropical rain forests contain phytoliths having interesting shapes. Particularly, the phytolith originated from *Palmae* trees shows the spiky star form (Plate 2-5), and is distributed at a high frequency in humic latosol and yellow latosol of the Amazonian Basin of Brazil (Plate 3-B). In Japan, the phytolith originated from *Palmae* trees is found in the humus layer of Red soil in the Bonin Islands. The occurrence of the *Palmae* phytoliths in Brazilian soils represents fairly well the present vegetation.

Reconstructing vegetative history (opal phytolith analysis) by the use of phytoliths in soils is still in an early stage of its development. However, based on the fact that many kinds of plant contain silica bodies having characteristics specific to each plant, it is highly possible that the opal phytolith analysis will be utilized as the means of vegetation analysis comparable to or supplemental to the pollen analysis in near future.

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