Supplementary Information For:

A 5000-Yr Vegetation and Fire History for *Tierra Firme* Forests in the Medio Putumayo-Algodón Watersheds, Northeastern Peru

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Supplementary Information Text

1. Modern Indigenous Agriculture and Forest Usage

In house gardens and *chacras* near living areas, modern indigenous societies in the Medio Putumayo-Algodón region grow maize (*Zea mays* L.), squashes (*Cucurbita* spp.), manioc (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* (L.) Lam), lerén (*Goeppertia allouia* (Aubl.) Borchs. & S. Suárez, formerly *Calathea allouia* Lindl.), chile peppers (*Capsicum* spp.), avocado (*Persea americana* Mill.), pineapple (*Ananas comosus* (L.) Merr.) cashew (*Anacardium occidentale* L.), cacao (*Theobroma cacao* L.), the *pehibaye* palm (*Bactris gasipaes* Kunth) and other native herbs and trees. Rice, sugar cane, bananas, and coconuts are also grown. The societies utilize a wide array of uncultivated products of the forest for food, utilitarian, and medicinal purposes (1, 2).

2. Phytolith Carbon-14 Dating and Charcoal Analysis and Carbon-14 Dating

When phytoliths form in plant cells some of the carbon from the cells is trapped inside the phytolith, forming a suitable substrate for carbon-14 analysis. A number of studies, including on paired modern plants/modern phytoliths and charred archaeological seeds/phytoliths from well-defined stratigraphic horizons, demonstrate the suitability of phytolith dating for archaeological and paleoecological research (e.g., 3-5). It is not possible to date a single or a few phytoliths representing a discrete moment of time as it is with charcoal. A ^{14}C phytolith age therefore represents the mean age of all the phytoliths present in a particular soil assemblage and will contain a mixture of younger and older phytoliths. With regard to the dating of combined 10-cm levels, phytolith quantities sometimes decrease with depth, which would increase the amount of younger phytoliths contributing to the uppermost and middle 20- and 30-cm levels in the samples.

To recover charcoal fragments, soils from each sample were deflocculated with 3% hydrogen peroxide and sieved with a 500 μm mesh sieve. Charcoal fragments were identified from the remaining material under a Zeiss Stem-C stereomicroscope. Charcoal fragments for each sample were photographed using ImageJ, and surface area of the charcoal was measured. The surface area measurements of each charcoal fragment were converted to volumetric measurements. The volumes for each fragment were summed for each sample (10 cm depth interval) and plotted in relation to phytolith abundances (Fig. 2). Fragments that were > 0.001 g were submitted for ^{14}C dating.

Also with regard to charcoal dating, it wasn't possible to date more charcoal from the same levels where dated phytoliths derived from because charcoal often occurred in sparse amounts. We also note that charcoal may derive from portions of a tree that do not reflect its last growth years, but rather material laid down a few hundred years earlier than the date of death, known as the old wood effect. Studied primarily in archaeological contexts in temperate, arid, and semi-arid regions, where continued use of timber may occur over multiple generations of a site's occupation, this effect varies considerably depending on tree age and environmental conditions (e.g., 6). Because in the humid Neotropics wood decay rates prior to carbonization would be high and the life spans of many trees studied appear not to be more than a few hundred years (7), any old age effects are likely not greater than that.

3. Monocotyledon Representation and Spheroidal Phytolith Identification

A. Monocotyledon Representation

Troughed bodies from *Heliconia* were observed (<1%) only in the camp 2 pinch sample and 50-60 cm level of camp 2, core 1. Druses and nodular bodies produced by Cannaceae, Costaceae, and Marantaceae, and nodular bodies from Marantaceae were not observed in 51 of the 67 samples analyzed from the camps. When present their frequencies ranged from <1% to 3% in all but one sample--40-50 cm at camp 1, core 2--where 5% druses occurred.

B. Rugose, Ornate, Psilate, and Granulate Spheroids, and Their Differentiation from Monocotyledons

Various studies indicate the production of rugose spheroids in Amazonian and other Neotropical eudicotyledons is predominantly confined to trees and shrubs, mainly trees (3, 8-10) (Fig. S2). A herbaceous genus, *Xyris*, not reported from the MP-A produced them in rare frequencies (8). Some monocotyledon families produce rugose phytoliths (e.g., Cannaceae, Heliconiaceae, Marantaceae) (3, 10). However, as noted above in Supporting Text 3A, absent to low frequencies of other distinctive phytoliths they produce (troughed bodies, druses, nodular spheroids, and conicals) in addition to the larger sizes of their rugose forms when compared with eudicots indicates the rugose phytoliths are predominately derived from the taxa stated in the main text.

Present work indicates that ornate spheroids (Figs. S3) encompass a variety of different phytolith forms produced in low frequencies in the leaves and less often twigs, stems, and fruits of a few arboreal species in the following genera found today at MP-A: *Aspidosperma*, *Eschweilera*, *Geissospermum*, *Hevea*, *Matisia*, *Protium*, *Ochroma*, *Pseudobombax*, *Sorocea*, *Vismia*, *Caryocar*, and *Qualea* (8). Of the spheroids, psilate forms have the widest taxonomic distribution in eudicotyledons, being found in mainly woody growth and also some eudicot (*Peperomia*, *Piper*) and monocot herbs (3, 8-10). Among numerous eudicots we studied, they occurred nearly exclusively in trees and shrubs (10). Genera reported from MP-A that they may derive from include *Cordia*, *Guatteria*, *Protium*, *Couepia*, *Hirtella*, *Licania*, *Acalypha*, *Eschweilera*, and *Pseudobombax*. As with rugose and ornate forms, the monocotyledons that produce psilates were rare to absent in the soils.

Granulate phytoliths predominantly derive from trunk wood, branches, and twigs, with occurrence in the foliage of a few species, and they are contributed by number of Neotropical genera (10, 11). Those reported at MP-A include *Anthodiscus*, *Couepia*, *Pseudoconnarus*, *Rourea*, *Erythroxylum*, *Senefeldera*, *Mayna*, *Lindackeria*, *Tovomita*, *Sacoglottis*, *Protium*, *Chrysophyllum*, *Pouteria, Licania, Parinari*, *Tovomita*, and *Vismia*.

C. Arecaceae Spheroids

Large reference collections of Amazonian palm phytoliths indicate that a sub-type originally called "globular echinate with short acute projections" (12) and termed here "spheroidal echinate with short acute projections" (SAP in Fig. 2 and Tables S2-4) occur in the following palm genera; *Oenocarpus*, *Euterpe*, *Manicaria*, *Syagrus*, *Chelyocarpus*, *Syagrus*, and *Prestoea*. Significant size differences exist among them, so that SAP phytoliths with maximum diameters of >20 µm are limited to *Oenocarpus* and *Euterpe* spp. (10, 12) (Fig. S4).

4. Sand Fraction Phytoliths

A. Sand fractions typically contain far fewer phytoliths than silts because contributing taxa are predominantly woody plants whose phytolith production can be lower than taxa with numerous silt-sized phytoliths, such as Arecaceae, Chrysobalanaceae, Poaceae, Cyperaceae, and other monocotyledons. Quantification at times could not be made for sand fractions, as not all samples had quantities allowing counts to reach 50-100 phytoliths. In these cases, slides were extensively scanned and presence of taxa was denoted. When taxa were not denoted, additional analysis would probably be needed to say with confidence they were not present in the sample.

B. *Protium* phytoliths are large psilate globular and one-half to three-quarter globular forms (Fig. S6). *Tapura* and/or *Stephanopodium* phytoliths are large irregular forms that were attached to hair bases (Fig. S7). Phytoliths from *Hirtella* are square baculates and elongates with rounded ends (Fig. S8). Annonaceae genera phytoliths in Fig. 2 are various facetate forms (Figs. S9, 10). Many Annonaceae elongated facetates in the soils are thin and tapered at one end, which are types produced in *Guatteria* spp. (Fig. S9). Small numbers of sclereid phytoliths produced by a variety of woody taxa (9) were also present through time. Unknown B phytoliths encompass a variety of often irregular shapes that probably derive from multiple taxa (Figs. S14-17). Detailed discussions of these and other phytoliths are found in ref. 10.

Table S1. Radiocarbon Ages of Phytoliths and Charcoal. Phytolith and charcoal ages were calibrated with the INTCAL04SHCAL13 curves.

Sampling Locality	Depth cm	Material	^{14}C Age BP	Calibrated Age BP (95% Probability)	Laboratory Number
Camp 1, Core 3	0-30	Phytoliths	2130 ± 30	2154-1941	Beta-547410
Camp 1, Core 3	30-60	Phytoliths	2810 ± 30	2952-2780	Beta-547411
Camp 2, Core 1	0-30	Phytoliths	1280 ± 30	1266-1068	Beta-522507
Camp 2, Core 1	40-70	Phytoliths	2740 ± 30	2863-2751	Beta-522508
Camp 2, Core 3	0-30	Phytoliths	340 ± 30	454-300	Beta-522509
Camp 2, Core 3	60-80	Phytoliths	4300 ± 30	4950-4647	Beta-522510
Camp 3, Core 2	40-70	Phytoliths	3030 ± 30	3255-3025	Beta-571497
Camp 1, Core 1	30-40	Charcoal	1659 ± 26	1687-1418	D-AMS 028671
Camp 1, Core 3	0-10	Charcoal	2121 ± 29	2289-2000	D-AMS 29482
Camp 2, Core 1	20-30	Charcoal	2675 ± 23	2846-2749	D-AMS 29483
Camp 2, Core 2	40-50	Charcoal	2423 ± 30	2695-2352	D-AMS 29481
Camp 2, Core 3	60-70	Charcoal	2245 ± 28	2337-2154	D-AMS 29484
Camp 3, Core 4	30-40	Charcoal	1962 ± 27	1984-1826	D-AMS 028670

Table S2: Distribution of *Oenocarpus* and/or *Euterpe* Phytoliths at Camp 1, Quebrada Bufeo. The following caption applies to tables S3 and S4. O/E = *Oenocarpus* and/or *Euterpe* phytoliths. They are present in a level if SAP phytoliths (spheroidal with short acute projections) > 20 µm in maximum size were recorded. Ten SAP phytoliths were sized in each sample unless they were rarely observed (<1%). When no mean value is given for SAP size only a few of the phytoliths were observed on extended scanning of the slide. For the range of size column (Range), the value after the comma is the largest GESP phytolith observed in extended scans outside of the calculation for mean size.

Quebrado Bufeo	Level cm b.s.	O/E Present	% SAP	% Total Arecaceae	Mean µm SAP	Range µm SAP
Camp 1, Core 1	Surface	Yes	2	12	15	10-22, 30
	0-10	Yes	<1	5	-	13-25
	10-20	Yes	<1	2	-	31
	20-30	Yes	<1	7	-	18-30
	30-40	Yes	<1	9	-	15-30
	40-50	Yes	<1	5	-	18
	50-60	Yes	<1	2	-	19-31
	60-70	No	<1	1	-	13
Camp 1, Core 2	0-10	Yes	1	8	23	15-30
	10-20	Yes	2	8	19	12-30
	20-30	Yes	1	8	20	12-33
	30-40	Yes	1	8	19	14-23
	40-50	Yes	<1	4	-	22-29
	50-70	Yes	<1	5	-	21-35
Camp 1, Core 3						
	0-10	Yes	1	9	26	20-35
	10-20	No	-	1	-	-
	20-30	Yes	<1	2	18	12-25
	30-40	Yes	1	2	18	12-25
	40-50	Yes	<1	4	21	15-25
	50-60	Yes	1	8	16	11-24
	60-70	Yes	<1	7	18	12-22
	70-80	Yes	1	5	19.6	14-30

Table S3: Distribution of *Oenocarpus* and/or *Euterpe* Phytoliths at Camp 2. It is possible that other SAP-producing palms such as *Chelyocarpus repens* and *Prestoea schultzeana* that have smaller phytoliths than *Oenocarpus* and *Euterpe* and were also recorded in the vegetation survey at camp 2, contributed SAPs to the records, particularly in upper levels.

Medio Aldodón	Level cm b.s.	O/E Present	% SAP	% Total Arecaceae	Mean µm SAP	Range µm SAP
Camp 2, Core 1	Surface	Yes	5	21	11	10-14, 26
	0-10	Yes	<1	4	13	9-22, 25
	10-20	Yes	2	11	13	8-20, 35
	20-30	Yes	<1	6	-	12-18, 33
	30-40	Yes	<1	<1	-	15-30
	40-50	Yes	1	8	-	9-28
	50-60	Yes	<1	5	22	17-31
	60-70	Yes	1	4	19	13-25
	70-80	Yes	<1	2	-	18-33
Camp 2, Core 2	0-10	Yes	1	10	19	15-19
	10-20	Yes	1	4	19	15-25
	20-30	No	<1	<1	14	12-15
	30-40	Yes	<1	3	23	21-25
	40-50	No	-	1	-	-
	50-60	Yes	<1	2	23	18-28
	60-70	No	<1	<1	17	15-19
	70-80	No	<1	<1	-	-
Camp 2, Core 3	0-10	Yes	6	20	12	9-15, 25
	10-20	Yes	6	20	12.8	10-24, 30
	20-30	Yes	4	20	12.3	9-18, 23
	30-40	Yes	2	9	14.2	9-20, 30
	40-50	Yes	5	14	12.3	8-17, 27
	50-60	Yes	2	12	18.5	10-45
	60-70	Yes	<1	7	18.3	13-23
	70-80	Yes	4	15	17.9	10-23, 37
Camp 2, Core 4	0-10	No	-	5	-	-
	10-20	No	<1	3	14.8	12-18
	20-30	Yes	1	5	17.9	15-23
	30-40	Yes	<1	1	23.4	23-25
	40-50	Yes	<1	5	21.5	15-28
	50-60	Yes	<1	<1	24.6	23-28
	70-80	Yes	<1	2	24	22-30

Table S4. **Distribution of *Oenocarpus* and/or *Euterpe* Phytoliths at Camp 3, Bajo Algodón**

Bajo Algodón	Level cm b.s.	O/E Present	% SAP	% Total Arecaceae	Mean µm SAP	Range µm SAP
Camp 3, Core1	0-10	Yes	<1	5	17	12-21
	10-20	No	1	5	14	12-15
	20-30	Yes	<1	4	-	18-25
	30-40	Yes	2	4	21	15-27
	40-50	Yes	<1	1	-	20-22
	50-60	Yes	1	3	18	15-23
Camp 3, Core 2	0-10	Yes	<1	4	-	16-20
	10-20	Yes	<1	4	-	20-26
	20-30	Yes	2	14	19.8	11-23
	30-40	Yes	<1	13	-	18-26
	40-50	Yes	<1	2	-	22-27
	50-70	Yes	<1	8	-	13-28
Camp 3, Core 3	0-10	Yes	1	10	20	12-25
	10-20	Yes	1	4	19	14-23
	20-30	Yes	<1	4	18	15-21
	30-40	Yes	<1	4	-	13-20
	50-60	Yes	<1	4	-	18-38
	60-70	Yes	<1	1	-	13-23
	70-80	No	-	<1	-	-

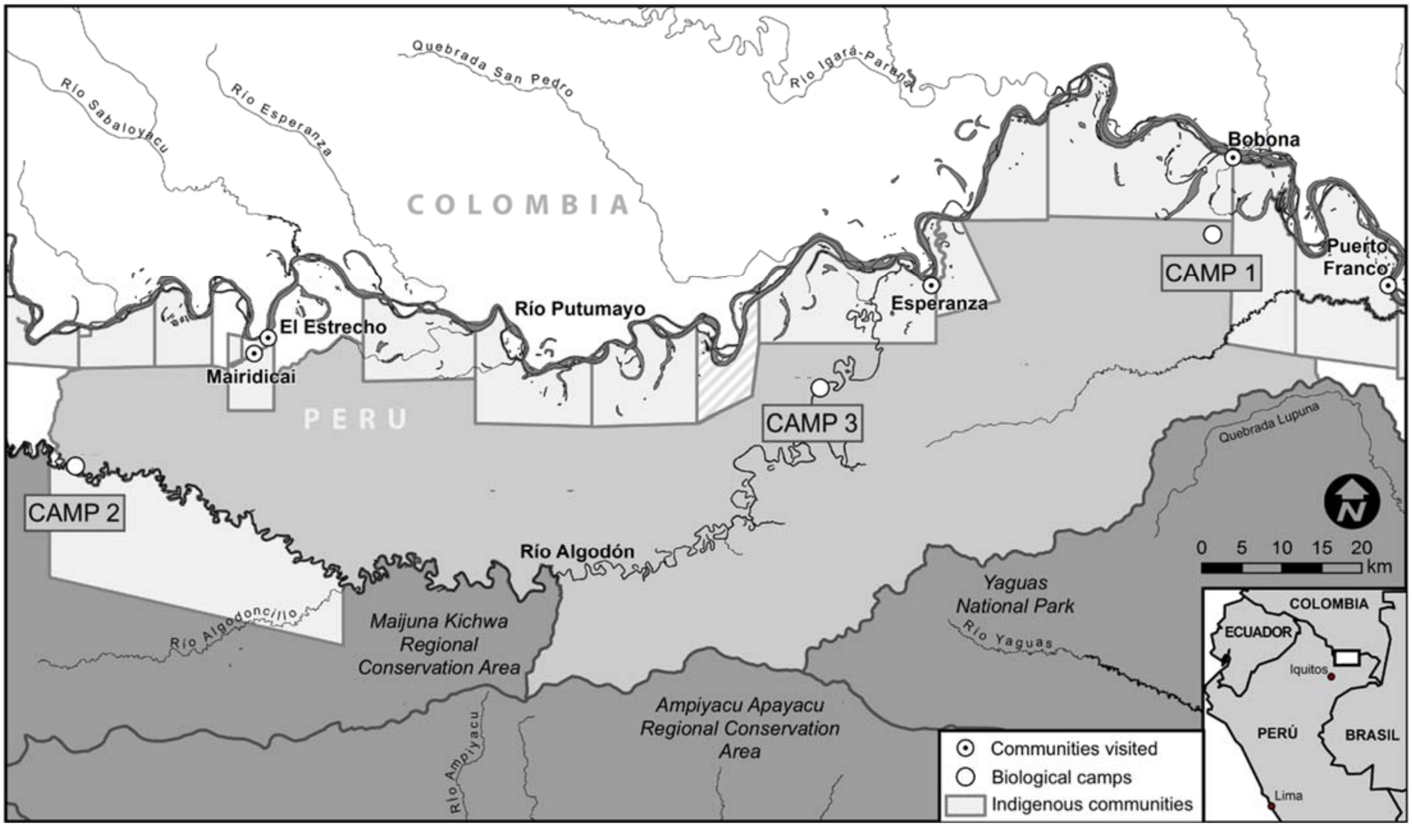


Fig. S1. Map of Medio Putumayo-Algodón study region. Locations of the three biological camps where soils were sampled for phytolith and charcoal studies are in open circles.

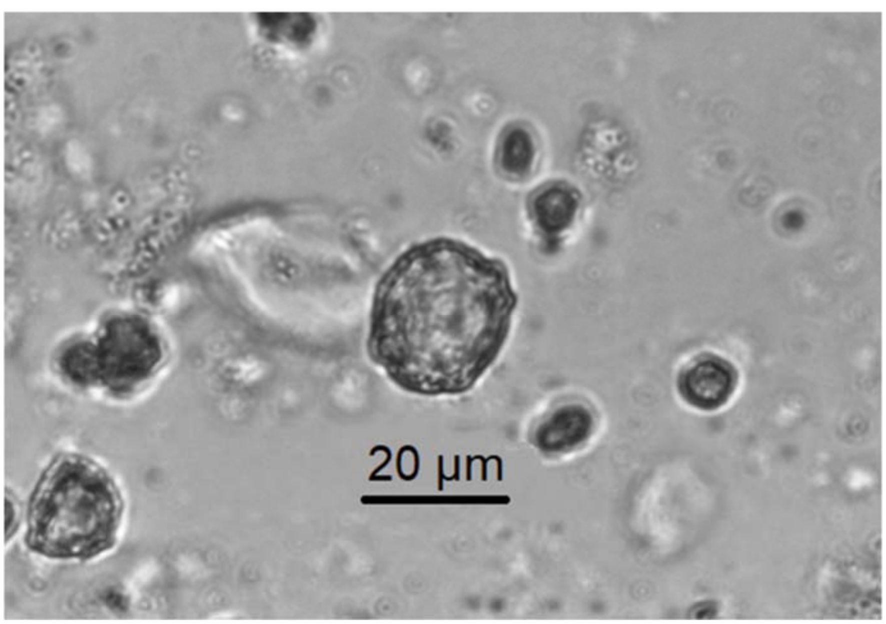


Fig. S2. Center, a spheroidal rugose phytolith from camp 2, Core 2, 10-20 cm.

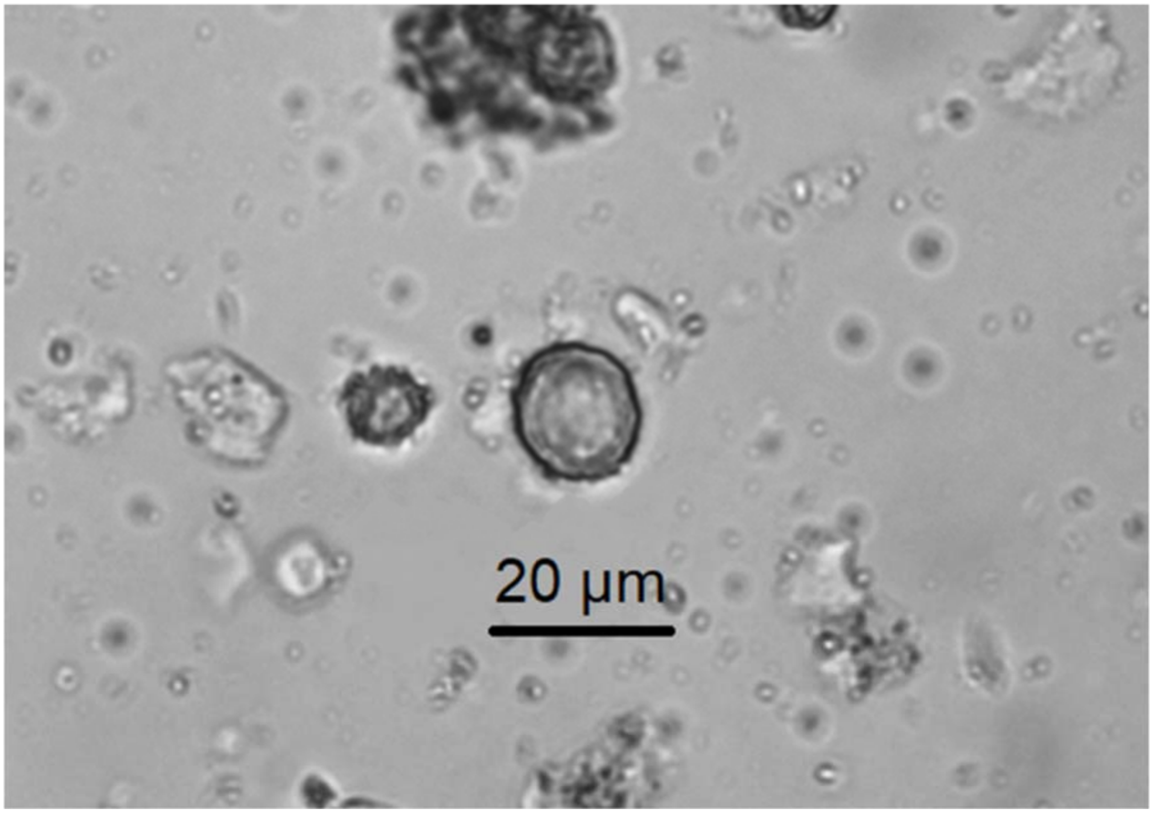


Fig. S3. Center, two spheroidal ornate phytoliths from camp 2, core 2, 10-20 cm.

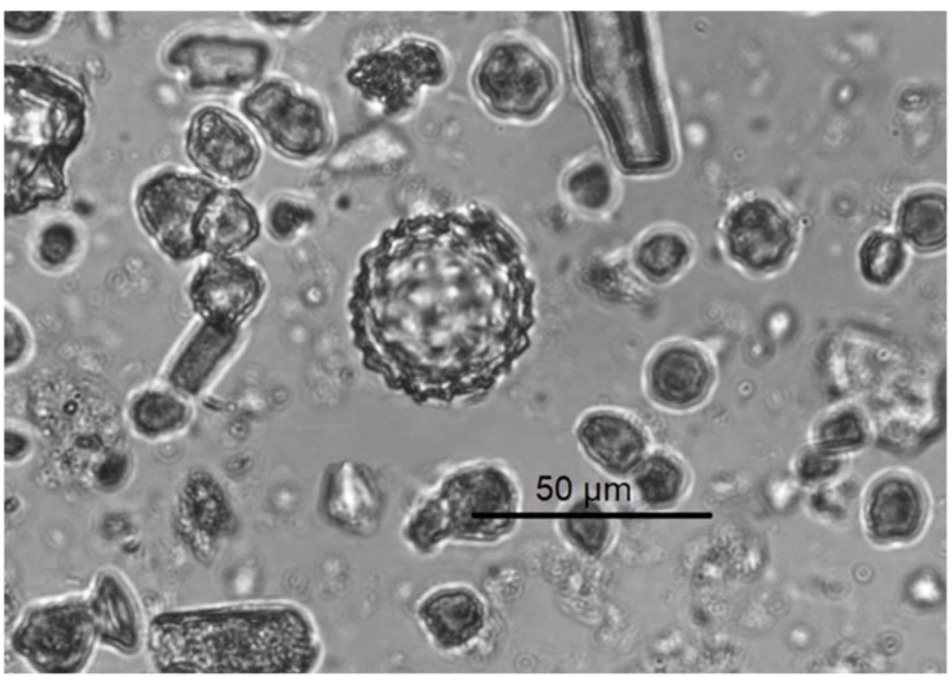
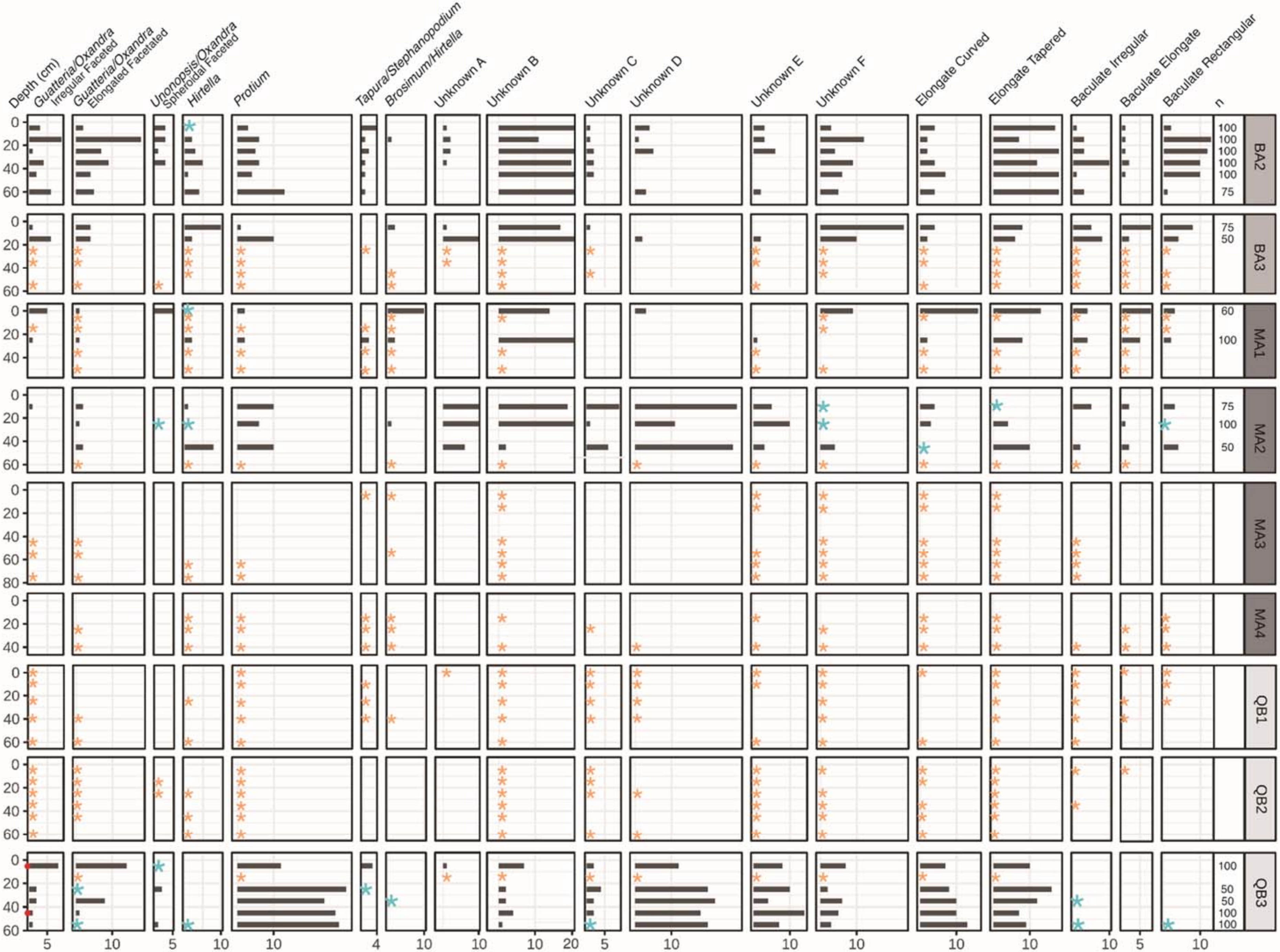


Fig. S4. Center, a large SAP palm phytolith from camp 1, core 2, 0-10 cm. It is likely from *Oenocarpus bataua.*

Fig. S5, next page. Phytolith sand fraction percentages. QB= Quebrada Bufeo (camp 1), MA=Medio Algodón (camp 2) and BA=Bajo Algodón (camp 3). For samples where counts of at least 50 phytoliths could not be achieved, taxa denoted with a yellow asterisk were observed. Additional analysis would probably be needed to say with confidence that taxa without asterisks were not present in the sample. A blue asterisk indicates phytoliths were observed in the sample upon extended scanning and are <1% of the count. The two red circles at Quebrado Bufeo, core 3 indicates the presence of *Mendoncia* seed phytoliths.


Depth (cm)
Guatteria/Oxandra Irregular Faceted
Guatteria/Oxandra Elongated Facetated
Unonopsis/Oxandra Spheroidal Faceted
Hirtella
Protium
Tapura/Stephanopodium
Brosimum/Hirtella
Unknown A
Unknown B
Unknown C
Unknown D
Unknown E
Unknown F
Elongate Curved
Elongate Tapered
Baculate Irregular
Baculate Elongate
Baculate Rectangular
n
BA2
BA3
MA1
MA2
MA3
MA4
QB1
QB2
QB3
100
75
50
60
0
20
40
60
80
5
10
4
20

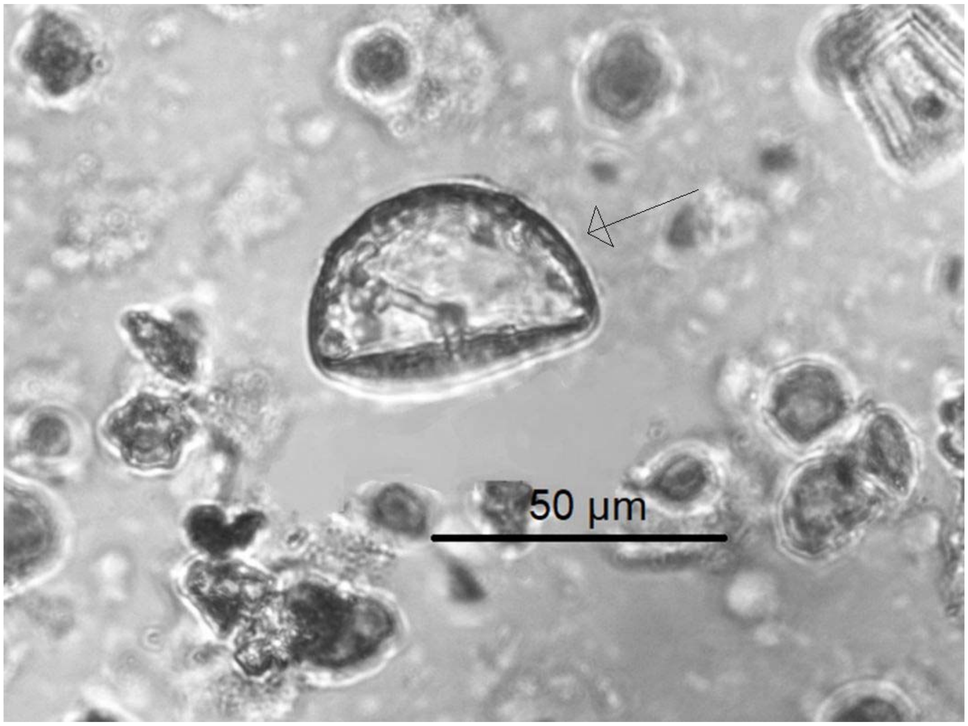


Fig. S6. Center, the arrow points to a phytolith from a *Protium* species from Camp 2, core 3, 30-40 cm. It is a one-half globular form.

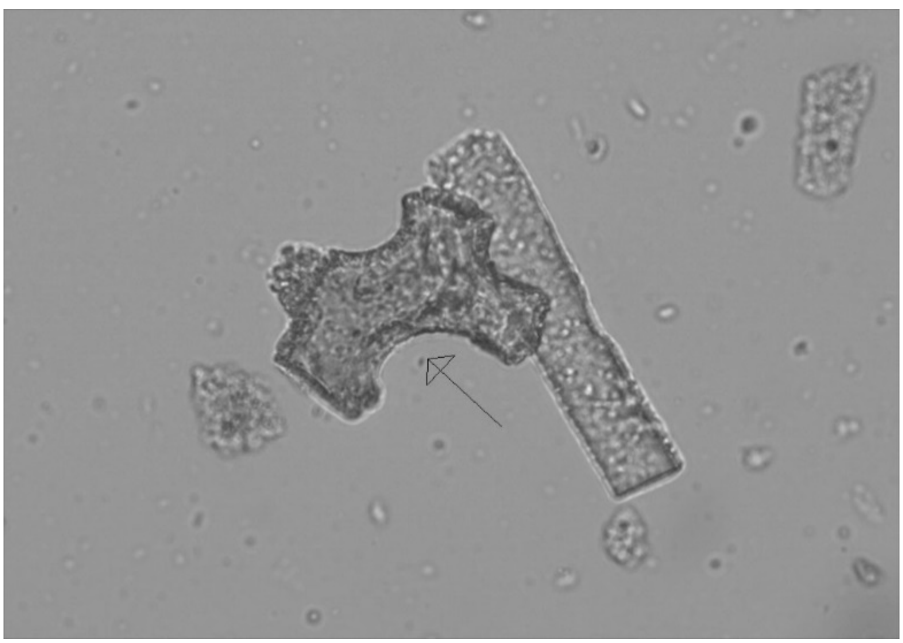


Fig. S7. Center, the arrow points to a phytolith from a *Tapura* and/or *Stephanopodium* species from camp 3, core 3, 20-30 cm. It is 84 µm long. On its right is an elongate phytolith.

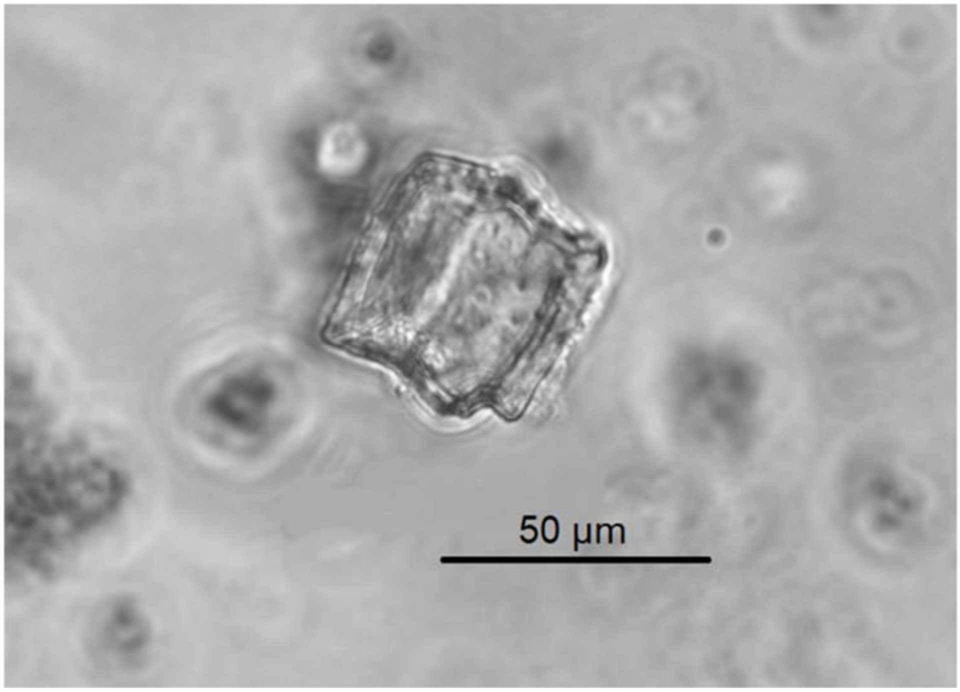


Fig. S8. A phytolith from a *Hirtella* species from camp 3, core 3, 0-10 cm. It is a square baculate type.

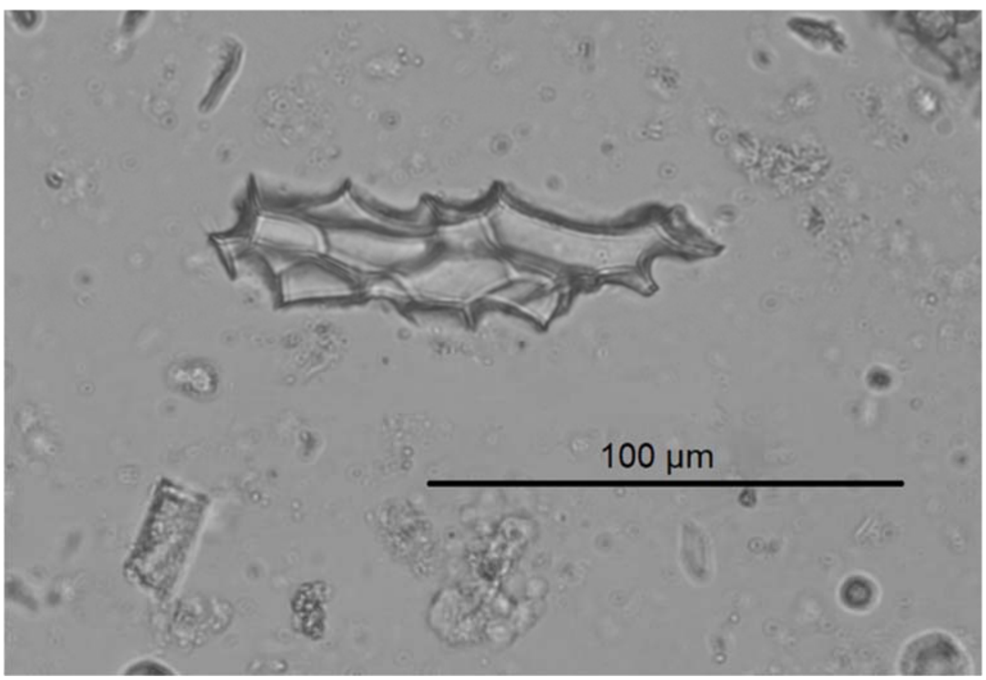


Fig. S9. A faceted elongate phytolith with a markedly tapered end characteristic of a *Guatteria* species (Annonaceae) from camp 1, core 3, 0-10cm.

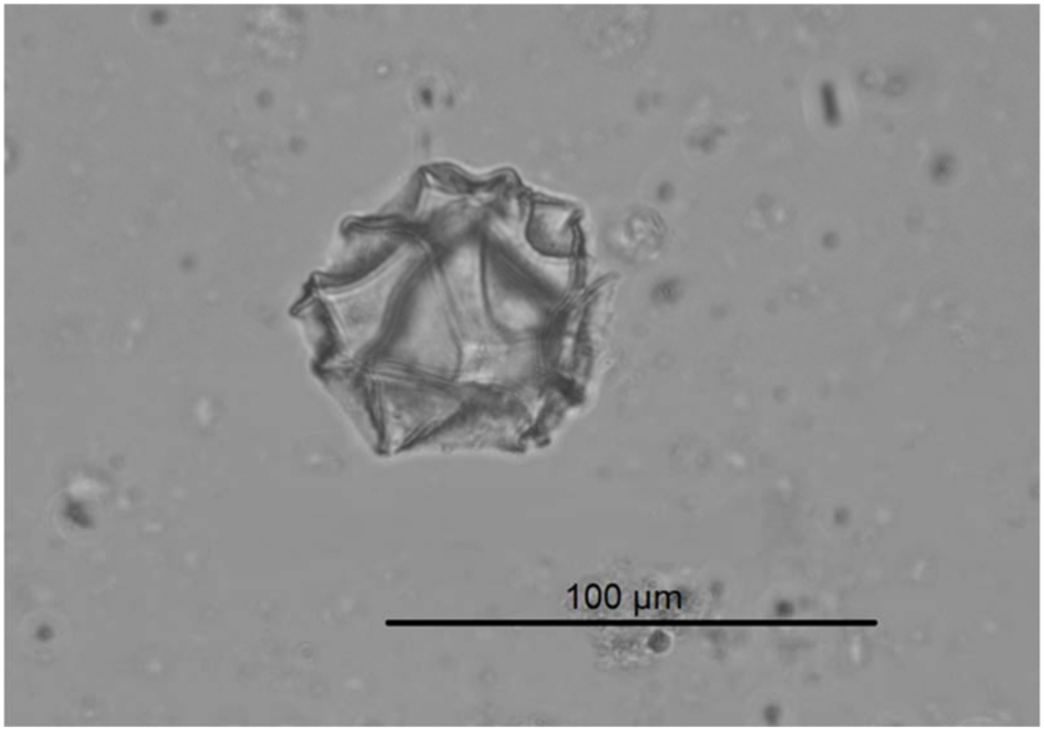


Fig. S10. A faceted spheroidal phytolith from *Unonopsis* and/or *Oxandra* (Annonaceae) from camp 1, core 3, 0-10 cm.

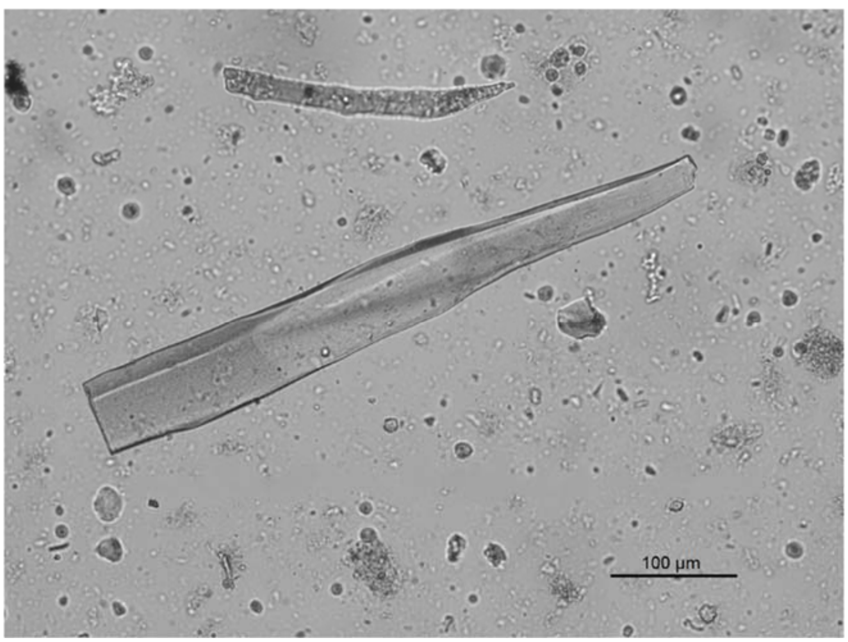


Fig. S11. Center, an elongate tapered phytolith from camp 1, core 3, 0-10 cm.

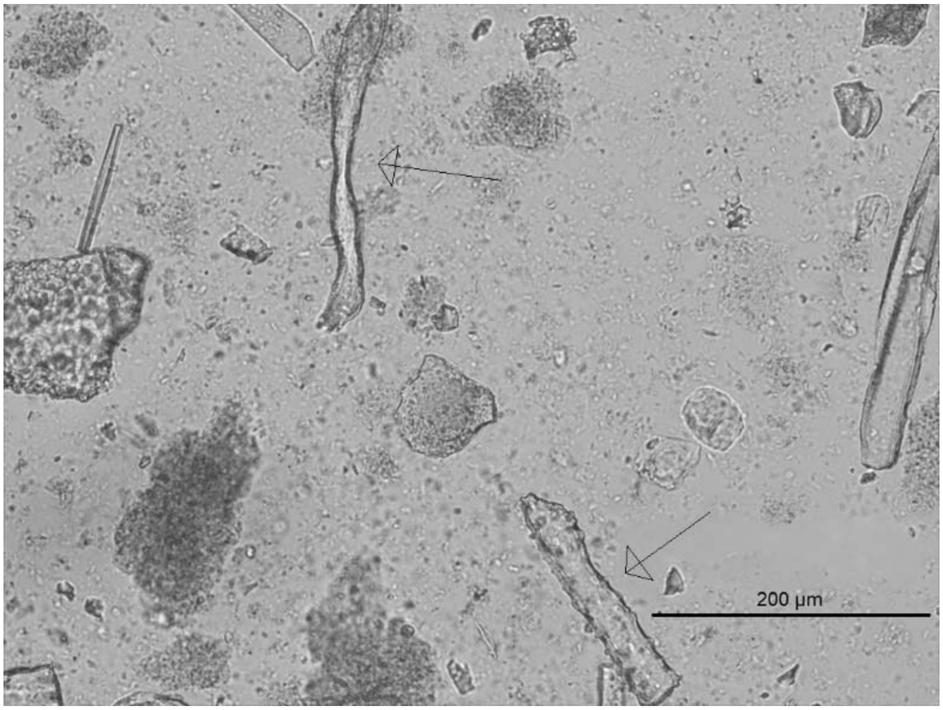


Fig. S12. Top arrow points to an elongate curved phytolith, and bottom arrow points to a rectangular baculate phytolih from camp 1, core 3, 50-60 cm.

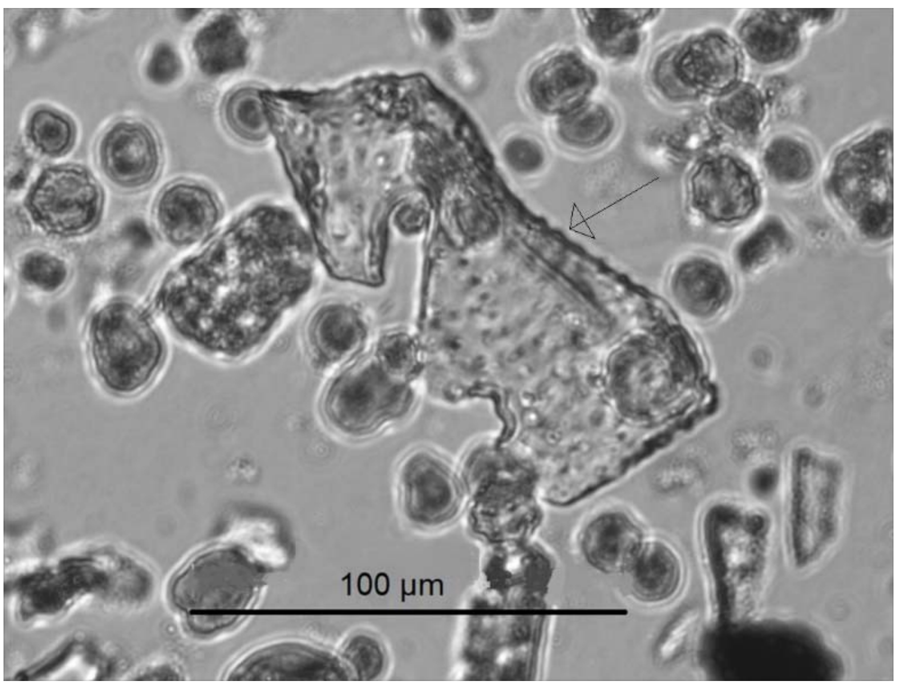


Fig. S13. Center, arrow points to an irregular baculate phytolith from camp 3, core 2, 30-40 cm.

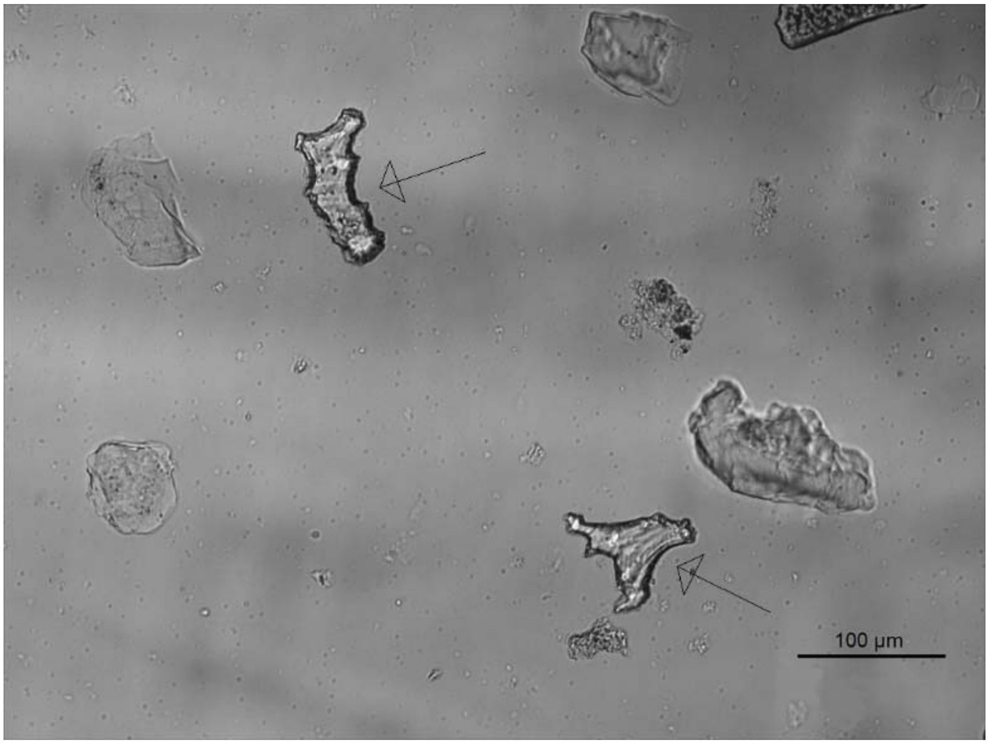


Fig. S14. Upper, left and bottom, right, arrows point to two Unknown A phytoliths from Camp 2, core 2, 40-50 cm. They are irregular forms with transverse (upper, left) and longitudinal (bottom, right) surface striations.

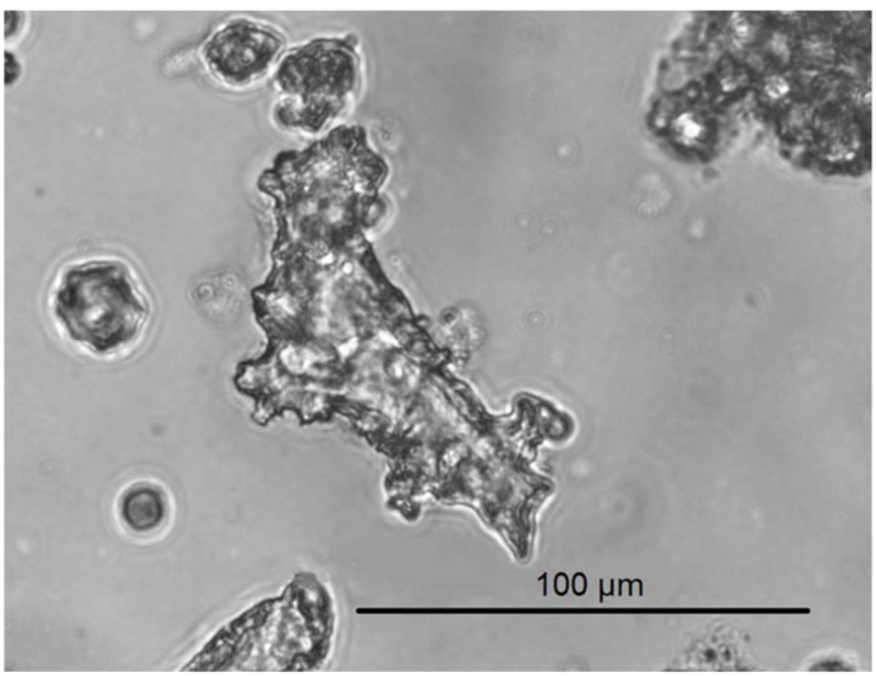


Fig. S15. Center, an Unknown B phytolith from camp 3, core 3, 0-10 cm. It has an irregular shape and knobbed surface decorations.

Fig. S16. An Unknown D phytolith from camp 1, core 3, 0-10 cm. It is elongated in shape and has circular depressions on the surface presumably created by pressure from adjoining cells pressing on it during formation.

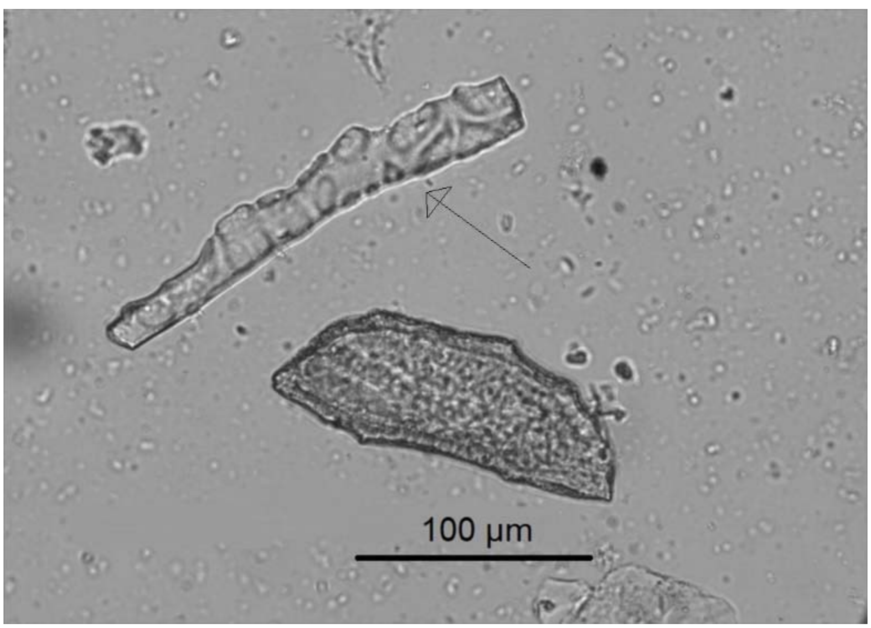


Fig. S17. Top, left, arrow points to an Unknown F phytolith from camp 1, core 3, 20-30 cm. It is elongated with a scalariform surface decoration. The bottom particle is an amorphous piece of plant silica.

Supporting References

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