PHYTOLITH DEPTH FUNCTIONS IN SURFACE REGOLITH MATERIALS

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Phytoliths are microscopic opaline silica particles that are common in many soils, forming a vital part of the global biogeochemical silica cycle (Alexandre *et al.* 1997, Conley 2002). Most are placed on the surface of the soil within litter and are released from their enclosing plant material by a combination of decay and digestion by soil fauna. Most studies of the distribution of phytoliths with depth in soils find a concentration of phytoliths in the topsoil with a decline in abundance with depth. A concentration at depth within a sediment has often been used as evidence for environmental change; however other interpretations have been suggested which change the basis of this explanation. In considering this issue we have recognized three distinct types of depth functions which are used as a framework to evaluate the contributing processes. The focus of this note is the distribution of phytoliths as reported in the Handbook of Australian Soils (Stace *et al.* 1968), which provides estimates of the relative abundance of phytoliths in each depth interval examined in sixty-nine profiles. These data are sufficient to describe phytolith depth distribution diagrams or Phytolith Depth Functions (PDFs) that can be evaluated in terms of site variables and soil type (Great Soil Group of Stace *et al.* 1968 and Principal Profile Form or PPF of Northcote 1979). This information provides the largest known database available and an evaluation of it has led us to recognise three generalised types of PDF (Figure 1).

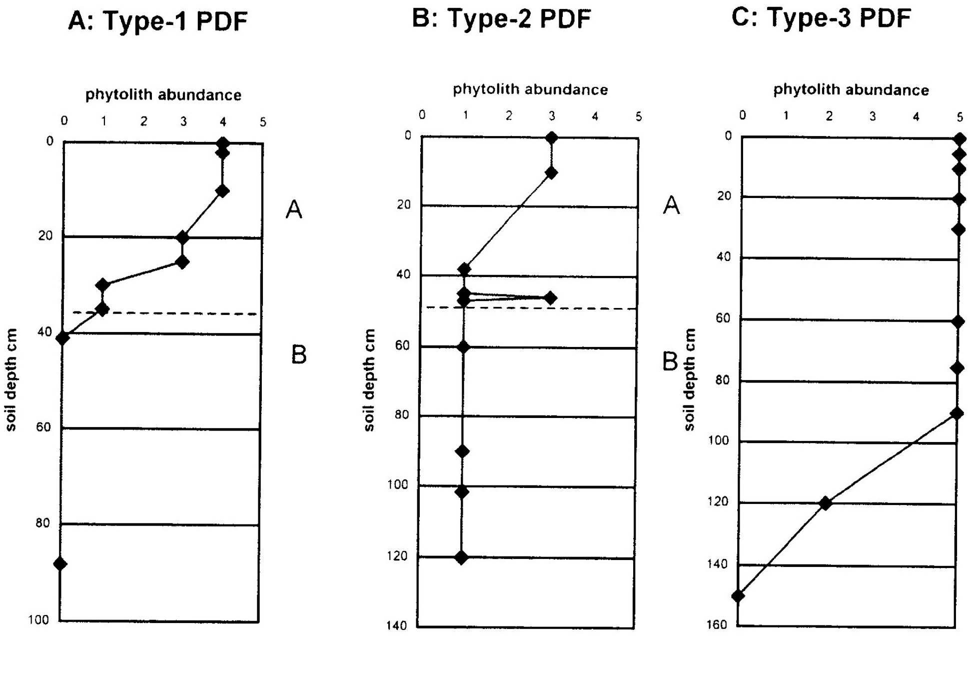

Figure 1: Examples of the main Phytolith Depth Functions from Stace *et al.* 1968. A: Type-1 PDF is a red podzolic, Dr 3.21, A/B boundary at 35 cm (page 321). B: Type-2 PDF is a solodized solonetz, Dy 5.43, A/B boundary at 46 cm (page 163). Note the distinct secondary peak at 45 cm. C: Type-3 PDF is a Ug 5.24 from the mound of a gilgai (page 88). Key: phytolith abundance: 1=Very Rare; 2=Rare; 3=Occasional; 4=Few; 5=Common

TYPE-1 DEPTH FUNCTION

This pattern shows a steady decrease in phytoliths from the surface (Figure 1A) and is usually considered, implicitly or explicitly, to be the "normal" distribution. The group can be subdivided into those where phytolith content declines to the top of the pedogenic B horizon and those where it penetrates into the B:

- Type-I(i): The first subgroup is the largest containing 36 of the 69 profiles in Stace *et al.* (1968). It can develop under a wide range of environmental conditions (Table 1). While it can occur in any Great Soil Group (GSG), it is rarely found in the dark or mildly leached soils, which include those with cracking clays. It includes some profiles where phytoliths are only found in the surface soil (generally in areas with the lowest precipitation). This group is found in all of Northcote's PPF's.

- Type-I(ii): In this group phytoliths decrease with depth and penetrate into the B2 or further. In Stace *et al.* (1968), this group includes 14 profiles. It occurs under two main conditions:
  1. In a very small group of 4 profiles where the soil has a sandy or earthy fabric (Northcote 1979) and the drainage is unimpeded (Northcote Uc's).
  2. In 10 profiles in fine sediments where the clay is a cracking-type (Northcote Ug's); often in gilgais where there are similar conditions to those for Type-3 PDF's.

Table 1: Summary of profile characteristics in Stace *et al.* (1968) in terms of recognized PDF's.

	Type-1 gradual decrease with depth			**Type-2 secondary peak at depth**		**Type-3 constant with depth**
	(i) to top of B (n=36)	***(ii) to B2 and deeper (n=14)***		***(i) density change (n=8)***	***(ii) stratigraph -ically layered (n=7)***	***(n=4)***
dominant texture	any	any, but mainly coarse	fine	coarse on fine; coarse	any	fine
Northcote PPF in Stace	D, G, U	Uc4,5,6,2.2	Ug	D; Uc2.3	D, Ug5, Um, S, O	Ug5
drainage	free	unimpeded	slow	impeded	slow/impeded	slow
precipitation	any	moderate	moderate	any	any	moderate
parent material	any	any	cracking clays	clay, quartz sand	alluvium, ash, other	cracking clays
Great Soil Group (Stace *et al* 1968)	any	chernozem, siliceous sand, prairie soil	mildly leached, grey, brown and red clays & prairie soils	solodized soils, podzols	any	mildly leached , grey, brown and red clays & prairie soils
example in Stace *et al* 1968 (page #)	321	354	108	163	132	88

TYPE-2 DEPTH FUNCTION

The Type-2 function (Figure 1B) shows a secondary zone of relative abundance of phytoliths at depth. In Stace *et al.* (1968) this is a group of 15 profiles most of which have impeded drainage due to an abrupt change in texture or density at the top of the B horizon or are in layered material. Again, these divide into two sub-groups:

- Type-2(i): This type occurs in 8 profiles where the rise occurs at a change in material density or texture. They are found in two main Northcote groups; the D's where there is a rise in density at the textural change in the B horizon and the Uc2 and 3's where the change in density is at a pan or pans.
- Type-2(ii): This type occurs in 7 profiles where the rise occurs within the A horizon of an apparent buried soil.

TYPE-3 DEPTH FUNCTION

This final group shows a relatively high but steady concentration of phytoliths with depth, with a slight increase near the surface (Figure 1C). In Stace *et al.* (1968) the group is represented by 4 profiles in the cracking clays (Northcote Ug5's), mainly in gilgais (both shelf and mound) and where drainage is often slow. This group is a natural extension of Type-1(ii) but is distinguished from it by the greater depth of penetration.

PROCESSES INVOLVED IN THE FORMATION OF PDF'S

Phytoliths are delivered to the surface of the soil by way of the litter layer and move into the soil by mixing processes. They are deposited within faecal material at varying depths throughout the soil, may be transported through the soil pores and cracks in water flow (pervection), or may fall down the vertical cracks which penetrate deep into cracking clay soils. They may also be buried slowly or rapidly and will, over time, suffer dissolution.

The extent to which phytoliths move vertically is a point with which archaeologists, in particular, are very concerned, since vertical movement, particularly movement below the top of the A horizon, may disturb archaeological information (Rovner 1986). The idea that phytoliths are immobile after deposition was termed the "static phytolith hypothesis" by Hart & Humphreys (1997). However, the movement of phytoliths vertically has been recorded by Bartoli & Guillet (1977) in podzols, in basaltic soils by Oberholster (1968, cited in Rovner 1986) and by Hallsworth & Waring (1964) in a solodized solonetz. This was termed the "mobile phytolith hypothesis" by Hart & Humphreys (1997).

MOBILITY PROCESSES

Pervection

Experimental work has shown that phytoliths do indeed move vertically; the extent depending on the strength of the mobilizing processes and their direction. This mechanism, observed by Bartoli & Guillet (1977) and by subsequent authors, refers to the movement (pervection) through interconnecting soil pores (Paton 1978). The process has been demonstrated in a podzol and a solodized solonetz, where diatoms of the same size and specific gravity as the phytoliths were used as a tracer in undisturbed soil cores (Hart 1992, Simons 1998). Pervection is influenced by the size and shape of phytoliths and differential vertical movement changes the characteristics of phytolith morphological assemblages in the profile and contributes to anomalous weathering patterns on phytoliths at depth (Simons 1998).

Simons predicted that the potential to move through the pores of the podzol's A2 would depend on shape and size of individual phytoliths. Spheroidal shapes such as single, small spheres (Figure 2A), were expected to move easily and accumulate at depth against a barrier such as a pan. As such they were expected to exhibit less weathering than other morphologies found at the same depth. Larger spheres (Figure 2B) would move at varying rates depending on sphericity and surface ornamentation. Larger, bulky phytoliths and plates (Figure 2C) would move slowly. These expectations were borne out by observation of individual morphologies, their weathering patterns and numbers with depth in the podzol (Simons 1998, Humphreys *et al.* 2003).

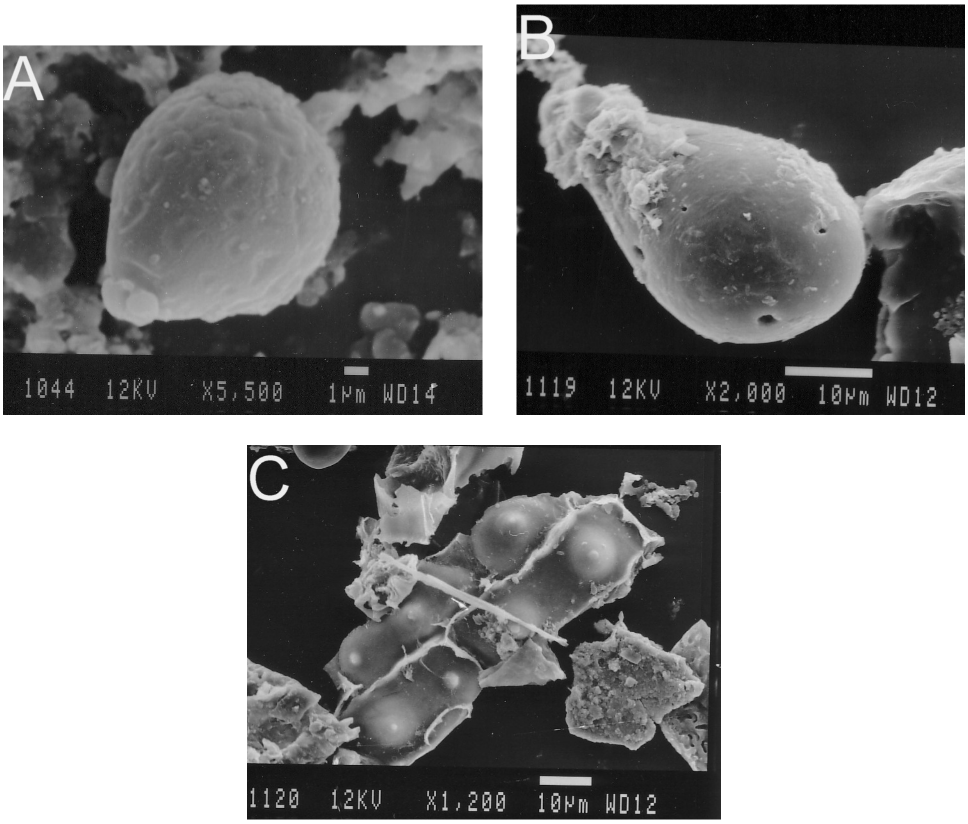

Figure 2: Phytoliths from topsoils. A: Small sphere. B: Large sphere. C: Plates. Scale bars of 1, 10 and 10 μm respectively.

The importance of soil texture in the pervection of phytoliths is obvious. In Northcote terms, Type-1 (ii) PDF's, where the phytoliths penetrate well into the B horizons, are found in the Uc PPF's; i.e. those with coarse textures throughout. The Type-2 (i) PDF's are also found where coarser topsoils allow for movement of the phytoliths; the D's and Uc's.

Bioturbation

It has been observed by many researchers that soil fauna move phytoliths and that such movement may occur in soils of any texture. Experimental work has shown that the phytolith content in bioturbated soils correlates with the percentage of faunal channels (Simons *et al.* 2000, Humphreys *et al.* 2003) and that the largest amount of phytolith material is to be found within faunal channels (Hart 2003). Lobry de Brun & Conacher (1990), in a review of the effects of ants and termites in soil modification, point out as many others have, that these taxa appear to select the clays and silts in preference to sands when re-arranging soil particles. Phytoliths fall within these size ranges and are moved as a consequence of burrowing. Termites feed on organic material and their faeces are used as a building material. Thus they may transport phytoliths deep into the soil in their channels, to the surface in their runways and to mounds above and within the soil. They may also transport phytoliths and other soil particles up into tree trunks. In a study which examined phytolith assemblages within a soil profile, Hart (2003) found that soil fauna may concentrate phytoliths in areas throughout a soil and change the soil phytolith assemblage at depth.

Mechanical mixing

The movement of phytoliths down cracks in soils has been examined by Boettinger (1994). She investigated the degree of mixing in G-D soil (red alfisols) and Ug (black vertisols), the later having a solum of high shrink-swell clays. She found that phytolith mixing occurred when dessication cracks extended deep into the soil material, enabling the surface soil material to fall to depth in the profile. An analysis of Boettinger's data shows that the alfisols have a Type-1 PDF while the vertisols exhibit a Type-3.

STATIC PROCESSES

Dissolution

Dissolution by weathering processes may remove small, fragile phytoliths, leaving the more robust morphologies. This process leads to the alteration of phytolith assemblages through time.

Burial

Both the rapid and slow accumulation of sediment will affect the phytolith distribution. Rapid burial will lead to an accumulation of phytoliths at depth where the phytoliths of the former topsoil become the bulge in a Type-2 PDF. Slower burial rates, where plant growth keeps pace with the accumulation of sediment on the surface, can be expected to produce a Type-3 PDF.

THE INTERPRETATION OF PDF'S

The potential processes operating under each hypothesis are summarized in Table 2. Distinguishing between the effects of each process and assessing the balance between them is of primary concern when interpreting a PDF. This requires a detailed examination of phytolith morphology (both shape and weathering characteristics), the way the phytolith assemblage varies with depth together with soil characteristics such as pore shape, size and connectivity, which will be influenced by soil texture and clay mineralogy. In addition it is necessary to determine the efficacy of various mixing mechanisms such as bioturbation and pervection.

Table 2: Hypothesised principal processes involved in distributing phytoliths.

Hypothesis	Potential processes operating under the static and mobile phytolith hypothesis		
	Type-1 PDF	**Type-2 PDF**	**Type-3 PDF**
Static phytolith	bioturbation dissolution	buried topsoil (rapid deposition of sediment)bioturbation	slow accumulation of sediment.
Mobile phytolith	bioturbation pervection	bioturbation pervection	mechanical mixing via cracking clays or fauna

While the above analysis is limited here to Australian soils, a survey of the international literature shows similar trends and it is suggested that these 3 PDF's are widespread. It may also imply common sets of processes and/or site histories especially in residual sites. In depositional sites, however, similar patterns may be produced from different sets of processes and assigning a causal mechanism may prove challenging. Nevertheless, changes in the type of PDF over time (e.g., Fredlund *et al.* 1998) probably indicates a change in the balance of processes and this presents an exciting field for paleoenvironmental studies.

CONCLUSIONS

The three main phytolith depth functions are related to soil characteristics and mixing processes. In particular, the PDF is related to soil texture, which, in turn, influences the processes of pervection and bioturbation. Interpreting these processes requires an investigation based on phytolith morphology, weathering characteristics and an understanding of faunal interactions within the host regolith, which are little studied at present. An understanding of these relationships is essential to the interpretation of trends in phytolith distribution with depth. When using phytoliths in archaeological and paleoenvironmental research it cannot be assumed that phytoliths are immobile. Their mobility will vary with their size and shape, with soil texture and the range of mixing processes present in the soil. This will in turn influence the phytolith assemblages at varying depths in soils and may lead to interpretation problems.

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