Assessing the potential of phytolith analysis to investigate local environment and prehistoric plant resource use in temperate regions

Assessing the potential of phytolith analysis to investigate local environment and prehistoric plant resource use in temperate regions: a case study from Williamson's Moss, Cumbria, Britain

Kali Wade [a]*, Lisa-Marie Shillito[b], John M. Marston[a,c] and Clive Bonsall [d]

[a]Archaeology Program, Boston University, Boston, USA; [b]School of History, Classics and Archaeology, Newcastle University, Newcastle Upon Tyne, UK; [c]Department of Anthropology, Boston University, Boston, USA; [d]School of History, Classics and Archaeology, University of Edinburgh, Edinburgh, UK

Kali Wade (corresponding author), Archaeology Program, Boston University, Boston, Massachusetts, USA, 02215; email: kaliwade@bu.edu

Assessing the potential of phytolith analysis to investigate local environment and prehistoric plant resource use in temperate regions: a case study from Williamson's Moss, Cumbria, Great Britain

The archaeological site of Williamson's Moss, located in north-west England, was excavated in the 1980s as part of an investigation of the Mesolithic, Neolithic, and Bronze Age populations living around the estuary of the River Esk in Cumbria. Recovery of plant remains was generally low, but bulk sediment samples were collected from different contexts as part of a project archive for future analysis. This paper presents the results of new analyses conducted on these archived samples, carried out to assess whether phytolith analysis could offer additional insights into the local environment and plant use at the site. Whilst the results indicate the presence of a diverse range of phytolith types from both monocotyledon and dicotyledon plants (along with sponge spicules, diatoms and microcharcoal), interpretation of the data is problematic. Comparison with existing palynological and excavation data indicate methodological limitations in using bulk archived samples. Nevertheless, the recovery of abundant microfossil material is encouraging for the emerging field of phytolith studies in temperate environments such as Britain, and suggestions are made regarding future sampling strategies and taphonomic considerations that will reduce problems for future analyses.

Keywords: phytolith analyses, pollen analysis, multivariate investigation, prehistoric archaeology, methods, Britain

Introduction

In Britain, understanding of plant use in early prehistory is hindered primarily by two factors: a relatively limited number of sites where conditions favour preservation of plant materials, and the nature of plant use which may preclude the types of traces that would be expected in the archaeological record (Zvelebil 1994). Wet sites like Star Carr (Clark 1954; Mellars and Dark 1998) and Williamson's Moss (Bonsall *et al*. 1989) where conditions have favoured the preservation of organic archaeological remains and associated palaeoenvironmental evidence are relatively rare in Britain.

Archaeobotanical studies are often limited by taphonomic processes and preservation conditions as plants generally have to be burnt, waterlogged, or desiccated to preserve. Interpretations are therefore often skewed towards the recovery of plant remains used for fuel (Boardman and Jones 1990; Matthews 2010) and food remains from burnt grain storage contexts (Van der Veen 2007, 979). Pollen analysis from offsite sediment sequences can be an indicator of human plant use against a backdrop of the natural landscape composition, but whilst pollen records for prehistoric Britain are extensive, direct links between vegetation change and anthropogenic activity remain unclear (Bishop *et al*. 2015) and pollen records are often limited in the precision with which they provide local ecological information (Simmons and Innes 1987, 395).

The use of durable plant microfossils is becoming increasingly common in archaeology to overcome some of these problems and to provide additional insights regarding ancient plant use, and the analysis of plant phytoliths is now well established in many parts of the world, though not without debate (see Shillito 2013). Phytoliths are bodies of biogenic silica that has hardened into place following deposition of monosilicic acid within and between the cells of plants. Monocotyledon (monocot) plants, and grasses in particular, tend to produce larger quantities of phytoliths per gram of plant material than dicotyledon (dicot) plants (Albert and Weiner 2001). Dicots produce both lower absolute quantities of phytoliths but also more amorphous types, which are difficult to assign to a particular genus or species, though the relative proportions or ratios of specific morphologies can be useful in determining broad categories of plant use and palaeoenvironmental reconstruction (Piperno 2006, 119-125; Strömberg *et al*. 2018, 264). The inorganic nature of phytoliths enables them to preserve under a wide range of conditions, including high temperatures and acidic soils (Pearsall 2014,

55; 2015, 274) meaning these microremains are useful where other plant remains are poorly preserved (Piperno 2006, 7).

Phytolith analysis is particularly well suited to semi-arid environments, as their formation within the plant is linked to water availability and evapotranspiration (Jenkins *et al*. 2016; Madella *et al*. 2009; Mithen *et al*. 2008; Rosen and Weiner 1994). In these environments, large 'conjoined' phytoliths from entire sections of plant tissue can form, making it possible to distinguish between different types of closely related plants, such as domesticated cereals, on the basis of the tissue morphology (Rosen 1993). In regions with lower rates of evapotranspiration, less water availability, and where plants grow on substrates with less silica availability, as well as when plants are not prolific phytolith producers, the formation and recovery of phytoliths may be limited or even non-existent (Piperno 2006).

A small number of British studies have recovered phytoliths from sediment samples (Elliott 2018; McQuilkin 2014; Murphy 1986; Powers *et al*. 1989; Robinson and Straker 1991) and from residues on artefacts and skeletal remains (Armitage 1975; Hart 2011; Maslin 2015; Milner and Gwynne 1974; Radini *et al*. 2016). Powers *et al*. (1989) examined phytolith assemblages from coastal sand dune environments in the Outer Hebrides and identified that phytolith assemblages associated with human occupation were orders of magnitude greater than those that occur naturally. Madella (2007) successfully identified phytoliths from the community of Braehead, Scotland, and investigation of deposits at Coppergate and 22 Piccadilly (ABC Cinema) in York has yielded promising results (McParland 2016). These studies have been small scale and important but limited by the lack of an established reference collection of phytoliths from native plant types in Britain.

Despite these problems, there is still significant potential for phytolith studies in Britain; in continental northern Europe, where the environment is similar to that of Britain, phytoliths have been analysed extensively (predominantly from medieval contexts) alongside soil micromorphological studies to try to understand the origin and depositional history of phytoliths in urban 'dark earths', where they are thought to represent the local environment and a range of human activities including fuel use and agricultural practices (Devos *et al*. 2009, 2013; Macphail *et al*. 2004; Simpson *et al*. 1998; Vrydaghs *et al*. 2015). The success of such studies indicates that this is an avenue worth pursuing in other contexts, albeit with careful consideration of taphonomy, as part of a multi-proxy approach. While interdisciplinary studies can better inform complex assemblages of archaeological and paleoenvironmental data (Macphail 1981; Ryan and Blackford 2010; Wouters *et al.* 2019), the application of such an approach is, unfortunately, not routine practice at most archaeological sites. By integrating phytolith data with archaeologically recovered material culture, pollen analyses, and radiocarbon dating, we elaborate our understanding of Williamson's Moss, as well as demonstrate the utility of phytolith analyses for the study of prehistoric British sites.

As noted by Hart (2016), archaeological phytolith analysis has recently entered a new phase of 'expanding applications' with the number of studies utilising phytoliths having increased considerably in the past decade. As phytolith analysis becomes better known and utilised within the wider discipline, the possibility of the application of such analyses retrospectively to earlier excavations is raised. In Britain and elsewhere, bulk soil samples may be retained especially for such purposes and, as demonstrated by McParland's (2016) work, archived

assemblages can contain important and preserved contexts for phytolith, diatom, soil geochemistry, and pollen analyses. Understanding how best to utilise such samples is therefore of significant interest, particularly for periods such as the Mesolithic where other types of plant remains are limited and the nature of human use of plants is thus poorly understood.

The aims of the analyses are to assess whether it would be possible to recover phytoliths in meaningful quantities from archived bulk soil samples and, if so, whether the phytolith assemblages could provide additional insights into Mesolithic plant use and environment at Williamson's Moss, and thus assess the potential for this type of analysis at other early prehistoric sites in similar environments.

The Williamson's Moss archaeological site

Williamson's Moss is one of a series of coastal Mesolithic sites near the estuary of the River Esk in Cumbria, northwest England, first recognized as lithic scatters during surveys of ploughed fields. The Williamson's Moss site was chosen for excavation owing to its proximity to a large peat-filled basin with palaeoenvironmental potential and because a substantial part of the site had escaped damage from ploughing. The site lies immediately behind a raised shingle beach (formed when the mid-Holocene marine transgression reached its maximum) where a low-relief ridge is flanked by Late Pleistocene palaeochannels. The palaeochannels had ceased to be active stream courses and were partly filled with sediment prior to the Mesolithic occupation which extended onto the channel surfaces. Elevated moisture levels in the palaeochannel infill sediments resulted in good preservation of organic

remains, primarily archaeological wood and bark. Following a test-pit survey in 1978, excavations were undertaken from 1981–1986 aimed at understanding the nature, chronology and environmental impact of the Mesolithic occupation. Settlement evidence proved not to be confined to the Mesolithic; sporadic traces of Neolithic and Bronze Age activity were also uncovered (Bonsall *et al*. 1989, 1994; Bonsall 2007).

Fig. 1

Archaeological features in excavation Areas E1 and E2, including raised platforms, were identified beneath fine-textured slope wash deposits that accumulated during the Holocene (Bonsall *et al*. 1989, 187–194). Structure 1 *(*Area E1) consisted of a raft-type foundation of oak branches overlain by a black well-humified peat of average thickness *c*. 20 cm containing abundant birch bark fragments (Figure 2). The peat layer was interpreted as the decayed remnants of an original brushwood cover laid over a timber lattice to create an artificial raised platform over marshy ground (Bonsall *et al*. 1989). Radiometric ^{14}C dates on birch bark fragments from the peat indicate an age of *c*. 4400 cal BC (Bonsall *et al*. 1989) for the structure, which falls close to the end of the Mesolithic or, conceivably, around the time of the Mesolithic/Neolithic transition.

Fig. 2

In Area E2, Structure 3 was a timber lattice (resembling Structure 1 in Area E1) which may have been connected to the higher ground at the edge of the palaeochannel by Structure 4, a raised linear feature of redeposited earth and stones. Structures 3 and 4 are undated but they

are older than (i.e. stratigraphically below) Structure 5 – a hearth feature overlying a thin layer of birch bark supported by foundation timbers – which is dated to the Bronze Age by a radiometric ^{14}C measurement of *c*. 1800 cal BC (Bonsall *et al*. 1989, 194).

The timber structures at Williamson's Moss and associated evidence of woodworking – in the form of radial splitting of oak trunks and whittling marks on branches (Bonsall *et al*. 1989) – find parallels in Mesolithic contexts elsewhere in northern England, at Star Carr (Conneller *et al*. 2012) and Bamburgh Kaims (Young *et al*. 2015).

Samples for palynological analysis were collected from the soil profile of Area E1 by Bonsall using overlapping Kubiena tins and kept in cold storage until analysed. A vertical series of 23 subsamples was extracted from the Kubiena tins, the resulting pollen profile spanning from *c*. 32-115 cm below the modern land surface and passing through the peat ('decayed brushwood') of Structure 1. The ^{14}C dates for the 'brushwood' of Structure 1 were used to 'anchor' the pollen sequence. The results of the pollen analysis were interpreted to indicate that the palaeochannel had been largely surrounded by trees and shrubs preferring carr wetland environments during the Mesolithic occupation (Tipping 1994), although this interpretation was contested by Bonsall *et al*. (1994) citing archaeological and pedological evidence for an extensive clearing on the northeast side of the palaeochannel during the Mesolithic.

Materials and Methods

Sampling strategy

In 1982, bulk soil samples (6-12 litres in volume) from successive excavation spits in 50 x 50 cm excavation quadrats associated with the various structures in Areas E1 and E2 were retained for post-excavation analysis. These were double bagged in 500-gauge (125-micron thick) polythene, and stored in cool, dark conditions. In 2015 bulk samples from Structures 1 and 5 were subsampled for phytolith analysis; no signs of drying out or fungal attack were observed. Though targeted sampling, also referred to as point sampling, during excavation is ideal for higher resolution interpretation, the approach adopted here makes use of previously underutilized, archived material, and as such is closer to the technique of 'pinch/composite sampling' (Pearsall 2015, 76).

In total, 12 subsamples were taken from the bulk soil samples in storage, six from Area E1 (within and adjacent to Structure 1, itself) and six from Area E2 (within and adjacent to Structure 5). Details of the subsamples are provided in Table 1 and Figures 3 and 4. The samples from Structure 1 were targeted initially as they corresponded to the earliest dated human activity in the palaeochannel and thus might provide information on Mesolithic plant use. These samples originated from Area E1 and were spatially constrained within a single 50 x 50 cm excavation quadrat. The Structure 5 samples were selected for comparative purposes. They came from three different grid squares, located successively further away from the structure.

Table 1

Area E1 samples within the EY 55 D quadrat were associated with the 'brushwood cover' of Structure 1 (Figure 3) and correspond to each of the four excavation levels (spits 16–19, between *c*. 0.75–0.95 m depth). Two sets of samples were analysed from spits 17 and 18 and this repetition of analyses provided useful information on inter-sample variability.

Fig. 3

Area E2 samples cover three excavation quadrats (EF 55A, EF 53A, EF 51A) spanning a horizontal distance of 4 m, and a depth range of approximately 25 cm. They were associated with Structure 5 and located near the hearth. One set of two samples originates from "like" contexts in spit 2 and offers additional comparison for inter-sample variability (Figure 4).

Fig. 4

Samples were subsampled and processed following protocols outlined by Shillito (2011, 27-29). In brief, processing included carbonate removal using HCl, removal of the clay fraction using density settlement, removal of organic matter in a muffle furnace, and separation of the phytoliths from non-biogenic mineral material using a process of centrifugation in a heavy density liquid. The recovered material was dried and weighed. Approximately 3 mg of extract was mounted in Entellan on a glass slide and examined using a Leica DM300 microscope under plane- and cross-polarized light at magnifications of x200 and x400. Microphotographs of phytoliths were captured using an integral digital camera.

Phytolith counting and identification

To ensure a representative sample, between 200 and 300 single phytoliths or 50 to 100 multicellular phytoliths were counted for each sample. According to Albert and Weiner (2001), error margin is reduced from 23% when counting 194 phytoliths to 12% by counting 265 phytoliths. The number of phytoliths per slide was calculated following Shillito (2011).

Phytoliths were identified by shape, surface texture/decoration and ornamentation, as outlined in the *ICPN* (Madella *et al*. 2005) and with reference to published standard literature (PhytCore Online Database; Piperno 2006; Rapp and Mulholland 1992; Twiss *et al*. 1969). On average, 300 phytoliths were counted within four transects of a slide; however, due to phytolith degradation in some samples, counting additional transects was necessary to reach a representative number of phytoliths.

Phytolith morphologies were grouped into broad categories that were then attributed to monocot or dicot plants and plant parts. Morphotypes were grouped into long cells (monocots primarily), short cells (monocots, and grasses specifically), platelets/aggregates (dicots), and miscellaneous/unidentifiable, based upon phytolith interpretations from sites with similar ecosystems (primarily Bobrov 2007; Madella 2007). Tracheids, mesophyll, and polyhedral phytoliths have widespread and repetitive production in many plants (Piperno 2006, 42-43) and so were not used for identifications in this assemblage and were categorized as miscellaneous. Other microfossils observed during microscopic examination included microcharcoal, diatoms and sponge spicules. These were counted but not identified beyond general type categories.

Statistical analysis

Statistical measurements were performed in Stata 12.1, employing the Fisher's Exact Test to analyse whether there were differences in phytolith category compositions among four morphological groups (Long cells, Short Cells, Miscellaneous, and Platelets/Aggregates between like-paired samples from Area E1 and Area E2 (Table 2). Like-paired samples are those sub-sampled from bulk samples taken from the same excavation quadrant, unit, and

spit. Comparisons of inter- and intra-site patterns of data are valuable interpretative methods (Piperno 2006, 114) but as control samples were unavailable, comparisons were drawn between samples within the Williamson's Moss site to assess variance among samples and verify intra-site spatial variation.

Results

Phytolith concentrations

The majority of samples from the Williamson's Moss palaeochannel have similar concentrations of phytoliths, ranging from 20,000–30,000 per gram of sediment (Figure 5). Notable exceptions include Samples 1 and 6, both from Area E1, which contained significantly higher and lower concentrations at 117,489 and 734 phytoliths per gram of sediment, respectively (Figure 5). Area E1 exhibits a greater dispersion of values away from the mean (standard deviation of 39,753 compared to Area E2 5,224), due to the two outlier values – Sample 1 containing the highest concentration of phytoliths and Sample 6 the lowest concentration.

The overall concentrations recovered from Williamson's Moss are considered relatively high compared to the phytolith values recovered from the coastal dune environments in the Hebrides (Powers *et al*. 1989). Powers *et al*. (1989, 35) described phytolith concentrations from both modern and archaeological samples, with those from archaeological middens and cultivated contexts ranging between 3,000 and 938,000 phytoliths per gram of sediment.

Fig. 5

Spatial variation in morphotypes

Raw counts of phytolith morphologies, along with their respective groups, categories and interpretations, can be seen in Table 3 and 4. Overall, the most frequent phytolith morphologies identified in the assemblage include psilate long cells and trichomes, which most likely indicate grasses, reeds, or sedges (see Tables 3 and 4). Square short cells and rugulated, irregular, multicellular aggregates are also common in the assemblage, and interpreted as dicot material. Multicellular aggregates were exclusively dicot material and counted as one articulated tissue, following the guidelines noted above (Albert and Weiner 2001, Shillito 2011). Jenkins *et al*. (2011, 390) recommend relative data as the most appropriate method of analysis when there is an uncertainty of sedimentation accumulation rate, and thus relative counts of identified phytolith morphotypes are presented here (Figures 6, 7, and 8).

Area E1 samples averaged 61% monocot to 39% dicot material (Figures 6 and 8) and although monocots dominate the assemblage, it has a surprisingly high percentage of dicot material. Like-paired samples (Samples 2 and 3, and 4 and 5) are quite distinct in composition, both when viewed in relative percentages (Figure 8) and when compared using Fisher's Exact Test ($p<0.001$; see Table 2). This test confirms that there are significant differences in composition observed between like-paired samples, which are highly unlikely to be due to random sampling.

Area E2 averages 67% monocot derived phytoliths, with one sample containing a higher proportion of dicot material (Sample 8, 56% dicot). Like-paired samples in Area E2, Samples

9 and 10, are also statistically distinct from one another ($p<0.001$ by Fisher's Exact Test; see Table 2).

Fig. 6

Fig. 7

Fig. 8

Discussion

Phytoliths tend to remain in the site of deposition (Piperno 2006, 21) and we understand this assemblage as local in origin; from the anthropogenic deposition of birch brushwood, the natural vegetation in the vicinity of Areas E1 and E2, and/or flooding events bringing in sediment from the surrounding landscape. While phytolith analyses have been shown to be effective in identifying human activity (Cabanes *et al*. 2011) or specific archaeological features such as hearths (Piperno 2006, 83), it is debatable whether this is the case with more ephemeral occupation surfaces, especially when the depositional environment of those contexts is not well understood (Shillito 2017; Strömberg *et al*. 2018, 248). The sampling locales in this analysis were identified as anthropogenic during excavations (Bonsall *et al*. 1989; Tipping 1994) but despite the sealed nature of Areas E1 and E2 identified during excavation, the phytoliths from these sediments cannot be definitively interpreted as anthropogenic in origin. The lack of high-resolution stratigraphic and spatial information, and a thorough understanding of the depositional and taphonomic activities in the areas of interest, permit only general interpretations of the phytolith and pollen assemblages.

Monocot plants dominate the phytolith assemblage and indicate vegetation including grasses, reeds, and sedges. Considering dicots' notoriously low phytolith production rate in comparison to grasses (Albert and Weiner 2001, 259), a fair proportion of the Williamson's Moss assemblage does consist of dicot material. The phytolith assemblages of both Areas E1 and E2 are comprised by at least 35% dicot types, with both Samples 2 and 7 containing a majority of dicot phytolith morphotypes. During excavation of Structure 1, the peat was observed to be "composed of twigs, thin branches, and bark" and was interpreted as the decayed remains of birch brushwood (Bonsall 1989, 190), which could explain the contexts' high dicot compositions. The lowermost sample in Structure 1 (Sample 6), exhibits very low dicot numbers, despite the associated feature being composed of wood and birchbark. This sample, however, had the lowest phytolith concentrations of all the samples analysed (Figure 6) and may more accurately be reflecting a degraded sample that was subject to silica recycling following abandonment of Structure 1. Overall, the phytoliths associated with Structure 1 generally indicate more varied kinds of plants and plant parts than those found in Area E2 (Figures 7 and 8), including a higher quantity of dicot (wood and bark) material.

The presence of microscopic charcoal, which was indeed identified in Williamson's Moss samples, would support the possibility of local anthropogenic burning, but again, it is impossible to say with certainty without further contextual information provided, for example, by micromorphological analysis. Other evidence of burning, such as melted phytoliths, were not noted during identification. In addition to water, wind is one of the most pervasive movers of phytoliths (Wallis 2001) and could have contributed microcharcoal and phytoliths from localised burning events or fire located some distance from the palaeochannel. When concentrations of microcharcoal and dicot material are examined (of all

the microparticles counted) there does not seem to be a correlation between the two (Figure 9). Pollen analysis raised the possibility of surface run-off and wind moving microremains into the palaeochannel (Bonsall *et al*. 1989), and we strongly suspect that water run-off from the higher ground surrounding the Williamson's Moss site, may have contributed to the phytolith assemblage over time. This does not mean the deposits are homogenous or that there was no vertical displacement of microremains, but that the remains may in part reflect the vegetation growing around the channel during the use and subsequent abandonment and decay of Structure 1 (Bonsall *et al*. 1989, 198).

Fig. 9

The pollen samples analysed from the Williamson's Moss site reflect the local environment rather than the anthropogenic constructions of Area E1 (Bonsall *et al*. 1989, 198). As expressed by Tipping (1994), it is difficult to extrapolate the activities suggested through pollen to features or areas that are not directly dated. The phytolith assemblage, which contains a substantial amount of dicot material, associated with diatoms and sponge spicules, could be seen as supporting an "expansion of wetland tree taxa" around the palaeochannel (Tipping 1994, 126); alternatively, it might reflect the *in situ* decomposition of anthropogenically deposited brushwood and colonization by vegetation, combined with surface runoff from the surrounding landscape.

Overall, the phytolith assemblage from the peat ('brushwood') of Structure 1 in Area E1 displays a decreasing amount of monocot and an increasing frequency of dicot material from bottom to top of the deposit (Figure 6). This general trend suggests a transitioning environment with increasing numbers of trees.

Sample 7 from Structure 5 came from near a hearth feature, and has a higher proportion of dicots, possibly related to fuel use. Sample 10 has a relatively high proportion of cuneiform bulliforms (4%) compared to other Area E2 samples (1–2%), a morphology that has been associated with wetland environments/plants (Bobrov 2007, 157; Golveya 2007, 199; Ramsay 2016), and could be representing *Phragmites australis* or *Danthonia decumbens* (McParland 2016). Cuneiform bulliform phytoliths can also originate from wild grasses (Madella 2007, 108), but nonetheless suggest an environment with riparian monocot plants. The high proportion of sponge spicules and diatoms, together with a low presence of microcharcoal ("Other Microremains" in Figure 7) throughout E2 supports a wetter environment, with fewer burning events, than seen in the much older samples of Area E1. Overall, the wetland plants indicated by phytolith analysis correspond with previous archaeological interpretations of the brushwood platform as an anthropogenic means to manage wetland, marshy environments.

The usefulness of bulk, archived samples from previously excavated sites

Whilst there is some support for the utility of phytolith analysis in providing localised environmental information, complementing that afforded by pollen data, possibly the most important results of this work are the methodological insights regarding the usefulness of archived samples (and bulk samples more generally) for phytolith analysis. Statistical analyses revealed significant differences between the morphological compositions of each of the three like-paired samples. Given this variability in composition, it is clear that there are significant differences between the assemblages, but it is not possible to determine whether these are due to spatial differences in plant deposition or to spatially distinct post-depositional

taphonomic and diagenetic conditions. Given that phytoliths are thought to represent "highly localised, if not in situ decay" (Piperno 2006, 83), it is not surprising that spatial variations are so marked. The spatial variation is significant but impossible to interpret without a better understanding of the micro-context from which these samples were excavated (Shillito 2011).

While excavators may assume that arbitrary levels of 5 centimetres will represent discrete contexts, the degree to which phytolith deposition is specific to a particular time and place renders this sampling approach a broad, undifferentiated sampling technique. It is evident that sampling techniques that cater to specific, isolated phytolith contexts and that are designed to address specific research questions are imperative for confident spatial interpretations of plant deposition, making bulk samples of limited use for phytolith analysis at sites where plant use was variable across space and time, beyond offering general presence/absence of broad categories of plant types.

Recent analysis of burnt mound deposits in Great Britain demonstrates the advantages of combining phytolith analysis simultaneously with sediment micromorphology (Gardner 2018), a combination of methods that also enables detection of whether plant microremains may have moved through sediment due to water action or other forces. Such a sampling strategy must be designed specifically for analysis at the microscale.

While it is impossible to make recommendations that would cover all the requirements for future methodological innovations, as the discipline of archaeology sees a shift in analytical methods to ever higher resolution microscopic and even molecular approaches, the collection of archive samples should adapt accordingly. Large bulk soil and sediment samples are

unlikely to provide the resolution needed for these methods. Our recommendations are therefore to collect samples with an emphasis on distinct features to assess plant use for specific activities, with control/contemporaneous samples from outside the site, and to provide environmental information to accompany the archaeological contexts as part of a multi-proxy sediment profile. Samples for high resolution analyses should be collected with a paired micromorphology block to provide depositional and micro-contextual information. British phytolith studies also need better reference collections that focus on likely candidates for plants exploited in early prehistory, and crucially, further experimental studies are needed to better understand taphonomic processes in temperate soils.

Conclusions

Whilst phytolith analysis is challenging for British sites compared to areas where plants produce more phytoliths and those phytoliths are better preserved, it is not only possible but also potentially highly informative. The aims of this analysis were to test whether phytoliths could be recovered in significant quantities from this type of site, and whether they could provide any insight into human-environment relationships and plant use in prehistoric Britain. Our analyses indicate that phytoliths are preserved in significant quantities, including both monocot and dicot types, along with other siliceous microfossils including sponge spicules and diatoms, illustrating that significant quantities of well-preserved phytoliths can be recovered from archived samples from previously excavated British archaeological sites. However, interpretation of these assemblages from bulk archived samples, which are typically collected for generic future analyses, is problematic. Bulk samples have limited precise contextual information, which is needed to provide insights into the depositional pathways and formation processes of the assemblage. A viable solution to this problem is to

place pollen samples in long-term storage for future phytolith analysis, to be used as complementary contextual samples. Statistical analyses have revealed the variable composition of like-paired samples and highlight the need for sampling techniques that have the precision needed to mirror research questions.

Overall, the Williamson's Moss phytolith assemblage complements local environmental interpretation derived from earlier pollen studies and confirms that phytoliths from bulk samples have some utility in assessing local environmental conditions in cases where pollen is absent or poorly preserved. The relative ease of the phytolith extraction method means it is a modest additional time input if pollen analysis is already being planned. Future studies should combine high-resolution interval sampling of deposits with complementary techniques such as sediment micromorphology, which can provide context for informed interpretations.

Acknowledgments

This paper is based on a dissertation submitted in partial completion of the requirements for the degree of Master of Science in Archaeology from the University of Edinburgh and contributes to the growing body of knowledge of the Eskmeals Project. Thank you to the University of Edinburgh and Boston University for use of their laboratory space and equipment. We would like to thank Tom Gardner, Alan Dalton, Richard Tipping, and Catriona Pickard for their guidance and advice throughout processing and analysis. We thank the Boston University Environmental Archaeology Laboratory Group and anonymous reviewers for their very helpful suggestions and input in improving this work. All errors remain our own.

Declaration of Interest Statement

References

Albert, Rosa Marie. 2011. PhytCore Database n.d. (Accessed May-July 2015). http://www.phytcore.org/phytolith/index.php

Albert, R. M. and Weiner, S. 2001. Study of phytoliths in prehistoric ash layers from Kebara and Tabun caves using a quantitative approach, pp. 251-266 in Meunier, J. D. and Coline, F. (eds.) *Phytoliths: Applications in Earth Sciences and Human History*. Lisse (Netherlands): Balkema.

Armitage, P. L. 1975. The extraction and identification of opal phytoliths from the teeth of ungulates. *Journal of Archaeological Science* 2, 187–197.

Bishop, R. R., Church, M. J. and Rowley-Conwy, P. A. 2015. Firewood, food and human niche construction: the potential role of Mesolithic hunter-gatherers in actively structuring Scotland's woodlands. *Quaternary Science Reviews* 108, 51–75. https://doi.org/10.1016/j.quascirev.2014.11.004

Boardman, S. and Jones, G. 1990. Experiments on the effects of charring on cereal plant components. *Journal of Archaeological Sciences* 17, 1–11.

Bobrov, A. A. 2007. Phytoliths and micropalaeontological data in a boggy soil, pp. 155–164 in Madella, M. and Zurro, D. (eds.), *Plants, People and Places: Recent Studies in Phytolith Analysis*. Oxford: Oxbow Books.

Bonsall, C. 2007. Human-environment interactions during the Late Mesolithic of the Cumbria coastal plain: the evidence from Eskmeals, pp. 25–43 in Cherry, P. (ed.), *Studies in Northern Prehistory: Essays in Memory of Clare Fell*. Kendal: Cumberland and Westmorland Antiquarian and Archaeological Society.

Bonsall, Clive, Sutherland, D. G., Tipping, R. and Cherry, J. 1989. The Eskmeals Project: Late Mesolithic settlement and environment in north-west England, pp. 175–205 in Bonsall, C. (ed.), *The Mesolithic in Europe*. Edinburgh: John Donald.

Bonsall, C., Sutherland, D. G. and Payton, R. W. 1994. The Eskmeals coastal foreland: archaeology and shoreline development, pp. 90–102 in Boardman, J. and Walden, J. (eds.), *The Quaternary of Cumbria: Field Guide*. Oxford: Quaternary Research Association.

Clark, J. G. D. 1954. *Excavations at Star Carr: An Early Mesolithic Site at Seamer, near Scarborough, Yorkshire*. Cambridge: Cambridge University Press.

Conneller, C., Milner, N., Taylor, B. and Taylor, M. 2012. Substantial settlement in the European Early Mesolithic: new research at Star Carr. *Antiquity* 82, 1004–1020.

Devos, Y., Vrydaghs, L., Degraeve, A. and Fechner, K. 2009. An archaeopedological and phytolitharian study of the 'Dark Earth' on the site of Rue de Dinant (Brussels, Belgium). *Catena* 78, 270–284.

Devos, Y., Nicosia, C., Vrydaghs, L. and Modrie, S. 2013. Studying urban stratigraphy: Dark Earth and a microstratified sequence on the site of the Court of Hoogstraeten (Brussels, Belgium). Integrating archaeopedology and phytolith analysis. *Quaternary International* 315, 147–166.

Elliott, S. 2018. The Phytoliths, pp. 333 - 345 in Fulford, M., Clarke, A., Durham, E. and Pankhurst, N. (eds.), *Late Iron Age Calleva: the pre-conquest occupation at Silchester Insula IX.* Society for the Promotion of Roman Studies.

Fishkis, O., Ingwersen, J., Lamers, M., Denysenko, D. and Streck, T. 2010. Phytolith transport in soil: a field study using florescent labelling. *Geoderma* 157, 27–36

Gardner, T. 2018. Assessing the contribution of integrated geoarchaeological approaches to understand the formation and function of burnt mounds: the example of Hoppenwood Bank, north Northumberland. *The Archaeological Journal* **176**, 1–33.

Golveya, A. 2007. Various phytolith types as bearers of different kinds of ecological information, pp. 196–200 in Madella, M. and Zurro, D. (eds.), *Plants, People and Places: Recent Studies in Phytolith Analysis*. Oxford: Oxbow Books.

Hart, T. C. 2011. Evaluating the usefulness of phytoliths and starch grains found on survey artifacts. *Journal of Archaeological Science* 38, 3244–3253.

Hart, T. C. 2016. Issues and directions in phytolith analysis. *Journal of Archaeological Science* 68, 24–31.

Jenkins, E., Baker, A. and Elliott, S. 2011. Past plant use in Jordan as revealed by archaeological and ethnoarchaeological phytolith signatures, pp. 381–400 in Mithen, S. and Black, E. (eds.), *Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley*. Cambridge: Cambridge University Press.

Jenkins, E., Jamjoum, K., Nuimat, S., Stafford, R., Nortcliff, S. and Mithen, S. 2016. Identifying water availability through phytolith analysis: an experimental approach. *Journal of Archaeological Science* 73, 82–93.

Macphail, R.I. 1981. Soil and Botanical Studies of the "Dark Earth" in Jones, M. and Dimbleby, G.W. (eds.). *The Environment of Man: The Iron Age to the Anglo-Saxon Period.* British Archaeological Reports, Oxford.

Madella, M., Alexandre, A. and Ball, T. 2005. International code for phytolith nomenclature. *Annals of Botany* 96, 253–260.

Madella, M. 2007. The analysis of phytoliths from Braehead archaeological site (Scotland, UK), pp. 101–109 in Madella, M. and Zurro, D. (eds.), *Plants, People and Places: Recent Studies in Phytolith Analysis*. Oxford: Oxbow Books.

Madella, M., Jones, M. K., Echlin, P., Powers-Jones, A. and Moore, M. 2009. Plant water availability and analytical microscopy of phytoliths: implications for ancient irrigation in arid zones. *Quaternary International* 193, 32–40.

Maslin, S. P. 2015. The taphonomy and micromorphology of sunken-featured buildings from Lyminge, Kent: a comparative mixed-method analysis. *Environmental Archaeology* 20, 202–220.

McParland, H. 2016. PhytoArchive Project Technical Report: Phytolith Assessment of Samples from 16022 Coppergate and 22 Piccadilly (ABC Cinema). York: York Archaeological Trust. https://www.yorkarchaeology.co.uk/wp-content/uploads/2015/05/PhytoArkive-Project-Report.pdf

Macphail, Richard, I., 1981. Soil and Botanical Studies of the 'Dark Earth', pp. 309 -331 in Jones, M. and Dimbleby, G. (eds.), *The Environment of Man: the Iron Age to the Anglo-Saxon Period*. Oxford: BAR British Series 87.

Macphail, Richard, I., Cruise, G. M., Allen, Michael, J., Linderholm, Johan, Reynolds. 2004. Archaeological soil and pollen analysis of experimental floor deposits; with special references to Butser Ancient Farm, Hampshire, UK. *Journal of Archaeological Science* 31: 175-191.

McQuilkin, A. 2014. Is it possible to determine plant material utilized in the construction of a Mesolithic domestic dwelling from an examination of phytoliths? Unpublished Bachelor's Dissertation, University of York.

Mellars, Paul and Petra Dark. 1998. *Star Carr in Context: New Archaeological and Palaeoecological Investigations at the Early Mesolithic Site of Star Carr, North Yorkshire*. Cambridge: McDonald Institute for Archaeological Research.

Milner, C. and Gwyne, D. 1974. The Soay sheep and their food supply, pp. 273–326 in Jewell, P. A., Milner, C. and Boyd, J. M. (eds.), *Island Survivors: The Ecology of the Soay Sheep of St. Kilda*. London: Athlone Press.

Mithen, S., Jenkins, E., Jamjoum, K., Nuimat, S., Nortcliff, S. and Finlayson, B. 2008. Experimental crop growing in Jordan to develop methodology for the identification of ancient irrigation. *World Archaeology* 40, 7–25.

Murphy, P. 1986. Botanical evidence, pp. 43–44 in Lawson, A. J., *Barrow Excavations in Norfolk 1950–1982*, East Anglian Archaeology Reports no. 29. Dereham: Norfolk Archaeological Unit.

Pearsall, D. M. 2014. Formation Processes of Pollen and Phytoliths, pp. 51–73 in Marston, J. M., D'Alpoim Guedes, J. and Warinner, C. (eds.), *Method and Theory in Paleoethnobotany*. Boulder, Colorado: University Press of Colorado.

Pearsall, D. M. 2015. *Paleoethnobotany: A Handbook of Procedures*, 3rd Edition. Walnut Creek, CA: Left Coast Press.

Piperno, D. R. 2006. *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists*. Oxford: Altamira Press.

Portillo, M., Llergo, Y., Ferrer, A. and Albert, R. M. 2017. Tracing microfossil residues of cereal processing in the archaeobotanical record: an experimental approach. *Vegetation History and Archaeobotany* 26, 59–74.

Powers, A. H., Padmore, J. and Gilbertson, D. D. 1989. Studies of late prehistoric and modern opal phytoliths from coastal sand dunes and machair in northwest Britain. *Journal of Archaeological Science* 16, 27–45.

Radini, A., Nikita, E. and Shillito, L-M. 2016. Human dental calculus and a Medieval urban environment, pp. 297-313 in Jervis, B., Broderick, L. and Grau-Sologestoa, I. (eds.), *Objects, Environment, and Everyday Life in Medieval Europe*. Turnhout: Brepols.

Robinson, M. and Straker, V. 1991. Silica skeletons and macroscopic plant remains from ash, pp. 3–13 in Renfrew, J. (ed.), *New Light on Early Farming: Recent Developments in Palaeoethnobotany*. Edinburgh: Edinburgh University Press.

Rosen, A. M. 1993. Phytolith evidence for early cereal exploitation in the Levant, pp. 160-171 in Pearsall, D. and Piperno, D. (eds.), *Current Research in Phytolith Analysis: Applications in Archaeology and Paleoecology*. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Rosen, A. M. and Weiner, S. 1994. Identifying ancient irrigation: a new method using opaline phytoliths from emmer wheat. *Journal of Archaeological Science* 21, 125–132.

Ryan, P. A. and Blackford, J. J. 2010. Late Mesolithic environmental change at Black Heath, south Pennines, UK: a test of Mesolithic woodland management models using pollen, charcoal, and non-pollen palynomorph data. *Vegetation History and Archaeobotany* 19: 545-558.

Shillito, L-M. 2011. *Daily Activities, Diet and Resource Use at Neolithic Çatalhöyük: Microstratigraphic and Biomolecular Evidence from Middens*. Oxford: Archaeopress.

Shillito, L-M. 2011. Simultaneous thin section and phytolith observations of finely stratified deposits from Neolithic Çatalhöyük, Turkey: implications for paleoeconomy and Early Holocene paleoenvironment. *Journal of Quaternary Science* 26: 576–588.

Shillito, L-M. 2013. Grains of truth or transparent blindfolds? Debates in archaeological phytolith analysis. *Vegetation History and Archaeobotany* 22, 71–82.

Shillito, L-M. 2017. Multivocality and multiproxy approaches to the use of space: lessons from 25 years of research at Çatalhöyuk. *World Archaeology* 49, 237–259.

Simmons, I. G. and Innes, J. B. 1987. Mid-Holocene adaptations and later Mesolithic forest disturbance in northern England. *Journal of Archaeological Science* 14: 385–403.

Simpson, I. A. Dockrill, Stephen, J., Bull, Ian, D. and Evershed, Richard, P. 1998. Early Anthropogenic Soil Formation at Tofts Ness, Sanday, Orkney. *Journal of Archaeological Science* 25: 729-746.

Struyf, E. and Conley, D. J. 2009. Silica: an essential nutrient in wetland biogeochemistry. *Frontiers in Ecology and the Environment* 7, 88–94.

Tipping, R. M. 1994. Williamson's Moss: palynological evidence for the Mesolithic-Neolithic transition, pp. 104–128 in Boardman, J. and Walden, J. (eds.), *The Quaternary of Cumbria: Field Guide*. Oxford: Quaternary Research Association.

Twiss, P. C., Suess, E. and Smith, R. M. 1969. Morphological classification of grass phytoliths. *Soil Science Survey of America Proceedings* 33, 109–115.

Vander Veen, M .2007. Formation processes of desiccated and carbonized plant remains – the identification of routine practice. *Journal of Archaeological Science* 34, 968–990.

Vrydaghs, L., Ball, T. B. and Devos, Y. 2016. Beyond redundancy and multiplicity. Integrating phytolith analysis and micromorphology to the study of Brussels Dark Earth *Journal of Archaeological Science* 68, 79–88.

Wallis, L. A. 2001. Environmental history of northwest Australia based on phytolith analysis at Carpenter's Gap 1. *Quaternary International* 83, 103–117.

Wouters, B, Devos, Y, Vrydaghs, L, Ball, T, Winter, N, Reygel, P. 2019. An integrated micromorphological and phytolith study of urban soils and sediments from the Gallo-Roman town Atuatuca Tungrorum, Belgium. *Geoarchaeology*, 1-19. https://doi.org/10.1002/gea.21722

Young, G., Dixon, G., Gardner, T., Gething, P., Paterson, D., Pederson, K. and Tipping, R. 2015. Bamburgh Research Project: Bradford Kaims Wetland Heritage Project – Archaeological Report. Blyth, Northumberland: Bamburgh Research Project.

Zvelebil, M. 1994. Plant use in the Mesolithic and its role in the transition to farming. *Proceedings of the Prehistoric Society* 60, 35–74.

Table 1: WM Area E1 and E2 sample summary (*, **, and * indicate 'like-paired samples'). Dates from Bonsall (2007).**

AREA E1 Structure One (4460- 4330 cal BC)	
Sample	**Sample Details**
1	EY 55 D spit 16 WM 137
2	EY 55 D spit 17 WM 133*
3	EY 55 D spit 17 WM 134*
4	EY 55 D spit 18 WM 136**
5	EY 55 D spit 18 WM 138**
6	EY 55 D spit 19 WM 135
AREA E2 Structure 5 (2030-1610 cal BC)	
7	EF 55 A spit 1 WM 691
8	EF 51 A spit 2 WM 692
9	EF 53 A spit 2 WM 693***
10	EF 53 A spit 2 WM 696***
11	EF 55 A spit 5 WM 697
12	EF 53 A spit 5 WM 699

Table 2: Fisher's Exact Test results on like-paired samples.

	Long Cells	Short Cells	Aggregates	Miscellaneous	Total
Sample 2	36	43	248	2	329
Sample 3	135	99	83	15	332
Total	171	142	331	17	661
Fisher's Exact = 0.000					

	Long Cells	Short Cells	Aggregates	Miscellaneous	Total
Sample 4	87	93	116	14	310
Sample 5	124	105	61	55	345
Total	211	198	177	69	655
Fisher's Exact = 0.000					

	Long Cells	Short Cells	Aggregates	Miscellaneous	Total
Sample 9	268	82	88	14	452
Sample 10	104	114	95	31	344
Total	372	196	183	45	796
Fisher's Exact = 0.000					

Table 3: Area E1 Phytolith Raw Counts, Groups, and Interpretations

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Group	Category	Interpretation
Psilate Long Cells	15	10	42	31	28	22	General Monocot - Long Cells	General Monocot - leaves, stems, inflorescences	Monocots
Fragmented Psilate Long Cells	25	23	52	56	80	54			
Echinate Long Cells	0	0	34	0	16	3			
Polylobate Long Cell	0	0	0	0	0	0			
Cylindrical Long Cells	1	3	7	0	0	3			
Cuneiform Bulliform	0	0	0	0	8	0			
Scutiforms	0	0	3	0	24	1			
Globulars	38	8	23	17	25	14			
Ovates/ Oblongs	18	7	29	36	7	35			
Trichomes	51	13	28	31	30	31			
Bilobate Short Cells	0	0	2	0	1	0	General Monocot - Short Cells	Poaceae, Panicoideae - C4	
Rondel Short Cells	15	15	14	9	10	13		Poaceae, Pooideae - C3	
Square Short Cells	62	45	49	53	35	42	Platelets/Aggregates	General Dicot - wood, bark, leaves	Dicots
Rugulated Irregular Platelets	17	132	9	36	6	0			
Rugulated, Irregular, Multicellular Aggregates	50	71	18	26	7	1			
Laminated Multicellular Aggregates	0	0	7	0	0	0			
Hairs	1	0	0	1	13	5			
Mesophyll	0	2	3	0	0	3	Short Cells - Misc.	Miscellaneous	Undiagnostic
Polyhedral Short Cells	3	0	5	14	51	4			
Tracheids	0	0	7	0	4	0			
Total Phytolith Count	**296**	**329**	**332**	**310**	**345**	**231**			
Sponge Spicules	2	3	2	0	0	0	Other Microremains		Environmental
Diatoms	0	0	48	6	24	6			
Fragmented Diatoms	4	0	29	12	25	5			
Microcharcoal	145	113	513	1232	884	1073			
Number of Transects Counted	4	6	4	5	4	7			

Table 4: Area E2 Phytolith Raw Counts, Groups, and Interpretations

	Sample 7	Sample 8	Sample 9***	Sample 10***	Sample 11	Sample 12	Group	Category	Interpretation
Psilate Long Cells	24	29	76	45	18	75	General Monocot - Long Cells	General Monocot - leaves, stems, inflorescences	Monocots
Fragmented Psilate Long Cells	21	38	144	54	19	19			
Echinate Long Cells	0	0	37	3	0	16			
Polylobate Long Cell	1	1	11	1	0	4			
Cylindrical Long Cells	0	0	0	1	0	0			
Cuneiform Bulliform	3	2	3	7	6	7			
Scutiforms	12	10	0	4	2	10			
Globulars	26	43	13	15	18	21			
Ovates/ Oblongs	8	17	33	55	10	32			
Trichomes	11	32	14	20	81	21			
Bilobate Short Cells	0	5	2	0	0	0	General Monocot - Short Cells	Poaceae, Panicoideae - C4	
Rondel Short Cells	6	20	17	13	25	28		Poaceae, Pooideae - C3	
Square Short Cells	32	59	55	50	51	114	Platelets/Aggregates	General Dicot - wood, bark, leaves	Dicots
Rugulated Irregular Platelets	0	0	0	0	0	0			
Rugulated, Irregular, Multicellular Aggregates	103	52	28	45	11	0			
Laminated Multicellular Aggregates	0	3	1	0	3	0			
Hairs	7	10	4	0	9	10			
Mesophyll	0	4	0	1	0	0	Short Cells - Misc.	Miscellaneous	Undiagnostic
Polyhedral Short Cells	32	20	10	28	31	32			
Tracheids	1	0	4	2	2	3			
Total Phytolith Count	**287**	**345**	**452**	**344**	**286**	**392**			
Sponge Spicules	1	3	17	3	0	3	Other Microremains		Environmental
Diatoms	3	3	38	3	2	48			
Fragmented Diatoms	5	2	26	1	3	56			
Microcharcoal	106	133	211	86	34	339			
Number of Transects Counted	5	6	4	4	4	4			

Fig. 1 Williamson's Moss, highlighting areas of phytolith sampling (Area E1 and E2), modified from Bonsall *et al*. (2007).

Fig. 2 Area E1, Structure 1 (photo © Clive Bonsall).

Fig. 3: Phytolith sample locations in Area E1 (Mesolithic/Neolithic transition), modified from Bonsall *et al*. (1989). The excavation was based on a grid of 1 m squares divided into 50 cm 'quadrats' to facilitate recording of the locations of artefacts and samples.

Fig. 4: Phytolith sample locations in Area E2 (Bronze Age hearth), modified from Bonsall *et al*. (1989).

Fig. 5: Number of phytoliths per gram of sediment in Area E1 (Samples 1-6) and Area E2 (Samples 7-12).

Fig. 6: Summary diagram of Area E1.

Fig. 7: Summary diagram of Area E2.

Fig. 8: Monocot (grasses, sedges, reeds) to dicot (wood and bark) total percentages in Area E1 (Samples 1-6) and Area E2 (Samples 7-12).

Fig. 9: Microcharcoal and Dicot Material as a percentage of the entire microremains in each sample.

Word Count: 5792/6000

Author's Checklist:

Author Details

1. Kali Wade:

1a: Social Media handles: instagram: @kalirwade, @archaeobot.adventures

twitter: @kalirwade

1b: Biographical Note: As the Environmental Archaeology Lab Supervisor, I get to play host to the varied and cutting-edge research projects taking place in the lab every day. Undergraduate, graduate, and professional researchers join our space to utilize equipment, reference collections, and collaborate on all kinds of projects. My personal research interests lie primarily in phytolith analysis, and particularly, phytoliths' potential to reconstruct ancient diet, technology, and paleoenvironment. I am currently building a laboratory phytolith reference collection focused on the Near East's Bronze and Iron Ages, and am working on two assemblages from Israel. This article is a reworking of my master's thesis, which focused on Williamson's Moss entire phytolith assemblage, investigating past fuel and technology plant use and the usefulness of sampling from bulk, archived samples.

2. Lisa-Marie Shillito:

2a: Social Media handles: twitter: @ArchaeologyLisa

2b: Biographical Note: LMS is a Senior Lecturer in landscape archaeology, School of History, Classics and Archaeology, Newcastle UK. She is an environmental archaeologist with expertise in geoarchaeology and chemistry. Her research focuses on understanding the relationships between people and their environments in the past, and how we can use the long term perspectives of archaeology to inform modern day responses to environmental change.

3. John M. Marston:

3a: Social Media handles: instagram: @archaeobot.adventures

3b: Biographical Note: John M. Marston is Assistant Professor of Archaeology and Anthropology at Boston University. He specialises in archaeobotany with research foci on agriculture, environmental change, and integration of environmental archaeological datasets. While his primary topic of study is the complex societies of the eastern Mediterranean and Southwest Asia, he also has conducted research in Africa, Europe, and Central Asia, spanning the Middle Pleistocene through recent times.

4. Clive Bonsall:

4a: Social Media handles: twitter: @CliveBonsall

4b: Biographical Note: Clive Bonsall is Professor of Early Prehistory at the University of Edinburgh. His interests include hunter-gatherer archaeology, the reconstruction of ancient diets using stable isotopes, raw material provenancing, and human–environment interactions. While his primary research focus over the past 25 years has been the post-glacial hunter-gatherers and early farmers of Southeastern Europe, he has also conducted fieldwork in northern England and Scotland.

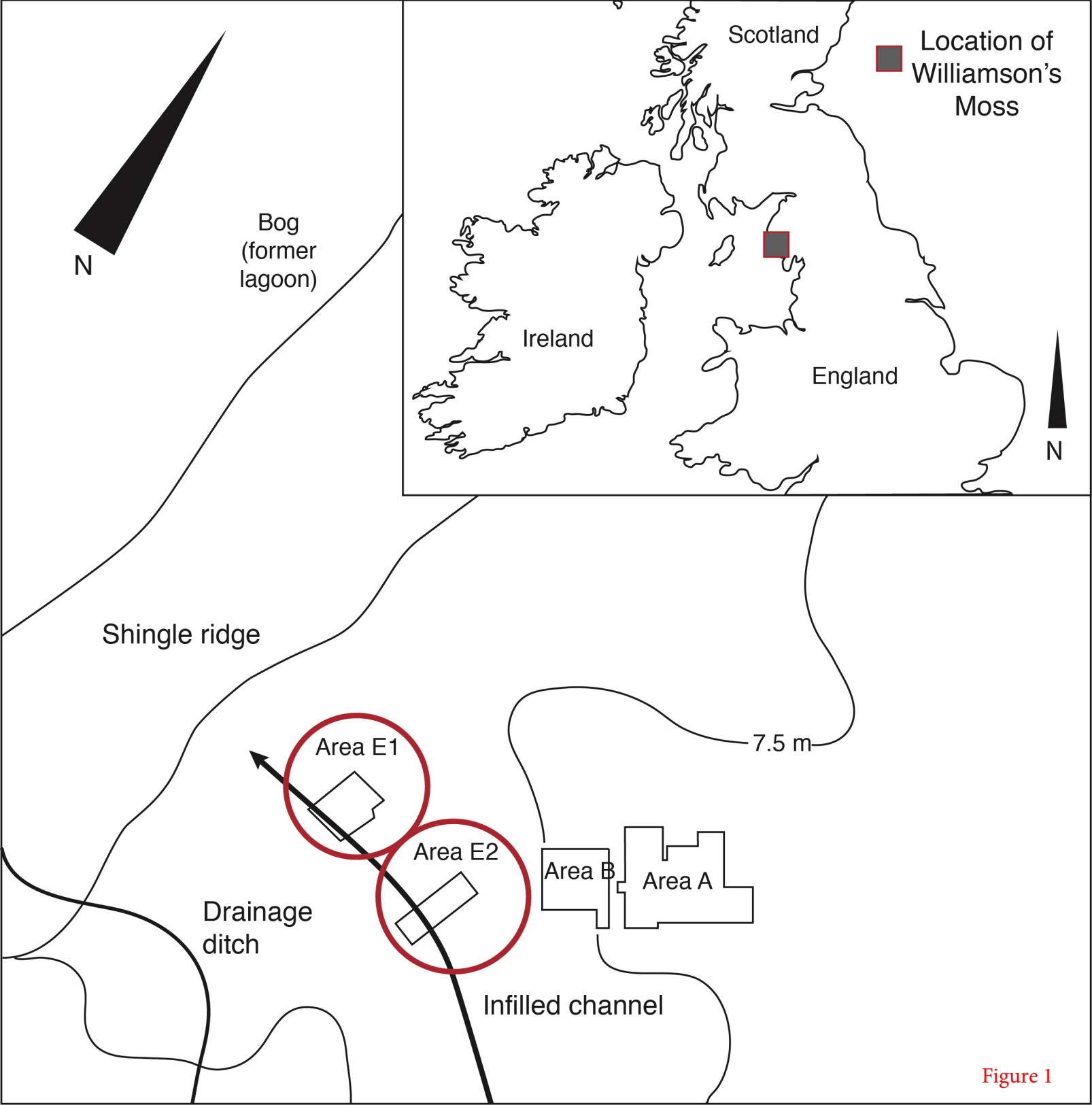
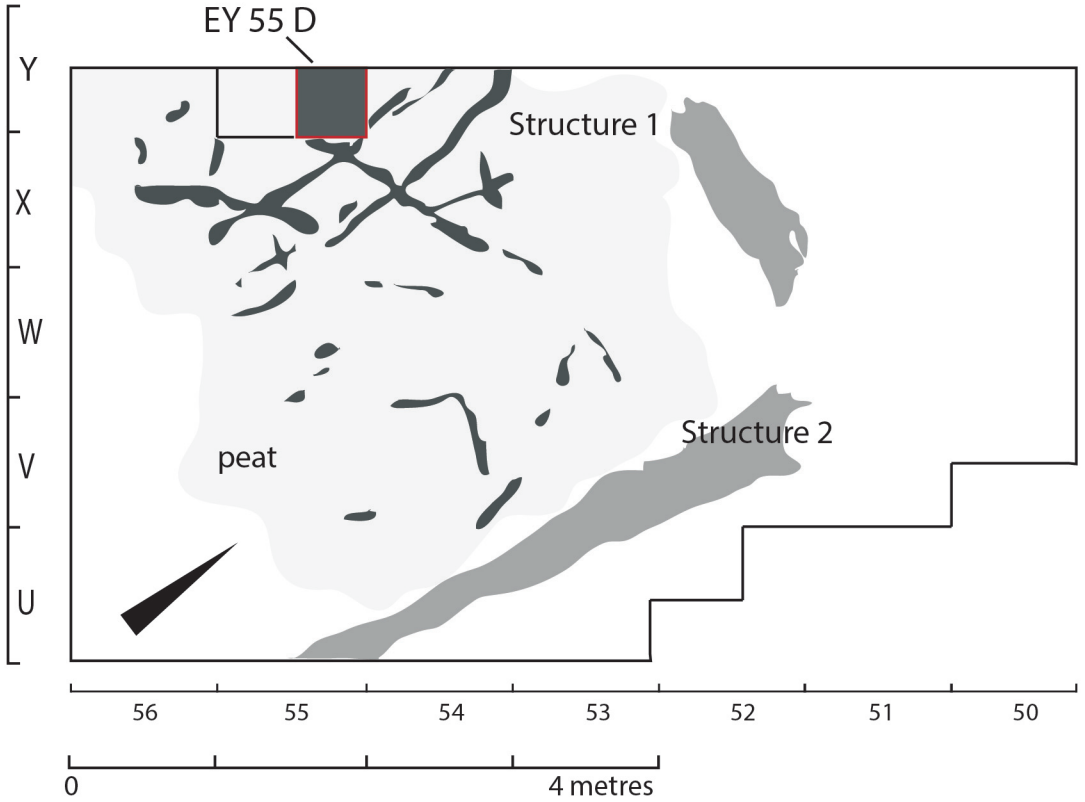

Scotland
Location of Williamson's Moss
Ireland
England
N
N
Bog (former lagoon)
Shingle ridge
7.5 m
Area E1
Area E2
Area B
Area A
Drainage ditch
Infilled channel

Figure 1

Figure 2


EY 55 D
Y
X
W
V
U
Structure 1
Structure 2
peat
56
55
54
53
52
51
50
0
4 metres

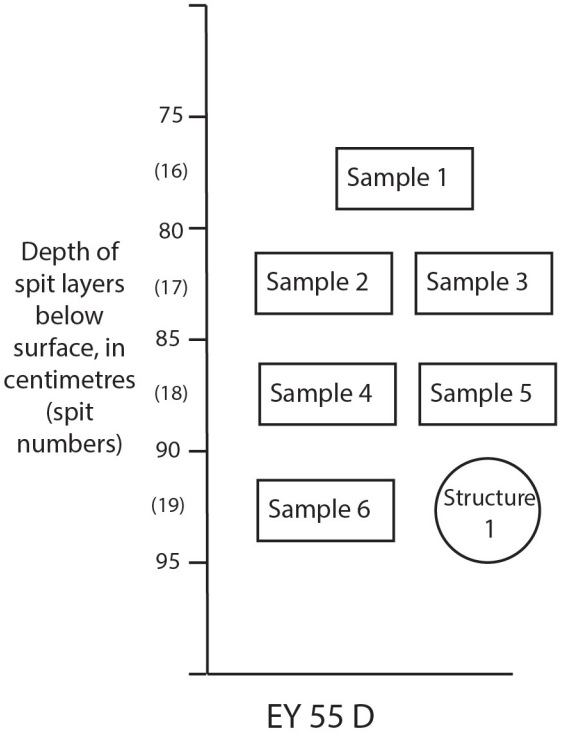
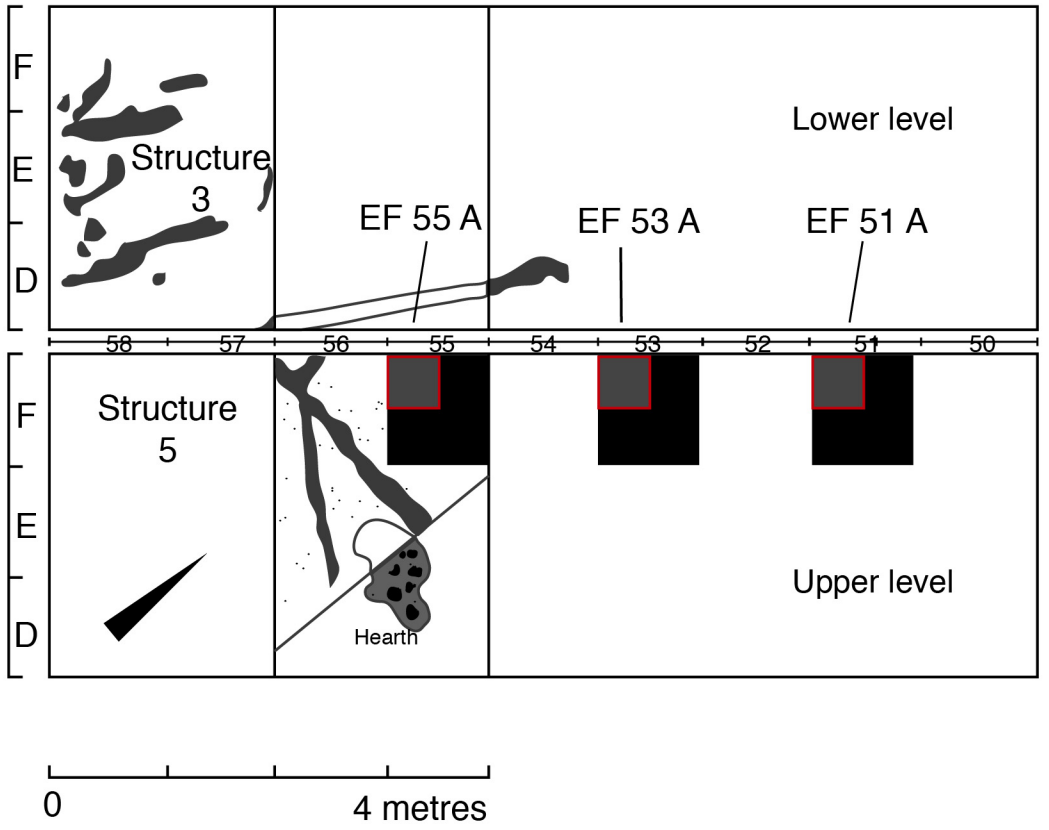

Depth of spit layers below surface, in centimetres (spit numbers)
75
(16)
80
(17)
85
(18)
90
(19)
95
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Sample 6
Structure 1
EY 55 D

Figure 3


F
E
D
Structure
3
EF 55 A
EF 53 A
EF 51 A
Lower level
58
57
56
55
54
53
52
51
50
F
E
D
Structure
5
Hearth
Upper level
0
4 metres

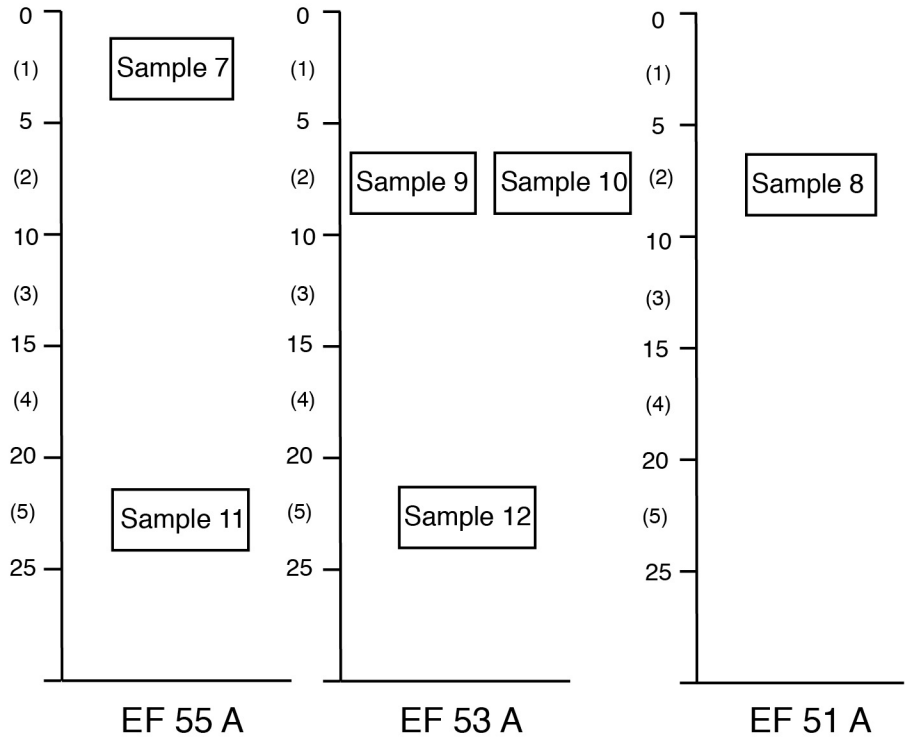

0
(1)
5
(2)
10
(3)
15
(4)
20
(5)
25
Sample 7
Sample 11
EF 55 A
Sample 9
Sample 10
Sample 12
EF 53 A
Sample 8
EF 51 A

Figure 4

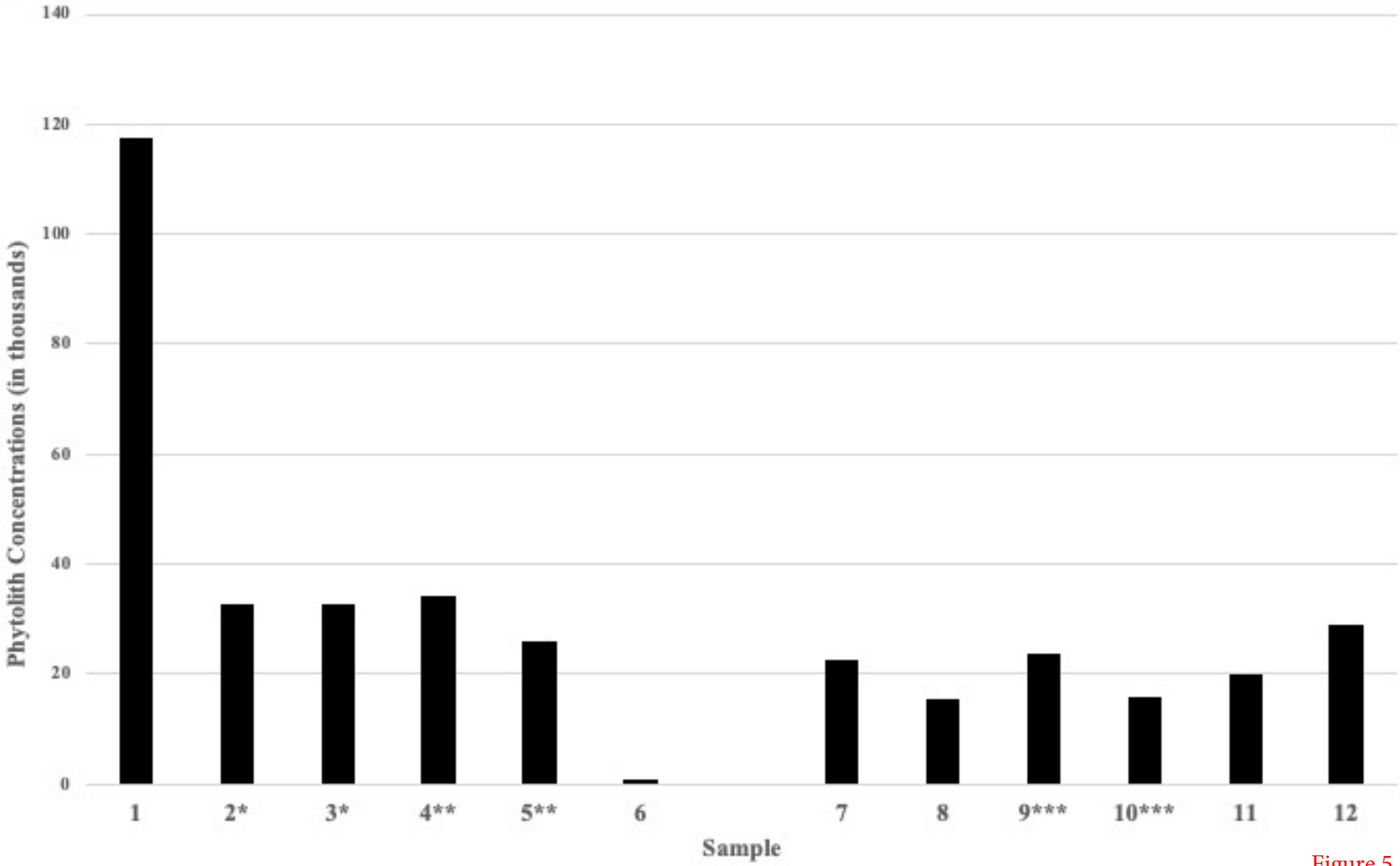

140
120
100
80
60
40
20
0
Phytolith Concentrations (in thousands)
1
2*
3*
4**
5**
6
7
8
9***
10***
11
12
Sample

Figure 5

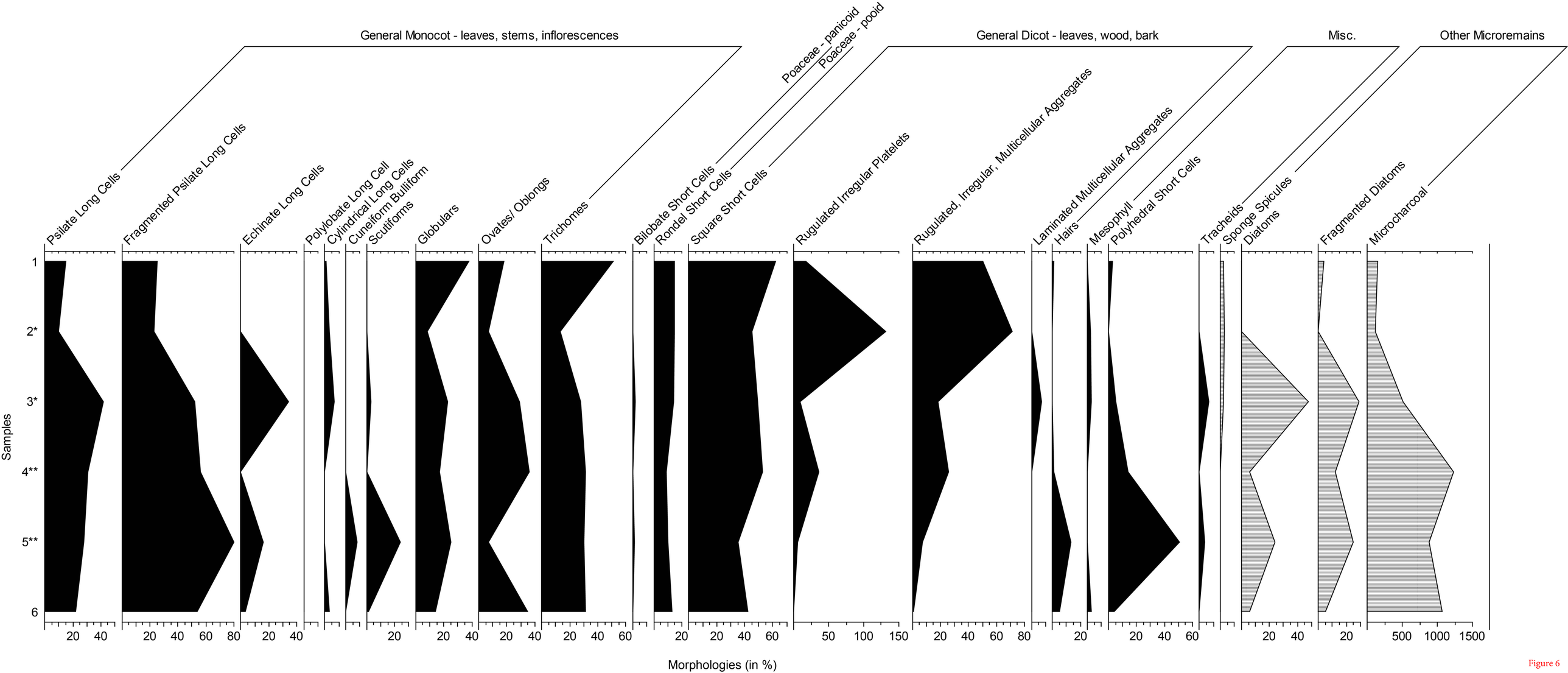

General Monocot - leaves, stems, inflorescences
General Dicot - leaves, wood, bark
Misc.
Other Microremains
Psilate Long Cells
Fragmented Psilate Long Cells
Echinate Long Cells
Polylobate Long Cell
Cylindrical Long Cells
Cuneiform Bulliform
Scutiforms
Globulars
Ovates/ Oblongs
Trichomes
Bilobate Short Cells
Rondel Short Cells
Square Short Cells
Poaceae - panicoid
Poaceae - pooid
Rugulated Irregular Platelets
Rugulated, Irregular, Multicellular Aggregates
Laminated Multicellular Aggregates
Hairs
Mesophyll
Polyhedral Short Cells
Tracheids
Sponge Spicules
Diatoms
Fragmented Diatoms
Microcharcoal
Samples
1
2*
3*
4**
5**
6
20 40
20 40 60 80
20 40
20
20
20
20 40
20 40
20 40 60
20
20 40 60
50 100 150
20 40 60 80
20
20 40 60
20 40
20
500 1000 1500
Morphologies (in %)

Figure 6

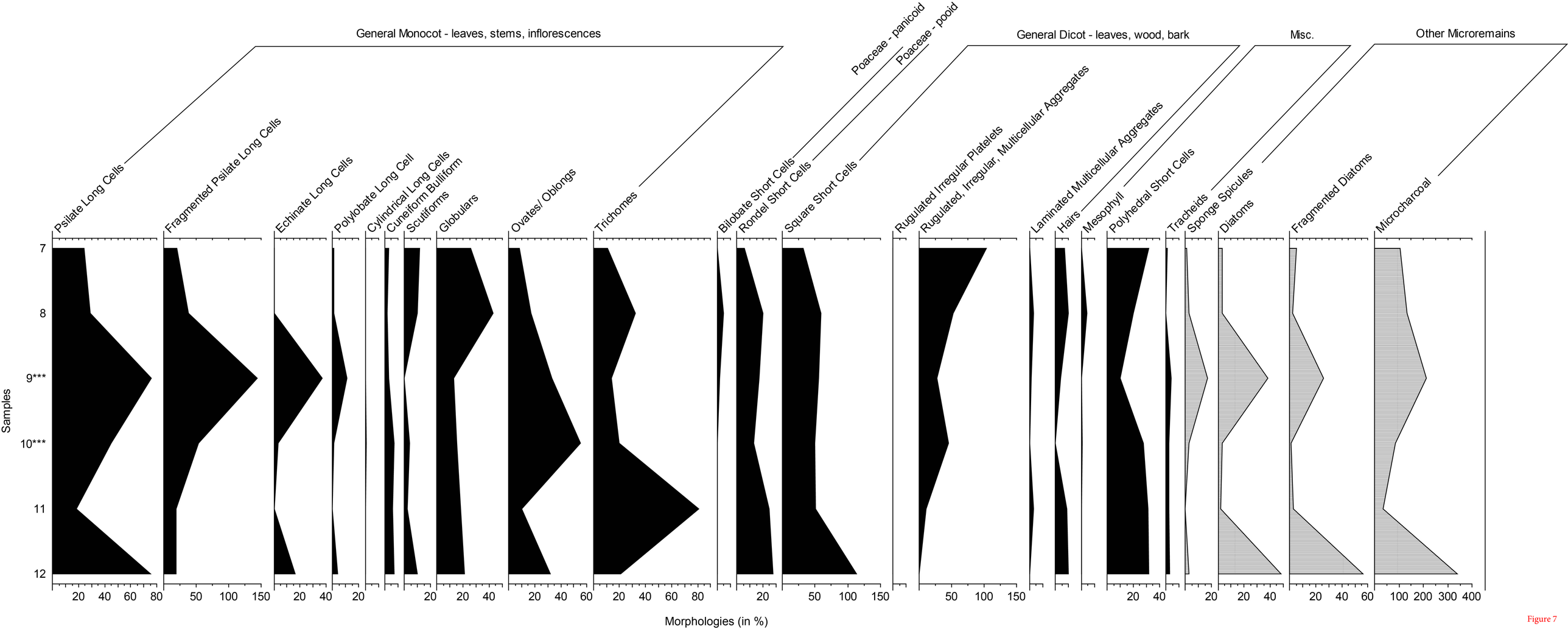

General Monocot - leaves, stems, inflorescences
General Dicot - leaves, wood, bark
Misc.
Other Microremains
Psilate Long Cells
Fragmented Psilate Long Cells
Echinate Long Cells
Polylobate Long Cell
Cylindrical Long Cells
Cuneiform Bulliform
Scutiforms
Globulars
Ovates/ Oblongs
Trichomes
Poaceae - panicoid
Poaceae - pooid
Bilobate Short Cells
Rondel Short Cells
Square Short Cells
Rugulated Irregular Platelets
Rugulated, Irregular, Multicellular Aggregates
Laminated Multicellular Aggregates
Hairs
Mesophyll
Polyhedral Short Cells
Tracheids
Sponge Spicules
Diatoms
Fragmented Diatoms
Microcharcoal
Samples
7
8
9***
10***
11
12
20 40 60 80
50 100 150
20 40
20
20
20 20 40
20 40 60
20 40 60 80
20
50 100 150
50 100 150
20 40
20
20 20 40
20 40 60
100 200 300 400
Morphologies (in %)

Figure 7

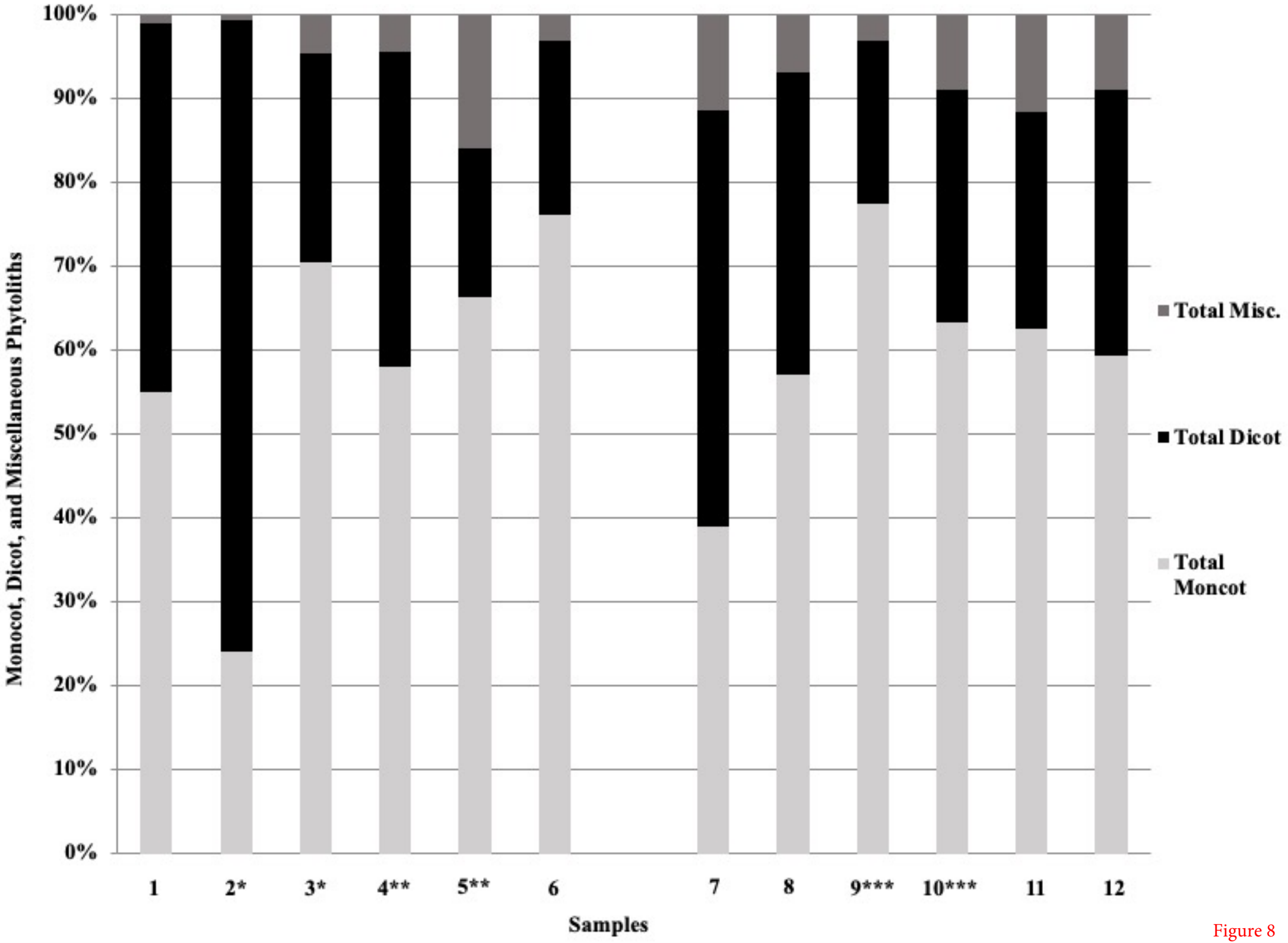

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Monocot, Dicot, and Miscellaneous Phytoliths
1
2*
3*
4**
5**
6
7
8
9***
10***
11
12
Samples
Total Misc.
Total Dicot
Total Moncot

Figure 8

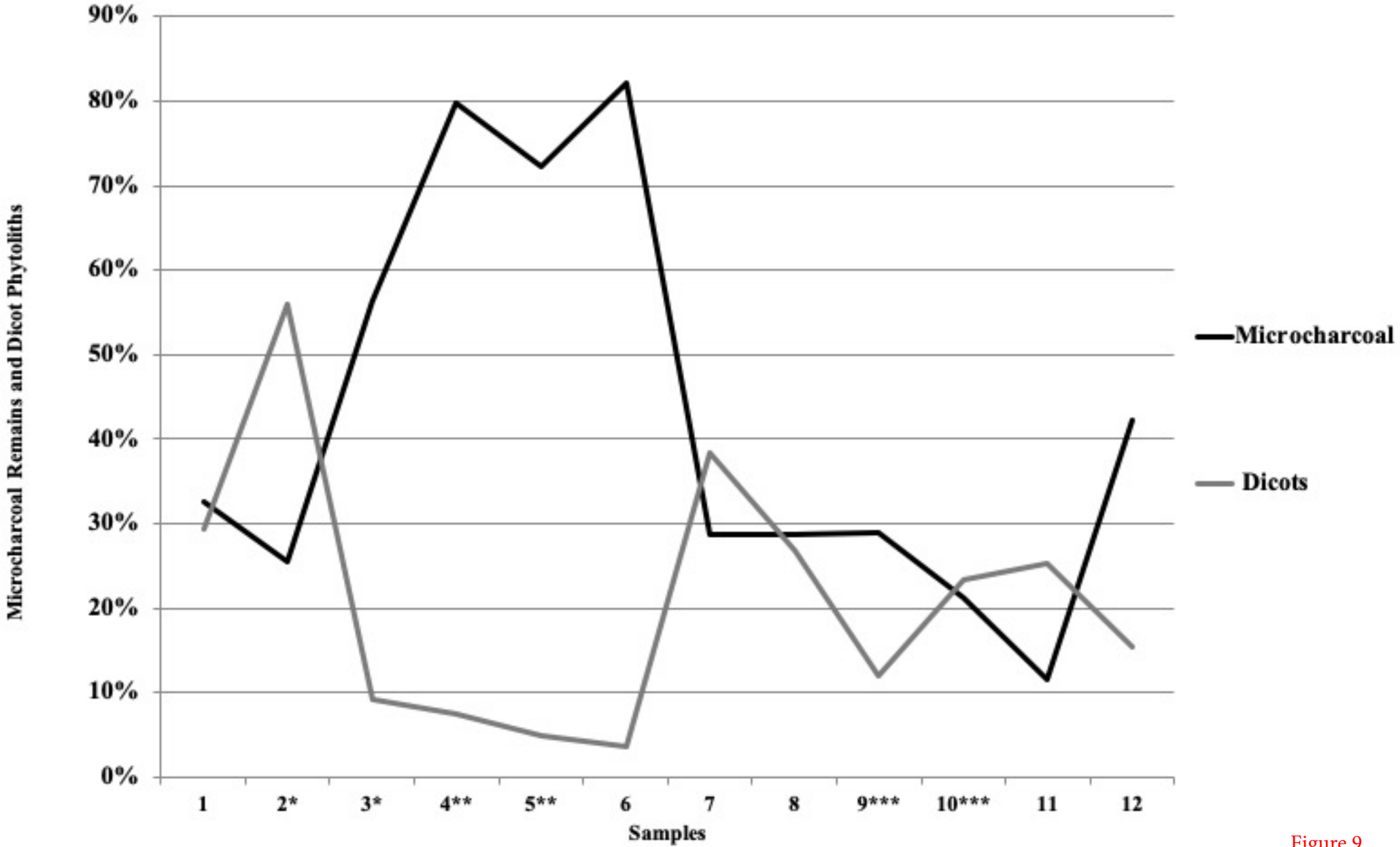

90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Microcharcoal Remains and Dicot Phytoliths
1
2*
3*
4**
5**
6
7
8
9***
10***
11
12
Samples
Microcharcoal
Dicots

Figure 9