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7. PHYTOLITHS

7.1 INTRODUCTION

Phytoliths, also called plant opals or opaline silica, are a type of plant microfossil ($SiO_2.H_2O$) which are amorphous in nature (Mann/Perry 1986). Soluble silica, in the form of monosilicic acid (H_4SiO_4) is absorbed by plants through groundwater uptake before being precipitated both within and around the cells within the plant (Piperno 1988; 2006; Hodson/White/Mead/Broadley 2005; Shillito 2011; 2013a; Hodson 2016). Phytoliths are an increasingly important archaeological archive due to their taphonomic durability (Ball et al. 2016; Hart 2016). In addition, they usually represent a more local vegetation input than pollen (Rovner 2001; Blinnikov/Busacca/Whitlock 2001). After the plant dies and plant organic matter is decomposed, the silica bodies, which are chemically stable and resistant to decomposition, remain as microfossils in soils and sediment. As phytoliths are mineral deposits, they are preserved for long time periods, in both aerobic and anaerobic conditions. Many phytolith are morphologically distinctive, although some taxa have less distinctive masses, which are difficult to characterise by shape and size. Phytolith analysis can provide insight into vegetation characteristics from both natural sequences, e. g. lake samples (Parker et al. 2004), or from archaeological contexts (Ishida/Parker/Kennet/Hodson 2003; Parker/Lee-Thorp/Mitchell 2011). Furthermore, phytoliths are well preserved in semi-arid environments, where pollen preservation is often poor (Jenkins/Baker/Elliott 2011; Burrough/Breman/Dodd 2012). However, pollen assemblages from Pleistocene cave deposits present such challenges to understanding, at every taphonomic stage, that reliable vegetational information from that source is rarely available.

The volume of phytoliths produced is highly variable, with most trees being low producers whilst monocotyledonous plants (mostly grasses) are prolific producers (Hodson/White/Mead/Broadley 2005; Barboni/Bremond/Bonneville 2007; Mercador et al. 2010; Weiner 2010); indeed, many Mediterranean trees (including most of the woody taxa recorded as charcoals in **Chapter 5**) may produce very few phytoliths and some none at all (cf. Tsartsidou et al. 2007), especially in their actual wood, as opposed to bark and leaves which may have somewhat higher phytolith content. This variability is important to consider when interpreting phytolith assemblages, especially as the causes of this variability (which may apply at intra- as well as at inter-specific and higher levels) are currently not well understood but are thought to be connected to both genetic and environmental factors (Jenkins/Jamjoum/Al Nuimat 2011; Shillito 2013a). In addition to variable levels of production, there are two further complications to be taken into consideration when interpreting phytolith assemblages. These are redundancy – where a particular morphotype occurs in many different plants – and multiplicity – where many different phytolith morphotypes occur in a single taxon (Twiss 2001; Jenkins/Jamjoum/Al Nuimat 2011). Furthermore, the lack of modern reference collections for some regions (such as the northeast of Morocco) will limit assemblage interpretation. Recent work on phytolith morphotypes from modern vegetation in Africa and the Mediterranean has yielded much needed new information for the application of plant biogenic silica studies in palaeoenvironmental reconstruction (Mercader et al. 2010; Cordova 2013). These studies suggest that a number of morphotypes traditionally used to separate C_3 and C_4 vegetation, especially grass silica short cell morphotypes, are found across a number of C_3 and C_4 grass tribes. There is thus greater redundancy in morphotypes than previously thought. Nevertheless, some morphotypes and morphotype groups can be attributed to particular grass sub-families, sedges and woody taxa. In particular, short cell short saddle forms are attributed to chloridoids, lobates to panicoids, papillae and achenes to sedges, and globular rugose/globular granulates to dicot trees and shrubs and globular echinate to palms (Mercader et al. 2010; 2013).

7.2 PREVIOUS STUDIES IN NORTH AFRICA

There are few published phytolith studies relevant to the latest Pleistocene of North Africa. In one marine core off the coast of Sierra Leone (CAMEL-1), researchers have utilised phytoliths (in conjunction with other proxy evidence) to reconstruct climatic changes on the African continent. High levels of phytoliths were observed in the Marine Isotope Stage 2 (MIS 2) levels of the core, also associated with lower levels of foraminifera. These high levels of phytoliths are interpreted as an indicator of more arid and increasingly seasonal conditions. These researchers have suggested that phytoliths are deposited in marine cores during arid periods due to the introduction of material into the atmosphere through increased wildfires from burning of tall-savanna grasslands (Flores/Bárcena/Sierro 2000), although surface erosion of burnt landscapes will also feed fluvial systems. In the Holocene period, lower levels of phytoliths were present compared to MIS 2. Wetter conditions were suggested as being indicative of reduced burning. The study was limited though, as it did not provide details of the phytolith morphotypes found or vegetation composition.

Two terrestrial sites are of interest here, Hattab II, northern Morocco (10,000-7,800 BP; Barton et al. 2008), and Aïn Misteheyia, eastern Algeria (9,800-6,000 cal BP; Shipp/Rosen/Lubell 2013; Lubell/Feathers/Schwenninger 2009). These deposits date from later than the sediments studied from Taforalt but can provide useful information regarding interpretation of phytolith assemblages in the region. Both Hattab II and Aïn Misteheyia suggest a mixed grassland ecology, dominated by temperate C_3 taxa but with some arid-adapted C_4 grasses[65]. In layers 6 and 6a of the older Hattab II cave site, the abundant phytoliths are interpreted as being evidence of the use of grasses as a fuel. Additionally, the high percentage of elongate dendritic phytoliths is interpreted as suggesting a spring-summer occupation of the cave (A. G. Parker in: Barton et al. 2008). The slightly later open air shell midden site of Aïn Misteheyia covers both the Typical and Upper Capsian periods dating to 9,800-9,500 cal BP and 8,000-7,200 cal BP, respectively. Multiple differences in the phytolith assemblages between these periods confirm that phytoliths are a useful palaeoenvironmental indicator, which can also help to identify changes in subsistence strategy. The Typical Capsian period contained a diverse abundance of phytoliths dominated by morphotypes from woody plants and Cyperaceae (sedges). These are interpreted as being the main fuel types utilised at the site, with dried Cyperaceae being used as a type of kindling. Moreover, the number of Cyperaceae multi-cells recovered could be interpreted as the remains of woven baskets, bedding or matting which were possibly disposed of (burnt) after use. The low ratio of elongate dendritic phytoliths in the Typical Capsian militates against a seasonal spring occupation at this site (Shipp/Rosen/Lubell 2013, 837-839).

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[65] The terms “C_3” and “C_4” refer to two of the (three) possible carbon-fixation pathways in plants, C_3 (more wasteful of carbon, water and energy due to photorespiration) being the most common and ubiquitous, C_4 (with an extra step to capture more carbon efficiently) being much rarer and often associated with higher temperatures and environmental drought/stress. The third pathway (CAM) is an even more specific drought (desert) adaptation, not recognised in the present data.

7.3 METHODS

The present text is based primarily upon analyses carried out during postgraduate research (Ward 2007; Jones 2013). The method described here is that used for the larger analysis (Jones 2013), in which phytolith samples were taken from the mollusc column MMC, a standing section in Sector 8 (see **Chapter 8**). Wherever possible, the sub-samples taken followed the stratigraphy of the deposits. However, in layers with large concentrations of fire-cracked rock, arbitrary sub-samples were taken at 5 or 10 cm intervals, with larger samples taken every 10 cm to obtain one litre of fine sediment.

Initially a systematic subsampling strategy (every fourth sample) was employed to ensure coverage of the entire sequence of deposits. A few additional subsamples were selected which corresponded to interesting peaks and troughs in the plant macrofossil remains. In total, 36 phytolith samples were prepared and studied.

The dry ashing method (rather than acid extraction) was chosen to remove organics rapidly from samples and to aid the preservation of multi-celled phytoliths (Piperno 2006, 92; Jenkins 2009; Jenkins/Baker/Elliott 2011). Samples were mounted onto slides using Canada balsam (Piperno 1988; 2006).

Samples were analysed using a Nikon Eclipse E400 microscope and a Leica DME microscope at x400 and x100 magnifications. All photographs were taken on the Leica DME microscope with a Leica DFC290 camera attachment. Phytoliths were identified and counted according to morphotype and described following the International Code for Phytolith Nomenclature (Madella/Alexandre/Ball 2005). Phytoliths of consistent morphology (Albert et al. 1999, 1254) were counted to a total of >500 per slide (actual subsample total counts falling into the range 509-611), larger consistent morphotype subsamples than available to Ward (2007) who used a target of >250. Phytolith results are presented using the program C2 (Juggins 2007) and shown in **figures 7.1, 7.4** and **Appendix 7.1a-c**.

7.4 RESULTS

A total of 46 morphotypes and some 19,600 phytoliths were identified and counted in the MMC column study (see **Appendices 7.1a-c** and **7.2** for the complete phytolith diagram and the numerical archive for the raw phytolith data respectively).

Local Phytolith Assemblage Zones

The total phytolith collection has been divided into four local phytolith assemblage zones (LPAZs), derived from the results of constrained cluster analysis in conjunction with a visual examination of the main changes in the phytolith stratigraphy shown in **Appendix 7.1a-c**. Zones are reported in MMC sample intervals (remembering that these Zones comprise only discontinuous subsamples of the whole sequence).

LPAZ-TAF-1 (MCC130-MMC108)

The basal sample of the sequence records the presence of high levels of woody taxa (see below), whilst the rest of the samples within this Zone show the dominance of C_3 grassland. C_4 taxa are present within the

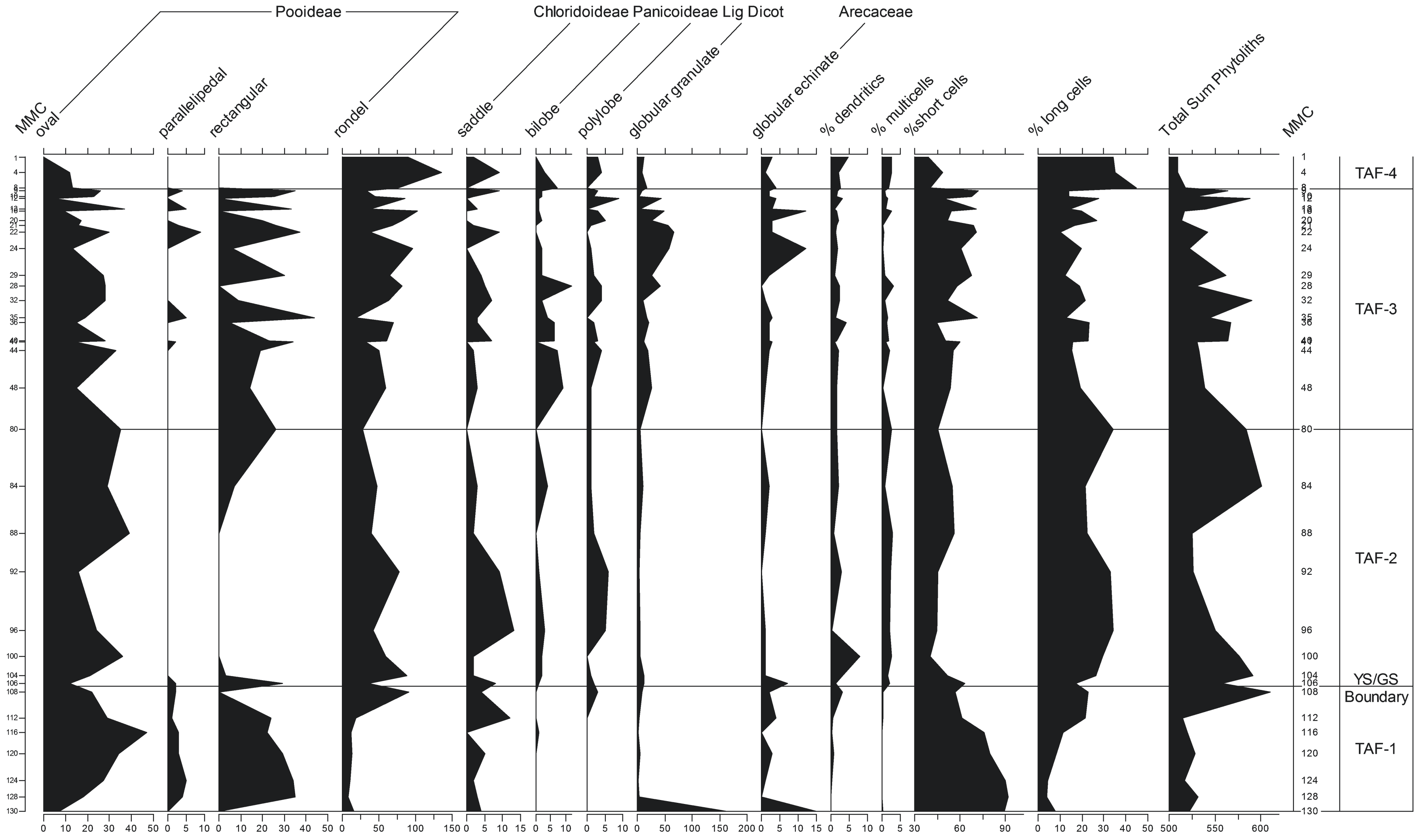

Fig. 7.1 Diagram showing the key phytolith morphotypes identified in the Taforalt assemblage; black lines demarcate phytolith Zones; note the varying scales between the graphs, all but the last four columns being actual counts (dividing counts by 5 will give an approximate conversion to percentages; see **Appendix 7.2** for exact subsample total counts).

local area, possibly reflecting high levels of water stress within this Zone. Short cell morphotypes dominate the phytoliths found with long cells appearing towards the top of the Zone. The top sample in this Zone lies just below the sedimentary transition from the Yellow to the Grey Series. The basal sample of this Zone has high levels of the ligneous dicotyledon (globular granulate, **fig. 7.2f-g**) morphotype and Arecaceae (formerly 'Palmae') types, which decline with the subsequent expansion of Poaceae (formerly 'Gramineae') morphotypes. In MMC112 (high in S8-Y2spit1), there is a small peak of Chloridoideae C_4 taxa, although, despite this, the majority of the grassland taxa comprise temperate C_3 taxa (oval – 50 counts and rectangular reaching <40 counts). Bilobate and polylobate forms often, but not exclusively, associated with Panicoideae grasses are very low in this Zone with trace levels present. In addition, high levels (174 instances) of an unidentified morphotype (**fig. 7.2n-p**) are present in the basal sample (MMC130, equivalent to the latest MSA interval in S8-Y4spit4) of this Zone. Short cell morphotypes dominate the assemblage (**fig. 7.1**) with low counts for long cells (less than 10 % in MMC130-MM120). Long cells increase from 12 % in MMC116 to 23 % in MMC108).

LPAZ-TAF-2 (MMC106-MMC80)

This Zone is characterised by the continuation of C_3 grassland dominance, with stable but low inputs from woody taxa. The reduction of the ligneous dicotyledon morphotype, globular granulate, to c. 10 observations throughout the Zone could suggest low water availability, which would also explain the low levels (<5 counts) of the Arecaceae morphotype. The lowest levels of woody taxa in the Zone do correlate to increased numbers of C_4 saddle morphotypes (MMC96, MMC92, **figs 7.1** and **7.2e**) indicating drier conditions compared to LPAZ-TAF-1. Polylobate panicoid morphotypes also increase in these two samples but the numbers are still relatively low (~4 counts in each). Despite this xeric grassland component, C_3 temperate taxa continue to dominate the assemblage (oval between 15-45 counts and rondel reaching 75 counts, **fig. 7.1**). At the base of the Zone there is an increase in dendritics to 8 % in MMC100. Multicell phytoliths, whilst low in number, appear throughout LPAZ-TAF-2 having been absent in LPAZ-TAF-1. The proportion of long cells to short cells in LPAZ-TAF-2 increases in LPAZ-TAF-2 (up to 34 % in MMC96 and MMC80) compared to LPAZ-TAF-1.

LPAZ-TAF-3 (MCC48-MMC10)

The phytolith assemblage in this Zone is again characterised by C_3 grassland dominance, although there is an increasing C_4 component as denoted by saddle morphotypes. Bilobate and polylobate forms are present throughout LPAZ-TAF-3 but in low numbers with higher levels of bilobates noted between MMC48-MMC28. Increasing levels of woody taxa were also observed throughout LPAZ-TAF-3 but notably from MMC24 upwards. This assemblage has been separated from TAF-2 based upon the increasing fluctuation in the levels of all morphotypes. High levels of globular granulate (up to 60 counts) and globular echinate (up to 12 counts) morphotypes are recorded between MMC24-MMC13. Oscillating but overall high levels of temperate Pooideae grasses (>100 rondels) are recorded with enantiomorphic peaks of C_4 types (saddle, bilobe and polylobe, **figs 7.1** and **7.2e. a-c. w** respectively). Dendritic forms are found throughout accounting for between 1 and >4 %. In LPAZ-TAF-3 the proportion of long cells falls slightly, with values ranging between 12 % in MMC29 to 27 % in MMC12.


20 µm
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20 µm
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w
20 µm
x

LPAZ-TAF-4 (MMC9-MMC1)

C_3 grassland dominance continues in this Zone, with C_4 saddle, bilobate and polylobate forms found throughout but in low numbers. Globular granulate (ligneous dicotyledons) and globular echinate (Arecaceae) forms are lower in LPAZ-TAF-4 compared to LPAZ-TAF-3. Overall, there is a drop in temperate Pooideae C_3 morphotypes (oval, parallelipedal, rectangular) but an increase in rondel forms with stable, but low, levels of C_4 (xeric) morphotypes, which decrease from about MMC4 upwards. Unfortunately, further analysis of this assemblage is problematical, due to the truncation of the sediments in the historic past and the possibility of some disturbance. Long cells values increase in LPAZ-TAF-4 20 ~40 %+ (MMC8 to MMC1)

Phytolith Short Cells-Long Cells and Multi-Cells

Overall, phytolith preservation was excellent (figs 7.2 and 7.3), although some pitting was observed in the lower Yellow Series samples and especially the basal sample MMC130. This suggests some post-depositional changes within this part of the sequence. Several studies have suggested that the ratio of short versus long cells can be applied to infer preservation and diagenesis. Long cells are more often less silicified and offer wider surface area to chemical and physical attack. Therefore, they represent weaker typologies than short cells, and tend to disappear more easily. Assemblages with a high number of long cells versus short cells should emphasize a higher degree of preservation (Madella / Lancelotti 2012). In LPAZ-TAF-1 the number of long cells is low when compared to shorts cells at less than 10 % in the lowermost samples but increasing up profile to ~20 at the top of the Zone. The proportion of long cells to short cells shows a marked increase in LPAZ-TAF-2 increasing to ~30 % with slightly lower proportions in LPAZ-TAF-3 to ~20 %. In LPAZ-TAF-4 long cells increase to ~40 %.

The percentage of multi-cells displays an interesting level of variation through the sequence. The shape of the trace shows an enantiomorphic tendency with respect to the graphs of globular granulate and globular echinate. Phytolith multi-cells are most commonly derived from monocotyledons, so the changing relative presence of woody taxa in these deposits probably explains this tendency. In addition, the lack of conjoined phytoliths in the midden thin section micromorphology sample MM02 (from Unit S8-L13, approximately equivalent to S8-G93-1 or MMC44; see Chapters 2 and 3) suggests that high levels of trampling could also influence the survival of multi-celled remains. The rarity of multi-cells (< 1 %) in the Yellow Series is taken up in the Discussion below. The peak of elongate dendritic morphotypes (8 %; figs 7.1; 7.2x; 7.3c-d) in MMC100 could be interpreted as an indicator of spring-summer occupation, as this morphotype is found in mature grass panicles (Barton et al. 2008, 206; Shipp / Rosen / Lubell 2013, 837; Novello / Barboni 2015). Novello / Barboni (2015) suggest that abundances of dendritics >> 3 % relative to the sum of grass silica short cell phytoliths plus dendritics are likely to indicate anthropogenic accumulation of grass inflorescences. It should be noted that these phytoliths could also and / or otherwise be due to storage activities or have entered the cave naturally, by wash or even wind; again, this point is taken up in the Discussion below.

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Fig. 7.2 Examples of single-cell phytoliths from the Taforalt sequence: **a-c** bilobe; **d** bulliform; **e** saddle; **f-g** globular granulate; **h-j** rondel; **k** conical; **l-m** trapezoid; **n-p** unidentified morphotype; **q-r** elongate sinuate; **s** elongate psilate; **t-u** elongate echinate; **v** lanceolate; **w** polylobe; **x** elongate dendritic. – (Images S. L. Jones).

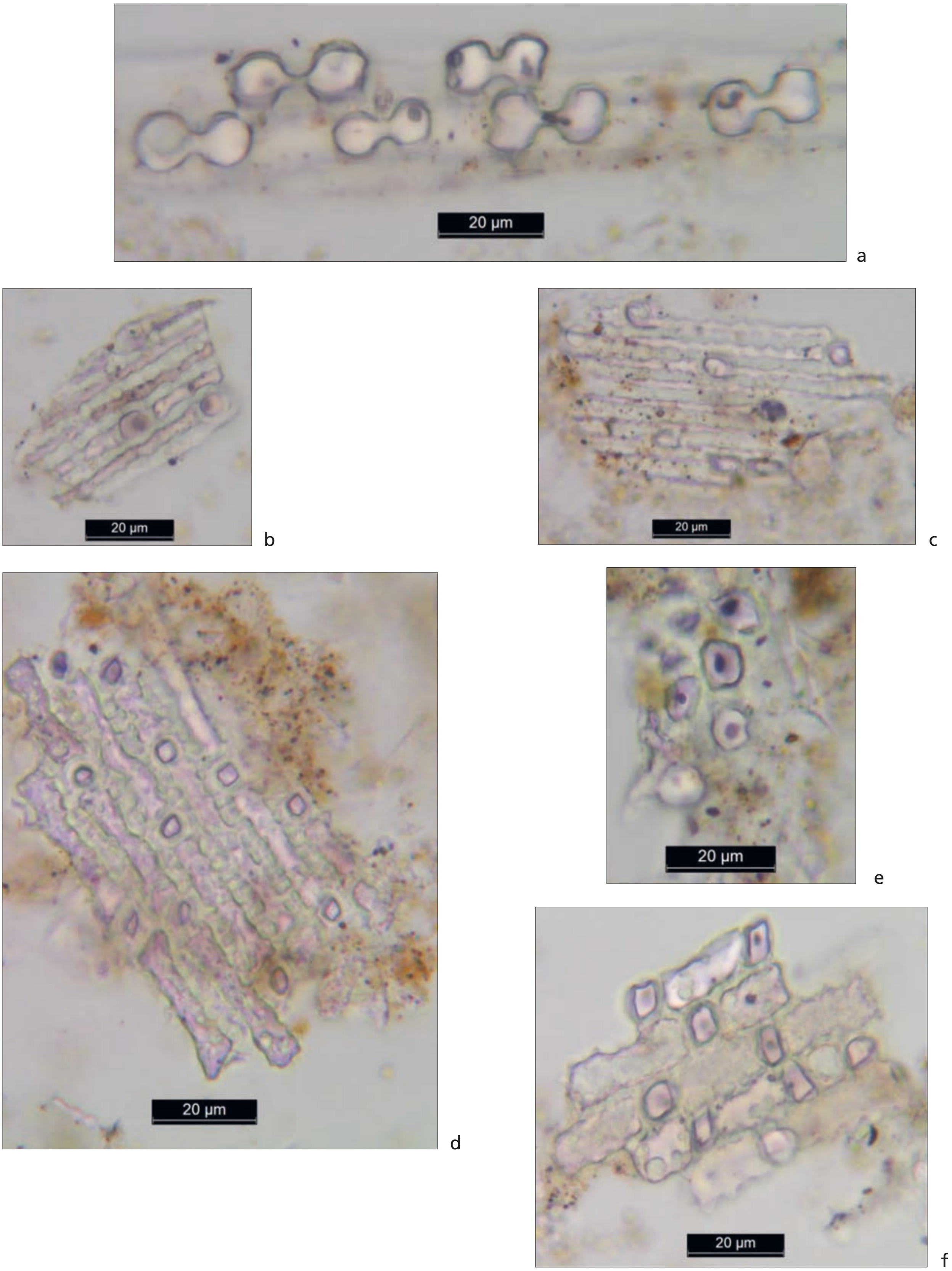

Fig. 7.3 Examples of multi-cell phytoliths from the Taforalt sequence: **a** articulated bilobes; **b** elongate sinuate multi-cell; **c** elongate dendritic multi-cell; **d** elongate dendritic and trapezoid multi-cell; **e** papillae multi-cell; **f** elongate echinate and short cell multi-cell. – (Images S. L. Jones).

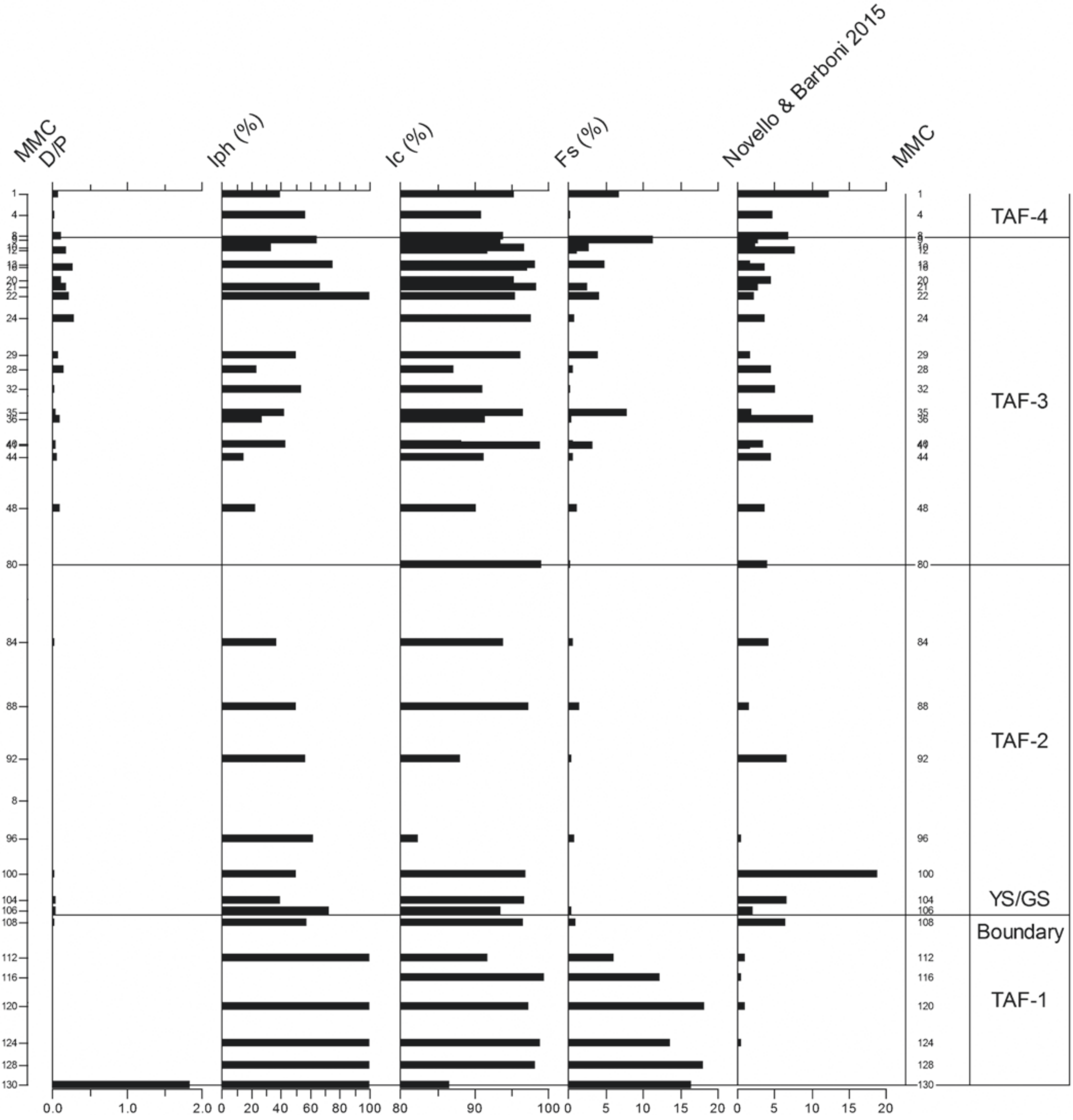

Fig. 7.4 Diagram showing the phytolith indices results for each sample; black lines demarcate phytolith Zones.

Phytolith Indices (fig. 7.4)

A number of phytolith indices have proved useful when interpreting phytolith assemblages, and to identify key vegetation changes in the Mediterranean (Bremond/Alexandre/Véla/Guiot 2004; Delhon et al. 2003) and Africa (Barboni/Bonnefille/Alexandre/Meunier 1999; Bremond/Alexandre/Peyron/Guiot 2005; Bremond et al. 2008; Parker/Lee-Thorp/Mitchell 2011; Burrough/Bremond/Dodd 2012). These indices are applied here to the Taforalt MMC column samples.

D/P

D/P is the ratio of ligneous dicotyledons (globular granulate and echinate morphotypes) to Poaceae short cells; the index was developed to provide an estimate of the density of woody species in West Africa (Alexandre et al. 1997). In Senegal, D/P values of <1 characterise environments with abundant grass species, like savannah, whilst in Ethiopia D/P values of 0.1-0.7 characterise shrub vegetation on the border of riparian forest (Barboni/Bonnefille/Alexandre/Meunier 1999, 96). At Taforalt, the basal sample (MMC130, the youngest MSA level in Sector 8) shows high levels of woody taxa (>2) compared to the rest of the sequence, which never exceeds 0.5. This means that, whilst in this basal sample woody taxa outnumber grasses, in the rest of the sequence, grass morphotypes always outnumber ligneous species. The D/P ratio is lowest in LPAZ-TAF-2 (MMC106-MMC80) with an increase in LPAZ-TAF-3 to ~0.3 towards the top of this Zone (MMC24-MMC12). D/P values fall in LPAZ-TAF-4 (MMC8-MMC1).

Iph %

The Iph % index expresses adaptation to aridity (Diester-Haass/Schrader/Thiede 1973) and measures the Chloridoideae percentage of C_4 grasses. High Iph % indicates Chloridoideae xeric adaptations, whilst low Iph % indicates Panicoideae mesic C_4 adaptation. 'Maximum' Iph % in most of the Yellow Series and in MMC21 should not be over-interpreted, due to the nature of the mathematical calculation (i.e. if no Panicoideae phytoliths are observed then 0/Chloridoideae = 0 %, hence the exaggerated "100 %" default). In West Africa, Iph % values at about 40-45 % would distinguish tall-grass mesic savannah (<40-45 %) from arid-adapted short grasses (>40-45 %) (Alexandre et al. 1997). The Iph % oscillates through the Taforalt sequence (range: 15-75 %), with mesic grassland types (<45 %) dominant between MMC84 and MMC35. Iph% values >45 % are found across the YS/GS transition (MMC108-MMC106), in LPAZ-TAF-2 (MMC96-MMC88) and in the upper part of LPAZ-TAF-3 (MMC22-MMC9).

Ic %

Ic % was defined by Twiss (1992) as a way to measure the ratio of C_3 plants in the American Plains. High Ic % indicates high levels of Pooideae temperate C_3 taxa, whilst low Ic % indicates a greater proportion of more xeric C_4 taxa. Barboni/Bonnefille/Alexandre/Meunier (1999) calculated, from data collected from the North American Plains by Fredlund/Tieszen (1994), that Ic % values of 70 % indicate C_3 dominated plains, whilst values around 30 % indicate C_4 dominance. The Ic % values from Taforalt fluctuate through the sequence but never fall below 82.5 %, showing the dominance of C_3 grasses throughout. Many of the grass species of potential importance to humans that were available in the Late Pleistocene were C_3 plants, including *Avena* sp., *Bromus* sp. and *Stipa tenacissima*. In addition, some C_4 non-grass species were present in the charred macro-botanical remains (Caryophyllaceae and Chenopodiaceae), which are not reflected in the phytolith assemblage (J. Morales, pers. comm.). Shipp/Rosen/Lubell (2013) identify the C_4 grass *Desmostachya bipinnata* (halfa/alfa grass) in their phytolith assemblage from Aïn Misteheyia (Algeria), although this grass species was only recovered from the Eastern Mediterranean zone in a comprehensive study of grass species in Egypt (Batanouny/Stichler/Ziegler 1988); in that study, C_3 plants comprised 52-63 % of the monocotyledonous flora in the Mediterranean coastal zone (ibid., p. 546).

Fs %

The Fs % index was defined by Bremond/Alexandre/Peyron/Guiot (2005) as an indicator for water stress. It measures the proportion of fan-shaped bulliform morphotypes (**figs 7.2d** and **7.4**) to Poaceae short cells. Samples taken from a longitudinal transect of climatic zones in West Africa found that Fs % values increased northwards towards the Sahelian and Saharan zones; thus, high Fs % levels indicate high water stress. At Taforalt, zone LPAZ-TAF-1 shows the highest Fs % levels. There is then a sharp decrease, with LPAZ-TAF-2 showing the lowest levels of water stress in this sequence. In LPAZ-TAF-3, the Fs % value fluctuates considerably and could indicate climatic events or could possibly record human selection of grass types. High levels of water stress are recorded at the onset of LPAZ-TAF-4, although a possible amelioration after this initial deterioration is also observed.

Statistical Analyses

Jones (2013) carried out multivariate analyses (Cluster Analysis and Detrended Correspondence Analysis [DCA]) on the main phytolith sequence. The first two DCA axes were found to display a significant similarity to the D/P and Fs % indices respectively, suggesting that the environmental eigenvector plotted against the first DCA axis largely represented the environmental gradient of woody to grassland vegetation, whilst the variation along the second DCA axis was mostly explained by changing levels of water stress. It would therefore seem that these two indices (see previous subsection) are the most sensitive to the changing environmental/climatic conditions at Taforalt. This having been said, Jones found that a very considerably lower percentage of the variance in the DCA analysis, especially that on the first axis, was accounted for in the Grey Series (GS) data than in that for the Yellow Series (YS), causing her to suggest that plants were being more heavily selected by people for specific uses in the Grey Series, as compared to a closer representation of the natural environment in the Yellow Series. Jones's final conclusion from her statistical analyses was that there did not appear to be evidence for a strong change in environment between MMC108 (her only S8-Y1 sample) and MMC106 (and higher samples), across the YS/GS boundary. One may also note that her statistical results for MMC112 (the upper part of S8-Y2spit1) look markedly 'intermediate' between those of the stratigraphic units directly below and above.

Phytolith Abundance

Quantitative analysis to asses overall phytolith abundance within the sediment samples was not undertaken (Jones 2013). Ward (2007) followed a semi-quantitative method, allowing him to isolate the 'acid insoluble fraction' (AIF) and the phytolith fraction, and thus, by micro-weighing, to estimate number of phytoliths per gram of AIF; since the resulting figures are very large numbers, for convenience here, they will be rounded to the nearest 1000 and referred to as an 'abundance index'. Whilst this approach does have the advantage of standardising phytolith counts (the index) to the non-soluble portion of the sediment fine-matrix, it cannot take into account either independent availability rates of non-solubles (such as fine quartzitic sand and silts) or overall sedimentation rates, such that care is needed to avoid the resulting intrinsic uncertainties (especially important in any comparison between the very different contexts in the YS and GS).

In the Yellow Series, fine quartzitic sand and silt was constantly added by natural processes but the sedimentation rate was relatively slow (cf. **Chapter 2**). Ward reported index values for his YS samples as follows

(2007, tab. 5.4 fig. 5.24): Y4spit1 = 1; Y3 = 10; Y2 = 8; Y1 = 6. Ward reported one more sample from the YS: a hearth in Y1 = 145.

Turning to the Grey Series, there was little opportunity at most levels for input of quartzitic sands by natural processes but the bulk sedimentation rate was at least ten times that of the YS, although much of this material was in the coarse (stone) grades (cf. **Chapter 2**); there is no way to calculate an accurate YS/GS comparative factor but it is suggested here that, were phytoliths to be generated at roughly the same rate throughout the sequence, one might expect the abundance index (as calculated) to show values perhaps 2-5 times higher in the GS than in the YS. Ward reported index values for his GS samples (none of them recorded as being from undisturbed burning events) as follows: G100 (approximately equivalent to MMC106) = 8; G98 (approximately equivalent to MMC104-MMC100) = 234; G96 (approximately equivalent to MMC95-MMC80) = 244; G94 (approximately equivalent to MMC50-MMC46) = 1600; G89 (approximately equivalent to MMC12-MMC5) = 138.

7.5 DISCUSSION

The MMC column analysis confirms the dominance of C_3 taxa found by Ward (2007), but also demonstrates that in many levels (as shown by the Iph %) there is a C_4 component. We may note, in passing, that nowhere in the Taforalt LSA sequence do phytolith morphotypes (e.g. jigsaw pieces) usually associated with more humid environments ever reach greater than trace proportions. Modern sediment samples, collected by Ward, local to the cave, showed that the grass morphotypes rondel and elongates were dominant (2007, 379-380). This is in agreement with the results of the more detailed MMC column study (**Appendices 7.2a-c** and **7.3**), which found rondels (2,105 counts) in conjunction with elongate echinate (2,269 counts) and elongate sinuate (2,376 counts) morphotypes to be dominant. In the following discussion, it should be remembered that phytolith analysis best reflects the state of the local grassland components, due to the normally much lower phytolith production in woody taxa and may also reflect a bias due to selected plant resources being collected and utilised at the site. It should also be noted that woody taxa produce fewer phytoliths than monocot taxa, especially grasses, so may be under represented in the sequence.

The phytolith sequence has been compared with the radiocarbon dating provided in **Chapter 4**, making possible suggestions of correlation with known sequences of Late Pleistocene climate change (the Greenland Ice Core Record being the standard global model used here).

Palaeoenvironment

The basal LPAZ-TAF-1 contains samples from the Yellow Series. This Zone sees the highest values of the Fs % index, interpreted as indicating a generally high level of water stress. The dating (see **Chapter 4**) would include the Last Glacial Maximum (LGM) and Heinrich Events 1 and 2 (HE 1 and 2) during MIS 2. The basal sample (MMC130, the latest MSA level) is recognised as separate in the statistical analyses, due to the high levels of woody taxa. This corresponds to Alboran Sea core data which indicates an abrupt rise in temperate taxa in this period before the onset of HE 2 (Combourieu Nebout et al. 2002; 2009). There is then a decline in woody taxa identified in the phytoliths from most of the remainder of LPAZ-TAF-1 (cf. also **Chapters 5-6**), coupled with a rise in various grasses, always dominated by shifting proportions of C_3 types. This having been said, the YS peak in C_4 Chloridoideae in MMC112 (equivalent to an interval from high within

S8-Y2spit1) stands out from the otherwise 'intermediate' (possibly physically mixed) trends and is plausibly a true signal from the driest phase of HE 1; in support of this proposition, one may note that Ward (2007) also found the lowest C_3/C_4 morphotype ratio in his Sector 8 LSA sequence within his Y2 sample. One may further cite the recording by Ward (ibid.) of a very low C_3/C_4 morphotype ratio in Unit 2 of Sector 9, an interval with early LSA, well developed in that part of the cave (just above sediments thought to date from HE 2; see **Chapter 2**) but extremely compacted (if present at all) in Sector 8. However, turning to the top of this Zone, in the phytolith assemblage for Y1, there is a marked decrease in the Fs % and corresponding decreases in the bulliform and saddle morphotypes. There is also an increase in woody taxa (especially platy forms). Additionally, there are increases in the rondel, conical and polylobe (Panicoideae) short cells and elongate dendritic and elongate sinuate long cells. These trends suggest a slight shift to more humid, possibly even warmer conditions. All this evidence suggests that phytoliths can be a reliable proxy for wider, as well as local, climatic variations.

This having been said, a note on comparative taphonomy is needed at this point. The Yellow Series in Sector 8 comprises relatively fine sediments, dipping out of the cave, interpreted as having been emplaced largely by natural processes, dominated by gentle wash but with some reworked aeolian input originating in the drier intervals (see **Chapter 2**). Whilst humans were certainly repeatedly present within YS time, vegetational structure and natural transport processes probably dominated the phytolith taphonomy, with most specific human input subject to some redistribution (note that the phytolith subsampling from the MMC column did not include any primary or strong secondary human accumulations, such as S8-Y3). The rare occurrence of multi-cells (< 1 %) in the YS samples is consistent with this taphonomic picture, although more localised diagenesis (cf. pitting) may also have played a part at some levels. This is supported by the low numbers of long cells to short cells, which are more prone to pitting and dissolution, suggesting that digenesis may have played a role (*sensu* Madella / Lancelotti 2012) in the YS and TAF-1 samples, especially in the lower part of this Zone (MMC130-116). The higher numbers of short cells may also reflect increased wind borne phytoliths being delivered into the sequence through selective entrainment of smaller phytoliths by wind from outside the site. In contrast, the Grey Series is overwhelmingly an anthropogenic accumulation (see **Chapter 2**). Whilst humans could only have selected from what the vegetation mosaic made available in any particular period, any environmental signal in the GS must be deciphered through the potential filter of human preferences. Indeed, looking again at the data from Y1, it may be that an increasing human presence was already affecting the phytolith assemblage rather more than had previously been the case, perhaps with the exploitation of a greater variety of plant resources and the deliberate selection of materials being brought into the site. This view is supported by the increase in dendritics observed in the GS from TAF-2 onwards with values reaching > 3 % (*sensu* Novello / Barboni 2015 – see below for discussion).

The remainder of the phytolith assemblage Zones (LPAZ-TAF-2 to 4) derive from the Grey Series. The basal sample of LPAZ-TAF-2 (MMC106) has an unusually high Iph % of 73 % indicative of a significant xeric C_4 component accompanying cool, arid conditions. Whilst some caution must be applied here, due to the demonstrable physical mixing associated with human activity at the base of the GS 'midden' deposits, it may be noted that there is also a very specific distribution of the various C_3 Pooideae phytolith types in MMC106 which could not have resulted from any plausible mixing of material from the samples immediately below and above, an observation which suggests that MMC106 retains some true environmental signal.

The LPAZ-TAF-2 assemblages generally have high values of temperate C_3 taxa, with lower C_4 elements and the lowest recorded values for water stress. After the very base (see above), this is a Zone of climatic amelioration, consistent with expectations for Greenland Interstadial 1e (GI 1e) time, the most temperate phase in this interstadial (Genty et al. 2006; Combourieu Nebout et al. 2009; Rodrigo-Gámiz et al. 2011). The division between LPAZ-TAF-2 (highest sample MMC80) and LPAZ-TAF-3 (lowest sample MMC50), at c. 14,200 cal BP (see **Chapter 4**), approximately at or just before the beginning of GI 1d, is based upon several characteristics. The phytolith signal becomes more 'noisy' and there is a rather erratic increase in Chloridoideae C_4 taxa and in levels of water stress from MMC44 upwards. This change would correspond with a date (c. 13,600 cal BP) a little into GI 1c time (Björck et al. 1998; Walker et al. 1999). The assemblage throughout LPAZ-TAF-3 remains dominated by C_3 species and also sees a slight increase in woody taxa which suggests the continuation of interstadial conditions and a certain level of water availability.

LPAZ-TAF-4 begins with an increase in water stress to an Fs % of 11, the highest since the values recorded in the Yellow Series. The xeric C_4 percentage of the assemblage also sees an increase (to an Iph % of 64) at the onset of this Zone, although this index was already showing erratic high values in the uppermost parts of LPAZ-TAF-3. These signs of aridity in the earliest sample of LPAZ-TAF-4 may presage the onset of the Younger Dryas (YD or Greenland Stadial 1 [GS1]), at c. 12,600 cal BP. The assemblage nevertheless does not show characteristics that would suggest that the climatic conditions were as severe as those seen in the Yellow Series, and especially not as in the HE 'minima' (cf. Fletcher/Sánchez Goñi 2008; Combourieu Nebout et al. 2009). As has already been stated, the upper part of LPAZ-TAF-4 is problematical and will not be discussed further here.

There would therefore appear to be some broad correlation between the Greenland isotopic stratigraphy of the last interstadial/stadial cycle and LPAZ-TAF-2 to (basal) 4. However, it has already been noted that only a relatively small proportion of the statistical variance in these phytolith assemblages can be attributed to climatic factors, the picture having most probably been blurred by human activity.

Palaeoeconomy and General Human Behaviour

As has been noted above, disentangling the environmental from the cultural signal in phytolith results is rarely a straightforward matter.

Phytolith Abundance

Several points of interest arise from Ward's (2007) analysis of phytolith abundance (always bearing in mind that only eight samples were considered from the whole LSA stratigraphic interval). Looking first at the Yellow Series (equivalent to Jones's LPAZ-TAF-1), the abundance index is generally low, with a slight up-turn in a unit (Y3) demonstrably comprising a strong but generalised (washed) anthropogenic influence. Most striking is the result for an undisturbed hearth in Unit Y1; this specific burning event is confirmed as producing perhaps two orders of magnitude higher phytolith abundance than the YS 'background'. Remembering that it has been estimated that a 'uniform' real abundance of phytoliths throughout the LSA sequence would be likely to result in index values perhaps 2-5 times higher in the GS than in the YS (see explanation above), the abundances actually observed by Ward in the Grey Series (his samples here excluding an undisturbed hearth) are noteworthy. At the very base, there is little appreciable change, suggesting that there is probably a strong admixture of YS sediment into this level of the GS. However, immediately upwards and through the lower part of the GS (equivalent to most of Jones's LPAZ-TAF-2), the index values rise by well over two orders of magnitude compared to the YS 'background', to levels about 2 times that seen in the sampled undisturbed hearth in Unit Y1. Furthermore, the phytolith abundance index rises to over three orders of magnitude higher than the YS 'background' in a sample near the base of the upper part of the GS (equivalent to a level low in Jones's LPAZ-TAF-3), although it must also be noted that the sedimentation rate is here known to have halved with respect to the lower part of the GS (see **Chapter 2**). Even if Ward (2007, 239) did dismiss any abundance figures of less than a million phytoliths per gram as "quite low" (presumably on the grounds that the Taforalt numbers are a little lower, perhaps by a factor of 3-5, than in phytolith studies in 'classic' eastern Mediterranean cave site, such as Kebara; cf. Albert/Weiner 2000; 2001), there can be no other explanation for these escalating numbers than correspondingly increasing human import of vegetable matter (remembering that phytolith abundance is naturally production-biased towards monocots and grasses in particular). However, Ward's uppermost sample (at least overlapping with the start of Jones's LPAZ-TAF-4) shows a down-turn, to an index level again only some two orders of magnitude above the YS 'background', plausibly interpreted as a moderate reduction in human input, perhaps as a cultural response to the climatic conditions slipping towards the Younger Dryas (GS1).

Phytolith Variance

From LPAZ-TAF-3 upwards, the phytolith signal shows increasing variation compared to the zones below. This noisiness, expressed both as 'saw-tooth' traces for individual morphotypes or groups on the graphs and as continually shifting combinations of morphotypes (cf. **fig. 7.1**), and also as increasing variability in indices (cf. **fig. 7.4**) as well as in the multivariate statistical analyses, is not typical of more smoothly varying natural sequences and is therefore suggestive of increasing human activity at the site.

Woody Phytolith Taxa

Although most of the Yellow Series and basal Grey Series samples all show very low levels of woody taxa in the phytolith record, the upper part of the GS (LPAZ-TAF-3) shows increasing, if sporadic, levels of such taxa (especially globular granulate forms). Jones (2013) counted only phytoliths of consistent morphology in the MMC column. It has been suggested (Albert et al. 1999; Albert/Weiner 2001; Albert et al. 2006) that irregular (or variable) morphotypes are typically more common in woody tissue and bark than in leaves and grasses. Thus, Ward (2007, 403-404) noted irregular/consistent morphotype (I/C) ratios that were relatively high (but still showing probable grass dominance) in G89, G95 and G100 samples (Sector 8 Grey Series), thought to reflect the increased wood burning and human occupation in these units. It should also be noted that woody taxa tend to produce fewer phytoliths than monocots and therefore may under-represent the proportions of woody taxa to non-woody taxa. These observations are consistent with the charcoal data from the cave (see **Chapter 5**), with the implication of increasing use of wood as a fuel.

Phytoliths from Grasses and Other Fibres

The grass and other monocot phytolith signal is by far the dominant motif throughout the Taforalt LSA sequence, as is not unexpected from the natural production bias. However, once the increasing phytolith abundance in the Grey Series is taken into account (see above), it is reasonable to assume that large proportions of the imported vegetation were indeed grasses and similar plants. Phytoliths are not usually fit for detailed plant identification, so that we must here point to the charred finds, such as *Avena* sp., *Bromus* sp. and *Stipa tenacissima*, reported in **Chapter 6**. Grasses could – plausibly would – have been an important dietary resource for Iberomaurusian peoples, with additional (perhaps even more important) uses for bedding, fire-lighting, cooking matrix, matting, cordage, basketry (for both collection and storage) and other crafts.

Jones (2013), looking at a GS thin section (equivalent to part of LPAZ-TAF-2, at the stratigraphic level of approximately G97/upper L28/MMC100-MMC96; cf. MM03 in **Chapter 3**), noted a section occurrence of c. 3 % phytoliths, dominantly grass short cells, with some multi-celled forms reaching 150 µm and some localised 'layering', which could be the result of plant material use for bedding or matting.

There is also sporadic evidence for possible plant storage at Taforalt in the phytolith record. As discussed, the Novello-Barboni index for sample MMC100 (in LPAZ-TAF-2) is 19 %, representing the peak (8 % of total consistent forms) in elongate dendritic morphotypes found in mature grass panicles. There is some support for this peak being the result of human activity, as Novello/Barboni (2015) argue that, if the elongate dendritic morphotype is markedly greater than 3 % (compared to the sum of Poaceae short cells and elongate dendritics), this is an indicator for an anthropogenic origin; the value of the Novello/Barboni index for this sample (MMC100) is 19 % (**Appendix 7.2**). In this case, the peak would either indicate spring-summer occupation or would point to storage outside the normal growing season. There is only one other small 'peak' of dendritic phytoliths corresponding to around 5 % of the assemblage (12 % on the Novello/Barboni index) in LPAZ-TAF-3 in MMC36. The lack of repetitive peaks elsewhere in the sequence may favour interpretation of these two instances as related to the storage of mature grass panicles in these units.

Neither Ward (2007) nor Jones (2013) recorded more than very low levels of burnt phytoliths, using simple visual recognition; indeed, in absolute terms, Jones's (very low) counts are three times higher on average for the YS than for the GS units (see **Appendix 7.2c**). Neither researcher used systematic refractive index techniques, and one must also take into account the fact that burnt phytoliths are more soluble (cf. Cabanes/Weiner/Shahack-Gross 2011), such that it appears likely that burnt specimens are markedly underrepresented in the available Taforalt data. It is nevertheless possible that significant quantities of discarded grasses and grass 'products' may have decayed *in situ* without conscious or accidental burning (see also the so far unsuccessful attempts, reported in **Chapter 2**, to recognise fragments of grass 'products' in a charred state, on the cusp between destruction by full burning or by normal decay).

Finally, not all fibrous plants are grasses. Higher levels of Arecaceae (formerly 'Palmae') phytoliths were recovered in samples MMC24 and MMC16 (increasing more than ten-fold with respect to neighbouring samples), in LPAZ-TAF-3 at around 13,300 cal BP. Palms do not only provide edible fruits but the leaves are also utilised as building and craft materials to produce containers, thatch and rope (Madella et al. 2002; Jenkins/Jamjoum/Al Nuimat 2011; Bretzke et al. 2013). It may also be noted that there is a slightly higher peak in the Arecaceae in MMC130 (latest MSA), but there in a context with a much higher ligneous wood presence overall. Overall, the trend for globular echinates follows that of globular granulate forms (ligneous dicotyledons).

7.6 CONCLUSIONS

These two sets of samples constitute an important terrestrial phytolith record, providing evidence relevant to Late Pleistocene environment and plant use, both at Taforalt and more widely in the Iberomaurusian/Later Stone Age of North Africa. The potential of phytolith studies in Pleistocene cave sediments is clear and this potential has been confirmed at Taforalt. It should be recognised, however, that such studies are arduous (involving multi-phase sample preparation, including heavy-liquid separation) and some detailed studies require access to advanced equipment. The two studies contributing to this chapter were carried out by individual researchers, each undertaking multi-topic analyses (beyond phytoliths alone). The actual coverage in the phytolith data from Taforalt is therefore still at very low stratigraphic precision and focus. Phytolith analysis requires only very small samples, compared with most other studies, and can therefore be targeted towards a whole range of subtle research questions. Even expressing the Taforalt deposits as a mere vertical sequence, there are some four metres of Grey Series sediments and a composite total (working in different sectors of the site) of up to two metres of LSA-relevant Yellow Series sediments, not to mention the thick MSA levels below. Few other sites will offer such access to small increments of microfossil biostratigraphy. It is to be hoped that future phytolith work at Taforalt can add volumes to the understanding achieved to date.