Ethno-geochemical and Phytolith Studies of Activity Related Patterns: A Case Study from Al Ma'tan, Jordan

Emma Louise Jenkins , Samantha Lee Allcock , Sarah Elliott, Carol Palmer & John Grattan

Submit your article to this journal

Article views: 8

View related articles

View Crossmark data

Association for Environmental Archaeology

Routledge
Taylor & Francis Group

Ethno-geochemical and Phytolith Studies of Activity Related Patterns: A Case Study from Al Ma'tan, Jordan

Emma Louise Jenkins [a], Samantha Lee Allcock [b], Sarah Elliott[c], Carol Palmer[c] and John Grattan[d]

[a]Department of Archaeology, Anthropology and Forensic Sciences, Bournemouth University, Poole, UK; [b]Plymouth University, Plymouth, UK; [c]Council for British Research in the Levant, British Institute in Amman, Amman, Jordan; [d]Office of the Vice Chancellor, University of Aberystwyth, Penglais, Aberystwyth, Ceredigion, UK

ABSTRACT

Understanding Neolithic sites in southwest Asia is often difficult because of the lack of preservation of organic remains and the effects of various taphonomic processes that alter the original record. Here, we use an ethnographic approach to test the potential of using plant phytoliths and geochemistry to aid our interpretation of southwest Asian Neolithic sites. Our study of a recently abandoned stone and mud constructed village in Jordan, shows that for certain activity types, phytoliths and geochemistry can help distinguish different construction methods and functions, particularly for burnt areas, animal use areas and where there has been the addition of a specific construction material. For features constructed from the same source materials distinctions are more problematic. Geochemical and phytolith proxies were individually effective in distinguishing activity areas and construction materials, but signals were diminished when the statistical analysis was run on both forms of evidence combined. It is therefore recommended that the data from plant phytolith and geochemical analyses are subject to separate statistical tests and that the two sets of results are used in combination to interpret archaeological sites and their uses.

Introduction

The Neolithic in Southwest Asia

The Neolithic in southwest Asia (*c* 11,700–7800 cal BP) is an important period in human history that saw the advent of sedentism, agriculture and ultimately paved the way for increased social complexity and urbanism. It is also, however, one of the most poorly understood. There are many factors that limit our understanding of this important period. One is the paucity of Neolithic sites and, often when sites are found, preservation is poor, particularly for organic remains. A further consideration for all archaeological investigations is that even when preservation is good, interpreting the evidence can be problematic because many variables influence the archaeological record and impede understanding. For example, the diverse nature of potential activities; specific site formation processes (e.g. cleaning prior to abandonment or periods of disuse); overlapping signatures for numerous activities; post-depositional mixing of sediments; post-depositional (and differential) leaching; and post-depositional alterations are just some of the processes that affect and alter the archaeological record. Furthermore, archaeologists frequently do not understand what types of

evidence and signals can be produced from different activities (see Shillito 2017 for a full discussion).

In the past artefact patterning has been used to interpret past activities, however artefacts rarely represent specific *in situ* actions because they may have been removed, purposefully placed or lost within contexts unrelated to their original use. Only a fraction, if any, of the material record of activities may remain in the archaeological record (Shillito 2017). An example of this is from the analysis of site activity areas in a Viking Age house in Iceland, where a spindle whorl was recovered from hearth deposits, clearly not representing *in situ* activity (Milek and Roberts 2013). Artefact distributions are also often the result of cleaning, abandonment or trampling (e.g. Çatalhöyük, Shillito 2017, 9). There has also been significant debate as to whether 'activities' can be detected or whether results are more representative of construction materials. Artefact and microremains can reflect other processes such as materials embedded within the floors resulting from construction rather than representing a specific activity on the floor itself (Tsartsidou et al. 2009; Shillito 2017). As a result, many archaeological sites, particularly form earlier time periods, are comprised of a series of structures, the form and function of which is difficult, if not impossible, to interpret.

CONTACT Emma Louise Jenkins ✉ ejenkins@bournemouth.ac.uk 🏢 Department of Archaeology, Anthropology and Forensic Sciences, Bournemouth University, Christchurch House, Talbot Campus, Poole, BH12 5BB, UK

In order to help address this problem, we took an ethnographic approach to further our understanding of how everyday activities leave microscopic or invisible traces. Human behaviour rarely produces a discreet signal and many different lines of evidence have been used to investigate activities and use of space (Shillito 2017). We selected a dual proxy approach, namely phytoliths and geochemical residues which, because they are inorganic, are more likely to survive in and be recovered from, the archaeological record compared with other evidence such as macrobotanical and faunal remains, making them a valuable source of information. Furthermore, as these remains are microscopic or invisible it is more probable that they will remain in the sediments in comparison to macroscopic artefacts that could have been removed or cleaned away. This analysis will be supported by targeted micromrophological sampling which will be the subject of a forthcoming paper.

Past Use of Phytolith and Geochemical Data in Ethnoarchaeology

Phytoliths

Phytolith analysis has frequently been employed in ethnoarchaeological research to address a wide range of research questions. Phytoliths have been investigated in modern contexts to: locate animal pens (Shahack-Gross, Marshall, and Weiner 2003; Shahack-Gross et al. 2004); examine domestic activities (Portillo et al. 2014); identify irrigation (Rosen and Weiner 1994; Madella et al. 2009; Jenkins, Jamjoum, and Al Nuimat 2011; Weisskopf et al. 2014; Jenkins et al. 2016); examine Bedouin tents (Jenkins, Baker, and Elliott 2011); further our understanding of cooking installations (Gur-Arieh et al. 2013); and to provide crop processing models (Harvey and Fuller 2005).

More pertinent for this study, Tsartsidou et al. (2008, 2009) conducted an ethnographic phytolith analysis of the use of space in a village in northern Greece with good effect. The results from these studies were then used to interpret phytolith assemblages from the Neolithic site of Makri, Greece and it was concluded that Markri was a permanently occupied site with a mixed agricultural and pastoral economy (Tsartsidou et al. 2009).

Geochemistry

Human habitation can significantly affect the chemical soil composition leading to enrichments and depletions of specific chemical elements and the formation of archaeological soils (Oonk, Slomp, and Huisman 2009). As such, elemental analysis has frequently been used to examine the use of space and activity areas in ethnoarchaeological and archaeological contexts (e.g. Middleton and Price 1996; Hutson and Terry 2006; Holliday and Gartner 2007; Wilson, Davidson, and Cresser 2009).

Considerable ethnographic research on how geochemistry provides information about the use of space has been undertaken by researchers working in Mexico. Extensive studies by Barba, Manzanilla and colleagues demonstrated that it was possible to identify different activity areas through changes in chemical concentrations with: *rest/sleeping areas* and *thoroughfares* being depleted in chemical compounds; *food preparation areas* having low phosphate values; and *food consumption* and *animal penning areas* having high phosphate values. They then used these results to interpret a number of archaeological sites in Mexico (Barba and Bello 1978; Barba and Denis 1981; Barba and Manzanilla 1987; Barba et al. 1987; Mejia and Barba 1988; Manzanilla and Barba 1990). Similarly, Middleton and Price (1996) analysed a range of floors from ethnographic and archaeological sites in Mexico. They demonstrated that floors could be identified on the basis of their geochemical signature and applied this method successfully to samples from two different archaeological sites ranging in age from 4000 BP to 800 AD (Middleton and Price 1996), while Smyth (1990) found increased concentrations of phosphorous (P) and calcium (Ca) in areas of maize treatment and preparation in Maya settlements in the Puuc region of Mexico.

However, there has been considerable debate and criticism of geochemical patterning studies to successfully distinguish the use of space and specific activities (e.g. Oonk, Slomp, and Huisman 2009; Canti and Huisman 2015, 100–101). Criticisms of this approach are based upon the numerous possibilities for each elemental signature e.g.: the diverse nature of potential activities; the overlapping of elemental signatures for numerous activities; post-depositional mixing of sediments; post-depositional leaching; differential leaching of elements; and post-depositional alterations.

Combined Approaches

Increasingly archaeologists are turning to combined approaches, or a multi-proxy methodology, to help understand the use of space. Shahack-Gross, Marshall, and Weiner (2003) used a combined phytolith and geochemical approach to study penning deposits from one occupied and four abandoned Masai settlements in southern Kenya. They found that the density of phytoliths was higher in penning deposits, while the geochemical analysis demonstrated that penning areas were distinct from regional sediments and from features inside the settlements such as hearths (Shahack-Gross et al. 2004).

Rondelli et al. (2014; see also Madella et al. 2014) used geoarchaeology to look at different activity areas within an ethnographic site in North Gujarat, India, to determine if certain activities left specific signatures.

They found that it was possible to distinguish *food storage areas* through high protein levels, *food preparation areas* through the presence of fatty acids and *areas of burning and fuel use* through geochemistry. Notably, their results found that *fire installations* where dung had been used as the fuel source, had higher values of aluminium (Al), barium (Ba), calcium (Ca), cobalt (Co), chromium (Cr), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and lead (Pb), while fire installations where wood had been used as the fuel source had higher values of Ca, potassium (K), magnesium (Mg), Al and P (Madella et al. 2014; Rondelli et al. 2014).

Ethnoarchaeological research involving phytoliths and/or geochemistry is becoming increasingly prevalent and a full review of geo-ethnoarchaeological methods, can be found in Friesem (2016). The body of research focused on this area demonstrates the value of ethnographic analysis as a means to further our understanding of how certain activities can leave specific anthropogenic signatures that can help us interpret these activities archaeologically. However, while these studies show great promise, the types of structures and settlements which were the focus of these earlier studies are not directly comparable to southwest Asian Neolithic sites, a time period and region which is critical for our understanding of the development from mobile hunter-gatherers to sedentary farmers.

The Ethnographic Village of Al Ma'tan

To address this problem, we conducted an ethnoarchaeological study in Jordan which could be used as a direct comparison for southwest Asian Neolithic sites. The abandoned village of Al Ma'tan was chosen because it was constructed using similar building materials and methods to southwest Asian Neolithic sites. Al Ma'tan is located in the At Tafila governorate of Jordan (Figure 1) and was founded in the late nineteenth or early twentieth centuries, with some reported variation as to the exact date of establishment. The village was slowly abandoned from the 1960s onwards, with the final inhabitants leaving in the 1980s, though some houses continue to be used for animal housing to the present day. The community resettled close-by in a modern village, now town, next to a major highway which provides better infrastructure and links to the capital city of Amman.

When Al Ma'tan was occupied, the inhabitants were semi-nomadic, practising rainfed arable farming, sheep/goat pastoralism and tree cultivation in adjacent orchards irrigated by local springs. The houses were most intensively lived-in during the winter, with goat hair tents used in the warmer months while out roaming in the landscape. Houses were important for year-round storage of food, fodder, agricultural equipment
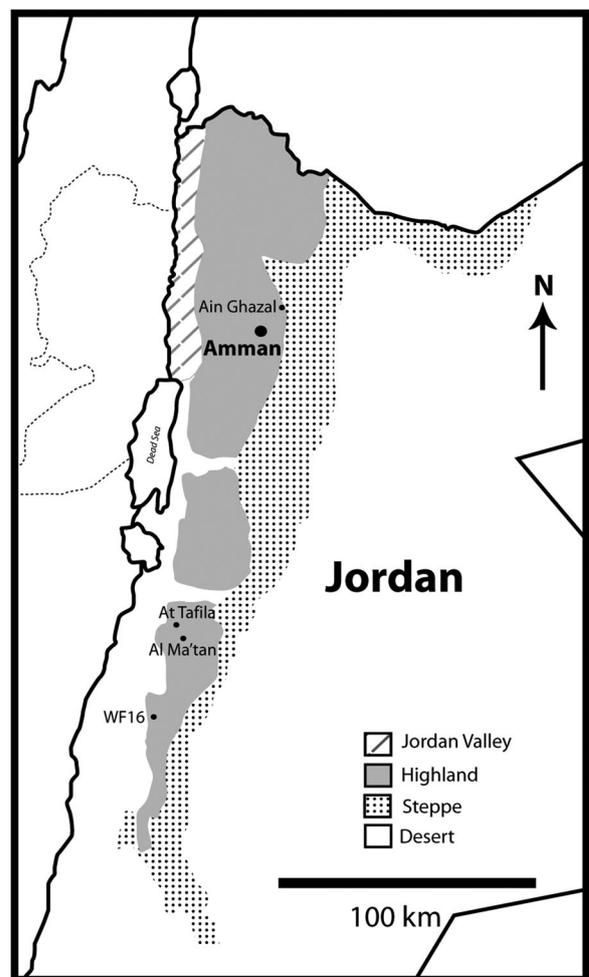

Figure 1. Map of Jordan showing location of Al Ma'tan in relation to Amman and At Tafila.

and household goods. In winter, the goat hair tents were also stored inside.

The architecture of the houses at Al Ma'tan is typical of southern Jordan and has been described by, for example, Khammash (1986), Biewers (1997) and, most recently, Twaissi, Abuhalaleh, and Abudanah (2016). The houses at Al Ma'tan are generally single-roomed, all one-storied and have flat roofs. Each one has a single entry door, usually with small openings above for ventilation. The most distinctive internal architectural feature is the use of arches which support the roof beams. Bays between the walls from which these arches spring are commonly used as 'rooms' for sleeping and for storage. The houses are fondly remembered by their former residents as very practical and warm in winter as well as cool in summer, but the use of natural materials meant that they required constant maintenance. Later in the village's history the residents started to use modern materials such as concrete, but most of the village is built from traditional materials.

From ethnographic discussions with the former Al Ma'tan residents, we know the village was built using local stone, mud and plant materials. One particularly

important clay used in construction at Al Ma'tan is regionally referred to as *samaga*-an unaltered natural 'clay' collected from known sources around the village. Technically *samaga* is comprised of clay sized particles and not clay minerals (smectites) and the *samaga* collected and used at Al Ma'tan has a high carbonate content (pers. comm. Dr Fathi Shaqour, 10/5/2016). *Samaga* can be found in the At Tafila area in three colour variations: red, yellow and blue/green. The colour of the clay is dependent on the amount of iron (Fe) oxides present. For example, 5% Fe oxide is required to make the clay red (pers. comm. Dr Fathi Shaqour, 10/5/2016). The plant material used for tempering the *samaga* is referred to as *tibn* which is chopped cereal straw, a by-product of the crop processing sequence after threshing and winnowing.

House walls were constructed out of stone and mud mortar and plastered over inside the house with layers of *tibn* tempered *samaga* (Figure 2(a–c)). Mud bricks were sometimes used to construct internal walls (Figure 2(c,d)). In addition to its use as wall plaster, the *samaga* and *tibn* mix was important in the construction of household 'furniture', such as shelves, niches and sleeping platforms, as well as on floors and to shape hearth features. It was also used to make the cloche-like dome of the local type of bread oven, a *tabun*, still in use in Jordan to the current day (Ebeling and Rogel 2016).

The house roofs were built using juniper beams (*Juniperus phoenicea* L.) as a support, with carefully aligned reed stems (*Phragmites australis* (Cav.) Trin. ex Steud.) on top (Figure 3(a)). This was followed by a shrubby packing layer of *bilan*, or Thorny Burnet (*Sarcopoterium spinosum* (L.) Spach.), a low, dense, profusely branching spiny sub-shrub from the Rosaeceae family (Figure 3(b)). The *bilan* is topped by a thick layer of sediment with stony inclusions (Figure 3(c)), with a top layer of the *tibn* tempered *samaga*
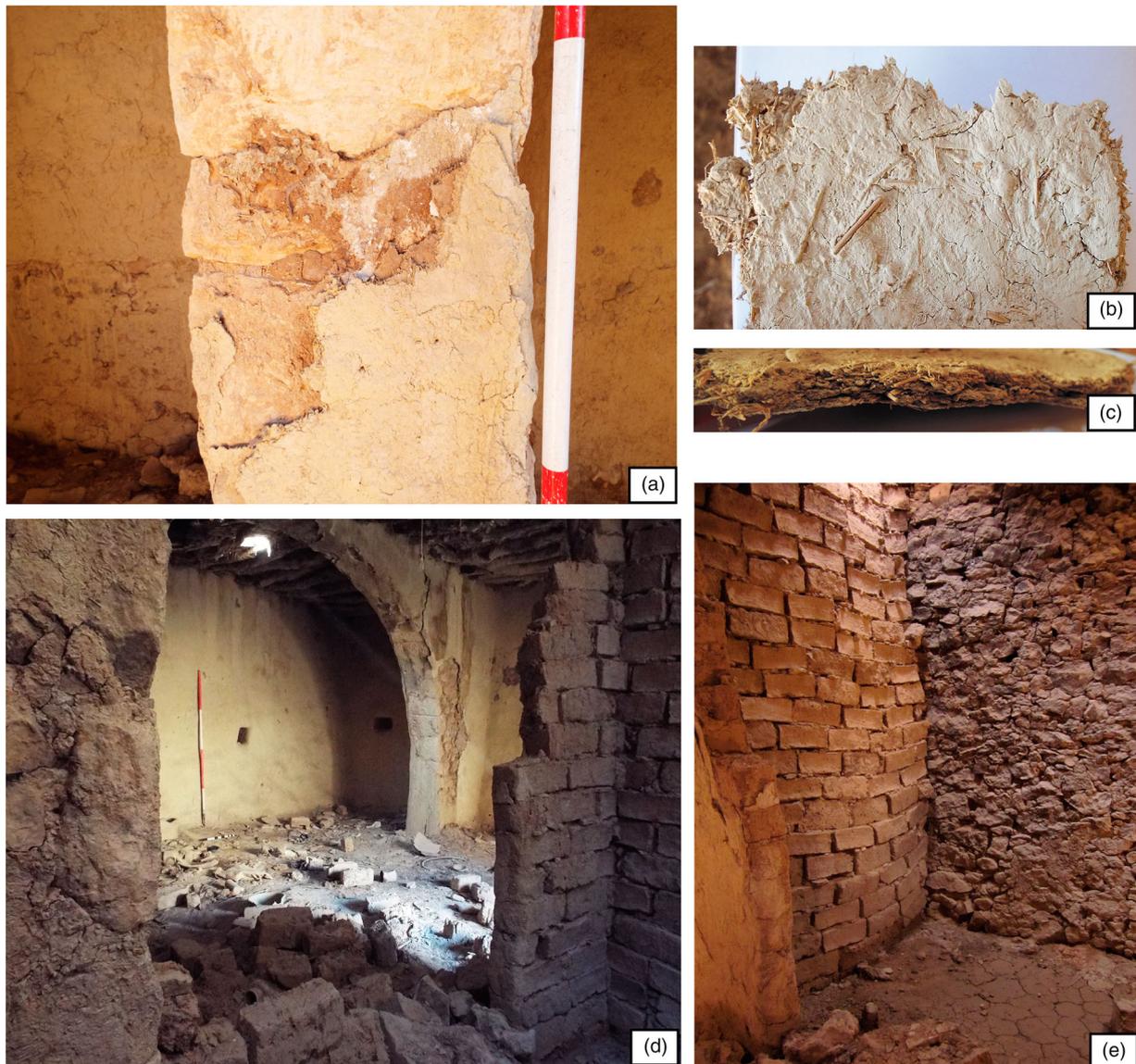

Figure 2. Al Ma'tan walls: (a) stone constructed wall with mud mortar covered in straw tempered clay plaster, Building 10; (b,c) Detail of straw tempered clay plaster; (d,e) mud brick internal walls, Building 65.

Figure 3. Al Ma'tan Roofs: (a) Typical roof construction showing supporting Juniper beams (*Juniper phoenicea*) with reeds (*Phragmites australis*), as seen in Building 1. (b): roof construction showing 'bilan' (*Sarcopoterium spinosum*) on top of the reeds, Building 1. (c) roof construction showing thick layer of sediment with stony inclusions above the 'bilan' and the reeds.

plaster for water-proofing, which was regularly re-applied before winter.

Many of the internal features found at Al Ma'tan are reminiscent of those found in southwest Asian Neolithic sites. For example, the food storage bins are made of clay and are similar in construction to those found at Neolithic sites such as Çatalhöyük (Figure 4); the niches carved into the walls of the buildings are similar to those found at Neolithic WF16 (Figure 5);

and the hearths set into the floors are frequently found in many southwest Asian Neolithic sites (Figure 6). Furthermore, the subsistence strategies at Al Ma'tan were comparable to those practiced by Neolithic populations with the villagers keeping sheep and goats and practising small-scale agriculture.

The proximity of the original occupants to the abandoned village, and their enthusiasm to help us, meant that we were able to talk at length to the former
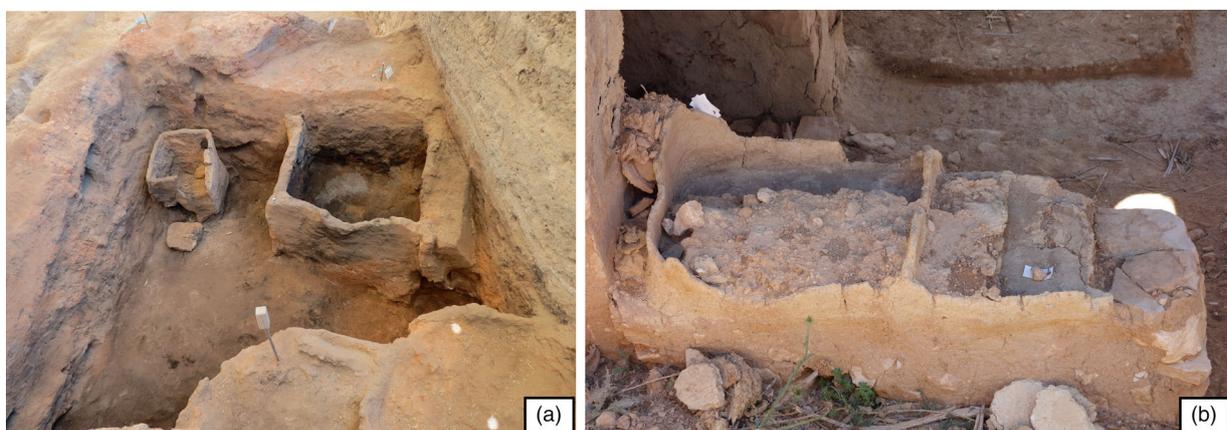
Figure 4. Storage bins: (a) A Neolithic clay storage bin from Çatalhöyük (with kind permission from the Çatalhöyük project); (b) a clay storage bin from Building 10 Al Ma'tan.

Figure 5. Wall niches: (a) Neolithic wall niches from Wadi Faynan 16, Jordan (with kind permission from the Wadi Faynan 16 Project); (b) Wall niches from Building 1 Al Ma'tan.

occupants of the buildings we sampled in order to understand how the buildings had been constructed and used. Ethnographic information was obtained verbally through interviews conducted by Palmer. Information was obtained regarding construction, the use of space and the life use history of the settlement, with specific information being recorded for the buildings and areas sampled. Off-site locations of clay sources used for building construction were also sampled with the help of former inhabitants who took us directly to the clay sources used in the construction of the buildings we sampled.

Figure 6. Hearths: (a and b) hearths from the Neolithic site of Wadi Faynan16, Jordan (with kind permission from the Wadi Faynan 16 Project); (c) Hearth from Building 10, Al Ma'tan; (d) Hearth from Building 1 Al Ma'tan.

Aims

The aims of this study are three-fold: (1) to determine if certain activity areas (e.g. middens, hearths and floor areas) and construction materials (e.g. roofing materials, plasters and mortars) in a southwest Asian modern traditionally built village have unique phytolith and geochemical signatures that can be used to identify these same areas archaeologically; (2) to assess how effectively portable x-ray fluorescence (pXRF) scanning can be used in the field to determine geochemical signatures from a range of past activities; and (3) to determine if the two forms of evidence, phytoliths and geoechemsitry, are more powerful for interpreting activity areas and construction materials when statistically analysed together or in isolation.

Materials and Methods

Field Methods

Survey and Excavation

Fieldwork at Al Ma'tan was conducted in April 2014. During this time a full topographical survey of the village was conducted using a Total Station (Leica TC407) and all buildings were planned at a 1:20 scale (Figure 7). Three well preserved houses were selected for analysis, Buildings 1 (B1), 10 (B10) and 65 (B65) (Figures 8–10), along with a range of external areas and features. Samples were classified based upon coherent groups that best represent 'activities' or 'construction make-up/types' (Table 1).

In order to analyse the targeted locations some minor excavation was carried out to remove collapsed structural material and mud in-wash in Buildings 10 and 65. In addition, four small trenches were excavated

to a depth of approximately 45 cm in Building 1 to allow the original building floors to be analysed and sampled. This was necessary because, post-abandonment, this building had been used for animal penning and, as a result, dung had accumulated.

Ethnographic Data Collection

The former inhabitants of Al Ma'tan were informally interviewed during the 10-day fieldwork season in 2014 and during subsequent visits to the village. Palmer is fluent in colloquial Arabic and undertook the interviewing with assistance from Firas Bqa'in (then a staff member for the Council for British Research in the Levant), Hussein Shabatat (a former resident of the village) and Emad Drous (Ministry of Tourism and Antiquities). Some of the informants were questioned about the history of the village and its development from the initial construction of the primary building (Building 1). Other informants provided information directly related to specific houses which we had selected for detailed analysis. Our selection of the three houses (Buildings 1, 10 and 65) was based on their exceptional preservation and the availability of former residents to provide us with the necessary information for our research; the former inhabitants of these three houses supplied accurate information to categorise the samples and to compare against the scientific analyses. Many of the older informants had memories of living in the village, collecting raw materials, constructing the houses and undertaking regular maintenance of them. Former residents provided details about construction practices, agricultural practices, herding practices, use of fuel, duration of occupation, family sizes and time of abandonment. All the information collected provided a robust background for understanding the village itself and more specifically the contexts that
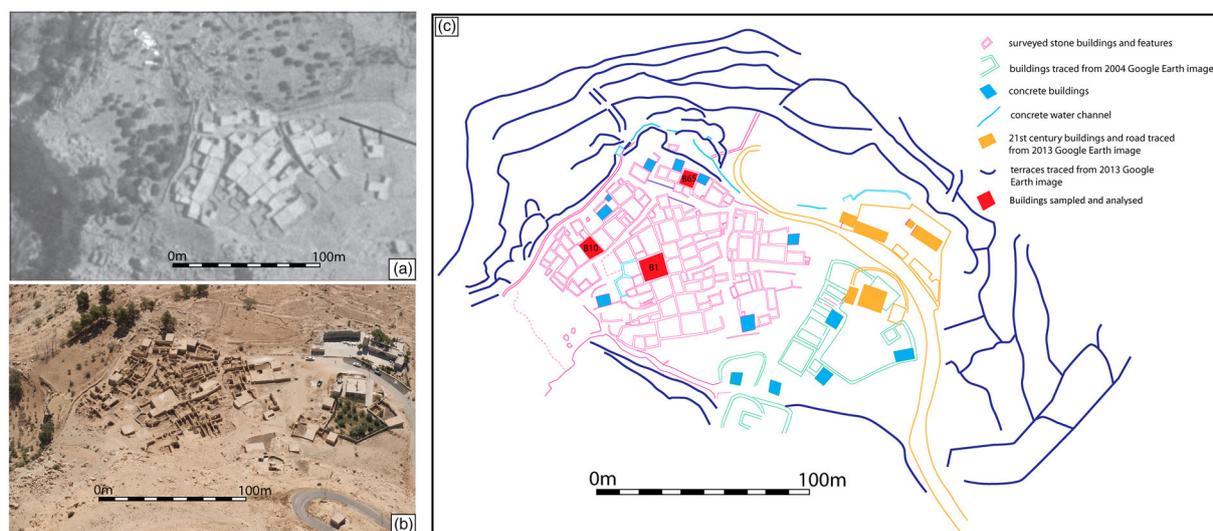

Figure 7. (a) Al Ma'tan village photographed in 1953 (Hunting Aerial Survey of Jordan. Photo courtesy of APAAME); (b) Al Ma'tan village photographed in 2011 (Photo courtesy of APAAME); (c) Al Ma'tan site survey showing locations of the buildings selected for sampling and analysis. (B1 = Building 1, B10 = Building 10 and B65 = Building 65).
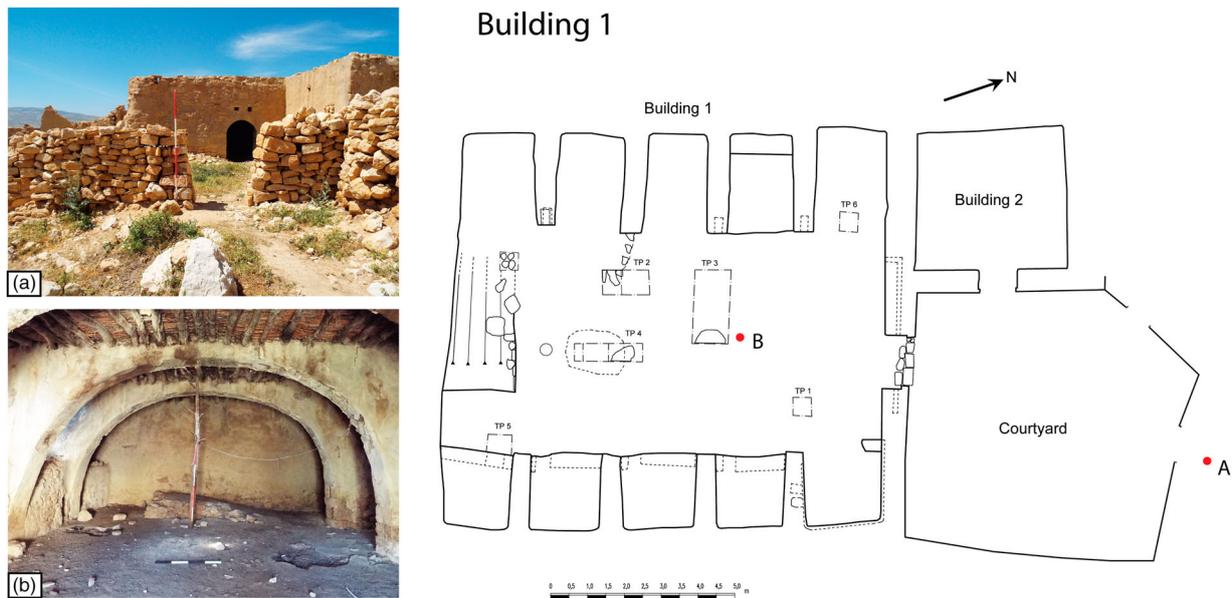
Figure 8. Photographs and plan of Building 1, Al Ma'tan. Locations of photographs A and B annotated on plan. Both photographs (a) and (b) taken facing south (scales in photos: A = 1m, B = 2 m and 1 m).

were being sampled and analysed from Al Ma'tan for this study.

Portable X-Ray Fluorescence (pXRF)

The locations selected for investigation at Al Ma'tan were analysed geochemically *in situ* (where possible) using a Niton Xl3t GOLDD+ pXRF analyser in the mining mode with the addition of helium purging from an attached portable helium canister. pXRF is a versatile and rapid technique that lends itself to a wide variety of sample types and a full suite of thirty-six elements can be recorded during analysis in the field. There are numerous highlighted limitations, such as low precision, variable analytical accuracy, lack of instrument calibration and data correction. Also ignorance of the effects of surface morphology and difficulties with quantification due to a lack of appropriate standards can all negatively impact results

Figure 9. Photographs and plan of Building 10, Al Ma'tan. Locations of photographs A and B annotated on plan. Photograph (a) taken facing east and photograph (b) taken facing west [photo (a) = general shot of Building 10, scales 2 m and 1 m; photo (b) = storage bin feature F51, scale 50 cm].
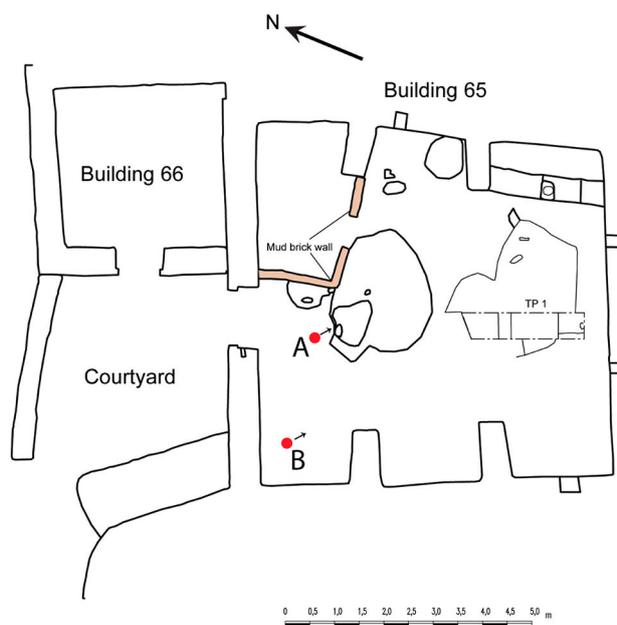
Figure 10. Photographs and plan of Building 65, Al Ma'tan. Locations of photographs A and B annotated on plan. Both photographs taken facing east (photo (a) = prior to rubble clearance; photo (b) = post-clearance with floor surface; scales 2 m).

(Goodale et al. 2012; Frahm 2013). When compared with laboratory-based XRF, the results have been found to be comparable for some elements (e.g. zirconium and strontium), but not for others (e.g. barium) (Goodale et al. 2012, 882). In comparison to other methods for the determination of elemental composition such as inductively coupled plasma mass spectrometry (ICP-MS), x-ray fluorescence and pXRF do not produce as accurate results. However, while ICP-MS is a versatile technique that can achieve limits of detection (LODs) many orders of magnitude lower than XRF, samples must be in liquid form, which often requires acid digestion and laborious sample preparations. While precision and accuracy using handheld analysers are not as great as with benchtop instruments (Craig et al. 2007; Frahm 2013; Piercey and Devine 2014), pXRF offers researchers the opportunity to gain readings in the field, alleviating the need for sample export which is becoming increasingly problematic in areas of southwest Asia, and can also be used as a prospection tool to select specific samples which, if promising, can be chosen for analysis using benchtop XRF or ICP-MS if more precise and accurate readings are needed.

Preliminary field tests were carried out to establish analytical timings in order to obtain low errors

Table 1. Summary of the number of samples analysed from Al Ma'tan by building number/area of collection and assigned INEA category.

	Building 1	Building 10	Building 65	Midden	Tabuns	Controls	Total
Samples (n)	37	42	41	14	3	7	144
Control type 1	n/a	n/a	n/a	n/a	n/a	2	2
Control type 2	n/a	1	n/a	n/a	n/a	5	6
Control type 3	n/a	n/a	n/a	n/a	n/a	n/a	0
External/Courtyard	4	0	2	n/a	n/a	n/a	6
Midden	n/a	n/a	n/a	14	n/a	n/a	14
Animal occupation	4	0	0	n/a	n/a	n/a	4
External fire installations and ashy deposits	n/a	n/a	n/a	n/a	3	n/a	3
Internal fire installations and ashy deposits	4	3	2	n/a	n/a	n/a	9
Hearth-make-up	3	5	1	n/a	n/a	n/a	9
Floors and surfaces	8	9	18	n/a	n/a	n/a	35
Human occupation/accumulation	0	0	0	n/a	n/a	n/a	0
Plasters and clay features	6	11	12	n/a	n/a	n/a	29
Storage features	0	7	1	n/a	n/a	n/a	8
Platforms and benches	5	1	1	n/a	n/a	n/a	7
Mortars	0	2	1	n/a	n/a	n/a	3
Roofs and roofing materials	3	3	3	n/a	n/a	n/a	9

(<10%). The pXRF analyser ran for a total of 210 s (main filter-60 s, low filter-40 s, high filter-20 s and light filter-90 s). The light filter needed a prolonged period of time for analysis to successfully detect the lighter elements such as Mg, silicon (Si) and P. The results of the analyses were examined for both elevations and depletions in elemental values, and for comparable patterns of major element concentrations. It was not our intention to use pXRF as a 'like for like' alternative to a benchtop XRF but to use pXRF as a portable instrument with a full appreciation of the limitations of this technique when compared to benchtop alternatives.

Sampling for Phytolith Analysis

Bulk sediment samples of approximately 50 g were taken for phytolith analysis from the same locations as the geochemical scanning using a clean trowel. Sample locations were photographed, added to plans and recorded using the Total Station (Leica TC407). The samples were double bagged and exported to the Department of Archaeology, Anthropology and Forensic Science, Bournemouth University for laboratory processing and analysis. In total, 144 samples were taken from a range of activity areas and construction materials (Table 1).

Modern Plant Reference Collection

A modern plant reference collection of 68 different plant species was processed to create a phytolith reference collection for the identification of phytolith morphotypes. The modern plant samples were collected in 2013 from a variety of locations in Jordan (see Vos 2016 for further details).

Laboratory Methods

Phytolith extraction followed Jenkins and Rosen (2007) with the exception that samples in this study were initially sieved through a 400 μm mesh not a 500 μm mesh. Identification of phytolith morphotypes was carried out using a Meiji MT4300 microscope at ×400, using our Jordanian plant reference collection and standard identification criteria (Twiss, Seuss, and Smith 1969; Brown 1984; Piperno 2006). More specific identification was carried out for the following taxa using the references stated: (1) reeds (Metcalfe 1960; Ollendorf, Mulholland, and Rapp 1988); (2) cereals (Rosen 1992; Tubb, Hodson, and Hodson 1993); and (3) dicotyledons (Albert et al. 1999).

Terms for each morphotype were allocated using the International Code for Phytolith Nomenclature (Madella, Alexandre, and Ball 2005). A minimum of 250 single-celled phytoliths and up to 50 conjoined or multi-celled phytoliths (where possible) were identified, counted and recorded. Weight percent of phytoliths for each sample was calculated based on the original weight of sediment processed (phytolith weight % = weight of phytoliths/weight of plant matter processed * 100).

Statistical Methods

Data Reduction

Thirty four elemental concentrations were determined from the pXRF scanning procedure. A considerable number of these elemental components had a high proportion of results under the limits of detection (< LOD) and individual values with high (> 10%) error readings (two-sigma precision value) which were removed from the analyses. However, a few low detection variables were retained because they are indicative of anthropogenic activities (following Reimann, Filzmoser, and Garrett 2002), for example elements such as P, chlorine (Cl) and Mg. This resulted in 12 elements being retained for further statistical analyses. For the remaining elements that had infrequent < LOD values recorded, numerical alterations were made to deal with the missing data. All < LOD values were replaced with their corresponding lower limit of detection which is the value provided as an error reading by the analyser (as recommended by the instrument's manufacturers-Niton).

Correlation Analysis (CA) was subsequently used to assess how the remaining 12 geochemical variables co-varied and to establish if there were any significant relationships between any two or more variables. This was important because in multivariate statistics correlated variables can bias the analysis. CA was conducted in a free downloadable statistical program called PAST (Hammer, Harper, and Ryan 2001) using standardised (mean of 0, standard deviation of 1) data. Both Pearson's Product Correlations coefficients (after transformation, see below) and Spearman's Rank Correlation coefficients (before transformation) were used as a measure of the degree of correlation. The strength of the correlation was judged using the published r-value. Any correlations which were higher or lower than +0.75 and −0.75 respectively, and had a p-value of below 0.05 in both correlation tests were deemed strong. For elements found to have strong correlations, one of the correlated elements was retained whilst the other was removed from further analysis to avoid using two very similar variables. Linked variables included: 1) Al and Si); 2) Si, titanium (Ti) and Al; 3) Ti and Fe; 4) zirconium (Zr) and Ti; and 5) Ca and strontium (Sr). As a result, we excluded Al, Si, Fe, Zr and Sr from the analysis and retained Mg, K, Ca, P, Ti, sulphur (S) and Cl.

Only single cell phytolith percent data were used in this study. In total, 39 single cell phytolith variables were identified and the phytolith counts were converted into percentage data for each phytolith type and sample. Variables containing less than 0.1% of

the total phytolith count were removed from further analysis, leaving a total of 28 phytolith types.

Results

Data Exploration

The selected elemental concentration data and the phytolith percentages were checked prior to statistical analyses to assess whether the observed values were sensible and to exclude any erroneous data. Through visual inspection, no analytical errors were identified but some data outliers were noticed. These data outliers were not errors but investigative outliers that resulted from anthropogenic sources, and as such were retained because they contained useful information about human practices.

The combined dataset was characterised and further inspected both visually and statistically for normality and skewness. Each variable had a different distribution shape, were often positively skewed and consisted of closed sum data (compositional data that are parts of a whole). Normalisation procedures were thus applied to the dataset to help it approach a normal distribution, reduce the compositional closure and lessen the effect of the data outliers; making most inferential statistics more applicable. Various monotonic transformations were trialled for the geochemical data, and while most made individual elements approximate normal, they did not work for the dataset as a whole. A centred log ratio (clr) transformation (Aitchison 1986) was found to be the most appropriate transformation for allowing all the geochemical variables to approximate or reach normality. Clr-transformations were conducted on the elemental data using a statistical application called CoDaPack v2 (Comas-Cufí and Thió-Henestrosa 2011). For the

phytolith results, an arcsine square root transformation was made in Microsoft Excel to the percentage data. This choice of transformation moves very high or low values towards the centre, reducing the impact of common phytolith types on rarer ones. It also controls for the non-normality of the percentage data which is constrained to 0–100% and can contain many low percentage values (McDonald 2014).

Principal Component Analyses (PCA) were performed in PAST (Hammer, Harper, and Ryan 2001) using the corrected and scaled data. PCA were run on a correlation matrix for the geochemical, phytolith and combined (geochemical and phytolith) datasets. Whilst transforming values prior to statistical analysis did make the data approximate normal and brought the variances more in line, there was still some difference in the variances. Therefore, it was necessary to standardise the variables first (PCA on a correlation matrix) so that they all had variance 1 and mean 0 to enable components to be found that best represented the variation in the original data, without being overly biased by those variables that showed the most variance. Standardisation also minimised the influence of different scales and units, and improved the significance of rarer phytolith types. A PCA ordination based on a correlation matrix showed differences in the variable compositions, rather than the variable concentrations as with a variance–covariance matrix. For the phytolith and combined PCAs, it was also deemed appropriate to ensure that the variances between groups was maximised to ensure that associations between variables and data groupings were made visually clearer.

PCA analysis was conducted on the geochemical and phytolith datasets individually (Figure 11(a,b)), and in combination (Figure 11(c)) to explore the internal data structure, to detect multi-variable
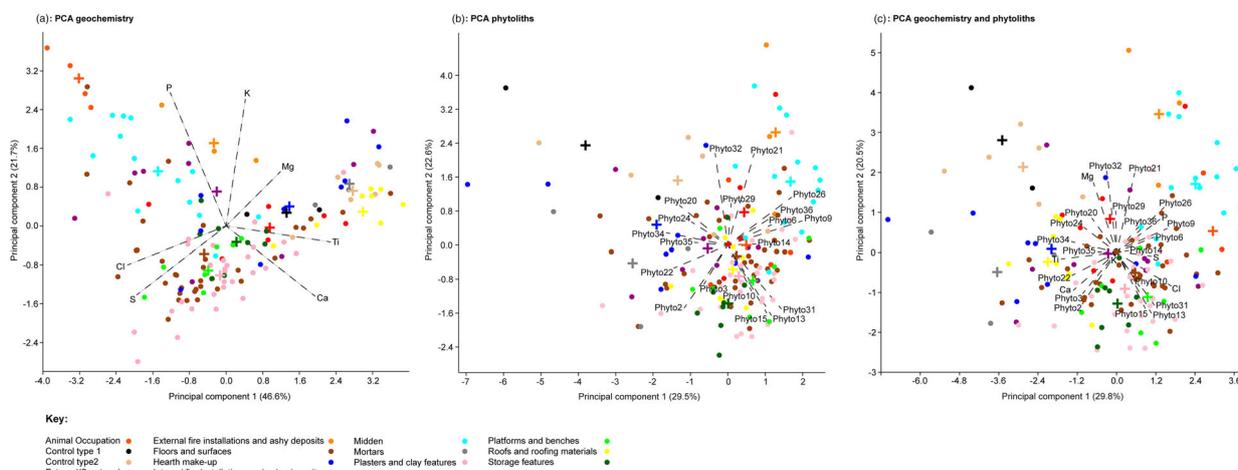
Figure 11. PCA biplots of the first two principal components (PCA1 vs. PCA2) for (a) the geochemical data; (b) the phytolith data; (c) the geochemical and phytolith data combined. PCA was conducted on normalised values using a correlation matrix i.e. each variable makes the same contribution to the analysis. Coloured dots represent individual samples assigned to a category type. Coloured addition symbols (+) mark the centroid of samples for each category. Black text delineates the variables driving most of the variance within the dataset, with the length of each dashed line defining the strength of each factor (longer lines = driving more variance).

associations, look for similarities between observations and visually interpret results. In this section, the geochemistry results will be discussed first, followed by the phytolith results, and finally the geochemical and phytolith results combined.

Geochemistry Results

The geochemical variability of the Al Ma'tan samples can be seen in 34 elements. Of the elements measured by the pXRF, Mg, Si, K, Ca, P, Fe, Ti, Al, Sr, S, Cl and Zr form the bases of our interpretations. High values were recorded for Ca (45273–293558 ppm) and Si (15084–189929 ppm), while values for Mg, P and Sr were much lower. Small value ranges were found for Ti (4029 ppm), Sr (538 ppm) and Zr (300 ppm). Sample values for K, Fe and Al are relatively high but some smaller values also exist. Sulphur is distinctive in that while its mean value is relatively high, its median value is much lower because of a few high values inflating the mean. Unmeasurable concentrations of Mg (23%), P (65%), S (6%) and Cl (13%) were recorded but these elements were kept in the analyses because concentration levels were of importance to the study and contained information about specific anthropogenic features of interest, such as hearths.

Samples show a clear patterning of element depletions and additions depending on the assigned category type (Figure 12). For example, *control/background* samples are relatively high in Mg, Fe, Ti and Al, whereas most other categories show depletions in these elements. *Animal occupation* and *midden* samples have high values of K and Cl, and relatively high P. Elevated Ca, and closely associated peaks in Sr, are documented for the following categories: *plasters and clay features*; *storage features*; *floors and surfaces*; *platforms and benches*; and *roofs and roofing material*. In contrast, lower concentration levels of Ca are recorded for *animal occupation* and mud *mortar* samples. Uniquely, *roof and roofing material* samples show elevated Zr and *external fire installations and ashy deposit* samples show elevated Si. The high average S value in the *control/background* samples is biased by the S concentration of just one clay-rich sample (*control type 1*). Higher S values are also found in *internal fire installations and ashy deposit* samples and in *plasters and clay feature* samples.

The samples studied revealed a number of interesting points if the differences are considered by category type. First, there is a significant depletion in some elemental values in comparison to the control samples. Second, the geochemical patterns for certain categories can be similar. Third, a marked elevation in K, P and Cl is apparent for specific categories and finally, high S concentrations are often associated with specific samples and not categories.

The first two axes for the geochemical PCA account for 68.3% of the overall variance in the dataset. Only one principal component was seen as statistically significant using the broken stick method (Frontier 1976; Legendre and Legendre 1998) but with bootstrapped data then axes two and three can also be considered significant. The first two axes have been selected for graphical illustration only because they represent a high proportion of the overall differences, and are significant or close to significant in both un-bootstrapped and bootstrapped analyses.

The resulting PCA (Figure 11(a)) shows well-defined groupings of samples which relate closely with the category assigned to each sample. Driving PCA axis 1 (PCA1) is the distinction between higher levels of Ti, Ca and Mg at the positive end and higher levels of Cl, S and P at the negative end. Driving PCA axis 2 (PCA2) is the difference in levels of P and K. In this regard, the PCA identifies two main latent variables or gradients that differentiate anthropogenic from natural sources on the one hand (PCA1) and the presence of animals and/or burning on the other (PCA2). Elements that associate with natural sediment sources are therefore Mg and Ti [and previously (see 'Methods' section) excluded correlated elements such a Fe and Al], whereas elements which are attributed to anthropogenic sources include S, Cl and P. These loadings imply that PCA1 defines a geochemical gradient that is driven by the presence or absence of lithogenic sediments (e.g. clays, colluvium), and their reduced signal due to more anthropogenic additions into the sediment matrix. The loadings also suggest a strong gradient associated with the presence of animal dung and burnt sediments that define PCA2; attributed by elevated levels of P and K respectively.

There is a clear discrimination of the category types according to the geochemical PCA results (Figure 11). *Mortar, roofs and roofing material,* and *hearth make-up* all show chemical concentrations similar to the *control/background* samples and are very distinct from *animal occupation* samples. The location of these samples at the positive end of PCA1 suggests they all have a common lithogenic signature when compared to *animal occupation* samples which have very little lithogenic influence. Other similarities are found for *storage feature*, *floors and surfaces*, *platforms and benches,* and *plasters and clay features* categories. These samples plot towards the centre of PCA1 and the negative end of PCA2, and are aligned closely to elevated S and Ca. The broadest chemical variation can be seen with *internal fire installations and ashy deposits. External fire installations and ashy deposits* and *internal fire installations and ashy deposits* plot beside each other and likely reflect similarities in higher K and P levels, elements typically associated with burnt ashy deposits (see Custer et al. 1986; Middleton and Price 1996; Holliday 2004; Price and Burton 2012).
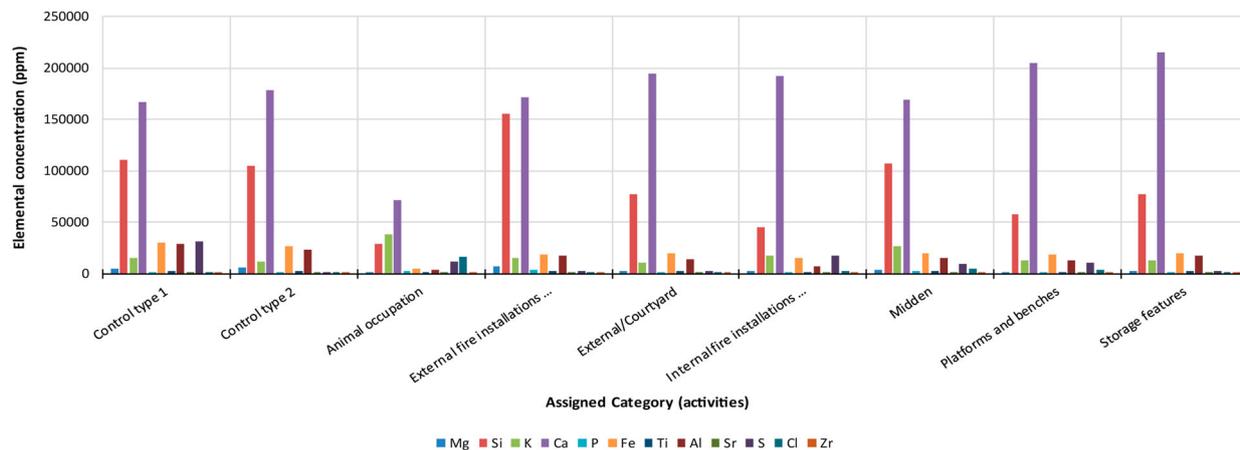
Category (Activities)	Mg	Si	K	Ca	P	Fe	Ti	Al	Sr	S	Cl	Zr
Control type 1	5452	110324	15148	166717	137	29701	3080	29324	200	31451	82	81
Control type 2	5714	105308	11822	178829	123	26937	2622	23152	189	891	48	123
Animal occupation	1971	29252	37661	71726	2897	4968	714	4108	120	11332	16471	18
External fire installations and ashy deposits	7662	155522	15415	172000	3863	18527	2218	17193	223	2457	877	101
External/Courtyard	2689	77316	11122	194480	629	19412	2422	14344	204	3124	952	122
Internal fire installations and ashy deposits	2889	45657	17679	191883	1257	15742	1508	7736	319	18110	2493	78
Midden	4073	107031	26327	169627	2446	19988	2064	14767	248	9958	4759	114
Platforms and benches	1930	58313	12810	205069	186	19127	1825	13419	265	10265	4275	54
Storage features	2681	77663	12977	215043	363	19768	2192	17047	291	3099	1971	59
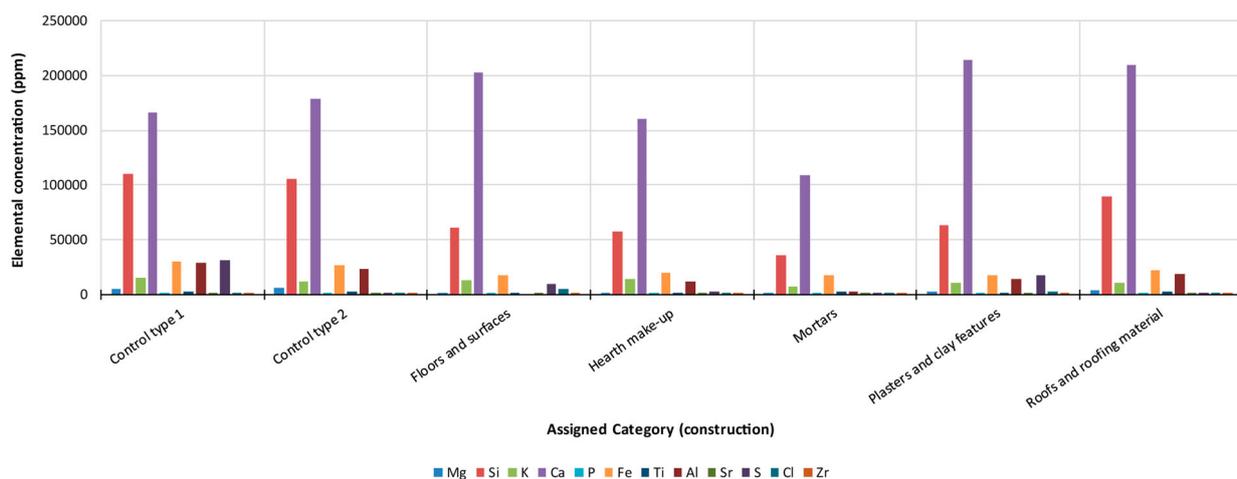
Category (Construction)	Mg	Si	K	Ca	P	Fe	Ti	Al	Sr	S	Cl	Zr
Control type 1	5452	110324	15148	166717	137	29701	3080	29324	200	31451	82	81
Control type 2	5714	105308	11822	178829	123	26937	2622	23152	189	891	48	123
Floors and surfaces	2088	60778	13183	202872	482	17711	1867	0	229	9903	4828	69
Hearth make-up	1877	57524	14157	159964	143	19596	2095	11462	234	2682	1635	112
Mortars	765	36266	7212	109525	136	17124	2234	3212	129	305	43	117
Plasters and clay features	2324	62830	10687	213963	280	17759	1858	13995	239	17450	2651	65
Roofs and roofing material	3637	89730	10307	209610	120	22288	2854	18990	227	1466	138	161

Figure 12. Top: Bar chart showing average (mean) elemental concentrations in parts per million (ppm) for control samples and samples assigned to categories that represent different types of activities (all buildings combined), with associated table of values for reference. Bottom: Bar chart showing average (mean) elemental concentrations in ppm for control samples and samples assigned to categories that represent different construction practices (all buildings combined), with associated table of values for reference.

Midden samples also plot closely with the two burning categories, indicating the comparable importance of high K and P in Al Ma'tan middening contexts; probably because the middens principally consist of dumped *tabun* oven ash (pers. comm., former Al Ma'tan residents).

Phytolith Results

Of the 144 samples analysed, 97% of the phytolith assemblages were dominated by monocotyledonous (monocot) phytoliths (Figure 13). A total of 57% of the samples had less than 2% dicotyledonous (dicot)
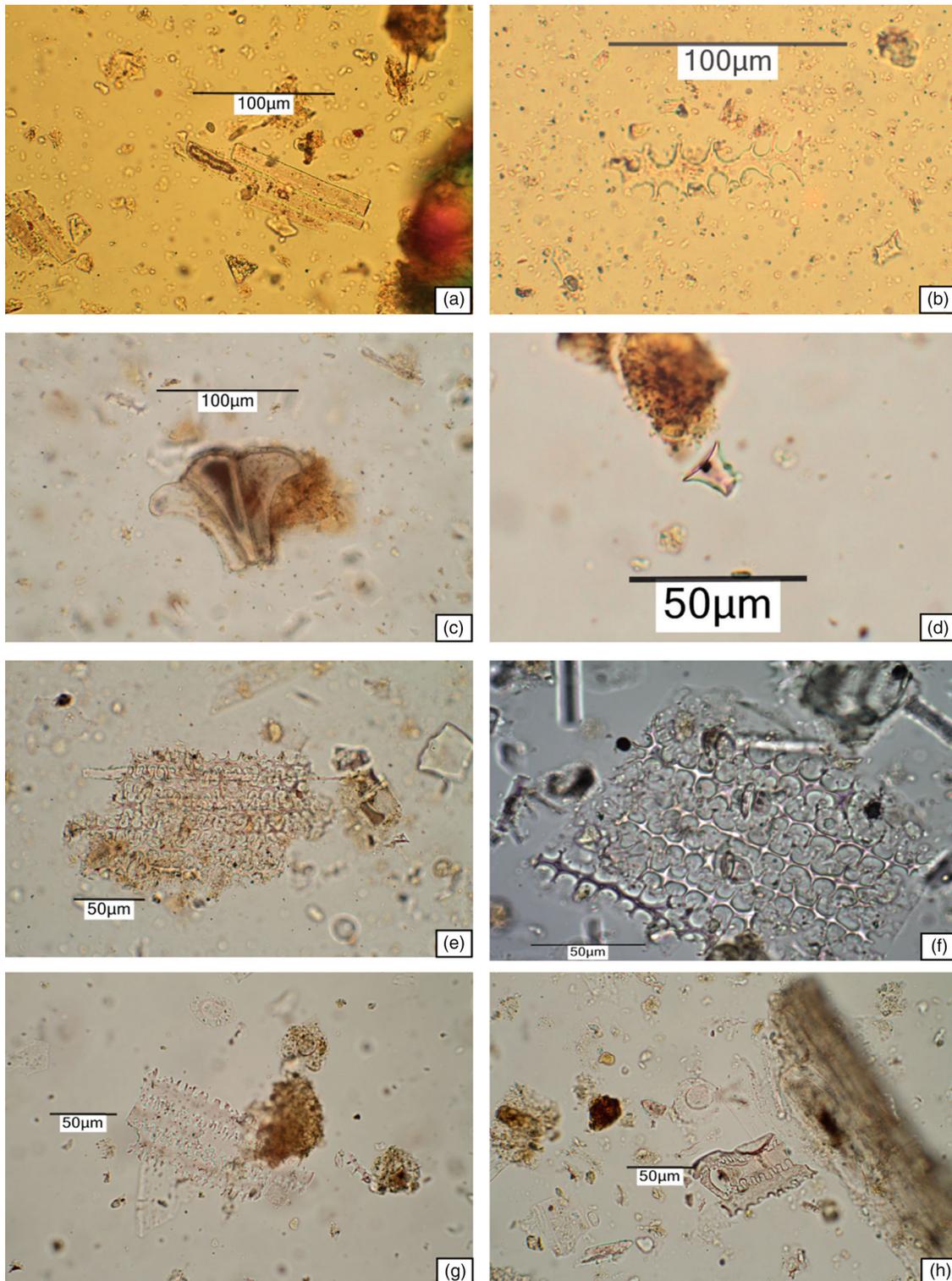
Figure 13. Phytoliths identified from Al Ma'tan samples: (a) elongate smooth forms from an External/courtyard area, Building 1 (sample P19), (b) elongate dendriform, from a Floor/surface in Building 10 (sample P67), (c) conjoined keystone bulliforms, from a Floor/surface in Building 10 (sample P61), (d) rondel, from a Plaster in Building 10 (sample P48), (e) *Triticum* (wheat) from a platform in Building 1 (sample P10); (f) *Hordeum* (barley) from external midden deposits (sample P149); (g) *Avena (*oat) from the tabun deposits (sample P194); (h) *Lolium (*ryegrass) also from the tabun deposits (sample P195).

phytoliths and 8% of the samples consisted of between 10 and 85% dicot phytoliths (Table 2). The samples with the highest percentage of dicots were samples from the *hearth make-up* and *control/background* categories (specifically *control type 1*) (Table 2). Categories dominated by samples with low percentages of dicot phytoliths were: *plasters and clay features*; *middens*; and *platforms and benches* (Table 2).

The majority of the samples in the categories analysed are dominated by common grass morphotypes; for example: elongate dendritic, elongate smooth, elongate sinuate and rondel short-celled phytoliths.

Table 2. Percentage of dicotyledonous phytoliths in samples from Al Ma'tan including the number of samples, percentage of total samples analysed and assigned categories.

Dicot phytoliths	% Dicot phytoliths	Number of samples	% of total samples	Categories (number of samples)
Low	<2	82	57	Plasters and clay features (23), Floors and surfaces (20), Midden (9), Platforms and benches (6), Storage features (5), Roofs and roofing materials (4), External/courtyard (4), Control type 2 (3), Internal fires installations and ashy deposits (3), Animal occupation (2), External fire installations and ashy deposits (2), Hearth-make-up (1)
Moderate	2–9	50	35	Floors and surfaces (13), Plasters and clay features (6), Midden (5), Roofs and roofing materials (4), Internal fire installations and ashy deposits (4), Hearth-make-up (4), Storage features (3), Control type 2 (3), Animal occupation (2), Mortars (2), Platforms and benches (1), Control type 1 (1), External fire installations and ashy deposits (1), External/courtyard (1)
High	10–24	8	6	Internal fire installations and ashy deposits (2), Hearth-make-up (2) Floors and surfaces (2), External/courtyard (1), Mortar (1)
Very high	50–85	3	2	Hearth-make-up, Control type 1

Furthermore, there are some categories with limited variability in the phytolith assemblages beyond these forms, such as: *external fire installations and ashy deposits; middens; plasters and clay features; and platforms and benches.*

One category which has a wider variety of phytolith morphotypes is *floors and surfaces.* In addition to the common grass phytolith morphotypes outlined above, there are low but significant numbers of papillae, platey, globular smooth, short celled bilobes and block phytoliths. Other category differences to highlight are the low, but consistent, presence of dicot morphotypes in the *hearth-make-up* and *internal fire installations and ashy deposits* categories; sheet and block phytoliths were identified in the *hearth-make-up* samples, and platey and sheet phytoliths in the *internal fire installations and ashy deposits* samples.

Reeds (*Phragmites*) can be identified as conjoined forms (Metcalfe 1960; Ollendorf, Mulholland, and Jr 1988) and further inferred from the identification of single-celled keystone bulliform phytoliths (Figure 13). Single-celled keystone phytoliths were identified in 104 of the samples analysed and conjoined reed forms in 89 of the samples. Categories where reed phytoliths where plentiful were: *roofs and associated deposits; internal fire installations and ashy deposits; external fire installations and ashy deposits;* and *middens* – while *plasters and clay features* were often devoid of reed phytoliths.

Conjoined husk phytoliths which were identifiable to genus in the samples included *Triticum* (wheat – 57 samples), *Hordeum* (barley – 83 samples), *Avena* (oat – 2 samples) and *Lolium* (ryegrass – 8 samples) (Figure 13). Conversely, conjoined husk phytoliths that were identifiable to genus level were low in the *hearth make-up* and *mortars* categories with an average of <1.5% of the total conjoined phytolith assemblages. Conjoined husk phytoliths identified to genus level were high in the following categories: *external fire installations and ashy deposits; middens* and *external/courtyard* with an average of >10% of the total conjoined phytolith assemblages (12.5–20.6%). The

highest average percentage of identifiable husk conjoined forms was from *external fire installations and ashy deposits* with 20.6%. Conjoined husk phytoliths identified to genus level comprised between 4.9 and 9.1% in the majority of the remaining categories: *animal occupation, floors and surfaces; internal fire installations and ashy deposits; plasters and clay features; platforms and benches; roofs and roofing materials;* and *storage features.* The only category where all the samples analysed had conjoined forms from husks was *storage features.* All identifiable husks from *storage features* were identified as *Triticum* and *Hordeum.*

The PCA biplot for the phytolith results (Figure 11 (b)) comprises the first two PCA axes only, which account for 52.1% of the total variance observed within the dataset. Using the broken stick method, axes 1–3 were deemed significant for the phytoliths which in total account for 66.3% of the total variance. Phytolith types that are commonly associated with grasses, and in particular grass inflorescences, including elongate smooth, rondel, elongate dendriforms, papillae and cork cells, all produce positive loadings on PCA1. At the opposite end, phytoliths that are typically attributed to dicots (e.g. sheet, block and globular smooth) as well as hair, keystone and stomata forms produce negative loadings. This distinction most likely separates sediments that contain cereal plant parts with those higher in wood/shrubs and reeds. At the positive end of PCA2, the variances seen are predominantly driven by hair base and saddle phytoliths, but also polyhedrol plain, papillae and globular smooth types. At the negative end, elongate echinate, elongate sinuate, elongate trapeziform, rondel and bulliform phytoliths dominate. Block type phytoliths also drive some of the distinction for negative PCA2.

Distinct category clusters in the phytolith data are less visually apparent; probably because of the greater variability in the dataset compared to the geochemical data and the larger number of variables included within the analysis. Reasonably well-defined comparable phytolith signatures for each category can however be seen for the *storage features, platforms and benches,* and

plasters and clay features categories which are strongly associated with elongate forms due to their location at the negative end of PCA2. Other comparable categories include *internal fire installations and ashy deposits, hearth make-up*, and *mortars* which are influenced by the presence of dicot material and plot at the negative end of PCA1. *Midden* and *external fire and ashy deposit* samples cluster at the positive end of PCA1 with cereal phytolith types and are further influenced by the presence of hair bases. *Floor and surface* samples are relatively widespread suggesting a diverse phytolith signature for samples attributed to this category. Whilst the centroid for *floors and surfaces* plots at the centre of both PCA axes, and close to elongates and rondels which are both monocot forms, *floor and surface* samples can also be seen plotting with dicot signatures (negative PCA1) and cereal signatures (positive PCA2). Therefore, it could be argued that on-floor activities can be more of a driver of the phytolith signature compared to the floor matrix signature in specific cases because of the mixed geochemical signals recorded.

External/courtyard samples are also distributed at opposite ends of the biplot with some samples aligning close to the influence of hair base phytoliths (positive PCA2) and others with elongate phytolith types (negative PCA2). *Animal occupation* samples likewise show a lack of sample clustering. There is further dissimilarity in the *control/background* samples so it is hard to compare other category signatures against the background observations. Their location at the negative end of PCA1 and positive PCA2, however, suggests associations with globular smooth, and reed phytolith types (e.g. keystone bulliform and saddle), more than other categories.

Combined Geochemistry and Phytolith Results

The combined PCA which includes both the phytolith and geochemical data (Figure 11(c)) is most comparable to the phytolith PCA. In total, thirteen axes were created during the combined data PCA but only the first four axes were deemed statistically significant. The first four axes have combined eigenvalues explaining 74.9%. Due

to the difficulty of understanding four latent variables only the first two will be discussed here.

Along PCA1 we see that Ti and Ca co-vary with hair, globular smooth, sheet, block, bulliform, keystone bulliform and stomata types at the negative end. For positive PCA1, Cl and P play an important role in delineating samples plotted here, as do elongate dendriform phytoliths and papillae phytoliths. Cl and Ca are key geochemical drivers of negative PCA2, as are the leaf/stem phytolith types of rondels, elongate sinuate and elongate trapeziform, and block phytoliths. Mg drives a lot of the variance seen for positive PCA2, as do saddle and hair base phytoliths.

The biplot (Figure 11(c)) of the first two principal components for the combined dataset shows some separation of clustered category samples (see Table 3 for summary of clusters). The first noticeable cluster (C1) includes *control/background*, *mortar*, and *hearth make-up* categories which are distinct because of higher levels of Ti, Ca and Mg, and phytoliths akin to woody plant and reed species. The second group (C2) includes *storage feature*, *plasters and clay features*, *platforms and benches*, and *floor and surfaces* categories which plot together because of elevated Ca and Cl, as well as leaf/stem phytoliths of elongate form and rondels. The third group (C3) includes *animal occupation*, *external fire installations and ashy deposits*, and *midden* categories, and variables such as P, S, grass inflorescence phytolith types and hair bases. *External/courtyard* samples are too varied to cluster but samples plot within each of the three clusters (C1–3) identified above and consequently signatures must relate more to specific activities conducted within the external setting rather than the make-up of the external setting. *Internal fire installations and ashy deposits* are again too diverse to provide a distinct group but they do not plot with the second cluster suggesting a lack of elongate phytolith types for samples of this origin. The centroid for *internal fire installations and ashy deposits* is central on both PCA axes and whilst this implies a mixed signal for these observations, it also suggests some relation to higher levels of K, which is an element commonly associated with burnt wood ash and would be expected to be inflated in fire-related deposits (see Holliday 2004; and references therein).

Table 3. Table showing the principal elements and phytolith types that drive distinctive clusters of category samples at Al Ma'tan.

Category		Distinctive elements driving clustering	Distinctive phytoliths driving clustering
Cluster 1 (C1)	Control/background	Ti, Ca, Mg	Dicot phytoliths, reeds
	Mortar		
	Hearth-make-up		
Cluster 2 (C2)	Storage feature	Ca, Cl	Grass leaf/stem elongates, rondels
	Plasters and clay features		
	Platforms and benches		
	Floor and surfaces		
Cluster 3 (C3)	Animal occupation	P, S	Grass inflorescence phytoliths and hair bases
	External fire installations and ashy deposits		
	Midden		

Discussion

Geochemistry

Lithogenic Influences: Mortars, Hearth-make-up, *and* Roofs and Roofing Materials

The geochemical results from Al Ma'tan showed clear divisions between activity contexts with categories such as *mortars*, *hearth-make-up*, and *roofs and roofing materials* consisting of mainly lithogenic elemental concentrations with other categories such as *animal occupation* having little lithogenic influence. We know from the ethnographic evidence that the mud *mortars* used in the wall construction are comprised of unaltered sediments obtained from areas close to the village. These were then mixed with water and used between the stones as an adhesive. The category *hearth make-up* is comprised of the sediment directly beneath the hearth, not the remnant fuel, and therefore consists of sediments or clays that are naturally deposited beneath the building prior to construction. Similarly, a large portion of the roofing material derives from unaltered colluvial sediments collected from the surrounding landscape which was placed on top of the beams, reeds and shrubby material as shown in Figure 3.

Anthropogenic Influences: Animal Occupation, Storage Features, Floors and Surfaces, Platforms and Benches, *and* Plasters and Clay Features

Categories such as *animal occupation* have little lithogenic influence and represent a more anthropogenic input. Typically anthropogenic influences were recognised in contexts such as: *animal occupation*; *storage features*; *floors and surfaces*; *platforms and benches*; and *plasters and clay features* (see the section 'Data Exploration').The *animal occupation* deposits have a reduced lithogenic sediment signature because they consist primarily of animal-faecal material and plant remains, and comprise virtually no local sediments. Contexts related to burning, *internal fire installations and ashy deposits, external fire installations and ashy deposits* and *middens*, also exhibited clear patterns (see the section 'Data Exploration').

The contexts which are relatively high in Ca and S (*storage features, floors and surfaces, platforms and benches*, and *plasters and clay features*), geochemically reflect the selection of *samaga* 'clay' used in plaster construction and the addition of materials such as gypsum. *Internal fire installations and ashy deposits, external fire installations and ashy deposits* and *middens* have similar signatures due to the elevation of two elements which commonly result from exposure to fire – P and K (Holliday 2004). Middens can be seen as indirect indicators of activities and represent the end product of those activities (Shillito 2017). The midden deposits sampled at Al Ma'tan predominantly consist of ashes from the *tabun* ovens which the local inhabitants informed us were fuelled with dung and are located next to the midden.

Phytoliths

The distinction between the categories from the phytolith results is less clear in comparison with the geochemical results. However, there are some divisions between categories which are supported by the ethnographic evidence.

Addition of Temper: Storage Features, Platforms and Benches, *and* Plasters and Clay Features

Storage features, platforms and benches, and *plasters and clay features* plot together in the PCA analysis (Figure 11(c)) and these categories are influenced by elongate phytolith forms. These are from the plant material which was used as temper which the former inhabitants informed us was preferably barley *tibn* because it was softer than wheat *tibn*. Conjoined phytoliths positively identified as barley were identified in approximately half of the samples in these categories.

Dicotyledonous Signatures: Internal Fire Installations and Ashy Deposits, Hearth-make-up, *and* Mortars

Other categories which have similar phytolith signatures are *internal fire installations and ashy deposits, hearth-make-up*, and *mortars*. These categories are influenced mainly by dicot forms with a paucity of conjoined monocot forms which could be identified to genus level. From the ethnographic information these categories are known to be made from natural clay sources which are littered with shrubs, and that *tibn* is not used in their construction. Therefore, the phytolith results match the ethnographic information gathered about these categories with the dicot material being naturally derived from the local clay source. The final category influenced by dicots, *internal fire installations and ashy deposits*, has a signature which represents wood fuel selection for the internal hearths. This correlates with the information obtained during the ethnographic investigation which was that only wood fuel was used inside the buildings.

Cereals: External Fire Installations and Ashy Deposits, Midden *and* Storage Features

Categories which are influenced by phytoliths indicative of cereals are the *external fire installations and ashy deposits*, and *middens*. As noted above, the percent of conjoined husk phytoliths which could be identified to genus level was high in these categories. These categories contain dung remains because they are comprised of the dung-fuelled *tabun* ovens and the adjacent ashy rake-out from them. The prevalent

husks identified from these categories are *Triticum* and *Hordeum* which was supplied as fodder to the animals demonstrating that the phytolith information accurately reflects the ethnographic information for these samples.

Similarly, the only category where all the samples analysed had conjoined husk forms is *storage features*. All identifiable husks from *storage features* were identified as *Triticum* and *Hordeum* which correlates with the ethnographic information from the former inhabitants who told us that these storage features had contained cereals.

Diverse Phytolith Signatures: Floors and Surfaces

There are some categories which have a more diverse phytolith signature, for example, the *floors and surfaces*. This varied signature in the floor samples is indicative of the different activities carried out on the floors within the buildings with samples being from a range of areas such as sleeping areas, entrance-ways, kitchen areas, areas adjacent to hearths, areas near to storage features and peripheral areas. Furthermore, material identified on *floors and surfaces* in some archaeological contexts has been observed to be transported and re-deposited from other contexts in the form of 'foot traffic' on the soles of peoples feet or shoes (Shillito 2017). Spreads of ashes on floors could produce a diverse signature more similar to hearth deposits (Regev et al. 2015). Therefore, the variation in phytolith signatures within this category is expected.

Combining the Proxies

When data from both the geochemical and phytolith analyses were statistically analysed together, the grouping of categories reflects the results from the phytolith analysis because there are a greater number of distinct variables in the phytolith assemblage than is found in the geochemical data. Some categories were identified as being too varied by the combined geochemical and phytolith PCA to form clusters. These categories were *external/courtyard* and *internal fire installations and ashy deposits*. The *external/courtyard* samples could be different because of external influences such as wind and rain which would deplete the geochemical and phytolith signatures or alternatively could concentrate them in certain courtyard areas. Similarly, the *external/courtyard* areas have a varied life history ranging from human use to post occupation animal penning areas and finally complete abandonment which all play a role in the geochemical signature witnessed i.e. the more diverse the range of activities, the more diverse is the resulting phytolith and geochemical signature. The variation between samples from the category *internal fire installations and ashy deposits*, could result from varied cooking activities. Other

differences could reflect differences in how the hearths were managed when they fell out of use.

Overall, it is apparent from our results that these two proxies are better statistically analysed separately rather than together. Results demonstrated that when trying to combine the results to run the statistical analysis the outcome was less powerful than the results considered for each proxy individually. The proxies provide different but complementary information that should then be interpreted together after statistical analysis. For example, geochemistry can help in identifying areas of burning through the presence of elevated levels of P and K, while phytolith analysis can help pinpoint what type of fuel was being used, for example dung or wood. In terms of how this relates to our first research aim it can be concluded that phytoliths and geochemistry can be effective in defining activity areas within southwest Asian Neolithic sites but are best statistically analysed separately.

Another important outcome of this research was in demonstrating that *in situ* pXRF analysis can be effectively used to help understand and interpret southwest Asian ethnographic contexts. Undoubtedly, more precise and accurate concentration results could have been obtained by using a laboratory-based instrument but this would have greatly increased costs both in terms of time and money (Frahm 2013; Frahm and Doonan 2013; Speakman and Shackley 2013). We found that *in situ* pXRF was adequate for our needs and we were able to see relative differences between certain elements within our samples both in terms of elevations and depletions from the natural control samples. This enabled us to understand the broader geochemical signatures left behind from certain activities. Based on the results from this study we would also suggest that pXRF is an effective tool for site prospection and can help identify promising contexts within the field that can be sampled and exported for further geochemical analysis if greater precision and accuracy are needed.

One potential limitation, but a key result of this research was that many of the different context types we analysed were, in fact, comprised of the same natural source material i.e. the *samaga* clay and *tibn* straw mix used to plaster walls and surfaces as well as to construct internal installations. This inevitably caused some blurring and mixing of the different categories. This was a due to the construction methods employed at Al Ma'tan but the same phenomenon can also be observed in southwest Asian Neolithic sites which are also largely built using natural resources. It may be possible to make distinctions between these categories and features in other types of archaeological sites which are built using different construction techniques. This complication is one of the key justifications for our intention to continue this research by utilising micromorphology as an additional proxy to

complement and supplement the geochemical and phytolith analyses. Micromorphological analyses can distinguish different depositional pathways even if the material is similar macroscopically, geochemically and in its phytolith content. The results of the integrated micromorphological analyses will be published in a forthcoming paper.

Overall as a pilot study based on 144 samples the dual phytolith/geochemical method provided results that could help identify these context types in southwest Asian Neolithic sites and could potentially be more effectively used on sites which do not rely so heavily on the same natural resources in their construction. The next stage of this research will involve cross-comparing our results with the phytolith and geochemical results from the sites of Wadi Faynan 16 (Pre Pottery Neolithic A) and 'Ain Ghazal (Pre Pottery Neolithic B) to verify the efficacy of these methods (Figure 1). In addition, micromorphological sampling will be conducted on blocks from Al Ma'tan to further our understanding of contexts on a microscopic scale.

Conclusion

The results of the analysis of the plant phytoliths and geochemistry from the ethnographic village of Al Ma'tan demonstrates that both forms of evidence are valuable in providing information about activity areas and building practices in traditionally constructed southwest Asian villages. The most important finding from this study is that when used in combination these proxies can provide vital insights into activity patterns and construction practices. However, the results also show that when running the statistical analysis the two proxies are best analysed separately because the greater number of variables in the phytolith assemblage dilutes the results from the geochemical analysis. The results provide different, but complementary information which can then be interpreted together to collect as much information about the analysed contexts and provide the fullest picture of the patterns left behind. When the two forms of evidence are used in combination their interpretative power is greater than when they are used individually. This is because many of the context categories and building materials were comprised of the same local clays and had a high organic matter content both of which lead to an elevation in the same chemical elements (Wilson, Davidson, and Cresser 2008; Milek and Roberts 2013). In these instances phytoliths provided an additional source of information which gave clarity to the data and allowed the categories to be more fully understood.

Micromorphology samples were also collected during fieldwork from Al Ma'tan to help further our understanding of the activities and formation processes. These samples will be used to examine some of the specifics of the results presented here. The combination of geochemistry, phytolith analysis and micromorphology is a rapidly growing area (Shillito 2011; Shillito et al. 2011; Mallol et al. 2013) and is proving powerful in its interpretive ability.

The fact that many of our results tallied with the information provided by the former inhabitants of the site leant confidence to our results and demonstrated that this integrated dual-method can provide valuable information about southwest Asian sites. In the future we intend to test this method on Neolithic sites from this region but we also suggest that this method is not restrictive either geographically or temporally but is a global method that can be used in any time period.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Notes on Contributors

Jenkins, E. L. is an Associate Professor at Bournemouth University. She is an Environmental archaeologist with specialisms in phytoliths, geochemistry and microfauna. Her research is focused on the Neolithic of southwest Asia and the advent of agriculture and sedentism.

Allcock, S. L. is a Researcher and Outreach Officer at Plymouth University. Samantha is involved in a number of collaborative research projects and has written several papers in the fields of Environmental Archaeology, Geochemistry, Past Climate Change and Palaeolimnology. She currently works extensively in educational outreach, encouraging young people to study at higher education level yet remains active in research.

Elliott, S. Is a Post-Doctoral Research Fellow at the British Institute in Amman (Council for British Research in the Levant). She is a Geoarchaeologist specialising in phytolith analysis and micromorphology and her research focuses on early Neolithic sites in the Middle East and Geo-ethnoarchaeology.

Palmer, C is Director of the British Institute in Amman, the Council for British Research in the Levant's institute in Jordan. Carol's research interests lie in the anthropology and archaeology of food production and consumption, particularly in the rural Middle East, and rural transformations in response to the social, developmental and political upheavals of the modern period.

Grattan, J is Acting Vice Chancellor at Aberystwyth University with a background in environmental and archaeological science. John has worked extensively in the Wadi Faynan region of Jordan and has a research focus' on geochemistry, the emergence of metallurgy, and volcanism.

ORCID

Emma Louise Jenkins 🅓 http://orcid.org/0000-0002-3483-5749

Samantha Lee Allcock 🅓 http://orcid.org/0000-0003-4019-8325

References

Aitchison, J. 1986. *The Statistical Analysis of Compositional Data. Monographs on Statistics and Applied Probability.* London: Chapman & Hall Ltd. (Reprinted in 2003 with additional material by The Blackburn Press).

Albert, R. M., O. Lavi, L. Estroff, S. Weiner, A. Tsatskin, A. Ronen, and S. Lev-Yadun. 1999. "Mode of Occupation of Tabun Cave, Mt Carmel, Israel During the Mousterian Period: A Study of the Sediments and Phytoliths." *Journal of Archaeological Science* 26: 1249–1260.

Barba, L., and G. Bello. 1978. "Análisis de fosfatos en el piso de una casa habitada actualmente." *Notas Antropológicas* 1: 188–193.

Barba, L., and P. Denis. 1981. "Actividades humanas y análisis químicos de los suelos: El caso de Osumacinta Viejo, Chiapas." *XVII Mesa Redonda de la Sociedad Mexicana de Antropología* 2: 263–277.

Barba, L., B. Ludlow, L. Manzanilla, and R. Valadez. 1987. "La vida doméstica de Teotihuacan: un estudio interdisciplinario." *Ciencia y Desarrollo* 77: 21–33.

Barba, L., and L. Manzanilla. 1987. "Estudio de areas de actividad." In *Coba, Quintana Roo Analisis de Dos Unidades Habitacionales Mayas*, edited by L. Manzanilla, 69–115. Mexico, D.F.: Universidad Nacional Autonoma de Mexico.

Biewers, M. 1997. *L'Habitat Traditional à 'Aima. Enquête Ethnoarchéologique dans un village Jordanien.* BAR International Series 662, Oxford: Archaeopress.

Brown, D. A. 1984. "Prospects and Limits of a Phytolith Key for Grasses in the Central United States." *Journal of Archaeological Science* 11: 345–368.

Canti, M., and D. J. Huisman. 2015. "Scientific Advances in Geoarchaeology During the Last Twenty Years." *Journal of Archaeological Science* 56: 96–108.

Comas-Cufí, M., and S. Thió-Henestrosa. 2011. "CoDaPack 2.0: A Stand-Alone, Multi-Platform Compositional Software." In *CoDaWork'11: 4th International Workshop on Compositional Data Analysis*, edited by J. J. Egozcue, R. Tolosana-Delgado and M. I. Ortego. Sant Feliu de Guíxols. http://ima.udg.edu/codapack/.

Craig, N., R. J. Speakman, R. S. Popelka-Filcoff, M. D. Glascock, J. D. Robertson, M. S. Shackley, and M. S. Aldenderfer. 2007. "Comparison of XRF and PXRF for Analysis of Archaeological Obsidian from Southern Perú." *Journal of Archaeological Science* 34: 2012–2024.

Custer, J., E. Coleman, W. P. Catts, and K. W. Cunningham. 1986. "Soil Chemistry and Historic Archaeological Site Activity Areas: A Test Case from Northern Delaware." *Historical Archaeology* 20: 89–94.

Ebeling, J., and M. Rogel. 2016. "The *Tabun* and Its Misidentification in the Archaeological Record." *Levant* 47 (3): 328–349.

Frahm, E. 2013. "Validity of "Off-the-Shelf" Handheld Portable XRF for Sourcing Near Eastern Obsidian Chip Debris." *Journal of Archaeological Science* 40: 1080–1092.

Frahm, E., and R. C. Doonan. 2013. "The Technological Versus Methodological Revolution of Portable XRF in Archaeology." *Journal of Archaeological Science* 40: 1425–1434.

Friesem, D. E. 2016. "Geo-ethnoarchaeology in Action." *Journal of Archaeological Science* 70: 145–157.

Frontier, S. 1976. "Étude de la Décroissance des Valeurs Propres Dans une Analyse en Composantes Principales: Comparaison Avec le Modd´le du Bâton Brisé." *Journal of Experimental Marine Biology and Ecology* 25: 67–75.

Goodale, N., D. G. Bailey, G. T. Jones, C. Prescott, E. Scholz, N. Stagliano, and C. Lewis. 2012. "pXRF: A Study of Inter-Instrument Performance." *Journal of Archaeological Science* 39: 875–883.

Gur-Arieh, S., E. Mintz, E. Boaretto, and R. Shahack-Gross. 2013. "An Ethnoarchaeological Study of Cooking Installations in Rural Uzbekistan: Development of a New Method for Identification of Fuel Sources." *Journal of Archaeological Science* 40: 4331–4347.

Hammer, Ø, D. A. T. Harper, and P. D. Ryan. 2001. PAST: Paleontological Statistics Software Package for Education and Fata Analysis. *Palaeontologia Electronica* 4/1, 1–9. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.

Harvey, E. L., and D. Q. Fuller. 2005. "Investigating Crop Processing Using Phytolith Analysis: The Example of Rice and Millets." *Journal of Archaeological Science* 32: 739–752.

Holliday, V. T. 2004. *Soils in Archaeological Research.* Oxford: Oxford University Press.

Holliday, V. T., and W. G. Gartner. 2007. "Methods of Soil P Analysis in Archaeology." *Journal of Archaeological Science* 34: 301–333.

Hutson, S. R., and R. E. Terry. 2006. "Recovering Social and Cultural Dynamics from Plaster Floors: Chemical Analyses at Ancient Chunchucmil, Yucatan, Mexico." *Journal of Archaeological Science* 33: 391–404.

Jenkins, E., A. Baker, and S. Elliott. 2011a. "Past Plant Use in Jordan as Revealed by Archaeological and Ethnoarchaeological Phytolith Signatures." In *Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley*, edited by S. Mithen and E. Black, 381–400.

Jenkins, E., K. Jamjoum, and S. Al Nuimat. 2011b. "Irrigation and Phytolith Formation: An Experimental Study." In *Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley*, edited by S. Mithen and E. Black, 347–372. Cambridge: Cambridge University Press.

Jenkins, E., K. Jamjoum, S. Nuimat, R. Stafford, S. Nortcliff, and S. Mithen. 2016. "Identifying Ancient Water Availability Through Phytolith Analysis: An Experimental Approach." *Journal of Archaeological Science* 73: 82–93.

Jenkins, E., and A. Rosen. 2007. "The Phytoliths." In *The Early Prehistory of Wadi Faynan, Southern Jordan; Archaeological Survey of Wadis Faynan, Ghuwayr and al-Bustan and Evaluation of the Pre-Pottery Neolithic A Site of WF16. Council for British Research in the Levant and Oxbow*, edited by B. Finlayson and S. Mithen, 429–436. London.

Khammash, A. 1986. *Notes on Village Architecture in Jordan*. Lafayette: University of Southwestern Louisiana.

Legendre, P., and L. Legendre. 1998. *Numerical Ecology*. Amsterdam: Elsevier.

Madella, M., P. Ajithprasad, C. Lancelotti, and P. Rakesh. 2014. North Gujarat Archaeological Project (India): metodología interdisciplinary para el studio de contextos socio-ecológicas en el Holocene. In: Infromes y Trabajos Excavaciones en el Exterior 2012.

Madella, M., A. Alexandre, and T. Ball. 2005. "International Code for Phytolith Nomenclature 1.0." *Annals of Botany* 96: 253–260.

Madella, M., M. K. Jones, P. Echlin, A. Powers-Jones, and M. Moore. 2009. "Plant Water Availability and Analytical Microscopy of Phytoliths: Implications for Ancient Irrigation in Arid Zones." *Quaternary International* 193: 32–40.

Mallol, C., C. M. Hernández, D. Cabanes, A. Sistiaga, J. Machado, Á Rodríguez, L. Pérez, and B. Galván. 2013. "The Black Layer of Middle Palaeolithic Combustion Structures. Interpretation and Archaeostratigraphic Implications." *Journal of Archaeological Science* 40: 2515–2537.

Manzanilla, L., and L. Barba. 1990. "The Study of Activities in Classic Households: Two Case Studies from Coba and Teotihuacan." *Ancient Mesoamerica* 1: 41–49.

McDonald, J. H. *Handbook of Biological Statistics*. http://www.biostathandbook.com/.

Mejia, E., and L. Barba. 1988. *El analisis de fosfatos en la arqueologia: Historia y perspectivas*. Anales de Antropologia: Universidad Nacional Autonoma de Mexico.

Metcalfe, C. R. 1960. *Anatomy of the Monocotyledons. I. Gramineae*. Oxford: Clarendon Press.

Middleton, W. D., and D. T. Price. 1996. "Identification of Activity Areas by Multi-Element Characterization of Sediments from Modern and Archaeological House Floors Using Inductively Coupled Plasma-Atomic Emission Spectroscopy." *Journal of Archaeological Science* 23: 673–687.

Milek, K. B., and H. M. Roberts. 2013. "Integrated Geoarchaeological Methods for the Determination of Site Activity Areas: A Study of a Viking Age House in Reykjavik, Iceland." *Journal of Archaeological Science* 40: 1845–1865.

Ollendorf, A. L., S. C. Mulholland, and Rapp G. Jr. 1988. "Phytolith Analysis as a Means of Plant Identification: *Arundo donax* and *Phragmites communis*." *Annals of Botany* 61: 209–214.

Oonk, S., C. Slomp, and D. J. Huisman. 2009. "Geochemistry as an Aid in Archaeological Prospection and Site Interpretation: Current Issues and Research Directions." *Archaeological Prospection* 16: 35–51.

Piercey, S. J., and M. C. Devine. 2014. "Analysis of Powdered Reference Materials and Known Samples with a Benchtop, Field Portable X-ray Fluorescence (pXRF) Spectrometer: Evaluation of Performance and Potential Applications for Exploration Lithogeochemistry." *Geochemistry: Exploration, Environment, Analysis* 14: 139–148.

Piperno, D. 2006. *Phytoliths: A Comprehensive Guide for Archaeologists and Palaeoecologists*. New York, NY: Altamira Press.

Portillo, M., S. Kadowaki, Y. Nishiaki, and R. M. Albert. 2014. "Early Neolithic Household Behavior at Tell Seker al-Aheimar (Upper Khabur, Syria): A Comparison to Ethnoarchaeological Study of Phytoliths and Dung Spherulites." *Journal of Archaeological Science* 42: 107–118.

Price, T. D., and J. H. Burton. 2012. *An Introduction to Archaeological Chemistry*. New York, NY: Springer.

Regev, L., D. Cabanes, R. Homsher, A. Kleiman, S. Weiner, I. Finkelstein, and R. Shahack-Gross. 2015. "Geoarchaeological Investigation in a Domestic Iron Age Quarter, Tel Megiddo, Israel." *Bulletin of the American Schools of Oriental Research* 374: 135–157.

Reimann, C., P. Filzmoser, and R. G. Garrett. 2002. "Factor Analysis Applied to Regional Geochemical Data: Problems and Possibilities." *Applied Geochemistry* 17: 185–206.

Rondelli, B., C. Lancelotti, M. Madella, A. Pecci, A. Balbo, J. Ruiz Pérez, F. Inserra, C. Gadekar, M. A. Cau Ontiveros, and P. Ajithprasad. 2014. "Anthropic Activity Markers and Spatial Variability: An Ethnoarchaeological Experiment in a Domestic Unit of Northern Gujarat (India)." *Journal of Archaeological Science* 41: 482–492.

Rosen, A. M. 1992a. "Phytoliths as Indicators of Ancient Irrigation Farming." In *Prehistory of Agriculture: New Experimental and Ethnographic Approaches*, edited by P. C. Anderson, 193–198. Paris: Centre National de la Recherche Scientifique.

Rosen, A. M. 1992b. "Preliminary Identification of Silica Skeletons from Near Eastern Archaeological Sites: An Anatomical Approach." In *Phytolith Systematics. Emerging Issues*, edited by G. Rapp (Jr) and S. C. Mulholland, 129–147. New York, NY: Plenum Press.

Rosen, A. M., and S. Weiner. 1994. "Identifying Ancient Irrigation: A new Method Using Opaline Phytoliths from Emmer Wheat." *Journal of Archaeological Science* 21: 125–132.

Shahack-Gross, R., F. Marshall, K. Ryan, and S. Weiner. 2004. "Reconstruction of Spatial Organization in Abandoned Maasai Settlements: Implications for Site Structure in the Pastoral Neolithic of East Africa." *Journal of Archaeological Science* 31: 1395–1411.

Shahack-Gross, R., F. Marshall, and S. Weiner. 2003. "Geo-Ethnoarchaeology of Pastoral Sites: The Identification of Livestock Enclosures in Abandoned Maasai Settlements." *Journal of Archaeological Science* 30: 439–459.

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. 2017. Multivocality and Multiproxy Approaches to the Use of Space: Lessons from 25 Years of Research at Çatalhöyük. *World Archaeology*, 1–23.

Shillito, L. M., W. Matthews, M. J. Almond, and I. D. Bull. 2011. "The Microstratigraphy of Middens: Capturing Daily Routine in Rubbish at Neolithic Çatalhöyük, Turkey." *Antiquity* 85: 1024–1038.

Smyth, M. P. 1990. "Maize Storage Among the Puuc Maya: The Development of an Archaeological Method." *Ancient Mesoamerica* 1: 51–69.

Speakman, R. J., and M. S. Shackley. 2013. "Silo Science and Portable XRF in Archaeology: A Response to Frahm." *Journal of Archaeological Science* 40: 1435–1443.

Tsartsidou, G., S. Lev-Yadun, N. Efstratiou, and S. Weiner. 2008. "Ethnoarchaeological Study of Phytolith Assemblages from an Agro-Pastoral Village in Northern Greece (Sarakini): Development and Application of a Phytolith Difference Index." *Journal of Archaeological Science* 35: 600–613.

Tsartsidou, G., S. Lev-Yadun, N. Efstratiou, and S. Weiner. 2009. "Use of Space in a Neolithic Village in Greece (Makri): Phytolith Analysis and Comparison of Phytolith Assemblages from an Ethnographic Setting in the Same Area." *Journal of Archaeological Science* 36: 2342–2352.

Tubb, H. J., M. J. Hodson, and G. C. Hodson. 1993. "The Inflorescence Papillae of the Triticeae: A New Tool for Taxonomic and Archaeological Research." *Annals of Botany* 72: 537–545.

Twaissi, S. A., B. Abuhalaleh, and F. Abudanah. 2016. "The Architectural Aspects of the Traditional Villages in Petra Region with Some Anthropological Notes." *Mediterranean Journal of Social Sciences* 7: 336–352.

Twiss, P. C., E. Seuss, and R. M. Smith. 1969. "Morphological Classification of Grass Phytoliths." *Soil Science Society of America Journal* 33: 109–115.

Vos, D. 2016. "Out of Sight, But Not Out of Mind: Exploring How Phytolith and Geochemical Analysis Can Contribute to Understanding Social Use of Space During the Neolithic in the Levant Through Ethnographic Comparison." *Bournemouth University PhD Thesis.*

Weisskopf, A., L. Qin, J. Ding, P. Ding, G. Sun, and D. Fuller. 2014. "Phytoliths and Rice: From wet to dry and Back Again in the Neolithic Lower Yangtze." *Antiquity* 89: 1051–1063.

Wilson, C. A., D. A. Davidson, and M. S. Cresser. 2008. "Multi-element Soil Analysis: An Assessment of Its Potential as an Aid to Archaeological Interpretation." *Journal of Archaeological Science* 35: 412–424.

Wilson, C. A., D. A. Davidson, and M. S. Cresser. 2009. "An Evaluation of the Site Specificity of Soil Elemental Signatures for Identifying and Interpreting Former Functional Areas." *Journal of Archaeological Science* 36: 2327–2334.