

A dual geochemical-phytolith methodology for studying activity areas in ephemeral sites: Insights from an ethnographic case study from Jordan

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Abstract

This study aims to contribute to the interpretation of ephemeral sites by exploring the efficacy of geochemistry and phytolith analysis to identify activity areas in seasonally occupied ethnographic sites. The application of a portable X-ray fluorescence (XRF) instrument and phytolith analysis to soil samples from six Bedouin campsites at Wadi Faynan, Jordan, provided insights about anthropogenic enrichment patterns and the effects of short periods of abandonment on these. The compatibility of the two analysis techniques and means to combine the results of both are addressed. The results of this study suggest that soil signatures can be found in ephemeral sites following abandonment, even in dynamic and harsh environments. The efficacy of the geochemical analysis to indicate variance within the data was found to be greater than that of the phytolith analysis in these case studies, while certain trends within the phytolith results were more useful in identifying specific activities. Due to the compatibility of the geochemical and phytolith data, it is proposed that a serial or parallel approach should be taken for their statistical analysis.

KEYWORDS

bedouin, ethnoarchaeology, ephemeral, geochemistry, phytoliths

1 | INTRODUCTION

Ephemeral occupation is characteristic of many pastoral and hunter-gatherer societies, whose settlement reflects the demands of their highly mobile lifestyles. These short-lived sites do not often preserve well, yet their remains represent many archaeological periods, especially prehistoric ones. Understanding the way in which ephemeral sites were used is important for our knowledge of key developments in human existence, such as the Upper Palaeolithic expansion of humans into challenging new environments, or the transition from mobile hunter-gatherer lifestyles to sedentary farming ones during the Neolithic. These, and other periods characterized by ephemeral occupation, can be difficult to interpret due to the low intensity of occupation, lack of permanent structures, and related poor preservation of many of these sites and the organic remains of which they comprise (Banning & Köhler-Rollefson, 1983; Cribb, 1991; Gifford, 1978). Nevertheless, understanding the use of space in ephemeral structures is vital to their interpretation. This can shed light on past ways of life that are currently underrepresented within archaeological narratives.

The division of space within human built environments can inform us about subsistence and daily activities, and can also reveal a great deal about notions of cleanliness, sacrality or gender, and relationships with animals or the natural environment (Bourdieu, 1990; Douglas, 1966; Parker Pearson & Richards, 1994).

Until recently, most archaeological studies of spatial patterns of activity areas have focused on reconstructions of the location of activities based on the distribution of artifacts (Hardy Smith & Edwards, 2004; Hodder & Orton, 1979; Kuijt & Goodale, 2009; Simek, 1987; Whallon, 1973). This approach carries limitations in the form of both prior- and postdepositional taphonomic processes influencing the location of artifacts, and often portray problematic links between the location of artifacts and other contextual, functional, or chronological evidence (Manzanilla & Barba, 1990; Ullah, Duffy, & Banning, 2015). The need for geoarchaeological approaches for the study of spatial activity patterns at archaeological sites has driven several research projects in the past two decades seeking to test and apply various microscopic techniques to the study of activity areas, such as micromorphology (Banerjea, Bell, Matthews, & Brown, 2015;

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Milek & Roberts, 2013; Shillito & Ryan, 2013), geochemistry (Middleton & Price, 1996; Terry, Fabian, Fernández, Parnella, & Inomata, 2004; Vyncke, Degryse, Vassilieva, & Waelkens, 2011), phytolith and spherulite analyses (Cabanes, Mallol, Expósito, & Baena, 2010; Portillo, Kadowaki, Nishiaki, & Albert, 2014; Tsartsidou, Lev-Yadun, Efstratiou, & Weiner, 2009), and mineralogy (Shahack-Gross & Finkelstein, 2008). These soil signatures are considered to be less prone to the effects of cultural or natural postdepositional disturbances that affect larger artifacts, and they generally reflect in situ activity (Canti & Huisman, 2015). Nevertheless, the influence of formation and taphonomic processes must be considered even for evidence at the microlevel, as emphasized by recent experimental and ethnographic studies (Banerjee et al., 2015; Cabanes & Shahack-Gross, 2015; Shillito, 2017).

Current publications summarizing developments in the application of geoarchaeological techniques emphasize the importance of ethnoarchaeological studies (Friesem, 2016) and a multiproxy approach (Canti & Huisman, 2015). In accordance with these observations, this study explores the potential of phytolith and geochemical signatures for understanding the use of space at ephemeral sites through the ethnoarchaeological analysis of soil samples collected from six Bedouin campsites in Wadi Faynan, Jordan. In addition, by considering the variation in length of time after abandonment of the campsites, this research aims to increase our understanding of taphonomic processes influencing these soil signatures within anthropogenic sites.

1.1 | Description of sites and field methods

The name “Bedouin” refers to populations across the steppes and deserts of the Arab world whose lifestyles were traditionally tied to a nomadic, pastoral existence (Na’amneh, Shunnaq, & Tasbasi, 2008; Saidel, 2009). The mobility of Bedouin populations has decreased over the past century due to external influences, which led to an increased rate of sedentism and modernization, and today herding practices range between transhumance and home range (Na’amneh et al., 2008; Palmer, 2002; Saidel, 2009). Ethnoarchaeological studies of Bedouin campsites became popular in the 1980s as part of efforts to establish a better understanding of different aspects of pastoral and nomadic occupation and to improve our understanding of archaeological pastoral communities. These studies provided insights into the material remains associated with the abandonment of pastoral campsites, the correlation between the location activity areas and refuse, and later studies expanded the methodologies used to identify the layout of Bedouin sites and formation processes related to their abandonment (Banning & Köhler-Rollefson, 1983; Goldberg & Whitbread 1993; Saidel, 2001; Simms, 1988). While micromorphology had been successfully applied for spatial analysis of a Bedouin floor (Goldberg & Whitbread, 1993), other geoarchaeology techniques could also carry potential for the study of activity areas in anthropogenic sites. Phytolith analysis in Bedouin campsites has so far been limited to the examination of dung samples (Shahack-Gross & Finkelstein, 2008), and geochemistry has previously only been used to establish the effects of pollution and waste resulting from ancient mining activities at Wadi Faynan (Grattan, Gilbertson, Waller, & Rusell, 2014).

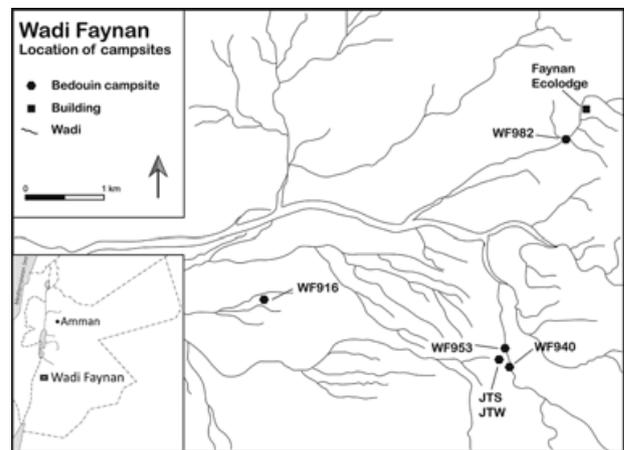


FIGURE 1 The locations of the Bedouin campsites in the catchment area of Wadi Faynan

The seasonally occupied ephemeral Bedouin campsites at Wadi Faynan provide an ideal case study for testing the efficacy of geochemistry and phytolith analysis to identify activity areas, because much is known about the use of space in Bedouin tents. Generally, Bedouin tents are divided into public male areas (*shigg*) and private female (*mahram*) areas. The public area is used for hospitality; coffee, tea, or food are served to honored guests here, and the central hearth can be used for preparing coffee and sometimes tea, though tea is usually prepared in the *mahram* and brought to guests. Various household activities take place within the private area, which includes a kitchen with a hearth which is used for cooking. The use of space within Bedouin households at Wadi Faynan has both static and dynamic aspects. While activities take place within designated areas, each section of the tent can change its function throughout the day. For example, the private area can be used for activities such as weaving, churning butter, or entertaining female guests, and will be used for sleeping at night. And when guests are not present, the public area is used by all members of the household.

The ethnographic soil samples analyzed in this study were collected from one occupied and five abandoned sites at Wadi Faynan (Figure 1). The majority of samples were collected as part of an ethnoarchaeological survey of abandoned Bedouin campsites at Wadi Faynan during 1999–2000, led by Carol Palmer and Helen Smith. The aims of this survey were to explore the nature of pastoral activity in the Wadi during the recent past and assess the potential for identifying ancient pastoral activity following abandonment. An initial survey during April 1999 documented the locations and main architectural characteristics (both durable and perishable) of Bedouin tents in the landscape (Figure 2). During the visits, several physical attributes were recorded, including tent size, orientation, position, spatial arrangement, and both common and supplementary features such as storage facilities or outdoor hearths (Palmer, Smith, & Daly, 2007).

These data were accompanied by narrative accounts given by the occupants of the area, who provided information about the abandoned campsites and the activities that took place at these. The team conversed with the tent inhabitants in order to gain a better understanding of the use of space at these campsites and where possible, about

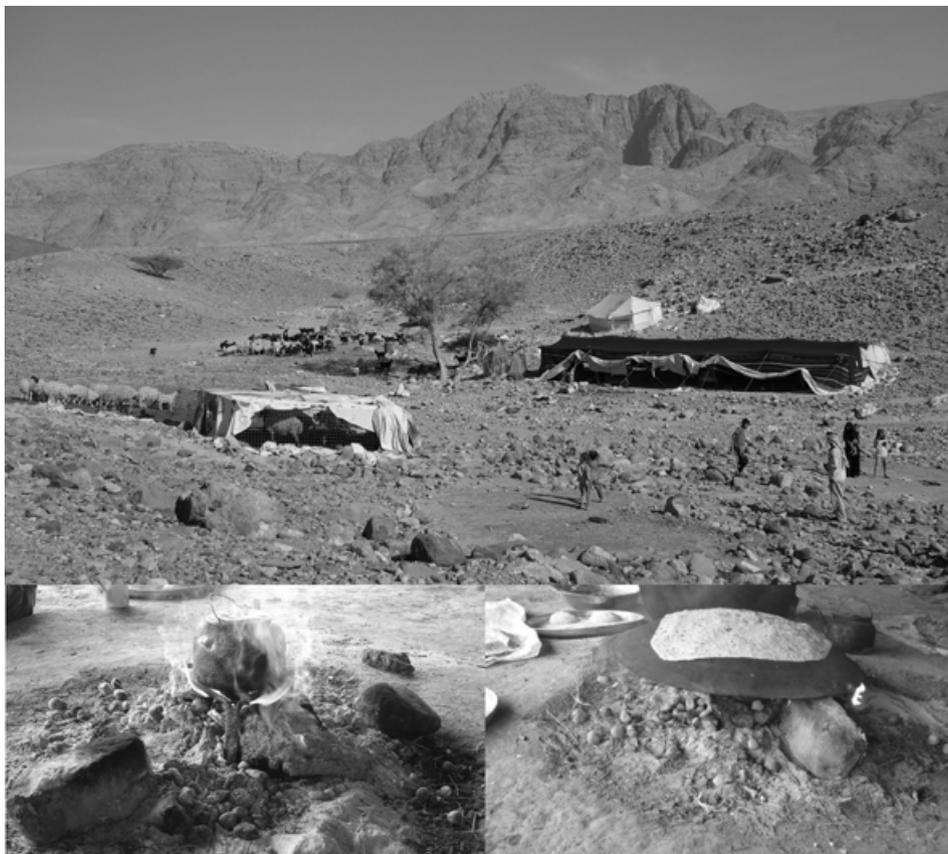


FIGURE 2 Photo of occupied Bedouin tent JTW, with a goat and sheep pen on the left and cleared circular areas marking the locations of old animal pens in the foreground

Notes. Images of a hospitality hearth and a kitchen hearth can be seen at the bottom left and bottom right (respectively).

the individuals that were living there and the animals owned by them. An accompanying local informant, Jouma' Aly Za'noon of the 'Azazma tribe, assisted with this (Palmer et al., 2007).

During 2000 the same campsites were revisited and studied in greater detail. An artifact distribution study was undertaken, and the soil samples analyzed in this study were collected from chosen sites (Palmer & Daly, 2006). The sampling was aimed at capturing the soil signals of the activity areas at each campsite. Sample locations included the kitchen and hospitality hearths, animal pens, animal pen floors, floor spaces in the hospitality area, and the private activity area and kitchen (Figure 3). In addition to these, three background samples were taken for each site from areas considered to reflect low human presence within approximately 40 m from its perimeter. The number of samples varied according to the available features at the sites, ranging from 7 to 34. The soil was collected using a clean trowel and bagged in plastic sample bags by Helen Smith and Carol Palmer for the sites WF916, WF940, WF953, and WF982 (Table 1). The amount of soil varied for each sample, some of the dung and hearth samples containing around 15 g of material, while others weighing approximately 40 g. The type of occupation and a schematic site plan were recorded for each campsite, including the available features such as hearths and animal pens.

In addition to the material obtained in 2000, this study includes samples from one campsite, which was occupied during sampling and one which was briefly abandoned. Incorporating samples from an

occupied site provided a reference point for soil signatures prior to abandonment, to compare to the abandoned sites in order to observe the influence of taphonomic processes. The additional campsites were sampled in May 2014 at Wadi Faynan (JTW and JTS, see Table 1 and Figure 3) by Daniella Vos, Carol Palmer, and Jouma' Aly Za'noon. The sample collection strategy followed that of the ethnoarchaeological survey carried out by Carol Palmer and Helen Smith (Palmer & Daly 2006; Palmer et al., 2007) as closely as possible, and the same context categories were used. As the tents were occupied, or very recently abandoned during sampling, understanding how different localities were used was straightforward as features were still recognizable in the field, and samples taken from the animal pens could be described in detail.

2 | METHODS

2.1 | Laboratory methods

The geochemical analysis in this study focused on the following chemical elements, measured in parts per million (ppm): magnesium (Mg), silicon (Si), potassium (K), calcium (Ca), phosphorus (P), iron (Fe), titanium (Ti), manganese (Mn), aluminium (Al), strontium (Sr), sulphur (S), chlorine (Cl), zinc (Zn), and zirconium (Zr). The analysis was performed using a Thermo Scientific Niton XL 3t Gold+ (geometrically optimized large area drift detector) handheld XRF analyzer (pXRF),

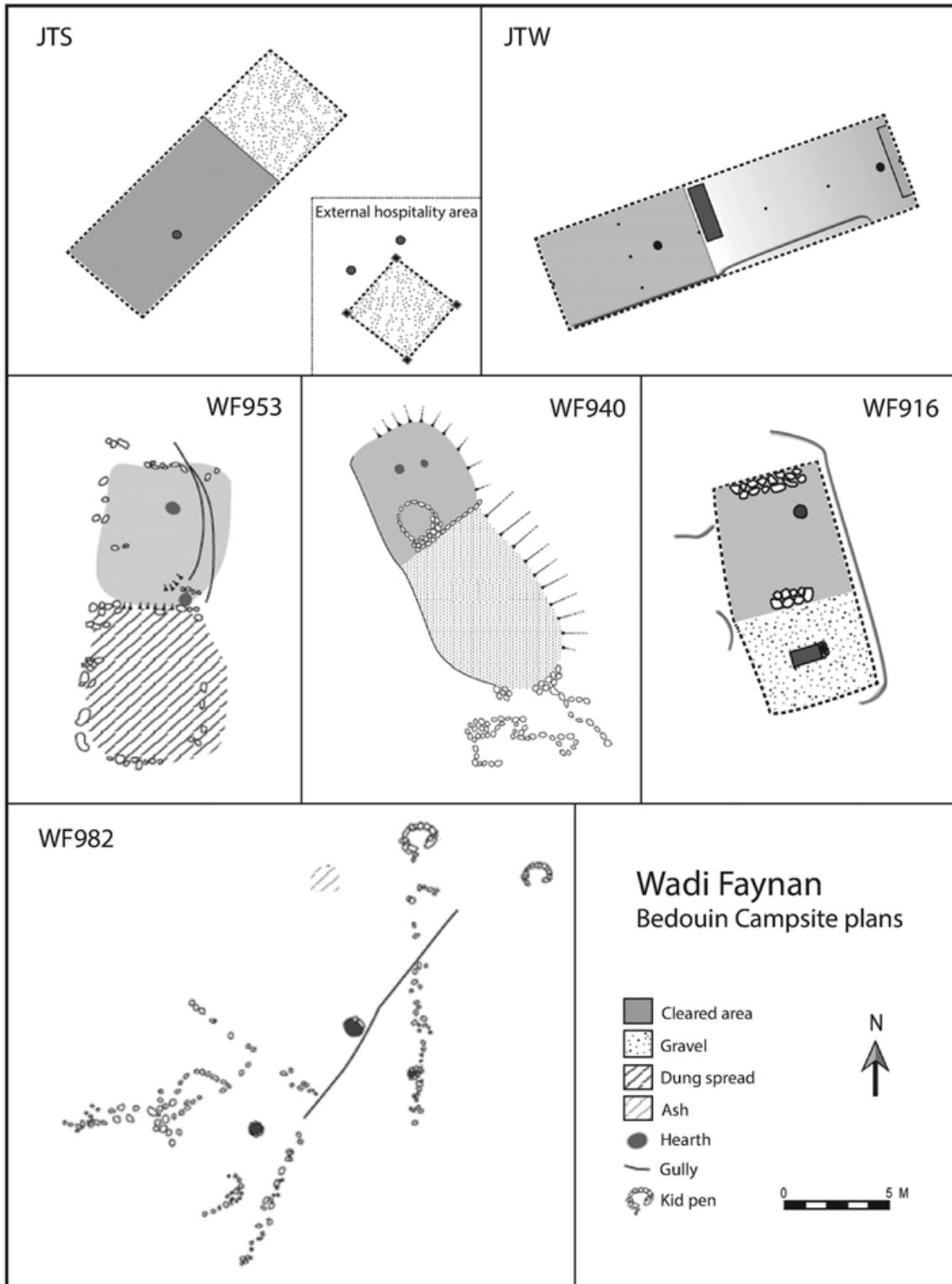


FIGURE 3 Plans of the Bedouin campsites at Wadi Faynan (plans of WF953, WF940, and WF982 after Palmer et al. 2007; 381–387. Plans of WF916, JTS, and JTW created by DV based on schematic drawings made in the field)

with an Ag anode 50 kV, 200 μ A tube. A helium purge was used in order to lower the detection limits for light elements. The samples were placed in 9 mm plastic cups, covered with a thin polypropylene film, and analyzed using a mobile test stand in order to provide reproducible measurement conditions. The pXRF machine was set to the “mining Cu/Zn mode” and the exposure time for each of the

ranges was adjusted to achieve the following settings: the main range was run for 40 s, the high and low ranges for 30 s each, and the light element range for 80 s to allow for reliable readings for elements on the edge of the detection limits of pXRF such as Mg and P. In total, each reading took 180 s. The helium was allowed to flow into the machine approximately 10 min before the first samples were run.

TABLE 1 Description of the Bedouin campsites at Wadi Faynan and sampled features

Site	Duration of abandonment	Description
WF916	Three years	Winter campsite, sampling included substantial stone-lined hospitality hearth, kitchen hearth, outdoor goat pen, gully, floors.
WF940	One year	Temporary occupation, no division between hospitality and private areas. Sampling included single hearth (remains of older hearth visible), indoor dung spread, gullies, floors. This campsite was previously published as WF942.
WF953	One year	Winter campsite, sampling included hospitality hearth, kitchen hearth, indoor dung spread, gullies, floors.
WF982	Approximately 15 years	Likely occupied during a number of winters, duration of occupation unknown. Sampling included: hospitality hearth, kitchen hearth, dung spread outside tent outline.
JTS	Six months	Summer campsite, in use for the past three years. Private area and kitchen were indoors, hospitality area and hearths were outdoors. Sampling included two hospitality hearths, kitchen hearth, outdoor sheep and goat pens, floors.
JTW	Occupied	Winter campsite, occupied by the family previously housing WF953. Sampling included hospitality hearth, kitchen hearth, outdoor sheep and goat pens, gullies, floors.

One silica (blank) standard and three National Institute of Standards and Technology (NIST) standards were analyzed using the same setting as the soil samples during each analysis session; SRM 2711a (Montana II soil), SRM 2709 (San Joaquin soil), and SRM 1646a (Estuarine sediment). Precision of all elements measured within the NIST standard reference material in this study was better than 5% when present at more than 5%, except for: Mg, P, and Mn (for a list of precision calculation for NIST standards see Supporting Information). For Mg precision was only measured for concentrations below 5% and was above 10%, for P precision exceeded 5% when present above 8%, and precision for Mn was better than 10% for concentrations above 5%.

Phytolith extraction was performed using the dry ashing method, where the soil sample is burnt in a muffle furnace in order to remove organic matter and isolate phytoliths (Rosen, 1992). Slides containing the phytolith material were counted using a Meiji infinity polarizing microscope at a magnification of $\times 400$, using a modern Jordanian phytolith reference collection prepared from plants collected in Jordan (housed at Bournemouth University and the CBRL British Institute in Amman). At least 250 phytoliths were counted per slide, and the entire slide was counted if this amount was not reached. The counted quantities of different phytolith types and (when relevant) taxa were documented on a tally recording sheet. The names of the phytolith types followed the International Code for Phytolith Nomenclature (Madella, Alexandre, & Ball, 2005).

2.2 | Statistical analysis

Separate databases for geochemical and phytolith data were created for each site, and a combination of sites, using IBM SPSS statistics version 23. The geochemical database included the readings of the chosen elements (see previous section) for each sample, which contained error readings of $\leq 3\%$. Other elements containing error readings (two-sigma precision) of $\geq 10\%$ were excluded from the analysis. An exception to this rule was made for Mg, Mn, and Zn, which contained error readings of 20, 23, and 13% (respectively), but was kept in the analysis as they are valuable indicators of anthropogenic activities. The phytolith database included the morphological categories used in the counting sheets and additional variables calculated from the raw data: dicots, monocots, single cell, multicell, Panicoideae, Pooideae, Chloridoideae, Arundinoideae, Palmaceae, *Hordeum sp.*, *Triticum sp.*, leaf, leaf/husk, leaf/stem, husk, awn, weight percent of extracted phytoliths, and number of phytoliths per gram. As the total number of fields of view varied per slide, the data were transformed to percentages in order to enable a comparison of the slides, which is not affected by the amount of counted fields. This was done by dividing the number for each counted category by the number of phytoliths counted for the relevant slide, and then multiplied by 100. The number of phytoliths per gram of sediment was calculated in order to get an estimate of the amount of phytoliths, which is not biased by the relative weight of different phytolith types of silica aggregate material, using the following formula:

$$\text{Number per slide} = (\text{phytolith count}/\text{number of counted fields})$$

$$\times \text{total number of fields on slide}$$

$$\text{Number per gram}$$

$$= (\text{number per slide}/\text{mass of phytoliths mounted in mg})$$

$$\times (\text{mass of phytoliths extracted in mg}/\text{total sediment weight in mg})$$

$$\times 1000$$

The data were explored using box plots and bar charts that were created for every variable and for related variables (such as plant parts or genus categories). When analyzing the results, it became clear that several categories plotted very similarly, in most cases these were variations of floor surfaces. For example, samples collected from the edges of hearths did not differ from the general floor samples, and so were grouped under the floor category.

Principal component analysis (PCA) was run in SPSS using the correlation matrix, a method which standardizes the variables. No rotation was applied to the analysis, and the components were extracted based on eigenvalues greater than 1, and saved as variables based on regression. Discriminant function analysis was carried out with the independents entered together and the prior probabilities computed from group size, including leave-one-out classification in the display option. A two-tailed Pearson correlation test was run with variables from both the geochemical and phytolith analyses in order to identify patterns that could influence the results of the PCA analysis. In addition to these analyses, decision trees were applied to the geochemical

readings, phytolith counts, and to a database combining variables from both methods. This was done in order to understand and visualize how well the data are categorized into activity areas, and which variables are important within this classification. The decision trees were created in Weka version 3.6.13 software, using the standard settings for classifier J48.

3 | RESULTS

3.1 | Geochemical analysis

The geochemical analysis of the Wadi Faynan campsites revealed patterns of enrichment and depletion in the context categories most affected by human activity; the hearths, dung sediments, and, to a lesser degree, the animal pen floors (Figures 4 and 5). The floor and gully samples plotted similarly to the background samples in the PCA scatterplot (Figure 6). The highest concentrations of Mg, Ca, Mn, S, and Sr among the context categories were found in the hearths, and Zn was selected by the decision trees as the best distinguishing factor between kitchen and hospitality hearths (Figure 7). High concentrations of K, P, and Zn were characteristic of both hearths and animal dung. However, while the highest concentrations of K were either associated with hearths or dung, depending on the site, P and Zn were highest in the fireplaces of all sites except for WF916 where dung samples contain higher elevations of these elements.

Animal dung at the Wadi Faynan sites also contained the highest concentrations of Cl, followed by the enrichment in hearths in all sites but WF916. The concentrations of this element, however, were found to diminish over time. Ti, Al, and Fe were abundant in the background and floor-related samples, the latter containing slightly higher concentrations of Cl, which allowed us to distinguish them from the natural sediment. These observations agree with findings of earlier studies—Table 2 summarizes the associations between chemical elements and anthropogenic activities found in several previous studies and in this research. The decision tree created for the geochemistry results (Figure 7) provides an overview of the role that different elements play within various activities. Sr divides the hearths from the rest of the samples, indicating that the hearths comprise the most distinctive traces of activity. K is used to separate between the dung and pen samples, after these two contexts were differentiated from the other samples through Mg.

The variation in abandonment episodes among the Bedouin campsites allowed this study to explore patterns of short-term dissolution. The only geochemical elements that were found to suffer from a reduction in their concentrations within the 15 years of difference in duration of abandonment are Cl and K (Figure 8). The clearest deterioration effect can be seen within the dung samples. The depletion of Cl and K through time could reflect the effects of exposure to sunlight and rain, mainly affecting outdoor animal pens, but also indoor areas after abandonment and removal of the tent. The depletions could also have resulted from anthropogenic inputs of decomposing organic matter and urine through animal dung, and water from household activities such as cleaning (Brito, Telles, Schnitzer, Gaspar, & Guimarães, 2014; Petrucci, 2007; Sconce, 1962). It is difficult to estimate which changes

would occur in the other chemical elements and phytolith attributes measured in this study over longer durations of abandonment than the 15 years represented at the Wadi Faynan campsites studied here. Generally, most geochemical taphonomic processes are slow, although anthropogenic impact can speed them up in some cases (Mulder & Cresser, 1994).

3.2 | Phytolith analysis

Trends seen within the phytolith analysis results are more variable and site specific than the geochemical patterns, as was the case in previous phytolith studies of spatial patterning (Portillo et al., 2014; Shahack-Gross, Marshall, Ryan, & Weiner, 2004; Tsartsidou, Lev-Yadun, Efstratiou, & Weiner, 2008). Nevertheless, some general observations can be made regarding the nature of anthropogenic input at the Wadi Faynan sites through phytolith analysis. A two-tailed Pearson correlation test (Table 3) shows a strong association between chemical elements characteristic of anthropogenic enrichment and, among others, the phytolith analysis categories monocots and multicelled phytoliths. High concentrations of these two variables in comparison to the opposed variables dicots and single-celled (respectively) are found in the hearth and animal dung contexts (Figure 9). The largest weight percent or number of phytoliths per gram is associated with either the hearths, animal dung, or animal pen samples—this varies among the individual sites (for details see Vos, 2017).

The average percentage of degraded phytoliths is highest in the context categories background, floor, and animal pen floor at WF982, the campsite with the longest duration of abandonment (Figure 9). The floor and background samples were also the context categories that contained the largest fraction of degraded phytoliths in the other sites. The general composition of phytolith morphotypes is similar in all sites except for WF916 (Figure 9). The variation in concentrations of morphotypes among sites does not seem to correlate to duration of abandonment.

4 | DISCUSSION

The dual geochemical-phytolith method used in this study was able to identify several correlations between known activities and soil signatures present at ephemeral sites prior to abandonment. Hearths were found to be the most visible, with the highest concentrations of Mg, Ca, Mn, S, and Sr, and contained large amounts of monocot and multicelled phytoliths. Animal dung had the highest enrichment of Cl, K, P, and Zn, and contained high concentrations of monocots and multicelled phytoliths. Animal pen floors at Wadi Faynan portray the same type of anthropogenic enrichment as dung layers, but to a lesser degree, and plotted between the dung and floor samples in the PCA scatterplots. Floors and gullies contain no elevations in the anthropogenic chemical markers described above such as Mg, P, K, Mn, Sr, and Ca, or the phytolith categories related to anthropogenic input such as high levels of monocots and multicells. Unlike floor areas that have been described as high-traffic zones (Middleton, 2004; Vyncke et al., 2011), the floors and gullies at Wadi Faynan do not show signs of a depletion in concentrations of chemical elements. They plot similarly to the background

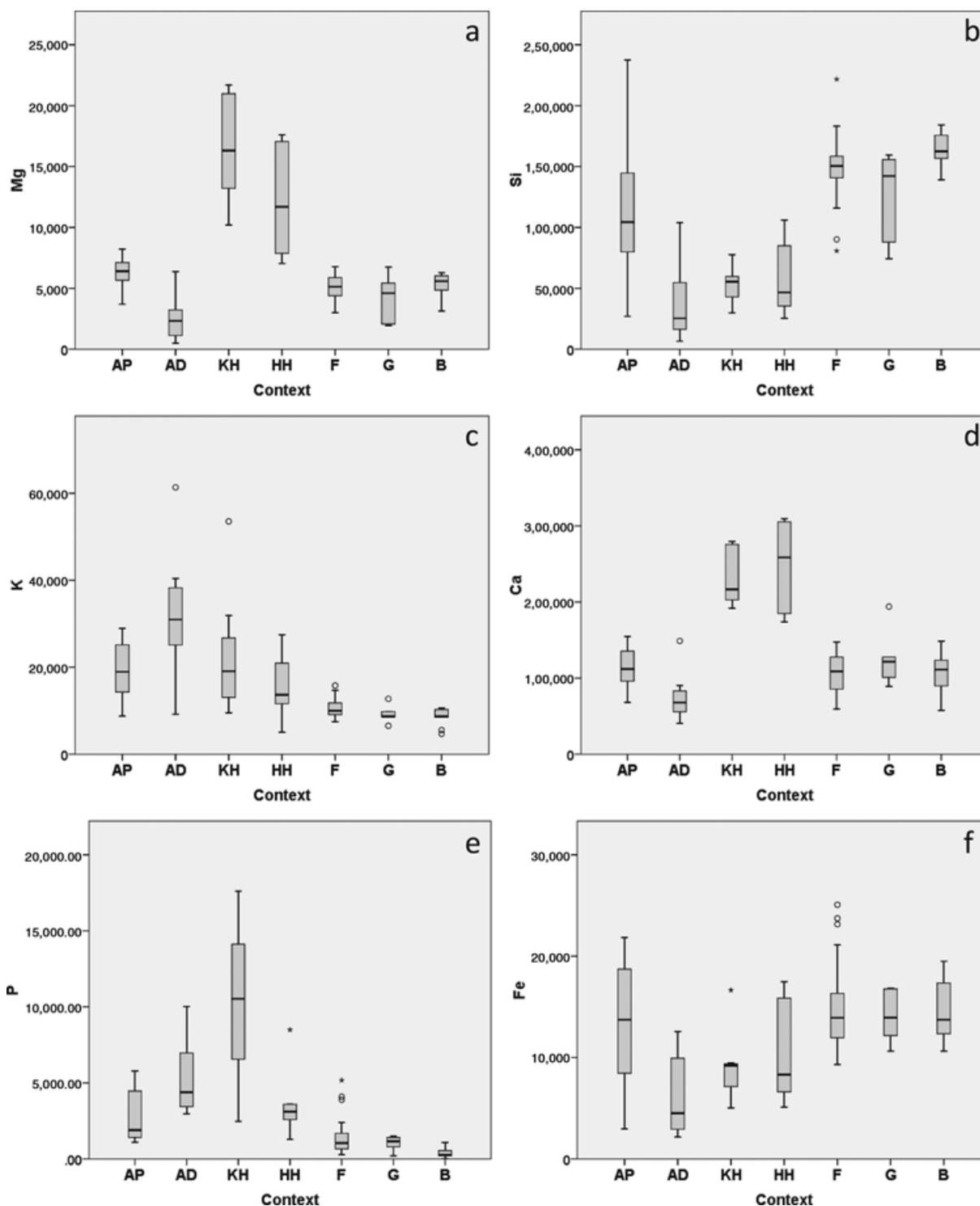


FIGURE 4 Average measurements in ppm for all samples within all of the sites per context category for the following chemical elements: (a) Mg, (b) Si, (c) K, (d) Ca, (e) P, and (f) Fe

Notes. Context categories abbreviations: AP, animal pen; AD, animal dung, KH, kitchen hearth, HH, hospitality hearth, F, floor, G, gully, B, background.

samples that suggest that signatures of activity remained local and did not spread out across the floor surfaces. While Ti, Al, and Fe were depleted in the hearths and dung contexts, they remained within background levels in the floors and gullies.

The phytolith trends reflect the input of plant material, in particular that derived from monocots, through grazing and the use of dung cakes

as fuel in the hearths, to the contexts mostly affected by anthropogenic behavior—hearths and animal enclosures (Figure 9). In addition to elevations of monocots and conjoined phytoliths, occasional enrichment of indicative plant material allows for specific activity areas to be distinguished. An example of such enrichment was found in the kitchen hearth of WF953, which contained a high concentration of *Triticum sp.*

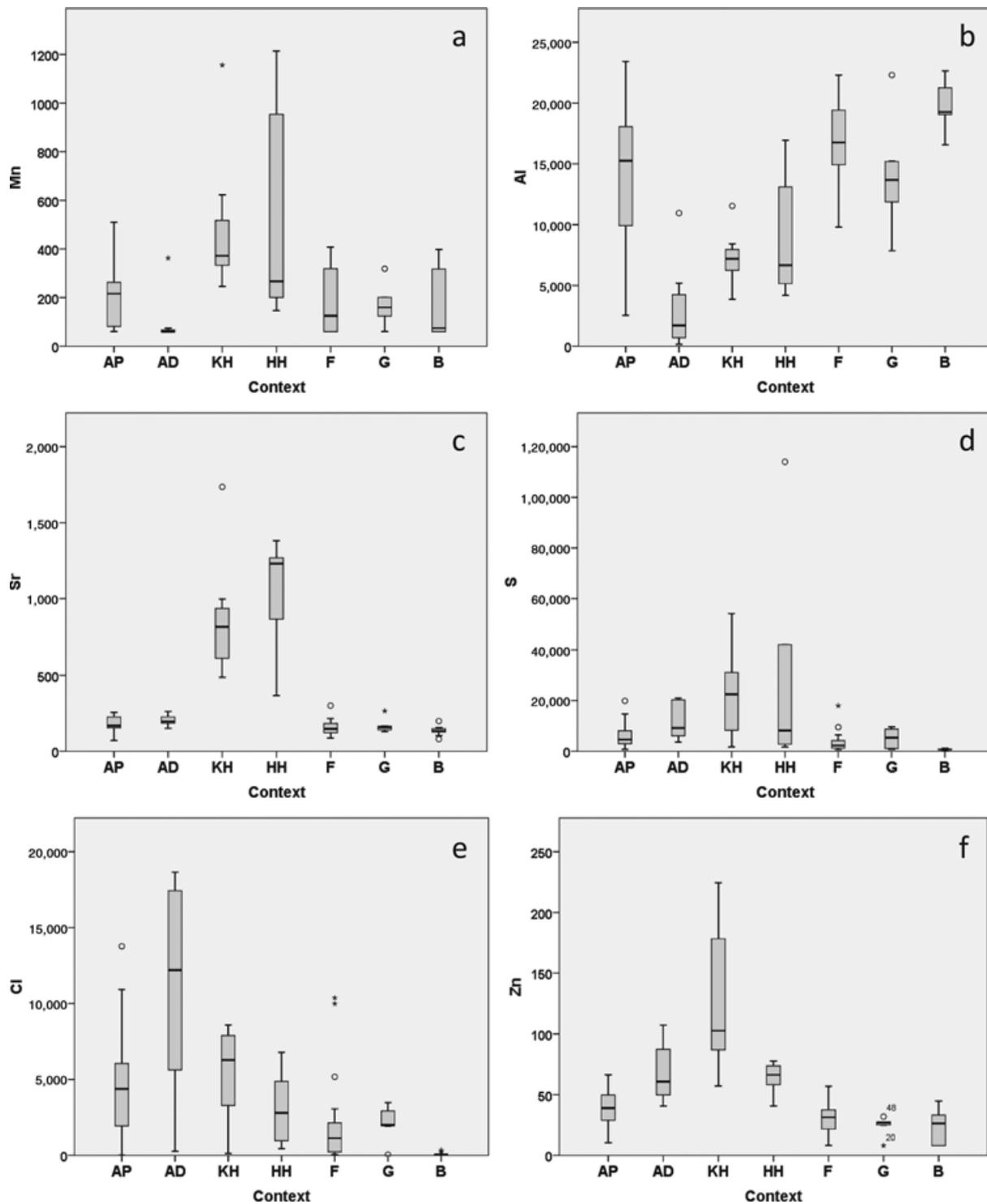


FIGURE 5 Average measurements in ppm for all samples within all of the sites per context category for the following chemical elements: (a) Mn, (b) Al, (c) Sr, (d) S, (e) Cl, and (f) Zn

Notes. Context categories abbreviations: AP, animal pen; AD, animal dung; KH, kitchen hearth; HH, hospitality hearth; F, floor; G, gully; B, background.

derived from the preparation of bread. The dominance of cereals associated with food preparation could provide an indication for cooking hearths and areas archaeologically, though such trends depend on local preferences for food consumption, the availability of identifiable cereal material, and abandonment processes. The hearth of JTW did not contain a high enrichment of wheat even though bread was prepared on it,

as the last activity that took place prior to sampling was the addition of dung cakes, which dominated the phytolith signature for this kitchen hearth.

This example illustrates the influence of abandonment processes and the importance of sampling, which was found to work best when specific activity locations were sampled at the Wadi Faynan sites.

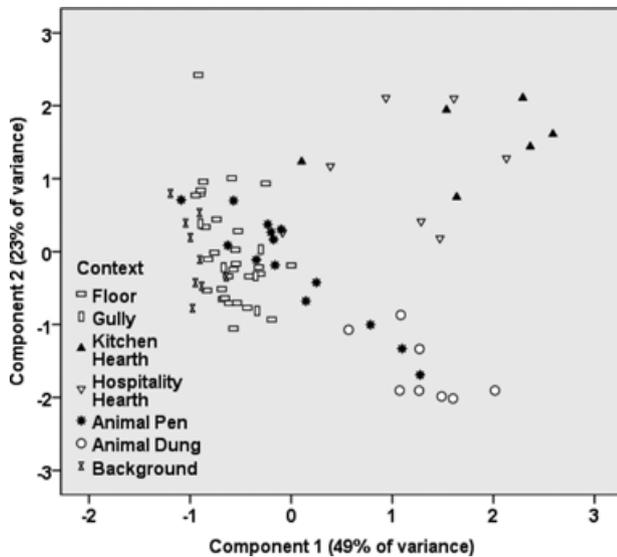


FIGURE 6 PCA scatterplot for all Wadi Faynan sites
Notes. The first component is driven by P, K, and Zn, and negatively by Si, Al, Ti, and Zr. The second component is driven by Ca, Mn, and Mg.

When analyzed, floor samples taken from the edges of hearths did not portray an enrichment typical of the fire places, but were rather identical in composition to the other floor samples. Phytolith and geochemical soil signatures at the Wadi Faynan sites appear to be spatially restricted rather than reflected in gradual transitions, and could only be identified by targeted sampling. An accurate sampling of activity locations, perhaps guided by laboratory analysis in the field, could provide a better analysis of soil signatures. In addition, the use of means to investigate formation processes such as micromorphology could benefit both the sampling strategy and interpretation of the analysis results.

The majority of chemical elements and phytoliths measured in this research do not appear to be affected by taphonomic processes within the short span of time differentiating the periods of abandonment of the Bedouin campsites. However, Cl and K concentrations, presu-

ably derived from salts, decrease over time more rapidly within dung deposits than with other context categories (Figure 8). This could be in part due to the organic nature of the dung and dung-related sediments they are found in, but probably also as a result of exposure to moisture and sunlight.

Within the phytolith data, the lack of clear influence by the short-term abandonment might relate to the depositional environment at Wadi Faynan, an arid region characterized by yellow steppic soils (Palmer et al., 2007). Arid conditions have long been considered favorable for phytolith preservation due to the high rates of evaporation under these conditions, which contribute to silica consolidation in the plant cell and a lesser degree of loss of phytolith material in the soil through water seepage (Hillman, 1984). In addition, the initial amount of available silica and the depth of burial will also have an impact on the chemical dissolution (diagenesis) of phytoliths in archaeological sites (Cabanes et al., 2012).

Beyond the depositional environment, the characteristics of the phytoliths themselves contribute to their preservation. The degree of silicification, shape, and surface area all influence durability, and there is evidence to suggest that phytolith dissolution rates vary among different plant taxa and even within a single plant (Bartoli & Wilding, 1980; Piperno, 2006; Wu, Yang, Wang, & Wang, 2013). A recent study by Cabanes and Shahack-Gross (2015) indicated that the dissolution of various morphotypes differs depending on their surface area to bulk ratio. Within the Wadi Faynan material, relative phytolith morphotype composition is similar across sites, and does not appear to reflect taphonomic trends. WF916 stands out in comparison to the other sites, but this is considered to reflect the differences in use of fuel rather than preservation (elaborated below). Similarly, the relative abundance of elongate dendriform at WF940 would not reflect dissolution, as this morphotype would preserve worse, not better than the bulliform type ones less abundant at this site. Overall, there does not appear to be a clear decrease through time in the presence of morphotypes, which would be expected to suffer from dissolution in a way that would exclude nontaphonomic explanations.

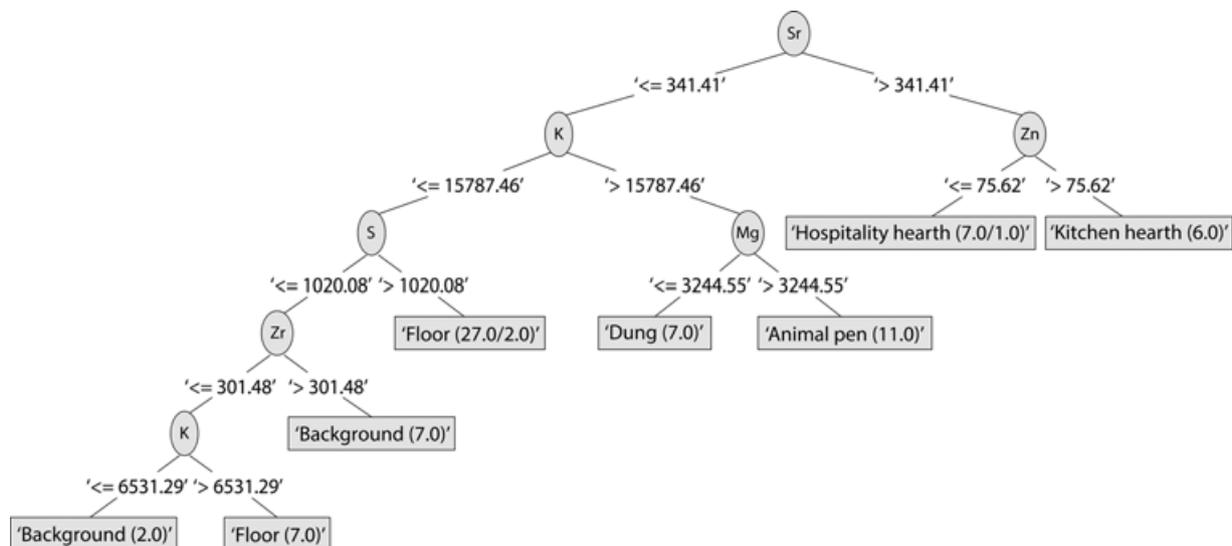


FIGURE 7 Decision tree created for all of the sites based on geochemistry, 77% of cases correctly classified

TABLE 2 Associations between chemical elements and anthropogenic related activities found in earlier studies and in the analysis of the site of Wadi Faynan

Chemical element	Associated activity in previous studies	Associated activity in this study
P	Food preparation and consumption (Fernandez, Terry, Inomata, & Eberl, 2002; Parnell and Terry 2002; Vyncke et al., 2011), burning and food storage (Middleton, 2004), refuse areas (Fernandez et al., 2002), excrements (Vyncke et al., 2011), byres (Wilson et al., 2008), meat (da Costa & Kern, 1999)	Hearths, animal dung
Mg	Wood ash (Middleton & Price, 1996), cooking hearths, food preparation and consumption (Fernandez et al., 2002), meat (da Costa & Kern, 1999)	Hearths, animal dung
Ca	Cooking hearths (Fernandez et al., 2002), food storage and preparation (Middleton, 2004; Vyncke et al., 2011), lime use (Middleton & Price, 1996)	Hearths
K	Wood ash (Middleton & Price, 1996), cooking hearths, food preparation and consumption (Fernandez et al., 2002)	Hearths, animal dung
Mn	Burning (Middleton, 2004), vegetable (da Costa & Kern, 1999)	Hearths
S	Not measured in previous studies	Hearths, animal dung
Sr	Hearths (Wilson et al., 2008), excrements and food preparation (Vyncke et al., 2011), lime use (Middleton & Price, 1996)	Hearths
Zn	Hearths and Byres (Wilson et al., 2008), refuse areas (Fernandez et al., 2002), vegetable (da Costa & Kern, 1999), meat (Tripathi et al. 1997)	Hearths (higher concentrations in kitchen hearths) and animal dung
Cl	Not measured in previous studies	Animal dung, hearths, animal pens
Fe	Craft production (high levels in combination with burning, Middleton, 2004), burning (Vyncke et al., 2011)	Background
Ti	Background (Middleton, 2004)	Background
Al	Background (Middleton, 2004)	Background

The discrepancies between WF916 and the other campsites, described in the geochemical and phytolith analysis results sections, are probably related to a preference for other fuel sources above dung cakes at this site. The occupants of WF916 belonged to a paramount group, the Rashayda Tribe, who use well-made stone lined hospitality hearths. The members of this tribe prefer the use of wood to dung cakes. The latter are sometimes avoided in the hospitality hearths of all campsites as they produce much smoke, yet preferred in the kitchen hearth because the burning temperature is lower and more consistent than with wood. This difference in fuelling between the two hearth types is most prominent within WF916. This observation also indicates that hearths at the other campsites were enriched with K and P

through the use of dung cakes, as their concentrations are significantly lower in the WF916 hospitality hearth (for details see Vos, 2017).

The nature of each method of analysis affects the way in which their results can be processed and combined. One aspect related to this is the level of universal applicability of each technique. The geochemical patterns can generally be directly correlated to known activities such as burning and food preparation, which are associated with specific chemical elements (see overview in Table 2). However, the phytolith trends must be explored within the context of the site since phytoliths derived from activities such as burning or animal husbandry may vary across sites depending on the local availability and use of plants and other materials leading to an indirect phytolith signature (such as the use of dung or wood for construction or fuel).

In addition, differences in the form the results take for each type of proxy influence their degree of compatibility. The measurement level of chemical elements was ppm. This allowed for one type of comparison within the geochemical data, one that is based on the concentrations of elements in the soil. The phytolith assemblages, on the other hand, could be compared through counts of phytolith types, taxonomic identifications, related attributes such as silica aggregate material or weight percent, and also through exploring ratios between related categories based on the phytolith counts such as multi- to single-celled phytoliths, or plant parts. This means that there are different levels of comparison within the phytolith data.

The efficacy of the geochemical analysis in identifying activity areas was found to be greater than that of the phytolith analysis. Decision trees created for each of the two techniques, and including the results of both of them, suggest that combining the variables from both analyses does not provide a better classification of cases than the geochemistry alone. The latter was able to classify 77% of all cases correctly, compared to 60% for a decision tree combining the results of both methods, while the phytolith decision trees classified a third of the cases correctly (Figures 7 and 10). In addition, the PCA scatterplots created for the geochemical data generally showed a better degree of clustering than the PCA scatterplots presenting the phytolith analysis results, and explained a higher degree of variance (Figures 6 and 11).

If the geochemical analysis generally provides the best certainty of identification of activity areas, why bother using the phytolith analysis? Although the geochemistry might explain the largest amount of variation within the data, it does not explain all of it. The strength of the phytolith analysis results lies within site-specific trends, where they can be used to fine-tune the more general interpretation provided by initial definition of context categories in combination with the geochemical analysis. Adding information from the phytolith analysis not only strengthened the classifications made through the geochemistry, but added new ones not visible within the geochemical results. The discriminant function analysis scatterplot graphs created for the geochemical and phytolith data show how this can work (Figures 12 and 13). While the scatterplot presenting the results of the geochemical analysis exhibits a differentiation between clusters of background and floor samples, animal pen, dung, and hearths, the one created for the phytolith analysis results provides a better separation between the kitchen and hospitality hearths, while the animal pen category plots closer to the floor and background samples. This seems to be related

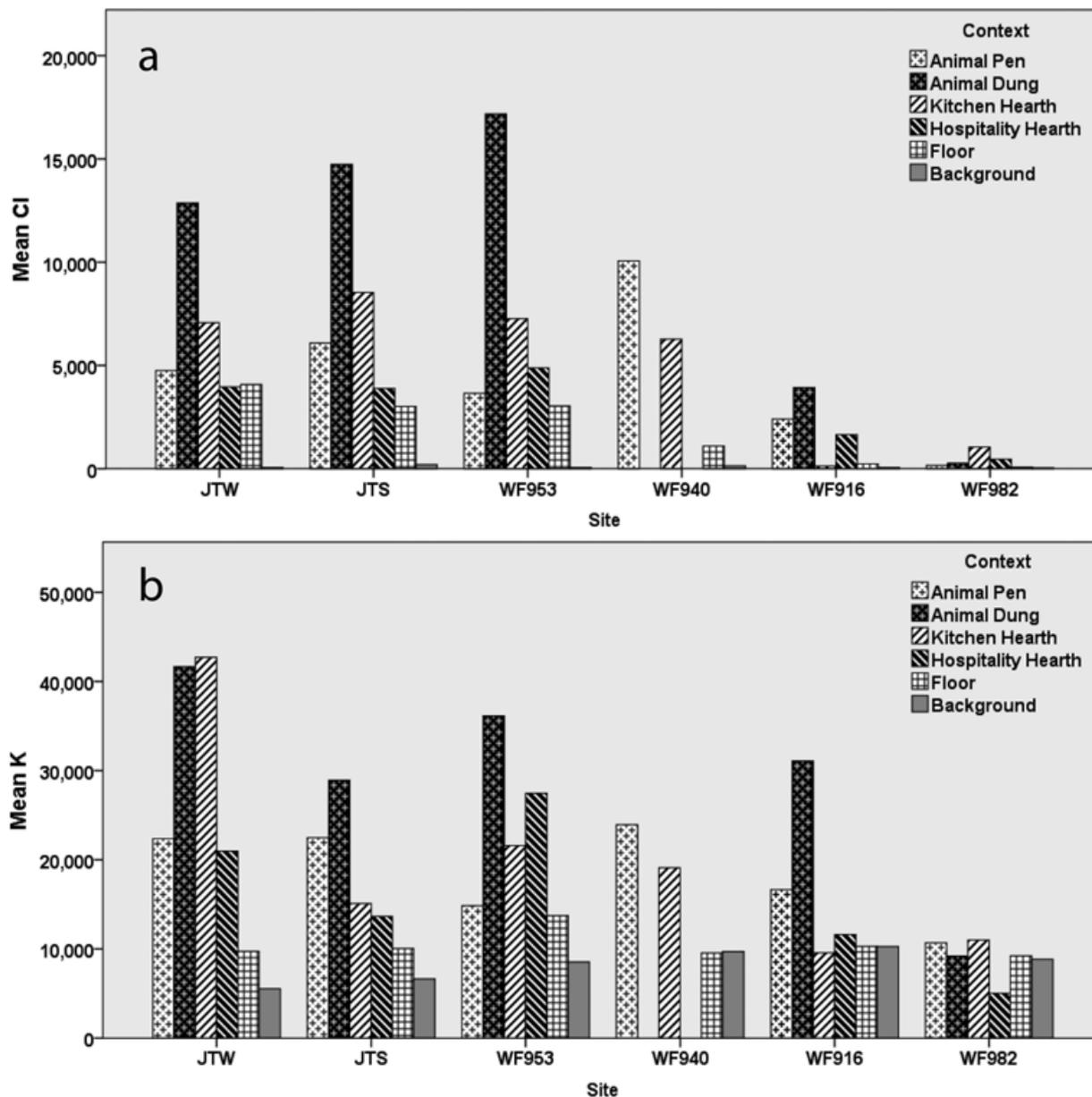


FIGURE 8 Average CI (graph a) and K (graph b) concentrations in ppm within all context categories

Notes. JTW was occupied during sampling, JTS had been abandoned for 6 months, WF953 and WF940 for a year, WF916 for 3 years, and WF982 for 10–15 years.

TABLE 3 Overview of correlations between geochemical and phytolith variables significant at the 0.01 level according to a two-tailed Pearson correlation test

	Monocots	Multicelled	Poorly silicified	Pooideae	Husk	Leaf/husk	Leaf
P	0.798*	0.663			0.677	0.714	
Zn	0.687	0.807*	0.807	0.656	0.630		
Sr			0.818*	0.792			0.646
Mg			0.807*				
S	0.671				0.618		0.661
Ca			0.690				
Ti	-0.707	-0.628			-0.620	-0.619	
Si	-0.643						

Very strong correlations are highlighted with *.

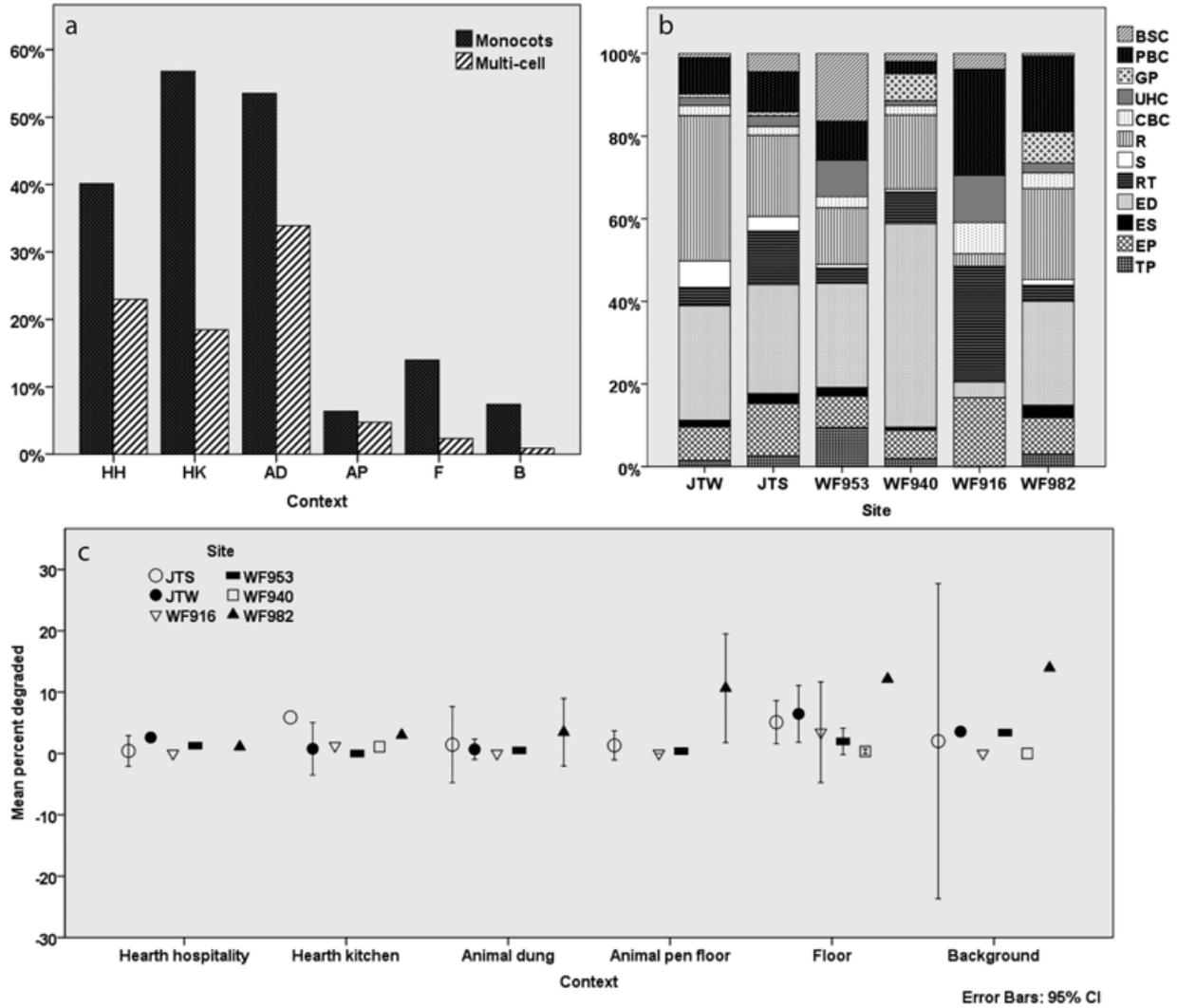


FIGURE 9 Trends in phytolith data: (a) concentrations of monocots and multicell phytoliths per context category for all samples in all sites: AP, animal pen; AD, animal dung; KH, kitchen hearth; HH, hospitality hearth; F, floor; B, background; (b) composition of the 12 most common morphotypes in all samples for each site: BSC, bilobate short cell; PBC, parallelepipedal bulliform cell; GP, globular psilate; UHC, unciform hair cell; CBC, cuneiform bulliform cell; R, rondel; S, saddle; RT, rectangle tabular; ED, elongate dendriform; ES, elongate sinuate; EP, elongate psilate; TP, trapeziform psilate; (c) average amount of degraded phytoliths in all samples per context category for each site

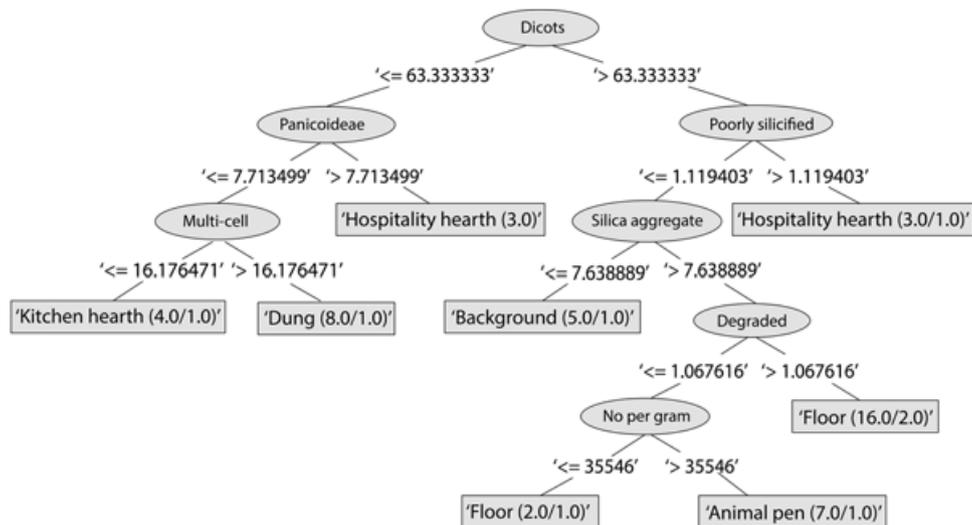


FIGURE 10 Decision tree created for all of the sites based on phytolith results, 33% of cases correctly classified

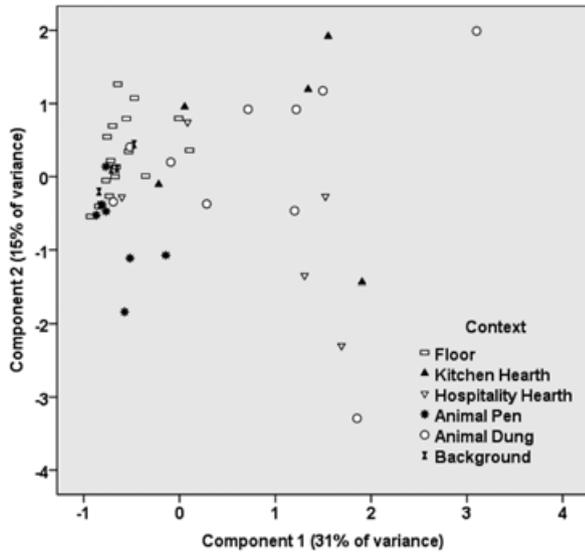


FIGURE 11 Combined PCA scatterplot for the sites JTS, JTW, WF916, and WF953

Notes. The first component is driven by monocots versus dicots, multi-versus single-celled phytoliths, husk material, and Poideae. The second component is driven by unidentified phytoliths, leaf, negatively by no per gram, weight percent, and *Triticum* sp.

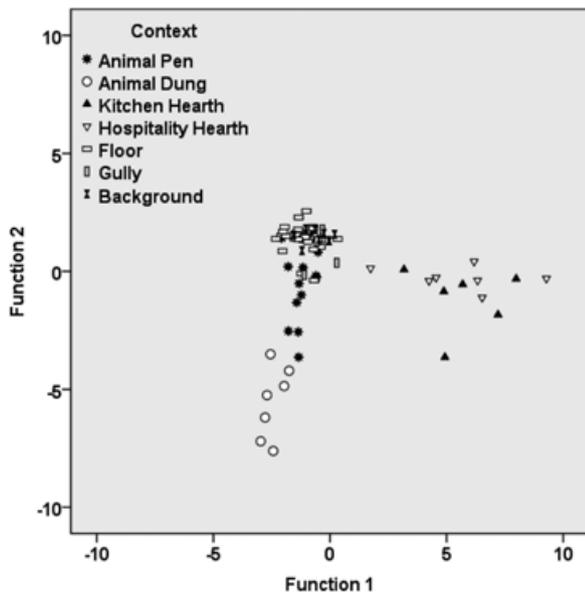


FIGURE 12 Discriminant function analysis scatterplot for ethnographic sites based on results of the geochemical analysis, 78% of original grouped cases and 58% of cross-validated grouped cases correctly classified

to the difference in use of fuel and addition of wheat in the kitchen hearths, which is better reflected through the phytolith analysis.

Addressing sources of information that potentially represent different inputs from anthropogenic activities, in our case plant material and chemical elements, provides a comprehensive approach for identifying various spatial divisions. The differences between the two sources of data might provide difficulties in combining them, but they are what make their integration worth while pursuing—each one can provide information about signatures of activity not captured with the other.

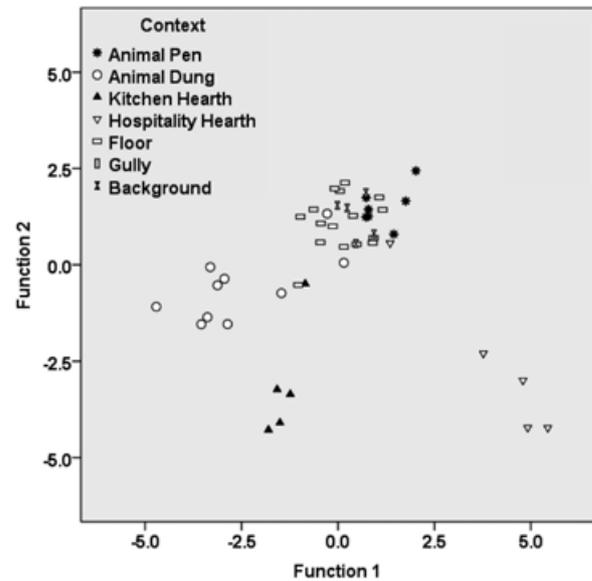


FIGURE 13 Discriminant function analysis scatterplot for ethnographic sites based on results of the phytolith analysis, 73% of original grouped cases and 33% of cross-validated grouped cases correctly classified

5 | CONCLUSIONS

The use of the dual geochemical-phytolith methodology was found useful for distinguishing between activity areas in ephemeral sites, confirming associations between chemical elements and phytolith attributes identified in earlier ethnoarchaeological studies. The results of the ethnoarchaeological analysis support the hypothesis that geochemical and phytolith signatures can be found in the soil at the locations where activities took place, and suggest that soil signatures at ephemeral sites can be preserved in harsh and dynamic environments, in our case those of the Near East. While the surfaces of the Bedouin campsites studied in this research were left exposed to wind erosion and rain after the tents covering them were moved to a different location, they retained phytolith and geochemical soil signatures for at least 15 years.

Within this study, the efficacy of the geochemical analysis was found to be higher than that of the phytolith analysis when it came to identifying activity areas. Decision trees and PCA scatterplots created for the geochemical results of both ethnographic and archaeological data provided a higher percent of correctly identified instances and explained a higher percent of variance within the data than those incorporating the results of the phytolith analysis. This is probably related to the use of dung cakes for fuel, a dominant activity that makes it difficult to distinguish between areas and may mask other traces. Nevertheless, adding information from both methods was found to be more useful in identifying activity areas than only one. While geochemistry may explain more variance within the data than the phytolith results, the two methods complement each other and provide information about different aspects of activities.

This study suggests that while the results of multiple geoarchaeological proxies cannot always be readily integrated due to differences in the nature of the used methods, a parallel analysis carries much

potential and helps combat issues of equifinality and equivocality when studying traces of human activities in soils. Geoarchaeological analyses of activity areas are a fairly recent development, and further studies looking into the compatibility and integration of such techniques will help determine the best approach for studying sites of different scale, date, nature of habitation, and taphonomic disturbance.

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SUPPORTING INFORMATION

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