ORIGINAL PAPER

Neanderthal use of plants and past vegetation reconstruction at the Middle Paleolithic site of Abrigo de la Quebrada (Chelva, Valencia, Spain)

I. Esteban[1] · R. M. Albert[1,2] · A. Eixea[3] · J. Zilhão[2,4] · V. Villaverde[3]

Abstract Despite phytoliths having been used to understand past human use of plants and palaeoenvironment in Middle Paleolithic sites, little is known on this aspect in the well-documented central region of Mediterranean Iberia. This paper presents the first phytolith and mineralogical study conducted at Abrigo de la Quebrada (Chelva, Valencia). Forty-one samples were analyzed through phytoliths and Fourier transform infrared spectroscopy (FTIR) from different areas, stratigraphic levels, and archeological contexts (hearth, hearth-related, and non-hearth-related sediments) of the shelter. The results obtained point towards a different pattern of preservation in the site depending firstly on the stratigraphy and secondly on the area where the samples were collected. Postdepositional processes that may have chemically affected phytolith preservation are discussed. Grasses are the main plant component identified in all the samples while woody plants are scarce. The abundance of grasses in the non-hearth-related sediments might be related, at least partially, to the dispersion of ashes from hearths, as indicated by the FTIR results. The results are indicative of an occupation of the site during the spring-autumn season. At this time, the area would be dominated by a semi-open environment with supramediterranean vegetation.

✉ R. M. Albert
rmalbert@ub.edu

[1] ERAAUB. Dept. de Prehistoria, Historia Antiga i Arqueologia, Universitat de Barcelona, Montalegre 4-10, 08001 Barcelona, Spain

[2] ICREA (Catalan Institution for Research and Advanced Studies), Barcelona, Spain

[3] Dept. de Prehistòria i Arqueologia, Universitat de València, Blasco Ibáñez, 28, 46010 Valencia, Spain

[4] SERP Dept. de Prehistòria, Historia Antiga i Arqueologia, Universitat de Barcelona, Montalegre, 4-10, 08001 Barcelona, Spain

Introduction

Plants are essential for modern hunter-gatherers, as they are involved in the majority of their daily activities, not only related to consumption but also to making fire, tools, bedding, sheltering, etc. (e.g., Jochim 1976; Burch and Ellanna 1994; Winterhalder and Smith 1981). The selection of plants for different purposes will depend mostly on their availability. Thus, the identification of plant remains in an archeological site will give valuable information on the palaeoenvironment and palaeovegetation during the time of occupation.

Traditionally, the studies carried out on Middle Paleolithic populations have been focused on the analyses of lithic and faunal material whereas considerably less importance has been given to plant remains. During the last decades, a number of papers have considered the exploitation of vegetal resources by Neanderthals (e.g., Couplan 1983). As with modern hunter-gatherers, it is expected that Neanderthals would have collected the plants necessary for their daily activities from close vicinity and that the corresponding remains should be represented in the archeological record.

Phytoliths, silica microremains formed in living plants, are a useful tool for plant identification since (i) they do not need to be combusted to be preserved due to their mineralogical composition—opaline silica and (ii) due to their formation inside the cellular tissue of plants, they retain distinctive morphologies that make them identifiable to the plant component and the type of plant, sometimes at species level (Twiss et al. 1969; Piperno 1988, 2006; Bozarth 1992, Ollendorf 1992; Rosen 1992; Berlin et al. 2003).

There are, nevertheless, some aspects that need to be taken into account when studying phytoliths. Being mainly silica, phytoliths are relatively soluble in alkaline conditions (Piperno 1988), and they can be rapidly dissolved when the calcite present in the sediments buffers the water to around 8.5 (Fraysse et al. 2006). Cabanes et al. (2011) also showed that burnt phytoliths are more soluble than unburnt phytoliths.

Phytolith analyses have been widely used to identify plant remains in Middle and Upper Paleolithic sites, mainly since the end of the 1990s (Albert et al. 1999, 2000; Madella et al. 2002) and have helped in the identification of different types of fuel used for fires in cave sites such as Kebara, Tabun, Hayonim, and Amud in Israel (Albert et al. 1999, 2000, 2003; Madella et al. 2002), Grotte XVI in France (Karkanas et al. 2002), Klissoura (Greece) (Albert 2010), etc. They have also been used to recognize spatial organization at Tor Faraj (Rosen 2003) and bedding practices in Esquilleu (Cabanes et al. 2010) and Sibudu (Wadley et al. 2011). Other studies from this period have focused on plant consumption, based mostly on the study of tooth enamel (Fox et al. 1996; Henry et al. 2011).

The Middle Paleolithic is well documented in the central region of Mediterranean Iberia. A number of sequences include both early and recent Middle Paleolithic levels: Cova de Dalt del Tossal de la Font, El Pinar, Bolomor, Foradada, Cova Negra, Petxina, Quebrada, Las Fuentes, Cochino, Pastor, and Salt (Fernández Peris and Villaverde 2001). Several of these sites (Bolomor and Cova Negra) have yielded Neanderthal human remains (Arsuaga et al. 2006, 2012). Archeozoological studies indicate the existence of limited resource specialization, with the presence of both large and medium size herbivores as well as small prey like rabbits, tortoises, and birds (Villaverde et al. 1998; Salazar-García et al. 2013; Blasco 2008; Blasco and Fernández Peris 2009, 2012). In most of the sites that have been excavated in recent decades, combustion features are abundant and the available data point to occupations of short duration and high level of territorial mobility.

Phytolith analyses have been carried out in different Middle Paleolithic sites from the Iberian Peninsula (i.e., Cueva Bajondillo (Torremolinos) (Albert 2007), Abric Romaní (Capellades) (Cabanes et al. 2007; Allué et al. 2012), El Salt (Alcoi) (Mallol et al. 2013), and Esquilleu (Cantabria) (Cabanes et al. 2010)). Despite the number of sites from this period with well-preserved hearths, no such studies have been conducted yet in the Valencian region, where the Middle Paleolithic site of Abrigo de la Quebrada is located. Here, we present the first phytolith study of this site.

The site of Abrigo de la Quebrada

The Middle Paleolithic site of Abrigo de la Quebrada is located in Chelva (Valencia, Spain) (Fig. 1). The site, situated on the left side of the Rambla de Ahillas canyon, corresponds to a sheltered, quite even horizontal platform at 38 m long and 2 to 9 m wide that slopes slightly from North to South. Given its position (NW-facing, and at the bottom of a narrow, steep gorge), the shelter is characterized by scarce insolation and high exposure to winds. The Rambla de Ahillas opens onto a wide plain known as Plano de Arquela, which, together with the canyon—which terminates in a dead end, forming a sort of natural trap for hunting—clearly hint at the reasons underpinning human use of the shelter.

To date, the stratigraphy of the Abrigo de la Quebrada consists of eight units with a thickness of approximately 4 m. The base of the sequence has not yet been reached. Level I, at the top, is disturbed as a result of the use of the shelter for penning. Middle Paleolithic human occupation is recorded in levels II to V, VII, and VIII, whereas level VI is archeologically sterile. Anthropogenic inputs are especially significant in units III, IV, and V.

The chronology, based on charcoal fragments dated by accelerator mass spectrometry (AMS) at Beta Labs, indicates, for level III, 40,500 ± 530 BP (Beta-244,003) (Villaverde et al. 2008) and for level IV (ABA-treated), 43,930 ± 750 BP (Beta-244,002). From this later level, ABOx dating gave a result of >50.8 kaBP (OxA-24,855) (Eixea et al. 2011a, b, 2012). For level VI, two samples dated by Optical Stimulated Luminescence (OSL) indicated 79 ± 5 ka (for the uppermost part) and 82 ± 5 ka (for the lowermost part) (Klasen 2015). These results indicate deposition of the sediments from levels II–V during MIS4, from level VI during MIS5e, and those from levels VII–VIII probably during MIS5b. The small mammal assemblage studied from levels VII–VIII is consistent with an Upper Pleistocene chronology (Tormo and Guillem-Calatayud 2015).

Lithic tools were produced using discoid and recurrent centripetal Levallois methods, and lateral side-scrapers, Levallois points, and Mousterian points dominate the lithic assemblage. The abundance of cortical fragments, cores, and flakes of different sizes suggest that knapping was carried out in situ. The assemblage is characterized by the small size of the artifacts (between 20 and 40 mm). Retouched flakes tend to be bigger than non-retouched ones and are out of the range of last extraction sizes measured in the cores (Villaverde et al. 2012). Raw-material procurement was carried out within a radius of 5 km around the site, where Neanderthals could find flint, quartzite, and limestone. Some flint coming from sources situated more than 100 km far away is also present (Eixea et al. 2011a, b, 2014). The faunal study, focused on level IV, has identified remains from eight different families: Bovideae, Equideae, Cervidae, Leporidae, Testudinidae, Suidae, Rhinocerotidae, and Canidae. Ibex (*Capra* sp.), horse (*Equus ferus*), and deer (*Cervus elaphus*) are the most represented species (Sanchis Serra et al. 2013). Most of the remains
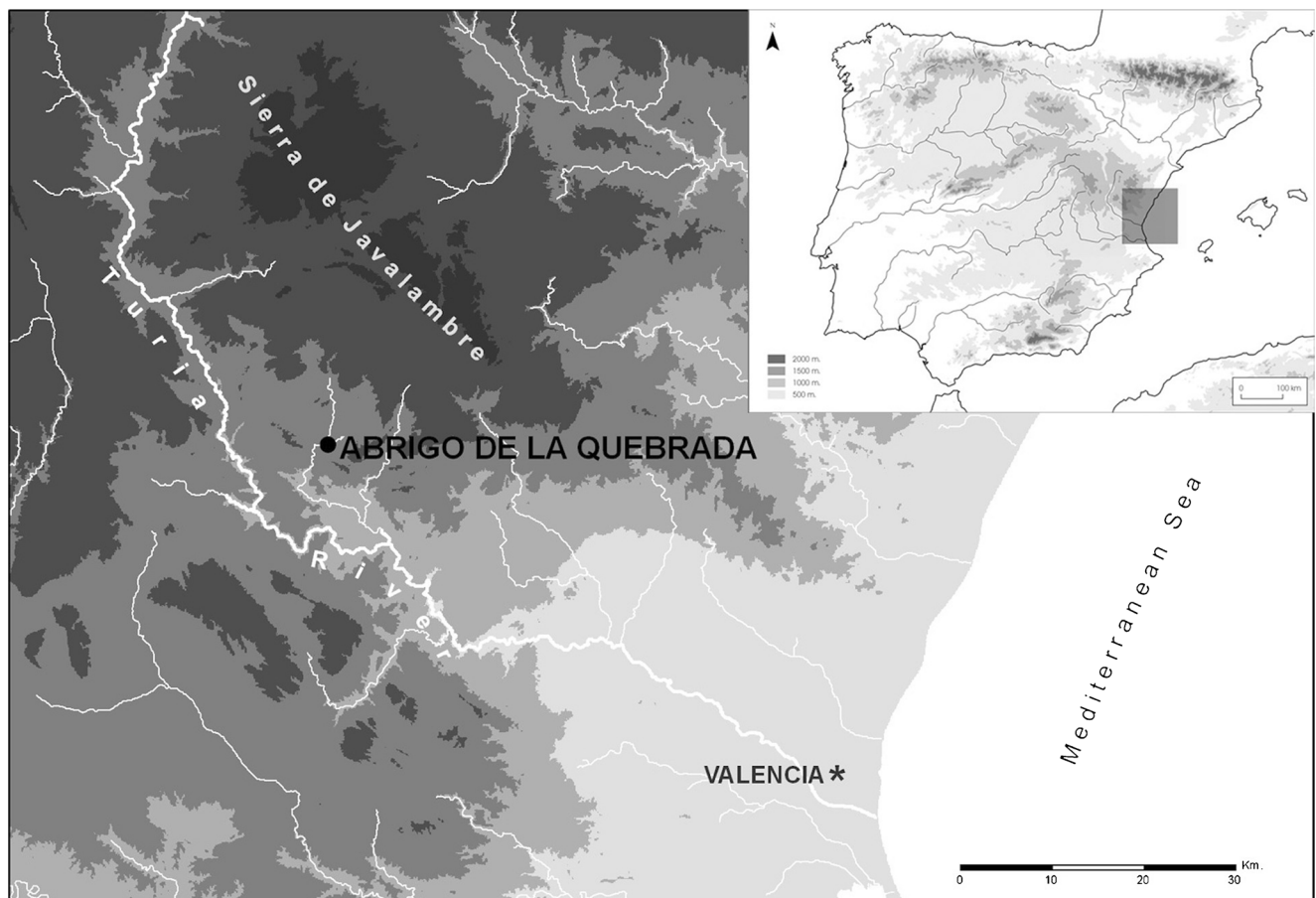
Fig. 1 Map showing the geographical location of the Abrigo de la Quebrada (Chelva, Valencia, Spain)

show a high degree of fragmentation, due to taphonomical processes.

Charcoal analysis of uppermost levels I to IV show a dominance of *Pinus* (*Pinus nigra* and *Pinus sylvestris*), Juniperus, and other gymnosperms. *Quercus*, *Rhamnus*, and other dicotyledonous plants were also identified but in low quantities (Badal et al. 2012). These results suggest dry or subhumid supramediterranean environmental conditions through the entire sequence, with no indication of warm episodes.

Available evidence suggests short-term occupations by a small number of individuals. The scarce protected space available, the high exposure to winds, the privileged position to control abrupt and open spaces, and the repeated visits related to episodes of hunting support this hypothesis. These conditions and the very slow sedimentation rate might explain the high density of faunal remains, their great fragmentation, and the overlapping of a large number of hearths (Eixea et al. 2011a, b, 2012; Sanchis Serra et al. 2013).

The phytolith study presented here aims to (i) discriminate between natural and anthropic deposition of plants, (ii) relate the use of plants to the different activities carried out in the shelter, and (iii) improve our knowledge on phytolith preservation under different conditions to obtain a more reliable archeobotanical interpretation. The results obtained shed more light on the activities, in relation to plants, carried out by the Neanderthal populations occupying this site. Additionally, the identification of the vegetation informs us on the vegetation and landscape conditions present during this time in the surrounding area of the site.

Materials and methods

Materials

Forty-one samples were collected from levels III to VIII from different locations (Fig. 2). Table 1 lists the samples analyzed, their provenance and stratigraphic location, as well as the general results obtained from the study: estimated number of phytoliths per gram of sediment, percentage of phytoliths with dissolution traits, number of interconnected cells identified, Fourier transform infrared spectroscopy (FTIR), and calcite grinding curve results. Out of these 41 samples, 11 were collected from the non-anthropic level VI to be compared with anthropic levels. The 30 remaining samples were classified as follows: (i) hearths (13), (ii) hearth-related sediments collected
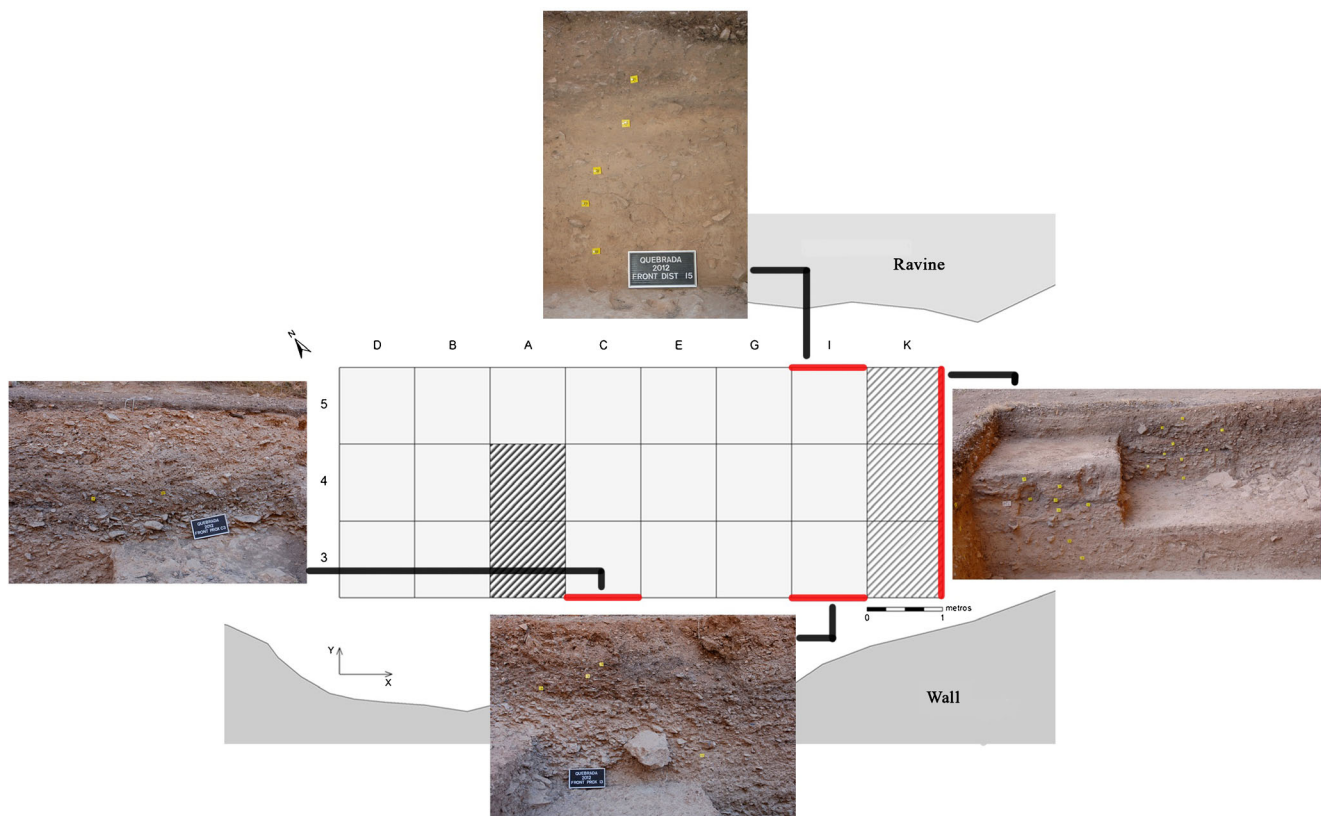
Fig. 2 Map of the excavation with location of the sampled areas and the field photographs of the sampled profiles

outside the hearths (3), and (iii) non-hearth-related sediments corresponding to sediments associated to dense occupation periods but not directly related to hearths (14).

Methods

Phytolith extraction was carried out at the Laboratory of Prehistory, Ancient History and Archeology of the University of Barcelona following the methods developed by Katz et al. (2010). A weight amount of between 30 and 50 mg of the sediment is placed in a 0.5-ml Eppendorf plastic centrifuge tube. Fifty microliters 6 N HCl are added using a micropipette (Finnpipette) in order to dissolve carbonate minerals and carbonated hydroxylapatite. After the bubbling has ceased, 450 ml of 2.4 g/ml sodium polytungstate solution [$Na_6(H_2W_{12}O_{40})vH_2O$] is added. The tube is vortexed and sonicated for ca. 10 min (Ultrasons, Selecta), vortexed again, and centrifuged for 5 min at 5000 rpm (MiniSpin plus, Eppendorf). The supernatant (phytoliths and charred organic material) is removed to a new 0.5 ml centrifuge tube and vortexed. For examination under the optical microscope, an aliquot of 50 ml of the supernatant is removed and placed on a microscope slide and covered with a 24 × 24 mm cover-slip. To quantify the total amount of phytoliths, we used a general approach based on the counting of 20 fields at ×200 magnification, whereas the morphological identification took place at

×400 magnification. For the morphological analysis, a minimum number of 200 phytoliths were counted whenever possible. Morphological identification of phytoliths was based on standard literature (Mulholland and Rapp 1992; Piperno 1988, 2006; Twiss et al. 1969) and our modern plant reference collections (Albert and Weiner 2001; Bamford et al. 2006; Albert et al. 2011). The terminology for describing phytolith morphologies is based on the anatomical origin of the phytolith, and when this is not possible, geometrical traits are followed. The International Code for Phytolith Nomenclature (ICPN) was also followed where possible (Madella et al. 2005). In order to determine whether phytoliths were burnt, refractive index (RI) of the phytoliths was checked following Elbaum et al. (2003), who fixed the limit between burnt and unburnt phytoliths at R.I. of 1.440. For the R.I. measurements, slides were prepared with Cargille medium with a refractive index of 1.440.

In addition to phytolith analysis, infrared spectroscopy (FTIR) was used to identify the gross mineral components of the sediments. Infrared spectra were obtained using KBr pellets at 4 cm^{-1} resolution with a Nicolet iS5 spectrometer. In order to assess the origin of the calcite, we have applied the infrared grinding curve method developed by Regev et al. (2010) based on the measurement of the ratio of v_2/v_4 heights (1420 and 713 cm^{-1}, respectively) normalized to a v_3 height (874 cm^{-1}).

Table 1 Abrigo de la Quebrada: provenance and stratigraphic location of samples, estimated number of phytoliths per gram of sediment, percentage of phytoliths with dissolution traits, number of interconnected cells, FTIR, and calcite grinding curve results

Sample number	Sample provenance	Stratigraphic location	General description	Phyt g/sed	No. of phyt identified	%weathered morphotypes	No. of interconnect phytoliths	Main mineral components	Calcite origin (Regev et al. 2010)
QB 1	Level III	K-4 right sagittal	Non-hearth-related sediment	2,300,000	179	12.4	3	Ca, Cl, Q, few Dah	Ash
QB 2	Level III	K-4 right sagittal	Hearth	1,200,000	230	6.6	2	Ca, Cl, Q	Ash
QB 3	Level III	K-4 right sagittal	Non-hearth-related sediment	25,000	4	–	–	Cl, Q, few Ca	Ash
QB 9	Level III	I-3 frontal proximal	Hearth-related sediment	0	0	–	–	Cl, Q, few Ca	Ash
QB 13	Level III	I-5 right sagittal	Hearth-related sediment	1,800,000	220	10.6	–	Ca, Cl, Q	Ash
QB 24	Level III	I-5 distal frontal	Hearth	2,200,000	226	10	4	Cl, Q Ca	Ash
QB 4	Level IV	K-4 right sagittal	Hearth	67,000	9	–	–	Cl, Ca, Q	Ash
QB 5	Level IV	K-4 right sagittal	Hearth	8000	1	–	–	Ca, Cl, Q	Ash
QB 10	Level IV	I-3 frontal proximal	Non-hearth-related sediment	0	0	–	–	Cl, Q, few Ca	Ash
QB 14	Level IV	I-5 right sagittal	Non-hearth-related sediment	1,200,000	218	5.1	–	Ca, Cl, Q	Ash
QB 15	Level IV	I-5 right sagittal	Hearth	3,700,000	233	7.7	1	Ca, Cl, Q	Ash
QB 17	Level IV	I-5 right sagittal	Hearth	2,500,000	215	9.8	–	Ca, Cl, Q	Ash
QB 25	Level IV	I-5 distal frontal	Non-hearth-related sediment	4,000,000	201	10.2	–	Ca, Cl, Q	Ash?
QB 20	Level IV	C-3 frontal proximal	Non-hearth-related sediment	0	0	–	–	Ca, some silicates	Geogenic
QB 11	Level V	I-3 frontal proximal	Non-hearth-related sediment	14,000	2	–	–	Cl, Q, Ca	Geogenic
QB 16	Level V	I-5 right sagittal	Non-hearth-related sediment	800,000	195	13.3	–	Ca, Cl, Q	Ash
QB 22	Level V	I-5 right sagittal	Hearth	1,800,000	215	17.2	2	Ca, Cl, Q, few Dah	Ash
QB 26	Level V	I-5 distal frontal	Non-hearth-related sediment	600,000	96	11.7	–	Ca, Cl, Q	Ash
QB 21	Level V	C-3 frontal proximal	Hearth-related sediment	0	0	–	–	Ca, Cl, Q, few Dah	Ash
QB 6	Level V	K-4 right sagittal	Non-hearth-related sediment	27,000	3	–	–	Cl, Q, Ca	Ash
QB 7	Level V	K-4 right sagittal	Non-hearth-related sediment	45,000	5	–	–	Ca, Cl, Q	Ash
QB 23	Level V	K-4 right sagittal	Hearth	300,000	102	23	–	Ca, Cl, Q	Ash
QB 12	Level VI	G-3 frontal proximal	Sterile	0	0	–	–	Ca, Cl, Q	Ash
QB 27	Level VI	I-5 distal frontal	Sterile	15,000	2	–	–	Ca, Cl, Q	Geogenic
QB 28	Level VI	I-5 distal frontal	Sterile	0	0	–	–	Ca, Cl, Q	Geogenic
QB 18	Level VI	I-5 right sagittal	Sterile	31,000	6	–	–	Cl, Ca, Q	Ash
QB 19	Level VI	I-5 right sagittal	Sterile	40,000	6	–	–	Ca, Cl, Q	Ash
QB 29	Level VIB	E-4 distal frontal	Sterile	0	0	–	–	Ca, Cl, Q	Geogenic
QB 30	Level VIC	E-4 distal frontal	Sterile	0	0	–	–	Q, Cl, Ca	Geogenic
QB 31	Level VIC	E-4 distal frontal	Sterile	0	0	–	–	Cl, Q, Ca	Ash
QB 32	Level VIC	E-4 distal frontal	Sterile	0	0	–	–	Q, Cl, Ca	Unknwon
QB 33	Level VIC	E-4 distal frontal	Sterile	0	0	–	–	Ca, Cl, Q	Ash
QB 8	Level VI	K-4 right sagittal	Sterile	7000	1	–	–	Ca, Cl, Q	Ash
QB 34	Level VII	E-3/4 left sagittal	Non-hearth-related sediment	0	0	–	–	Cl, Q, Ca	Ash?
QB 35	Level VIII	E-3/4 left sagittal	Hearth	0	0	–	–	Ca	Ash

Table 1 (continued)

Sample number	Sample provenance	Stratigraphic location	General description	Phyt g/sed	No. of phyt identified	%weathered morphotypes	No. of interconnect phytoliths	Main mineral components	Calcite origin (Regev et al. 2010)
QB 36	Level VIII	E-3/4 left sagittal	Non-hearth-related sediment	7000	1	–	–	Ca, some silicates	Ash
QB 37	Level VIII	E-3/4 left sagittal	Hearth	0	0	–	–	Ca, some silicates	Ash
QB 38	Level VIII	E-3/4 left sagittal	Hearth	0	0	–	–	Ca	Ash
QB 39	Level VIII	E-3/4 left sagittal	Non-hearth-related sediment	8000	1	–	–	Ca	Ash
QB 40	Level VIII	E-4 right sagittal	Hearth	0	0	–	–	Ca, some silicates	Ash
QB 41	Level VIII	E-4 right sagittal	Hearth	47,000	6	–	–	Ca, some silicates, few Dh	Ash

Results

Out of the 41 samples analyzed, 16 did not have any phytoliths and 13 had small amounts (Table 1). Twelve samples (QB 1, 2, 13, and 24 from level III; QB 14, 15, 17, and 25 from level IV; QB 16, 22, 23, and 26 from level V) did show enough phytoliths for a reliable morphological interpretation (Table 1). Samples from sterile level VI contained few or no phytoliths. The lowermost levels with anthropic occupation (levels VII and VIII) had few phytoliths and could not be used for the morphological interpretation. The only exception was sample QB 41, a hearth sample from level VIII in which fragments of dicotyledonous-leaf epidermis with polyhedral structures apparently burnt were identified (from 50 to 200 μm). In addition to phytoliths, diatoms, from the pennate order, were identified in some of the samples although in low number (Tappan 1980).

Mineralogy and phytolith preservation

There is a general decrease in phytolith preservation from uppermost levels III–V to lowermost levels VI–VIII, in agreement with a decrease in the lower levels of the more breakable interconnected cell phytoliths. In the upper levels, phytolith abundance and preservation are not homogeneous, indicating varying postdepositional processes. In the right sagittal profile, phytoliths were abundant and well preserved in the uppermost levels III, IV, and V, with the exception of square K4. Conversely, samples from these same levels but from the frontal proximal profile yielded phytoliths in low number and in a bad state of preservation (Table 1).

FTIR analyses indicate that calcite, clay, and quartz are the major mineral components in most of the samples, although in varying concentrations. Dahllite (carbonate hydroxylapatite) is also present in three samples, albeit in small quantities (Table 1). In lowermost level VIII, calcite is the major mineral component and silicates were identified in lesser amounts (Table 1). Samples from sterile level VI are dominated by calcite (in levels VI and VIB) or quartz and clay (in level VIC). Following Regev et al. (2010), the major source for the calcite is wood ash in most of the samples with the exception of the non-hearth-related samples QB 20 (level IV) and QB 11 (level V), which showed calcite of geogenic origin. These samples were collected from the frontal proximal profile (Table 1; Fig. 2). The analysis of the refractive index of phytoliths from the 12 samples morphologically analyzed shows that more than 60 % of these morphotypes were burnt irrespectively of their provenance (hearth, hearth-related, and non-hearth-related sediments) (Table 2). This is consistent with the calcite being of wood-ash origin and indicates dispersion of ashes throughout the occupation floor. Contrary to expectations, samples QB 8, 12, 18, 19, 31, and 33 from sterile

Table 2 Results for the refractive index test indicating the percentage of phytoliths above and below refractive index at 1.440

Sample number	Sample provenance	No. of phyt. counted	RI above 1.440 (%)	RI below 1.440 (%)	Burnt
QB 1	Level III	200	63.5	36.5	Yes
QB 2	Level III	200	73	27	Yes
QB 13	Level III	200	72	28	Yes
QB 24	Level III	200	70.5	29.5	Yes
QB 14	Level IV	201	66.7	33.3	Yes
QB 15	Level IV	202	67.3	32.7	Yes
QB 17	Level IV	200	70	30	Yes
QB 25	Level IV	201	62.7	37.3	Yes
QB 16	Level V	201	62.7	37.3	Yes
QB 22	Level V	213	65.3	34.7	Yes
QB 23	Level V	203	63.1	37	Yes
QB 26	Level V	209	69.4	30.6	Yes

level VI also present wood-ash calcite. The remaining samples from this level have geogenic calcite (Table 1).

Morphological analysis

Table 3 lists the different phytolith morphotypes identified, their plant attribution, and their relative presence in the samples. For an easier comprehension of plant presence, phytoliths corresponding to the 12 samples morphologically analyzed have been grouped in relation to the type of plant or plant component in which they have been formed (Fig. 3). Although all the samples present a generally similar morphological distribution, differences related to the types of sediments have been observed (Table 3; Fig. 3). Grasses dominate in all the samples, being slightly higher in the non-hearth-related sediments (Fig. 3). This grass dominance is accompanied by elongate phytoliths whose classification to family level (grasses, sedges, palms, etc.) was not possible. Among these, cylindroids and parallelepiped elongates were more uniformly distributed in hearth samples.

Grasses are excellent environmental indicators because of their short life cycle and rapid shifts (expansion and contraction) that mimic climate zone migration. They fall into two physiological groups, using the C_3 and C_4 carbon fixation processes. Silicified grass short cells are traditionally used to distinguish between different grass subfamilies (Pooideae, Panicoideae, Chloridoideae, etc.) (Twiss et al. 1969; Mulholland and Rapp 1992; Fredlund and Tieszen 1994; Piperno 2006), as well as to differentiate between C_3 and C_4 grasses. At Quebrada, the grass phytoliths identified belong to the leaves and stems of these plants as well as the inflorescence, representing the whole plant. Among the morphotypes identified, short cells formed both in the leaves/steams and the inflorescence are present in all the samples. Short cell rondels

are dominant irrespective of sample provenance and type of sediment (Fig. 4a, b). Long trapeziforms (Fig. 4c) and towers follow in abundance with the exception of sample QB 13 (level III), from hearth-related sediment, where they occur in low numbers. Conversely, this sample presents a higher percentage of short cell polylobates. Short cell bilobates are also identified in most of the samples, mainly in the uppermost level III, although never in large amounts. Short cell saddles are rare. Long cell echinate phytoliths (Fig. 4d) were identified in most of the samples, irrespective of level and sample type (Table 3). Interconnected cells from grass husk and leaves/steams were also noted, particularly in level III and in the hearth-related sediments (Fig. 4e, f). The presence of husk phytoliths from the inflorescence is suggestive of a spring-summer occupation of the site. Only one single spheroid echinate phytolith, characteristic of the palms, was identified in sample QB 1 from level III, which does not allow for further interpretation.

Phytoliths from leaves and wood/bark of woody plants are present in all the samples, although in much lower numbers than grasses (Fig. 3). Interestingly, even though phytoliths from the leaves of woody plants were not numerous, some morphotypes from this plant part, mostly epidermal appendage hair, with tracheid and sclereid in lesser amounts (Fig. 4g–i) are more abundant in non-hearth-related sediments, with the exception of sample QB 26 (level V). Conversely, polyhedral multicellular structures characteristic of dicotyledonous-leaf plants were only present in hearths (Fig. 4j, k). Even though polyhedral multicellular structures from the epidermis tissue of dicotyledonous leaves are commonly silicified in plants, they do not survive well in soils and sediments due to their fragile silicification (Piperno 2006).

The low numbers of wood/bark phytoliths recovered (spheroid rugulates and irregular smooth morphotypes) come mostly from hearth samples (Fig. 4l, m). Wood/bark phytoliths are least common in uppermost level III, increase in level IV, and reach its maximum in hearth samples QB 22 and 23 from level V (Fig. 3). Finally, fruit phytoliths were identified in the non-hearth-related sediments of samples QB 1 (level III) and QB 25 (level IV) (Figs. 3 and 4n, o, respectively).

Discussion

Postdepositional effects on phytoliths

The results obtained from this study point towards a different pattern of preservation in the site depending firstly on the stratigraphy and secondly on the area where the samples were collected. The good preservation of phytoliths observed in all the samples from square I5, right sagittal profile, for uppermost levels III, IV, and V (Table 1) is in agreement with the

Table 3 List of the morphotypes identified in Abrigo de la Quebrada samples, their attribution to different plants, plant parts and their relative presence in the samples

| Morphodata	Attribution	QB 1	QB 2	QB 13	QB 24	QB 14	QB 15	QB 17	QB 25	QB 16	QB 22	QB 23	QB 26
Bulliform	Grass leaves	–	0.9	–	3.1	0.5	–	0.5	–	1.2	0.6	1.3	–
Sclereid	Dicot leaves	–	–	0.5	–	–	–	–	–	–	–	–	–
Cylindroid	–	6.4	3.7	9.7	15.9	7.7	9.3	4.6	7.8	10.1	3.9	16.9	3.6
Ellipsoid	Dicot wood/bark	0.6	–	–	–	–	0.5	–	–	0.6	0.6	–	–
Epidermal appendage hair	Dicot leaves	0.6	0.5	1.5	–	1.9	1.4	–	1.1	1.2	–	1.3	–
Epidermal appendage papillae	Grass leaves	–	–	–	1.3	–	–	–	–	–	–	–	–
Epidermal appendage prickle	Grass leaves	5.7	9.8	1	5.3	5.8	2.8	5.2	5.6	9.5	2.8	6.5	6.0
Long cell echinate	Grass inflorescences	2.6	3.3	6.2	2.2	1	3.7	6.2	1.7	–	3.9	3.9	2.4
Long cell polylobate	Grass leaves	–	–	–	0.4	–	–	–	–	–	–	–	–
Long cell wavy	Grass leaves	–	–	–	–	0.5	–	–	–	–	–	–	–
Parallelepiped blocky	Dicot wood/bark	–	–	0.5	–	0.5	–	–	–	0.6	0.6	–	–
Parallelepiped elongate	–	7.6	9.8	5.1	6.6	13.5	11.2	17	8.9	10.1	14.6	13	4.8
Parallelepiped thin	Dicot wood/bark	–	–	–	–	–	2.3	–	–	–	0.6	–	–
Short cell rondel	Grasses	48.1	53.5	64.6	55.3	58	54	52.6	55	59.8	57.3	39	68.7
Short cell bilobate	Grasses	2.6	2.3	1.5	2.7	1	2.3	1	2.2	0.6	1.7	–	–
Short cell saddle	Grasses	0.6	–	0.5	–	–	–	–	–	–	–	–	–
Short cell polylobate	Grasses	–	–	6.2	–	–	–	0.5	–	–	0.6	–	–
Short cell cross shape	Grasses	0.6	–	–	–	–	–	–	–	–	–	–	–
Short cell tower	Grasses	5.7	4.7	1.0	1.3	3.4	1.4	1.6	2.8	0.6	0.6	–	2.4
Long trapeziform	Grasses	16.6	9.8	0.5	5.3	5.8	10.2	9.8	13.9	3	9	10.4	8.4
Spheroid echinate	Palms	0.6	–	–	–	–	–	–	–	–	–	–	–
Spheroid rugulate	Dicot woo/bark	–	–	0.5	0.4	0.5	–	0.5	–	–	2.3	–	–
Tracheary elements	Dicot leaves	0.6	–	–	–	–	–	–	–	–	–	–	–
Irregulars	Dicot Wood/bark	–	0.9	–	–	–	0.9	0.5	–	3	1.1	7.8	3.6
Irregular with protuberances	Dicot fruits	0.6	–						0.6				
Indeterminate	Indeterminate	–	–	0.5	–	–	–	–	0.6	–	–	–	–
Multicell Polyhedral	Dicot leaves	–	0.9	–	–	–	–	–	–	–	–	–	–
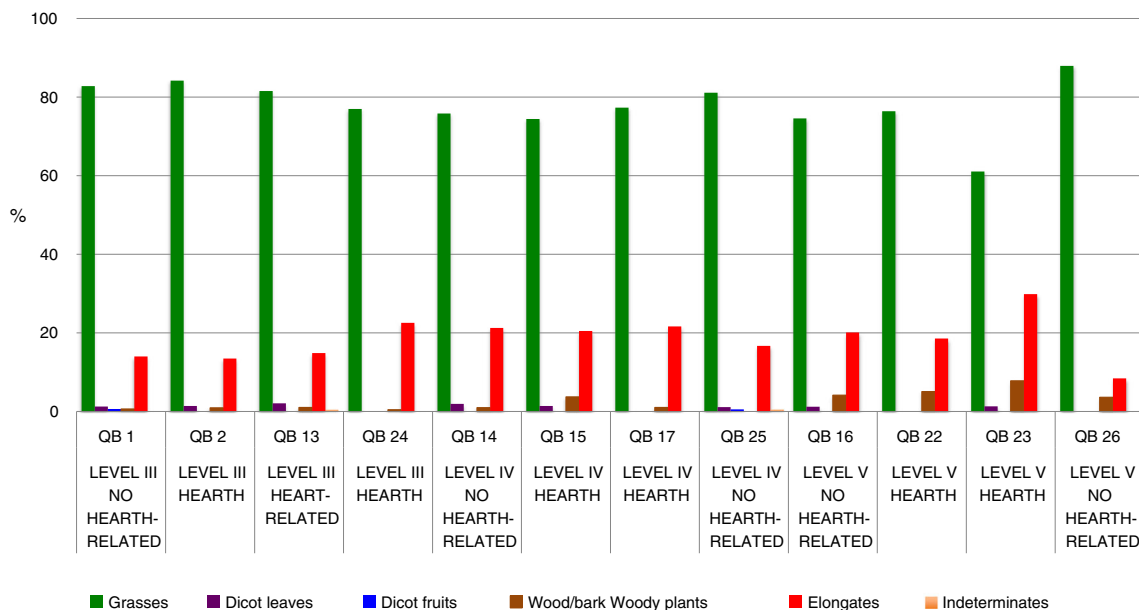
Fig. 3 Histogram showing the distribution, by plant type and plant parts, of the phytolith morphologies present in the Quebrada samples
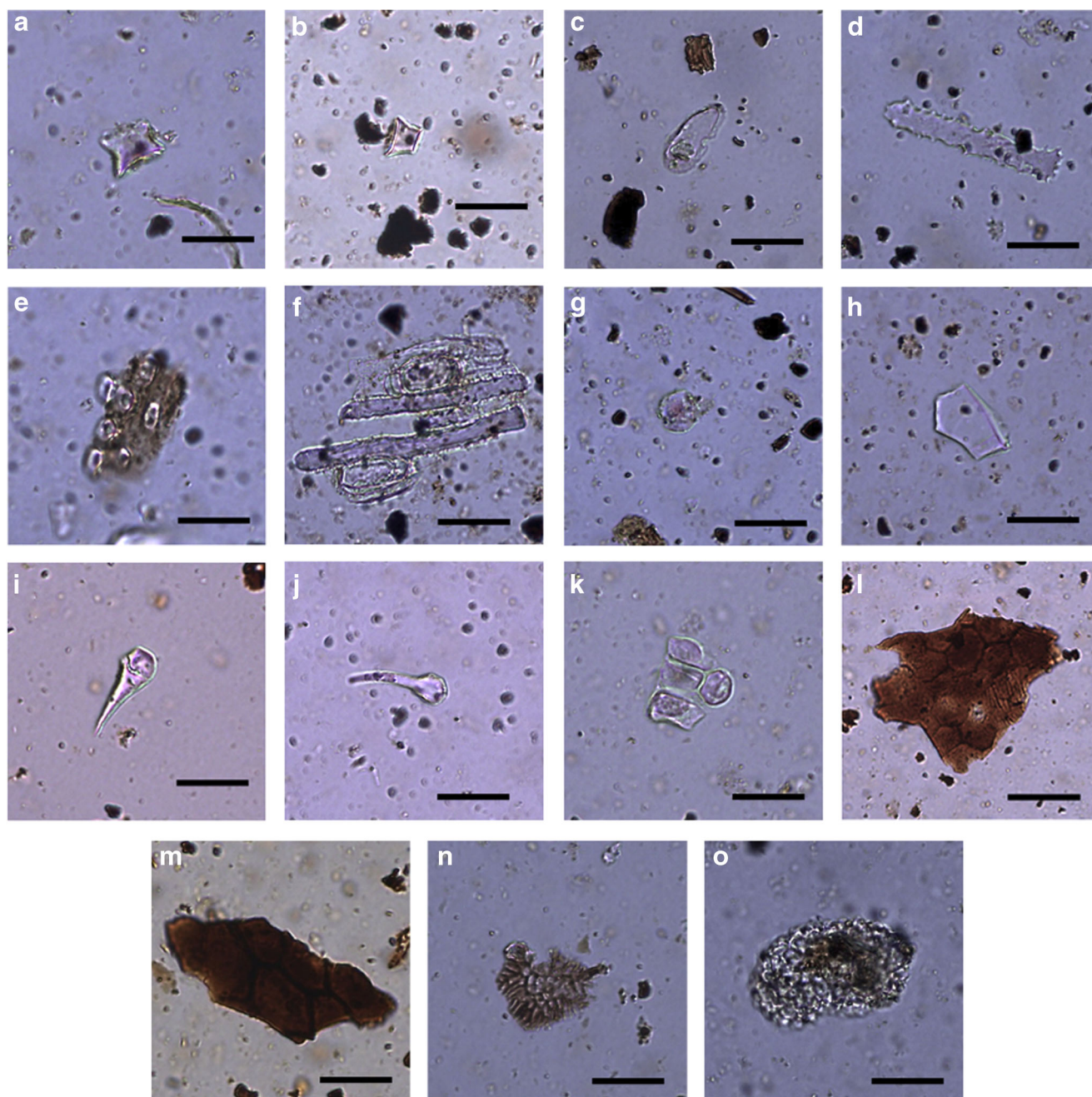
Fig. 4 Microphotographs of phytoliths identified in the Quebrada samples. Pictures taken at ×400. *Black bar* represents 20 μm. *a* Short cell rondel phytolith from the non-hearth-related sample QB 1 (level III); *b* short cell rondel phytolith from the non-hearth-related sample QB 25 (level IV); *c* long trapeziform phytolith from hearth sample QB 23 (level V); *d* long cell echinate phytolith from the hearth sample QB 17 (level IV); *e* interconnected short cell rondel phytoliths from grass epidermis from the hearth sample QB 15 (level IV); *f* Interconnected long cells and epidermal appendage prickle phytoliths from grass epidermis from the hearth sample QB 24 (level III); *g* epidermal appendage hair cell phytolith from the non-hearth-related sample QB 14 (level IV); *h* epidermal appendage hair cell phytolith from the non-hearth-related sample QB 16 (level V); *i* tracheid element from the non-hearth-related sample QB 1 (level III); *j* multicellular structure polyhedral from the hearth sample QB 2 (level III); *k* multicellular structure polyhedral from the hearth sample QB 41 (level VIII); *l* spheroid (*globular*) rugulate phytolith from the hearth sample QB 22 (level V); *m* irregular psilate morphology from the hearth sample QB 23 (level V); *n* fruit phytolith from the non-hearth-related sample QB 1 (level III); *o* fruit phytolith from the non-hearth-related sample QB 25 (level IV)

identification of interconnected cells in samples from hearth sediments. The presence of wood-ash calcite related to high phytolith concentration attests the chemical stability of the sediments (Cabanes et al. 2011; Albert and Marean 2012).

Conversely, the near absence of phytoliths in most of the samples from square K4 and all the samples from the frontal proximal profile, close to the wall of the rock shelter (I3, C3 and G3 squares), is probably related to postdepositional

processes, since there is no evidence for variations in the occupational patterns; variation in the use of plants across the shelter's occupation space cannot therefore be assessed (Table 1; Fig. 2). Furthermore, the micromorphological analysis shows that the frontal proximal profile was the most postdepositionally active area of the site (Bergadà, personal communication). The location of the site in a karstic environment, together with the presence of wood-ash calcite in contact with water, would account for an increase in pH and thus for phytolith dissolution in all the samples from the frontal proximal profile. To date, this area still presents moistures due to the water seeping through cracks and fissures of the wall (Fig. 2).

The karstic environment might also affect the preservation of pyrogenic calcite in all the samples from the frontal proximal profile, which is more disordered than the geogenic form. On the contrary, the presence of geogenic calcite may be due to its deposition in the sediments from saturated solutions of water percolating from the walls (Table 1).

Considering that, according to the charcoal data, vegetation seems to be the same as in the uppermost levels (Badal and Carrión, personal communication), the low presence or absence of phytoliths recorded in levels VII and VIII suggests that such microremains have been dissolved. One exception would be sample QB 41 in level VIII, where the identification of leaf epidermis with polyhedral shape characteristic of dicotyledonous plants suggests a much stable chemical preservation for this sample. In any case, the preservation of wood-ash calcite in level VIII, highly unstable in alkaline environments, suggests that dissolution was not extensive enough to alter calcite and thus should have not totally affected phytoliths. Ongoing micromorphological analysis and further sampling from other areas of level VIII will help to better understand the reasons for the absence of phytoliths in the samples from level VIII analyzed so far.

Anthropogenic/non-anthropogenic input

One of the most relevant aspects when studying phytoliths at archeological sites is to establish whether such plant remains represent an anthropogenic input. At Abrigo de Quebrada, level VI was characterized as sterile. The preliminary results of the micromorphological analysis showed that this level was formed by repetitive low-energy flooding, which impeded the occupation of the site (Bergadà, personal communication). The near absence of phytoliths noted in this level VI, which contrasts with the high phytolith concentration observed in overlying levels III, IV, and V, suggests that plants were closely related to anthropic activities in these upper levels and were brought into the shelter for different purposes. Interestingly, wood-ash calcite was identified through the grinding curve method in some of the samples from level VI (Table 1). For

the time being, it is not possible to draw any conclusions concerning this presence.

The use of plants at Abrigo de la Quebrada

The results obtained show differences in the distribution of the phytolith assemblages from hearth and non-hearth-related sediments. However, the presence of wood-ash calcite in most of the samples, in association with burnt phytoliths (~60 %) and independently of the type of sediment (hearth, hearth-related and non-hearth-related), indicates dispersion of ashes through the site (Tables 1 and 2; Fig. 3). Trampling, cleaning activities, the exposure to the winds, and the palimpsest structure of the site, especially in levels III, IV, and V, might have been the major causes for ash dispersion through the occupation floor. Dispersion of ashes has also been noted in other Middle Paleolithic sites such as Kebara cave in the Eastern Mediterranean region (Albert et al. 2000).

Wood/bark phytoliths have been commonly identified in hearths and hearth contexts from Middle and Upper Paleolithic sites such as Bajondillo, Klissoura cave, Kebara Cave, Grotte XVI, Amud Cave, Esquilleu, and El Salt (Albert 2010; Albert et al. 1999, 2000, 2007; Karkanas et al. 2002; Madella et al. 2002; Cabanes et al. 2010; Mallol et al. 2012). At Quebrada, the charcoal study conducted in levels III and IV shows a predominance of *P. nigra*, *P. sylvestris*, and *Juniperus* sp., with the sporadic presence of *Quercus* sp. and *Rahmnus* (Badal et al. 2012). The preliminary results for levels V and VIII indicate similar spectra (Badal and Carrión, personal communication). The wood/bark phytoliths identified in the Quebrada samples are mostly represented by psilate and rugulate spheroids, blocky parallelepipeds, and smooth irregular morphologies. As the use of wood as fuel in hearths is well documented by the charcoal analyses, the scarcity or absence of woody phytoliths in some of the archeological sediments may be related, in addition to partial dissolution of phytoliths, to the low production of these microremains in living trees rather than to the non-use of wood fuel. The wood of dicotyledonous plants and gymnosperms contains in general fewer phytoliths per unit weight of dry plant material than do the leaves (Albert and Weiner 2001), and the difference is even more significant when phytolith production in these plants as a whole is compared with that of monocotyledonous plants (Albert and Weiner 2001; Tsartsidou et al. 2007).

The identification of hairs and multicellular polyhedral phytolith characteristic of dicotyledonous-leaf plants is consistent with the charcoal results as corresponding to angiosperms (Badal et al. 2012). For example, *Quercus* species produce multicellular structures with polyhedral and tracheid elements similar to those observed in Quebrada samples (Albert and Weiner 2001; Albert and Cabanes 2007). Runge and Runge (1997) have also identified parenchyma cells and

tracheid elements in the leaves of the Eastern African *Rhamnus prinoides*. However, tracheids and sclereids may also be present in some gymnosperms (Klein and Geis 1978). Pine needles and *Juniperus* mainly produce cylindroids (Albert and Weiner 2001; Tsartsidou et al. 2007), tracheid cells, and spiny irregular bodies (Blinnikov et al. 2002; Bozarth 1993; Kerns 2001). Whereas no spiny irregular bodies were recognized in the samples, the abundance of cylindroids in the hearth samples may be partially related to pine needles since this genus is the dominant taxa in the site's charcoal assemblage (Badal et al. 2012). The identification in our hearth samples of dicotyledonous-leaf and probably gymnosperm phytoliths can be explained by the fact that, when collecting the fuel for the fires, the inhabitants of Quebrada would collect fresh wood with the leaves still attached to the branches, to make quick fires while using the site as a shelter. A similar situation was observed in the Middle Paleolithic levels of Hayonim cave, also interpreted as short-term occupations, and where dicotyledonous-leaf phytoliths were abundant (Albert et al. 2003).

Previous studies on modern reference collections from the Mediterranean region showed that grass phytoliths may attach to the bark of trees (~30 %) (Albert and Weiner 2001; Tsartsidou et al. 2007). Hence, the identification of grasses in hearths, may derive, at least partially, from contamination and were introduced into the hearths in association with the wood fuel. This situation was observed in other Middle Paleolithic sites from the Levant such as Kebara, Tabun, and Hayonim caves (Albert 2010; Albert et al. 1999, 2000, 2003, 2012). At Abrigo de Quebrada, the high phytolith concentration as well as the high proportions of grass phytoliths in all the samples (~77 %) is suggestive, in addition to their presence as contamination, of the intentional introduction of grasses into the site. The use of grasses might be related to several purposes, such as to help start or maintain the fire. Other interpretations may be found at Amud cave (Madella et al. 2002), where the authors interpreted the higher presence of grass husk phytoliths as indication of dehusking of grass seeds through their drying in hearths or other seed processing, and thus as being derived from grass consumption. Similar interpretations can also be found in Shanidar (Henry et al. 2011) and much recently in Theopetra cave (Tsartsidou et al. 2014). At Quebrada, although there do seem to be a slightly higher presence of husk phytoliths in the hearth and hearth-related sediments, this difference is not enough to be interpreted as derived from grass consumption. The abundance of grasses in the non-hearth-related sediments might be related to the dispersion of ashes, as suggested by the FTIR results; alternatively, it may represent bedding accidentally or intentionally fired for site cleaning purposes, as previously suggested for Grotte XVI (France) by Karkanas et al. (2002).

Seasonality and climate

The phytolith results show a high percentage of grass inflorescences in all the samples analyzed (~20 %) (Table 3). Grasses in the western Mediterranean area bloom from June to October. Thus, the identification of this part of the plants in the studied sediments might imply some degree of seasonality (summer - autumn), meaning that the site was occupied during the warmer/temperate months of the year. This is consistent with the faunal studies of Level IV based on the analysis of dental remains (Sanchis Serra et al. 2013).

Short cell rondels, which dominate in most samples, are commonly identified in the C_3 Pooideae subfamily (Twiss et al. 1969; Twiss 1992). However, Bamford et al. (2006) and Barboni and Bremond (2009) observed that rondels are also found in C_4 chloridoid grasses associated to the saddle short cell type. Barboni and Bremond (2009) observed as well that long trapeziforms morphotypes were only associated to the C_3 pooids. Based on the very low number of saddles (C_4 chloridoid grasses) and the high presence of long trapeziforms and towers, we relate the rondel type to the C_3 Pooideae grass subfamily. C3 grasses occur predominantly in Northern Hemisphere's cold climates. The dominance of C3 pooid grass phytoliths together with the wood species identified in the charcoal analyses (*P. nigra-sylvestris* and also *Juniperus* spp.) (Badal et al. 2012) suggest a semi-open habitat characteristic of supramediterranean vegetation implying colder conditions than today. This is consistent with the chronological results, which date the occupation of the levels II–V to MIS4 (Villaverde et al. 2008; Eixea et al. 2011a, b, 2012). Cold environmental conditions during this period have also been observed in other Middle Paleolithic sites from the Mediterranean Coast of the Iberian Peninsula such as Riera dels Canyars (e.g., Daura et al. 2013 and references therein). At Cueva Antón, Cueva Foradada, Las Fuentes de Navarrés, and El Salt, the results show the presence of *P. nigra* suggesting an open, steppic landscape with scattered stands of mountain pine (Aparicio 1981; Badal 1984; Badal et al. 2012).

Conclusions

Our results indicate variable, intra-site phytolith preservation conditions, depending firstly on the stratigraphy and secondly on the area where the samples were collected. Whereas most of the uppermost samples yielded phytoliths in high numbers, phytoliths were scarce in the lowermost levels. The differences in phytolith presence between anthropic and non-anthropic levels indicate that Neanderthal populations brought plants into the shelter for various purposes, mostly related to fire production. All the anthropic levels were dominated by grass phytoliths, while wood phytoliths were identified in much lower numbers, probably due to the fact that this part

of the plant produces fewer phytoliths; in some samples, dissolution processes must also be part of the explanation. The use of grasses in the shelter may be related to the set up of fires, to obtain different combustion properties, or to uses other than fire making; at least in part, some of the grasses may well be incidental inputs, as they could have been brought in attached to the bark of the tree branches used as fuel. The identification of wood-ash calcite in non-hearth-related samples, together with the phytoliths' refractive index analyses, suggest that ashes were dispersed throughout the uppermost levels' occupation floors, probably as a result of trampling and cleaning activities. The shelter would have been occupied through spring to autumn, in an environment dominated by semi-open habitats.

References

Albert RM (2007) Identificación de restos vegetales en las capas de cenizas de Cueva Bajondillo (Torremolinos, Málaga): Los estudios de fitolitos. Chapter XIV, Cueva Bajondillo (Torremolinos). Secuencia cronocultural y paleoambiental del Cuaternario reciente en la Bahía de Málaga, CEDMA (Servicio de Publicaciones del Centro de Ediciones de la Diputación de Málaga), Málaga, pp 451–460

Albert RM (2010) Hearths and plant uses during the Upper Paleolithic Period at Klissoura cave 1 (Greece): the results from phytolith analyses. Monograph of Klissoura Cave. Eurasian Prehistory 7(2):71–85

Albert RM, Cabanes D (2007) Fire in prehistory: an experimental approach to combustion processes and phytolith remains. Isr J Earth Sci 56:175–189

Albert RM, Marean CW (2012) The exploitation of plant resources by early *Homo sapiens*: the phytolith record from Pinnacle Point 13B Cave, South Africa. Geoarchaeol 27:363–384

Albert RM, Weiner S (2001) Study of phytoliths in prehistoric ash layers using a quantitative approach. In: Meunier JD, Coline F (eds) Phytoliths: applications in Earth sciences and human history. A.A. Balkema Publishers, Lisse, pp 251–266

Albert RM, Tsatskin A, Ronen A, Lavi O, Estroff L, Lev-Yadun S, Weiner S (1999) Mode of occupation of Tabun Cave, Mt Carmel Israel during the Mousterian period: a study of the sediments and the phytoliths. J Archaeol Sci 26:1249–1260

Albert RM, Weiner S, Bar-Yosef O, Meignen L (2000) Phytoliths in the Middle Palaeolithic deposits of Kebara Cave, Mt Carmel, Israel: study of the plant materials used for fuel and other purposes. J Archaeol Sci 27:931–947

Albert RM, Bar-Yosef O, Meignen L, Weiner S (2003) Phytolith and mineralogical study of hearths from the Middle Palaeolithic levels of Hayonim Cave (Galilee, Israel). J Archaeol Sci 30:461–480

Albert RM, Esteve X, Portillo M, Rodríguez-Cintas A, Cabanes D Esteban I, Hernández F (2011). Phytolith CoRe, Phytolith Reference Collection. Retrieved Nov 11, 14, from: http://www.phytcore.org

Allué E, Cabanes D, Solé A, Sala R (2012) Hearth functioning and forest resource exploitation based on the archaeobotanical assemblage from level J, In: Carbonell i Roura E (ed) High resolution archaeology and Neanderthal behavior. Time and space in level J of Abric Romaní (Capellades, Spain). Vertebrate Paleobiology and Paleoanthropology Series, Springer, pp 373–385

Aparicio J (1981) Primeras dataciones C14 para el musteriense valenciano. Archivo de Prehistoria Levantina 16:2–38

Arsuaga JL, Baquedano E, Pérez-González A (2006) Neanderthal and carnivores occupations in Pinilla del Valle sites (Community of Madrid). Proceeding of XV Congrés Union International des Sciences Prehistoriques et Protohistoriques UISPP, Lisbon

Arsuaga JL, Fernández Peris J, Gracia-Téllez A, Quam R, Carretero JM, Barciela González V, Blasco R, Cuartero F, Sañuso P (2012) Fossil human remains from Bolomor Cave (Valencia, Spain). J Hum Evol 62(5):629–639

Badal E (1984) Contribución al estudio de la vegetación prehistórica del sur de Valencia y Norte de Alicante a través del análisis antracológico. University of Valencia, Master thesis,

Badal E, Villaverde V, Zilhão J (2012) Middle Paleolithic wood charcoal from three southern Iberian sites: biogeographic implications. Wood and charcoal. Evidence for human and natural history. Saguntum Extra 13:13–24

Bamford MK, Albert RM, Cabanes D (2006) Assessment of the lowermost bed II Plio-Pleistocene vegetation in the eastern palaeolake margin of Olduvai Gorge (Tanzania) and preliminary results from fossil macroplant and phytolith remains. Quatern Int 148:95–112

Barboni D, Bremond L (2009) Phytoliths of East African grasses: an assessment of their environmental and taxonomic significance based on floristic data. Rev Palaeobot Palynol 158(1–2):29–41

Berlin AM, Ball T, Thompson R, Herbert SC (2003) Ptolemaic agriculture. 'Syrian wheat' and Triticum aestivum. J Archaeol Sci 30: 115–121

Blasco R (2008) Human consumption of tortoises at level IV of Bolomor Cave (Valencia, Spain). J Archaeol Sci 35(10):2839–2848

Blasco R, Fernández Peris J (2009) Middle Pleistocene bird consumption at level XI of Bolomor Cave (Valencia, Spain). J Archaeol Sci 36(10):2213–2223

Blasco R, Fernández Peris J (2012) A uniquely broad spectrum diet during the Middle Pleistocene at Bolomor Cave (Valencia, Spain). Quatern Int 252:16–31

Blinnikov M, Busacca A, Whitlock C (2002) Reconstruction of the Late Pleistocene Columbia basin grassland, Washington, USA, based on phytolith records in Loess. Palaeogeogr Palaeoclimatol Palaeoecol 177:77–101

Bozarth SR (1992) Classification of opal phytoliths formed in selected dicotyledons native to the Great Plains. In: Rapp Jr G, Mulholland SC (eds) Phytolith systematics. Emerging Issues, Advances in Archaeological and Museum Science. Plenum Press, New York, pp. 193–214

Bozarth SR (1993) Biosilicate assemblages of boreal forests and aspen parklands. In: Pearsall DM, Piperno DR (eds) Current research in phytolith analysis: applications in archaeology and paleoecology. University of Pennsylvania, Philadelphia, PA, MASCA Research Papers in Science and Archaeology, pp. 95–105

Burch ES, Ellanna LJ (eds) (1994) Key issues in hunter-gatherer research. Berg Publicers, Oxford

Cabanes D, Allué E, Vallverdú J, Cáceres I, Vaquero M, Pastó I (2007) Hearth structure and function at level J (50 kyr, BP) from Abric Romaní (Capellades, Spain): phytoliths, charcoal, bones and stone-tools. In: Madella M, Zurro D (eds) Plant, people and places—recent studies in phytolith analysis. Oxbow Books, Oxford, pp. 98–106

Cabanes D, Mallol C, Expósito I, Baena J (2010) Phytolith evidence for hearths and beds in the Late Mousterian occupations of Esquilleu Cave (Cantabria, Spain). J Archaeol Sci 39:2697–2705

Cabanes D, Weiner S, Shahack-Gross R (2011) Stability of phytoliths in the archaeological record: a dissolution study of modern and fossil phytoliths. J Archaeol Sci 38(9):2480–2490

Couplan F (1983) In: Encyclopedie des Plantes Comestibles de l'Europe, In: La Cuisine Sauvage: Comment Accommoder Mille Plantes Oubliés, vol 2. Debard, Paris

Daura J, Sanz M, García N, Allué E, Vaquero M, Fierro E, Carrión JS, López-García JM, Blain HA, Sánchez-Marco A, Valls C, Albert RM, Fornós JJ, Julià R, Fullola JM, Zilhão J (2013) Terrasses de la Riera dels Canyars (Gavà, Barcelona): the landscape of Heinrich stadial 4 north of the "Ebro frontier" and implications for modern human dispersal into Iberia. Quat Sci Rev 60:26–48

Eixea A, Villaverde V, Zilhão J (2011a) Aproximación al aprovisionamiento de materias primas líticas en el yacimiento del Paleolítico medio del Abrigo de la Quebrada (Chelva, Valencia). Trab Prehist 68:65–78

Eixea A, Villaverde V, Zilhão J, Sanchis A, Morales J, Real C, Bergadà M (2011b) El nivel IV del Abrigo de la Quebrada (Chelva, Valencia). Análisis microespacial y valoración del uso del espacio en los yacimientos del Paleolítico medio valenciano Mainake XXXIII: 127–158

Eixea A, Villaverde V, Zilhão J, Bergadà, M, Sanchis A, Morales J, Real C, Martínez JA (2012) Variation in the use of space through time at Abrigo de la Quebrada (Chelva, Valencia). The case of Middle Paleolithic levels IV and VII, In: García A, García J, Maximiano A, Rios J (eds.) Debating spatial archaeology: International workshop on landscape and spatial analysis in archaeology. Santander: 153–166.

Eixea A, Villaverde V, Roldán C, Zilhão J (2014) Middle Palaeolithic flint procurement in central Mediterranean Iberia: implications for human mobility. J Lithic Stud 1(1):103–115

Elbaum R, Weiner S, Albert RM, Elbaum M (2003) Detection of burning of plant materials in the archaeological record by changes in the refractive indices of siliceous phytoliths. J Archaeol Sci 30:217–226

Fernández Peris J, Villaverde V (2001) El Paleolítico Medio: el tiempo de los Neandertales. Periodización y características. In: Villaverde V (ed) De neandertales a cromañones. El inicio del poblamiento humano en las tierras valencianas. Universidad de Valencia, Valencia, pp. 147–176

Fox CL, Juan J, Albert RM (1996) Phytolith analysis on dental calculus, enamel surface, and burial soil: information about diet and paleoenvironment. Am J Phys Anthropol 101(1):101–113

Fraysse F, Pokrovsky OS, Schott J, Meunier JD (2006) Surface properties, solubility and dissolution kinetics of bamboo phytoliths. Geochim Cosmochim Acta 70:1939–1951

Fredlund GG, Tieszen LT (1994) Modern phytolith assemblages from the North American great plains. J Biogeogr 21:321–335

Henry AG, Brooks AS, Piperno DR (2011) Microfossils in calculus demonstrate consumption of plants and cooked foods in Neanderthal diets (Shanidar III, Iraq; spy I and II, Belgium). Proc Natl Acad Sci U S A 108:486–491

Jochim MA (1976) Hunter-gatherer subsistence and settlement: a predictive model. Academic Press, New York

Karkanas P, Rigaud JP, Simek JF, Albert RM, Weiner S (2002) Ash, bones and guano: a study of the minerals in the sediments of Grotte XVI (Dordogne, France). J Archaeol Sci 29(7):721–732

Katz O, Cabanes D, Weiner S, Maeir A, Boaretto E, Shahack-Gross R (2010) Rapid phytolith extraction for analysis of phytolith concentrations and assemblages during an excavation: an application at Tell es-Safi/Gath, Israel. J Archaeol Sci 37(7):1557–1563

Kerns B (2001) Diagnostic phytoliths for a ponderosa pine-bunchgrass community near Flagstaff, Arizona. Southwest Nat 46:282–294

Klasen N (2015) OSL dating of sediment samples from Spain by order of SFB 806, subproject C1 (series Quebrada). Unpublished report

Klein RL, Geis JW (1978) Biogenetic opal in the Pinaceae. Soil Sci 126: 145–156

Madella M, Jones MK, Goldberg P, Goren Y, Hovers E (2002) The exploitation of plant resources in Amud Cave (Israel): the evidence from phytolith studies. J Archaeol Sci 29:703–719

Madella M, Alexandre A, Ball TB (2005) International code for phytolith nomenclature 1.0. Ann Bot 96:253–260

Mallol C, Hernández CM, Cabanes D, Sistiaga A, Machado J, Rodríguez A, Pérez L, Galván B (2013) The black layer of Middle Palaeolithic combustion structures. Interpretation and archaeostratigraphic implications. J Archaeol Sci 40(5):2515–2253

Mulholland SC, Rapp C Jr (1992) A morphological classification of grass silica-bodies, In: Rapp Jr G, Mulholland CS (eds) Phytolith systematics. Emerging Issues, Advances in Archaeological and Museum Science. Plenum Press, New York, pp 65–89

Ollendorf AL (1992) Toward a classification scheme of sedge (Cyperaceae) phytoliths. In: Rapp Jr G, Mulholland SC (eds) Phytolith systematics. Emerging Issues, Advances in Archaeological and Museum Science. Plenum Press, New York, pp. 91–111

Piperno DR (1988) Phytolith analysis: an archaeological and geological perspective. Academic Press, San Diego

Piperno DR (2006) Phytoliths: a comprehensive guide for archaeologists and paleoecologists. AltaMira Press, Lanham, MD

Regev L, Poduska KM, Addadi L, Weiner S, Boaretto E (2010) Distinguishing between calcites formed by different mechanisms using infrared spectrometry: archaeological applications. J Archaeol Sci 37:3022–3029

Rosen AM (1992) Preliminary identification of silica skeletons from near Eastern archaeological sites: an anatomical approach. In: Rapp Jr G, Mulholland SC (eds) Phytolith systematics. Emerging Issues, Advances in Archaeological and Museum Science. Plenum Press, New York, pp. 193–214

Rosen AM (2003) Middle palaeolithic plant exploitation: the microbotanical evidence. In: Henry DO (ed) Neanderthals in the Levant. Behavioral organization and the beginnings of human modernity. Continuum, London, pp. 156–171

Runge F, Runge J (1997) Opal phytoliths in East African plant and soils. In: Pinilla A, Juan-Tresserras J, Machado MJ (eds) The state of the art of phytoliths in plant and soils. CCMA-CSIC, Madrid, pp. 72–81

Salazar-García DC, Power RC, Sanchis Serra A, Villaverde V, Walkere MJ, Henry AG (2013) Neanderthal diets in central and southeastern Mediterranean Iberia. Quatern Int 318:3–18

Sanchis Serra A, Morales Pérez JV, Real Margalef C, Eixea A, Zilhão J, Villaverde V (2013) Los conjuntos faunísticos del Paleolítico medio del Abrigo de la Quebrada (Chelva, Valencia): Problemática del estudio, metodología aplicada y síntesis de los primeros resultados. Animals i Arqueologia Hui 65

Tappan H (1980) The paleobiology of plant protists. W. H, Freeman and Company, San Francisco, CA

Tormo C, Guillem-Calatayud PM (2015) Los micromamíferos del yacimiento del Paleolítico medio del Abrigo de la Quebrada (Chelva, Valencia): niveles I-VIII. In: Pascual JL (ed) Sanchis A. Preses petites I grups humans en el Passat, Museu de Prehistòria de València, pp. 181–208

Tsartsidou G, Lev-Yadun S, Albert RM, Miller-Rosen A, Efstratiou N, Weiner S (2007) The phytolith archaeological record: strengths and weaknesses evaluated based on a quantitative modern reference collection from Greece. J Archaeol Sci 34(8):1262–1275

Twiss PC (1992) Predicted world distribution of C3 and C4 grass phytoliths. In: Rapp Jr G, Mulholland SC (eds) Phytolith systematics: emerging issues. Advances in Archaeological and Museum Science. Plenum Press, New York, pp. 113–128

Twiss PC, Suess E, Smith RM (1969) Morphological classification of grass phytoliths. Soil Sci Soc Am J 33:109–115

Villaverde V, Aura JE, Barton CM (1998) The Upper Paleolithic in Mediterranean Spain: a review of current evidence. J World Prehist 12:121–198

Villaverde V, Eixea A, Zilhão J (2008) Aproximación a la industria lítica del Abrigo de la Quebrada (Chelva, Valencia). Treballs d'Arqueologia 14:213–228

Villaverde V, Eixea A, Rios J, Zilhão J (2012) Importancia y valoración de la producción microlevallois en los niveles II y III del Abrigo de la Quebrada (Chelva, Valencia). Zephyrus LXX:13–32

Wadley L, Sievers C, Bamford M, Goldberg P, Berna F, Miller C (2011) Middle Stone age bedding construction and settlement patterns at Sibudu, South Africa. Science 334:1388–1391

Winterhalder B, Smith EA (1981) Hunter-gatherer foraging strategies. University of Chicago Press, Chicago