Formation processes through archaeobotanical remains: The case of the Bronze Age levels in El Mirador cave, Sierra de Atapuerca, Spain

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Abstract

El Mirador site has a sequence formed by burnt dung resulting from pastoral activities during the Bronze Age and the Neolithic period. Because there is a high sediment variation in the profile, facies descriptions were used to guide the archaeologists in their work. Paleobotanical and mineralogical analyses were used to describe and understand the formation of the facies from the MIR 4 level. Furthermore, the paleobotanical results serve to reconstruct the landscape in Atapuerca during the Bronze Age.

Most seeds recovered are from Triticum aestivum/durum, but other cereals and also Leguminoseae and fruits have been identified. Charcoal analysis has yielded mainly deciduous and evergreen Quercus. Pollen analysis has revealed a low arboreal cover, with Pinus, Quercus and riverside trees. Most of the pollen record corresponds to herbs, such as Poaceae and Asteraceae. All these results indicate a mosaic of different biota with forest, pastureland and cultivated fields near the site.

Most of the phytoliths come from the leaves and stems of festucoid grasses. However, there are some differences in the phytolith type and number, the amount of faecal spherulites, the mineralogical composition and the percentage of multicellular structures that indicate that not all the facies in the site have been formed in the same way. Thus, the work carried out has demonstrated that some facies are related more to agricultural activities than to pastoralism activities, and that other facies have been affected by incipient diagenetic processes.

1. Introduction

During the Neolithic and the Bronze Age, caves were frequently used as pens in the European Mediterranean area (Brochier et al., 1992; Boschian, 1997; Macphail et al., 1997; Bergadà, 1998; Badal, 1999; Boschian and Montagnari-Kokelj, 2000; Alday et al., 2003; Karkanas, 2006; Thiébault, 2006). Frequently these caves contain stratigraphic sequences formed by alternating burnt dung layers, called fumiers (French) and "burnt layers" in English, and non-burnt dung layers. The objective of burning the dung was to eliminate the parasites existing in the cave due to livestock penning, or to reduce the volume of accumulated dung (Brochier et al., 1992). As a consequence of these periodic burning events, the texture and the color variability of the sediment forming the Holocene infilling of the cave increase dramatically. This is probably because not all the sediment-dung of the cave has suffered the same combustion intensity, or even because some sediments and dung have not been burned. In addition, the existence of phosphates in the fresh dung and the liquid waste increases diagenesis of the previously deposited and burned sediments (Macphail et al., 1997; Shahack-Gross et al., 2003; Karkanas, 2006).

This is the case in the El Mirador cave site in the Iberian Peninsula. The cave is located on the southern slope of the Sierra de Atapuerca, near Burgos (Fig. 1), and forms part of the karstic system of the Sierra, which has reported sites with human occupations from the Lower Pleistocene to the present (Rodríguez et al., 2001). In the Mirador site a test pit of 6 m2 has been investigated since 1999. The aim of the test pit was to collect archaeological and paleoenvironmental data to construct the reference sequence for the site. The test has allowed description of a sequence that extends from the Late Upper Pleistocene to the Holocene. The uppermost layers of the sequence, MIR 3A and MIR 4, correspond to the Late and Middle Bronze Age, respectively, and the MIR 6 layer downwards the layers were formed during the Neolithic period. The MIR 5 layer represents an abandonment phase of the site. From the MIR 50 layer downwards the sequence enters in the Pleistocene and the origin of the sediments changes.

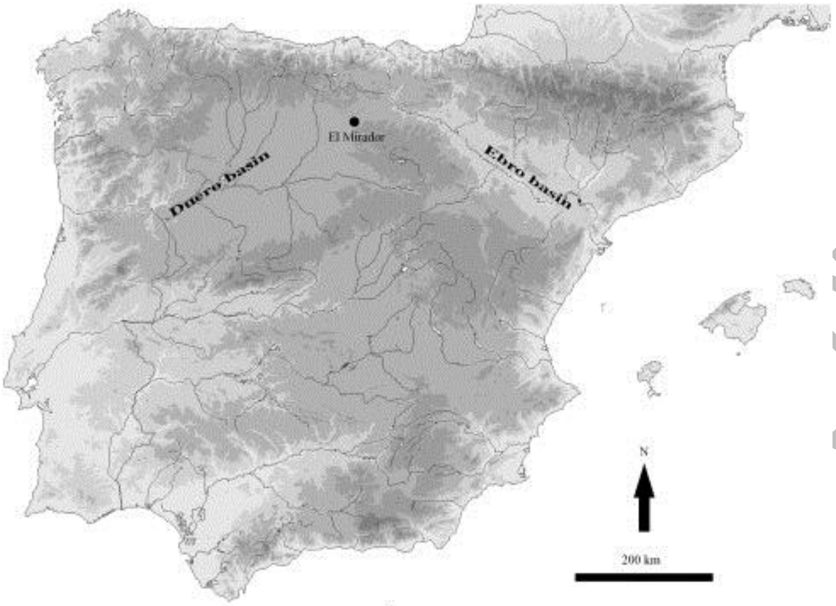

Figure 1. Map showing the location of the site and the main river basins in the north of the Iberian Peninsula

The purpose of this work is to characterize the facies identified in the MIR 4 level through the archaeobotanical remains, mainly phytoliths, but also through the pollen, charcoal and seeds, and through the bulk mineral composition of the samples. In addition, the aim of the investigation is to better understand the formation processes and diagenesis of the site and to reconstruct the landscape and human activities in the Sierra de Atapuerca during the Bronze Age.

2. MIR 4 level: archaeological remains and facies identified

The MIR 4 level has been dated using 14C AMS on two wood charcoals from evergreen Quercus sp., one from the base and the other from the top of the level (Table 1) (Vergès et al., 2002). A secondary burial of six individuals has been recovered at this level. The human remains reveal evidence relating to gastronomic cannibalism (Cáceres et al., 2007).

Table 1. Results for the dated charcoal with C14 AMS in the level MIR 4

Archaeological level	Material	Taxon	Laboratory number	Measured Radiocarbon Age	Conventional Radiocarbon Age	2 Sigma calibrated result BP	2 Sigma calibrated result BC	13C/12C ratio

MIR 4 (top level)	Charcoal	*Quercus* sp. (evergreen)	Beta-154894	3020±40	3040±40	3350–3140	1400–1190	−23.9‰
MIR 4 (base level)	Charcoal	*Quercus* sp. (deciduous)	Beta-153366	3380±40	3400±40	3720–3560	1760–1610	−23.8‰

The faunal remains principally correspond to domestic animals. The most common species are sheep and goat, but cattle, pigs, and to a lesser degree, horses and dogs are present. Five percent of the total faunal remains recovered correspond to non-domestic animals, namely rabbits, deer and wild boars. Most of this faunal spectrum relates to pastoralism (Vergès et al., 2002). The stone tools are scarce and the main raw material used was flint. Quartzite and limestone cobbles, correlated with hammerstones, pestles and anvils were found in the MIR 4 level. The retouched tools are mainly denticulate, and some of them are associated with sickle elements.

The pottery is scarce and has a high degree of fragmentation. They are simple forms, with decorations that indicate relationships with the Ebro and Duero basins. In addition, there is a small amount of excised decorated pottery linked to the Duffaits group from central western France (Moral et al., 2003). The MIR 3A level has yielded a small bronze axe of the original French Medocaine style (Vergès et al., 2002). The archaeological remains for the MIR 4 level indicate trans-Pyrenean contacts and also the strategic position of the site between the two main basins of northern Spain (Fig. 1).

Because of the previously mentioned formation conditions, in the course of the excavation of El Mirador site, "facies" description was used to differentiate the variation in the sediments of the same archaeological layer. This procedure was applied in all the archaeological layers to identify a described type of sediment. The facies are recurrent in all the sequence and can appear more than once in the same layer (Fig. 2). These facies forms rhythmic sequences, normally discontinuous and with abrupt limits, and they are organized horizontally or with a slight inclination to the N or W of the cave. Table 2 presents the description of the facies used by the archaeologists in the field.

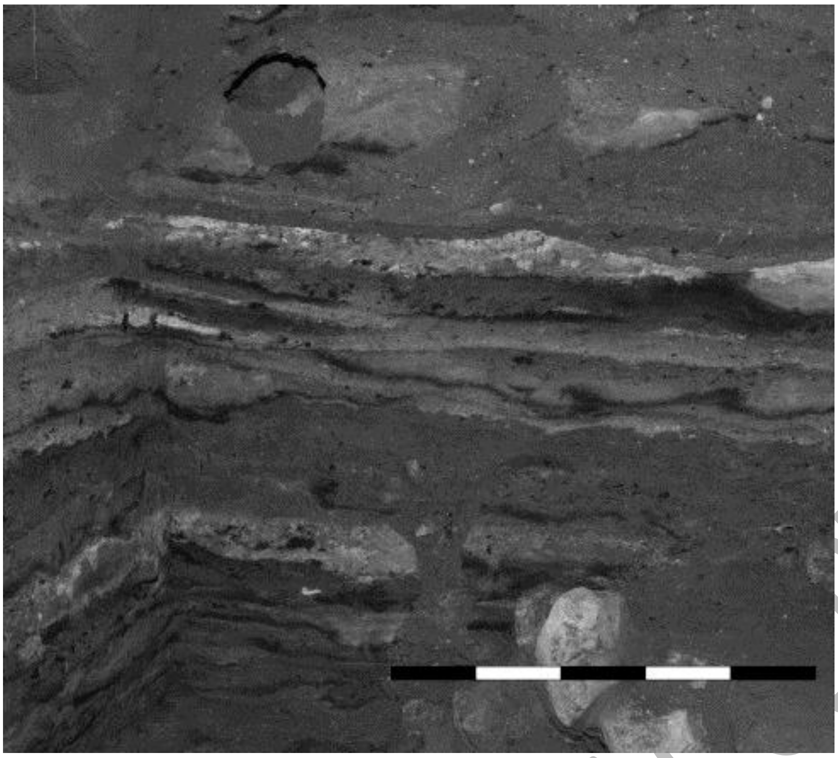

Figure 2. Picture showing the south profile of El Mirador site. The picture shows the variability of the facies from the level MIR 4 to the level MIR 11. The scale is 50 cm.

Table 2. Description of the facies used by the archaeologist during the fieldwork

Facies name	**Facies description**
facies *a*	Pale yellow silty clay, with variable amount of rock fragments (limestone fragments, subangular and heterometric). It has an elevated porosity, with a high presence of organic material and common biological activity. It contains dispersed ashes and microcharcoals between the matrix. It is the most common *facies* and the other *facies* appear between this *facies*
facies *b*	Ashes (practically pure), silty appearance, white in color, with charcoals of variable size, massive and occasionally with thin laminations. It can contain small and dispersed yellow stains. It is a product of combustion in an oxidizing environment, substantially in situ
facies *bg*	Ashes with features between the *facies b* and *facies g*. Result of combustion in an oxidizing environment, substantially in situ
facies *c*	Accumulations of vegetal charcoal fragments of variable size (millimetrics to centimetrics). Result of combustion in situ in a reducing environment

facies *d*	Black organic material with a clotted structure, formed by moderately decomposed animal dung (coprolites), sometimes joined to each other
facies *f*	Thin ash lenses, white or very pale grey in color, with vegetal fibre structures. It displays a sub-horizontal inclination and a sub-perpendicular pattern. It is the product of the oxidizing combustion of vegetal material on the surface
facies *g*	Silt sediment, pale grey, massive with abundant dispersed ash in the matrix. Result of oxidizing combustion, mainly in situ
facies *i*	Greenish silt with abundant dispersed ashes
facies *m*	Pale brown ash accumulations, compact (sometimes granular), with poor resistance. It contains millimetric charcoals and fragments of reddened sediment dispersed in the matrix. It is the product of combustion in situ and the accumulation of successive combustion residues
facies *o*	Organic material accumulations, black and homogeneous, without structure or recognizable excrement to the naked eye
-r	Any of the former *facies* but with evidence of reddening caused by thermal alteration

3. Materials and methods

All the sediment extracted from the MIR 4 level was washed and floated using a flotation machine, to recover the seeds and charcoal. The volume floated was almost 2000 l (Table 3, Table 4). For charcoal analyses a fraction of 4 mm was used. For the carpological analyses the entire residue was studied. Facies differentiation was not used during this procedure, but the samples were separated by depth at 10 cm intervals.

Table 3. Taxa identified through the charcoal analysis in the MIR4 level

Depth (cm)	**1190–1200**	**1200–1210**	**1210–1220**	**1220–1230**	**1230–1240**	**1240–1250**	**1250–1260**	**1260–1270**	**1270–1280**	**Total**	**%**
Volume floated (l)	**103.5**	**226**	**127**	**213.9**	**174**	**218**	**278**	**234.5**	**303**	**1877.9**	
Cornus		1							1	2	0.18
Corylus avellana		3	1		3	3	2		2	14	1.25
Fagus sylvatica									2	2	0.18
Fraxinus			2	4	4	3	5	3	2	23	2.06
Hedera			1							1	0.09
Fabaceae				1	2	2		1	1	7	0.63
Lonicera								1		1	0.09
Maloideae		5	6	5	2	2	11	3	2	36	3.22
Pinus sylvestris type		1	2		1		1	1		6	0.54
Prunus				1	1	1	8	1		12	1.07
Quercus		1	1	5	5	2	3	1	2	20	1.79
Quercus sp. deciduous	14	90	81	62	91	115	60	56	57	626	55.99
Quercus sp. evergreen	15	33	18	23	29	26	51	51	55	301	26.92
Rhamnus			1							1	0.09
Salix		3							1	4	0.36
Sambucus		2	4	3	11	4	1	1		26	2.33
cf. *Betula*		1								1	0.09
cf. *Hedera*	1									1	0.09
cf. *Prunus*			1	1				1		3	0.27

cf. Maloideae			1		1					2	0.18
cf. *Sambucus*		1	1							2	0.18
Undeterminated		1	2	5		1		1	2	12	1.07
Undetermined		2	3		2	2	3	3		15	1.34
Total	30	144	125	110	152	161	145	124	127	1118	100

Table 4. Results of the seed analysis showing the main crops and weeds identified in the MIR 4 level

Depth (cm)	**1170–1180**	**1180–1190**	**1190–1200**	**1200–1210**	**1210–1220**	**1220–1230**	**1230–1240**	**1240–1250**	**1250–1260**	**1260–1270**	**1270–1280**	**1280–90**	**Total**	**%**
Volume floated (l)	**10.7**	**17**	**103.5**	**226**	**127**	**213.9**	**174**	**218**	**278**	**234.5**	**303**	**94**	**1999.6**	
Crops														
Hordeum vulgare nudum			4	4	14	12	3	2	11	9	12		71	2.77
Pisum sativum		1	1	2		6	7	8	4		3	2	34	1.33
Triticum aestivum/durum	3	6	28	50	85	119	95	186	132	291	263	81	1339	52.20
Triticum dicoccum		2	10	13	26	23	41	65	32	85	96	17	410	15.98
spikelet forks cf. *T. dicoccum*										1	1		2	0.08
Triticum sp.				7	4	11	17	16	21	10	5		91	3.55
Total crops	3	9	43	76	129	171	163	277	200	396	380	100	1947	75.91
Weeds														
Avena sp.			3			2	1	1	1	1	1		10	0.39
Bromus sp.					2	4	8	7	2	5	6	1	35	1.36
Carex sp.		3	2		4	6	9	13	7	8	8	6	66	2.57

Chenopodium album							5	1	1		3		10	0.39
Chenopodium sp.					1	2		5	2	3	2		15	0.58
Galium aparine		1	3	1	4	5	4	10	6	7	9		50	1.95
Malva sp.		1	1	2	6	2	2	3	4	7	4		32	1.25
Medicago sp.		1			4	3	4	5		4		2	23	0.90
Melilotus sp.			1	2	4	6	3	1	5	9	7		38	1.48
Polygonum convolvulus		1	1				1	3		4	1		11	0.43
Polygonum sp.					3	4	6	1	2	1			17	0.66
Trifolium sp.			3	15	29	47	22	54	23	34	27	36	290	11.31
Vicia sp.					3	2	5	4	1	2	1	3	21	0.82
Total weeds	0	7	14	20	60	83	70	108	54	85	69	48	618	24.09
TOTAL	3	16	57	96	189	254	233	385	254	481	449	148	2565	100

Taula 1. Results of the seed analysis showing the main crops and weeds identified in the MIR 4 level

For charcoal identification the remains were fragmented by hand in order to obtain three wood anatomy sections, which makes it possible to describe the cell structure. Charcoal fragments were observed through a metallographic microscope with reflected light (Olympus BX-41) with dark and light fields, using ×50, ×200, and ×500 magnifications. Identification was supported with a reference collection and various wood anatomy atlases (Schweingruber, 1990; Hather, 2000). Seeds were observed with a CETI Steddy-T binocular microscope, at ×10 and ×40 magnifications. The identification was supported with a reference collection and seed identification atlases (Bertsch, 1941; Beijerinck, 1947; Villarías, 2000).

For the pollen and phytolith analyses, samples were extracted from the different facies that forms the MIR4 level (Table 2). Facies b was sampled in duplicate for comparison between the same facies in different spots (samples 10 and 13). For the phytolith analyses, two control samples were collected, one from the surface of the site and another from a modern soil in front of the site.

The pollen samples were treated using the Goeury and Beaulieu (1979) technique, which was slightly modified in accordance with Girard and Renault-Miskovsky (1969), and based on the protocol developed by Burjachs et al. (2003). The paleoecological interpretation is based on the average of the 14 samples analyzed. Calculation of AP/NAP percentages excluded from the basic sums all the palynofacies taxa, as well as the Asteraceae, Cerealia-type and fern spores. These have a specific pollinization system and/or are favoured by anthropic activity. The pollen concentration (PC) was calculated using the volumetric method (Loublier, 1978).

The phytolith extraction was carried out using the methods proposed by Albert (2000) and Madella et al. (1998). About 1 mg of dried residue was mounted on a slide using New Entellan from Merk for phytolith analyses. Wherever possible, the terms used to describe phytolith morphologies follow the terms of the international code for phytolith nomenclature (Madella et al., 2005). The calculation of the phytolith number was done following Albert and Weiner (2001). The phytolith number calculation is based on the acid insoluble fraction (AIF), which is the fraction of the sample that remains after the carbonates, phosphates and organic material have been removed, and wherever phytoliths are present. Using the AIF allows comparisons between samples independently of the diagenesis suffered by the sediment (Albert et al., 1999, Albert et al., 2000, Albert et al., 2003; Karkanas et al., 2000; Albert and Weiner, 2001). Additional counting of the multicellular structures was performed using the entire slide surface. For the calculation of the faecal spherulites and calcium oxalate druses number, about 1 mg of the dried initial sample was mounted on a slide. Phytoliths, spherulites and calcium oxalates were examined using an Olympus BX41 microscope with polarized light for spherulites and calcium oxalates identification.

During the phytolith extraction the volume lost during the acid and peroxide treatment was measured. This was carried out by weighing the initial sample, and weighing the dried residue of the sample after the acid or peroxide treatment. Although these measures are not as exact as the measurements obtained by other well-defined procedures, they provide useful information about the volume of carbonates/phosphates and organic material present in the samples.

The bulk mineral composition of each facies was determined using a Jasco 680 plus FTIR spectrometer. The spectra were collected at a resolution of 4 cm−1 and approximately 1 mg of the original sample was mixed up using an agate mortar with 80 mg of KBr.

4. Results

4.1. Charcoal

The results from the MIR4 level show up to 15 different taxa (Table 3). The most significant in relation to their percentage representation are deciduous and evergreen oaks (Quercus sp. deciduous; Quercus sp. evergreen). Other taxa are present in very low percentages, with ash (Fraxinus), pomes type (Maloideae) and elder (Sambucus) the most abundant. The difference in the percentages among the most important taxa and the rest is indicative of a direction in the exploitation of certain resources: firstly, because of their abundance in the environment and secondly, because of the availability and quality of oaks. The identified taxa belong to different biota, indicating the exploitation of different environments, with priority to the most abundant and extensive. Although deciduous oaks cannot be classified into different species by anatomical observation, it is assumed that there were at least two species: Quercus pyrenaica and Quercus faginea. At present both species grow near the cave. The distribution of Q. pyrenaica type would be related to the acidic soils developed at the terraces, whereas evergreen oaks and Q. faginea type grew on the calcareous soils of the Sierra. Some of the other taxa, such as Fraxinus, Corylus, Cornus, Sambucus and Salix, with greater water needs, probably spread near the river or closer water sources. Pinus sylvestris type and Fagus sylvatica were probably distributed in higher altitudes at the Sierra de la Demanda.

4.2. Seeds

For the MIR4 level the majority of the crops and weeds are represented by 18 taxa (Table 4). Most of these remains were charred seeds, and only two spikelet forks were recovered during the analysis. The seeds come mostly from cultivated plants, namely cereals and pulses. Two wheat species (Triticum aestivum/durum and Triticum dicoccum) account for more than the 50% of the recovered seeds. Hordeum vulgare nudum has also appeared at the site but in smaller quantities. Cultivated pulses are only represented by Pisum sativum, representing less than the 2% of the total remains. Avena sp. and Vicia sp. are also identified. These plants were cultivated in more recent periods, but here are computed as weeds because they lack the main morphological features that ensure they have been cultivated (Alonso, 1999; Arnanz, 2000). Weeds have higher taxa variability than the cultivated plants. Note that the most abundant weed is the Trifolium sp., which relates to ovicaprine alimentation (Abdel-Monein and Abd-Alla, 1999). Other plants related to sheep and goat feeding are the Medicago sp. and Melilotus sp., which appear in smaller quantities in the MIR4 level.

4.3. Pollen

Pollen analysis has provided high values of palynological concentration and taxonomic diversity, which is unusual for archaeopalynological analyses (Fig. 3). These high values are related not only to pollen rain and pollen sedimentation, but also to animal contributions (dung, dust accumulated in the fur, etc.) and humans (bedding for animals, craftwork with vegetable fibres, etc.) (Burjachs, 1988). Most of the pollen record was formed by Poaceae and Asteraceae, with an anthropic artefact of Cerealia-type in facies f (Vuorela, 1973). Secale pollen was also detected; this plant forms part of the weeds growing with the wheat and other cereals before its cultivation during Roman-Middle Ages in the Iberian Peninsula (Buxó, 1997). The arboreal cover was low (36% AP) and the most represented trees are deciduous Quercus, evergreen Quercus, Pinus spp. and cf. Juniperus. Tilia and Ilex, included within the deciduous trees in Fig. 3, are both relictual taxa from the Iberian Peninsula. The riverside trees identified were Corylus, Salix, Ulmus and Alnus. Betula, clearly a mountain taxon, was also identified. Shrubby vegetation was dominated by Cistaceae, Erica and Buxus. Ferns were also present (monolete and trilete spores, Ophioglossum, Isoetes and Polypodium).

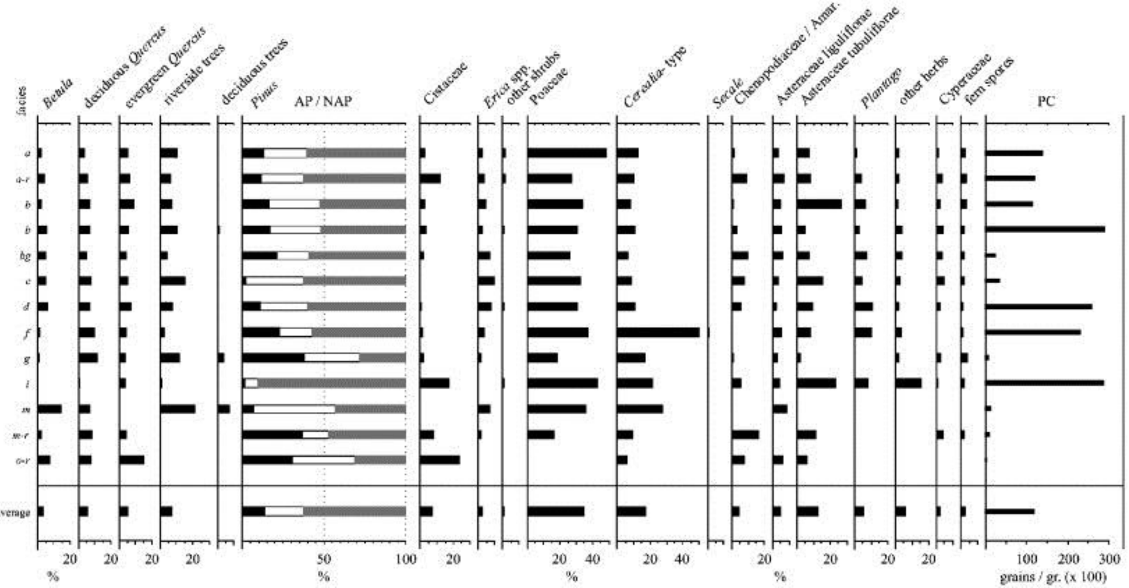

Figure 3. Diagram showing the results of the pollen analysis for the selected taxa in the MIR 4 level.

As expected, the pollen concentration was low in the facies with thermal alteration. There was a low concentration of pollen in the facies related in the field with ashes (facies b, bg and g), with charcoal (facies c) or with reddened sediments (ar, o-r, m-r). The highest concentration and taxonomy diversity were observed in the sediments with no thermal alteration, for example, facies d (identified as dung in the field), f (formed by fibres) and facies i (plastic clay). The pollen results showed high percentages of Poaceae and Cerealia-type in facies f and the highest taxonomical diversity (39 taxa) was found in facies i (Fig. 3).

4.4. FTIR and volume of the main components

The main minerals identified through the FTIR in most of the samples are the calcite and the opal from the phytoliths. Dahllite was also present but in smaller quantities (Table 5). Clay and quartz were only identified in the facies i sample and in the modern soil control sample.

Table 5. Minerals detected in the samples through the FTIR

Sample	Main mineral 1	Main mineral 2	Presence
facies *a*	Opal	Calcite	Dahllite
facies *a-r*	Opal	Calcite	Dahllite
facies *b* (*s*10)	Calcite	Opal	Dahllite
facies *b* (*s*13)	Calcite	Opal	Dahllite
facies *bg*	Opal	Calcite	Dahllite
facies *c*	Calcite	Opal	Dahllite
facies *d*	Calcite	Opal	Dahllite
facies *f*	Opal	Calcite	–
facies *g*	Opal	Calcite	Dahllite
facies *i*	Clay	Calcite	Quartz
facies *m*	Opal	Calcite	Dahllite
facies *m-r*	Calcite	Opal	Dahllite
facies *o-r*	Opal	Calcite	Dahllite
Surface control sample	Calcite	Opal	Dahllite
Modern soil sample	Clay	Calcite	Quartz

The two first columns indicate the main minerals; the position in each column indicates which mineral is most common in the facies. The third column indicates only the presence.

Fig. 4 shows the distribution of the carbonates, organic material and AIF in the samples. All the facies have mostly the same distribution of carbonates, organic material and AIF. In most cases the carbonates are slightly higher than the AIF; in other cases, for example, in facies ar, f and i, the AIF is a little higher than the carbonates. The exceptions are facies b, where the carbonates are more much abundant than in the rest of the samples. Another exception is the modern soil sample which contains much more AIF than carbonates. Note that in all the samples the percentage of organic material is low. The samples with the most organic material are the samples from facies d (identified in the field as a dung accumulation), facies c (identified as charcoal accumulation) and the modern soil control sample.

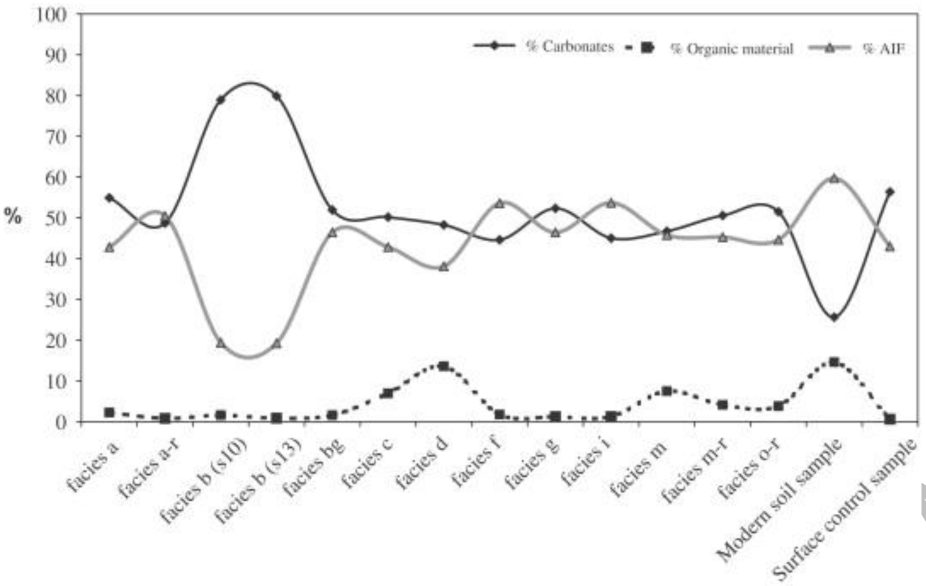

Figure 4. Distribution of the percentages of carbonates/phosphates, organic material and acid insoluble fraction (AIF) in the different facies.

4.5. Phytoliths, spherulites and calcium oxalate druses

4.5.1. Phytoliths, spherulites and calcium oxalate quantification

The amount of phytolith is high in all the facies, but there are considerable variations between them. The sample with the most phytoliths is the modern soil control sample (Table 6). This is probably because when the modern soil control sample was collected, parts of dried grasses present in the surface were also collected, thus artificially increasing the number of phytoliths. The archaeological sample with the highest concentration of phytoliths per gram of AIF is the sample from facies f. The facies bg, facies a and facies a-r also have a considerable quantity of phytoliths.

Table 6. Table showing the estimated number of phytoliths in 1 g of acid insoluble fraction (AIF), the estimated number of faecal spherulites in 1 g of untreated sediments and the estimated number of calcium oxalate druses (CaOx) in 1 g of untreated sediment

Sample	**Phytoliths in 1 g of AIF**	**Spherulites 1 g sediment**	**CaO_x in 1 g of sediment**
facies *a*	9.500.000±1.290.000	4.200±300	550±40
facies *a-r*	12.900.000±1.700.000	11.700±800	1.130±80
facies *b* (*s*10)	3.800.000±402.000	2.200±150	0
facies *b* (*s*13)	3.700.000±530.000	2.300±160	0
facies *bg*	13.600.000±1.390.000	13.600±1400	0
facies *c*	2.500.000±392.000	5.600±500	720±70
facies *d*	4.400.000±530.000	3.800±400	330±30
facies *f*	25.000.000±4.736.000	1.700±200	420±50
facies *g*	10.000.000±1.270.000	6.700±400	740±50
facies *i*	4.300.000±676.000	4.700±300	250±20
facies *m*	5.300.000±1.000.000	3.500±200	350±20
facies *m-r*	6.900.000±958.000	6.400±400	990±60
facies *o-r*	3.100.000±278.000	9.200±700	600±50
Surface control sample	5.800.000±530.000	10.500±1000	790±80
Modern soil sample	36.400.000±6.230.000	0	0

The number of spherulites varies in each facies (Table 6). The facies with the most spherulites are facies bg and facies ar. The surface control sample (which is probably a mix of the upper archaeological sediments) also has a high amount of spherulites as well as facies o-r. Note that the facies defined as a dung accumulation (facies d) does not have an exceptional amount of spherulites.

Calcium oxalates druses were not observed in the two facies b samples, in the facies bg sample and in the modern soil control sample (Table 6). The facies with the highest amount of calcium oxalates is facies a-r (more than 1000 calcium oxalate druses in 1 g of sediment), followed by facies m-r (close to 1000 in 1 g of sediment).

4.5.2. Phytolith morphologies

Most of the phytoliths identified correspond to monocotyledons. The dicotyledonous phytoliths are poorly represented. The sample with highest concentration of dicot phytoliths is the facies m-r sample (23%). No phytoliths other than grass phytoliths were found in the monocotyledon group. The phytoliths from the grasses were formed mainly in the leaves and the stems of these plants (Fig. 5, Fig. 6). The phytoliths from inflorescence are present in lower percentages. The facies with the highest concentration of inflorescence morphotypes are facies f and facies a. More than 96% of the short cells identified in all the facies correspond to festucoid short cells (Fig. 6B). The results for the multicellular structures have shown a dominance of leaves/stem multicellular structures over inflorescence multicells (Fig. 6, Fig. 7). The exception is the facies f, where there are more inflorescence multicells than leaves/stem multicellular structures. Most of the inflorescence multicellular structures from facies f are represented by dendritic morphologies (Fig. 6D).

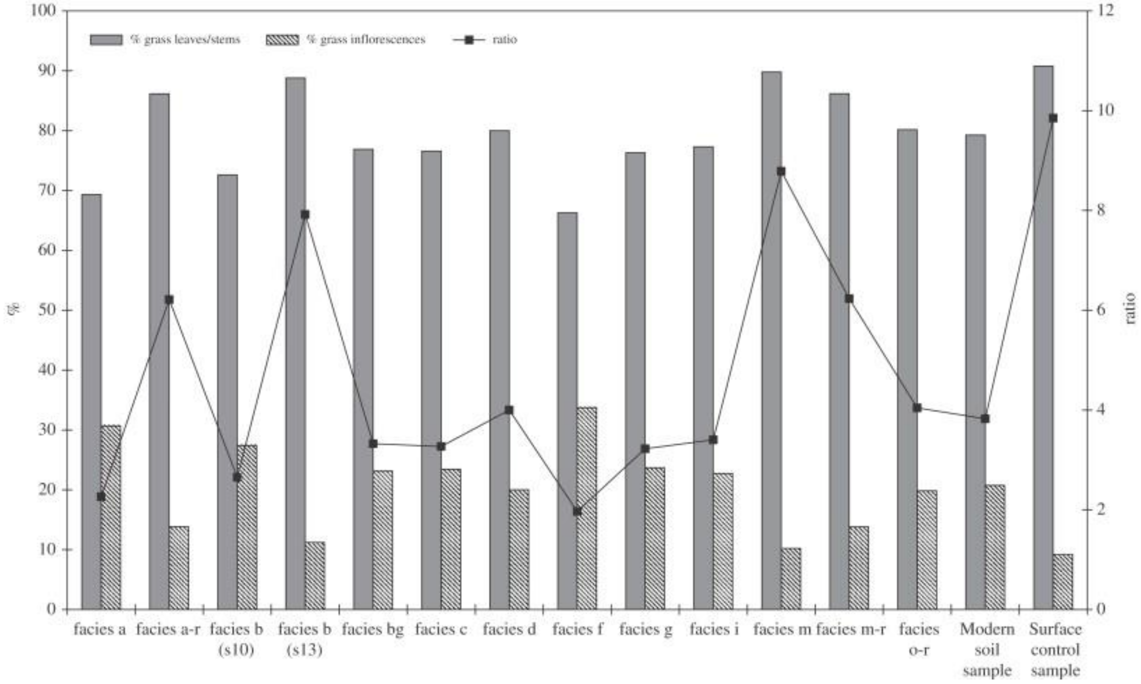

Figure 5. Anatomical origin of the grass phytoliths identified in the samples.

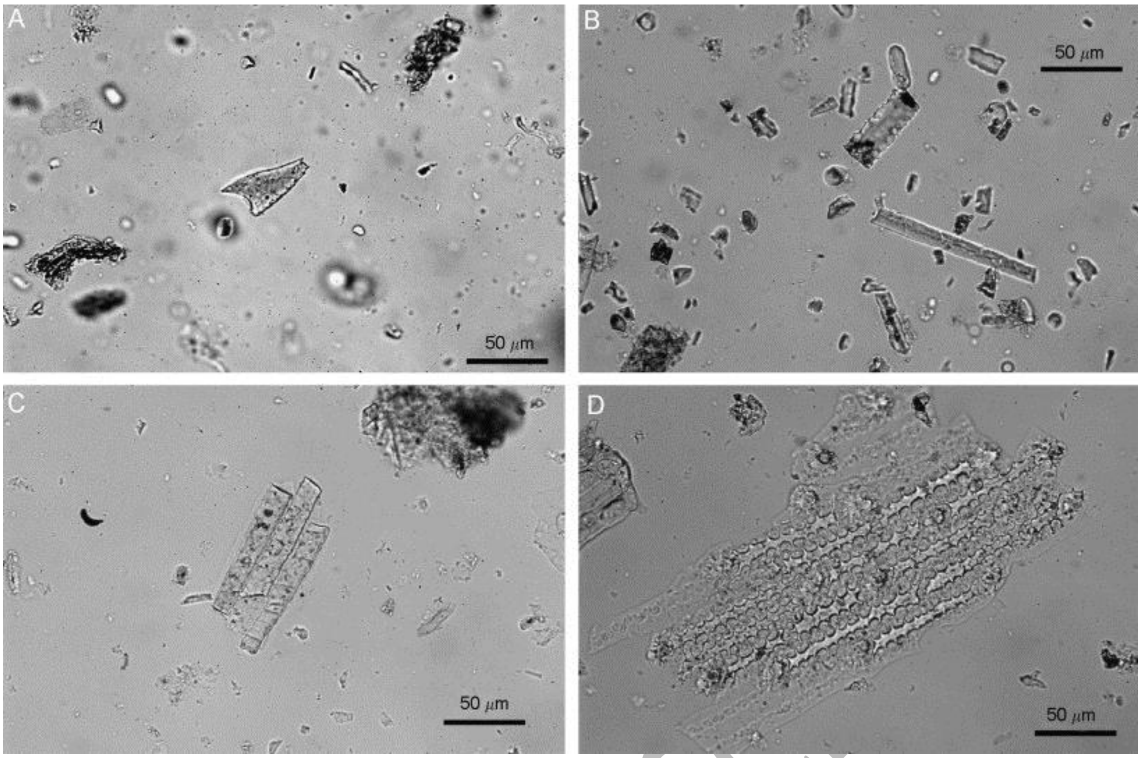

Figure 6. Microphotographs from the phytoliths identified in the MIR 4 level: (A) Prickle from a monocot leaf, facies a. (B) Festucoid short cells (rondels) together with psilate long cells, facies a. (C) Multicellular structure formed by psilate long cells from

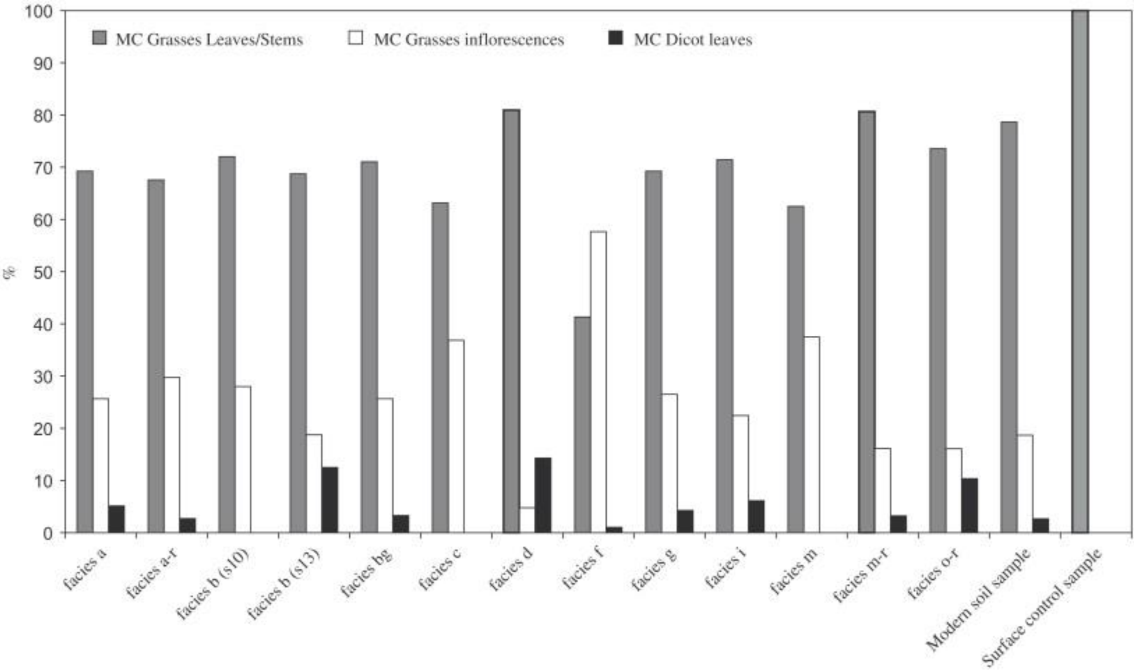

Figure 7. Origin of the multicellular structures identified in the MIR 4 level.

5. Discussion

The origin of El Mirador Holocene sediments is principally the dung from the animals kept in the cave during the Bronze Age. This hypothesis is not only supported by the archaeological remains but also by the archaeobotanical remains and the mineralogical composition of the sediments. The phytoliths from the facies of the Bronze Age come mainly from the leaves and stems of the grasses. Such grasses were probably part of the diet of these animals or their bedding. Thus, the existence of calcium oxalates, which could originate in the dicotyledonous leaves (Franceschi and Horner, 1980; Prychid and Rudall, 1999), must be related to the foddering or bedding of the animals enclosed in the cave (Rasmussen, 1993). Most of the species from the charcoal record can be used to fodder animals. Oak and ash are especially preferred by cattle. The relation between the percentages of the most abundant woody taxa, evergreen and deciduous oaks, and the rest of the taxa, indicates that there was a strategy to exploit these species. The wood fodder was usually exploited during the winter seasons when grazing was not possible. This strategy has been documented in other archaeological sites and recorded ethnographically (Haas et al., 1988; Rasmussen, 1993; Karg, 1998). The presence of faecal spherulites in all the samples is a clear indicator of the dung deposition in the cave (Brochier et al., 1992; Canti, 1997, Canti, 1999). The mineralogical composition shows the presence of dahllite, which could be indicative of a relatively high phosphate level in the sediments. These phosphates could come from fresh dung (Macphail et al., 1997; Shahack-Gross et al., 2003; Karkanas, 2006).

However, not all the facies are the product of burned dung. The results for facies f indicate that this facies is more related to the crop-processing residues than to dung accumulation (Vuorela, 1973; Macphail et al., 1997; Harvey and Fuller, 2005). Some spherulites, as well as calcium oxalates, have been detected in this facies, but the origin of those elements should be related to the difficulty in sampling this facies, which is formed by very fine fibres surrounded by the other facies. The high presence of husk phytoliths indicates that the crop-processing stage could be the threshing/winoning or the milling/pounding (Harvey and Fuller, 2005). Storage areas also should contain husk phytoliths, but no evidence of storage structures has been detected during the excavation of the MIR 4 layer. Most of the inflorescence phytoliths found are dendritic morphologies that might be related to the presence of husk of Triticum aestivum/durum, whose seeds have been recovered from the same archaeological layer. Nevertheless, morphometrical analysis of the dendritic phytoliths must be carried out to confirm this hypothesis (Ball et al., 1999, Ball et al., 2001). The destination of the final product of the crop-processing can be the human consumption or the foddering of livestock present in the cave. The discrimination of grain for human consumption or grain for animal foddering at a minimum is complicated (Jones, 1998). Nevertheless, Karkanas (2006) has proposed the use of cereal inflorescence for animal foddering. Feeding animals with cereal grains destined for human consumption is an expensive practice, even if there are few animals, and only possible when the surplus of grain is considerable. In this sense, prior to the mechanization of agriculture, the cultivation of fodder was labour-intensive (Halstead, 1996). Nevertheless, the question arises whether the whole inflorescence (including the grains) was used to feed the animals or only the husk was used as fodder.

The different characteristics of facies i indicate that the origin of this facies is a mix of dung and clay, from outside the cave, not related to the general context deposition for the MIR 4 level. The FTIR results for facies i are very similar to the results from the soil control sample. In addition, the pollen record of facies i presents similarities to a soil pollen spectrum (Bottema, 1975). Note that the pollen deposited in the dung can be biased by the alimentary preferences of the animals (Carrión et al., 2000) or, in the case of the Mirador site, by the burning of the dung. Consequently, the diversity of the pollen record formed by the mix of dung and clay, from outside the cave, should be higher than the diversity of most of the pollen samples from el Mirador site, which are formed mainly by burned dung. Moreover, the presence of clay for preparing floors and carrying out other activities has been detected in many caves where animal dung was also burned (Karkanas, 2006, personal observation in the Portalón Cave, Sierra de Atapuerca).

The type and amount of phytoliths from the reddened facies do not show major differences to the same facies type without this feature. However, the calcium oxalates concentration is higher in the reddened facies than in the not reddened facies of the same type, and there is a slight increase in the dicot phytolith percentage in these types of facies. The calcium oxalates and the dicot phytoliths could indicate a differentiated combustion processes in terms of fuel for the reddened facies.

Wood ash is the probable origin of the two samples from the facies b. However, there is not a significant increase in wood and bark phytoliths in these samples. Note that grasses can produce 20 times more phytoliths than wood and bark and that part of the phytolith contained in the wood and bark used as fuelwood can contain grass phytoliths in form of "contamination" (Albert, 2000). Most of the sediment contained in facies b probably has its origin in wood ashes, but also the contribution from other sources (i.e. dung) needs to be taken into account, because the faecal spherulites have lower concentrations than in other samples but they are still present in facies b. In comparison with the samples from facies b, the samples from facies g and bg show larger quantities of phytoliths and spherulites. This can be explained by the presence of more burnt dung in the facies g and bg samples than in the facies b samples, and can also be explained by a different depositional event in these facies.

Finally, a good correlation exists between the amount of multicellular structures and the amount of spherulites (Fig. 8). When no other indicators discard the presence of dung in the samples (i.e. in facies f, facies i and probably facies b), the low presence of multicellular structures and spherulites could indicate the reworking of these sediments. The hypothesis is that the reworking processes disaggregate the existing multicellular structures converting these into regular phytoliths, and increase the solubility of the faecal spherulites, which seem to be formed by a relatively unstable form of calcium carbonate (Shahack-Gross et al., 2003). Furthermore, good preservation of the multicellular structures and the spherulites could indicate the human import of plants to the cave for bedding the animals (Macphail et al., 1997). Facies a-r and the surface control sample do not follow this correlation. These samples, especially the sample from the facies ar, are relatively rich in calcium oxalates. Lower number of phytoliths and a sediment rich in calcium oxalate remains has been related to foddering animals with hay leaves (Macphail et al., 1997). This could explain why there is a considerable quantity of faecal spherulites in the sediment but fewer multicellular structures from grasses. The soil micromorphological analysis, which is still in progress, will help to confirm or reject this hypothesis.

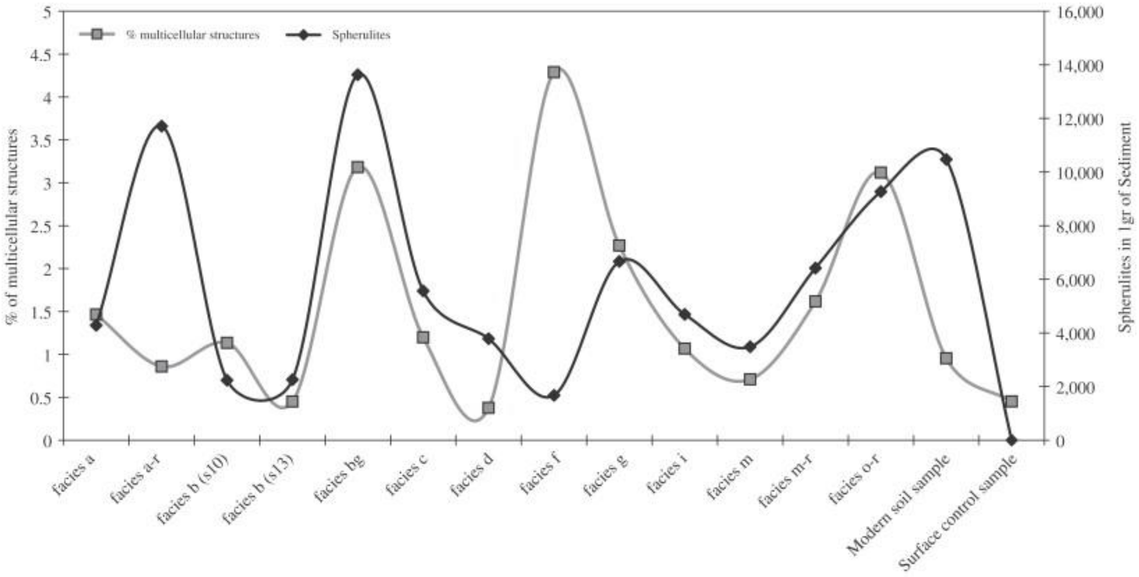

Figure 8. Comparison of the amount of multicellular structures and the amount of faecal spherulites in the facies studied.

According to the results obtained through the seed, charcoal, pollen and phytolith analyses, the archaeobotanical record was formed by human activities related to agriculture and pastoralism. Charcoal analyses show that the landscape was at least partially formed by arboreal cover which, due to the intensive exploitation, clearly shows a transformation that favoured the development of open environments with more open shrubby vegetation. The results of the pollen analysis show similar conditions. The landscape is a mosaic of different biota: oak forest with evergreen and deciduous elements, mountain range vegetation, riverside species and cultivated cereals. This mosaic can be summarized into three types of vegetal cover: the forest, the pastureland and cultivated fields. The climate during the formation of level MIR 4 was similar to the current continental Mediterranean climate (Rivas, 1987), but with some Atlantic influences (i.e. Quercus sp. deciduous and Fagus). Moreover, some of the taxa identified by pollen and charcoal analyses show a higher degree of humidity in the environment.

6. Conclusions

Most of the facies variability in the MIR4 level depends on variables such as humidity, duration of the combustion, type of animal dung, etc., which affect the combustion processes of the accumulated dung. Nevertheless, some of the clearest differences are due to the different origins of the sediment, and probably the reworking of those sediments in ancient times. The relationship between single phytoliths, multicellular phytoliths and spherulites can be a clear indicator of postdepositional processes in these types of sediments. The archaeological remains show that the site was used during the Middle Bronze Age as an animal enclosure and a burial site. However, other activities related to crop-processing and agriculture have also been detected through seed, charcoal, pollen, phytolith and mineralogy analyses. Such analyses can be combined to understand the paleoecology of the site. These disciplines are complementary to each other not only to explain the past landscape, but also to increase understanding of formation and diagenetic processes in sites such as El Mirador Cave.
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