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Modern pollen analysis in caves at the Patagonian steppe, Argentina

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ABSTRACT

Cave fossil records from the Patagonian steppe (Argentina) have been largely used as a source of archaeological and palaeoenvironmental information. Major uncertainties exist, however, regarding the degree to which the fossil pollen assemblages from caves reflect past environments because of the complex site formation processes and post-depositional bias. Studies within caves from other regions have demonstrated that the understanding of modern pollen taphonomy helps to recognise the record bias improving thus the inferences. The present study therefore aims to understand how modern plant communities are represented within two caves at the Patagonian steppe and to establish the modern pollen taphonomic processes. Cave pollen assemblages provided a good representation of the local vegetation indicating therefore that cave fossil pollen assemblages are a reliable source for inferring the past vegetation. However, the modern taphonomic analysis pointed out that cave pollen assemblages are not homogeneous but show spatial variability due to different factors. Vegetation distribution, physiognomy and pollination type, biotic transport and human disturbance were the major factors affecting the cave pollen assemblages whereas orientation and topographic position seemed not to be significant. Biotic transport caused unexpected deposition patterns while animal and human post-depositional disturbance the homogenization of pollen assemblages. Other factors such as the cave internal topography, morphology and microclimatic circulation might be determinant on floor pollen assemblages so should be further investigated.

1. Introduction

Fossil pollen sequences from caves and rockshelters have been largely used to reconstruct past vegetation communities and environmental conditions in arid and semiarid regions where other deposits for pollen and macrofossil analysis are not common (e.g. Gale et al., 1993; Carrión et al., 1999; Mancini et al., 2002; Pirson et al., 2006; Polk et al., 2007; de Porras et al., 2009). Given that cave fossil records are mostly the result of environmental, climatic and cultural interactions, it is essential to understand the complex site formation processes and the post-depositional bias that could have affected the sequences before reconstructing the past vegetation and then inferring the environmental and climatic conditions.

The knowledge of modern cave pollen taphonomy has provided fundamental clues to understand the taphonomic processes operating on the fossil pollen records from caves. Several studies from Europe, USA and Asia lead some general trends about pollen transport, deposition patterns and preservation (Burney and Pigott Burney, 1993; Carrion, 2002; Coles and Gilbertson, 1994; Hunt and Rushworth, 2005; Navarro et al., 2001; Prieto and Carrion, 1999; Weinstein-Evron, 1994). These studies showed that caves are idiosyncratic so the taphonomic processes vary depending on the cave nature and morphology, the pollen transport pathways and the surrounding vegetation characteristics.

Cave fossil records from the Patagonian steppe, particularly from the Santa Cruz Central Plateau, Argentina (46–49°S; 67–71°W; Fig. 1a), have been largely used as a source of archaeological and palaeoenvironmental information (e.g. Cardich et al., 1973; Cardich and Paunero, 1994; Mancini, 1998; Paez et al., 1999; Borromei, 2003; Mancini et al., 2002; Miotti, 1998; Paunero, 2003a, b). However, little research has been done regarding the modern and fossil pollen taphonomic processes within these caves to recognise the potential pollen record bias (de Porras et al., 2009). Actually, the meaning and reliance of the past vegetation changes of the Santa Cruz Central Plateau will not be completely clear until the taphonomic pathways inside the caves are known and understood.

The present study is the first approach to understand the modern cave pollen assemblages at the Patagonian steppe and aims to establish how the plant communities surrounding the caves are represented within them and to explain the modern pollen taphonomic processes.

2. Environmental setting

Caves “La Última” (CLU) and “La Cocina” (CLC) are located at La María archaeological locality (48°24′40″ S; 68°51′24″ W) which lies in the

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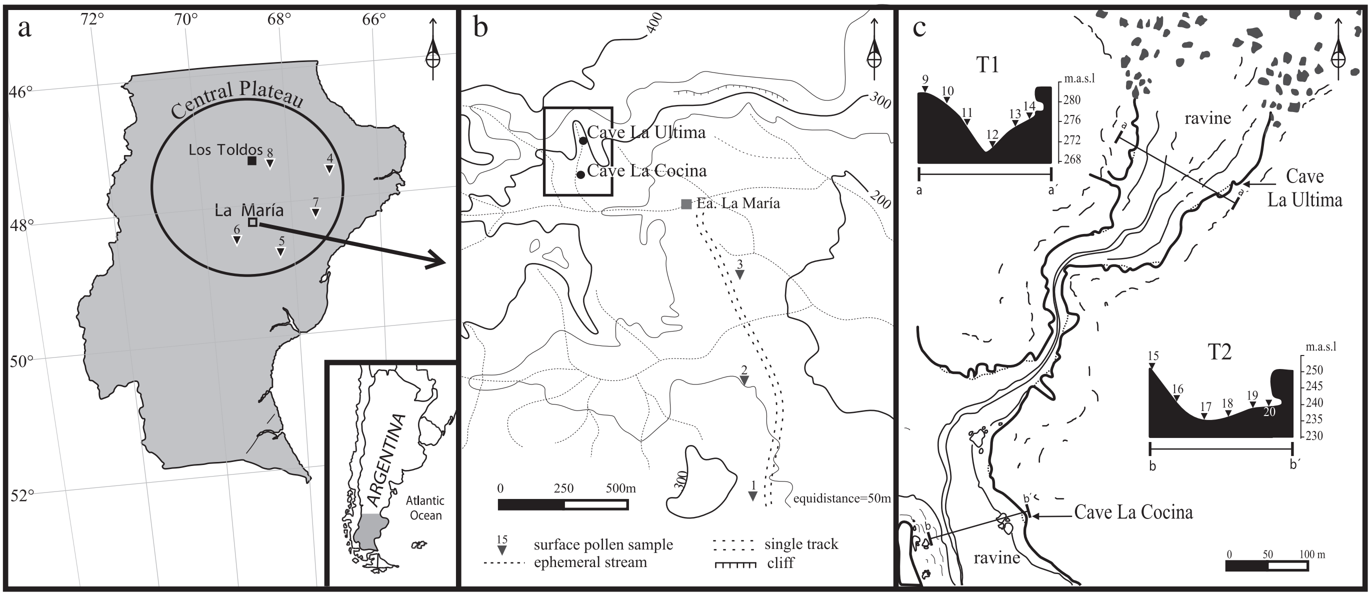

Fig. 1. a. Map of Santa Cruz province showing the location of La María and other sites mentioned in the text; b. Topographic map of La María showing the location of caves La Ultima and La Cocina; c. Plan of the ravines showing the location of caves and the distribution of the ravine surface pollen samples in transects T1 and T2.

southeastern Santa Cruz Central Plateau (Fig. 1a and b). CLU and CLC were selected to perform the present study due to their differences in morphology, topographic position and orientation but similar surrounding plant communities (Figs. 1c, and 2a, b). The caves are erosional features of Jurassic ignimbrites and are located in ravines (very small canyons or gullies which are mainly the product of stream cutting erosion; Fig. 2a and b) where abundant and constant traces of human activity, from paleoindians (*ca.* 12.000 ^{14}C years B.P.) to the historical colonisation during the 20th century were found (Paunero et al., 2008). The Central Plateau caves are archaeologically important because of the coexistence of extinct faunal and human remains and the continuity and density of the human occupations since the Pleistocene–Holocene transition (Miotti and Salemme, 2003; Paunero, 2003a).

The climate in the Central Plateau is cold-semiarid with a mean annual temperature and an annual precipitation of about 8.5 °C and 180 mm, respectively (Hoffman, 1975). Precipitation is evenly distributed throughout the year, falling as snow in winter on the high plateaus. The dryness of the plateau is caused by both the scarce precipitation and the strong west winds (westerlies) which cause high evaporation rates (Roig, 1998).

The most widely distributed plant community in the Central Plateau is a dwarf-scrub steppe integrated by dwarf shrubs such as *Nassauvia glomerulosa*, *N. ulicina*, *Ephedra frustillata*, *Chuquiraga aurea*, *Acantholippia seriphioides*, *Azorella seriphioides*, *A. caespitosa*, *A. monanthos*, *Satureja darwinii* and *Nardophyllum obtusifolium* and grasses (*Poa*, *Stipa* and *Festuca*). However, medium to tall shrub communities with *Colliguaja integerrima*, *Schinus polygamus*, *Berberis heterophylla*, *Junellia ligustrina*, *J. tridens*, *Anarthrophyllum rigidum*, *Lycium chilense*, *Senecio* spp. and *Nardophyllum obtusifolium* (Asteraceae subf. Asteroideae) are present either to the NE of Santa Cruz Central Plateau or in ravines, depressions and valley bottoms (León et al., 1998; Roig, 1998; Soriano et al., 1983). The physiognomy and composition differences between the plant communities are related to higher water availability, temperature and wind protection within the ravines than on the plateaus.

3. Caves description

Cave La Última (277 masl) is a *ca.* 16 m deep cavity with a single entrance which leads to the main chamber and further to a minor chamber through a narrow passage (Fig. 2a). The entrance 3.5 m high and 3.1 m wide faces to the northwest, 1.3 m above the ravine floor (Fig. 2a). The height of the cave diminishes to the rear, being 1.2 m in the minor chamber. At the centre of the main chamber, airfall material and faeces were accumulated forming a small mound (Fig. 2a).

Cave La Cocina (239 masl) is a 22 m deep three-chambered cave which entrance 5 m high and 13 m wide faces westwards (Fig. 2b). Although this cave is at the ravine level floor, there is a slope between the chambers I and II so the latter is 1.5 m above.

The entrances of both caves are surrounded by shrubs such as *C. integerrima* and *Senecio* spp. (Asteraceae subf. Asteroideae; Fig. 2a and b). The floors of CLU and CLC are covered with dry sediments, volcanic ash from the 1991 Hudson volcano eruption and whole and fragmentary sheep faeces.

3.1. Present pollen deposition pathways within the caves

The predominant pollen deposition pathways operating at present in CLU and CLC are airfall and biotic. The airfall deposition includes material that has blown into the cave which dynamics is unknown since no microclimatic circulation studies were still performed. The main biotic vectors determining pollen deposition through their faeces, fur and paws at CLU and CLC are sheep (*Ovis ammon aries*) which were introduced at the beginning of the 20th century (Barbería, 1995). Rodents (*Phyllotis* sp.) are another potential source of pollen in CLU where three middens were found in the minor cell (Fig. 2a). However, rodent faeces were not found on the cave surface so the pollen introduction pathway could have been through the transport of the gathered plants remains towards the middens. Other biotic vectors could be predators such as foxes (*Canis* (*Pseudalopex*) spp.) and pumas (*Puma concolor*) although there was no evidence of their presence in CLU and CLC. Nesting areas from raptors such as the black chested buzzard eagle (*Geranoaetus melanoleucus*) were seen in several caves at La María but no nests were found in CLC and just a small one was present in the main chamber of CLU. Bats (*Histiotus montanus*) are widespread distributed to the east of the Central Plateau (Barquez et al., 1993) but were not seen within the caves at La María.

4. Materials and methods

Thirty-three samples of cave floor sediment were collected (15 from CLU and 18 from CLC, Fig. 2) applying an entrance-rear sampling strategy that avoided footprints and disturbed areas. Neither CLU nor

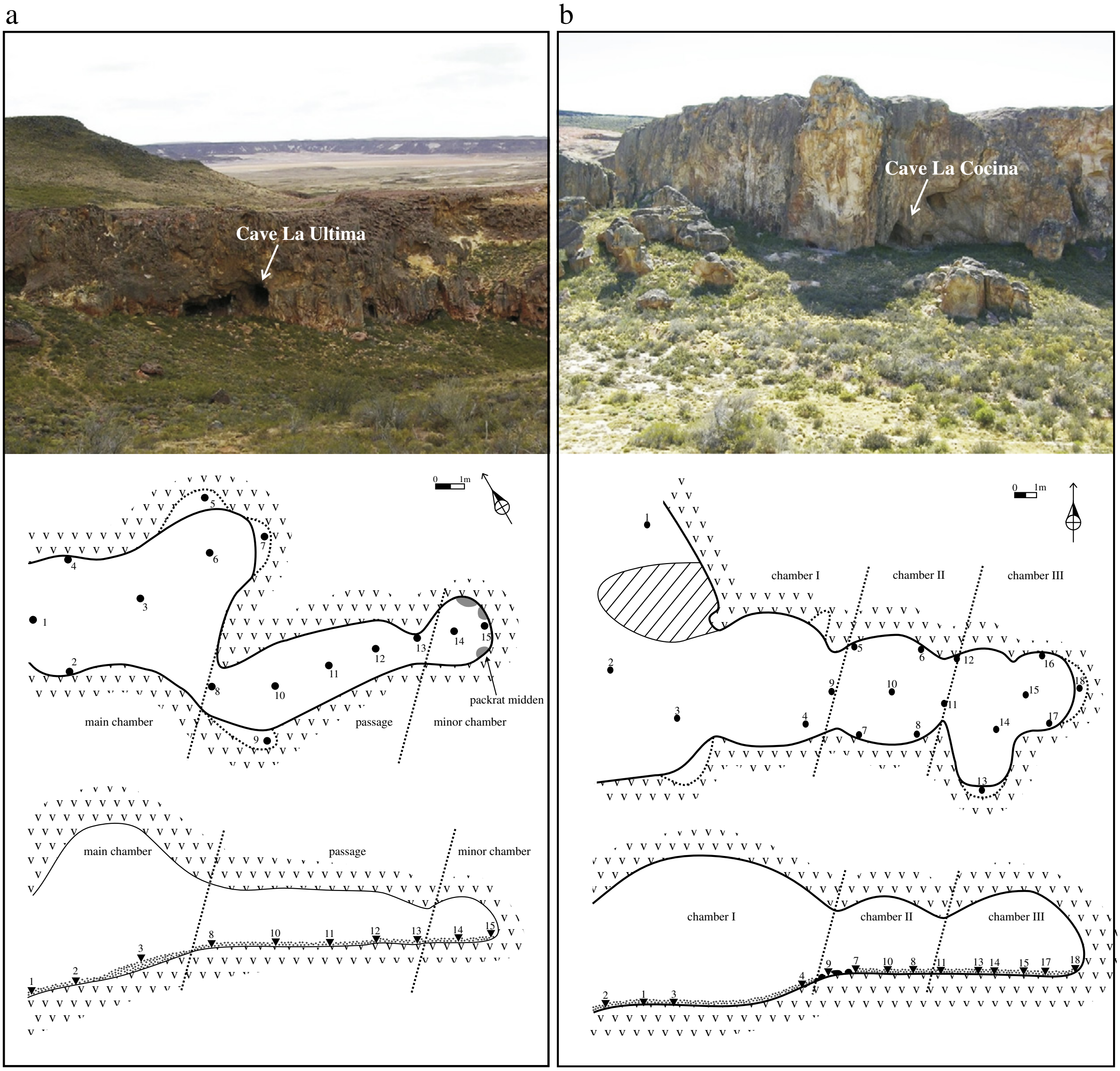

Fig. 2. Photographs, plan and cross-sections of a. Cave La Ultima and b. Cave La Cocina.

CLC had been excavated by the time of sampling but both cave surfaces and particularly CLC's, were slightly disturbed because of human and sheep trampling. In addition, 20 surface sediment samples arranged in two transects (T1 and T2) across the ravines (Fig. 1c) and eight from the plateaus (Fig. 1a and b) were collected to study pollen–vegetation relationships and then compare to the cave surface pollen assemblages.

Cave sediment samples were firstly sieved through a 300 μm mesh in order to separate whole and fragmentary sheep faeces from sediment. Then, 10 to 15 g of sediment subsamples were treated following standard methods to extract pollen content (Faegri and Iversen, 1989; Gray, 1965). Three *Lycopodium* spore tablets were added to each subsample before extraction in order to calculate pollen concentration (grains/g).

Even though whole and fragmentary sheep faeces were separated from the cave floor samples before processing, it was likely that some faecal pollen content from some fully disintegrated faeces had been mixed with the sediment pollen content in the floor pollen assemblages. It was important to consider the latter since the percentages and concentration of faeces pollen assemblages are highly variable depending on the animal's diet and behaviour (Bjune et al., 2005; de Porras, 2010; Moe, 1983) and cave floor pollen assemblages could therefore be biotically biassed. As sheep faeces are mainly organic and cave sediments in the Central Plateau are highly inorganic (organic matter <3%; de Porras, 2010), the organic matter content of the cave floor samples was used as an indicator of disintegrated faeces (and therefore biotic pollen deposition) within the samples. Firstly, an organic matter content reference level of the faeces was set by performing loss on ignition (LOI) to 15 faeces (six from CLC and nine from CLU, Table 1) and then to all the cave floor samples (550 °C, 4 h; Heiri et al., 2001). Finally, an organic matter content index that ranges between 1 and 0 was calculated for all the cave floor sediment samples (% LOI cave floor sample/mean value % LOI faeces CLU-CLC). Thus, the closer the index value to 1, the higher the organic matter in the sample, the higher the disintegration of faeces and mixture with the sediment and then, also the probability of incorporation of faeces pollen content in the cave floor samples.

Aditionally, *Sporormiella* spores were counted to support the evidence of biotic influence on the pollen assemblages through sheep faeces since these coprophilous fungi are found only on the faeces of herbivores (Ahmed and Cain, 1972) and are particularly common on the faeces of domestic herbivores (Ebersohn and Eicker, 1997).

Table 1
Organic matter values (%) from faeces of caves La Ultima and La Cocina. Note that faeces sample numbers are the same that those of the corresponding cave floor pollen sample.

Cave	Sample	Organic matter (%)	Media OM (%)
CLU	F1	78.12	78.28
	F2	84.76	
	F3	69.92	
	F8	80.55	
	F9	74.98	
	F11	76.54	
	F12	75.85	
	F14	81.64	
	F15	82.14	
CLC	F15	79.14	72.56
	F14	79.14	
	F10	70.11	
	F6	74.24	
	F4	68.88	
	F2	63.85	

The reference collection of the Laboratorio de Paleoecología y Palinología at the Universidad Nacional de Mar del Plata was used to determine pollen grains and spores. Pollen sum ranged from 561 to 1079 grains. Each taxon was expressed as a percentage of the total pollen sum. Long distance pollen, Chenopodiacecae, undetermined pollen and spores were excluded from the total pollen sum. Long distance pollen includes trees (e.g. *Nothofagus dombeyi*-type, *Podocarpus*, and *Drymis*) that reflect the Subantartic forests located 200 km westwards from the study site. Chenopodiaceae represent local halophytic plants related to the ephemeral stream dynamics. The undetermined pollen comprises “unknown” and “unidentified” pollen. The former refers to pollen which botanical affinities are unknown whereas the latter is pollen broken or crumpled. Pollen types were grouped according to their pollination characteristics in anemophilous and entomophilous. Those pollen types which taxonomic resolution was at the family, sub-family or genera level were classified considering the predominant pollination type of those species present in the local plant communities.

Pollen diagrams were plotted with TG View 2.0.2 (Grimm, 2004). Those pollen types and spores excluded from the pollen sum excepting the undetermined and *Sporormiella* were not drawn in the diagrams. Cave iso-lines maps of total pollen concentration, organic matter index and *Sporormiella* percentages were carried out and drawn with ArcGis 9.3. Data were interpolated applying the kriging method, choosing the Quadratic Drift option because data points were not evenly dispersed on the cave floor surface.

Two ordination analyses were carried out between the cave floor and the surface pollen assemblages to establish how the plant communities surrounding the sites are represented within the caves. A detrended correspondence analysis was performed with the whole surface (plateaus, T1 and T2) and cave floor (CLU and CLC) samples. The plateau samples were excluded in the second correspondence analysis since they arranged separately masking the closest relationships between the surface and the cave floor samples. Pollen variables were selected if the mean value of each variable in percentage was higher than 2%, except for entomophilous pollen types representative of the ravine vegetation such as *J. tridens* and *Schinus*.

5. Results

5.1. Surface pollen assemblages

Plateau pollen assemblages are dominated by *Nassauvia* (35–50%) associated with *Chuquiraga*, *Ephedra frustillata* (<20%) and Poaceae (15–45%) and represent the dwarf-shrub steppe regionally spread in the Santa Cruz Central Plateau (Fig. 3). On the other hand, ravine pollen assemblages (T1 and T2) are dominated by *Colliguaja integerrima* (85–30%) associated with Poaceae (25–10%), Asteraceae subf. Asteroideae (25–5%), *Junellia tridens* (<8%) and *Schinus* (<5%) (Fig. 3) and reflect the medium to tall shrub communities growing

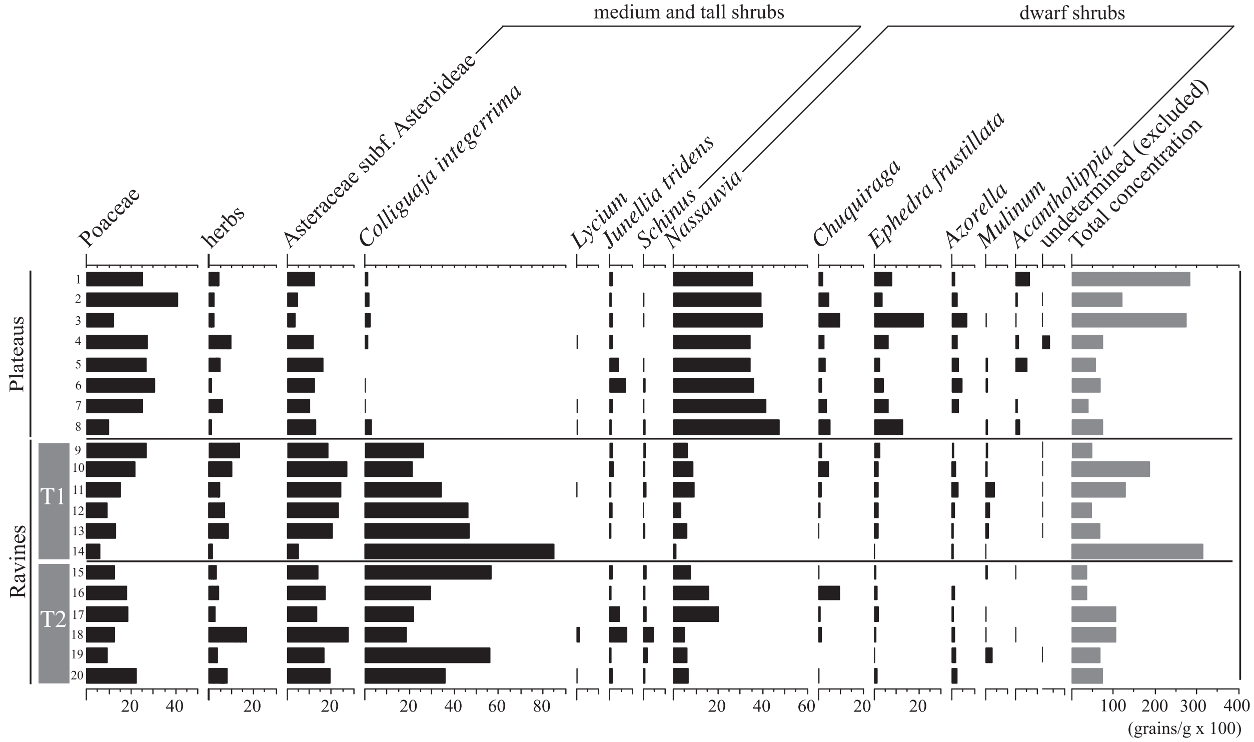

Fig. 3. Plateaus and ravines (T1 and T2) pollen diagram in percentages. The ravine pollen assemblages are shown according to their order in the transects T1 and T2.

within them. Dwarf shrubs are represented with values <20%. *Colliguaja integerrima* dominates ravine pollen assemblages representing at least 20% of the pollen sum and reaching up to 85% in sample 14 (Fig. 3). Total pollen concentration from plateau and ravine samples ranges between 31,400 and 3600 grains/g (Fig. 3).

5.2. Cave floor pollen assemblages

CLU pollen assemblages (Fig. 4a) are dominated by *Colliguaja integerrima* (25–70%) associated with Poaceae (5–15%), Asteraceae subf. Asteroideae (5–25%) and herbs (10–20%). The total pollen concentration and the organic matter index show the same trend, increasing gradually from the entrance to the rear whereas the *Sporormiella* percentages are lower than 3% all over the cave (Fig. 5).

CLC pollen assemblages (Fig. 4b) are co-dominated by *Colliguaja integerrima* (10–55%), Asteraceae subf. Asteroideae (15–40%) and Poaceae (15–40%) accompanied by *Lycium*, *J. tridens* and *Schinus* (<10%). The total pollen concentration, the organic matter index and the percentages of *Sporormiella* (Figs. 4 and 5) show the same trend, increasing suddenly to the rear of the cave but with fluctuating values.

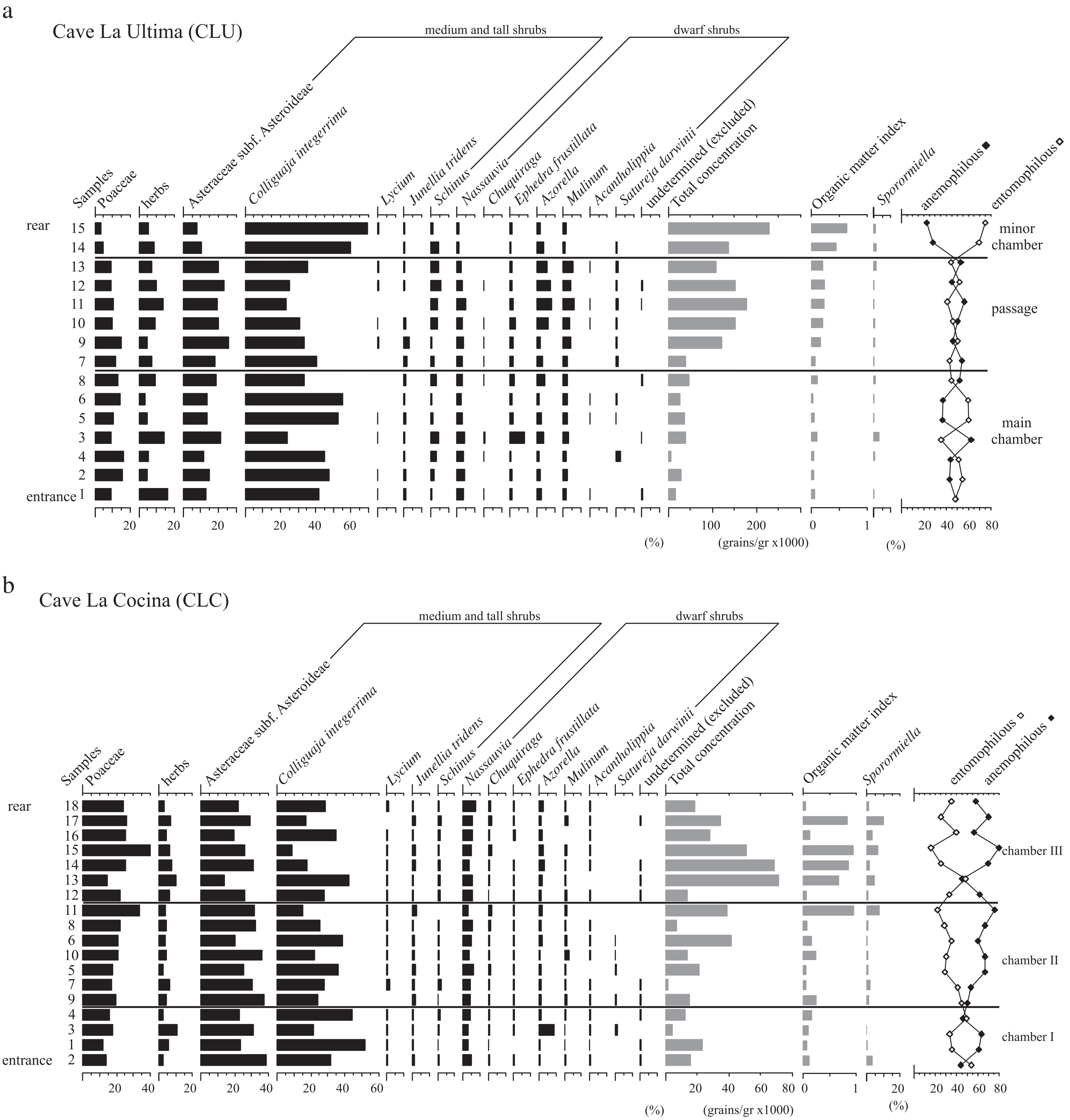

Fig. 4. Pollen diagram of a. CLU and b. CLC in percentages, showing also the total pollen concentration and the organic matter index and the *Sporormiella* percentages. Note that cave samples are ordered according the distance to the entrance of the cave.

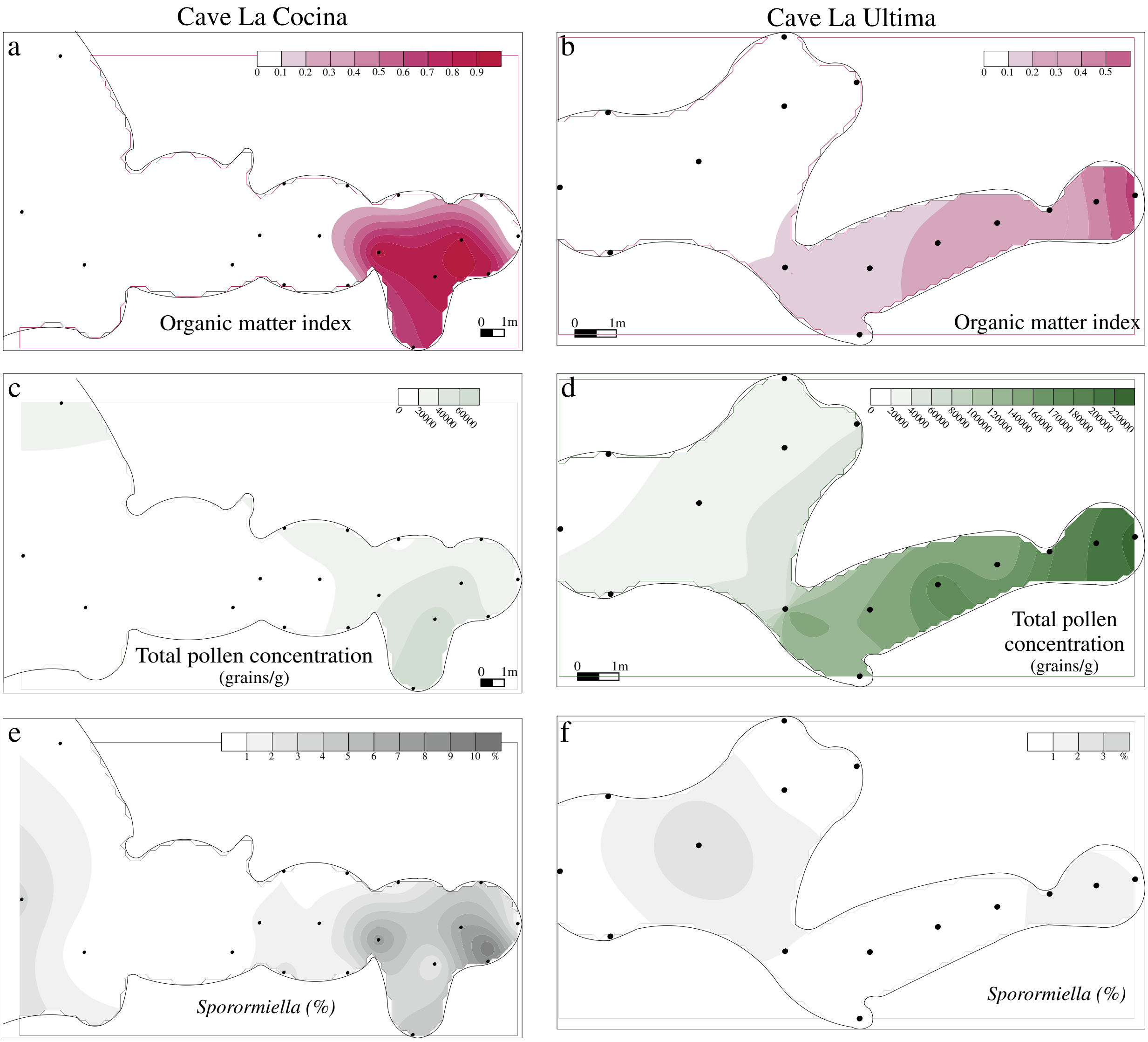

Fig. 5. Cave iso-lines maps of CLU and CLC showing the spatial patterns of a, b. Organic matter index; c, d. Total pollen concentration; and e, f. *Sporomiella* percentages.

Colliguaja integerrima dominates and co-dominates the pollen assemblages from CLU and CLC, respectively varying between 10 and 70% within both caves (Fig. 4a and b).

Undetermined pollen percentages are lower than 2% in CLU and CLC surface samples whereas total pollen concentration values vary between and within the caves (240,000–2000 grains/g) being generally higher than those from the plateau and ravine samples (Figs. 3 and 4a, b).

There are not clear relationships between the anemophilous or entomophilous percentages and the distance to the entrance in both caves (Fig. 4a and b). The percentages of anemophilous and entomophilous in CLU range between 40 and 60% in the main chamber and the passage (Fig. 4a), decreasing and increasing, respectively in the minor chamber. At CLC, both anemophilous and entomophilous percentages range from 10 to 80% within the different chambers (Fig. 4b) showing general trends that suggest slight entrance-rear gradients either for anemophilous or entomophilous taxa. Thus, the anemophilous taxa tend to increase towards the rear whereas the entomophilous ones decrease.

Detrended correspondence analysis (DCA; Fig. 6a) shows that cave floor samples order together to those samples from ravines whereas plateau's arrange separately. The first are defined by *Colliguaja integerrima*, Asteraceae subf. Asteroideae, *Junellia tridens* and Poaceae while the latter by *Nassauvia*, *Chuquiraga* and *Ephedra frustillata*.

Correspondence analysis (Fig. 6b) shows that CLC floor samples and ravine surface samples order coinciding partially along axis 1. Some samples are defined by *Colliguaja integerrima* while others by Poaceae, Asteraceae subf. Asteroideae, *Junellia tridens*, *Nassauvia* and *Chuquiraga*. On the other hand, CLU floor samples order basically according to their location within the cave (main chamber, passage and minor chamber). Samples from the main and the minor chamber arrange along the positive values of axis 1 whereas those samples from the passage order on positive values of axis 2. The main and minor chamber samples are mainly defined by *Colliguaja integerrina* whereas the passage ones by *Azorella*, *Mulinum*, *Schinus* and *Ephedra frustillata*. Contrary to CLC, just the samples from the CLU main chamber order close to the ravines surface samples.

6. Discussion

6.1. Ravine and plateau pollen assemblages

The modern pollen assemblages reflect the vegetation composition and distribution growing in and around La María archaeological

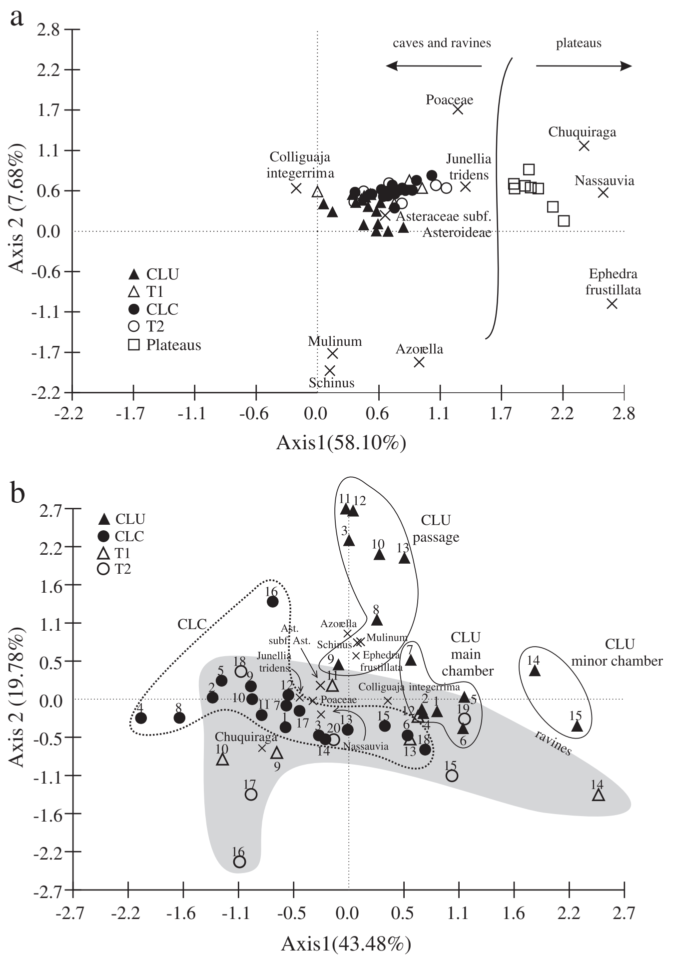

Fig. 6. a. Detrended correspondence analysis between surface pollen assemblages from plateaus, T1, T2, CLU and CLC pollen assemblages; b. Correspondence analysis between surface pollen assemblages T1, T2, CLU and CLC pollen assemblages.

locality (Fig. 3), the dwarf shrub community on the plateaus and the tall to medium shrub community in the ravines. Ravine pollen assemblages also reflect the variability between and within them. Even though the ravine pollen assemblages (T1 and T2; Fig. 3) are very similar in composition, there are some differences regarding the proportions of tall and medium shrubs such as *Colliguaja integerrima*, *Junellia tridens* and *Schinus*. Besides, the variability of the pollen assemblages within the ravines do not reflect vegetation changes but the differential distribution of the shrub thickets which are mainly integrated by entomophilous taxa whose pollen show scant lateral travel falling almost directly to the floor.

According to de Porras et al. (2009), *C. integerrima* is over-represented in those ravine surface samples where its percentages are over 45%. This species over-representation would be a consequence of the balance among the pollen production, the pollination characteristics (entomophilous) and the spatial distribution in mono-specific thickets.

6.2. Cave floor pollen assemblages

CLU and CLC floor pollen assemblages reflect the tall to medium shrub communities growing within the ravines (Fig. 6a and b) whereas the dwarf shrubs from the surrounding plateaus are under-represented as in the surface pollen assemblages (Figs. 3 and 4). The cave pollen assemblages from CLU and CLC (Central Plateau) reflect therefore the local vegetation coinciding to that recorded in other caves from England (Coles and Gilbertson, 1994) and Israel (Weinstein-Evron, 1994) but differing from caves at southeastern Spain whose modern pollen assemblages reflect both local and regional vegetation (Navarro et al., 2001).

The differences between CLU and CLC pollen assemblages may be related to the minor vegetation differences between the ravines (T1 and T2). Cave orientation is not an important factor affecting CLU and CLC pollen assemblages maybe due to the slight differences between the caves entrances which face to the west and northwest, respectively but also due to the wide and random distribution of the dwarf-scrub and medium to tall shrub communities. These results differ from those found at Mount Carmel (Israel) where differences between the floor pollen assemblages from two closely located caves but on opposite facing slopes were related to both, differences in the slopes vegetation and the caves entrances orientation (Weinstein, 1981). Cave topographic position seemed not to affect CLU and CLC pollen assemblages. If so, the dwarf-shrub community from the surrounding plateaus should be better reflected in CLU than in CLC because of the higher and consequently, closer position to the plateau. Conversely, Coles and Gilbertson (1994) determined that the differences between the cave pollen assemblages at Creswell Crags gorge (England) were mainly related to the differential topographic position together to the vegetation distribution at the local scale as well as to the microclimatic circulation dynamics within the caves.

Plants located at the entrances of CLU and CLC do not seem to cause screening and filtering effects, contrary to that found in other caves at the Central Plateau (Los Toldos; de Porras et al., 2009) (Fig. 1a). These differences might be related to the fact that CLU and CLC entrances are just surrounded by plants whereas the plants cover almost completely the cave entrances at Los Toldos. However, plants growing close to CLU and CLC entrances (*C. integerrima* and Asteraceae subf. Asteroideae) are over-represented in the cave surface pollen assemblages located closest to the entrances, as registered in Los Toldos (de Porras et al., 2009).

The differential heterogeneity of pollen assemblages within CLU and CLC (Fig. 6) may be the result of the differential post-depositional disturbance in both caves. Thus, the lower heterogeneity of the pollen assemblages in CLC from the entrance to the rear could be due to the slight post-depositional mixture of the surface sediment by human and animal trample while the higher heterogeneity (samples are ordered according to their position within the cave, Fig. 6) in CLU could be a consequence of the low disturbance that kept the differences between the chambers.

The spatial heterogeneity of the pollen assemblages within CLU and CLC might be explained either by differential preservation or the existence of entrance-rear gradients in the caves, as recorded in other caves (Coles and Gilbertson, 1994; Navarro et al., 2001; Weinstein-Evron, 1994). On one hand, differential preservation might not be a feasible cause since CLU and CLC floor pollen assemblages showed low indeterminate pollen percentages (<2%) and higher total pollen concentration than the surface samples. On the other hand, anemophilous and entomophilous taxa's entrance-rear gradients were scarcely distinct (Fig. 4), contrary to that recorded in most of the caves from England (Coles and Gilbertson, 1994), southeastern Spain (Navarro et al., 2001; Prieto and Carrion, 1999) and USA (Burney and Pigott Burney, 1993). The presence of entrance-rear gradients implies that the frequency of pollen airfall deposited decreases with increasing the distance into the caves (Burney and Pigott Burney, 1993; Coles and Gilbertson, 1994; Navarro et al., 2001) whereas the pollen introduced through biotic transport (faeces, fur and paws) increases (Navarro et al., 2001). The entrance-rear gradients found in the other caves also suppose the existence of exclusive relationships between the pollen deposition pathways and the pollination of the plant taxa (airfall-anemophilous and biotic-entomophilous). However, these relationships would not be as exclusive in CLU and CLC as in other caves since both are biotically rich (mainly related to sheep) and therefore, the spatial variability of pollen assemblages is conditioned by the animal's behaviour and diet. For example, the high percentages of anemophilous taxa such as Poaceae in chamber III (CLC; Fig. 4b) and Asteraceae subf. Asteroideae in the passage (CLU; Fig. 4a) do not follow the expected gradients and might be consequence of biotic transport. Similar deposition patterns of anemophilous taxa pollen found in caves at Spain with similar morphology to that of CLU and CLC were also interpreted as the result of biotic transport (Navarro et al., 2001).

Other evidence of biotic transport within CLU and CLC is the total pollen concentration increase to the rear (Figs. 4 and 5). Even though this pattern differs from that recorded in other caves with narrow and long chambers from southeastern Spain (Navarro et al., 2001) and England (Coles and Gilbertson, 1994), it matches that recorded in caves without passages and a single entrance at Spain (Navarro et al., 2000; Prieto and Carrion, 1999) where biotic and aquatic pollen deposition dominated to the rear of the caves.

The joint increase of the total pollen concentration, the organic matter index and the *Sporormiella* percentages (Fig. 5) demonstrate that biotic pollen transport is particularly important to the rear of both caves. However, the biotic vectors might have been different in CLU and CLC. The high percentages of *Sporormiella* to the rear of CLC (Fig. 5e) point out sheep faeces disintegration due to trampling as the main pathway. On the other hand, the low percentages of *Sporormiella* at the rear of CLU (Fig. 5f) indicate sheep faeces as a minor source of pollen so that the major biotic transport might have been through the plant remains taken by the rodents into the cave.

Nevertheless, the presence of prominent entrance-rear gradients within CLU and CLC should not be completely dismissed considering that both (anemophilous–entomophilous) gradients might be superimposed since the cave floor pollen assemblages include pollen airfall and biotically transported. Furthermore, the spatial variability of the cave pollen assemblages could be also associated with other factors such as the cave internal topography and morphology.

7. Final remarks

Our results of modern cave pollen taphonomy at the Patagonian steppe indicate that modern cave pollen assemblages are a reliable source to infer the surrounding vegetation at the local scale. However, as seen in other biologically rich caves, the search of general trends on pollen taphonomic processes is at present difficult to achieve since they are strongly associated to the animal's behaviour. The differences between CLU and CLC pollen assemblages are related to minor local vegetation differences between ravines. On the other hand, pollen assemblage differences within CLU and CLC might be associated to entrance-rear gradients which are strongly conditioned by biotic transport particularly by sheep and rodents. However, other factors such as the cave internal topography and morphology together to the microclimatic circulation should be evaluated in the future to asses a more complete knowledge of the Patagonian steppe caves pollen taphonomy. The development of further research on taphonomic processes applying traditional and new techniques would also lead to interesting improvements on the inferences from this kind of depositional environments.

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