Palynology of surface sediments from caves in the Zagros Mountains (Kurdish Iraq): patterns and processes.

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Abstract

Cave palynology has been widely used to reconstruct past vegetation in areas where other conventional sources of pollen are scarce. However, the mechanisms involved in pollen transport, deposition and accumulation in caves are still poorly understood, mostly because of the number of interplaying factors that affect these processes. In this paper we explore some of these factors further by assessing differences in pollen assemblages in transects of surface samples from six caves in the Zagros Mountains of Kurdish Iraq. Simple sac-like caves show a clear pattern in pollen distribution with anemophilous taxa declining from the highest percentages near the front of the cave to lower percentages at the rear of the cave and entomophilous taxa showing the opposite trend. There is a tendency for this pattern to be most marked in caves which are narrow in relation to their length. It is less clear at Shanidar Cave, most probably because of the geometry of the cave but also because of the disturbance and mixing of the superficial sediments caused by the large numbers of people visiting the cave. Only one of the sampled caves shows a different pattern, which is likely to reflect its geomorphological complexity and, consequently, its air circulation. Other factors, such as the presence of a cave

entrance flora, are considered but here they seem to have little influence on the pollen assemblages, contrary to that found in temperate-zone caves.

Keywords: Caves, Palynology, Taphonomy, Zagros Mountains, Vegetation

1. Introduction:

The central Near East has always been an area of particular interest for archaeology and prehistory because it is a location through which European, Asian and African populations interchanged. It is also a hearth of early domestication of plants and animals (Solecki, 1963). In comparison with Europe, however, the history of vegetation and climate change in this critical region has been the object of relatively few studies with most of them undertaken in Turkey, Iran and Syria (e.g. Van Zeist and Bottema, 1977; Van Zeist and Woldring, 1978; Bottema and Woldring, 1984; Van Zeist and Bottema, 1991; Bottema, 1975, 1995; Litt *et al*., 2009, 2011, 2012, 2014; Kaplan, 2013; Pickarski *et al*., 2015; Beug and Bottema, 2015; Van Zeist and Bottema, 1977; Djamali et al., 2008; 2009; 2011; Nickewski and van Zeist, 1970; Deckers *et al*., 2009). For many years, the only pollen-based palaeoenvironmental work in Iraq was by Arlette Leroi-Gourhan on the Shanidar Cave deposits (Solecki and Leroi-Gourhan, 1961; Leroi-Gourhan, 1968, 1975, 1998, 2000). Shanidar Cave is an important Mousterian site located in the Zagros Mountains in the northeast of the country. This site is particularly important because a substantial number of Neanderthal skeletons were recovered in the 1950s and 1960s (Solecki, 1963). The context of one of these skeletons, Shanidar IV, was studied palynologically by Leroi-Gourhan (1975). The area around the skeleton contained clumps of pollen of spring flowers, which led Leroi-Gourhan (1975) and Solecki (1975, 1977) to the conclusion that complete flowers were deposited with the body as part of a funerary ritual. This interpretation caused considerable controversy (e.g. Sommer, 1999) but the political situation in Iraq prevented reassessment of the cave deposits at Shanidar for many years.

As part of the re-excavation and reassessment of the archaeology of Shanidar Cave (Reynolds et al. 2016) we have conducted pollen taphonomic work at Shanidar and other caves in the High Zagros with the aim of reaching an understanding of the processes leading to the pollen assemblages reported by Leroi-Gourhan (1975) and of the palynological sequence in the cave (Leroi-Gourhan 1968, 1975, 1998, 2000). Our preliminary reassessment of this remarkable find suggests that other processes than those suggested by Leroi-Gourhan (1975) may have been implicated in forming the clumps of pollen that she linked with complete flowers (Fiacconi and Hunt 2015). Shanidar Cave is, however, a major tourist destination, visited by hundreds of people a day during the spring and early summer, and the superficial deposits in the cave have been much disturbed by visitor footfall. It is therefore necessary to examine the taphonomic signature of other similar caves which are not affected by visitor presence, but are close to Shanidar Cave, in order to better evaluate the hypotheses of Leroi-Gourhan (1975) and Solecki (1975, 1977).

2. Pollen taphonomy in cave environments

In the last few decades, cave palynology has been widely used to reconstruct the past vegetation at local and regional scales, especially in arid and semi-arid areas where other depositional environments suitable for preserving pollen are scarce (e.g.

Gale et al., 1993; Carrion et al., 1999; Hunt et al., 2011; de Porras et al., 2011; Edwards et al., 2015). However, the mechanisms involved in pollen transport, deposition and accumulation inside caves are still under investigation because of the number of interconnected factors that can affect them. These include

- environmental setting of the cave, including issues such as aspect and exposure to prevailing winds (e.g. Weinstein, 1983) and properties of vegetation outside the cave (e.g. Coles & Gilbertson, 1994; de Porras et al., 2011);
- geomorphology of the cave, including number and size of entrances, complexity of the cave network and air-circulation patterns (e.g. van Campo & Leroi-Gourhan, 1956; Coles et al., 1989; Coles & Gilbertson, 1994; Simpson & Hunt, 2009);
- inputs of pollen via drip waters and fluvial processes (e.g. Peterson, 1976; Coles et al., 1989; Genty et al., 2001);
- presence of cave entrance-flora (e.g. Hunt & Gale, 1986; Coles et al., 1989; Coles & Gilbertson, 1994)
- activities of animal and human vectors (e.g. van Campo & Leroi-Gourhan, 1956; Bottema, 1975; Bright & Davis, 1982; Davis & Anderson, 1987; Coles et al., 1989; Hunt & Rushworth, 2005; Fiacconi & Hunt, 2015).

Experimental studies undertaken during the last fifty years in caves in different areas of the world, and especially in Spain, have shown the presence of some general patterns in pollen distribution in this kind of environments even if the local characteristics can have a strong influence in the final pollen assemblages. In general, those studies (van Campo & Leroi-Gourgan, 1956; Burney & Burney, 1993; Coles & Gilbertson, 1994; Prieto & Carrión, 1999; Camacho et al., 2000; Navarro et al., 2001; Navarro et al., 2002; Hunt & Rushworth, 2005; de Porras et al., 2011) identified:

- the importance of the cave morphology, with small cave mouths and narrow shapes related to lower pollen concentration
- a decline of anemophilous/airfall pollen with distance from the cave mouth contrasting with greater importance of animal-transported pollen near the back of the cave;
- higher pollen concentrations in caves with high human and animal presence;
- good agreement between cave assemblages and those on open-air sites nearby;
- generally good representation of the vegetation at a local scale but often an under-representation of arboreal pollen and over-representation of fern spores;
- the positive impact of dryness in pollen preservation;
- the relevance of post-depositional processes such as differential preservation.

Clearly, the influence of these factors is quite variable. In this paper we explore some of them further by assessing differences in pollen assemblages in transects of surface samples from six caves in the Zagros Mountains of Kurdish Iraq. Most of the caves studied are simple phreatic remnants in morphology, none have streamways, all have little or no entrance flora and all have comparatively low levels of ingress of drip-water. They are therefore relatively simple systems in which to explore factors such as aspect and the influence of animal vectors relative to deposition of windblown pollen. The present study aims to understand the mechanisms involved in pollen transport and deposition in this kind of environment and the influence of the factors mentioned above on the composition of the related pollen assemblages.

3. Environmental setting

The study area is located in the northern part of Iraq within the Irano-Analatolian phytogeographic region (Guest and Al-Rawi, 1966). This region is species-rich, with altitudinal and topographic influence on the composition of the vegetation, which is characterised by zones of forest, steppe, halophytic and psammophytic vegetation (Fig. 1a). The caves studied in this paper are located within the mountain-forest zone, situated in the western slopes of the Zagros Mountains. The zone lies altitudinally between 500 and 1750-1800 m (Fig. 1b).

The main arboreal element of the forest is *Quercus* (*Quercetum aegilopidis*, *Quercetum aegilopidis-infectoriae* and *Quercetum infectoriae-libani*), while in some small areas near Mosul *Pinus halepensis* var. *brutia* is predominant. In undisturbed areas the tree cover is high, resulting in a closed forest that becomes an open forest in more densely populated places, since near villages, trees are slashed (their side branches are removed) to provide winter fodder for goats. Steppe vegetation can completely replace forest in those areas were the trees have been over-exploited and in dry places (Guest and Al-Rawi, 1966). In the study area, close to Shanidar Village, oak forests are rather open and quite heavily grazed, with grass-rich swards between the trees, characterised by abundant wild cereals and a rich herb flora (Fiacconi & Hunt, 2015).

[Insert Figure 1]

The studied caves differ in morphology, aspect, location and human and animal presence (Table 1).

Table 1. Name and characteristics of the caves studied.

Cave	Characteristics
Shanidar Cave	GPS 36˚50’ 0.1” N, 44˚ 13’ 11.8” E, 747 m asl. Cave of phreatic origin; it shows well-developed half-domes and other phreatic features. There are some vadose features, particularly in the network of narrow vadose canyons which open off the right side of the main chamber. There is also a small second chamber to the rear right of the main chamber that is largely infilled with sediment and appears to have no archaeological significance. Until recently the cave was inhabited, during winters, by tribal Kurds with their animals; more recently it has become a popular local tourist destination and it is visited by up to several thousand people per day in the spring and summer. The cave floor is covered by silty organic sands, mostly derived from granular disintegration of the cave roof, with an admixture of aeolian dust and animal dung.
SLS203	GPS 36˚ 42’ 22.3” N, 44˚ 12’ 29.6” E, 581 m asl. Shows a sub-tubular morphology with half-domes characteristic of formation in a phreatic system. An adjacent cave shows vadose features but there are none in SLS203. The cave is single-chambered, but has two entrances and is 36 m long and up to 12 m wide, with the accessible mouth to the south. To the north, the back of the cave opens on to a cliff face and is partially blocked by a drystone wall. During the work in the cave (a period

	of some 10 days) a strong draft came through the northern entrance to the cave. The cave floor is covered by silty highly-organic sands with very abundant dung of sheep and cattle. The cave is still used on occasion by local shepherds to keep their animals safe from wild creatures overnight.
SLS207	GPS 36^0 49’ 12.8” N, 44˚ 14’ 22.1” E, 559 m asl. This cave is developed along a gull, where cambering is dragging the bedrock to the west of the cave outward and downward into the valley which runs parallel to and to the west of the chamber. There are no phreatic or vadose features. The cave is single-chambered, single-entranced, 13 m long, 7 m wide at the front and 2 m at the back, facing north. The cave floor deposits are predominantly inorganic sandy silts, most probably primarily of aeolian origin with some material derived from granular disintegration of the cave walls and roof.
SLS210	GPS 36˚ 49’ 10.1” N, 44˚14’ 15.6” E, 623 m asl. This is a complex phreatic remnant, single-chambered, single-entranced, 6 m long, 8 m wide. The floor deposits are organic silts with occasional animal dung.
SLS215	GPS 36˚ 49’ 8.7” N, 44˚ 14’ 15.3” E, 681 m asl. This is another complex phreatic remnant. It is single-chambered, single-entranced, 6 m long, 8 m wide. The cave floor is composed of slightly gravelly sand and there are seeps on joints to the rear and right side of the cave
SLS218	GPS 36˚ 49’ 37.2” N, 44˚ 14’ 35.3” E, 771 m asl.

	The cave is a phreatic tube remnant, terminated now by highly-cemented rockfall. It is single-chambered, single-entranced, 10 m long, 9 m wide. The cave floor deposits are slightly organic slightly sandy silts, disturbed in places by small-scale shallow irregular digging. The sampling transect was placed to avoid disturbed areas of the cave floor.

4. Material and methods

Caves were located by ground survey and through conversations with local informants. The caves were selected on the basis of their morphological characteristics and human and animal presence in order to understand the influence of those factors on the pollen composition and in particular: single vs double entrances, narrow vs wide shapes and human and/or animal presence or absence. Their locations were noted using handheld GPS units and on a Google Earth image. These GPS locations proved to be unreliable in the narrow, precipitously-sided valleys in the survey area. Locations obtained using GPS, when compared with the Google Earth locations, showed considerable discrepancies.

Surface samples were collected in each cave along a linear transect going from the back to the front of the caves in order to study the influence of sample location in the pollen composition and, in particular, the distribution of anemophilous and entomophilous taxa at different distances from the cave entrance (Fig. 2). At least one sample was collected outside each cave entrance to analyse the different pollen transport and deposition inside and outside the caves and to provide a 'baseline' of the local pollen rain close to the cave. A total of 48 surface samples were analysed (12 from Shanidar Cave, 9 from SLS203, 7 from SLS207, 7 from SLS210, 6 from SLS215 and 7 from SLS218). Additionally, six moss samples from polsters growing on seeps in the east wall of SLS203 were analysed. SLS203 was the only cave where moss polsters were present and they offered an opportunity to compare polster material with the pollen recorded in the surface soil samples, considering the inconsistencies usually noticed between these sampling methods (Cundill, 1991). Finally, four samples of bird droppings, two of droppings of sheep/goats, eight dripwater samples and two pollen trap samples from the period March-August 2016 from Shanidar Cave were analysed for comparative purposes.

Samples were prepared by boiling in potassium hydroxide (KOH) solution to disaggregate the matrix and dissolve the humic material. Carbonate-rich sediments were treated with dilute hydrochloric acid (HCl). Boiling in sodium pyrophosphate ($Na_4O_7P_2$) solution was used for clay-rich sediments (following Bates et al., 1978). Only for samples from Shanidar Cave was it necessary for KOH and HCl treatments to be followed by density separation using a solution of sodium polytungstate (SPT) in water adjusted to a specific gravity of 1.9 in order to separate mineral fragments from organic according to their relative density (Munsterman and Kerstholt, 1996). Samples were stained with aqueous safranin and mounted using glycerine. Pollen grains were identified (with reference to Reille, 1995; Moore et al., 1991 and Faegri and Iversen, 1975) and then counted using an optical microscope (Meiji MT4000 Series with magnification of ×400 and ×1000). Relative pollen percentage frequencies have been calculated on the basis of a pollen sum including all terrestrial pollen and spores including unidentifiable grains to produce the relative pollen diagrams. Unidentified pollen grains reflect the fraction of deteriorated grains and their number was used as an indication of the preservation of the pollen and, therefore, of the environmental conditions where the pollen has been found (Moore et al., 1991).

[Insert figure 2]

2. Results

4.1 Shanidar Cave

Results from Shanidar Cave have already been published in a previous preliminary work (Fiacconi & Hunt, 2015). Here we report the relative pollen diagram (Fig. 3) annotated to show the anemophilous and entomophilous pollen types, while the significance of the results is examined in relation to the findings from the other caves in the discussion. The samples from the transect in Shanidar Cave all show good concentration (187-508 grains per sample) and preservation (87.2-97.7% identifiable grains). Herbs are the more abundant (62.6-93.9-%) followed by trees (0.6-22.6%) and shrubs (1.0-93.9%).

The comparative animal dropping, dripwater and pollen trap data for the cave are shown in Table 2. Very few pollen grains were recovered from these experiments.

[Insert Figure 3]

Table 2. Water samples, pollen traps, goat/sheep dung and bird dropping pollen count from Shanidar Cave..

	Water samples								Pollen traps		Goat/sheep dung		Bird dropping			
Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**1**	**2**	**1**	**2**	**3**	**4**
Poaceae	1	0	0	0	0	0	0	0	1	1	5	3	0	1	0	0
Quercus	0	0	0	0	0	0	0	1	0	1	1	1	0	1	0	0
Brassicaceae	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Fabaceae	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Cyperaceae	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Senecio-type	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Fern spores	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
VAM	0	0	0	0	0	0	0	0	0	0	10	2	0	0	0	0
Indeterminate	0	0	0	0	0	0	1	0	1	1	5	2	0	0	0	0

4.2 Cave SLS203 (Caf Sidar)

Samples from cave SLS203 all show good concentration (241-492 grains per sample) and preservation (92.5-100% identifiable grains) with the exceptions of the two outside samples where a higher percentage of grains (2.2-7.5%) were poorly preserved. Herbs are the more abundant (75.2-97.0%) followed by trees (2.7-10.8%) and shrubs (0.3-5.5%); ferns are also present with a peak in one of the samples (SLS203/S1, 39.4%) from outside the cave probably reflecting the fern-rich flora on the rocky ground outside the cave. The main taxa identified are Poaceae, Asteraceae, Lactuceae, Cyperaceae, Caryophyllaceae and *Quercus*. Anemophilous taxa show higher percentages at the back of the cave, decreasing towards the entrance then increasing again outside, while entomophilous taxa increase from the back to the front of the cave (Fig. 4).

[Insert Figure 4]

The moss polster samples show a very different pattern (Fig. 5). Preservation is good (97.8-99.4% identifiable grains) with herbs showing the highest values (57.3-96.6%) followed by trees (1.7-15.3%) and shrubs (0.0-16.1%). The two samples most distant from the humanly-accessible entrance are characterised by fairly uniform assemblages with very high Lactuceae, high monolete and trilete spores, some cereal sized Poaceae, Chenopodiaceae, *Bidens* type, a little *Quercus* and Poaceae. The next sample is very different, being marked by very high *Centaurea* and *Artemisia*. The three samples near the accessible southern entrance to the cave have very high Chenopodiaceae, some *Quercus* and Rosaceae.

[Insert Figure 5]

4.3 Cave SLS207

The samples show good preservation (100-94.3% identifiable grains) but generally a lower concentration (107-344 grains per sample) compared to the previous cave, especially for the samples from the middle of the transect (SLS207/3, 70 grains). Herbs are the more abundant (12.9-96.7%) followed by trees (1.2-18.35%) and shrubs (0.0-2.4%). Ferns reach high values (71.8% and 50.2%) in the two samples near the cave entrance. The main taxa identified are Lactuceae, Asteraceae, Poaceae, *Quercus*, Caryophyllaceae and Brassicaceae. Cupressaceae and *Pistacia* are almost absent inside the cave but their abundance increases dramatically outside. Anemophilous taxa increase strongly from the back to the front of the cave and zoophilous taxa show the opposite trend (Fig. 6).

[Insert Figure 6]

4.4 Cave SLS210

The concentration and preservation of the pollen are good (313-674 grains per sample and 96.7-99.2% identifiable grains) with the exception of samples SLS210/6 and SLS210/7 (located just inside the cave entrance and outside it, respectively). Herbs are the more abundant (50.2-84.4%) followed by trees (11.1-33.7%) and shrubs (2.0-10.0%). The main taxa identified are Lactuceae, *Quercus*, Asteraceae, Poaceae, *Pistacia* and Brassicaceae. The increase of anemophilous taxa and decrease of entomophilous taxa towards the cave entrance is gradual (Fig. 7).

[Insert Figure 7]

4.5 Cave SLS215

Concentration and preservation of the samples are both good (220-312 grains per sample and 96.8-98.9% identifiable grains). Herbs are the more abundant (30.0-89.1%), followed by trees (4.2-34.5%) and shrubs (0.0-10%) with trees percentage higher compared to the other caves. The main taxa identified are Lactuceae, *Quercus, Pinus*, Poaceae, Asteraceae and Chenopodiaceae. Ferns are present and their percentage increases from the back to the front of the cave. Anemophilous taxa show again the rear to front increasing trend seen before (Fig. 8).

[Insert Figure 8]

4.6 Cave SLS218

The samples from the cave and outside show a good preservation (97.9-99.0% identifiable grains) and a general good concentration (178-300 grains per sample) Herbs are the more abundant followed by trees and shrubs. The main taxa identified are Lactuceae, *Quercus*, Asteraceae, Poaceae and *Pistacia*. Anemophilous taxa increase towards the entrance of the cave where they reach their maximum to then decrease again outside (Fig. 9).

[Insert Figure 9]

5. Discussion

The palynological results obtained from the six caves studied provide interesting insights for understanding the influence of different factors in the formation of cave pollen assemblages and for evaluating the stratigraphic results from Shanidar Cave.

Cave morphology

The morphology of the cave seems to be one of the main element influencing the pollen distribution. In four of the five sac-like caves with a single entrance there is a clear and consistent pattern, with anemophilous pollen showing the highest percentages near the mouths of the caves and declining towards their backs. The distribution of entomophilous pollen is the inverse of this pattern, with higher percentages at the backs of the caves and a decline towards the fronts (Fig. 10). This finding is similar to that noted by van Campo & Leroi-Gourhan (1956), Coles &

Gilbertson (1994), Camacho et al. (2000), Navarro et al. (2001) and de Porras et al. (2011) and it can therefore be regarded as a general pattern.

[Insert Figure 10]

This pattern is most marked in relatively narrow caves, such as SLS207, and less noticeable in broad caves, such as SLS210. This may well be because relatively wider caves are prone to more lateral circulation of air than narrow caves are, thus carrying anemophilous pollen into the rear of the cave. The relationship seems not to be scale-dependant, however, since it is as marked in SLS215, which is a little over 4 m deep, as it is in SLS207 and SLS208, which are both over twice as long. The pattern is considerably less clear at Shanidar Cave probably because its geometry, relatively broad in comparison to its depth, that also influences the air circulation. In fact, on some days during the recent excavations in the cave (Reynolds et al., 2016) there was a noticeable lateral air circulation in the cave, with air entering on the west side of the cave mouth, passing up the west wall, around the rear of the cave, then down the east side and finally exiting from the east side of the cave mouth. The limited results from pollen trapping (Table 2) suggest, however, that the influx of anemophilous pollen to the cave is low (4-6 grains per cm^2 per year) and thus that the anemophilous pollen in the surface sediments of the cave has accreted over a considerable number of years. It is also possible that the pattern at Shanidar Cave has been influenced by other factors (below).

Only at SLS203 there is a different pattern from the sac-like caves that reflects its greater geomorphological complexity. When the cave was surveyed, a few days later when the sample transect was made and later when further work in the cave occurred, there was a strong draft from the narrow north entrance on the cliff-face towards the wider south entrance through which the survey team entered the cave. If this circulation is consistent through the main periods of pollen shedding, it is possible that this might influence the pattern of pollen dispersal within the cave, with the anemophilous pollen deposited preferentially proximal to the point of ingress into the cave.

Human presence

The only cave with a constant and significant human presence is Shanidar. The less clear anemophilous/entomophilous pattern recorded in here might be related to the disturbance and mixing of the superficial cave sediments caused by the thousands of people who visit the cave every year. It is also possible that there may have been contributions to the cave-floor pollen from the numerous bunches of flowers (particularly wild *Anenome* and *Ranunculus* spp., but also commercially-grown roses, lilies and orchids) deposited by them. At Creswell Crags, Coles & Gilbertson (1994) noted that the flow of visitors to Robin Hood's Cave seems to have enhanced pollen deposition in the cave, thus corroborating the similar observation of van Campo & Leroi-Gourhan (1956). At Shanidar, however, the pollen concentration in the surface sediments of this highly-visited cave was sufficiently low that a heavy liquid step was required to obtain countable slides. This might suggest that the visitors did not import very much pollen into the cave on their feet. The rather irregular decline of anemophilous and rise of entomophilous pollen towards the rear of the cave is likely, however, to be at least in part the result of trampling and stirring of the surface sediments in the cave by the feet of visitors.

Animal vectors

We analysed droppings from birds at Shanidar Cave but these contained only very few pollen grains (Table 2), which are unlikely to have impacted on the surface assemblages there. An alternative hypothesis to explain the distribution of pollen on the cave floor in SLS203 might be pollen brought into the cave by the sheep and cattle sometimes kept there overnight, and deposited with the abundant dung on the floor of the cave. The limited analyses of animal dung (Table 2) shows that import of pollen by sheep and cattle is likely to have occurred. The animals were stalled at the rear of the cave and the differences between assemblages at the front and rear of the cave may reflect this patterning. Previous studies underline the great impact that animals can have on pollen influx and distribution, such as the work of Hunt & Rushworth (2005) at the Great Cave of Niah in Malaysian Borneo where birds and bats had a strong influence on the taxonomic pollen composition, especially below their roosting areas where very high numbers of pollen with entomophilous and zoophilous pollination biology had accumulated.

Cave entrance flora

The presence of plants within the Kurdish caves is worthy of note as influencing the pattern of pollen distribution. This is particularly marked in temperate-zone caves in England and France, which can have their mouths largely blocked by ferns (e.g. Hunt & Gale, 1986; Coles et al., 1989). In Kurdish Iraq, ferns were present in few caves. *Adiantum* spp. were noted growing on the walls of SLS207 close to the entrance, but these are small plants which would not have appreciably disrupted air circulation in the cave. These seem to be well-represented by monolete spores in the pollen diagram (Fig. 6). Similarly a few *Adiantum* spp. were noted on the walls of Shanidar Cave, mostly within 5 m of the entrance. These small ferns were, however, several metres from the sampled transect and do not seem to have influenced the pollen diagram appreciably (Fig. 3).

During the spring 2016 season, the very wet weather led to a considerable number of drips appearing within Shanidar Cave. Grasses, *Cardamine* sp., *Ranunculus* spp., *Malva* sp.and seedlings of *Fraxinus* sp. all appeared on the cave floor in response to the drips. Conversation with the custodians of the cave indicated that the appearance of plants in any quantity within Shanidar Cave was a rare occurrence. Nevertheless, it is possible that plants growing there during previous wet years did contribute to the pollen in the cave-floor sediments

Drip water

Pollen may also have been carried by the ingress of water in the drips at Shanidar – although here the quantities of water entering the cave were very small and the quantities of pollen in dripwater samples were minimal (3 pollen grains in eight dripwater samples:Table 2).

Other factors also seem to be operating at Caf Sidar. It can be hypothesised that the three quite different assemblages in the moss polster transect might come from water that was entering the cave through three separate small conduits. The polsters therefore would mostly contain pollen and spores generated by plants growing close to the entrance to the respective conduits, with only a minor part of the pollen load arriving by airfall in the cave. Pollen has previously been shown to enter caves through meteoric waters by Genty et al. (2001). At present these remain untestable hypotheses, awaiting further work.

8. Archaeological and palaeoecological implications

These observations are important for cave-palynological studies in the following ways. First, the fact that there are regular and relatively predictable distribution patterns for pollen in sac-like caves means that sampling location is important in caves of this type. A sampling point near the mouth of a cave will be in a location where anemophilous pollen is well-represented, whereas one near the rear of the cave will have relatively better representation of entomophilous or zoophilous taxa. This patterning will be most marked in relatively narrow caves and less so in broad caves and rock-shelters. Outside the tropics, this phenomenon in turn is likely to influence palaeoecological deductions drawn from the pollen assemblages, particularly at the crude ‘arboreal/non-arboreal’ level, since the anemophilous taxa include many trees whereas the majority of entomophilous taxa are herbaceous or shrubby. A sampling strategy based on a single sample column will reduce ‘noise’ which might otherwise be introduced by moving the sampling point. If multiple localities in a cave are sampled for pollen, it would be advisable to ensure stratigraphic overlap between localities so that such effects could be quantified. In the case of Shanidar Cave, the trench sampled by Leroi-Gourhan (Solecki and Leroi-Gourhan, 1961; Leroi-Gourhan, 1968, 1975, 1998, 2000) lies close to the entrance to the cave and thus her pollen assemblages should reflect a predominance of anemophilous taxa. Some of these assemblages are, however, dominated by entomophilous Asteraceae, raising the possibility either that insect transport was more prominent in the past, or that other taphonomic factors, most probably oxidative and/or microbial degradation of pollen may have influenced their composition.

Second, taphonomic patterns are less predictable in geomorphologically complex caves with multiple entrances. There is no substitute for a preliminary taphonomic study in such caves.

Third, other sources of complexity include inputs from ingressing meteoric waters, human activity, bats and birds, livestock and so on. In some cases it is possible to establish whether these processes have operated in the past. Thus, ingressing meteoric waters may leave characteristic fluvial bedforms in the sediments (e.g. Hunt et al., 2010) or may have led to induration. Vertebrate activity may result in characteristic *fumier* deposits in the case of intensive livestock keeping, or a proportion of guano in the deposits which is often recognisable micromorphologically or chemically (e.g. Shahack-Gross, 2011; Canti & Huisman, 2015 and references therein).

9. Final remarks

This paper presents palynological results from surface sediment transects of six caves in the Zagros Mountains of Kurdish Iraq, exploring primarily the influence of cave morphology and animal vectors in the composition of pollen assemblages. The four simple sac-like caves show a clear and consistent pattern in pollen distribution with anemophilous taxa recording the highest percentages near the mouth of the cave and entomophilous taxa showing the opposite trend.. The same pattern occurs, but less clearly at Shanidar Cave, most probably because of the disturbance and mixing of the superficial sediments by people visiting the cave and because of the geometry of the cave, relatively broad in comparison to its depth. Only Caf Sidar shows an opposite pattern that likely reflects the geomorphological complexity of the cave and, consequently, its air circulation, although other factors, particularly pollen import by animal vectors are also likely to have been involved. These results suggests that the main factors acting in caves in Iraq are the cave morphology and the presence of biotic vectors such as animals, insects and humans. Further research on air circulation and its relation to morphology would lead to a better understanding of pollen taphonomy in caves. Other factors that played an important role in the pollen assemblages of caves elsewhere, such as the presence of entrance flora, seem to be of little importance here, the same can be said for the impact of drip water, even if some kind of influence can be presumed at least in Shanidar Cave and Cave SLS203.

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References

Bates, C. D., Coxon, P. & Gibbard, P. L. (1978). A new method for the preparation of clay-rich sediment samples for palynological investigation. *New Phytologist* 81(2), 459-463.

Beug, H. J., & Bottema, S. (2015). Late Glacial and Holocene vegetation history at Lake Yeniçağa, northern Turkey. *Vegetation history and archaeobotany*, *24*(2), 293-301.

Bottema, S. (1975). The interpretation of pollen spectra from prehistoric settlements (with special attention to Liguliflorae). *Palaeohistoria* 17, 17-35.

Bottema, S. (1995). Holocene vegetation of the Van area: palynological and chronological evidence from Söğütlü, Turkey. *Vegetation History and Archaeobotany*, *4*(3), 187-193.

Bottema, S., & Woldring, H. (1984). Late Quaternary vegetation and climate of southwestern Turkey, Part II. *Palaeohistoria*, *26*, 123-149.

Bright, R. C. & Davis, O. K. (1982). Quaternary paleoecology of the Idaho national engineering laboratory, Snake River Plain, Idaho. *American Midland Naturalist* 21-33.

Burney, D. A. & Burney, L. P. (1993). Modern pollen deposition in cave sites: experimental results from New York State. *New Phytologist* 124(3), 523-535.

Camacho, C. N., Carrión, J. S., Navarro, J., Munuera, M. & Prieto, A. R. (2000). An experimental approach to the palynology of cave deposits. *Journal of Quaternary Science* 15(6), 603-619.

Canti, M. & Huisman, D.J. (2015). Scientific advances in geoarchaeology during the last 20 years. *Journal of Archaeological Science* 56, 96-108.

Carrión, J. S., Munuera, M., Navarro, C., Burjachs, F., Dupré, M. & Walker, M. J. (1999). The palaeoecoloical potential of pollen records in caves: the case of Mediterranean Spain. *Quaternary Science Reviews* 18(8), 1061-1073.

Coles, G. M., Gilbertson, D. D., Hunt, C. O. & Jenkinson, R. D. S. (1989). Taphonomy and the palynology of care deposits. *Cave Science* 16(3), 83-89.

Coles, G. M. & Gilbertson, D. D. (1994). The airfall-pollen budget of archaeologically important caves: Creswell Crags, England. *Journal of Archaeological Science*, 21(6), 735-755.

Cundill, P. R. (1991). Comparisons of moss polster and pollen trap data: a pilot study. *Grana*, *30*(2), 301-308.

Davis, O. K. & Anderson, R. S. (1987). Pollen in packrat (Neotoma) middens: pollen transport and the relationship of pollen to vegetation. *Palynology* 11(1), 185-198.

de Porras, M. E., Mancini, M. V. & Prieto, A. R. (2011). Modern pollen analysis in caves at the Patagonian steppe, Argentina. *Review of Palaeobotany and Palynology* 166(3), 335-343.

Deckers, K., Riehl, S., Jenkins, E., Rosen, A., Dodonov, A., Simakova, A. N., & Conard, N. J. (2009). Vegetation development and human occupation in the Damascus region of southwestern Syria from the Late Pleistocene to Holocene. *Vegetation history and archaeobotany*, *18*(4), 329-340.

Djamali, M., de Beaulieu, J. L., Shah-hosseini, M., Andrieu-Ponel, V., Ponel, P., Amini, A., ... & Brewer, S. (2008). A late Pleistocene long pollen record from Lake Urmia, NW Iran. *Quaternary Research*, *69*(3), 413-420.

Djamali, M., De Beaulieu, J. L., Miller, N. F., Andrieu-Ponel, V., Ponel, P., Lak, R., ... & Fazeli, H. (2009). Vegetation history of the SE section of the Zagros Mountains during the last five millennia; a pollen record from the Maharlou Lake, Fars Province, Iran. *Vegetation History and Archaeobotany*, *18*(2), 123-136.

Djamali, M., Biglari, F., Abdi, K., Andrieu-Ponel, V., de Beaulieu, J. L., Mashkour, M., & Ponel, P. (2011). Pollen analysis of coprolites from a late Pleistocene–Holocene cave deposit (Wezmeh Cave, west Iran): insights into the late Pleistocene and late Holocene vegetation and flora of the central Zagros Mountains. *Journal of Archaeological Science*, *38*(12), 3394-3401.

Edwards, K. J., Fyfe, R. M., Hunt, C. O. & Schofield, J. E. (2015). Moving forwards? Palynology and the human dimension. *Journal of Archaeological Science* 56, 117-132.

Faegri, K. & Iversen, J. (1975). *Textbook of pollen analysis*. Fourth ed. Oxford: Blackwell.

Fiacconi, M. & Hunt, C. O. (2015). Pollen taphonomy at Shanidar Cave (Kurdish Iraq): An initial evaluation. *Review of Palaeobotany and Palynology* 223, 87-93.

Gale, S. J., Gilbertson, D. D., Hoare, P. G., Hunt, C. O., Jenkinson, R. D. S., Lamble, A. P., O'Toole, C., van der Veen, M. & Yates, G. (1993). Late Holocene environmental change in the Libyan pre-desert. *Journal of Arid Environments* 24(1), 1-19.

Genty, D., Diot, M.-F. & O'Yl, W. (2001). Sources of pollen in stalactite drip water in two caves in southwest France, *Cave and Karst Science* 28 (2), 59–66.

Guest, E. & Al-Rawi, A. (1966). *Flora of Iraq, vol. 1*. Baghdad: Ministry of Agriculture.

Hunt, C. O. & Gale, S. J. (1986). Palynology: A neglected tool in British cave studies. In *New Directions in Karst,* 323-332. Norwich: Geo Abstracts.

Hunt, C. O. & Rushworth, G. (2005). Pollen taphonomy and airfall sedimentation in a tropical cave: the West Mouth of The Great Cave of Niah in Sarawak, Malaysian Borneo. *Journal of Archaeological Science*, 32(3), 465-473.

Hunt, C., Davison, J., Inglis, R., Farr, L., Barker, G., Reynolds, T., Simpson, D. & el-Rishi, H. (2010). Site formation processes in caves: the Holocene sediments of the Haua Fteah, Cyrenaica, Libya. *Journal of Archaeological Science* 37*,* 1600–1611.

Hunt, C. O., Brooks, I., Meneely, J., Brown, D., Buzaian, A. & Barker, G. 2011. The Cyrenaican Prehistory Project 2011: Late-Holocene environments and human activity from a cave fill in Cyrenaica, Libya. *Libyan Studies* 42, 77-87.

Kaplan, G. (2013). Palynological analysis of the Late Pleistocene terrace deposits of Lake Van, eastern Turkey: Reconstruction of paleovegetation and paleoclimate. *Quaternary International*, *292*, 168-175.

Leroi-Gourhan, A. (1968). Le Néanderthalien IV de Shanidar. *Bulletin de la Société préhistorique française. Comptes rendus des séances mensuelles*, 79-83.

Leroi-Gourhan, A. (1975). The flowers found with Shanidar IV, a Neanderthal burial in Iraq. *Science*, *190*, 562-564.

Leroi-Gourhan, A. (1998). Shanidar et ses fleurs. *Paléorient*, 79-88.

Leroi-Gourhan, A. (2000). Rites et langage à Shanidar?. *Bulletin de la Société préhistorique française*, *97*(2), 291-293.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., Franz, S.O., Ülgen, U.B., Niessen, F., (2009). “PALEOVAN”, International Continental Scientific Drilling Program (ICDP): site survey results and perspectives. Quat. Sci. Rev. 28, 1555e1567.

Litt, T., Anselmetti, F.S., Çagatay, M.N., Kipfer, R., Krastel, S., Schmincke, H.-U., Sturm, M., (2011). A 500,000-year-long sediment archive drilled in eastern Anatolia. EOS Trans. Am. Geophys. Union 92 (51), 477e479.

Litt, T., Anselmetti, F.S., Baumgarten, H., Beer, J., Çagatay, N., Cukur, D., Damci, E., Glombitza, C., Haug, G., Heumann, G., Kallmeyer, J., Kipfer, R., Krastel, S., Kwiecien, O., Meydan, A.F., Orcen, S., Pickarski, N., Randlett, M.-È., Schmincke, H.-U., Schubert, C.J., Strum, M., Sumita, M., Stockhecke, M., Tomonaga, Y., Vigliotti, L., Wonik, T., The PALEOVAN Scientific Team, (2012). 500,000 years of environmental history in Eastern Anatolia: the PALEOVAN drilling project. Sci. Drill. J. 14, 18e29.

Litt, T., Pickarski, N., Heumann, G., Stockhecke, M., & Tzedakis, P. C. (2014). A 600,000 year long continental pollen record from Lake Van, eastern Anatolia (Turkey). *Quaternary Science Reviews*, *104*, 30-41.

Moore, P.D.,Webb, J.A. & Collison,M.E. (1991). *Pollen Analysis*. Oxford: Blackwell Scientific Publications.

Munsterman, D. & Kerstholt, S. (1996). Sodium polytungstate, a new non-toxic alternative to bromoform in heavy liquid separation. *Review of Palaeobotany and Palynology*, 91(1), 417-422.

Navarro, C., Carrión, J. S., Munuera, M. & Prieto, A. R. (2001). Cave surface pollen and the palynological potential of karstic cave sediments in palaeoecology. *Review of Palaeobotany and Palynology* 117(4), 245-265.

Navarro, C., Munuera, M., Prieto, A. R. & García, J. S. C. (2002). Modern cave pollen in an arid environment and its application to describe palaeorecords. *Complutum* 13, 7-18.

Niklewski, J., & Van Zeist, W. (1970). A Late Quaternary pollen diagram from northwestern Syria. *Acta Botanica Neerlandica*, *19*(5), 737-754.

Peterson, G. M. (1976). Pollen analysis and the origin of cave sediments in the central Kentucky karst. *Bulletin of the National Speleological Society* 38, 53-58.

Pickarski, N., Kwiecien, O., Djamali, M., & Litt, T. (2015). Vegetation and environmental changes during the last interglacial in eastern Anatolia (Turkey): a new high-resolution pollen record from Lake Van. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *435*, 145-158.

Prieto, A. R. & Carrión, J. S. (1999). Tafonomía polínica: sesgos abióticos y bióticos del registro polínico en cuevas. *Asociación Paleontológica Argentina* 6, 59-64.

Reille, M. (1995). *Pollen et Spores D'Europe et D'Afrique Du Nord. Supplement 1*. Marseille: Laboratoire de botanique historique et palynology.

Reynolds, T., Boismier, W., Farr, L., Hunt, C., Abdulmutalb, D. & Barker, G. (2016). New investigations at Shanidar Cave, Iraqi Kurdistan. Kopanias K. & MacGinnis J. (Eds.) *The Archaeology of the Kurdistan Region of Iraq and Adjacent Regions*. (pp. 369-372). Oxford: Archaeopress.

Shahack-Gross, R. (2011). Herbivorous livestock dung: formation, taphonomy, methods for identification, and archaeological significance. *Journal of Archaeological Science,* 38, 205-218.

Simpson, D. J. & Hunt, C. O. (2009). Scoping the past human environment: a case study of pollen taphonomy at the Haua Fteah, Cyrenaica, Libya. *Archaeological review from Cambridge*, 24(2), 27-46.

Solecki, R. S. (1963). Prehistory in Shanidar valley, northern Iraq. *Science*, *139* (3553), 396-396.

Solecki, R. S., & Leroi-Gourhan, A. (1961). Palaeoclimatology and archaeology in the Near East. *Annals of the New York Academy of Sciences*, *95*(1), 729-739.

Sommer, J. D. (1999). The Shanidar IV ‘Flower Burial’: A re-evaluation of Neanderthal burial ritual. *Cambridge Archaeological Journal* 9(1), 127-129.

van Campo, M. & Leroi-Gourhan, A. (1956). *Notes préliminaire à l'étude des pollens fossiles de différents niveaux des grottes d'Arcy-sur-Cure*.

Van Zeist, W., & Bottema, S. (1977). Palynological investigations in western Iran. *Palaeohistoria Bussum*, *19*, 19-85.

Van Zeist, W., & Bottema, S. (1991). *Late quaternary vegetation of the near East*. Reichert.

Van Zeist, W., & Woldring, H. (1978). A postglacial pollen diagram from Lake Van in East Anatolia. *Review of Palaeobotany and Palynology*, *26*(1), 249-276.

Weinstein, M. 1983. The influence of slope direction on the pollen spectra*. Pollen et Spores*, 23, 381-387.

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