УДК 902.67 (365)

PALINOLOGICAL ANALISIS OF COUPLED SEDIMENT-CONTROLE SAMPLES: THE POLLINIC TAPHONOMI FROM THE MIDDLE PALEOLITHIC LEVEL M OF ABRIC ROMANI (CAPELLADES, SPAIN)

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The analysis of coupled coprolite and surrounding sediment samples from the archaeological level M (Middle Paleolithic) of the Abric Romaní rock shelter (north-eastern Spain) has proven an efficiency of palynological studies of coprolite samples. Although pollinic concentration in both coprolite and surrounding sediment samples is relatively low, the research provides reliable taphonomical and paleoenvironmental data. Thus, hyena dietary habits do not influence coprolite pollen spectrum. Reconstructed vegetation communities reflect unstable climatic conditions of MIS 3 and comprise variety of opened and closed vegetation communities. Based on non-pollen palynomorph analysis local environmental conditions are reconstructed.

Keywords: *Paleoenvironment, Pollen and non-pollen palynomorphs analysis, Middle Paleolithic, MIS 3, Abric Romaní, Pollen taphonomy*

Introduction

Cave palynology, as well as coprolite pollen analyses enables the strengthening of the regional paleoenvironmental reconstructions based on continental deposits analysis. The Abric Romaní cave deposits and coprolite samples give an opportunity to obtain information for the dry region of north-eastern Spain, where conventional palynological researches are less effective because of bad preservation of pollen grains. The regional data, coming directly from the investigated area provide a basis for reliable paleoenvironmental reconstructions and enable direct correlation of multi-proxy data, avoiding interpolation of the data from other regions. The aim of the current research is taphonomic study of the coupled coprolite – surrounding sediment samples from the archaeological level M (Middle Paleolithic) of the Abric Romaní rock shelter. Both pollen analysis and non-pollen palynomorphs study were carried out to get information about regional (pollen) and local (non-pollen palynomorphs) environment. The reliability of the coprolite analyses was verified by comparison of the results to pollen spectrum of the surrounding sediment and data available from the former palynological study of the corresponding level of the Abric Romaní calcium carbonate deposits.

Abric Romaní is a travertine rock shelter providing a unique environmental and archaeological record spanning the Late Pleistocene and Early Holocene of north-eastern Iberia and corresponding to the period, when *Homo neanderthalensis* was present on the Iberian Peninsula. The sequence dated at the present day between 70 and 40 ka is characterised by high temporal resolution within a well-calibrated chronology, which enables detailed archaeological and paleoenvironmental implications. Due to its location, Abric Romaní is a source of information about the territory significant for the *Homo neanderthalensis* dispersal on the Iberian Peninsula and environmental context of the corresponding period. The emergence of early modern Europeans and the fate of the Neanderthals are major topics in human evolution research and this is especially so in the Iberian Peninsula because, south of the *Ebre* basin (the «*Ebre* frontier»), Neanderthals seem to have persisted longer than elsewhere in Western Europe [45; 21; 46; 18].

Abric Romaní rock shelter gives wide possibilities for interdisciplinary studies, providing several proxy-data – micro- and macro-fauna, palynological and anthracological data, as well as archaeological material. The stratigraphy of the cave is pronounced and allows reconstruction of formation processes and corresponding climatic and hydrological conditions. The main part of the studied Abric Romaní stratigraphy was formed during Marine Isotope Stage MIS 3, and only the bottom layers correspond to MIS 4.

Abric Romaní: Presentation of the site

The Abric Romaní is a wide rock shelter («*abric*» in Catalan) in a travertine cliff called *Cinglera del Capelló*, located in a karstic landscape near Capellades (Barcelona, Spain) on the west bank of the Anoia River, 50 km west of Barcelona (UTM Zone 31T, E 390695.5, N 4599032) [37]. The Abric Romaní has an elevation of 317 m a.s.l. and 50 m above a narrow gorge of the Anoia River [39].

Two main lithological units characterise the stratigraphy of Romaní rock shelter. The uppermost unit, composed of 3 m of red silts and sands, is an aeolian deposit and was largely removed by early excavations. The basal unit, with a minimum thickness of 17 m, is mainly composed of tufa, tufa gravels, carbonate sands and silts [4; 12; 44]. The sequence has yielded a series of U/Th dates between 70 and 40 ka cal BP, with only the bottom layers coresponding to Marine Isotope Stage (MIS) 4 and the main part of the studied Abric Romaní stratigraphy to MIS 3 [10].

At the Abric Romaní all excavated levels belong to the Middle Paleolithic, except the uppermost level A which belongs to the Early Upper Paleolithic. The sequence is formed by a succession of well stratified travertine platform, where the archaeological levels appear as sandy layers interstratified and well delimited in between those platforms [19]. Several lines of evidence emphasize the differences between the rock shelter interior, where occupation was more intense, and the exterior [37].

The botanical data have been yielded by palynological and anthracological sequences. The pollen sequence includes the entire known deposit, and the charcoal record comes from the different excavated layers and has an anthropic origin [10]. The summarised paleobotanical studies reveal very low variability of taxa. The sequence is mainly related to pine forests, and near or within these dominant forests there were smaller plant formations and/or secondary species with a Mediterranean and/or Atlantic character: a patchy landscape, with different vegetation assemblages including forests, riverside forests, prairies, and steppes with more or less humid connotations. This landscape has no present analogy [38], as such rapid and abrupt climatic changes have not occurred again since then [10].

Materials and methods

The studied level M is located beneath 8-cm-thick coarse tufa platform and has a maximum thickness of 44 cm, although archaeological remains are concentrated within a maximum thickness of 20 cm. The excavated area is about 180 m^2 and has a high density of artefacts, including faunal and lithic remains, hearths, and plant remains (charcoal and wood imprints) [37]. The travertine layer on the top of the archaeological level M is dated to 51.8 ±1.4 ka (Ref.Lab. 02-23) and 61.7 ±2.2 ka (Ref. Lab. 03-67) by the U/Th dating method [40]. It corresponds to MIS 3 which is characterised as a cold period, alternating with warmer and more humid phases [6]. Previous pollen analysis revealed a higher number of taxa that were probably located in the surroundings of the shelter. Open habitat taxa, such as Poaceae, *Artemisia*, and *Pinus*, were identified, whereas in the more temperate periods taxa like *Quercus*, cf. *Juniperus*, *Olea-Phillyrea*-type, *Pistacia*, or *Cistus* are present [6; 19].

Among the samples collected during the excavation season 2002, 12 coupled coprolite – surrounding sediment (coprolite periphery) samples were chosen for palynological analysis to enable comparison between these two kinds of samples. The coprolite producing agent is identified at the field as spotted hyena (*Crocuta crocuta*). This explains the position of the samples: in living spotted hyenas, social defecation tends to occur not far from the cave opening [5] and the Abric Romaní level M coprolite samples were discovered near or close to the cave entrance (K, L, and M squares lines), on or outside the conjectural drip line (Fig. 1).

The samples were treated using the protocol proposed by Goeury and Beaulieu (1979), slightly modified by the elimination of acetolysis (which enables distinguishing of modern pollen grains due to preservation of protoplasm of the pollen grains, clearly visible under the microscope) according to Girard and Renault-Miskovsky (1969), and the protocol developed by Burjachs et al. (2003). The procedure included the following key steps: Hydrochloric acid sediment reduction *(HCl, 50%)* for removing of the carbonates from the carbonate-rich travertine samples; Sodium hydroxide *(NaOH, 10%)* digestion to break up the matrix and dissolves the humic materials; Thoulets heavy liquid (water solution of Potassium Iodide (*KI)* and Cadmium Iodide (*CdI*) with a specific gravity 2.1 g/cm^3, which allows pollen to float on its surface) flotation to concentrate pollen grains and non-pollen palynomorphs contained in the sample with subsequent filtration through the glass filter; Hydrofluoric acid *(HF, 70%)* treatment aims for destruction of glass fibre filter as well as removal of silicates and clay materials; Hydrochloric acid *(HCl, 50%)* processing aims for removing of silicofluorides formed during the Hydrofluoric acid treatment and colloidal silicon dioxide (SiO_2); conservation of the residue and mounting the slides. The slides were counted on an optical microscope (*Nikon* SE) at 600x magnification (15x eyepiece used with a 40x objective lens). The total sum of approximately 300 pollen grains (including *Pinus*) were counted. For some slides it was not possible to count this amount. In these cases, every line was counted until the end of the slide was reached. For non-pollen palynomorphs two lines of each slide were counted. Identifications were made using the pollen reference collection of IPHES (Tarragona, Catalonia, Spain) and pollen atlases of Moore et al. (1991) and Reille (1995; 1998; 1999), van Hoeve & Hendrikse (1998) and van Geel (1978). Calculations and pollen and NPP diagrams elaboration were carried out using the TILIA 1.7.16 software [24; 25].

Results

Pollen data. Taphonomic analysis. Palynological characteristics of the studied samples are given in Table. 4.1. Results of palynological study of the samples are presented as pollen diagrams. Occurrence of taxa is expressed as absolute frequencies, calculated as pollen grains per gram of dried sediment (volumetric method, Loublier, 1978), and relative frequencies (%) of pollen of each taxon in total pollen sum of arboreal and herbaceous plants of this sample, excluding Cyperaceae (local taxon). Exclusion of Cyperaceae is a common practise when dealing with small specific areas, where the local pollen source can predominate over the regional contribution [33]. The *Pinus* pollen wasn't excluded from the pollen sum in this case, because abundance of pine trees in the surroundings of the site during the studied period is confirmed by anthracological data [1; 8; 9].

«Indeterminate» and «indeterminable» pollen grains were also excluded from the pollen sum. Their percentage in a sample was calculated as a sum of arboreal and herbaceous plants in each sample plus amount of «indeterminate» / «indeterminable» pollen grains in this sample related to the amount of indeterminate pollen grains in this sample.

Some post-depositional contamination by modern pollen grains is observed in all samples except of K41-15B coprolite sample.

Pollen concentration (PC) is higher in the surrounding sediment samples, being, however, generally very low for all samples. Pollen taxa diversity is intermediate, with 45 types in total, equal or exceeding 15 types in most samples. The diversity of herbaceous plants (24 taxa) is only insignificantly higher than that of arboreal ones (21 taxa) (Fig. 2, 3). Both arboreal and non-arboreal taxa diversity is higher in the surrounding sediment samples (Table 1).

The main pollen dominant in both coprolite and sediment samples is *Pinus*, with the highest content of 70% and an average content of 57,4% (Fig. 2). Other arboreal taxa don't reach high concentration, having the highest value for *Quercus deciduous* (12.1%), an average content – 5,4%, and *Quercus ilex-coccifera* – 7,7% as the highest and 1,4% as an average (Fig. 2). Non-arboreal plants reach relatively high values in some samples: *Artemisia* (highest value – 23,8%, average content – 9,0%), *Poaceae* (highest value – 15,8%, average content – 5,3%) and Asteraceae (Asteraceae tubuliflorae-type – 12,5%, Asteraceae liguliflorae-type – 24,0%; an average content of 4,2% and 5,7% respectively) (Fig. 2). Other common non-arboreal types, represented in most of the samples, although not reaching high concentrations, are (an average content): Chenopodiaceae (1,2%), *Helianthemum* (2,4%), and Apiaceae (1,0%). Percentage of Cyperaceae (excluded) is quite high in most of the samples, reaching the maximum of 28,9%.

Pollen concentration (Fig. 3) is low for most arboreal and non-arboreal taxa. Taxa, that have higher absolute concentration and non-zero values in most of the samples, are *Pinus* – 6.6 grains x g, *Quercus* deciduous – 8.78 grains x g, and *Quercus ilex-coccifera* – 7.7 grains x g. Herbaceous plants with relatively stable and high concentration are *Helianthemum* (6.1 grains x g), *Artemisia* (18.4 grains x g), Poaceae (7.9 grains x g), Asteraceae tubuliflorae-type (6.7 grains x g), Asteraceae liguliflorae-type (9.3 grains x g) – the highest absolute frequencies values are given. Absolute frequencies of Cyperaceae is relatively high in all samples with the maximal value of 17.2 grains x g.

The pollen content of ecologically significative taxa (Fig. 4) shows great variability, but there is difficult to trace any distinct correlation between pollen frequency fluctuations of different taxa. *Pinus* pollen is present in great amounts in all samples, while other ecologically interesting arboreal types such as *Alnus* and *Olea*, occur sparsely in low concentrations. Although also ecologically significative, such taxa as *Betula*, *Acer*, *Corylus*, and *Viburnum* only occur sporadically (Fig. 3). In contrast, significative herbaceous species, such as *Helianthemum, Artemisia,* Poaceae and Asteraceae are generally abundant.

This comparative diagram (Fig. 4) shows that despite of the low pollen concentration in the samples, there is almost no contradiction between relative frequencies (dependent variable) and absolute frequencies (independent variable). This reinforces the value of the results.

Non-pollen palynomorphs (NPPs) data. As it has been shown by Carrión & Navarro (2002), non-pollen palynomorphs (NPP) records, combined with pollen analysis, can be important for detailed taphonomy and paleoenvironment reconstructions on the local level.

The NPP data on the samples are given in Table 2. Non-pollen palynomorphs where identified in all coprolite and sediment samples and their overall diversity comprise 26 taxa and 2 groups of «*varia*» remains: algae and zoo.

For nomenclature of NPPs of unknown or controversial biological origin, the sequence established by van Geel et al. (1978) was followed. The types indicated by a number can be considered as provisionally, but not formally, named form-taxa [14; 28].

Identified NPPs were grouped into the following categories: spores, algae, fungi and zoo-remains. There is also a category of «undefined» NPPs, including those ones which origin is still unclear.

Spores are only represented by monolete spores, while algae category includes 3 taxa, fungi – 12 taxa, and zoo-remains – 4 taxa. 6 taxa were classified as «undefined». Some of identified algae and zoo-remains were specified as «*varia*» inside the categories, because more precise identification was impossible or unknown.

The non-pollen palynomorphs relative frequency (percentage) diagram (Fig. 6) shows continuous abundance of *Gloeotrichia* algae with the highest value of 41,0% and an average content of 11,4%, together with presence of «*varia* (algae)» in all samples with their maximal content of 28,6% and an average of 4,8%. *Zygnema* and *Spirogyra* only occur sporadically in some samples.

The category of fungi is mostly represented by «hyphae», which are abundant in all samples with the highest content of 43,8% and have an average frequency of 13,0%. Polyporisporites-type occur in some samples, having very high maximal frequency of 46,8%, but relatively low average frequency of 7,5%. Other fungi species only show sporadic occurrence in some samples.

For both of these categories – algae and fungi – maximal values are characteristic for coprolite samples. There is also sporadic occurrence of monolete spores in only one surrounding sediment - coprolite sample couple.

Zoological material is quite frequent and is mostly represented by «type 52» (with the highest frequency of 50,0% and an average frequency of 25,2%). There are also single micro remains of acari, as well as sporadic presence of «type 36» and «type 36c». «*Varia* (zoo)» is presented non-continuously and generally has low frequency (with the highest value of 7,4% and an average content of 2,0%). In this case the highest values were discovered in surrounding sediment samples.

Among the NPPs being placed to the undefined category, «protists» and «type 303» are present continuously and demonstrate quite high frequencies (maximal of 40,0% and 24,3% and an average of 17,9% and 11,8% respectively). Other species are only present in low frequencies in some of the samples.

NPP concentration ranges from 29.4 to 451.0 grains x g in the coprolite samples, and from 26.7 to 173.5 grains x g in the surrounding sediment samples, being thus significantly higher than absolute concentration of pollen grains (Table 1). However, it differs greatly in different samples and for different taxa (Fig. 6).

Comparative diagram of relative and absolute frequencies was constructed for selected significative NPP taxa. In this case some of the algae and fungi taxa were grouped according to the ecological conditions under which they normally occur [142; 17; 41] (Table 3, Fig. 5, 6). Other species were united in two general categories of «zoo-remains» and «indifferent», because their presence does not indicate any specific environmental parameters.

Comparative diagram of non-pollen palynomorphs percentage and absolute frequency generally demonstrates a good correlation of these values.

The M46-7B coprolite sample shows the highest concentration of Polyporisporites (178.3 grains x g), «type 52» (111.9 grains x g), and «type 303» (31.5 grains x g), as well as one of the highest «protists» frequency (35.0 grains x g). Consequently, this sample has the highest total frequency of fungi, zoo-remains, and monolete spores and high total frequency of algae. At the same time this sample has very low absolute concentration of pollen grains (29.8 grains x g) and the highest percentage of indeterminate pollen (18,1%) (Table 1).On the contrary, K41-14B, L41-18B, and K52-10B surrounding sediment samples and K52-20B coprolite sample, demonstrating high absolute NPP frequency (Table 2), show relatively high absolute frequency of pollen grains and relatively low relative frequency of indeterminate pollen at the same time (Table 1). All of these four samples are characterised by high values of *Gloeotrichia*, «hyphae» and «type 52» zoo-remains.

The couple of surrounding sediment – coprolite samples L41-16B – L41-17B, which have the lowest NPP absolute frequency, have intermediate and low absolute frequency of pollen grains respectively, and intermediate relative frequency of indeterminate pollen. *Gloeotrichia* was identified in both of these samples, while *Zygnema* is only present in the L41-17B coprolite sample. Nevertheless algae, including also «*varia* (algae)», comprise the most represented NPP category in these samples. The category of fungi is only represented by «hyphae», and zoo-remains – by «type 52». Both of these samples are also characterised by relative abundance of undefined NPP («protists» and «type 303»).

Discussion

According to Carrión et al. (2004), the reliability of palynological investigations can be estimated basing on pollen counts (more than 200 grains/sample) and taxonomic diversity (above 15 taxa/sample). Not all investigated samples meet these conditions. Taxa diversity is lower than 15 taxa in three of the samples, and the pollen counts range from 96 to 199 in one of these samples and in two other samples. However, as it was pointed out above, the reliability of the results is supported by good correlation of relative and absolute pollen frequency – two independent variables fluctuating in a similar way.

All studied samples demonstrate quite low absolute pollen frequency (grains x g), which is however also typical for most of Abric Romaní palynological samples investigated during the previous studies. Previously studied calcium carbonate sediments of the cave demonstrate absolute frequency of ca. 100 grains x g, with maximal values of about 3000 grains x g at the top and the bottom of the Abric Romaní sequence [6]. In the currently studied samples the highest absolute frequency value is 99.4 grains x g for the surrounding sediment and 77.4 for the coprolite samples. All of the investigated coprolite samples were polliniferous, which can be considered a successful case regarding to the age of the coprolites and existence of partly negative results for the Paleolithic coprolite samples from caves in Spain [36].

The exine thinning in pollen grains, reported for brown hyena coprolites of South Africa [34], and spotted hyena coprolites of north Spain [20] and southern Africa [35] generally wasn’t observed. Pollen preservation in coprolite and surrounding sediment samples is similar.

Due to existence of pine forest in the proximity of the site, *Pinus* pollen is present in high quantities in all samples, indicating climatic and ecological conditions favourable for this taxon. Other arboreal taxa – Cupressaceae (cf *Juniperus*), *Betula*, *Fagus*, *Quercus*, *Acer*, *Castanea*-type, *Tilia*, *Platanus*, *Juglans*, *Syringa*, *Viburnum*, and *Olea* – didn’t participate in the landscape to such extend. Low frequency of *Betula* pollen in the samples agrees with the hypothesis of relatively closed pine forest, as this heliophilous taxon can only inhabit open spaces not occupied by pine.

Acer, which don’t participate in formation of the pine forest, could be a part of mesothermophilous forest of deciduous *Quercus*. This kind of forest was residual at that period of time and was only preserved in microclimatic refuges. Apart from this *Acer* – is a taxon with low pollen productivity. Both of these factors explain low pollen frequency of this taxon in the samples.

Olea and *Viburnum* are taxa that actually constitute a part of evergreen oak forests. They also can be present in thermophilous vegetal formations, which exist on the margins of microclimatic refuges. These taxa only occurred sparsely, having low frequency in the samples, which corresponds to low presence of these plants in the vegetation community.

Other arboreal taxa, such as *Corylus*, *Ulmus*, *Fraxinus*, *Alnus*, and *Salix*, could comprise a part of the riverside wood. Low values of these taxa in the palynological spectrum means that this kind of forest must have been reduced, which indicates that the climate of this period was cold and arid. At the same time Cyperaceae frequency is relatively high, reflecting humid local conditions.

Arid climate favoured the development of dry steppic vegetation communities with presence of *Helianthemum* and *Artemisia*; steppic taxa Asteraceae and *Ephedra* were abundant as well. Cool and dry climatic conditions generally resulted in dominance of bushes and herbs in the landscape.

Some identified taxa reflect an existence of more or less humid conditions of Mediterranean meadows. Most of these taxa – *Plantago*, *Rumex*, Fabaceae, *Euphorbia*, Caryophyllaceae, Scrophulariaceae, Dipsacaceae, Liliaceae, *Galium*, Ranunculaceae, and Apiaceae – have sporadic occurrence in the samples, and only Poaceae shows constant presence in most of the samples.

Based on the previous palynological analysis of the Abric Romaní calcium carbonate sediments [6; 7] level M was characterized by high frequencies of *Artemisia* and Poaceae, a pine forest (pine pollen reaching 68,8%) with up to 33% warm temperate taxa. During the warmer periods (short climatic oscillations) of MIS 3 such mesothermophilous arboreal taxa as cf. *Juniperus, Quercus* spp., *Olea-Phillyrea*-type, *Rhamnus*, and *Fabaceae* and *Scrophulariaceae* herbs were also present in the pollen assemblages [10]. Resulting palynological data can be interpreted as those corresponding to a patchy landscape (Fig. 8), including pine stands, forests and riverside wood, as well as steppe vegetation with more or less humid connotations. The level M pollen spectrum reflects MIS 3 unstable climatic conditions [10; 43]. Although not strongly pronounced on the Iberian Peninsula [6], this climate favoured creation of particular vegetal communities that reflected rapid changes and strong climatic fluctuations. Periods of forest formation alternated with development of semi-arid communities as a response to warm and cool phases respectively [10].

Non-pollen palynomorphs analysis gives additional information as to the local environmental conditions of the site. Four categories of NPPs present in the samples demonstrate existence of various microenvironments (Fig. 9). The category of algae is represented by oligotrophic *Gloeotrichia* algae and mesoeutrophic *Spirogyra* and *Zygnema* which indicate presence of shallow stagnant water [14]; algal zygospores in the coprolites are possibly derived from drinking water [13; 36]. Oligotrophic algae, only represented in the studied samples by one taxon, are nevertheless the most abundant and are present in all samples.

The most abundant group of fungi comprise saprofita fungi *Alternaria*-type and *Helminthosporium*, as well as «type 3Ba», «type 16c», «type 18», indicating the decay of organic matter.

Coprophilous fungi Polyporisporites-type and Exesisporites-type, inhabiting the environments with higher concentration of faecal material and dungs, were identified in both coprolite and sediment samples.

Despite of the abundance of hearths in the archaeological level M, carbonicolous fungi *Chaetomium*-type, corresponding to charcoal accumulation, were only identified in low amount in one sediment sample. The possible explanation is that the samples don't come from the direct proximity of the hearths or burned wood accumulations (Fig. 1).

Glomus spp., which indicate erosion or wood decay (lignicolous fungi), were only present in low frequency in one surrounding sediment sample.

Among the taxa considered «indifferent» stomata gives an interesting information. Although it has been concluded by Solé et al. (2013) that the wood was introduced to the cave by Neanderthals, NPP studies suggest that high frequency of stomata in some samples has natural origin as it doesn't correspond to the wood imprints or hearths (Fig. 1).

According to previous coprolite analysis from Abric Romaní level I [2; 8] all *Crocuta* coprolite specimens were sterile. Thus, the current study of the Abric Romaní coprolite samples is the first successful one. Difference between pollen content and taxa diversity in the coprolite and surrounding sediment samples can be due to influence of the behaviour of spotted hyenas on coprolite pollen spectra, as these might reflect the vegetation of particular areas visited. Spotted hyenas are known to range up to 50 km from their dens (Carrión et al., 2001; Mills, 1989) and disparity in the composition of the pollen spectra in hyena coprolites reflects the existence of a range of habitats in the surrounding area, including pine-dominated forests and steppe-like landscapes with a sparse tree and shrub cover [16; 18]. Thus, reconstructed patchy landscape may be considered representative and not influenced substantially by hyena dietary.

There are no distinct taphonomic differences between coprolite and surrounding sediment samples. All distinctions, when present, are not specific to a particular sample type. *Zygnema* can be considered as the only exception, being generally more abundant in the coprolite samples (Fig. 7).

Pollen analysis of hyaena coprolites may certainly provide valuable information on past vegetation and landscape. But there are surely many pitfalls behind the interpretation of such data, because very little is known on how pollen is incorporated and preserved into hyaena droppings and coprolites, and it is necessary to rely on comparison with pollen sequence of cave infill, which limits the quality of correlation [13].

Conclusions

Investigation of both cave sediments and coprolites is considered «risky» from the palynological point of view [36]. That makes successful investigations of this materials even more important, encouraging following research in this field.

The current study of the Abric Romaní coupled coprolite – surrounding sediment samples from the archaeological level M bears first of all taphonomic character, supporting the palynological results previously obtained for the Abric Romaní stratigraphic sequence. This is the first successful coprolite study for this site and one of the few successful Paleolithic coprolite studies for the northern Spain region (Carrión 2007, 2009).

The palynological results obtained fit well with the character of the MIS 3 vegetation communities. There is a clear evidence of changeable climatic conditions of this period, reflected in the mosaic of open and wooded habitats. Both coprolite and surrounding sediment samples pollen spectra correspond to a patchy landscape including closed pine stands, mixed deciduous forests and riverside wood communities, as well as steppe and Mediterranean meadows vegetation. This kind of landscape can be considered typical for MIS 3 with strong and abrupt climate fluctuations. Two older samples from the sub-level M3 demonstrate lower presence of the arboreal pollen (excluding Pinus), that reflects colder, in respect to the upper sub-level M2, climatic conditions.

Results obtained are also broadly in keeping with previous paleoenvironmental reconstructions for Abric Romaní calcium carbonate sediment for this period [6; 7]. Availability of palynological data on the Abric Romaní sequence gives additional advantage of comparing two types of analysed material. It can be inferred that hyaena coprolite pollen spectrum is not markedly biased compared with the regional pollen rain.

Non-pollen palynomorphs study gives extra information about the local conditions of the cave. Detected NPP taxa indicate presence of the suitable environments for oligotrophic and mesotrophic algae, which inhabit shallow stagnant water (karstic waters in the cave, present during the level M formation), and different types of fungi, specific for the decay of organic matter – coprolites, wood and carbon, as well as saprofita fungi.

Successful results of this study contribute to the experience of coprolite pollen analysis, supporting the opinion, that coprolite can provide reliable information on the vegetation of the surrounding area. An important question of how well pollen spectra in hyaena coprolites are preserved and how well they represent contemporary vegetation can be answered in a positive way in this case, since both coprolite and surrounding sediment pollen analyses provided reliable results. It is possible to conclude, that pollen data are not biased by the influence of hyena dietary habits, as no pronounced and distinct differences are traced in the coprolite and surrounding sediment sample pollen spectrum. The investigation can provide a basis for further Abric Romaní coprolite studies as well as contribute to subsequent taphonomic coprolite studies.

ACKNOWLEDGEMENTS

The research was carried out at the laboratory of Institut Català de Paleoecologia Humana i Evolució Social (IPHES), Tarragona, Catalonia, Spain. The team of paleobotanical department is sincerely thanked for their support. Many thanks to colleague and friend Demet Beltekin for sharing her valuable experience in palynology.

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Палінологічний аналіз зразків копролітів і прилеглого ґрунту: тафономія пилку середньопалеолітичного шару М печери Абрик Романі (Капельядес, Іспанія)

Аналіз зразків копролітів і прилеглого ґрунту з археологічного шару М (середній палеоліт) печери Абрико Романі (північно-східна Іспанія) підтвердив ефективність палінологічного дослідження копролітів. Це перше успішне дослідження копроліту для цієї стоянки й одне з небагатьох успішних палеолітичних досліджень копроліту у північній частині Іспанії.

Достовірні тафономічні та палеоекологічні дані отримані, незважаючи на відносно низьку концентрацію пилку в обох типах зразків. Отже, дієта гієни не впливала на палінологічний склад зразків копролітів. Реконструйований характер рослинності відображає нестабільні кліматичні умови Морської Ізотопної Стадії 3 (МІС 3) і включає різноманітні закриті та відкриті рослинні угруповання. Спектри пилку зразків копроліту й оточуючих відкладень відповідають плямистому ландшафту, включаючи замкнуті соснові насадження, змішані листяні ліси та прибережні лісові суспільства, а також рослинність степових і середземноморських лугів. Цей вид ландшафту можна вважати типовим для МІС 3 із сильними та різкими коливаннями клімату. Два старіших зразки з підрівня М3 демонструють більш низьку присутність деревного пилку (виключаючи Pinus), який відображає більш холодні, порівняно з верхнім підрівнем М2, кліматичні умови.

Локальні екологічні умови реконструйовані на основі дослідження непильцевих паліноморфів. Виявлені таксони НПП вказують на наявність відповідних середовищ для оліготрофних і мезотрофних водоростей, що населяють мілку застійну воду (карстові води у печері, присутні під час утворення рівня М), і різні види грибів, специфічні для розпаду органічної речовини – копроліти, дерево та вуглець, а також сапрофітні гриби. Успішні результати цього дослідження сприяють досвіду аналізу пилку копролітів, підтверджуючи думку, що копроліти можуть надати достовірну інформацію про рослинність навколишньої місцевості.

Ключові слова: *палеоекологія, аналіз пилку та непилкових паліноморфів, середній палеоліт, МІС 3, Абрик Романі, тафономія пилку*

Надійшла до редакції / Received: 29.09.2018 *Схвалено до друку / Accepted: 23.10.2018*

Table 1. Palynological characteristics of hyena coprolites and surrounding sediment samples: absolute pollen concentration, percentage of indeterminable pollen, total pollen sum, and taxa diversity (AP – arboreal plants, NAP – non-arboreal plants)

Sub-level	*Sample*	*Absolute pollen concentration (grains x g)*	*"Indeterminate" / "indeterminable" pollen (%)*	*Pollen sum (AP+NAP)*	*Number of taxa*	
					AP	*NAP*
M2	K41-14B, Sur. sed.	99.4	4.7	259	13	12
	K41-15B, Coprolite	38.9	10.3	96	6	10
	L41-18B, Sur. sed.	85.1	4.1	267	10	10
	L41-19B, Coprolite	77.4	1.8	265	3	7
	L41-16B, Sur. sed.	61.8	6.5	298	12	9
	L41-17B, Coprolite	29.9	8.4	247	7	9
	M46-6B, Sur. sed.	29.5	10.3	199	4	7
	M46-7B, Coprolite	29.8	18.1	258	11	8
	K52-10B, Sur. sed.	87.4	5.9	358	16	13
	K52-20B, Coprolite	52.2	2.2	144	9	9
M3	L44-39B, Sur. sed.	50.0	7.2	317	5	10
	L44-40B, Coprolite	67.0	6.2	315	5	7

Table 2. Non-pollen palynomorphs data on the studied samples.

Sub-Level	Sample	Non-pollen palyno-morphs concentration (grains x g)	Non-pollen paly-nomorphs sum	Number of taxa
M2	K41-14B, Sur. sed.	157.1	117	16
	K41-15B, Coprolite	97.4	37	8
	L41-18B, Sur. sed.	173.5	93	13
	L41-19B, Coprolite	50.4	49	10
	L41-16B, Sur. sed.	26.7	30	6
	L41-17B, Coprolite	29.4	34	9
	M46-6B, Sur. sed.	78.6	46	8
	M46-7B, Coprolite	451.0	129	14
	K52-10B, Sur. sed.	147.2	132	15
	K52-20B, Coprolite	161.0	38	9
M3	L44-39B, Sur. sed.	92.8	107	9
	L44-40B, Coprolite	57.5	45	8

Table 3. Grouping of ecologically significative species of algae and fungi.

Category	*Name of the group*	*Species included*	*Ecological conditions*
ALGAE	Oligotrophic	*Gloeotrichia*	Poor environment
	Mesoeutrophic	*Spirogyra* *Zygnema*	Medium to rich environment
FUNGI	Saprofita	*Alternaria*-type *Helminthosporium* type 3Ba type 16c type 18	Decaying of organic matter
	Coprophilous	Polyporisporites Exesisporites	Presence of faecal material, dungs
	Carbonicolous	*Chaetomium*-type	Presence of charcoal accumulations
	Lignicolous	*Glomus* spp.	Wood decay; may also indicate erosion

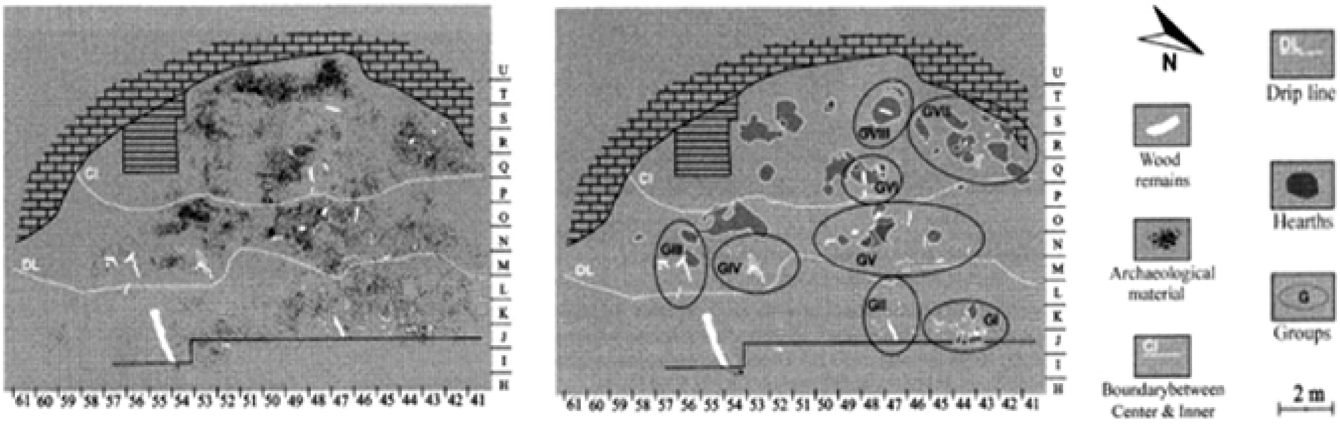

Fig. 1. Two views of Abric Romaní level M showing position of the studyed samples as to wood remains, archaeological material, hearth, and the various wood groupings identified in the three areas (inner, centre, and outer) (modified from Solé et al., 2013)

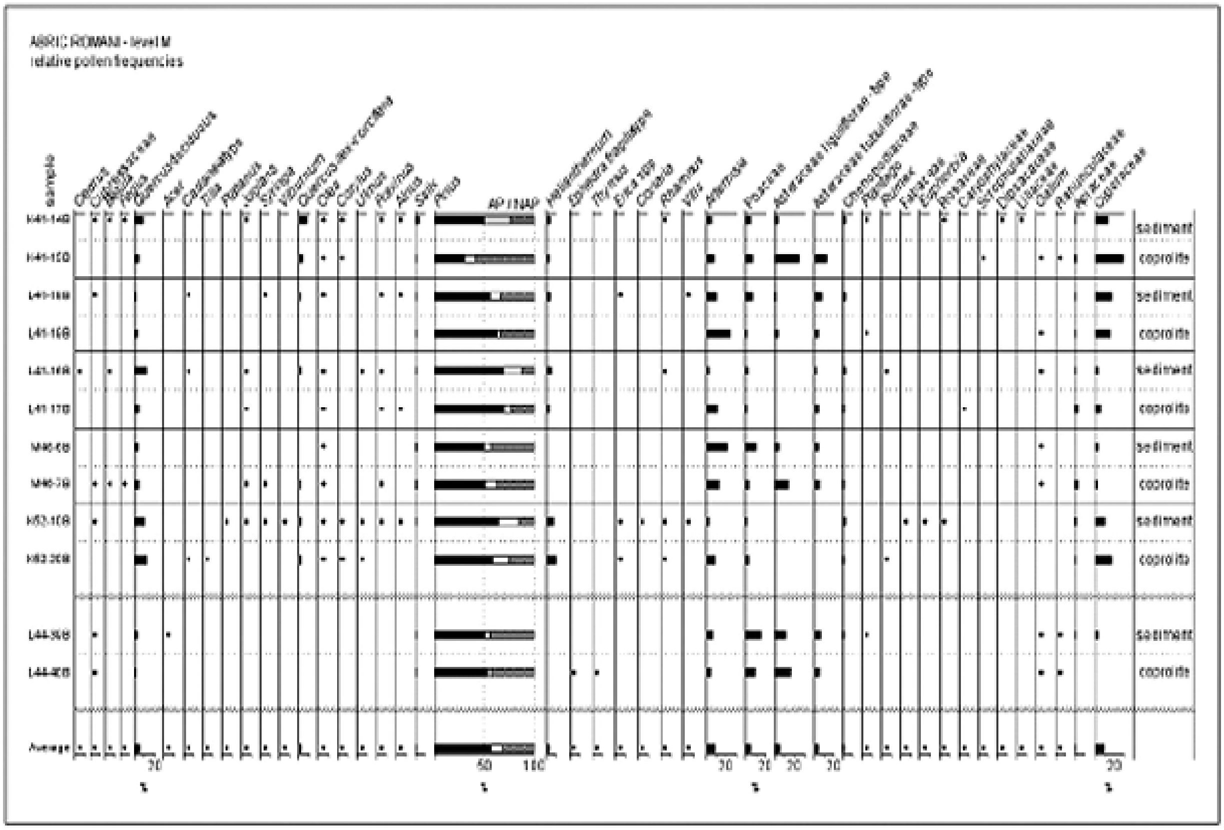

Fig. 2. Abric Romani level M. Diagram of pollinic taxa relative frequencies (%) in coprolite and surrounding sediment samples. For taxa having trace values (i.e. taxa whose occurrence was less than 1%) only presence is indicated (spot on the diagram). As samples were taken from two different sub-levels of the level M (M2 and M3), for L44-39B and L44-40B samples (M3 sub-level) are placed separately in the bottom of the diagrams according to their stratigraphical position.

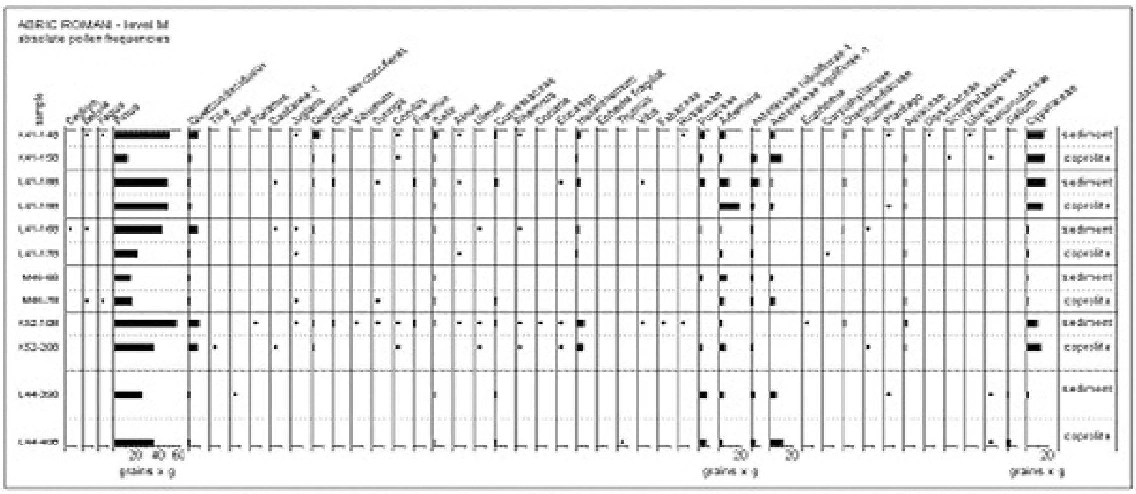

Fig. 3. Abric Romaní level M. Diagram of pollinic taxa absolute frequencies (grains x g) in coprolite and surrounding sediment samples.

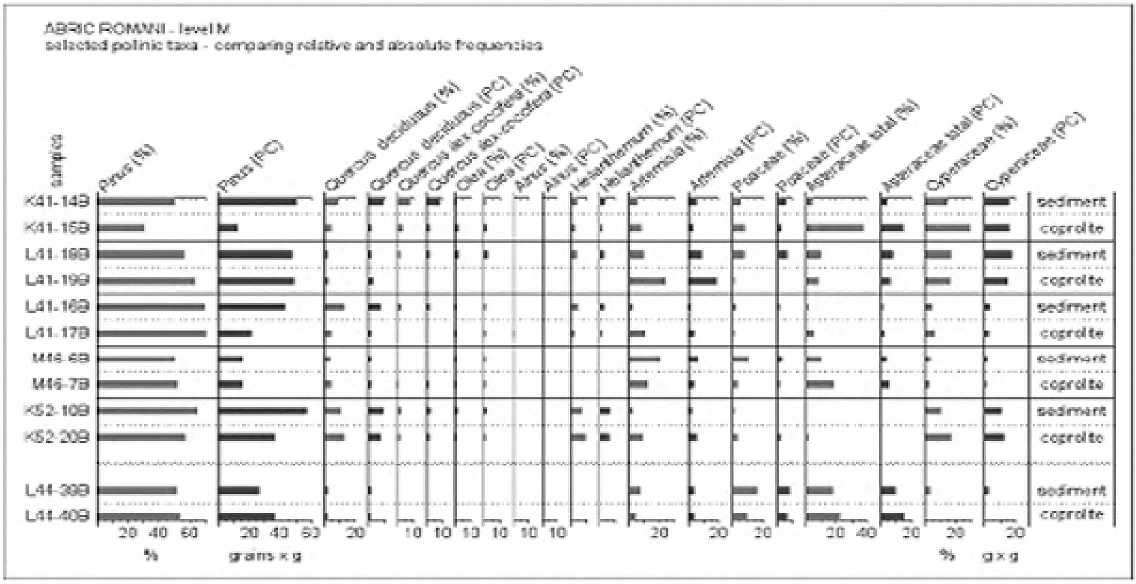

Fig. 4. Abric Romaní level M. Comparative diagram of pollen relative (%) and absolute (grains x g) frequencies for selected significative taxa.

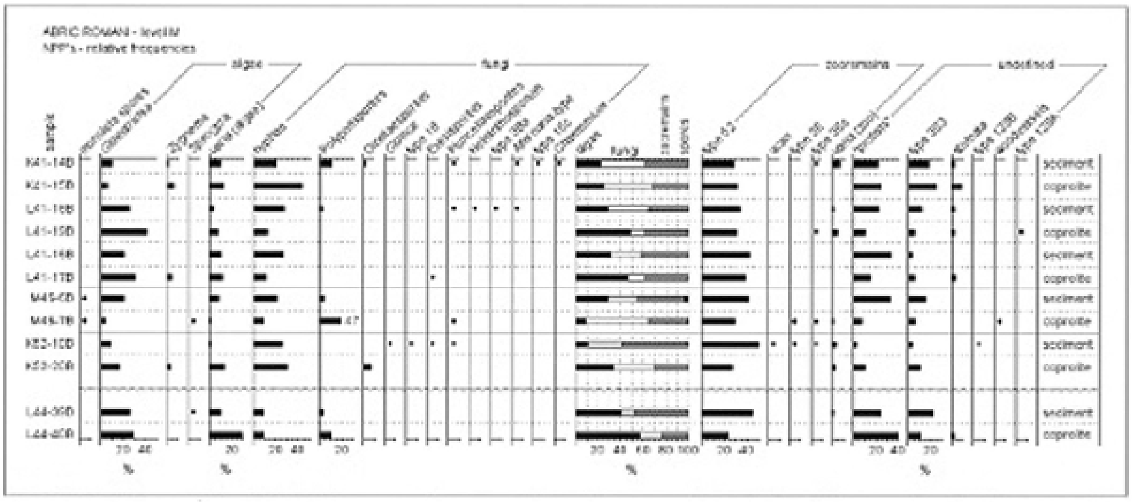

Fig. 5. Abric Romaní level M. Diagram of non-pollen palynomorphs relative frequencies (%) in coprolite and surrounding sediment samples.

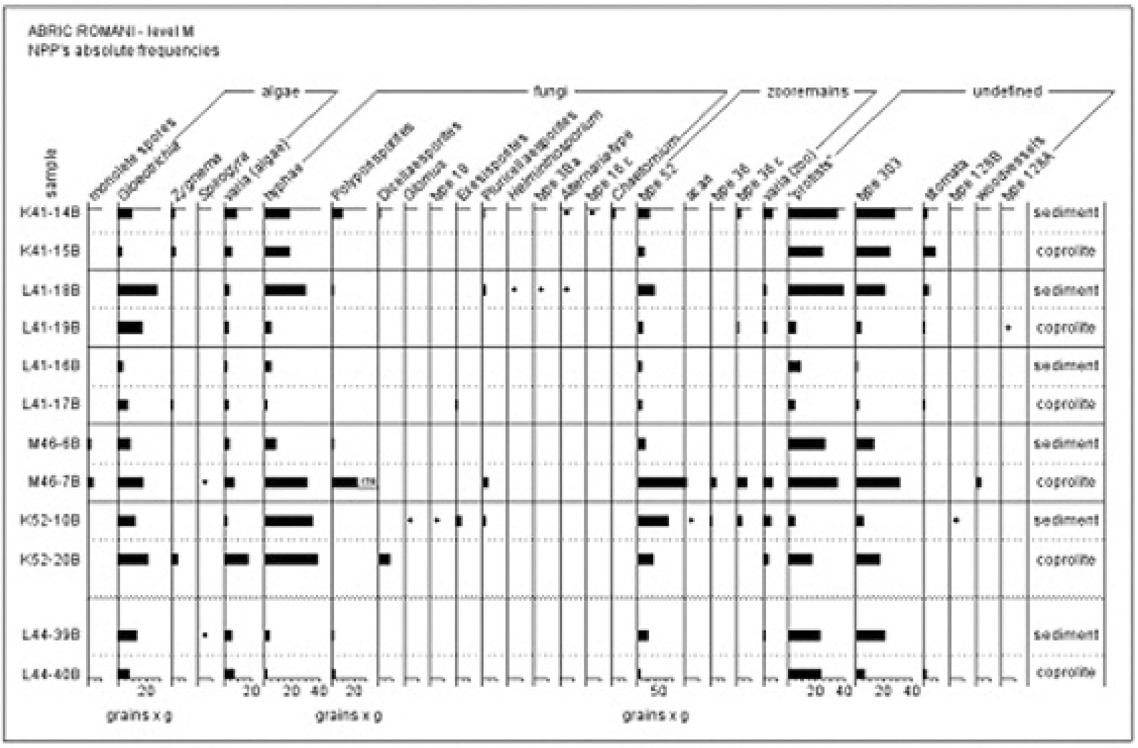

Fig. 6. Abric Romaní level M. Diagram of non-pollen palynomorphs absolute frequencies (grains x g) in coprolite and surrounding sediment samples.

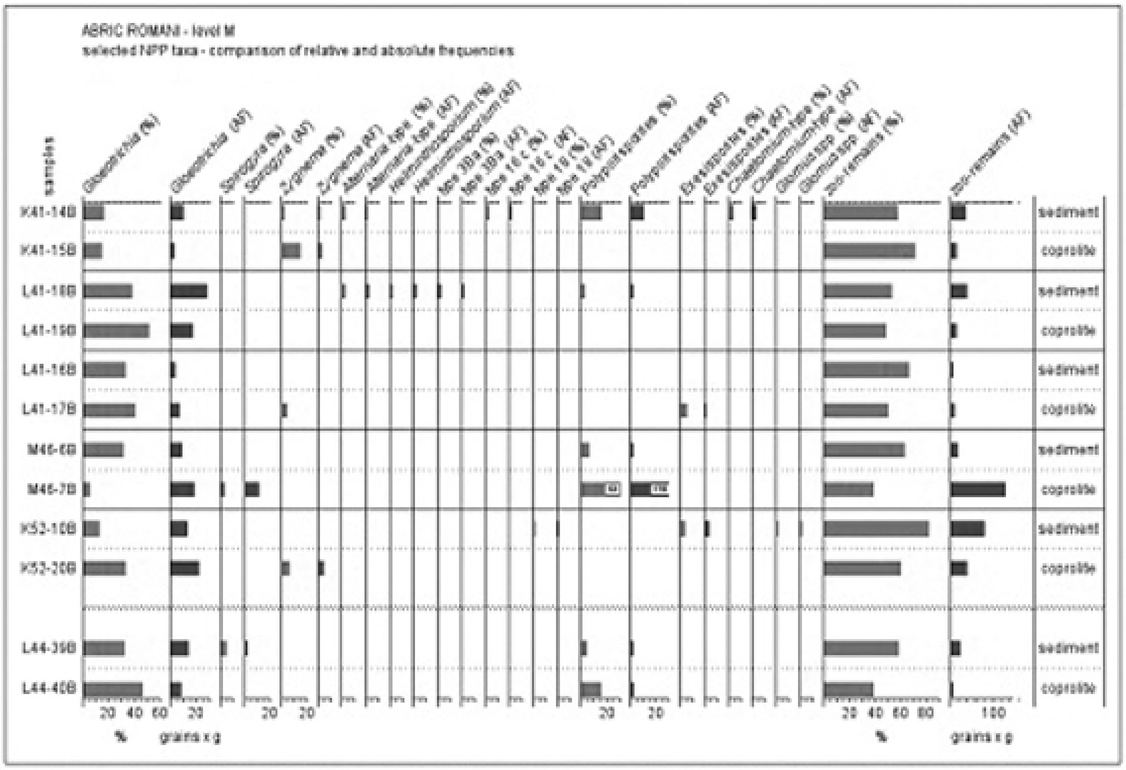

Fig. 7. Abric Romaní level M. Comparative diagram of relative (%) and absolute (grains x g) frequencies for ecologically significative NPP taxa.

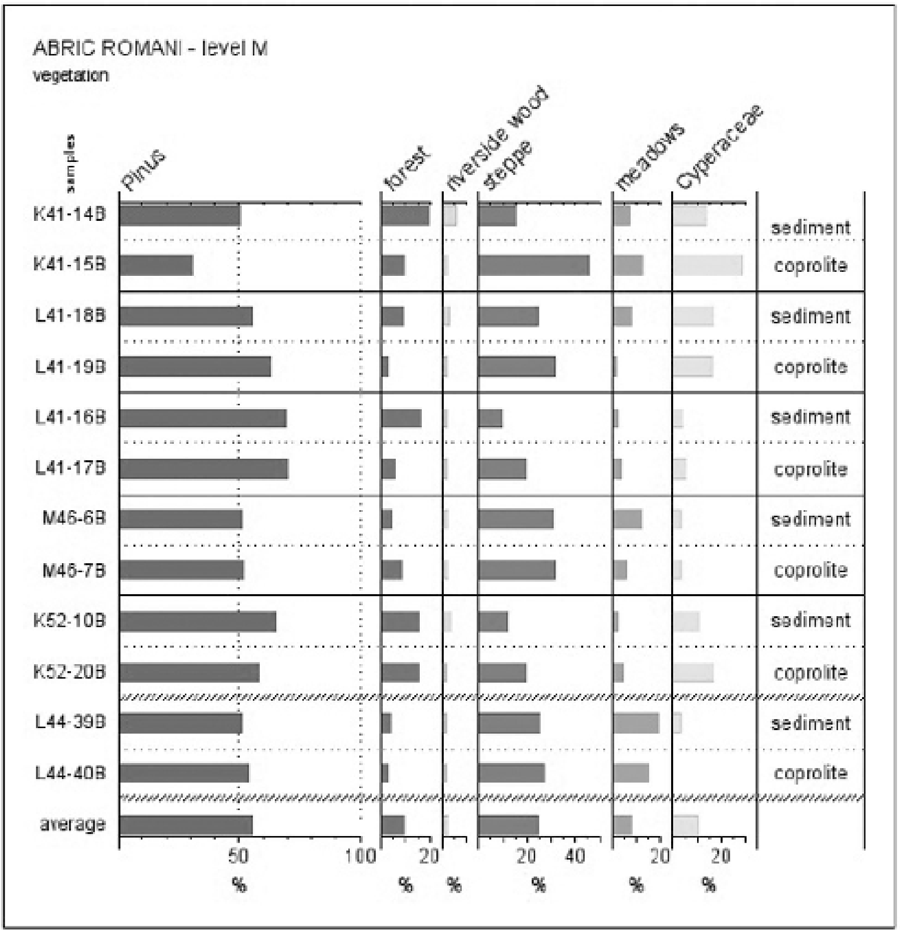

Fig. 8. Abric Romaní archaeological level M. Vegetation communities reconstructed from the coupled surrounding sediment – coprolite samples

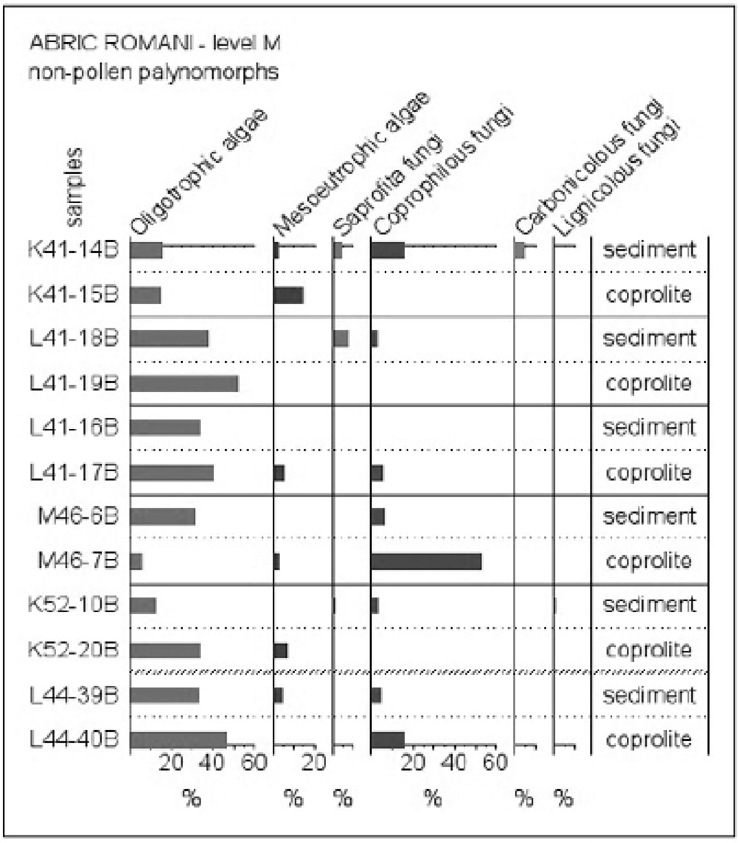

Fig. 9. Abric Romaní archaeological level M. Non-pollen palynomorphs categories reconstructed from the coupled surrounding sediment – coprolite samples.