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The palaeoenvironment of Carihuela Cave (Granada, Spain): a reconstruction on the basis of palynological investigations of cave sediments

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Abstract

Two new pollen diagrams from Carihuela Cave (southeastern Spain) are presented completing the Pleistocene sequence which covers the interval between the last Interglacial and the Lateglacial. There is a correspondence between the litho- and biostratigraphy including pollen and microfauna. Thermoclastic scree, cryophyllous rodents, and *Artemisia* and/or Poaceae steppes are associated with the recession of thermophilous vegetation. The best palynological criterion for palaeoenvironmental reconstruction from cave sediments is the composition of the pollen assemblages rather than the pollen frequencies, with the number of mesothermophilous taxa being of critical importance. In the absence of absolute dates for much of the record, there is evidence in the Carihuela pollen record for: (a) interglacial conditions at ca. 117,000 yr B.P., with assemblages dominated by *Quercus* and *Olea*; (b) a pre-Würmian phase with episodic forest regressions; (c) two Pleniglacial maxima with an extension of steppe-like vegetation and disappearance of thermophilous elements; (d) an inter-Pleniglacial episode beginning at ca. 45,200 yr B.P., with *Pinus* and the consistent presence of mesothermophilous taxa; and (e) Lateglacial including several short stages of *Quercus* colonization, one of them at ca. 12,320 yr B.P., and the Younger Dryas event afterwards. © 1998 Elsevier Science B.V.

Keywords: Spain; caves; palaeoecology; palynology; Upper Pleistocene

1. Introduction

Palynology of karstic caves is one of the potentially important sources of information on the Quaternary plant palaeoecology of the western Mediterranean area. However, the processes by which pollen is incorporated, distributed and altered in cave deposits are still not completely understood. During recent decades, workers like Coûteaux (1977) and Turner and Hannon (1988) have repeatedly stigmatized archaeopalynology as a technique with many limitations and questioned the palaeoecological value of cave pollen assemblages. The limitations were ascribed to undetected sedimentary hiatuses, selective transport of entomophilous palynomorphs, differential preservation or massive deterioration, downward movement, contamination by intrusive pollen, reworking, insufficient pollen concentration, etc. In the face

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of such pessimism, palynologists might take two basic positions: First, one might accept that cave palynology is incapable of providing well-founded data, and find more reliable sites if available. However, sites for conventional pollen analysis are usually not available in semi-arid areas such as southeastern Spain. Second, palynologists might take a more positive approach by improving the presentation of cave pollen data so that the sites can be revisited when basic taphonomic research develops.

Current methodological research on the potential of karstic infillings as a record of regional environments is still in the very early stages, but some available pollen-trapping experiments which include the use of microscope slides coated in petroleum jelly, Tauber traps and speleothems, suggest that they can provide a reliable proxy of the regional and local vegetation (Brook et al., 1990; Burney and Burney, 1993; Coles and Gilbertson, 1994). On the other hand, several case studies in Israel show that open-air sites are more likely than caves to be subjected to selective corrosion and infiltration of recent pollen (Weinstein-Evron, 1994).

This study is aimed at reconstructing past conditions on the basis of the palynological record of Carihuela Cave, a karstic cavity in southeastern Spain. Our aims are to show that:

(1) Although stratigraphic resolution cannot equal those of other deposits, pollen spectra from cave sediments can be of palaeoecological value and should not be too hastily discarded. Their value will potentially be determined by taphonomic research, which is clearly insufficient in the present state of the art.

(2) Instructions given for testing the reliability of the pollen assemblages in, for instance, peat, lacustrine and marine records do not apply in the case of cave sequences. Although a theoretical basis is clearly lacking, it is unwise to underestimate the value of cave deposits for possible palynological research.

(3) Replication of results may render them a significance but their usefulness will ultimately be dictated by the aim of the study. In the meantime, sequences studied should provide pollen percentage and concentration estimates, including the frequency of indeterminable palynomorphs, in order to give some indication of the extent of alteration in the pollen assemblages.

Pollen diagrams for five stratigraphical sections from Carihuela Cave were presented in a previous report by Carrión (1992a). Sediments considered in that study contained Middle Palaeolithic artefacts and were mostly of allochthonous origin through the main entrance. Pollen spectra showed abrupt changes in the representation of the major elements, namely *Pinus*, Poaceae and *Artemisia*. The vegetation appeared to have oscillated between an arboreal type with *Pinus* and the presence of mesothermophilous taxa such as *Quercus*, *Olea*, *Phillyrea*, *Pistacia*, etc., and a herbaceous type suggestive of stadial conditions. A Mediterranean vegetation with sclerophyllous elements was described for a level previously interpreted as inter-Pleniglacial on the basis of its lithostratigraphy (Vega-Toscano et al., 1988). The present study is a continuation of that by Carrión (1992a), giving a more complete record of the Upper Pleistocene sequence. In addition, new dating suggests that one part of apparent middle last glacial deposits is in fact of last interglacial origin. In view of this, the results of previously published papers (Carrión, 1992a; Carrión and Sánchez-Gómez, 1992; Carrión and Dupré, 1994) are also reviewed in the present paper. Therefore the new sequence, although discontinuous, covers a longer time span including pollen spectra from the last interglacial up to the Lateglacial.

2. Present setting

Carihuela Cave is located 45 km northeast of Granada city in south-central Spain. It is situated on the north slope of the Sierra Arana Mountains in the valley of the southwesterly flowing Río Piñar. The cave opening faces north, being situated on the south side of the valley at approximately 3°25′47″W, 37°26′56″N. Elevation of the cave is about 90 m above the valley floor at approximately 1020 m above sea level.

The climate of the area is warm temperate with a mean annual temperature of 12.7°C, a mean of the coldest month of 5.1°C, and a mean of the warmest month of 22°C. The mean annual precipitation of the region about the Río Piñar is 57.4 cm/yr. Winters are wet in this area due to the prevalence of seasonal maritime polar air masses with cyclonic storms and ample rainfall. The dry season occurs during the summer. The Granada basin to the south of Piñar is drier and warmer in both seasons.

The area which includes the Río Piñar Valley is placed within the potential vegetation zone of *Paeonio–Quercetum* sclerophyllous forest (Rivas-Martínez, 1987). This zone is characterized generally by *Quercus rotundifolia*, with *Q. faginea* on the most humid soils. The surroundings of the cave are dominated by cultivars, mainly almonds and cereals, and stands of *Pinus halepensis*.

3. Cave description and lithostratigraphy

The local relief reflects primarily the karstic nature of the region and Carihuela is just one of the many caves located in the area. It has two main entrances, which join after a short distance to form a single chamber with a corridor continuing deeper into the hillside. The cavern axis is orientated in a generally southeasterly direction from the main entrance (Fig. 1). The entrance chambers have been designated from east to west as CI, CII and CIII. The largest entrance chamber (CIII) is about 13 m long and 4 to 6 m wide, and is joined in the east by the corridor formed by the combination of chambers I and II. At the south end of Chamber III a corridor about 2–3 m wide opens into Chamber IV (CIV). It is in the corridor leading to the former that sampling for this study has been carried out. Towards CIV the cavern floor slopes primarily downwards and, therefore, most sediments come from the exterior via the three entrances described, although in the corridor the presence of autochthonous material is noteworthy. At CIV, however, the slope of the cavern floor begins to trend steeply upward towards the far end of CV.

Of the twelve lithostratigraphical units described by Vega-Toscano et al. (1988) for CIII and CIV, the palynology of units XI to IV was considered in Carrión (1992a). Both the unit XII and the lowermost levels of XI contained no pollen. The present study is based on pollen analysis of two new profiles from CIV comprising units VI to III (Fig. 1). Unit VI shows sedimentological differences according to distance to the main entrance. Thus, it is mainly clayey in the innermost part of the cavity but sandy close to the opening. Unit V comprises angular clasts in clayey matrix. Unit IV contains clays and gravels with powdery concretions. Unit III is only clearly noticeable in CIV section 2. It displays thermoclastic scree alternating with calcium carbonate concretions.

4. Archaeology

Most lithic implements of units XII to V fall into the typical Mousterian–Charentian complex (Fig. 2). In its uppermost part, unit IV displays a Mousteroid industry (Middle Palaeolithic s.l.). Human remains are attributable to *Homo sapiens neanderthalensis* for units VI, V and the lowermost levels of unit IV; and *H. sapiens sapiens* for the unit III and the uppermost beds of unit IV (García-Sánchez, 1960; Vega-Toscano, 1988).

Carihuela Cave is renowned for providing the youngest evidence for Neanderthal populations in Europe (Vega-Toscano, 1993), although chronological control for this is not yet entirely satisfactory. At first, the site was well known for the finding of anatomically modern human remains seemingly associated with the Mousterian industry (Spahni, 1955). It was in strong disagreement with traditional views suggesting the exclusive relationship between Neanderthal and Mousterian lithics, a debate continuing currently (Trinkaus, 1991). The latest excavations in Carihuela Cave suggest, however, that such an association is not stratigraphically coherent (Vega-Toscano, 1988). Thus, while human remains found in the uppermost levels of Chamber III could have been introduced by carnivores inhabiting the cave at that time, most Middle Palaeolithic tools seem not to be synchronous with the deposition of sediments comprising unit III in the area where they were found.

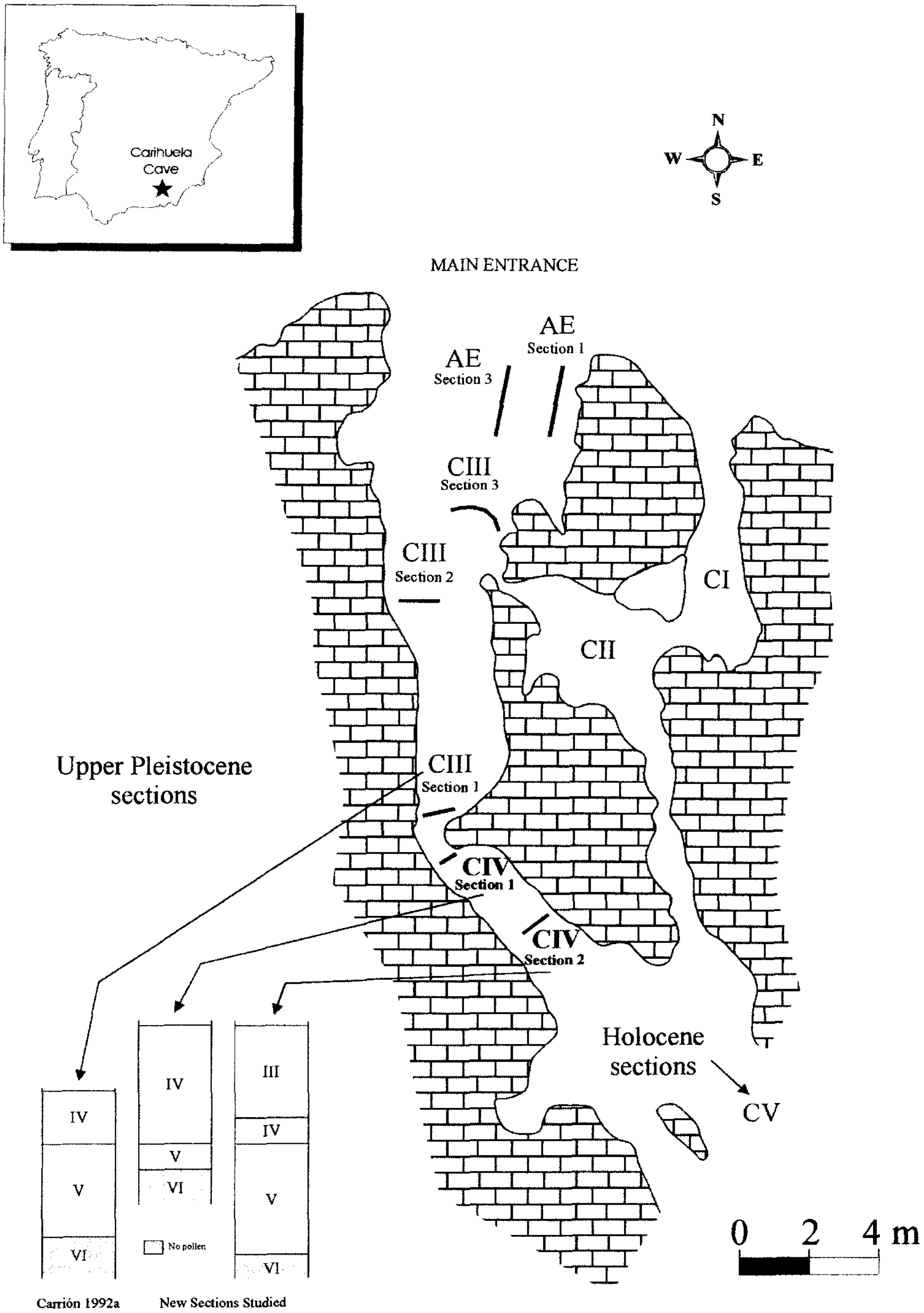


Fig. 1. Longitudinal section of the cave showing the situation of the main chambers and stratigraphical sectic

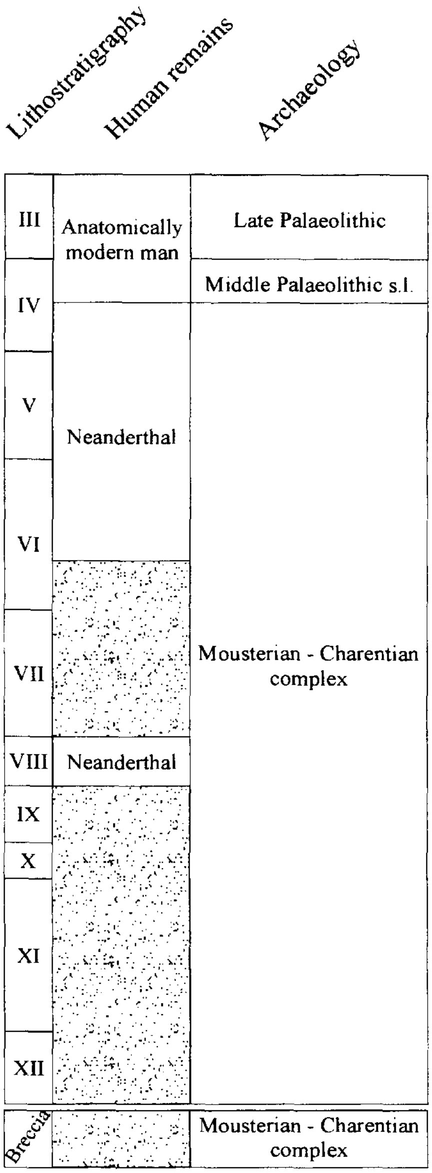


Fig. 2. Stratigraphical and archaeological relationships of human remains found in Carihuela Cave.

Table 1
Thermoluminescence dating for CIII section 1 (units XI–III) in accordance with the modifications by Göksu (thesis, unpublished) from those previously determined by Fremlin (1974)

Sample No.	TL estimated age (yr B.P.)
B48	13,400 ± 600
B52	19,300 ± 500
B6	20,200 ± 1200
B47	20,950 ± 1200
B43	21,100 ± 1300
B44	37,350 ± 2200
B54	42,400 ± 1500
B49	49,200 ± 2500
B53	68,000 ± 1800
B46	82,500 ± 4900

5. Dating

Some thermoluminescence dates became available after the excavations by H.T. Irwin and R. Fryxell of Washington State University in the 1970s (Tables 1 and 2). The first two series were determined at Birmingham University on burnt flint (Fremlin, 1974, Göksu et al., 1974). Subsequently, after resolving technical problems, H. Göksu (unpubl. thesis) and K. Sammers (pers. commun. to J.M. Fremlin) made additional determinations to provide a more detailed account. It must be pointed that, when the first two series were investigated, the thermoluminescence dating technique was in its very early experimental stage. The dates by Göksu (thesis) and Sammers were published by Vega-Toscano (1988) and Davidson (1989), respectively (Tables 1 and 2). A major limitation of all these reports is that they fail to specify the exact stratigraphical origin of each dating. They only refer to the nature of material and industrial typology which is not of great help when the Mousterian implements hardly show internal evolution. Despite these limitations, some conclusions can be made from the thermoluminescence dating at Carihuela in the context of subsequent excavations. They show a time span of some 70,000 yr for materials extracted from units XI to III, ranging between approximately 82,500 and 11,200 yr B.P. The Mousterian people appear to have been present until at least ca. 25,000 yr B.P., which re-opens the debate about who is responsible for the production of the last Middle Palaeolithic tools in southern Spain (Davidson, 1989; Vega-Toscano, 1993).

Two samples of sediment from CIV section 2 were submitted to Beta Analytic Inc., Miami, for

Table 2
Thermoluminescence dating for CIII and CIV sections (units XI–III) in accordance with Göksu et al. (1974) and subsequent modifications by Göksu (thesis, unpublished) (Vega-Toscano, 1988) and K. Sammers (Davidson, 1989)

Sample No.	Göksu et al. (1974)	Göksu (thesis) (Vega-Toscano, 1988)	Sammers (Davidson, 1989)	Archaeology	Suggested lithostratigraphy
TB7	12,000–14,000	13,600±800	11,200	Late Palaeolithic	uppermost III in CIII section 2
TB6	20,000±3000	20,200±3000	17,000	Late Palaeolithic	IV–III in CIV
TB8b	20,000–21,000	27,000±1000	23,000	Late Palaeolithic	IV in CIV
TB12	39,000	27,400±1000	25,700	Mousterian	XI–IV
TB2	28,000	28,000±1000	27,300	Mousterian	XI–IV
TB5	31,000–35,000	33,000±1200	25,200	Mousterian	XI–IV
TB1	32,000	39,400±2000	34,000	Mousterian	XI–IV
TB3	46,000	57,700±2500	45,200	Mousterian	XI–IV
TB9a	48,000	58,800±2500	47,800	Mousterian	XI–IV
TB8a	80,000	–	–	Mousterian	XI–IV

AMS dating. The dates, obtained from charred material, are listed in Table 3.

Given the difficulties found in the stratigraphical position of the breccia-like sub-unit VIIa (Carrión, 1992a), three samples extracted from CIII AE section 3 were submitted to the Departamento de Física of Universidad Autónoma de Barcelona for $^{230}Th/^{234}U$ dating. Only one was suitable for dating and provided an age of 117,000±41,000 (Table 4). The high uncertainty of this date is due to the detritic correction needed in the dating procedure. In any case, the date suggests that the hitherto named sub-unit VIIa was formed during the last interglacial stage.

6. Methodological considerations

Two vertical profiles from CIV were investigated palynologically. Samples were taken according to lithological features at irregular intervals of 5 to 15 cm for CIV section 1, and 3 to 10 cm for CIV section 2. In the case of section 2, sampling at such short 3 cm intervals was possible because of

Table 3
Radiocarbon dating of CIV section 2

Laboratory No.	Depth (cm)	Sample material Analytical method	Radiocarbon age (yr B.P.)	Lithostratigraphy (Unit)
Beta 74380	55	organic AMS	12,320±60	III
Beta 74381	183	organic AMS	45,200±1270	lowermost VI

Table 4
$^{230}Th/^{234}U$ dating of CIII AE section 3

Laboratory	Depth (cm)	Sample material	$^{230}Th/^{234}U$ age (yr B.P.)	Lithostratigraphy
Laboratory Radiactivitat Ambiental, UAB	40–60	Breccia	117,000±41,000	VIIa

a well-defined stratification consisting of very thin layers.

Laboratory treatment was performed following the conventional HCl, HF and KOH method and *Lycopodium clavatum* tablets containing a known quantity of spores were added to each sample prepared to enable estimation of pollen concentration. Pollen grains were concentrated by means of the heavy-liquid flotation method outlined by Girard and Renault-Miskovsky (1969). Residues were mounted in silicone oil. Pollen identification was performed by comparison with the reference collection of the Plant Biology Department at Murcia University (Plate I). Pollen of *Cytisus reverchonii* was identified because of its particular reticulate pattern (Plate II), with narrower lumina than in the other species (*Chronanthus biflorus*, *Cytisus baeticus*, *C. oromediterraneus*). Distinction of *Asphodelus fistulosus* pollen was based on the existence of a reticulum with broader muri than in *A. cerasiferus*. *Potentilla caulescens* type includes also other possible species such as *Potentilla reptans* and *Prunus prostrata*. Any damaged grains of which identification was not secure were placed in an 'indeterminable' category.

Percentages of each taxon for each sample were based on a pollen sum excluding spores of cryptogams, Asteraceae and indeterminable pollen. Zoophilous Asteraceae have been excluded from the pollen sum, in accordance with their hypothetical overrepresentation, chiefly by differential transport, in the deposit (Bottema, 1975; Carrión, 1990, 1992a). The mean value of the pollen sum was ca. 346 in CIV section 1, and ca. 272 in CIV section 2. Pollen percentage diagrams are presented in Fig. 3 (CIV section 1) and Fig. 5 (CIV section 2). A comparison of the percentage and concentration curves for the major pollen taxa is presented in Fig. 4 (CIV section 1) and Fig. 6 (CIV section 2). Local pollen assemblage zones were determined from the results of CONISS analysis using a square-root transformation (Edwards and Cavalli-Sforza's chord-distance) (Grimm, 1987). The correlation between the zones of both sections and their correspondence with CIII section 1 (Carrión, 1992a), is shown in Fig. 8.

A synthetic pollen diagram is presented in Fig. 9 taking into account the lithostratigraphical correlation of Vega-Toscano et al. (1988), but moving the relative position of zone R down to the base, according to the mentioned $^{230}Th/^{234}U$ dating and the biostratigraphical correlations shown in Figs. 8 and 10. As we have repeated pollen analysis for some lithological beds, it was necessary to exclude overlapping spectra in the construction of the synthetic diagram. Thus, although the curves in Fig. 9 seem to be continuous, one should bear in mind that hiatuses may occur at the changes in sections. We have chosen a different nomenclature for the zones in the synthetic (Fig. 9) and section diagrams (Figs. 3–6) in order to make the results of this report consistent with the previous one (Carrión, 1992a).

7. Results and discussion

7.1. The new sequences

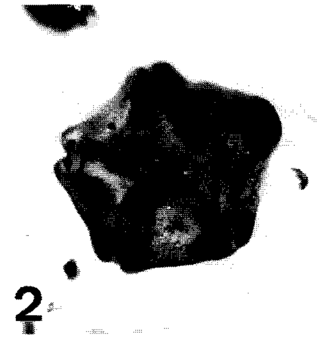
7.1.1. General considerations

The main features of the pollen zones (Figs. 3–6) are outlined in Fig. 7. Major pollen contributors are Poaceae, *Artemisia*, *Pinus*, Cichorioideae and Asteroideae. In comparison with the pollen sequences of the sections studied previously (Carrión, 1992a) such pollen taxa as *Helianthemum*, Lamiaceae, *Juniperus* and Chenopodiaceae reach higher values while *Pinus*, Pteridophyta, Cichorioideae and Asteroideae are generally lower.

At first sight, the differences in the pollen dominants and the variation of entomophilous versus wind-pollinated taxa in the profiles cannot be explained by their relative location in relation to the cave entrance. Unfortunately, there are not yet any distance–decay models to predict pollen deposition in caves. Prediction in cases like Carihuela Cave are especially difficult because there are several entrances which could have changed through time, thereby affecting the airflow. Studies performed in archaeologically important caves near Sheffield, England, suggest that an abundance–distance relationship is not a universal rule (Coles and Gilbertson, 1994), and that pollen airborne transport and deposition does not always decrease with increasing distance into the caves.

PLATE I

1



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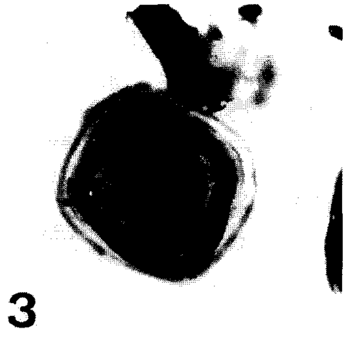

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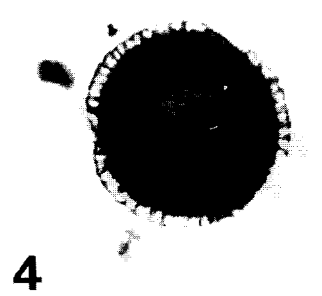

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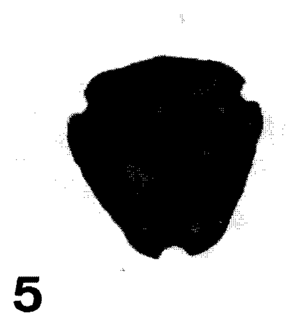

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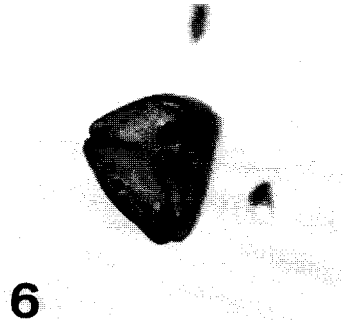

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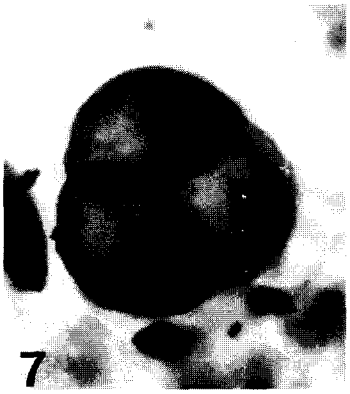

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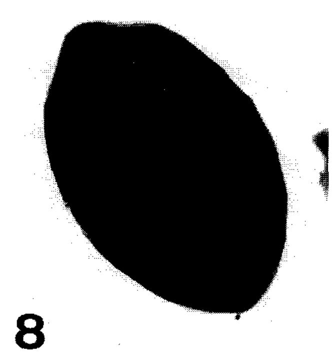

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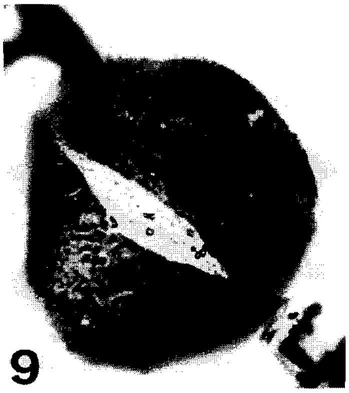

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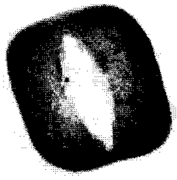

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PLATE II

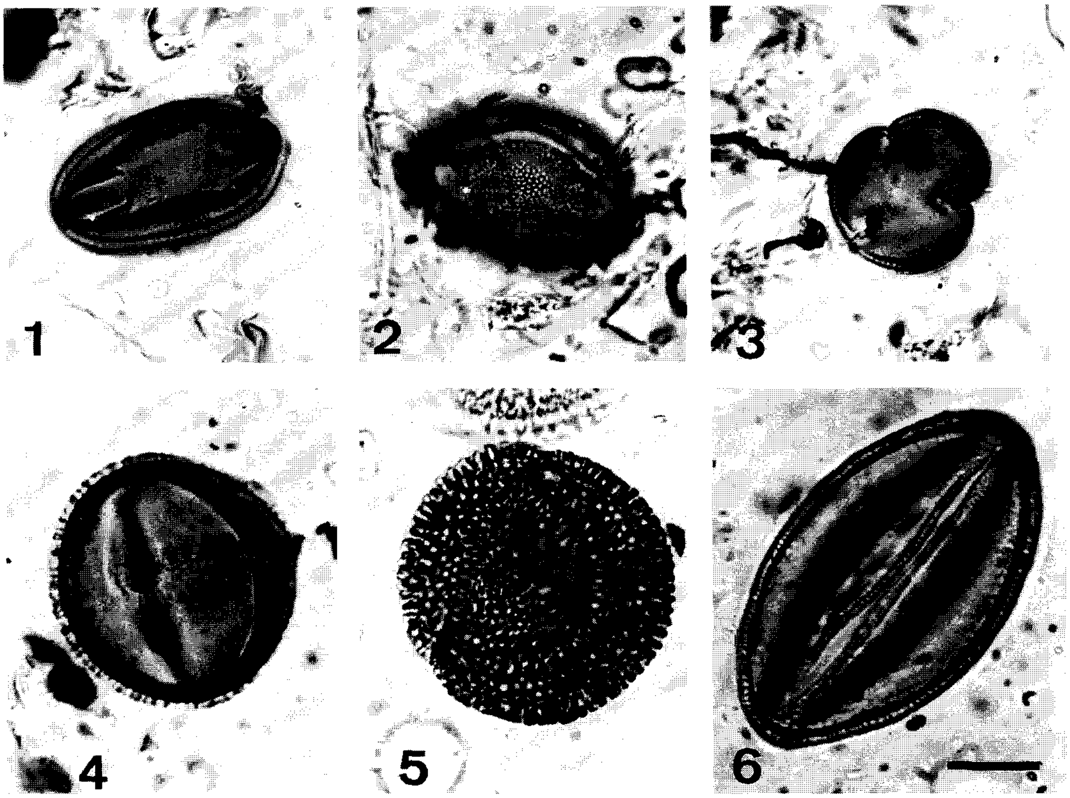


PLATE II LM micrographs of some pollen grains from Carihuela Cave. Scale: 10 μm.

1–3. *Cytisus reverchonii.*
4. *Viburnum.*
5. *Cistus.*
6. *Acer.*

PLATE I LM micrographs of some pollen grains or spores from Carihuela Cave. Scale: 10 μm.

1. *Juniperus.*
2. *Alnus.*
3. *Quercus.*
4. *Olea.*
5. *Rhamnus.*
6. *Myrtus.*
7. Ericaceae.
8. *Helianthemum.*
9. *Asphodelus.*
10. *Ephedra distachya.*
11. *Lamiaceae.*
12. *Sideritis.*
13. *Bartramia.*

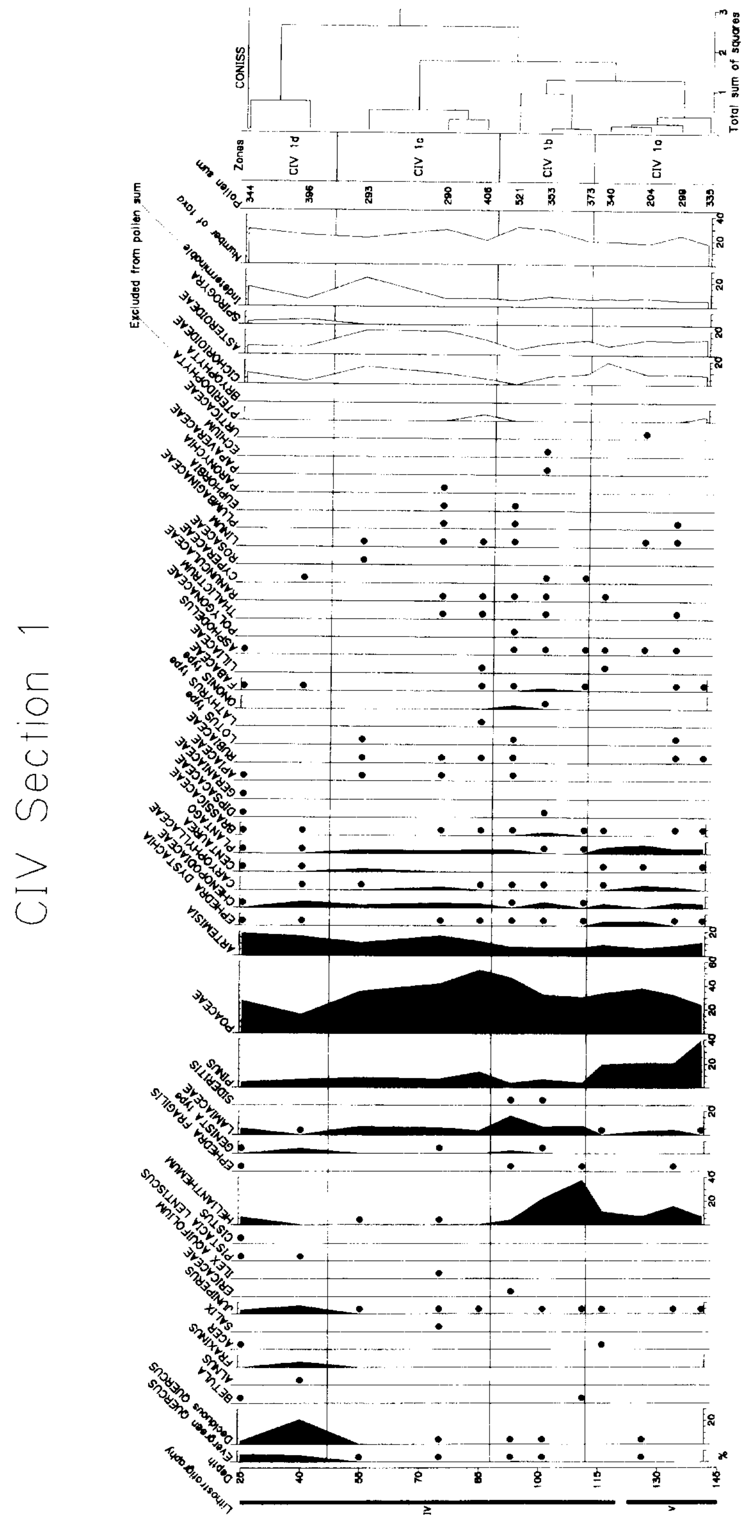


Fig. 3. Percentage pollen diagram of CIV section 1.

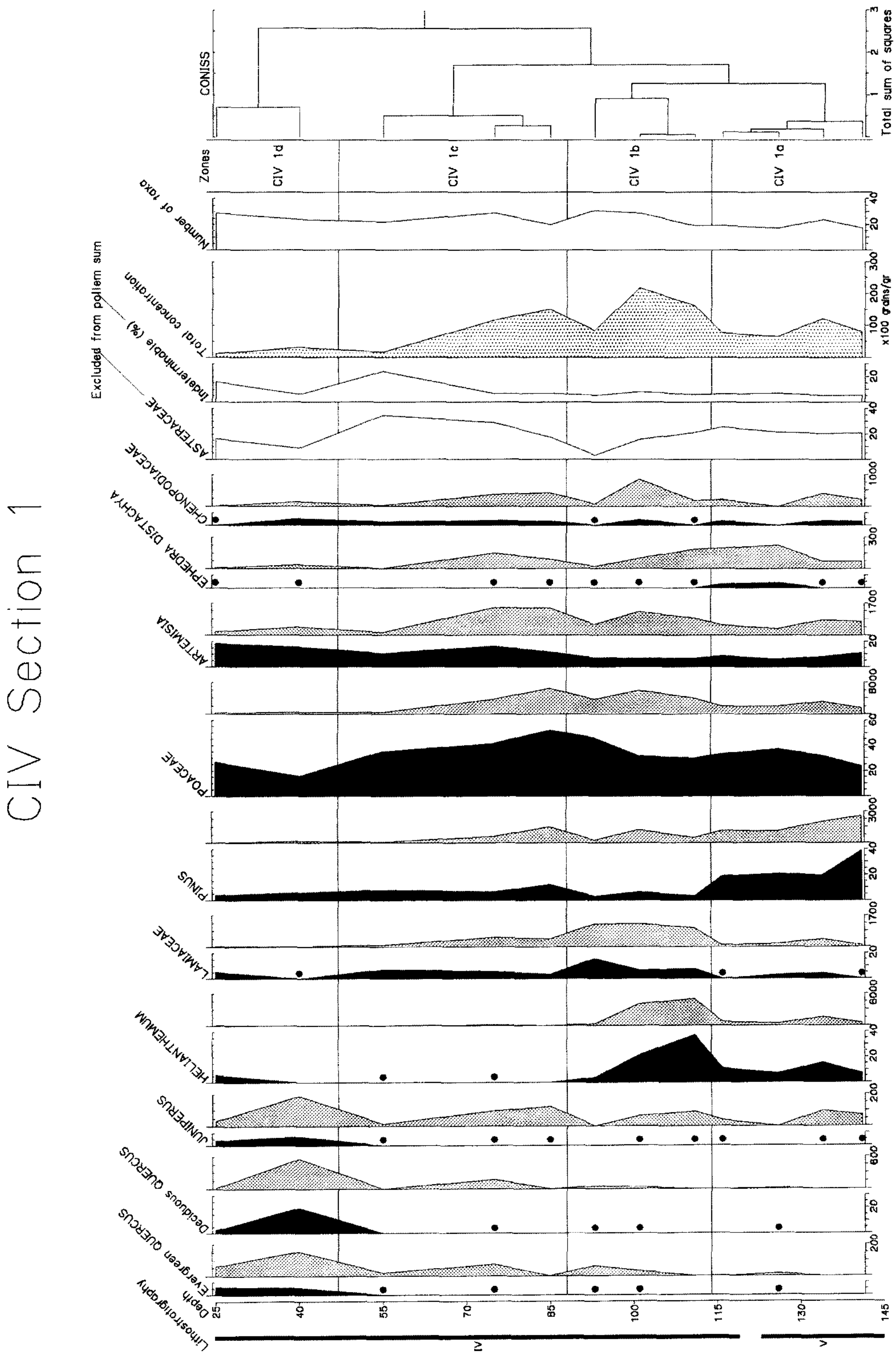


Fig. 4. Comparative pollen diagram of percentages (black) and concentrations (grey, grains/g) for selected taxa of CIV section 1.

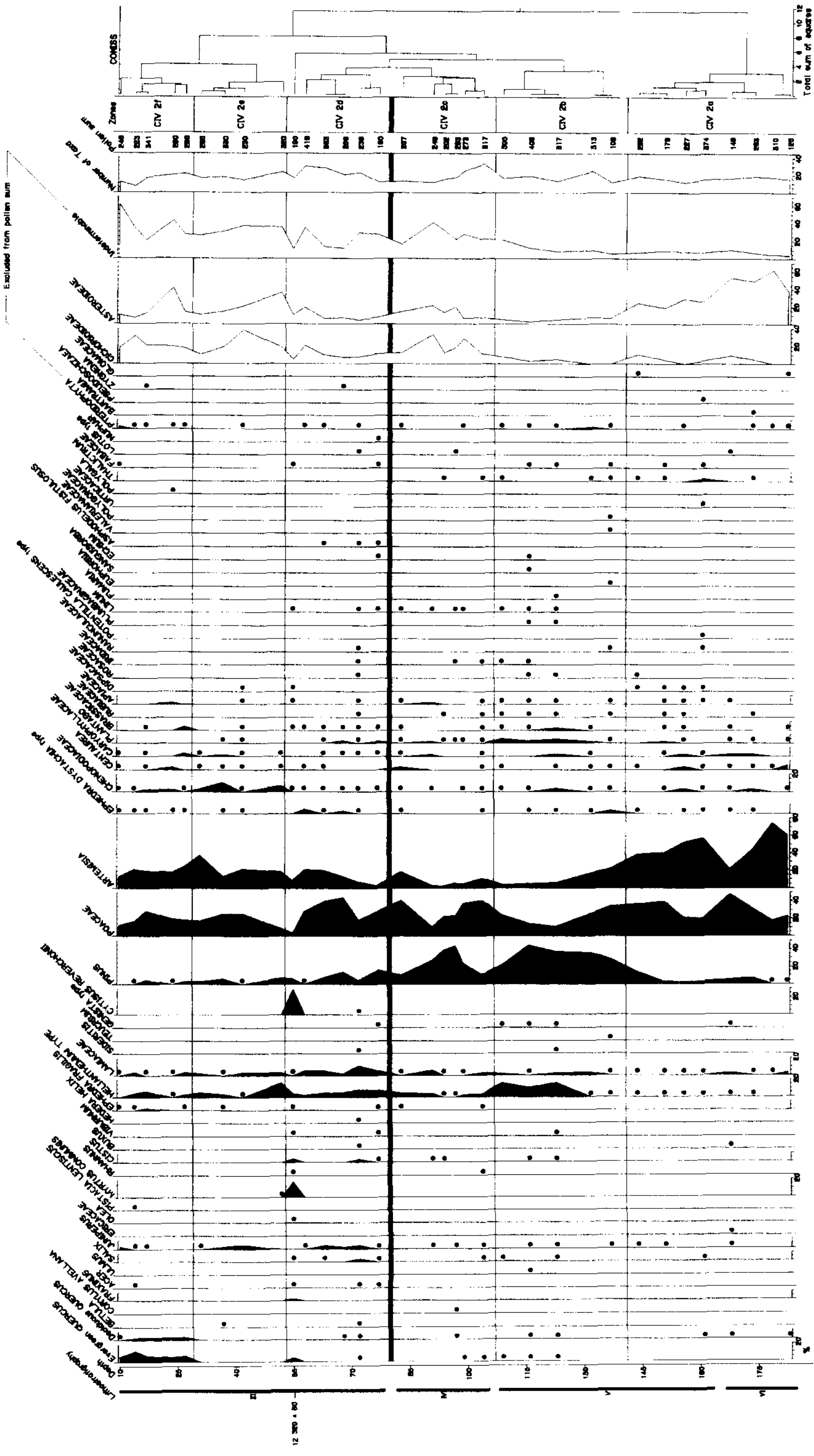


Fig. 5. Percentage pollen diagram of CIV section 2.

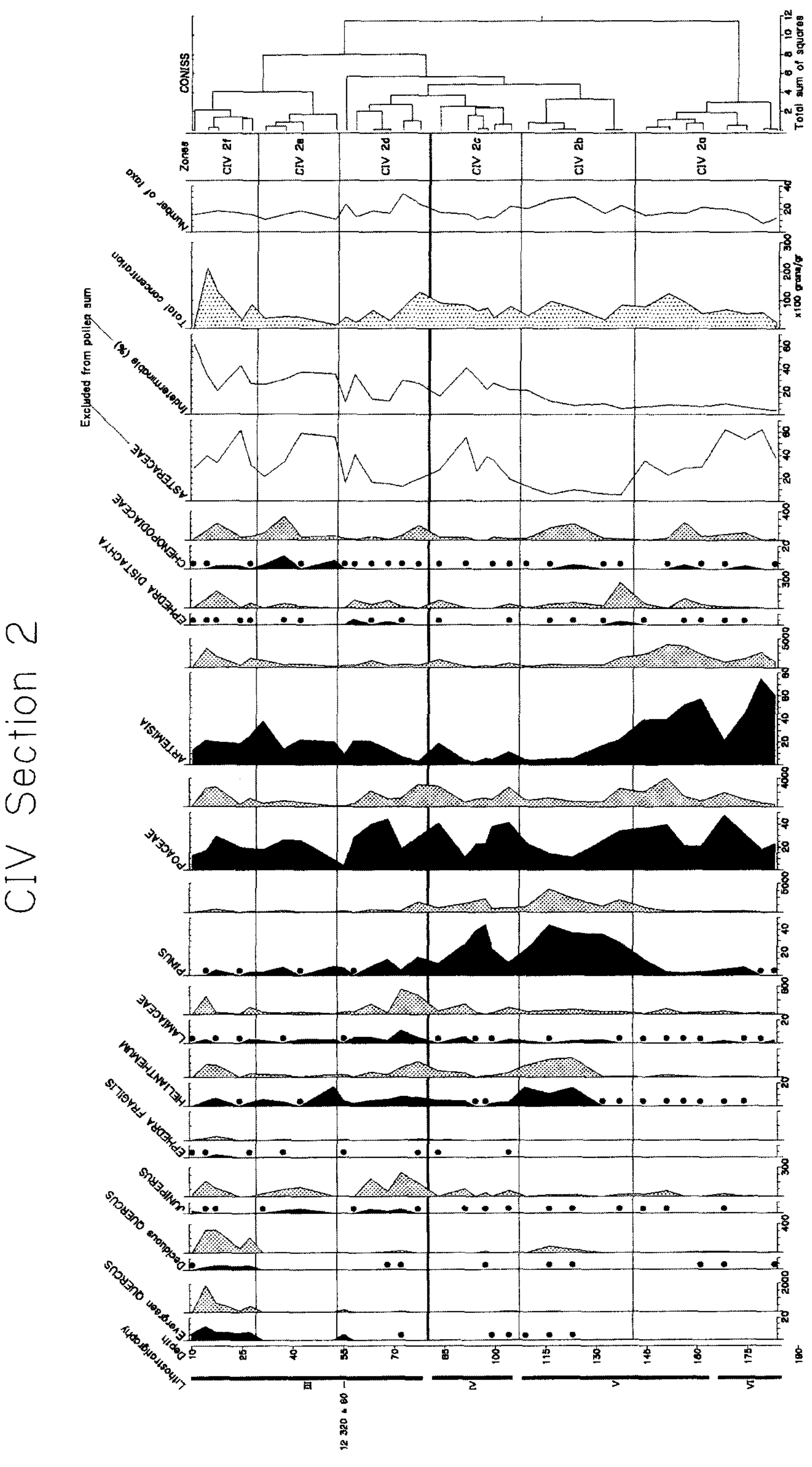


Fig. 6. Comparative pollen diagram of percentages (black) and concentrations (grey, grains/g) for selected taxa of CIV section 2.

Section	Pollen zone	Characteristics
CIV 1	d	*Pinus* 6, *Poaceae* 16-32, *Artemisia* 16-21, Evergreen *Quercus* 6-8, Deciduous *Quercus* 21-2, *Juniperus* >2, *Genista* >2, Other mesothermophilous taxa, Concentration < 5000
	c	*Pinus* 7-14, Poaceae 57-44, *Artemisia* 12-18, Concentration 3000 - 14,500
	b	*Pinus* 4-8, Poaceae 32-49, *Artemisia* 7, *Helianthemum* up to 39, Lamiaceae 7-16, Concentration 8000 - 20,000
	a	*Pinus* 41-20, Poaceae 25-40, *Artemisia* 6-11, *Helianthemum* 7-16, *E. distachya* >2, Concentration 6000 - 13,500
CIV 2	f	*Pinus* 0-6, Poaceae 25-36, *Artemisia* 24-32, *E. fragilis* >2, Evergreen *Quercus* 9-19, Deciduous *Quercus* 1-5, Other mesothermophilous taxa, Concentration 3900 - 22,800
	e	*Pinus* 1-12, Poaceae 13-41, *Artemisia* 19-52, *Chenopodiaceae* 3-16, Concentration 1700 - 4400
	d	*Pinus* 1-22, Poaceae 4-50, *Artemisia* 4-33, Lamiaceae up to 15, Other mesothermophilous taxa, Concentration 14,800 - 2700
	c	*Pinus* 12-57, Poaceae 17-52, *Artemisia* 4-42, Concentration 3800 - 11,500
	b	*Pinus* 30-50, Poaceae 12-36, *Artemisia* 23-5, *Helianthemum* up to 20, Concentration 4100 - 10,000
	a	*Pinus* 1-15, Poaceae 19-53, *Artemisia* 78-24, Concentration 3500 - 14,000

Fig. 7. Major features (percentages and concentrations in grains/g) of the pollen zones in Figs. 3 and 4 (CIV 1) and Figs. 5 and 6 (CIV 2).

Pollen concentration at Carihuela Cave varies from 1110 to 21,865 grains/g for CIV section 1 (Fig. 4) and from 1237 to 22,800 grains/g for CIV section 2 (Fig. 6). It has not been usual to present pollen concentration values in cave palynological studies in Europe (e.g. Cattani and Renault-Miskovsky, 1989; Carrión and Dupré, 1994), which precludes comparison. Based on data from southwestern USA, Davis (1990) emphasizes that concentrations in caverns can be extremely variable. Thus, at Cowboy Cave (Spaulding and Petersen, 1980), pollen concentration varies from 10,000 to 290,000 grains/g, and in four caves from the Central Grand Canyon (O'Rourke, 1985) from ca. 2000 to 140,000 grains/g. Burney and Burney (1993) explain the differences in the pollen influx inside caves as due to stochastic and episodic forms of particle transport which may influence pollen deposition in proportions unique to each site. Until now, pollen analyses carried out in western Mediterranean caves show relatively low concentrations. At Beneito Cave, Alicante (eastern Spain), they are from ca. 510 to 7100 grains/g (Carrión and Munuera, 1997). However, pollen concentrations in peaty sediments from the same area can be also less than 10,000 grains/g (Carrión and Dupré, 1996).

In general terms, there are similar fluctuations in the curves of pollen concentration and pollen percentages (Figs. 4 and 6), which suggests that the events to be described are real, rather than statistical artifacts. Apart from this, it is apparent that the total concentration decreases are not universally related to increased values of Indeterminable and/or Asteraceae types except perhaps in some particular cases such as at 55 cm of CIV section 1 (Fig. 4) and at 10 cm of CIV section 2 (Fig. 6). Total concentration can be less than 10,000 grains/g while Asteraceae and Indeterminable show low values and the number of taxa is above 20, such as at ca 90 cm in CIV section 1. Yet, total concentration can be above 10,000 grains/g matching with Asteraceae frequencies at above 60% (excluded from pollen sum) such as in zone CIV 2a (Fig. 6).

Spearman correlation coefficients (Table 5) show significant correlations between (a) Asteraceae and *Artemisia* percentages in CIV section 2 and in the synthetic diagram, and (b) total concentrations and number of taxa in CIV section 2. A significant negative correlation can be noticed for (a) Asteraceae percentages and number of taxa in CIV section 2, and (b) *Artemisia* percentages and number of taxa in CIV section 2 and in the synthetic diagram.

These correlations, particularly the positive correlation between *Artemisia* and Asteraceae in the synthetic diagram strongly suggests that Asteraceae could have been part of some kind of steppe-like, floristically poor vegetation during the stadial stages, as has been proposed for other arid lands (Hall, 1985; Anderson and Van Devender, 1991; Scott, 1995). Past communities which have

Table 5
Spearman correlation coefficients relative to the overall sequence, CIV section 1 and CIV section 2

	CIV section 1 (Figs. 3 and 4)			CIV section 2 (Figs. 5 and 6)			Synthetic diagram (Fig. 9)	
Asteraceae	−0.0175	–	—	0.3443*		—	0.5635**	–
Number of taxa	0.2748	−0.5027	–	−0.2294	−0.5443**	—	−0.6092**	−0.2699
Total concentration	−0.4238	−0.1538	0.0708	−0.0364	−0.2073	0.4460**	—	—
	Artemisia	Asteraceae	number of taxa	*Artemisia*	Asteraceae	number of taxa	*Artemisia*	Asteraceae

*Significance level 0.05, **significance level 0.01. Calculations were made using the program SPSS 5.01, which automatically controls the significance level.

abundant Asteraceae plants, have present counterparts in the semi-arid Spain (Peinado et al., 1992). We cannot categorically discard, however, that a differential mechanism of biotic transport which introduced Asteraceae pollen into the deposit has been favoured during those stages of open landscape. In either the case, there is no sedimentary and/or cultural evidence for increased human or animal activity during the *Artemisia*-dominated phases.

Compared to the sections reported previously (Carrión, 1992a), the new sequences of Carihuela Cave show relatively high pollen taxa diversity. A total of 76 pollen types have been recognized in a count of 17,930 palynomorphs. For the whole sequence 84 pollen types have been identified. Other regional caves with relatively high number of pollen types are Abric Romani, Catalonya, with 64 taxa (Burjachs and Julià, 1994) and Perneras Cave, Murcia, with 70 taxa (Carrión et al., 1995a).

For CIV section 2 there is certain positive correlation between the number of taxa and the total concentrations (Table 5). The experiments by Coles and Gilbertson (1994) on the airfall input of pollen and spores highlight that the number of grains caught is the principal determinant of the number of plant taxa identified. One limitation of that study is that the sampling exclusively recorded the airborne component. In this sense, the lack of correlation between the number of taxa and total concentration in CIV section 1 emphasizes our ignorance about the post-depositional processes affecting cave pollen assemblages.

A relevant question that cave palynology must face is that of the pollen spectra representativeness. The pioneering work by Van Campo and Leroi-Gourhan (1956) and Bui-Thi-Mai (1974) show that the distribution of different pollen types is not homogeneous along caves with an overall higher distortion for some types deep inside the cavity. This distortion basically affects the relative frequencies of taxa but considering only their presence or absence, the representativeness of the local vegetation seems to be generally acceptable. Recent experiments of Burney and Burney (1993) on modern pollen deposition in caves from New York State show that samples from inside caves can register all the pollen types recorded from the outside except the aquatic and swamp types. They recommend a greater use of caves in palynological studies. Different results are found by Bottema (1982) in Greek sites, and Bottema and Woldring (1993) in Early Bronze and Byzantine samples from Kestel tin-mine, Turkey. They demonstrate that pollen contained in the archaeological layers provides little information on the upland vegetation of the past, but it is clearly biased by biotic input including insect and human activities. Regarding Carihuela, we accept that, for several reasons, some species of the past vegetation might have not been recorded, but those recorded seem to provide some ecologically plausible inferences of vegetation types (Fig. 11).

7.1.2. CIV section 1

Zone 1a shows similar features to those found in L4-K (Fig. 8) of CIII section 1 (Carrión, 1992a). Zones 1b and 1c are not very different to zone 1a except for variations of *Pinus* and *Helianthemum* values (Fig. 3). *Pinus* is less and less abundant towards the top of the sequence while *Artemisia* slightly increases but these variations are not seen

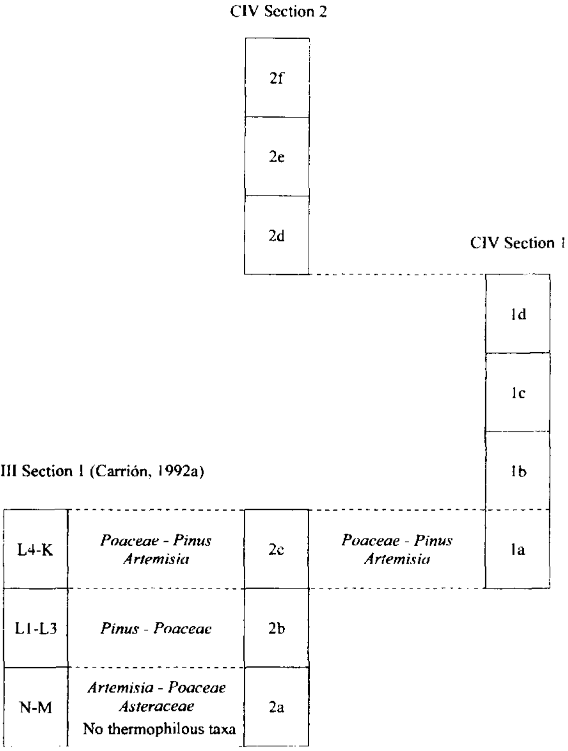


Fig. 8. Correlation between pollen zones in CIII section 1 (Carrión, 1992a), CIV section 2 and CIV section 1.

in the concentration curves (Fig. 4). *Helianthemum* and Lamiaceae have their maxima in 1b. Although the sediments do not comprise abundant thermoclastic scree, mesothermophilous taxa continue to be rare (*Quercus, Acer*, Ericaceae). Zones 1a–1c may therefore indicate a continuation of the Upper Pleniglacial conditions which began in unit V (Carrión, 1992a).

Zone 1d is characterized by an increase of *Quercus, Fraxinus, Juniperus* and *Genista* type, by the presence of *Betula, Alnus, Acer, Pistacia* and *Cistus* (Fig. 3), and by the decreased concentrations of total pollen and spores (Figs. 3 and 4). This zone suggests climate change at the onset of the Lateglacial, which has been dated in Padul at ca. 15,200 yr B.P. (Pons and Reille, 1988).

7.1.3. *CIV section 2*

The existence of pollen in zone 2a (Fig. 5) seems to be related to downward movement, because: (1) the pollen record is the typically Pleniglacial type described in the lowermost layer and characterized largely by *Artemisia* (Carrión, 1992a); (2) over the whole cave, the correlative unit VI shows sedimentary features that accord better with the presence of thermophilous taxa (Fig. 11); and (3) the strata involved display a crumbly structure suitable to percolation.

Zones 2b and 2c show increases in *Pinus, Helianthemum* and Lamiaceae while *Artemisia* declines (Figs. 5 and 6). Zone 2c coincides with unit IV, which shows an erosional surface on the top (Fig. 8).

Although there is no clear evidence of water transport, this must have been an episodic source of sediment in some parts of the cave and the cause of sediment removal in others. It is therefore likely that, during the time of the erosion of CIV section 2 and deposition of unit IV in CIV section 1, the chamber CIV was either beneath bedrock crevices or affected by water entrance via the breached chimney in CV (Carrión, 1992a).

The Lateglacial sequence of CIV section 2 begins in zone 2d as suggested by the curve of *Juniperus*, the presence of *Betula* and the date of ca. 12,320 yr B.P. at 55 cm (Figs. 5 and 6). Likewise, there are indicators of climate improvement such as evergreen (*Q. ilex, Q. rotundifolia, Q. coccifera*) and deciduous *Quercus* (cf. *Q. faginea*), and others like *Fraxinus, Acer, Olea europaea* and *Myrtus communis*, which had not occurred before. The appearance of these pollen taxa together with *Corylus, Salix, Rhamnus, Cistus, Viburnum tinus, Hedera helix, Ephedra fragilis* and *Cytisus reverchonii* suggests a general, mosaic-like, picture of a Mediterranean landscape together with occasional soil water-dependent communities of mesophilous trees, hygrophytic shrubs and lianas.

Zone 2e is characterized by the nearly total disappearance of mesothermophilous taxa, while pollen of *Artemisia*, Asteraceae and especially Chenopodiaceae, *Juniperus, Betula, Ephedra fragilis* and *Ephedra distachya* type increase. Given these palynological features and the date of ca. 12,320 yr B.P. at the end of the previous zone, zone 2e could coincide with the Younger Dryas period. This severe cold spell, mostly dated between 11,000 and 10,000 yr B.P. (Berger, 1990) has been noticed in southern (Pons and Reille, 1988) and eastern Spain (Carrión and Dupré, 1996). Zone 2f displays continuous curves for *Quercus* and the presence of *Acer*, *Pistacia* and *Ephedra fragilis*. Mesothermophilous elements are less common than in 2d but *Quercus* is more abundant. Zone 2f could represent the very early Holocene period.

7.2. The whole sequence

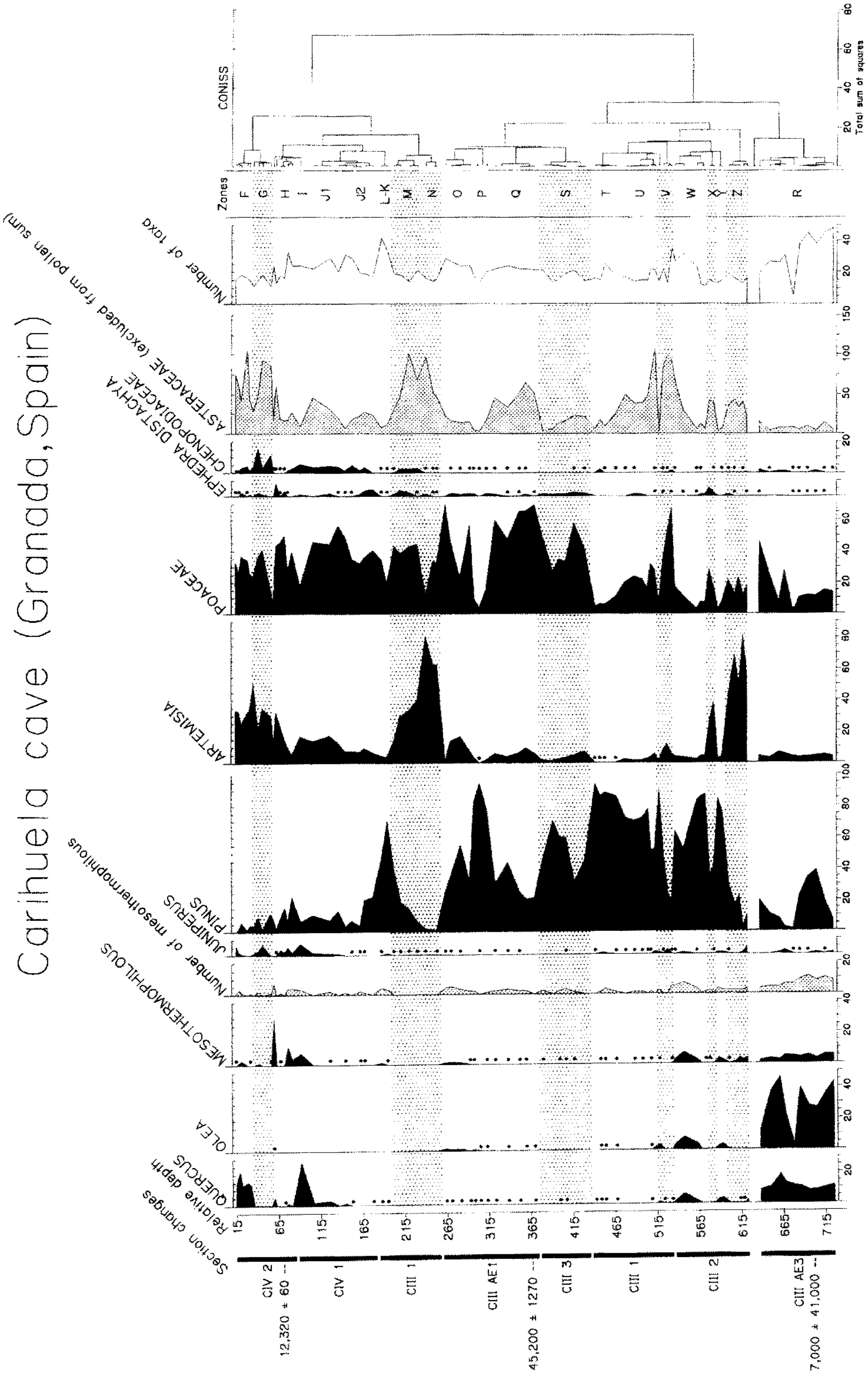
7.2.1. Carihuela and the potential of cave palynology

The results of this paper together with those published before (Carrión, 1992a) demonstrate the potential of cave palynology in reconstructing Quaternary environments. At Carihuela, there is a good correlation between the litho- and biostratigraphy (Fig. 11). In order to compare such different sources of evidence, the best criterion is the composition of the pollen assemblages rather than the pollen frequencies. Thus, the number of mesothermophilous taxa conforms better with the lithological and faunal events than the vegetation types (Fig. 11). Thermoclastic scree is particularly abundant in units VII and V, where rodents indicating cold conditions occur, such as *Allocricetus bursae* and *Microtus arvalis*, and where pollen spectra suggest a steppe-like vegetation without thermophilous elements. Formation of calcium carbonate concretions is apparent in the basal brecchia and in units XI, VI and IV–III, where the pollen spectra contain a number of thermophilous taxa.

It is difficult to isolate the primary type of sediment source for each unit. Apparently, the relative importance of eolian, fluvial and biotic transport has varied through time. Because of the north-facing, overhanging situation of the cave opening, eolian transport may have been present all the time introducing wind-blown silt and clay but nowhere inside the cave is the typically uniform sedimentary structure visible that characterizes eolian transport (Davis et al., 1986). Considering the particle features, water transport could have been important in units XII, XI, VIII, VI and parts of IV (Carrión, 1992a). Biotic transport is evident in units VII and VI. On the other hand, internal weathering of walls and roofs has been a source of sediment in units X, VII, V and III, which coincide with stadial stages in the pollen sequence (Figs. 9 and 11).

Carihuela Cave is well orientated as a site for pollen analysis. First, it shows three large entrances favouring strong air circulation which should in theory permit good pollen input. Second, there are sedimentary strata covering the pleniglacial stages, which are present as gaps within the infillings of many European caves (Campy and Chaline, 1993). Third, the excavations have opened wide areas with a number of profiles where lateral comparison of pollen spectra can be performed. Fourth, some units contain calcium carbonate which permit a fine sampling interval and ensures a good pollen preservation and analytical utility (Brook et al., 1990). Fifth, human activity has been intense in many parts of the cave as deduced from the perceptible accumulation of artifacts and bones in, for instance, unit VI in the exterior area. This raises the possibility of correlation of pollen zones with cultural phases but also the danger of bioturbation since fire pits, material storage and food gathering could have occurred. However, studying the sediment formation processes in archaeological sites in North America, Kelso (1993, 1994) has demonstrated that soil compression and rapid matrix accumulation linked with heavily utilized sites precludes pollen percolation. In such places, this author found a clear correlation between pollen concentration and the shift in pollen types, just as we have in CIV section 2 (Table 5).

Sixth, notwithstanding the absence of seeds and other plant remains in the deposits, the value of aridity for biotic preservation and the negative effect of sediment moisture and frequent soil hydration–dehydration cycles are substantiated at Carihuela Cave. The units XII and lowermost XI in CIII sections 1 and 2, and unit VI in CIII and CIV contain no pollen and spores. Although these deposits are the richest in organic content in the cave they have been affected by post-depositional humidity and occasionally experienced stagnant water (Vega-Toscano, 1988). Interestingly, unit VI is polliniferous in the entrance area (CIII AE section 1) where the sediment formed in less humid conditions. Finally we reiterate that aspects such as substantial pollen concentrations and number



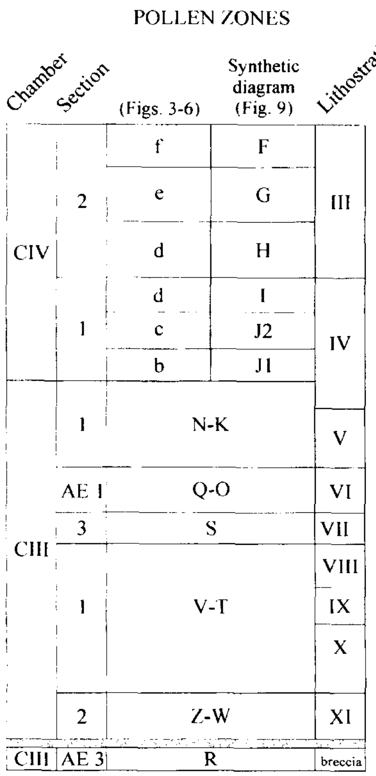
ig. 9. Synthetic pollen diagram of Carihuela Cave. Shaded zones are interpreted as arid stages.

of taxa, parallelism between the curves of percentages and concentrations, ecological plausibility of the pollen spectra, etc., make Carihuela a useful pollen sequence.

7.2.2. *Pollen stratigraphy, vegetational developments, and correlations*

With the modification of the relative position of zone R towards the bottom of the Carihuela stratigraphy (Figs. 9–11), the sequence fits generally into the Padul pollen record (Pons and Reille, 1988), as well as into other continental pollen sequences from the Mediterranean basin such as Valle di Castiglione (Follieri et al., 1988) and Lago di Vico (Leroy et al., 1996). It also conforms with deep-sea records of the eastern (Cheddadi et al., 1991) and western Mediterranean (Hooghiemstra et al., 1992).

The chronology of Carihuela remains imprecise as, for instance, we do not know if the basal breccia deposited in the external area (zone R) is coeval or not, with unit XII (Carrión, 1992a). What we can realistically observe is: (1) a last Interglacial stage (zone R) with *Quercus*–Oleaceae dominated assemblages; (2) a pre-Würmian phase (zones Z–W) with an alternation of herbaceous and forest taxa; (3) two Pleniglacial maxima (zones S and N–M) with a reduction in thermophilous taxa; (4) an inter-Pleniglacial episode (zones Q–O); and (5) a Lateglacial stage (zones I–G) including the Younger Dryas event.

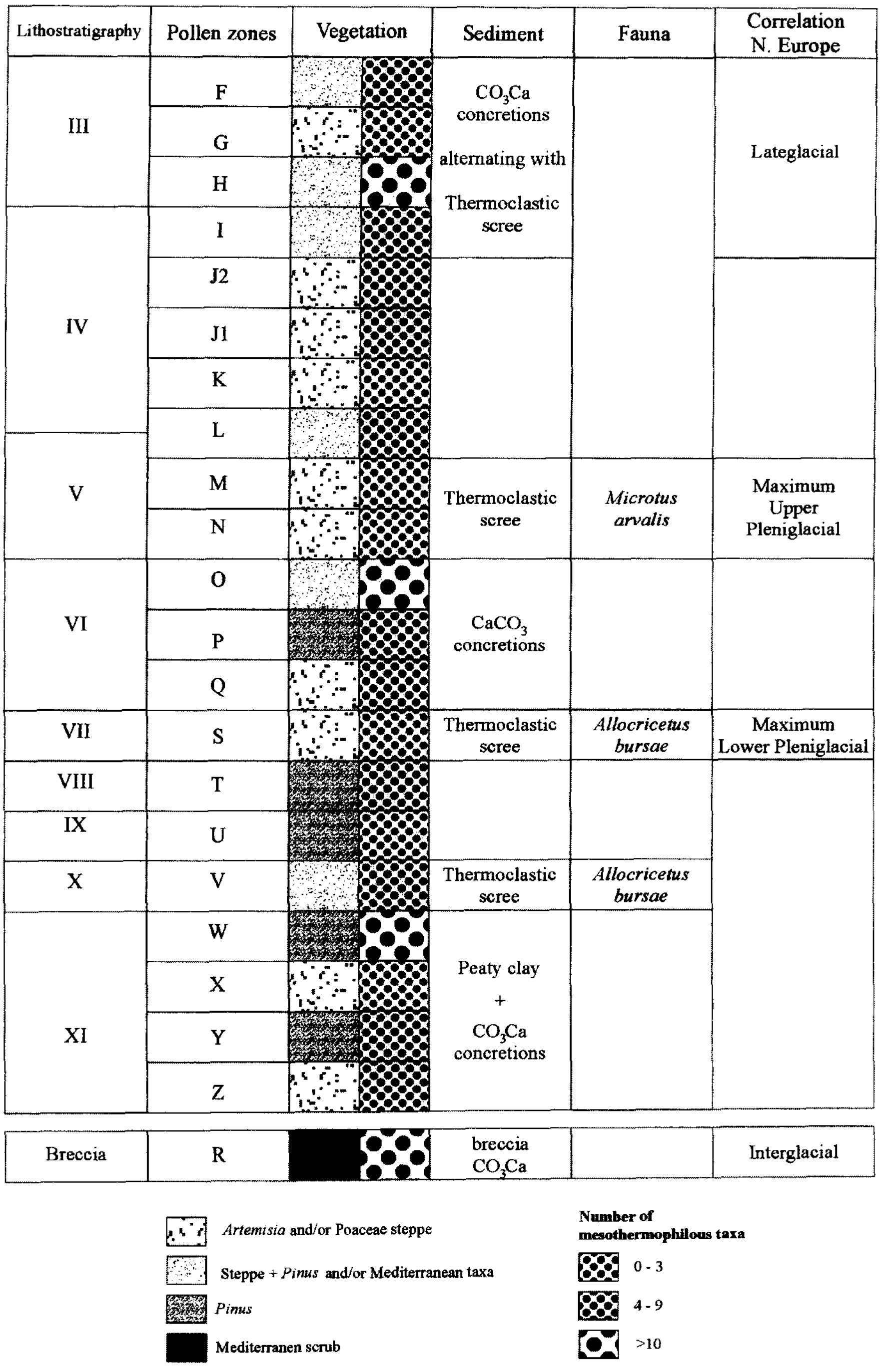


Chamber	Section	POLLEN ZONES (Figs. 3-6)	POLLEN ZONES Synthetic diagram (Fig. 9)	Lithostratigraphy
CIV	2	f	F	III
		e	G	
		d	H	
	1	d	I	IV
		c	J2	
		b	J1	
CIII	1	N-K		V
	AE 1	Q-O		VI
	3	S		VII
	1	V-T		VIII
				IX
				X
	2	Z-W		XI
CIII	AE 3	R		breccia

Fig. 10. Correspondence between the pollen zones and the lithostratigraphical units involved in the synthetic diagram of Carihuela Cave (Fig. 9).

At least six important regressions of mesothermophilous taxa are noticed within the sequence (zones Z, X, V, S, N–M and G, Fig. 9), all of them characterized by the establishment of a wide range of herbs, suggestive of discontinuous vegetation cover. The expansions of *Artemisia* and especially Chenopodiaceae are inferred to mark climatic shifts to increased dryness. Thus, aridity could have been maximal in zones N–M and G, that is during the Upper Pleniglacial and Younger Dryas. A similar interpretation has been made from continuous pollen and isotopic records of the Mediterranean sea. The pollen sequence from the anoxic Bannock Basin (Cheddadi et al., 1991) suggest that throughout the deglaciation from 18,000 to 11,000 yr B.P., the aridity progressively increased, culminating at 11,000 yr B.P. during the Younger Dryas chronozone.

The new sequence of Carihuela Cave does not show any important expansion of *Quercus* and/or other Mediterranean taxa during the inter-Pleniglacial zones, albeit their presence is constant throughout zones Q–O (especially the latter) contrasting with their rarity or absence in the lower- and uppermost beds. Clearer regional developments of Mediterranean vegetation have been shown in the present-day thermo-Mediterranean sites of Beneito Cave just before 38,800 yr B.P. (Carrión, 1992b), Perneras Cave in late Mousterian beds (Carrión et al., 1995a,b), Abric Romani from 46,200 to 40,800 yr B.P. (Burjachs and Julià, 1994), and marine pollen records at the northern fringe of the Sahara between 50,000 and 40,000 yr B.P. (Hooghiemstra et al., 1992). The assessment of the interstadial event at Lake Banyoles between 30,000 and 27,000 yr B.P.



Lithostratigraphy	Pollen zones	Vegetation	Sediment	Fauna	Correlation N. Europe
III	F	░ ⁘	CO_3Ca concretions alternating with Thermoclastic scree		Lateglacial
	G	⁖ ⁘			
	H	░ ●			
IV	I	░ ⁘			
	J2	⁖ ⁘			
	J1	⁖ ⁘			
	K	⁖ ⁘			
	L	░ ⁘			
V	M	⁖ ⁘	Thermoclastic scree	*Microtus arvalis*	Maximum Upper Pleniglacial
	N	⁖ ⁘			
VI	O	░ ●	$CaCO_3$ concretions		
	P	▒ ⁘			
	Q	⁖ ⁘			
VII	S	⁖ ⁘	Thermoclastic scree	*Allocricetus bursae*	Maximum Lower Pleniglacial
VIII	T	▒ ⁘			
IX	U	▒ ⁘			
X	V	░ ⁘	Thermoclastic scree	*Allocricetus bursae*	
XI	W	▒ ●	Peaty clay + CO_3Ca concretions		
	X	⁖ ⁘			
	Y	▒ ⁘			
	Z	⁖ ⁘			
Breccia	R	■ ●	breccia CO_3Ca		Interglacial

⁖ *Artemisia* and/or Poaceae steppe

░ Steppe + *Pinus* and/or Mediterranean taxa

▒ *Pinus*

■ Mediterranen scrub

Number of mesothermophilous taxa

⁘ 0 - 3

⁘ 4 - 9

● >10

Fig. 11. Stratigraphical framework for the Pleistocene deposits of Carihuela Cave.

(Pérez-Obiol and Julià, 1994) is far from conclusive as the *Quercus* expansion is no more prominent than, for instance, those of the middle Würm at Padul (Pons and Reille, 1988). Whether or not these small peaks in mesothermophilous taxa are representative of major warming trends is debatable, despite the common tendency to consider them as interstadials.

Independent of the fact that pollen spectra of zones Z–O are dominated by *Pinus* and grasses, we suggest that *Quercus* forests accompanied by a number of mesophytes and thermophilous shrubs must have developed regionally during that time. The situation could be similar to that described above for CIV 2d (zone H, Fig. 9) and comparable tendencies could be observed for zones Z, W, T and F. We must take into account that Carihuela Cave is situated at 1020 m a.s.l. on a rocky escarpment on the north side of a 50 ha calcareous hill surrounded by continental plains, especially towards the north. These surroundings, presumably favouring the growth of grasses and *Artemisia* on the marls, and pines on the calcareous hills, must have been the main pollen source area for the cave. Weinstein-Evron (1994) has demonstrated that the major influence for palaeoenvironmental records from cave sediments is the cave's opening orientation. However, considering a wider geographical extent, *Quercus* forests must have been important during zones Q–O in the region north to the Betic ranges of Sierra Arana, Sierra de Baza, and Sierra Nevada. Such an interpretation is consistent with the presence in the pollen record of a number of thermophilous indicators (Figs. 9 and 11). This line of reasoning is further supported by the prevailing oak forest microfauna of unit VI (*Elyomis quercinus*, *Clethrionomys glareolus*, *Arvicola sapidus*, *Sorex minutus*, *Erinaceus europaeus*) (Ruiz-Bustos and García-Sánchez, 1977). Likewise, these strata contain calcium carbonate nodular concretions deposited under relatively warm conditions. There distribution within the profile suggests an intense supply of water. Organic matter is also abundant suggesting forested biotopes outside the cave (Vega-Toscano, 1988). Finally, we must consider that human activity has been intense in this unit and biased pollen spectra are likely. Thus, it is premature to speculate about the significance of the internal behaviour of the *Pinus* and Poaceae curves.

Pollen grains of *Juglans regia* have not been found in the new profiles of Carihuela Cave. Taken into account that the larger counts where made in zone R and that it reached zone T (Carrión, 1992a) we must consider the survival of walnut beyond the last interglacial, at least, until Early Pleniglacial times. It could have disappeared definitively from the area with the onset of full-glacial conditions. Other western Mediterranean pollen records indicate a consistent presence of walnut until ca. 43,800 yr B.P. in the northeastern Iberian Peninsula (Burjachs and Julià, 1994), even reaching the Lateglacial (Renault-Miskovsky et al., 1984; Munuera and Carrión, 1991). Yet, it is not unlikely that walnut may have survived as a relict in the western Mediterranean until Roman times when it was spread widely by man, particularly in southeastern Spain where favourable niches are plausible. Nowadays, under regional xeric conditions, *Juglans regia* is found growing wild together with relics of *Betula celtiberica*, *Corylus avellana*, *Ilex aquifolium*, *Sorbus torminalis*, *Sorbus domestica*, *Ulmus glabra* and pure individuals of *Quercus ilex*. The 'refugia' from this overall stressful climate are in river valleys, gullies or watercourses within the eastern Betic ranges (Carrión and Sánchez-Gómez, 1992).

As for the recent results at Beneito Cave (Carrión and Munuera, 1997), there is no evidence in Carihuela for such interstadial events as Arcy, Kesselt, Tursac, etc., described for the European Upper Palaeolithic (Leroi-Gourhan and Renault-Miskovsky, 1977; Leroi-Gourhan, 1980; Cattani and Renault-Miskovsky, 1989). Pollen spectra during zones N–J (Fig. 9) are characterized by *Artemisia*, grasses, Chenopodiaceae, Asteraceae, and *Ephedra distachya*, as in many full-glacial floras from other parts of Europe (Turner and Hannon, 1988) and north Africa (Le Houérou, 1992). Moreover, zones N–M record the most critical time for forest development with the disappearance of thermophilous taxa (Fig. 11), which strongly suggest that the zones correspond to the height of the last glacial period.

The Lateglacial spans the interval from approximately J to G–F during which there is substantial evidence for several expansions of Mediterranean taxa (I, H, F) and one period of climatic cooling and/or increased aridity after ca. 12,320 yr B.P., with the important recession of thermophilous taxa (zone G) coinciding with the maximum values in Chenopodiaceae (Figs. 9 and 11). There is no uniform pattern of vegetation response to the Younger Dryas in Spain but the hypothesis that its effects are attenuated in southern latitudes within Europe does not fit with evidence from Padul (Pons and Reille, 1988), Banyoles (Pérez-Obiol and Julià, 1994), and Navarrés (Carrión and Dupré, 1996). The sequence from Carihuela suggests a southern manifestation of the Younger Dryas cold spell at high altitudes. In order to confirm this and other aforementioned hypotheses, a better chronological control is needed for Carihuela Cave, together with multidisciplinary studies integrating these data with pollen studies from lakes, bogs and deep-sea cores. It could help to clarify regional vs. local processes, and extend dated pollen records of the region well beyond the radiocarbon time-scale.Carrión, 1990

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