

Late Quaternary pollen sequence from Carihuela Cave, southeastern Spain

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ABSTRACT

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This study forms part of an interdisciplinary research project, the aim of which is to provide a regional palaeoecological sequence suitable for inter-regional comparisons. Carihuela Cave is a major archaeological site in the Granada province of eastern Andalusia. It falls within the Upper Mesomediterranean bioclimatic belt, lies at 1020 m a.s.l. and has a northerly aspect. An overview of the background of archaeological, palaeontological, sedimentological, and geochronological research at the cave is followed by a presentation of new palynological data from its Pleistocene deposits. The sediments contain Middle Palaeolithic artefacts and are of exogenous origin. Samples for pollen analysis were taken from five stratigraphical sections and a pollen diagram was drawn up for each. Correlation of these permitted two synoptic diagrams to be constructed, with the exclusion in one of them of Asteraceae pollen other than *Artemisia* and *Centaurea*.

Würmian vegetation fluctuated between an arboreal type indicative of a mild climate and a herbaceous type suggestive of cold, dry conditions. Marked expansion of *Pinus* in one stage coincided with slight expansion of mesothermophilous taxa. For the first time in the Iberian Peninsula, there is evidence for the existence of a last glacial warm oscillation characterized by Mediterranean vegetation. *Juglans regia* and *Castanea sativa* pollen, associated with mild/warm episodes during the Pre-Würm, Eo-Würm and Middle Würm, support the interpretation of these as autochthonous Western Mediterranean species. Arid climatic crises are marked by abrupt increases in *Artemisia* or Poaceae, with occasional over-representation of entomophilous Asteraceae.

Correlations are proposed between the Carihuela sequence and other palaeoclimatic findings. The sequence shows correspondence to marine oxygen-isotope stages 2–5, i.e. to the first three Würm stadia, as well as to other regional stratigraphical records. There is a complex interpleniglacial period, very similar to the Würmian interstadial described from the Aquitanian Basin. The Carihuela pollen zones correlate well with the sedimentary sequence. The chronostratigraphical interpretation supports the long survival of the Mousterian in the south of the Iberian Peninsula.

Introduction

As part of a long-term research project involving integration of data from many sources with the aim of establishing a regional palaeoecological sequence appropriate for wider geographical comparisons, the palynological analyses of the Pleistocene deposits at Carihuela Cave (Piñar, Granada) formed the bulk of my doctoral dissertation (Murcia University, 1990). Excavation of Palaeolithic deposits commenced in 1954–1955, with the discovery of Neanderthal bones in three layers of sedimentary refill and of an anatomically modern

man associated with Mousterian artefacts (Spahni, 1955; García-Sánchez, 1960; Lumley, 1969). Holocene deposits were studied by Pellicer (1964). H.T. Irwin and R. Fryxell (Washington State University) and M. Almagro (Universidad Complutense, Madrid) conducted subsequent excavations, of which only preliminary reports have appeared so far (Almagro et al., 1970; Garralda, 1970).

In 1979 an interdisciplinary research project was set up between the Universidad Complutense of Madrid, the Consejo Superior de Investigaciones Científicas at Madrid, and the Institut du Quaternaire at Bordeaux. The palynological analysis pre-

sented here forms part of the project. It is important because: (1) The cave lends itself to the evaluation of palaeoclimatic conditions on account of its high altitude, northerly aspect, strongly continental surrounding terrain, exogenous sedimentary components and proximity of deposits analyzed at the entrance. (2) Compared to most archaeostratigraphical records, that at Carihuela covers a long period, namely the last Quaternary climatic cycle. (3) Most of its lithostratigraphical units can be studied in at least two sections, facilitating multiple correlations and avoiding problems caused by absence of palynomorphs in parts of the sedimentary refill. (4) The eastern Andalusian region where the cave lies is one of the least-studied regions of the Iberian Peninsula as regards palaeopalynology. Previously the most important station analyzed was the Padul peat bog in the foothills of the Sierra Nevada (see Fig.1) (Florschütz et al., 1971; Pons and Reille, 1988).

This study concentrates on the Pleistocene deposits with Middle Palaeolithic artefacts. Holocene deposits, together with transitional ones of uncertain correlation, will be considered in a separate paper.

Geographical location and cave description

Carihuela Cave lies at 1020 m a.s.l. on the northern slopes of Monte del Castillo, Piñar, some 45 km northeast of Granada, at N 37°26'56", W 3°25'47" (Fig.1). The R. Piñar valley opens towards the north with small rounded hills of marl and marly limestones. The area is bounded by four tectonic masses: to the west the Loja-Granada depression, to the north the Jaén ridges, to the east the Guadix-Baza-Huéscar depression, and to the south the Sierra Arana. This last feature is separated from the Sierra Nevada by the Genil and Darro river valleys (Fig.1).

The cave opens onto a rocky scarp formed by the Piñar fault on the northern face of Monte del Castillo, a calcareous hill of some 50 ha formed of Lower Jurassic limestones. Small dolines and very worn lapiaz covered by rubifacted clays are the principal exogenous karstic features. The cavern runs for 300 m, of which only the first third has been explored archaeologically. Most galleries

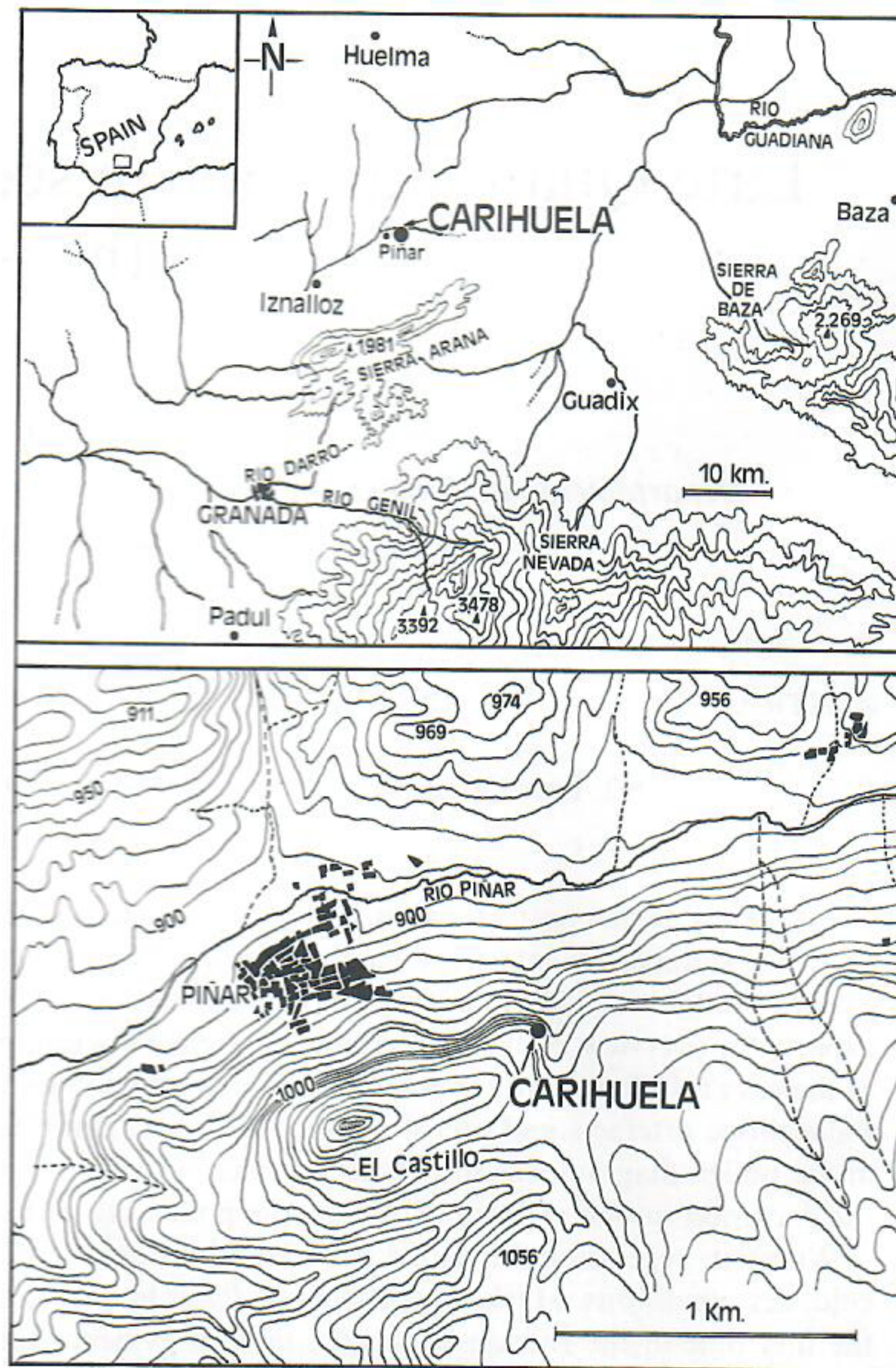


Fig.1. Location of Carihuela Cave (Granada, Spain).

and passages have a high roof running N-S or NW-SE (Fig.2). Weathering has affected the entrance overhang and adjacent walls.

Samples for pollen analysis were taken from the "Entrance Area" (AE) and the Main Chamber (CIII); Figure 2 shows the locations of the corresponding sections. Most CIII sediments are derived from the entrance and the sedimentary layers dip strongly inwards from it. Chamber IV (CIV), on the other hand, contains sediments of mixed origin, those from the main entrance (mainly Pleistocene) blending with others which entered via the chimney that breached Chamber V in the final Upper Pleistocene and Holocene.

Climate and vegetation cover

The cave lies in an area of continental Mediterranean climate. The nearest meteorological station,



Fig.2. Longitudinal situation of sections.

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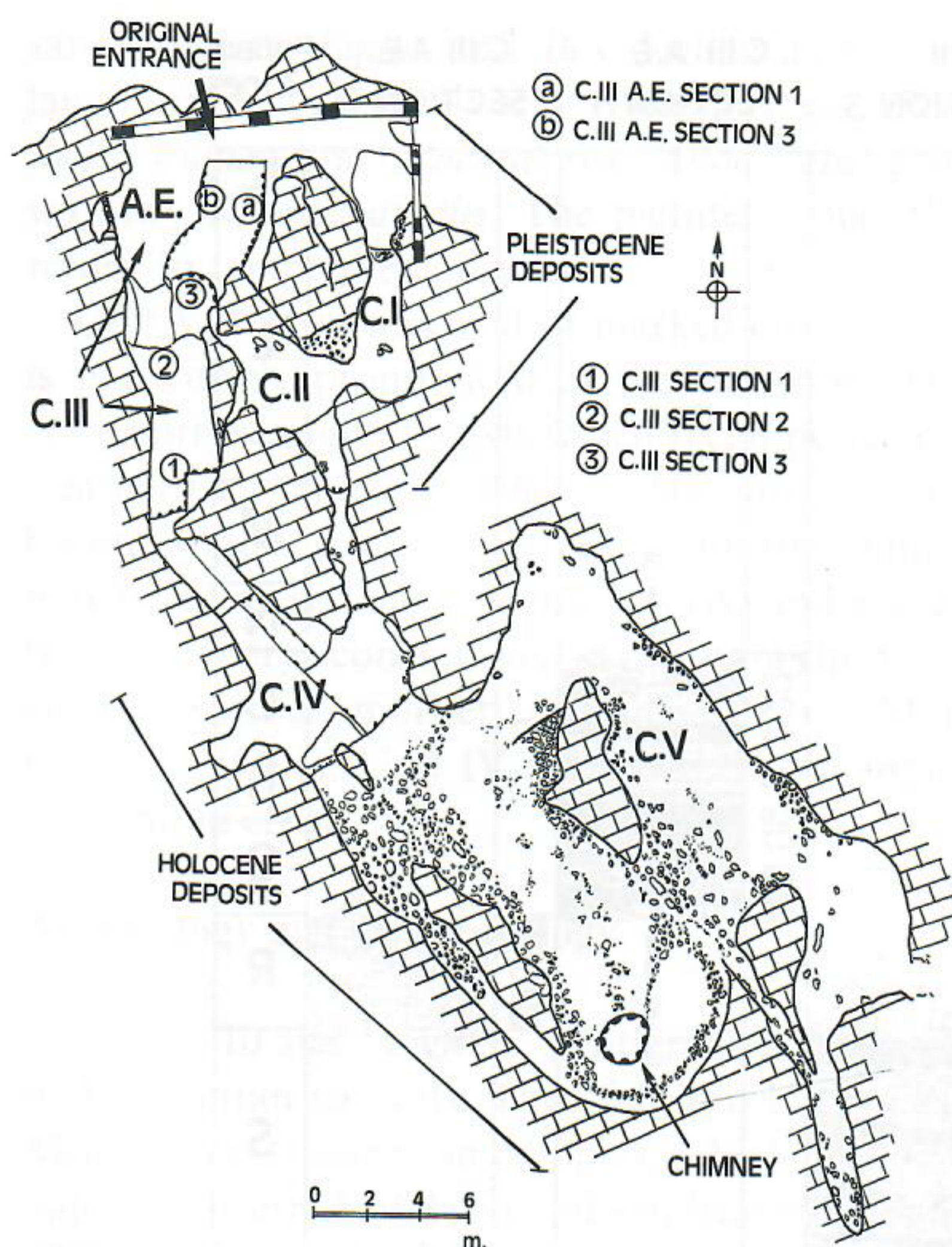


Fig. 2. Longitudinal section from Carihuela Cave showing the situation of the main chambers, passages and stratigraphical sections.

at Iznalloz, has a mean annual temperature of 12.7°C and rainfall of 574 mm. Phytoclimatology places the area in the Upper Mesomediterranean belt with a dry ombroclimate, although the nearby Supramediterranean belt has some influence. Biogeographically it belongs to the Betic Province, Subbetic Sector (Rivas-Martínez et al., 1977; Rivas-Martínez, 1987).

The vegetation around the cave is in an advanced state of degradation, caused mainly by overgrazing and over-intensive use of the deepest soils for growing poplars, almond trees, vines and cereals. Climax vegetation corresponds to a *Quercus rotundifolia* forest rich in geophytes such as *Paeonia broteroi* or *Helleborus foetidus*, sometimes accompanied by *Quercus faginea*. These forests are present only in patches near Iznalloz. Much more common is "chaparral" with thickets of *Quercus coccifera*, *Crataegus monogyna*, *Cytisus reverchonii*, *Asparagus acutifolius*, etc. Below 700–800 m evergreens are accompanied by thermophilous species

such as *Pistacia lentiscus*, while above 1200–1300 m spiny shrubs such as *Echinopartium boissieri* and *Erinacea anthyllis* increase. In the Sierra Arana above 1800 m an open vegetation occurs with, for example, *Pinus sylvestris*, *Juniperus sabina*, *Juniperus communis* and *Genista longipes*.

Lithostratigraphy and palaeontology

Stratigraphical and sedimentological studies were undertaken by Vega-Toscano et al. (1988) on the sections from CIII, which correlate well (Fig. 3). Most of the bony remains were identified by Ruiz-Bustos and García-Sánchez (1977). 12 lithostratigraphical units were established, of which the three uppermost only appear as traces, being better represented in CIV; they are still under investigation, problems of correlation notwithstanding.

Unit XII is the lowest yet reached; its sandy clay is rich in organic matter and altered stalagmitic crusts. It seems to correspond to a humid thermal optimum. Unit XI is peaty clay containing pseudomycelia of calcium carbonate and gravels. Sand and gravel increase in and after XI-8, no doubt a consequence of weathering of both roof and walls: the picture is one of gradually deteriorating climatic conditions.

Unit X comprises abundant blocks and angular clasts in a sparse, clayey silt. Unit IX is mainly pebble-sized clasts in a clayey sand matrix. X and IX are characterized by *Equus*, *Cervus*, *Bos*, *Microtus nivalis* and *Allocricetus bursae*. A pronounced cooling is indicated. Unit VIII comprises small gravel in sand with nodular concretions and some limestone pebbles. *Allocricetus* and *Microtus nivalis* are less common and some warming may be inferred. Subunit VIIb marks the onset of harsher conditions and decreasing temperatures. Limestone pebbles and blocks alternate with sandy clays. Cryophilous species such as *Allocricetus bursae* characterize the microfauna. Subunit VIIa comprises several calcium carbonate levels in sparse sandy clay, the whole being sealed by a stalagmitic layer.

Unit VI appears in CIII as organic silty clays containing charcoal, scattered calcareous concretions, bones, lithic materials and recent bioturbation. In CIII AE Section 1, it comprises a more

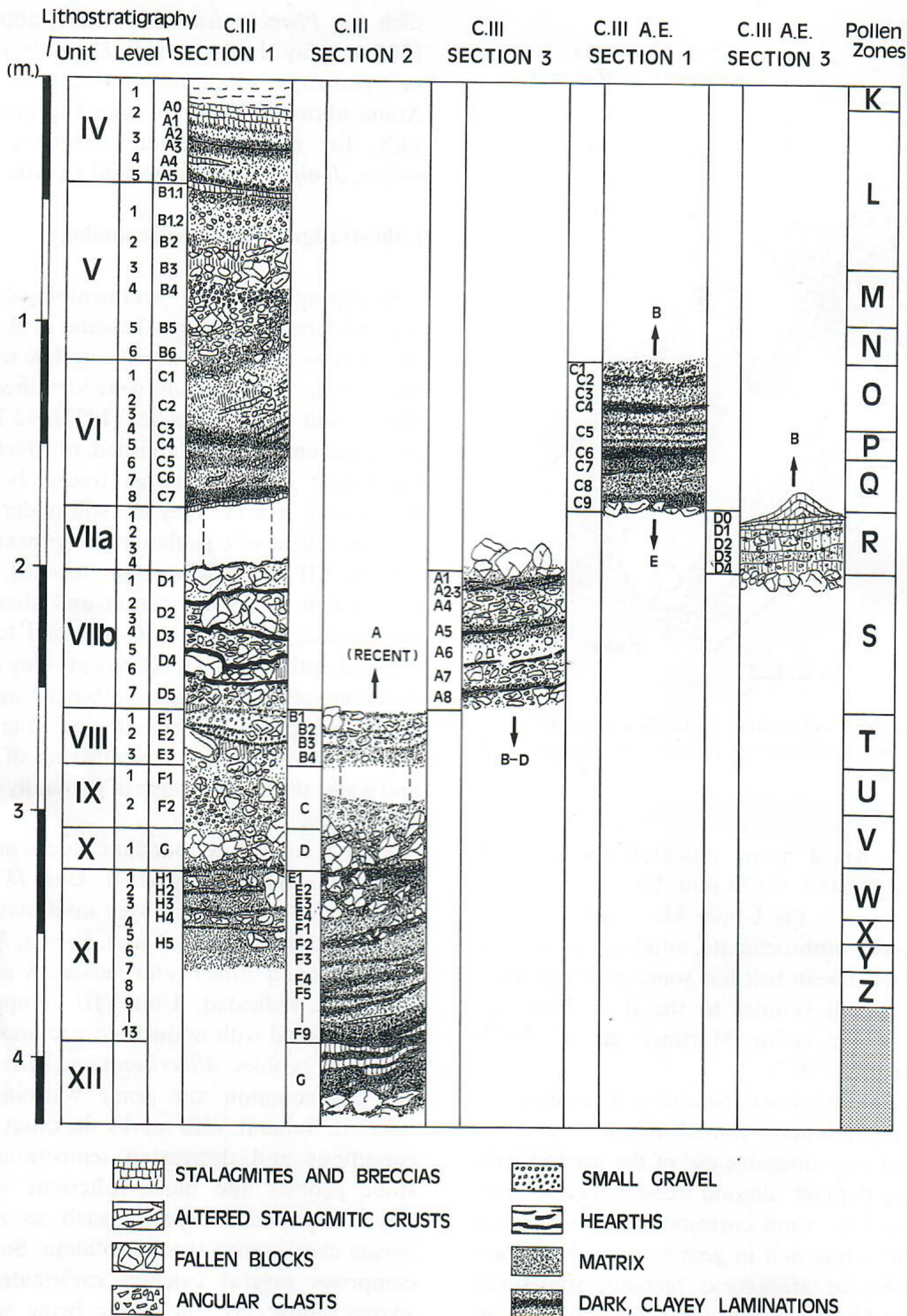


Fig.3. Correlation between the Pleistocene stratigraphical sections from Carihuela. In accordance with Vega-Toscano et al.(1988).

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sandy matrix. *Equus* and *Bos* decline as *Cervus*, lagomorphs and carnivores (*Canis*, *Ursus*, *Panthera*, *Vulpes*, and *Crocuta*) rise. *Allocricetus* gives way to *Microtus arvalis*. The picture is one of a return to temperate conditions.

Unit V follows a period of marked erosion that is particularly pronounced at the entrance (AE). It comprises angular clasts which recall periglacial weathering (Butzer, 1964). *Microtus arvalis* becomes more common. A very cold, dry climate may be inferred. Unit IV contains clays and gravels with powdery concretions. There are hints of slightly warmer, moister conditions. In the Main Chamber (CIII), Unit IV is capped by a complex stalagmitic crust.

Archaeology and geochronology

Figures 10 and 11 list the stratigraphical changes in Mousterian variants. They fall into his Typical Mousterian–Charentian complex, which predominates in eastern Andalusia and southeastern Spain. The technique indices are homogeneous, showing only random variations throughout the sequence. All the series are non-Levalloisian, with a faceted striking-platform technique (Vega-Toscano, 1988, 1990). A “Mousteroid” industry without leptolithic transformation (Middle Palaeolithic s.l.) characterizes the uppermost levels.

Many thermoluminescence dates were determined at Birmingham University on burnt flint from the Washington State University excavations (Fig.4). They show a time-span of some 70,000 years, similar to that which must have elapsed between Units IV–XI (Vega-Toscano, 1988). The precise stratigraphical correspondence of each is hard to assess because the excavation records refer to the nature of the material and industrial typology. Moreover, thermoluminescence-dating was still at an experimental stage when the first two series were investigated (Fremlin, 1974; Göksu et al., 1974). Fremlin’s chronological assessment was based on samples collected entirely from CIII Section 1, whereas Göksu et al. (1974) reported on samples from all three sections in CIII. Both series were modified in H. Göksu’s subsequent thesis (unpublished), after technical problems had been resolved (Fig.4, Table I). It seems that a

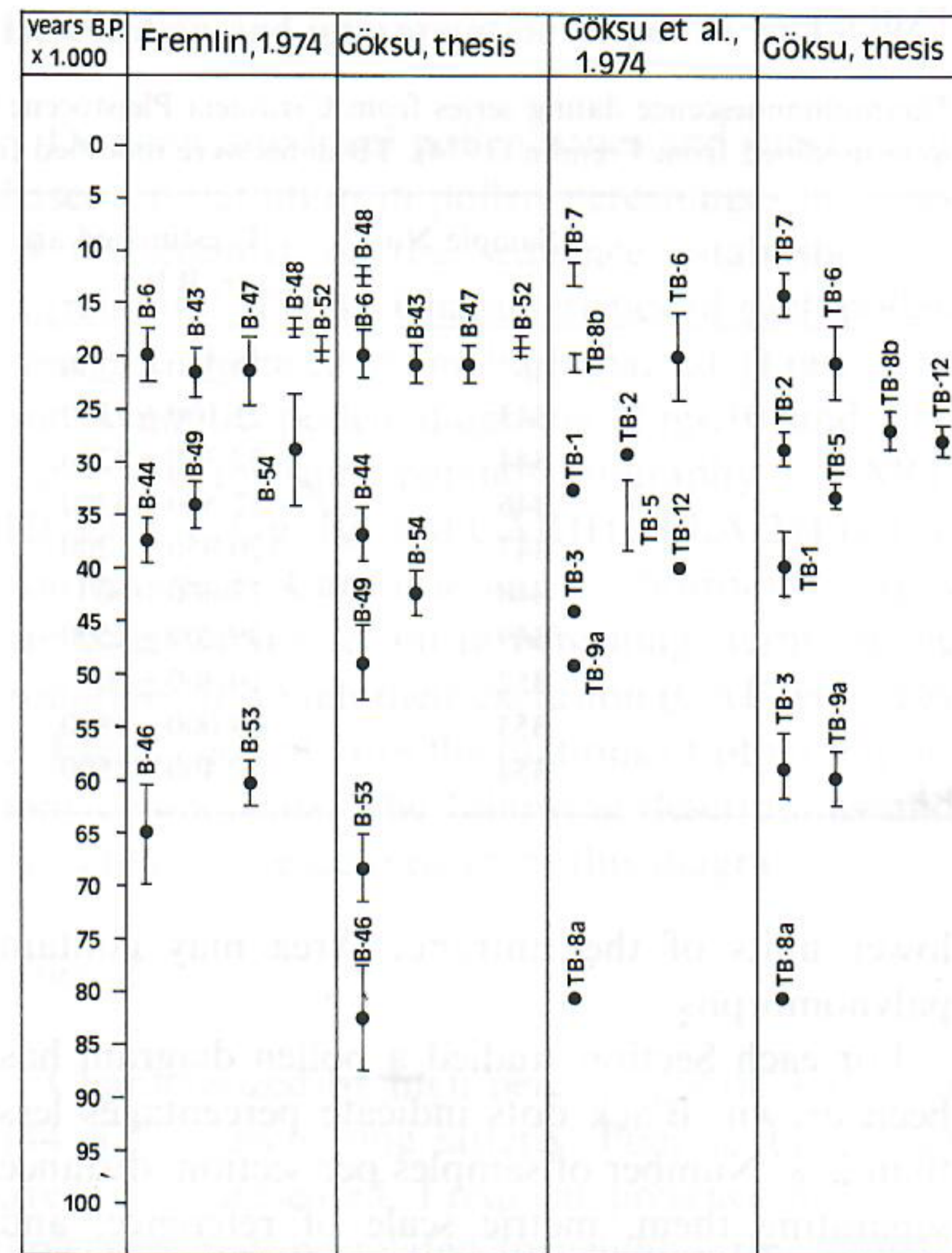


Fig.4. Several thermoluminescence dating series from Carihuela Pleistocene deposits. For explanation see paragraph “Archaeology and geochronology”.

systematic error made the first dates published younger than they are now interpreted to be.

Palynological methods

Sampling was undertaken from vertical stratigraphical profiles, as indicated for archaeological deposits by Girard (1975). Samples were taken from CIII Sections 1, 2 and 3, which encompass sedimentary Units XII to IV, although absence of pollen in Units VI and part of VII made it necessary to sample some sections at the Entrance Area, particularly those corresponding to the aforementioned units in CIII AE Sections 1 and 3. Palynological study of lithostratigraphical Units XII and the lowermost part of XI has not yet been possible because both sections are sterile, although it is hoped that future excavations, aimed at investigating older Palaeolithic industries, may extend the cuttings in area and depth sufficiently for palynology to be possible. It is also likely that the

TABLE I

Thermoluminescence dating series from Carihuela Pleistocene deposits in accordance with H. Göksu (thesis, unpublished). B-dates were modified from Fremlin (1974). TB-dates were modified from Göksu et al. (1974). All the materials were previously burnt

Sample No.	Tl estimated age (yr. B.P.)	Sample No.	TL estimated age (yr. B.P.)
B6	20,200 ± 1200	TB-1	39,400 ± 2000
B43	21,100 ± 1300	TB-2	28,000 ± 1000
B44	37,350 ± 2200	TB-3	57,700 ± 2500
B46	82,500 ± 4900	TB-5	33,000 ± 1200
B47	20,950 ± 1200	TB-6	20,200 ± 3000
B48	13,400 ± 600	TB-7	13,600 ± 800
B49	49,200 ± 2500	TB-8a	80,000
B52	19,300 ± 500	TB-8b	27,000 ± 1000
B53	68,000 ± 1800	TB-9a	58,800 ± 2000
B54	42,400 ± 1500	TB-12	27,400 ± 1000

lower units of the Entrance Area may contain palynomorphs.

For each Section studied a pollen diagram has been drawn. Black dots indicate percentages less than 2%. Number of samples per section, distance separating them, metric scale of reference, and stratigraphical position are shown in each diagram (Figs.5 to 9). A synoptic pollen diagram has also been drawn up: CARIHUELA 1 (Fig.10). It takes account of stratigraphical correlations (Fig.4), which are corroborated by the pollen spectra obtained in the various strata. In calculating synoptic pollen diagram CARIHUELA 2 (Fig.11), Asteraceae pollen grains have been excluded from the pollen sum (other than of *Artemisia* and *Centaurea*) because this group is presumed to be over-represented, owing to factors specific to the depositional site and to factors in the production and

dispersion of entomophilous Asteraceae pollen. This matter has been repeatedly discussed (Bottema, 1975).

Samples not included in the synoptic diagrams (Figs.10 and 11) and those correlated with them are shown in Table II. Spectra 27-32 from Fig.5 were replaced with 10-23 from Fig.6, because their related Units VIII, IX and X were pollen-analytically more reliable in CIII Section 1 than in CIII Section 2, where vertical mixing or down-wash of pollen by percolating water seems more likely. With regard to the Subunit VIIb, spectra 24, 25 from Fig.6 and 2, 3 from Fig.7 were selected because of their more accurate stratigraphy. All these samples served as controls for connecting the separate diagrams and comparing pollen spectra from different sectors within the cave. Pollen percentages from the same bed, but from

TABLE II

Excluded and correlative pollen samples in the synoptic diagrams CARIHUELA 1 (Fig.10) and CARIHUELA 2 (Fig.11) and its litho- and palynostratigraphical relationships

Excluded samples (No.)	Section	Correlative samples (No.)	Section	Lithostratigraphy	Pollen zones
27	C III 2	10-13	C III 1	X-1	V
28	C III 2	14-19	C III 1	IX-1	U
28-32	C III 2	20-23	C III 1	VIII-4,3	T
5	C III 3	24,25	C III 1	VIIb-6,7	S1
26	C III 1	2,3	C III 3	VIIb-3,4	S2

different sections, tend to show some variation, although this is always below 10% for the main types (e.g. *Pinus*, Poaceae, Asteraceae) and no vertical or lateral pattern can yet be established.

Laboratory methods followed the classical chemical method (Dimbleby, 1957), modified to optimize palynomorph concentration by densimetric procedures (Girard and Renault-Miskovsky, 1969). Pollen and spore identification was performed by comparison with the reference collection of the Plant Biology Department at Murcia University. Counting involved all spores and pollen within an entire preparation by regularly spaced columns within it. In total 67,622 palynomorphs were counted, excluding those unidentified and non-vascular cryptogam diaspores. The number of pollen types varied between 8 and 48, 66 taxa being recognized in all. Percentages of indeterminate pollen were not systematically calculated. Nevertheless, as a general rule, preservation was better in those strata showing processes of calcification such as Subunit VIIa. The peaty, moist sediment below the Unit X contained as much as 40% of deteriorated pollen, whereas mainly well-preserved pollen were observed in samples from the uppermost, drier levels (e.g. Unit V). On the other hand, no relationship was apparent between samples containing higher proportions of Asteraceae and those with poorly preserved pollen.

There are lingering doubts over identification of some pollen groups. The majority of pine pollen are believed to belong to a small sized morphotype (*Pinus nigra*, more probably *Pinus sylvestris*), although some from Zone R (Fig.8) might be attributable to *Pinus halepensis*. As regards *Quercus*, almost all palynomorphs seem to correspond to *Quercus rotundifolia* and *Quercus coccifera*. *Ephedra distachya* type also refers to *Ephedra nebrodensis* and the *Ononis*, *Lotus* and *Plantago lanceolata* types correspond to those described by Moore and Webb (1978). The Anthemideae type includes the sum of the *Anthemis*, *Aster* and *Bidens* types of Moore and Webb (1978). The Cardueae type includes the *Carduus*, *Cirsium* and *Serratula* types of the same authors. Finally, the Cichorioideae type includes all echinolophate pollen grains.

Description and interpretation of pollen zones

Division into local pollen zones and subzones is based on variation in pollen percentages in terms of the context of the sequence established by correlations (Fig.4). Characteristics of each pollen zone are deduced from both partial (Figs. 5–9) and synoptic pollen diagrams (Figs.10 and 11): they show the same palynostratigraphy in CARIHUELA 1 (Fig. 10) and CARIHUELA 2 (Fig.11). Anthemideae, Cardueae and Cichorioideae types are considered relevant in percentage terms in the zonation, although their exclusion (CARIHUELA 2, Fig.11) accentuates fluctuations of other important components. The following descriptions and percentages are derived from this diagram.

Zone Z

Characterized by high percentages of *Artemisia* (44–82%), decreasing latterly. Poaceae (10–25%) are well represented. Frequent presence of *Alnus*, however, may be related to neighbouring growth in wet locations, particularly beside the river Piñar — formerly much nearer the cave. Other thermophilous taxa occur in low proportions (*Quercus*, *Phillyrea*).

Zone Y

Artemisia decreases sharply to below 5% while *Pinus* rises to above 83%. Both evergreen *Quercus* and *Olea europaea* were important and were accompanied by *Quercus faginea*, *Phillyrea* and Ericaceae. Appearance of *Juglans regia* is noteworthy on account of its palaeobiogeographical significance.

Zone X

Conditions characteristic of the end of Zone Z return. Landscape is open, dominated by *Artemisia* (25–38%) and Poaceae (17–27%) with a greater relative presence of *Pinus* (34–40%). *Ephedra distachya* type attains its highest value (5%) along with *Plantago lanceolata* type (2%), Chenopodiaceae, Rubiaceae, *Ephedra fragilis*, etc. *Quercus*, *Olea*, *Phillyrea*, *Juglans* and *Alnus* disappear.

Zone W

There is an important fall in *Artemisia* to less than 4%, and a general increase of *Pinus* (47–80%) and AP (68–86%). In W1 pollen spectra indicate a pine forest with gradual incorporation of Mediterranean elements (*Quercus*, *Olea*, *Phillyrea*, *Ephedra fragilis*) and deciduous trees (*Alnus*, *Betula*). In W2 the *Pinus* forest opens up and there is an expansion of vegetation dominated by *Quercus ilex-coccifera* (4%), *Olea europaea* (7%), and *Phillyrea* (2%) with other taxa such as *Juglans regia*, *Salix*, *Pistacia*, *Buxus* and Ericaceae also present.

Zone V

Characterized by fluctuations of *Pinus* (15–90%) and Poaceae (3–67%), the former tending to fall, the latter to rise. *Artemisia* is no longer relevant, as grasses now dominate the herbaceous component. In V1 an initial decrease in *Pinus* is followed by a rise (15–48%), while the opposite holds for Poaceae (36–67%). Noteworthy in Subzone V2 is a maximum in the *Pinus* curve (90%), difficult to interpret given the lithological features of Unit X. It is highly improbable that the pollen was contemporary with the sediment. In Subzone V3 *Pinus* (50%) and Poaceae (26–32%) achieve a similar importance to that in V1.

Zone U

Characterized by heliophilous forest of *Pinus* (67–75%), with the lower stratum occupied mainly by grasses, with sporadic presence of other arboreal and shrub-like taxa (*Juniperus*, *Alnus*, *Betula*, *Buxus*). Some woody thermophilous elements disappear, such as *Quercus*, *Olea* and *Phillyrea*.

Zone T

In this period *Pinus* forest cover became more closed, particularly towards the end (93%). There is a greater diversity within AP: *Quercus ilex-coccifera* type and *Juniperus* are constant; *Quercus faginea*, *Betula*, *Juglans*, *Olea*, *Phillyrea* and Ericaceae occur occasionally; *Corylus* and *Lonicera* appear for the first time. The woodland field-layer

must have been principally covered by grasses, which tend to show a low pollen representation when the forest canopy is closed (Heim, 1970).

Zone S

The most noteworthy feature of this Zone is an overall rise in Poaceae (21–57%) and fall in *Pinus* (31–58%). As in Zone V, these pollen types show reciprocal variations. In S1 a steppe may have existed, with scattered stands of *Pinus*. Rarely present were *Artemisia*, *Ephedra distachya* type, and *Plantago*. Attention should be drawn to the massive disappearance of AP components, which is significant in the case of *Juniperus* which is otherwise found in clear steppe phases. In S2, there is partial recolonization of open areas by *Pinus*, with expansion of *Quercus faginea*, *Betula*, *Corylus*, *Phillyrea* and *Juniperus*. Subzone S3 shows *Pinus* to have abated and Poaceae to be spreading. Vegetation is once again open, although *Artemisia*, *Ephedra* and *Plantago* fail to achieve the same importance as in S1.

Zone R

Of note is the reappearance of *Quercus ilex-coccifera* type (7–11%), at the same time as *Olea* fluctuates from 19 to 45%, and *Phillyrea* is almost always greater than 2%. This phase represents a profound modification of the Carihuela area, towards typically Mediterranean sclerophyllous and thermophilous vegetation. A certain distortion of the pollen spectra cannot be discounted, perhaps due to the local over-representation of some taxa (e.g. *Olea*, Brassicaceae): calcification of the lithological Subunit VIIa is consistent with filtration of calcareous waters as the cave-roof karst deteriorated, allowing water to enter through cracks, with possible introduction of diaspores into the pollen spectra.

A vegetational mosaic seems likely: *Pinus sylvestris* and/or *Pinus nigra* on the highest ground; forests of *Quercus rotundifolia* on the deeper and sunniest soils; high matorral with *Quercus coccifera*, *Pistacia lentiscus*, *Phillyrea*, *Olea*, *Rhamnus*, and areas of broom of *Genista*, *Cytisus* or *Retama*; *Quercus faginea*, *Corylus avellana*, *Juglans regia*

and *Fraxinus ornus* in gullies or on shady slopes; riparian vegetation of *Alnus*, *Betula*, *Ulmus*, *Salix*, Cyperaceae and Ranunculaceae; and a wide variety of shrubs and pastures, etc.

Some elements (*Pistacia*, *Phillyrea*, *Rhamnus*) could have been commoner than the spectra suggest, to judge from their usual underrepresentation in surface-pollen analyses (Wright et al., 1967; Van Zeist et al., 1968; Heim, 1970). Pollen identifications support the existence in low numbers of *Pinus halepensis*, probably in the more xeric environments, perhaps with *Ephedra fragilis*.

Differences between R1, R2 and R3 are mainly based on variations in *Pinus*, which must have been geographically very close to the typically sclerophyllous formations.

Zone Q

Poaceae is the chief component (50–69%) followed by *Pinus* (21–44%). As well as the greater pollen representation of Asteraceae, mesophilous and thermophilous taxa are present throughout (*Quercus*, *Olea*, *Phillyrea*, Ericaceae, *Betula*, *Alnus*). Variation between Q1, Q2 and Q3 affects only the *Pinus* and Poaceae cover, and should be treated with caution. Van Campo (1969) indicated many factors which might influence in this phenomenon, from the proximity of the producing agent to a change in prevailing wind-direction.

Zone P

Pinus increases to 93% with a reciprocal decrease in Poaceae (4%) showing a return to closed forest. Mesothermophilous elements (*Olea*, *Quercus*, *Phillyrea*, *Corylus*) are still present.

Zone O

Pinus declines (22–55%) against a rise in Poaceae (22–57%) and *Artemisia* (9–17%). Mesothermophilous taxa remain constant. *Ulmus* and *Fraxinus ornus* appear in addition. Subzones O1, O2 and O3 are characterized by *Pinus* and Poaceae oscillations. *Artemisia* is less abundant in O1, however, and *Centaurea* and *Ephedra distachya* type are present in O3.

Zone N

As in the initial phase Z, vegetation is now very open and dominated by *Artemisia*, which attains a maximum of 81%. Meanwhile *Pinus* drops to below 2%. With the exception of *Juniperus*, there are no more AP elements: other mesothermophilous trees and shrubs fail to contribute to the pollen spectra. The vegetation takes on the appearance of the traditional Quaternary steppes of Western Europe (Frenzel, 1987). In the lower strata, *Artemisia* is accompanied by Poaceae, *Centaurea*, other Asteraceae, Chenopodiaceae, Caryophyllaceae, *Ephedra distachya* type, etc.

Zone M

Artemisia begins to decrease to 27% and *Pinus* slowly recovers to 17%. Poaceae are well represented. In contrast with the previous episode, there is now partial substitution of *Artemisia* by grasses, without any particular modification of the floristic composition of NAP: *Centaurea* persists (2–3%), *Ephedra distachya* type increases slightly (4%), as do Chenopodiaceae and Caryophyllaceae. A greater diversity is found in Asteraceae.

Zone L

Pinus increases, *Artemisia* decreases substantially, while Poaceae shows slightly lower values than in the previous phase. Whereas L1 is a transitional zone, L2 is marked by a significant rise once more in *Pinus* (45–65%), matched by a great diversification of herbaceous and small shrub communities. The predominant Poaceae (16–37%) are accompanied by *Artemisia* (5%), *Ephedra fragilis*, Geraniaceae, *Linum*, Plumbaginaceae, etc. Reappearance of *Quercus faginea*, *Salix*, *Myrtus*, *Phillyrea*, *Buxus* and Ericaceae is also noteworthy. In L3 *Pinus* tends to decrease, varying around 40% whereas there is some increase in Poaceae (34–42%) and even in *Artemisia* (8–13%). In L4 many of the characteristics of L2 reappear, although *Pinus* cover is less (50%). To the return of *Quercus faginea* and *Phillyrea* must be added *Quercus ilex-coccifera*, *Olea*, and *Corylus*, which

had disappeared from the pollen spectra after phase O.

Zone K

Represented by one pollen spectrum only, this Zone is marked by characteristics similar to those of Zone M, suggesting the onset of another important stepic phase.

General remarks on the vegetational history and palaeobotanical implications

The vegetational evolution described above reveals periods of woodland alternating with open vegetation marked by scattered stands of *Pinus* and *Juniperus*, the only AP taxa to appear with continuous representation. Those stages with marked development of *Pinus* (Zones Y, W, T and P) coincide with a slight expansion in Mediterranean or sub-Mediterranean floristic elements. That may be due to "chronological overlap" of pollen spectra. Sedimentary features of the units in question and the geomorphology of the study-area point to simultaneous development of *Pinus* (locally abundant) and of Mediterranean formations in adjacent areas. Some studies, for instance, suggest that altitudinal zonation during the last glacial was much more marked than nowadays (Bastin, 1970; Bernard, 1971), hence Mediterranean communities further north might have developed close to undoubtedly periglacial regions. In Zone R this sclerophyllous vegetation seems to be of a local nature and shows great floristic richness.

Increase of conifer cover is less during U, S2, O2, L2 and L4, although only in S2, L2 and L4 are there signs of any resurgence of mesothermophilous taxa. Zones of open vegetation are dominated by grasses (V1, S1, S3, Q, O1, O3, L1, L3 and K), by *Artemisia* (Z and N), or both (X and M). That implies over-representation by other Asteraceae, because otherwise they would be dominant in V1 and V3 and codominant in Z, X, Q, N, M, L3 and K. Usually these formations are well diversified.

Different degrees of susceptibility to decay may have contributed to the composition of pollen spectra in Zones V, N and M, which show extraor-

dinarly pronounced values for Asteraceae. Of course, pollen assemblages like these have no relation to any general pollen rain. It is more likely that they are influenced by biotic transport, as suggested by the abundance of bony remains, especially from bats (Sevilla, 1986). Simultaneously, other zoogamous pollen (e.g. Caryophyllaceae, Fabaceae, Lamiaceae) might have been carried into the cave by bats and other animals, such as raptors, carnivores, rodents and humans. However, their overall percentage contribution is unimportant.

From a palaeobotanical and palaeoecological viewpoint, the sequence studied shows a most important feature: predominance of *Pinus* in the arboreal vegetation and marked variations in its cover. Sometimes, its high pollen percentages suggest a closed type of forest, although it must be borne in mind that in fact oromediterranean formations with *Pinus nigra* and *Pinus sylvestris* are almost invariably open, with an impoverished shrub-like and herbaceous stratum quite compatible with a local over-representation of *Pinus*.

As mentioned above, it has not always been possible to identify the *Pinus* species concerned. Today, *Pinus nigra* has a more northeasterly distribution, being dominant in the pre-Betic Sierra del Segura, Sierra de Alcaraz and Sierra de Cazorla, whereas *Pinus sylvestris* occurs close, in the Betic Baza and Mágina mountain ranges and the limestone sector of the Sierra Nevada, and is not found to the northeast until the mountain ranges of Cuenca or Albarracín are reached, where both species are present. Phytogeographical data support the local presence of *Pinus sylvestris*, a hypothesis reinforced by the more continental nature of the areas that the species occupies today. On the other hand, *Pinus nigra* ssp. *clusiana* (southern morphotype) has a wider ombroclimatic amplitude and withstands summer dryness.

In any case, there is definite pollen evidence of the existence, albeit in small numbers, of *Pinus halepensis* in Zone R. Some Pleistocene pollen analyses from southeastern France assign this species a Mediterranean status (Bernard, 1971; Renault-Miskovsky, 1972), although from the Holocene it shows only an appreciable presence (Vernet et al., 1987).

Other palaeobotanical and biogeographical impossibilities — the absence of *Juniperus* (Van Zeist, 1970) — al- though studies, never- theless, have demon- strated the presence of *Juniperus* (Quézel, 1986).

The evolution of floristic elements at Cazorla was v- ery different. Never- theless, the disappearance of *Pinus* although com- monly has been ap- preciated by Zor- zar, 1970. Bazile-Rob- ert, 1970, have demon- strated the presence of sub-Mediterranean elements in the harshest Upper Pleistocene. *Pinus* *folia* was like- ly to increase in

Abundance of *Pinus* is worthy. Literature is comparable for the Mediterranean for the peninsula, Italy (Cattaneo, 1970). Although *Olea* and *Lyrea* are frequent in the Iberian ecosystem, their over-representation is assumed. On the other hand, *Olea* with good representation (Janssen, 1970).

Presence of *Castanea sativa* concerning their distribution. Walnut is regarded as originating in Europe and as a Western Mediterranean species. However, the time at which it arrived is much disputed. Pollen data offer many palynological sites suggest

Other palaeoecological problems arise from the impossibility of differentiating *Juniperus* specifically and biotypically. Its pollen is rarely abundant — they are often poorly preserved (Heim, 1970) — although continuously present. Other studies, nevertheless, point to some affinity between *Juniperus* and sclerophyllous taxa (Niklewski and Van Zeist, 1970; Weinstein-Evron, 1976; Pons and Quézel, 1985) or steppe environments (Birks, 1986).

The evolution of mesothermophilous floristic elements at Carihuela suggests that climatic conditions were very harsh over the period studied. Nevertheless, it would be wrong to interpret their disappearance as due to extensive migration, although contraction of some populations may have been appreciable during the periods represented by Zones S, N and M. Charcoal analyses by Bazile-Robert (1979) in the south of France have demonstrated how most Mediterranean and sub-Mediterranean taxa persisted even during the harshest Upper Pleistocene stages. *Quercus rotundifolia* was likely most abundant in the coldest periods, whereas *Quercus coccifera* seems linked to increases in *Olea*, *Pistacia*, *Rhamnus*, etc.

Abundance of Oleaceae in Zone R is noteworthy. Literature consulted does not mention comparable findings from the Western Mediterranean for the period in question, except from Liguria, Italy (Cattani and Renault-Miskovsky, 1989). Although *Olea europaea* var. *sylvestris* and *Phillyrea* are frequent in thermo-Mediterranean Andalusian ecosystems (Rivas-Martínez, 1987), some over-representation due to local growth can be assumed. On the other hand, firm data associate *Olea* with good pollen dispersal (Van den Brink and Janssen, 1985).

Presence of *Juglans regia* pollen and that of *Castanea sativa* raises a long-standing question concerning their possibly autochthonous nature. Walnut is regarded in almost all botanical texts as originating in Central Asia and southeastern Europe and as having been introduced into the Western Mediterranean for cultivation. Nevertheless, the time and manner of its introduction are much disputed. Renault-Miskovsky et al. (1984) offer many palynological data from various depositional sites suggesting the presence of *Juglans* in

Western Europe from Plio-Pleistocene to Holocene times. In Spain, it is very rare in the Upper Pleistocene, but commoner in the Lower or Middle Pleistocene. At Carihuela, *Juglans* is found in early and middle Upper Pleistocene phases Y, W2, T and R. This is in accord with French findings of its increasing scarcity in Würm II (Renault-Miskovsky et al., 1984). Moreover, the *Juglans* pollen distribution in the Carihuela sequence cannot be explained away as due to contamination by recent pollen.

As for chestnut, it is often presumed to come from Asia Minor. There are, however, pollen data which link it to Western Europe from Tertiary to Holocene times (Renault-Miskovsky, 1972; Follieri, 1979; Oldfield and Huckerby, 1979; Huntley and Birks, 1983). In Spain, it is abundant in Guipuzcoa (Sánchez-Goñi, 1988) in the context of Mousterian industries, as at Carihuela.

Palaeoclimatological reconstruction

It would be inadvisable to reconstruct past climatic conditions at Carihuela from pollen diagrams only. The basic principles of Quaternary pollen analysis (Birks and Gordon, 1985) and the philosophical principle of methodological uniformitarianism (Gould, 1965) are followed here, although, given the high vegetational diversity present in Mediterranean ecosystems, taxonomic determination is hardly ever enough from an autoecological viewpoint. Some studies point to the former requirements, now different, of some species or types of vegetation lacking modern equivalents (Pons and Vernet, 1971; Kolstrup, 1980; Frenzel, 1987), hence it is necessary to invoke complex climatic conditions that are no longer present. It is therefore important to take note of findings in cognate disciplines.

Carihuela pollen data can be fitted into the climatostratigraphy of Vega-Toscano (1988). Climatic ameliorations mainly correspond to forest development, especially when the proportions of Mediterranean elements increase. Periods of NAP predominance are regarded as climatically harsh. Nevertheless, the following points should be borne in mind:

- (1) Vegetational changes at Carihuela may be

more sensitive guides to climatic processes than its depositional lithogenesis. This greater sensitivity is revealed by internal variations within the overall climatic tendencies indicated by Vega-Toscano (1988) for each lithostratigraphical unit. This is clear in Units XI and VI, although it is hard to elucidate the precise causes which intervened in this faster vegetational response. In that respect, it should not be forgotten that Pleistocene solifluction features occurred down to about 1000 m on the Sierra Nevada (Wigand, 1978) and it is known that the solifluction line becomes the upper limit for the closed forest. Therefore during the cold stages, Carihuela Cave would have been located at the boundary between pine forest and steppe communities.

(2) In spite of the fact that the present environmental interpretation implies that changes in the forest-cover can be inferred from fluctuations in the *Pinus*-*Poaceae* percentages, the main palaeoclimatic marker must be the occurrence or disappearance of thermophilous taxa. Not only nearby vegetation, but also human and animal transport, might have been responsible for many pollen spectra. For example, the association of lithic material, charcoal and bony remains in strata such as Units VIIb and VI suggests that human bioturbation occurred, although pollen samples were taken from relatively undisturbed areas. Unfortunately, experimental studies have not yet been carried out in order to separate those pollen data that might reflect palaeoenvironment from those data that might denote cultural activities, old biogenic deposits, passive transport by mammals, etc.

(3) The climatostratigraphical correlation is valid only for temperature, which is a good indicator of more general climatic phenomena. The term "humidity" has to be interpreted in terms not only of precipitation, but also of water availability for vegetation due to run-off, temporary freezing, or evapotranspiration.

(4) The optimum corresponds to Zone R of the pollen sequence. This seems to contradict the climatic interpretation based on the sediment. Pollen deposition in Unit VIIa is closely related to illuviation and calcretion processes affecting the sparse matrix between the blocks, hence the time-

span involved in Zone R corresponds to the hiatus between VIIa and VI. Therefore Unit VI (Zones Q, P and O) may only represent the end of a longer, more complex period incorporating some intermediate arid phases (Q, O1 and O3).

(5) The most critical episodes coincide with Zones V-U (Units X and IX) and particularly with S (Unit VIIb) and N-M-L1 (Unit V). These zones witness the disappearance of mesothermophilous taxa and the extension of herbaceous communities. Bones of *Microtus nivalis*, *Microtus arvalis* and *Allocricetus bursae*, as well as the incorporation of thermoclastic scree, are further evidence for climatic severity.

(6) *Artemisia maxima* can be regarded as corresponding to marked aridity crises. As it is clear that the species involved are neither anthropozophilous (Behre, 1981) nor halophilous (Triat-Laval, 1978), *Artemisia* is interpreted as a good indicator of steppic environment (Bertolani-Marchetti, 1985). Given the presence of Mediterranean taxa in Zone Z, it is reasonable to argue that the aridity crisis of that interval would have had a primarily hydric component. However, the possibility of differential preservation favouring *Artemisia* has also to be entertained.

(7) Identification of the edaphic and climatic factors that determine the *Poaceae maxima* is complicated, because grass formations occur in ecologically very diverse biotopes. Nevertheless, whatever their regional palaeoecological significance, some *Poaceae maxima* may be due to more or less local expansions.

(8) Establishment of *Pinus sylvestris* and/or *Pinus nigra* forests are inferred from the Carihuela sequence to indicate relatively favourable thermic conditions within an overall ice-age context. It has to be borne in mind that these coniferous formations have a orophilous character, today occupying the uppermost forest belts on the Iberian mountains.

Chronological interpretation

The Carihuela pollen record can be placed within a period corresponding to the last Quaternary climatic cycle (Broecker and Denton, 1990). This is supported by the regional morphogenetical

context (Vega-T samples from investigations (I Vega-Toscano, tures (Vega-Tos (Ruiz-Bustos worth remembering dates were obtained a range of ma blackened bone graphical conte have been shown Table I). All the the beginning of Pleistocene and 70,000 years.

Palaeoclimatic tions involves (Fig.12), backed and local stratig sought between mum expression

	Lithostratigraphy	Pollen zones
IV	K	
	L	
V	M	
	N	
VI	O	
	P	
	Q	
VIIa	R	
VIIb	S	
VIII	T	
IX	U	
X	V	
	W	
XI	X	
	Y	
	Z	

Fig.12. Carihuela p

context (Vega-Toscano, 1988, 1989), by dating of samples from the Washington State University investigations (Fremlin, 1974; Göksu et al., 1974; Vega-Toscano, 1988) the cultural and human features (Vega-Toscano, 1988) and the rodent bones (Ruiz-Bustos and García-Sánchez, 1977). It is worth remembering that the thermoluminescence dates were obtained for experimental purposes on a range of materials (burnt and unburnt flint, blackened bones, etc), of unknown precise stratigraphical context, and that the published dates have been shown to require upward revision (Fig.4, Table I). All the same, they do allow us to ascribe the beginning of the sequence to the early Upper Pleistocene and to assign to it a total span of some 70,000 years.

Palaeoclimatic interpretation of pollen variations involves recourse to several correlations (Fig.12), backed up by dating, lithic industries, and local stratigraphical data. Correspondence is sought between periods of maximum and minimum expression for the phenomena detected, bear-

ing in mind that distant climatic events are usually metachronous. It is interesting to try correlate the Carihuela sequence with the marine oxygen-isotope record (Shackleton, 1977). One must bear in mind the problems which arise when attempts are made to extrapolate from such data to the continental domain (Turon, 1984), with the resulting uncertainty about chronological limits for these stages once outside the oceanic ambit.

All the data concerning pollen Zones Z-W indicate that they can be correlated with one part of isotopic stage 5, although correlation of its 5 substages is conjectural, due to the lack of pollen data from Unit XII. Zones Z-W can be attributed to Würm I in its conventional meaning and to the Pre-Würm of Beaulieu and Reille (1984).

This stage has been well defined biostratigraphically at Padul (Pons and Reille, 1988), although correlation with this pollen sequence is much more problematical because the Carihuela area shows more markedly continental features, responsible, in turn, for a perceptibly colder climate and sharper temperature contrasts. Notwithstanding the geographical proximity of both sites (see Fig.1), the Carihuela sequence shows a *Pinus* cover, whereas the Padul depression was populated by Mediterranean formations of *Quercus*. These findings should not be considered to exclude altogether the possibility of the occurrence of *Quercus* communities on the plains near Carihuela. It could be assumed that many of the pollen assemblages at Carihuela result from cultural activities, animal transport or local over-representation, hence consideration of bioclimatic gradients is only one of several possibilities for interpreting those vegetational differences aforementioned.

Palynological studies carried out on European sequences presumed contemporaneous with Carihuela Zones Z-W offer a discouraging panorama for wider-scale correlation. Agreement is lacking over geochronological interpretations of the Lower Weichselian interstadials (Paepe and Zagwijn, 1972), and their hypothetical equivalence with the post-Eeemian cycles at La Grande Pile (Woillard, 1978) or Les Echets (Beaulieu and Reille, 1984). The Carihuela results throw no new light on this unresolved matter, due to the lack of any firm chronology.

Lithostratigraphy		Pollen Zones	¹⁸ O/ ¹⁶ O STAGES	CONVENTIONAL ALPINE SEQUENCE	PADUL (Pons & Reille)
IV	K				
	L	2	?	Würm Pleniglacial	
V	M				
	N	3	Würm III	Middle Würm	
VI	O				
	P				
	Q				
VIIa	R	Würm II			
VIIb	S				
VIII	T	Würm I-II			
IX	U	4	Würm I	Eowürm	
X	V				
XI	W	5	Würm I	Pre-Würm	
	X				
	Y				
	Z				

Fig.12. Carihuela pollen record: tentative correlations.

Zones V and U, which show the first major regression of thermophilous taxa, seem to correspond to isotopic stage 4 which is characterized by a pronounced oceanic increase in the $^{18}\text{O}/^{16}\text{O}$ ratio. Fixing the upper limits of this phase is controversial because fully pleniglacial conditions do not manifest themselves until lithostratigraphical Unit VIIb, although it is likely that pollen Zones T and S1 ought to be placed in chronoclimatic stage 4. On the other hand, most studies suggest a very short time-span, placing the 5a/4 transition at about 75,000–70,000 B.P. (Labeyrie, 1984; Cheddadi, 1988). It therefore seems convenient to put Zones V and U earlier than a conventional Würm I–II (Laville et al., 1983) making that interstadial equivalent to Carihuela pollen Zone T.

In light of the above, it seems sensible to relate Zone S with the commencement of Middle Würm (Welten, 1984) and hence to that of conventional Würm II, perhaps before what in Holland has been characterized as the Moershoofd complex (Kolstrup and Wijmstra, 1977). In southern France, archaeological deposits at Combe-Grenal in Dordogne (Paquereau, 1974) and L'Hortus in Languedoc (Renault-Miskovsky, 1972) show phases very like that of Carihuela Zone S, although associated with a deeper sedimentary infill, in which numerous slight variations characteristic of S2 are well matched.

Zones R–P correspond to the Würmian Interstadial of 40,000 and 34,000 B.P. in southern France (Laville et al., 1983). The climatic optimum, characterized in the French deposits by weathered paleosols, could well correspond to Carihuela Zone R. The Padul sequence of Pons and Reille (1988) shows no climatic fluctuation, elsewhere so characteristic of Middle Würm. Nevertheless, earlier studies at Padul (Florschütz et al., 1971) correlated a series of minor variations to the Dutch interstadials of Moershoofd, Hengelo and Denekamp (Van der Hammen et al., 1967; Kolstrup and Wijmstra, 1977). Influence of the stratigraphy of the Middle Weichselian is also felt in the correlations by Wijmstra (1969) of the Keraklitsa, Kalabaki and Krinides phases at Tenaghi Philippon in Greek Macedonia.

Differences between the Padul and Carihuela

pollen records are particularly pronounced for the Middle Würm. As mentioned, taphonomy of pollen assemblages from Carihuela Zones R to O is hard to elucidate; moreover, their associated Units VII and VI show uneven stratification, erosional surfaces being conspicuous below, between, and above them. On the other hand, discontinuities and other stratigraphical complications derived from differential subsidence within the Padul basin should not be discounted.

The important pollen sequences of Les Echets (Beaulieu and Reille, 1984) or La Grande Pile (Woillard, 1978) do not reflect marked warming during the middle of the last glacial. Other diagrams, however, show important progressions of forest: e.g. northern Greece (Bottema, 1974), Calabria (Grüger, 1977), northern Italy (Bertoldi, 1980; Cattani and Renault-Miskovsky, 1989), and Mediterranean Spain (Carrion, 1991). Other geomorphological, lithological, and biostratigraphical studies also indicate an important inter-Würmian rise in temperature in SE Spain (Carrion, 1991).

Presence of a well-marked erosional episode between Carihuela pollen Zones O and N strongly limits the possibility of correlating the upper part of the sequence (Zones N–K), which seems to reflect the return of cold pleniglacial conditions in the region. All the litho- and biostratigraphical data from Carihuela for this phase suggest that stage 2 continental periglacial conditions began in Zones N and M. It is not at present possible to associate Subzones L2 and L4 with one or more chronozones of the recent Würm, although features of the upper Carihuela phases confirm the long Mousterian survival in the southern Iberian Peninsula.

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