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The sequence at Carihuela Cave and its potential for research into Neanderthal ecology and the Mousterian in southern Spain

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A B S T R A C T

Hitherto unpublished ^{14}C and ^{230}Th–^{234}U determinations from Carihuela Cave (Granada province, Andalusia, Spain) raise a possibility of late survival here of Neanderthals and their Mousterian technocomplex into an advanced stage of the Late Pleistocene (MIS-3), when anatomically-modern humans with Upper Palaeolithic toolkits were penetrating the region, and when also several carnivore taxa competed for access to the cave. Previous palaeopalynological studies are reinforced by new pollen analyses of samples extracted from coprolites. The palaeoecological and sedimentological records bear comparison with new data from the Padul peat deposits in the Sierra Nevada, and are in line with the view that there was late persistence of the Mousterian in Granada. There is a pressing need for renewed international multidisciplinary research at Carihuela Cave, with up-to-date lithostratigraphical and dating techniques that can expand on results obtained from fieldwork undertaken by a previous generation of researchers. Carihuela Cave continues to hold out great promise for analysing Neanderthal palaeoecology during the Late Pleistocene up to the appearance in southeastern Iberian Peninsula of anatomically-modern Upper Palaeolithic people, particularly with regard to the earlier phases of the Middle Palaeolithic at the cave which await intensive excavation but apparently extend back in time to the last interglacial period.

1. Introduction

We highlight the potential of Carihuela Cave for further studies on Late Pleistocene archaeology and human evolution concerning Neanderthals and early anatomically-modern humans in the southern Iberian Peninsula. We take into account many geochronological dates from the cave (^{14}C, ESR, and ^{230}Th–^{234}U), both new determinations presented here, as well as older ones including several that are not well known. We present new pollen analyses of samples extracted from coprolites. We consider the available information regarding the chronology and palaeoecology of the Pleistocene sequence. In order to resolve outstanding problems of interpretation and reach definitive conclusions there is urgent need for renewed systematic re-excavation within a multidisciplinary research programme.

2. The site

Carihuela Cave (3° 25′ 47″W, 37° 26′ 56″N; 1020 m a.s.l.) lies in Piñar municipality, 45 km northeast of Granada, on the northern slope of the Sierra Arana, in eastern Andalusia, southern Spain

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(Fig. 1). Among several caverns near Carihuela Cave is the adjacent Cueva de las Ventanas (Carrión et al., 2004; Riquelme, 2002; Carrión et al., 2004; Sánchez-Tarifa, 2004; Riquelme and Carrión, 2010; Cortés-Sanchez et al., 2018). Carihuela Cave has three entrances giving access to a single chamber with a corridor penetrating further into the hillside. The cave runs mainly southeastwards from its main entrance (Fig. 2). From a large entrance chamber, ~13 m long by 4–6 m wide (Chamber III; CIII), an eastward passage leads to Chambers I and II (CI, CII). At the south end of CIII a 2–3 m-wide passage leads to Chamber IV (CIV) that is ~7 m in both length and width. In the south wall of CIV an eastward opening leads down into Chamber V (CV). Here, the cave floor rises steeply upward towards the far end of CV, flood-lit by daylight from a high chimney occupied by an extensive scree slope.

3. Excavations

Carihuela Cave interested Madrid Central University's Professor Hugo Obermaier (1877–1946) (Obermaier, 1924, 1934), though excavation had to await 1954–1955 when Jean-Christian Spahni (1923–1992) carried out two campaigns (Spahni, 1955a, 1955b, 1955c; Kobi and Spahni, 1956). Spahni opened two trenches, in CIII and CIV, was impressed by the prevalence and persistence of the Mousterian industry, and discovered not only Neanderthal bones in three layers of the sedimentary deposits, but also anatomically-modern human bones in a Mousterian context (García-Sánchez, 1960). In 1959–1960 Professor Manuel Pellicer Catalán (1926–2018), then at Granada University, excavated Neolithic and Bronze Age assemblages in CIV (Pellicer, 1964a, 1964b) (Fig. 2). Subsequently, Professor Henry de Lumley (1934-present: De Lumley, 1969) of the Institut de Paléontologie Humaine at Paris reported on Spahni's finds stored at Granada's Archaeological Museum. Between 1969 and 1971 Washington State University Professors Roald Fryxell (1934–1974) and Henry Irwin (1938–1974) with Professor Martín Almagro Basch (1911–1984), University Complutense of Madrid, excavated in the Exterior or Entrance Area (AE), CIII, and CIV (Fig. 2), with exhaustive exploration of CI and CII. On finding that Spahni had dismantled some levels in C III AE when he dynamited entrance breccia, they selected intact areas suitable for productive research (Almagro et al., 1970; Garralda, 1970). With due reference to the archaeological profiles (sections) exposed by the aforementioned excavations in CIII, Madrid University's Professors Luis Gerardo Vega Toscano (1957-present) and Manuel Hoyos Gómez (1944–1999) extended the archaeological excavation between 1979 and 1992 in a multidisciplinary research project, and put forward a chronostratigraphical interpretation (Vega-Toscano

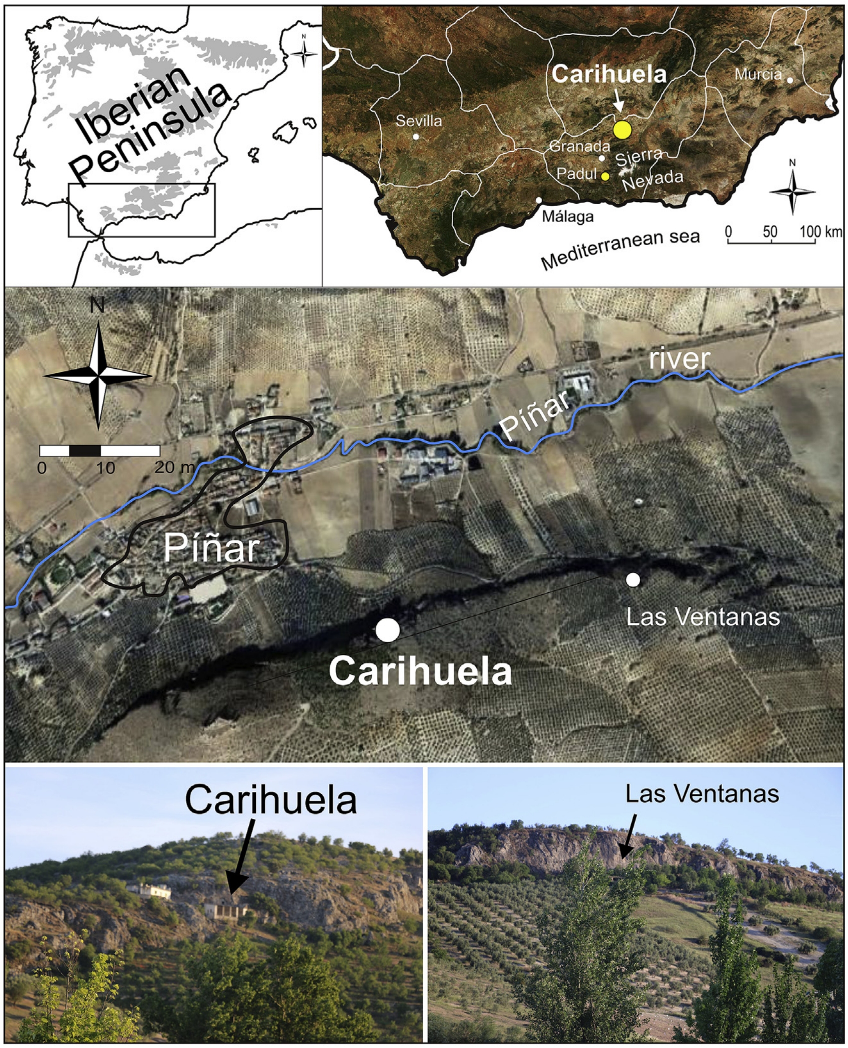

Fig. 1. Location of the Carihuela and Las Ventanas Caves in the Monte del Castillo de Píñar, and the Padul peat-bog in the Sierra Nevada (Granada, southern Spain).

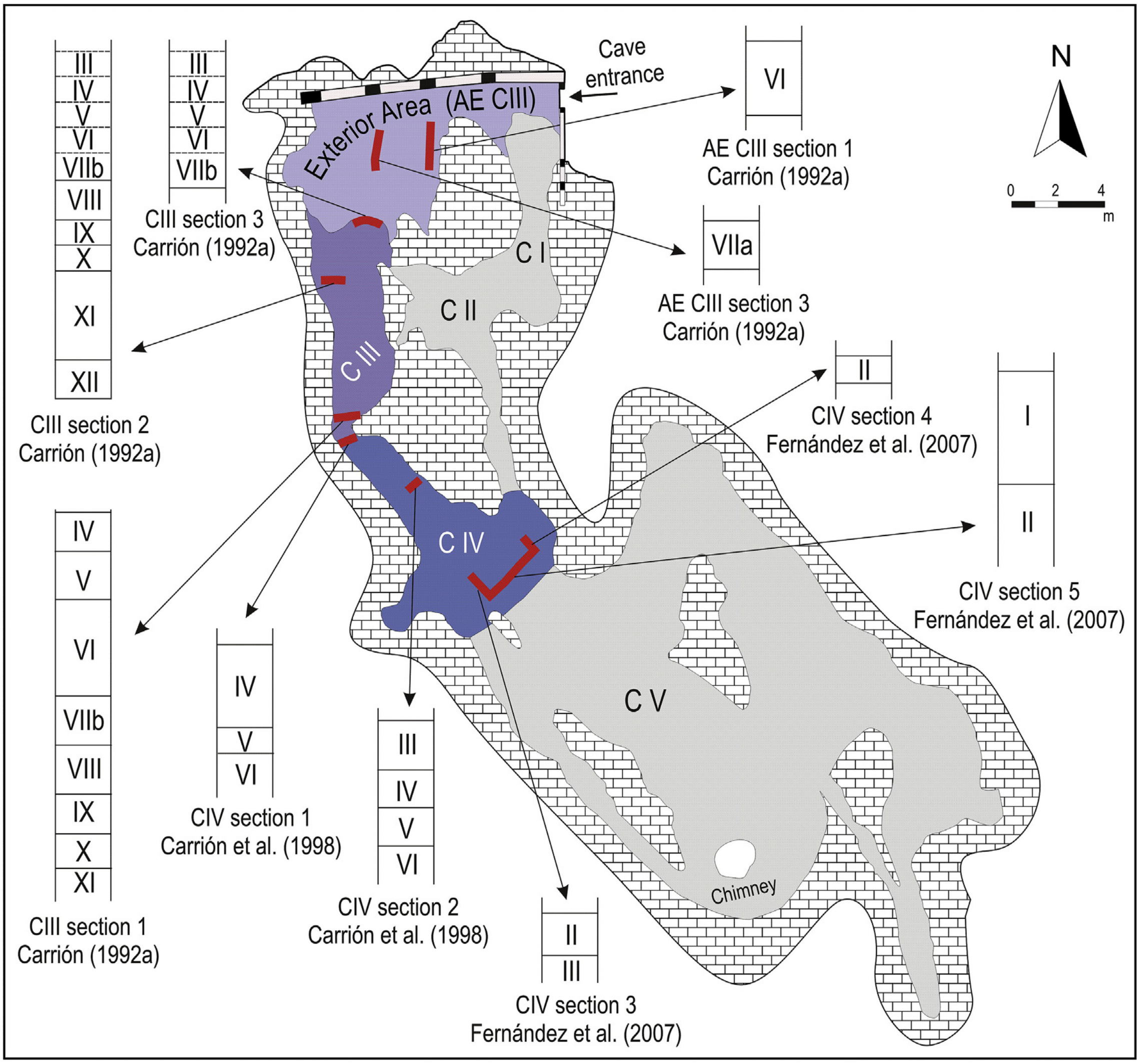

Fig. 2. Longitudinal section of Carihuela Cave, showing the situation of the chambers, stratigraphical sections and sedimentological units studied palynologically (Carrión, 1992; Carrión et al., 1998; Fernández et al., 2007, and this paper).

et al., 1988). Notwithstanding transfer of site-ownership from its land-owner (D.Leopoldo Alcalá Pleguezuelos of Piñar) to Spain's Ministry of Science and Education in 1969, excavation permits have not been forthcoming latterly from the Andalusian regional government (Junta de Andalucía) beyond authorization, from its Directorate General of Cultural Heritage, for sampling on September 5th-6th, 2011, of sediment, bones, teeth and charcoal for some ^{14}C and ^{230}Th–^{234}U determinations (Tables 1–6, Figs. 3–7). It is anticipated that shortly the regional Andalusian authorities will be in a position to facilitate controlled access to this most important site where sporadic unauthorized entry has damaged excavated areas. Concerns over public safety are belied by inspections undertaken by both Piñar Town Council technicians and an independent engineer who neither found life-threatening structural dangers inside the cave nor of the portal at its mouth. The scientific significance of a site containing both Middle and Upper Palaeolithic levels implies, as matters of utmost urgency, their protection and renewed systematic excavation under a multidisciplinary research team.

Table 1
Thermoluminescence dating for Carihuela CIII section 1 (Units XI-III) which became available after the excavations by H.T. Irwin and R. Fryxell of Washington State University between 1969 and 1971. Vega-Toscano (1988), Fernández et al. (2007).

Sample	TL estimated (yr BP)	Unit	Archaeology/Human remains
B48	13,400 ± 600	III	Late Paleolithic/Sapiens
B52	19,300 ± 500	IV	Palaeolithic indet.
B6	20,200 ± 1200	IV	Palaeolithic indet.
B47	20,950 ± 1200	IV	Palaeolithic indet.
B43	21,100 ± 1300	V-IV	Mousterian/Neanderthal
B44	37,350 ± 2200	VI-(V)	Mousterian/Neanderthal
B54	42,400 ± 1500	VI	Mousterian/Neanderthal
B49	49,200 ± 2500	VI	Mousterian/Neanderthal
B53	68,000 ± 1800	X–VIII	Mousterian
B46	82,500 ± 4900	XI	Mousterian

4. Stratigraphy and palaeontology

12 lithostratigraphical units described by Vega-Toscano et al. (1988) comprised Pleistocene units XII–III followed by Holocene units II-I (Figs. 2–7). Whereas CIII provided only sparse traces of the 3 uppermost units, these were well represented in CIV. Ruiz-Bustos and García-Sánchez (1977) studied the fauna, which was revisited by Vega-Toscano et al. (1988) to provide a basis for chronostratigraphical interpretation.

Units XII and XI, consisting of peaty clays with stalagmitic crusts

Table 2
Thermoluminescence dating for chambers CIII and CIV, Units XI to III, in accordance with Göksü et al. (1974), Göksu (thesis, unpublished), and subsequent modifications by Göksu & K. Sammers (published by Davidson, 1989). Suggested lithostratigraphy according to Carrión (1992), and Fernández et al. (2007).

Sample nº	Göksü et al. (1974)	Göksu (thesis)	Davidson (1989)	Archaeology/Human remains	Chamber	Unit
TB4	–	4500 ± 400	–	Bronze Age	CIV	I
TB7	12,000–14,000	13,600 ± 800	11,200	Late Palaeolithic/Sapiens	CIV	III
TB6	20,000 ± 3000	20,200 ± 3000	17,000	Late Palaeolithic	CIV	III
TB8b	20,000–21,000	27,000 ± 1000	23,000	Late Palaeolithic	CIV	IV
TB12	39,000	27,400 ± 1000	25,700	Mousterian/Neanderthal	CIII	V
TB2	28,000	28,000 ± 1000	27,300	Mousterian/Neanderthal	CIII	V
TB5	31,000–35,000	33,000 ± 1200	25,200	Mousterian/Neanderthal	CIII	V
TB1	32,000	39,400 ± 2000	34,000	Mousterian/Neanderthal	CIII	VI-V
TB3	46,000	57,700 ± 2500	45,200	Mousterian/Neanderthal	CIII	VI
TB9a	48,000	58,800 ± 2500	47,800	Mousterian/Neanderthal	CIII	VI
TB8a	80,000	–	–	Mousterian	CIII	XI
TB10	–	100,000	–	–		
TB9b	–	140,000	–	–		
TB13	–	180,000	–	–		
TB14	–	380,000	–	–		

Table 3
Results of ESR analyses by Volterra (2000) calculated using in-situ dosimetry results and sediments INAA results. De calculated using Vfit and dates by ROSY 1.3. All dates as calculated for sediments at 10% moisture. Recovered industry in all layers is Mousterian.

Sample	Fauna	Enamel	Removed μm		De	EU ka	LU ka	Unit-Level
		Thick's μm	Out	In				
Calculated using in-situ dosimetry results								
CAR ESR 9	Bovid	1037	49	68	59.43 ± 1.6	45.2 ± 2.0	53.7 ± 2.0	V-2
CAR ESR 14	Equid	1159	65	60	65.32 ± 1.6	56.0 ± 2.0	61.5 ± 2.0	V-3
Average layer V-2/3						50.6 ± 2.8	57.6 ± 2.8	
CAR ESR 5	Equid	1191	119	113	45.92 ± 1.0	70.5 ± 1.0	74.9 ± 1.0	V-5
CAR ESR 10	Equid	1223	57	42	54.27 ± 1.0	58.5 ± 1.0	74.7 ± 1.0	V-5
CAR ESR 11	Equid	750	48	80	70.81 ± 2.1	74.3 ± 2.0	95.6 ± 2.0	V-6
Average layer V-5/6						67.8 ± 2.5	81.7 ± 2.5	
CAR ESR 7	Equid	1379	36	37	55.51 ± 1.2	118.3 ± 1.5	126.4 ± 1.3	VIIb-1
CAR ESR 20	Rhino	2428	50	48	37.59 ± 0.7	79.6 ± 1.2	81.0 ± 1.8	VIIb-1
CAR ESR 17	Equid	1401	48	60	54.03 ± 4.4	79.7 ± 5.0	87.4 ± 5.0	VIIb-2
CAR ESR 28	Equid	1606	75	108	41.98 ± 1.3	68.4 ± 1.1	71.5 ± 1.1	VIIb-2
CAR ESR 33[a]	Cervid	1321	101	81	58.09 ± 1.0	87.8 ± 1.0	89.3 ± 1.0	VIIb-2
CAR ESR 34[a]	Equid	1212	85	48	51.19 ± 1.0	87.5 ± 1.0	90.1 ± 1.0	VIIb-2
Average layer VIIb						86.9 ± 2.5	91.0 ± 2.5	
Calculated using sediments INAA results								
CAR ESR 9	Bovid	1037	49	68	59.43 ± 1.6	57.3 ± 2.0	72.6 ± 2.3	V-2
CAR ESR 14	Equid	1159	65	60	65.32 ± 1.6	65.09 ± 2.4	74.0 ± 2.4	V-3
Average layer V-2/3						61.6 ± 3.3	73.3 ± 3.3	
CAR ESR 5	Equid	1191	119	113	45.92 ± 1.0	41.9 ± 1.0	43.3 ± 1.0	V-5
CAR ESR 10	Equid	1223	57	42	54.27 ± 1.0	40.4 ± 1.0	46.8 ± 1.0	V-5
CAR ESR 11	Equid	750	48	80	70.81 ± 2.1	54.4 ± 1.6	64.0 ± 1.9	V-6
Average layer V-5/6						45.6 ± 1.5	51.4 ± 1.7	
CAR ESR 7	Equid	1379	36	37	55.51 ± 1.2	66.2 ± 1.9	76.2 ± 1.9	VIIb-1
CAR ESR 20	Rhino	2428	50	48	37.59 ± 0.7	54.7 ± 1.0	55.3 ± 1.0	VIIb-1
CAR ESR 17	Equid	1401	48	60	54.03 ± 4.4	65.0 ± 5.1	69.7 ± 5.2	VIIb-2
CAR ESR 28	Equid	1606	75	108	41.98 ± 1.3	54.5 ± 1.1	56.3 ± 1.1	VIIb-2
CAR ESR 33[a]	Cervid	1321	101	81	58.09 ± 1.0	70.8 ± 1.4	71.7 ± 1.5	VIIb-2
CAR ESR 34[a]	Equid	1212	85	48	51.19 ± 1.0	68.9 ± 1.4	70.3 ± 1.4	VIIb-2
Average layer VIIb						63.4 ± 2.7	66.6 ± 2.8	

[a] Teeth recovered in-situ.

and calcium carbonate pseudomycelia, contained scarce faunal remains, mainly small herbivores and turtles, whilst relatively abundant *Apodemus flavicollis*, *Eliomys quercinus*, *Clethrionomys glareolus* and *Sorex minutus/araneus* imply warm, humid conditions with wooded landscapes.

Lying above unit VIIb in CIII AE 3, Vega-Toscano et al. (1988) considered the brecciated unit VIIa as signifying MIS-3 (Vega-Toscano et al., 1988). However, a single sample from VIIa gave a $^{230}Th/^{234}U$ age-estimation at the Autonomous University of Barcelona Physics Department of 117,000 ± 41,000 BP (Carrión et al., 1998, 1999) (Table 6) which might imply the last interglacial stage, MIS-5, though the wide margin of error reflects the imprecision involved by application of a detritic correction-factor, whilst nonetheless implying a noteworthy departure from the chronology inferred by Vega-Toscano et al. (1988) (Fig. 7).

Units X-VIIb contained stone blocks and angular clasts in clayey silt followed by sandy clays, and a fauna of *Equus caballus*, *Equus hydruntinus*, *Bos primigenius*, *Stephanorhinus (Dicerorhinus)*

Table 4

Radiocarbon dating results of Carihuela Cave, Units I-VI. Four additional samples from Unit IV, three from Unit V and one from Unit VI were not suitable due to insufficient carbon. Lithostratigraphy and archaeology according Vega-Toscano (1988), Vega-Toscano et al. (1988), Carrión (1992), Carrión et al. (1998), and Fernández et al. (2007). Total organic carbon was used for bulk sediment samples. Calibration: OxCal v4.3.2 Bronk Ramsey (2017); r:5; IntCal13 atmospheric curve (Reimer et al., 2013).

Lab.No.	Sample material	Chamber/Section	Unit	Level	yr BP	cal yr BP 95.4% prob.	cal yr BP (midpoint)	Archaeology/Human remains
[a]Beta-141048	Bulk sediment	CIV 5	I	1	1250 ± 60	1293–1011	1152	Sapiens
[a]Beta-141049	Bulk sediment	CIV 5	I	1	5470 ± 90	6437–6003	6220	Neolithic/Sapiens
[a]Pta-9162	Bulk sediment	CIV 5	I	5	5690 ± 30	6553–6405	6479	Neolithic/Sapiens
[a]Pta-9163	Bulk sediment	CIV 5	II	2	6220 ± 20	7242–7020	7131	Neolithic/Sapiens
[a]Beta-141050	Bulk sediment	CIV 4	II	4	6910 ± 70	7926–7616	7771	
[a]Pta-9166	Bulk sediment	CIV 4	II	5	7700 ± 90	8701–8342	8522	
[a]Pta-9165	Bulk sediment	CIV 3	II	6	8130 ± 100	9403–8724	9064	
[a]Beta-74380	Bulk sediment (AMS)	CIV 2	III		12320 ± 60	14686–14070	14378	Late Palaeolithic/Sapiens
[a]Pta-7892	Bulk sediment	CIV 3	III	18	15700 ± 220	19531–18545	19038	Upper Palaeol/Sapiens
Poz-45200	Bulk sediment	CIII 1	IV	A1-A2	24940 ± 210	29490–28560	29025	Palaeol. Indet./Sapiens
Poz-45201	Bulk sediment	CIII 1	IV	A3	23020 ± 190	27683–26965	27324	Palaeol. Indet./Sapiens
Poz-45193	Bone fragments	CIII 1	IV	A5	29490 ± 360	34323–32863	33593	Mousterian/Neanderthal
Poz-45195	Sediment + charcoal	CIII 1	IV	A5	37100 ± 860	42934–40056	41495	Mousterian/Neanderthal
Poz-45194	Charcoal	CIII 1	IV	A5	39800 ± 1200	46005–41976	43991	Mousterian/Neanderthal
[a]Pta-8745	Bulk sediment	CIII 1	V	B1	21430 ± 130	25990–25491	25741	Mousterian/Neanderthal
Poz-45202	Sediment + bones	CIII 1	V	B1	39300 ± 1100	45346–41775	43561	Mousterian/Neanderthal
Poz-45192	Charcoal + charred bone	CIII 1	V	B1–B2	>43000	–	–	Mousterian/Neanderthal
[a]Pta-8746	Bulk sediment	CIII 1	V	B3	25850 ± 180	30623–29548	30086	Mousterian/Neanderthal
Poz-45203	Bulk sediment	CIII 1	V	B4	28060 ± 310	32828–31271	32050	Mousterian/Neanderthal
Poz-45197	Sediment + bones	CIII 1	V	B4	28490 ± 330	33398–31556	32477	Mousterian/Neanderthal
Poz-45204	Sediment + bones	CIII 1	V	B5	28460 ± 370	33430–31495	32463	Mousterian/Neanderthal
Poz-45199	Sediment + bones	CIII 1	V	B6	20530 ± 140	25180–24316	24748	Mousterian/Neanderthal
Poz-45205	Bulk sediment	CIII 1	V	B6	22350 ± 170	27117–26172	26645	Mousterian/Neanderthal
Poz-45196	Bone (vertebra)	CIII 1	V	B6	32750 ± 520	38371–35730	37051	Mousterian/Neanderthal
[a]Pta-8733	Bulk sediment	CIII 1	V	B6	28440 ± 240	33138–31601	32370	Mousterian/Neanderthal
Poz-45206	Bulk sediment	CIII 1	V-VI	B6–C1	25590 ± 230	30465–29146	29806	Mousterian/Neanderthal
Poz-45207	Bulk sediment	CIII 1	VI	C1	22830 ± 180	27510–26665	27088	Mousterian/Neanderthal
Poz-45209	Bulk sediment	CIII 1	VI	C2–C4	26060 ± 260	30863–29634	30249	Mousterian/Neanderthal
Poz-45210	Bulk sediment	CIII 1	VI	C5–C6	25970 ± 250	30790–29565	30178	Mousterian/Neanderthal
[a]Beta-74381	Bulk sediment (AMS)	CIII AE 1	VI	C8–C9	45200 ± 1270	- 46509	>46509	Mousterian/Neanderthal

[a] Published formerly in Carrión et al. (1998), and Fernández et al. (2007).

Table 5

AMS radiocarbon dating results of Carihuela Cave coprolites. Car-1 to Car-12: specimens obtained from stored material at the Granada Archaeological Museum, derived from excavation campaigns between 1970 and 1971 (Almagro et al., 1970; Garralda, 1970; Vega-Toscano, 1988). Car-13 was sampled by us from the profile where it was embedded. Calibration: OxCal v4.3.2 Bronk Ramsey (2017); r:5; IntCal13 atmospheric curve (Reimer et al., 2013). Suggestions about coprolite-embedded units follow correspondence with WSU excavation levels by Vega-Toscano (1988). The precise position of specimens is unknown.

Lab No	Coprolite sample	Chamber-Section/s	Unit (suggested intervals)	Coordinates (excavation notes)	yr BP	cal yr BP 95.4% prob.	cal yr BP (midpoint)	Industry in "excavation labels"
Poz-55205	Car-13	CIV-3	I-II	701S/701W	7040 ± 50	7965–7757	7861	Neolithic
ETH-49314	Car-11	CIV-2	I-III	696S/702W	9543 ± 33	11081–10713	10897	Recent Prehistory
ETH-49306	Car-3	CIV-2	II-III	697S/701W	11407 ± 36	13323–13143	13233	Neolithic (?)
ETH-49307	Car-4	CIV-2	II-III	697S/701W	11417 ± 36	13338–13146	13242	Neolithic (?)
ETH-49313	Car-10	CIV-1	I-III	694S/702W	12100 ± 37	14105–13799	13952	Recent Prehistory
ETH-49312	Car-9	CIV-2	I-IV	698S/701W	14836 ± 43	18210–17875	18043	"Bronze"
ETH-49315	Car-12	CIV-2-3[a]	III-V	699S/701W	16139 ± 48	19644–19277	19461	Final Middle Palaeolithic
ETH-49308	Car-5	CIV 2–3[a]	III-V	700S/701W	16711 ± 74	20405–19939	20172	Early Upper Palaeolithic
ETH-49311	Car-8	CIV-2	IV-V	698S/701W	17691 ± 50	21656–21164	21410	Final Middle Palaeolithic
ETH-49304	Car-1	CIII 2–3[a]	IV-V	507,45S/508,87W	19499 ± 89	23781–23141	23461	Palaeolithic
ETH-49310	Car-7	CIV-2-3[a]	III-V	699S/701W	20551 ± 247	25404–24130	24767	Final Middle Palaeolithic
ETH-49305	Car-2	CIII 2–3[a]	IV-VI	507,45S/507,50W	26158 ± 188	30874–29866	30370	Middle Palaeolithic
ETH-49309	Car-6	CIV-2-3[a]	III-V	700S/701W	27027 ± 205	31322–30803	31063	Early Upper Palaeolithic

[a] Coprolites in materials removed from trenches between two current stratigraphical sections.

Table 6
Uranium-thorium dating at University of Sevilla for sections 2, 3, and AE1 (units XI-VI) of Carihuela Chamber CIII (Fig. 2), all corresponding to Mousterian levels. The sample materials were *Equus* teeth (T) and bones (B), generally fragmented.

Sample	Material	Chamber/Section	Unit	238U	234U	230Th	234U/238U	230Th/234U	234U/238/U	Age (ka)
1	B	CIII AE 1	VI	62.80 ± 1.28	67.19 ± 1.35	15.30 ± 0.49	1.0699 ± 0.0180	0.2277 ± 0.0086	1.0756 ± 0.0195	27.96 ± 1.21
2	B	CIII AE 1	VI	86.73 ± 1.75	91.46 ± 1.84	21.80 ± 0.96	1.0545 ± 0.0159	0.2383 ± 0.0116	1.0592 ± 0.0172	29.47 ± 1.64
4	B, T	CIII AE 1	VI	43.36 ± 0.77	47.85 ± 0.84	14.45 ± 1.42	1.1037 ± 0.0173	0.3020 ± 0.0302	1.1156 ± 0.0193	38.78 ± 4.64
6	B	CIII AE 1	VI	16.97 ± 0.40	19.70 ± 0.44	14.06 ± 1.07	1.1609 ± 0.0299	0.7136 ± 0.0564	1.2313 ± 0.0430	129.9 ± 19.3
9	B	CIII AE 1	VI	22.53 ± 0.50	27.28 ± 0.58	17.10 ± 0.40	1.2108 ± 0.0272	0.6268 ± 0.0198	1.2810 ± 0.0362	102.91 ± 5.25
10	B, T	CIII AE 1	VI	32.57 ± 0.66	36.97 ± 0.73	17.20 ± 0.39	1.1351 ± 0.0224	0.4652 ± 0.0139	1.1629 ± 0.0271	66.94 ± 2.73
13	B	CIII AE 1	VI	23.58 ± 0.53	26.85 ± 0.58	12.80 ± 0.68	1.1384 ± 0.0264	0.4766 ± 0.0274	1.1678 ± 0.0320	69.18 ± 5.48
1	B	CIII 3	VIIb	34.1 ± 0.7	35.0 ± 0.7	17.2 ± 0.7	1.0266 ± 0.0222	0.4922 ± 0.0221	1.0326 ± 0.0273	73.27 ± 4.68
2	B, T	CIII 3	VIIb	8.31 ± 0.19	8.43 ± 0.19	3.87 ± 0.15	1.0136 ± 0.0266	0.4586 ± 0.0207	1.0163 ± 0.0320	66.48 ± 4.14
1	B	CIII 2	VIII	20.65 ± 0.42	21.22 ± 0.43	9.50 ± 0.27	1.0274 ± 0.0236	0.4476 ± 0.0155	1.0327 ± 0.0282	64.20 ± 3.03
2	B	CIII 2	VIII	17.56 ± 0.33	12.61 ± 0.25	5.24 ± 0.22	1.0535 ± 0.0232	0.4155 ± 0.0153	1.0629 ± 0.0272	57.97 ± 3.55
3	B, T	CIII 2	X	33.47 ± 0.58	36.60 ± 0.62	19.95 ± 0.44	1.0937 ± 0.0188	0.5450 ± 0.0153	1.1186 ± 0.0238	84.25 ± 3.52
4	B, T	CIII 2	XI	78.65 ± 1.42	89.03 ± 1.59	63.31 ± 1.12	1.1320 ± 0.0141	0.7111 ± 0.0178	1.1898 ± 0.0203	129.88 ± 6.10
5	B	CIII 2	XI	69.41 ± 1.19	78.82 ± 1.33	51.29 ± 1.64	1.1356 ± 0.0145	0.6507 ± 0.0235	1.1848 ± 0.0197	110.82 ± 6.78
[a]UAB	Breccia	CIII AE 3	VIIa	–	–	–	–	–	–	117.00 ± 41.00

[a] Determination on breccia at University Autónoma of Barcelona, Laboratory Radiactivitat Ambiental (Carrión et al., 1998).

kirchbergensis, Cervus elaphus, Apodemus sylvaticus, Microtus nivalis and *Allocricetus bursae* (Ruiz-Bustos and García-Sánchez, 1977). Woodland and open landscape existed in a cold, albeit humid, continental Mediterranean climate.

Unit VI is organic, with silty clays, charcoal, calcareous concretions, and predominance of lagomorphs and carnivores (*Canis, Ursus, Panthera, Vulpes,* and *Crocuta*). Warmer conditions and woodland are indicated by presence of *Microtus arvalis*, *Clethrionomys, Neomys anomalus, Erinaceus europaeus*, *Sorex*, and absence of *Allocricetus*. In CIII AE 1, unit VI was polleniferous (Carrión, 1992) and presented a stable matrix, whereas it lacked pollen in CIII where it showed a crumbly structure with recent bioturbation.

Units V–III comprised angular clasts, with noteworthy calcium carbonate precipitates in units IV and III; *Microtus arvalis* was especially frequent, and lagomorphs and carnivores remained significant. In CIII, unit V followed a phase of widespread erosion that particularly affected sediments near the cave entrance, inward retraction of which followed frost-shattering of the cave-mouth roof (Vega-Toscano, 1988). Unit V offers evidence of a cold climate, an arid open landscape, and periglacial impingement on nearby mountain sides and the exokarstic relief. Lithostratigraphical sections show thermoclastic scree in unit V throughout the cave. Units IV and III point towards fluctuating, slightly warmer and moister conditions; for instance, in CIII and CIV up to 12 finely-deposited levels are exposed. An erosive episode separated units III and II.

Hearths abound in the clays of units II and I (somewhat gravelly in unit II) that contain Lagomorpha (*Lepus, Oryctolagus*), Rodentia (*Eliomys, Arvicola, Pitymys, Apodemus/Sylvaemus*), Carnivora (*Canis, Vulpes, Genetta*), Equidae, Suidae, Cervidae, and Bovidae (*Ovis, Bos, Capra*) (Wigand, 1978). Units II and I throughout the cave provided many bones that show traces of burning and gnawing or cut-marks; deer antlers are particularly frequent, mostly broken or splintered, albeit lacking traces of use as artefacts.

5. Archaeology and human fossils

The long sequence from unit XII to V includes some 50 archaeological levels with Mousterian artefacts characterized by facetted striking-platforms albeit not prepared by Levallois reductive techniques (Vega-Toscano, 1990). The uppermost layers in unit IV provided a Middle Palaeolithic (*sensu lato*) Mousterian-like flake assemblage lacking leptolithic (bladelet) items in contrast to unit III which contained a final Palaeolithic assemblage. According to Vega-Toscano (1988) backed bladelets and microgravettes characterized an Epipalaeolithic assemblage containing a “substratum with Mousteroid tradition”. No published description exists of Aurignacian finds alleged by some authors. Concerning the Epipaleolithic assemblage is relevant to point out that all the ceramic levels contains like-Mousterian lithics because Recent Prehistory groups in Carihuela used Mousterian lithics as supports which they re-knapped (Martínez Fernández, 1985). In any case, no Epipaleolithic levels have been defined after Pellicer (1964a) although Carihuela anatomically-modern human mandible —previously defined as Paleolithic (García Sánchez, 1960)— presents mtDNA that resemble that of other Epipaleolithic individuals from the Iberian Peninsula (Olalde et al., 2019).

Units II and I mainly contained Neolithic material, albeit with some Bronze Age finds in the uppermost part of unit I. Potsherds predominated in CIII and CIV. Other finds included worked bones, shell beads, shell pendants, schist and shell bracelet fragments, flint blades, including sickle blades and pieces showing polish, grinding stones, marble and bone idols, bronze daggers, gold and silver rings, bones of sheep, goat, cattle and pig, and carbonized grains of wheat and barley (Pellicer, 1964a; Wigand, 1978). It is worth noting that several caves, among them Carihuela, were used as cemeteries during Recent Prehistory (Carrasco Rus et al., 2014, 2016; Santana et al., 2019). Specifically, during Neolithic the burial ritual implied excavation of graves and removal of underlying sediments, placing more recent human bones in lower layers. In addition, for the particular case of Carihuela cave, it is well known that excavations, especially during the 50s and early 60s, were carried out without strict excavation protocols (Vega-Toscano, 1988).

Alas, Carihuela finds are scattered among Granada's Archaeological Museum (which alone holds 150,000 lithic items), Madrid's National Archaeological Museum, Madrid Complutense University, National Museum of Natural Sciences, Washington State University, Granada University Anthropology Laboratory, and private collections. Sadly, the excavated provenance (and therefore scientific relevance) of innumerable finds is unknowable owing to a dearth of such archival documentation such as inventories of collections, excavation diaries or log books, annual excavation reports, or memoires, let alone comprehensive monographs.

Homo neanderthalensis remains, including teeth and fragments of parietal and frontal bones of adults and children come from CIII units VIII, VI, V, and lowermost IV (du Souich Henrici and Jiménez Brobeil, 2011; García Sánchez, 1960; De Lumley and García-Sánchez, 1971; De Lumley, 1973; Jiménez Arenas et al., 2019). An infantile Neanderthal frontal bone was found in CII unit VIII (Fuste, 1956; García Sánchez, 1960; de Lumley and García Sánchez, 1971;

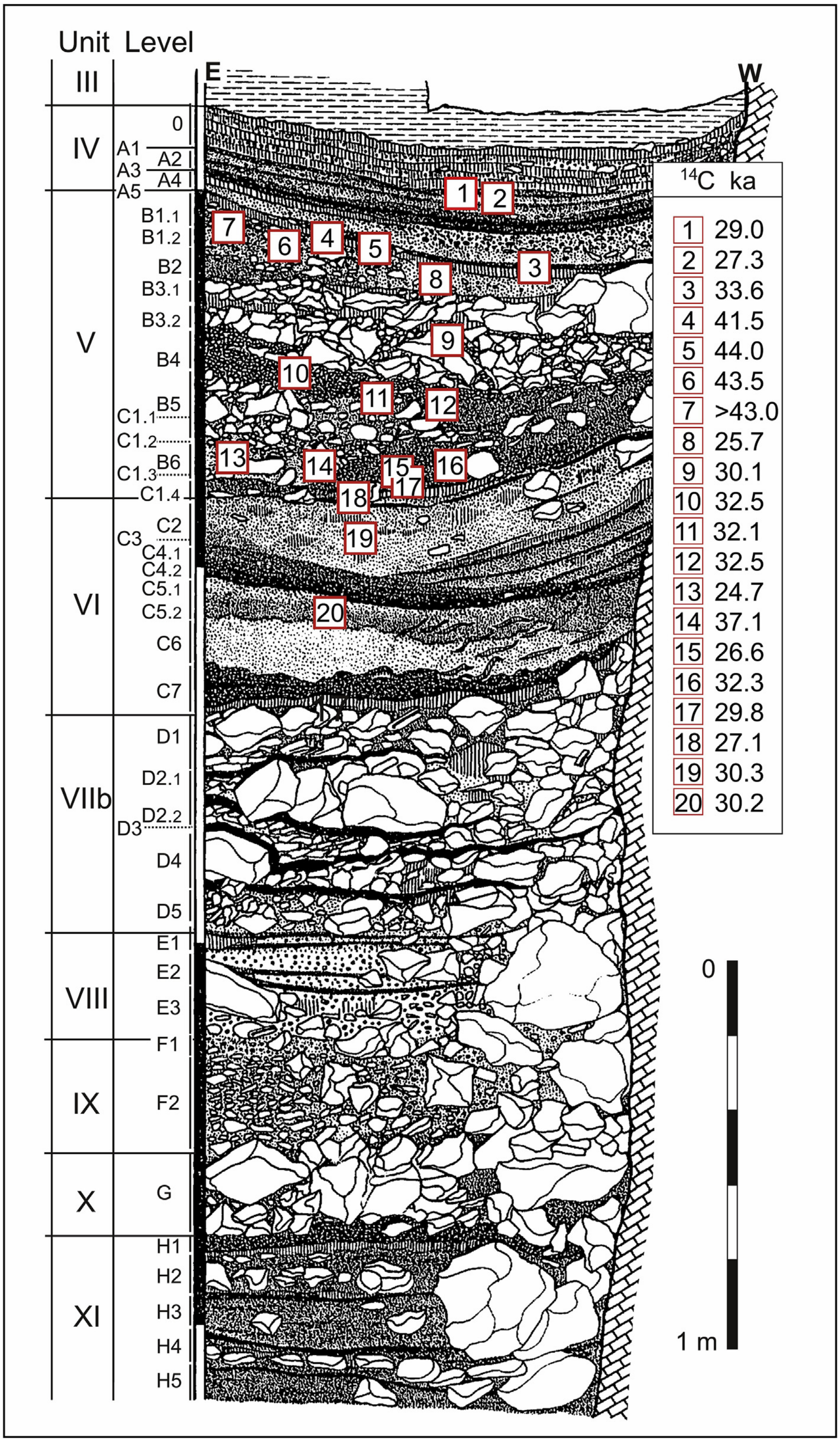

Fig. 3. Position of the samples used for ^{14}C estimation (this work, Table 4) in CIII section 1 (units XI-III).
Original artwork is from Vega-Toscano (1988).

De Lumley, 1973; Jiménez-Arenas et al., 2019). Six infantile Neanderthal teeth come from CI AE (García-Sánchez et al., 1994), a permanent incisor tooth from CIII 1 unit VI, a premolar from CIV 1 unit VI (Vega-Toscano, 1988), and from CI, CIII and CIV at least two molars and a premolar appear to be Neanderthal among 14 teeth classified by García-Sánchez from the 1969–1971 excavations (as does yet another he reported from the spoil-heap) several of which came from late Mousterian levels and could include specimens from modern humans (du Souich Henrici and Jiménez Brobeil, 2011). In addition, three unpublished Neanderthal teeth were

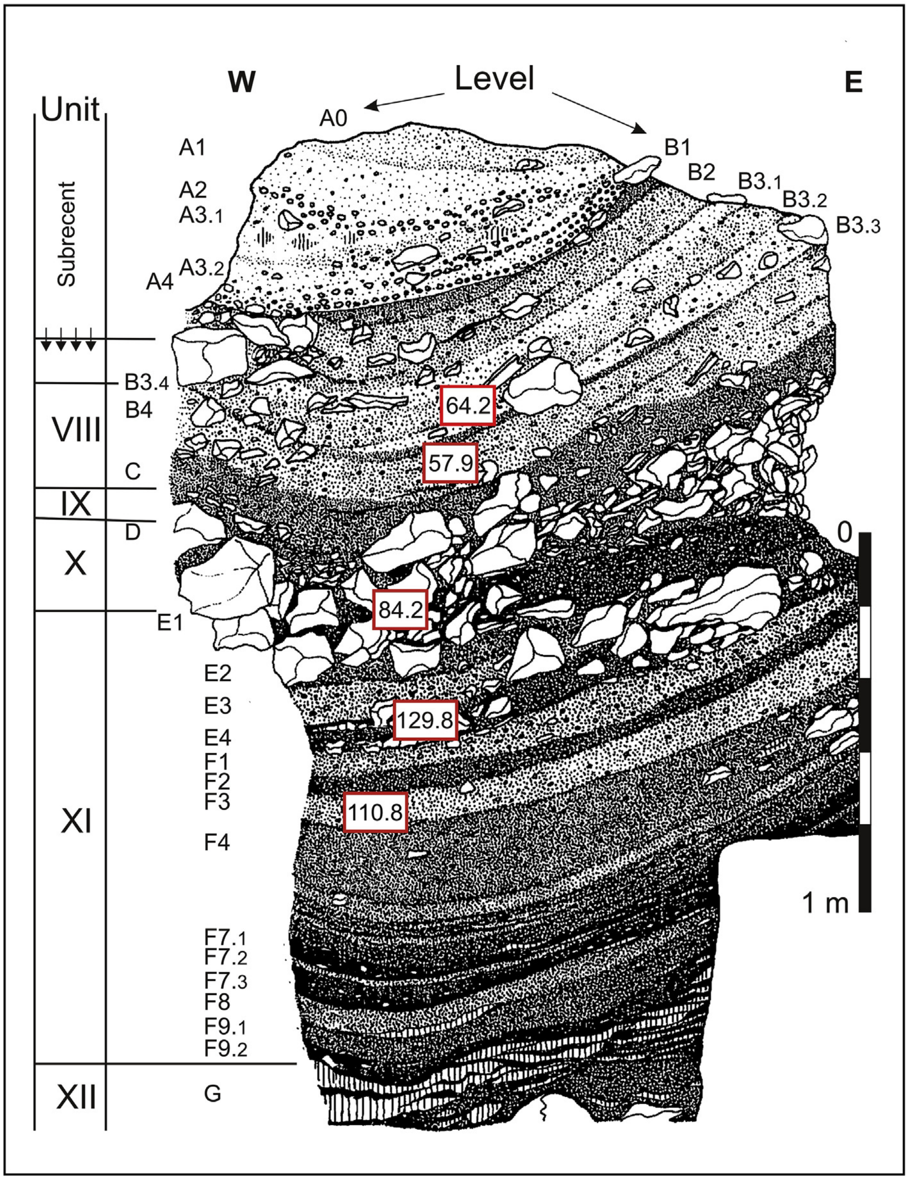

Fig. 4. Position of the samples for $^{230}Th–^{234}U$ determination (Table 6) in CIII section 2 (units XI-VIII).
Original artwork is from Vega-Toscano (1988).

found in the Granada's Archaeological Museum (Jiménez-Arenas et al., 2016). It is worth mentioning that García-Sánchez carefully documented the precise find-spot of each tooth, as annotated meticulously on site by Washington State University excavators, though the levels and sub-levels they recorded diligently are not easy to correlate with the lithostratigraphical units and subdivisions of Figs. 3–7.

Anatomically-modern human (*Homo sapiens*) remains, including cranial and tibial fragments, come from uppermost unit IV and units III–I (García-Sánchez, 1960; Vega-Toscano, 1988; Jiménez-Arenas et al., 2019). There are also human remains from Neolithic and Bronze Age individual and collective burials in CIV and CV (Wigand, 1978). It is noteworthy that anatomically-modern human remains in uppermost unit IV (IVa, thus Vega-Toscano, 1988) were found in a Mousterian assemblage. A conjecture that they had been the object of cannibalism was discarded as uninvestigable. The fine laminar interstratification of pebbles, gravel and clays of unit IV (Fig. 3) argues against their attribution to intrusive Neolithic burials or significant sedimentary disturbance. Perhaps carnivorous scavenging on human carrion was responsible, given presence in the uppermost layer of their bones and coprolites, which, together with post-depositional modification of flint artefacts and absence of hearths, could imply a time when wild predators alone frequented the cave. The artefacts could derive from reworking of underlying sediments affected by colluvial erosive processes in the entrance area, AE. In any case, a taphonomical study of fossil remains is needed to explore the interaction between humans and carnivores on the fauna, and the issue of cannibalism.

Area AE lacks deposits corresponding to units III and IV. Somewhat further inside, in CIV, their composition betrays an exogenous source. By contrast, in the entrance area (CIII AE1; Fig. 6) unit VI contained several Mousterian layers, whereas there are fewer in the same unit further within the cave (CIII 1: Figs. 3 and 7). Plausibly, unit V here could owe to displacement inwards (implying high transport energy) of sediments resulting from considerable erosion at the entrance. That could account for both the absence of pollen in unit VI here and its relatively recent radiocarbon estimates (Table 5).

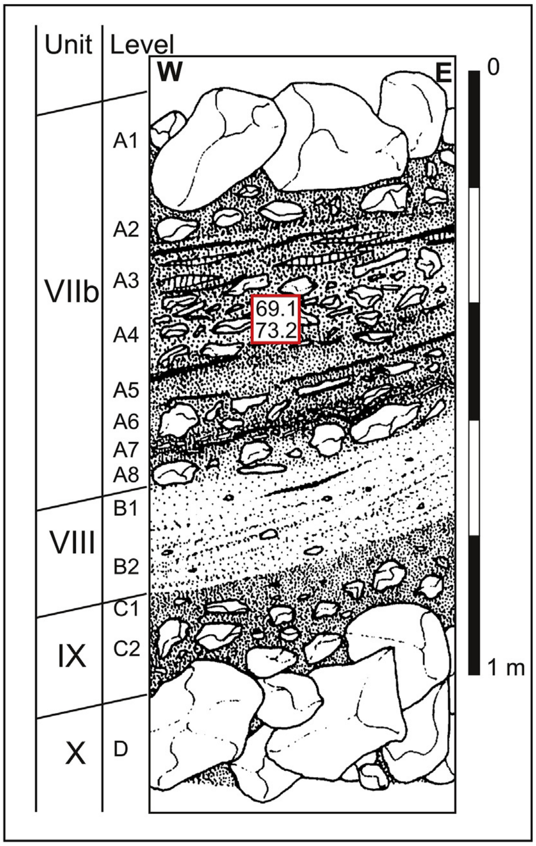

Fig. 5. Position of the samples for $^{230}Th-^{234}U$ determination (Table 6) in CIII section 3 (unit VIIb).
Original artwork is from Vega-Toscano (1988).

6. Chronology

One of the aspects to which more attention has been paid in Carihuela research has been chronology. In fact, Carihuela has became an archaeological site where it was experimented with thermoluminescence. Tables 1 and 2 show thermoluminescence (TL) determinations (Fremlin, 1974; Göksü, 1973; Göksü et al., 1974) from units XI to III spanning 82,500 to 11,200 BP, made on mainly burnt chalcedony and chert pieces from archaeological and palaeoanthropological contexts albeit lacking precise stratigraphical details. Thermoluminescence dating was then in its infancy and Table 2 includes subsequent amendments (cf., Davidson, 1989).

Eleven electron spin resonance (ESR) determinations (Volterra, 2000, Table 3) were made on 2 herbivore teeth excavated by Spahni in 1954 from unit V 2/3, 3 from unit V 5/6 and 4 from unit VIIb stored at Madrid's Natural Science Museum, as well as 2 from VIIb collected in 1995–1996 when dosimeters for γ-ray spectrometry were inserted into the unit V section exposed by Washington State University and the unit VIIb section of Vega-Toscano's excavation (they were extracted in 1997). A significant fall of rock from the cave roof in the 1995–6 winter obstructed further access to unit V in Spahni's trench and there was collapse of the exposed unit VIIb in Vega-Toscano's. Volterra's tables give both the *in situ* dosimetry results and instrumented neuron activation analysis (INAA) computations, with early uptake (EU) and linear uptake (LU) data in each case. Based on the *in situ* dosimetry, the approximate ages were summarized as follows: V2/3 50.6 ka (EU) 57.6 ka (LU); V5/6 67.8 ka (EU) 81.7 ka (LU); VIIb 86.9 ka (EU) 91.0 ka (LU) (Volterra, 2000, Table 3). The corresponding INAA computations (Table 3), however, were: V2/3 61.6 ka (EU) 73.3 ka (LU); V5/6 45.6 ka (EU) 51.4 ka (LU); VIIb 63.4 ka (EU) 66.6 ka (LU). Nevertheless, Volterra (2000) remarked not only that, taking into consideration radiocarbon determinations, a unit V 2/3 ESR (EU) estimate of 45.2 ka could mean that "an age ranging between 45 and 70 ka for the entire layer V seems appropriate", but also that the ESR estimates indicated "the recent presence of Neanderthals in Andalusia"

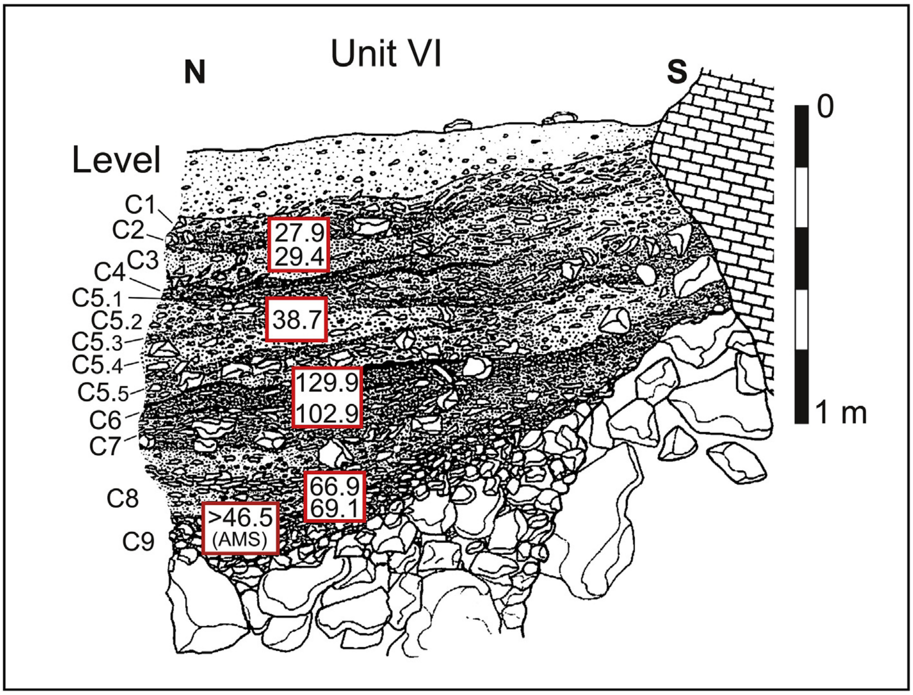

Fig. 6. Position of the samples for $^{230}Th-^{234}U$ determination (Table 6) in CIII AE section 1 (unit VI).
Original artwork is from Vega-Toscano (1988).

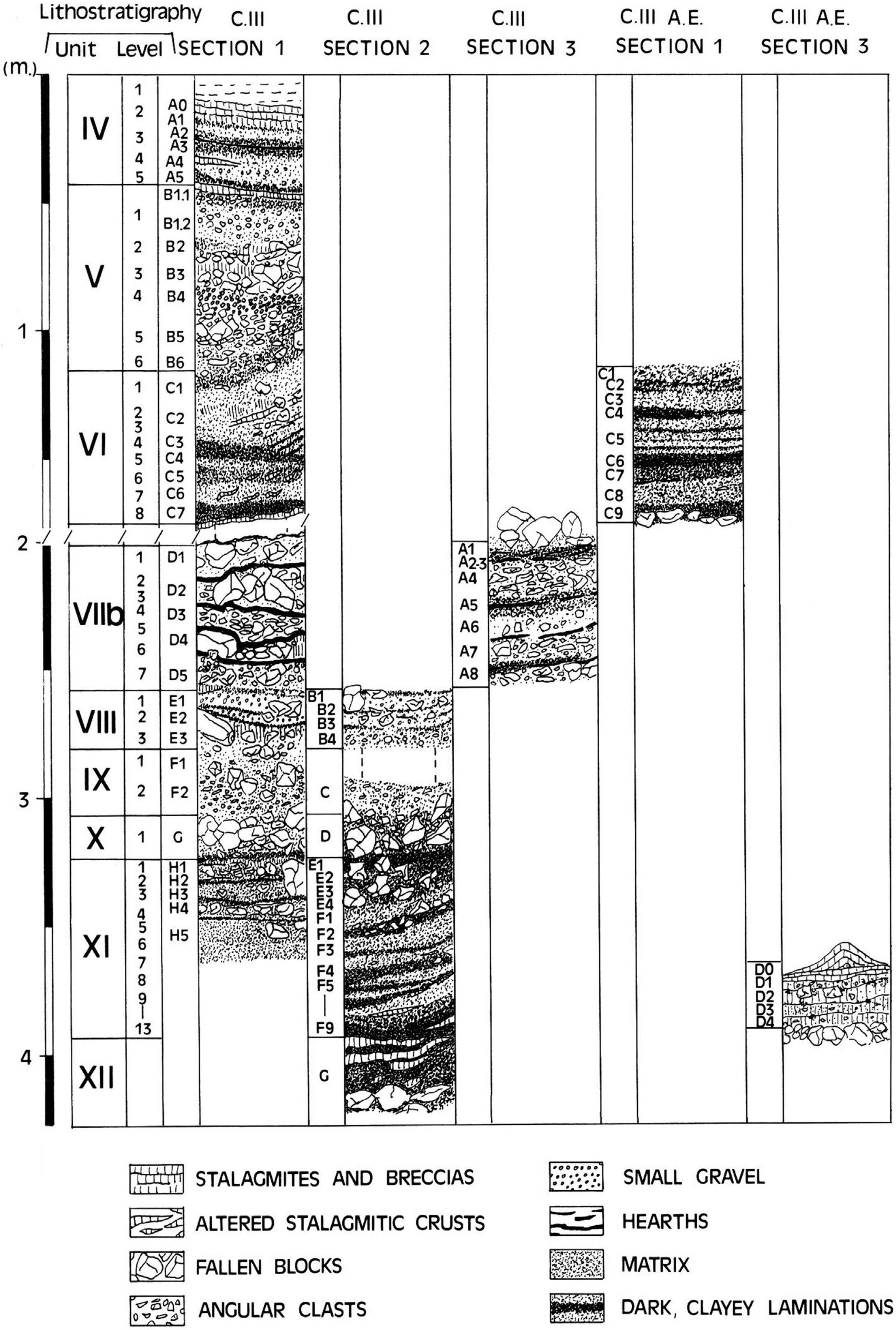

Fig. 7. Correlation between the Palaeolithic lithostratigraphical sections and archaeological levels from Carihuela Cave (modified from Vega-Toscano et al., 1988).

(Volterra, 2000, 173). Volterra was unable, however, to date either the uppermost level of unit V or unit IV.

Age determinations by AMS ^{14}C of ca. 14.3 ka from unit III and >46.5 ka from unit VI level C8–C9, and by $^{230}Th-^{234}U$ of 117,000 ± 41,000 BP from unit VIIa (Carrión et al., 1998, 1999a,b) were expanded by ^{14}C estimates from units I to VI (Fernández et al., 2007) that include determinations of 33–25 ka from Mousterian deposits suggestive of Neanderthal presence lingering late in MIS-3 (Fernández et al., 2007), as have been contended from research in Gorham's Cave, Gibraltar (Finlayson et al., 2006, 2008a,b; Finlayson and Carrión, 2007; Bailey et al., 2008). Table 4 includes 17 new ^{14}C determinations by the Poznan Radiocarbon Laboratory on organic carbon from bulk sediment, bones and charcoal. Table 5 presents 13 new ^{14}C determinations on coprolites by ETH Zürich (Department of Physics, Institute for Particle Physics and Astrophysics) together with another on a coprolite determined at the Poznan Laboratory (which found 8 further samples to be unsuitable owing to insufficient carbon). Table 6 offers 14 new $^{230}Th-^{234}U$ estimates from animal bones and teeth determined at Seville University.

The new dated materials in Table 4 were collected in 2011 from excavation sections after careful cleaning of their surfaces and detailed observation of the stratigraphical units and levels described by Vega-Toscano (1988). The sections have been the object of archaeological, geochronological, and palaeoecological scrutiny (Carrión, 1992; Carrión et al., 1998, 1999a,b; Vega-Toscano, 2005; Fernández et al., 2007, 2018; Jiménez Arenas et al., 2016). The coprolite samples (Table 5) came from specimens at Granada's Archaeological Museum collected during the Washington State University excavations.

The new dates (Tables 4–6, Figs. 3–6) merit comment. Whether determined on charcoal, bones, teeth, or bulk sediment, they include several disconcertingly late dates for the Mousterian of ca. 30 ka from units IV, V and even VI. Three estimates from units IV and V, of 41.5, 44.0, and 43.5 stand out vis-à-vis others of between 37.1 and 24.7 ka. Poz-45192 offers a possible fourth of >43 ka. The four in question come from the top of unit V (level B1) and base of unit IV (level A5) in CIII, where a brecciated matrix may have developed quickly in an eroded hollow (Fig. 3). Unit IV is poorly developed in CIII where it is sealed by a 15 cm-thick bed of brecciated sediment that slopes down into the chamber (unit IV, level 0: Fig. 3). Levels A5 and B1 are cemented more heavily than those immediately above or below; their fine-grained matrix slopes obliquely down and eastwards by virtue of the process that consolidated it (Vega-Toscano, 1988), perhaps at a time indicated by the 4 dates from before 40 ka. Nevertheless, $^{230}Th-^{234}U$ determinations of 38.7 ka, 29.4 ka and 27.9 ka (Fig. 6, Table 6) come from the upper part of unit VI in the entrance area AE, suggesting lateness.

Regarding CIII Section 2, uncertainty (cf., Vega-Toscano, 1988) surrounds stratigraphical correlation of the upper levels (A and to a lesser extent B: Fig. 4) which might correspond to unit VIII but show intrusive components from VIIb or VI, or even later, though dates of 64.2 and 57.9 ka (Fig. 4; Table 6) could correspond to early deposits. Notwithstanding an erosive contact between them, levels A and B, dipping markedly southwards, seem to form a relatively cohesive bed (subjected to some subsequent alteration) of yellowish gravel in a sandy matrix, including dark bands and containing crumbly calcretions and pebbles.

Unit VI in CIII AE (Fig. 6) provided $^{230}Th-^{234}U$ determinations of ca. 129 and 102 ka from deposits lying *above* others with $^{230}Th-^{234}U$ estimates of 66.9 and 69.1 ka. Both the two earliest dates come from the isolated lens of sediment that is level C6, over which lie interdigitating black layers containing innumerable charcoal fragments. Given its position in the western part of the trench quite near the entrance, C6 could well contain intrusive last interglacial (MIS-5) material (cf., Carrión et al., 1998).

Comparison of $^{230}Th-^{234}U$, TL and ^{14}C determinations (Fig. 10) suggests that units from XI to VIII correspond to MIS-5. Unit VIIb seems correspond to a period straddling the end of MIS-5 and MIS-4, to which some ESR estimates lend support whilst others imply that unit V2/3 corresponds to MIS-4, as likewise should unit VI given the aforementioned $^{230}Th-^{234}U$ estimates of 66.9 and 69.1 ka. Unit VI seems to belong to MIS-3 according to the dates in Tables 3–6 Unit IV provides several dates indicating MIS-2. Units III, II and I belong to MIS-1. As outlined above, problems surround unit V. Maybe it comprises a lower block of sediments deposited in MIS-4 and uppermost sediments deposited in MIS-3 (perhaps quite late).

7. The relevance of palaeoecological information for establishing a chronostratigraphical framework

7.1. Palynological potential of the Carihuela sediments

The Carihuela archaeological deposits are important for palynological research. There are relatively high pollen concentrations, a considerable number of pollen taxa, correlations between the curves of percentages and concentrations, ecological plausibility of the pollen assemblages, and good possibilities of correlation of pollen spectra from different sections of the same lithological units. Most sections are particularly rich in pollen, which is gratifying in the difficult context of cave palynology (Carrión and Scott, 1999; Carrión et al., 1999a,b; Navarro et al., 2001; Hunt and Fiacconi, 2018). Exceptions were unit XII and the lowermost levels of XI, which contained no pollen. Pollen was lacking also in unit VI in CIII and CIV (Carrión et al., 1998). These sediments, although rich in organic content, showed signs of repeated fluctuations of water levels during their formation, which may have contributed to oxidation of pollen grains and spores (Carrión et al., 2009). The three cave entrances favour a circulation of air that enhances the input of pollen. Conveniently, the sedimentary strata account for most of the Late (Upper) Pleistocene and last ice age, with few, if any, of the chronological gaps found often in sedimentary sequences at other sites (Carrión et al., 1999a,b; Navarro et al., 2000).

An initial palaeocological study provided records for five CIII sections containing Middle Palaeolithic artefacts, embracing units XI–IV (Carrión, 1992). After improving palynological resolution, CIV Sections 1 and 2 were studied (Carrión et al., 1998), with replication of analyses for units VI–III, givng results that reinforced the 1992 findings. Notwithstanding its disquietingly wide standard error, a single $^{230}Th/^{234}U$ age-estimate of 117,000 ± 41,000 BP (Carrión et al., 1999a,b) from unit VIIa led to the proposal (Fernández et al., 2007) for its transfer to the last interglacial period (MIS-5), to which unit XI belongs (Table 6), from the glacial stage to which unit VIIb stratified *beneath* unit VIIa corresponds. In the area excavated by Pellicer (1964a), Sections 3, 4 and 5 in CIV provided a detailed palynological record for the late glacial and Holocene (Fernández et al., 2007) that embraced units III-I dated to between ca. 19 ka and 1.17 ka (Table 4).

7.2. Summary of the pollen sequence and vegetation changes

Fig. 9 summarizes the main palaeoecological findings of the Carihuela sequence. It is proposed that starting in MIS-5 zone 1 is characterized by predominance of *Olea*, *Quercus*, and continuous presence of other Mediterranean taxa (*Phillyrea*, *Pistacia*, *Rhamnus*, *Myrtus*, *Erica*, *Ephedra fragilis*) and broad-leaf trees (deciduous *Quercus*, *Corylus*, *Fraxinus*, *Alnus*, *Betula*, *Ulmus*, *Castanea*, *Salix*, *Juglans*) (Carrión et al., 1999a,b). Interglacial *Pinus* developments involve declines of the *Olea-Quercus* assemblage.

The Pleistocene pollen shows a millennial-scale pattern of vegetation changes affecting principally *Pinus*, Poaceae and *Artemisia*, and depicts landscapes fluctuating between an arboreal vegetation with pines and angiosperm woody taxa, and a herbaceous type suggestive of cold conditions. Two stadial maxima show the highest values of xerophytic vegetation (*Artemisia, Ephedra*, Amaranthaceae), eventually with Poaceae increases, and, crucially, disappearance of any thermic indicator. These two phases could correlate with MIS-4 (zone 9, unit VIIb) and final MIS-3 and MIS-2 (pollen zones 13–17, units V-IV). However, two MIS-3 interstadial episodes could lie within zones 11–12 (unit VI) and zone 15, characterized by pine forests and reappearance of Mediterranean sclerophylls (*Quercus, Phillyrea, Olea, Buxus, Myrtus*) and deciduous trees (*Quercus, Salix, Corylus*) following achievement in zones 13–14 of the *Artemisia* sequence maximum with pollen percentages of up to 81% (Carrión, 1992). The late glacial pollen shows the typical early *Quercus* colonization of southern Spain (Pons and Reille, 1988; Carrión et al., 2010, 2013; Camuera et al., 2019) which increased and was prolonged in the Holocene (Fig. 9) with a higher diversity of Mediterranean and temperate taxa (Carrión et al., 2010; Tarroso et al., 2016).

7.3. Coprolite pollen analysis and dating

We present a summary of the pollen composition of 3 coprolites (presumably *Crocuta*), Car-1, Car-2 and Car-6, dated respectively to ca. 23.4, 30.3 and 31.0 ka (Table 5, Fig. 8), and analysed in accordance with accepted methods for faecal fossils (Carrión, 2002a; Scott et al., 2003; Carrión et al., 2007). Characteristically accompanied by the Amaranthaceae and *Ephedra*, *Artemisia* predominates in Car-6, and is still abundant in Car-2 though somewhat less so in Car-1. Conversely, *Pinus* and Poaceae rise as *Artemisia* declines. The few indicators of Mediterranean and temperate forest (*Quercus, Corylus, Myrtus, Salix, Phillyrea*) are absent in Car-6 and Car-2 but occur in low frequencies in Car-1. The pollen spectra found in Car-6 and Car-2 are identical to those obtained from pollen zones 13 and 14 (unit V in CIII 1) (Carrión, 1992; Carrión et al., 1998). The pollen spectra from Car-1 correlate well with those from pollen zones 15–17 (unit IV in CIII and CIV) (Carrión et al., 1998; Fernández et al., 2007). The vegetation and the AMS ^{14}C dates are compatible with late MIS-3 and MIS-2 (Fig. 9).

Other coprolites gave more recent dates (Table 5), perhaps owing to contamination by later carbon (if, indeed, *Crocuta* was responsible for them and, as generally accepted, became extinct during MIS-2). The obligatory removal of the cortex from coprolites before pollen analysis may not exclude altogether possibilities of contamination that are greater for fossils long stored in museums (open to risks of cortical cracking), than when excavated *in situ* and protected straightaway. In that regard, it is worth remarking that Car-6 and Car-2 dated to ca. 30–31 ka gave xerophyte percentages commensurable with those ca. 40 ka from Padul. Further light might be shed on the chronological problems through pollen analysis of coprolites that are relatively abundant at the adjacent Cueva de las Ventanas (Carrión et al., 2001a,b,c; Scott et al., 2003).

7.4. Palaeoclimatic significance

The best palynological criterion for palaeoclimatic reconstruction from Carihuela cave sediments is the composition of the pollen assemblages rather than the pollen frequencies, with the number of mesothermophilous taxa being of critical importance (Carrión et al., 1998, 1999a,b). Abundant thermoclastic scree in units VIIb and V, and to a lesser extent in X, IX, IV and III, is in step with the cold-indicator *Microtus arvalis*, and steppe/grassland-like vegetation with disappearance of mesothermophilous elements and depletion of the Mediterranean forest at low altitudes (González-Sampériz et al., 2010; Carrión et al., 2013; Camuera et al., 2019), in contrast to pollen spectra, containing thermophilous taxa, from units VIII, XII, XI, VI, II, I, in which $CaCO_3$ concretions are present.

7.5. Comparison with the Padul pollen sequence

The Carihuela pollen records for the Pleistocene, comparable (Fernández et al., 2007) to the renowned pollen sequence defined by Pons and Reille (1988) from the nearby Padul peat-bog, accord well with recent palynological, and palaeoclimatological findings from Padul-15-05 (Camuera et al., 2019) (Fig. 9). Xerophyte and Mediterranean forest peaks, as well as cold and warm peaks in the pollen climate index (PCI) calculated for Padul, afford correspondence with Carihuela, and provide signals for global climatic changes, such as those recorded during the last glacial period in the Greenland ice cores (Rasmussen et al., 2014). Nevertheless, when

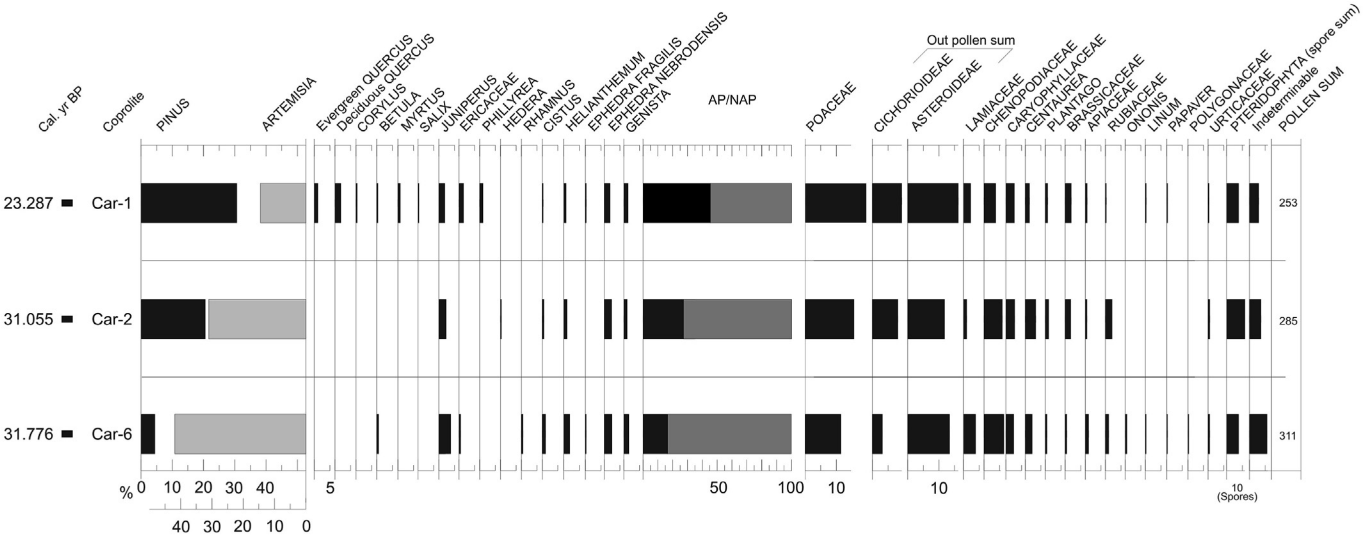

Fig. 8. Pollen diagram of three Pleistocene coprolites from Carihuela Cave (Table 5). Minor taxa not included in this diagram are: *Ononis, Linum, Papaver*, Polygonaceae, Urticaceae, Pteridophyta spores. Total pollen sums above 250, with Asteroideae, Cichorioideae, and Pteridophyta excluded.

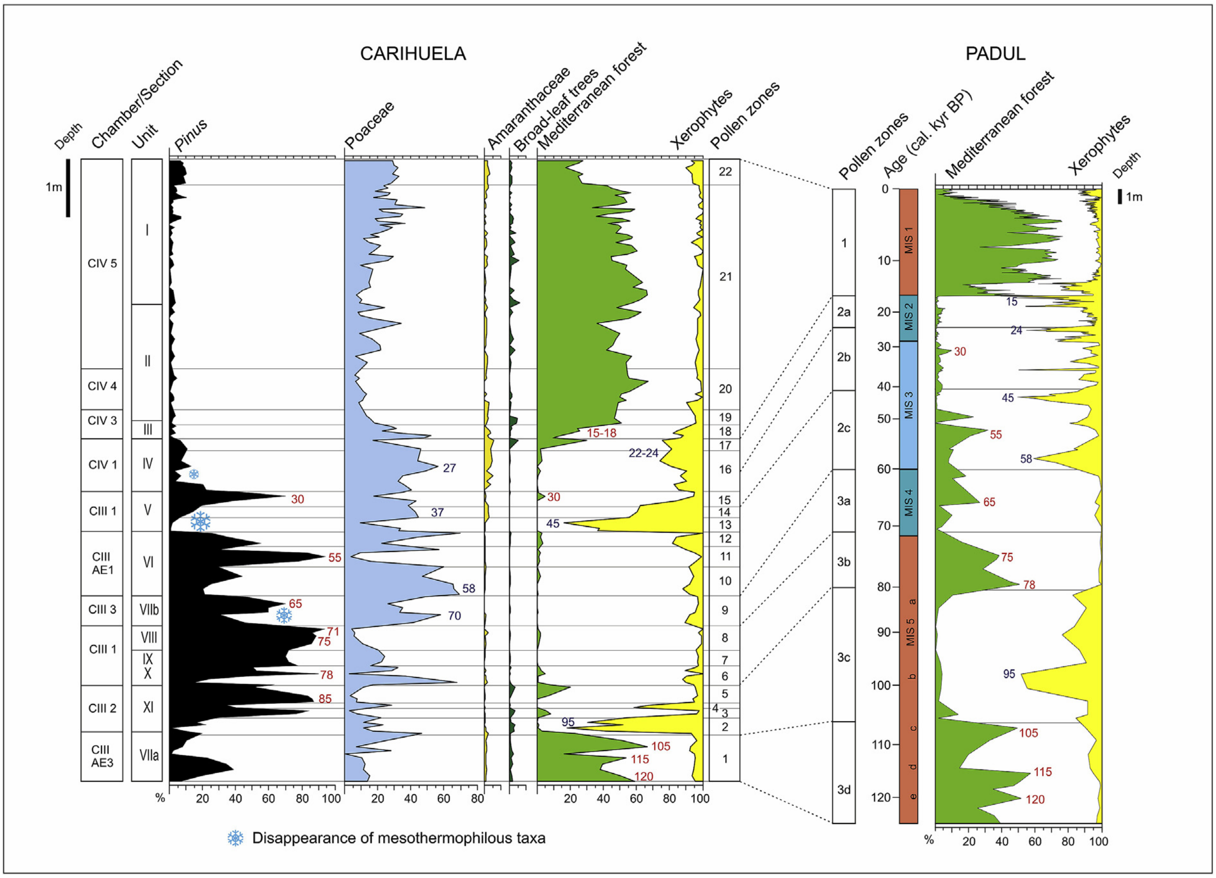

Fig. 9. Tentative correlation between the pollen sequences of Carihuela (Carrión, 1992; Carrión et al., 1998; Fernández et al., 2007) and Padul (Camuera et al., 2018). Red and blue numbers indicate forest and steppe maxima, respectively, in the Padul pollen sequence and their counterparts at Carihuela. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

drawing comparisons due account must be taken of taphonomical differences between assemblages of pollen from sediments in peatbogs and those in caves. Furthermore, lying to the south of Carihuela, nearer to the Mediterranean Sea, Padul enjoyed a warmer, less continental climate and, plausibly therefore, a somewhat different vegetation during glacial stages. As at Carihuela, the Padul pollen record spans MIS-5 to MIS-1. Mediterranean, mainly *Pinus*, forest predominated, alternating with herbaceous taxa, principally *Artemisia* and Poaceae, as well as such typical xerophytes as *Ephedra* and Amaranthaceae. *Pinus* pollen is more continuously abundant at Padul, and probably over-represented in its pollen record (Camuera et al., 2019), though nonetheless providing us with a sensitive component for discerning changes to the tree-line during the last ice age which likely are relevant at Carihuela.

Palynological research at ecotonal sites throws light on altitudinal changes in high-altitude pine forests and xerophytic grassland-scrub, and their sensitivity to changes in temperature (Carrión et al., 2001a,b,c). For instance, comparison between the main Holocene vegetational shifts at Cañada de la Cruz and Siles (in the Betic mountain system) reveals climatically-induced altitudinal displacement of the vegetational belt and (inverse) correlation of advancing grassland with shrinkage of woodlands and *Pinus* forest (Carrión, 2002). Of interest for Carihuela, upward displacement of oak woodland accompanied expansion of pine forest. Consequently, some climatic ameliorations may correspond to oak pollen peaks at Padul and pine at Carihuela (with minor pollen signals for oak). Cold dry spells gave rise to xerophyte maxima at both sites and sometimes to Poaceae maxima at the higher-altitude site of Carihuela, suggesting that grassland spread to the detriment of coniferous woodland (Fig. 9).

Bearing the foregoing in mind, the following correlations are proposed between Padul and Carihuela as a working hypothesis:

(i) MIS-5: Padul 3d ≡ Carihuela 1 (unit VIIa), Padul 3c ≡ Carihuela 2–5 (unit XI), Padul 3b ≡ Carihuela 6–8 (units X–VIII);
(ii) MIS-4: Padul 3a ≡ Carihuela 9 (unit VIIb);
(iii) MIS-3: Padul 2c ≡ Carihuela 10–14, Padul 2b V ≡ Carihuela 15-lowermost 16 (units VI- V);
(iv) MIS-2: Padul 2b-2a ≡ Carihuela uppermost 16–17 (unit IV);
(v) MIS-1: Padul 1 ≡ Carihuela 18–22 (units III-I).

A more detailed correlation is eschewed, given differences between the sites regarding pollen taphonomy and physical geography. Fig. 9 offers plausible correlations between the most prominent peaks of the main taxa. Thus there could be parallel patterns in the increases of xerophytes and/or Poaceae ca. 95, 70, 58, 45 and 24 ka, and in forest development ca. 120, 115, 105, 65, 55, and 30 ka (well before the onset of the last glacial maximum in MIS-2), corresponding to Carihuela zones 16–17 (unit IV). Pine forest expansion in Carihuela zones 3, 5, and 6–8 (units XI to VIII) is comparable to that of pine and oak forests ca. 90 and 71 ka at Padul where sharp declines ca. 80 and 70 ka may have their counterpart in short-lived increases in grassland at Carihuela. The disappearance of mesothermophilous taxa observed at Carihuela has no counterpart at Padul where the lower altitude and less rigorous climate likely enabled their persistence. In that regard, it is worth

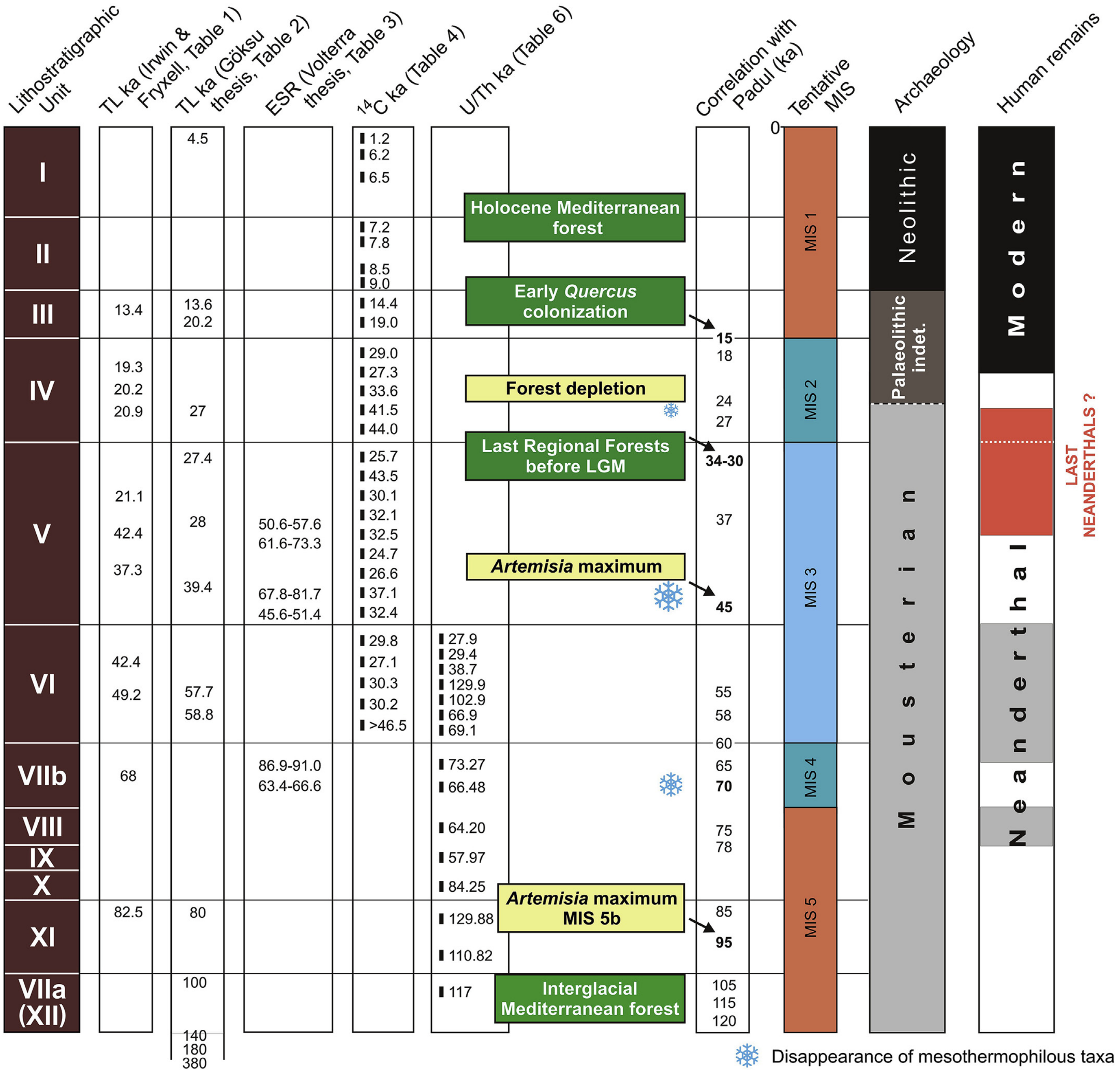

Fig. 10. Working hypothesis for the Carihuela chronostratigraphy and biostratigraphy in the framework of archaeological and palaeoanthropological findings. This figure follows the correlation proposed in Fig. 9.

remarking that during late glacial times there was early colonization by oak (as elsewhere in the region) at both Carihuela and Padul (Pons and Reille, 1988; Carrión et al., 2010, 2013; González-Sampériz et al., 2010).

MIS-4 is characterized by humid conditions at Padul, with decreasing temperatures, and Ericaceae as the characteristic pollen taxon (Camuera et al., 2019). At Carihuela, this phase may be reflected by abundant horse bones and teeth in unit VIIb where sedimentological features indicate cold, humid conditions, with grassland prevalent, notwithstanding a *Pinus* peak in the uppermost zone 9, perhaps synchronous with a Padul *Quercus* peak ca. 65 ka (Fig. 9). Consideration of the sedimentological characteristics of Carihuela unit X might suggest the onset of MIS-4 (Carrión, 1992), though evidence of more severe environmental conditions, increase in the proportion of cryophilous fauna, and disappearance of mesothermophilous taxa, must await unit VIIb; moreover, unit VIII implies intervention of temperate conditions between units X and VIIb.

At Padul MIS-3 commenced with a dry period when xerophytes prevailed ca. 60–55 ka (early MIS-3), until prevalence of both deciduous and evergreen *Quercus* indicates warmer, more humid conditions ca. 55 ka. Carihuela pollen zones 10 and 11 exhibit a similar evolution. At Padul an intensely cold, arid period ensued, characterized by abundant xerophytes and absence of Mediterranean forest. It plausibly corresponds to the time of MIS-3 ca. 40 ka when harsh conditions during Greenland Stadial 9, GS-9

(Rasmussen et al., 2014) in the northern hemisphere resembled those, over ten millennia later, in MIS-2. The Carihuela 12–14 interval exhibits similar features, with high values of *Artemisia* and *Ephedra* in unit V where thermoclastic scree and cryophilous fauna prevail, and *Artemisia* predominates in two coprolites (Fig. 8) ascribable to pollen zones 13–14.

In Carihuela pollen zone 15, *Pinus* increases (45–65%) while *Artemisia* decreases substantially, and deciduous and evergreen *Quercus, Olea, Corylus, Salix, Myrtus, Phillyrea, Buxus*, and Ericaceae reappear (Carrión, 1992; Fernández et al., 2007). This was to be the last forest development before the last glacial maximum, in MIS 2. As well as pine-oak forest data from Padul, further corroboration comes from correlation with the latest Pleistocene phase of Mediterranean vegetation (*Quercus ilex-coccifera*, *Quercus suber, Pinus pinaster, Erica arborea, Arbutus, Olea, Phillyrea, Pistacia, Myrtus*) and deciduous trees (*Quercus, Alnus, Betula, Corylus, Salix, Fraxinus*) in the pollen sequence from Navarrés in Valencia (at 225 a.s.l.), dated to ca. 34.2–30.4 ka (Carrión and van Geel, 1999; Carrión et al., 1999a,b; 2000a, 2000b). The Carihuela pollen record (Fernández et al., 2007) is also similar to Padul during the Holocene (another appropriate Holocene comparison is a high-resolution study published by Ramos-Román et al., 2018).

The Carihuela palynological sequence indicates a severely cold, arid phase in unit V, plausibly ca. 40 ka, whereas a previous consideration (Fernández et al., 2007) based on high pollen values for *Artemisia* and other xerophytes had assigned it to the last glacial maximum in MIS-2. As suggested earlier, unit V at Carihuela might take its origin in MIS-4 and reach the onset of MIS-3. This, however, carries the worrying implication of the unreliability of several estimates from unit V that give a more recent age from TL and ^{14}C determinations. It is extensive to deeper units also. Possible causes could range from post-depositional disturbance of sediments to circumstances of sampling and conservation of specimens. Resolution of the matter requires renewed on-site research and sampling, and taphonomic studies together with collaboration by laboratories using a variety of dating methods that are appropriate for accurate and precise dating of Pleistocene materials.

8. Carihuela and late Mousterian chronology

8.1. Introduction

In Europe, exclusively Neanderthal human remains characterize Middle Palaeolithic (MP) assemblages with Mousterian artefacts, whereas the Earliest Upper Palaeolithic (EUP) is attributed to anatomically-modern humans notwithstanding paucity of human fossils (Hublin, 2015; Bae et al., 2017), and dispute surrounds the authorship of Proto-Aurignacian, Chatelperronian, and so-called “transitional” industries (Finlayson and Carrión, 2007; Zilhão et al., 2015; Slimak, 2019). It should be pointed out that in western Eurasia Mousterian artefacts accompanied early anatomically-modern humans in Israel (at Mugharet es-Skhul and Jebel Qafzeh), and they are widespread in northern Africa which lacks Neanderthal humans (Finlayson and Carrión, 2007). Claims of the identification of teeth of anatomically-modern humans in a few western European EUP assemblages from 45–40 ka have aroused debate over the accuracy of morphological identification, dating, and archaeological context (Higham et al., 2011), though they lie outwith our scope which is confined to the Iberian Peninsula. Interwoven with, and often overriding, claims and counter-claims about the substantive arguments are conjectures drawn from formal inferences about the exclusiveness, or otherwise, of correlations between Neanderthal humans with European MP artefacts and anatomically-modern humans with EUP assemblages. There are enthusiastic supporters of an inference that neither Neanderthals nor Mousterian assemblages lingered on after 40 ka in the Iberian Peninsula (cf., Wood et al., 2013a,b; Higham et al., 2014; Hublin, 2015). Only with reservations is their later survival contemplated, at most until 38–37 ka, at sites with MP assemblages, backed up by ^{14}C or TL determinations, such as Cueva Antón and Abrigo de La Boja in southeastern Spain (Zilhão et al., 2017) or Gruta da Oliveira in Portugal (Angelucci and Zilhão, 2009) which contained Neanderthal skeletal remains (Willman et al., 2012). There may have been MP persistence elsewhere around the Eurasian periphery, namely in high latitudes, as at Byzovaya (Slimak et al., 2011; Slimak, 2019).

Nevertheless, up to the early years of this century it was held widely that by taking advantage of glacial refuges Neanderthals survived later still in southern Iberia, both in favourable montane refuges and in benign coastal localities (Vega-Toscano, 1990, 1993; Vega-Toscano et al., 1988, 2005; Finlayson et al., 2006, 2008a; 2008b, 2011; 2012; Carrión et al., 2008, 2011, 2018; Blain et al., 2013; Jiménez Espejo et al., 2013; Rodríguez Vidal et al., 2013). Recent palynological research in Vanguard Cave strengthens this model (Carrión et al., 2019). Neanderthal and Mousterian finds at the Cueva del Boquete de Zafarraya (Barroso, 2003), lying 1100 m. a.s.l., 25 km from the Andalusian port of Málaga, were regarded as late until ^{14}C results with collagen ultrafiltration dated them to ca. 43 ka (Wood et al., 2013a,b; see also Barroso and Caparrós, 2015). At Cueva del Bajondillo, on the Málaga coast, Mousterian and Aurignacian artefacts are claimed from deposits dated to ca. 45–43 ka cal BP (Cortés-Sánchez et al., 2019). Former publications (Cortés-Sánchez, 2003, 2007, 2010; Cortés-Sánchez et al., 2008) mentioned Mousterian and “probably” Aurignacian pieces in levels Bj13-Bj12, perhaps suggestive of disturbance between Bj14 and Bj11. The lack of human remains at Bajondillo is yet another instance of their notoriously conspicuous absence from almost all early Aurignacian assemblages in western Europe. In any case, not even appearance of anatomically-modern people need imply regional Neanderthal extinction ipso facto. Such extinction, however, seems to lie behind the contention of Cortés-Sánchez et al. (2019), offered without tangible evidence, that Carihuela Cave lacked late Neanderthal presence.

The Atlantic belt of northern Spain has sites with early Aurignacian assemblages dating from ca. 43.3–45 ka cal BP, overlapping with Chatelperronian ones dating from ca. 42.6–41.5 ka that are later than Mousterian assemblages from 47.9 to 45.1 ka (Marín Arroyo et al., 2018; Straus, 2018; Wood et al., 2014). The Aurignacian ends ca. 34.6–33.1 ka (Marín Arroyo et al., 2018). Anatomically-modern human remains are conspicuous by their absence. In Central Spain the Cueva de Los Casares provided MP and Neanderthal remains dating from ca. 45–42 ka (Alcaraz Castaño et al., 2017). A high-resolution loess record, including stable isotope analysis, from the Upper Tagus Basin suggests Neanderthal abandonment of inland Iberian landscapes by ca. 42 ka, even before the intensely cold GS-9 (Wolf et al., 2018).

8.2. Late Neanderthals, EUP, chronology, and palynology, in the eastern Spanish coastal belt

Chronological aspects of the Middle-Upper Palaeolithic transition in the eastern Spanish coastal belt require attention, given the location of Carihuela in southeastern Spain. At the most northerly, Cova de L'Arbreda (Serinyà, Gerona), lying at 200 m a.s.l., 35 km from the Mediterranean Sea, Mousterian deposits gave way ca. 42.3–40.3 ka to Aurignacian assemblages, though further dating research is desirable (Wood et al., 2014). Abric Romaní (Capellades, Barcelona) lies at 300 m a.s.l., 35 km from the Catalan coast; here an 18-m deep Mousterian sequence, probably beginning in MIS-5, provides a palynological sequence embracing MIS-4 that reflects thermophilous woodland, albeit with *Pinus* dominance, between ca. 70 and 66 ka, with intermittent episodes characterized by steppe vegetation, which was followed by climatic oscillations between ca. 57 and 50 ka that included milder, humid interludes, after which cold, dry conditions prevailed followed by a milder phase between ca. 46 and 40 ka with thermophilous trees and Mediterranean trees or shrubs (Allué et al., 2012; Burjachs and Julià, 1994, 1996). Middle Palaeolithic deposits ca. 60–40 ka, (dated by ^{230}Th–^{234}U and ^{14}C) offer a palaeoecological sequence in acceptable accord with the Greenland ice-cap palaeotemperature record (Vallverdú et al., 2014). Whether the Middle Palaeolithic continued after 40 ka is unknown. Old excavations reported Aurignacian finds in (largely dismantled) high levels affording ^{14}C determinations ca. 38–36 ka (Camps and Higham, 2012; cf., Bischoff et al., 1994; Carbonell et al., 1994).

At Cova Foradada (Calafell, Tarragona), scarcely 2 km from the sea, an assemblage with split-base points, commonly taken as a proto-Aurignacian hall-mark, is undated as yet (Morales et al., 2016; Rodríguez Hidalgo et al., 2018; SERP, 2015). At Cova de les Mallaetes (Barx, Valencia), lying at ca. 700 m.a.s.l. barely 10 km from the coast, the Aurignacian plausibly dates from ca. 34.5 ka (Villaverde, 2014) – an old ^{14}C determination (KN–I.920) gave ca. 29.69 ka (Fortea and Jordá, 1975–1976); skeletally-modern human bone came from a Gravettian deposit of ca. 25 ka (Arsuaga et al., 2002). Merely 2 km from the coast, Cova Foradà (Oliva, Valencia) provided Neanderthal (Aparicio-Pérez et al., 2014; Lozano et al., 2013) and Mousterian remains followed by "Gravetto-Aurignacian", Solutrean and Magdalenian assemblages, though no ^{14}C dates are older than 17 ka (Aparicio-Pérez et al., 2014). Cova Foradada (40 m above the sea on Cape San Antoni at Xàbia, Alicante) provided Upper Palaeolithic artefacts and faunal remains (Casabó, 1997a,b; 2001; Pantoja et al., 2011) from deposits giving 4 ^{14}C estimates between ca. 34 and 27 ka (Casabó, 2001; Pantoja et al., 2011); palynology and anthracology indicate decline in *Pinus* and *Juniperus* and an increasingly dry and open landscape that finally underwent partial arboreal recolonization (including *Olea* and even *Alnus*) and favoured an increasing range of herbivores.

The El Salt rock shelter (Alcoi, Alicante), at 600 m a.s.l., 35 km from the coast, afforded Neanderthal remains, Mousterian artefacts, and 54 combustion features, spanning 67–45 ka (according to U-ser, TL and OSL determinations), followed by sterile sediment (Galván et al., 2001, 2014a,b; Garralda et al., 2014; Rodríguez et al., 2002). Not far away, at a similar altitude (680 m. a.s.l.) and distance from the coast, Cova Beneito (Muro d'Alcoi, Alicante) afforded Mousterian deposits ca. 38.8 ka followed, perhaps discontinuously, by Aurignacian ones ca. 33.9 ka: both were single University of Arizona ^{14}C AMS estimates, corresponding to the respective estimates of ca. 30.2 and 26 ka from Gif-sur-Yvette (Iturbe and Cortell, 1987, 1992; Iturbe et al., 1993). (Higher layers with Solutrean artefacts and modern skeletal remains afforded a date of 16.5 ka). The Mousterian occupied a landscape with *Pinus* and *Juniperus* that subsequently acquired *Quercus*, *Myrtus*, *Olea*, *Phillyrea* and eventually *Q. faginea*, *Fraxinus* and *Corylus*, reflecting increases in rainfall and temperature, before reverting to pollen spectra indicative of falling temperature and increasing aridity throughout the Aurignacian sequence (Fumanal and Carrión, 1992; Iturbe et al., 1993; Carrión and Munuera, 1997).

Cueva Antón and Abrigo de La Boja (Mula, Murcia), some 65 km from the coast and about 300 m.a.s.l., contain late Mousterian assemblages that existed until 37.1 ka at Antón, whilst at La Boja the Aurignacian commenced ca. 36.5 ka; ^{4}C and OSL determinations and high-resolution excavation support the conclusions (Zilhão et al., 2017). Higher in the Segura basin, beside the Embalse de Fuensanta reservoir at 680 m a.s.l., ca. 115 km NW from the Murcian Mediterranean coast, the El Palomar rock-shelter (Yeste, Albacete) afforded an early Gravettian sequence (de la Peña and Vega-Toscano, 2013) beginning perhaps ca. 32–30 ka, depending on which of the uncalibrated ^{14}C determinations are held most reliable (see de la Peña and Vega-Toscano, 2013, p.90, Fig. 3). The excavators propose that bladelets with inverse retouch at El Palomar are comparable to "Dufour" bladelets at various sites regarded as Aurignacian where an early Gravettian assignation could be plausible, and here they include Carihuela (140 km SW from Yeste). Also in the upper reaches of the Segura basin, at a roughly similar altitude and distance from the coast, the Cueva del Niño (Ayna, Albacete), recently reassessed (Davidson and García Moreno, 2013; García Moreno et al., 2014, 2016), contained both deep Mousterian deposits, dated to 55.5 ka by amino-acid racemization, which provided carbonized *Celtis* fragments, and later ones (formerly thought to be Upper Palaeolithic) dated by ^{4}C at 29–28 ka (UGAMS-7737,-7739) and calibrated to 33–32 ka BP.

The Sima de las Palomas del Cabezo Gordo (Torre Pacheco, Murcia) overlooks (from 125 m. a.s.l.) the saltwater Mar Menor lagoon on the Mediterranean coast 5 km away (Walker et al., 2012, 2017a). Dated by OSL to 130–90 ka (MIS-5), sediments with Neanderthal and Mousterian remains (phase 1) lay beneath cemented thermoclastic scree ("conglomerate B") dated by ^{230}Th–^{234}U to 68–65 ka (Walker et al., 2017b). Above it, 3 Neanderthal skeletons in anatomical connexion, dating from ca. 55–50 ka (phase 2), lay within a rock-tumble cone incompletely cemented by $CaCO_3$ ("conglomerate A"). Its porosity enabled rainstorms to flush sediment out laterally, including a few small, Neanderthal, bone fragments that became mixed with later Neanderthal bone fragments, Mousterian artefacts, and sediment (phase 3), fallen from the mouth, forming horizontal layers of hybrid composition (including a lens of burnt sediment) against the rock-tumble, filling the cavity up to its overhanging rock roof. Phase 3 lacks Upper Palaeolithic artefacts and anatomically-modern human fossils. The phase 2 rock-tumble and phase 3 sediment comprised an L-shaped 3 × 2 m vestige atop an 18-m deep column of breccia forming the inner wall of the karstic shaft (reopened ca. 1900 when miners extracted <80% of the breccia). Excavation, initiated in phase 3 sediment, progressively exposed the poorly-consolidated rock-tumble. A few stones forming its tip escaped attention; this, together with displacement of small elements to barely 30 cm beyond the rock-tumble and their consequent coexistence in phase 3 sediments with later finds, underlies misunderstandings by commentators on early publications (e.g., Galván et al., 2014b; Santamaría and de la Rasilla, 2013; Wood et al., 2013a,b; Zilhão et al., 2017). Although the hybrid phase 3 deposit contains Neanderthal fragments, none need be later than 40 ka.

Most important is the ^{230}Th–^{234}U determination APSLP-1 of 54.1 ± 7.7 ka cal BP (Pike, 2008) on a metacarpal bone of the morphologically "hyperpolar" Neanderthal skeleton SP96 (95% confidence interval CI: 61.6–46.6 ka). Neither SP96 nor fossils of 12 other Neanderthals from the site suggest hybridization with skeletally-modern humans (only a trapezium of SP92 is commensurate with modern morphology: Trinkaus and Walker, 2017; Walker et al., 2011a,b). Because SP96 lay inclined, with hands raised to its face, the dated bone was excavated high in "conglomerate A", near phase 3 sediment.[1] APSLP-6 of 51.0 ± 2.5 ka (95% CI: 53.5–48.5 ka) is from unburnt animal bone lying deeply in sediment beside conglomerate "A", probably displaced laterally from it. Another

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[1] In an early manuscript the bone was misidentified as SP92r, which in fact is the identifier of a different bone, belonging to skeleton SP92, excavated lower down in level 2 h. The transcription error led to mistaken ascription of the SP96 metacarpal to level 2 h in the legend to SI Fig. 7 in Walker et al. (2008); this was rectified subsequently (Walker et al., 2012, 13, Fig. 6).

fragment of unburnt animal bone gave APSLP-4 43.8 ± 1.5 ka (95% CI: 45.3–42.3 ka); it was excavated, 0.15–0.2 m above APSLP-6, in the lens of burnt sediment (see above) which it likely dates.[2] OSL dating of quartz grains (Schwenninger, 2008) from sediment sample X2509 extracted from that lens gave 54.7 ± 4.7 ka cal BP; its 1σ standard error admits a 95% CI of ca. 64–45 ka, approaching that of 45.3–42.3 of APSLP4. Burnt lagomorph bone in sample X2509 gave ^{14}C estimate OxA-15423 of 35,030 ± 270 BP (Higham, 2008), resembling OxA-10666 of 34,450 ± 600 BP for a burnt bone fragment cemented to unburnt Neanderthal mandible fragment SP59 from the burnt sediment lens. The determinations, performed without collagen ultrafiltration, allow a 95% CI of 40,986–38,850 and 40,950–37,662 cal BP respectively.[3] The APSLP-4 CI limit of 42.3 ka or 42,300 BP approaches the CI limits nearly 41,000 BP of OxA-15423 and OxA-10666. SP59 may well have been a fossil *before* OxA-10666 became attached, perhaps when sinters developed, by $CaCO_3$ deposition, in fissures opened by sedimentary retraction during phase 3: if so, SP59 could pre-date OxA-10666. Vertical displacement of small objects such as Oxa-10666 can happen (cf., Hofman, 1986; Stockton, 1973). Regarding OxA-10666 and OxA-15423, Wood et al. (2013a,b) commented that from "*the same stratigraphic unit, there are two significantly older results: a U-Series date on bone where the uranium uptake history could not be established (43.8 ± 0.75ka APSLP4) and an optically stimulated luminescence date (54.7 ± 4.7ka X2509). Given the problematic nature of these contradictory dates, the age of this unit and its Neanderthal fossils remains uncertain*". The hybrid formation of the phase 3 sedimentary accumulation and the chronologically heterogeneous nature of elements contained in it overcome the objection.

There is no overwhelming argument for regarding any Neanderthal remains at the site as being later than ca. 40 ka (pace Zilhão and Villaverde, 2008). The ^{14}C and ^{230}Th–^{234}U determinations could imply a time ca. 44–40 ka for the culmination of phase 3 sediments that include pollen of *Maytenus*, *Periploca*, *Withania, Myrtus, Corylus, Buxus, Betula, Fraximus, Arbutus, Ulmus, Salix, Hedera* and deciduous *Quercus,* which are incompatible with a bitterly cold, arid environment (Carrión et al., 2003, 2005) such as that during GS-9 after 39.9 ka. A similar flora (Carrión et al., 1995) existed at Cueva Perneras (Lorca, Murcia), lying almost at sea level and barely 5 km from the coast, where excavation (Montes, 1985) confirmed Middle and Upper Palaeolithic deposits (probably including Aurignacian components) that had undergone disturbance. The Greenland palaeotemperature records indicate "*predominantly mild*" climate between ca. 54–44 ka during GI-14,-13 and −12 interstadial episodes in MIS-4 (Rasmussen et al., 2014) when thermophilous and meosphilous taxa could have flowered near the two sites. Because all human skeletal remains from the Sima de las Palomas show typically Neanderthal morphology, notions of hybridization with skeletally-modern folk are unsustainable.

9. How late were late Neanderthals?

Several important European sites with Neanderthal and Mousterian remains once regarded as late have been re-dated to before 40 ka (e.g., Vindija in Croatia: Devièse et al., 2017). Such has been the influence of advances in ^{14}C methodology, especially accelerator mass spectrometry and ultrafiltration of bone collagen (Brock et al., 2010), that scepticism has increased about the accuracy of many published ^{14}C estimates (especially on collagen), were some to have been made unwittingly on finds contaminated by humic acids or other processes. A matter open to question is whether all kinds of samples previously dated, regardless of their weight or composition, are equally suspect (seeds, wood, charcoal, sediment, bone, textiles, leather, coprolites, shell, inorganic carbonate, etcetera). After all, ultrafiltration does not always greatly alter conventional AMS ^{14}C, as demonstrated at the Cantabrian Sopeña Cave (Pinto-Llona and Grandal-d'Anglade, 2019).

The problem concerns some important Mousterian assemblages, such as that of Gorham's Cave, Gibraltar, proposed as a final Neanderthal outpost (Tattersall, 1995), where the reliability of ^{14}C determinations later than 40 ka from late Mousterian deposits (Finlayson et al., 2006; Finlayson et al., 2008a) has been questioned (Wood et al., 2013a,b). Critics maintain that, in the absence of recourse to the latest laboratory methodology, formal inferences about the chronology of the final Mousterian not only might, but *should* make us wary about what otherwise appear to be substantive data. What kind of overwhelming support for those data might be needed, not merely to assuage or allay our wariness, but also — and here's the rub — to rebut a formal argument that rests its case on extraneous instances chosen from elsewhere? Certainly, renewed fieldwork and dating of resulting samples are in order, and, undoubtedly, should be attempted at Gorham's Cave. However, it is doubtful whether any reasonable corroboration of its published chronology could ever satisfy its fervent critics, for whom "one swallow need never make a summer" with regard to their preferred interpretation of the replacement of Neanderthals by anatomically-modern humans throughout western Eurasia. They regard it as an irrefutable paradigm for interpreting an opaque period in the deep past and raise it to the status of modern scientific truth. Its irrefutability is its Achilles' heel if it be little more than a plausible albeit self-serving conjecture that is immune to refutation by particular attempts to falsify it that make their appeal to the Palaeolithic record of a given site.

Unresolved chronological problems and paradoxes complicate considerations of the Carihuela stratigraphical sequence without doubt. Nevertheless, its biostratigraphical data contribute to a plausibly coherent interpretation. It must be borne in mind that many estimates of its dates come from specimens that were not sampled during excavation campaigns but often were extracted

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[2] APSLP-4 also suffered from a transcription error, appearing as APSLP-1 in one place in Walker et al., 2012).

[3] Oxford Radiocarbon Accelerator Unit's routine acid-base-acid treatment for charcoal was applied to OxA-10666 and OxA-15423, likewise collagen diagnostics, and respective 5.3% and 2.5% yields gave %C values of 8.0% and 40.9% with δ^{13}C at −21.0‰ and −22.3‰ which, although low, are within Late Pleistocene faunal ranges (cf., Stevens and Hedges, 2004; Trinkaus and Richards, 2013) and need not reflect absorption of non-collagenous carbon. Regarding OxA-10666, Higham (2008) commented, *"the δ13C value of −21.0‰ is consistent with collagen-derived carbon, implying >75% of the carbon dated is from the bone. Sediment-derived carbon cannot be ruled out; it is most likely to have an age similar to that of the bone in which it was deposited, though it could be younger or older. There is, therefore, a possibility that the bone is older than measured, because a small amount of younger carbon would have a disproportionate effect on the age. The C:N atomic ratio of 6.9 is higher than the range for fresh bone, but this is not unexpected given the burning of the sample. A similar situation applies to OxA-15423. However, the combustion yield (%C) indicates that this sample is composed of much higher amounts of carbon than OxA-10666. There are two possibilities. First, the sample is composed of a majority of plant-derived carbon. This is considered less likely, since there is a significant proportion of nitrogen in the sample, which is not expected from plant matter, and therefore a low C:N atomic ratio closer to collagenous values was obtained. Second, the bone is partially pyrolyzed, and there is a higher proportion of collagenous material than usually expected. The analytical data are consistent with this conclusion. The δ13C value is more indicative of collagen-derived carbon. Taken together, the results provide increased confidence in the results being finite and not underestimates of age. The consistency in the two ages is a further measure of the probable finite nature of these dates*" (Higham, 2008). Subsequently Higham told one of us (M.J.W.) they might be *infinite* estimations. Given that the analyses took place without ultrafiltration, perhaps repetition with it is in order if the Oxford laboratory has retained parts of the samples. Even were the dates to be finite, they could nevertheless be compatible with an interpretation (see above) making appeal to possible commensurability of the upper CI limit of 42.300 AP for APSLP-4 with the lower limits of 41,000 BP for OxA-15423 and OxA-10666.

from sections, exposed by excavations many years before, the cleaning of which before extraction of samples may not always eliminate contaminants. Moreover, some degree of radiochronological inconsistency is only to be expected in the light of the stratigraphical complexity of the cave. Unit VI, for instance, could be susceptible to contamination in CIII 1 which shows signs of evident bioturbation. On the other hand, units V and IV present a fine-layered stratigraphy in CIII 1 and lithic evidence (from analyses of surface alteration, pseudo-retouch, fractures, etc.) of undisturbed remains that are synchronous with the sedimentary matrix (Vega-Toscano, 1988); there can be little doubt about the presence of Mousterian artefacts in unit V (Almagro et al., 1970; Vega-Toscano, 1988).

A possibility never to be dismissed lightly in Palaeolithic archaeological contexts is that sometimes lithics, charcoal, or bones may not be synchronous or coetaneous with the sediment in which they were excavated. An example of possible indications of that problem may be deduced from the contrasts presented by the 3 dates Poz-45193 (33.6 ka), Poz-45194 (43.5 ka), and Poz-45195 (41.5 ka) from level A5 in CIII 1 unit IV, obtained on bone, charcoal and sediment + charcoal, respectively (Fig. 3, Table 4). On the other hand, there are examples of three almost identical dates, obtained on sediment and bone, respectively, which are Poz-45203 (32.0 ka), Poz-45204 (32.4 ka), and Poz-45197 (32.4), from level B4 in CIII1 unit V. Rejuvenation is likely to have affected some ^{14}C determinations from the upper layers of CIII 1 (Table 4); this is proposed in Fig. 10. Nevertheless, skewing of the results of dating procedures ought not necessarily be so marked as to affect the principal corollary that is the late (i.e., MIS-3) persistence of the Mousterian at Carihuela, particularly given the palaeoecological and geochronological coherence of the sequence (Figs. 9 and 10), and given the absence of any plausible alternative proposal with sufficient explanatory power to account for the botanical, faunal and sedimentological changes outlined here.

We need to keep in sight the human biology underpinning both the Palaeolithic technology and its chronological trajectory. It has been accepted for almost a decade that modern *Homo sapiens* interbred with archaic humans, including Neanderthals (Green et al., 2010; Rogers et al., 2017) and Denisovans (Reich et al., 2010), eventually replacing them in Eurasia (Kolodny and Feldman, 2017). The interesting theoretical proposal by Greenbaum et al. (2019) suggests that an increase in inter-population connectivity across Eurasia drove coordinated local processes of cultural evolution (maybe Neanderthals could make “Aurignacian” bone points: Doyon, in press 2018). Plausibly, it involved both long-distance population dispersals and the increased intensity of regional or local networks of interaction between different human groups. They may have involved Neanderthals with anatomically-modern humans. Cultural traffic interactions need not necessarily have been invariably one-way. If anatomically-modern humans once had made Mousterian artefacts in Palestine and North Africa, might they have found those made by Neanderthals met their own requirements in some European regions where they encountered them? Relevant aspects to bear in mind include ecological, demographical, evolutionary, and cultural matters when considering MP-EUP transitions.

However, in southern Spain there is no evidence, as yet, of coexistence let alone hybridization. Absence of evidence stimulates research because the unknown is more fascinating always than what is known. More pertinently, even were anatomically-modern people to have met Neanderthals, extinction of the latter need not have taken place quickly. Perhaps inter-population connectivity even enhanced behavioural complexity throughout, albeit with differences that might have had technological consequences, such as appearance of so-called “transitional” Palaeolithic industries (Slimak, 2019). Further research at Carihuela may very well shed light on alternative or alternating Palaeolithic behaviours during MIS-3, and perhaps episodes of abandonment of the cave to scavenging carnivores.

Disentangling Palaeolithic palimpsests calls for diligent, high-resolution fieldwork. Moreover, the high-altitude, inland location of Carihuela offers the ability to study Neanderthal behaviour in continental climatic circumstances very different from those beside coastal shelves (Finlayson et al., 2006; Bailey et al., 2008) where, according to Cortés-Sánchez et al. (2019) inter-group competition is particularly likely to have taken place that gave an advantage to incoming anatomically-modern folk.

10. Final thoughts

The foregoing considerations suggest the basis for developing working hypotheses for investigating not only the possibly late (i.e., MIS-3) persistence of some Neanderthal groups in the south of the Iberian Peninsula, but also, most important, particular matters concerning MP chronology that remain unclear. The first step has to be that of systematic excavation at Carihuela by a multidisciplinary research team. Modern dating techniques, new analytical procedures, and novel proxies are required to test the tentative correlation proposed here (Figs. 9 and 10).

In the context of this special volume on Neanderthals, the proposed field and laboratory research is especially pertinent. High-resolution excavation is necessary. The political and administrative authorities need to acknowledge that Carihuela is an exceptionally important scientific site and therefore requires meticulous research. The importance is underlined by the enormous quantity of finds from the relatively small areas of earlier excavations. The Washington State University campaigns alone excavated a mere cubic metre of deposit that nevertheless yielded up between 400 and 500 retouched Palaeolithic artefacts, 50,000 unretouched flakes and spalls, a vast number of faunal remains, and even a few Neanderthal teeth. Moreover, very few other Palaeolithic sites in Europe have provided remains of both Neanderthal and anatomically-modern humans. Particularly important from the standpoint of Quaternary research are the circumstances of excellent preservation in the sediments that have provided an enormous abundance of macro- and microfaunal remains, coprolites, charcoal, pollen grains, spores and other microfossils suitable for palaeopalynological and botanical microscopy or anthracology. Also relevant is the presence of a complex stratigraphy that not only can be studied in several parts of the cave, but also embraces separable layers that reflect climatic fluctuations. The adjacent Cueva de las Ventanas also offers considerable potential for archaeological, geochemical, palaeontological and palaeoecological research (Carrión et al., 2004; Cortés-Sanchez et al., 2018), and for studying in detail the alternation between human and carnivore utilization of the cave. The depositional history is undoubtedly complex at Carihuela, with several instances of evidence of weight-induced deformation of strata, erosive features, and collapse of rock (e.g., from the cave roof). The cave is in a semi-fossilized karst and undoubtedly has lower chambers or passages full of sediment awaiting study. The sedimentary sequence that has been dated so far extends back into the last interglacial period, more than 100,000 years ago. There assuredly exist older sediments. A particularly deep sequence is likely to be present in the Exterior Area and perhaps outside the present entrance also (where the access path lies over old spoil-heaps). New finds of Palaeolithic human remains also can be anticipated from future excavations that will enable their stratigraphical, chronological and archaeological circumstances to be defined with accuracy and precision.

From a palaeoecological perspective it is of scientific interest that Carihuela is in the sub-Betic, meso-Mediterranean altitudinal belt close the supra-Mediterranean zone, putting it an ideal situation, as regards bioclimatic ecozone and biogeographical transition, for studying human, animal and plant relationships from the standpoint of enabling sensitive analysis of abrupt climatic changes. That is why the Carihuela palynological sequence shows changes that are well correlated with those at Padul (Camuera et al., 2019), Navarrés (Carrión and van Geel, 1999), and other Peninsular sequences (Carrión et al., 2013), as well as with global climatic changes (Rasmussen et al., 2014). Thus in a future excavation Carihuela pollen will provide a reliable biochronological marker (which is by no means the case at other Quaternary localities: Carrión, 2003). Problems with disparate dates from one and the same unit, for instance in the upper part of CIII 1, could be resolved by meticulous excavation here accompanied by geochemical analyses, though it should be stressed that the palynology of these deposits differs from those affected by disturbance or intrusive features (Carrión et al., 2009).

To sum up, although it would be premature to infer from data presented here that the Carihuela sequence constitutes evidence of Neanderthal survival beyond MIS-3, nevertheless dating problems at the cave are not so overwhelming as to require that Carihuela be dismissed out of hand from discussions about the chronology of the last Neanderthals. To do that would be to disregard the reasonable consideration, drawn from the data, which is that chance alone is unlikely to have given rise to those coincidences between lithic, biostratigraphical, and archaeostratigraphical sequences, seen from the perspective of correlations with other records. Finally, it has to be admitted that it would be swimming against the tide of opinion to assert that some last Neanderthal populations dispersed in southern Iberian might have survived until the last glacial maximum … though the thought is a provocative parting shot!

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Appendix A. Supplementary data

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