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Terrasses de la Riera dels Canyars (Gavà, Barcelona): the landscape of Heinrich Stadial 4 north of the “Ebro frontier” and implications for modern human dispersal into Iberia

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ABSTRACT

Terrasses de la Riera dels Canyars is an Upper Pleistocene fluvial deposit containing the remains of large mammals, principally accumulated in the framework of hyena denning in the area, as well as a few artifacts. Radiocarbon-dated to ~39.6 ka cal BP, the time of Heinrich Stadial (HS) 4, this site enables us to reconstruct the environmental conditions then prevalent in the NE of the Iberian Peninsula. The concentration in a single locus of finds generated by different agents relates to a flash-flood event, the rapidity of which, combined with the absence of archaeological, ecological or paleontological incongruities in the composition of the assemblage, warrants an assumption of broad contemporaneity for its contents. The ecofactual evidence (fauna, pollen, charcoal, phytoliths) indicates a steppe-dominated environment for the coastal areas between the Pyrenees and the Ebro delta; the dominant elements are cold- and dry-adapted species but a Mediterranean component is present, implying a less rigorous climate than farther north in Europe. The artifacts are clearly Upper Paleolithic, and assignment to the modern human-associated Aurignacian technocomplex is supported by the radiocarbon dates and the typology of a bilaterally retouched blade. This evidence is consistent with the notion that anatomical modernity spread across Europe over open landscape niches. Available pollen data from deep sea cores indicate that, during some of the interstadials of Marine Isotope Stage (MIS) 3, a significant vegetation gradient existed at 40°N, broadly coincident with the “Ebro frontier:” temperate and warm temperate trees expanded significantly to the south, while steppe-tundra landscapes remained dominant to the north, a contrast best seen during Greenland Interstadial (GI) 8. Such an environmental boundary must have implied a durable barrier to diffusion and migration during interstadials. Under the cold and arid conditions of HS4, the site of Canyars shows that the Eurasian steppe-tundra extended as far south as the Llobregat delta; however, the environmental reconstructions available for the lower Ebro valley and adjacent mountains of the Iberian Range farther south suggest that they formed at this time a belt of

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semi-desert or steppe-desert landscapes, thus maintaining the boundary effect despite the climatic reversal. The persistence of such a boundary through HS4 and the interstadials that bracket it must have played a role in the delayed arrival of the Aurignacian (and modern humans) to southern and western Iberia, which continued to be settled by Middle Paleolithic Neanderthals well beyond 40 ka cal BP.

1. Introduction

The emergence of early modern Europeans and the fate of the Neanderthals are major topics in human evolution research and this is especially so in the Iberian Peninsula because, south of the Ebro basin (the "Ebro frontier"), Neanderthals seem to have persisted longer than elsewhere in Western Europe (Vega Toscano, 1990; Villaverde and Fumanal, 1990; Zilhão, 1993, 2000, 2009). In the framework of arguments and observations made in marine and ice cores dated to MIS3 (e.g., Huber et al., 2006), both the role of climate change in this persistence and the duration of the pattern have been the subject of much debate (d'Errico and Sánchez-Goñi, 2003; Jöris et al., 2003; Finlayson, 2004, 2009; Finlayson et al., 2006, 2008; Zilhão, 2006, 2009; Zilhão and Pettitt, 2006; Jiménez-Espejo et al., 2007; Sepulchre et al., 2007; Zilhão et al., 2010a, 2010b). Models that question the reality of the geographic segregation underlying the "Ebro frontier" model have also been proposed (Baena et al., 2005, 2012; Vaquero, 2006; Martínez-Moreno et al., 2010); with variants, such alternative models revolve around the notion of a long-term coexistence between Neanderthals and modern humans in Iberia as a whole, both north and south of the Ebro, permitted by the mosaic nature, at both the inter and intra-regional levels, of the peninsular landscapes of the time.

Twenty years on, it is clear that additional high resolution archaeological and radiocarbon data are required to advance the discussion of these issues. For the northern areas in particular, progress along these lines has already contributed considerable clarification (e.g., Mallol et al., 2010; Mora et al., 2011; Camps and Higham, 2012; Maroto et al., 2012). For instance, the very young dates obtained for the uppermost Middle Palaeolithic levels of the Cueva Esquilleu, in Cantabria, can now be understood in the framework of the geological study of the site, which showed that those levels were severely affected by post-depositional disturbance, namely cryoturbation. Where Catalonia is concerned, the apparent late persistence of the Mousterian at sites such as Cova dels Ermitons has been shown to be an artefact of incomplete decontamination of the radiocarbon samples used in support of the argument, while recent dating work at the rock-shelters of L'Arbreda and Abric Romaní confirmed that the chronological interface between the Protoaurignacian (assumed to be modern human-related) and the preceding Neanderthal-associated industries lies at ~36.5 ^{14}C (~41.5 cal) ka BP (as in adjacent France, and as previously proposed on the basis of continent-wide chrono-stratigraphic patterns; Zilhão and d'Errico, 1999, 2003; Zilhão, 2006; Zilhão et al., 2007).

South of the Ebro, on the other hand, the persistence pattern remains consistent. Recent radiocarbon and U-series dating supports an age ≤40 ka cal BP for the uppermost levels of the Middle Paleolithic sequences from Sima de las Palomas and Cueva Antón, Murcia, and Gruta da Oliveira, Portugal (Walker et al., 2008; Zilhão et al., 2010b; Hoffmann et al., in press). And wherever an Aurignacian assemblage has been found in long stratigraphic successions spanning the Middle to Upper Palaeolithic transition, its affinities lie invariably with the Aurignacian II (a.k.a. "Evolved Aurignacian") or the Aurignacian III/IV (a.k.a. "Late Aurignacian"). This is the case at Cova Beneito, Alicante (Domènech, 2001), Cueva Bajondillo, Málaga (Cortés-Sánchez et al., 2011), and Pego do Diabo, Portugal (Zilhão et al., 2010b), where reliably associated dates are no earlier than ~37 ka cal BP. Whether a sedimentation hiatus is present or not, the Protoaurignacian and the Aurignacian I are always lacking, and, where the latter is concerned, its index fossil, the split-based bone point, has never been seen in these regions, not even as isolated finds devoid of stratigraphic context. Some have even questioned the Aurignacian status of the assemblages above, arguing that the earliest Upper Paleolithic of these regions is the Gravettian and suggesting that Neanderthals could have persisted in Gibraltar up until the LGM (Last Glacial Maximum) (Finlayson et al., 2006; Jiménez-Espejo et al., 2007).

Palaeoenvironmental conditions have played a prominent role in explanations of this Neanderthal persistence pattern. The "Ebro frontier" model proposed that this river's drainage divided regions to the north, which, except perhaps during less cold interstadials, would have been part of the Eurasian steppe-tundra, from those to the south, where tree cover would always have been significant and, during warmer interstadials, perhaps extensive. d'Errico and Sánchez-Goñi (2003) and Sepulchre et al. (2007), in turn, emphasized the impact of extreme aridity during HS4 (i.e., the Greenland stadial during which occurred the shorter episode of iceberg discharge known as Heinrich Event 4; cf. Sánchez Goñi and Harrison, 2010). During this cold event, semi-desert landscapes would have developed in central and southeastern Iberia, thus hindering the southward dispersal of Aurignacian moderns and creating a refugium for Neanderthals in the south and west. Others (e.g., Finlayson, 2004) suggested that the mosaic woodlands of the latter regions were less favorable for the subsistence economy of modern humans and that these would have settled them only after they were vacated by the Neanderthals. This abandonment would have been caused by the rapidity and amplitude of the period's climate oscillations—the hypothesis being that the world of the Neanderthals changed faster than they could cope with, eventually leading them to extinction.

Our model of site formation process at Terrasses de la Riera dels Canyars (henceforth, Canyars) indicates that the finds made here can be treated as a closed context from a paleoenvironmental perspective. Under this assumption, and because it is dated to the HS4 stadial, Canyars is the only continental site north of the "Ebro frontier" where paleoenvironmental reconstructions for this period can proceed unhampered by concerns related to the possibility of post-depositional disturbance. The site thus provides an opportunity to assess the impact of HS4 on the regional landmass and to fine tune the climate models that have been used to assess the issue.

2. General setting

Canyars (41°17′46″N, 01°58′47″E) is located in the Garraf Massif, near Gavà, 20 km south of Barcelona (Fig. 1). The Garraf Massif is part of the *Serralades Costaneres Catalanes* (Catalan Coastal Range), a low-relief mountain chain (<600 m high) composed of Jurassic and Cretaceous limestone and dolomite (Esteban and Julià, 1973) overlaying Triassic deposits. This massif features one of the most important karstic systems of NE Iberia. With an area of ~500 km^2 (Solé, 1964; Salas, 1987), it contains several Lower and Middle

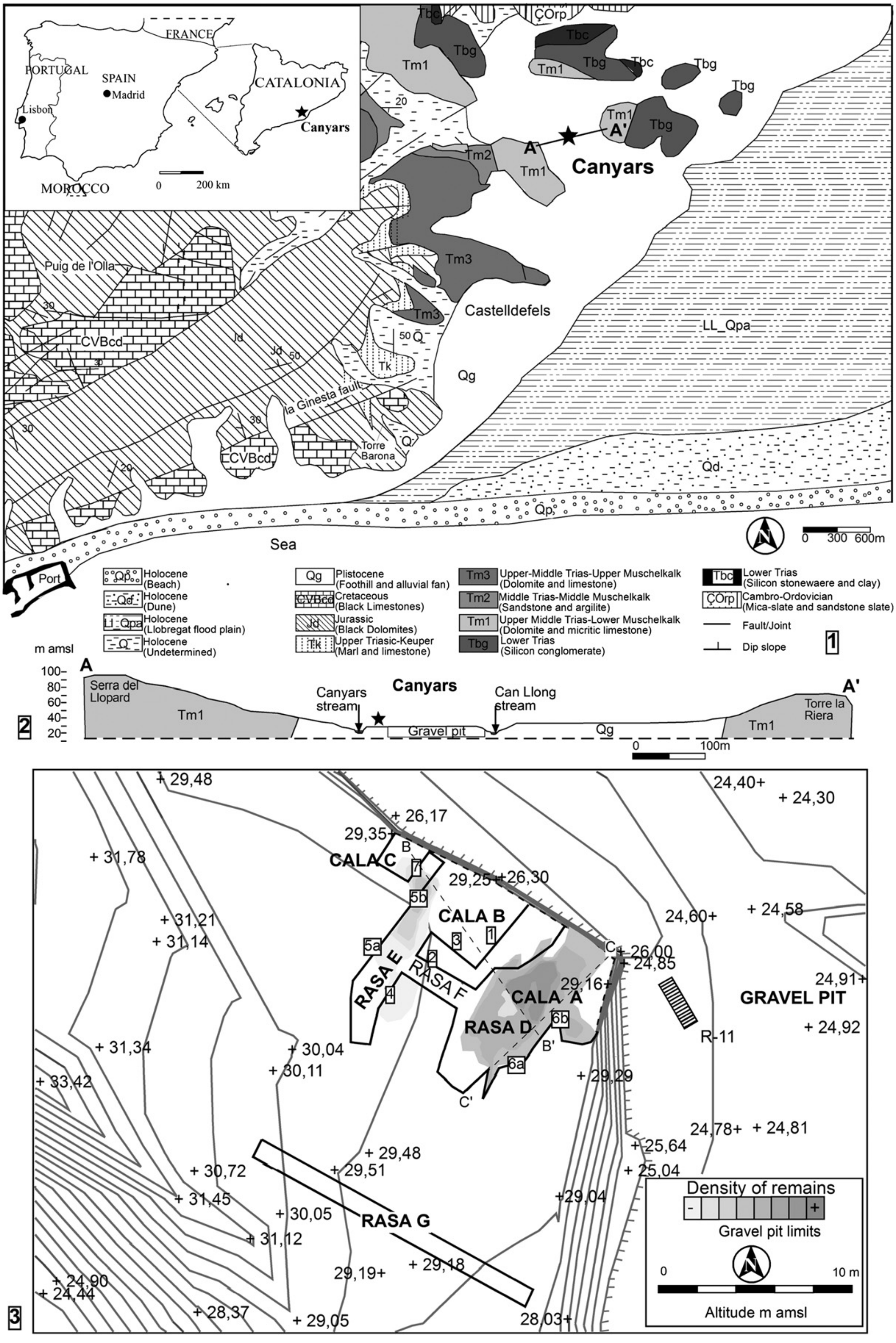


Fig. 1. The Canyars site. 1: Location with basic regional geology. 2: Schematic geological profile. 3: Site plan showing the excavated areas (Cala A-Rasa D, Cala B-Rasa E and Cala C) and the delimitation trenches (Rasa F and Rasa G); the positions of stratigraphic profiles 1–6b and of one of the sterile test pits (R11) excavated by Arqueociència in 2007 are also indicated.

Palaeolithic localities, such as Cova del Rinoceront (Daura et al., 2005a, 2005b), Cova del Coll Verdaguer (Daura, 2008) and Cova del Gegant (which also yielded Neanderthal remains; Daura et al., 2005a, 2005b; Rodríguez et al., 2011), while the Upper Palaeolithic is represented at Dolines de les Alzines (Daura et al., 2011a, 2011b) and Balma de la Griera (Fullola et al., 1994).

The locality is an abandoned gravel-pit, and the find horizon was exposed by quarrying, entailing partial (but unquantifiable) loss. Pleistocene fossils have been forthcoming from the same general area: Villalta (1953) describes an Upper Pleistocene paleontological collection whose exact location is unknown; and isolated Proboscidian remains (cf. *Mammuthus*) from a different gravel-pit some 700 m away are mentioned by Daura and Sanz (2009). The locality discussed here was discovered in 2005 (Daura and Sanz, 2006) by one of us (C. V.), and was completely excavated between June and November 2007, with the recovery of >5000 large mammal remains, by the Grup de Recerca del Quaternari (GRQ) (Figs. 2 and 3). Prior to the GRQ excavation, 26 test pits had been

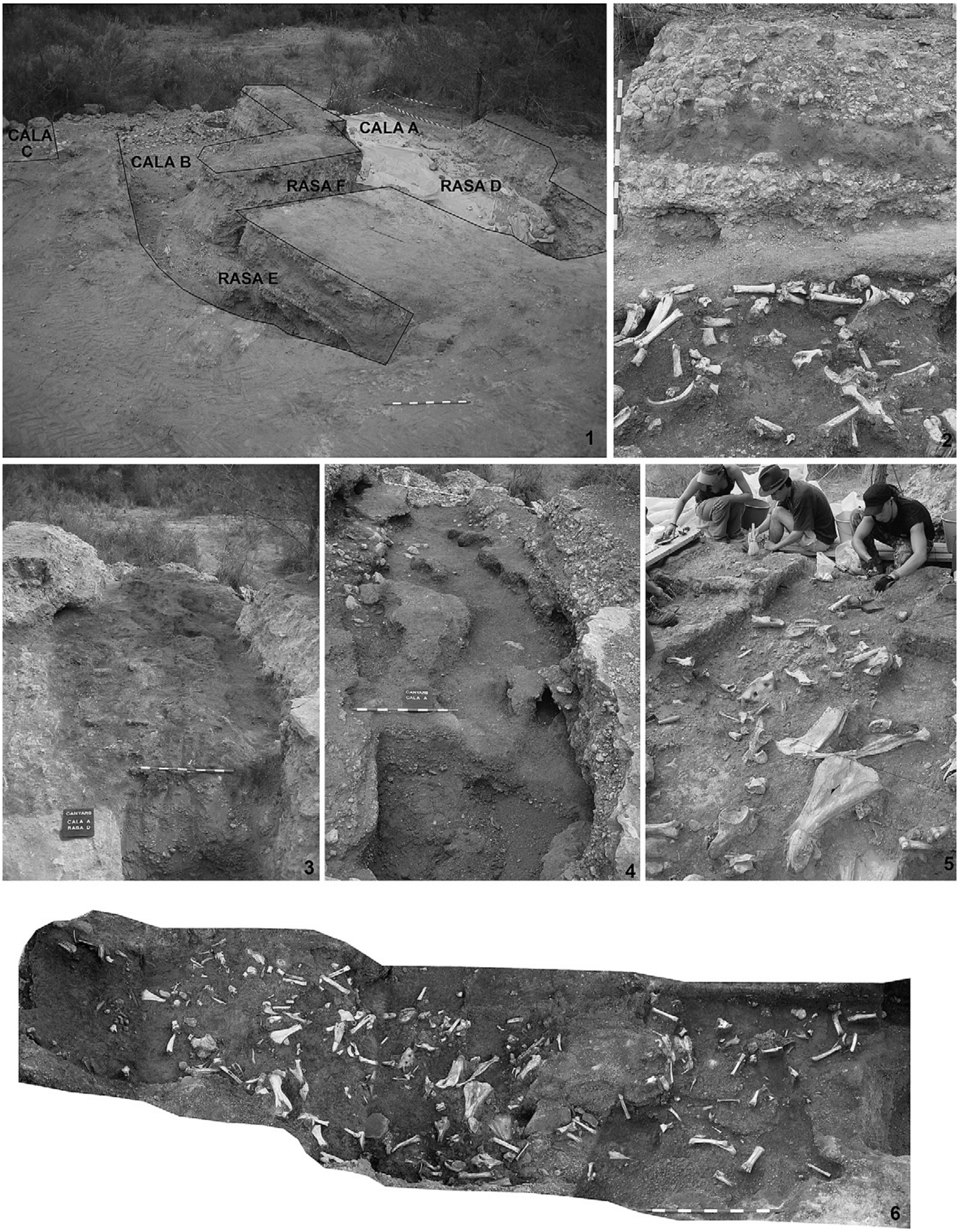


Fig. 2. The Canyars site during the 2007 excavation work: 1–2: Cala A-Rasa D and its stratigraphy. 3: The paleochannel before archaeological excavation. 4: The paleochannel after excavation. 5: The paleochannel during excavation. 6: Photo composition of the paleochannel in Cala-Rasa D with in situ large mammal remains.

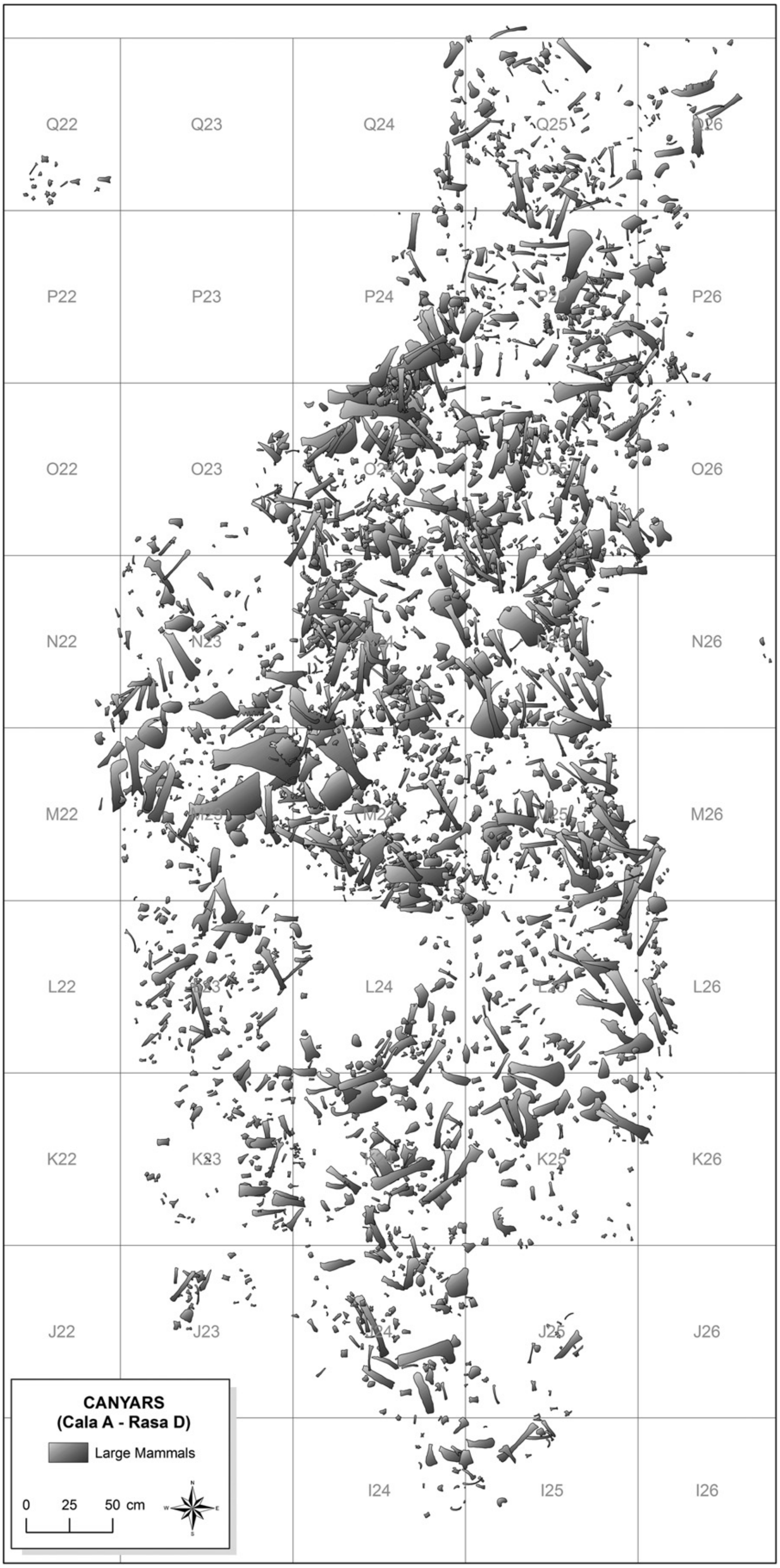


Fig. 3. Distribution of the large mammal remains in Cala A-Rasa D plotted against the excavation grid.

rescue-excavated in the area by Arqueociencia, an archaeological consultancy, but no remains were found at that time (Harzbecher, 2007).

The site lies at an altitude of 27.2–27.8 m amsl, 3.5 km from the extant coastline. The deposits correspond to the terrace of a short (about 9 km long) and torrential stream, the Canyars, part of a complex and extended hydrological network that drains the footslopes of the Garraf massif onto the beaches of the Mediterranean seaboard (see below).

3. Materials and methods

3.1. Excavation methodology

Fieldwork was carried out using standard archaeological methodology, with three-dimensional plotting of finds and features. Stone tools, large mammal bones, charcoal fragments and lagomorph cranial remains were mapped in situ prior to removal, while land snail shells and lagomorph post-crania were bagged by 1 m^2 units of provenience. Sediments were dry-sieved using superimposed 5 and 1 mm mesh screens. Recovery of the micromammal remains was effected via wet-sieving of the 2.0–0.5 mm fraction of a sample of ∼500 kg of the excavated sediments, carried out in the archaeological laboratory of the Castelldefels City Council.

The site was first demarcated via the excavation to an average depth of 50 cm of three test trenches with a total area of 31 m^2. Once this was done, the area of concentration of the finds was excavated in three different sectors—Cala A-Rasa D, Cala B-Rasa E and Cala C. Work proceeded by removal of the overlying sterile deposits with a power shovel to expose the fertile layer, which was then completely excavated down to the next sterile unit. Two additional trenches (Rasa F and Rasa G) were open in order to delimit the site to the south; they were both sterile and were also excavated with a power shovel.

Cala B-Rasa E was 10 m long and 1.5–3 m wide and was taken down to a depth of 1.5 m in the Rasa E subsector. Laid out perpendicularly to the face of the gravel pit, this is, together with the 2.5 m^2 Cala C (where the find horizon was only testimonial), the area of lowest density of remains. The main area of the site was the 12 × 6 m Cala A-Rasa D. This is where the main paleochannel (∼18 m^2) was exposed and where most of the finds, contained in a single fertile unit (layer I), come from.

3.2. Sampling and laboratory methods

Stratigraphic description and sediment sample collection were carried out along eight vertical sections: two in Cala A-Rasa D, two in Cala B, one in Rasa F, and three in Rasa E. The samples were then analyzed at the Department of Earth Sciences of the University of the Balearic Islands. After air-drying for 24 h, a total of 17 samples were color-described (dry and humid) using the MUNSELL© soil color chart, and then analyzed for grain-size, mineralogy and organic matter. Organic matter lost-on-ignition (LOI) was weighed after placing the samples in a furnace at 550 °C for three hours. The particle size distribution was determined using a Beckman Coulter-LS™ particle size analyzer. Cumulative curves, frequency histograms and summary statistics were calculated.

Clay mineralogy was determined with a Siemens© D-5000 X-ray diffractometer, using randomly oriented powder from the bulk samples. Samples were pre-treated with H_2O_2 to remove organic matter. Replicates were heated to 375 or 600 °C for 1 h or treated with ethylene glycol at 60 °C to differentiate between clay minerals. Selected samples were analyzed by EDX (Bruker© X-Falsh Detector 4020) or observed by SEM (Hitachi© S-3400N). Semi-quantitative mineral analyses were based on the peak areas obtained using EVA© ver. 7.0 software.

A taxonomic study of faunal remains was accomplished in several ways using classic paleontological methods. For large mammals, taxonomic assignments and Minimum Number of Individuals (MNI) are provided; skeletal part counting is still in progress. The micromammal and bird bone remains were obtained as described above. Given the small size of the samples, it has already been possible to calculate MNI and Number of Identified Specimens (NISP) for each taxa.

Different samples were processed for phytolith analyses (Table 4). Phytolith extraction took place at the laboratory of the Department of Prehistory, Ancient History and Archaeology of the University of Barcelona. For the tooth samples, the methods used followed Middleton (1990); whenever possible, a sample ≥0.02 g was treated with approximately 1 ml of a 30% solution of hydrogen peroxide (H_2O_2) to eliminate organic materials that could interfere in the correct identification and quantification of phytoliths. Samples with initial weights below 0.01 g were directly mounted on slides with Entellan New (Merck). For the sediment samples, we followed Albert et al. (1999). This method is based on the dissolution of carbonates, phosphates and organic material through the adding of an equivolume solution of 3N HCl, 3N HNO_3 and hydrogen peroxide. The mineral components of the remaining sample, the Acid Insoluble Fraction (AIF), are then density-separated by adding 5 ml of sodium polytungstate solution $[Na_6(H_2W_{12}O_{40})\cdot H_2O]$ of 2.4 g/ml density to isolate phytoliths from other silicate minerals such as quartz.

Slides were studied using an Olympus BX41 optical microscope. Morphological identification of phytoliths was based on the standard literature (Twiss et al., 1969; Piperno, 1988, 2006; Mulholland and Rapp, 1992), as well as on the modern plant reference collection from the Mediterranean area (Albert et al., 2000; Albert and Weiner, 2001; Tsartsidou et al., 2007). When possible, the terms describing phytolith morphologies follow anatomical terminology, and otherwise they describe the geometric characteristics of the phytoliths. The International Code for Phytolith Nomenclature was also followed when possible (Madella et al., 2005).

Pollen from four coprolites and one sediment sample was processed in the Department of Plant Biology of the University of Murcia. The coprolites were first cut open with a steel spatula; to minimize contamination from external surfaces, we targeted the material from the centre, which was scraped out and weighed. Laboratory treatment was performed following the conventional HF, HCl, KOH method and *Lycopodium clavatum* tablets containing a known quantity of spores were added to each prepared sample for the calculation of pollen concentration. Pollen grains were concentrated by means of heavy-liquid flotation. The pollen diagram was constructed using the p-simpoll software (Bennett, 2000). Percentages of each taxon for each sample were based on a pollen sum (c. 150–2000 grains) excluding hydro-hygrophytes and non-pollen microfossils.

Charcoal analysis was carried out at the Institute of Human Paleoecology and Social Evolution-Rovira i Virgili University (Tarragona) using a metallographic microscope with reflected light (Olympus BX41). The identification is based on the analyses of the wood cell structure by observing the three wood anatomical sections. The Schweingruber (1990) wood anatomy atlas was used when needed.

4. Results

4.1. Stratigraphy

The lithological succession of the Canyars fluvial valley consists of a poorly sorted, coarse grained complex sequence of aggradational and incised fluvial deposits developed between the foot of the Garraf Massif and the Llobregat delta plain (Marquès, 1974). A well-marked talus occurs between the alluvial fans developed at the foot of the littoral relief and the delta plain, which corresponds to the last Mediterranean sea oscillation. The occurrence of red soils with pedogenic calcretes in the perched alluvial fans has been used as a chronostratigraphic criterion to assign a Pleistocene age to these deposits. During the Holocene, the Riera dels Canyars torrent developed an alluvial fan prograding over the Llobregat delta plain.

Nowadays, Canyars is located at the confluence of the Riera dels Canyars and Riera de Can Llong creeks. The main stream is the former, and its distal part probably consisted of a floodplain crossed by channels, nowadays modified by farming.

Seventeen layers identified during excavation were correlated across the different areas of the site. These layers are referred to in this article with Arabic numerals (1–17), while the Roman numeral I designates the deposits containing the find horizon, only present in Cala A-Rasa D (Ia), Cala B-Rasa E (Ib), and Cala C (Ib). Sediment descriptions, clay mineralogy and grain size data for the different stratigraphic units recognized in each excavation area are given in Table 1 and Fig. 4.

The lowermost unit is LSU (Lower Sandy Unit), composed of fine sands and present in the NW area only. The Lower Detritical Unit (LDU) overlies this facies, and the separation between the two probably corresponds to an erosional scar. Lightly fining upward, LDU corresponds to a well preserved channel abandoned through avulsion and cut-off. The formation of the find horizon relates to the lateral migration of the active channel and subsequent burial of the abandoned meander under the sediments of the Middle Unit (MLU). Two sectors with infillings of different characteristics have been differentiated: Cala A-Rasa D is a well-defined paleochannel filled with mud-supported gravel (Ia), while Cala B-Rasa E and Cala C are irregular parts of the same paleochannel filled with gravelly muddy sand (Ib).

Table 1
Canyars sediment descriptions and stratigraphy.

Unit	Layer	Section	Description
Topsoil	0	1, 2, 3, 4 5a, 5b, 6a, 6b, 7	**Topsoil layer**. Sandy lutites with scarce subangular pebbles. It corresponds to the current soil and is present in all the sections (1–7). Thickness is irregular (~5 cm, 28.35 and 28.20 m asl) due to the topography and ongoing land use. Contact with the carbonated deposits ("caliche") of the underlying layer 1a/d is sharp; live roots of shrubs and trees are frequent.
Hardpan	1d	1, 2, 3, 4, 5a, 5b, 6a, 6b	**Laminar Calcrete**. Thinly laminated white (2.5 YR 8/1) calcrete mainly composed of lutites and sands without pebbles and cobbles. Strongly cemented.
	1a	1, 2, 6a	**Cemented muddy sand**. Underlying layer 1d at a depth of 28.05 m–28.20 m asl, it is composed of light yellowish brown (10 YR 6/4) lutites and sands with scarce pebbles.
Upper Detritical Unit (UDU) *Strongly cemented*	1b	1, 2	**Cemented cobbles and gravels**. Underlying layer 1a, it is made up of a brown (7.5 YR 5/3) and light yellowish brown (10 YR 6/4) silty sands matrix with gravels and cobbles.
	7	1	**Gravely sand**. Irregular pink (7.5 YR 7/4) gravels found in Cala B only between layers 1b and 2; thin (~15 cm), and without lateral continuity; somewhat similar to layer 9.
	9	2	**Gravels and cobbles**. Underlying layer 1a/b, it is a chaotic, ~1 m-thick unit formed by well-rounded clasts ranging from medium gravels to small cobbles.
	10	6a	**Gravels and granules**. Formed by medium gravels, granules and light boulders, and 40-50 cm-thick; found in Cala A-Rasa D only. Sands and lutites are present and cemented; lateral transition is not clear and defined; it can be correlated with the basal unit of section 2 (layer 8).
Upper Sandy Unit (USU) *Slightly cemented*	1c	4, 5a, 5b, 7	**Cemented sands**. Fine cemented sands forming the upper part of layer 2.
	2	1, 2, 3, 4, 5a	**Silty sand with scattered gravels**. Uniform reddish yellow (5 YR 5/8) to strong brown (7.5 YR 576) medium to very fine sands (79%), well cemented and with no apparent structure; found at 27.40–27.80 m asl, it corresponds to a flood silt sediment formed mainly by sand and lutites in the 20–600 μm size range; gravel only represents 3%; a horizontal sublayer (2b) of coarse sands and granules (3.5%) is present in Cala B-Rasa E.
	11	6a	**Slightly gravelly sand**. Found only in Rasa F and Cala A-D, where it underlies layers 9 and 10, and possibly correlated with layers 2 and 4; fine and medium reddish yellow (7.5 YR 6/6) sands; lightly cemented.
Middle Detritical Unit (MDU) *Locally cemented*	3	1, 4, 5a, 5b	**Conglomerate**. Very thin (~5–8 cm) division of the sandy silt layers (2 and 4) composed of a mixture of pebbles and sands in a cemented lutitic matrix; light brown (7.5 YR 6/4) in color; located between 27.25 and 27.35 m asl; the lower and upper contacts are sharp and regular.
	8	2	**Gravels and sands**. Irregular and chaotic unit composed mainly of gravels, sands and boulders (ø 50 cm) at the base. Somewhat similar to layer 12; irregular thickness (~90 cm).
	12	6b	**Gravels and granules**. Present in parts of Cala A-Rasa D underlying layer 11; somewhat similar to layer 10 (formed by gravels and granules but with fewer boulders); upper contact is sharp in section W, but merges with layer 10 to the south.
	13	6a	**Sands**. Very coarse and coarse sands underlying layer 12 it consists of a thin (~1 cm–30 cm) unit with classified sand grains.
Middle Sandy Unit (MSU)	4	1, 5a	**Silty sand**. Silty sand, similar to layer I in composition and color (7.5 YR 5/4–5 YR 6/6); also somewhat similar to layer 6a; present in Rasa E-Cala D only, between 26.95 and 27.25 m amsl, it disappears to the SE.
Middle Lutitic Unit (MLU)	Ia	6a, 6b	**Sandy gravelly mud**. Main find horizon, consists of a 30–80 cm-thick coarse and medium sandy mud with occasionally gravels (max. ø 10 cm) filling a paleochannel network oriented N–S; yellowish red (5 YR5/6) in color; upper and lower contacts are sharp; high-density of faunal remains and a few stone tools; disturbed by roots in the area close to the gravel pit cut.
	Ib	4, 5b	**Muddy sands with occasional gravels**. Find horizon underlying layer 3 in Cala B and Cala C; cemented muddy sand matrix with scattered gravel (texturally similar to layer 4); high porosity and granulate texture; faunal remains are low-density; disturbed by roots; found between 27.16 and 26.83 m amsl.
Lower Detritical Unit (LDU)	8t	2	**Gravels and sands**. Irregular and chaotic unit composed mainly of gravels, sands and boulders (ø 50 cm) at the base. Somewhat similar to layer 12; irregular thickness (~90 cm).
	15	6a	**Gravels and sands.** Paleochannel bed underlying the find horizon (Ia) in Cala A-Rasa D. Mainly composed of gravels, sands and light boulders; two subunits can be distinguished—sands in the uppermost part of the layer (5–10 cm), with grain size increasing below that (>40 cm).
Lower Sandy Unit (LSU) *Strongly cemented*	6	4, 5a, 5b	**Silty sand with scattered pebbles**. Lowermost layer defined in Cala B-Rasa E; as layers 2 and 4, it consists of sand; found between 26.60 and 26.90 m amsl and with a maximum observed thickness of ~30 cm; strongly cemented, reddish yellow in color (7.5 YR 6/6).

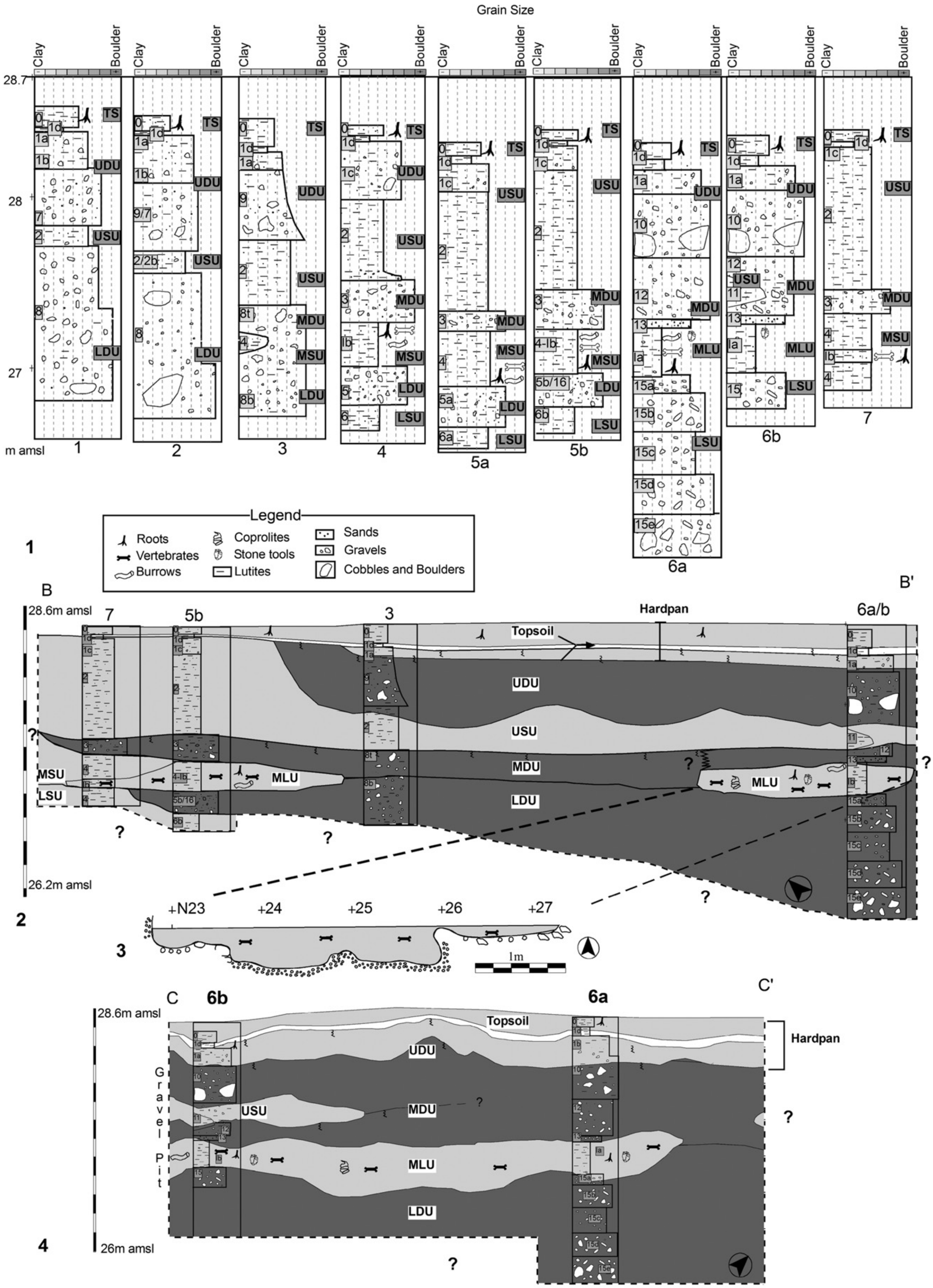


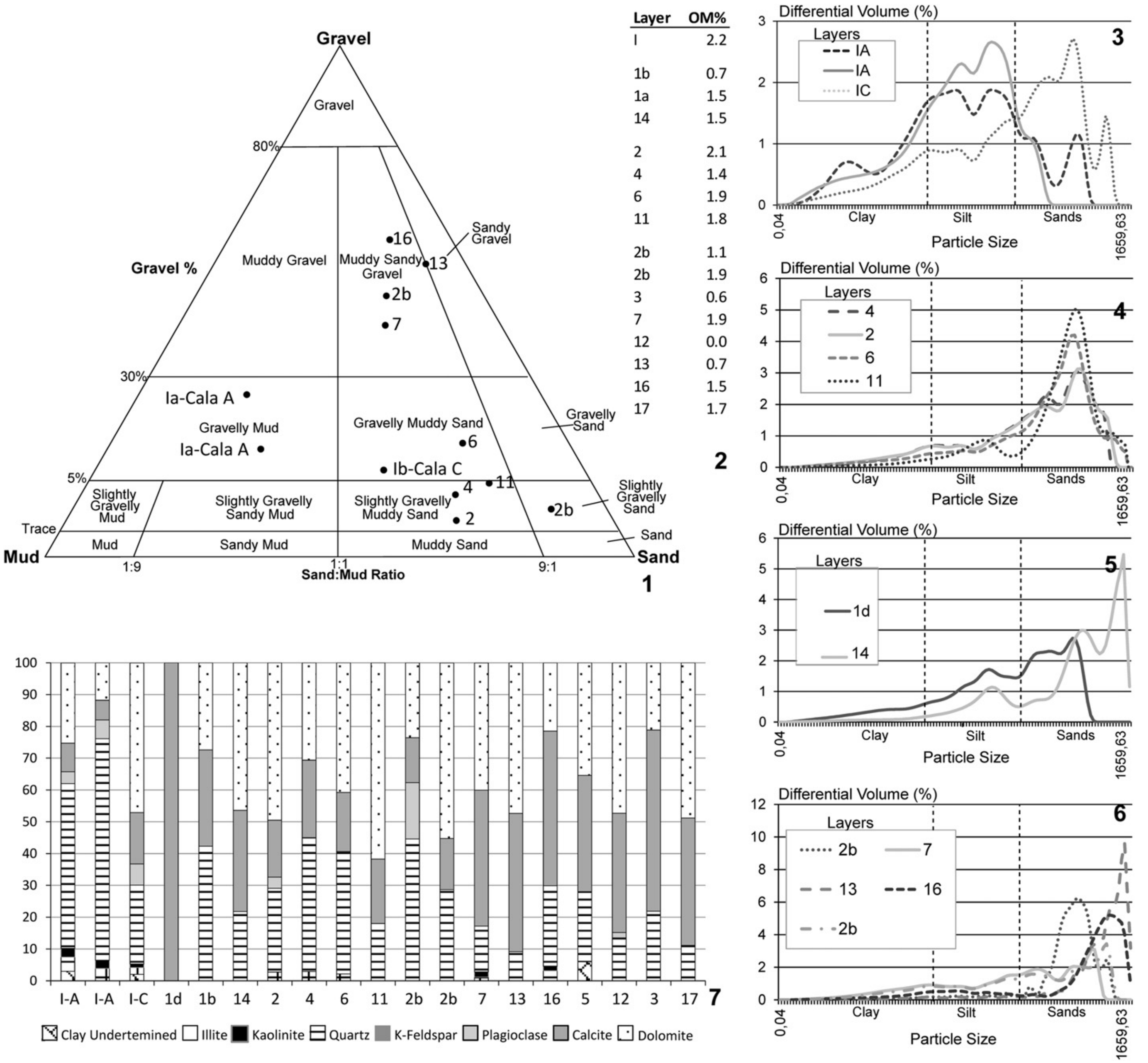
Fig. 4. Stratigraphic profiles in Cala B (1 and 3), Rasa F (2), Rasa E (4, 5 and 5b) and Cala A-Rasa D (6a and 6b). The position of the profiles is indicated in Fig. 1.

The textural analysis of samples from layer Ia of Cala A shows a higher proportion of mud than elsewhere, which is consistent with filling in the framework of a “flash flood” event characterized by the presence of a muddy matrix supporting the gravel. The layer Ib sample from Cala C is sandier, which may be indicative of silt flooding of a kind also observed in layers 2, 4 and 11 (Fig. 5).

Two different facies are recognized above the MLU. To the NW, the MLU is partly covered by the Middle Sandy Unit (MSU) and to the SE by the Middle Detritical Unit (MDU). The latter probably corresponds to the migration of the same watercourse and is locally strongly cemented at the top due to a channel encrusting process.

A similar cycle with two intervals ensued, accumulating two other depositional units: a lower one of flood sands, the Upper Sandy Unit (USU), which is separated by an erosional interval from the gravels, cobbles and boulders forming the Upper Detritical Unit (UDU) above. A Petrocalcic Hardpan Horizon (layers 0, 1d and a1) developed subsequently; it is composed of a thin laminated calcium carbonate deposit (1d) and cemented muddy sand (1a) and can be observed under the topsoil (layer 0) across the whole of the excavated area.

The sharp lower boundary of the deposit containing the accumulation of finds indicates that we are dealing with a paleochannel whose bottom was exposed for a significant amount of time, not with a channel cut and then filled in the framework of a single depositional event. Thus, we reconstruct the formation of the paleochannel as related to the lateral migration of the active channel and consequent abandonment of the meander, followed by use of the latter as a hyena denning site and, eventually, burial of



Layer	OM%
I	2.2
1b	0.7
1a	1.5
14	1.5
2	2.1
4	1.4
6	1.9
11	1.8
2b	1.1
2b	1.9
3	0.6
7	1.9
12	0.0
13	0.7
16	1.5
17	1.7

Fig. 5. Clay mineralogy and particle size data for selected sediment samples from Canyars. 1: Triangular diagram for the representation of particle size using Gradistat updated v.8.0 program (Blott and Pye, 2001). 2. Organic matter lost-on-ignition (LOI). 3–5: Particle size using a Beckman Coulter-LS™ particle size analyzer. 7: Clay mineralogy.

Table 2
Radiocarbon dates from Canyars layer I. Ages are calibrated with the OxCal 4.1.7 software (Bronk Ramsey, 1995) using the IntCal09 curve (Reimer et al., 2009).

Site Inventory #	Material	Lab #	Pre-treatment	$\delta^{13}C$	Age BP	calBP (2σ)
TC07J24I921D	*Equus ferus* tooth	Beta 233098		–	Failed	–
TC07-I-N25-MCV	Charcoal (*Pinus sylvestris* type)	P-27862 (OxA)		–	Failed	–
TC07-I-L24-MCV	Charcoal (*Pinus sylvestris* type)	Beta 273965	ABA	−23.5‰	33,800 ± 350	37,405–39,720
TC07-I-L25-MCV	Charcoal (*Pinus sylvestris* type)	OxA-23643 OxA-2416-44	ABA ABOx-SC	−23.0‰ −22.89‰	34,540 ± 330 34,980 ± 350	38,756–40,516 39,048–41,004
TC07-I-L25-MCV	Charcoal (*Pinus sylvestris* type)	OxA-23644 OxA-24057	ABA ABOx-SC	−23.35‰ −22.77‰	34,810 ± 360 34,900 ± 340	38,904–40,849 38,993–40,916

the exposed surface under the deposits accumulated by a flash flood.

4.2. Dating

Given the absence of collagen in the large mammal bones, the OSL additive dose technique was applied to sand grains sampled from the layer Ia muddy gravel as a first approach to secure a chronology for the site. A multi-grain average date of 23.8 ± 1.9 ka was obtained (Daura et al., 2009; García et al., 2010). However, because of the methodology used, this result cannot be taken to represent a true assessment of the age of the depositional event.

Five radiocarbon dates were subsequently obtained on charcoal for layer Ia in Cala A. They are presented in Table 2 and related to the isotopic ice curve (Andersen et al., 2006; Svensson et al., 2006; Sánchez Goñi and Harrison, 2010; Wolff et al., 2010) in Fig. 6. The ABOx method is more robust in removing trace contaminants from very old charcoal. At Canyars, however, it did not result in ages statistically distinguishable from those obtained on samples pre-treated with the standard ABA protocol; with Calib 6.1. Reimer et al., 2009, Ward and Wilson's (1978) test of the contemporaneity of the five results returns $t = 7.55$ [$\chi^2(0.05) = 9.49$, with 4 degrees of freedom], enabling rejection of the hypothesis that they are of different ages. Assuming that the samples were strictly contemporaneous, a mean pooled radiocarbon date of ~34.6 ^{14}C (~39.6 cal) ka BP can thus be estimated for the deposition of the charcoal.

4.3. Lithic assemblage

The Canyars lithic assemblage is comprised of six artifacts only; one is a quartz flake and the other five are flint, one of which (a flake with a distal break and marginal trimming) is of uncertain stratigraphic provenance. Other quartz fragments lacking clear attributes of intentional knapping were also recovered but their presence in the deposit is not securely anthropogenic. These are the raw materials commonly found at other Pleistocene sites of the Garraf Massif, such as Cova del Rinoceront and Dolina de l'Esquerda de les Alzines (Daura et al., 2011a, 2011b).

Two of the securely provenanced flints are retouched tools: one is a fragment of a tool made on a cortical flake and bearing a denticulated edge; the other (Fig. 7) is a mesial blade bearing bilateral, straight, relatively invasive and scalar retouch. The other two are: a small laminar flake with a punctiform striking platform

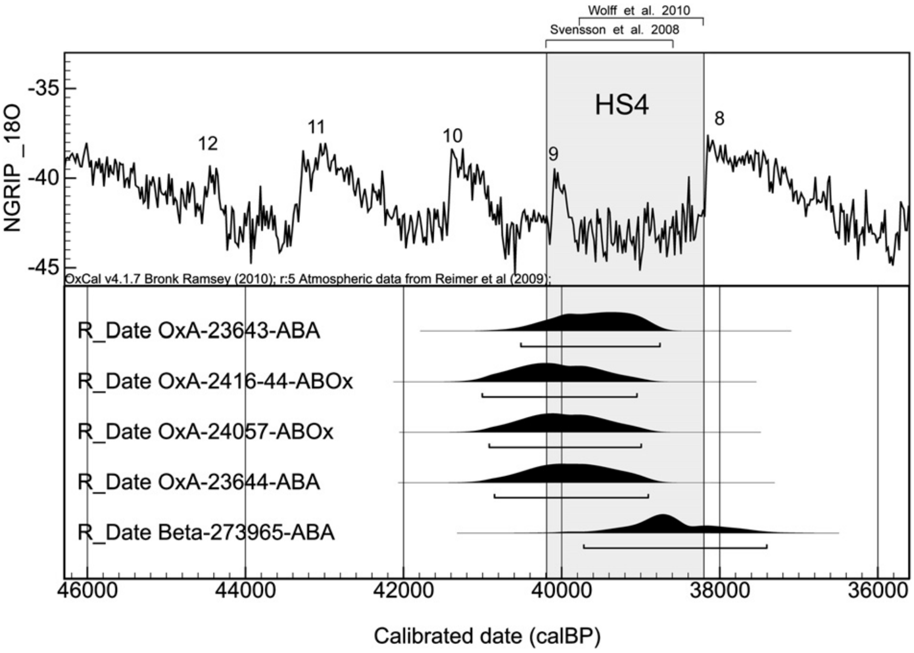


Fig. 6. Plot of the Canyars ^{14}C dates in Table 2 calibrated with the Intcal09 curve (Reimer et al., 2009) and compared with the NGRIP (North Greenland Ice Core Project) $\delta^{18}O$ ice-core record of Svensson et al. (2006) and Andersen et al. (2006) showing GI interestadials; the duration of Heinrich Stadial 4 is indicated according to both Svensson et al. (2008) and Wolff et al. (2010) [Prepared using OxCal v. 4.1.7; Bronk Ramsey, 1995].

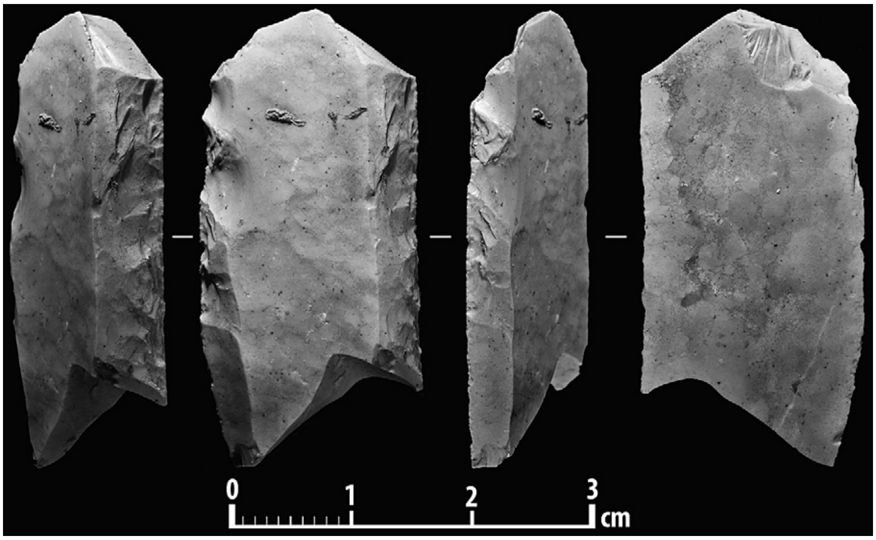


Fig. 7. Blade with Aurignacian retouch from Canyars (Photo: R. Álvarez).

and a dorsal pot-lid fracture; and a small fire-cracked flint flake. Technological inference is limited by the small size of this assemblage but it is nonetheless clear that it reflects the use of Upper Paleolithic prismatic blade production strategies.

Assuming that the radiocarbon-dated charcoal and the flints are behaviorally associated (see below), this evidence indicates occupation of the area at a time that, in the region, corresponds to the Aurignacian I (a.k.a. "Early Aurignacian") culture-stratigraphic slot. The typology of the retouched blade—although in and of itself insufficiently diagnostic—is consistent with assignment of the anthropic component of the Canyars deposit to this phase of the technocomplex because blades with unilateral or bilateral scalar retouch (often called Aurignacian retouch) are typical of Early Aurignacian assemblages and absent from those of the preceding Protoaurignacian.

4.4. Charcoal

All of the recovered charcoal remains—241 fragments (Table 3)—were collected manually during excavation. Given the nature of the context, the origin of this material—natural or anthropic—is difficult to assess. If due to wild fires, however, one would expect evidence for burning among the other finds, namely the large mammal bones, to be ubiquitous, but burning marks were observed on only fifteen shaft fragments. Moreover, the low diversity and the absence of plant species representing a range of environments can be taken to suggest a selection pattern, and to indicate that the charcoal assemblage results from firewood used during human occupation. Therefore, in conjunction with the burnt flints and the few burnt bones, the Canyars charcoal is most likely to represent the remains of a hearth context swept into the paleochannel by the flash flood event that filled it.

Table 3
Taxonomic identification of the Canyars charcoal.

Taxon	Total	%
Acer	8	3.3
Pinus sylvestris type	179	74.3
Maloideae	1	0.4
Quercus sp. deciduous	11	4.6
Rhamnus cathartica/saxatilis	2	0.8
Thymelaceae	4	1.7
cf. *Prunus*	1	0.4
Undetermined conifers	15	6.2
Undetermined angiosperms	7	2.9
Undetermined	12	5
Total	241	

Seven taxa were identified, with the *Pinus sylvestris*-type being the most abundant. It accounts for 75% of the charcoal, while the percentages of the other taxa are all below 5%. The *P. sylvestris*-type comprises three pine species sharing anatomical features: *P. sylvestris* (Scots pine), *Pinus nigra* ssp. *salzmanni* (European black pine) and *Pinus uncinata* (mountain pine). These three species can be found in today's Mediterranean mountains at different altitudinal ranges (Blanco et al., 1998)—*P. uncinata* above 1700 m, *P. sylvestris* between 1000 and 1700 m, and *P. nigra* ssp. *salzmanni* between 800 and 1000 m.

In NE Iberia, charcoal records concerning the transition between the Middle and the Upper Palaeolithic are scarce, although material has been retrieved from a number of sites, namely: L'Arbreda, layers H and I (Girona) (Ros, 1987; Maroto, 1994); Roca dels Bous (Piqué, 1995); Abric Romaní, layer D (Barcelona); Fuentes de San Cristóbal, layer G (Huesca) (Allué, 2002); and Coll Verdaguer, layer IV (Barcelona) (Daura et al., 2009). These records show a clear dominance of the *P. sylvestris*-type and low values of meso-thermophillous taxa similar to the pattern seen at Canyars. However, they come from sites located further inland and in higher elevation settings.

4.5. Phytoliths

A total of five samples were analyzed for phytolith contents. They are listed in Table 4 together with their provenience and the main results obtained (percentage of AIF fraction, number of phytoliths morphologically identified, and number of estimated phytoliths per gram of AIF). Three of the samples correspond to dental calculus from three different samples and two to sediment collected nearby. The two samples from *Equus ferus* are from separate teeth whereas the *Cervus elaphus* sample comes from a single maxillary fragment with four teeth present. For a more reliable interpretation of the results, each tooth sample was divided in two parts, one corresponding to an extract from the potentially contaminated adhering sediment (control samples) and the other collected directly from the dental calculus.

Table 4
Canyars phytoliths. List of samples and main analytical results.

Sample #	Sample type	% AIF	# Phytoliths identified	# Phytoliths per 1 g of sediment
TC07 K25I 1893 (1)	Sediment	49.9	85	38,000
TC07 N25I 3330 (2)	Sediment	64.9	84	100,000
TC07 M24I 1750 (3)	*Cervus* maxilla	63.9	70	30,000
TC07 M24I 1750 ext. (6)	Control sample 1750	58.6	29	25,000
TC07 M24I 2197 (4)	*Equus* molar	36.5	24	22,000
TC07 M24I 2197 ext. (7)	Control sample 2197	61.5	19	78,000
TC07 O25I 2304 (5)	*Equus* molar	36.8	61	26,000
TC07 O25I 2304 ext. (8)	Control sample 2304	66.3	68	46,000

Phytoliths from teeth are good indicators of the diet consumed immediately before the death of the animal (Piperno, 2006). Moreover, their identification yields information about the vegetation and, consequently, the climatic conditions pertaining at a specific time and place. All the samples contained phytoliths, although in low numbers, which is consistent with results from comparable studies on tooth remains (Lalueza et al., 1996; Piperno et al., 2001; Staller and Thompson, 2002).

Grass phytoliths are predominant in all the samples, but phytoliths from the leaves and the wood/bark of dicotyledonous plants are also present (Fig. 8). Grasses produce 20 times more phytoliths than wood/bark and 16 times more phytoliths than the leaves of dicotyledonous plants (Albert and Weiner, 2001). Thus, the numbers for the latter are much more representative than it would seem at first glance.

Regarding grasses, two features need to be noted. Firstly, the abundance, both in sediments and in the dental calculus, of bulliform cell phytoliths, which are formed in the leaves of these plants, especially under high evapotranspiration conditions (Sangster and Parry, 1981; Brémond et al., 2005); their identification may be indicative of short-term aridity during the period in which the studied animals inhabited the area. Secondly, no phytoliths from the inflorescence of these plants was found, which may be indicative of winter feeding.

The inference of environmental aridity is supported by the identification of starch granules in some of the samples, mostly those from the sediments and the *Cervus* teeth. Starches are the main energy source for plants, stored as a food source in various parts of the plant structure: leaves, stems, seeds, roots, etc. Since they are trapped inside a concreted matrix, starches may survive during long periods of time in dental calculus (Hardy et al., 2009).

Overall, the phytolith and starch granule results point to arid winter(s) as the time of accumulation of the sampled context. Concerning possible differences in the diet, the higher amounts of dicotyledonous plants found in the sampled *Equus* do not necessarily imply that the *Cervus* individual consumed such resources to a lesser extent; the differences are not statistically significant and are best interpreted as showing that the sampled horses and the sampled red deer probably lived in the same general area and had a similar diet.

4.6. Pollen

Four coprolites were analyzed, but one (TC07I-Q25-3882) was palynologically sterile (Fig. 9). A sample from the sediment in which the coprolites were embedded (TC07-N25-I) was also analyzed for pollen, without success. The pollen spectra of the polleniferous coprolites are diverse in the relative abundance of their types.

Coprolite samples TC07I-M22-1672 and L26-I-2943 are dominated by *Pinus* pollen with a minor incidence of Asteroideae, Poaceae, *Artemisia*, and, to a lesser extent, deciduous *Quercus*. The

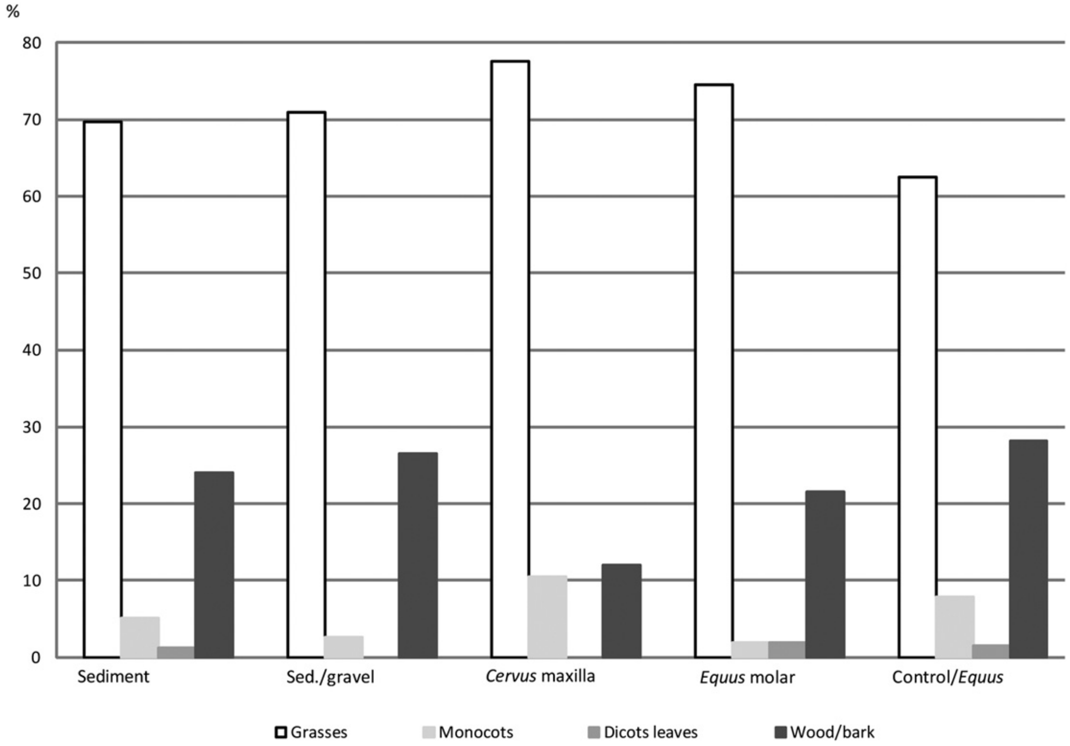


Fig. 8. Results from the phytolith analysis of sediment and dental calculus samples.

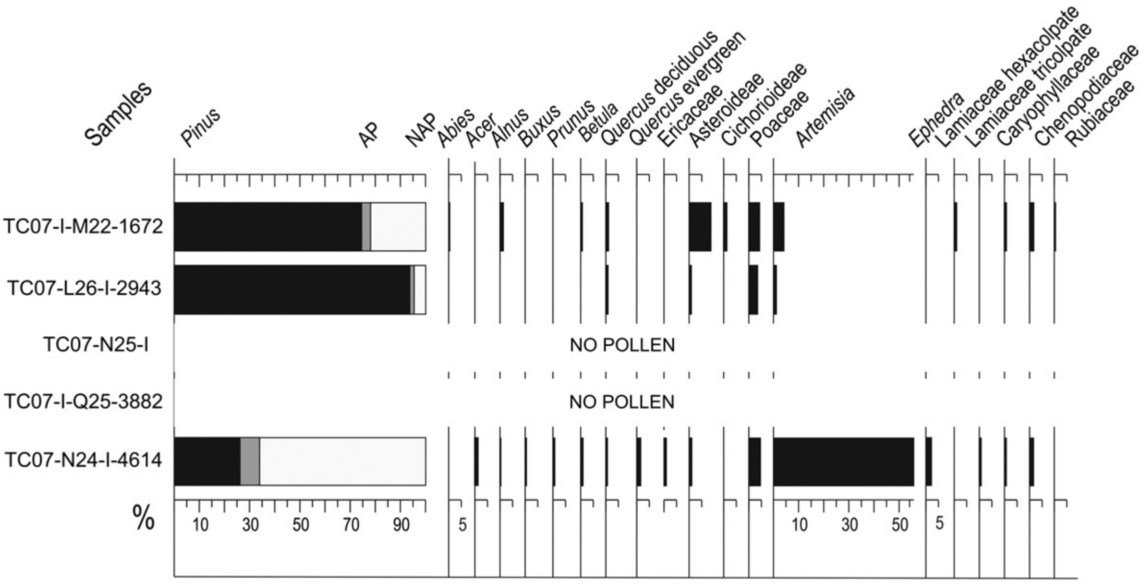


Fig. 9. Pollen spectra from hyena coprolites (#1122, 1672, 2943, 3882, 4616) and sediment (I).

former is also characterized by minor amounts of *Alnus*, *Betula*, and *Abies* among the AP (arboreal pollen) types, and the presence of Lamiaceae, Caryophyllaceae, Chenopodiaceae and Rubiaceae among the NAP (non-arboreal) types. In contrast, coprolite sample TC07-N24-I-4614 is dominated by *Artemisia* pollen with comparatively low frequencies of pine pollen (about 25%). The woody component of this sample is however, relatively diverse, with *Acer*, *Alnus*, *Betula*, deciduous *Quercus*, *Buxus*, *Prunus*, evergreen *Quercus* and Ericaceae (*Erica arborea* type) being present.

Based on taphonomic experience with hyena and canid coprolites (Carrión et al., 2008), we are inclined to think that this disparity in the composition of the pollen spectra reflects the existence of a range of habitats in the surrounding area, including pine-dominated forests and steppe-like landscapes with a sparse tree and shrub cover. The extent of land cover that can be inferred from the thermophilous taxa is less significant than recorded during MIS3 at lower latitudes of the Iberian Peninsula (Carrión, 2002; Carrión and Leroy, 2010; González-Sampériz et al., 2010).

4.7. *Large mammals*

As the >5000 faunal remains recovered are still under analysis, NISP and MNE counts are not yet available. Therefore, Table 5 only provides taxonomic assignments and MNI estimates based on diagnostic skeletal elements. In terms of MNI, herbivore (including Artiodactyla, Perissodactyla and Proboscidea) and carnivore (Carnivora) taxa are almost evenly represented, the former accounting for 60% of the assemblage (excluding rabbits) and the latter for 40%. The most abundant herbivores are the horses, mostly caballine horse, followed by the large bovids, red deer and rhino. Wild boar, ibex, and elephantids are present but with MNIs of 1 in all cases. Among the carnivores, lynx and hyena are largely dominant.

As briefly reported by García et al. (2010), this large mammal assemblage (Figs. 10 and 11; Table 5) includes cold-adapted and open landscape taxa. The fossil remains of *Coelodonta antiquitatis* stand for the *Mammuthus*–*Coelodonta* faunal complex (Kahlke, 1999; Kahlke et al., 2011). The elephantid remains correspond to an immature specimen and the skeletal parts present are insufficient to discriminate between *Mammuthus* and *Elephas*. Based on the chronology of the site, the parsimonious classification of this material is as *Mammuthus primigenius*.

Most of the identified bones belong to *E. ferus*, which is also the predominant species in terms of MNI (47% of the herbivores and 28% of the large mammals), and is mainly represented by limb bones and cranial elements. In the region, this taxon is present during the Last Glacial (e.g., at Abric Romani and Cova del Gegant) but absent from the faunas of the previous interglacial (MIS5) as documented, for instance, at Cova del Rinoceront (Daura, 2008; Daura and Sanz, 2011); therefore, at this latitude, *E. ferus* can be considered as a cold climate indicator. The lesser represented *Equus hydruntinus*, in turn, is indicative of an arid and open landscape (Burke et al., 2003; Orlando et al., 2006).

Where the bovids are concerned, discriminating between *Bos* and *Bison* is a complex task and the material was therefore referred

Table 5
The Canyars large mammals and their Minimum Number of Individuals (MNI).

	Total MNI	Skeletal part used to quantify
Artiodactyla		
Bos primigenius	15	Metapodials
Capra sp.	1	Dentition
Cervus elaphus	7	Metapodials
Sus scrofa	1	Dentition
Perissodactyla		
Coelodonta antiquitatis	2	Astragali
Equus ferus	27	Metapodials
Equus hydruntinus	4	Metapodials
Proboscidea		
cf. *Mammuthus* sp.	1	Postcrania
Carnivora		
Panthera leo	2	Dentition
Panthera pardus	1	Dentition
Lynx pardinus	13	Dentition
Felis silvestris	2	Dentition
Crocuta crocuta	13	Dentition
Ursus arctos	1	Dentition
Canis lupus	4	Dentition
Cuon alpinus	1	Dentition
Vulpes vulpes	3	Dentition
Lagomorpha		
Lagomorpha indet	~221	Mandibles

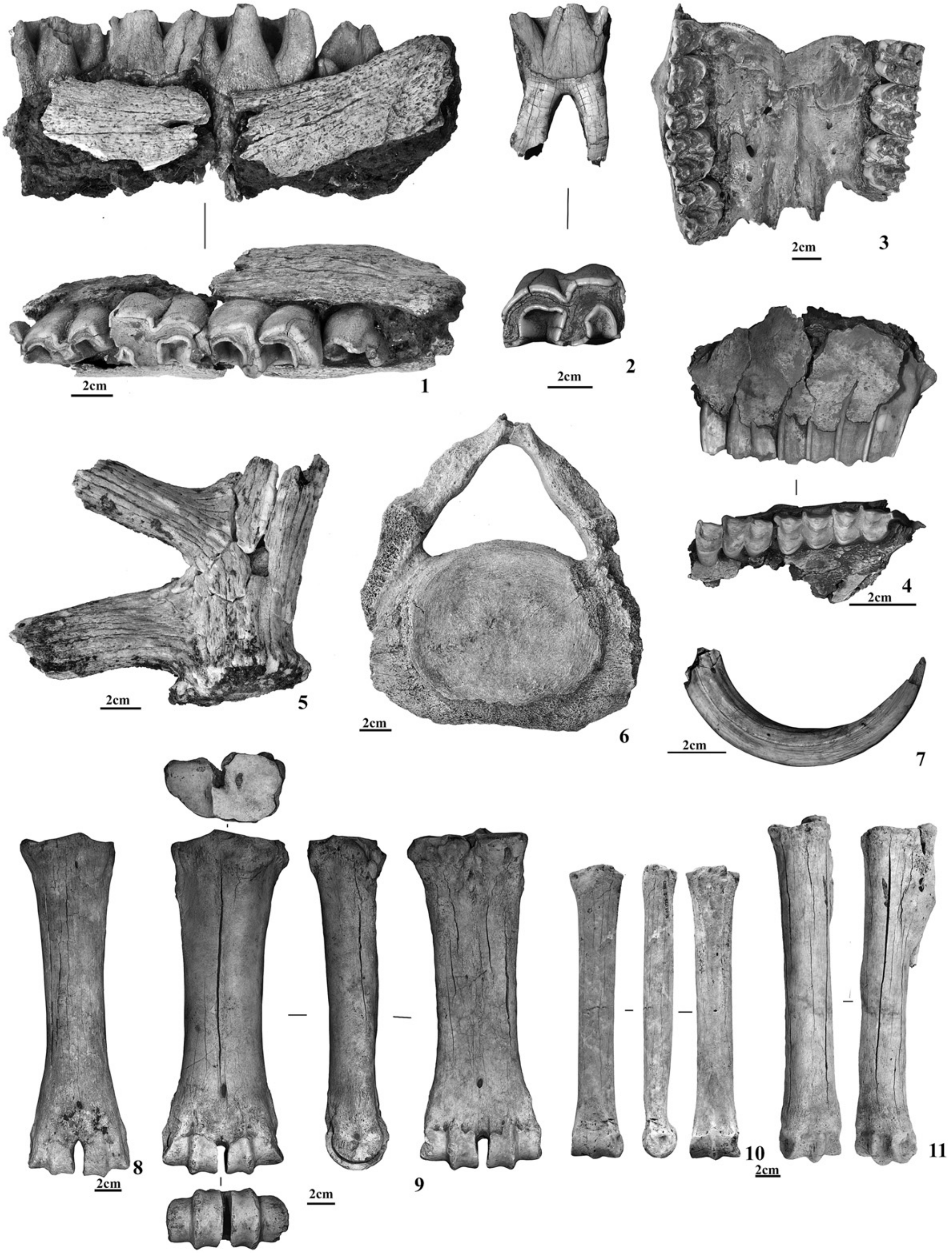


Fig. 10. Ungulates from Canyars: *Coelodonta antiquitatis*, hemimandible (1) and isolated lower molar (2); *Bos primigenius* maxilla (3), female and male metacarpal (8 and 9, respectively); *Capra* sp., maxilla (4); *Cervus elaphus*, shed antler (5); Proboscidean vertebra (6); *Sus scrofa*, canine tooth (7); *Equus hydruntinus*, metacarpal (10); *Equus ferus*, pathological metatarsal (11).

to *Bos*/*Bison* in initial excavation reports (Daura et al., 2009). Subsequently, García et al. (2010) noted that the material presented features setting it apart from *Bison priscus* and speculated that a late persistence of *Bison schoetensacki* might explain the observed differences. Following Gee (1993), however, we assign the Canyars bovids to *Bos primigenius* on the basis of the overall morphology of the metacarpals and noting in particular the smoothness of the distal metaphyses (lack of the bison-diagnostic "kink") and the quadratic aspect of the proximal end in proximal view (Fig. 10, n° 9).

The other ungulate well represented at Canyars is *C. elaphus*; *Capra* and *Sus* are also present, but their remains are scant. Red deer

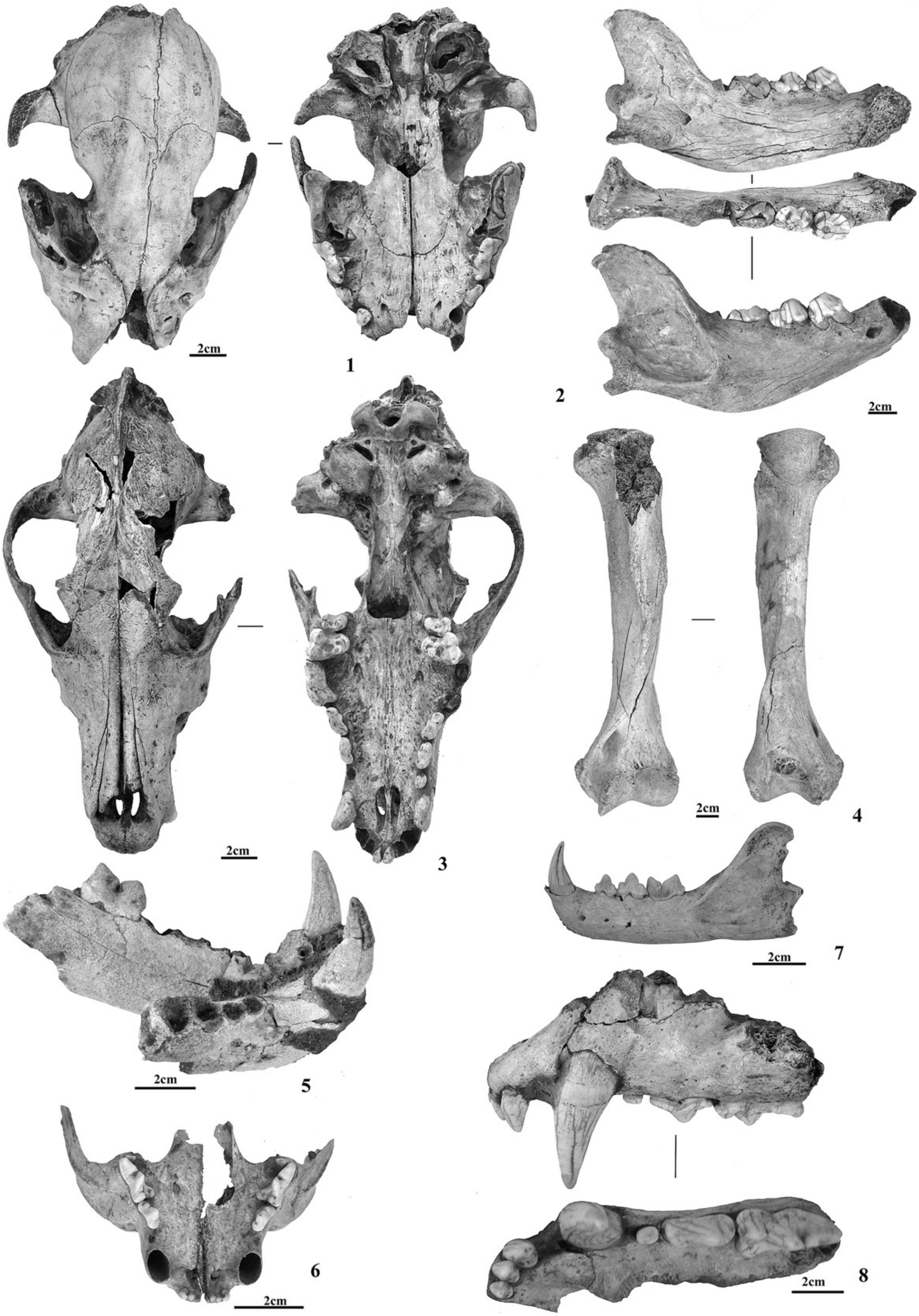


Fig. 11. Carnivores from Canyars: *Crocuta crocuta*, immature cranium (1) and senile hemimandible (2); *Canis lupus*, cranium (3); *Panthera leo*, humerus (4) and maxillary fragment (8); *Panthera pardus*, mandible (5); *Felis silvestris*, cranium (6); *Lynx pardinus*, mandible (7).

is an ubiquitous and generalist species present in a wide range of habitats, such as deciduous woodlands, coniferous forests, open parklands, light forests and grasslands (Lister, 2004; García et al., 2009). *Sus scrofa* is common in but not exclusive of interglacial faunas; it is rare in the Canyars assemblage and does not characterize the ecosystem.

Most of the carnivores recovered can occupy a wide range of habitats. A significant feature of the assemblage is the large number of lynx, all of which are *Lynx pardinus*, the Iberian lynx. Today, this species is restricted to the Mediterranean forests and scrublands of southwestern Iberia, in contrast to their nearest Eurasian relative, *Lynx lynx*, whose habitats are more diverse. The presence of *Ursus arctos* might be taken to suggest a temperate forest setting, although, as with wild boar, the numbers are very low (and, hence, not indicative of a particular type of ecosystem) and the fossil record shows that the species was widespread across mainland Europe before and during the LGM (Valdiosera et al., 2007).

The patterns of bone weathering indicate a short time of subaerial exposure and in progress taphonomic analysis suggests that carnivores were responsible for the bone accumulation. This is supported by six facts: (a) carnivores represent 40% of the total MNI, (b) 12 of the minimum number of 13 hyenas are juveniles, (c) 133 hyena coprolites were recovered, (d) the limb bones of the herbivores display gnawing damage (Fig. 12), (e) the under-representation of ribs and vertebrae among the herbivores, which is suggestive of the transport of selected body parts (Arribas and Palmqvist, 1988; Brugal et al., 1997), in contrast with the proportional representation of the different elements of the skeleton among hyena and lynx, and (f) the low degree of fragmentation of the bone remains (Fosse, 1996).

This evidence links the assemblage to the behavior of hyenas as bone accumulators, although we cannot eliminate the possibility that lynx also played a role. Hyena denning must have involved some burrowing against the bottom or the sides of the paleochannel, entailing rapid burial of at least some of the accumulated bones and thus contributing to explain the good surface condition of the assemblage (Behrensmeyer et al., 1988).

Assessing the contribution of humans to the formation of the Canyars bone assemblage is difficult. Initial taphonomic observation of the material indicates the presence of surface marks on the bone but also that distinguishing between trampling and butchering is problematic. Human involvement is apparent, however, in the case of the few burnt shaft fragments.

4.8. Small vertebrates

Fifteen small vertebrate taxa were identified in the material sorted from the wet-sieved sediments (Table 6). In terms of the Catalonian classification of small vertebrates by chorotypes (Sans-Fuentes and Ventura, 2000; López-García et al., 2010a), the association found has no modern analogue. Some species, namely *Crocidura* sp., *Microtus* (*Terricola*) *duodecimcostatus* or *Microtus* (*Iberomys*) *cabrerae* are related to Mediterranean requirements (chorotype 3). Other taxa, namely *Anguis fragilis*, *Coronella austriaca*, *Talpa europaea*, *Microtus arvalis* and *Microtus agrestis* have middle Europe requirements (chorotypes 1 and 2) that currently do not pertain in the area—average summer temperatures below 20 °C, average annual temperatures between 10 and 12 °C, and rainfall above 600 mm.

The microvertebrate assemblage thus indicates climatic conditions cooler than present. The species association is also indicative of an environment dominated by open landscapes, mostly dry but with a degree of moisture—as indicated by the presence of *A. fragilis*, *C. austriaca*, *Bufo bufo*, *T. europaea* and *M.* (*Iberomys*) *cabrerae*.

4.9. Birds

A total of eight avian taxa have been identified on the basis of 13 remains (Table 6), all of which are currently resident in Mediterranean areas of Iberia. Only one remain can be ascribed to waterfowl, namely the mallard (*Anas platyrhynchos*).

The monk vulture (*Aegypius monachus*) is represented by three bones, one of them, the metatarsal of digit I, is fairly distinguishable from that of the griffon vulture (*Gyps fulvus*) on morphological features. The oldest Iberian record of the monk vulture is in the Lower Pleistocene of Cueva Victoria (Sánchez Marco, 2004).

The local paleoornithocoenosis of Canyars also includes a partridge of the genus *Alectoris*. *Perdix*, which replaced *Alectoris* in the Atlantic and northern Iberian regions after the climatic amelioration of the mid-Holocene (Sánchez Marco, 2004, 2007), is absent.

One incomplete humerus belonging to a thrush (*Turdus*) cannot be assigned to a particular species for lack of distinctive features. Thrushes are typical of environments with shrubs. The hawfinch (*Coccothraustes coccothraustes*) identified in the Canyars assemblage is a common inhabitant of forest edge and open woodland (Tellería et al., 1999).

The group of the corvids is represented, as in most Pleistocene sites of Europe (Tyrberg, 1998). The magpie (*Pica pica*) is an open country dweller. It needs some trees in its territory to build nests. As inhabitants of rock cavities, the yellow- and the red-billed choughs (*Pyrrhocorax graculus* and *Pyrrhocorax pyrrhocorax*) are recorded in practically every karstic infilling (cf. Tyrberg, 1998), and these closely related avian species also appear in Canyars. The yellow-billed chough currently lives in high mountain areas, but was widespread throughout Europe during the Pleistocene, so its presence need not imply conditions colder than present (Sánchez Marco, 1996, 2005; Tyrberg, 1998).

5. Paleonvironmental reconstruction

A number of different components can be recognized in the Canyars assemblage: (a) a human camp site, indicated by the burnt bone, the charcoal and the artifacts; (b) a hyena den, indicated by the bones of the hyenas and their coprolites, as well as the herbivore remains brought by them; (c) additional bone remains of a kind that is to be expected in a riverside thanatocoenosis, including, namely, the carnivore taxa (e.g., bear, lion and panther), with the under-represented and isolated bones of large felids possibly relating to hyena scavenging too (Diedrich, 2009). The combination of these components in such a well-defined, restricted area is parsimoniously explained under a site formation scenario whereby the flash flood responsible for the filling of the paleochannel acted as an agent of concentration in a single locus of remains originally deposited over a wider area of the channel itself and of the immediately adjacent floodplain.

The torrential nature of Mediterranean streams is conditioned by the short length and marked inclination of their drainages, so it seems safe to infer that, regardless of climate change, flash floods must have been as frequent at the time of formation of Canyars as they are today. However, bone surfaces were not modified by transport, and the same applies to the stone tools, which are not patinated. This implies rapid burial and short transport distances, which means that hypotheses concerning the origin of the displaced material can be reduced to essentially two:

(1) The first is that, at the time of displacement, the finds formed surface scatters accumulated over an interval of time of the order of magnitude of the season(s) or year(s); in this scenario, Canyars could be seen as the result of the sweeping onto a single locus of the material accumulated on the ground surface over such a short time interval and across a limited stretch of the paleochannel and surrounding terrain.
(2) The second is that the finds were already buried at the time of displacement, the flash flood being of the one-in-a-century or one-in-a-millennium order of magnitude, i.e., powerful enough to remove and redeposit at some distance a number of subsurface accumulations of archeological and/or paleontological

Fig. 12. Examples of damage inflicted by carnivores to limb bones: humeri of *Bos primigenius* (1, 3), *Cervus elaphus* (5) and *Equus hydruntinus* (6); tibia of *Equus hydruntinus* (2); femur of *Cervus elaphus* (4).

material formed by previous floods of normal magnitude; in this scenario, Canyars would correspond to a potentially heterogeneous palimpsest and, if a horizontal stratigraphy with significant time-depth existed across the Canyars floodplain, material from rather different ages could conceivably have been brought together in this single locality.

The high MNI of lynx seems to be inconsistent with the first hypothesis, as the species is solitary, territorial (with little or no overlap between home ranges) and has large roaming areas (with population densities that, nowadays, are 0.7–0.4 ind/km^2 for the highest density) (Palomares et al., 2001). The presence of two juveniles of identical age (around six months post-natal) and of

Table 6
Small mammals, herpetofauna and avifauna from Canyars.

	NISP	MNI
Amphibians		
Pelodytes punctatus	24	4
Bufo cf. *bufo*	2	1
Bufo calamita	98	5
Reptiles		
Lacertidae indet.	6	2
Anguis fragilis	5	1
Coronella cf. *austriaca*	6	1
Vipera sp.	8	1
Ophidia indet.	12	–
Birds		
Anas platyrhynchos	1	1
Aegypius monachus	3	1
Alectoris sp	2	1
Turdus sp	1	1
Coccothraustes coccothraustes	1	1
Pica pica	1	1
Pyrrhocorax pyrrhocorax	1	1
Pyrrhocorax graculus	1	1
Rodents		
Microtus arvalis	3	2
Microtus agrestis	2	1
M. (*Terricola*) *duodecimcostatus*	2	1
M. (*Iberomys*) *cabrerae*	1	1
Apodemus sylvaticus	9	3
Eliomys quercinus	2	1
Insectivores		
Talpa europaea	1	1
Crocidura sp.	1	1

a female adult might indicate a local denning episode (or the hyena kill of competitors approaching the den in the search of carrion at a time of food scarcity), but this would still leave the other ten adult individuals unexplained. The lynx evidence, therefore, seems to imply a time depth for the accumulation in the range of several decades at least.

On the other hand, there is nothing in the composition of the faunal assemblage to indicate that it mixes material from different periods. The breakage patterns are not indicative of dry bone fracturing (to be expected in a scenario of high-energy, long-distance remobilization), and the matrix adhering to the external side of long shaft fragments is identical to that filling the shaft cylinders, so there is no evidence to support the notion that the original stratigraphic provenience of the material could have been rather disparate. Moreover, if Canyars represented the sweeping into a single locus of distinct accumulations spanning several millennia of middle MIS3 times we would expect an incongruous mix of taxa to be represented among the fauna; by the same token, we would expect Middle Paleolithic artifacts also to have been incorporated in the accumulation. Such inconsistencies of association, however, do not exist. At other sites from the same region—for instance, the Abric Romaní (Cáceres et al., 1998; Fernández-Laso, 2010) or the nearby Cova del Gegant (Santafé and Casanovas, 1986; Fèlix et al., 2006)—the faunas from earlier MIS3 times include the tortoise *Testudo hermanni* and, among the large herbivores, the prairie rhino *Stephanorhinus* (*Dicerorhinus*) *hemitoechus* instead of the woolly rhino *C. antiquitatis*, but such species were not found at Canyars.

Our working hypothesis, therefore, is that the Canyars finds accumulated over a time interval comprised between several decades and less than a millennium, i.e., one that was no longer than the uncertainty interval associated with the radiocarbon dates obtained for the anthropic component of the deposit. As this interval broadly coincides with that estimated for HS4 (Fig. 6), the different signals emitted by the range of Canyars paleoenvironmental indicators can therefore be taken to represent coeval diversity. In other words, they should be interpreted as proxies for synchronic variation across the landscape rather than for diachronic change in local conditions as a result of the regime of abrupt and rapid climatic oscillations characteristic of MIS3.

Under these assumptions, the local HS4 landscape can be reconstructed along the lines of the conifer-steppe biomes that, according to Finlayson and Carrión (2007), would have covered the mountain ranges of southern Iberia during the cold episodes of MIS3—but, in this case, in a lowland setting. General aridity and the presence of grasslands are indicated by the phytoliths, while the coprolite pollen indicates the persistence of a temperate component (*Quercus* and *Acer*) alongside the steppe taxa (*Artemisa* and *Ephedra*) and the conifers. On the basis of the charcoal evidence, the latter are of the *P. sylvestris*-type, which is the dominant taxon in all charcoal studies of the Upper Pleistocene vegetation of NE Iberia and must have been ubiquitous in the region at this time (Burjachs and Julià, 1994; Carrión et al., 1999; Rivals et al., 2009; Burjachs et al., 2012).

Hypotheses about the relative importance and spatial distribution of the different components of such a landscape can also be advanced but, at present, must remain tentative. In this respect, the differences in the pollen composition of the coprolites analyzed—one dominated by non-arboreal taxa (*Artemisia*), the other two by pine—may have two different explanations: (a) the regional landscape was a complex mosaic of tree stands and open spaces, depending on local soil and humidity conditions, and the remains accumulated at the site span two different seasons, i.e., March to June, when *Pinus* flowers, and August to October, when *Artemisia* does, or (b) the landscape was steppe-dominated, with pines forming discrete stands (and perhaps a more extensive cover in the slopes of the adjacent Garraf Massif) and the more thermophilous taxa (e.g. *Quercus* or *Acer*) being part of the humid environments and riparian communities whose existence is indicated by the presence of *Alnus* in both groups of coprolites (under this scenario, the *Pinus*-dominated coprolites would therefore represent episodes of roaming across forest stands prior to the excreting episode they represent).

The second alternative is consistent with the evidence for aridity retrieved from the phytoliths in the teeth of both deer and horses, as well as with the presence in the assemblage of such cold-adapted species as the woolly rhino (certain) and the mammoth (possible). The dominance of open landscape herbivores also supports this alternative. In terms of MNI, they represent 84% of the corresponding total, for the most part equids (54%) and bovids (26%), with *E. hydruntinus* (Burke et al., 2003), a species adapted to semi-arid conditions, being represented among the former. Red deer, which are more ubiquitous, should in this case be included among the open space herbivores (bringing the above total up to 96.5%) because of the phytolith evidence, which indicates they were feeding on the same resources (~70% grasses) as the horses (a similar conclusion was previously reached for the Middle Pleistocene of Atapuerca on the basis of carbon isotope analysis; García et al., 2009).

The microvertebrate assemblage is also indicative of a dry, open landscape, with the presence of *A. fragilis*, *B. bufo*, *T. europaea* and *M.* (*Iberomys*) *cabrerae* implying the presence of humid biotopes, to be expected in a riverside situation. Similar results—generally cold, and with varying indications of humidity—have been obtained for coeval records from elsewhere in northern Iberia, namely: L'Arbreda, layer I (Girona) (López-García and Cuenca-Bescós, 2010); Xaragalls, layer C3 (Tarragona) (López-García et al., n.d.); El Portalón, layer P16 (Burgos) (López-García et al., 2010b); and El Conde, layers N10b, N2a1 and N104 (Asturias) (López-García et al., 2011). The wetland component of the landscape—the Canyars stream itself or shallow ephemeral lakes in the floodplain—is further indicated by the presence of the mallard (*A. platyrhynchos*).

6. Implications for Neanderthals and modern humans

Assuming a lowering of sea level to −50 m, the average value obtained by different reconstructions for the period around ~40 ka cal BP (Rabineau et al., 2006), and considering the impact of the post-Pleistocene formation of the Llobregat delta, Canyars would, at the time of formation, be <10 km from the coastline and at an elevation of <100 m. The environmental reconstruction discussed above thus carries the implication that, ~39,600 years ago, the regional lowlands formed a steppic landscape with mesophilous elements largely restricted to favorable (probably riparian) niches. Mountain pinewoods, today typical of the supra and oromediterranean belts, had extended down to such low elevations, and may have existed either as clustered tree stands in the plains or as open forest cover on the adjacent slopes of the Garraf Massif.

Can this landscape configuration be extended to the entirety of the territory between the Pyrenees and the Llobregat, and to the whole period of the Middle to Upper Palaeolithic transition in this area? Or does it reflect conditions that, in this area and within this period, were specific to HS4? This issue must remain open for the time being, but the presence in the faunal assemblage of woolly rhino and, possibly, mammoth, i.e., of significant elements of the Eurasian steppe-tundra, supports the notion that we are dealing with conditions that, in MIS3, pertained in the Llobregat drainage only during a restricted interval coinciding with HS4.

In Iberia, woolly rhino and mammoth are known to occur also in the Cantabrian strip and in the central Meseta, with the Padul mammoth remains documenting the extension of this species to the southernmost boundary of the latter (Álvarez-Lao et al., 2009; Álvarez-Lao and García, 2011a, 2011b). No elements of chronology are available for the central Mesetan sites, although stratigraphic correlation and skeletal morphology suggest a late Middle or early Pleistocene age (Álvarez-Lao and García, 2010). Based on direct radiocarbon dating results placing them in the 30–40 ka cal BP interval (Álvarez-Lao et al., 2009), the Padul remains would be younger. However, their real chronology should be considered an open issue because the samples were not pretreated with an ultrafiltration step, and bone dates in this time range obtained on samples lacking such a pretreatment step have often been shown to underestimate, in some cases very significantly, the true age of the material (Higham, 2011).

In the Cantabrian strip, the presence of mammoth during the Upper Paleolithic is attested by cave paintings (e.g., El Pindal in Ríos et al., 2007), as well as by the recovery of ivory, dental and cranial remains from Late Gravettian, Solutrean and Lower Magdalenian contexts (Álvarez-Lao and García, 2011a). This evidence is suggestive of mammoth presence during MIS2 times, with the scattered evidence for ivory objects from the earlier Upper Palaeolithic (e.g., the sagaies from the Aurignacian levels of Cueva Morin and El Castillo; cf. Liolios, 2006) conceivably reflecting the exchange and/or circulation of objects, raw-materials and personnel with the Aquitaine basin to the north, not necessarily the local availability of the resource. When dated, woolly rhino occurrences also seem to coincide with the colder periods of the late Middle Pleistocene (MIS6) or the Upper Pleistocene (MIS2), but a few finds suggest presence in the later part of MIS3 as well (Álvarez-Lao and García, 2011b).

The evidence from Catalonia is consistent with this picture. When dated, directly or by association, the presence of mammoth coincides with the LGM, as in the Solutrean context of Cau de Les Goyes, and that of woolly rhino with the Middle Paleolithic (possibly indicating a MIS4 age for the corresponding context), as at the El Toll cave. At Cau de Les Goyes, however, the evidence comes from an awl, and availability of the raw-material through exchange is a conceivable explanation, as may also be the case for the ivory present in level H of L'Arbreda (Maroto et al., 1996). Riera de Sant Llorenç (Viladecans), a paleontological site excavated in the framework of our project, yielded partial skeletons of both species, documenting their presence in the Barcelona area during the early Upper Pleistocene, probably in MIS4 (Daura et al., 2011a, 2011b). That such a presence must have been sporadic, however, is indicated by the absence of their remains from the excavated part of the long, high-resolution Middle Paleolithic sequence of Abric Romaní, precisely dated by U-series to the ~40–60 ka interval, i.e., all of MIS3 up to just before HS4 (Bischoff et al., 1988; Cáceres et al., 1998; Burjachs et al., 2012).

In Catalonia, therefore, the presence of mammoth and woolly rhino in the regional landscape during the Upper Pleistocene seems to be intermittent and, specifically, to coincide with a restricted number of time intervals: during the first glacial maximum, perhaps during the last one too, with Canyars documenting a third episode in an intervening time period coinciding with HS4. From this we can therefore conclude that HS4 did have a stronger impact in the region than normal MIS3 cold stadials and that it essentially represented the establishment, for a brief period of time, of climatic and environmental conditions akin to those of the two glacial maxima of the Upper Pleistocene. Given lower latitude, however, animal and plant species that at such times are not found to the north of the Pyrenees continued to thrive in restricted niches of a predominantly steppe-tundra landscape.

From the above we can surmise that HS4 must also have had a significant impact at lower latitudes, as indeed indicated by the pollen spectra from deep sea cores drilled off both the Mediterranean and Atlantic coasts of southern Iberia (Sánchez Goñi et al., 2000, 2002). Although we lack direct, high-resolution evidence from continental records, the conditions then extant can be assessed from those marine records and from simulation studies. According to Fletcher et al. (2010), warm and warm temperate elements remain present during HS4, but their percentages are low (<10% of the pollen spectra), and the global picture for south-eastern Iberia and the central Meseta returned by Sepulchre et al.'s (2007) simulations is one of very dry climate and very low vegetation cover. Given the presence of high rising mountain ranges between the narrow Mediterranean coastal strip and the Mesetan plateau, this evidence suggests that, south of the Ebro, the temperate component of the vegetation that persisted through HS4 occupied mid-altitudinal sheltered niches, forming a discontinuous belt located between alpine deserts at higher elevation and arid lowland steppes.

The absence of mammoth and woolly rhino from the archeological and paleontological records of the Middle and Upper Pleistocene of Valencia and Murcia indicates that the steppe-tundra illustrated by Canyars, although present at the latitude of Barcelona during HS4, never extended much farther down the Mediterranean coast. As pointed out by d'Errico and Sánchez-Goñi (2003), this observation must be understood in the context of the difference in the plant composition of the steppic environments extant on either side of the Ebro boundary during HS4. To the north, they would have been formed by a mix of productive heath and grassland communities (Ericaceae, *Calluna*, Poaceae, Asteraceae, *Helianthemum*, Cyperaceae, Plumbaginaceae) with a high above- and below-ground carbon storage. To the south, they would have been dominated by *Artemisia* and Chenopodiaeae and, thus, would have featured a much lower capacity for carbon storage. As a result, the northern Iberian grasslands were capable of feeding such large cold-adapted herbivores as mammoth and woolly rhino, while the coeval grasslands covering the central Meseta and the

Mediterranean coast of southeastern Spain would have been akin to a desert-steppe, supporting a low biomass of large mammals.

Such a large scale pattern, however, does not exclude smaller-scale physiographic complexity of vegetational landscapes, as suggested by pollen data in particular regions where they are abundant (González-Sampériz et al., 2010). The contrast between north and south in the composition of the two types of steppes reconstructed for HS4 Iberia by d'Errico and Sánchez-Goñi (2003) should not be taken to imply that, in southern areas, such steppes covered the entire landscape. As pointed out above, fragmented forest environments must have persisted through the periods of increased aridity, underpinning the recovery of trees that is characteristic of interstadials in those areas (Carrión, 2004). In particular, the woody angiosperms, including mesothermophytes, were doubtless far more abundant southward of the Ebro during the cold stages of the Pleistocene (Carrión, 2002; González-Sampériz et al., 2010).

During Greenland Interstadial (GI) 8, which followed HS4 and lasted from ~38.2 to ~36.6 ka cal BP (Wolff et al., 2010), a strongly expressed vegetation gradient existed circa 40°N, with temperate (deciduous oaks) and warm-temperate (Mediterranean taxa) elements undergoing a very significant expansion to the south, where the corresponding average percentage in marine pollen records is ~40%, more than twice the values observed in equivalent records situated between 40 and 44°N (Fletcher et al., 2010). During the preceding interstadials, similar values are observed below 40°N, but the contrast is not as clear because, above that latitude, temperate elements reach higher values than during GI8. Still, we speculate that (a) steppe-tundra remained the dominant kind of environment north of the 40th parallel even through the interstadials preceding HS4, (b) for several millennia either side of 40 ka cal BP the average position of the boundary between the Eurasian steppe-tundra and the broken woodlands with temperate elements of southern and western Iberia was located in the Ebro basin, albeit with oscillations (e.g., extending as far south as the Llobregat delta during HS4 but perhaps remaining along the southern foothills of the Pyrenees at other times), and (c) this frontier pattern was strengthened rather than weakened during HS4 because of extreme aridity, which caused the development of a desert-steppe across the regions located immediately to the south of the Ebro valley. In short, we hypothesize a persistence of the frontier effect over several millennia under climatic conditions of opposite signal because of extreme aridity in the northern slopes of the *Sistema Ibérico* (Iberian Range) during HS4 and because of temperate forest expansion in its southern slopes during the interstadials that bracket it.

Combined with the obstacle to movement represented by swampy terrain at the mouth of the Ebro, this pattern could explain why diffusion and/or migration across the mountainous terrain of the Iberian Range may have been very limited during the few millennia comprising GI9/10, HS4 and GI8. The existence of such an eco-geographical barrier could explain why, in SW Iberia, the chronostratigraphic slot of the Protoaurignacian and the Aurignacian I of northern Spain and France is occupied by a Neanderthal-made late Middle Paleolithic. Simulation of the niches occupied at this time by the two technocomplexes confirms the ecological basis of the cultural boundary (Banks et al., 2008).

7. Conclusion

The combined geological and paleontological evidence from Canyars indicates that the find horizon is a closed context. The faunal assemblage was primarily accumulated in the framework of hyena denning in an abandoned meander. This material eventually came together with a few artifacts, burnt bones and charcoal as a result of a flash flood event that filled the paleochannel with sediments and brought into it additional faunal remains from natural riverside deaths as well as finds related to the activity of other agents, namely humans, originally scattered along its margins. Dating of the charcoal places the human component of the assemblage in HS4, while bone taphonomy and the lack of incongruities of association warrant an assumption of broad contemporaneity for the find horizon as a whole. The presence of woolly rhino and, possibly, mammoth, indicates an extension of the Eurasian steppe-tundra to the latitude of Barcelona, but these species are not found at coeval sites located along the Mediterranean coast south of the Iberian Range. This contrast is probably due to the establishment of a belt of semi-desert or desert-steppe conditions in the lower Ebro valley and adjacent slopes of the Iberian Range. As a result, the eco-geographical segregation extant during the interstadials that bracket HS4 between southern and western Iberia, on one hand, and northern Catalonia and the Cantabrian strip, on the other, was maintained through the duration of this cold and arid phase, with attendant implications for human settlement.

The role played by the Ebro basin and adjacent mountains of the Iberian Range as a barrier to diffusion and/or migration during the coldest periods of the Pleistocene is otherwise well illustrated by an example from the LGM. In the Upper Solutrean, a cultural facies characterized by the Parpalló or barbed-and-tanged point is found across the same areas of Iberia where a post-40 ka cal BP Middle Paleolithic is documented. Spreading over the ~1000 km separating Lisbon from Valencia, this point type did not make it into areas located to the north of the Iberian Range and of the Ebro drainage, only ~200 km NE of the Valencian occurrences. This culture-geographic boundary persists even after the Upper Solutrean, which is succeeded by the Solutreo-gravettian in the area where Parpalló points are known, but by the unrelated Badegoulian in Pyrenean regions (Banks et al., 2009, 2011).

This LGM pattern persisted for an interval of time in the range of three to four millennia, which goes to show that the "Ebro frontier" pattern proposed for the Middle to Upper Paleolithic transition in Iberia is not unique and has analogues during other moments of the Upper Pleistocene with similar climatic conditions. We believe that such a barrier effect remains at present the parsimonious explanation for the interaction (actually, the lack thereof) between the presumably modern human groups of the Protoaurignacian and the Aurignacian I that settled Catalonia, the Basque Country, Cantabria and Asturias after ~41.5 ka cal BP and the Neanderthal groups of the Middle Paleolithic that persisted in Valencia, Murcia, Andalucia and Portugal beyond ~40 ka cal BP.

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