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Palaeoenvironmental forcing during the Middle–Upper Palaeolithic transition in central-western Portugal

Thierry Aubry [a], Luca A. Dimuccio [b,c,*], Miguel Almeida [d], Maria J. Neves [d,f], Diego E. Angelucci [e], Lúcio Cunha [b]

[a] IGESPAR-IP, Parque Arqueológico do Vale do Côa, Avenida Gago Coutinho e Sacadura Cabral, 19-A, 5150-610 Vila Nova de Foz Côa, Portugal
[b] Centro de Estudos em Geografia e Ordenamento do Território (CEGOT), Departamento de Geografia, Faculdade de Letras, Universidade de Coimbra, Praça da Porta Férrea, 3004-530 Coimbra, Portugal
[c] Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, Largo Marquês de Pombal, 3000-272 Coimbra, Portugal
[d] iDryas/Dryas Octopelata, Rua Aníbal de Lima, 168, 3000-030 Coimbra, Portugal
[e] Dipartimento di Filosofia, Storia e Beni Culturali, Università di Trento, Piazza Venezia 41, 38122 Trento, Italy
[f] Centro de Investigação em Antropologia e Sáude (CIAS), Departamento de Ciências da Vida, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, Apartado 3046, 3001-401 Coimbra, Portugal

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ABSTRACT

Geoarchaeological analysis of the Middle and Upper Palaeolithic record preserved in cave, rock-shelter and open-air sites in the northern sector of the Meso-Cenozoic of the Western Iberian Peninsula margin (Portugal) reveals several disconformities (erosive unconformities), hiatuses and surface stabilization phases. A recurrent disconformity, dated to ca. 29,500–32,000 cal yr BP, in the time range of Heinrich event 3, must correspond to a main erosive event related to the impacts of climate change on the landscape, including a reduction in vegetation cover and altered precipitation patterns, with the consequent accelerated down-cutting by stream systems, slope reactivation and endokarstic reorganisation, causing the erosion of sediments and soils accumulated in cave, rock-shelter and open-air sites. These processes create a preservation bias that may explain why Early Upper Palaeolithic finds in primary deposition context remains exceptional in the carbonate areas of central-western Portugal, and possibly elsewhere in the other places of Iberia. The impact of such site formation processes must therefore be duly considered in interpretations of the current patchy and scarce archaeological record of the Middle-Upper Palaeolithic transition in south-western Iberia.

Introduction

In the time-span between ca. 29,000 and 45,000 cal yr BP the archaeological record of different West European regions shows significant, but not synchronic, technological, behavioural and physical–anthropological changes. The question of whether these changes represent the replacement of Neanderthal populations by newly arrived anatomically modern humans, or if they are the result of local Neanderthal cultural developments coupled with genetic exchange with immigrating modern populations has been widely discussed (see Zilhão and D'Errico, 1999). Yet, substantial differences persist in the scientific community concerning the process and its biocultural implications, as well as its exact chronology (Zilhão, 2000, 2006b; Finlayson et al., 2006; Vaquero, 2006; Zilhão and Pettitt, 2006; Carrión et al., 2008).

It is consensually accepted that the south-western part of the Iberian Peninsula represents the end of the line in Europe for the expansion of modern humans and the persistence of lithic operational schemes and stone tools of Neanderthal/Middle Palaeolithic affinities. Two distinct models have been proposed for the timing of the Middle–Upper Palaeolithic (MP–UP) transition in Portugal based on radiometric dating of archaeological layers and lithic assemblages (Zilhão, 1997; Bicho, 2000; Straus et al., 2000a,b; Zilhão and Trinkaus, 2002; Trinkaus et al., 2007). These models essentially disagree on two points: (a) the dating of the later Middle Palaeolithic record; and (b) the existence of Aurignacian assemblages in south-western Iberia.

The first model recognizes Middle Palaeolithic industries until ca. 37,000 cal yr BP (Walker et al., 2008; Angelucci and Zilhão, 2009; Zilhão et al., 2009), contemporaneous with the earliest Upper Palaeolithic to the north of the Pyrenees (Zilhão and D'Errico, 1999), and the existence of a late Aurignacian in Portugal since at least 34,500 cal yr BP, represented by a cluster of open-air sites in the Rio Maior basin, 80 km north of Lisbon and three small caves in the Alentejo and Estremadura regions (Zilhão, 1997, 2006a; Thacker, 2001; Zilhão et al., 2009). The open-air site of Gândara de Outil 1, located in the Lower Mondego River Valley of central Portugal (see Gândara de Outil 1), has

* Corresponding author. Present address: Departamento de Geografia, Faculdade de Letras, Universidade de Coimbra, Praça da Porta Férrea, 3004-530 Coimbra, Portugal. Fax: +351 239836733.
E-mail addresses: thaubry@sapo.pt (T. Aubry), luca@ci.uc.pt (L.A. Dimuccio), miguel.almeida@dryas-arqueologia.pt (M. Almeida), mjoao.neves@dryas-arqueologia.pt (M.J. Neves), diego.angelucci@lett.unitn.it (D.E. Angelucci), luciogeo@ci.uc.pt (L. Cunha).

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also been attributed to the late Aurignacian on the basis of the technological characteristics of its lithic assemblage (Almeida et al., 2006a,b; Aubry et al., 2006, 2008a,b). Zilhão (2006a,b) argues that, despite the scarcity of the available data and its difficult interpretation, derived from the marked functional differentiation between the sites known so far, the data indicate a permanent peopling of these regions during the late Aurignacian (Zilhão et al., 2009), as also proposed for southern Spain (Cortés Sánchez, 2007). Following-up on the argument that the number of sites per area is strongly conditioned, throughout the entire duration of the Portuguese Upper Palaeolithic, by deposition/erosion dynamics and, therefore, cannot be used for palaeodemographical inferences (Zilhão et al., 1995; Zilhão and Almeida, 2002), the scarcity of Southern Iberia's Aurignacian and Early Gravettian record is attributed not to the absence or low density of human populations but to preservation factors (Zilhão and Almeida, 2002; Aubry et al., 2008a).

The second model (Bicho, 2000; Marks, 2000; Straus et al., 2000a,b) considers that no Portuguese assemblage can be attributed to the Aurignacian techno-complex and that the earliest Upper Palaeolithic of Portugal is an early or even middle Gravettian. This model argues that Neanderthals survived in Southern Iberia until ca. 32,500 cal yr BP (and possibly as recently as ca. 29,000 cal yr BP), based on the AMS radiocarbon dating of charcoal and bones form Gorham's Cave, Gibraltar (Finlayson et al., 2006), or as late as 24,000 cal yr BP (Carrión et al., 2008), based on a comparison of Balearic basin marine sediments (ODP Site 975) with continental and other marine records (Jiménez-Espejo et al., 2007).

Site formation processes are essential to explain the features of the archaeological record underlying current disagreements and need to be duly considered before wider behavioural or anthropological considerations can be derived from them (Bordes, 1972; Laville et al., 1980; Texier, 2009). However, systematic geoarchaeological data concerning the middle and early Upper Palaeolithic of south-western Iberia remain scarce, limited to Oliveira Cave (Angelucci and Zilhão, 2009) and the Lagar Velho Rock-shelter (Angelucci, 2002a,b). In order to shed further light on the issue of the replacement of Neanderthals by anatomically modern humans in Iberia, we present and discuss in this paper new geoarchaeological data from five central Portugal cave, rock-shelter and open-air sites whose stratigraphic sequences contain erosive unconformities (disconformities according to Doglioni and Bosellini, 1990) that affect the archaeological record of the MP-UP transition.

Regional setting

All the studied sites are located in the northern sector of the Western Iberia margin Meso-Caenozoic deposits (Wilson et al., 1989) (Fig. 1), including marine, littoral and continental sediments, often carbonates, covering the Iberian Hercynian crystalline basement (Ribeiro et al., 1979). Three of the sites (Buraca Escura, Buraca Grande and Vale das Buracas) are caves or rock-shelters located in two fluviokarstic canyons cut in the Middle Jurassic carbonate formations of the western belt of the Sicó Massif (Cunha, 1991), while a fourth (the Lagar Velho Rock-shelter) is set in Cretaceous limestone inside the small fluviokarstic gorge of the Lapedo Valley at the edge of the Pousos syncline (Teles, 1992; Angelucci, 2002a,b). The open-air site (Gândara de Outil 1) is located on the Middle Jurassic carbonate rocks of the Outil/Cantanhede Plateau (Barbosa et al., 1988; Dimuccio, 1998; De Marco and Dimuccio, 1999; Dimuccio and Cunha, 1999).

Materials and methods

The information presented here is mostly derived from stratigraphic and chronological data collected using the standard geoarchaeological fieldwork approach: geomorphological study of the site surroundings; field description of the site deposits; and stratigraphic correlation, taking into account also the results of the study of archaeological assemblages and the radiometric dating. Fieldwork at the sites included the systematic description of exposed cross-sections and profiles to reconstruct stratigraphic successions and their vertical and lateral variations, as well as anthropogenic inputs and features. The description was made by means of a comprehensive form addressing the sedimentary, pedogenetic and anthropogenic characteristics of the deposits (e.g., Keeley and Macphail, 1981; Langohr, 1989; FAO-Isric, 1990), in order to reconstruct site formation processes. Informal geoarchaeological field units (GFU from now onwards) were identified on the basis of lithostratigraphic, pedological or archaeological criteria and used as field categories. The field units were later grouped into geoarchaeological complexes (GC herein) through stratigraphic correlation, which provides the framework for the archaeostratigraphic reconstruction proposed in this paper. Chronometric data are derived from radiocarbon results obtained with both conventional and Accelerator Mass Spectrometry (AMS) methods on selected samples of charcoal, bone and shell at the Oxford (OxA), Gif-sur-Yvette (Gif and Gif-A) and Beta Analytic (Beta) laboratories. When appropriate, original conventional and AMS radiocarbon data were converted into calendar age (cal yr BP) using CalPal calibration from Weninger and Jöris (2004) with the Calcurve CalPal_2007_HULU (www.calpal-online.de). All the errors are 1 sigma. Uranium-series dating (U/Th) of horse teeth was carried out by Curtis McKinney (Department of Anthropology, Southern Methodist University), and the results are reported using "early uptake" assumptions.

Geoarchaeological sites

Gândara de Outil 1

The Gândara de Outil 1 (GO) Open-air site was discovered in 2002 (excavated in 2003), during systematic survey after deep soil tillage for a tree plantation. It is located at an altitude of 90 m, in a small valley tributary of the Mondego River that cuts the southern limit of the Middle Jurassic outcrops of the Outil/Cantanhede Plateau (Almeida et al., 2006a,b; Aubry et al., 2006) (Fig. 1). In this area, the Bajocian–Bathonian limestone shows abundant and large, but poor-quality flint nodules (Barbosa et al., 1988).

The several-meter-thick succession was divided into ten field units, later grouped in four geoarchaeological complexes separated by three main disconformities (Fig. 2). The different deposition phases relate to slope dynamics, involving the reworking of superficial siliciclastic covers through the combined action of hydraulic, aeolian and soil formation processes. Geomorphological and stratigraphic studies of the site's surroundings have shown that similar sequences are commonly found in the same paleokarstic closed depressions of this area (Dimuccio, 1998; De Marco and Dimuccio, 1999; Dimuccio and Cunha, 1999; Almeida et al., 2006a).

The lithic assemblage collected from the site is technologically homogeneous and exhibits a carinated core reduction strategy based on carinated and (less commonly) busked burin schemes that are well represented in the GC3 complex (Fig. 2). This core-reduction strategy is unknown in all other assemblages of the region (Almeida et al., 2006a; Aubry et al., 2006), while typo-technological analysis reveals strong similarity to the bladelet-burins-core operative scheme found at the Vale de Porcos Open-air site (Rio Maior, Portugal) (Zilhão, 1997; Aubry et al., 2006). Zilhão (1997, 2000, 2006a) and Zilhão et al. (2009) have related these burin-cores to the Dufour bladelet blanks recovered at the Pego do Diabo Cave (Loures, Portugal), associated with ca. 34,500 cal yr BP AMS radiocarbon dates obtained on samples of horse and deer teeth pre-treated with both standard ABA and ultrafiltration techniques. Thus, the probable age of the GC3 lithic assemblage of Gândara do Outil 1 is Final Aurignacian (Fig. 2).

Buraca Escura

The Buraca Escura (BE) Cave was discovered during systematic survey and excavated between 1991 and 2002 (Aubry and Moura, 1993; Aubry et al., 2001, 2006). It is located at an altitude of 223 m, on the southern slope of a deeply incised valley cut in Middle Jurassic carbonate rocks (Fig. 1). The valley, named Poio Novo, follows a

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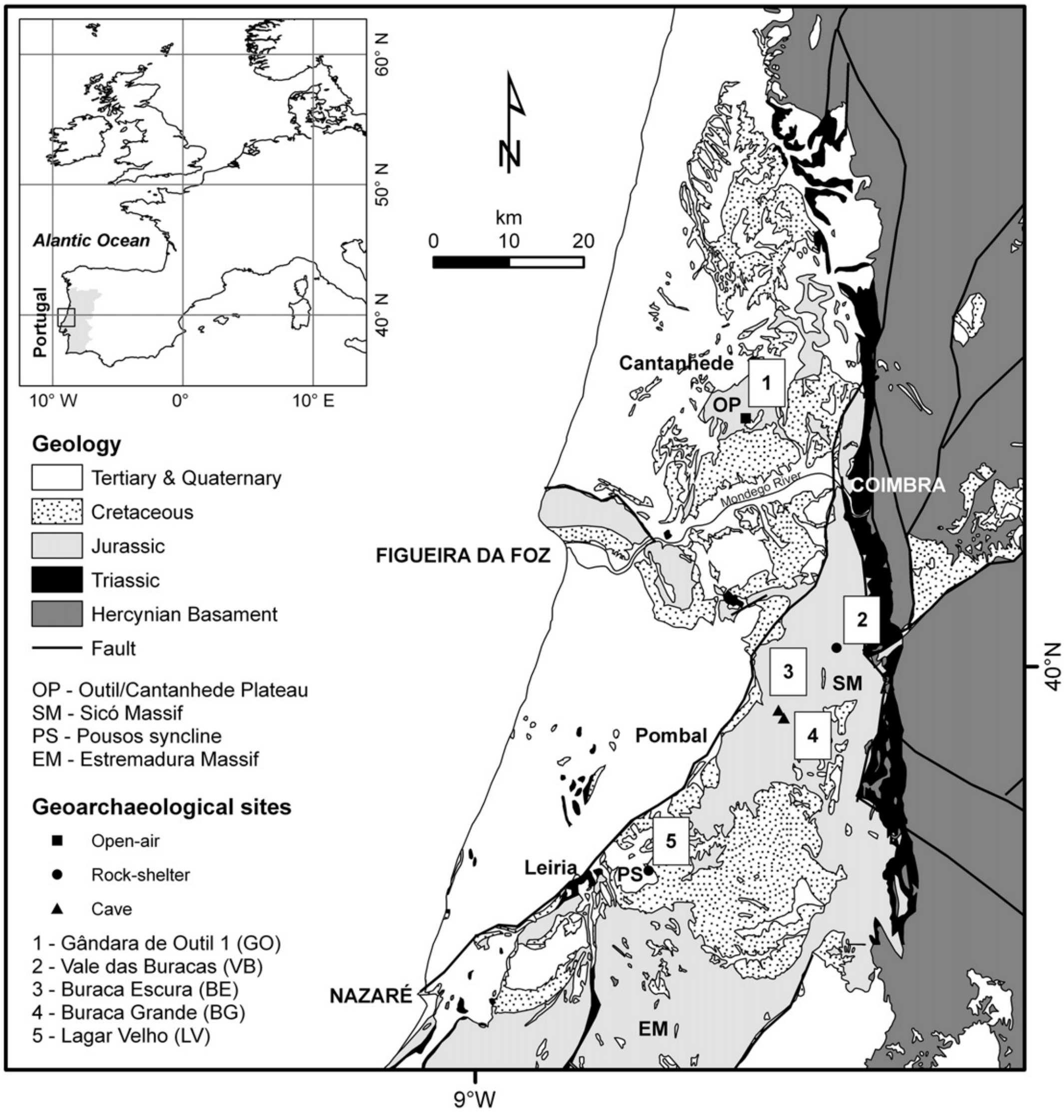

Figure 1. Geological map of central-western Portugal (modified from Wilson et al., 1989) and location of the geoarchaeologically investigated sites.

structurally controlled E-W orientation, which is almost perpendicular to the major fault zone that constitutes the western border of the Sicó Massif of central Portugal (Cunha, 1991).

During excavation, the BE succession was divided into eight field units, later grouped into four geoarchaeological complexes separated by three main disconformities (Fig. 3). Sediment accumulation is mostly related to dripping water processes associated with mechanical weathering of the cave walls and roof (often controlled by frost action-cryoclastism), decalcification, reworking and deposition of superficial siliciclastic covers and incipient soil formation (Fig. 3).

The site records evidence of both Middle Palaeolithic (in GC4 complex) and Gravettian occupations (in GC3 and 2 complexes) (Fig. 3). The Middle Palaeolithic layers contain lithic implements extracted from Levallois, discoidal, Kombewa and bipolar cores with hard-stone hammers (Almeida et al., 2003). The U/Th dates were obtained from faunal remains with carnivore marks and produced results with extremely large errors: $50{,}000 \pm 30{,}000$ yr, $70{,}000 + 22{,}000 / -19{,}000$ yr and $81{,}000 \pm 16{,}000$ yr but with an overlap in the 80,000–65,000 yr interval (Aubry et al., 2001; Almeida et al., 2003) (Table 1 and Fig. 3). These radiometric and lithic technology results are consistent with an attribution to the Middle Palaeolithic of the archaeological material contained in the GC4 complex, thus providing an inferior limit for the overlying disconformity (Fig. 3).

The earliest age for this erosive event is defined by the archaeological content of GFU2f (Fig. 3): a single Gravette point fragment associated with *Capra ibex* remains dated to 30,790–31,712 cal yr BP (GifA-97258) (Table 1). The technological and radiometric similarity to known early Gravettian archaeological assemblages from Spain (Fullola et al., 2007) and France (e. g., the Pataud Rock-shelter; Bricker, 1995) supports the association of the dated bone with the backed point and provides a terminus ante quem for the erosive event observed at the interface between GC4 and 3 complexes.

Buraca Grande

The Buraca Grande (BG) Cave is located at an altitude of 256 m in the same valley as the Buraca Escura (Fig. 1), but on the opposite slope. Three distinct sedimentary sequences were recognised in the three different areas of BG that were excavated (Aubry and Moura, 1994; Aubry et al., 1997): (a) at the entrance and in the first chamber of the cave, (b) in the second, intermediate chamber, where fieldwork uncovered a 3 m-thick sequence and (c) in the innermost chamber of cave, where a thin sequence with lithic artefacts, fauna and ceramics results from the erosion and secondary deposition of the second chamber deposits. During the excavation of this second chamber, fourteen field units were recognised, which were later grouped into

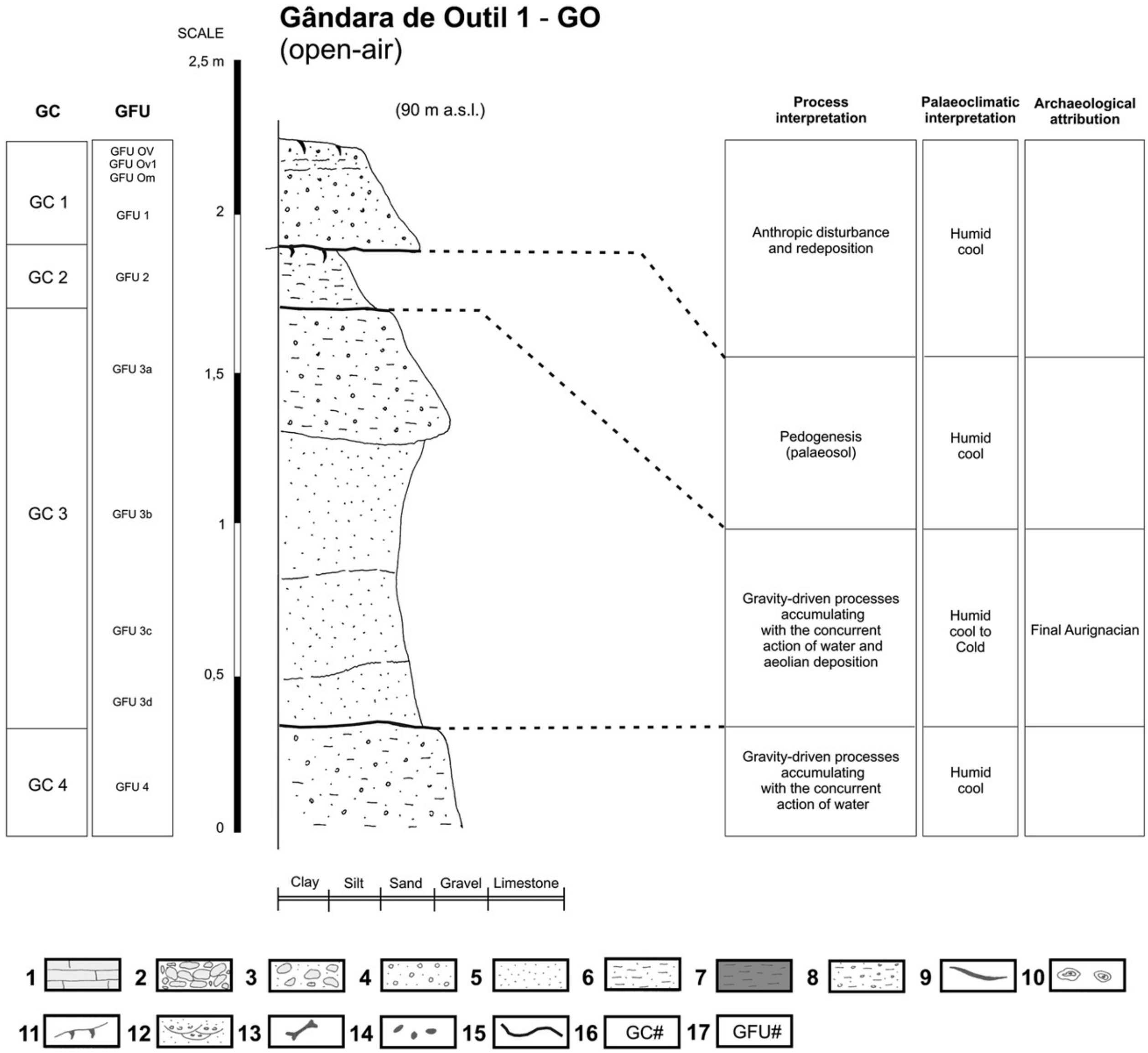

Figure 2. Gândara de Outil 1 synthetic log showing archaeostratigraphic sequence. Legend (also valid for Figs. 3, 4, 5, 6, and 7): 1 = Limestone, 2 = Clast supported conglomerate bearing limestone fragments with low sphericity, angular to sub-angular, 3 = Matrix supported conglomerate, 4 = Polymodal sand bearing quartz and quartzite clasts with high sphericity, sub-rounded to sub-angular, 5 = Unimodal sand, 6 = Silt, 7 = Clay, 8 = Sandy clay loam, 9 = Fe and/or Mn oxides, 10 = Carbonate nodules and concretions, 11 = Bioturbation, 12 = Trough cross-bedding, 13 = Bones, 14 = Charcoal fragments, 15 = Disconformity (erosive unconformity), 16 = Geoarchaeological Complex, and 17 = Geoarchaeological Field Unit.

four geoarchaeological complexes separated by three main disconformities (Fig. 4). The sedimentary processes are the same described previously for Buraca Escura. The archaeological remains collected and the radiometric dates obtained at the entrance and in the second chamber of the cave (Table 1), reveal multiple Pleistocene and Holocene occupations extending from the Middle Palaeolithic to the modern age (Aubry et al., 1997).

The bottom of the sequence, corresponding to the GC3 and 4 complexes, was excavated in a small area of less than 4 m². GFU10 only contained a few *Capra ibex* remains and scarce artefacts (three quartz flakes and one quartzite flake obtained by a Levallois reduction scheme). The lower part of GFU9b produced a lithic assemblage of some 100 flint artefacts, the only retouched tools being notches; this assemblage remains undated, due to the low collagen content of the bones. The upper part of GFU9b yielded backed, truncated and retouched bladelets and microgravettes. The latter were produced from truncated burin-cores or from splintered pieces. AMS radiocarbon dating of a charcoal fragment collected at the cave entrance in facies equivalent to GFU9b yielded a result of 28,355–29,255 cal yr BP (GifA-93048) (Table 1). This lateral correlation is confirmed by the stratigraphic and spatial analysis of refitted sets (involving 73 out of the 7694 excavated lithics), which also showed that significant stratigraphic disturbance affected some areas of the site (Fig. 4).

Typological and technological analysis of the stone and bone tools recovered in GFU9a reveal that this unit contains distinct Upper Palaeolithic components. An occupation of the cave during the Solutrean is attested by heat-treated flakes and lithic points; similar lithic material is dated elsewhere in the region to around 24,000–24,500 cal yr BP (Zilhão, 1997; Zilhão and Almeida, 2002). At least two distinct Magdalenian occupation phases are attested by a typical *baguette demi-ronde*, directly dated to 15,525–16,356 cal yr BP (OxA-5522) and a bone fragment dated to 13,137–13,454 cal yr BP (GifA-96307) (Table 1 and Fig. 4). Thus, the lithic assemblages, together with the stratigraphic distribution of the large number of age data from GC3 and 2 complexes,

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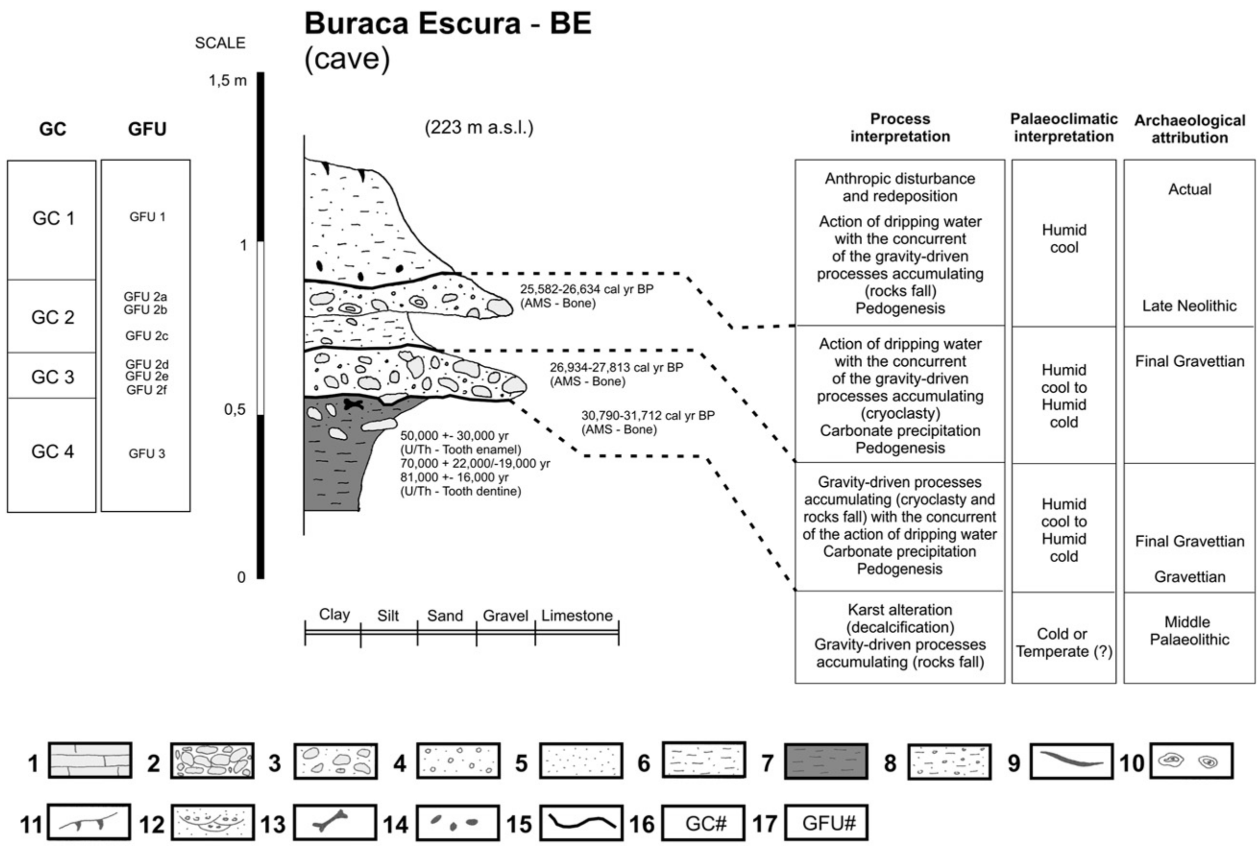

Figure 3. Buraca Escura synthetic log showing the archaeostratigraphic sequence.

indicate the existence of at least two distinct erosive phases, one after the middle Solutrean and the other one younger than ca. 7300 cal yr BP (Fig. 4).

Vale das Buracas

Vale das Buracas (VB), excavated in 1998 and 1999 (Almeida et al., 1999; Almeida and Neves, 2002; Almeida et al., 2006c), is a rock-shelter located at an altitude of 290 m, at the bottom of a small fluviokarstic valley cut in the Middle Jurassic carbonate rocks of the Sicó Massif and developing along a structurally controlled, SSE to NNW direction (Fig. 1). Both walls of the valley show many rock-shelters (locally named "*Buracas*") whose origin probably relates to cold-phase slope degradation processes (Cunha, 1991; Cunha et al., 2006). The VB succession was divided into six field units, organized into four geoarchaeological complexes separated by three main disconformities (Fig. 5).

The sediment fill accumulated mainly through gravity-driven slope processes, with the participation of water, and includes reworked cryoclastic deposits resulting from the formation of the valley's *buracas*. Decalcification, reworking and deposition of superficial siliciclastic covers and soil formation, are also evident (Fig. 5). As no radiometric dates could be obtained, the site's chronology is based in the composition of the lithic assemblages recovered in the GC2 and 3 complexes, which frequently show evidence of a short-distance, high-energy transport.

GFU3b unit contains soft hammer-struck, marginally retouched bladelets with facetted striking platforms extracted from unidirectional or bidirectional prismatic cores, correlated on a techno-typological basis to archaeological contexts ascribed to a Middle or Early Gravettian phase elsewhere in Portugal (ca. 31,000–29,000 cal yr BP; Zilhão, 1997). GFU3a yielded a typical bifacial point fragment and bifacial thinning flakes indicative of a Solutrean occupation of the area. GFU2 contained Upper Palaeolithic remains similar to those of GFU3a, but associated with Early Neolithic and Chalcolithic objects derived from upslope locations; the co-occurrence of such a diverse collection of stone stools can most probably be explained by erosion and remobilization during the event marking the stratigraphic limit between the GC2 and 1 complexes (Fig. 5).

Lagar Velho

The Lagar Velho (LV) Rock-shelter was discovered in December 1998 and yielded abundant Palaeolithic finds and features, among which the well-known LV1 child burial (Duarte et al., 1999; Zilhão and Trinkaus, 2002). Located at an altitude of 90 m, along the base of an E-W oriented calcareous cliff at the exit of the Lapedo Valley, a short fluvial gorge cut in Upper Cretaceous limestone at the edge of the Pousos syncline (Teles, 1992), LV site contains a several-meter-thick succession spanning late Marine Oxygen Isotope Stage 3 (MIS 3) and early-mid MIS 2 times (Angelucci, 2002a,b). The large number of field units recognised during excavation was later grouped into six geoarchaeological complexes separated by five main disconformities (Fig. 6). The chronological framework for the Lagar Velho succession is supported by twenty-three radiocarbon dates obtained on charcoal and bone samples (see Pettitt et al., 2002; Zilhão and Almeida, 2002).

The earliest phases of deposition are represented by the alluvial sediments of the GC6 complex, which was truncated by an erosive event that took place between ca. 29,585–30,230 cal yr BP (OxA-10674) and 32,123–37,448 cal yr BP (OxA-11318) (Table 1 and Fig. 6).

From this moment onwards, the Lagar Velho system was dominated by gravity-driven processes, which worked through pulses and with periodic interruptions of the accumulation. The sedimentary sources of the deposits were varied, and the sedimentary facies

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Table 1
Synthesis of characteristics and radiometric dating for three of the five geoarchaeologically studied sites.

Site	Site characteristics	GC[a]	Laboratory code	Material	Dating method	Date (^{14}C yr BP)	Calibrated age (cal yr BP)[b]	Age (yr)	Cultural attribution	Reference
Buraca Grande (BG)	Cave (second chamber)	1	Gif-9942	Charcoal	^{14}C conventional	4530 ± 20	5094–5290		Final Neolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	1	Gif-9941	Charcoal	^{14}C conventional	5030 ± 20	5746–5867		Middle Neolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	1	Gif-9497	Charcoal	^{14}C conventional	5670 ± 70	6382 – 6554		Early Neolithic (epicardial)	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	Sac-1458	Shell	^{14}C conventional	6560 ± 140	7332–7567		Late Mesolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	Sac-1461	Charcoal	^{14}C conventional	6850 ± 210	7537–7906		Late Mesolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	Gif-9940	Charcoal	^{14}C conventional	7000 ± 60	7764–7913		Late Mesolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	Gif-9707	Charcoal	^{14}C conventional	7580 ± 30	8380–8408		Early Mesolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	Gif-9679	Charcoal	^{14}C conventional	8120 ± 70	8998–9192		Early Mesolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	Gif-9939	Charcoal	^{14}C conventional	8445 ± 20	9470–9495		Early Mesolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	Gif-9708	Charcoal	^{14}C conventional	8680 ± 40	9577–9680		Early Mesolithic	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	GifA-96307	Bone	^{14}C AMS	11,390 ± 110	13,137–13,454		Upper Magdalenian	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	2	Gif-9502	Charcoal	^{14}C conventional	17,850 ± 200	20,966–21,875		Final Solutrean	Aubry et al. (1997)
Buraca Grande (BG)	Cave (entrance)	3	GifA-93048	Charcoal	^{14}C AMS	23,920 ± 300	28,355–29,255		Gravettian	Aubry et al. (1997)
Buraca Grande (BG)	Cave (second chamber)	–	OxA-5522[c]	Bone industry	^{14}C AMS	13,050 ± 100	15,525–16,356		Middle to Upper Magdalenian	Aubry et al. (1997)
Buraca Escura (BE)	Cave	2	OxA-5524	Bone	^{14}C AMS	21,820 ± 200	25,582–26,634		Final Gravettian	Aubry et al. (2001)
Buraca Escura (BE)	Cave	3	OxA-5523	Bone	^{14}C AMS	22,700 ± 240	26,934–27,813		Final Gravettian	Aubry et al. (2001)
Buraca Escura (BE)	Cave	3	GifA-97258	Bone	^{14}C AMS	26,560 ± 450	30,790–31,712		Gravettian	Aubry et al. (2001)
Buraca Escura (BE)	Cave	4	277[d]	*Equus* tooth enamel	U/Th	–	–	50,000 ± 30,000	Middle Palaeolithic	Almeida et al. (2003)
Buraca Escura (BE)	Cave	4	295[d]	*Equus* tooth dentine	U/Th	–	–	70,000 + 22,000/−19,000	Middle Palaeolithic	Almeida et al. (2003)
Buraca Escura (BE)	Cave	4	296[d]	*Equus* tooth dentine	U/Th	–	–	81,000 ± 16,000	Middle Palaeolithic	Almeida et al. (2003)
Lagar Velho (LV)	Rock-shelter	2	OxA-8420	Charcoal	^{14}C conventional	21,180 ± 240	24,918–25,758		Final Gravettian	Zilhão and Almeida (2002)
Lagar Velho (LV)	Rock-shelter	2	OxA-8418	Charcoal	^{14}C conventional	22,180 ± 180	26,212–27,371		Final Gravettian	Zilhão and Almeida (2002)
Lagar Velho (LV)	Rock-shelter	3	OxA-9571	Bone	^{14}C AMS	23,130 ± 130	27,273–28,112		Final Gravettian	Zilhão and Almeida (2002)
Lagar Velho (LV)	Rock-shelter	3	OxA-9572	Bone	^{14}C AMS	23,170 ± 140	27,510–28,142		Final Gravettian	Zilhão and Almeida (2002)
Lagar Velho (LV)	Rock-shelter	4	Beta-139361	Charred bone	^{14}C AMS	> 22,720 ± 90	27,027–27,803		Final Gravettian	Zilhão and Almeida (2002)
Lagar Velho (LV)	Rock-shelter	5	OxA-10674	Bone	^{14}C AMS	24,950 ± 230	29,585–30,230		Gravettian	Zilhão and Almeida (2002)
Lagar Velho (LV)	Rock-shelter	6	OxA-11318	Bone	^{14}C AMS	29,800 ± 2500	32,123–37,448		?	Zilhão and Almeida (2002)

[a] Geoarchaeological complex.
[b] Calibration used CalPal with the Calcurve CalPal_2007_HULU (www.calpal-online.de). All the errors are 1-sigma.
[c] Undetermined stratigraphic position.
[d] McKinney C., Department of Anthropology, Southern Methodist University.

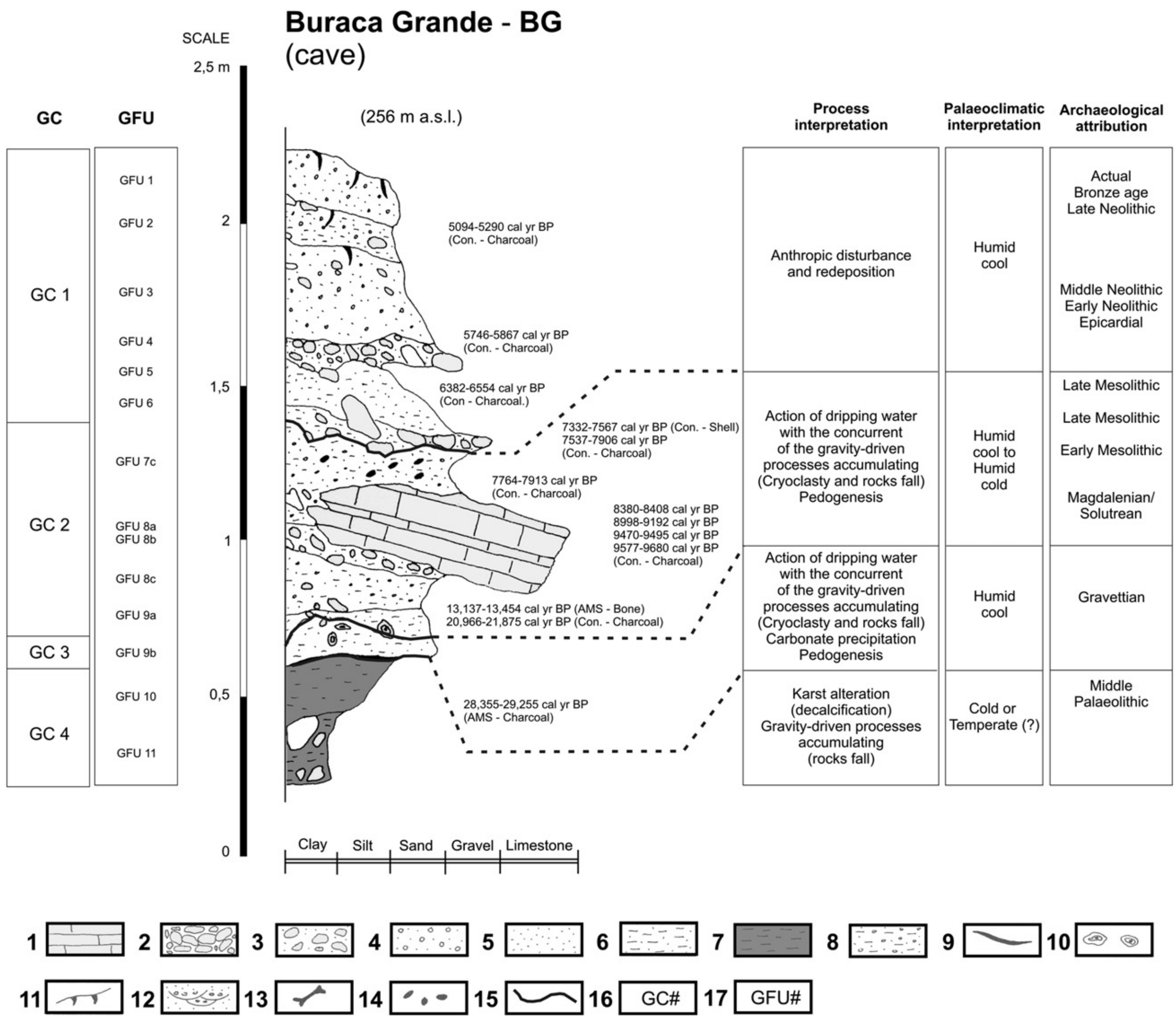

Figure 4. Buraca Grande synthetic log showing the archaeostratigraphic sequence.

indicate that slope accumulation was the main sedimentary mechanisms, with the energy being attenuated inside the rock-shelter. These facies denote intense erosion, probably as a result of a more or less severe loss of the vegetation cover all around the Lapedo Valley. The onset of such slope denudation processes is recorded in the GC5 complex, whose deposition started before ca. 29,585–30,230 cal yr BP (Angelucci, 2002a,b). The Lagar Velho child burial registers a short interruption in sedimentation. The sediments of the overlying GC4 complex document a massive accumulation of soil-sediment after ca. 30,000 cal yr BP, with a minor interruption before ca. 28,000 cal yr BP, which led to the formation of a shallow soil profile. Soil-sediment accumulation (GC3 complex) started again soon after, with the presence of anthropogenic conglomeratic pavements and features indicating that this was an episodic, not continuous process. A change in slope dynamics is recorded in the GC2 complex (see Angelucci 2002a,b for details), whose accumulation started after ca. 27,273–28,112 cal yr BP (OxA-8571) (Table 1 and Fig. 6). The lower boundary of this complex forms channels eroding the underlying sediment, indicating deep erosive surfaces, truncating the sedimentary fill of the rock-shelter. Such processes occurred repeatedly throughout the ca. 26,400–24,000 cal yr BP interval, leading to the formation of cut-and-fill features containing reworked anthropogenic material. This process may be linked to a shift towards colder and moister conditions, and its age corresponds to the beginning of the Last Glacial Maximum (LGM) interval as identified on the basis of magnetic susceptibility at Caldeirão Cave (Tomar) (Ellwood et al., 1998), ca. 30 km SE of Lagar Velho site.

The stratification of the upper unit is poorly preserved, due to agricultural terracing prior to discovery, and an almost three meter-thick succession is missing. The soil sealing the succession records various processes (decarbonation, brunification, and clay translocation) and is still undated. Taking into account its development, it is likely that this last episode of soil formation encompasses the entire Holocene and that accretion at the site came to an end in the Late Glacial period.

Results and discussion

Stratigraphic correlations

In the karstic archaeostratigraphic sequences of the Sicó Massif and Pousos syncline, a set of the upper geoarchaeological complexes (Vale das Buracas GC1–3, Buraca Escura's GC1–3, Buraca Grande's GC1–3 and Lagar Velho's GC1–5) contain Upper Palaeolithic and younger archaeological remains. At all these sites, as well as at Gândara de Outil 1 (Outil/Cantanhede Plateau), a main erosive event, materialized by a disconformity, has been detected at the base of the complexes containing the Upper Palaeolithic assemblages (Fig. 7).

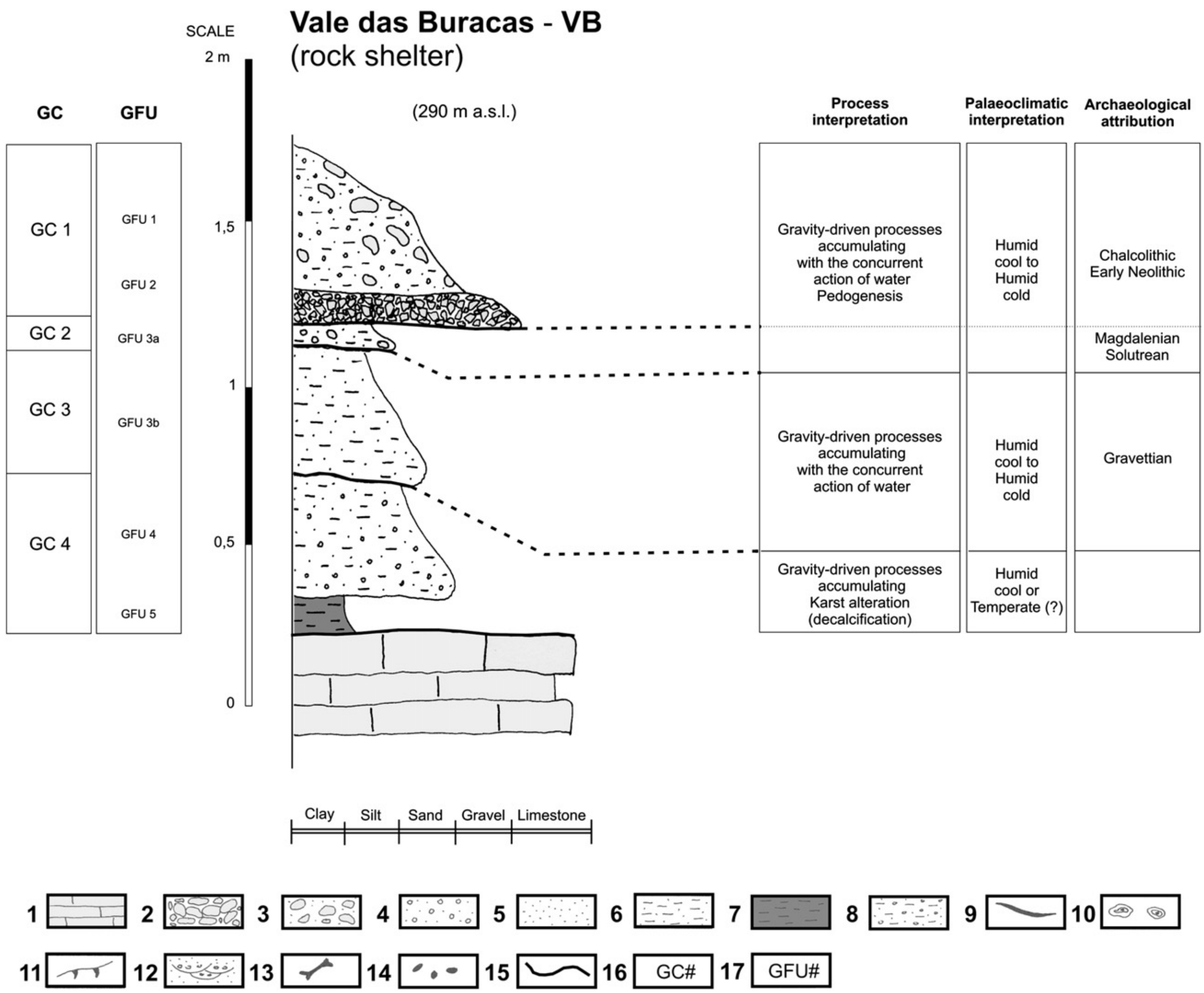

Figure 5. Vale das Buracas synthetic log showing the archaeostratigraphic sequence.

The dating of this erosive event is as follows (Table 1 and Figs. 3, 4 and 6): (i) at Buraca Grande, it cuts the GC4 complex and is capped by the GC3 complex and thus predating 28,355–29,255 cal yr BP; (ii) at Buraca Escura, it predates 30,790–31,712 cal yr BP and post-dates the ca. 50,000–100,000 yr interval indicated by the large-error U/Th results for GC4 complex; (iii) at Lagar Velho, it is dated to between 32,123–37,448 cal yr BP and 29,585–30,230 cal yr BP.

This disconformity separates the Upper Palaeolithic from underlying deposits featuring: (1) at Buraca Grande (GC4 complex), a small assemblage of lithic artefacts that is technologically consistent with a Middle Palaeolithic attribution; this complex is covered by the lower part of the GC3 complex, which contains a lithic assemblage of uncertain culture-stratigraphic affinities, typologically dominated by notches, and with no blade/bladelet production (Aubry et al., 2006); (2) at Buraca Escura (GC4 complex), Middle Palaeolithic stone tools extracted from Levallois or discoidal cores with hard-stone hammers (Almeida et al., 2003).

Correlation of these erosive and soil stabilization phases with possible regional environmental changes, particularly with cold phases, is supported also by the geochemical analysis of the Caldeirão Cave deposits (Cruz, 1990). In the sequence of the Caldeirão Cave several cold phases were detected with two clear peaks appearing: i) in the layers containing Solutrean assemblages (Zilhão, 1997; Elwood et al., 1998); and ii) at the base of level K, which yielded a Middle Palaeolithic lithic assemblage and underlies Upper Palaeolithic level Jb. Further down in the sequence, layer L features few but characteristic Middle Palaeolithic artefacts and hyena-accumulated faunal remains (Davis, 2003), and is separated from unit K by another major disconformity (Zilhão, 1997). Two of the three AMS radiocarbon bone results for level K were obtained on samples with a very low collagen content and are minimum ages only, while the third (of ca. 30,724–33,620 cal yr BP; OxA-1941 in Zilhão, 1997) is on a sample from the upper part of the level and, as such, could be intrusive. All were obtained in the early days of AMS radiocarbon bone dating and, as shown by recent re-dating of such samples with the new ultrafiltration pre-treatment (Higham et al., 2006), could be rejuvenated by several thousand years, even in the case of those for which the reported carbon and nitrogen contents are seemingly reliable; this is especially true for samples whose real ages are in excess of ca. 35,000 cal yr BP.

Palaeoclimatic interpretation

The climatic fluctuations of MIS 2 and 3 are fairly well-known on the Portuguese continental margin, and include various events of abrupt change (e.g. Lebreiro et al., 1995; Zahn et al., 1997; Bard et al., 2000; Shackleton et al., 2000; Thouveny et al., 2000; de Abreu et al., 2003; Skinner and Elderfield, 2007). During the last glacial period, Greenland Stadial–Interstadial cycles (also called Dansgaard–Oeschger, D/O cycles) are associated with severe changes in surface water temperatures (ca. 7°C in decades; de Abreu et al., 2003) and a periodicity of 1500 yr (Bond et al., 1997; Grootes and Stuiver, 1997; Debret et al.,

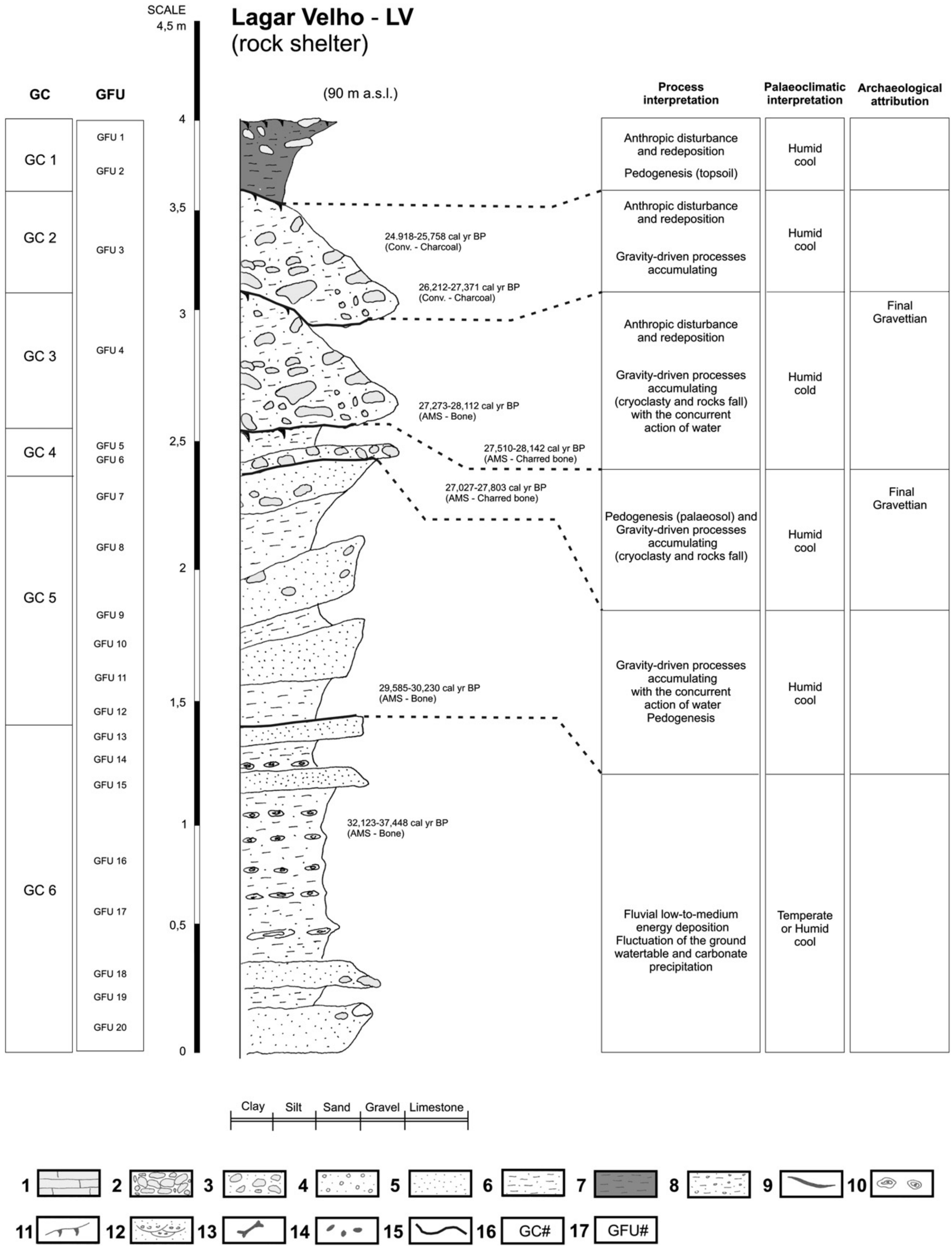

Figure 6. Lagar Velho synthetic log showing the archaeostratigraphic sequence.

2007). A number of stadial–intestadial cycles terminated in massive ice-discharges from the Northern Hemisphere ice sheets (Heinrich, 1988), every 7000–10,000 yr (Bond cycles; Bond and Lotti, 1995), known as Heinrich events (Bond et al., 1993). These Heinrich events (HE) have been described in cores along the Portuguese continental margin (Lebreiro et al., 1995; Cayre et al., 1999; Sánchez Goñi et al., 2000; Roucoux et al., 2001; D'Errico and Sánchez Goñi, 2003; de Abreu et al., 2003; Roucoux et al., 2005; Sánchez Goñi et al., 2008; Lebreiro

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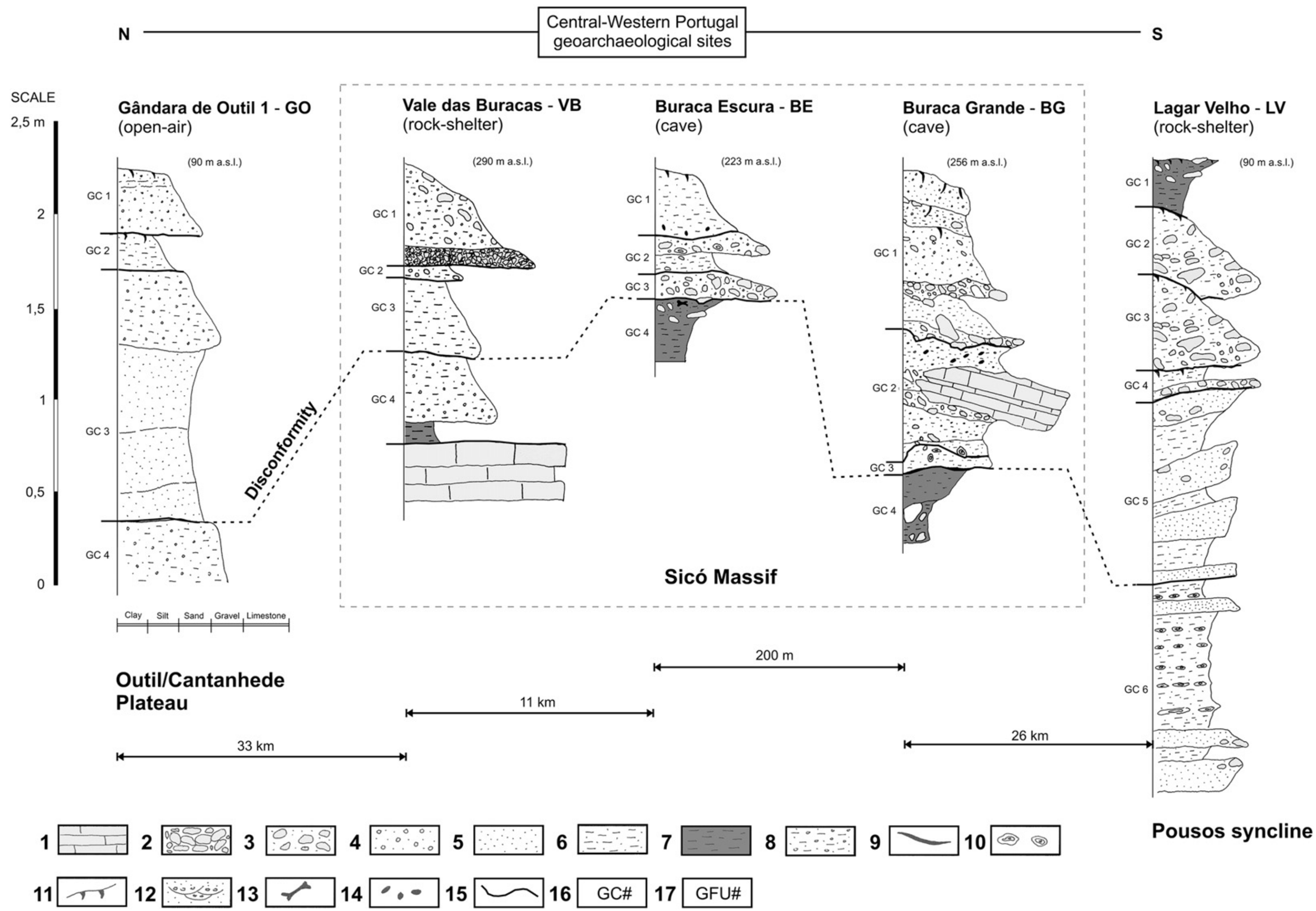

Figure 7. Stratigraphic correlation between the geoarchaeologically studied sites. The upper Geoarchaeological Complexes (GC) contain Upper Palaeolithic and younger archaeological remains.

et al., 2009), and reflect even cooler temperatures with sea-surface gradients of ca. 10°C in decades (de Abreu et al., 2003). During HE, ice-rafted debris was delivered when the polar front reached the Iberian Margin. Although the forcing mechanisms behind Greenland Stadial–Interstadial cycles are not yet fully explained (Schulz et al., 2002), ocean temperature changes have certainly influenced all the North Atlantic ocean (Bard et al., 2000), even southwards to the Iberian Margin, in the Gulf of Cadiz (Voelker et al., 2006) and the Alborán Sea (Cacho et al., 1999; Combourieu Nebout et al., 2002; Fletcher and Sánchez Goñi, 2008). Recent proposal by Debret et al. (2007) indicate that circum-Atlantic climate records cannot be explained exclusively by solar forcing, but require changes in ocean circulation. In detail, these cold events show a three-phase structure, with a lag between the drop in sea-surface temperatures and changes in the temperature of adjacent land masses revealed by contemporaneity between the ocean's initial cooling and the persistence of a still mild and wet climate in South-Western Europe (Sánchez Goñi et al., 2000; Naughton et al., 2007). Continental conditions rapidly oscillated through cold-arid and warm-wet environments in the course of these stadial–interstadial climate jumps. At the time of Heinrich events, correlations between marine and continental proxy data in a core off Portugal show large development of dry climate-type vegetation in the western Iberia, with low percentages of arboreal pollen during cold events and herb and shrub vegetation with steppe species dominating. Lowered temperatures and precipitation were also accompanied by intensified winds leading to increased upwelling (Boessenkool et al., 2001; Combourieu Nebout et al., 2002; Sánchez Goñi et al., 2002; Turon et al., 2003).

Achieving a precise chronology of the D/O and HE is the critical point to consistently link atmospheric, oceanic and sedimentary processes occurring at the high frequency of multi-centennial to millennial scales. The SFCP2004 time scale (Shackleton et al., 2004) unified different age scales (GISP2, GRIP, SS09sea), which are now accurate to a few hundred years, was used for core MD95-2042 on the Portuguese margin.

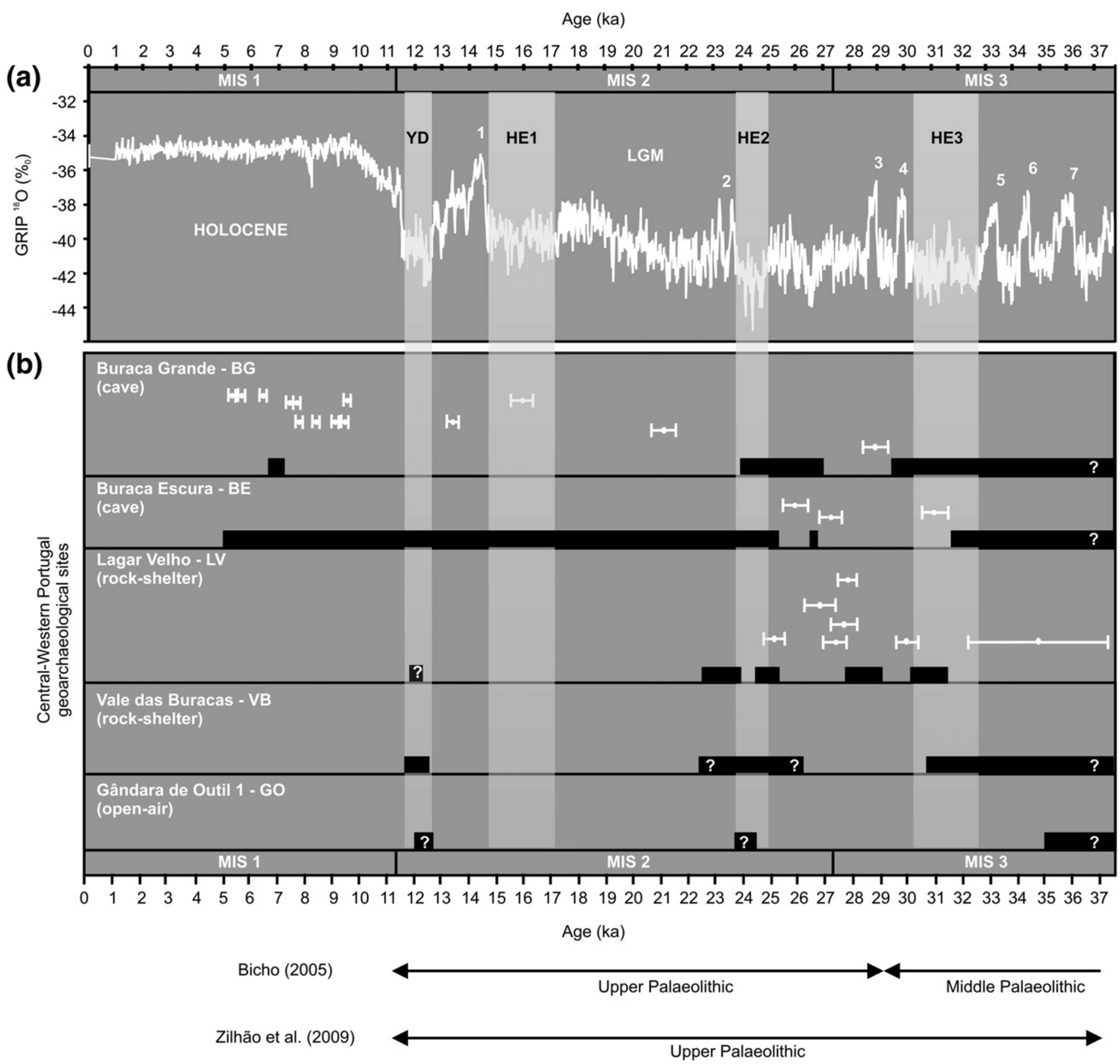

Figure 8. Tentative correlations between the Greenland ice core climate proxy record, Heinrich events, age of geoarchaeological studied sites samples and main erosive phases detected in the studied archaeostratigraphic sequences. (a) Greenland Ice Core Record (GRIP; Johnsen et al., 2001) plotted on the SFCP2004 time scale of Shackleton et al. (2004). Vertical stripes place Heinrich events (HE) 1–3, and the Younger Dryas (YD). Numbers 1–7 refer to the D/O or Greenland interstadials. (b) Narrow white bars correspond to radiocarbon calibrate age and error range for samples from geoarchaeological complexes studied. Black horizontal bars correspond to the likely sedimentation hiatus (disconformities) detected in this work. MIS = Marine Isotope Stage ($\delta^{18}O$), LGM = Last Glacial Maximum.

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At Lagar Velho, in the Pousos syncline, correlation of the two main erosive phases identified therein with the environmental changes brought about by the HE2 and 3 was previously proposed (Angelucci, 2002a,b) (Fig. 8). The sequences studied in the Sícó Massif provide evidence for one (or more) erosive event(s) that date to the same chronological interval as the earliest of the two Lagar Velho ones. We propose that this main archaeostratigraphic disconformity corresponds to the cold peak of HE3, dated to ca. 29,500–32,000 cal yr BP (Fig. 8) in cores MD95-2042 (37°48′N, 10°10′W, Tagus abyssal plain, 3146 m water-depth; Cayre et al., 1999; Sánchez Goñi et al., 2000, 2008), MD95-2039 (40°34′N, 10°20′W, ca. 180 km off the Portuguese coast, close to the latitude of the mouth of the Douro River at a water-depth of 3381 m; Roucoux et al., 2001, 2005) and in the pelagic piston core D11957P, located on the Tore Seamount (39°03′N, 12°36′W; Lebreiro et al., 1995). This disconformity, in fact, testifies to a sudden change of the climate impacts on the landscape, including reduced vegetation cover and altered precipitation patterns with the consequent accelerated down-cutting by stream systems, slope reactivation and endokarstic reorganisation.

The second of the Lagar Velho main erosional phases (dated to ca. 24,000 cal yr BP, after the middle Solutrean) is also recorded at Buraca Grande, strengthening the proposed correlation with the HE2, as detected in the MD95-2042, MD95-2039 (Lebreiro et al., 1995, 2009; Sánchez Goñi et al., 2000, 2008; Roucoux et al., 2001, 2005) and SU 81–18 cores (37°46′N, 10°11′W, at a water-depth of 3381 m; Turon et al., 2003).

Other minor erosive phenomena are recorded between the two main disconformities that we correlate with HE3 and 2 (Fig. 8). They may have been caused by hydrological changes which could indicate the transition toward harsher environmental conditions related with minor climatic modifications within an unstable rhexistasy mode. The characteristics of the deposits stratigraphically comprised between these two main disconformities are indicative of unstable environmental conditions, with alternating phases of sedimentation, non-sedimentation, soil formation, gravity-driven processes and underground water flow.

A terminus ante quem for the disconformity at the interface between levels K and Jb of the Caldeirão Cave that is consistent with correlation to HE3 is in any case provided by 30,576–31,372 cal yr BP (OxA-5542 in Zilhão, 1997) result obtained for level Jb. Further support for such a correlation comes from the high magnetic susceptibility measurements observed in layer L, which are suggestive of accumulation during a long, relatively mild, late MIS 3 interstadial (Zilhão, 1997; Ellwood et al., 1998).

Conclusions

Our results show that several disconformities (erosive unconformities), hiatuses and surface stabilization phases exist in several Pleistocene sequences of central-western Portugal containing cultural remains from the Middle Palaeolithic to the end of the Upper Palaeolithic. These results, derived from the geoarchaeological study of the sedimentary sequences of one open-air site and four karstic caves and rock-shelters, contribute to explain the scarcity of the evidence relating to the Middle–Upper Palaeolithic (MP–UP) transition in the region. These data also provide a better estimation of the impact of erosive processes and related palaeoenvironmental forcing on the differential preservation of archaeostratigraphic layers.

A main erosive phase that we correlate with the HE3 was detected in sites distributed along ca. 60 km of the Meso-Cenozoic Occidental margin of the Iberian Peninsula. This disconformity corresponds to a change of the environmental background towards colder conditions and reflects a climate control on the landscape. Even if during the later part of the Pleistocene (MIS2 and 3) the littoral environment of the studied region were characterized by large and relatively wet aeolian dune fields, shifting to drier conditions at the transition to the Holocene (Granja et al., 2008). At the time of Heinrich events the continental precipitation and temperature were most probably significantly modified. This was reflected in the alluvial regime (therefore hydrography, both superficial and endokarstic) and the vegetation cover, namely changing the overall density and the tree *vs.* shrub ratio. Such events were reflected in the depositional record due to changes in sediment availability (inverse to the vegetation cover) and transport capability (linked to the hydrographic regime). The radiometric dating of the deposits overlying the correlated disconformities places this erosive event no later than ca. 29,500 cal yr BP.

A new increase of the sedimentation rate or deposition renewal is detected in the 26,000–27,500 cal yr BP interval, during which the well-preserved "Terminal Gravettian" occupations took place at many sites in central-western Portugal (Aubry et al., 2001; Angelucci, 2002b; Zilhão and Almeida, 2002). Correlation between the period of stabilization and soil formation and D/O events 4 and 3 (Dansgaards et al., 1993), or interstadials 4 and 3 of the Greenland ice cores climate proxy record, post-dating the HE3, has yet to be confirmed.

The HE3-related major erosive event had a widespread effect in caves and rock-shelters containing the latest Middle and earliest Upper Palaeolithic occupations of central-western Portugal (although open-air sites do not seem to have been affected to the same extent). In this situation, the preservation of early Upper Palaeolithic remains in primary deposition in sites of the regional karstic areas is to be expected only in especially protected, uncommon depositional environments. Unless where localised and rapid deposition of sediments occurred, archaeological remains of this interval are likely to have been systematically eroded and/or reworked. This hypothesis is consistent with the fact that, in Portugal, most Aurignacian and early Gravettian sites are open-air (Zilhão, 1997), with occupations of these periods in caves being documented principally by finds of isolated, diagnostic lithic point types and the AMS radiocarbon dating of associated organic materials (Zilhão, 1997, 2006a,b; Zilhão et al., 2009). However, despite these erosion processes, Middle Palaeolithic remains revealing short human occupations alternating with carnivore-related accumulations are conserved in some caves of the Sicó Massif (Aubry et al., 2001), although none date to the very end of the period, except the case of level 8 of the Oliveira Cave, Torres Novas (Marks et al., 2001; Trinkaus et al., 2007; Angelucci and Zilhão, 2009).

At the broader geographic scale of southern Iberia, the reality and dating of the archaeological evidence pertaining to Middle Palaeolithic and Aurignacian lithic technologies after ca. 34,500 cal yr BP remain controversial (Bicho 2005; Finlayson et al., 2006; Zilhão 2006a,b; Zilhão and Pettitt, 2006; Cortés Sánchez, 2007; Zilhão et al., 2009). The few data available have been used to argue for a sudden rupture or for a long and diffuse spatiotemporal mosaic involving two different genetic populations in an interval ranging from ca. 40,000 cal yr BP (Mellars, 2006) to ca. 29,000 cal yr BP (Marks, 2000; Bicho 2005; Finlayson et al., 2006), or even ca. 24,000 cal yr BP (Carrión et al., 2008). A geoarchaeological approach and systematic surveys focusing on the detection of additional sites, either open-air or in favoured karstic geomorphological situations (aeolian deposits, sites where tectonic processes increased sedimentation rates, etc.) are necessary to overcome the current shortcomings of the evidence.

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