

Human adaptive responses to climate and environmental change during the Gravettian of Lapa do Picareiro (Portugal)

Jonathan Haws^{a,f,*}, Michael Benedetti^{b,f}, Milena Carvalho^{c,f}, Grace Ellis^d, Telmo Pereira^e, João Cascalheira^f, Nuno Bicho^f, Lukas Friedl^{f,g}

^a Dept. of Anthropology, University of Louisville, Louisville, KY, 40292, USA

^b Dept. of Earth and Ocean Sciences, University of North Carolina Wilmington, Wilmington, NC, 28403-5944, USA

^c Dept. of Anthropology, University of New Mexico, Albuquerque, NM, 87131, USA

^d Dept. of Anthropology and Geography, Colorado State University, Fort Collins, CO, 80523, USA

^e Dept. of History, Arts, and Humanities, Universidade Autónoma de Lisboa, 1169-023, Lisbon, Portugal

^f Interdisciplinary Center for Archaeology and Evolution of Human Behaviour (ICAR-EHB), Universidade do Algarve, Faro, 8005-139, Portugal

^g Dept. of Anthropology, University of West Bohemia, 30614, Plzen, Czech Republic

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ABSTRACT

On the Iberian Peninsula, abrupt climate shifts during the Late Pleistocene impacted human and natural systems. Our knowledge of human adaptive responses to these climatic perturbations has improved in recent years with the development of new radiocarbon techniques that have increased the temporal resolution of cultural chronologies. At the same time, new high-resolution paleoclimatic records from Greenland ice cores, deep-sea sediment cores, speleothems, and microfaunal assemblages have permitted detailed paleoenvironmental reconstructions. Combined with the archaeological record of culture change, these data sets allow for a better understanding of the nature of human socio-ecological systems during the Late Pleistocene. Here we present new data on the Gravettian occupations at Lapa do Picareiro, a cave site in Portugal with a long continuous stratigraphic sequence spanning MIS 3 and 2. The ongoing excavation of Lapa do Picareiro has revealed at least three Gravettian levels with very different patterns of raw material use and technological reduction. The Early Gravettian levels contain a quartzite flake assemblage with several refitting clusters and a small chert assemblage with nosed endscrapers and bladelet technology. The Late or Terminal Gravettian level contains carinated endscraper/core-bladelet technology, mainly quartz, with chert blade production, and a few bone tools. The faunal assemblages also have a different character. Both contain a similar range of medium and large ungulates but the earlier Gravettian has a much richer and more diverse assemblage of small animals. These combined archaeological data sets provide a new perspective on Gravettian human adaptations in response to climate shifts, especially Heinrich Event 3 and Greenland Interstadials 4 and 3.

1. Introduction

Climate variability is a key driver of environmental change and thus impacts human socio-ecological systems as well. Humans adapt to climate and environmental conditions through land-use patterns, technological and subsistence organization, and social networks to mitigate ecological risk (Burke et al., 2017). Global climate records from the deep sea and Greenland ice sheet document centennial and millennial-scale fluctuations between stadial and interstadial conditions during MIS 3 and 2 that affected ocean and atmospheric circulation that in turn

caused changes in temperature and precipitation impacting terrestrial ecosystems. During this period, humans successfully adapted to the abrupt climate shifts by maintaining social networks that allowed for cultural transmission and ensured reproductive success. Between ~33 ka and 25 ka technological innovations that characterize the Gravettian spread rapidly across Eurasia.

The Gravettian is characterized by considerable technological variability but widespread similarities in symbolic elements (Kozłowski, 2015). The broad distribution of Venus figurines, graphic representation in caves and rock panels, perforated animal teeth and shells point to a

* Corresponding author. Dept. of Anthropology, University of Louisville, Louisville, KY, 40292, USA.

E-mail addresses: jonathan.haws@louisville.edu (J. Haws), benedettim@uncw.edu (M. Benedetti), mcarvalho@unm.edu (M. Carvalho), m.grace.ellis@colostate.edu (G. Ellis), telmojpereira@gmail.com (T. Pereira), jmcasca@gmail.com (J. Cascalheira), nunofbicho@gmail.com (N. Bicho), lukas.friedl@gmail.com (L. Friedl).

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cohesive socio-cultural complex stretching from France to Siberia, albeit with regional variants in style and form. In much of Iberia, the linkages to the larger Gravettian world are evident in lithic technology, the use of personal adornments, and a general increase in the number and density of sites coupled with evidence for resource intensification (Straus, 2018).

The Gravettian in Portugal shares many of the technological characteristics of the western European tradition concentrated in south-western France (Douka et al., 2020). Clusters of sites in Estremadura, the Côa Valley, Alentejo, and a stratified sequence at Vale Boi, in Algarve, point to a marked increase in human presence on the landscape during the Gravettian time period (Bicho et al., 2015; Marreiros and Bicho, 2013; Straus et al., 2000; Zilhão, 1997). The chronological and technological organization of the Gravettian has been the focus of numerous studies over the last 25 years (Almeida, 2000; Almeida et al., 2009; Aubry et al., 2001, 2007, 2016; Bicho, 2000; Bicho et al., 2013, 2015, 2017a,b; Gaspar et al., 2016; Marreiros et al., 2013, 2015, 2018; Pereira et al., 2012a,b; Straus et al., 1988; Zilhão, 1997, 2000; Zilhão and Almeida, 2002). Subsistence is largely known through the analysis of faunal assemblages from a handful of sites including, Vale Boi, Picareiro, Anecrial, Lagar Velho, and Buraca Escura (Aubry et al., 2001; Brugal, 2006; Davis, 2002; Haws, 2012; Manne, 2014; Manne and Bicho, 2009; Moreno-Garcia and Pimenta, 2002). Glimpses into the symbolic and ideological realm are possible at Lagar Velho, where the well-documented child burial was found (Vanhaeren and d'Errico, 2002; Duarte, 2002), and Vale Boi, where dozens of shell ornaments have been found throughout the Gravettian sequence (Tátá et al., 2014).

Our knowledge of the Early Upper Paleolithic, and the Early Gravettian in particular, is relatively sparse compared to the Late and Terminal Gravettian. The reason for this pattern may be due to environmental forcing caused by climatic instability during late MIS 3 and MIS 2. Aubry et al. (2011) have argued that widespread erosion during Heinrich events, especially H3, effectively erased much of the record on the landscape. A few caves and shelters in the Mondego and Lis river region are marked by erosive discontinuities (Aubry et al., 2011). At the onset of MIS 2, sea level regression due to ice sheet growth lowered base levels in streams and climate changes reduced vegetation cover, exposing the land to widespread erosional episodes that continued through the LGM (Angelucci, 2002). Landscape instability during the Late Pleistocene had significant impact on the preservation of human activities.

The focus here is on Lapa do Picareiro, a cave site located in central Portugal that preserves an important, continuous stratigraphic sequence with minimal disturbance and no erosional discontinuities spanning all of MIS 3 and 2. The cave contains a stratified, multicomponent archaeological record of Late Middle and Upper Paleolithic human occupation. Our work at Lapa do Picareiro centers on fundamental questions about human response to climate and environmental change. In this article, we use the archaeological and geological records from Lapa do Picareiro to investigate the connection between abrupt climate change and human socio-ecological systems during the Gravettian. We investigate lithic technological change over time and how that might reflect human adaptive responses to environmental change. How did these climate shifts impact lithic technology and raw material procurement? And, do we have sufficient age control and stratigraphic integrity to determine any correlation between abrupt climate shifts and technological changes? To answer these questions, we use three main lines of evidence: sedimentological analyses, lithic assemblages, and radiocarbon dates. Sedimentological analyses, including magnetic susceptibility, link the cave deposits with North Atlantic records of Upper Pleistocene climate from the Greenland ice cores and regional ones from deep-sea cores off Portugal. We use stratified lithic artifact assemblages to identify patterns of technological change during this period. Radiocarbon dates provide age control for the sequence presented here. Faunal remains contribute preliminary data on local paleoenvironments during the Gravettian. Finally, we combine these data to synchronize a

diachronic record of abrupt climate changes and human ecodynamics between ~33–25 ka.

2. Cave setting

Lapa do Picareiro is a limestone cavern located 570 m a.s.l., on the west-facing slope of Serra de Aire, a karst mountain north of the Tagus River valley in west-central Portugal (Fig. 1). The cave is approximately 15×15 m and situated in a larger bedrock depression of roughly 25×30 m (Fig. 2). Full details of the cave sediments have been published and are summarized here (Benedetti et al., 2019). The sedimentary fill consists mostly of limestone clasts between 5 and 300 mm diameter supported by a matrix of fine silt and clay. The cave sediments have a $10\text{--}12^\circ$ inclination from the front with a slight inclination of about $2\text{--}4^\circ$ in the middle before levelling towards the back of the cave. The deposits run oblique to the main axis of the excavation grid, which has been in place since 1995 when the cave dimensions were much narrower and full of sediment. Beds of coarse and fine clasts tend to alternate suggesting semi-periodic variations in the weathering environment. Several beds are cemented by secondary carbonates, and others contain an abundance of large cobbles/boulders. Previous studies of site formation in limestone karst suggest that most of the éboulis is derived from roof spalling, large clasts from mechanical weathering or possibly tectonic events, and fine sediment from chemical weathering and percolation through cave wall fractures (Stein and Farrand, 2001; Woodward and Goldberg, 2001; White, 2007).

Lapa do Picareiro is a unique site in Portugal containing a thick and continuous sedimentary fill with archaeological remains from the Iron Age to the Middle Paleolithic. We have excavated a 10.6 m deep section with 36 Pleistocene-aged strata (Levels E-NN), almost all of which contain archaeological and/or paleoecological remains that increase in richness towards the back of the cave. These deposits contain a long Upper Paleolithic sequence in the upper 7 m with Middle Paleolithic occupations in the lower third. Most of the archaeology lies within the full range of radiocarbon dating. The ongoing excavation has not reached bedrock and ground penetrating radar (GPR) suggests another 3 m may exist below.

The four Late Magdalenian levels (E, F/G, I, J) dated 11.3–14.8 ka cal BP have been published in detail (Bicho et al., 2000, 2006; Haws, 2006; Haws and Hockett, 2006; Hockett, 1999; Hockett and Bicho, 2000; Hockett and Haws, 2002, 2009). Our recent work has focused on the Solutrean and Terminal Gravettian occupations (Levels N-U) dated 19.5–28 ka cal BP (Haws et al., 2019). We focus here on the earlier Gravettian levels (Levels V-X) dated 29.2–31.3 ka cal BP that contain lithic artifacts, faunal assemblages, and a single combustion feature. As the excavation is ongoing, we present here the preliminary results of the lithic and faunal assemblages, spatial analyses, and sedimentological context.

3. Materials and methods

The excavation was laid out using a 1×1 m grid system (Fig. 3). Each unit is excavated according to the natural stratigraphy and artificial levels of 5 and 10 cm are used within the thicker natural layers depending on the presence of archaeological levels. Artifacts, bones, features, and stratigraphic topography are mapped in three dimensions using a total station. All sediment is sieved through 2 and 4 mm mesh screens. The excavators embed different mesh sizes to separate the finer sediment from the larger fraction which is mostly limestone éboulis. The larger fraction is sorted in the field. The remaining sediment in the 2 mm screen is water-sieved in the laboratory in order to recover small bones, lithics and macrobotanical remains. This allows for the recovery of small rabbit and rodent elements, fish bones, shell fragments, stone chippage, personal ornaments and charcoal.

The stratigraphic levels identified to date were designated based on changes in clast size, color, mud content, firmness, and bone or charcoal



Fig. 1. Map of Iberia with the location of Lapa do Picareiro.



Fig. 2. Photographs of the cave from above, at the entrance, and the interior excavation.

concentrations. Sediment samples were collected at 10 cm depth intervals from the top of the sequence. The 10 cm sampling interval was the most practical without disrupting the archaeological profiles, given that many beds contain very little fine sediment, and many contain clasts larger than 5 cm in length. Results are presented in detail in [Benedetti et al. \(2019\)](#). Clasts were assigned a modal clast size category (very small to very large) and samples were measured to calculate a mean large clast

size (in mm). Additional sedimentological analyses were completed on the <2 mm fraction of the profile samples at the UNC Wilmington Soils & Sedimentology Laboratory.

Sediment samples for magnetic susceptibility (MS) analysis were collected from a stepped profile of the entire sequence. For this analysis, fine sediment was collected in 1 cm³ plastic boxes to standardize sample size and exclude large limestone clasts. Most of the profile was sampled

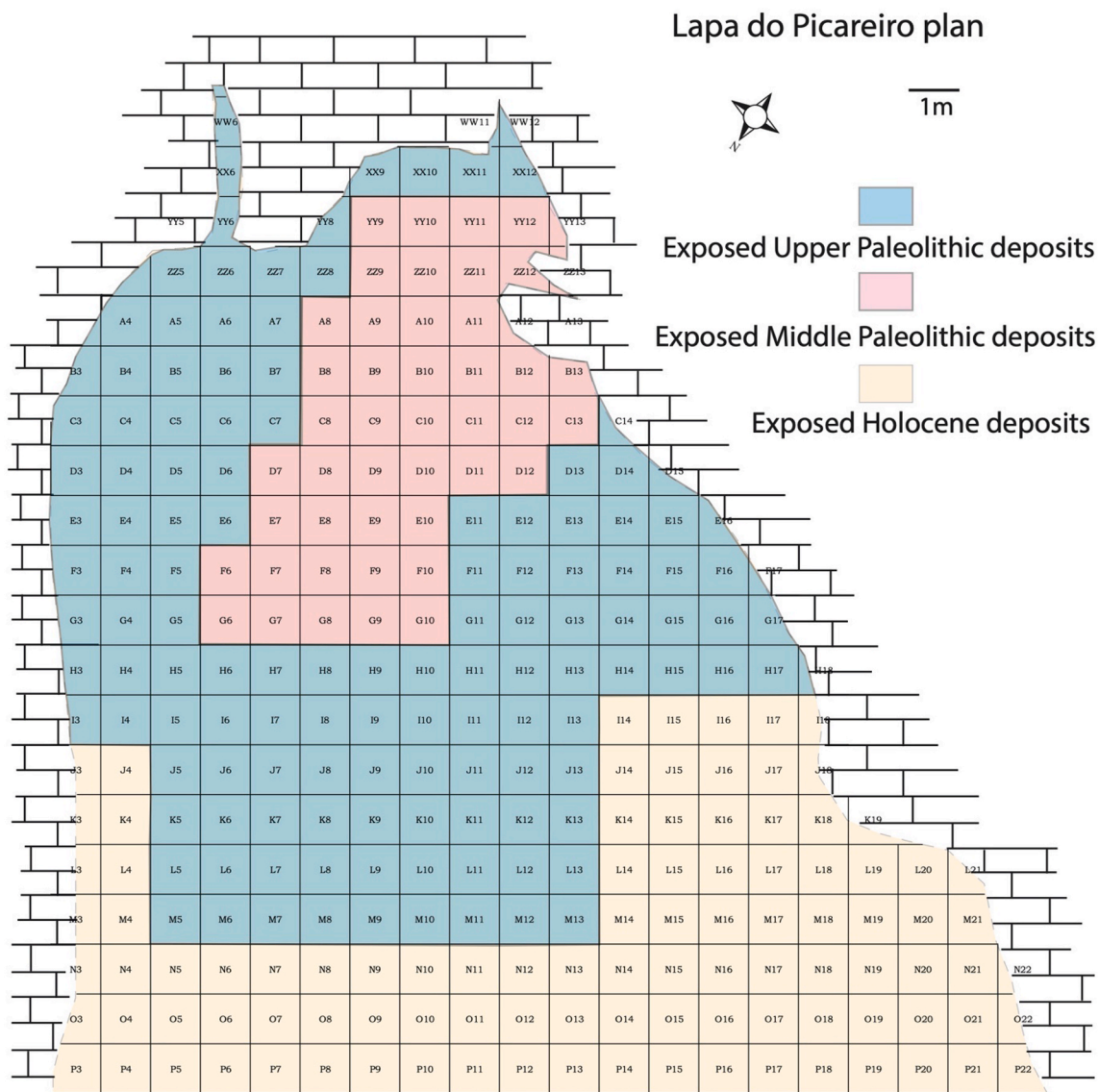


Fig. 3. Excavation plan of the cave.

at 2 cm depth intervals, although the interval is greater (up to 5 cm) in strata containing very little fine sediment. MS was measured using the susceptibility bridge at Louisiana State University, described in [Ellwood et al. \(1998\)](#). Data from the Terminal Pleistocene were published in [Ellwood et al. \(2001\)](#), which also describes the analytical procedures used, discusses the interpretation of MS in cave settings, and compares the magnetic stratigraphy of several cave sequences across southern Europe.

Age control for archaeological and sedimentary sequence at Lapa do Picareiro comes from 80 radiocarbon dates run on charcoal and bone. These samples were collected to establish the age of archaeological features and stratigraphic levels throughout the excavation. Sample depths were recorded during excavation, including bulk charcoal samples collected from excavation spits. The samples were analyzed at four different radiocarbon laboratories (Curt-Engelhorn-Centre of Archaeometry, Waikato Radiocarbon Dating Lab, University of Georgia Center for Applied Isotope Studies, and Beta Analytic, Inc.). Bone samples that were pre-treated by the well-documented ultrafiltration method provide more accurate age determinations ([Brock et al., 2013](#); [Bronk Ramsey et al., 2004](#); [Talamo et al., 2012](#)). At Waikato, bone samples were decalcified in 2% HCl, rinsed and dried. Then they were gelatinised at pH = 3 with HCl at 90° for 4 h, ultrafiltered, and freeze dried. These

samples have C:N ratios within the range of 3.0–3.5, indicating good preservation of bone collagen. Charcoal samples at all three labs were pre-treated using the traditional acid-base-acid (ABA) method. The samples were treated with 5% HCl at the temperature 80 °C for 1 h, then they were washed and with deionized water on the fiberglass filter and rinsed with diluted NaOH to remove possible contamination by humic acids. After that the samples were treated with diluted HCL again, washed with deionized water and dried at 60 °C. The cleaned samples were then combusted at 900 °C in evacuated/sealed ampoules in the presence of CuO. The resulting carbon dioxide was cryogenically purified from the other reaction products and catalytically converted to graphite.

Artifact and bone analyses were done at the Interdisciplinary Center for Archaeology and Evolution of Human Behavior (ICArEHB) at the Universidade do Algarve. Methods follow those used previously in [Bicho et al. \(2006\)](#). Lithic assemblages were analyzed using a techno-typological approach focused on raw material use, refitting, core preparation, and blank or flake attributes including platform type, dimensional analysis and the degree of retouch. Faunal assemblages are used here as an independent means to track paleoenvironmental change through time since they contain inputs from multiple taphonomic agents. Thus, they are not biased solely by human diet choice but reflect

a broader range of animal communities on the landscape. Taxonomic identification of the faunal remains was done using comparative reference collections at the Laboratório de Arqueociências of the Direcção-Geral do Património Cultural (DGPC) in Lisbon and the Estación Biológica Doñana of the Consejo Superior de Investigaciones Científicas (CSIC) in Seville. This preliminary work enabled us to establish the composition of the assemblages and correlate changes in species representation with the sedimentological and magnetic susceptibility results in order to achieve a high resolution record of environmental response to climate change. Ongoing taphonomic analyses follow methods outlined in Lyman (1994), Lloveras et al. (2008), and Fernández-Jalvo and Andrews (2016). The full taphonomic and subsistence details are beyond the scope of this paper. Instead, the focus here is on the taxonomic and paleoenvironmental information provided by the diverse range of sources for animal bones in the caves.

4. Results

4.1. Stratigraphy and dating

The levels containing Gravettian occupations include Levels X, W, U, and T. The occupations occur in a ~80 cm thick representing ~4,000 years.

Level X is a small-medium (2–4 cm) limestone clast layer with very little fine sediment that varies in thickness (10–30 cm) across the cave. The layer contains mainly small animal and some ungulate bones along with chert artifacts often patinated. Radiocarbon dates on charcoal and medium-sized ungulate long bone provide an age of 31.4–30.8 ka cal BP (Table 1).

Level W is a ~20 cm thick layer characterized by small and medium (2–4 cm) limestone clasts in a reddish-brown, muddy matrix (Fig. 4). The layer traces well across the cave varying between 15 and 25 cm in thickness. This layer contains relatively abundant faunal remains and a small quartzite lithic assemblage described below. A medium-sized ungulate long bone sample returned a radiocarbon date of 31.1–30.2 ka cal BP.

Level V is a 10–20 cm thick layer of large (5–15 cm) limestone clasts that occurs unevenly across the cave. This deposit was partially cemented on the left margin of the cave. The layer contains sparse lithic artifacts and relatively abundant animal bones in the rear portion of the cave. The radiocarbon date of 30.1–29.2 ka cal BP derives from a medium-sized ungulate long bone shaft fragment.

Level U is a ~15 cm thick layer of medium-sized limestone clasts with varying amounts of muddy fine sediment. In the center portion of the cave, this layer had very little fine sediment but in the back of the

cave the mud content increases so that it doesn't distinguish much from the overlying Level T deposits. The layer contains quartz and chert artifacts and abundant animal bones, especially in the back of the cave where muddy content occurs.

Level T is roughly 50 cm thick and marked by medium-sized limestone clasts with reddish-brown muddy fine sediment. The lower ~15 cm contains lithic artifacts and abundant faunal remains. Radiocarbon determinations on charcoal recovered from the lower excavation spits give ages of 28.1–27.2 ka cal BP.

4.2. Archaeology

The excavation has only recently encountered Early Upper Paleolithic archaeology in the deeper cave deposits. As the excavated area increased towards the back of the cave, new evidence of human occupation emerged. In 2015, we opened a sealed off niche in the rear cave wall that measured about 3 × 3 m in diameter. This area yielded a series of Upper Paleolithic combustion features with associated artifacts and animal remains. The details of the Solutrean and possible Proto-Solutrean levels have been published (Haws et al., 2019). An in-depth technological analysis of the lithic industries from the Terminal Gravettian and Proto-Solutrean using the assemblages from Picareiro and Vale Boi is included in this volume (Belmiro et al., n.d.). The combined artifact and faunal assemblages are summarized below. In the last five seasons, additional lithic artifact assemblages have been recovered in Levels X and W, attributed to the Gravettian on the basis of their stratigraphic position, dating and technological attributes. There appears to be two components, one which a small lithic scatter associated with the combustion feature, and a second component with large quartzite flakes and chert blades/bladelets. The fauna include ungulates, mainly red deer and ibex. These levels also contain a superabundance of small animal remains including rabbit, birds, and microfauna, often in clusters indicative of non-human avian and mammalian predators. The artifacts and their spatial distribution are discussed below along with the associated hearth feature and faunal assemblages.

4.2.1. Early Gravettian

Level X has extremely sparse archaeological evidence. The only feature encountered during the excavation was a circular concentration of charcoal roughly 50 cm in diameter and with a vertical thickness of about 15 cm (Fig. 5). Charcoal from this feature returned a date of $27,230 \pm 80$ BP (UGAMS-23723). A few patinated chert flakes were found in the same small gravel deposit within 1 m away from the edge of the feature. Additional lithic pieces, equally patinated, were encountered in the same level towards the back of the cave. These were limited

Table 1
Radiocarbon dates for the levels dated to the Gravettian time period.

N	Cultural affiliation	Lab number	Sample material	¹⁴ C age	cal BP range ^a (2-sigma)	Yield (%)	δ ¹³ C (‰)	%C	C:N
(T6)		UGAMS-29380	charcoal	23,850 ± 60	28,159–27,758		–22.2		
(T8)	Terminal Gravettian	Wk- 37656	charcoal	23,097 ± 131	27,676–27,203		–23.8		
U	Terminal Gravettian	Beta-208222	charcoal	22,660 ± 240	27,352–26,389		–26.1		
		Beta-234373	charcoal	22,560 ± 110	27,180–26,456		–23.1		
		Beta-234374	charcoal	22,590 ± 110	27,210–26,453		–23.8		
V	Gravettian	Wk-31353	bone	25,579 ± 173	30,135–29,285	0.5	–20.2	44.27	3.31
W	Gravettian	Wk-30539	bone	26,505 ± 270	31,130–30,205	0.38	–19.4	42.3	3.2
X	Gravettian	UGAMS-23723	charcoal	27,230 ± 80	31,474–31,087		–24.2	56.95	
		MAMS-42271	bone	26,680 ± 80	31,111–30,836	7.1	–19.8	44.2	3.1
Y		Wk-41389	bone	28,430 ± 210	33,272–31,877	0.2	–19.0	41.04	3.29
Z		MAMS-42272	bone	28,330 ± 90	32,970–31,978	6.0	–18.9	42.5	3.0
		Wk-30538	bone	28,161 ± 329	33,280–31,412	0.1	–19.6	43.5	3.3
		Wk-32280	bone	29,054 ± 224	34,226–32,976	0.5	–19.4	43.48	3.24

^a Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The IntCal20 northern hemisphere radiocarbon age calibration curve (0–55 cal kBP). Radiocarbon, 1–33.

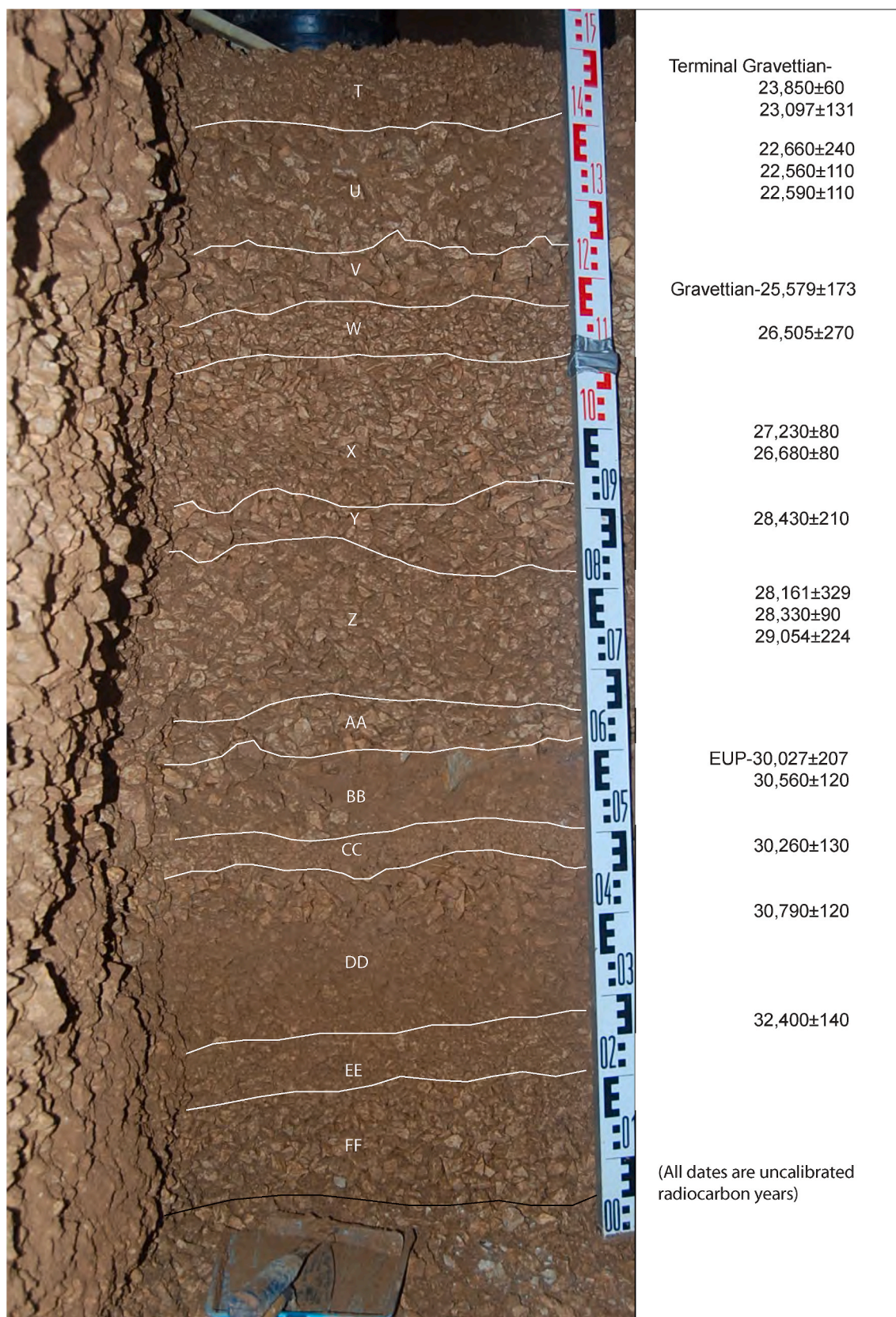


Fig. 4. Stratigraphic profile showing the levels discussed in the text.



Fig. 5. Hearth feature in Level X shown in profile, plan view, and an adjacent circular arrangement of large clasts. Also shown is a cluster of small animal bone characteristic of Level X.

to a small exhausted bladelet core, a backed bladelet, and several flakes (Table 2; Fig. 6).

Faunal remains are equally infrequent in Level X. Identified remains include a few specimens of red deer (*Cervus elaphus*) and a small number of medium ungulate bones (Table 3). The majority of the faunal remains are dominated by rabbit (*Oryctolagus cuniculus*), micromammals, including moles (*Talpa occidentalis*), birds, lots of amphibians, mainly common toad (*Bufo bufo*), and a single Cyprinae fish vertebra (Tables 4–6). The small animal bones are often clustered in patches (Fig. 6).

Level W contains a relatively larger lithic assemblage but of a different character. The small assemblage is dominated by quartzite with a few quartz and chert artifacts. The quartzite portion is mostly flakes and chips with a few retouched pieces and a single core (Fig. 7). These have been the subject of a refitting exercise that resulted in eight clusters representing several nodules that were brought to the site whole (Fig. 8).

The faunal assemblage is again dominated by rabbit but also includes

red deer and ibex (*Capra pyrenaica*). Horse (*Equus* sp.) is also present. A small number of lynx (*Lynx pardinus*) remains have been identified. Birds are also present in Levels X and W. Both levels contain similar taxa including partridges (*Alectoris rufa*), thrushes (Turdidae), passerines, and corvids, mainly (*Pyrrhocorax* and *Corvus*). The amphibian assemblage is slightly richer in taxa, including frogs (*Rana*) and the Iberian spadefoot toad (*Pelobates cultripes*) and Iberian endemic species. A cyprinid fish vertebra was also recovered in this level.

4.2.2. Terminal Gravettian

The lower part of Level T and all of Level U contains a ~30 cm-thick Terminal Gravettian archaeological deposit (Haws et al., 2019). These layers have abundant bones and charcoal but lack well-preserved hearth features. In the rear left part of the cave, associated with the majority of the lithic artifacts, the deposits are characterized by patches of dark brown sediment with small, dispersed pieces of charcoal. A few lenses are visible in profile. The overlapping radiocarbon dates on charcoal samples suggests some vertical movement due to bioturbation, but the

Table 2
Lithic artifact counts by raw material and class.

Class	LowerT/U			V			W			X			Total
	Quartzite	Quartz	Chert	Quartzite	Quartz	Chert	Quartzite	Quartz	Chert	Quartzite	Quartz	Chert	
Flake		15	5	1	2	2	19	4	2		3	9	62
FlakeFrag							9						9
Blade			5						1				6
Bladelet		94	26			1						2	123
RetouchedPiece			1				6		3				10
Core		3					1	1	1			1	7
CoreFrag							1						1
CorePreparProd							1						1
Hammer		1			1		1						3
Shatter													0
Chip	2	80	12				16	1			2	6	119
Total	2	193	49	1	2	3	54	6	6	0	5	18	341

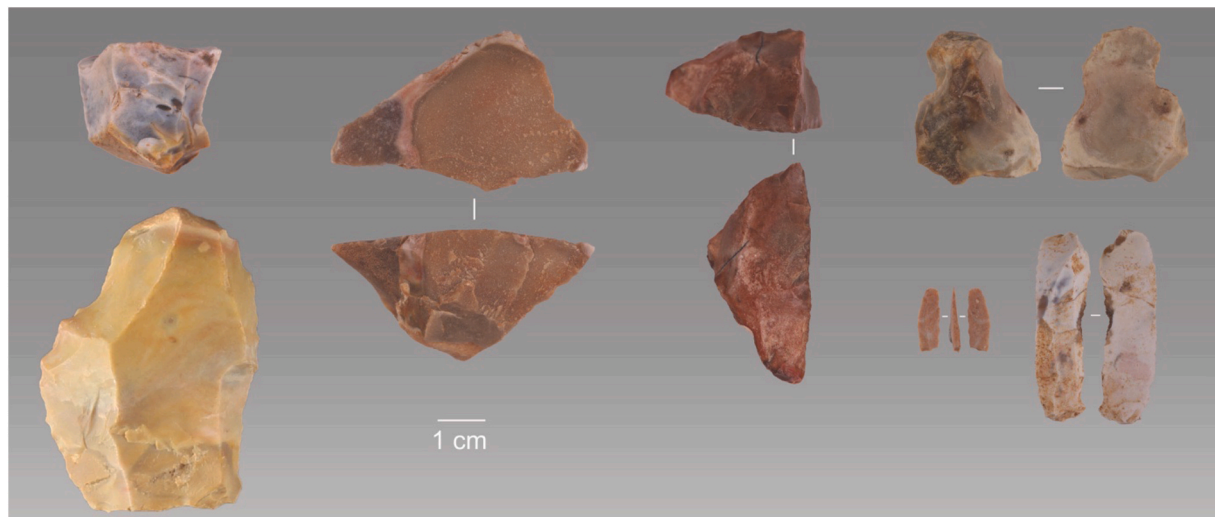


Fig. 6. Chert assemblage from Level X and W.

Table 3

Mammalian taxa from Levels Z-T in Picareiro.

Taxon	Lower T	U	V	W	X	Y	Z
<i>Cervus elaphus</i>	21	12	2	18	1		3
<i>Capreolus capreolus</i>		1					
Cervidae	1						
<i>Capra pyrenaica</i>	24	1	1	21		3	3
<i>Rupicapra rupicapra</i>				1			1
Capridae					1		
<i>Sus scrofa</i>	2						
Medium ungulate	671	111	194	1,237	23	13	31
<i>Equus caballus</i>	3		1	1			1
<i>Lynx pardinus</i>	14	4	2	7	1		1
<i>Felis sylvestris</i>	1						
<i>Canis lupus</i>	3						
<i>Vulpes vulpes</i>	1						
<i>Ursus</i> sp.							2
<i>Oryctolagus cuniculus</i>	7,138	4,205	896	3,405	673	2	60
subadult	537	341	36	328	55		
<i>Lepus granatensis</i>				1			
<i>Erinaceus europeus</i>				1			
<i>Talpa occidentalis</i>	36	28	5	17	10		
Muridae	40	10					
Micromammal	409	240	54	767	92	0	1

artifact and bone plots indicate a distinct occupation horizon from the layers above and below that contain different raw material and technological characteristics (Fig. 9).

The few artifacts found in Level V appear to be technologically related to the lower Level T/U assemblage but the 2019 excavation encountered a distinct charcoal lens in between Level W and U. Further excavation may yield more evidence for a discreet occupation during this period of deposition.

The lithic assemblage from lower Level T/U is relatively small (~200 pieces) compared to other sites, but is much larger than the Level X-W deposits. This assemblage is presented in detail by Belmiro et al. (this volume) and is only summarized here (Table 2). The occupations of lower T/U mainly involved bladelet production from carinated end-scrapers/cores (Fig. 10).

Lower T/U also contains evidence for bone tool use but these are fairly rare. The finds include a bone point fragment and two horse 3rd metapodials in proximity to a couple of perforated marine shells. The

Table 4

Herpetological taxa from Level Z-T in Picareiro.

	T	U	V	W	X	Y	Z
Anura							
<i>Rana perezi</i>	4	2		2			
<i>Rana iberica</i>	2	1		1			
Ranidae	6	3					
<i>Bufo bufo</i>	119	150		30	21	14	21
<i>Bufo calamita</i>	28	31		6	1	2	1
Bufo	29	40		5			1
<i>Pelobates cultripes</i>	10	13		1			1
Anura	57	11					
Testudines							
Testudinidae	1					1	
Caudata							
<i>Proteus anguinus</i>		1					
Squamata							
Squamata							1
Total indet	2,138	241	337	1,132	556	1	22
Total	2,394	493	337	1,177	578	18	48

Table 5

Fish taxa from Levels Z-T in Picareiro.

Taxon	Lower T	U	V	W	X	Y	Z
<i>Salmo salar</i>	6	3	1				
<i>Salmo</i> sp.	2						
Salmonidae	2						
Clupeidae	2						
Cyprinidae	1	1	1	1	1		
Anguillidae							
<i>Anguilla anguilla</i>	2						
Fish	24	4	2	6			

bones may have been used as tools but they have not been formally studied. The lower T/U deposits yielded several perforated marine shells, mainly *Littorina obtusata*, and red deer canine teeth (Fig. 11).

Lower T/U faunal group is by far the richest taxonomically and in

Table 6

Avian taxa from Levels Z-T in Picareiro.

	Lower T	U	V	W	X	Y	Z
Galliformes							
<i>Alectoris rufa</i>	13	20	2	4	1	1	3
<i>Perdix perdix</i>	3	3	1	1	1		1
<i>Alectoris/Perdix</i>	2	1	1				
Pteroclidiformes							
<i>Pterocles orientalis</i>		1					
Columbiformes							
<i>Columba livia</i>			1				
Charadriiformes							
<i>Pluvialis apricaria</i>		3			1		
<i>Calidris canutus</i>	1	4					
<i>Tringa totanus</i>		1					
<i>Scolopax rusticola</i>		1					
Scolopacidae		2					
<i>Philomachus pugnax</i>		1					
Passeriformes							
<i>Turdus pilaris</i>	10	6	2	1	2	1	5
<i>Turdus merula</i>	2	1		1	1		
<i>Turdus philomelos</i>	1						
Turdidae	3	4		3	1		
cf. <i>Sturnus unicolor</i>				1			
<i>Passer sp.</i>		1					
Passeriformes	1						
Corvidae							
<i>Pyrrhocorax pyrrhocorax</i>	10	10		2	1		
<i>Pyrrhocorax graculus</i>	2						
<i>Corvus corax</i>	3						
<i>Corvus monedula</i>	3	7		1			
<i>Pica pica</i>	1						
<i>Garrulus glandarius</i>		1					
Corvidae	1					1	
Strigiformes							
<i>Asio flammeus</i>	1						
<i>Strix aluco</i>	1	1			1		
<i>Bubo bubo</i>	1						1
Accipitriformes							
<i>Aquila chrysaetos</i>	1						
<i>Aquila adalberti</i>				1			
Accipitridae	1	1					
Total indet Aves	462	475	155	669	142	0	22
Total Aves	538	544	162	684	150	3	32

Number of Identified Specimens (NISP). The large mammal remains in lower T/U include ungulates such as red deer, with ibex making secondary contributions. Chamois, wild boar, and horse are also present. The most abundant species is rabbit. In addition to lynx, a few other carnivores are present, including wild cat, wolf, and fox. There are also marked increases in the NISP and taxonomic richness of micromammals, birds, amphibians, and fish. At least 27 bird species have been identified in lower T/U. The best represented taxa include the red-legged partridge, *Alectoris rufa*, followed by thrushes (*Turdus* sp.) and corvids (*Pyrrhocorax* and *Corvus*). Raptors are represented by four species of owls, an eagle, and a falcon.

5. Discussion

The sedimentological record for the Gravettian-aged sequence compares very favorably with paleoclimate proxy records from Greenland and the deep sea off Portugal (Benedetti et al., 2019). An age-depth model for the cave sediments, sampled at an interval of 10 cm, yields slow accumulation rates of 0.09–0.26 mm a⁻¹ for a temporal resolution of ~300–1,100 years between consecutive samples (Benedetti et al., 2019). The MS data (2 cm sampling intervals) have a finer resolution of ~80–220 years between samples. These data are within the time scale of abrupt climate fluctuations of MIS 3–2, including Dansgaard-Oeschger and Heinrich events with durations of ~200–2,000

years (Hemming, 2004; Rasmussen et al., 2014). The sensitivity of other sedimentological data reported in Benedetti et al. (2019) to climate change appears to be quite variable. The % gravel, median large clast size, and MS values appear to match the periodicity of rapid climate fluctuations during MIS 3–2 (Fig. 12).

Generally, the levels with coarse éboulis, little fine sediment, and MS minima, correspond to cold, dry conditions, especially Heinrich events. Cold, humid periods corresponding to Greenland stadials (GS) tend to have smaller clasts with some fine sediment. The levels with MS peaks, muddy sediments with small-medium clasts correspond with relatively warm, humid conditions, matching Greenland interstadials (GI).

Dates for Greenland stadials and interstadials provided by Rasmussen et al. (2014) are used here for matching with the Picareiro record. GS-5.2, dated to 32.0 ka, correlates closely with level Y, an archaeologically sterile layer marked by large clasts with little fine sediment and low MS values, dated 33.2–31.8 ka cal BP. Level X, dated 31.4–30.8 ka cal BP and characterized by small limestone gravel with little reddish-brown fine sediment along with low MS values, appears to have formed under cool conditions during the latter part of GS-5.2. The influx of reddish-brown mud during the deposition of Level W is suggestive of the return to more humid conditions. The date of 31.1–30.2 ka cal BP for Level W accords with the onset of GI-5.1, at 30.8 ka cal BP. The large clast deposition of Level V, dated 30.1–29.2 ka cal BP, falls within the range of GS-5.1 and the generally accepted timeframe for H3 (30.6–28.8 ka cal BP). The dates for the lower part of Level T overlap with those from Level U. This may be due to inadequate cleaning of charcoal samples from Level U and new dates on bone are pending. The spike in MS values in lower T/U likely corresponds to GI-3, but better resolution is necessary.

The changes in lithic raw material use and technology also appear to be synchronous with the fluctuations in sediment texture and the MS values. Real shifts are apparent between Level X, with a small chert bladelet assemblage and level W, with its emphasis on quartzite flake production. The Level X assemblage is extremely small, lacking Microgravettes or Gravettes typical of the Gravettian. The condition of the artifact surfaces suggests that they were exposed to chemical weathering on the cave surface for a considerable period before burial. The Level W assemblage dates earlier in time than other EUP or Gravettian sites like Terra do Manuel, Alecrim, and Fonte Santa, but may be contemporary with Caldeirão level Jb (Pereira, 2012 a, b.). Quartzite industries are relatively common strategies for flake production throughout the Upper Paleolithic in Portugal (Pereira et al., 2012 a,b). Analyses of quartzite assemblages from several Gravettian, Solutrean, and Magdalenian sites show that six different reduction strategies for flake production existed in the Portuguese Upper Paleolithic: extensive, stepped, prismatic, centripetal, polyhedral, and random (Pereira et al., 2012 a,b). The Level W assemblage appears to follow the prismatic, stepped, and extensive reduction strategies based on the refittings. Furthermore, the refittings demonstrate a high degree of assemblage integrity suggesting a very short-term knapping event.

The complete quartzite reduction sequence is evident in Level W. Quartzite nodules were likely brought to the site as part of a provisioning of place strategy as outlined by Kuhn (1991, 1992). Quartzite flakes produced are not heavily retouched suggesting an expedient use of raw material although quartzite is not available in the immediate surrounds. The nearest sources are in the Tertiary gravels ~5 km away. Tools made from quartzite flakes are thought to be utilized for domestic activities such as scraping, cutting, and perforating various materials such as hides, wood, bones, and antler (Pereira et al., 2012b). Carcass processing appears to be a common activity throughout the Upper Paleolithic in Picareiro and especially during longer occupation sequences. The chert artifacts are few in number but are mainly retouched pieces and an exhausted core. The lack of cortical flakes and degree of retouch suggests that these artifacts were manufactured elsewhere and transported to the site as part of a personal tool kit.

A major shift in lithic technology and raw material use occurs

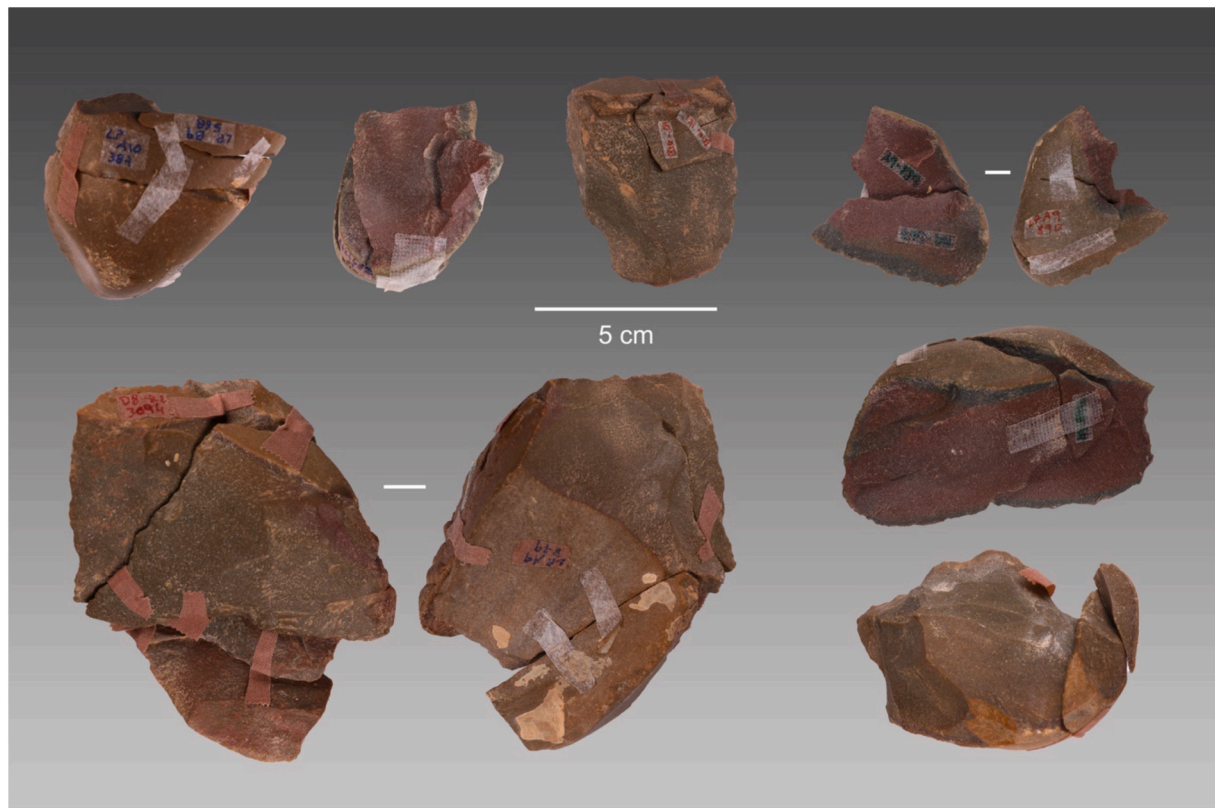


Fig. 7. Quartzite assemblage from Level W.

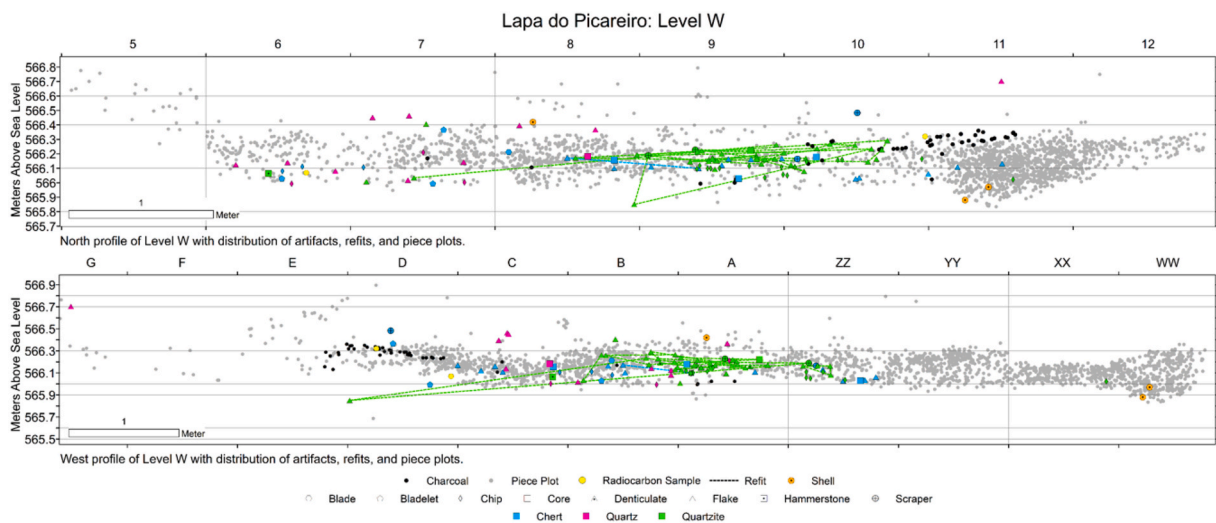


Fig. 8. Plot of Level W lithic artifacts and lines corresponding to refits.

between Level W and U. The quartzite industry disappears and a new one based on bladelet production. Quartz, which dominates the assemblage, was mainly used to produce small bladelets that were likely inserts for hunting tips as reported by Tomasso et al. (2018) for a Late Gravettian find in France. The preferential manufacture of weapons tips suggests a completely different use of the cave by people during the Terminal Gravettian. A significant portion of these were made from crystalline quartz, another common feature of Late and Terminal Gravettian raw material preference in Portugal (e.g., Almeida, 2000; Almeida et al., 2007; Aubry et al., 2007, 2016; Gaspar et al., 2016; Zilhão, 1997). Retouched quartz pieces are rare but the high number of chips, especially tiny ones recovered in the 1.25 mm screen suggests

manufacture and resharpening took place at the site. The preferred raw material, quartz, is not immediately available in the vicinity of Picareiro. The lower T/U lithic assemblage has a few discarded cores but not evidence for core preparation. In this case, prepared cores were brought to the site to make bladelets.

Chert use is also more frequent in lower T/U than the preceding Level W. The chert portion of the assemblage has more blades and retouched tools but with fewer chips suggesting a different intention for use of that raw material (Belmiro et al., n.d.).

Personal ornamentation further distinguishes the Terminal Gravettian from the Early Gravettian levels at Picareiro. Perforated marine shells and red deer canine teeth are also common elements of Late

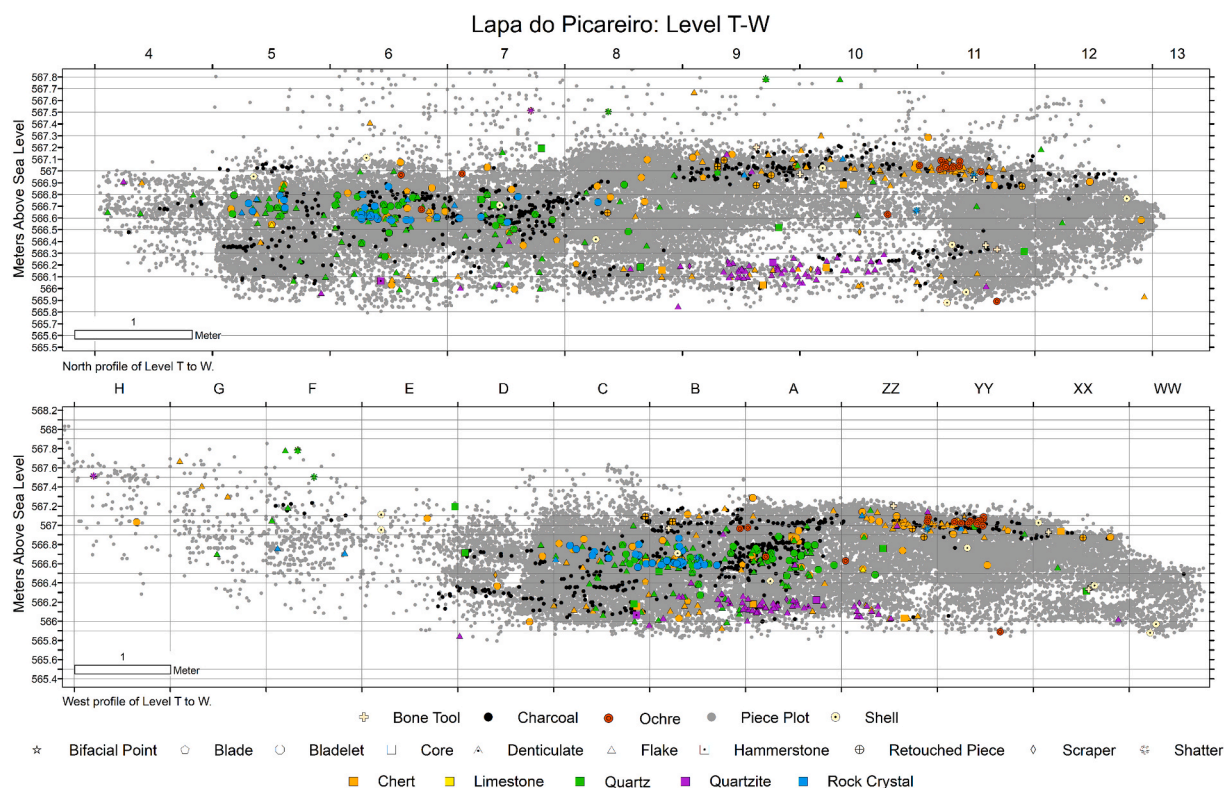


Fig. 9. Spatial plots of artifacts from Levels X-T.



Fig. 10. Quartz artifacts from lower Level T and U.

Gravettian sites in Portugal.

The faunal assemblages vary over time but the relationship to climate and environmental change is unclear. There appears to be a general increase in taxonomic richness through time, especially in lower T/U. This increase may represent improved climatic conditions that made the cave a more attractive location for human and non-human habitation. It may also reflect greater animal biomass due to more

abundant food sources. Notably absent in the assemblages are remains of now-extinct fauna. All species identified are from extant species on the Iberian Peninsula.

The small size of the faunal assemblage in Level X may be due to the reduced climatic conditions that made the cave location unattractive to humans and non-humans. The large mammal portion of the assemblage is highly fragmented into small pieces making taxonomic identification

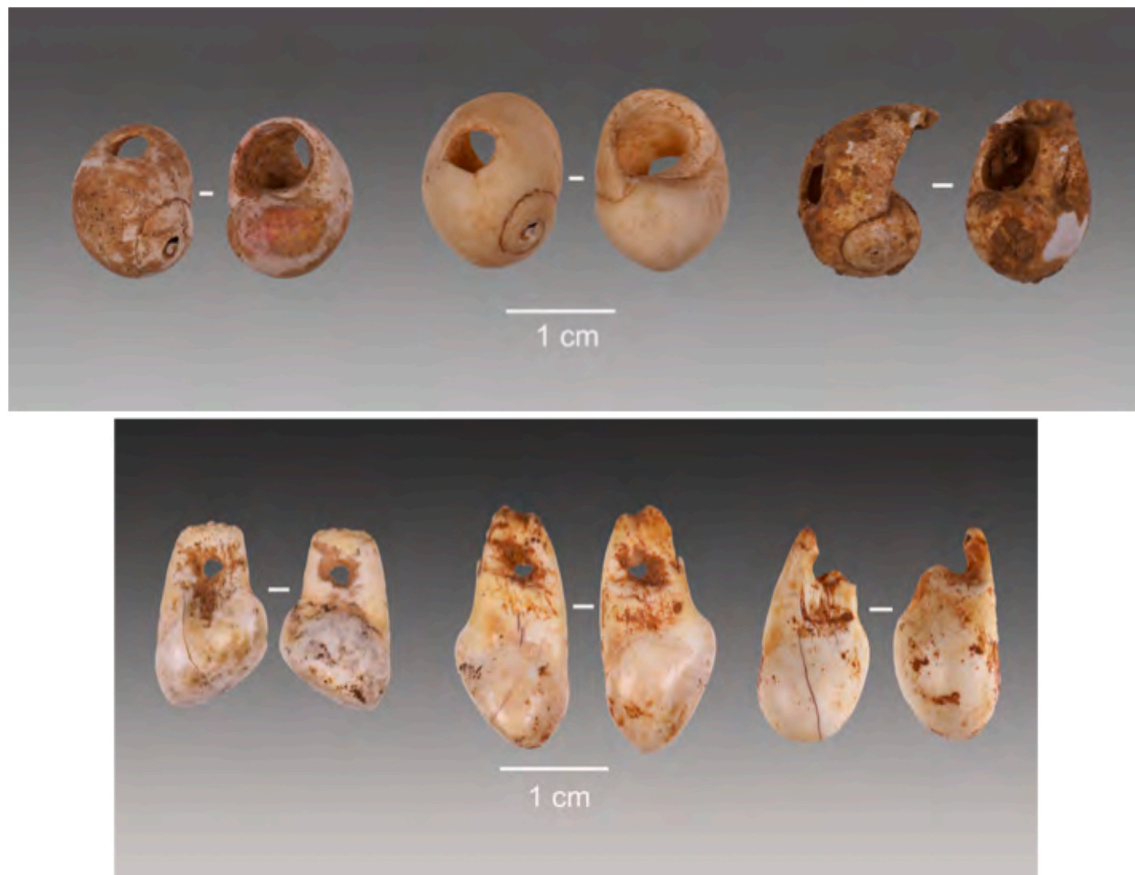


Fig. 11. Perforated shells and teeth from lower Level T and U.

difficult. A few red deer long bone shaft elements have evidence for percussion scars and breakage consistent with marrow extraction. Most of the small animal bones appear to be deposited by non-human predators possibly derived from degraded pellets, scats, or nests. The good preservation quality of these bones in scattered patches across the back of the cave suggests that the sparse evidence for anthropogenic faunal material reflects an absence of human occupation throughout much of the deposition time of Level X.

The presence of taxa such as *Talpa occidentalis* and Muridae indicate grass and shrublands near the cave during the Early Gravettian. The most abundant amphibians are Anurids, including the toads, *Bufo bufo*, *Bufo calamita*, and *Pelobates cultripes*. The former is common in different bioclimates across broad swaths of Eurasia. *Bufo calamita* is generally found in coastal dunes, heathlands and pine glades in northwestern and southwestern Europe. *Pelobates cultripes* and *Rana perezi* are endemic Iberian species living in a variety of habitats, including temperate and Mediterranean shrublands, marshes and lakes.

The faunal remains from level W are more abundant, likely due to improved climatic conditions that facilitated increased human occupation time. Ongoing analyses indicate a greater frequency of anthropogenic indicators such as percussion scars, impact fractures, and cut marks on the ungulate bones, except horse remains which do not show anthropic bone surface modifications. The lack of anthropogenic marks on rabbit bones and the presence of tooth punctures suggest that lynx may be responsible for much of the rabbit in this level.

The further increase in the number of taxa identified in lower T/U is related to a larger sample size but also suggests favorable climatic and environmental conditions in the region. The bones were deposited by human and non-human predators or scavengers. Archaeological signatures of human use of animals include percussion and impact fractures, few cutmarks, and limited evidence of burning. Non-human

intervention is evident by the presence of tooth scoring and punctures on young ungulate long bone shaft cylinders. On the small animal bones, mainly rabbits and birds, tooth and beak punctures, breakage patterns, and skeletal element representation suggest inputs by lynx and owls.

Lower T/U has a high taxonomic diversity of birds compared to the other levels, which could be due to increased activity in the cave due to warmer/wetter conditions. Most of these remains appear to be inputs by owls and lynx. The red knot, *Calidris canutus*, golden plover (*Pluvialis apricaria*), ruff (*Philomachus pugnax*), woodcock (*Scolopax rusticola*), and redshank (*Tringa totanus*) are found in lower T/U, associated with interstadial conditions. These species of waders indicate the nearby presence of water. The likeliest source is in the *polje* of Minde, which lies ~3 km from Picareiro. Today, the *polje* fills with water during winter if there is sufficient rainfall. Before industrialization water regularly filled this karst valley in winter and it was likely a permanent lake during the Late Pleistocene (Martins, 1949; Rodrigues, 1991). This may have been a magnet for plants and animals, including humans living in the area.

Overall, results of the investigation at Picareiro have important implications for our understanding of the Gravettian in Portugal and various models that have been proposed to explain aspects of the regional archaeological record (Aubry et al., 2011; Bicho et al., 2017; Bradmoller et al., 2012; Cascalheira et al., 2017; Haws, 2012; Schmidt et al., 2012). The linked radiocarbon and MS data demonstrate a continuous sedimentary deposition at Picareiro. The cave served as a sediment trap during a time in which many sites appear to have been eroded away. This rare sequence preserves a record of MIS 3 and 2 paleoclimate and paleoenvironmental change and human occupation.

During the Gravettian period, dated ~33–25 ka, the cave provided shelter to human groups whose purpose changed over time. The occupations record significant differences in the use of lithic resources and technological organization in phase with abrupt climate changes. It is

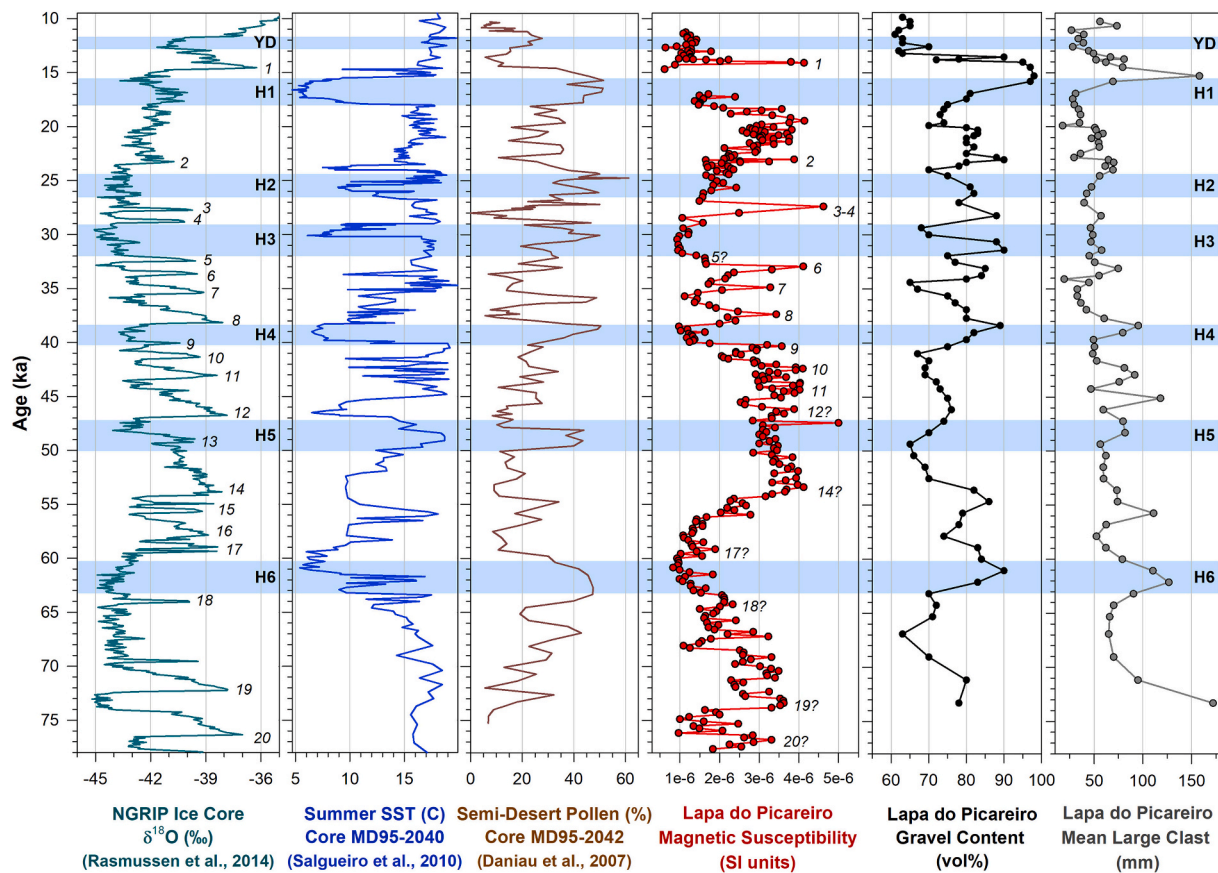


Fig. 12. Plot of sedimentological data against NGRIP and summer sea surface temperatures from the deep-sea off Portugal (Daniau et al., 2007; Rasmussen et al., 2014; Salgueiro et al., 2010).

important to note that these climate changes did not determine the nature of technological changes or in the specific use of the cave. We only observe that changes took place and that the technological and raw material preferences alternate in correspondence with the observed shifts in the sedimentary record. Because of the correlation between paleoclimatic changes and technological shifts, we cannot eliminate ecological factors in the explanation for these observed patterns. Thus, it is likely that technology and raw material selection were adaptations to changing environmental conditions but the nature of these changes were ultimately worked out through social relations. As Riel-Salvatore notes, “new technological systems are most likely to be developed and adopted under conditions of resource unpredictability and low overall residential mobility.” (2010: 339).

Changes in raw material preferences between Levels X and lower T/U could reflect shifting mobility patterns due to increasing resource unpredictability brought on by late MIS 3/early MIS 2 abrupt climate fluctuations. Quartz and quartzite are more commonly available on the landscape than chert, which is widespread but found in discrete locations near primary outcrops in the Jurassic and Cretaceous limestone uplands and the gravels of the Rio Maior, about 20 km away. Expedient, low-cost, flake technologies usually lack formal tools and assemblages exhibiting these characteristics are often associated with the use of quartz and quartzite. Chert is most often associated with bladelet production for weapons tips but during the Gravettian, microcrystalline quartz like rock crystal replaced chert in sites further away from sources (Thacker, 1996). This latter tool production strategy is easily maintainable as prepared blanks can be replaced and inserted into composite tools (Bleed, 1986). Thus, the observed changes in technology and raw material use at Picareiro could represent shifts between reliable vs. maintainable production strategies. Climate and environmental changes may have also constrained raw material availability and procurement

during MIS 2 (Pereira and Benedetti, 2013). Furthermore, the raw material preferences for flake production vs bladelet production and association of the former with domestic activities and the latter with hunting suggests that the cave served different purposes over time. Increased domestic activities might indicate more residential occupation time spent at the cave. Levels with mainly hunting hear might indicate more logistic use of the cave as a hunting station. Therefore, the changes in technology and raw material use could signal shifts in residential mobility patterns in phase with climate shifts observed in the sedimentary record.

The faunal assemblages show a pattern of increasing frequency during warmer and wetter climate phases and a decrease during cold, dry phases. Taxonomic richness appears to increase as the overall numbers of remains increase as well, however, we do not have enough data at this time to make proper evaluations of Gravettian subsistence. The species composition in each archaeological horizon is relatively stable. The medium-sized ungulates, red deer and ibex, show the most definitive evidence for human intervention. Rabbit was likely hunted with increasing frequency beginning in the Early Upper Paleolithic but the evidence from Early Gravettian sites is too sparse to identify a diachronic pattern (see also Lloveras et al., 2011). Most of the small fauna in the Gravettian levels at Picareiro lack signs of anthropogenic traces, having instead the telltale damage from mammalian carnivore and raptorial bird predation. Thus, they largely represent the natural background of animal communities in the cave vicinity but provide a critical source for paleoenvironmental reconstructions. Ongoing analyses should significantly increase the number of identified specimens and improve the paleoenvironmental signal. The continuing work should also help reveal subsistence strategies in each level to allow for a diachronic understanding of dietary choice.

The lithic and faunal records of Picareiro point to a significant degree

of resiliency in human adaptation and animal communities during the ~33–25 ka interval. The resilience of socio-ecological systems is conditioned by the capacity to experience perturbations and retain structure (Folke, 2006). Adaptability and transformability are important properties that affect system dynamics allowing for resilience or fundamental change. Renewal, innovation, and reorganization depend on the cross-scale interplay of connections based on accumulated experience or system history (Folke, 2006). According to Holling and Gunderson (2002), adaptive cycles are characterized by slow accumulation of structure drawing on resources and energy, punctuated by abrupt perturbations leading to a rapid release of the connections, and subsequent reorganization, renewal, and innovation followed by exploitation and growth. This framework allows us to conceptualize the dynamics of abrupt climate change during the Pleistocene and Paleolithic socioecological systems because both are characterized by diachronic patterns of continuity and change (Bradt Möller et al., 2017). Seen through this perspective, the Gravettian occupations of Picareiro, and Portugal more broadly, show that while abrupt climate shifts created significant perturbations in the physical and possibly social environment, the overall structure of this human socio-ecological system was retained through its flexibility or connectedness. Societies underwent periodic reorganization that led to innovations but certain adaptive behaviors such as bladelet production and red deer hunting were retained due to their inherent flexibility.

6. Conclusion

To summarize, the sequence at Picareiro provides new data on human land-use strategies during the Gravettian, dated ~33–25 ka. Taken together, chronological, sedimentological, artifact, and faunal data sets, while relatively small and still incompletely analyzed suggest a pattern of synchronous change in the use of the cave with climate and environmental change. The age control provided by the radiocarbon sequence allows us to link the sedimentological data with global and regional paleoclimate records. The unique landscape position, in a montane setting away from flowing water and lithic raw material sources, makes Lapa do Picareiro particularly sensitive to changes in human socio-ecological systems. There are clear differences in the lithic technological organization and raw material preference that appear to relate to changing conditions around the cave. Significant shifts between bladelet production using chert, flake production using quartzite, and bladelet production using quartz correspond to abrupt climate shifts. At the same time, the ubiquity of red deer and rabbit in all levels points to the ecological plasticity and resilience of these taxa. The strategic importance of red deer in subsistence and symbolic representation is further evidence of resiliency in human socio-ecological systems throughout the Gravettian. The exact relationship between climate change and human adaptation remains uncertain and requires greater chronological precision and larger sample sizes of the artifact and faunal assemblages. More regional-scale data are also needed to know how Picareiro fits into the regional Gravettian world and if the observed changes reflect adaptive responses to abrupt climate shifts.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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