Evidence of specialized resource exploitation by Modern Humans in Western Iberia associated to Pleistocene and Holocene extreme environmental conditions

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ABSTRACT

Throughout prehistory, landscapes were repeatedly subjected to both global and localized climatic fluctuations that changed the regional environments where human groups lived. This instability demanded constant adaptation and, as a result, the functionality of some sites changed over time.

In this light, the western coast of Iberia represents an exceptional case study due to the proximity between at least some oceanic cores and archaeological sites, which should facilitate an accurate reconstruction of the relationships between paleoenvironmental conditions and the coeval patterns of human behavior. This region, and in particular the valley of the River Lis, is marked by wide exposed plateaus cut by narrow and deep canyons. In this paper we present the stratigraphic, archaeometric, technological and archaeobotanical record of Poço Rock Shelter, located in one of these canyons, which hints at the human responses to such changes, and discuss the link between its Solutrean and Epipaleolithic occupations to specific activities. During the coldest part of the Last Glacial Maximum, we hypothesize that there was intensive exploitation of a chert outcrop above the roof to produce blades and Solutrean tips. Later, during Bond Event 6, after that outcrop had been exhausted, there was intensive consumption of shellfish gathered between the mouth of the canyon and the sea. We hypothesize that these strikingly different roles demonstrate how hunter-gatherers adapted to local conditions, and exploited specific resources, promising to provide a better understanding about its functional role during specific extreme climate events.

1. Introduction

The climatic variability in Europe and the North Atlantic is well defined (Austin and Hibbert, 2012; Dansgaard et al., 1993; Missiaen et al., 2019; Rasmussen et al., 2014; Sánchez Goñi et al., 2008). However, vegetational responses to these fluctuations differed from region to region (Carrión, 2012; Duprat-Oualid et al., 2017; Fletcher et al., 2010) namely depending on location, geomorphology and soils. In turn, the variability and density of vegetation influenced the presence, absence, abundance and diversification of animals (Rivals et al., 2017; Sommer and Nadachowski, 2006). Therefore, human cultures show geographic variabilities that are strongly related to the specific characteristics of each region at each specific time (Richerson and Boyd, 2020).

The arrival of anatomically modern *Homo sapiens* (AMHs) in western Iberia is marked by constant adaptation of hunter-gatherers to climatic instability. As a result, human cultures are broadly chronologically placed between marked climatic shifts (Banks et al., 2019). At local scales, since the landscape was constantly changing, the functions of some sites may also change over time, based on the resources exploited in each settlement at certain times (Bahn, 1982; Bailey and Davidson, 1983; Brysbaert, 2014; Romano et al., 2022; Shydlovskyi, 2018).

Western Iberia has several sites where specific resources were exploited in specific climatic periods. This is particularly evident for the Last Glacial Maximum (Aubry et al., 2016; Gameiro et al., 2017; Haws et al., 2020; Hockett and Haws, 2009; Manne, 2014; Manne et al., 2012; Stiner and Bicho, 2002; Zilhão, 1997) and the Early Holocene (Araújo, 2012, 2003a, 1998, 1993; Bicho et al., 2011; Haws, 2006, 2003; Hockett and Haws, 2009; Soares and Silva, 1993; Valente, 2008). The regional Last Glacial Maximum (LGM) (ca. 23.5 ka cal BP to 18.5 ka cal BP) is characterized by the increase of semi-desert arid steppe vegetation, the decrease of the Mediterranean forest and the continuation of the Atlantic forest (Carrión, 2015). These conditions were followed by a general European demographic contraction (Posth et al., 2016; Soares et al., 2010) rapid technological changes towards robustness of the tool kits (Zilhão, 2013), and emergence of cultural clusters (Burke et al., 2017; Cascalheira, 2019).

After the post-LGM warming until the Middle Holocene forests expanded with an increase of Mediterranean vegetation (Carrión, 2015). At the same time, the proliferation of archaeological sites suggests an increase in population (Thacker, 2002, 2006), of intensity in resource exploitation (Bicho et al., 2011, 2000; Haws, 2006, 2003; Hockett and Haws, 2009), and the diversity of regional technological traits with rapid but discrete chronological changes (Bicho, 1992; Gameiro, 2012; Gameiro et al., 2020; Holst, 2017; Zilhão, 1997). Precisely during the Early Holocene, the regional toolkits are very similar to the Magdalenian, but already include the introduction of geometrics made on Upper Paleolithic-like bladelets (Araújo, 2012; Bicho, 1998, 2002; Pereira and Carvalho, 2015). Despite this, the way of life of these hunter-gatherer societies is marked by an important change consisting on the introduction of marine/estuarine resources (*Cerastoderma edule, Scrobicularia plana*, Mytillus sp., *Venerupis decussata*,) as a recurrent and important asset in the diet, even in sites located dozens of kilometers inland (Araújo, 2003a, 2003b, 1998, 1993; Valente, 2014, 2008).

To investigate the link between chronological periods and resource exploitation during these harsh climatic periods, a new site in the Lis Basin was excavated between 2015 and 2018: Poço Rock shelter. In this article, we present the multidisciplinary finds of this excavation and link the intensive exploitation of chert during the Solutrean and of shellfish during the Epipaleolithic.

1.1. Geological and archaeological background

The basin of the River Lis is located on the coast of central Portugal. It has an area of 850 km^2 (945 km^2 if the underwater drainage is also considered), and incises mostly Miocene sandstones and Cretaceous limestones of the western *meso*-Cenozoic Iberian Margin. The River Lis basin is located between two major karstic systems, the Estremadura Limestone Massif and Condeixa-Sicó-Alvaiázere (Angelucci, 2004, 2003; Cunha-Ribeiro, 1999) and ranges between 585 and 0 m.a.s.l. Its composition, along with its geological-structural situation, allowed for dissolution processes such that, during the Pleistocene (and even today in higher elevations), drainage and tectonics together shaped a hilly landscape with karst morphologies composed of a network of canyons with steep cliffs where caves and rock shelters offered refuge to Pleistocene and Holocene modern humans (Angelucci, 2004, 2003; Cunha-Ribeiro, 1999). Overall, the landscape is characterized by wide exposed rocky plateaus covered by Cenozoic sands and gravels and cut by narrow canyons formed by tectonics and shaped by the incision of streams. Amongst these canyons, the Chitas Valley is a 10 km torrential stream, dry in the summer but with a strong flow during winter, that runs through the canyon for about 4 km, joining the Lis on its right margin. (Fig. 1).

Dozens of rock shelters, along with abundant fauna, flora, springs, gravels, chert and rock salty outcrops are identified in the Chitas Valley. In its upper section it flows from SE to NW, forming a slightly open valley in the lower Cenomanian, Albian, Aptian and Neocomian limestones. Reaching the Pousos synclinal, it crosses Turonian limestones and abruptly changes its course towards the ENE-WSW, becoming more incised and meandering until Pousos, where it crosses Cretaceous limestones again, whereupon it runs East-West until its mouth, progressively widening and forming an alluvial valley (Angelucci, 2003). The intercalation of softer and harder formations of the Turonian unit brought about the formation of rock shelters (Angelucci, 2003), as well as the asymmetry of the canyons' section, with a soft southern slope and steep northern slope. The valley bottom is filled, regularized and flattened by a Holocene fluvial terrace shaped by humans in its altimetry and hydrography (Angelucci, 2003).

1.2. Poço Rock Shelter

Poço Rock Shelter was discovered in 2002, in the Chitas canyon, an affluent of the Lis, during a rescue archaeology project in which dozens of test pits across the valley were excavated prior to the installation of a sewer pipeline. Areas tested included the platform adjacent to the slope where the site is. At that time, test pits revealed abundant shells, charcoal and lithics in a colluvial deposit about 6 m below the site (Brás et al., 2006). Between 2015 and 2018, the site was excavated in the scope of the project "EcoPLis – Human Occupations in the Pleistocene Ecotones of River Lis". Overall, the vertical extension of the site runs from 98 m.a.s.l. (the bottom of the 2002 test pits) to 115 m.a.s.l. (where a nodular chert outcrop exists) (Fig. 2). The site is located ca. 4 km from the canyon mouth to the River Lis, ca. 26 km from the present seacoast and ca. 45 km from the coast during the lowest sea level of the Last Glacial Maximum (LGM).

2. Methods and materials

2.1. Field methods

The site was divided horizontally into a 1x1 m grid, and was excavated in a 9x1 m trench across the slope deposits, from the carbonated remnant under the roof down to the path leading to the site. Each excavated square meter was further subdivided into 0.5x0.5 m clockwise quadrants (A, B, C, D). Each quadrant was then vertically subdivided into 10-litre volumes, corresponding to buckets following the natural layers. From a practical point of view, this methodology results in having the stratigraphic units vertically subdivided into intervals ca. 2–3 cm thick. The buckets' contents were dumped into bags, with their respective opening and closing labels added, sealed, and transported to the field laboratory. All excavated sediment was processed by flotation in a 0.25 mm mesh, allowing the recovery of all elements with dimensions equal to or greater than 0.26 mm. All finds were piece-plotted
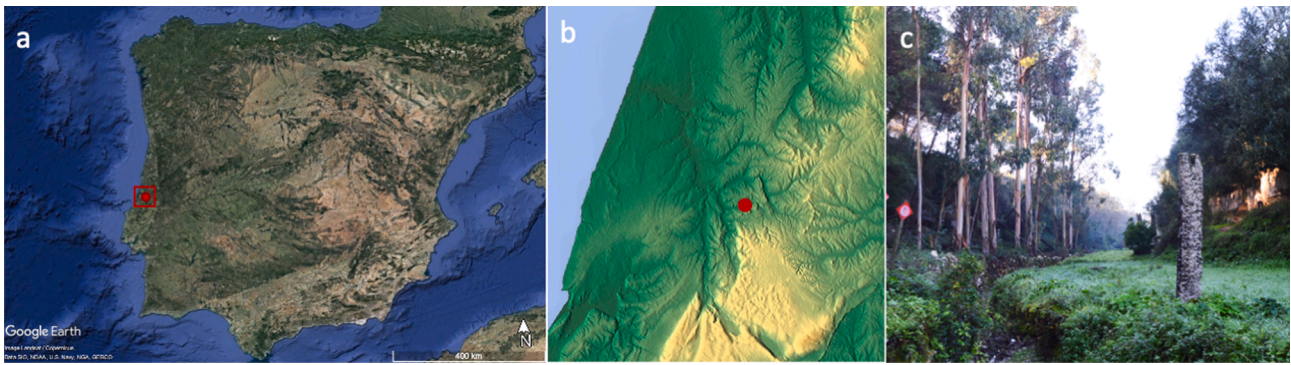
Fig. 1. Poço Rock Shelter: a) Location in the Iberian Peninsula; b) Topographic framework of the River Lis basin; c) General aspect of Chitas Valley.
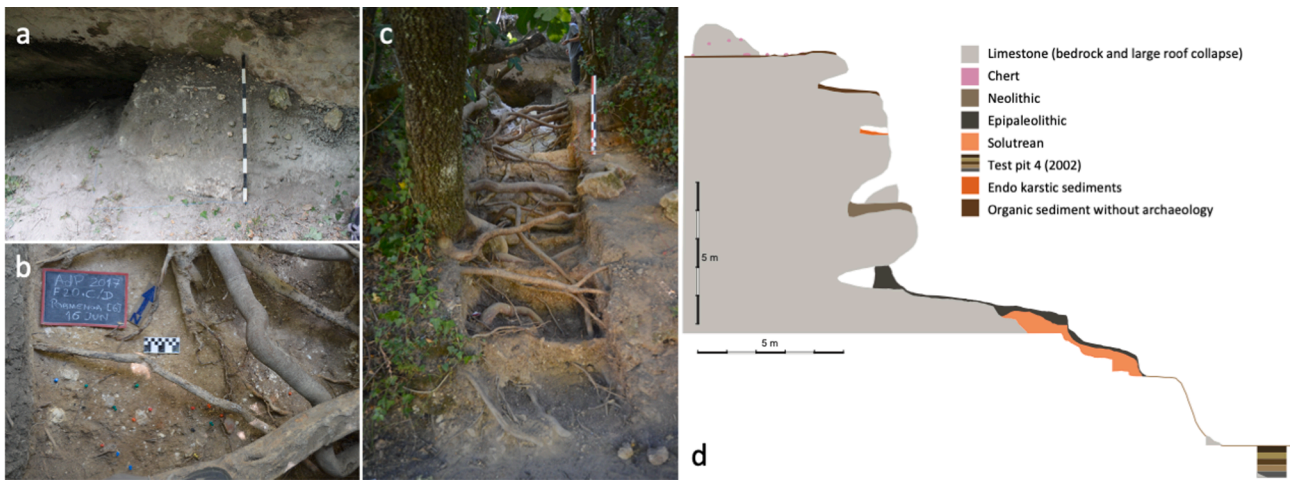
Fig. 2. Poço Rock Shelter: a) Cemented sediments with charcoal and shell under the roof; b) Detail of concentrated finds; c) General view of the site highlighting the disturbance by roots; d) Schematic profile.

using a total station linked to a computer running the software EDM and NewPlot (freely available at https://www.oldstoneage.org). Each artifact received its own ID. The extremely small organic elements whose individual recovery would result in their pulverization (e.g., millimetric fragments of coal and shells), were piece plotted in order to obtain their spatial location, receiving a summary indication of their nature

Fig. 3. Poço Rock Shelter: a) Overall aspect of the fieldwork; b) Detail of the laptop during fieldwork showing the position of the trench; c) projection of the plotted finds; d) Flotation process in the fieldlab; e) Detail of the light fraction collected in the screen during the flotation process.

(Charcoal or Shell) together with the indication "Not Collected" but kept in the excavated sediment collected in the bucket. The integral flotation of the excavated sediments ensured recovery of all charcoal and other minute fragments, although it is not possible to make a direct relationship between each of them to the field XYZ reading (their location is, however, associated to the volume corresponding to each unit of 0.5x0.5 m square and ca. 2–3 cm depth). Our methodology allows for the recognition and recovery of very small elements, enabling a richer and more detailed spatial analysis, as well as the collection of a greater number of organic elements that would otherwise be irretrievably lost (Fig. 3).

During the excavation, stratigraphic units were defined according to sedimentological criteria, while evident burrows or root holes were also mapped and individualized, such that the finds associated with these would not get mixed with those from surrounding unaffected sediments during analysis (Fig. 4).

2.2. Radiocarbon dating

The two occupations were dated via seven radiocarbon dates using ultrafiltration performed by the Oxford Radiocarbon Laboratory. We sent six samples, three to date the Holocene occupation (OxA-36804 - *Arbutus unedo*, OxA-35206 - *Scrobicularia plana*, OxA-35207 - *Cerastoderna edule*) and three to date the Paleolithic occupation (OxA-36770 – *Salix/Populus*, OxA-X-2766-17 - indeterminate bone, OxA-37085 - *Cervus elaphus*). In the lab, the *Cervus elaphus* bone was divided and dated twice (OxA-37085 and OxA-37086).

2.3. Charcoal analysis

The charcoal analysis was performed focusing on taxonomic identification. Fragments larger than 2 mm (Chabal, 1992) were selected using a stereomicroscope. Then, these fragments were observed in their transversal, longitudinal tangential and longitudinal radial sections using a reflected light microscope Leica DP2500 at x100 and x200 magnification lenses for taxonomic identification. Taxonomic identification was achieved through comparison with wood anatomy atlases (Schoch et al., 2004; Schweingruber, 1990) and the reference collection of modern charcoal of ICArEHB.

2.4. Zooarchaeological analysis

The detailed zooarchaeological and taphonomic analysis has not yet been done within the scope of a thesis or dissertation (training is another goal of the EcoPLis project). Therefore, the classification reported here is limited to an overview of the collection for species identification and selection of samples for radiometric dating.

2.5. Lithic analysis - geochemistry

Since the valley has several chert outcrops, including one right above the site, and people settled here instead of elsewhere, we also performed geochemical analysis on these chert sources. Several chert samples were collected across the valley and its vicinities, from all known sources to sample their internal variability. The geochemical composition of each specimen was analyzed using a portable Bruker S1 Titan X-ray fluorescence spectrometer. The detailed results of this study have already been published (Pereira et al., 2021), but an overview of these results are reported here, and integrated with the datasets available from the site.

2.6. Lithic analysis – technology and typology

As in the case of the zooarchaeological analysis, the extensive and detailed techno-typological characterization of the lithic assemblages will be performed within the scope of a thesis or dissertation. Nonetheless, preliminary observation of the assemblages follows standard terminology (Sonneville-Bordes and Perrot, 1956, 1955, 1954; Tixier et al., 1980).

3. Results

3.1. Field results

Several stratigraphic units (SU) were recognized (Fig. 5), representing lateral variations of two main occupations. The descriptions of each SU are presented in Table 1. The upper occupation, in the carbonated remnant, is Epipaleolithic and characterized by ash, charcoal and shells (*Scrobicularia plana*, *Ensis* sp. and *Cerastoderma edule*), while the lower one, in the slope layers, is Solutrean and characterized by abundant lithics (mostly flint) and a few red deer (*Cervus elaphus*) bones. While these two occupations could be individualized, the site is severely affected by roots of an old fig tree and an old holm oak tree.

3.2. Chrono-cultural occupations

The SU's could be grouped into two main timeframes based on the combination of color and texture of the sediments, artefacts, and radiometric dates. These are Aggregate 1, composed of units 1, 4 and 5 (Epipaleolithic occupation), and Aggregate 2, composed of units 6, 7, 10 (Middle Solutrean occupation), as well as 13 and 14 (Upper Solutrean occupation). Stratigraphic unit 2 and 12 are burrows, the former with Epipaleolithic elements and the latter with Solutrean elements. Stratigraphic unit 3 is bedrock. Stratigraphic units 8 and 9 have artefacts mixed between the two aggregates with a predominance of Epipaleolithic implements in stratigraphic unit 8 and a predominance of Solutrean implements in stratigraphic unit 9.

The current available data suggest that the Solutrean may have had two episodes. In this case, the original position of the earliest occupation

Fig. 4. Poço Rock Shelter: square E20 quadrants A and C stratigraphic layer 12. a) Identification of a burrow; b) excavation of the burrow separately from the sediments surrounding it; c) final aspect of the burrow after excavation and marked with white pins - each one piece-plotted with the total station to delimit the burrow sediment.
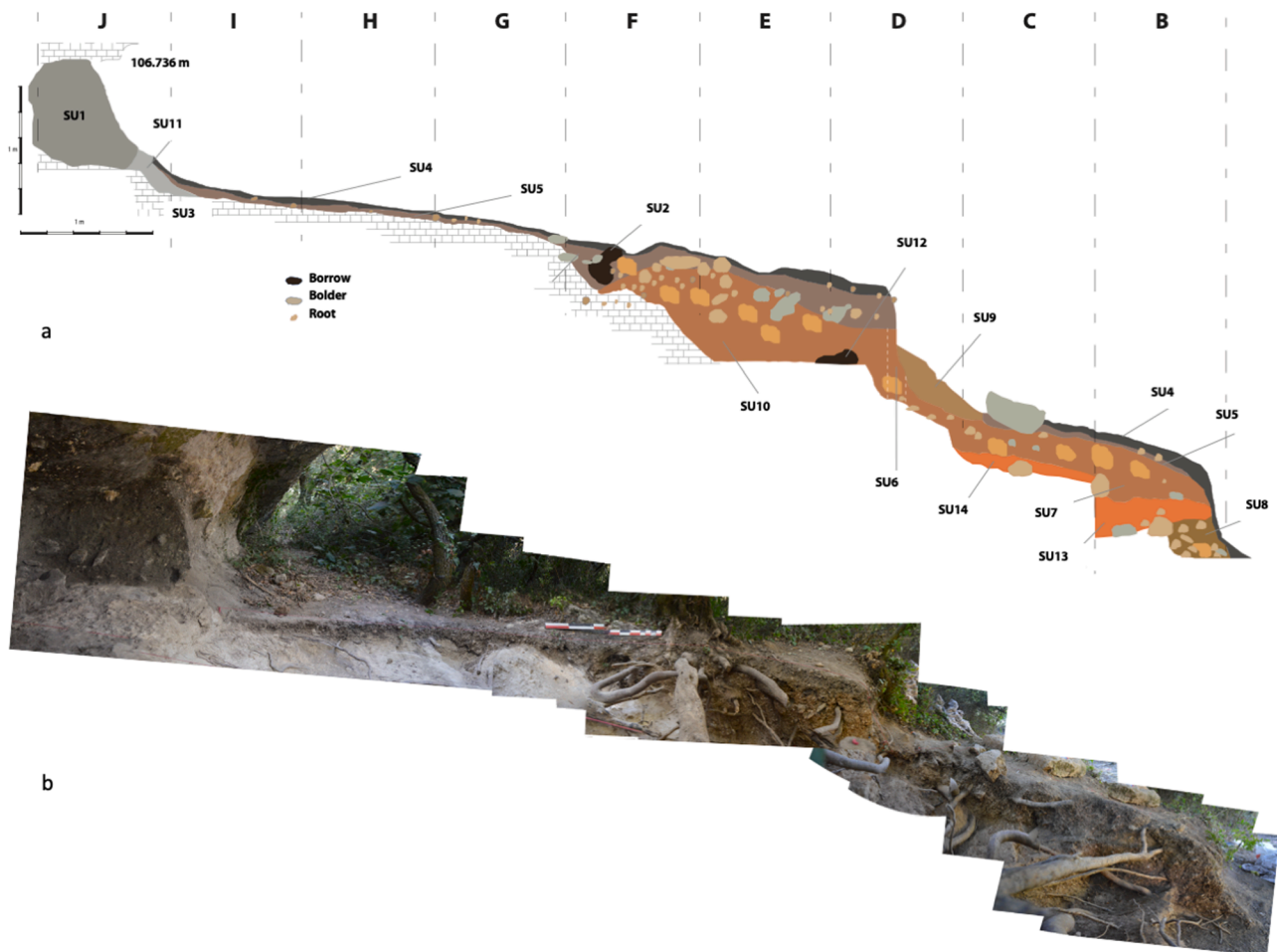
Fig. 5. Poço Rock Shelter: a) Drawing of the profile with an indication of the stratigraphic units. b) Photomosaic of the same profile.

would have been near the rock shelter, at F-D20 (corresponding to SU10), and the position of the later occupation is on the lower step, at D-B20 (corresponding to SU13-14). SU13-14 has, above it, a colluvium like that of F-D20 with Solutrean material. Since the top of the Solutrean at F-D20 is marked by an erosive discontinuity and boulders detached from the cliff wall, an erosive event may have caused the collapse of the wall that, in turn, dismantled the upper part of the earliest Solutrean deposit over the later. If this is correct, then it may have happened sometime after the later Solutrean occupation and before the Epipaleolithic occupation.

On the other hand, it can also be argued that the deposit may correspond to several occupations during the Solutrean, with older and younger artefacts mixed and stratigraphically inverted, which could easily happen in slope deposits, especially-one as affected as this one. In fact, the deposit is highly disturbed by tree roots (at least at a century scale as shown by the OxA-36770 – *Salix/Populus* sample), but these cut across the site almost horizontally, giving us some confidence in reconstructing its archaeological context. We have also refined the interpretation via absolute dating and observation of the lithics. Nevertheless, further detailed geoarchaeological analysis is required for confirmation of the deposit's formation. Similarly, a detailed lithic analysis for confirmation of distribution of the technological and typo-logical traits is needed, and, lastly, a site formation process analysis, including with refitting, will be required for confirmation of the asso-ciation between the deposits and the archaeological evidence.

Additionally, in a platform above the roof of the rock shelter, in what seems to have been another rock shelter with very little sediment that was possibly wider before the rockfall, two 1x1 m test pits revealed a deposit with a few remains of *Scrobicularia plana*, *Ensis* sp. and *Cera-stoderma edule* shells that suggest an Epipaleolithic occupation of this ledge as well. Atop this deposit, two sherds of Chalcolithic incised pot-tery were recovered. With regard to these, we hypothesize that a small cavity in the wall just above, too small for human entry, could have been used for funerary purposes, a widely known Chalcolithic practice in the region, although nothing else associated with the Chalcolithic was recovered from this site.

3.3. Radiocarbon dating

The excavation area is a 1 m wide trench, which in some areas is quite shallow. This means that thus far in ca. 4 m³ we have 6 samples radiocarbon dated (Table 2).

Overall, the Accelerator mass spectrometry (AMS) results are consistent with the lithic assemblages, although one outlier exists for each context. In the Epipaleolithic the older result from *Scrobicularia plana* can be explained by the ecology of this species, which uses a siphon to burrow into the sediment in order to process organic material. This tends to give this species unusually older dates, sometimes by several centuries. In contrast, *Cerastoderma edule* filter feeds from the water around it, incorporating carbon from the surrounding environ-ment. Therefore, the most reliable results are those from *Cerastoderma edule*, which is consistent with the date obtained from a charcoal sample of *Arbutus unedo* for the same layer.

In the Solutrean context, the result from the indeterminate bone also gave an older date. However, this sample had 3.3 mg collagen obtained from 446 mg of bone, which is less than the cutoff for ideal values of 5

Table 1
Poço Rock shelter Stratigraphic units (SU) identified in the excavation.

SU	Description
SU1 (80 cm)	Silty deposit, dark grey color, with strong carbonation carbonate cementation likely resulting from its position in contact with the rock shelter's roof. It presents a high density of well-preserved charcoal and shell fragments, ash, firecracked pebbles, rare vertebrate microfauna and a few lithics. The assemblage is consistent with the Epipaleolithic.
SU2 (35 cm)	Small vertebrate burrow on top. Medium-grained, not very compact, dark brown silty layer. Contains a large amount of microfauna, shells, charcoal fragments, and the lithic assemblage is mostly composed of small chert implements consistent with the Epipaleolithic.
SU3 (100 cm)	Silty, loose sediment, light yellow beige. It represents the eroded top of the limestone bedrock and has archaeological remains on its top and contact with layer 5.
SU4 (7 cm)	Silty humic, not very compact, dark-brown layer, with variations in shades of brown. The archaeological assemblage consists of microfauna, mollusks, charcoal, and very small quartz, quartzite and chert implements consistent with the Epipaleolithic.
SU5 (10 cm)	Fine-grained, not very compact, dark greyish-brown silty layer. The archaeological assemblage consists of charcoal, mollusks, vertebrate microfauna and lithics in quartz, quartzite and chert consistent with the Epipaleolithic.
SU6, 7, 10 (200 cm)	A moderately compact silty layer of orange-brown color, with some yellow and orange domains. In squares C and B it shows a dark orange-brown color due to significant bioturbation caused by roots (which also led to some mixing between Epipaleolithic and the Solutrean materials on the top). At the top, there are some angular limestone boulders that reach 60 cm in diameter. The archaeological assemblage is composed of microfauna, charcoal and mollusks, the last two in small quantities, poorly preserved and concentrated on the top. Apart from some mixed material in the upper centimeters consistent with the Epipaleolithic, the lithic assemblage below is composed of chips, blades, bladelets and bifacial thinning chips of chert, as well as quartz and quartzite cores, flakes and chips consistent with the Solutrean. In units B20, C20 and half of D20, it seems to correspond to the colluvium of the top of what was previously present in the units topographically above.
SU8 (20 cm)	Dark brown medium-grained silty layer with some yellowish spots. This unit appears in a very small area limited to quadrants C and D of B20, and cut SU 14 in this flank. It yields lithics, some microfauna and charcoal. The lithic assemblage is consistent with the assemblage indicates a mixture of Solutrean and Epipaleolithic contexts, with predominance of Epipaleolithic.
SU9 (15 cm)	Moderately compact, medium-grained, dark-brown silty layer with yellowish spots that yields chert chips, flakes, bifacial thinning flakes and fragments, quartz and quartzite flakes, microfauna, and charcoal. The charcoal and mollusk fragments are small and badly preserved. This layer is only visible in quadrant D20. The assemblage indicates a mixture of Solutrean and Epipaleolithic contexts with predominance of Solutrean.
SU11 (5 cm)	Concentration of precipitation of calcium carbonate derived from the rock shelter's dripline. Present in squares I20 and J20 and not visible on the profile.
SU12 (30 cm)	Small vertebrate burrow. Medium-grained, not very compact, dark brown silty layer with little archaeological material including microfauna, lithics and firecracked pebbles consistent with the Epipaleolithic.
SU13, 14 (>80 cm)	A moderately compact, silty-clayey layer of a bright orange-brown color, with some yellow and orange patches. The archaeological assemblage has larger and better-preserved faunal fragments, along with abundant chert flakes, bladelets, bifacial trimming flakes, slivers, and chips consistent with the Solutrean.

mg according to Oxford Radiocarbon Accelerator Unit protocol (and is also less than 1 % collagen by weight), while all other parameters were acceptable. Therefore, a more reliable date for this context should be that from *Cervus elaphus*. As seen in Table 2, yet another date was obtained for piece of charcoal that yielded an historical age.

3.4. Charcoal assemblage

The charcoal assemblage (Fig. 3e) recovered from the Epipaleolithic layer was scattered and not associated with any evident combustion structure or concentration. Despite the abundance of charcoal fragments identified and piece-plotted in SU 1, a lower number of fragments were

separated for taxonomical analyses due to dimension requirements. This totaled 179 charcoal fragments separated for taxonomical analysis which allowed the identification of *Olea europaea/*cf. *Olea europaea*, *Quercus* (deciduous), *Quercus* sp., *Pinus* sp., *Arbutus unedo*, Ericaceae, Monocotyledonous and indeterminate Angiosperms. The assemblage presented a larger representation of *Olea europaea/*cf. *Olea europaea* (olive tree or wild olive tree) with 81 fragments, as well as of *Arbutus unedo* (strawberry tree) with 31 fragments, followed by 20 fragments of indeterminate Angiosperm (Table 3). *Quercus* (deciduous), *Quercus* sp., *Pinus* sp., Ericaceae and Monocotyledonous were identified in less than 10 fragments each (Table 3).

The charcoal samples recovered from Aggregate 2, associated with Solutrean occupations, are most likely part of post-depositional perturbation in these deposits, which was confirmed by radiocarbon dating of a charcoal with historical age.

3.5. Faunal assemblage

The preliminary analysis of the faunal assemblage (Fig. 6) shows a strong asymmetry between the two contexts. The Epipaleolithic is primarily characterized by the abundance of shells from *Scrobicularia plana*, *Ensis* sp. And *Cerastoderma edule*, all adapted to low energy saltwater or brackish environments. These elements, mostly fragmented, would have been brought inland as part of the movement of the Epipaleolithic communities between the coast and the inland mountains, thus supporting our hypothesis of transit between these two territories through this E-W oriented canyon. Along with the shell assemblage, this context also has some Leporidae, a fragmented unidentifiable micromammal diaphysis, and micromammals. The Epipaleolithic occupation layer generally lacks medium- and large-sized fauna.

Interestingly, the Solutrean assemblage is almost devoid of fauna, except for fragments of *Cervus elaphus* bones that we used for dating. There is also a considerable number of small bones mostly belonging to leporids, but also others belonging to rodents, birds or reptiles. Throughout the stratigraphy clearly intrusive terrestrial gastropods are found (Table 4).

3.6. Lithic analysis – geochemistry

The detailed analysis of the geochemical results has already been published elsewhere (Pereira et al., 2021). In general, the archaeological chert samples from Poço Rock Shelter are very similar to each other and to the nodules from the presently depleted source right on the top of the cliff. At the same time, they are different from other sources from the Lis Basin, namely from within Chitas Canyon. Together this suggests a source with very distinct characteristics. This may have been the reason why this location was selected over others, including with larger chert exposures but with less silica and extensively fractured by tectonics, for the production of Solutrean points.

3.7. Lithic analysis – technology and typology

The lithic assemblage is in accordance with the chronologies obtained by the absolute dates. The assemblage collected from the Aggregate 1 (Fig. 7), corresponds to a single, typically Epipaleolithic package, with parallels to other assemblages with ages ≥ 8.2 ka cal BP (Araújo, 2012; Bicho et al., 2014; Pereira and Carvalho, 2015). It is characterized by a combination of chert, quartz and quartzite, with chert predominating. The chert component is composed of small prismatic cores that produced small flakes, bladelets, fragments as well as burins intended for the production of burin blows to be used as barbs. The overall assemblage shows a predominance of chips, with few retouched pieces and only rare dorsal retouch. The quartz component is also made of small prismatic and bipolar cores, small flakes, bladelets, fragments and chipped stones. Finally, the quartzite assemblage consists of hammerstones, anvils, choppers, semi-cortical flakes that sometimes show

Table 2

Poço Rock shelter. AMS dates.

Layer	Context	Ref.	Material	δ 13C	Date BP	Date cal BP	Probability
1	Epipaleolithic	OxA-36804	*Arbutus unedo*	−24.45	8208 ± 38	9290–9021	95.4 %
1	Epipaleolithic	OxA-35206	*Scrobicularia plana*	−1.11	9205 ± 40	10496–10247	95.4 %
4	Epipaleolithic	OxA-35207	*Cerastoderma edule*	−0.54	8276 ± 40	9426–9039	95.4 %
6/10	Solutrean	OxA-36770	*Salix/Populus***	−24.04	209 ± 27	304–267	29.6 %
						215–145	48.8 %
6/10	Solutrean	OxA-X-2766–17	Bone (ind)*	−20.32	19170 ± 120	23708–22900	95.4 %
14	Solutrean	OxA-37085	*Cervus elaphus****	−20.14	18510 ± 100	22744–22210	95.4 %
14	Solutrean	OxA-37086	*Cervus elaphus****	−20.06	18510 ± 100	22744–22210	95.4 %

* This sample had a lower than ideal collagen yield. 3,3 mg of collagen was obtained from 446 mg of bone, which is less than the ideal 5 mg threshold (and less than 1 % collagen by weight) used by the Oxford Accelerator Unit. All other parameters measured were acceptable.

** Intrusive charcoal.

*** OxA-37085 and OxA-37086 are two dates taken from the same *Cervus elaphus* bone.

Table 3

Poço Rock shelter. Charcoal assemblage.

Taxa	Nr.
Arbutus unedo	30
Ericaceae	6
Olea europaea/cf. *Olea europaea*	81
Pinus sp.	4
Quercus (deciduous)	2
Quercus sp.	4
Monocotyledon	1
Angiosperm (indeterminate)	21
Indeterminate	30
Total	**179**

atypical retouch, notches, denticulates and many firecracks consistent with the abundant charcoal in the sediment.

In turn, the assemblage collected from the underlying Aggregate 2 corresponds to a package with typically Solutrean artefacts (Fig. 8), with parallels to other sites from Estremadura (Zilhão, 1997; Zilhão and Trinkaus, 2002). This assemblage is characterized by the overwhelming predominance of chert over quartz and quartzite. In the chert, there is a large quantity of chips, fragments, bifacial trimming flakes, Solutrean bifacial preforms and bifacial fragments, flakes, bladelets, blades with bidirectional dorsal patterns, prismatic cores with bidirectional detachments, crests and core flanks. Many of them have color, luster and breakage consistent with *in situ* heat-treatment and some fragments also have crackles associated with burning. This evidence and its disparity with the quantity of fauna suggest to us that the use of the site was for the exploitation of the chert source above it to produce finished products, particularly of bifacial Solutrean tips and blades. In turn, the quartz and quartzite component constitutes a smaller fraction of the assemblage, with flakes, chips, fragments, choppers, bipolar cores and domestic tools including tools like flakes with atypical retouch, notches, and denticulates, but also hammerstones, anvils and firecracks.

4. Discussion

Human cultures tend to present geographic variabilities strongly connected with the specific characteristics of each region at each specific time (Richerson and Boyd, 2020). A host of different types of data

Fig. 6. Poço Rock Shelter: a) Samples of shellfish collected from the Epipaleolithic occupation (Stratigraphic Unit 1), with evidence of ash and carbonates; b) Small vertebrate samples collected during flotation; c) One of the very few bone samples that give reliable dates for the Solutrean occupation.

Table 4

Poço Rock shelter. Distribution of the general inventory of piece-plotted finds through the stratigraphic units.

Culture	Solutrean						Epipaleolithic					Neolithic	Total
Material/ Strat Unit	6,7, 10	12	13	8	9	14	1	2	3	4	5	Upper shelter Test 1-UE 2	
Pottery												2	**2**
Bone	163	1	3		16	2	14	1	26	72	17		**315**
Charcoal	259		1	3	7		983		4	3	15		**1275**
Clasts	96		15	27	6		147	5	9	169	106		**580**
Firecracks	26	1	3		3		55	1		9	24		**122**
Lithics	1100	5	33	9	35		39	6	295	86	155	2	**1765**
Other	8			1	1		6			4	3		**23**
Pebbles	7						2		4	2	3		**18**
Shells and gastropoda	217	1	5	10	2		303	3	21	133	234	3	**932**
Total	**1876**	**8**	**60**	**50**	**70**	**2**	**1549**	**16**	**359**	**478**	**557**	**7**	**5032**
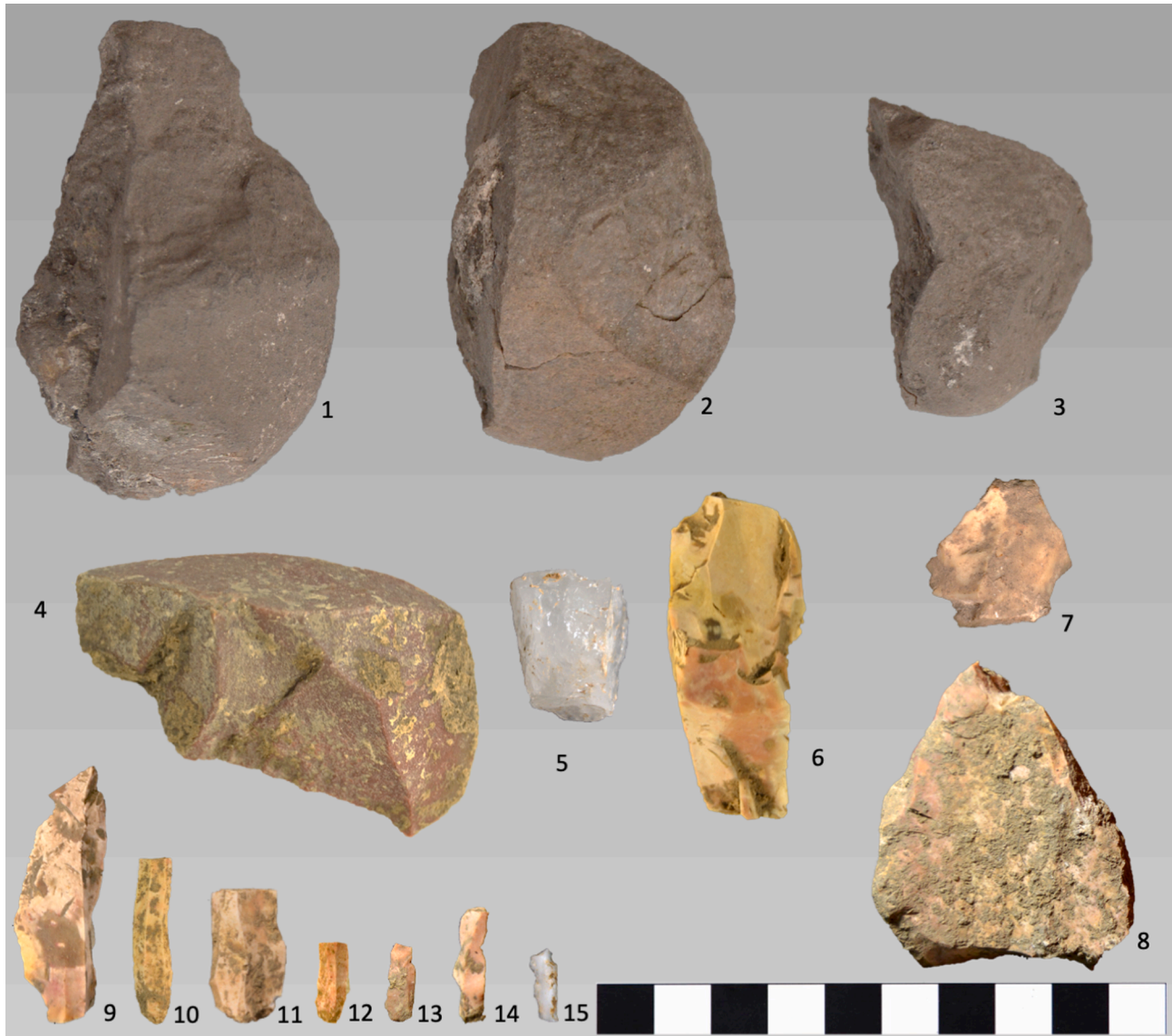
Fig. 7. Poço Rock Shelter: Lithic assemblage from the Epipaleolithic occupation. 1, 4: Core fragments; 2, 3: Fire cracks; 5, 6: Prismatic core fragments; 7,8: Burins; 9–15: Simple and retouched bladelets and bladelet fragments.

consistently show that the Late Pleistocene and Early Holocene were marked by an environmental instability, which was followed by a response from human ecodynamics. Aside from the changes in the tool kits, the greater exploitation of specific resources at given times leads to sites with specialized functions but, since the landscape was constantly changing, the functions of some sites may have also changed over time, based on the resources exploited at each time (Bahn, 1982; Bailey and Davidson, 1983; Brysbaert, 2014; Romano et al., 2022; Shydlovskyi, 2018).

The data obtained from Poço Rock shelter, despite the limited

Fig. 8. Poço Rock Shelter: Lithic assemblage from the Solutrean occupations. D20-61, F20-308: Retouched flake fragments; B20-148: Crested blade; C20-565, E20-101, F20-308: Burins; F20-155, F20-307, F20-45: Blade and bladelet fragments; E20-692: Prismatic core; E20-727, B20-62: Trimming flakes; F20-156, B20-496: Bifacial tips; C20-525: Proximal end of pedunculate tip.

number of radiocarbon results, suggest that the occupations occurred during harsh climatic events of global impact occurring during the LGM and the Holocene (Fig. 9).

4.1. The LGM occupations

The LGM was an extreme globally cold and dry climatic period spanning between ca. 25 and 20.5 ka cal BP, with the peak of glacial conditions at 22.1 ± 4.3 ka cal BP. It was characterized by the formation of extensive thick ice sheets in the northern hemisphere, leading to a consequent drastic reduction of vegetation and sea level drop worldwide (Shakun and Carlson, 2010). Unfortunately, a tentative refined paleoenvironmental reconstruction only based on terrestrial data is, for now, not possible for the regional Solutrean. The only site with rich archaeobotanical data published is the nearby Lagar Velho (Queiroz et al., 2002) (also in a canyon), but the chronology is slightly older than Poço.

Nevertheless, the available data is coherent with that of the ocean cores SU81-18, MD95-2042 deep-sea cores (Daniau et al., 2007; Hodell and Abrantes, 2016; Sánchez Goñi, 2006; Sánchez Goni et al., 2000; Sánchez Goñi et al., 2008; Shackleton and Hall, 2000; Stow et al., 2011). In particular, the SU81-18 core collected at the coast (37° 46′ N | 10° 11′

O) gives a reference record for the timeframe between 0 and 27.5 ka, and similarly indicates a moment of rapid and intensive increase of semi-desert steppe aridity-tolerant vegetation (*Artemisia*, Chenopodiaceae, *Ephedra*) on the continent along with the contraction of Mediterranean forest (deciduous and evergreen *Quercus, Olea, Phillyrea, Pistacia, Cistus*, and Ericaceae) and the continuation of a limited Atlantic forest (deciduous *Quercus* and *Betula*) (Carrión, 2015) that was also followed by an increase of wildfires (Daniau et al., 2007; Sánchez Goñi et al., 2008). It is possible that, in western Iberia, the semi-desert steppe aridity-tolerant vegetation may have become the predominant in the more exposed areas, while the Mediterranean forest occupied the more sheltered and humid areas like the canyons during this time.

The absence thus far of Solutrean sites in the most exposed areas of this territory, which has been intensively surveyed within the scope of large Cultural Resource Management projects (Carvalho, 2011; "Plano Diretor Municipal - CM Leiria," n.d.), and its presence in the canyons is noteworthy. The interval of the calibrated radiocarbon dates points to two Solutrean occupations. The Middle Solutrean radiocarbon date has an interval of more than 800 years which makes it harder to fit into a specific climatic event, but this interval covers a timeframe of intense instability with several century-scale events. These includes the end of
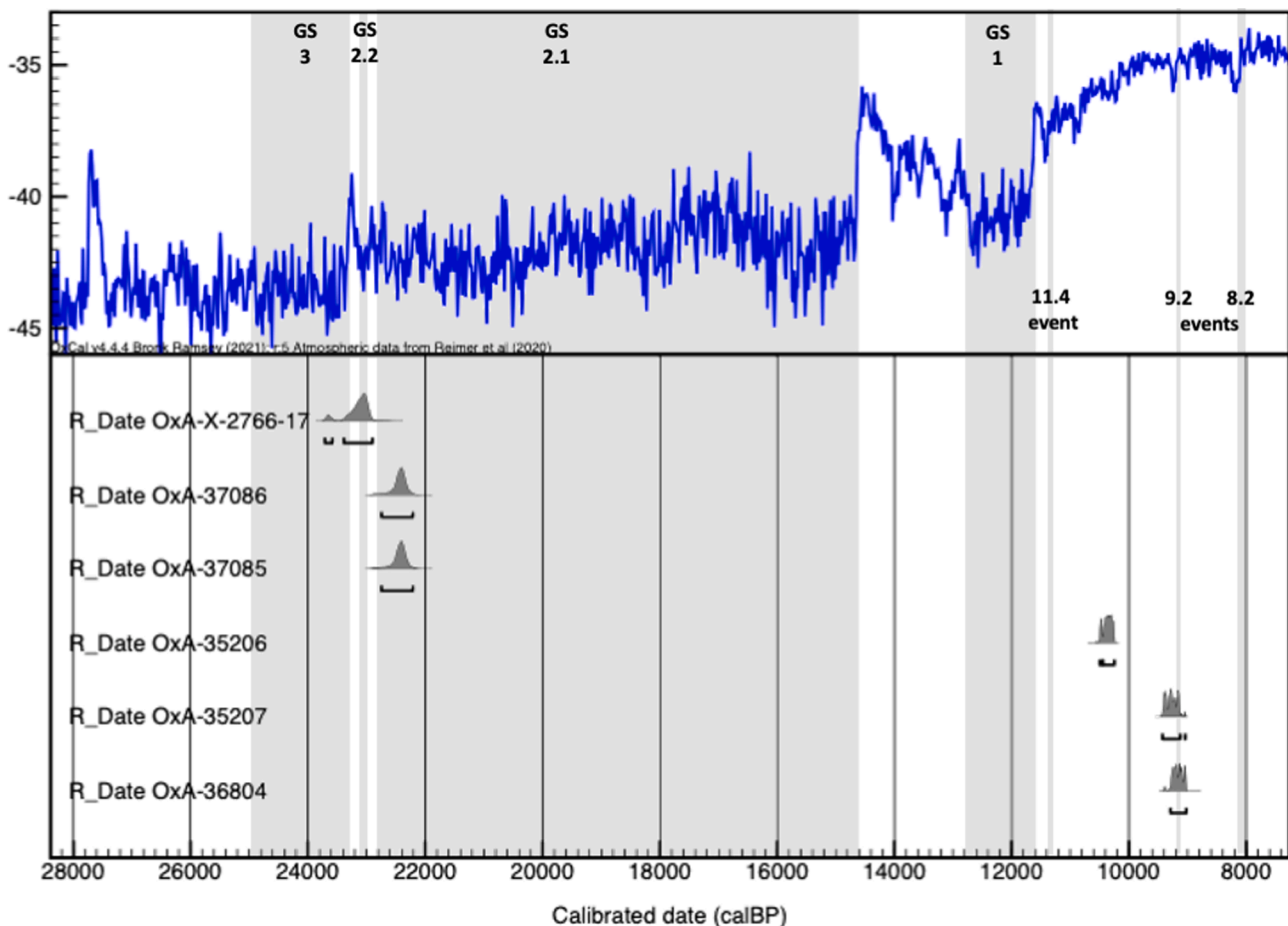
Fig. 9. Poço Rock Shelter: Radiocarbon dates calibrated using IntCal20 (Reimer et al., 2020) and OxCal v4.4.4.

the dust pick of Greenland Stadial 3, Greenland Interstadial 2.2 and Greenland Stadial 2.2 and Greenland Interstadial 2.1. In western Iberia, this time period has been hard to define in detail because it corresponds to the formation of stalagmitic crusts in caves, as happened at Caldeirão over layer H and Anecrial over layer 1 (Zilhão, 2013), but not in Lapa do Picareiro, where are there is no evidence of a hiatus related to the formation of speleothems, but rather abundant fauna, lithics, bone tools and charcoal abound in areas deep within the shelter (Benedetti et al., 2019). In contrast, the Upper Solutrean radiocarbon date has a smaller interval that fits to the coldest phase of Greenland Stadial 2.1. This cold climate was felt not only on the western coast of Iberia but in both the northern and southern hemispheres, coinciding with the start of the second period of glacial advance in the major Iberian mountains (Ruiz-Fernández et al., 2016) and with the end of the sedimentary hiatus inside Caldeirão and Anecrial.

Overall, it seems that the location of Poço Rock shelter, in a narrow and straight east–west valley, at a lower slope facing southeast protected against the generally cold conditions, including prevailing harsh winds from the coast (even if this was farther away than today), in a more humid and lush environment next to a spring, supports the pattern and predictable selection of locations with these conditions during this period (Straus, 2018). In addition to Poço, Lagar Velho and Caldeirão are also in similarly narrow sheltered valleys. These conditions may have played a triple role of attracting people, allowing sedimentation including during the same period in which caves were predominantly forming stalagmitic crusts, and preserving the deposits from erosion. This makes canyons ideal settings to investigate human ecodynamics during the LGM.

The harsh conditions of the LGM mandated a change in human behavior namely by shifting from the maintainable toolkits composed of

modular, light and portable tools designed for quick repairing, resharpening, and recycling (Bousman, 1993) that characterize almost all Upper Paleolithic toolkits from western Iberia, to more reliable toolkits composed of specialized, overdesigned curated implements, the manufacture of which was planned in advance (Bleed, 1986). These latter tools characterize the Solutrean and are a direct consequence of environmental deterioration (Bicho et al., 2017; Pereira and Benedetti, 2013). Among other things, the Solutrean toolkit seems to have been powerful to allow modern humans to survive the extremely difficult environmental conditions so characteristic of inland territories such as central Iberia, a region apparently that remained unoccupied during the Upper Paleolithic until ~25.5 ka cal BP (Alcaraz-Castaño et al., 2021).

In the case of Poço Rock shelter, despite the abundance of easily accessible chert outcrops in the valley, geochemical analysis shows that the assemblage was made on a very different type of chert (Pereira et al., 2021). This type is almost impossible to find except for very small fragments still attached to the top of the cliff right above the site, suggesting that it was chosen as consequence of the unique quality of this chert (Pereira et al., 2021). In the preliminary observation of the lithic assemblage, it was noted the absence of complete Solutrean tips, the small number of blades and tips in relation to configuration and maintenance products makes the lithic assemblage from both Solutrean occupations which is consistent with a workshop specialized in the production of blades and tips intended for exportation. These occupations are different from that of Lagar Velho where the assemblage is consistent with a slightly older Middle Solutrean base camp, although most of the Solutrean context was obliterated, with only an infill on a fissure along the shelter's back wall surviving (Zilhão and Trinkaus, 2002). It has to be said that there are not many Solutrean workshops known in western Iberia, but those that are known are in relatively well

delimited places with large amounts of lithic implements and the absence of fauna such as the case of Passal (Pereira et al., 2007; Zilhão, 1997), although in the open air sites this result may be driven by taphonomic reasons.

At Poço Rock shelter, the top of the Middle Solutrean occupation is marked by an erosive discontinuity and rockfall from the cliff wall sometime between the formation of this Solutrean pack and the formation of a later Solutrean pack. It is possible that this erosion occurred during the GI 2.2 and GI 2.1 or later, during the Pleistocene/Holocene, since we see this at other sites in central Portugal such as Picareiro Cave (Benedetti et al., 2019) and Cadaval Cave (Oosterbeek, 1985). Such erosion may explain the inversion of dates between the Middle and Upper Solutrean. This will require further detailed investigation of the site and more radiometric dates. Nevertheless, Poço Rock shelter is nonetheless a new Solutrean site with at least two occupations, radiocarbon dates and a rich lithic assemblage. The continuation of its study will bring critical information about stratigraphy, site formation processes, and elucidate the integrity of the contexts and fundamental association between the radiocarbon dates with the assemblage to ensure that these specific contexts have the necessary quality to contribute to the refinement of age models (Banks et al., 2019) that, in turn, will and help refine/clarify the Solutrean sequence in western Iberia.

4.2. The Early Holocene occupation

The Epipaleolithic occupation dates to the Bond Event 6 marking the Preboreal-Boreal transition (Bond et al., 1997) and perhaps corresponding to the 9.3/9.2 ka cal BP Event (Fig. 7). This event had similar causes, characteristics and consequences as the 8.2 ka cal B.P. event, although it is of smaller magnitude. Nevertheless, both events remain the most severe and rapid climatic changes during the Holocene. Like the 8.2, the 9.3/9.2 cal BP Event seems to have been caused by a sudden flush of freshwater into the North Atlantic in sufficient volume to affect the thermohaline circulation, which caused globally cold/dry and more arid conditions across the Northern Hemisphere (Fleitmann et al., 2008; Zhang et al., 2018). The main effect of the 8.2 ka cal B.P. event was an impact on upwelling that led to changes in the distribution of marine resources, such that they were no longer available along the coast but rather were concentrated farther upstream in the Tejo and Sado palaeoestuaries (Bicho et al., 2010). It is hypothesized that as a direct consequence of this, the small and dispersed Epipaleolithic hunter-gatherer groups who had previously exploited coastal resources began to cluster together, resulting in the appearance of larger sites such as the Muge and Sado shell midden complexes. These complexes were characterized by burial grounds and the organization of living spaces, strongly suggestive of a higher degree of sedentism and social complexification (Bicho et al., 2010). The lithic component also changed dramatically and become highly standardized, based on chert collected from long distances, with elongated blanks that are regular in size and shape and with frequent retouch to create a large amount of geometrics through the micro burin technique. These geometrics appear in large quantities in each site but with low diversity, with each type being almost exclusive for each site (Bicho et al., 2010; Pereira and Carvalho, 2015).

Regarding the 9.3/9.2 ka cal B.P. event, there is no strong evidence for similarly dense settlements, which could be explained by some combination of two possibilities: a) the phenomenon was not intensive and/or long enough to demand a definitive and drastic change in behavioral patterns, and b) the society itself was not yet at the stage (complexity, demographic, etc.) where the pressure exerted by the event led to a definitive and drastic behavioral shift. Although there is no clear evidence of societal collapse or decline, or of long distance migrations, namely in the complex societies of the Eastern Mediterranean (Flohr et al., 2016), the western coast of Iberia likely more strongly felt its effects.

The Poço Rock shelter Epipaleolithic occupation fits perfectly into the regional Epipaleolithic patterns for which available data cover a variety of landscapes including the coast, the basins of the Douro, Mondego, Lis, Tejo, Sado, Guadiana valleys, but also caves and rock shelters sometimes dozens of kilometers inland with shell middens inside (Araújo, 2012). The preliminary lithic observation allowed the identification in the assemblages of combined local chert, quartzite, and quartz. They also show the systematic exploitation of small nodules, the production of small size and irregular chert and quartz bladelets, using burins as cores, low frequency of retouch, and the contrasting larger size of expedient chopper-and-flake production from quartzite (Araújo, 2012; Cura et al., 2004; Monteiro et al., 2016; Pereira, 1994; Pereira et al., 2012; Pereira and Carvalho, 2015). The characteristics of these sites suggest relatively short-term occupations in a scenario in which small human communities were circulating across large territories and exploiting different landscapes, sometimes only returning to the same place several decades or centuries later (Araújo, 2012; Pereira et al., 2021).

Parallelly, the site also has an overwhelming presence of brackish/saltwater species (these may have been opened and cooked over fire, given the amount of shell, charcoal and firecracked pebbles recovered) and, in this case, the nearly complete absence of herbivore remains. This dietary pattern on the western central coast of Iberia, one in which the marine resources had a strong component, started centuries earlier, during the Preboreal, as an adaptive response to lower temperatures and decreased rainfall, along with increased aridity and significant changes in vegetation (Bicho et al., 2011), which may have been triggered by the reduced the distance to the shore as postglacial sea levels rose. At this time, conspicuous shell middens appear in the archaeological record both along the coast (Soares, 2003; Soares and Silva, 1993) and in the karstic rock shelters of the Estremadura Limestone Massif (Arnaud and Bento, 1988; Bicho, 1995). The detailed analyzes of fauna remains will allow to further address this hypothesis.

The archaeobotanical remains from Poço Rock shelter provide a local snapshot that, combined with the already available data for the coast of Estremadura, contributes to the regional a paleoenvironmental reconstruction of this period.

Despite the low number of charcoal fragments analyzed, those testify the exploitation of firewood in the local landscape by Epipaleolithic populations. The taxa identified in the charcoal assemblage are common in Holocene landscapes of western Iberia, as attested by other paleoenvironmental data such as continental (Charco da Candieira in Serra da Estrela) (Fletcher et al., 2012; van der Knaap and van Leeuwen, 1995) and oceanic (SU80-18) (Fletcher et al., 2012; Lézine and Denèfle, 1997; Turon et al., 2003) pollen cores. Also, anthracological records of archaeological sites in the region, Buraca Grande (Figueiral and Terral, 2002), Pena d'Água (Figueiral, 1998) and S. Julião (Queiroz and Van Leeuwaarden, 2003) show combinations of thermophilous taxa such as *Olea, Pistacia, Arbustus unedo, Rhamnus/Phillyrea* and *Quercus*. Although the radiocarbon dates of this Epipaleolithic occupation suggest the correlation with an abrupt event of decreasing temperatures within the Holocene, the charcoal results indicate that thermophilous vegetation was present in the landscape, was being exploited as fuel and that this pattern corroborates other paleoenvironmental data, suggesting the 9.3/9.2 cal BP Event was not drastic enough to affect already established vegetation during the Holocene.

Based on this, we hypothesize that during the event, small group(s) gathering shellfish on the coast or in the Lis estuary moved to an area sheltered from cold winds similarly to what happened during the Solutrean. After the event, these groups may have returned to their previous patterns; this may have occurred quickly because the 9.3/9.2 ka event may have lasted but a few decades (Flohr et al., 2016). At the same time, the presence of Epipaleolithic occupations with evidence of consumption of marine resources in caves located deep inland and separated by dozens of kilometers (Araújo, 2003b), suggest that these Early Holocene hunter-gatherers had, by this time, developed routes between the inland mountains and the coast. These routes may include sheltered canyons

like Chitas that probably existed for millennia before and continued to exist for many millennia afterwards. However, we still lack robust comparative programs to facilitate understanding these economic and chronological dynamics in greater detail. This pattern seems to have changed considerably only after the 8.2 cal BP event, when people moved to the estuarine areas of the big Tejo and Sado rivers, leaving the Upper Paleolithic-like hunter-gatherer way of life behind and forming a much more complex and sedentary society, one characterized by burial grounds (Bicho et al., 2010; Paixão et al., 2018; Pereira et al., 2016; Pereira and Carvalho, 2015).

In sum, Poço Rock shelter represents a singular case study in which a deeper understanding may be reached when the relationship between human behaviour and adaptation to environmental conditions is considered. Humans are found in places where key resources are available, and biotic resources tend to concentrate near water. During climatic crises the exposed wide plateaus must have been drier, more arid, fustigated by wind and becoming rapidly depleted of vegetation and forested areas. Despite this, they were likely populated by herds of larger game such as horses and aurochs. This is exactly the type of game that we did not find at either occupation. In turn, vegetation and forested areas must have become mostly confined to the much more protected and wetter canyons that, like today, are significantly moister, leafier, and therefore flourish with a greater diversity of biotic and abiotic resources (and with rock shelters). Further study of Poço Rock shelter datasets (lithics, fauna, phytoliths and micromorphology) will allow to deepen these questions and address these hypotheses.

5. Conclusion

Environmental conditions had a strong impact in regional landscapes and the resources therein and were driving forces for prehistoric hunter-gatherer behavior, ecodynamics, and culture. This work is an overview of the first investigations performed in Poço Rock shelter, a site with at least three occupations, all fitting abrupt climatic events. Each one of these occupations is related to the exploitation of specific resources at each specific time: chert during the Solutrean and brackish/saltwater species during the Epipaleolithic.

These occupations may be related to the sheltered conditions of this and similar valleys in western Iberia where there was more fresh water and better conditions for wider biodiversity, attracting people at the time. It is also important in this same territory in the sense that it has uneven conditions for sedimentation and preservation of the archaeological sites, meaning that the specific position of Poço Rock shelter may have allow sedimentation during and between occupations, which partially saved the deposits from erosion since then, something that does not happen in other more exposed areas of western Iberia. These two points are fundamental leads for future investigation of hunter-gatherer ecodynamics, settlement patterns and mobility across the Late Pleistocene and Early Holocene in western Iberia. They may also be relevant to the scope of other chronologies in territories under the influence of the Atlantic or other oceans.

Nonetheless, at least two questions remain: 1) to what extent, and to where, were people exporting the finished chert tools during the Solutrean?, and 2) from where, exactly, were people collecting shellfish during the Epipaleolithic, and why did they stop at Poço Rock shelter?

The answers to these and other questions along with specific analysis will be presented in future work.

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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