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# IDENTIFYING SHORT-TERM CLIMATIC CHANGES THROUGH ISOTOPIC CHARCOAL ANALYSES

early Holocene warming and the “9.3 ky” event at the Mesolithic site of La Baume de Monthiver (Var, France)

Benjamin Audiard<sup>a</sup>, Giulia Ricci<sup>b</sup>, Guillaume Porraz<sup>b</sup>, Louise Purdue<sup>a</sup>, Antonin Tomasso<sup>c</sup>, Carlo Mogni<sup>a, d</sup>, Thierry Blasco<sup>e</sup>, Giovanna Battipaglia<sup>f</sup>, Isabelle Théry-Parisot<sup>a</sup>

## Résumé

Les approches permettant de caractériser les évolutions environnementales et climatiques à différentes échelles temporelles/géographiques sont essentielles dans l'étude de la réponse des sociétés anciennes faces aux changements de leur milieu. Ici, à travers l'application combinée de l'analyse taxinomique et isotopique ( $\delta^{13}\text{C}$ ) des charbons archéologiques des charbons du site mésolithique de La Baume de Monthiver (Var, France) avec un échantillonnage sous-stratigraphique, nous soulignons le potentiel de cette méthode pour fournir un proxy de haute sensibilité renseignant les tendances environnementales à long terme comme les épisodes climatiques plus rapides. On observe ainsi sur le site : (i) la composition taxinomique du couvert arboré de la phase d'étude, (ii) une évolution climatique à court terme, interprétée comme le réchauffement du début de l'Holocène et/ou l'événement climatique sec de « 9,3 ka ».

## Mots clés

Anthracologie, isotopie ( $\delta^{13}\text{C}$ ), paléoclimat, événement « 9,3 ka », Préalpes

## Abstract

Methodological approaches that allow the characterization of environmental and climatic changes on complementary temporal and geographical scales are essential in the study of the response of ancient societies to changes in their environment. Here, through the combining taxonomic and isotopic ( $\delta^{13}\text{C}$ ) analysis of archaeological charcoal from the Mesolithic site of La Baume de Monthiver (Var, France) with sub-stratigraphic sampling, we highlight the potential of this method to provide a highly sensitive proxy for long-term environmental trends as well as more rapid climatic episodes. Thus, we observe at the site: (i) the general taxonomic composition of the tree cover for the study phase, (ii) a high-resolution isotopic signal highlighting short-term climatic evolution, interpreted as early Holocene warming and/or the “9.3 ka” dry climate event.

## Keywords

Anthracology, Isotopy ( $\delta^{13}\text{C}$ ), Paleoclimate, “9.3 ky” event, Prealps

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## INTRODUCTION

The investigation of the evolution of human/environment interactions requires understanding all the diachronic and geographical variability in the environment and climate that prehistoric groups faced. Thus, the intra-regional environment and short climatic events must be considered within the global climatic pattern to better understand the human strategy in their exploitation of a particular territory.

In recent decades, the development of complementary paleoenvironmental approaches has emerged. Among these, taxonomic analyses of archaeological charcoal provide local information on the forest composition of the firewood harvesting area (ASOUTI, AUSTIN 2005; CHABAL 1992). The diachronic variations in the frequency of taxa by analogy with current ecological conditions is interpreted in terms of forest structure and ecology, and thus indirectly documents the climatic context (BADAL GARCÍA, HEINZ 1991; BAZILE-ROBERT 1979; VERNET *et al.* 1987). Furthermore, charcoal analysis provides complementary information on the acquisition and management of wood fuel related to the economy of societies (THÉRY-PARISOT 2001; UZQUIANO *et al.* 2012). Nevertheless, methodologic constraints, indirect climatic information, and the slow response of forest evolution can limit the interpretation of the anthracological assemblage.

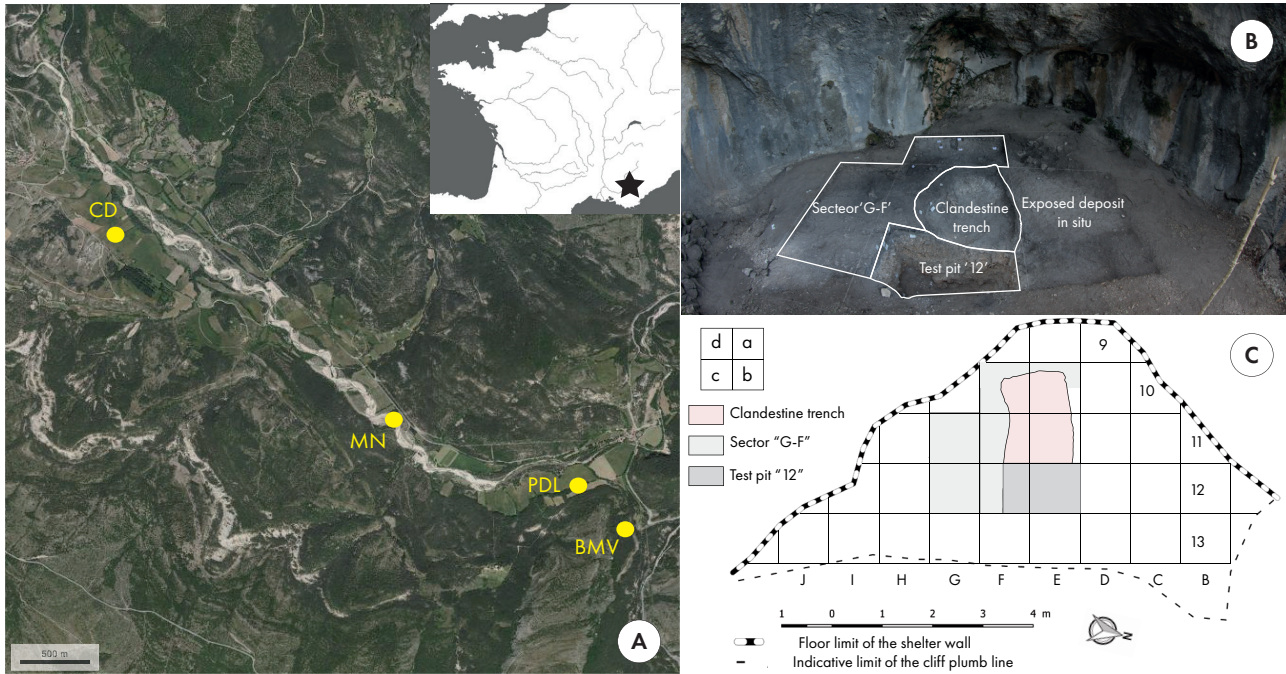
Previous studies of wood carbon isotope composition ( $\delta^{13}\text{C}$ ) have shown that the general discrimination ( $\Delta$ ) of carbon isotopes by  $\text{C}_3$  metabolism plants, observed during atmospheric  $\text{CO}_2$  absorption and photosynthesis, was recorded in isotopic tree-ring signals (CERNUSAK, ENGLISH 2015; MCCARROLL, LOADER 2004). The different stress factors (drought, high temperatures, etc.), controlling the stomatal opening and thus the isotope discrimination, therefore constrain the  $\delta^{13}\text{C}$  tree-ring series record (*e.g.*, water availability increase or temperature decrease lead to  $\delta^{13}\text{C}$  decrease) (FARQUHAR, LLOYD 1993; FARQUHAR *et al.* 1989). Furthermore, it is now recognized that the climatic signal is conserved during carbonization, and it is possible to use carbon content (% C) for the correction of isotopic depletion during carbonization (VOLTAS *et al.* 2008; AUDIARD *et al.* 2018; FERRIO *et al.* 2006). Pioneer research has been conducted on isotopic signals from archaeological charcoal in semi-arid to Mediterranean zones (AGUILERA *et al.*, 2009; AGUILERA *et al.*, 2012; ARRANZ-OTAEGUI *et al.* 2017; CARACUTA *et al.* 2016; DECKERS 2016; FERRIO *et al.* 2006; FIORENTINO *et al.* 2008; FIORENTINO *et al.* 2012; FIORENTINO *et al.* 2010; MASI *et al.* 2013; VOLTAS *et al.* 2008), and more temperate areas or glacial periods (AUDIARD *et al.* 2019; AUDIARD *et al.* 2020; BATON *et al.* 2017; FEBRUARY 2000, HALL *et al.* 2008; VERNET *et al.* 1996), which demonstrates the current potential to investigate climate data on

different temporal scales (*Ibid*), complementary to taxonomic signals.

Thus, the recent methodological development of isotopic analyses on paleolithic charcoal and its application in archaeology suggest new opportunities (AUDIARD *et al.* 2019; AUDIARD *et al.* 2020; CARACUTA *et al.* 2016; HALL *et al.* 2008). Indeed, despite the use of a mean isotopic signal from non-contemporaneous charcoal, by integrating inter-individual records and short-term climatic variability it is possible to observe long-term climate and environmental changes. Moreover, shorter climatic episodes can also be observed with a higher resolution than stratigraphic or anthracological data (AUDIARD *et al.* 2019; Audiard *et al.* 2020). The weaker sensitivity to annual climatic variation and/or reduced signal variability compared to current tree populations have been proposed to explain the strength of the mean  $\delta^{13}\text{C}$  signal (AUDIARD *et al.* 2020; AUDIARD 2020).

The end of the last glacial ice age and the beginning of the Holocene are associated with an increasing number of continuous sedimentary sequences. The palynological study of these sequences provides extensive documentation of forest recovery from the Provence region to the south of the Alps (BRISSET *et al.* 2015; DE BEAULIEU JORDA 1977; FINSINGER *et al.* 2020; MOCCHI *et al.* 2008; NICOL-PICHARD, DUBARD 1998; TRIAT-LAVAL 1978). Conversely, data on local vegetation, particularly that provided by anthracology or carpology, are sorely lacking in the Var prealps, concentrating more broadly on the Mediterranean rim, western Provence, Languedoc, the Rhodanian valley and the Vercors (BATTENTIER *et al.* 2020; BAZILE-ROBERT 1983; BAZILE-ROBERT 1984; BAZILE-ROBERT 1987; DELHON THIÉBAULT 2009; DELHON *et al.* 2010; HEINZ, THIÉBAULT 1998; THIÉBAULT 1988). However, the relief heterogeneity, the hydrographic network and the numerous climatic influences in southeast France lead to mosaic and layered landscapes with their own climatic characteristics (OZENDA, BOREL 2000; QUEZEL, MEDAIL 2003). The study of the evolution of these landscapes must necessarily take into account their geographical variability: timberline position, local forest composition, local sensitivity to warming in the early Holocene or certain climatic events such as the “9.3 ky” or “8.2 ky” events (FLEITMANN *et al.* 2008; RASMUSSEN *et al.* 2007).

In this study, we present combined taxonomic and isotopic approaches applied to charcoal to analyze the pre-alpine site of la Baume de Monthiver in the Jabron middle valley (Var, France) (PORRAZ *et al.* 2018). We particularly focus on the US M-B’3, associated with rich Sauveterrian occupation between 10 – 8 ky cal. BP (PORRAZ *et al.* 2018; Ricci *et al.*, in progress). The aim of this study was two-fold: (i) to document the paleoenvironmental context at the local scale and at different time resolutions, with a particular focus on the diversity of the intra-assemblage climatic signal



**Fig. 1.** La Baume de Monthiver: A - Aerial view of the middle Jabron valley, with the location of the main excavations [Pres de Laure (PDL); Baume de Monthiver (BMV); Moulin Neuf (MN); Condamines-sur-Trigance (CD)] (modified from Costa *et al.*, 2015), B - Photograph of La Baume de Monthiver in west view, C - Site map (Photograph and DAO: G. Porraz).

through the isotopic record study; (ii) to capture original data on the prealpine environment and climate in the context of heterogeneous and diachronic global warming and forest recovery in the Early Holocene. This investigation will help us to better understand the expression of climatic changes between the Mediterranean and alpine region, as well as the intra-regional environmental variability. It will ultimately offer essential data on Sauveterrian evolution during the Boreal and adaptation to climatic constraints in southeast France.

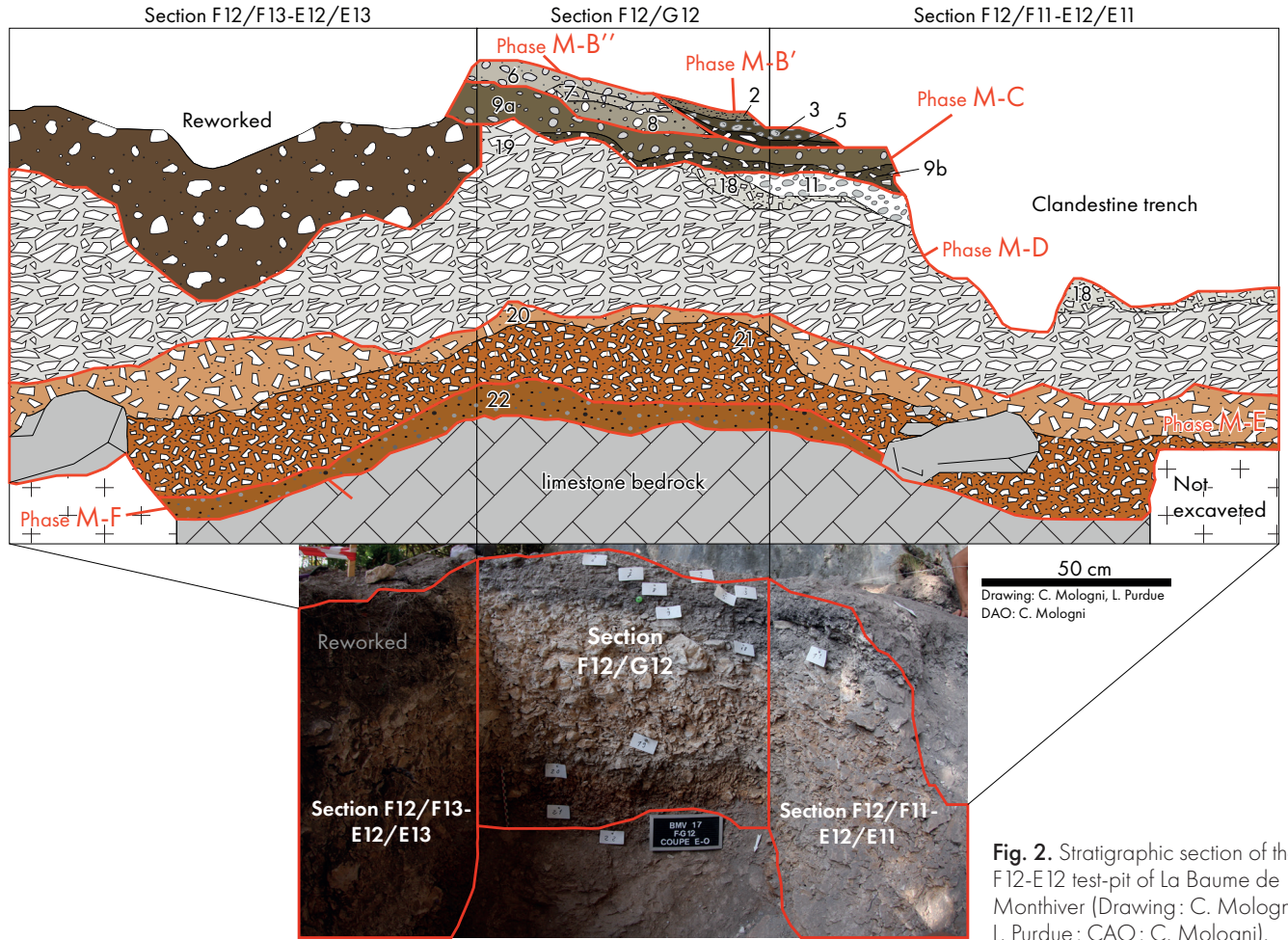
## ARCHAEOLOGICAL AND SEDIMENTARY CONTEXT

La Baume de Monthiver (BMV) corresponds to a small rock shelter (about 10 m wide and 5 m deep), cut in the Jurassic massif of the same name (Comps sur Artuby, Var, 83840) (fig. 1A). Located at an altitude of 900 m, it opens to the east above the Montade Dale, at the southeastern end of the Middle Jabron Valley (700 to 750 m in altitude, tributaries of the Verdon, 945 mm/m<sup>2</sup>/an, 10.3 °C on average) (PORRAZ *et al.* 2017; PORRAZ *et al.* 2018b) (fig. 1B,C). The discovery of the site followed the field campaigns in the valley which aimed: (i) to investigate the history of archaeological occupations in the Prealps and their place at the regional scale; and (ii) to deepen the knowledge of past environmental evolution in the region (BINDER 2014; COSTA *et al.* 2015; PORRAZ *et al.*

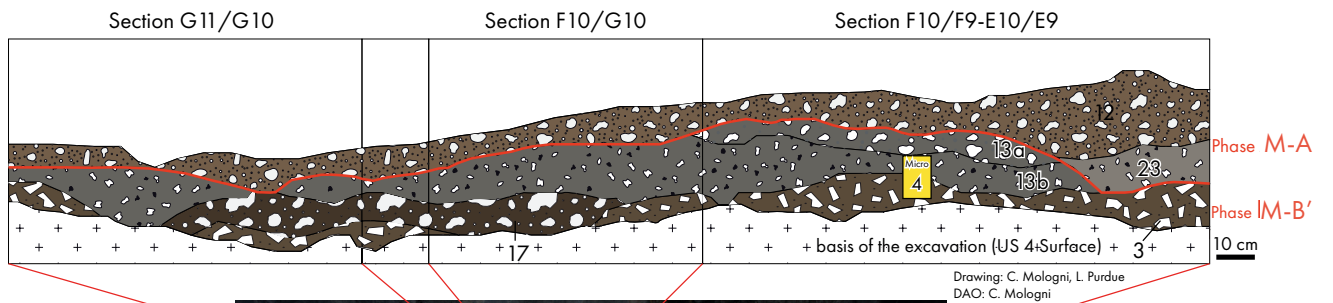
2016; PORRAZ *et al.* 2018a; PORRAZ *et al.* 2019; PORRAZ *et al.* 2014; TOMASSO *et al.* 2016; TOMASSO *et al.* 2019).

The release of reworked sediment from a previous clandestine east-west trench in the center of the shelter revealed a well-preserved sedimentary sequence in the southern half of La BMV, reaching up to 90 cm (sector “G-F”) (PORRAZ *et al.* 2018b; RICCI *et al.* in progress). The fill, trapped between the wall and a talus at the front of the Baume, comes from a combination of runoff, erosion, cryoclasty and anthropogenic inputs at the top of the sequence (MOLOGNI, PURDUE 2017). Sedimentary and geomorphological studies enabled the identification of seven major sedimentary phases (M-A to M-F, with phases M-B’ and M-B’’) and 23 stratigraphic units (*ibid*) (fig. 2 & 3). Three large geomorphological and archaeological sets can be distinguished:

- The first set comprises 4 sedimentary phases (from M-F to M-D). It is characterized by north-dipping deposits successively associated with bedrock erosion, runoff and oxidation (slope with little vegetation, M-G to M-E). Phase M-E has revealed weak traces of human frequentation related to the later part of the Upper Paleolithic. In addition, rare charcoal were identified as *Juniperus* sp. and *Pinus* type *sylvestris/nigra* (AUDIARD 2020). The upper part of the sequence, phase MD, is composed of uncemented gravity scree, subject to pronounced freeze/thaw action.
- The second set, comprising phases M-C to M-B, is characterized by west-dipping deposits associated with



**Fig. 2.** Stratigraphic section of the F12-E12 test-pit of La Baume de Monthiver (Drawing: C. Mogni, L. Purdue; CAO: C. Mogni).



**Fig. 3.** Western stratigraphic cross section (shelter bottom) of La Baume de Monthiver (Drawing: C. Mogni, L. Purdue; CAO: C. Mogni).

an increase in the fine fraction and organic matter input of anthropogenic origin (mainly M-C and M-B'). Phase M-B', containing the US M-B'3 studied here, shows an east-west lateral orientation (US M-B'5/2 before to hole F12, US M-B'13 at the bottom of the shelter). We also note that the contact between the US M-B'3 and the US M-B'13 seem to be affected by complex sedimentary processes with erosive phenomena and hiatuses, as suggested by preliminary field and micromorphological observations (sample "Micro 4", fig. 3) (MOLOGNI, PURDUE 2017; PURDUE personal communication). This ensemble corresponds to an intensified human occupation of the shelter, with more than 400 diagnostic lithic pieces found, associated with combustion remains (charcoal, ashes), fauna, malacofauna and ornamental elements (PORRAZ *et al.* 2018b; RICCI *et al.* in progress). The study of the lithic industry documents reduction systems and general features that are characteristics of the first Mesolithic (RICCI submitted). In this region, the cultural tradition covering the first Mesolithic period is the Sauveterrian technocomplex.

- The third set, represented by phase M-A, corresponds to horizontal deposits with a decrease in the sedimentary input and a halt to human occupation in the shelter.

The excavation of all these stratigraphic units was carried out by *décapage* (*dec*), which involves creating artificial subhorizontal subunits, which rarely exceed 2.5 cm thick, during the excavation to study the evolution of the archaeological assemblage. The US M-B'3 is then characterized by 6 *dec*, with a lateral variability of thickness that decreases towards the top of the US.

## MATERIALS AND METHODS

Charcoal comes from the systematic sieving of M-B'3 sediments over the entire excavated surface (sector "G-F"), conducted with water and a 2 mm mesh. The macro-remains

were sorted and charcoal samples were studied using a reflection optical microscope (magnification  $\times 100$  to  $\times 500$ ). Two dates have already been processed in this stratum (tab. 1) and in order to verify the age of the anthracological assemblage and improve the chronological framework of this unit, we processed three extra radiocarbon dates: (i) one on a *Juniperus* charcoal in the US M-E21 and (ii) two on the US M-B'3 (*dec* 2 and 6).

Charcoal identified as *Pinus* type *sylvestris/nigra* (including *mugo* and *uncinata*) were selected for isotopic study, following the method proposed in AUDIARD *et al.* 2019. Considering the lack of *Pinus* charcoal in *dec* 1, the study is focused on *dec* 2 to 6. A total of 60 charcoal were analyzed, pooled in groups of 5 according to their *dec* attribution (in squares where the US M-B'3 is the most dilated, between 10 – 15 cm). An infrared test of a few complementary charcoals revealed no significant humic acid contamination according to VAIGLOVA *et al.* (2014), thus only a pretreatment for carbonates was applied to each group (1 M HCl for 45 min at 80 °C, rinsed repeatedly with distilled water to a neutral pH) (VAIGLOVA *et al.* 2014).

The isotopic and elemental analysis ( $\delta^{13}\text{C}$  and  $\% \text{C}$ ) was performed with an Elementar Vario PyroCube coupled to a continuous flow Isoprime 100 isotope ratio mass spectrometer at the Villefranche Oceanographic Laboratory (LOV, CNRS/SU). The internal calibration was applied using a caffeine standard (isotopically certified, AIEA-600) calibrated relative to V-PDB, and a secondary standard calibrated with caffeine (acetanilide from Merck, CAS 103-84-4). Uncertainties were in the range of up to 0.1 ‰.  $\delta^{13}\text{C}$  values were corrected using a monopoint standard correction and were reported per mille.

Elemental data ( $\% \text{C}$ ) were relatively stable between 65 and 72 ‰ (average 69 ‰) indicating a similar degree of charring (below 400 °C). The impact of carbonization on the isotopic signal was therefore considered constant and no correction for the carbonization effect was applied to  $\delta^{13}\text{C}$  data. Furthermore, considering the relatively low variations in the atmospheric parameters on the early Holocene

$^{14}\text{C}$ Lab label	Sector	US. <i>dec</i> (Str.)	Sub-Square	Sample	$^{14}\text{C}$ Age BP $\pm 2 \sigma$ (95.4 ‰)	Age calibrated BP, 2 $\sigma$ (95.4 ‰)	Series of dates
Poz-96290	"G-F"	M-B'3.1	E10d	Fauna bone	7,240 $\pm$ 50	8,168-7,971	PORRAZ <i>et al.</i> , 2018
Poz-96291	"G-F"	M-B'3.1	F10d	Fauna bone	7,930 $\pm$ 50	8,985-8,611	PORRAZ <i>et al.</i> , 2018
Lyon-18086	"G-F"	M-B'3.2	F10a	Charcoal ( <i>Pinus</i> sp.)	8,100 $\pm$ 40	9,262-8,787	New Date
Lyon-18087	"G-F"	M-B'3.6	G11b	Charcoal ( <i>Pinus</i> sp.)	8,770 $\pm$ 60	10,121-9,551	New Date
LTL17693	"S12"	M-E21 (UA1)	E12d	Charcoal ( <i>Pinus</i> sp.)	11,639 $\pm$ 70	13,589-13,303	PORRAZ <i>et al.</i> , 2018
Lyon-18088	"S12"	M-E21	F12c	Charcoal ( <i>Juniperus</i> sp.)	11,980 $\pm$ 60	14,047-13,617	New Date

**Tab. 1.** Synthesis table of radiocarbon dates on La Baume de Monthiver, calibrated with OxCal v4.4.2 software from the IntCal20 calibration curve (REIMER *et al.* 2020). "Str." is the structure with which the charcoal is associated.

(< 10 ppmv between 12 and 6.8 ky cal. BP for CO<sub>2</sub><sub>atm</sub>; +0.07 ‰/1,000 yrs between 12.4 and 7.1 ky cal. BP for δ<sup>13</sup>C<sub>atm</sub>) (BARNOLA *et al.* 1987; EGGLESTON *et al.* 2016), we decided to use raw isotopic data in our study.

Finally, for each *dec* of the US M-B'3, a weighted mean signal of δ<sup>13</sup>C was calculated (weighted by the number of charcoals per group). In addition, a margin of error was defined according to the normal distribution of the inter-tree δ<sup>13</sup>C, with a maximum isotope deviation set at 2 ‰ (maximum values obtained in actual wood studies) (LEAVITT 2010) and a minimum deviation set at 1 ‰ (maximum variations obtained for 10 replications in bootstrap statistics from the normal variation of δ<sup>13</sup>C from a population of 100 individuals) (LOADER *et al.* 2013). This method, already applied in other archaeological contexts (AUDIARD 2020, AUDIARD *et al.* 2019), allowed us to approximate the potential variability of the individual isotopic signal (without pooling) and to avoid over-interpretation.

## RESULTS

### Synthesis of radiocarbon chronology

The radiocarbon chronology of La BMV is summarized in table 1. The first human occupation of the shelter, in the base of the sequence, is dated to 14<sup>th</sup> millennium cal. BP. Furthermore, the date obtained from *Juniperus* sp. confirms the age of the anthracological assemblage of the US M-E21.

The top of the US M-B'3 (*dec* 1) is associated with two dates, the first one at the beginning of the 9<sup>th</sup> millennium and the second one at the end. This difference could be explained by the existence of complex erosive phenomena and hiatuses affecting the US MB'3 and US M-B'13 contact (MOLOGNI, PURDUE 2017, Purdue, personal communication). In contrast, the two dates obtained deeper appear to be older, successively attributed around the 10-9<sup>th</sup> millennium transition for the US M-B' *dec* 2 and to the beginning of the 10<sup>th</sup> millennium for the US M-B' *dec* 6. This chronology argues in favor of the *décapage* excavation method integrity where isotopic study has been conducted (*dec* 2 to *dec* 6).

### Taxonomic study of carbonized remains

The results of the anthracological study of US M-B'3 are summarized below in table 2 and figure 4. The study of the carbonized botanical remains of US M-B'3 revealed a very high concentration of carbonized hulls (identified as hazelnut, *Corylus* sp.) associated with rarer charcoal. In total, 1,935 hazelnut fragments were identified for 189 charcoal samples (2,142 elements in total).

Identification	US M-B'3	
	N Charcoal	% Charcoal
<i>Pinus type sylvestris/nigra</i>	74	39.2
<i>Quercus</i> fc.	6	3.2
<i>Quercus</i> sp.	12	6.3
cf. <i>Acer</i> sp.	1	0.5
<i>Buxus</i> sp.	4	2.1
Gymnosperm	7	3.7
Angiosperm	18	10.6
Undeterminable	63	34.4
Charcoal	185	100 (9.2 % Te)
Hull type <i>Corylus</i> sp.	1,821	(90.8 % Te)
Total elements	2,006	(100 % Te)

**Tab. 2.** Synthesis of charcoal identifications obtained by taxons on US M-B'3 of La Baume de Monthiver, with % Te corresponding to the percent of the total elements.

Despite the relatively large size of the charcoal fragments (> 2 mm), their poor preservation conditions made it difficult to observe specific anatomical features and led to a low rate of identification (65/189 charcoals identified). Most of the charcoal fragments were identified as *Pinus* type *sylvestris/nigra* (including *mugo* and *uncinata*) (N = 74). They were secondarily associated with oak (*Quercus* sp., N total = 18), including 6 determined to be deciduous oaks (*Quercus* fc.). One maple charcoal (*Acer* sp.) and 4 boxwood charcoals (*Buxus* sp.) were also observed. Although the latter can be found during the Mesolithic in the Prealps (*e.g.*, Unang/Vaucluse; THIÉBAULT 1988), we noted that all *Buxus* fragments came from the closest sampled square of the clandestine trench, calling into question the contemporaneity of these charcoals. Despite the presence of *Corylus* sp. hulls, no charcoal of this genus was identified. Finally, due to alteration and lack of discriminating criteria, the remaining charcoal were identified only as angiosperm (N = 20) or gymnosperm (N = 7).

### Isotopic study of charcoal

The isotopic results are summarized below by *dec* of the US M-B'3 (tab. 3 and fig. 4). Firstly, we observe that the variability within the same pickling process is relatively low (maximum difference between 0.15 and 0.85 ‰). The maximum variability observed for US MB'3.4, with a relatively high value compared to the others (at -25.31 ‰, outside the proposed margin of error).

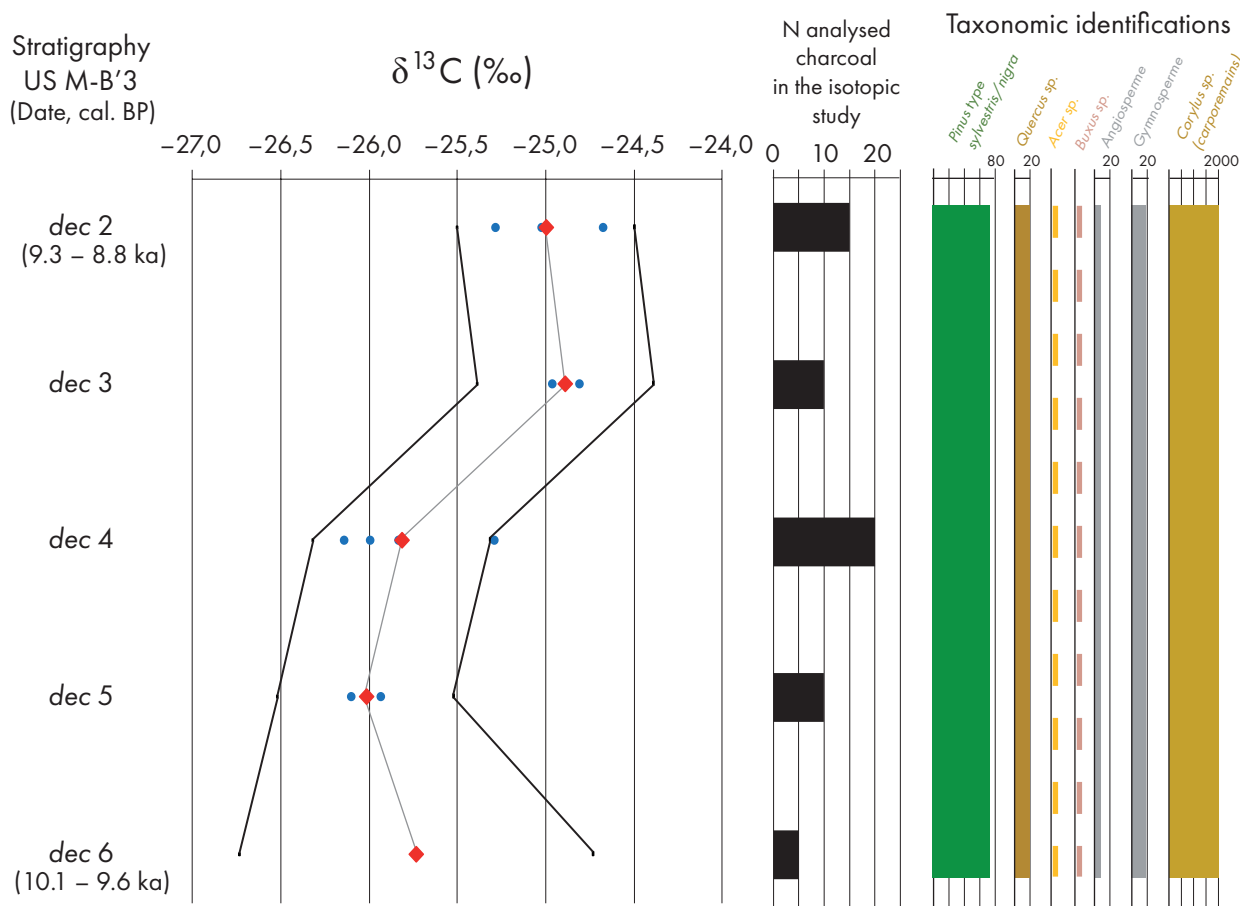
The mean δ<sup>13</sup>C evolution can be summarized by (i) a small decrease between *dec* 6 to 5, (ii) a relative stability

in *dec* 5 to 4 (increase less than 0.2 ‰), then (iii) a sharp increase at *dec* 3 ( $\approx +1.0$  ‰) remaining at a high value in *dec* 2 ( $-0.1$  ‰). This difference in values between *dec* 4 and 3 is highlighted by non-overlapping margins of error, mitigated by the high value for US M-B'4 (at  $-25.31$  ‰). By excluding this isolated value, a common mean around  $-26.0$  ‰ is observed for 5 and 4 (accentuating the mean isotopic difference from *dec* 3).

## INTERPRETATION

### Taxonomic study of carbonized remains

Despite a pronounced concentration in carbonized remains and the identification efforts, the number of determined charcoal samples ( $< 200$ ) makes it difficult to quantitatively interpret the taxonomic results (THÉRY-PARISOT *et al.* 2010a;



**Fig. 4.** Synthesis figure of charcoal taxonomic and isotopic data obtained on the US M-B'3 of La Baume de Monthiver, with (i) *décapage* unit and chronology; (ii) isotopic results [red diamonds; the mean  $\delta^{13}\text{C}$  values by *dec* are represented by the blue dots; and the raw analytical  $\delta^{13}\text{C}$  values are shown with the black lines], the limits of the calculated margin of error; (iii) taxonomic identifications in the number of determined elements [Total for the US M-B'3, dotted line for less than 5 identifications].

Stratigraphic unit. <i>dec</i>	N charcoal (N Analyses)	Mean $\delta^{13}\text{C}$ (‰)	Standard deviation of $\delta^{13}\text{C}$ (‰)	Deviation max of $\delta^{13}\text{C}$ (‰)	Square(s)
US M-B'3.2	15 (3)	$-24.99$	0.30	0.61	F10ac
US M-B'3.3	10 (2)	$-24.88$	0.11	0.15	F10c, G11a
US M-B'3.4	20 (4)	$-25.81$	0.37	0.85	F10a, G11b
US M-B'3.5	10 (2)	$-26.01$	0.12	0.17	F10dc
US M-B'3.6	5 (1)	$-25.73$	/	/	G11ab, F11c

**Tab. 3.** Synthesis of the charcoal isotopic data obtained from La Baume de Monthiver; with (i) N charcoal, the total number of charcoals analyzed and (ii) N analyses, the number of EA-IRMS analyses performed.



CHABAL *et al.* 1999). However, the dominance of *Pinus* type *sylvestris/nigra* (pioneer heliophile taxon with drought/frost resistance), largely associated with *Quercus* sp. (mesophile taxon, temperate to cold resistant) and other mesophilic genera (*Acer* sp., heliophile/more developed soil; *Buxus* sp., ubiquitous taxon), presents an ecological coherence. In particular, the current supra-Mediterranean formations, despite being the result of late reforestation of the pasture areas, present similarities with the anthracological assemblage of La BMV, with the dominance of dense to loosely wooded forests of *Pinus sylvestris*, followed by *Quercus pubescens* and supplemented by other mesophilic species adapted to the climate and relief (*Quercus ilex*; *Buxus sempervirens*, *Cornus sanguinea*, *Acer* sp., *Corylus avellana*, *Juniperus phoenicea*, *Juniperus oxycedrus*) and riparian assemblages of varying densities towards the Jabron river (*Salix* sp., *Populus* sp., *Fraxinus* sp., *Cornus* sp.) (filed observations).

Experimental studies have shown that charcoal assemblages are representative of the diversity of firewood taxa, here dominated by *Pinus sylvestris/nigra* then *Quercus* sp. (THÉRY-PARISOT *et al.* 2010b). The ecological coherence, partly referring to the forest composition at the time, seems to express a low impact of human selection during wood harvesting. Overall, the assemblage indicates a mostly forested environment with a cool to temperate and likely wet climate particularly occurring during global warming phases. In order to consolidate these interpretations, it would be interesting to integrate them with the study of the evolution of the anthracological assemblage on La BMV site, in particular at the Tardiglacial level (US M-E21), which, for the moment, is only represented by a dozen juniper and three pine fragments (AUDIARD 2020).

In addition, despite being absent from the anthracological assemblage, the presence of large quantities of hazelnut pericarp fragments raises questions about the presence of hazel (*Corylus* sp.) in the landscape. This mesophilic taxon appears relatively early in the plant succession during the glacial/interglacial transition (pre-oak forest) and it is in accordance with our landscape interpretation. Furthermore, the absence of *Corylus* charcoal raises two possibilities: (i) hazel trees were not present around the site, but further down in the valley (where there were wetter conditions and more favorable soil development). Thus, the hazelnut was transported to the site for consumption; or (ii) the wood was not harvested where this species was intended for consumption (VALDEYRON 2013; RUIZ-ALONSO, ZAPATA 2015). In both cases, we assume that the substantial number of hazelnuts suggests the presence of hazel in or close to the Jabron Valley.

### Isotopic study of charcoal

Due to the pooling method adopted for the charcoal isotope measurements, the isotope values obtained correspond

to mean  $\delta^{13}\text{C}$  and do not account for the actual isotope variability within the anthracological assemblage. Using the calculated margin of error allows us to determine the potential variability of the signal in the tree population and discuss the power of the mean isotopic signal (AUDIARD 2020; AUDIARD *et al.* 2019). Moreover, studies on isotopic signals from paleolithic charcoal suggest that the use of mean  $\delta^{13}\text{C}$  values (several charcoal samples, several tree-rings) leads to a decrease in high-frequency variability (seasonal and annual recording), and thus, these authors incorporated it in the margin of error (AUDIARD 2020; AUDIARD *et al.* 2020). This low variability of mean signal appears to be verified here with a maximum isotopic deviation by *dec* which does not exceed 0.85 ‰. Furthermore, these data are consistent with several studies which propose that 15 to 30 charcoal samples (or tree-rings) would be enough to obtain a significant low-frequency mean  $\delta^{13}\text{C}$  signal (although fewer would already be informative) (AUDIARD *et al.* 2020; ESPER *et al.* 2015).

In this respect, and considering the lack of overlap between margins of error of the lower *dec* (*dec* 6 to 4) and upper *dec* (*dec* 3 and 2), the mean  $\delta^{13}\text{C}$  signal increase is considered significant (correlated with climate) and not only due to signal variability. Moreover, the high variability of isotopic values obtained in *dec* 4 could correspond to several isotopic records (from a mixture of noncontemporary charcoal). In contrast, the small evolution of the  $\delta^{13}\text{C}$  values between the *dec* from the same set remains difficult to interpret.

Considering the taxonomic results and their coherence with contemporaneous regional data (temperate early Holocene), the impact of both humidity and temperature changes must be considered as possible limiting climatic factors (drier or warmer conditions lead to plant hydric stress and thus  $\delta^{13}\text{C}$  decrease) (CERNUSAK, ENGLISH 2015; GAGEN *et al.* 2007; MCCARROLL, LOADER 2004). Thus, the increase in the observed mean  $\delta^{13}\text{C}$  could correspond to an increase in temperature and/or aridity. Given the chronology (between 10.1 and 8.8 cal. ky), the early Holocene warming could be the main stress factor for *Pinus* type *sylvestris/nigra*. The abrupt  $\delta^{13}\text{C}$  evolution between *dec* 4/3, as opposed to a gradual evolution, could be explained by: (i) discontinuous human occupation with a record of two distinct climatic phases, or (ii) a hiatus similar to the one observed at the US M-B'3/13 contact. Nevertheless, our record could also correspond to the “9.3 ky” cal. BP climatic event (FLEITMANN *et al.* 2008; RASMUSSEN *et al.* 2014; RASMUSSEN *et al.* 2007). This event, mainly recorded in the northern hemisphere, appears to be a climatic event similar to the better-known dry “8.2 ky” event (*ibid*). Moreover, in the northern Mediterranean rim, this event is principally associated with a sedimentary hiatus (BERGER, GUILAINE 2009). At La BMV site, the “9.3 ky” and “8.2 ky” events might be connected with the sedimentary gap identified

at the US M-B'3/13 contact, and could also explain the abrupt evolution of the isotopic signal in the US M-B'3.

In summary, two phases are recorded: (i) the first one characterized by cooler conditions at the beginning of the 10<sup>th</sup> millennium (M-B'3 *dec* 6 to 4), then (ii) a second one during a warmer and/or dryer phase. In this context, the “9.3 ky” event could both lead to the aridity of the second phase and/or to a sedimentary hiatus (MB'3 *dec* 3 to 2).

## DISCUSSION

Due to the limited number of charcoal samples and their poor preservation, the taxonomic analysis is not very robust (few specific identifications). Nevertheless, it provides general information on the past environment (mainly forested with a cool to temperate climate), which appears to be consistent with the known early Holocene vegetation in the region: the progressive colonization of pine (*Pinus* type *sylvestris/nigra*) towards the Alps, followed by more mesophilic species such as oak (*Quercus* FC.) and hazelnut (*Corylus* sp.) (DE BEAULIEU, JORDA 1977; DE BEAULIEU *et al.*, 1994; DELHON *et al.* 2010; MOCCI *et al.* 2008; TRIAT-LAVAL, 1978; THIÉBAULT 1988). The latter in particular, represented by hull remains, is characteristic of this period and found in numerous archaeological sites and natural sequences in the Alps of the 9<sup>th</sup> millennium, up to high alpine altitudes ( $\approx 1,700$  m) (DE BEAULIEU, JORDA 1977; MOCCI *et al.* 2008; ANGELIN *et al.* 2016; VALDEYRON 2013; FINSINGER, TINNER 2007). However, given the challenges in anthracological assemblage interpretation and the absence of hazel charcoal, it is difficult to further develop the comparison with the above-mentioned sites.

Contrary to the taxonomic study, the isotopic analysis of charcoal from US M-B'3 allowed us to identify a short-term climatic evolution. This was interpreted as a possible record of early Holocene warming and putative erosive phenomena, and/or as the “9.3 ky” dry event. At a global scale, if the early Holocene is characterized by a significant temperature increase during the Preboreal, this rise then declines towards the Boreal (RASMUSSEN *et al.* 2014; RASMUSSEN *et al.* 2007; ROHLING, PÄLIKE 2005). Thus, if the 10<sup>th</sup> millennium is still associated with slight global warming, the question of its intensity in the region can be raised. Similarly, the regional impact of the “9.3 ky” event, which is an order of magnitude smaller than the “8.2 ky” event, can also be questioned (FLEITMANN *et al.* 2008). The expression of these climatic oscillations has also been investigated through deep-water records and atmospheric/thermohaline circulation in the western Mediterranean (FRIGOLA *et al.* 2007; JALALI *et al.* 2016).

In the forested context introduced earlier, we can observe that the evolution from the pine colonization at high altitudes

to the development of a mesophile forest (oak then hazel) occurs around the end of the Preboreal and the beginning of the Boreal (expressed through southeastern France, progressively with altitude) (DELHON *et al.* 2010; THIÉBAULT 1988; GUENET, REILLE 1988; DELHON, THIÉBAULT 2009; HEINZ, THIÉBAULT 1998; BRISSET *et al.* 2015; MOCCI *et al.* 2008). Thus, the increasing isotopic values observed in US M-B'3, interpreted as climatic stress on *Pinus* type *sylvestris/nigra*, is in accordance with the decrease of this species in the perialpine region, attributable to a temperature increase and competition from other forest species. Nevertheless, these records also suggest the possibility of an intensified episode of general warming and/or a dry episode, with large-scale tree die-off (particularly *Pinus* if it incorporates a warming episode). The replacement by mesophilous species would thus occur during the next wetter phase (with soil developed, less competition for water, optimal conditions for reproduction) (ROYER *et al.* 2011). This could explain the rapid Boreal forest change observed in the Alps and Prealps (*Corylus*, *Quercus*, *Abies*) (BRISSET *et al.*, 2015, DE BEAULIEU, JORDA 1977; MOCCI *et al.* 2008). In an analogous example, the end of the “8.2 ky” episode is marked by a peak of fires in southeastern France (8.1-8.0 ky cal. BP) (ARNAUD-FASSETTA *et al.* 2005; BERGER, GUILAINE 2009) and central Italy (Lake Accesa) (MAGNY *et al.* 2006). In this respect, the isotopic observations made in our study would correspond to the consequences of the conjectured “9.3 ky” event and a warming phase at the beginning of the Holocene. Moreover, if we continue the analogy proposed between the climatic “9.3 ky” and “8.2 ky” events, the period around 9.3 ky cal. BP would be associated with a sedimentary hiatus, recurrent in sites contemporary with the “8.2 ky” event (BERGER, GUILAINE 2009). This hypothesis aligns with the observed isotopic gap and the radiocarbon chronology but could also be consistent with the hypothesis of successive effects of the “9.3 ky” dry event (hiatus,  $\delta^{13}\text{C}$  *dec* 3-2) and global warming ( $\delta^{13}\text{C}$  *dec* 6-4 to 3-2).

At the western Mediterranean scale, a larger event dated from the 10<sup>th</sup> millennium to 7.8 ky cal. BP, following an early Holocene warming (FRIGOLA *et al.* 2007; JALALI *et al.* 2016) has been recorded in the MD99-2343 core (Gulf of Lion) with the deposition of coarser sediments (fraction > 10 mm) and a decrease in *G. bulloides*  $\delta^{18}\text{O}$  (FRIGOLA *et al.* 2007). Regarding isotopic, sedimentary and radiocarbon data from La BMV, the US M-B'3 to US M-B'3/13 contact could indicate a warming phase until 9 ky cal. BP before a decrease in temperature associated with a dryer event. This record framed between 10 to 8.2 ky cal. BP seems interspersed with several hiatuses (possibly associated with the “9.3 and 8.2ky” events).

Furthermore, it should be noted that we consider the variations in atmospheric  $\text{CO}_2$  observed in the ice cores to be too small to have a significant impact on the  $\delta^{13}\text{C}$  signal

(RASMUSSEN *et al.* 2007). However, several studies proposing a finer resolution of the variations in CO<sub>2atm</sub> (centennial) on the basis of the *stomatal index*, observe greater variations of CO<sub>2atm</sub> at the beginning of the Holocene (up to 40 ppmv in the Preboreal) (JESSEN *et al.* 2007; WAGNER *et al.* 2004). Thus, although the *stomatal index* evolution points towards the hypothesis of a constant *ci/ca* (negligible effect on δ<sup>13</sup>C) (FARQUHAR *et al.* 1989), the isotope gap observed in our study could also have been accentuated by a significant decrease in CO<sub>2atm</sub> between the two phases recorded.

## CONCLUSION

Even if the anthracological and isotopic observations deserve to be consolidated in parallel with a deepening of the sedimentogenic interpretation, the multiproxy study of the charcoal of La Baume de Monthiver demonstrates the complementarity of both methods and provides general and local information on the forest environment and climatic discontinuities in the Preboreal/Boreal period.

We identified a forested environment typical of the warm beginning of the Holocene as well as a short-term climatic shift, framed around “9.3 ky”, characterized by drier conditions. Furthermore, thanks to good stratigraphic preservation and a microstratigraphic sampling method (*dec*), the time resolution of the isotopic study can help us understand the importance of such climatic shifts in the general dynamics of forest evolution. The use of this comparative charcoal study over the entire sequence of La Baume de Monthiver, and also on a larger scale across the study of all sites in the middle Jabron valley, could provide a unique environmental and climatic signal in a geographical area where data have thus far been insufficient.

The study also provides a precise framework for the study of the occupations of phase B’ that are considered to be linked to the Sauveterrian tradition (PORRAZ *et al.* 2018b; RICCI *et al.* in progress; RICCI submitted). While these variations do not necessarily lead to breaks in the technical traditions of human groups, their impact (climatic perception, occasional migration of fauna, deadwood formation, fires, etc.) could have led contemporaneous populations to acclimatize. This question will be addressed in future by combining paleoenvironmental and archaeological data.

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