



Archaeobotanical investigations and experimental activity performed at Bàsura Cave (Toirano, NW Italy) reveal clues on Epigravettian cave lighting systems

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ABSTRACT

The Bàsura Cave (Toirano, NW Italy) is one of the most important caves in northern Italy conserving the fossilised footprints of a walking trail left by a small group of humans accompanied by a canid dating to the Epigravettian and an impressive cave bear bone deposit of the middle Pleistocene. In 2016 a new research project entitled “The Bàsura Revisited”, returned to fieldwork through a multidisciplinary approach, with the aim of understanding the nature of the human and animal presence in the cave.

In this paper we present the results of a multidisciplinary investigation of archaeobotanical remains, stratigraphic sequences, and experimental reconstructions relating to Late Upper Palaeolithic human activity in the Bàsura Cave. The study is centered on the anthracological and palynological remains which led to the identification and interpretation of cave lighting system based on controlled experiments. The study provides new insights into the patterns of human exploration in Palaeolithic cave systems, highlighting the reliance on small-diameter pine twigs as a source of light. The interpretation of the local vegetation environment has been inferred from palynological evidence.

The palynological analysis conducted on samples from the innermost space of the cave (“Hall of Mysteries”) suggests that the landscape around the cave consisted of a sparse pine forest of *Pinus sylvestris/mugo*-type interspersed with steppe herbaceous formations. In the upper level, this is enriched with modest amounts of mesophilous broadleaved trees and thermophilic species. The pollen input likely derived from particles adhering to the fur of bears and infiltrations from the external environment of the cave. Finally, we performed an experimental study aimed at understanding the cave's lighting systems adopted at Bàsura Cave, reconstructing the nature of the lighting instruments and the way the prehistoric explorers moved in the cave. The test confirmed the burning of small twigs rather than the use of torches. The use of twigs is inferred by the traces of

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small-diameter branches obtained from *Pinus sylvestris*-type, used individually or tied in small bunches. The experiment revealed that, despite the small size, burning twigs produces enough light to ensure a longer permanence in the cave depth and a safe pathway back, and at the same time minimises dazzling and fast consumption of wood fuel.

1. Introduction

The Bàsura Cave, located near Toirano (Western Liguria, NW Italy, 44°08'16.3"N; 8°12'07.4"E), opens at 186 m above sea level and has a total development of approximately 800 m, with a sub-horizontal orientation and a vertical difference of $\pm 20/22$ m from the entrance (Fig. 1).

It is part of the karst system developed in the calcareous-dolomitic massif of the San Pietro dei Monti and Costa Losera formations of the Middle Triassic, within the watershed of the Varatella Torrent (Menardi, 1984; Columbu et al., 2021; Audra et al., 2022).

The atrium of the Bàsura Cave has been known since the late 19th century, whereas the hypogeal part was discovered only in May 1950, when a group of young locals opened a passage in the stalagmitic diaphragm separating the atrium hall from the hypogeal part (Tongiorgi and Lamboglia, 1954; Lamboglia, 1960). Virginia Chiappella was the first archaeologist to recognise the exceptional importance of this site, due to the presence of human footprints, finger flutings, clay lumps on the walls, as well as traces of charcoal on the ground and cave walls along with numerous bone remains of *Ursus spelaeus*. The first scientific studies and test excavation date back to the first two decades after the discovery (Chiappella, 1952; Blanc, 1960; Blanc and Pales, 1960). These studies focused on exploring the nature and consistency of the fossiliferous deposit, and the anthropogenic traces that were initially attributed to Neanderthals (Pales, 1960). In the 1970s, first radiometric dates, particularly those on charcoal samples collected on the paleosurface, returned values of about 12,300 years ago (uncal), challenging the

previous attribution by Pales to Neanderthals. After abandoning the Neanderthal hypothesis, the footprints were correctly attributed to Epigravettian groups, whose presence in the territory is widely documented (Delibrias, 1986; Yokoyama et al., 1986; Molleson et al., 1972; De Lumley and Vicino, 1984; De Lumley and Giacobini, 1986).

New multidisciplinary investigations started in 2016, thanks to the "Bàsura Revisited" project. The aim was to resume the study considering the whole evidence of human and animal presence in the various parts of the cave (Fig. 1). We started with taphonomic, sedimentologic and micromorphologic analyses of the cave bear deposit, the ichnological documentation and study, performing new radiometric dates (Citton et al., 2017; Romano et al., 2019; Pozzi et al., 2019; Avanzini et al., 2021; Rellini et al., 2021; Arobba et al., 2022; Zunino et al., 2022; De Sario et al., 2026).

This paper aims to present the results of a new archaeobotanical study (charred macroremains and pollen grains). The first determinations of a limited number of charcoal remains defined as "fossil torch residues" that were collected in the '1960s by Professor C. A. Blanc in the Bàsura Cave, led to the recognition of *Pinus laricio* (Follieri, 1962). A subsequent study, conducted more recently by R. Nisbet on a single charcoal specimen collected in the SdM determined the sample as *Pinus sylvestris* (Maggi and Ottomano, 2008). Palynological analyses of speleothems and of samples from the sedimentary sequence of the "Cave Bear Cemetery" ("Cimitero degli Orsi", hereafter CdO) have been performed in the same years (Arobba, 1986; Arobba and Caramiello, 2008).

These previous works involved the study of the sampling from an old exposed profile in the CdO brought to light by the excavations of V.

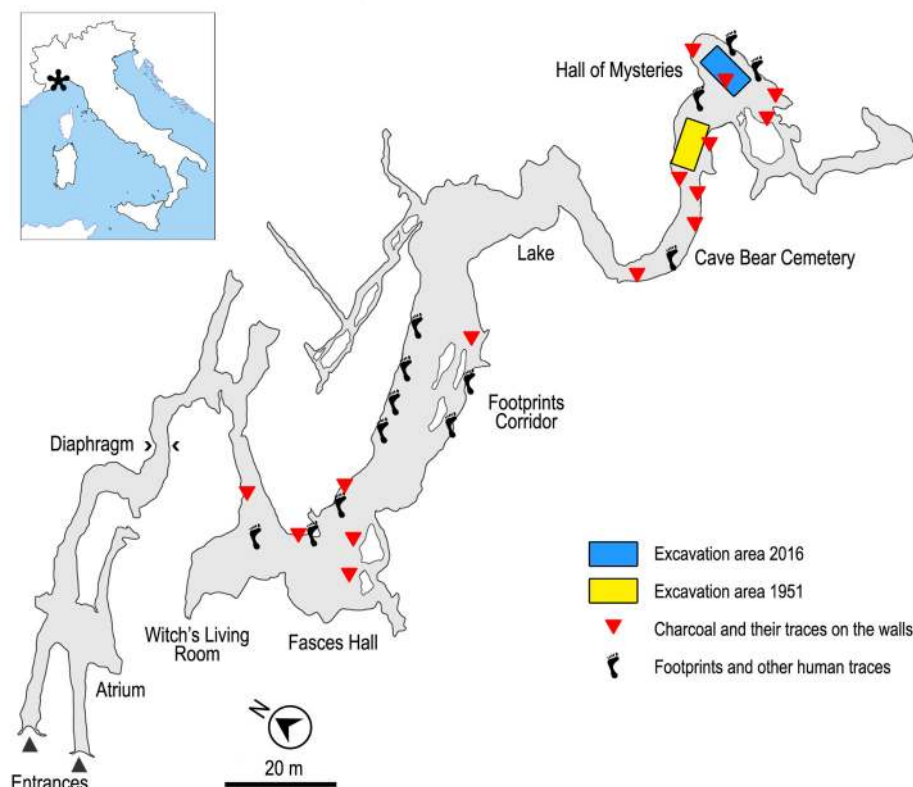


Fig. 1. Map of the Bàsura Cave with the location of the test trenches, the traces of charcoal and human footprints distribution. Drawing: D. Arobba.

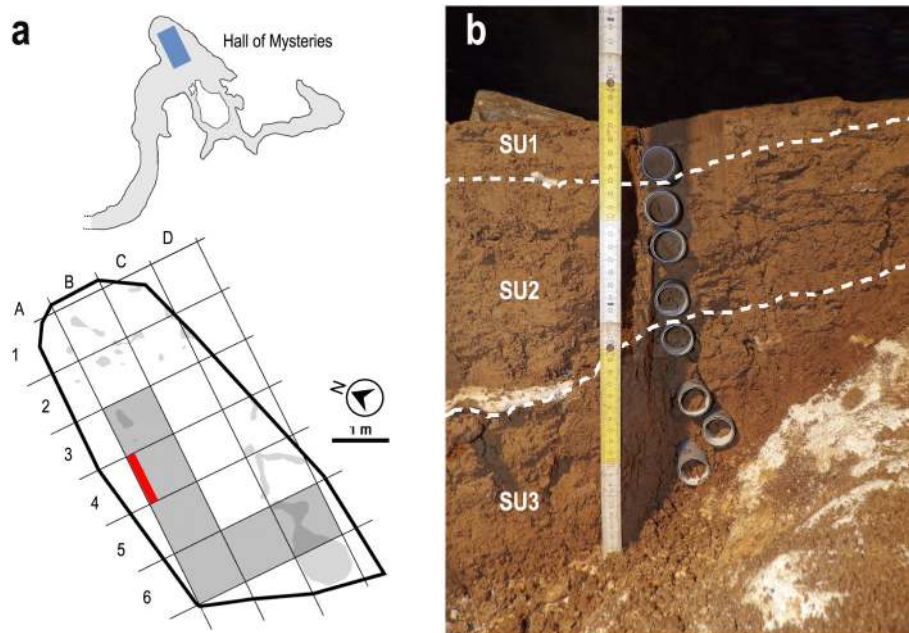


Fig. 2. Bàsura Cave: a) map of the 2016 excavation grid in the “Hall of Mysteries”. Excavated squares in dark grey; the red line shows the sampled profile for pollen analysis. The black contour line indicates the position of the railing of the touristic pathway constructed inside the cave in the last century; b) Stratigraphic profile in square B4 showing the sedimentary units and the location of the palynological samples. Drawing: D. Arobba. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Chiappella (1952). In contrast, the archaeobotanical analyses presented in this paper concern the first stratigraphic excavation carried out within the framework of the aforementioned “Bàsura Revisited” project. In 2016, a test excavation was carried out in the “Hall of Mysteries” (“Sala dei Misteri”, hereafter SdM) where a consistent number of human traces has been documented since the last century (Blanc, 1960). The scope of the new excavations was to test the existence of an archaeological buried deposit attributable to the Epigravettian human activity in the cave and, eventually its nature (Starnini et al., 2021; Zunino et al., 2023). New charcoal and pollen samples have been collected during the excavations along the stratigraphic profile.

Other micro- and macro-remains of archaeobotanical interest have been unexpectedly recovered and collected at the base of a small speleothem located in the “Fasces Hall” (“Sala del Fascio”, hereafter SdF), which was sampled for palaeoclimate studies in 2018 (Hu et al., 2022a, 2022b). They have been radiocarbon dated providing possible evidence of other periods of human presence during the Upper Palaeolithic.

The presence of charcoals on the surface of the Bàsura cave floor led to the idea of possible lighting systems used by the Epigravettian human group and inspired the experimental activity.

We know that controlled use of artificial lighting was essential for the exploration of deep cave environments, requiring careful management of combustion conditions and spatial constraints in the most internal halls, and that different means of lighting were available to Upper Palaeolithic people allowing them to venture dark underground, transforming such inhospitable and potentially hazardous settings into accessible spaces for exploration and symbolic activity (Perlès, 1977; Beaune, 2000; Medina-Alcaide et al., 2021; Kedar et al., 2023). Among them, torches have been assumed to be the more plausible method of lighting used by the Bàsura Palaeolithic explorers, based on the charcoals distributed on the cave floor surface (Molleson, 1986, p. 370).

Exploration visits testified by the footprints left on the ground in a completely dark underground environment, could reasonably have been possible only thanks to some type of light source (Beaune, 2000; Avanzini et al., 2021). The totality of the carbonised wood fragments is therefore to be related to the use of “torches”, which in the 1950s were believed to be made of large-calibre branches, used by Neanderthal

individuals in exploring the cave. A drawing by Neave Parker, published by Blanc (1953), in fact highlights this interpretation, which was considered convincing until the publication by Molleson et al. (1972) of new radiocarbon dating that attributed the footprints to the Epigravettian.

In 2024 an experimental study aimed at understanding the lighting systems used by the human group that entered the Bàsura Cave, was performed. It focused on reconstructing the nature of the lighting instruments and the way the prehistoric explorers moved in the cave. In this work, after the results of the archaeobotanical study, we present the results of this experimental activity based on proxies obtained from the study of the anthracological remains and carbon traces documented during the excavations and archaeological explorations.

2. The site: fieldwork and sample collection

In 2016, an archaeo-palaeontological excavation was conducted in the central part of SdM opening a test trench of 6 m² (Fig. 2), carefully choosing an area where the surface of the cave floor did not conserve traces of prehistoric footprints and in correspondence with charcoal traces on the above ceiling (Starnini et al., 2021).

In this hall, in addition to human footprints and finger prints conserved along the perimeter (Citton et al., 2017; Romano et al., 2019), a large amount of charcoal traces are present on the cave walls, ceiling and stalactites: they have been attributed to human Palaeolithic activity (Rembado and Vicino, 1986; Giannotti, 2008; Clementi et al., 2022).

Various types of charcoal traces can be observed: hand and finger prints and spots that have been interpreted as the result of the action of rubbing burning wood to refresh the flames (Blanc, 1960).

As mentioned, the excavation trench was positioned in correspondence with charcoal marks on the ceiling and stalactites and charcoal remains on the cave floor. All the sediment has been excavated by hand with the use of VHS trowels and wet-sieved to collect also micro-remains. No stone or bone artefacts attributable to human presence were found along the entire excavated sequence. The stratigraphic succession, about ca. 40 cm deep, is composed of three Stratigraphic Units (SU1-SU3) separated by discontinuity boundaries lying above a

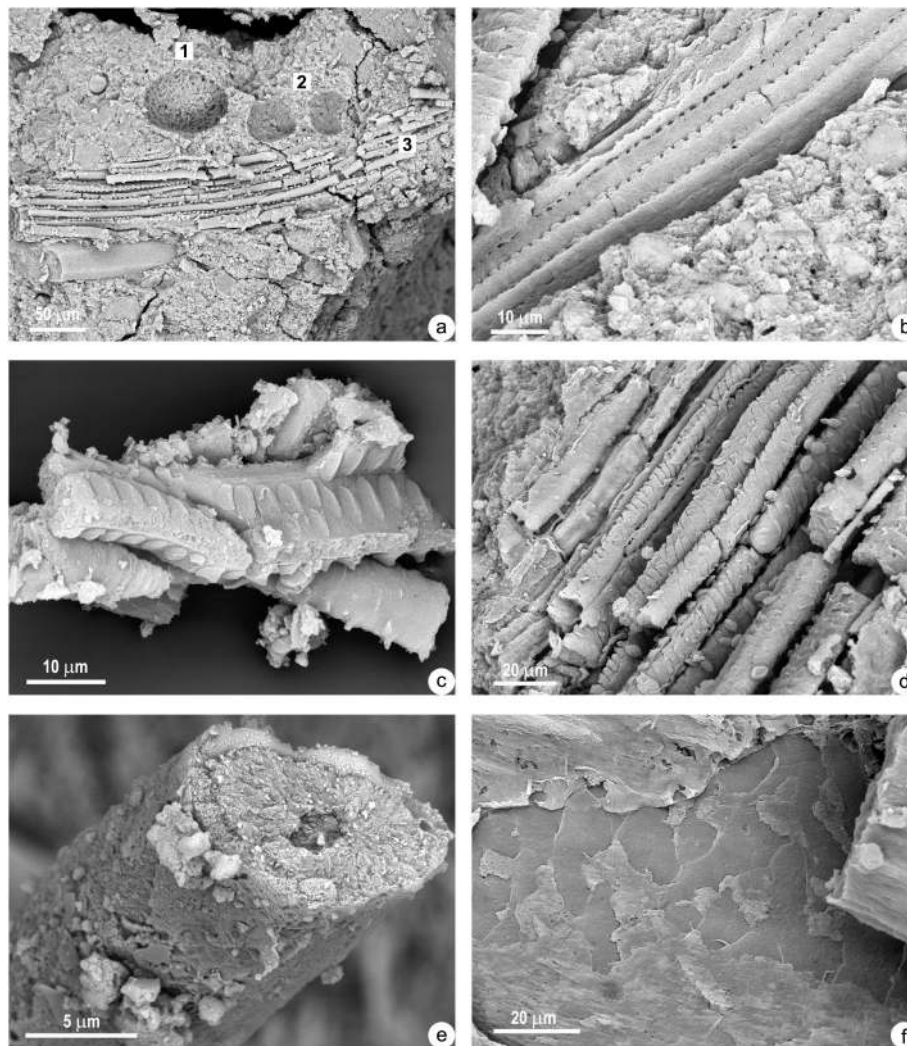


Fig. 3. Backscattered electron micrographs of botanical microremains and bear hair in the surface level of the Hall of Mysteries deposit: a) pollengrain of *Pinus* sp., corpus with exine sculpture verrucate-rugulate (1) and two sacci detached from the central corpus (2); at the bottom casts of vessel elements with intervessel pits (3); b) phytolith skeleton with long elongate dentate elements; c) casts of alternate intervessel pitting of Angiospermae; d) casts of long helical thickenings in vessel of Angiospermae; e) fine bear hair in which the cuticle, cortex and medulla are visible from the periphery to the center; f) external cuticle of bear hair with scale-shaped pattern. Photographs: I. Rellini.

corroded flowstone surface (Rellini et al., 2021) as follows:

- SU1: depth 0-3 cm up to a maximum of 5 cm. Yellowish-brown silty sands (Munsell Chart: 7.5 YR 4/6) with bone fragments (*Ursus* sp.) and charcoal, which show a random distribution, probably due to trampling; rare fragments of subangular speleothems, calcareous gravels were also found;
- SU2: depth from 3/5-20 cm. Brown silty sands (Munsell Chart: 7.5 YR 4/4) with many centimetre-sized concretions, accompanied by bear bones (*Ursus spelaeus* and *Ursus arctos*), increasing towards its base; tubular microstructures attributable to phosphate bear “hair tufts” embedded in fine sediments were observed in the upper portion of this unit. Its lower boundary corresponds to a stratigraphic discordance, probably linked to depositional hiatuses.
- SU3: depth from 20 to a maximum of 42 cm. Brown silty sands darker than the previous ones (Munsell Chart: 10 YR 7/3) with abundant speleothem and bone fragments (*Ursus spelaeus*) concentrated at the base of the level, associated with manganese coatings and P nodules. Its lower boundary corresponds to a weathered flowstone.

Sedimentological and micromorphological analysis showed that the

deposit formed by the dismantling of a former bear bone-bearing deposit and subsequent reworking and redeposition through short but intensive flooding events, with injection of siliciclastic allogenic sediment by sinking streams, from before 50 ka to the Holocene. After the final deposition on the floor of the SdM, sediments making up the succession suffered important diagenetic changes probably triggered by guano deposits, whose former presence is inferred from nutrient concentrations and mineral species of the chemical group of phosphates and from bat claw traces present on the vault of the cave. The study of undisturbed samples in thin section revealed the exceptional presence in SU2 of copied forms and structures of hairs and vegetal tissues, phytoliths and pollen within fossilised fur fragments (Rellini et al., 2021) (Fig. 3).

3. Material and methods

3.1. Pollen analyses

Along the stratigraphic sequence, eight samples were taken for palynological analysis from the north section of square B4 at a distance of about 5 cm from each other (Fig. 2b).

For the extraction of palynomorphs, the usual chemical-physical

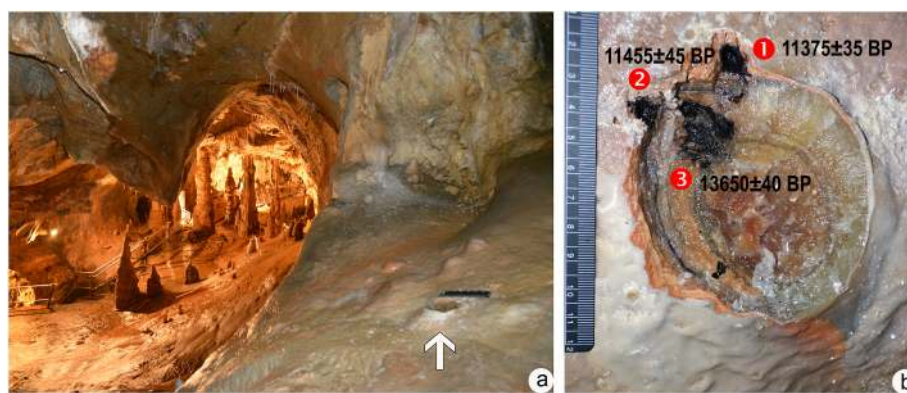


Fig. 4. Bàsura Cave: a) view of the "Fasces Hall" with the indication of the position of the small stalagmite sampled (white arrow) for palaeoclimate analysis at the base of which some charcoals have been found; b) detail of the base of the stalagmite with the three *Pinus-sylvestris/mugo*-type charcoals still in situ dated by ^{14}C (1 = GrM-18802: 11375 $\pm$ 35 BP; 2 = GrM18751: 11455 $\pm$ 45 BP; 3 = GrM18819: 13650 $\pm$ 40 BP). Photographs: D. Arobba.

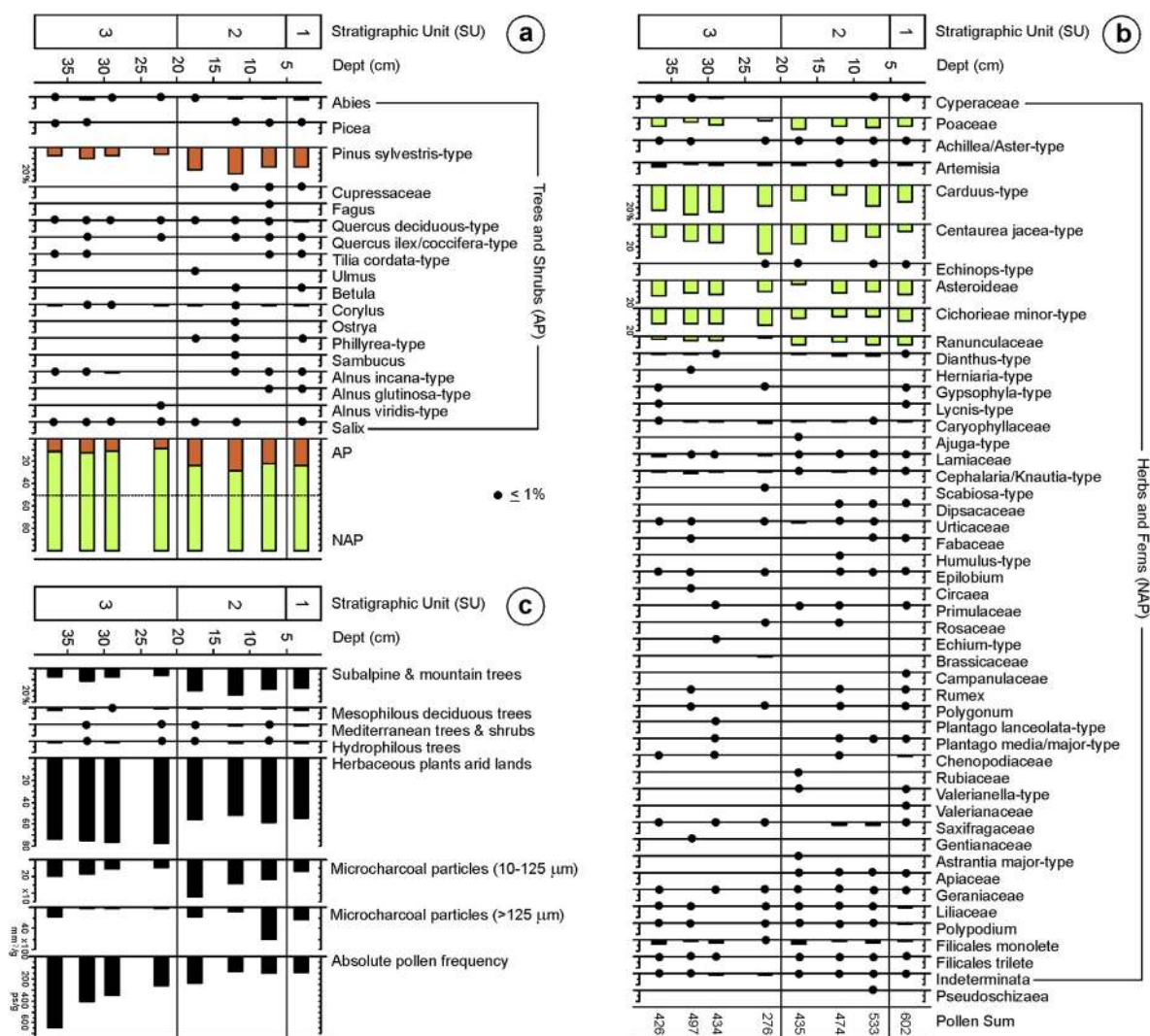


Fig. 5. Bàsura Cave: pollen diagram from "Hall of Mysteries" deposit; a) trees and shrubs (AP); b) herbs and ferns (NAP); c) main floristic-vegetation categories, microcharred particles and absolute pollen frequency. Drawing: D. Arobba.

treatments (HCl, KOH, HF) and enrichment with heavy liquids (Goeury and de Beaulieu, 1979; Riding, 2021) were followed. The preparation was observed under a light microscope (Leitz Diaplan) at 400-630x, and for the determination of the finds, atlases, analytical keys, and the palynological collection of the Archaeological Museum of Finale (Fægri

and Iversen, 1989; Moore et al., 1991; Reille, 1992; Beug, 2004) were used.

The absolute pollen frequency and microcharcoal concentration were calculated by adding *Lycopodium* spores (Stockmarr, 1971; Whitlock and Larsen, 2001).

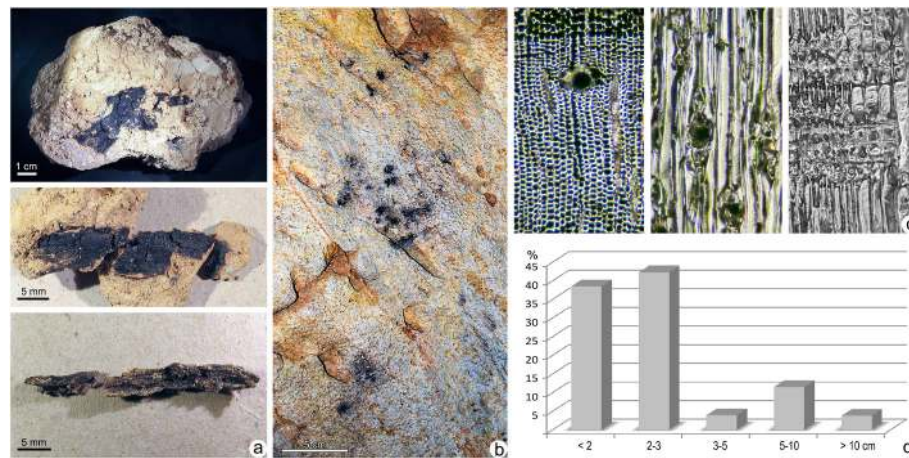


Fig. 6. “Hall of Mysteries”: a) some charcoal fragments sampled in SU1; b) charcoal traces on the stalagmite wall in the centre of the room; c) three anatomical planes (transverse, tangential and radial: 100-300-500x) of the wood of *Pinus sylvestris/mugo*-type sampled in SU1; d) percentage histogram of the apparent diameters of the charcoal sampled in SU1. Photographs: D. Arobba.

In the pollen samples, the microcharcoal particles occur and were subdivided into two fractions 10-125 μm and >125 μm (Whitlock et al., 2010).

3.2. Charcoal analyses

Charred macro remains have been collected only from the first 5 cm of the stratigraphic succession (SU1). The entire amount of SU1 sediment, equal to ca. 150 L, was water sieved with a 3-5 mm mesh for the recovery of micro- and macrocharcoal remains. This recovery method allowed the collection of only 56 identifiable charcoals. The other units (SU2 and SU3) did not yield any charred remains. The archaeobotanical macro-remains, after drying at 60 °C, were examined under a stereomicroscope (Olympus SZH10) at 10x for the preparation of standard sections and subsequently identified under episcopic microscopy in dark field (Olympus BHMJ) at 50-500x (Greguss, 1955; Jacquiot, 1955; Sweingruber, 1990; Vernet et al., 2001).

Furthermore, the analysis of the wood charcoals took into account other parameters, such as shape, the presence of fungal hyphae in the vessels, insect degradation and the presence of radial cracks.

The apparent diameters of the charred wood fragments were measured based on the degree of curvature of the annual rings and/or the divergence of the parenchyma rays highlighted in the cross-sections (Dufraisse and García Martínez, 2011; Kabukcu, 2018).

Three other carbonised fragments come from the base of a small speleothem sampled from the flowstone in the SdF for U-Th dating and palaeoclimate studies (Fig. 4). The three charcoals have been determined and used for radiocarbon dating.

4. Results

4.1. Pollen analysis

The absolute pollen frequency is relatively low (Fig. 5), varying between 640 (SU3), 142 (SU2) and 149 (SU1) pollen grains/gram, although the state of preservation of the grains is good, despite the alkaline reaction of the soil (pH between 8.0 and 8.2). The results presented in Fig. 5 highlight the presence of two distinct phases corresponding to these stratigraphic units. In SU3, the tree cover (AP = Arboreal Pollen) is attested at clearly lower values (on average AP = 11.3%) compared to what is recorded in the upper SU2 (on average AP = 24.9%). In both levels, herbaceous formations dominate, with elements characteristic of arid and steppe environments (*Artemisia*, *Centaurea*, *Carduus*-type, *Achillea*/*Aster*-type, *Echinops*-type), with values

of 75.4 and 55.4% of NAP (Non-Arboreal Pollen) on the total, respectively. In both phases, the scarce arboreal component is mainly constituted by *Pinus sylvestris*-type (on average 7.5 and 19.5%) to which a modest contingent of other mountain/subalpine entities (*Abies*, *Picea*, *Fagus* and *Alnus viridis*-type) is associated. Very limited are the testimonies of mesophilic tree species, including *Quercus* deciduous-type, *Tilia cordata*-type, *Ulmus* and *Corylus*. Modest values of thermophilic species, such as *Quercus ilex-coccifera*-type and *Phillyrea*-type, are also present, whereas riparian environment taxa (*Alnus incana/glutinosa*-type and *Salix*) are even more limited.

4.2. Anthracological analysis

In the same pollen samples described above, the presence of micro-charcoal particles occur. The excavation carried out in 2016 in the SdM allowed for the first time the collection and study of a good quantity of charred macroremains from the top of the stratigraphic sequence (Fig. 6a).

As already mentioned, the collection area is located corresponding to a stalagmitic formation in the centre of the chamber, on which carbonised traces due to the impacts of “torches” for their revival are still evident (Fig. 6b), which may have caused the fall to the ground of their fragments.

The analysed wooden remains ($n = 56$) range from 3 to 65 mm in total length, with a mean length of 15.6 mm. Of the total assemblage, 55.4% has been identified as *Pinus sylvestris/mugo*-type (Fig. 6c). These attributions are associated with *Pinus* sp. (3.6%) and Coniferae (1.8%), with a high value of indeterminate remains (39.2%) due to the damage caused by trampling which has strongly deteriorated their structure. The shape of these macro-remains is mostly sub-angular/angular (60.9%), whereas the remaining ones are rounded/subrounded (39.1%): an aspect to be related to mechanical actions due to their dislocation in the sediment, capable of partially modifying the typical net fracture, characteristic of the charcoals of this entity. Fungal hyphae are absent.

The apparent diameters of the carbonised wooden remains recovered in the SdM have allowed the assignment of 80.8% of the material to young twigs with a diameter less than 2-3 cm; only a modest quantity (3.8%) was obtained from stems with a diameter greater than 10 cm (Fig. 6d). From stems of the latter category, easily flammable splinters could have been obtained, useable as small torches, of which there is documentation even in later times, with findings that persist until historical times (Castelletti and Castiglioni, 1990; Grabner et al., 2010).

The three charcoals unexpectedly found and sampled from the base of a speleothem growing on a flowstone in the SdF (Fig. 4a) were also

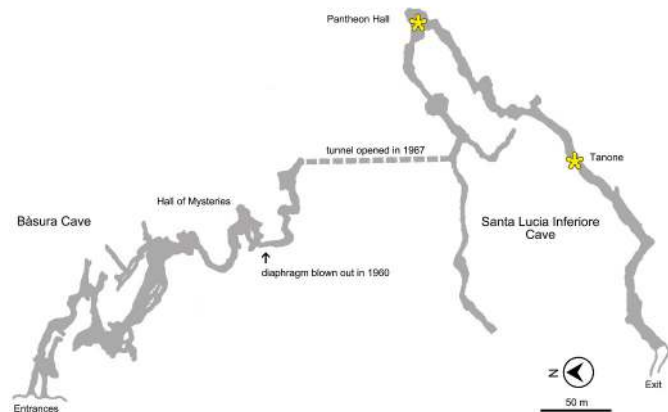


Fig. 7. Map of Bäsura and Santa Lucia Inferiore Caves with the location of the “Tanone” and “Pantheon Hall” where the experimental lighting tests were carried out. Drawing: D. Arobba.

determined as *Pinus sylvestris/mugo*-type. They yielded ^{14}C dates slightly older or recent than those of the SdM (GrM18819 = 13650 ± 40 BP, GrM18751 = 11455 ± 45 BP and GrM18802 = 11375 ± 35 BP,

respectively).

4.3. Lighting the cave with pine twigs: an experimental approach

For the experimental activity, aimed at studying the lighting system used by the humans entering the cave in the Upper Palaeolithic, branches of the same botanical taxon identified in the archaeological sample (*Pinus sylvestris*) were used, evaluating the ignition and combustion times according to their diameter and the brightness of their flame in a hypogeal environment. We collected branches from Scots pines in a forest on the Maritime Alps at about 900 m asl.

Twigs with a round section of 1–2 cm in diameter and radial splinters obtained from *Pinus sylvestris* wood, dried for 2 days at 60°C , were prepared. We obtained three sets of twigs: the first with a 1 cm diameter; the second measuring 2 cm in diameter; the third consisting of a radial splinter obtained from a 2 cm diameter twig (see [Supplementary material 1](#)).

During the experiment, the following parameters have been recorded: length of the twig, diameter, and duration of the flame ([Supplementary material 1](#)).

The ignition took place about 1 m above the ground in hypogeal environments with an average temperature of 16°C and relative humidity of 98%. For the different tests, five experimenters were used,

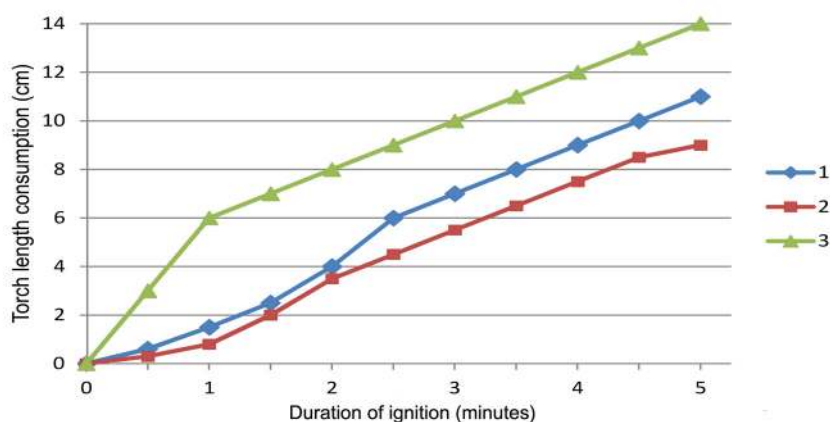


Fig. 8. Santa Lucia Inferiore Cave: a) wood twigs used for the experimental lighting tests consisting of single twigs of *Pinus sylvestris*; b) duration trend diagram of the combustion of three different experimental torches in relation to time (1 = twig 1 cm diameter; 2 = twig 2 cm diameter; 3 = radial splinter obtained from a 2 cm diameter twig). Photographs and drawing: D. Arobba.

corresponding to the number of individuals calculated based on the survey and ichnological study (Romano et al., 2019; Avanzini et al., 2021).

To plan the experiment, we considered as constraints all the archaeological traces documented in the Bäsura Cave, including the charcoal traces on the cave walls and on the floors, and their position in correspondence of the footprints (Fig. 1).

To avoid contamination in the archaeological part of the Bäsura Cave, to perform the experiment we chose a portion of the corridor in the adjacent Santa Lucia Inferiore Cave, connected to the Bäsura Cave by a tunnel built in 1967 (Fig. 7). This cavity has similar characteristics, both in terms of size, shape and colour of the walls, to those of the Bäsura where most of the carbonised remains were found, but it has never been used in prehistoric times.

Experiments were carried out in the tunnel called “Tanone” with variable width and height (between 1.5 and 2 m and 1.7 and 3 m) with dark grey limestone walls and in the large environment called “Sala del Pantheon” (“Pantheon Hall”, about 20 m in diameter and 15 m in height) with light-coloured walls due to the presence of extensive stalagmitic coatings (Fig. 7).

The microclimate conditions during the experiment were similar to those of the Bäsura cave and can be summarised as follows: humidity 98%, temperature 15.8 °C as measured by the instruments located at the entrance of the touristic pathway.

Six people took part in the experiment. Five is the number of individuals that the ichnological study of the footprints in the “Footprint Corridor” (“Corridoio delle Impronte”, hereafter CdI) identified (Romano et al., 2019; Avanzini et al., 2021), and one more person was necessary to take note of the experimental data. The experiment consisted of 1) testing the duration and light intensity of the combustion of a single stick with the aid of a digital lux meter (Wintect WT81), 2) simulating the prehistoric walk inside the cave in the darkest part moving along only with the aid of the flame light, and 3) extinguishing the torch stick when it is becoming too short against the wall. We registered on a form (Supplementary material 1) how many metres it is possible to advance in the darkness with one single torch, measuring distances with a metric tape; 2) how a group of five people arrange themselves to move forward most safely; 3) in what position the torch was held and the position of the individual holding the light in the group; and 4) how long does a twig used as a torch last before the flame goes out, timing with the aid of a precision chronometer. At the same time, traces of charcoal that had fallen to the ground and those left on the walls by the extinguishing of the torches after the lighting of the following one were documented. We repeated the walk three times under different conditions, i.e. position of holding person, and the number of the torches used at the same time (see Supplementary Material 1 for further details).

The samples studied in the present work come predominantly from the surface level of the SdM deposit, whereas in other parts of the cavity, only charcoal traces on the walls are attested, probably left by the impact of these torches to revive the flame (Fig. 1).

The small diameters of the studied wooden remains are in contrast with what was hypothesised by the previous authors based on observations not supported by detailed analyses (Molleson, 1986; Giacobini, 2008; Giannotti, 2008).

The remarkable dimensional uniformity of the charred wooden remains that have been found shows that the predominant material, used to obtain this type of lighting, derived from small-calibre twigs rather than large branches of *Pinus sylvestris*/mugo-type (Medina-Alcaide et al., 2015, 2021, 2023).

To verify the possibility of igniting such twigs, the duration of the flame and the effectiveness of the lighting, experimental tests were carried out.

From the time elapsed from the ignition to the full combustion of three different experimental torches we produced a duration trend diagram (Fig. 8).

The following observations could be made:

- To ensure that the group of five persons can safely proceed, i.e. overcome difficulties along the path, such as crawling zones, small climbs, obstacles such as speleothemes in the tunnel, the light of two torches is enough. The optimal situation is achieved when one torch is held by the second person in line and another by the last. Keeping in contact with each other with one hand on the shoulder of the preceding person helps stay safe together, sensing any unevenness or obstacles, and maintaining constant lighting.
- The person at the front of the line would be at risk of being dazzled by the light if carrying a larger torch, no matter how high it is held.
- In the “Sala del Pantheon”, after about 10 min, the eyes have adjusted to the complete darkness, and a single torch provides visibility up to around 10 m. It is well known that when the eye has adjusted to a darker environment, a lower intensity of lighting may be enough to give the impression of brightness. Adding a second torch doesn't make a significant difference in the lighting.
- The small torches are suitable for dynamic movement along the path, and the splinters proved to be more functional than the round twigs; neither solution shows spontaneous extinguishing, despite the air movements generated by the advance of the group.
- Both types of torches produce little smoke in comparison with bundle-torches (Lacanette et al., 2017; Hoare et al., 2023), which do not particularly disturb the journey.
- The average consumption of the torches carried during the journey is about 4 cm per minute.
- To cover 100 m along a moderately rough path, a torch that consumes about 18 cm in 4 min and 30 s is sufficient.

5. Discussion and conclusions

The results of pollen analyses are in agreement with those from previous sedimentological and soil micromorphology (Rellini et al., 2021). The considerable floral richness detectable among the herbaceous species can be attributed to the pollen rain that could be captured by the bears' fur during the favourable season in the different environments frequented, not necessarily linked to well-characterised habitats.

Pollen analyses initiated in the SdM are essentially superimposable on those previously highlighted in a study on samples taken in the nearby CdO (Arobba and Caramiello, 2008). The formation of the two stratigraphic units SU3 and SU2, which occurred over a long period of time through discontinuous deposition, does not allow the results of the analyses to be interpreted following a strictly diachronic criterion. However, the pollen content detected in the SdM sequence may derive mostly from particles adhering to the bears' fur along with other micro-remains, as well as from infiltrations from the environment outside the cave. The original entrance used by the animals is believed to have been located at a short distance from the SdM and probably closed in the past by a flowstone.

The exceptional find of bear hair remains in SU1 (Fig. 3) reaffirms the role of this animal's fur as an important vector for the transport of micro-remains, including, in addition to the pollen grains, also fragments of plant tissues and phytoliths observed with the SEM (Rellini et al., 2021). The periodic recurrence of the entrance of these animals, which hibernated and sometimes died here, explains the accumulation of organic material.

It should be emphasised, as previously mentioned, that the deposit in the SdM derives from secondary inputs and is therefore constituted by a succession of at least three non-diachronic levels, resulting from flood events that have displaced sediments and organic remains from adjacent areas located upstream. Nevertheless, pollen could have been transported by other factors like underground water, but since we still do not know where the original entrance was, it remains difficult to discuss possible wind transport (Hunt and Fiacconi, 2018).

The palynological analysis suggests that the landscape around the

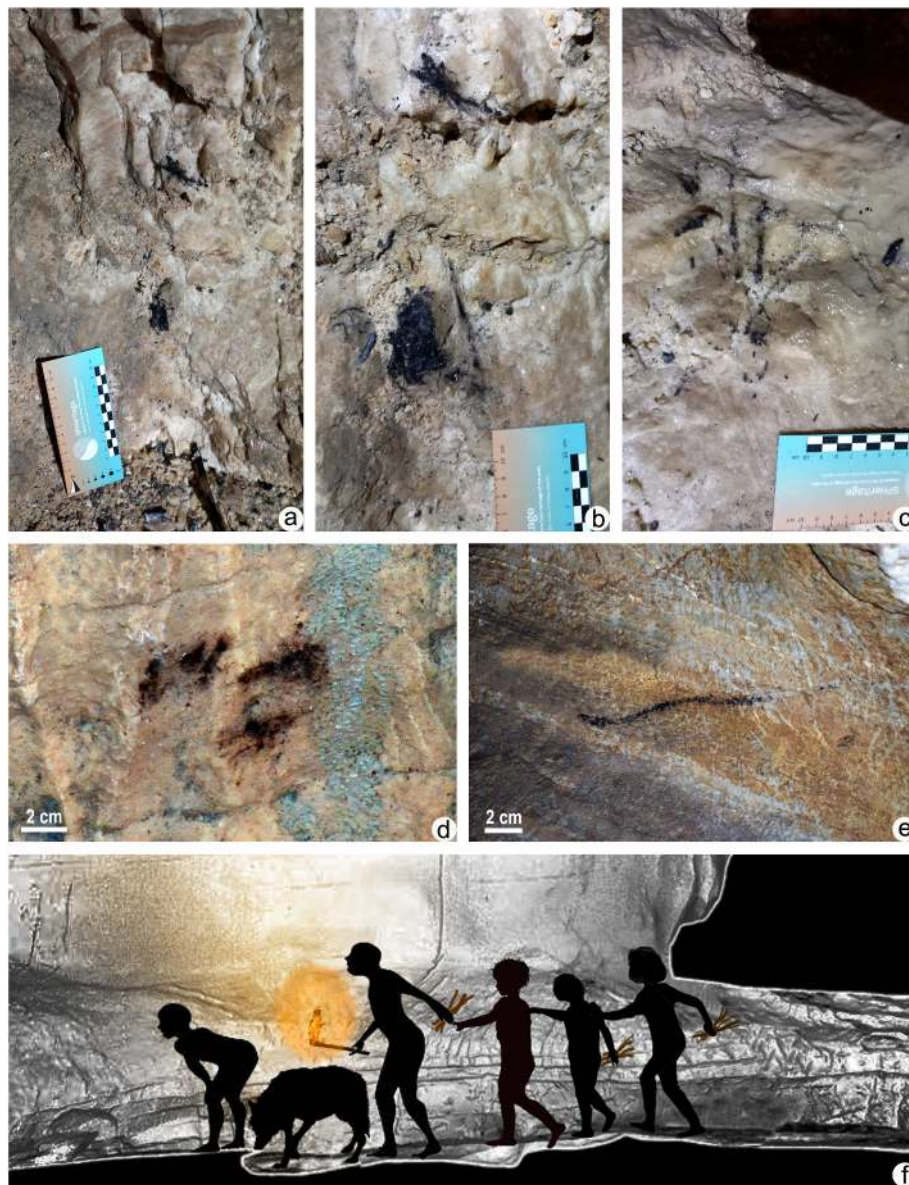


Fig. 9. Results of the lighting experiments in the “Tanone”: a) charcoal traces on the wall left by turning off the torch and charred wood torch fragments just below on the floor; b-c) different shapes of charcoal traces left on the wall during our experiments; d-e) similar archaeological traces on the cave walls of the “Hall of Mysteries” in the Bäsura Cave; f) reconstruction of the scenario of the human group’s walk. Photographs: D. Arobba, E. Starnini.

cave consisted of a sparse pine forest of *Pinus sylvestris/mugo*-type accompanied by a scarce component of broad-leaved and sclerophyllous species able to settle in small climatically more favourable refugia, interspersed with steppe herbaceous formations (*Artemisia*, *Centaurea*, *Carduus*-type, *Achillea*/*Aster*-type, *Echinops*-type).

The predominance of this tree species in the plant landscape surrounding the cave justifies its exclusive use for the lighting system employed by the human group.

The particularly low AP/NAP ratio, recorded throughout the sequence, therefore highlights the lack of forest formations and the dominance of steppes consisting of herbaceous species of cold and arid environments (cf. Poaceae, Asteraceae, *Achillea*/*Aster*-type, *Artemisia* and *Centaurea jacea*-type), able to colonise even the rocky slopes surrounding the cave. The apparent increase in *Pinus sylvestris*-type pollen in the upper levels of this sequence is not easily interpretable due to the presence of sediments deriving from alternating inputs due to depositional and erosive processes linked to water transport flows, not directly

related to an increase in tree cover and the Epigravettian anthropogenic event.

Only the charred wood fragments, found in the uppermost part of the SdM deposit, are to be related to the documented phase of human use of the cave. The belonging of these finds to *Pinus sylvestris/mugo*-type is, however, consistent with the results from palynological analyses, which have allowed to identify how, over a long period of the last Pleniglacial, before human penetration into the cave, the main tree formation surrounding the area was constituted by a sparse pine forest associated with a predominant steppe formation. *Pinus sylvestris/mugo*-type charcoal is attributable to three morphologically similar species that are indistinguishable from an anatomical point of view: *Pinus sylvestris*, *Pinus uncinata* and *Pinus mugo*. In the Ligurian territory, the formations that include these three species, considered critical from a taxonomic point of view, are still characteristic today of mountainous and subalpine areas (Montacchini and Caramiello, 1968; Pignatti, 2017). In particular, *Pinus sylvestris* (Scots pine) is a heliophilous, xerophilic and widely

Table 1

Bàsura Cave: results of ^{14}C dates of charcoals and bones collected from the stratigraphic sequence during 2016 excavations inside the “Hall of Mysteries” (SdM) and the charcoals found in the same room and at the base of the stalagmite in the “Fasces Hall” (SdF). Drawing: D. Arobba.

Sample name	Provenance	Dated material	Description	Lab. Code	F14C $\pm$ 1s	14C Age yr BP $\pm$ 1s	Cal yr BCE (95,4% prob.)	%C	%N	$\delta^{13}\text{C}$ (in ‰ $\pm$ 1s)	$\delta^{15}\text{N}$ (in ‰ $\pm$ 1s)	C/N ratio	Reference
-	SdM Base "concrezione zoomorfa"	charcoal	<i>Pinus sylvestris</i>	Beta-116396	-	12330 $\pm$ 80	12693-12125	-	-	-	-	-	Maggi and Ottomano (2008), Tab. 3
-	SdM Charcoal from floor	charcoal	undetermined	GrN-5007	-	12340 $\pm$ 160	13139-11924	-	-	-	-	-	Molleson et al., (1972), Table 1
Bàsura SM B5 17B	SdM square B5 SU1	charcoal	<i>Pinus sylvestris</i> / <i>mugo</i> -type	GrA-69598	0.2160 $\pm$ 0.0016	12310 $\pm$ 60	12720-12110	71.4	-	-25.24 $\pm$ 0.14	-	-	Romano et al., (2019), Table 1
Bàsura SM D6 33B	SdM square D6 SU1	charcoal	<i>Pinus sylvestris</i> / <i>mugo</i> -type	GrA-69597	0.2145 $\pm$ 0.0016	12370 $\pm$ 60	12830-12165	63.3	-	-26.37 $\pm$ 0.14	-	-	Romano et al., (2019), Table 1
Bàsura Sdf1 under speleothem	SdF	charcoal	<i>Pinus sylvestris</i> / <i>mugo</i> -type	GrM-18802	-	11375 $\pm$ 35	11359-11161	-	-	-	-	-	this study
Bàsura Sdf2 under speleothem	SdF	charcoal	<i>Pinus sylvestris</i> / <i>mugo</i> -type	GrM-18751	-	11455 $\pm$ 45	11453-11257	-	-	-	-	-	this study
Bàsura Sdf3 under speleothem	SdF	charcoal	<i>Pinus sylvestris</i> / <i>mugo</i> -type	GrM-18819	-	13650 $\pm$ 40	14721-14306	-	-	-	-	-	this study
Bàsura SM04	SdM square B5 SU1	collagen	humerus diaphysis fr., <i>Ursus</i> sp.	GrM-11615	0.0026 $\pm$ 0.0005	>45000	age beyond the detection limit of 44500 yrBP	46.6	16.8	-19.96 $\pm$ 0.12	2.42 $\pm$ 0.10	3.2	Rellini et al., (2021), Table 1
Bàsura SM B4-482 US1	SdM square B4 SU1	collagen	tooth root P3 inf., <i>Ursus</i> sp.	GrM-18800	0.0464 $\pm$ 0.0004	24670 $\pm$ 75	26959-26526	38.7	14.0	-22.28 $\pm$ 0.15	5.40 $\pm$ 0.30	3.2	Rellini et al., (2021), Table 1
Bàsura SM02	SdM square B4 SU2	collagen	left carpal bone, <i>Ursus spelaeus</i>	GrM-10848	0.0034 $\pm$ 0.0006	>45000	age beyond the detection limit of 44500 yrBP	46.1	16.5	-20.30 $\pm$ 0.11	2.26 $\pm$ 0.10	3.3	Rellini et al., (2021), Table 1
Bàsura SM B3-272 US2b	SdM square B3 SU2	collagen	humerus, <i>Ursus spelaeus</i>	GrM-18208	0.0036	>44500	age beyond the detection limit of 44500 yrBP	33.5	11.9	-20.12 $\pm$ 0.15	2.85 $\pm$ 0.030	3.3	Rellini et al., (2021), Table 1
Bàsura SM03	SdM square B4 SU3	collagen	rib fr. <i>Ursus spelaeus</i>	GrM-10849	0.0440 $\pm$ 0.0007	25090 $\pm$ 120	27527-26857	46.2	16.7	-19.18 $\pm$ 0.11	6.14 $\pm$ 0.10	3.2	Rellini et al., (2021), Table 1
Bàsura SM B4-354 US3	SdM square B4 SU3b	collagen	phalanx I <i>Ursus spelaeus</i>	GrM-18207	0.0038	>44500	age beyond the detection limit of 44500 yrBP	39.9	14.3	-20.27 $\pm$ 0.15	1.89 $\pm$ 0.30	3.3	Rellini et al., (2021), Table 1

adaptable species, finding wide distribution from the hilly to the mountain belt, whereas *Pinus uncinata* (mountain pine) prefers rocky slopes and subalpine scree.

Finally, *Pinus mugo* (creeping pine), with a predominantly shrubby and prostrate habit, forms extensive thickets on cold and snowy slopes on calcareous soils between 1500 and 2700 m asl.

The two microcharcoal fractions can be respectively interpreted, the first as the result of long-distance transport, the second as locally derived (Whitlock et al., 2010). The highest concentration of this type of micro-remains has been detected in SU2, presumably due to the fragmentation and dispersion in the uppermost level of burned particles deriving from the torches used by the Epigravettian visitors. The fact that in the larger fragments fibro-tracheids with areolate pits have been identified would confirm their origin from coniferous woods, in agreement with the results of the anthracological analyses (Supplementary material 2). Absence of fungal hyphae in all the examined charcoals indicates that branches were collected from living trees. This would suggest that, after being collected, branches were dried for lighting purposes, excluding opportunistic collections of dead branches collected on the ground.

The group of five “adult and young Epigravettians”, whose traces have been found on the cave, is presumed to have covered a distance of 800 m in about 2 h (round trip from the current entrance of the cave to the SdM), using approximately 20 torches, each 30 cm long, to illuminate the path for at least two of the participants.

Breaking down the calculations, a track distance of 400 m from the entrance would have required an estimated time of 60 min, which is in agreement with previous calculations (Garate et al., 2023).

Moreover, during the experiment, we observed that charcoal traces on the wall left by turning off the torch and charred wood torch fragments just below on the floor are very similar to the archaeological traces on the walls of the “Hall of Mysteries” in the Bàsura Cave (Fig. 9a–e). A reconstruction of the scenario of the human group's walk is presented in Fig. 9, f.

The use of small torches has been supported by anthracological analysis, and their efficiency is also confirmed by our preliminary experimental tests consistent with the likely means available in the late Upper Palaeolithic (Fig. 8a).

Laboratory tests have shown slight differences in the consumption rate of the material when using twigs of different diametres, providing values that attest to variable durations, between 1.8 and 2.8 cm/min. Consumption was lower in the absence of air currents, compared to their use in the cave, where conditions were different due to the movement of the torches along a more or less uneven path (Fig. 8b). From these findings, it seems evident that the use of large-diameter branches can be excluded from this site due to their difficulty in lighting and handling. It has therefore been ascertained that small branches 20–30 cm long are optimal for obtaining individual “matches” that could be easily carried, even clamped between the teeth after lighting, to proceed on hands and knees and use both hands freely; these small torches were probably oriented horizontally or upwards to slow down combustion (Castelletti and Castiglioni, 1990; Reschreiter and Kowarik, 2019; Grabner et al., 2021). To confirm the more effective use of round-section “matches” or long, thin “splinters” obtained by radial splitting, rather than actual torches, it is observed that the flame produced by the former is weaker, but less blinding compared to the flames produced by large-diameter stems.

The presence in the Bàsura Cave of a group of Epigravettians, dating back to about 14400 cal BP, corresponds to the period between the end of the Pleniglacial and the beginning of the Bølling-Allerød interstadial, coinciding with a progressive climatic improvement that favoured the increase of coniferous forests and a general rise of the tree line (Ravazzi et al., 2007). As already observed for other sites, the choice of wood was mainly linked to the availability of material in the surrounding areas, as well as to the intrinsic characteristics of the individual species. Among the most significant examples are the interesting observations about the

predominant use of *Pinus sylvestris*/mugo-type emerging from the study of wood resource management in the Chauvet-Pont d'Arc Cave, even in periods before the human presence in the Bàsura Cave (Théry-Parisot et al., 2018).

Preliminary experimental tests, carried out with materials of the same type and measures as the analysed finds, confirm the use of torches, formed by single small-diameter branches, by their bundles or by splinters, which the first Epigravettian visitors had made as tools to ensure sufficient lighting in the exploration of the cave. As testified by human footprints, the behaviour of the five explorers, who proceed in all the cave in a single file accompanied by a canid (De Sario et al., 2026) staying close to the cave wall, is considered the safest approach also used by bears or wolves when moving in dark and unknown subterranean environments; in such condition, even a dim lighting would be sufficient to ensure view and safety of the entire group (Fig. 9, f).

Such experiences provide suggestions on the possible and best strategies for illuminating underground environments, minimising the consumption of woody fuel necessary for a safe visit.

Finally, the three charcoals unexpectedly found at the base of a speleothem growing on a flowstone in the SdF have been embedded in the calcite during at least two subsequent periods: one older and one younger than the radiocarbon dates obtained from the SdM (Fig. 4b).

As suggested by their stratigraphic position inside the progressive growing speleothem and according to their ¹⁴C dates, the age of these charcoals does not coincide with that of the walk of the small group of Epigravettian individuals (Table 1). Therefore, they revealed different episodes of human activity in the cave. However, these charcoals could have been transported by the water flowing along the flowstone surface from external inputs or from a different branch of the cave. At present, we cannot give an interpretation for the presence of these charcoals inside a speleothem that was still growing when it was sampled, and further research will be necessary. In any case, the presence of human groups in the region during the Epigravettian is not surprising.

CRedit authorship contribution statement

Daniele Arobba: Conceptualization, Data curation, Investigation, Methodology, Validation, Visualization, Writing – original draft. **Rosanna Caramiello:** Conceptualization, Investigation, Methodology, Validation, Visualization, Writing – original draft. **Elisabetta Starnini:** Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft. **Ivano Rellini:** Data curation, Investigation, Validation, Visualization, Writing – original draft. **Marco Avanzini:** Investigation, Validation, Visualization, Writing – review & editing. **Isabella Salvador:** Investigation, Validation, Writing – review & editing. **Paolo Citton:** Investigation, Validation, Writing – review & editing. **Marco Romano:** Investigation, Validation, Writing – review & editing. **Fabio Negrino:** Investigation, Validation, Writing – review & editing. **Marta Conventi:** Validation, Visualization. **Marta Zunino:** Data curation, Investigation, Supervision, Validation, Writing – original draft.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quaint.2026.110335>.

Data availability

Data will be made available on request.

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