

## Multianalytical and multiproxy approach to characterization of a paleolithic lamp. An example of the Nerja cave (Malaga, Spain)

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Lighting; Palaeolithic lamp; Decorated cave; Upper Palaeolithic; Iberian Peninsula

### Abstract:

Understanding the illumination systems used by Paleolithic groups in caves gives us essential information about the Paleo-speleological capabilities of our ancestors and their activities in darkness space. In this paper, we present a multianalytical and multiproxy approach (wood charcoal and soot) to characterize a Palaeolithic lamp. The methodology was employed on an endokarstic clastic block (speleothem) with a natural concavity located in decorated galleries in Nerja cave (Spain). Anthracological analysis has demonstrated that the Pinus sp. *Sylvestris/nigra* (Scots pine/Black pine) was used as fuel for this illumination system. <sup>14</sup>C-AMS dating shows that this light point was lit during the Solutrean period. Palaeolithic art from chambers near this fixed lamp present a similar chronology. HD/HG ratio calculus obtain of  $\mu$ -Raman spectra from pine charcoal shows that burning reached temperatures of more than 700°C. Thus, wood suffered complete combustion without sudden extinguishing. Furthermore, spherical particles of soot aggregates on the edge of the lamp have been identified, obtained from wood combustion, through TEM-EDX analysis. Finally, 3D modelling of the lamp was carried out. Concerning interpretation, the singular localization of the light point suggest that it could have encompassed more functions than just the illumination of the cave.

### Highlights:

- A new Palaeolithic lamp at a cave in Nerja (Solutrean era) was discovered.
- We present a pioneering, multianalytical approach to the characterization of a Paleolithic lamp.
- The combustion residue identified consists of wood charcoal and soot marks.
- The Pinus sp. *Sylvestris/nigra* was the wood fuel employed in the fixed lamp.

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- The lamp generated temperatures of up to 700 °C.

## **1. Introduction:**

Conquest of the subterranean environment was an essential milestone in the history of fire control during prehistory and essential for the spread of rock art in these contexts. The use of fire in the underground domain dates back to the Middle Paleolithic (Jaubert et al., 2016) although this activity is more common in the Upper Paleolithic in relation to caves with Paleolithic art. Knowledge of the illumination systems used to inhabit these space, otherside devoid of any light, give us information about the Paleo-speleological capabilities of our ancestors. This information is important to understand the activities in which they engaged in caves, their duration, and their symbolic and socioeconomic significance.

Whit regards to Palaeolithic objects suspected of being lamps, heir use for this end has only been proven in 28.15% of cases; that is, with evidence of fire found in their active components/parts. Only 85 of the 302 artefacts examined by S. de Beaune (1987) have been confirmed as having been put it this use. According to this researcher, the discovery of this evidence in only the active part of the lamp, as well as its suggestive form, allows us to differentiate this instrument from other objects featuring a similar morphology (for example, colour palettes). This evidence of fire may be residue from vegetable fuel (wood charcoal, vegetable fibre), animal fuel (fat) and other alterations, such as rubefaction or soot. Currently, there are very precise tools for the elemental analysis and adequate microscopic observation of the combustion residues present in these elements. Below, we present the multianalytical and multiproxy approach used for the scientific characterization of a Paleolithic fixed lamp located in the inner galleries of Nerja cave.

The Nerja cave, located in the district of Maro (Nerja, province of Málaga, Spain), represents one of the largest decorated caves in Southern Spain (Iberian Peninsula) (Fig. 1a and b), and is comprised of the dolomitic marble of the south-western flank of the sierra Almijara mountain range. Its surface area is approximately 35,484 m<sup>2</sup>, while it measures 4,843 m long. The entrance of the cave site is located at a distance of 940 m from the current coastline, and 158 m above sea level.

Their outermost chambers, where systematic excavations were undertaken from 1960 to 1987, contain a wide range of quaternary clastic deposits, with various sedimentary sequences, encompassing several human occupations dated to the Upper Palaeolithic (from the Gravettian and Solutrean to the Upper Magdalenian periods). The top of the sequence includes Neolithic and Chalcolithic levels (4,830-3,600 cal. BP.) (Jordá and Aura, 2009; Jordá et al., 2011; Sanchidrián and Márquez, 2005).

Their interior galleries, upon which this study focuses, were also repeatedly used by prehistoric societies, and manifold indications of human activity have been recorded in them, consisting of more than 500 graphic manifestations, including animals, signs and other remnants of painting produced with red, yellow and black pigment. The greater part of Palaeolithic art features a Premagdalenian, chronology, between the Gravetian and Solutrean (Sanchidrián, 1994; Valladas *et al.*, 2017) periods. There also exist black marks dated to the Lower Magdalenian (Sanchidrián *et al.*, 2017). In addition, numerous archaeological materials -such as flint tools, bone fragments, nodules of ochre and, above

all, charred plant remnants - are present on the cave floor. According to C14-AMS analyses of wood charcoal fragments sampled on the soil, human occupation in these galleries spanned an extensive period, from 40,695 to 5,970 cal. BP. (Medina-Alcaide et al., 2015).

In this article, we focus on the sector called the “Camarín del Ciervo” (Deer’s Noche) and its surroundings. These spaces are located in the Upper Galleries, down to 265 metres of depth from the Paleo entrance (Fig. 1c). The Paleo path to reach this sector contains many difficult obstacles (climbing zones, ledges, etc.). This site is formed by a narrow gallery (9x3x3 metres) preceded by a little room. The geomorphology of the two space is similar, with speleothems being very numerous, especially the eccentric stalactites. The cave floor is irregular, consisting of large blocks and featuring hundreds of scattered, prehistoric fragments of wood charcoal (Seven of these remains have been identified, five as conifer wood and two as *Pinus tp. Sylvestris/nigra*).

Moving between the previous chamber and gallery is possible by climbing a flowstone measuring 3.29 m long, at a 45-degree incline. Parietal art is found only in the narrow gallery, and not in the preceding chamber (where the lamp is located). In this gallery, there are numerous black marks, and a panel containing figurative art; located at the back of the space (Sanchidrián, 1994). In this part, there is a figure with a morphology similar to the of a deer (for which these spaces are named), but this image has been also interpreted as a compositions of an aurochs, or a horse, next to a small head of hind in “trilineal convection” (Villaverde, 2009; Sanchidrián *et al.*, 2013).

In the small space that precedes the “Camarín del Ciervo”, next to the entrance to this area, a fixed Paleolithic lamp has been found, its morphology similar to the fixed points of light located in other areas of the cave (Medina-Alcaide et al., 2012). It is a clastic block with a slightly concave, horizontal surface. Its maximum height is 95 cm, and its minimum, 43 cm. It measures 58 cm long and 43 cm wide. Inside the concavity, there are traces of combustion; in particular, wood charcoal and smoke marks, along with a grey, carbonated substance, possibly ash (Fig. 2). The charcoals and soot will be examined below from an interdisciplinary approach for scientific characterization (Additional information, Fig. A and B). This element did not, it seems, directly illuminate any rock art, as it is located in a chamber without any Paleolithic images, in a marginal space that is slightly hidden.

## **2. Materials and methods:**

### **2.1 Sample selection**

In the Nerja cave there are at least five fixed light points presenting combustion residue. In a previous paper, we presented all the endokarstic formations suggesting the existence of fixed lamps, based on its morphology (Medina-Alcaide et al., 2012). We selected this lamp for this methodological study because it includes different types of combustion residue (charcoal, smoke and, possibly, ash). Also, these are preserved in a primary position (according to S.A. de Beaune, 1987); that is, the soot, above all, on the sloping upper part of the concavity, in contact with the flame and the charcoals and ashes lower part of it (Fig. 2). We must indicate that there is no presence of rubefaction in the lamp. In additional information we include information about the petrographic nature of the

active part of the lamp (Additional information, Fig. C). The minimal presence of iron oxides could be the cause of the absence of rubefaction (Canti and Linford, 2000). This nature is similar at others speleothems analysed in this cave (Reyes et al., 1993).

The concavity of the lamp measures 30 cm long, 19 cm wide, and 10 cm deep. It has a natural origin, resulting from corrosive processes visible in other formations in this space (Additional information, link to Sketchfab to see the 3d of the lamp). In addition, similar processes have been studied in adjacent chambers (Caballero et al., 1995). We have not observed anthropic traces linked to the elaboration of the concavity.

The combustion residue located on the lower part of the lamp consists of charcoal and a grey carbonated substance (probable ash) (Additional information, Fig. A). The preserved volume of this sediment is approximately 32 cm<sup>3</sup>. Half of this sediment has been collected for different analyses. In particular, five fragments of wood charcoal were analysed, measuring less than 3–4 mm long and up to 1.5 mm wide. These were manually collected from a half part of the sediment preserved in the lamp (Fig. 2). The sampling was conducted with a binocular microscope. Charcoal collection was not done through water flotation, so as to preserve the sediment for future analyses (e.g., phytoliths and gas chromatography). The other half of the residue has been preserved in the concavity and, also, its content charcoals (Fig. 2). Therefore, not all the charcoal preserved has been analysed, but only a sample.

The soot residue was analysed through a small fragment of the blackened surface on the upper part of the lamp, which we found cracked (Fig. 2). It measures 2 cm long, 1 cm wide and 2 mm thick. The sample presents a thin film of calcium carbonate on what is thought to be soot. This was observed with a fluorescent light (Additional information, Fig. B).

## **2.2. Multianalysis and multiproxy approach**

### **2.2.1 Wood Charcoal: Anthracological identification, <sup>14</sup>C-AMS dating and $\mu$ -Raman Spectroscopy.**

Anthracological analyses were conducted to determine the nature of the wood charcoal; in particular, its origins (Chabal et al., 1999) and taphonomic alterations (Théry-Parisot, 2001). Several studies have pointed out the importance of anthracological analysis prior to <sup>14</sup>C-AMS dating, in order to determine chrono-ecological coherence and detect possible taphonomic problems (for example, Carrión et al., 2018). Charcoal samples were separated into two samples to perform the anthracological study and <sup>14</sup>C-AMS analysis. To identify the anatomical and biometric properties of the wood specimens, clean cuts were made on each fragment to obtain transversal, tangential and radial sections (Chabal et al., 1999). The classification of each specimen was determined by comparison with various reference sources (García et al., 2002, Schweingruber, 1990, Vernet et al., 2001). A BA410 Motic light microscope was used with light reflected to a light-dark reflection field at magnifications ranging from 40 to 600 $\times$  (Nerja Cave Research Institute, IICN). We also used SEM (SICAI of the Cordoba University) for the taxonomic identification and sample pictures.

One of these wood charcoal fragments was sent to a Beta Analytic Laboratory for <sup>14</sup>C-AMS dating. To manage and interpret the date of the radiocarbon result included in this

work, we used Oxcal 4.3© online software; in particular, we used the Outlier Charcoal model in order to better characterise the atypical values and account for the long life of this material (Bronk, 2009).

$\mu$ -Raman Spectroscopy was carried out on wood charcoal, this time to obtain information from the Raman spectrum on temperatures, in accordance with the work of D. Deldicque et al. (2016). This examination is based on direct measurement, without prior adjustment, of the relationship between the height of the D-band (Defect band) and that of the G-band (Graphite band) to obtain the maximum temperature reached during combustion (HTT), using the HD/HG ratio as a paleo thermometer. The Raman tool used was a Renishaw inVia Reflex Raman Confocal Microscope, and the wavelength employed was 532 nm (University of Malaga).

### **2.2.2 Soot: SEM-EDX, TEM-EDX, LIBS and $\mu$ -Raman Spectroscopy.**

We applied these techniques to characterize the soot traces present on surfaces of the fixed lamp. In particular, we analysed a small fragment of the blackened surface of the lamp that we found fractured. Scanning Electron Microscopy – Energy Dispersive X-ray spectroscopy (SEM-EDX) is a technique that yields analytical profiles and distribution maps using the energy dispersed by X-rays. This analysis is carried out as a supplement to microscopic observation using a beam of electrons for scanning. The Scanning Electron Microscope was a JEOL JSM-6490LV (University of Malaga) model. This methodology proved able to determine the origin of black deposits in karst caves in Slovenia (Šebela et al., 2015).

Laser-induced Breakdown Spectroscopy (LIBS) is an analytical technique used to obtain information about the multi-elemental chemical composition of various kinds of samples. It does not require prior preparation, and is non-destructive, at least to the naked eye. It uses a high-energy laser as its excitation source. These advantages, along with the possibility of using portable instruments for it, make this technique an ideal tool to work in hostile environments, such as deep cave (Carrasco-Huertas et al., 2016). The LIBS used was a Big Sky Ultra 100 mJ/Avantes Spectrometer, and the samples were subjected to a laser with an intensity of 50 mJ per pulse at a frequency of 10 Hz. The crater size is approximately 300  $\mu$ m in diameter. We also used  $\mu$ -Raman Spectroscopy to characterise the soot traces (technical features presented in the previous section).

Finally, Transmission electron microscopy – Energy Dispersive X-ray spectroscopy (TEM-EDX) allows for the characterization of solid organic and inorganic samples on a nanometric level, via the observation of the anatomical structure and the production of analytical maps. Prior to our work, this tool was used to characterize soot layers located on some speleothems in the Dominica cave in Slovakia (Pawlyta and Hercman, 2016). The transmission electron microscope we used was a JEOL JEM-1400-FEI Talos F200X (University of Malaga).

Before applying these techniques, the sample underwent analytical pre-treatment (as reported by Pawlyta and Hercman, 2016), given the high fluorescence it presented, due to being covered in calcium carbonate (Additional information, Fig. B): a) acid dissolution with HCl 1 M (2 h), b) rinsing with distilled water, and c) filtration to obtain nano-sized particles.

### **2.2.3 Graphic documentation**

The graphic document produced on the lamp is both two-dimensional and three-dimensional, using the SfM (Structure From Motion) photogrammetric technique, which allows us to create 3D models with photographic equipment much easier to transport than a laser scanner – an essential advantage due to the location of the lamp and the characteristics of the cavity.

The equipment used for this task was a Nikon D610 full frame camera, with a Nikkor AF-S 24-85 mm VR F3.5-4.5G ED lens and Yongnuo Speedlite YN560 IV flashes; the SfM software used was Agisoft PhotoScan Professional.

### **3. Results**

The anthracological analysis has identified the five samples of wood charcoal as *Pinus tp. sylvestris/nigra* (Scots pine/Black pine) with reaction wood signs (Fig. 3A). This alteration is related to branches of limited thickness and other mechanical actions (Marguerie and Hunot, 2007).

The SEM-EDX analysis carried out on the carbonated substance, located in the concavity next to the charcoal, indicates an elemental composition similar to that of the ash (Canti, 2003) (Additional information, Figs. D.1–D.2). However, we cannot confirm, for the moment, the origin of the calcium carbonates (pyrogenic or endokarstic).

The result of <sup>14</sup>C-AMS dating from one of the pine wood samples of the lamp is  $18540 \pm 60$  uncal. BP (Beta-438097, 95.4%  $2\sigma$  IntCal13 22490–22345 cal. BP) (Table 1). The lighting of this point of fixed illumination occurred at some point during the Solutrean period. The Paleolithic art present in this part of the cave has been attributed to Solutrean, based on chrono-stylistic data (Sanchidrián, 1994) and indirect dating of a sample of wood charcoal taken a few centimeters from the “deer” discussed previously. This radiocarbon result was  $19900 \pm 210$  uncal. BP (Sanchidrián and Valladas, 2001). The Bayesian analysis performed on these dates indicates, with a 99.3 agreement, that these dates could correspond to the same occupation phase (GifA98191: IntCal13, 24455–23447 cal. BP), between 25740 and 20760 cal. BP (average numbers) (Additional information, Table A and Fig. E).

The HD/HG ratio obtained from 7  $\mu$ -Raman spectra on two pine wood samples was  $0.68 \pm 0.05$  (Fig. 3B), this corresponding to D. Deldicque et al., 2016, with a maximum combustion temperature for charcoal  $\approx 750$ – $800$  °C (residence time at Highest Temperature of Treatment: 1 h.) and  $\approx 700$ – $750$  °C (residence time at Highest Temperature of Treatment: 6 h.) (Deldicque et al., 2016).

The black substance (Fig. 4A) on the surface in the hollow of the lamp was identified as soot particles. Their analytical profiles, from SEM-EDX and LIBS, suggest carbon, with other elements of the rock platform included O, Na, Mg, Al, Si, K, Ca, Mn, Fe, etc. (Fig. 4C and D). Also, some of these elements can be present in the wood charcoal and the ash, such as O, K, Mg, Ca, K. Besides,  $\mu$ -Raman analysis indicates spectra typical of carbon (not wood charcoal), between 1000 and 1800  $\text{cm}^{-1}$  (Fig. 4B). Finally, TEM-EDX observation confirmed, definitely, that this surface has smoke marks, through the observation of the spherical particles of soot aggregates obtained from the combustion of

wood (Fig. 4E and F); similar to those found in previous studies, such as Pawlyta and Hercman (2016).

#### **4. Discussion**

Our initial supposition of the use of this natural block as a fixed light point was confirmed via a multianalytical and multiproxy approach showing that endokarstic formations were used as fixed light points during the Upper Paleolithic. Through anthracological identification, we have identified the presence of wood fuel in the active part of the charcoal lamp through anthracological identification, the date of combustion through <sup>14</sup>C-AMS dating; and, through  $\mu$ -Raman Spectroscopy, the maximum temperature reached during combustion. Also, the possible presence of ash next to the charcoal in the concavity has been identified via SEM-EDX, although we cannot ensure their pyrogenic origin. Other analyses could round out the study, potentially enriching interpretations of its functionality; e.g. micromorphology for the final characterization of the ashes, as well as phytolith analysis or gas chromatography to determine whether other non-woody fuels were used in addition to wood.

It is necessary to search for an appropriate methodology to investigate this Paleolithic lighting system, because it features a natural origin, and because there are many of these types of concavities in decorated caves that can be misinterpreted as lamps. Also, a black surface that appears in these endokarstic formations could be associated with other types of organic and inorganic substances, such as manganese, guano, etc.; without being related to a combustion process. Moreover, these elements can contain vestiges of wood charcoal, but this does not indicate combustion. This wood charcoal could have undergone post-depositional alterations (due to cave water flow) or could be associated with the use of torches around the concavity. For this reason, to characterize a point of light it is advisable to employ a multianalytical and multiproxy approach.

The choice of pine wood could be related to its availability close to the cave, and because this wood is suitable for lighting activities. Paleobotanical studies confirmed the presence of *Pinus* sp. *sylvestris-nigra* (Scots pine/Black pine) in the vicinity of the Nerja cave, especially during the Upper Paleolithic period (Badal, 1996, Jordá et al., 2011). Wood from Scots pine was used as fuel for lighting in other caves containing Paleolithic art, such as the Chauvet Cave (Théry-Parisot and Thiébault, 2005, Théry-Parisot et al., 2018); in the Cosquer Cave (Clottes et al., 2005), in Réseau Clastres (Clottes and Simonnet, 1990), etc. In the Nerja cave 64% of the charcoal fragments examined, which are from the interior of decorated areas, and are related to residue from fireplaces and torches used for lighting the cave, belongs to *Pinus* sp. *sylvestris-nigra*. The remaining 36% correspond to *Pinus* sp. (13%), gymnosperm (2%), Leguminosae (10%), *Pinus* sp. *pinaster* (3%), indeterminate angiosperm (2%) and wood charcoal (6%) (Medina-Alcaide et al., 2015). Therefore, the main fuel of the fixed fires, torches and of the lamp analysed in this work was pine, especially *Pinus* sp. *sylvestris-nigra*. Bushy species, such as leguminous plants, generally burn well owing to their small size, especially when in a dry state, which accounts for their use as a means of starting fires (Chabal, 1997). During the Upper Paleolithic the collection of small branches of pine must have been frequent, due to the ease of its gathering, on account of the natural pruning of this tree, as well as the benefits that this species offers for lighting, particularly the height of its flame, linked to its richness in terpene hydrocarbons (resin) (Théry-Parisot and Thiébault, 2005).

The combustion temperature reached in the lamp is compatible with an advanced combustion stage and with the presence of ash (although this has not been definitively described). We can suggest a practically full use of the lamp, without a sudden interruption. Ash appears starting at 700 °C, in the advanced phase of the combustion process. If the combustion process stops between 270 and 700 °C, in the pyrolysis stage, charcoal is produced (Chabal et al., 1999, Carrión, 2005). Rubefaction, meanwhile, appears at 250 °C (Brodard, 2013). Its non-appearance is related to the minimal presence of clay and iron oxides on the clastic surface of the lamp (Canti and Linford, 2000), possibly related to the geological composition of the site (Aranburu et al., 2018). This alteration usually appears in sediments and surfaces that have iron oxides, and the red colour is indicative of their oxidation (Lelong and Souchier, 1982, Macphail and Goldberg, 1990).

Concerning the topographic location of this light point, we should indicate that the lamp did not directly illuminate any rock art or the paleo path, unlike other lamps located in the cave (Medina-Alcaide et al., 2012). It is located in a chamber without Paleolithic images, in a marginal space, removed from the main path; that is, in a site that is somewhat hidden, with very limited visibility. This suggests that the lamp may have been used for more than lighting.

Other functions could have been: a site to maintain a fire with which to ignite mobile lighting systems, or a site to burn wood to produce pigment. This first interpretation as a “fire-relay” has been previously indicated for other small fireplaces located in decorated caves, such as the Marsoulas Cave (Beaune, 2000). This function may require a prolonged use of the lamp incompatible with its volume as a container, with the amount of combustion residue preserved (probably, linked to unique use) and the exclusive use of wood as a fuel. If animal fat had been used as an additional fuel, its time of use would have extended, although the use of animal fat as a main fuel is incompatible with the production of black smoke. Experimental activities carried out by us have allowed us to determine that the production of black smoke is related to the prevalent burning of resin and conifer woods, such as pine. However, we cannot rule out the predominant use of pine wood charcoal and the occasional addition of animal fat. Also, the preservation of the bottom of the concavity without smoke residue (similar to the lamp in Nerja) has been related, based on experimental evidence, with the use of animal fat as fuel in Paleolithic lamps (Beaune, 1987, Rigaud, 2000).

The production of pigment cannot be discarded, even though the presumed presence of ash in the concavity would discourage this interpretation. It should be borne in mind that the maximum temperature reached during combustion is higher than the temperature for the production of wood charcoal, and more consonant with complete combustion (the production of ash). This role has also been suggested for other fireplaces in other caves featuring Paleolithic art in black, such as the Chauvet Cave (Théry-Parisot et al., 2018), Cosquer Cave (Clottes et al., 2005), and Arcy-sur-Cure (Baffier and Girard, 1998). Finally, other functions cannot be discarded either, such as the signalling of certain sites for unknown circumstances, or as a brûloir, or roaster, as has been suggested for the sandstone lamp in the Lascaux Cave (Glory, 1961).

The combustion of this lamp produced black smoke, a fact that could explain its singular location. Recent studies reflect the importance of the correct location of fireplaces in

caves, in relation to the circulation of the air, so that these did not generate toxicity problems (Kedar and Barkai, 2019). Also, experimental studies have observed the distribution of smoke above the height reached by the flame (Lacanette et al., 2017, Fabien et al., 2019). This could explain why a block (with a height of 70 cm) was selected for the combustion location, and not the floor. The other fixed lamps located in the Nerja cave are also located high off the floor, several centimeters from the ground, around 1 m high.

From our point of view, we cannot rule out other, probably coincident, less utilitarian functions associated with the ritual illumination of underground spaces and the symbolic use of fire. The ritual use of fire, beyond mere illumination, has also been suggested to explain large fires in the Chauvet Cave, where smoke, heat and light may have been intentionally produced, as part of practices associated with the symbolism of Paleolithic art (Ferrier et al., 2012, Ferrier et al., 2014). Fire, as well as its functional characteristics (light, heat, protection, etc.), has many important symbolic connotations in many cultures, both contemporary and past (Morehart et al., 2005; Vaté and Beyries, 2007, Bradley, 2005).

The adequate characterization of illumination systems used by Paleolithic groups is essential to understand the activities of prehistoric groups under conditions of darkness. A complete study of residue combustion allows us to identify objects serving as light points (lamps), but also this is the first step to can simulate the light used by our ancestors, its combustion/use time, as well as to know the previous planning of the underground activities (for example, the amount of wood to be transported inside the cave) and the possible symbolic use of lighting in decorated caves.

## **5. Conclusion**

In this article, we have presented a multianalytical and multiproxy approach (wood charcoal and soot) in order to characterize a Paleolithic lamp. Specifically, the methodology was employed on an endokarstic clastic block (speleothem) with a natural concavity located in decorated galleries in a Nerja (Malaga, Spain) cave. Wood charcoal analysis revealed the wood fuel used in this illumination system: small branches of *Pinus* sp. *sylvestris/nigra* (Scots pine/Black pine). The reasons for the use of pine appear to be linked to its presence in the vicinity of the cave, as indicated by certain Paleobotanical markers, its properties as a fuel, and, above all the fact that it contains resin, a highly flammable substance. C<sup>14</sup>-AMS dating shows that this light point was used during the Solutrean period. Graphic evidence in chambers proximate to this static lamp present a similar chronology. HD/HG ratio calculus obtain 12  $\mu$ -Raman spectra from wood charcoal shows that it burns at over 700 °C, probably wood suffered complete combustion, without extinguishing suddenly. Furthermore, spherical particles of soot aggregates on the edge of the lamp have been identified, obtained from wood combustion through TEM-EDX analysis.

Finally, we consider it necessary to continue studying these types of light resources in caves with Paleolithic art, through an interdisciplinary approach, to understand the role that these small fixed lights could have played in the anthropization of the [underground environment](#).

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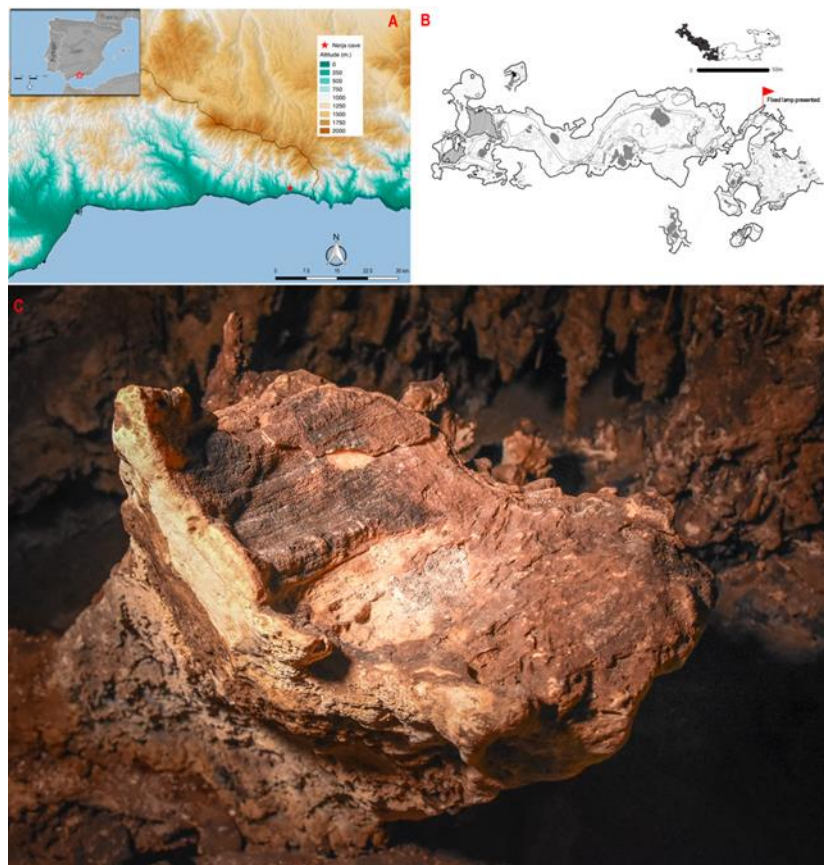
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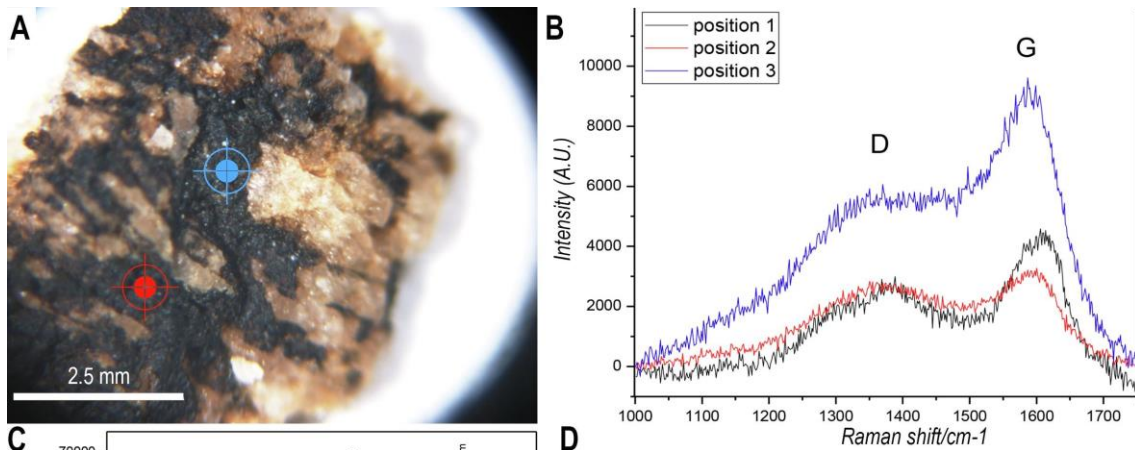
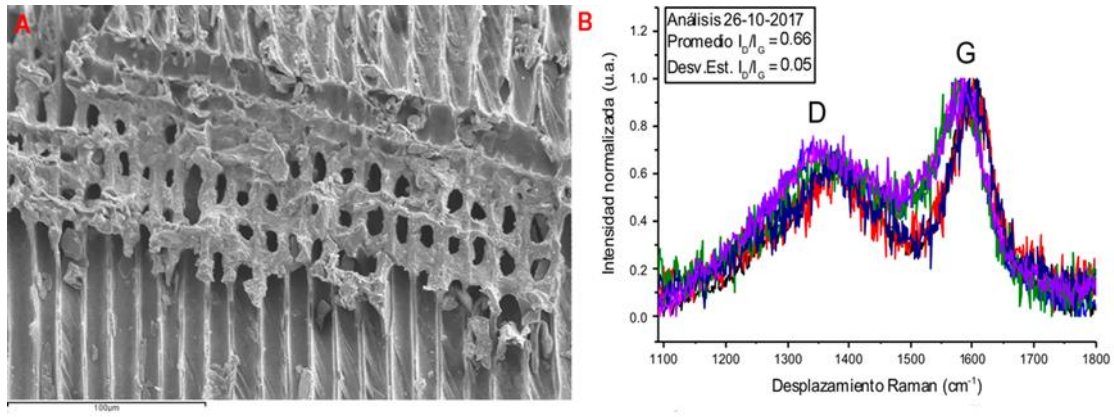
**Figure 1:** Set of images of fixes lamp and its context space.

**Figure 2:** Soot multianalysis approach. A. Sample of blackness surface of lamp after first analytical pre-treatment. B. Set of  $\mu$ -Raman spectra realised in this sample. C. LIBS spectra in this sample. D. Elemental analyses from this sample (SEM-EDX). E. Soot aggregates obtained by TEM from the combustion of wood localized on the edge the concavity.

**Figure. 3.** Multi-analysis approach to wood charcoal. A. Radial section of *Pinus tp. sylvestris/nigra* viewed using Scanning Electron Microscopy, also it is noted reaction wood. B. Set of  $\mu$ -Raman spectra realised in pine charcoals for HD/HG ratio.

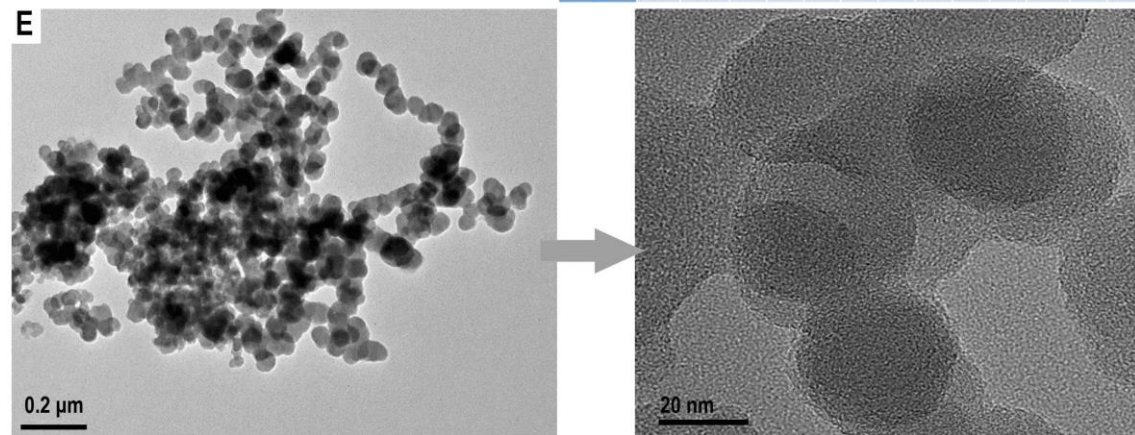
**Figure. 4.** Multianalytical approach to soot. A sample of black substance on the surface of the lamp after initial analytical pre-treatment by removing the calcium carbonate (in blue, point analysed with  $\mu$ -Raman; in red, point analysed with LIBS). B. Set of  $\mu$ -Raman carried out on this sample. C. LIBS spectrum on this sample. D. Elemental analyses of this sample (SEM-EDX). E. Soot aggregates obtained by TEM from the combustion of wood located on the edge of the concavity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)





**D**

Spectrum	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Mn	Fe
1	16.49	56.78					1.62				25.11		
2	8.01	55.64									36.34		
3	24.68	53.48		2.28	1.33	2.53	5.10	0.27		0.32	9.68		0.32
4	21.96	48.77		5.10	1.34	3.78	5.65	0.53		0.33	11.71		0.84
5	16.39	42.07		0.73	0.25	0.83	7.65	0.48		0.26	31.35		
6	23.70	59.51	0.20	1.83	0.79	1.44	4.74	0.25	0.06	0.18	7.29		
7	26.10	66.28									7.62		
8	26.03	51.73	0.15	1.53	0.65	1.84	6.66	0.33	0.14	0.11	10.69	0.13	
9		100.00											
10	30.06	38.08		2.20	1.09	3.93	7.19	0.45		0.33	15.87		0.80
11	4.82	26.88		1.02		1.75	4.95	0.50			55.02	1.63	3.43
12	27.52	57.54	0.18	2.30	1.22	3.91	2.42	0.17	0.09	0.13	3.73		0.80



<b>Laboratory reference</b>	<b>Conventional Age (uncal. BP)</b>	<b>Calibrated BP (IntCal 13, 2<math>\sigma</math> 95,4%)</b>	<b>Nature</b>	<b><math>\delta^{13}C</math></b>
Beta-438097	18540 $\pm$ 60	22490-22345	<i>Pinus tp.sylvestris/nigra</i>	-22,8

Table 1: 14C-AMS Dating of wood charcoal located inside fixed lamp.