

ANTHROPOLOGY

Neanderthal woodworking at Abric Romaní: Insights into the role of wood in a Middle Palaeolithic domestic context

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Wood technology likely played a key role in human evolution, yet it remains poorly documented because organic materials rarely preserve in archaeological contexts. The Middle Palaeolithic site of Abric Romaní (Capellades, Barcelona) provides exceptional evidence of Neanderthal woodworking preserved through travertine incrustation. We document 597 wooden imprints and charred wood remains recovered from 16 archaeological levels dated between ~62,000 and 40,000 years ago. The assemblage includes wood imprints, charred wood imprints, and charred macroremains, among which several anthropogenic objects can be identified. These include tools and weapons, domestic artifacts, and structural elements, revealing a wide range of woodworking activities. Key discoveries include wooden spears, pointed sticks, and domestic objects such as trays and tripods. A club-like artifact recovered from level P represents a unique object with no clear parallel in the prehistoric record. The Abric Romaní assemblage highlights the importance of wood within Neanderthal technological systems and provides previously unknown insights into the role of organic materials in Middle Palaeolithic societies.

INTRODUCTION

Pinpointing the time at which wood technology became integral to human evolution is challenging. Observations of our closest living relatives, chimpanzees, have revealed that they use plant materials for various purposes, including building nests (1, 2) and engaging in activities like ant dipping, honey fishing, bone marrow extraction, and nut cracking. Sticks often serve as hammers to break nuts, while leaves act as sponges for cleaning (3), behaviors frequently accompanied by the preparation of the tools themselves. Sticks are stripped of bark, twigs, and leaves and are often sharpened or cut to specific lengths. Wooden tools have also been identified in hunting contexts (3). Given these findings, it is reasonable to propose that wood technology may have undergone a complex process of development that

accompanied and paralleled the earliest stone technology. Ethological data suggest that wood has been used as a raw material since the origins of our lineage. Furthermore, ethnoarchaeological evidence highlights the major role that wood played in the toolkits of hunter-gatherer societies, where it was deliberately transformed and shaped, often through the combined use of fire and stone tools.

Lithic use-wear analyses yield some of the most reliable evidence of early woodworking, with findings indicating that wood manipulation dates back at least 2 million years (4–6). Use-wear on quartz and quartzite flakes from Kanjera South suggests that woodcutting and scraping were notable activities, possibly related to the production or maintenance of wooden tools (4–6). Although the perishable nature of wood makes deriving specific interpretations from archaeological remains complicated, evidence of wooden artifacts from the Palaeolithic is significant, indicating that the use of wood dates back at least the Lower Palaeolithic (7–10). These findings highlight an early diversification in the production of wooden tools and weapons, suggesting that early humans may have even developed the ability to combine different materials to construct structures. Recent discoveries from sites such as Marathousa 1 in Greece and Gantangqing in China further support the idea that woodworking behaviors were geographically widespread and occurred across different *Homo* species and ecological contexts, highlighting the growing recognition of complex wood use during the Lower and Middle Palaeolithic (11–13).

The Abric Romaní site offers unique evidence of wood used in a Neanderthal context, with imprints preserved through travertine incrustation. Located on the northern side of the travertine cliff of Cinglera del Capelló in Capellades, Barcelona, the site has been undergoing excavation campaigns since its discovery in 1909 (section S1.1). Ongoing excavations, which began in 1983, have revealed a rock shelter covering an area of ~300 m². The stratigraphy of Abric Romaní documented through the Romaní Pit comprises ~20 m of well-stratified

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calcareous sediments accumulated over ~15 thousand years (kyr). A 30-m borehole extends the known sequence to at least 30 m in thickness, indicating a total time span of ~110 to 40 kyr (14, 15). Rock fragmentation, combined with alluvial and biochemical sedimentary processes, has produced stratigraphic units of megablocks and block gravels, calcarenites, and calcilitites, interspersed with very fine archaeostratigraphic units (section S1.2). This rapid sedimentation process has resulted in anthropic deposits with high temporal and spatial resolution, creating clear vertical separations between human and natural deposits (16). Except for level A, all levels correspond to the Middle Palaeolithic, providing a rich archaeological record, including abundant lithic and faunal remains and well-preserved combustion structures (17–19). Charcoal is also prevalent in all archaeological levels, with *Pinus sylvestris* (Scots pine) representing more than 90% of the identified charcoal assemblage (20–22) (complete information about the site and archaeological remains can be consulted in section S1).

A distinctive feature of the Abric Romani site is the abundance of wood remains, primarily preserved as wood imprints (WIs) or partially charred wood imprints (CWIs). The imprints appear as hollow cavities that replicate the original shape of the wood. They are formed when calcium carbonate precipitates onto plant structures, including wood, as part of the travertine formation process (23, 24). The preservation process involves the decay of the wood under anaerobic conditions, after which it is gradually coated by calcium carbonate, leaving behind negative imprints once the wood has fully decomposed. The resolution of these imprints can, in some cases, reach the cellular level, allowing the identification of anatomical features such as tracheids and cross-field pits (25). Alongside these, a collection of charred wood (CW) has also been recovered, offering further evidence of wood use and craftsmanship (20–22). In addition, other plant remains, including leaf and pinecone imprints, have also been documented throughout the sequence. The exceptional preservation of these remains provides a unique opportunity to investigate the role of wood within Neanderthal technological systems throughout the Abric Romani sequence.

The wooden assemblage from Abric Romani comprises 597 specimens recovered from 16 archaeological levels dated between ~62 and 40 ka. Most of the assemblage consists of trunks, branches, twigs, roots, and firewood accumulations of natural or anthropogenic origin (figs. S3, S4, S8 to S10, S12, S15, and S16). However, a smaller subset of remains exhibits morphological, technological, and contextual characteristics consistent with intentional modification by Neanderthals. These anthropogenic elements include domestic artifacts, structural components, tools, and weapons (Table 1).

The now identified anthropogenic assemblage comprises 13 wooden artifacts distributed across levels D, H, I, J, N, O, P, and R (Table 1). Four artifacts recovered from levels H and O correspond to bark trays preserved as CW remains. Level I yielded an accumulation of crossed wooden poles interpreted as part of an elevated structure, whereas level N produced a long branch-free pole considered a possible construction element. A split pointed wooden implement was recovered from level D. Level J yielded a large pointed wooden object showing evidence of shaping, whereas level O produced a curved pointed implement interpreted as a possible digging stick. Level R contains the most diverse assemblage of worked wooden artifacts, including a pointed stick and two spears. Last, level P yielded a singular club-like object preserved as a CWI. Together, these artifacts document a broad range of woodworking activities, including the manufacture of domestic utensils, structures, tools, and weapons. These artifacts constitute the analytical sample discussed in the following sections.

RESULTS

The distribution of the 597 wooden specimens among the archaeological levels is uneven, with the highest concentrations found in levels R (140 specimens), O (113 specimens), and P (101 specimens) (table S4). Most of these specimens consist of WI, both burned and unburned (see detailed description of the inventory of wood remains in section S2). These findings can be categorized into two broad groups: natural and nonanthropogenic remains and anthropogenic

Table 1. Anthropogenic wooden elements identified at Abric Romani. Classification of anthropogenic wooden elements identified at Abric Romani, including domestic items, structural components, tools, and weapons. The table lists the category, element type, preservation type (CW, CWI, or WI), number of specimens, and their corresponding inventory codes.				
Category	Element	Type	Number	Identification
Domestic elements	Tray	CW	4	AR89-H-O50-1
				AR90-H-O58-1
				AR89-H-M51-1
				AR10-Oinf-T57-18
Structures	Elevated structure (tripod)	WI	1	AR92-I-K44-45/L44-45
Structure	Construction element	WI	1	AR04-Nb-S47-1
Tool	Pointed split	WI	1	AR92-D-R54-2
Tool/structure	Indeterminate	WI	1	AR93-Ja-O47-27
Tool	Digging stick	WI	1	AR05-Osup-S47-1
Tool/structure	Digging stick/construction element	WI	1	AR24-Ra-V58-1
Weapons	Spears	WI	2	AR23-Ra-W52-3
				AR25-Rinf (in situ)
Tool/weapon?	Wooden club	CWI	1	AR11-Psup-S54-1

elements (25), the latter including wood used for fuel, and the 13 hominin modified and used elements (table S5).

The preserved natural wood at Abric Romaní exhibits a diverse range of forms and distributions throughout the site. In the outer areas of the shelter, tree trunks in their original life positions were found in levels P and O, surrounded by fallen branches, leaves, and occasionally pinecones. Accumulations of pine needles were also observed at various levels (J, L, M, O, and P). However, it is unclear whether these were naturally occurring or brought to the site as part of firewood assemblages.

Anthropogenic woodpiles

The human introduction of wood into the site is most evident in its role as fuel, particularly as firewood, which is often found partially charred within combustion structures (figs. S9, S12, and S15). The anthracological analysis of the sequence found that Scots pine (*P. sylvestris* type) was the primary fuel used to sustain the hearths (21). The characterization of the firewood suggests distinct collection strategies based on the size of the wood and the effort involved in obtaining and transporting it (25). The quantities of firewood found across the different occupation surfaces vary, from isolated pieces to large accumulations of wood, representing firewood reserves. These pieces range in size from small twigs just a few centimeters long to large logs (17), with the largest measuring up to 7.2 m in length. However, most of the recovered specimens fall within the small to medium-sized range. Spatially, the firewood is typically distributed toward the back of the shelter, near the wall, or in the outermost parts of the occupation surface. Most of the firewood remains are associated with combustion structures, further highlighting their role in heating and cooking within the settlement (sections S2 and S3 and supplementary and figures).

Domestic items

The objects considered domestic items are trays crafted from bark that have been preserved in a carbonized state (CW). These consist of four items originating from level H ($n = 3$) and level O ($n = 1$) (Fig. 1).

The first object (AR89-H-O50-1) is a partially carbonized wooden artifact measuring 55 cm by 20 cm by 1 to 2 cm (Fig. 1, A to E). One end of the object tapers to a sharp point, which appears to have been intentionally shaped.

The second object (AR89-H-M51-1) is a fragment of charred juniper (*Juniperus*) wood (24). Its shape is elliptical, although it narrows at one end, making it not perfectly regular. Its maximum dimensions are 30 cm in length and 20 cm in width (Fig. 1, B to F). The profile reveals a concave upper surface with irregular edges, resembling a plate or shallow scoop.

A third elliptical wooden artifact (AR90-H-O58-1) was discovered in 1990 embedded within a rubified travertine area associated with a poorly preserved combustion structure. Its morphology closely resembles that of AR89-H-M51-1, although it is slightly smaller, with maximum dimensions of 30 cm in length and 20 cm in width (Fig. 1C).

The fourth object (AR10-Oinf-T57-18), recovered from level O, is another charred wooden artifact displaying a concave profile similar to the previous examples. It measures 34 cm in length, 29 cm in width, and up to 4 cm in thickness (Fig. 1D).

The spatial distribution of wooden artifacts associated with combustion structures (26) suggests a relationship with domestic activities carried out around the hearths. However, it is important to acknowledge the difficulties involved in distinguishing intentionally modified bark containers from bark fragments detached naturally. Nevertheless, several observations support the interpretation that at least some of these elements correspond to anthropogenic objects rather than natural remains. These include their relatively large and regular dimensions, their close spatial association with hearths, and the use of juniper bark, in contrast to the predominance of pine both as fuelwood and as the raw material used for most worked wooden objects throughout the sequence. This choice may reflect the particular anatomical and mechanical properties of some juniper species, whose bark is fibrous and longitudinally exfoliating and whose wood has been described as unusually elastic among conifers. Such characteristics may have favored the manufacture of lightweight and

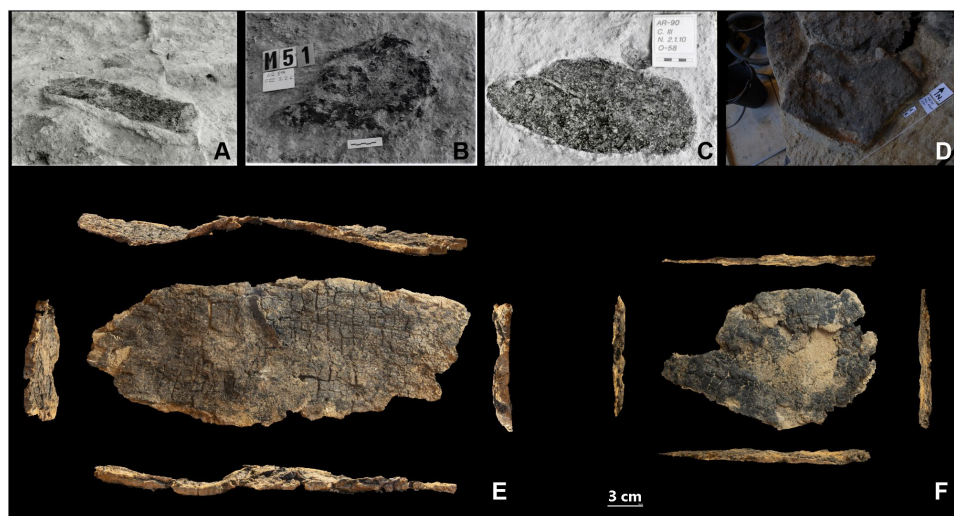


Fig. 1. Trays crafted from bark that have been preserved in a carbonized state, recovered from levels H and O. (A) AR89-H-O50-1; **(B)** AR89-H-M51-1; **(C)** AR90-H-O58-1; **(D)** AR10-Oinf-T57-18 in situ. In the bottom images, **(E)** AR89-H-O50-1, and **(F)** AR89-H-M51-1 are shown in sagittal view, along with all of their edges. Credit: M. D. Guillén/IPHES.

resistant bark containers, although the functional significance of this taxonomic selection remains uncertain (27).

In addition, the CW and ember remains recovered from combustion structures generally preserve cylindrical morphologies corresponding to branches or trunks, differing from the flattened and hollowed morphologies documented in these objects.

Hollowed wooden containers, often canoe-shaped, are common among some contemporary forager populations. For example, coolamon or pichi vessels are dishes used by Indigenous Australian populations (28–30). These are shallow containers primarily manufactured from tree bark, with dimensions ranging between 30 and 70 cm. They commonly served multiple purposes, from gathering food to carrying infants. Based on these ethnological parallels, the Abric Romani wooden trays may have functioned as containers for transporting food or as scoops or ladles, perhaps for collecting embers or ashes. Nevertheless, these comparisons should be treated cautiously, because the specific functions and biographies of the archaeological objects remain difficult to determine with certainty for some elements.

Structures

Two structures in different forms and with different purposes have been identified.

The first corresponds to an accumulation of WI (AR92-I- K44-45/L44-45) of large dimensions from level I (Fig. 2). It consists of 11 fragments belonging to three straight and cylindrical sticks, two of which were crossed on the ground. Their lengths range from 170 cm (the most complete pole) to 15 cm, with circumferences varying between 9 and 4 cm at their maximum diameter. This accumulation was located over a thick hearth, an association suggesting that it may have been part of an elevated structure made up of several sticks (23), conceivably related to food processing.

The second structure item is a WI from level N (AR04-Nb-S47-1). It is a single straight object measuring 510 cm in length, with one end measuring 6 cm and the other tapering to 3 cm, both of them fractured (Fig. 3). What stands out about this fragment is that, despite its length, it does not retain any branches, suggesting that they were deliberately removed. Its presence and anthropogenic modification can be inferred on the basis of its characteristics. Its spatial association with combustion structures is a distinctive feature that contributed to its interpretation as a structural element and as part of a resting area (18).

The WI was found in the innermost part of the shelter, associated with five hearths aligned in a rectangular area of 18 m², where very few other archaeological remains have been recovered (fig. S13). The structure highlights the radial relationship between the central hearth and the arrangement of hearths in both the inner and outer zones. The central hearth is connected to an arc formed by hearths in the inner zone, located 3 m away. Another radial arrangement consists of a double arc around two hearths, with the first arc 3 m from the center and the second arc 5 m farther out, both involving hearths at varying distances. The distribution and content of these combustion structures led to the interpretation of the area as a sleeping and resting activity space (Fig. 3 and section S2.12) (18). Two dripping domes and the shelter's back wall formed the general structure. The stick would have been located on a third side. This arrangement suggests a simple triangular architectural structure leaning against the wall, possibly functioning as a windbreak or a small hut-like shelter.

Nevertheless, this interpretation warrants further reflection considering current debates on Middle Palaeolithic constructions, which focus less on their mere presence and more on how to identify and define built features in contexts of poor organic preservation and how to distinguish architecture from the planned use of space (31). Although level N has been interpreted as representing brief occupational events, this does not necessarily contradict the existence of light architectural features. On the contrary, the recurrent use of the site, the diversity of raw materials present, and the repeated structuring of space, particularly the superposition and spatial organization of hearths (18), suggest that the reuse of space among Neanderthals became sufficiently routinized for a degree of spatial patterning to be visible even within this palimpsestic deposit. Meanwhile, the preservation of a single wooden element is more likely to reflect preservation biases affecting organic components. The recovered stick most likely formed part of a more complex architectural arrangement composed of perishable materials that have not been preserved. In such a context, the investment in simple, light, and potentially reusable constructions, such as windbreaks, would be fully compatible with short-term but recurrent occupations.

Pointed objects

Five-pointed objects have been identified throughout the sequence, each with its own distinct characteristics and dimensions. A WI of a pointed split wood was discovered in level D (AR92-D-R54-2). Its



Fig. 2. Wooden structure from level I. Credit: IPHES-CERCA photographic archive.



Fig. 3. Wooden structural element from level N. The main photograph shows the complete imprint. Panels (A) and (B) show enlarged details of the element, in which the absence of branches can be observed. The element is interpreted as part of a hut-like structure. The branches were likely removed intentionally. Credit: G. Campeny/IPHES.

dimensions are 12.2 cm in length, with a maximum width of 1.1 mm and 0.4 mm at the pointed end (Fig. 4). Longitudinal striations from scraping are macroscopically visible, indicating the shaping of the pointed end (Fig. 4). Both its morphology and dimensions make it comparable to the pointed split woods described in the collection found at Schöningen (11). Leder and colleagues (11), drawing analogies with bone and antler tools from the Upper Palaeolithic, suggest that these wooden tools were used as awls for working soft materials.

A CWI of a pointed object (AR93-Ja-O47-27) made of Scots pine was recovered from level J. It is a wooden stick measuring 94 cm in length with a maximum diameter of 10 cm at its distal end (Fig. 5A). The pointed portion begins ~80 cm from this point, tapering down to a blunt tip with a diameter of 2 cm.

From the top of level O, specimen AR05-Osup-S47-1 corresponds to the distal portion of a branch exhibiting an arched morphology (Fig. 5B). The proximal end is pointed and exhibits anatomical features consistent with the original insertion of the branch into the trunk. This area preserves perpendicular fibers surrounding the tip, as well as the circular growth structure marking the contact perimeter between the branch and the trunk. These features indicate that the specimen was detached close to its natural point of attachment. The distal end, although lacking preserved surface texture due to fossilization, presents a rounded morphology. The overall dimensions of the specimen are 76 cm in length, with a maximum width and diameter of 5 cm. In areas where surface preservation is optimal, the WIs exhibit a bark-free surface with fibers showing a degree of polish resembling abrasion produced by flowing water. This surface modification could suggest postdepositional smoothing related to hydrodynamic processes before final burial. However, the observed surface alteration also shows similarities to the smoothed surfaces described on the Schöningen pointed split wood objects (11, 32), where they have been interpreted as the result of intentional woodworking activities,

including shaping, finishing, maintenance, or use of the objects. The irregular properties and preservation characteristics of the travertine complicate the taphonomic interpretation of these smoothed surfaces, and the cause of the polish must therefore remain open, without excluding a possible anthropogenic origin.

The length of both artifacts, ~1 m, suggests that they may have been digging sticks. Digging activities are typically associated with the search for underground food resources. However, in the context of the Abric Romaní site, an alternative explanation must also be considered: the excavation of soil to prepare areas for constructing basin-shaped hearths dug into the ground or for creating concavities used for the disposal of refuse (33). In level J, where one of these pointed objects was found, midden sediments are common, indicating surface modifications of the occupation area due to human activities such as soil excavation, food procurement, or possibly both.

The diameters of the objects from levels J and O diverge significantly from that of digging sticks documented in Neanderthal contexts, such as those found at Poggetti Vecchi (13) or Aranbaltza III (12), which have diameters not exceeding 4 cm and are notably more slender than the objects found in level J and level O at Abric Romaní (fig. S21). The Abric Romaní specimens also differ from the dimensions, particularly the diameters, of the wooden objects documented at Schöningen (11) and Marathousa 1 (9). Nevertheless, the dimensions of these artifacts are highly variable across contexts with abundant wooden assemblages, which may suggest a diversity of functions and uses. The artifacts from Poggetti Vecchi are also characterized by a rounded edge that, according to Aranguren and colleagues (13), would have functioned as a handle.

The Abric Romaní specimens, particularly the object from level O, show dimensional and morphological similarities to some of the chisel-like wooden artifacts from Gantangqing (10) and to the rounded wooden implements documented in the Acheulean horizons of



Fig. 4. Split wood AR92-D-R54-2. (A) Complete element. (B) Detail of the pointed distal end of AR92-D-R54-2. (C) Detail of the central part of AR92-D-R54-2 with visible scraping striations. Credit: M. D. Guillén/IPHES.



Fig. 5. Pointed objects identified throughout from levels J, O, and R. (A) CWI-pointed object AR93-Ja-O47-27 made of red pine. The image shows a polyurethane resin cast made during the excavation of the object. (B) WI-pointed with arched morphology AR05-Osup-S47-1. (C) Possible pointed stick AR23-Ra-W52-3; (C1) distal end detail of the stick AR23-Ra-W52-3. Credit: M. D. Guillén/IPHES [(A) and (C)] and G. Campeny/IPHES (B).

Kalambo Falls (34). Shared features include rounded edges, oblique or beveled distal ends, and varying degrees of curvature. However, the specimen from level J is notably more robust than the now known examples from these assemblages. Overall, the morphological and dimensional variability observed among these wooden artifacts may reflect technological differences, distinct functional requirements, or different categories of implements.

An alternative interpretation that must be seriously considered for the specimen from level Ja is that it does not represent a complete object but rather a fragment of a larger structure. In this case, it could correspond to a construction component comparable to those documented in level N. In contrast, the pronounced curvature of the specimen from level O makes this hypothesis unlikely and instead supports its interpretation as a functional tool.

In level R, the last of those excavated to date, three-pointed items have been recovered: a pointed stick and two spears. In level Ra, a possible pointed stick (AR23-Ra-W52-3) was recovered with one-pointed end, a total length of 74 cm, and a maximum diameter of 3 cm. The pointed end has a diameter of 1.8 cm, dimensions that also fall within the metric variability of the double-pointed sticks from Horizon13 II-4, at the Schöningen site, raising the possibility that it could be a throwing stick (Fig. 5C). However, two key characteristics suggest otherwise. First, it exhibits only one pointed end. Second, the throwing sticks recovered at Schöningen share a consistent location for their maximum diameter, which is positioned between 50 and 70% of the total length when measured from the front end, with a coefficient of variation of 16%. According to Leder and colleagues (11), this low variability indicates that this feature is important for flight. In contrast, the maximum diameter of specimen AR23-Ra-W52-3 is at the proximal end, which does not align with the aerodynamic attributes typically associated with throwing sticks. It is also worth noting that the dimensions of this item are comparable to Stick No. 2 from Poggetti Vecchi (13), which is almost completely preserved and features a single-pointed end. The excellent preservation of the wooden tool assemblage from Poggetti Vecchi is noteworthy, and the assemblage has been interpreted as a collection of multipurpose digging sticks based on its size and characteristics.

Spear AR24-Ra-V58-1 is a wooden artifact measuring 245 cm in length with a maximum diameter of 3.66 cm (Fig. 6). The thickest part of the spear is located 121.5 cm from one end, corresponding to 49.5% of its known maximum length. One end, unfortunately, the most poorly preserved, appears to be pointed and has a maximum diameter of 1.5 cm. The opposite end exhibits a fracture (Fig. 6, E and G), which, based on its morphology, has been interpreted as having occurred during the manufacturing process rather than during use. If this interpretation is correct, then it represents the proximal end of the spear, which would not have been pointed. The spear exhibits a slight curvature in its proximal portion, likely reflecting the natural shape of the tree trunk from which it was crafted. While it lacks visible branches, it does feature several knots. It presents a rounded to oval cross section throughout most of its length, becoming narrower toward one of its ends (Fig. 7).

Specimen AR25-Rinf corresponds to a wooden negative of a fragmented pointed implement, preserved in three sections (Fig. 8). It was recovered in direct association with an accumulation of plant remains, including additional sticks, branches, and a pinecone, suggesting that the artifact may have been discarded after breakage. The specimen preserves a total length of 199 cm, with a maximum distal diameter of 4.9 cm and a central shaft diameter of 3.6 cm. The distal

tapered portion measures 13 cm in length and terminates in a pointed end with a diameter of 0.6 cm. The entire shaft surface is clean and smooth, lacking additional branch outgrowths, although natural knots are present along its length. As observed in the preceding specimen, the proximal end does not exhibit shaping or evidence of intentional pointing, consistent with its current state of preservation and morphometric attributes.

Based on ethnographic parallels and experimental studies, the design of spears is closely linked to their intended function, with key factors such as mass and point of balance playing a critical role in flight mechanics, biomechanics, and the kinetic energy delivered upon impact (32, 35). Additionally, tip design plays a critical role in penetration and the damage inflicted by the weapon. The specimen from level R at Abrić Romaní exhibits general dimensional and morphological similarities to some Middle Pleistocene wooden spears, including specimens from Schöningen and Lehringen (11, 36) (fig. S22). However, caution is required when making direct morphological comparisons, as several of these objects are incomplete or affected by postdepositional deformation. In particular, the morphology and original length of Spear VII from Schöningen remain uncertain (11), while the curvature observed in both the Schöningen and Lehringen (11, 36) specimens may be partly taphonomic in origin. Nevertheless, the overall morphology, dimensions, and pointed configuration of AR24-Ra-V58-1 can be consistent with its interpretation as a thrusting spear. Palaeolithic wooden spears have previously been documented at sites such as Clacton-on-Sea (England) (8), Lehringen (Germany) (36), and Schöningen (Germany) (11, 37, 38).

Level Ra, where the spear was recovered, is particularly notable in that the ungulate remains consist exclusively of red deer. The minimum number of individuals in the assemblage has been calculated as four, represented by axial and cranial skeletal elements. Three skulls were deposited in a single area, surrounded by several WIs, including the spear itself (Fig. 6A) and combustion structures. The skulls of these adult male individuals retain their antlers, suggesting that they were probably hunted during the autumn or winter seasons. The use of spears for ambush hunting has been previously proposed and supported by indirect evidence such as prey mortality profiles [e.g., (39)]. The faunal record from the site provides compelling evidence of active hunting by Neanderthals at Abrić Romaní, who likely used sophisticated strategies that may have included ambush and stalking techniques, with the support of weapons such as spears [e.g., (39)]. The absence of direct marks on the skeletal remains in level Ra and other levels aligns with broader patterns observed in the archaeological record. Evidence supporting the use of spears for close-range hunting by Neanderthals on skeletal remains is rare and often difficult to detect. In level Ja of Abrić Romaní, evidence of spear technology is complemented by the discovery of a unique bone spear-head designed for thrusting and/or throwing (40).

Wooden club

A singularly shaped CWI (AR11-Psup-S54-1) was recovered from level P, perhaps the most exceptional wooden object identified in the assemblage to date (Fig. 9). It consists of a single-piece artifact with a handle at one end and an expanded distal portion at the opposite end (Fig. 9). The presence of a handle and a differentiated distal end gives the object a club-like morphology. The handle measures 16 cm in length and 4.2 cm in width. The distal portion is elongated and pointed, roughly triangular in outline. Its base is flat, and the two lateral edges are curved, with curvature more pronounced on one

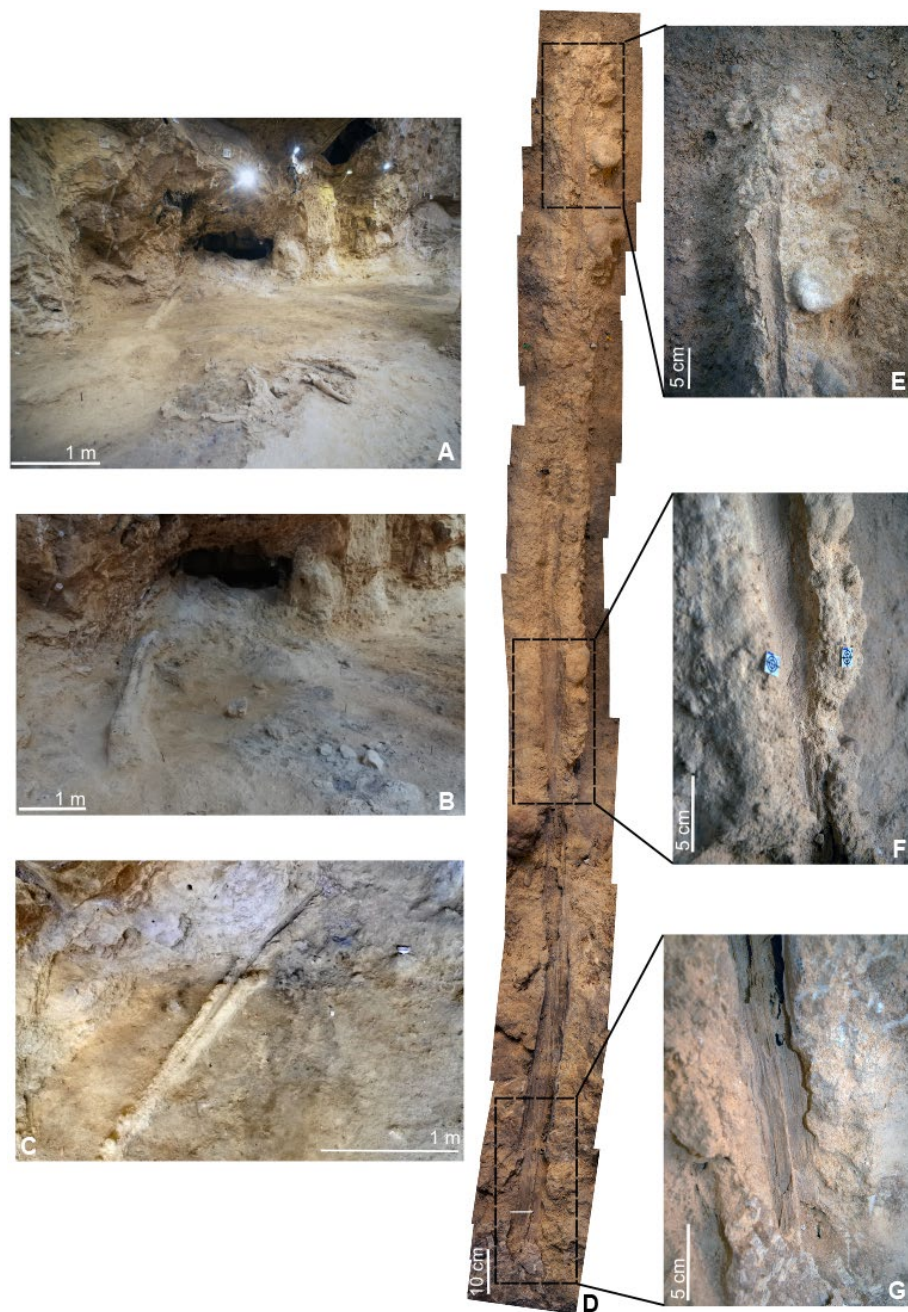


Fig. 6. WI of the spear AR24-Ra-V58-1 recovered from level R. The complete specimen is shown in the center of (D). The images on the left (A to C) show the object from different perspectives during the excavation of level R. In the first image (A), several deer skulls with antlers are visible in the foreground. The images on the right (E to G) show details of both ends and the central portion of the item. Credit: P. Saladié/IPHES [(A) to (C)].

side. The head measures 14.2 cm in height, with widths of 6.2 cm at the base, 6.5 cm at mid-height, and 0.4 cm at the distal tip. Longitudinal traces with parallel striations are visible (Fig. 9), indicating scraping during shaping. Evidence of burning is irregularly distributed across the surface and cannot be linked to deliberate hardening but likely resulted from incidental exposure after discard.

Additional morphological features indicate a deliberate and technically controlled shaping process. The handle exhibits a slightly larger diameter at its terminal end, a feature ethnographically associated with

implements intended to be securely retained in the hand during swinging or pulling motions. Furthermore, a marked 90° transition between the handle and the distal portion produces an abrupt change in section. Such a configuration would require greater technical control than a gradual transition and may have functioned as a stop element, either to reduce slippage or to protect the hand during use. The distal portion displays a biconvex section and progressive thinning toward the tip, forming a carefully shaped working end. Together, these features reflect a notable degree of conceptual planning and technical investment.

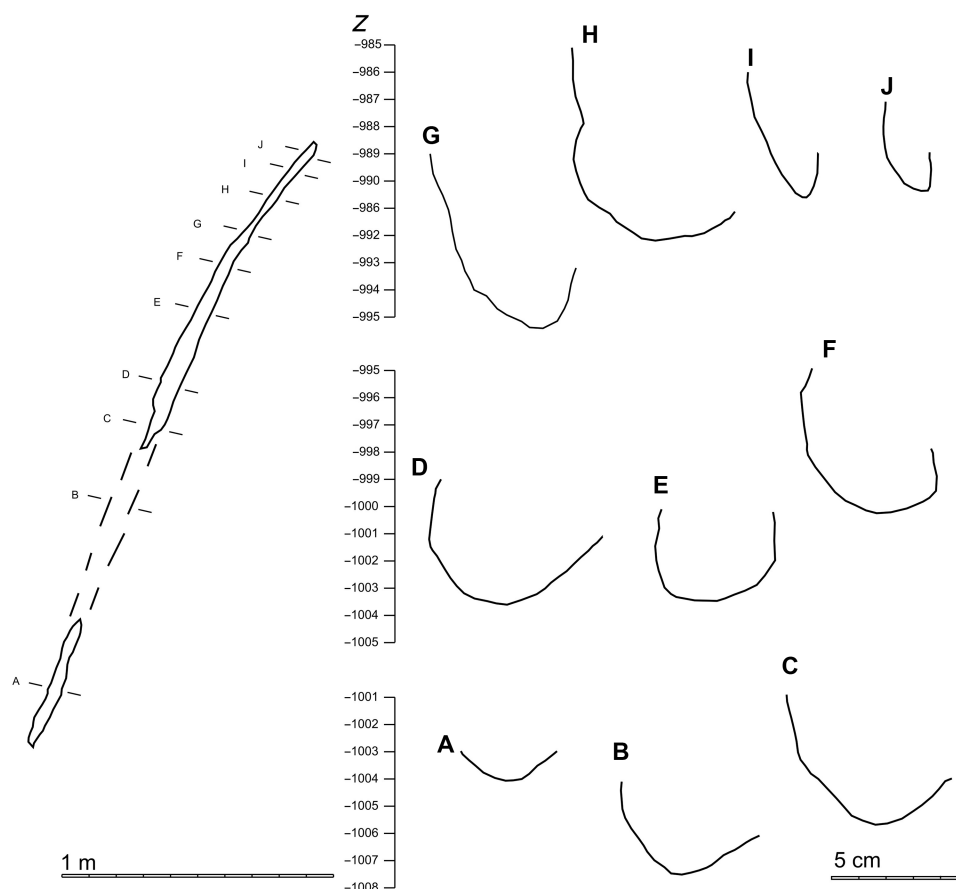


Fig. 7. Plan view and transverse sections of the negative imprint of spear AR24-Ra-V58-1 preserved in the travertine deposit. Cross sections (A to J) were recorded at different points along the artifact and are shown according to their original elevation (Z) relative to the excavation reference datum. The drawing illustrates the variation in the spear's cross-sectional morphology and diameter along its preserved length.

The distal portion displays a biconvex section and progressive thinning toward the tip, forming a carefully shaped working end. Together, these features suggest a notable degree of conceptual planning and technical investment in the manufacture of the artifact.

The overall shape of this specimen supports its interpretation as a club-like implement. Although certain aspects of the distal morphology could evoke digging implements, its marked asymmetry and pointed form would make efficient excavation difficult, particularly for repetitive or forceful digging. In this respect, the morphology is more consistent with a percussive implement than with a tool designed for systematic soil displacement. Nevertheless, occasional or expedient use in digging-related tasks cannot be entirely excluded.

Comparable morphologies are reported in ethnographic and archaeological contexts, including wooden throwing sticks from Florisbad (41), although direct functional equivalence should not be assumed. Overall, the artifact reflects a notable degree of conceptual planning and technical investment. Such characteristics are consistent with implements used in percussive or friction-related activities and do not contradict its interpretation as a club while also allowing for situational or complementary uses, such as working hides, plant materials, or fibers.

Among recent foraging populations, clubs and throwing sticks are widespread and morphologically variable (42, 43). These implements are used in interpersonal violence, hunting, and fishing contexts (42).

Ethnographic data indicate their effectiveness in dispatching medium-sized to large animals, including taxa comparable in size to the deer and horses documented in the Abric Romaní sequence (42, 44). Their use is typically associated with close-range encounters. Ethnographic accounts also emphasize that clubs may carry symbolic or social significance and are not used exclusively as weapons.

In the Palaeolithic archaeological record, wooden clubs are exceedingly rare. To date, only one possible example has been reported from Kalambo Falls (Zambia), dated to ~400 kyr (34). Consequently, assessing the precise function, use intensity, or behavioral context of such implements, particularly in relation to Neanderthal occupations at Abric Romaní, remains challenging given the limited comparative record and the functional variability documented among recent hunter-gatherers.

Working debris

Small wood chips measuring less than 6 cm are common throughout the sequence. These were accumulated in levels I, J, K, L, M, O, Q, and R, pointing to woodworking activities in these levels. Unfortunately, this interpretation is not supported by the use-wear studies of the lithic industry (Supplementary Text). It is important to note the limitations of functional studies at Abric Romaní. These are due to postdepositional alterations, such as the formation of a white patina and water-induced erosion on the surfaces of the lithic tools (see section S1.3).

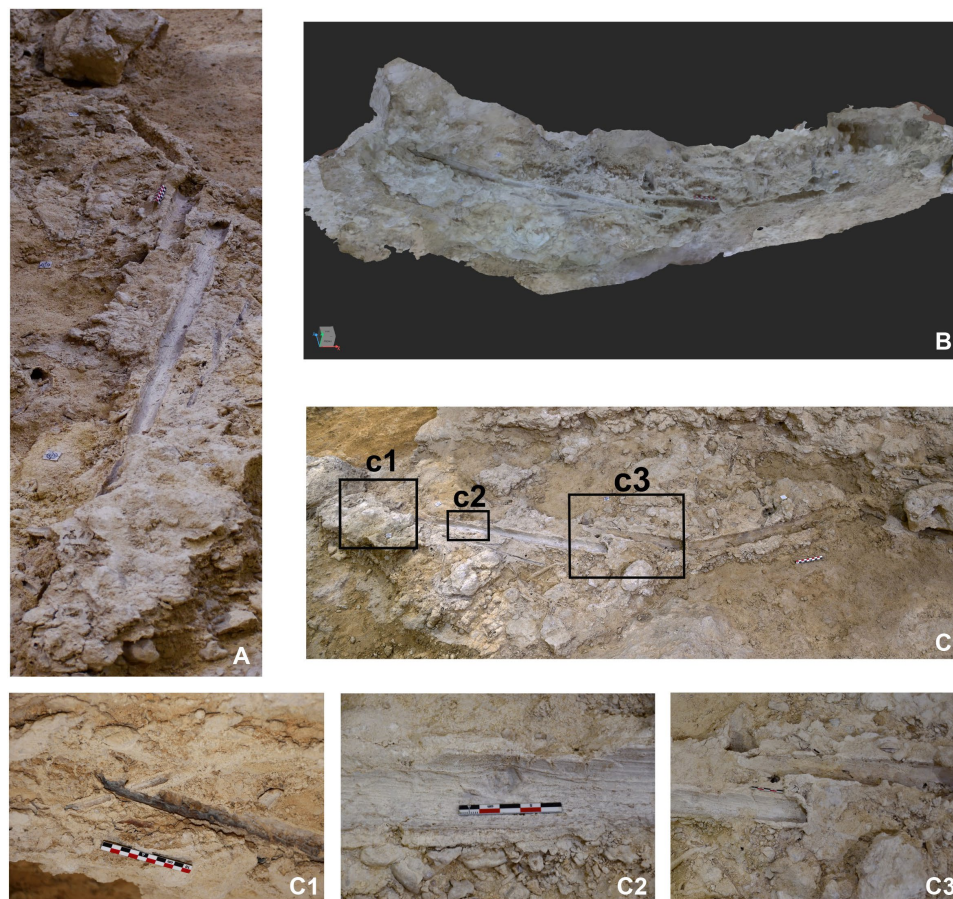


Fig. 8. Spear recovered in Rinf. Views of the three fragments that comprise the spear recovered in Rinf (A to C). (B) A 3D model captured with a Revopoint Miraco Scan Pro. (C1) Detail of the distal end. (C2) Detail of the shaft showing the knot of a cut branch. (C3) Detail of the fracture between two of the fragments. Credit: P. Saladié/IPHES.

DISCUSSION

The inventory of wooden remains from Abric Romani is extensive and represents a particularly unique case as it comes from a prehistoric domestic archaeological context. Throughout the site's sequence, Neanderthal occupations alternated between two types of settlements. First, the evidence points to settlements associated with functional mobility (17, 18, 45–47) related to the procurement of lithic raw materials and big-game hunting. Second, the site was used for the establishment of base camps, where human groups stayed for several weeks or even one or two seasons, engaging in all the activities typical of their daily lives [e.g., (48)]. The introduction of wood was common in all of these settlements, indicating that wood was a central component of these communities' economies, alongside rocks and animal resources, and was particularly important for fueling fires. According to anthracological studies, especially significant at this site, forest management focused on the exploitation of mountain pines (20–22, 49, 50), whose local availability was extensive (51, 52).

Although wood was predominantly used as fuel, the preservation of imprints and charred remains has revealed its use in the manufacture of a wide variety of objects and tools. Most of the wood artifacts correspond to Scots pine (*P. sylvestris* type). From a technological perspective, this wood is relatively compact and resistant, yet easy to work with, offering a favorable balance between hardness and workability. It dries rapidly, has good dimensional stability, and, due to its

high resin content, is notably resistant to moisture and weathering. This set of properties makes it particularly suitable for the manufacture of tools, weapons, and utensils. Archaeological evidence indicates that Pleistocene hominins deliberately selected wood species according to their mechanical and functional properties. At Schöningen, wooden artifacts were produced predominantly in spruce (*Picea* sp.) and pine (*P. sylvestris*) (11), while, in other contexts, such as Poggetti Vecchi, Neanderthals selected denser species such as boxwood (*Buxus sempervirens*), reflecting careful management of raw material properties (13). The combined properties of *P. sylvestris* further suggest that its transformation involved a relatively low energetic and temporal cost compared with other types of wood, making such objects easily replaceable and consistent with technological strategies based on the production of simple, light, and short-lived equipment.

The travertine molds encasing the wooden objects and tools/weapons from Abric Romani have made analyzing the processes by which they were manufactured challenging. Nevertheless, it is possible to conclude a general operational sequence that begins with selecting branches or trunks with the appropriate dimensions for crafting these objects. The branches were removed as observed in elongated items such as the stick from level N or the spears from level R. The wood splinters documented in the different occupation layers suggest peeling, while the pointed shapes indicate scraping, both actions aimed at achieving the desired final morphology.

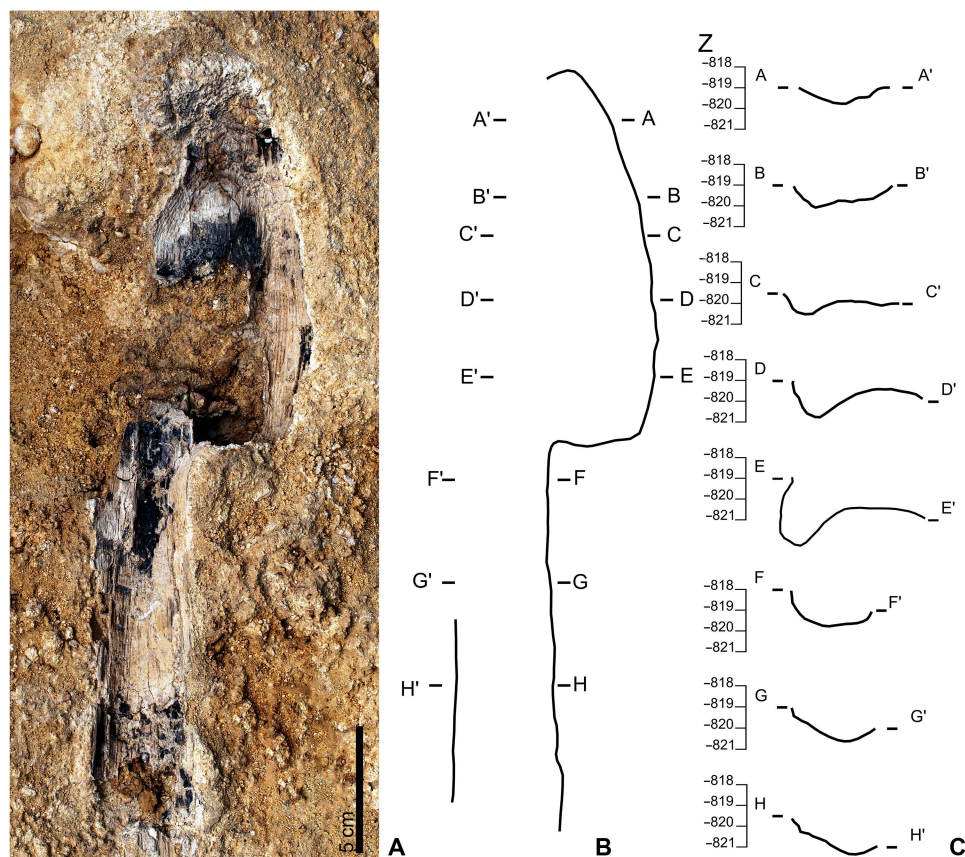


Fig. 9. CWI AR11-Psup-S54-1 from level P, interpreted as a club. (A) Photograph of the artifact as preserved in situ. (B) Plan view of the complete object showing the location of the transverse sections (A to H). (C) Transverse sections recorded at different points along the artifact and plotted according to their elevation (Z) relative to the excavation reference datum. The sections illustrate the morphological variation of the club along its length, including the head and handle. Credit: M. D. Guillén/IPHES.

These manufacturing phases are similar to those documented at other Middle Palaeolithic sites (11–13).

Although relatively small, this collection of artifacts is notable for the varied morphology and functionality of the items that comprise it, demonstrating a remarkable technological versatility and the diversified exploitation of wood as a raw material. Evidence from various prehistoric sites has indicated both the use of wood as a basic resource and the breadth of its functional spectrum. However, the poor preservation of these organic elements has limited the number of available assemblages, which, with a few exceptions like Gantangqing, Schöningen, Poggetti Vecchi, and Aranbaltza III (11–13, 53), contain few preserved remains and display a certain homogeneity in their forms and uses. This is not the case at Abric Romaní, where the archaeological evidence collected reveals the crafting of wooden posts, a tripod, trays, pointed objects, spears, and a club, suggesting significant diversity in forms and functions. This diversity in wood use parallels contemporary foragers' domestic lives and subsistence strategies (32, 42, 54, 55). Among the objects, the club recovered from level P is particularly noteworthy as no similar parallel is known in the prehistoric record of the Old World. The morphology and the composite nature (an active part and a handle) of this artifact suggest a complex manufacturing process, requiring a considerable time investment and technical knowledge. It is worth stressing that the lithic assemblage from this layer is also characterized

by a particularly complex technology, including the production of blades/bladelets and the provisioning of high-quality raw materials (47, 56). The wooden artifact from level P should therefore be interpreted in the context of a generalized high-investment technology, evident in different domains of material culture.

The main difference between the wooden tool assemblages from these sites lies in the documented use of fire at Poggetti Vecchi (13), whereas comparable evidence has not been identified at Gantangqing, Marathousa I, Schöningen, and Aranbaltza III (9, 11–13, 53). In the Poggetti Vecchi assemblage, fire was used to char specific portions, facilitating the scraping of boxwood. There is no doubt that fire played a fundamental role in the daily life of the Neanderthals who occupied Abric Romaní, as attested by the abundant presence of diversified hearths across all levels (18, 19, 33, 57). Some of the wooden objects and tools exhibit evidence of partial or complete charring. However, the available evidence is inconsistent with the use of fire during their manufacture, as it may instead be related to intentional or accidental burning events after the artifacts were abandoned.

The use and working of wood coexisted with lithic production throughout the stratigraphic sequence. At Abric Romaní, woodworking is mainly associated with expedient technological systems, which characterize much of the technological behavior documented in this long Middle Palaeolithic sequence (45, 58–60). Retouched tools are consistently scarce, representing less than 4% of the knapped

assemblages. Notable exceptions occur in levels O and P, where more complex reduction sequences are documented, including Levallois strategies (levels O and P) and blade production (level P) (61, 62). The lithic assemblages also evidence behavioral variability, such as microlithic production and core-on-flake exploitation, which may reflect differences in mobility strategies and degrees of planning depending on the occupational phase (63, 64). The recurrent association of woodworking with diverse lithic reduction strategies suggests that wood exploitation was not dependent on any single knapping method or level of technological complexity. Rather, it points to the flexibility and effectiveness of Neanderthal technological systems.

Although functional analyses of the stone tools recovered at the site remain limited, mainly due to postdepositional alterations such as concretions and surface patination (65) and, to a lesser extent, thermal alterations, it is reasonable to infer that wooden implements were shaped and maintained using stone tools. The available evidence indicates that woodworking formed an integrated component of Neanderthal technological practices, likely independent of specific lithic strategies and probably representing a recurrent aspect of Middle Palaeolithic technological behavior. In line with recent lithic studies (66–68), the Abri Romaní record highlights the coexistence of different degrees of technological investment within the same human groups or chrono-cultural phases. Within this framework, woodworking likely required substantial technical knowledge and skill, indicating a meaningful investment in organic technologies.

The versatility of wooden tools and their handling likely involved varying degrees of planning and technical investment. As in lithic technology, woodworking probably encompassed a spectrum of complexity and production costs, ranging from expedient implements to more carefully shaped forms. Some artifacts could have required the ability to conceptualize specific morphologies before production, whereas others were produced with minimal transformation. This variability reflects a flexible technological system supported by detailed technological knowledge and adaptive capacities. In this sense, woodworking contributes to broader evidence for Neanderthal technological competence without implying uniform levels of abstraction or planning across all wooden implements.

Beyond their deftness with stone, Neanderthals had a remarkable ability to work with organic materials such as bone [e.g., (40)], shell [e.g., (69)], fiber (70), and wood, as evidenced by findings from the MIS 3 sequence at Abri Romaní. Wood likely played a more significant role among prehistoric foraging groups than can be inferred from indirect evidence, with a technological evolution parallel to that of stone. Middle Palaeolithic archaeological collections are varied and do not allow for the identification of widely spread technological traditions, despite observable parallels between objects, such as the spear from level Ra at Abri Romaní and Spear VII from Schöningen. However, in spite of these limitations, the crafting of a variety of objects and tools highlights Neanderthals' understanding of the mechanical properties of these resources and their skill in optimizing them according to functional needs.

MATERIALS AND METHODS

This study aimed to document and analyze the wood assemblage recovered from the Middle Palaeolithic sequence of Abri Romaní to evaluate the role of wood within Neanderthal technological systems and domestic contexts. The research focused on the morphology,

technological traits, and preservation of the wooden remains, as well as their spatial and stratigraphic associations.

Our analytical framework assumes that woodworking formed a recurrent component of Neanderthal technological behavior at the site. The analyses presented here are primarily descriptive and comparative, with functional interpretations proposed cautiously and grounded in morphological, technological, and contextual observations.

The archaeological research conducted at Abri Romaní has been extensive, and 18 archaeological levels have been fully excavated to date. Evidence of wooden items has been recovered from most of them (see the Supplementary Materials). All objects, including small fragments and wooden remains, were individually recorded and plotted on the surface using a Cartesian coordinate system. The remains were labelled with the campaign (e.g., AR24), level (e.g., J), grid square (e.g., M42), and a sequential number along with other objects from the same grid square. A total of 597 wooden specimens were recovered across all the levels of the sequence. Wood remains and WIs were recorded and analyzed using an integrated morphological, anatomical, taphonomic, and conservation-orientated approach. Morphological characterization focused on general shape, metric attributes, cross-sectional morphology, end-shape configuration, and the presence, arrangement, and type of branching. These variables were used to infer the anatomical origin of each element within the tree (e.g., trunk, branch, and twig) and to assess the degree of fragmentation and disarticulation, providing proxies for fuel selection and predepositional processes.

Three main categories related to wooden remains have been defined in the field:

- 1) WIs: These are travertine molds that indicate the volume and shape of the original object, including a high-definition calcite crystal cast of the wood, showing the surface characteristics and the negative shape of the wood bark.
- 2) CWIs: These are imprints with evidence of charring on the original object or with charcoal adhered to the imprint or filling a segment of the negative. This category is assumed to result from localized or incomplete exposure of wooden elements to fire.
- 3) CW remains: These are charcoal wood remains larger than 5 cm.

Taxonomic identification was not always possible for all wooden remains, particularly in the case of noncarbonized WIs. Identifications were primarily based on carbonized wood remains (CW) and CWIs, in which anatomical structures were sufficiently preserved for analysis. Taxonomic identification of these remains was conducted through anatomical observation under a metallographic microscope and supported by comparison with modern reference collections and wood anatomy atlases [e.g., (71)]. Taxonomic attributions were only proposed when diagnostic anatomical features could be confidently observed.

Other macroremain imprints recovered include leaf and pinecone impressions.

The first step in the recovery and conservation of the WIs from Abri Romaní consisted of cleaning, consolidation, and extraction. For charcoal WIs, once a sample was collected for taxonomic identification, PEG 4000 was used for consolidation. For wood impressions (composed mainly of calcium carbonate), Paraloid B-72 diluted in acetone was used in different concentrations as needed, within a 10-cm perimeter around the piece and injected into cracks and

holes in the sediment without applying it directly onto the piece. Travertine blocks (around WIs) were consolidated using ethyl silicates (Tegovakon and/or Stel 1000).

During the archaeological fieldwork, six attributes of WIs are documented: (i) length; (ii) width; (iii) presence or absence of charring; (iv) orientation of the object; (v) thickness of concretions; and (vi) spatial arrangement of the objects in relation to one another (for example, juxtapositions, which may have an anthropogenic or natural origin). To compare the dimensions of the wooden objects, we used violin plots and the Kruskal-Wallis test for sets with a non-normal distribution and unequal medians. The lengths and widths of the pointed wooden objects (spears, digging sticks, and other pointed implements) were compared against published datasets from comparable archaeological contexts using scatter plots. Metric data were compared with those reported by Liu *et al.* (10), Barham *et al.* (72), Leder *et al.* (11), Aranguren *et al.* (13), Clark (34), and Rios-Garaizar *et al.* (12) (to evaluate dimensional variability and potential morphological convergence among the pointed wooden implements). Last, the three-dimensional (3D) models of three objects (AR11-Psup-S54-1, AR24-Ra-V58-1, and AR25-Rinf) have been deposited in the CORA Research Data Repository (RDR), managed by the Consorci de Serveis Universitaris de Catalunya (CSUC), and are now associated with permanent DOI identifiers (<https://doi.org/10.34810/DATA3430>).

Supplementary Materials

This PDF file includes:

Supplementary Text
Figs. S1 to S22
Tables S1 to S4
References

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Neanderthal woodworking at Abric Romaní: Insights into the role of wood in a Middle Palaeolithic domestic context

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