



ANTHROPOLOGY

Nobody's land? The oldest evidence of early Upper Paleolithic settlements in inland Iberia

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The Iberian Peninsula is a key region for unraveling human settlement histories of Eurasia during the period spanning the decline of Neandertals and the emergence of anatomically modern humans (AMH). There is no evidence of human occupation in central Iberia after the disappearance of Neandertals ~42,000 years ago until approximately 26,000 years ago, rendering the region “nobody’s land” during the Aurignacian period. The Abrigo de la Malia provides irrefutable evidence of human settlements dating back to 36,200 to 31,760 calibrated years before the present (cal B.P.). This site also records additional levels of occupation around 32,420 to 26,260 cal B.P., suggesting repeated settlement of this territory. Our multiproxy examination identifies a change in climate trending toward colder and more arid conditions. However, this climatic deterioration does not appear to have affected AMH subsistence strategies or their capacity to inhabit this region. These findings reveal the ability of AMH groups to colonize regions hitherto considered uninhabitable, reopening the debate on early Upper Paleolithic population dynamics of southwestern Europe.

INTRODUCTION

The Iberian Peninsula is renowned for its rich Paleolithic archeological record and for being a strategic territory for European populations during the Upper Paleolithic. Despite being considered a refuge for Paleolithic genetic populations over the past 40,000 years (1), evidence points

to an uneven occupation of the Iberian territory. This has been attributed to topographic, paleoecological, and lithological factors, with the availability of caves and rock shelters being a key determinant (2–7).

Specifically, Iberia has an abundant Upper Paleolithic record, both in terms of archeological occupation levels and rock art, mainly found on the Cantabrian coast (3, 8), but also present in the Mediterranean and Atlantic coastal regions (Fig. 1, fig. S1, and dataset S1). However, evidence is sparse concerning the inland areas of the peninsula; thus, this territory has traditionally been considered unpopulated for most of the Upper Paleolithic, especially during its early phases (3, 5, 9). The central part of the Iberian Peninsula consists of two plateaus [average altitude of 650 meters above sea level (m.a.s.l.)], divided by the *Sistema Central* Mountain system. It has been suggested that these plateaus and their surrounding mountain ranges served as ecogeographic barriers for human populations during the coldest periods of the last glacial cycle, especially during the transition from the Middle to the Upper Paleolithic (6, 10). In particular, the central part of the peninsula (i.e., Central Iberia) has often been depicted as “nobody’s land” between the demise of the Neandertals in the region until the retreat of the Last Glacial Maximum around 19 thousand years (ka) ago [see discussion in (5, 10)]. There has been extensive discussion regarding the possible reasons behind the lack of occupation by anatomically modern humans (AMH) during the first few millennia of the Upper Paleolithic, with paleoclimatic and ecological factors at the center of the debate (5, 6, 11–13). However, several researchers have suggested that the traditional depiction of inland Iberia as either a desolate landscape or a mere crossing area during most of the Upper Paleolithic is not necessarily accurate and, in part, likely reflects historical preference biases of researchers toward the coastal regions of the peninsula, at the expense of the large Iberian hinterland (5, 9, 13, 14).

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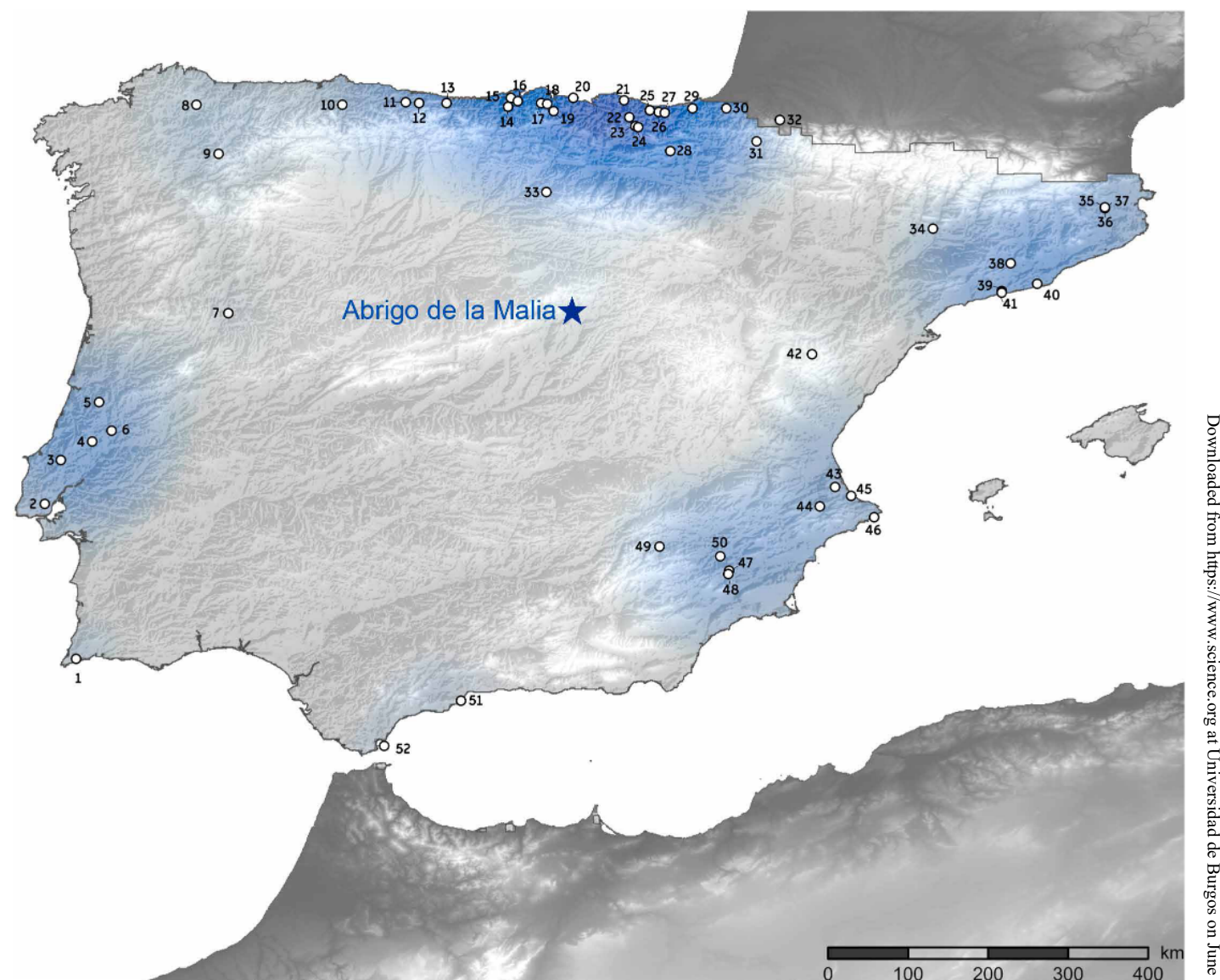


Fig. 1. Location of early Upper Paleolithic sites. Map of the Iberian Peninsula showing the location of the Abrigo de la Malia (blue star) site and a kernel density analysis of early Upper Paleolithic sites in the time range from 40 ka to 30 ka cal B.P. Note the total absence of sites in most of the Iberian hinterland, besides the data from Abrigo de la Malia. Key sites are available in fig. S1 and dataset S1.

During marine isotope stage 3 (MIS 3; 60 to 27 ka), frequent and rapid climate shifts played a crucial role in the transition from the Middle to the Upper Paleolithic in Europe (10, 15–17). Toward the end of MIS 3, a cooling trend occurred, resulting in more open landscapes and several aridity episodes, identified through various proxies in the Iberian paleontological and archeological records (18–21). These colder and drier conditions have been linked to the disappearance of Neandertals from the region around 42 ka cal B.P. (calibrated years before the present), preceding Heinrich stadial 4 (10). Because of the scarcity of archeological records from the central region of Iberia from 42 to 26 ka cal B.P., there is limited understanding of the impacts of paleoecological and paleoclimatic conditions on human populations at the regional scale. However, recent studies of loess deposits in the Tagus basin have identified variations in

environmental conditions resulting from climate changes (7, 10). The climate inferred from a hyena den site in Segovia at 34.2 ka and 40.4 ka cal B.P. (19) suggests a steppe environment in which cold-adapted species thrived in open areas. It remains unclear whether these tundra-steppe conditions hindered the establishment of permanent AMH occupations across inland Iberia.

In recent years, knowledge of population dynamics and human-environment-climate interactions in inland Iberia during the last glacial cycle has grown, supported by the latest research focused on surveying and excavating both known and previously unknown sites and territories (4, 5, 14, 18, 19, 22–26). However, even when considering the most recent data, there is still a hiatus of about 16,000 years between the last persistence of Middle Paleolithic populations in Central Iberia, currently dated to ~42 ka cal B.P. at

several sites (10), and the first appearance of the Upper Paleolithic, as recorded at the Peña Capón rock shelter at ~26 ka cal B.P. (5) and potentially at Los Enebrales rock shelter at ~27 ka cal B.P., respectively (27). Here, we present results obtained at the Abrigo de la Malia, a rock shelter located in the southeastern foothills of the *Sistema Central* range, where robust evidence of early Upper Paleolithic human occupations is reported in Central Iberia. These results fill a historic gap in the archeology of the first modern human peopling of Southwest Europe and open alternative perspectives on how our species colonized and settled challenging territories.

The Malia rock shelter

The Abrigo de la Malia site (herein Malia) is located in Tamajón (Guadalajara, Spain), central Iberia (texts S2 and S3), in the easternmost foothills of the *Sistema Central* Mountain range (Fig. 1). The site is on the boundary between the Meso- and the Supramediterranean biogeographic regions (20). The rock shelter is nestled between the Sorbe and Jarama rivers, at an altitude of 1100 m.a.s.l., half a kilometer away from the Cueva de los Torrejones (4), and a few kilometers from other Paleolithic sites such as Jarama VI (26) and Peña Capón (28). The bedrock of the Malia rock shelter site consists of marine limestone and dolostone deposited during the Upper Cretaceous (text S3) (29). These rocks are intensely karstified, giving rise to numerous caves and shelters that have been explored archeopaleontologically and speleologically for several decades (30).

The Malia rock shelter contains an Upper Pleistocene sedimentary infill record that was found in 2017 by A. Arribas during survey work conducted in the Tamajón karst area. Since then, an area of 18 m² has been excavated (texts S3 and S4) in extension. The site consists of in situ Paleolithic units with Late Prehistoric negative structures crossing through them. These negative structures have been excavated first to identify the occupations of the communities during the late prehistory and to prevent contamination or mixing of archeological elements between the different occupational phases of the rock shelter (text S3).

RESULTS

Geological and stratigraphic framework

The sedimentary sequence excavated at the Malia rock shelter currently has an average thickness of 110 cm, spanning from the mid-Holocene to the Late Pleistocene. The Malia sedimentary record can be subdivided into five lithostratigraphic units (LU-I to LU-V, from top to bottom) (Fig. 2 and texts S4 and S5).

LU-I includes all late prehistory stratigraphic units (UEs) that comprise human-made negative structures (pits and silos) and their infills, along with other deposits described in the field and represented in the Harris matrix (text S3.1). These negative structures cut through the other lithostratigraphic units, creating net contacts that are typically subvertical. The sediments are characterized by a heterogeneous composition and texture, without sorting. Some areas are clast-supported, while others are matrix-supported, characterized by a high content of organic matter. The framework elements consist of centimeter- and millimeter-sized lithoclasts of dolostone and black shale, fragments of pottery, botanical and faunal remains dominated by domestic species, and lithic industry attributed to Chalcolithic and Bronze Age (text S6).

LU-II represents a clast-supported deposit with noticeable channel morphology. It crosses vertically through LU-III and LU-IV. The

deposit contains lithic industry and faunal remains. The channel morphology is lost laterally, but the unit appears to maintain erosive contact with LU-III throughout the entire area. A total of six radiocarbon ages from this level provide evidence of mixed artifacts with different chronologies (see below; text S6). In addition, analysis of the artifacts reveals a mixture of Paleolithic tools and late prehistory ceramic fragments and lithic tools (text S10). This unit, therefore, corresponds to fluviokarstic reactivation during the Holocene, producing a mixture of previous archeological materials. LU-II is also delimited in the archeostratigraphic projections (fig. S5).

LU-III is partially eroded by LU-II and crossed through by LU-I. This unit does not outcrop throughout the entire excavated surface; rather, it extends to the northern end of the excavation area. It consists of an alternating sequence that dips slightly to the north, comprising 5- to 7-cm-thick sandy-silty facies alternating with 2- to 3-cm-thick clastic facies. Very few archeological materials have been found in this unit, only at its base and in contact with the underlying lithostratigraphic unit, and therefore, it possibly incorporates materials from the older unit. Because of the limited surface excavated to date, the archeological potential of LU-III is currently being examined with caution.

LU-IV has been excavated to the greatest extent and depth and has yielded most of the archeological remains, including lithic tools, vertebrate fossils, in situ hearths, charcoal, and iron oxides small fragments scattered in this unit. It is generally a sandy-silty unit with millimeter- to centimeter-sized black shale lithoclasts, angular lithoclasts of autochthonous dolostone ranging in size from millimeters to meters, and abundant archeological materials. The distribution of gravel elements is not uniform throughout the unit. The dolostone lithoclasts are more prominent in the basal part of the unit and are identified as collapsed blocks from the shelter roof. These collapsed fragments may have altered and deformed the initial morphology and texture of the unit (text S5 and fig. S6). There are areas with localized and discontinuous facies of millimeter- and centimeter-sized black shale clasts, which appear far from the large blocks and cut through massive sandy-silty facies.

LU-V: The basal unit is in concordant contact with LU-IV throughout the excavated area so far. This unit is primarily matrix-supported and homogeneous, composed of gravel, sand, and silt, and has a composition similar to LU-IV. In more sheltered areas of the site, there is a noticeable level change from light brown to more orange-brown sediment, while in other areas, the transition between the two levels is more gradual. This could be attributed to the continuation of collapsed blocks, especially those ranging from decimeter-to-meter size, pedogenic processes, and soil moisture loss after excavation. A substantial amount of archeological material, including lithics and bone industry, as well as the remains of ungulates and other species of fauna, has been recovered from this unit.

Chronostratigraphic framework of the Upper Paleolithic units

The geochronological framework has been established using three different dating techniques applicable to bone, charcoal, teeth, and sediments, namely, AMS radiocarbon dating (text S6), single-grain quartz optically stimulated luminescence (OSL) dating (text S7), and combined uranium series and electron spin resonance (US-ESR) dating (text S8). Bayesian modeling has been used to integrate all our chronological and stratigraphic results and derive final modeled age ranges using all of the chronological evidence available for

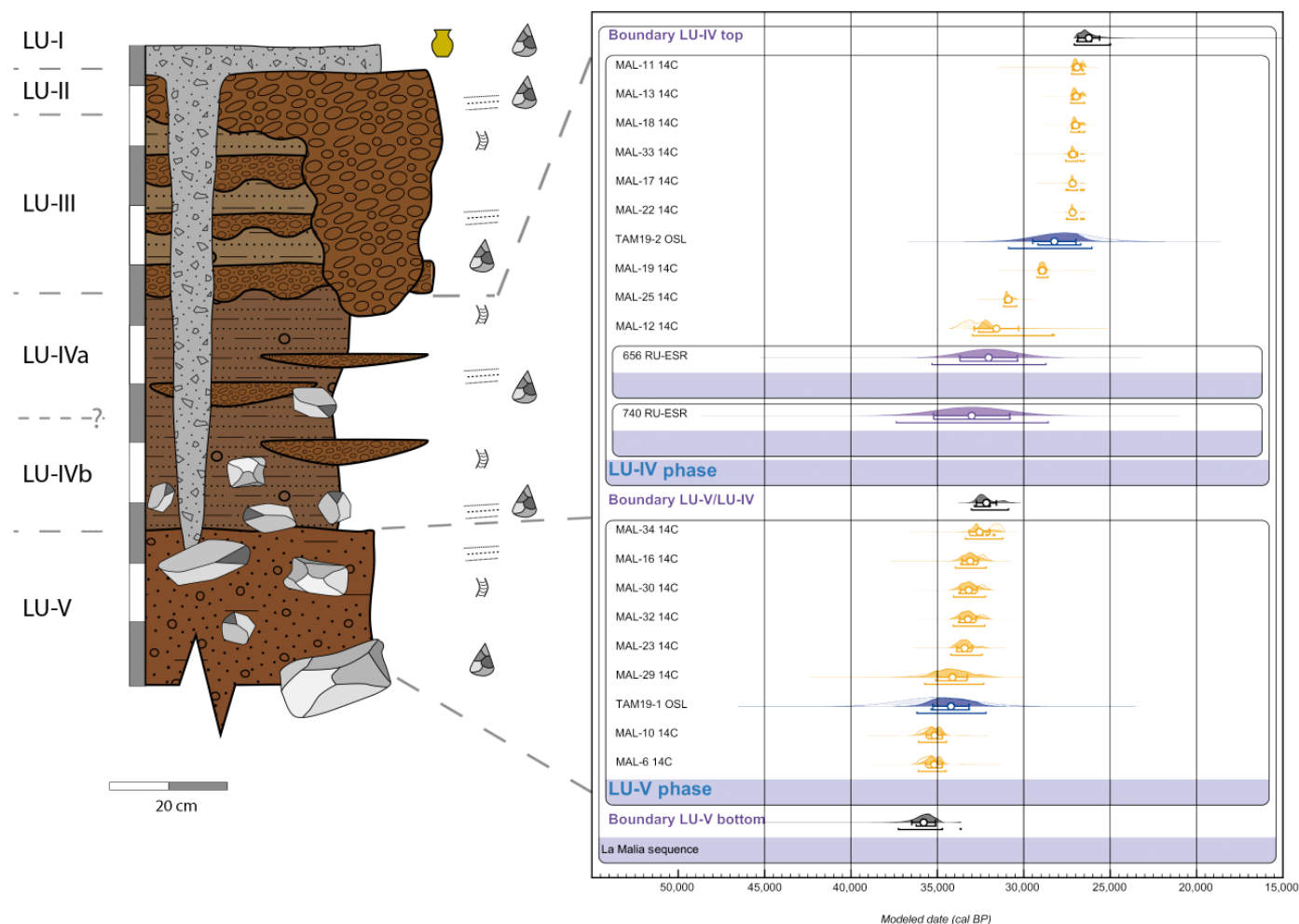


Fig. 2. Stratigraphic and chronological context of the Malia site. Stratigraphic column and Bayesian age modeling results for the Malia site. The colors used for LU-II to LU-V correspond to those of the Munsell color system for wet sediment. LU, lithostratigraphic unit. Bayesian modeling has been undertaken in OxCal v.4.4.4 (45), assuming that each likelihood has a 5% prior probability of being an outlier within a general t-type outlier model. The unmodeled age distributions for the optically stimulated luminescence (OSL; blue), electron spin resonance (ESR; green), and radiocarbon (red) dating determinations (likelihoods) are shown as light shaded color probability distribution functions (PDFs). The modeled posterior distributions for the dating determinations and stratigraphic unit boundaries are shown as dark shaded color and gray PDFs, respectively. Unmodeled and modeled ages are shown on a calendar year time scale, and both are expressed in years before AD 1950. The white circles and associated error bars represent the mean ages and 1σ uncertainty ranges of the PDFs. The 68.3 and 95.4% ranges of the highest posterior probabilities are indicated by the horizontal bars underneath the PDFs.

the most extensively excavated Paleolithic units LU-IV and LU-V (text S9).

Table S4 summarizes the environmental dose rates, single-grain D_e values, and final ages for the two OSL dating samples from LU-IV and LU-V (TAM19-1 and TAM19-2). The single-grain D_e distributions of grains that passed the single-aliquot regenerative-dose (SAR) quality assurance criteria are shown as radial plots in fig. S7. In general, the single-grain OSL D_e distributions of both samples are consistent with well-bleached, unmixed sediments [see, e.g., (31–36)]. The single-grain OSL datasets display limited D_e dispersion that is well-represented by the weighted mean value (as indicated by the large proportions of grains lying within the 2σ gray bands of the radial plots) (fig. S7), and low overdispersion values of $26 \pm 2\%$ to $27 \pm 2\%$ (table S4). These overdispersion values are consistent with (i.e., within 2σ) those typically reported for well-bleached and

undisturbed single-grain D_e datasets [see, e.g., (34, 37, 38)] and they are comparable to, albeit slightly higher than, the 2σ overdispersion range obtained in the dose recovery tests for sample TAM19-1 (13 to 25%). Both D_e datasets are considered to be normally distributed according to their weighted skewness scores (32, 39). Application of the maximum log-likelihood ($L_{\max}$) test (40) indicates that the central age model (CAM) is statistically favored over the three- or four-parameter minimum age models (MAM-3 or MAM-4) (41) for the two D_e datasets.

Collectively, these single-grain OSL D_e characteristics suggest that samples TAM19-1 and TAM19-2 do not suffer from major D_e scatter related to insufficient bleaching before burial [see, e.g., (35, 39)], syn-depositional mixing with pre-existing rock shelter deposits before burial [see, e.g., (37, 42, 43)], or widespread post-depositional sediment mixing between units [see, e.g., (44)]. We have therefore

used the weighted mean (CAM) D_e values to derive the final OSL burial dose estimates for both samples. Weighted mean OSL ages of 27.7 ± 1.7 ka and 35.1 ± 2.1 ka are obtained for LU-IV and LU-V, respectively (table S4).

Apparent U-series ages obtained for two fossil teeth from LU-IV (samples #656 and #740) range between ~15 ka and ~30 ka. Assuming that there has been no uranium leaching, these ages should be regarded as minimum age constraints for the fossils since uranium incorporation into dental tissues may be significantly delayed after the death of the organism. However, it is not possible to derive finite ages for samples #656 and #740 using the combined US-ESR age calculation, suggesting the presence of uranium leaching in some dental tissues. Sensitivity tests carried out using different uranium uptake models nevertheless provide largely indistinguishable age estimates. They vary by 4.2-ka (#656) and 7.3-ka (#740) maximum, indicating that uranium leaching has a limited impact on the calculated U-series/ESR age results (table S9). Consequently, we can reasonably conclude that the true age of the fossils from LU-IV lies somewhere between the combined mean modeled estimates of 26.8 ± 1.7 ka and 29.6 ± 0.5 ka (1σ), with maximum age constraints of 32.1 ± 1.6 ka and 33.1 ± 1.7 ka calculated for #656 and #740, respectively, using the RU (recent uptake) model. Further details regarding the robustness and reliability of the ESR and U-series analytical results are provided in text S8.

Radiocarbon ages were obtained for 28 samples from the archaeological sequence. Except for the three pieces of charcoal, all samples were tooth and bone fragments with clear traces of human manipulation in the form of cut marks or anthropogenic fractures (text S6). Of these, three correspond to LU-I, six to LU-II, one to LU-III, and the rest to Paleolithic units LU-IV and LU-V (10 and 8 samples, respectively). The LU-I radiocarbon dating samples correspond to the site's Chalcolithic and Bronze Age occupations (table S3). The scattered dating results from LU-II are consistent with the mixture of archaeological materials detected during the excavation (table S3). The individual radiocarbon ages for Paleolithic unit LU-IV range between 33,983 and 32,009 cal B.P. (MAL-12) and between 25,922 and 25,696 cal B.P. (MAL-24), while those obtained for Paleolithic unit LU-V span 36,237 to 34,662 cal B.P. (MAL-6) to 32,825 to 31,111 cal B.P. (MAL-34) (95.4% calibrated age ranges) (table S3).

Bayesian age modeling confirms the consistency of the radiocarbon, OSL, and ESR chronological dataset for Paleolithic units LU-IV and LU-V (table S10), which favors the calculation of combined modeled ages for these two units from their upper and lower boundary posterior probability distributions [using the OxCal *Date query*; (45)]. The modeled ages reveal that the LU-V human occupation of the Malia rock shelter spans 36,200 to 31,760 cal B.P. and the overlying LU-IV human occupation occurred between 32,420 and 26,260 cal B.P. (95.4% credible intervals; Fig. 2), both of which correspond to the early and middle phases of the Upper Paleolithic during late MIS 3 and early MIS 2.

Human occupation evidence

The entire lithostratigraphic sequence of the Malia site preserves evidence of human occupation, from the upper units corresponding to late prehistory (LU-I and LU-II) to the lowermost Paleolithic units (LU-III to LU-V). This is demonstrated by the abundance of lithic industry (text S10.1) and ungulate remains with marks indicating anthropogenic intervention (cut marks, intentional fracture, and bone industry) throughout the sequence (text S11). The

archeological assemblages include lithic and bone tools associated with hunting activities (assegai) (text S10).

The lithic assemblage assigned to LU-V is composed of 131 items, all of which are classified as knapping products. Sixty-four (48.8%) are complete, while 67 (52.7%) present fractures. Regarding surface alterations, whitish patinas or dehydration are recorded for 39 flint pieces (29.8% of the total assemblage and 62.9% of the flint collection), while rounding is absent and pseudo-retouches are only marginally found in some quartz pieces. Thermal alterations, including color change, potlids (oval-shaped scalar fractures), and internal cracking (interpreted as the result of fire exposure) are recorded for 10 flint artifacts (7.6%). Flint and quartz are the most common raw materials, followed by quartzite and hyaline quartz or rock crystal (table S11). Raw blanks are the most represented technological category, followed by knapping waste (*microdébitage* and chunks), decortication products (cortical flakes), cores, retouched tools, and tool maintenance by-products (table S11). No natural blocks interpreted as supplies for knapping have been recorded.

Although the recorded assemblage is scarce, the obtained results (dataset S2) strongly point to a largely fragmented operational sequence, showing that lithic products were brought into the rock shelter after the initial preparation and the first knapping of cores had been undertaken elsewhere. The exploitation stage (phase 2) of the *chaîne opératoire* is, by far, the most represented (88.6%), followed by the consumption and abandonment stage (phase 3) (5.3%) and the initialization stage (phase 1), which is only marginally represented (1.1%).

Retouched artifacts, all produced on flint, include a backed bladelet (Fig. 3.4), a blade with discontinuous retouch on one edge (Fig. 3.8), a sidescraper (Fig. 3.10), a denticulate, and a small-nosed endscraper (Fig. 3.7), the latter three configured on flake blanks. As for knapping methods, the raw blanks are dominated by flakes (83.6%), followed by bladelets (12.7%) and blades (5.1%), most of them produced on flint (62.0%), especially in the case of the laminar productions (table S12). Cores, all of which were abandoned during the advanced stages of the production phase, include a laminar prismatic core on medium-grained quartzite (Fig. 3.11), a narrow-sided bladelet core on hyaline quartz (Fig. 3.1), a carinated burin core on flint (Fig. 3.9), and two expedient flake cores on quartz and quartzite. Despite the relatively high abundance of flakes, the blade and bladelet component is significantly represented in the assemblage, as three of the five recorded cores were prepared to produce blades and bladelets and these blanks present significant variability (Fig. 3 and table S12).

Two proximal fragments of assegai points with single-bevel bases have been recovered to date in the Malia shelter. One of them is made of deer antler from the LU-IV and the other, made of bone, comes from the LU-V. Neither of the two pieces has decorations on the shaft or on the platform of the bevel (Fig. 4 and text S10).

Despite its small size, the lithic and bone tools assemblages of LU-V show distinctive techno-typological features compatible with the Aurignacian technocomplex. The relevant presence of bladelet productions, including a carinated burin core on a large flake (Fig. 3.9) and a narrow-sided bladelet core that could also be classified as a carinated burin on classic typological grounds (Fig. 3.1) (46, 47), supports an Aurignacian attribution and strongly points to the Evolved Aurignacian. Although similar bladelet cores are found throughout the Upper Paleolithic sequence of Europe, carinated pieces used to produce bladelets, including burin cores and scraper

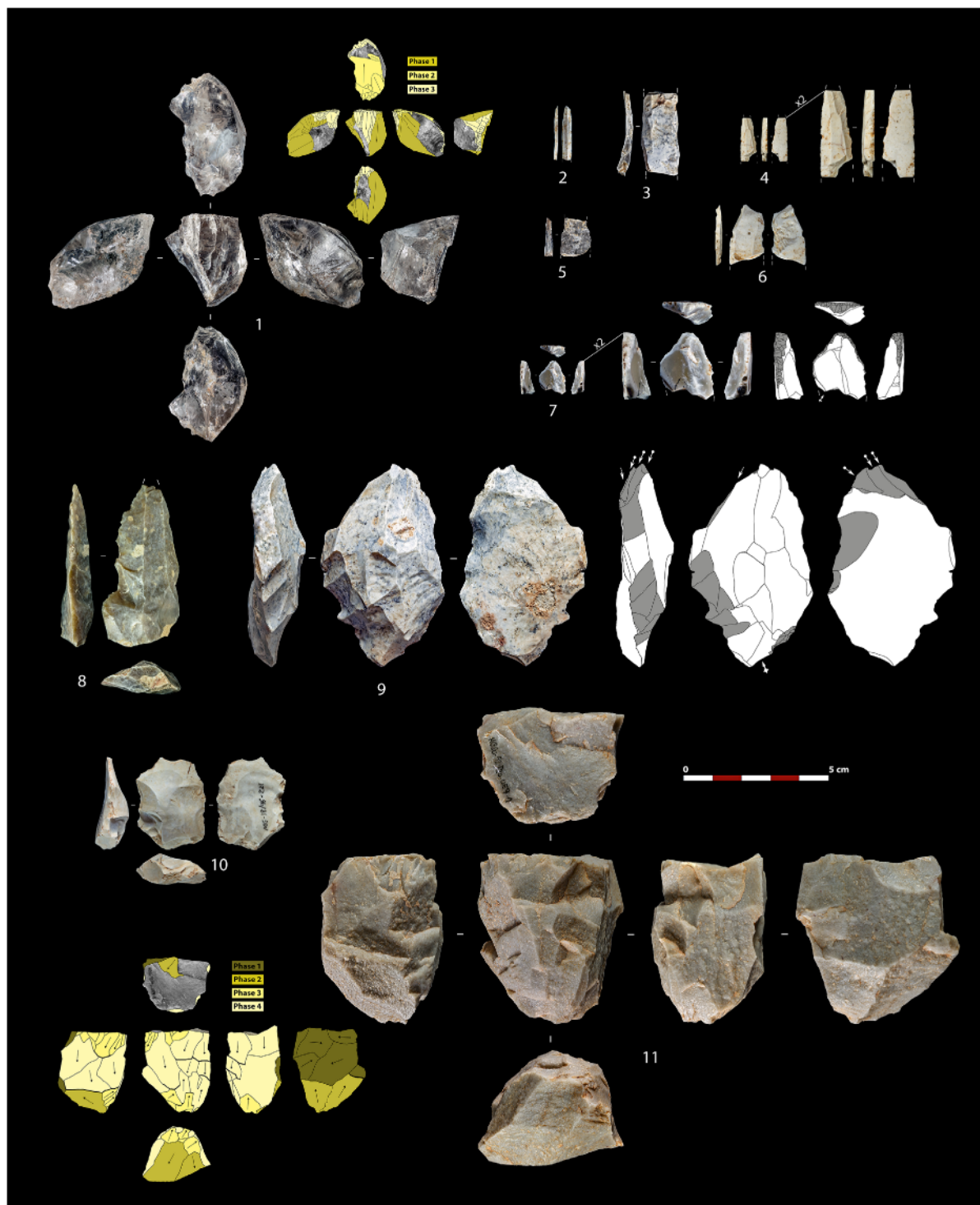


Fig. 3. Selected lithic artifacts from LU-V of La Malia rock shelter. 1: Narrow-sided bladelet core (carinated burin) on a hyaline quartz crystal (MG22/084-I19-UE9-21). 2: Flint bladelet fragment (MG22/084-J19-UE4/UE9-25). 3: Flint blade fragment (MG22/084-I19-UE9-38). 4: Flint-backed pointed bladelet (MG23/51-I19-UE9-5). 5: Hyaline quartz blade/bladelet fragment (MG22/084-I19-UE9-54). 6: Flint blade fragment showing thermal alterations (MG23/51-J19-UE9-16). 7: Small-nosed endscraper on a flint flake fragment (MG22/084-I19-UE9-83). 8: Flint blade with discontinuous retouch (MG23/51-K19-UE9-9). 9: Carinated burin core on a flint flake (MG21/21-J19-UE9-36). 10: Sidescraper on a flint flake (MG18/46-J20-UE9-221). 11: Semicircumferential (prismatic) bidirectional blade core on quartzite (MG20/52-J20-UE9-1). Diacritic drawing of core 1: Phase 1: First removals to prepare the flaking surface are produced on a prismatic hyaline quartz crystal. Phase 2: Preparation of the notable platform perpendicular to a narrow face. Phase 3: Exploitation of the flaking surface to produce bladelet blanks. Diacritic drawing of core 2: Phase 1: Preparation of the flaking surface. Phase 2: Preparation of the notable platform. Phase 3: Corniche maintenance. Phase 4: Exploitation of the flaking surface from two opposing platforms used to produce elongated blanks, including blades and laminar flakes (however, the lower removals were likely produced to clean the hinges produced from the opposite platform). Arrows indicate the direction of the removals.

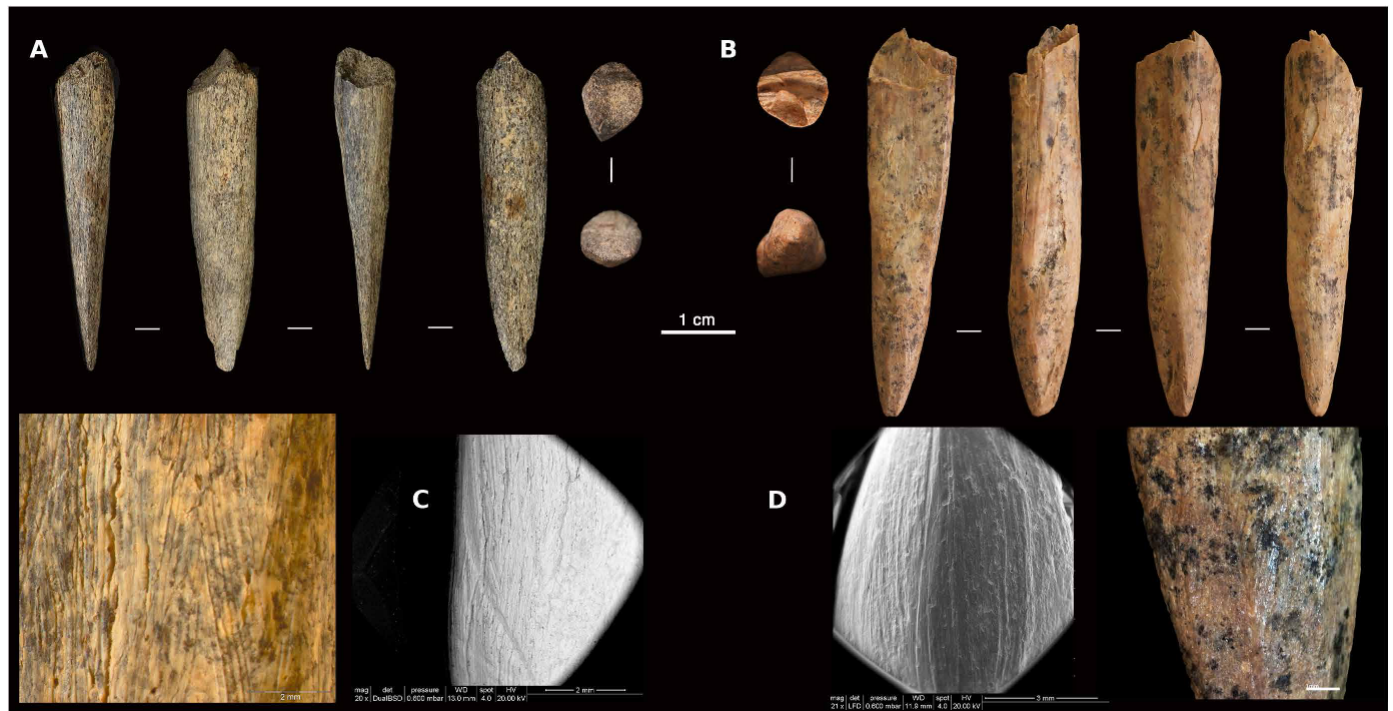


Fig. 4. Bone industry recovered from the Malia rock shelter. (A) Assegai of LU-IV made on deer antler (M20-UE4-I19-12). (B) Assegai of LU-V made on bone (M23-UE9-I21-4). (C) Scanning electron microscopy (SEM) image of the assegai made on the antler. (D) SEM image of the assegai made on bone.

cores, are widespread in Aurignacian contexts, especially during its later phases (47, 48). The presence of a nosed endscraper, despite it being small-sized and hence atypical (Fig. 3.7), provides further support for the Aurignacian attribution of LU-V. The only distinctive features of the Evolved Aurignacian absent from LU-V are steep/scaled Aurignacian retouched blades and Dufour bladelets, as the only retouched bladelet found at the site shows semi-abrupt direct retouch (Fig. 3.7)—a type which is also present in Aurignacian contexts. The existence of a single-beveled bone point in this unit is also consistent with an Evolved Aurignacian attribution (text S10.2).

In addition to the lithic tools, faunal skeletal remains found in the Paleolithic units provide insight into human activity for both the LU-V and LU-IV archaeological complexes. A detailed zooarcheological analysis of these units can be found in text S11. Both assemblages are well preserved, allowing meticulous anatomical and taxonomic identification, and a detailed examination of bone surfaces and fracture patterns. The faunal assemblages are dominated by ungulate species that represent typical human prey in Iberia during the Upper Paleolithic (*Cervus elaphus*, *Equus ferus*, Bovidae cf. *Bos primigenius*/*Bison priscus*, Caprinae, and mesovertebrates, such as Leporidae, the hares and rabbits' family). The high abundance of ungulates, particularly *C. elaphus* (red deer) and *E. ferus* (wild horses), is notable in both units. The absence of carnivorous mammal remains in the assemblage is notable. A ZooMS analysis has verified some of the initial taxonomic attributions and identified some bones classified as large-size mammals (text S14).

The two assemblages (LU-V and LU-IV) mainly exhibit traces of human activity (Fig. 5), accompanied by minor intrusions and contributions from nonhuman predators or natural processes. Anthropogenic modifications, including cut marks, breakage, and burning,

are prevalent in both units, particularly for macromammal remains (text S11). Cut marks on ungulate bones are abundant and reflect all stages of the butchery process, from skinning and evisceration to filleting. Signs of intensive defleshing and filleting and systematic breakage of bones for the extraction of marrow indicate the intensive use of the carcasses. In relation to this behavior, we have observed Artiodactyla (one from a red deer and one from Caprinae) phalanges that have been broken when they were still fresh to extract marrow. Modifications related to human activity are rounded out by the presence of thermal alterations on small remains (<4 cm), which are mainly carbonized and calcined. This is compatible with the combustion structures (hearths) present in unit LU-IV. Carnivore modification of macromammal remains affects only a very small proportion of the specimens and takes the form of tooth marks and signs of digestion (text S11). At an anatomical level, the macromammal assemblage is characterized by a high representation of fragments of long limb bone diaphyses and metapodials, which display characteristics of green and anthropogenic breakage (percussion pits, notches, and abrasions). Despite the open-air environment of the rock shelter, both the LU-IV and LU-V assemblages show minimal evidence of subaerial exposure. The absence of rounded bones in both assemblages further reinforces the lack of water-related influences. The mesovertebrate subgroup is mainly composed of complete bones. Leporids represent a high percentage of remains and elements, though taphonomic indications lead us to rule out their relationship with human occupation. Signs of nonhuman predators, including scoring and beak/talon scratching, are present on the leporid remains.

The overall taphonomic picture of LU-V and LU-IV indicates a faunal assemblage of anthropogenic origin with very minor intrusions



Fig. 5. Evidence of human occupation. Selected bones with anthropogenic marks (cut marks and intentional fractures) in bones directly dated from the Aurignacian unit LU-V. Left: Proximal phalanx of small bovid with cut marks (MAL-29; MG22/084-119-UE9-29). Right: Metatarsal of a red deer with cut marks and percussion marks (MAL-34; M22/084-K19-UE4/9-5). A more diverse selection of bones with butchery marks is available in fig. S16. Three-dimensional models of these remains can be found in datasets S3 and S4. Scale bars in millimeters.

of material accumulated/modified by nonhuman (probably small) predators, agents, and processes. The exception is the mesovertebrate remains, which must be primarily natural accumulations, supplemented by minor input from raptors and/or small mammalian carnivores. There is no evidence of use, or alternating use, of the shelter by large carnivores and humans nor of alteration of the record by the former, which is common in Early Upper Paleolithic occupations in Iberia (49). In turn, inputs in the form of mesovertebrate remains correspond to human abandonment of the site, revealing the diachrony inherent in the formation of archeological levels.

Paleoecological Inferences

A multifaceted approach has been adopted to investigate dominant climatic and ecological conditions at the Malia rock shelter, comprising micromorphological analysis, the examination of micro- and macrovertebrate faunal communities, the study of fossil pollen and charcoal remains, and the stable isotope analysis of ungulate assemblage.

Some useful paleoenvironmental information can be gleaned from isotopic analysis of the macromammal communities (text S14), particularly from the Equidae specimens, despite the small

sample size considered. No collagen $\delta^{13}\text{C}$ value is lower than -22.5% , suggesting that the herbivores were consuming C3 plants in a regular and relatively open landscape, according to Drucker *et al.* (50), outside the influence of the canopy effect (51). $\delta^{13}\text{C}$ values are consistent over time, suggesting a limited change in tree cover, climate, or atmospheric carbon in the region during late MIS 3 to early MIS 2, and a predominantly open landscape prevailed. Typically, horses selected poor-quality, low-protein, high-fiber browse, resulting in relatively depleted $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values (52) compared to red deer dietary habits. This pattern has been detected in other Paleolithic faunal assemblages in Iberia (53) and Central Europe (54, 55). Although there are limited sample sizes at the Malia site, the offset in $\delta^{13}\text{C}$ values might indicate niche partitioning of equids and cervids feeding differently.

Lithostratigraphic unit V

LU-V preserves evidence for eolian processes via the formation of loess deposits (text S5). However, the presence of large amounts of allochthonous black shales also indicates the influence of water-related processes. Considering that the most common microfacies in this unit are matrix-supported with a bimodal grain size distribution

favoring fine particles, surface runoff is interpreted as the dominant process (text S5). Occasional eolian and fluvial processes might have occurred, but they were partially reworked and disrupted by the prevailing runoff processes. These characteristics show that there were more humid periods in comparison to LU-IV, which resulted in significant water-related events.

Analysis of the microvertebrate communities from LU-V indicates the richest and most diverse small mammal fossil assemblages for the known Malia Paleolithic units (text S12). Arvicolinae rodent species from LU-V, such as the snow vole, *Chionomys nivalis*; the field, common, and pine voles *Microtus agrestis*, *Microtus arvalis*, and *Terricola pyrenaicus-gerbei*; and the Iberon or Cabrera's vole *Iberomys cabreræ*, are dwellers of humid meadows. A slight climatic deterioration from the bottom to the top of this stratigraphic unit is observed through the presence of the tundra vole (*Alexandromys oeconomicus*) in the upper part, and the decline in specimens of the Gliridae and Muridae species such as *Eliomys quercinus* and *Apodemus* respectively, both inhabitants of Mediterranean wood and shrublands.

The charcoal assemblage is dominated by thermophilus taxa, such as evergreen and deciduous *Quercus* (text S13.2, fig. S20, and table S22). These data show a general correspondence with the pollen assemblage (text S13.1, fig. S19, and table S21), for which *Quercus* is also the main taxa. Overall, unit LU-V indicates advantageous conditions were present locally 36,200 to 31,760 cal B.P., supporting increasing biodiversity, as well as a relatively mild Mediterranean climate.

Lithostratigraphic unit IV

A shift from loess-related to water-related processes, including fluvial and runoff events, is observed within LU-IV. The higher prevalence of eolian processes compared to the underlying unit indicates that aridity predominated during the formation of this unit, with occasional relatively extreme water-related events leading to the alternation of fluvial deposits. In addition, it appears that major roof collapse processes occurred throughout this level, possibly due to cryoclastic processes that intensified during cold periods (text S5).

LU-IV has fewer microvertebrate taxa, and the faunal assemblage indicates that climatic conditions were less favorable compared to LU-V. The species *A. oeconomicus* lives in wet tundra or alpine wet meadows, usually near water. Therefore, it indicates that tundra meadows and marshes were in the vicinity of the cave at the base of LU-IV. Other arvicoline rodents such as the snow vole, *Ch. nivalis*, and the Gerbe's vole or the Pyrenean pine vole, *T. pyrenaicus-gerbei*, as well as forest and shrub lands, such as the wood mouse, *Apodemus*, and the dormouse, *E. quercinus*, indicate meadows and wood/scrublands that were less rich than in the LU-V layer. Thus, alpine meadows, water bodies, and Mediterranean forests were present and located near the Malia rock shelter during the formation of both LUs. Noticeably, the Mediterranean and mild conditions, represented by the small mammal assemblages, deteriorate from the bottom to the top of the stratigraphic sequence (text S12).

This climatic trend toward colder and drier conditions is also evident in the pollen record, which is marked, above all, by a gradual loss of arboreal pollen, affecting thermomediterranean pines, in particular, toward the top of unit LU-IV and a greater presence of grasses (text S13.1), as the landscape became dominated by *Quercus*-Poaceae open woodlands. The increasing aridity and lower temperatures might also be identified in the charcoal record by the higher percentage of *Juniperus* sp. (in the base of LU-IV), while the colder

conditions are evident from the higher percentage of *Pinus* sp. *sylvestris-nigra* type (top of LU-IV) (text S13.2, figs. S19 and S20, and table S22).

DISCUSSION

All recorded evidence—stratigraphic, chronometric, techno-typological, and taphonomic—strongly supports the attribution of the LU-V archaeological assemblage to the Aurignacian techno-cultural tradition and, consequently, to AMH (56). The stratigraphic position of LU-V, located at the bottom of the sedimentary sequence recorded to date and containing Upper Paleolithic artifacts (text S10, fig. S13, and dataset S2), suggests an early Upper Paleolithic age. This is further corroborated by the coherent and significant number of chronometric ages (Fig. 2), derived from radiocarbon determinations of anthropogenic-modified bones and charcoal pieces, as well as OSL assays of the sedimentary matrix, which place this unit in the 36,200– to 31,760–cal B.P. range. For all regions of the Iberian Peninsula where archaeological assemblages from this period have been recorded, they mostly correspond to the advanced phases of the Aurignacian technocomplex, with a few cases of Early Gravettian starting about 35 ka to 33 ka cal B.P. in the Cantabrian region (8). The latest Mousterian is currently recorded between ~45 ka and 41 ka cal B.P. in the north and center of the Iberian Peninsula (10, 20), and the few cases attesting to a later persistence along the southern Mediterranean coasts and, to a lesser extent, in mid-southern Portugal, are not younger than ~37 ka cal B.P. (6). Likewise, Châtelperronian sites in Iberia are older than ~39 ka cal B.P. and are all found north of the Ebro basin (57). Concerning the Aurignacian, after its early arrival in the north by 43 ka to 42 ka cal B.P., this technocomplex was well established in the southern coastal regions of the peninsula by ~37 ka cal B.P. (6, 20, 58–61)—although earlier cases have been claimed for the sites of Bajondillo and Picareiro, these remain controversial (6, 58–65). To date, no Aurignacian contexts have been reported in central Iberia (5), and the most interior occurrence of this technocomplex is represented by the single site of Cardina-Salto do Boi (9), located at the very western fringe of the northern plateau (Fig. 1). Therefore, the presence of an Aurignacian occupation at the Malia rock shelter, right at the center of the peninsula, represents a significant discovery that changes our understanding of population dynamics in Iberia during the early Upper Paleolithic.

Malia rock shelter constitutes unequivocal evidence of the settlement of central Iberia during the early Upper Paleolithic and thus provides the oldest traces of AMH activity in the center of the Spanish plateau. More significantly, these data refute widely assumed interpretations of AMH population dynamics and initial settlement patterns of the Iberian Peninsula, as the whole Iberian hinterland has traditionally been considered a “Nobody's land” during the early and middle stages of the Upper Paleolithic due to ecological constraints (5).

The climatic and ecological conditions inferred from the small mammal assemblages, pollen, sedimentology, and stable isotope studies of the two Paleolithic units at the Malia shelter help to facilitate further understanding of MIS 3 and 2 paleoenvironments across this region. Precisely, favorable conditions in LU-V between 36 ka and 32 ka cal B.P. coincide with a period of human presence. This episode is preceded by much more severe climatic conditions in the center of the peninsula, which has been well documented at the nearby site of Portalón de Tejadilla located ~80 km away. Between 40.4 ka and 34.2 ka cal B.P., the inferred setting in the Segovian piedmont depicts an environment characterized by cold and arid conditions that enabled the establishment of steppe tundra ecosystems, predominantly inhabited by species adapted

to open landscapes but also including cold-adapted species such as the woolly rhinoceros and giant deer (19). These conditions contrast with those detected in the Malia rock shelter LU-V, whose conditions were undoubtedly less severe. Following a short period of more temperate and humid conditions within the Malia rock shelter sequence, a gradual cooling between 32 ka and 25 ka cal B.P. is detected in LU-IV, compatible with late MIS 3 peninsular records marking a trend toward cooler conditions, more open landscapes, and episodes of enhanced aridity (20). Wolf *et al.* (7) demonstrated a strong correlation between the sedimentation phases of loess deposited in the Tagus basin and North Atlantic marine dynamics. Specifically, a correlation is observed between the most intense Greenland stadials and Heinrich events. At Malia rock shelter, an increase in loess deposits is similarly detected in LU-IV compared to LU-V, correlating with loess deposit sediment unit 7 identified between 31.7 ± 2.6 ka and 28.4 ± 2.4 ka. Wolf *et al.* (7) suggested that the relationship between the most intense marine cold phases and the formation of loess in the Iberian interior during MIS 4, MIS 3, and MIS 2 was due to severe environmental aridity caused by a substantial decrease in the sea surface temperature of the North Atlantic compared to the Iberian margin, in turn reducing the transfer of moisture to the interior. This gradual increase in aridity led to a decrease in vegetation cover, together with stronger winds caused by greater temperature and pressure gradients, favoring an increase in wind dynamics and loess formation (7).

The directly dated cut-marked bones of ungulates indicate the presence of AMHs in inland Iberia during the early and mid-Upper Paleolithic. The paleoecological inferences suggest that human populations occupied Malia when climatic and ecological conditions were not particularly severe in terms of aridity and temperature. The change of these paleoclimatic conditions, marked by increased aridity, did not prevent human populations from reoccupying the territory maintaining similar subsistence strategies based on the hunting of red deer and horses. Malia LU-IV shows that these human populations occasionally, but recurrently, inhabited this area, probably during periods with the most available resources, and despite facing abrupt climate changes during MIS 3 and MIS 2, as also recorded at the nearby site of Peña Capón from at least ~ 26 ka cal B.P. (5). Notwithstanding the lack of sites with evidence of human occupation in the central Iberia region between 40 ka and 27 ka cal B.P., the Castilian plateau does not appear to have been an ecogeographic barrier for *Homo sapiens*, at least not at specific times, as evidenced by the Malia rock shelter record. Therefore, population dynamics models proposed for this period, depicting an absence of human populations in the peninsular interior, should be revised in light of the Malia findings. These discoveries demonstrate that, when thoroughly investigated, the archeological record left by modern humans of the Upper Paleolithic in inland Iberia has still much to tell us.

MATERIALS AND METHODS

Given the number and variety of techniques and disciplines used in this study, the materials and methods of each one of them are described in the corresponding section of the Supplementary Materials.

Supplementary Materials

This PDF file includes:

Supplementary Text

Figs. S1 to S21

Tables S1 to S25

Legends for datasets S1 to S4

References

Other Supplementary Material for this manuscript includes the following:

Datasets S1 to S4

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Acknowledgments: We are indebted to A. Gómez-Olivencia, D. Rodríguez-Iglesias, L. Martín Francés, M.J. de Miguel, M.J. Alonso Escarza, A. Churrua Clemente, C. García Rodríguez, G.E. Abismo (especially R. Coronado), and G. Ross. We thank M. Carmen and F. Moñeco for contribution during the excavation. The Ayuntamiento de Tamajón was particularly helpful in logistical, financial, and bureaucratic issues, especially E. Esteban de la Morena. We thank all the administrative and technical staff of the CENIEH laboratories. L. Ames reviewed the manuscript. **Funding:** This work was supported by Junta de Comunidades de Castilla la Mancha annual projects SBPLY/23/180801/000041; Centro Nacional de Investigación sobre la Evolución Humana (CENIEH); European Research Council (ERC) under the European Union's

Horizon 2020 Research and Innovation Programme: DEATHREVL (no. 949330 to N.S., A.P.-P., E.T., M.R.-A., and C.C.-S.), MULTIPALEOIBERIA (no. 805478 to M.A.-C., S.C., and L.L.), and SUBSILIENCE (no. 881299 to A.B.M.-A.); Ministerio de Ciencia e Innovación PID2021-122355NB-C31 and PID2021-122355NB-C33 funded by MCIN/AEI/10.13039/501100011033/FEDER, UE (to N.S., M.R.-A., A.P.-P., and A.P.); Ramón y Cajal grants funded by the Fondo Social Europeo and Agencia Estatal de Investigación, MCIN/AEI/ 10.13039/501100011033 and by 'FSE Investing in your future' RYC2020-029656-I (to N.S.), RYC2019-026697-I (to M.C.), RYC2018-025221-I (to M.Du.), and RYC2022-037802-I (to A.R.-H.); Junta de Andalucía EMERGIA20_00403 (to A.P.); Australian research Council (ARC) Future Fellowship Project FT200100816 (to L.J.A. and M.De.); and Discovery Early Career Researcher Award DE160100743 (to M.De.). The dating work is part of Grant PID2021-123092NB-C22 funded by MCIN/AEI/ 10.13039/501100011033/"ERDF A way of making Europe." This work was also supported by the Palarq Foundation "Abrigo de la Malia – Escenarios Ecológicos para la Evolución y Biogeografía de *Homo* en el interior peninsular mediante el análisis polínico de los sedimentos" – Tamajón, Guadalajara (to J.O. and J.S.C.). **Author contributions:** Conceptualization: N.S. and A.P. Investigation: N.S., M.A.-C., M.Arr., V.M.-P., A.P.-P., A.R.-H., E.T., M.C., S.C., L.J.A., M.De., M.Du., A.A.-B., J.L., J.O., G.C.-B., A.B.M.-A., and M.M.S. Fieldwork: N.S., M.A.-C., M.Arr., V.M.-P., A.P.-P., A.R.-H., E.T., M.C., S.C., J.L., C.A.-L., M.Arl., M.R.-A., B.I., F.C., and A.P. Writing—original draft: N.S., M.A.-C., M.Arr., V.M.-P., A.P.-P., A.R.-H., E.T., M.C., S.C., L.J.A., M.De., M.Du., A.A.-B., J.L., J.O., G.C.-B., A.B.M.-A., M.M.S., and L.L. Writing—review and editing: All authors have reviewed the final manuscript. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials.

Submitted 30 January 2024

Accepted 17 May 2024

Published 26 June 2024

10.1126/sciadv.ado3807