

# *Initial Upper Paleolithic bone technology and personal ornaments at Bacho Kiro Cave (Bulgaria)*

Article

Accepted Version

Creative Commons: Attribution-Noncommercial-No Derivative Works 4.0

Martisius, N. L., Spasov, R., Smith, G. M. ORCID: <https://orcid.org/0000-0001-7155-5140>, Endarova, E., Sinet-Mathiot, V., Welker, F., Aldeias, V., Horta, P., Marreiros, J., Rezek, Z., McPherron, S. P., Sirakov, N., Sirakova, S., Tsanova, T. and Hublin, J.-J. (2022) Initial Upper Paleolithic bone technology and personal ornaments at Bacho Kiro Cave (Bulgaria). *Journal of Human Evolution*, 167. 103198. ISSN 0047-2484 doi: 10.1016/j.jhevol.2022.103198 Available at <https://centaur.reading.ac.uk/117102/>

It is advisable to refer to the publisher's version if you intend to cite from the work. See [Guidance on citing](#).

To link to this article DOI: <http://dx.doi.org/10.1016/j.jhevol.2022.103198>

Publisher: 1095-8606

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the [End User Agreement](#).

[www.reading.ac.uk/centaur](http://www.reading.ac.uk/centaur)

## **CentAUR**

Central Archive at the University of Reading

Reading's research outputs online

# Initial Upper Paleolithic bone technology and personal ornaments at Bacho Kiro Cave (Bulgaria)

Naomi L. Martisius <sup>a,b,c,\*</sup>, Rosen Spasov <sup>d</sup>, Geoff M. Smith <sup>b,e</sup>, Elena Endarova <sup>d,f</sup>, Virginie Sinet-Mathiot <sup>b</sup>, Frido Welker <sup>g</sup>, Vera Aldeias <sup>h</sup>, Pedro Horta <sup>h</sup>, João Marreiros <sup>i,h</sup>, Zeljko Rezek <sup>b,j</sup>, Shannon P. McPherron <sup>b</sup>, Nikolay Sirakov <sup>k</sup>, Svoboda Sirakova <sup>k</sup>, Tsenka Tsanova <sup>b,l</sup>, Jean-Jacques Hublin <sup>b,m</sup>

<sup>a</sup> *Department of Anthropology, The University of Tulsa, 800 South Tucker Drive, 74104, Tulsa, OK, USA*

<sup>b</sup> *Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Deutscher Platz 6, 04103, Leipzig, Germany*

<sup>c</sup> *Department of Anthropology, University of California, Davis, One Shields Ave., 95616, Davis, CA, USA*

<sup>d</sup> *Archaeology Department, New Bulgarian University, 21 Montevideo Str., 1618 Sofia, Bulgaria*

<sup>e</sup> *School of Anthropology and Conservation, University of Kent, Canterbury, CT2 7NR, UK*

<sup>f</sup> *National Museum of History, 16 Vitoshko lale Str., 1618 Sofia, Bulgaria*

<sup>g</sup> *Section for Evolutionary Genomics, GLOBE Institute, University of Copenhagen, Øster Voldgade 5-7, 1350, Copenhagen, Denmark*

<sup>h</sup> *Interdisciplinary Centre for Archaeology and the Evolution of Human Behaviour, Universidade do Algarve, FCHS, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal*

<sup>i</sup> *TraCER, Laboratory for Traceology and Controlled Experiments at MONREPOS Archaeological Research Centre and Museum for Human Behavioural Evolution, RGZM, Schloss Monrepos, 56567, Neuwied, Germany*

<sup>j</sup> *University of Pennsylvania Museum of Archaeology and Anthropology, University of Pennsylvania, Philadelphia, 3260 South Street, 19104, Philadelphia, PA, USA*

<sup>k</sup> *National Institute of Archaeology with Museum, Bulgarian Academy of Sciences, 2 Saborna Str., 1000 Sofia, Bulgaria*

<sup>l</sup> *Paleoanthropology, Institute for Archaeological Sciences and Senckenberg Center for Human Evolution and Paleoenvironments, Eberhard Karls University of Tübingen, Rümelinstraße 23, 72070, Tübingen, Germany*

<sup>m</sup> *Collège de France, 11, place Marcelin Bertholot, 75231, Paris Cedex 05, France*

**\*Corresponding author.**

*Email-address: naomi-martisius@utulsa.edu (N. Martisius).*



Initial Upper Paleolithic bone technology and personal ornaments at Bacho Kiro Cave (Bulgaria)

### Abstract

The expansion of *Homo sapiens* and our interaction with local environments, including the replacement or absorption of local populations, is a key component in understanding the evolution of our species. Of special interest are artifacts made from hard animal tissues from layers at Bacho Kiro Cave (Bulgaria) that have been attributed to the Initial Upper Paleolithic. The Initial Upper Paleolithic is characterized by Levallois-like blade technologies that can co-occur with bone tools and ornaments and likely represents the dispersal of *Homo sapiens* into several regions throughout Eurasia starting by 45 ka or possibly earlier. Osseous artifacts from the Initial Upper Paleolithic are important components of this record and have the potential to contribute to our understanding of group interactions and population movements. Here, we present a zooarchaeological, technological, and functional analysis of the diverse and sizable osseous artifact collection from Bacho Kiro Cave. Animal raw material sources are consistent with taxa found within the faunal assemblage including cervids, large bovids, and cave bear. A variety of bone tool morphologies, both formal and informal, indicate a diverse technological approach for conducting various on-site activities, many of which were focused on the processing of animal skins, likely for cold weather clothing. Technological flexibility is also evident in the manufacture of personal ornaments, which were made primarily from carnivore teeth, especially cave bear, though herbivore teeth and small beads are also represented. The osseous artifacts from Bacho Kiro Cave provide a series of insights into the bone technology and indirectly on the social aspects of these humans in southeast Europe, and when placed within the broader Initial Upper Paleolithic context, both regional and shared behaviors are evident

indicating widespread innovation and complexity. This is especially significant given the location and chronology of the site in the context of *Homo sapiens* dispersals.

**Keywords:** Southeast Europe; Late Pleistocene; *Homo sapiens*; tooth pendants; osseous artifacts; use-wear

## 1. Introduction

### 1.1. Background

The Eurasian archaeological record shows a shift from Middle Paleolithic (MP) to Upper Paleolithic (UP) stone tool technologies that varies regionally in its details (Bar-Yosef, 2002; Mellars, 2005; Teyssandier, 2008; Zilhão, 2013; Hublin, 2015; Slimak et al., 2022). Generally, however, lithic production shifted from Levallois and other techniques to those primarily based on (volumetric) blade extraction. At the same time, osseous technologies, objects created from hard animal tissues like bone, antler, or ivory, became more abundant and varied in the types manufactured and materials used. This proliferation in the exploitation of animal-derived raw materials stands in contrast to the typical informal bone artifacts most often reported from MP or earlier contexts (e.g., Vincent, 1993; Radmilli and Boschian, 1996; Mania and Mania, 2005; Hardy et al., 2014; Julien et al., 2015). During the so-called MP–UP transition period, a variety of new technologies or adaptations to previous technologies became widespread across Eurasia. Some of these, such as those of the Châtelperronian in western Europe, were arguably produced by Neanderthals (Welker et al., 2016), while other distinct technological features designated as Initial Upper Paleolithic (IUP) are thought to represent a series of dispersal events by *Homo sapiens*, albeit not excluding potential technological convergence in certain regions (Kuhn and

Zwyns, 2014; Hublin, 2015; Zwyns et al., 2019). The varied assemblages of this period often share certain features such as formal bone tools, but also pendants and beads made from a variety of materials including animal teeth or shells, usually reflecting the respective local resources (Stiner, 2014). These are regularly interpreted to be ornaments used for signaling or identifying group affiliation and reflecting social challenges related to growing populations and broadening social networks (Gamble, 1998; Kuhn, 2014), processes that were likely at play when *Homo sapiens* and other local populations such as Neanderthals inhabited the same regions. However, our understanding of the relation and interactions of these groups and the technological and sociocultural developments of our species is currently at a coarse scale of resolution. This is mainly due to the current state of research of the IUP record, which is very much in its incipient stage. Studying the archaeological material from newly excavated and well-preserved deposits, such as those in Bacho Kiro Cave, therefore, will provide critical data for understanding these processes during the IUP, particularly in southeast Europe.

Even though the IUP has been defined based on stone tools, bone tools and ornaments are a common feature of IUP deposits when organic preservation conditions are good (Newcomer, 1974; Newcomer and Watson, 1984; Derevianko and Rybin, 2003; Kuhn et al., 2009; Kuhn and Zwyns, 2014; Hublin et al., 2020; Shunkov et al., 2020). Early occurrences of the IUP are found in southwest Asia starting from around 50 ka (Marks and Volkman, 1983; Boaretto et al., 2021), and then spread into regions such as central and north Asia and in Europe by roughly 48–45 ka or perhaps earlier (Richter et al., 2009; Kuhn and Zwyns, 2014; Zwyns et al., 2019; Slimak et al., 2022). To address questions about interregional group interactions and population movements, studies of the IUP should include discussions on the production and use of bone tools and ornaments, which are all too often left out of the conversation (Kuhn, 2019). Several sites in

southwest Asia and southeast Europe have the potential to bring osseous artifacts into the discussion. Notably, Ksâr 'Akil in Lebanon and Üçağızlı Cave I in Turkey have been intensively investigated and have preserved both bone tools and a great number of marine shell ornaments (Newcomer, 1974; Newcomer and Watson, 1984; Kuhn et al., 2009; Bosch et al., 2019). In the southeast European Balkans, three sites in Bulgaria, Bacho Kiro Cave and the caves of Temnata and Kozarnika, also have bone tools, personal ornaments, and a number of other osseous artifacts in deposits that correspond chronostratigraphically to the IUP (Guadelli et al., 2005; Tsanova, 2008; Fewlass et al., 2020; Hublin et al., 2020; Tsanova et al., 2021).

Osseous artifacts found within IUP sites are generally formal tools, made with techniques specific to working hard animal tissues such as scraping, grinding, and grooving (Mellars, 1973; Klein, 2009; d'Errico et al., 2012), though informal bone artifacts are also found in some deposits (Kozlikin et al., 2020). Similar informal or expedient bone tools including knapped bones have been documented from African Early Stone Age sites as well as in later Eurasian assemblages (e.g., Vincent, 1993; Radmilli and Boschian, 1996; Mania and Mania, 2005; Daujeard et al., 2014; Julien et al., 2015; Zutovski and Barkai, 2016; Pante et al., 2020; Sano et al., 2020; Villa et al., 2021). While formal bone tools are sometimes recognized within later MP deposits (Gaudzinski, 1999; Soressi et al., 2013; Stepanchuk et al., 2017), formal bone working appears to have a deeper history in Africa beginning from around 120–90 ka in northwest Africa (El Hajraoui and Debénath, 2012; Jacobs et al., 2012; Bouzouggar et al., 2018; Hallett et al., 2021) and shortly after in other regions (Yellen et al., 1995; d'Errico and Henshilwood, 2007; d'Errico et al., 2012). After 50 ka, formal bone tool working is more frequently recognized in various regions outside of Africa, such as within the IUP deposits of southeastern Europe and central and north Asia, and later in other UP contexts (Newcomer, 1974; Kozłowski, 1982; Derevianko and

Rybin, 2003; Kuhn et al., 2009; Guadelli, 2011; Hublin, 2015; Zwyns and Lbova, 2019; Hublin et al., 2020; Shunkov et al., 2020; Lbova, 2021).

The earliest known potential personal ornaments are naturally perforated and potentially modified shells of gastropods and bivalves found in deposits dated to Marine Isotope Stages 5 and 6 in north Africa and southwest Asia (Bouzouggar et al., 2007; d'Errico et al., 2009; Dibble et al., 2012; Steele et al., 2019; Bar-Yosef Mayer et al., 2020; Schasseh et al., 2021). Similar marine shell ornaments, including those that are clearly anthropogenically perforated, later become more ubiquitous in various parts of Africa (Steele et al., 2019). Around 45 ka, southwest Asian IUP populations utilized a great number of both anthropogenically and naturally perforated marine gastropod shells as beads (Kuhn et al., 2009; Stiner et al., 2013; Stiner, 2014; Bosch et al., 2019), while those from other regions used ornaments made from a wider variety of materials. In central and northern Asia, IUP assemblages contain beads and pendants made from soft stone, bone, teeth, ostrich eggshell, and ivory (Derevianko and Rybin, 2003; Shunkov et al., 2020; Lbova, 2021), while assemblages from about the same time in southeast Europe similarly include a combination of diverse beads and animal teeth pendants (Guadelli, 2011; Hublin et al., 2020). Similar artifacts made from various local raw materials are found across Eurasia in subsequent time periods (Vanhaeren and d'Errico, 2006; Stiner, 2014; Lbova, 2021).

The assemblage of osseous artifacts preserved within the IUP deposits of Bacho Kiro Cave is among the earliest known at the onset of the European UP and includes a wide variety of artifact types, both formal and informal bone tools, animal teeth pendants, and beads (Kozłowski, 1982; Guadelli, 2011; Hublin et al., 2020). Characterizing the technologies that these humans were using will provide a baseline for understanding behaviors that may have been brought to Europe from other regions, as well as emergent behaviors from local social interactions adapted to

specific materials found in the local environment. Understanding the production and use of these artifacts contextualizes other IUP bone tools and ornaments in Europe and in nearby regions (e.g., Newcomer, 1974; Derevianko and Rybin, 2003; Kuhn et al., 2009; Lbova, 2010; Guadelli, 2011; Shunkov et al., 2020).

## *1.2. Archaeological context*

Situated in northcentral Bulgaria, Bacho Kiro Cave is part of a large karst system several kilometers in length comprising a complex labyrinth of galleries and corridors (Fig. 1). In 1938, R. Popov (Bulgarian Academy of Sciences) and D. Garrod (American School of Prehistoric Research) conducted one of the first excavations at the cave (Garrod et al., 1939) followed by J.K. Kozłowski and B. Ginter in 1971–1976 (Kozłowski, 1982). New excavations beginning in 2015 by the National Archaeological Institute with Museum of the Bulgarian Academy of Sciences in Sofia and the Max Planck Institute for Evolutionary Anthropology focused on two areas in the cave adjacent to the 1970s excavation (Main Sector and Niche 1; Fig. 1). The archaeological sequence in the Main Sector confirms the previously reported stratigraphy (Ginter and Kozłowski, 1982), while the Niche 1 only preserves the lower part of the sequence including MP and significant IUP deposits (Fig. 1).

The lithic assemblages from Layers 11 and 11a of the previous excavations, known originally as the Bachokirian, were considered to be the earliest appearance of the UP in Europe based on the presence of blade technology and retouched tools typical for the subsequent Aurignacian (Kozłowski, 1982; Kozłowski and Otte, 2000). Re-examination of the Layer 11 lithic assemblage showed characteristics that differ from the Aurignacian and are more consistent with the variability of transition period assemblages from central Europe and southwest Asia (Tsanova

and Bordes, 2003; Teyssandier, 2008; Tsanova, 2008). This assemblage is characterized by imported fine-grained raw material, Levallois-derived blade technology, and the production of generally elongated and convergent blanks. Tools are mostly UP-types, but the material also includes retouched forms typical for the MP such as sidescrapers, small Levallois flakes, and portions of robust retouched points reminiscent of MP Mousterian points (Tsanova, 2008). The lithic assemblages from the previous and recent excavations are highly fragmented and exhibit intense reduction of the blanks and tools by bipolar knapping (on anvil; Tsanova, 2008; Hublin et al., 2020).

The new stratigraphic nomenclature is used here where Layer 11 from previous excavations corresponds to Layer I from the new excavations, and Layer 11a similarly corresponds to Layer J. The IUP Layer I is the richest in lithic and faunal remains of all layers and represents the densest anthropogenic input at the site (Smith et al., 2021). Layer I is easily recognizable by its dark color (Fig. 1c) that resulted from a large portion of organic remains including charcoal and burned bone (Hublin et al., 2020). While the upper portion of Layer J within the Niche 1 deposits contains lithic artifacts that are techno-typologically consistent with those in the overlying Layer I, the bottom portion of Layer J preserves artifacts that are more similar to the underlying MP Layer K, making the precise start of the IUP occupations unclear. Nonetheless, human remains found within Layers I and J in both sectors of the site associate the deposits with *Homo sapiens* of recent Neanderthal ancestry (Hublin et al., 2020; Hajdinjak et al., 2021). A new high-precision radiocarbon chronology from the recent excavations, using IntCal20 (Reimer et al., 2020) in OxCal v.4.4 (Ramsey, 2009) places the start of the upper part of Layer J from around 45,990 cal BP and Layer I into the period from 45,040 to 43,280 cal BP (Fewlass et al., 2020; Smith et al., 2021).

The Layers I and J faunal record at Bacho Kiro Cave includes a diversity of taxa characteristic of Marine Isotope Stage 3 within southeast Europe (Guérin, 1982; van der Made, 2018; Hublin et al., 2020). The assemblage has a high percentage of taxa identified to species with major taxa including large bovids (*Bos primigenius* or *Bison priscus*), cervids (especially *Cervus elaphus*), and cave bear (*Ursus spelaeus*; Smith et al., 2021). Other herbivore taxa are also present including caprines (especially *Capra ibex*) and equids (*Equus ferus* and *Equus hydruntinus*), and carnivores such as canids (*Canis lupus*, *Cuon alpinus*, *Vulpes vulpes*), felids (*Panthera leo spelaea*, *Panthera pardus*), and cave hyaena (*Crocota crocuta spelaea*). Layers I and J also contain species from the *Mammuthus-Coelodonta* Faunal Complex including woolly mammoth (*Mammuthus primigenius*), giant deer (*Megaloceros giganteus*), and reindeer (*Rangifer tarandus*). This distribution of species suggests a mix of cold and temperate environments during the IUP occupations (Hublin et al., 2020; Smith et al., 2021).

The fauna from the IUP layers is remarkably well-preserved with minimal weathering and surface abrasion resulting in a high degree of bone surface readability that permits the identification of both human and carnivore bone surface modifications (Smith et al., 2021). Despite a significant number of carnivore remains, especially those of cave bear, carnivore modifications on the bone surfaces are minimal, especially within Layer I. Anthropogenic surface modifications including cutmarks and impact fractures are found on both herbivores and carnivores, which suggests that both taxa were processed for subsistence purposes, though cutmarks on cave bear foot bones and crania suggest they may have been specifically targeted for their pelts (Smith et al., 2021). In addition, a large number of osseous materials preserve modifications indicative of their use as tools or for other purposes. Here, we describe and characterize the osseous artifacts from the recent excavations (Hublin et al., 2020), which adds to



the collection of similar artifacts previously found in the cave (Kozłowski, 1982; Guadelli, 2011).

## **2. Materials and methods**

All finds larger than 2.0 cm from the recent excavations at Bacho Kiro Cave were piece-provenienced and all sediments were wet-sieved through 6- and 1.2-mm meshes. See Hublin et al. (2020) for more information on the excavation methods. We assessed all faunal specimens for anthropogenic modifications recovered thus far (temporally curated at the National Museum of Natural History in Sofia), both piece-plotted ( $> 2.0$  cm) and those found in the screened materials from Layers I and J and their contact zones. Some of the artifacts presented here are assigned to Layers H/I or I/J, because they were found at the layer boundaries and could not reliably be placed in either of the relevant layers. We set aside over 200 potential osseous artifacts from Layers H/I, I, I/J, and J for more detailed analyses, which included an examination for baseline preservation state (Behrensmeyer, 1978), burning (Stiner et al., 1995), anthropogenic and natural traces (Binford, 1981; Shipman and Rose, 1988; Bonnicksen and Sorg, 1989; Hannus et al., 1993; Fisher, 1995; Blumenschine et al., 1996; Backwell and d'Errico, 2001; Villa and d'Errico, 2001; Backwell and d'Errico, 2004; Fernandez-Jalvo and Andrews, 2016), and fracture patterns (Villa and Mahieu, 1991) of the faunal remains (Smith et al., 2021).

We assessed the raw material of the osseous artifacts through traditional zooarchaeological methods. Whenever possible, we recorded each bone specimen to species, skeletal element, and bone portion, and assigned specimens not identifiable to species to a body size class. We assessed a small subset of the available morphologically unidentifiable assemblage ( $n = 24$ ), mostly ornaments or formally modified tools, for species determination using previously

described non-destructive zooarchaeology by mass spectrometry (ZooMS) methods (McGrath et al., 2019; Martisius et al., 2020a). See Hublin et al. (2020) and Fewlass et al. (2020) for additional details on the ZooMS screening at Bacho Kiro Cave. Specimens were either stored in separate plastic curation boxes, suspended between two flexible polyurethane membranes (membrane boxes), or in plastic storage bags (Supplementary Online Material [SOM] Table S1) most often for several months prior to sampling. Each box or bag had not been used to store other specimens prior to those in the current study. We removed each specimen from their storage container before sampling. We heated a 50 mM ammonium bicarbonate solution ( $\text{NH}_3\text{CO}_3$ , AmBic; 200  $\mu\text{l}$  for bag sampling and 1 ml for membrane box sampling) to 65°C for one hour and dragged it across the plastic polymer surfaces with a standard pipette to catch any microparticles and/or collagen molecules adhering to the surfaces. For easier access, we used sterilized scissors to cut the plastic bags in half. We processed each sample following standard ZooMS protocols (Welker et al., 2016; Buckley et al., 2009). Briefly, we heated each sample incubated in the AmBic buffer for one hour at 65°C and added 1  $\mu\text{l}$  of trypsin (0.5  $\mu\text{g}/\mu\text{l}$ , Promega) for overnight digestion at 37°C. Next, we acidified each sample using 10% TFA and cleaned them on C18 ZipTips (Thermo Scientific). We spotted the eluted peptides in triplicate on a MALDI Bruker plate with the addition of a matrix solution (CHCA). Finally, we conducted MALDI-TOF MS analysis at the IZI Fraunhofer in Leipzig (Germany) and identified spectra in comparison to a database containing peptide marker masses for all known medium- to large-sized mammalian genera in Europe during the Pleistocene (Welker et al., 2016). To assess any potential contamination by non-endogenous peptides, we performed laboratory blanks alongside the artifact samples. These remained empty of collagenous peptides excluding the possibility of modern laboratory or storage contamination.

For all potential osseous artifacts, we used digital calipers to generate morphometric data including, when possible, length, width, and thickness metrics of the artifacts and ornament perforations (to the nearest 0.1 mm). We compared common morphologies with established osseous artifact types from prehistoric contexts and assigned typologies (e.g., Camps-Fabrer et al., 1990; Camps-Fabrer and Barge-Mahieu, 1991; Knecht, 1993; d'Errico et al., 2003; d'Errico and Henshilwood, 2007; d'Errico et al., 2012; Tartar, 2012; Baumann et al., 2020). Typological classification of formal osseous artifacts is based on the morphology of the distal or working end of the objects and their cross-sectional shape. Classification of the informal tools is dependent on either the type of damage or alterations to the tools due to use or intentional shaping of the tool from knapping. The large variety of informal tools along with their tendency to have been used for multiple purposes meant that typological classification was arbitrary in some cases. Given the diversity of morphologies and raw material animal sources used for the pendants, we developed a typological classification based on taxa, tooth type, and modifications to the tooth root. First, we separated teeth by taxa, noting any differences in their modifications. We further separated the pendants by tooth type followed by manufacturing technique used. Five manufacturing methods and/or stages during the process served as the basis for the main pendant classification types.

We employed traditional functional analyses (Newcomer, 1974; d'Errico et al., 1984; Olsen, 1984; Bergman, 1987; Shipman and Rose, 1988; Campana, 1989; Sidéra, 1993; Christidou, 1999; Choyke et al., 2001; Backwell and d'Errico, 2005; Legrand, 2007; Falci et al., 2019; Haddow et al., 2019; Mateo-Lomba et al., 2020; Osipowicz et al., 2020) for studying various aspects of each artifact using a Nikon SMZ 1000 stereomicroscope with a magnification range of 8× to 80×. We used a Nikon D7100 for micrographs that captured images at an optical

magnification range of 16× to 160×. We studied a portion of the formal artifacts including the pendants and beads ( $n = 33$ ) at a higher magnification using one of two different microscopes: a confocal disc-scanning microscope (Nanofocus AG) using an optical 20× objective (numerical aperture = 0.4, field of view = 0.8 mm<sup>2</sup>) provided by the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany and a metallurgical microscope (Olympus BX) with an optical magnification range of 5× to 50× provided by the New Bulgarian University in Sofia, Bulgaria. We recorded type, direction, and location of manufacturing traces, and additional alterations to the bone surface including shape of active end, state and extent of use, development of use, surface portion used, volume deformation, asymmetry, flaking, crushing, and discard and reuse (d'Errico et al., 1984; Olsen, 1984; Sidéra, 1993; Christidou, 1999). If microscopic striations and topographic reliefs were visible, we also recorded striation direction, morphology, and organization and surface topographic smoothing (Christidou and Legrand, 2005; Buc and Loponte, 2007; Legrand, 2007; Buc, 2011; Stone, 2011).

### 3. Results

We retained 74 osseous objects from the Layers I and J and their contact zones after the initial assessment. These objects include both formal and informal osseous tools as well as ornaments (Table 1). Most occur on bone ( $n = 41$ ), but a portion of these objects is on animal teeth ( $n = 27$ ), and a small number are on antler ( $n = 5$ ) and ivory ( $n = 1$ ; Table 1). These objects were found in both sectors of the site, in nearly every excavation square, and primarily within Layer I ( $n = 51$ ; 69%) and the contact zone with Layer J ( $n = 9$ ; 12%) and Layer H ( $n = 7$ ; 9%) above (Fig. 2; SOM Fig. S1; SOM Table S2). A small portion of the artifacts come from the upper part of Layer J ( $n = 7$ ; 9%). Due to slow accumulation, low density of artifacts, and the presence of

carnivores, it is not yet clear exactly where in the lower part of Layer J the IUP began. However, one pendant found deeper in Layer J and associated with lithics that are techno-typologically consistent with those of the overlying layers indicate the probable beginning of ephemeral IUP occupations (Fig. 2a). Thus far, the only clearly identified bone tools from MP contexts (Layer K) at Bacho Kiro Cave are retouchers, i.e. bones used to resharpen lithic implements (SOM Table S3). Retouchers ( $n = 44$ ) were also found in the IUP layers but these and the MP retouchers have yet to be studied in detail. Here, we focus on the 74 osseous objects from the IUP layers that have purposeful modifications or a well-defined working end or edge (Table 1).

### *3.1. Bone and antler artifacts*

While bone and antler artifacts are preserved within all IUP layers in both sectors, the majority are from Layer I ( $n = 32$ ; Table 2). The osseous artifacts within these IUP layers are highly varied with several objects made using formal techniques such as scraping and grinding. These include artifacts typologically categorized as awls, smoothers, beveled objects, and indeterminate items ( $n = 16$ ). Many artifacts appear to be informal and expedient in nature and include bones with utilized tips, unworked intermediate tools, and knapped tools ( $n = 16$ ; SOM Table S4). Many of these artifacts have traces indicating they were intensively used in multiple ways, so typological classification may be arbitrary in some cases (SOM Table S5). In addition, there are several linearly marked bones with simple cuts, well-defined incisions, and deep notches ( $n = 13$ ). Some of these pieces appear to have been used during a specific task while the function of others is less clear. Though the bone and antler artifacts were found distributed throughout most of the excavation area, most of the bones with subparallel incisions and notches were located within a roughly 50 cm<sup>2</sup> area in Niche 1 (Fig. 2b). A patterned artifact distribution may be

related to site use, maintenance, activity partitioning, or caching behaviors (e.g., Binford, 1979; Speth et al., 2012; White et al., 2017). Spatial patterning reported from the previous excavation indicates the presence of a hearth adjacent to the recently excavated Niche 1, which may have influenced the distribution of artifacts (Kozłowski, 1982; e.g., White et al., 2017). However, it is difficult to resolve comparisons between the old and new excavations at this level of detail. Further research combining other lines of evidence from the newly excavated and well-preserved Bacho Kiro Cave deposits may reveal site specific activities.

The bone and antler artifacts derive from taxa that are abundant in the faunal assemblage and are dominated by large bovids, cervids, and cave bear (Smith et al., 2021; Table 3; SOM Table S4). Because these objects are modified and fragmented, many morphological identifications could only be assigned to a body size class. Proteomic ZooMS results on a portion of the unidentifiable artifacts were consistent with those taxa found at the site (Table 3; SOM Table S1), including *Bos/Bison* sp. and *Ursus* sp. Similarly, the osseous tools could only be identified to a specific skeletal element in some cases and are most often on long bones and ribs. A smaller portion were made on antler and other elements (Table 3; SOM Table S4). The majority of informal tools are on long bones. Formal tools and incised bones show more diversity in the skeletal elements selected with ribs being the most frequently utilized skeletal material (Fig. 3).

Overall, artifact bone surfaces exhibit minimal subaerial weathering (stages 0–2; Behrensmeyer, 1978) and abrasion (0–30%), which indicates that bone surfaces exhibit high visibility (75–100%; SOM Table S6). Further, there are minimal pre- and post-depositional surface modifications unrelated to anthropogenic manufacture and use (2–7% with carnivore gnawing, burning, root etching, and sediment concretions; SOM Table S6), which allows for detailed descriptions of the bone and antler artifacts including technological and functional traces.

Awls Six bones classified as awl fragments, two of which refit, were found in the Niche 1 within Layer I (Fig. 4; Table 3). The bone awls are most often made from rib fragments of unknown mammals, though many of the awls are too modified or fragmented to make a more specific identification. Longitudinal scraping, deep subparallel marks accompanied by finer striations, is preserved on all these tools (Fig. 4d, g), while oblique grinding traces, irregular overlapping marks, are observed on BB8-1705 (Fig. 4q). Of the two fragments that retain the proximal portion (Fig. 4b, e), manufacturing traces appear on nearly the entire length of the artifacts, but distribution is irregular and minimally affects the shape of the proximal part. For example, scraping traces end at roughly 3 cm from the distal break on the right face of CC8-1091 (Fig. 4b), while the left face exhibits scraping traces that extend to the proximal break. All bone awls exhibit use alterations including breaks at the distal or mesial parts of the tools. Of the two awl fragments that refit, the proximal part, CC8-1091, exhibits a dry break, which suggests the bone was not fresh or used after this artifact broke (Fig. 4d). The distal fragment, CC8-1047.3, preserves a crushed awl tip (Fig. 4c) that could indicate the bone tool was used by indirect percussion to punch holes through a hide (Christidou and Legrand, 2005). Forceful application of pressure on the object may have caused it to break during use. There is some variation in microwear patterns across the awls (SOM Table S5), but the distal portions most often exhibit progressive smoothing that obliterates the manufacturing traces left from shaping the objects (Fig. 4i, m). In some cases, elongated longitudinal striations are observed on the distal end and short, transversal striations are present along margins or partially encircle the distal parts (Fig. 4j, l, p, r). Three of the fragments do not exhibit micro-striations at the magnification observed (Fig. 4a, b, e). The alterations on the awls at Bacho Kiro Cave are consistent with use as a perforator for a soft material such as animal skin (Campana, 1989; Lemoine, 1994; Griffiths and Bonsall,

2001; Christidou and Legrand, 2005; Buc and Loponte, 2007; Legrand and Radi, 2008). In addition, several of the awls, as well as many other objects within this assemblage, exhibit patches of red discoloration (SOM Table S5). Further research will confirm whether this staining is due to iron-rich sediments or related to pigment use, though one awl preserves small flecks of ochre affixed to the surface in a number of places (Fig. 4e).

Smoothers Three artifacts classified as smoothers (lissoirs) have convex and polished distal ends and are made from medium to large herbivore ribs (Fig. 5; Table 3). The most complete object is made from a large bovid rib and comes from the Main Sector Layer J (*Bos/Bison* sp. based on ZooMS; Fig. 5l; SOM Table S1). The two others are distal fragments from Layer I in the Niche 1. The complete artifact was fashioned from a partially split rib with the dorsal end removed to form the working end (Fig. 5l). The rest of the rib was left unsplit and minimally modified aside from scraping and grinding traces on multiple faces (Fig. 5m), especially the concave surface, to shape the working end. The two distal fragments are too fractured to indicate exactly how they were manufactured, but also exhibit scraping and grinding traces on the edges and faces of the bones (Fig. 5c, d). Similar use signatures are exhibited across the artifacts including progressive smoothing on all bone faces (Fig. 5c, f). Multidirectional striations and micro-pitting are also common to the artifacts (Fig. 5b, c, h, n). Proximal to the working end along the left edge and concave surface, the complete object, F6-622, is highly polished with smoothing of the upper reliefs including long transversal striations (Fig. 5m, o). The two smaller fragments exhibit longitudinal breaks, while AA8-1434 preserves traces of grinding overlain with additional smoothing and polish, which indicates that the artifact was reworked and reused after initial breakage (Fig. 5d). AA8-1434 and F6-622 both have large flake damage at the very tip of their working ends (Fig. 5c, n). The similarity of surface alterations at the distal part of all three



smoothers is consistent with use on a soft material such as animal skin (Christidou and Legrand, 2003; Buc, 2011; Stone, 2011; Soressi et al., 2013), though AA8-1434 and F6-622 were likely used more intensively, and possibly in multiple ways, as evidenced by the intensive smoothing and flake damage to the working end (Tartar, 2009, 2012). In addition, the angular left edge of the complete tool (F6-622) also preserves traces consistent with the working of a soft material, likely fresh animal skin (Christidou and Legrand, 2003; Martisius et al., 2018).

Beveled objects (formal intermediate tools) Five artifacts typologically classed as beveled objects were found within the Niche 1 in Layers H/I, I, and J (Table 3). These tools either have a unifacially or bifacially beveled distal part and are most often made from cervid antler (Fig. 6a, d, g, j), though one artifact, BB8-881, comes from a *Megaloceros giganteus* (giant deer) tibia (Fig. 6m). Only two of these objects are complete (Fig. 6j, m), while three are fragmented and only preserve the distal part (Fig. 6a, d, g). Many of the objects exhibit oblique marks left from wedging during the antler splitting process (Tejero et al., 2012) but minimal longitudinal and oblique scraping marks to refine the distal parts of the tools (Fig. 6h, i, k). The outer antler surface is minimally altered in most cases. No clear manufacturing traces are visible on the beveled portion of BB8-881 to indicate how the cortical bone was modified, but multidirectional scraping and grinding traces on the superior face may be related to manufacturing (Fig. 6o). All objects exhibit evidence consistent with use as intermediate tools (e.g., wedges, chisels) such as splintering and crushing (Fig. 6b, c, i), sometimes at both distal and proximal extremities (Fig. 6l; Tartar, 2009, 2012; Tejero et al., 2012). In addition, some degree of smoothing is observed on all objects (Fig. 6a, d, g), while a few exhibit striations from use (Fig. 6b; SOM Table S5). Two of the antler objects, DD8-512 and DD8-327.3, have compacted and faceted distal extremities likely produced through use, which are both associated with red staining (Fig. 6e, h). The bone

object, BB8-881, also exhibits red staining. In addition, there are deep transversal marks on the superior face near the working end likely produced during use as a wedge (Fig. 6n). A variety of functions have been proposed for this tool type including wood or antler working, wedging for splitting, hide processing, among other uses (Semenov, 1964; Stordeur, 1980; Camps-Fabrer et al., 1998; Rigaud, 2007; Tartar, 2009, 2012; Tejero et al., 2012). The degree of damage along with three fragmented artifacts indicates that these beveled objects were utilized through indirect percussion on intermediate to hard materials with a substantial amount of force.

Unworked intermediate tools Seven unworked intermediate tools, similar to ‘pièces esquillées’ or splintered pieces (Hayden, 1980; Demars and Laurent, 1989; Villa et al., 2005; d’Errico et al., 2012), also come from Layer I and its contact layers within the Niche 1 (Fig. 7; Table 3). These are not formally modified tools but simple long bone diaphyseal fragments of medium to large mammals and are extremely variable and only recognizable by their use alterations at their opposing extremities (Tartar, 2012; Baumann et al., 2020). Fracturing is common among this tool type due to the forceful impact sustained during indirect percussion, so most of the identified intermediate tools at Bacho Kiro Cave are fragments that originated from a larger tool. Indications of use on these objects are abundant and include splintering and crushing, repeatedly on both extremities (Fig. 7b, c, h, k, l, n, q). Some degree of smoothing is often exhibited at both ends and is regularly associated with longitudinal and oblique striations of varying sizes (Fig. 7c, e, f, h, i, q). In addition, many of these objects exhibit a variety of alterations, which suggests they were used in multiple ways. For example, three bones in this category (BB7-439, BB8-207, AA7-158) preserve marks indicative of use as retouchers (Fig. 7d, m; SOM Table S5). One of these (BB8-207) plus an additional object (A8-543) have modifications such as smoothing, compression, and short transversal striations along the tool margins indicating their sharp edges

were also used, likely for scraping (Fig. 7j; Mateo-Lomba et al., 2020). A8-543 even has a retouched right edge to facilitate this additional task (Fig. 7j). AA7-158 also exhibits some similarities along its long, straight left edge, and includes flaking, possibly from both shaping and use, which is overlain with smoothing and polish (Fig. 7o). It is possible this edge was used for cutting or sawing (Mateo-Lomba et al., 2020). Lastly, BB8-1896.2 exhibits a cluster of deep, transversal linear marks that likely originated from scoring the bone surface repeatedly (Fig. 7r), though there is no clear function for these marks. The unworked intermediate tools at Bacho Kiro Cave are extremely variable, often indicating they were used for up to three different functions, but all have damage at their opposing extremities as a result of indirect percussion on intermediate to hard materials, similar to the beveled objects (Tartar, 2012; Baumann et al., 2020).

Utilized tips Five bones have modifications to one extremity that is often rounded or smoothed, though the commonality between these artifacts ends there. Some of the artifacts have minimal manufacturing modifications to the surface or edges but are generally made on simple long bone diaphyseal fragments of medium to large mammals. Most of the artifacts in this group come from Layer I, while one is from J, and were found within the Niche 1 (Table 3). All objects exhibit smoothing and/or polish that is often associated with micro-striations, but the way they are exhibited on each artifact is quite different (SOM Table S5). CC7-2458, an extremely thin, elongated spatula-shaped bone flake exhibits a highly polished, localized area at the margin of the distal extremity with long, longitudinal striations, micro-pits, and a flat surface relief (Fig. 8b, c). Such a wear pattern is consistent with contact against a soft, but somewhat abrasive and rigid object, possibly vegetal material (Buc, 2011; Stone, 2011). A8-1135 and A8-715.5 (not pictured) exhibit a few similarities including longitudinal microwear striations and transversal

depressions on the edges (Fig. 8h, i). On A8-1135, the depressions are associated with long, transversal striations emanating from the edge, where a flexible material may have been wrapped around the bone (Fig. 8i, j). BB7-1223 has a wear facet at the tip of the distal part with long, deep oblique striations, which likely resulted from grinding or use against an abrasive and gritty material (Fig. 8l; d’Errico and Backwell, 2003). This object also has marginal smoothing on both faces (Fig. 8l, m). DD8-1236 exhibits short, organized transversal striations associated with micro-pits on the right edge of its distal part (Fig. 8e, f). In addition, these two artifacts (BB7-1223 and DD8-1236) have knapped edges, which are overlain with smoothing and polish consistent with their sharp edges having been also used for cutting or other possible activities (Fig. 8d, k; Mateo-Lomba et al., 2020). These objects are similar in that a naturally pointed or slightly rounded extremity was utilized for some purpose, but the vastly different microwear traces on these objects indicates that they were used on different materials and in varying ways.

Knapped tools Four tools with knapped and, in some cases, retouched extremities and edges with few other modifications come from Layers I and J and their contact layers in the Niche 1 (Table 3). The objects in this category are simple long bone diaphyseal fragments that exhibit knapped distal ends and/or edges to shape the objects and produce sharp edges likely for cutting or scraping (SOM Table S5). This type of modification is found in other artifacts previously described (Figs. 7j, m and 8d, k). In some cases, the knapping is precise and resulted in a retouched active end (Fig. 9a, h). For example, the triangular pointed distal part of BB8-193 was shaped by retouch on the superior tip (Fig. 9i). Similarly, the distinct size and shape of DD7-1397 is reminiscent of a lithic end- or sidescraper including the retouched working end and beveled profile (Fig. 9b, c). It is unclear whether the large flake removals at the rectilinear distal extremity of DD7-1086 resulted from shaping to thin the bone or from use (Fig. 9f), but the

elongated mesial section was deliberately modified through percussion to produce straight edges. Both DD7-1397 and DD7-1086 exhibit polish, smoothing, and striations consistent with repeated use for scraping a soft material such as animal skin most often using a transversal motion (SOM Table S5; Mateo-Lomba et al., 2020). DD7-1397 made use of the denticulate distal extremity and was used at a low angle, while DD7-1086 was intensively used along the edges, especially the right edge that exhibits distinct discoloring compared to other surfaces (Fig. 9d, g). BB8-193 is a unique artifact with unknown function, but exhibits moderate smoothing and long, longitudinal and oblique fine microwear striations on both faces of the distal part (Fig. 9j). It also preserves distinct features related to splitting and shaping the bone including an area along the proximal right edge with a cluster of oblique incisions that likely resulted from wedging to split this bear femur (Fig. 9k; Table 3). These objects are similar in that their ends and/or edges were shaped through retouch to produce sharp edges, which seem to have been used for scraping in addition to other possible activities (Mateo-Lomba et al., 2020).

Indeterminate worked items Two indeterminate items come from the Niche 1. An antler tip fragment (CC6-445.1, not pictured) from Layer I/J preserves oblique marks from a wedge used to split the antler tine (Tejero et al., 2012). This object may be a waste fragment from the production of a tool. CC7-180 is a medium to large herbivore rib bone object from Layer I that exhibits an irregular convex extremity (Fig. 5i; Table 3). Manufacturing traces such as longitudinal and oblique scraping are on both faces. Scraping on the inferior face completely flattens the bone surface and abruptly ends at about 5 mm from the end forming a slight transversal shelf with long, transversal markings, similar to faint grinding traces (Fig. 5k). On the opposite face at about 5 mm from end, depressions are associated with transversal markings and striations. The surface near the oblique break has the most intense polish and smoothing,

suggesting that this object was larger, broke at or after discard, and may not preserve the identifying features needed to ascertain the object's function. Nonetheless, the preserved features are consistent with a flexible material having been wrapped around this part of the artifact, which may indicate that this object was the proximal end of a tool and/or a part of a composite tool (Cristiani et al., 2016; Pedergrana et al., 2021).

Notched bones Four notched bones, two of which refit, come from Layer I in the Niche 1 (Table 3; SOM Table S7). One is from a rib, while the skeletal elements of the other artifacts are more difficult to determine. One of these objects is highly fragmented and only preserves two notches (Fig. 10m), while the other artifacts display longer sequences. DD7-979.8 (Fig. 10a) and DD8-1616 (Fig. 10c) refit to form an elongated bone object with 13 total notches on two separate faces. The object exhibits longitudinal scraping striations that are overlain by notches (Fig. 10b, d). In addition, small nodules of black residue are present on the endosteal surface. Unfortunately, the object is too fragmented to indicate a type of use. DD7-203 is an elongated flat bone with seven notches along the slightly concave edge (Fig. 10i). Four of these notches were deepened and widened after the notches were produced. The widening of the notches is asymmetrical and resulted in one roughened, damaged rim that is consistently on the same side of the notches (Fig. 10k). This asymmetrical wear indicates that a flexible material was most likely either secured within the notches to hang the object or was pulled repeatedly in one direction during the process of string making or some other repetitive tasks that required twine or cordage. Both unique notched objects exhibit smoothing and polish, which could indicate prolonged use and/or handling during curation (d'Errico, 1993).

Incised bones Nine bones with subparallel incisions come from Layers I, I/J, and J, both in the Main Sector and the Niche 1 (Table 3; SOM Table S7). Five are on ribs, two from long bones,

and one on a cranio-frontal fragment of a large herbivore. The incised bone artifacts are quite variable and exhibit a mixture of simple cuts and well-defined incisions (Fig. 10p, v), sometimes repeated to deepen the markings. Most incisions on the individual artifacts are regular, exhibiting marks of similar size, shape, and angle and were likely incised consecutively with the same lithic implement (Fig. 10o, w; d'Errico, 1995). However, DD8-726 exhibits a sequence of incisions with three different groups of marks clustered together: deep, faint and long, and short and distinct (Fig. 10q). The different sizes and shapes of these marks could indicate that they were produced at different times (d'Errico, 1995). Most of the incised objects are on flat bone fragments, often ribs that were intentionally split (e.g., Fig. 10r), though few other traces are observed to indicate these objects were used beyond these markings. An exception is AA8-1951, which is a highly polished rib fragment with a tapered but blunted proximal extremity (Fig. 10g). Longitudinal and oblique scraping covers all faces to regularize the surface. There are two clusters of faint transversal and oblique incisions on opposing faces near the dry break that may have been produced to add surface texture and facilitate grip of the tool (Fig. 10f, h; Henshilwood et al., 2001). Because the artifact is transversely broken, it is unclear how the object functioned. Polish covers the entire object, possibly the result of prolonged curation (d'Errico, 1993), but no clear surface alterations related to use are present. Another unique artifact (DD8-1124) is a tubular rib fragment of a medium sized carnivore with six oblique incisions (Fig. 10s). One end of the artifact exhibits pitting due to carnivore gnawing, while the other extremity of the tube preserves an oblique ancient break. The surface of the rib preserves longitudinal and oblique scraping on all faces overlain by the incisions. Parts of the object are smoothed and polished including the fractured surface of the oblique break (Fig. 10t), which could suggest that the rib was intentionally broken to create a tubular object. In addition,

transversal striations and red staining are present on the surface near the oblique break (Fig. 10t). The use alterations at one end of the ‘tube’ may indicate that this bone object was used as an ornament and the regular subparallel incisions were for decoration. The variable nature of the incised bone fragments indicates that the humans at Bacho Kiro Cave utilized incisions for various purposes, some possibly functional while others were likely decorative.

### 3.2. *Ornaments (beads and pendants)*

A significant component of the recent Bacho Kiro Cave excavations is the numerous ornaments. Pendants or pendant fragments ( $n = 27$ ) made from both carnivore and herbivore teeth and three broken beads made on ivory, bone, and stone have been found within the Niche 1 (Fig. 11; SOM Tables S8 and S9). The teeth pendants and beads that have secure context all come from layers attributed to the IUP. Two additional objects, a pendant and a bead, were found out of stratigraphic context, but their morphological attributes suggest affinity with the ornaments from the IUP layers (SOM Tables S8 and S9).

Beads Three disk-shaped beads, all of which were broken in half, were recovered from Layers H/I and I (Table 4; SOM Table S8). One bead (DD7-719.6; Figs. 11 and 12a) is bone from an unknown mammal, the second (AA8-222; Figs. 11 and 12e) is made of elephantine ivory, and the last bead (AA8-1630.1; Figs. 11 and 12h) is made from sandstone. The ivory and bone beads have perforation diameters that are roughly the same size (~4 mm), while the diameter of the sandstone bead perforation is much smaller (2 mm; Table 4). No manufacturing traces are present on the ivory bead, but the regularity of the rounded perforation could suggest it was drilled (Fig. 12e). This method seems to have been used on the sandstone bead, which features a biconical perforation with a moderately defined circular rim and concentric striations inside the



perforation (Fig. 12i). The bone bead preserves pronounced grinding traces on both flattened faces and on the faceted edges (Fig. 12b, c, d), which indicates that this bead was ground against coarse sandstone to flatten both surfaces and regularize the edges. The perforation of the bead is irregular due to exposed spongy bone, which may indicate that the artifact was manufactured from a long bone. All of these artifacts exhibit smoothing and other signs of use (SOM Table S8). The ivory bead is highly polished and preserves many multidirectional striations of varying sizes on most surfaces. The central portion of the longest edge features a depressed area with a completely smoothed surface topography and fine, short micro-striations transversal to the edge, which suggests that the bead may have been fastened at this location (Fig. 12f, g). Further, traces of pigment such as dark black and brown staining on the ivory bead (Fig. 12e) and reddish residues on the bone bead (Fig. 12a) indicate that these items were either colored prior to use or the colorants rubbed off onto the objects while in use. Alternatively, the pigments could have been used as abrasive additives to facilitate perforation of the beads (Tejero et al., 2021a; Tejero et al., 2021b).

Pendants Twenty-seven tooth pendants and pendant fragments are preserved in all IUP layers within the Niche 1, most often in the richest Layer I ( $n = 18$ ; Table 5). The teeth show signs of weathering (stages 0–2; Behrensmeyer, 1978; SOM Table S6) with twelve exhibiting different degrees of surface flaking where the cementum has or partly peeled away from the dentin layer (e.g., Fig. 13a, d). Eleven teeth exhibit cracks in the crown and/or root (e.g., Fig. 13n). Despite this, tooth surface preservation is good with most surfaces entirely ( $n = 10$ ; 37%) or largely ( $n = 14$ ; 52%) visible (SOM Table S10). Only one has sediment concretions over a large portion of the surface.

575 Sixteen of the pendants were made from carnivore teeth based on morphological characteristics  
 576 of the crown and root shape. One pendant is a wolf (*Canis lupis*) incisor, while the other 15  
 577 derive from cave bear (*Ursus spelaeus*) incisors ( $n = 9$ ), premolars (P;  $n = 2$ ), and molars (M;  $n =$   
 578 4) from both the maxilla and mandible (Fig. 11; Table 5). Given the diversity of teeth pendants  
 579 preserved, the minimum number of cave bears contributing to the pendants is two based on three  
 580 different types of teeth (lower left first and second incisors and fourth premolars) represented  
 581 twice in the pendants (Table 5). All other identified cave bear teeth are unique. Due to  
 582 preservation issues or anthropogenic modifications, 11 of the 27 teeth could not be identified  
 583 based on morphological characteristics alone but are most often single-rooted. Three of the  
 584 artifacts were identified using ZooMS: two as *Bos/Bison* sp. and one as *Cervidae/Saiga* sp.  
 585 (Table 5; SOM Table S1). The remaining eight are from unknown mammals, but based on the  
 586 size, shape, and similarity of modifications to several of the pendants identified through ZooMS,  
 587 six of these appear to be produced on herbivore teeth, possibly incisors or vestigial canines  
 588 (Table 5). Given that large bovids do not form vestigial canines, the teeth identified as *Bos/Bison*  
 589 sp. most likely derive from incisors. Notably, one of the *Bos/Bison* sp. artifacts (AA7-1635.1),  
 590 and two others without ZooMS identifications (A7-219.1 and AA8-1644), preserve scraping  
 591 traces on and/or adjacent to the crowns of the teeth indicating deliberate alteration of this area  
 592 (e.g., Fig. 13n, u, v). In addition, it appears that the enamel surfaces of many of the herbivore  
 593 crowns have been modified through intentional abrasion, a feature observed elsewhere in  
 594 subsequent UP assemblages (White and Normand, 2015). Modification to the tooth crown is  
 595 likely unrelated to the method of suspension but rather to the intended shape of the objects. This  
 596 feature is not observed on any of the carnivore teeth.

Both carnivore (C) and herbivore (Hb) tooth pendants preserve a variety of evidence for hanging and use as ornaments including differing manufacturing methods that served as the basis for a pendant classification system (Figs. 11 and 14; Table 5). Sixteen pendants are completely pierced bidirectionally (BD), three are scraped to form a shelf-like feature towards the root apex (SS), two are exclusively grooved (GV), one is pierced through gouging (GO), and one is partially pierced (PP). Some of these types may represent unfinished pendants at an early manufacturing stage. An addition four teeth are fragments that preserve evidence of scraping and are either waste fragments or broken pendants (Fig. 15; Table 5). Most pendant types with a variety of animal raw material sources are found within Layer I, while a few examples are found within the other layers. No observable change in the representation of pendant types or raw materials utilized are evident across the IUP layers, albeit a small sample in some layers may obscure any patterns (Fig. 15).

The largest pendant type, those scraped and biconically drilled, are made on herbivore (Hb-BD) and carnivore incisors (C-BD) and cave bear molars (CM-BD), and come from Layers H/I, I, and J (Figs. 13, 15, 16m, and 17a; Table 5). Incisor roots preserve scraping traces longitudinally and obliquely most often on the wider mesial and distal faces (e.g., Fig. 16m). The molars have had at least one root removed, and their main modified root is thoroughly scraped similar to the single rooted pendants along the widest faces so that they are regularized flattened surfaces resulting in distinct v-shaped profiles (Figs. 13n, s, 14, and 17a). This modification is so extensive that the dentin is exposed on roughly two-thirds of the distal portion of the root (e.g., Fig. 13). The scraped root apices feature biconically drilled perforations that pierce the roots mesiodistally, or buccolingually in the case of the molars (e.g., Figs. 13 and 17a). Perforation rims are most often circular with well-defined edges and concentric striations inside the

perforation (e.g., Fig. 13f, k, l, p, w). Perforation rims often exhibit polish and rounding (e.g., Fig. 13i, q), while interior concentric striations are partially smoothed or entirely smoothed from use (SOM Table S9). In addition, three pendants (AA8-1393.1, A8-1138.7, and AA7-1194) feature wear facets or similar deformations widening the rim of the holes laterally (e.g., Fig. 16n). Most pendants ( $n = 14$ ) preserve modifications including polish and smoothing on the root of the surface near the perforation. A subset of these ( $n = 9$ ) feature directionally oriented transversal modifications (perpendicular to the axis of the root), or oblique in one case (CC8-1496.1), such as striations and furrows adjacent to the perforations (e.g., Figs. 13c, t and 16o; SOM Table S9). Most of the pendants preserve polish and smoothing in other locations of the root surface that often overlay the manufacturing traces (e.g., Figs. 13i, q and 16p). All of these features are consistent with the pendants having been either tightly strung together on a cord or twine so that the pendants contacted one another or fastened to a material such as clothing (d'Errico, 1993; Cristiani and Borić, 2012; Osipowicz et al., 2020).

The majority of the biconically drilled pendants have been broken at the perforation ( $n = 11$ ), likely due to sustained use (Table 5). Two of these indicate that they were reworked by grooving after they broke to suspend the artifacts using a string or cord fixed in the grooves (Fig. 13g, CC8-1047.1; Fig. 13m, A7-219.1). The fracture of the larger projecting remnant of the broken perforation on A7-219.1 is rounded and smoothed, consistent with being used after the perforation broke (Fig. 13p, q). The smaller remnant preserves a small groove and the bases of adjoining grooves on multiple faces (Fig. 13o, p). The root is broken along these grooves, which demonstrates that the pendant was broken a second time after grooving and further use.

Similarly, CC8-1047.1 has grooving on one of the projecting remnants of the broken perforation (Fig. 13h, i). There are three distinct grooves on the faces that are not part of the perforation and

two of these cut across the drilled hole indicating that the pendant was grooved after the perforation was made and likely broke.

Two pendants primarily modified by incising a groove are found in Layer I (Fig. 15; Table 5). A cave bear incisor (C-GV, BB7-1074) and premolar (CP-GV, BB8-2302) have well-defined grooves that encircle the roots with indications of smaller incisions likely related to slips or false starts (Figs. 11 and 17i, j). Incisions within the grooves are mostly obliterated from use, due to a string or cord fixed in the groove, while the outer rims exhibit polish and rounding. Both pendants preserve other indications of use including smooth greyish impressions encircling the root of BB7-1074 and the smoothed and polished broken mesial root of BB8-2302 (Fig. 17k). This broken root was likely removed during manufacture of the pendant to allow for the complete grooving of the distal root.

One pendant (CC7-314) perforated by bifacial gouging comes from Layer I (Fig. 16a; Table 5). The cave bear incisor (C-GO) is extensively scraped and gouged on both the mesial and distal root surfaces so that an oblong perforation with irregular edges was formed (Fig. 16b, c). Long transversal striations are preserved on both sides of the perforation on the distal face of the root (Fig. 16d), and the apex on the same surface shows smoothing of the upper reliefs of the surface microtopography with invasive polish, pitting, and multidirectional fine striations. These features are consistent with the pendant having been fastened to soft material such as leather using a cord or twine (Cristiani and Borić, 2012; Osipowicz et al., 2020).

A cave bear incisor from Layer J (C-PP, CC7-2858) is partially pierced exposing a hollow interior (Fig. 16e; Table 5), but it is not clear how the perforation was made given the state of preservation though perforation through pressure or indirect percussion seems the most plausible (White, 2007; White and Normand, 2015). The perforation edges that are better preserved lack

clear manufacturing traces, but fine striations and scratches emanate from the large hole (Fig. 16g, h). One edge preserves an ancient chip, initiated from inside the hole, which occurred after the striations were produced (Fig. 16g). The root surface is highly polished with transversal striations of various sizes and lengths on much of the root. Towards the apex on the mesial face, transversal indentations co-occur with large flat grey marks that partially circumscribe the object and appear to be impressions from a material that was wrapped around the root of the tooth (Fig. 16f). Similar grey transversal impressions are also observed on one of the grooved pendants (BB7-1074; Fig. 11; SOM Table S9). Given its irregular features, this object may be an unfinished pendant.

Three teeth from Layers I and I/J preserve scraping traces that form a shelf or knob at the distal end, and they are made on an herbivore incisor, (Hb-SS), a carnivore incisor (C-SS), and a cave bear molar (CM-SS; Fig. 15; Table 5). The roots of these teeth (Figs. 11, 16i, and 17d) were repeatedly scraped, most often on the concave face, to form a flat surface that ends abruptly before the root apex to form a shelf-like border (e.g., Fig. 16j, k). A similar modification is observed on one of the indeterminate worked bone items (Fig. 5i). This feature is distinct from the shape of the root apices that are biconically drilled, which do not have the sharp border but tend to have uniformly scraped apices (e.g., Fig. 14). Of the three pendants with shelves/knobs, no additional manufacturing modifications are present aside from scraping (e.g., Figs. 16j and 17e, f). CC8-1571 is perforated on both sides of the root, but the edges of these holes are irregular and flaky indicating recent breakage resulting from thinned, weakened root walls damaged by post-depositional processes (Fig. 16l). Given their minimally modified features, it is possible that these objects are unfinished and represent an early stage in the manufacture of perforated pendants (White, 2007). Interestingly, all three teeth have additional traces that could

indicate use or provide further insight into the pendant manufacturing or storage process. For example, all three demonstrate crushing of the lacunae of the cellular cementum along the shelf-like feature (Fig. 16k), and in some cases long transversal striations are present in the same or adjacent regions. The lateral edges of the shelf-like feature are altered in a way that could have been caused by something wrapped around the root at this location to suspend or fasten the objects. The clearest example of this is DD8-782 where deep depressions can be followed around the root surface from the shelf-like feature (Figs. 17f). In addition, long fine subparallel transversal striations that overlay the longitudinal scrapes are also in the vicinity of the deeper depressions (Figs. 17g). Extensive smoothing and polish of the upper surface reliefs of the surface is also observed, especially at the very apex of the root. All of these surface alterations are consistent with the teeth having been secured at the shelf-like features, possibly for use or for other purposes in the early stages of the pendant manufacturing process.

The remaining items are found in Layers I and I/J and preserve scraping traces along their roots, but do not share other characteristics (Table 5). These include a thoroughly scraped molar fragment (A8-1471; Fig. 11), a fragmented premolar with scraping on both root faces (AA7-1465.1; Fig. 11), a tooth root fragment with a large groove and several smaller incisions (BB8-510; Fig. 11), and an incisor with scraping and grinding along multiple faces of the root including across the break of the root (DD7-472.7; Fig. 11). Some of these exhibit smoothing, which may indicate that they had been used (Table 5; SOM Table S9), though A8-1471 and BB8-510 were likely root fragments removed during the production of pendants with more than one root (Fig. 11).

The large diversity of animal teeth pendants from Bacho Kiro Cave do not exhibit a diachronic trend in pendant type or animals utilized across the IUP layers (Fig. 15). Biconically drilled

pendants are found throughout the layers, while the other pendant types with only one or a few examples each are too rare to discern a pattern. The diversity in pendants indicates that these humans utilized various methods for modifying, suspending, and fastening these artifacts, methods common in other transition period assemblages and in later European UP contexts (Granger and Lévêque, 1997; Vanhaeren and d'Errico, 2006; White, 2007; White and Normand, 2015; Vanhaeren et al., 2019; Arrighi et al., 2020). Many of the pendants from these differing manufacturing types feature evidence of use including staining or pigmentary residues, which could support their interpretation as used pendants, albeit the pigments may have been added during initial manufacturing stages to facilitate root modifications (Tejero et al., 2021a; Tejero et al., 2021b). In particular, 12 teeth feature small fragments of ochre that are often trapped in surface depressions like cracks, perforations, grooves, or roughened features of surface breaks, while a few have more widespread residues on the surface (e.g., Fig. 13j; SOM Table S9). Many of the pendants have extensive alterations including two exhibiting two distinct manufacturing events indicating that these artifacts were curated and sometimes restrung after breaking.

#### 4. Discussion

The large assemblage of osseous artifacts presented here ( $n = 74$ ) provides the opportunity for assessing behavioral patterns of some of the earliest *Homo sapiens* in Europe. Though timing and intensity is often debated, IUP assemblages with combinations of Levallois blanks, blade technologies, and UP tool types as well as a variety of shaped bone tools and ornaments appear in central and eastern Europe, southwest Asia, and in north and central Asia from 50–45 ka (Kuhn, 2019; Zwyns et al., 2019). The presence of a variety of formally modified hard animal tissues within these assemblages is significant given the paucity of similar objects preserved



within earlier MP deposits (e.g., Gaudzinski, 1999; Soressi et al., 2013), while both late MP and transition period assemblages, contemporary or subsequent to the IUP, attributed to Neanderthals preserve osseous objects with similar features to those found in the IUP (e.g., d’Errico et al., 2003; Peresani et al., 2016; Majkić et al., 2017; Stepanchuk et al., 2017; Julien et al., 2019; Vanhaeren et al., 2019; Arrighi et al., 2020). The proliferation of such technologies around 45 ka or possibly earlier (Richter et al., 2009; Slimak et al., 2022) is likely the result of global human dispersal events and broadening cultural networks.

Osseous objects have been the focus of several recent studies within the north and central Asian IUP (Derevianko and Rybin, 2003; Rybin, 2014; Zwyns and Lbova, 2019; Kozlikin et al., 2020; Shunkov et al., 2020; Lbova, 2021). Many of the IUP sites in the regions surrounding southeastern Europe lack well-preserved faunal remains, and thus technological and cultural objects made of these materials (Kuhn, 2019; Smith et al., 2021). However, the regional landmark Paleolithic sites within southeastern Europe (Temnata, Kozarnika) and southwest Asia (Ksâr ’Akil, Üçağızlı Cave I), including material from previous excavations at Bacho Kiro Cave, preserve osseous artifacts allowing for a comparison with the newly excavated materials presented here and a more nuanced understanding of IUP technological innovations (Table 6).

Within southeast European and southwest Asian IUP contexts (Table 6), Bacho Kiro Cave preserves a particularly diverse assemblage. The osseous artifacts recovered from the recent excavations of this cave significantly increase the previous collection (Table 6; Kozłowski, 1982; Guadelli, 2011). The material from the new collection is distributed across the IUP deposits. Almost every artifact type is found across the layers, except awls, which are exclusive to the Layer I. All of this is consistent with previous observations and interpretations that these deposits contain a coherent lithic assemblage (Tsanova, 2008), borne out by consistent 14C dating results

and accompanying records from interdisciplinary research (Fewlass et al., 2020; Hublin et al., 2020; Smith et al., 2021). The IUP occupation of the cave began around 46 ka, with intensified use of the cave from 45–43 ka, as indicated by the substantially increased anthropogenic input of organic matter in Layer I (Fewlass et al., 2020; Hublin et al., 2020; Smith et al., 2021). A substantial portion of this organic matter is millimeter- and submillimeter-sized bone fragments, though it is not clear how much if any of these bone fragments belong to bone waste produced during bone tool manufacture at the site. Even among the formal tools, large portions of the objects remain unaltered, so technological waste was likely minimal. Despite this, the presence of a handful of osseous waste materials including an antler tine fragment and two modified tooth roots suggests that manufacture occurred on site.

The faunal assemblages from the IUP layers are characteristic of taxa found during the Marine Isotope Stage 3 in southeast Europe and are dominated by large bovids (*Bos primigenius*, *Bison priscus*, and *Bos/Bison* sp.; I = 26%; J = 10%), cervids (*Cervus elaphus* and *Cervidae* sp.; I = 26%; J = 8%), and cave bear (*Ursus spelaeus* and *Ursidae* sp.; I = 24%; J = 63%; Smith et al., 2021). The modified osseous objects that could be identified to species most often belong to one of these three well-represented taxa. Notable exceptions are the wolf incisor pendant and the elephantine ivory bead, which likely derives from woolly mammoth (*Mammuthus primigenius*). Whereas teeth seem to have been used exclusively for ornamentation, the other osseous artifacts are made from long bones and ribs, and a small portion come from antler.

Nearly all informal bone tools, those either not shaped prior to use (e.g., unworked intermediate tools) or shaped using percussive techniques (e.g., knapped tools), are from long bones. Within the overall faunal assemblage, limb bones are most common (Smith et al., 2021) so the utilization of these bone fragments as expedient tools is not surprising. Some of these fragments

were likely by-products of marrow extraction, which is directly observed on about 4% of the faunal remains in the form of hard hammer percussion notches (Smith et al., 2021). Some of these same impact fractures are found on the informal bone tools and indicates that the bone blanks were the result of marrow extraction and later minimally or not altered prior to their use as tools. However, thick cortical bone and elongated fragments ( $> 50$  mm) are common features of these tools, and would be beneficial for some tasks (e.g., strength and resisting compression during use as an intermediate tool, long blanks to facilitate grip). Such features could indicate that some blanks were selected and extracted during the butchery process (Costamagno et al., 2018), regardless if these features are the product of the dominant faunal species found at the cave (Smith et al., 2021).

Unlike the informal tools, the formal bone tools and the incised and notched bones were made on a wider variety of osseous materials likely reflecting the different raw material requirements for shaping and using these bone objects. A few of these artifacts are made from long bones but tend to be elements with thin cortical bone that would have taken minimal effort to shape. Ribs, which also have thin cortical bone, are used in many cases, and includes the awls, smoothers, an indeterminate worked artifact, as well as several incised and notched objects. The choice of ribs for such a wide variety of purposes is likely reflective of the ease of using ribs as a preferred raw material (Martisius, 2019). In some cases, the rib shape would have been an asset. For example, smoothers all tend to be elongated flat objects with a convex distal extremity (Camps-Fabrer, 1966; Averbouh, 2000; Tartar, 2009; Soressi et al., 2013; Martisius et al., 2020a; Martisius et al., 2020b). To achieve this shape, a rib requires little modification. For many of the subparallel incised bone objects, a flat surface, a feature of herbivore ribs, may have been the desired attribute. While the purpose of many of the incised artifacts is unclear, the shape of flat ribs is

804 beneficial for several reasons, not least of which is ease of bundling and storage, which could be  
805 supported by their clustered spatial pattern in the Niche 1. Further, a flat rib surface lends itself  
806 to easily displayed markings. In the case of the tubular incised artifact, the naturally rounded  
807 carnivore rib could have provided a useful shape that similarly required minimal modifications.  
808 Interestingly, axial skeletal elements such as ribs (Layer I minimum animal units [MAU] large  
809 bovid = 0.38; MAU cervid = 0.27) are under-represented in the Bacho Kiro Cave faunal  
810 assemblage when compared with forelimbs (Layer I MAU large bovid humerus = 8 and radius =  
811 7.5; MAU cervid humerus = 6.5 and radius = 7) and hindlimbs (Layer I MAU large bovid femur  
812 = 8.5 and tibia = 10; MAU cervid femur = 9.5 and tibia = 9.5), a pattern that has been interpreted  
813 to have occurred due to selective transport of skeletal elements into the cave as part of  
814 subsistence practices (Smith et al., 2021). The 14 worked rib fragments (Layers I, I/J, and J)  
815 likely derive from at least 8 different ribs based on size, curvature, provenience, and taxa, many  
816 of which could have easily come from the same animal. With this in mind, and given the overall  
817 skeletal part pattern observed at Bacho Kiro Cave, it is possible that ribs were selected during  
818 butchery and brought back to the cave for bone working. However, it should be noted that using  
819 ribs in calculations of relative abundance is problematic due to their tendency to fragment as well  
820 as a dearth of diagnostic features. Further, the modifications on worked ribs may result in  
821 entirely unidentifiable fragments, making inferences difficult.

822 Five artifacts, four of which are beveled objects, are made from antler, an osseous material with  
823 a higher fracture toughness than long bone. This material property is the result of its low mineral  
824 content and more irregular microcrack propagation pattern compared to long bones making  
825 antler more resistant to fracture during flexion (Currey, 2002; Chen et al., 2009). Further, antler  
826 working requires a more complex process beginning with beam segmentation followed by

827 longitudinal splitting of the segmented blocks, whereas bone fragments produced during  
828 butchery can easily be modified into efficient tools (Tejero et al., 2012; Tejero and Grimaldi,  
829 2015; Tejero et al., 2016). This difference is likely the reason why worked antler is rarely  
830 documented prior to and within the Early Upper Paleolithic and only became more regularly  
831 exploited after 40 ka during later UP phases, most often for highly modified projectile points  
832 (Tejero, 2014). A modified antler fragment was found in the IUP Layer XXII at Ksâr 'Akil  
833 (Newcomer and Watson, 1984; Table 6), but there is no indication of antler working within other  
834 contemporary or more recent early Eurasia UP assemblages (e.g., Gilead, 1991; Coinman, 1996;  
835 Kuhn et al., 2009; d'Errico et al., 2012; Tejero, 2014; Tejero and Grimaldi, 2015; Arrighi et al.,  
836 2020). While neither the bone or antler tools at Bacho Kiro Cave exhibit complete  
837 transformation of the tool blanks (i.e., large portions of the objects remain un- or minimally  
838 modified), the antler artifacts would have required more time and technological investment even  
839 for relatively simple beveled objects, a common tool type in later UP assemblages (Provenzano,  
840 1998; Tejero et al., 2012). We can argue that the choice of antler as a raw material was deliberate  
841 given its mechanical properties such as fracture resistance during stress and sustained use  
842 (MacGregor and Currey, 1983; Currey, 2002; Chen et al., 2009). In fact, worked antler makes up  
843 a substantial portion (38%) of total antler fragments ( $n = 13$ ) in the IUP layers at Bacho Kiro  
844 Cave, which further supports the choice of antler as a desirable raw material even if antler is  
845 under-represented in the overall faunal assemblage (Smith et al., 2021). The origins of antler  
846 working are vague but the objects preserved at Bacho Kiro Cave indicate that these humans had  
847 already expanded their use of raw material types. Because the antler tools were all used  
848 similarly, this suggests that the selection of different osseous raw materials was tied to function.

849 The osseous assemblage at Bacho Kiro Cave exhibits a high degree of variation in the types of  
850 objects made, and in the techniques used to fashion them. Some of the informal methods are also  
851 seen in earlier time periods and are likely adapted from techniques used to exploit marrow for  
852 subsistence purposes or for flaking stone (Gürbüz and Lycett, 2021; Villa et al., 2021). A  
853 significant portion of the assemblage exhibits methods specific to working hard animal tissues,  
854 including scraping, grinding, and grooving, and the repetition of some of these items at the site  
855 suggests that there was some degree of standardization in the production process, as well as a  
856 need for conducting specific tasks with similar tools repeatedly.

857 Percussive methods were used to shape bone into tools throughout the Paleolithic. In these cases,  
858 impact fractures occur on various surfaces of a bone and not only within the medullary cavity as  
859 is common for marrow extraction. Knapped or flaked bone tools of this type have a long history  
860 in the African Early Stone Age (Zutovski and Barkai, 2016; Pante et al., 2020; Sano et al., 2020)  
861 and have been preserved in Middle and Late Pleistocene assemblages (e.g., Vincent, 1993;  
862 Radmilli and Boschian, 1996; Mania and Mania, 2005; Julien et al., 2015; Baumann et al., 2020;  
863 Kozlikin et al., 2020; Doyon et al., 2021; Villa et al., 2021), including those within the MP and  
864 UP in southeast Europe (Guadelli, 2011). Both direct and indirect percussive techniques were  
865 used on the Bacho Kiro Cave bone tools to produce and shape the bone tool blanks, but also to  
866 refine their ends and edges for cutting or other tasks that required a sharp edge. A small number  
867 of the knapped bone objects exhibit precise retouch to sharpen and alter their working ends into  
868 specific shapes, as is the case for the bone object that appears to mimic lithic end- or  
869 sidescrapers. This scraper was fashioned from a long bone, and the method used to shape it was  
870 adapted from stone tool manufacture. Further, this bone object and many of the Bacho Kiro Cave  
871 IUP lithic artifacts, mainly blade sidescrapers and retouched blades, exhibit microwear traces

872 consistent with hide working (Marreiros et al., 2019). Replication of a tool that substituted bone  
873 for lithic as the raw material is likely related to the costs of procuring fine-grained flint from  
874 different sources 80–150 km away from the site (Hublin et al., 2020). Most of the lithic artifacts  
875 at Bacho Kiro Cave are reshaped and highly fragmented (Tsanova et al., 2020), and show  
876 intensive development of microwear, including items used for wood and hide working  
877 (Marreiros et al., 2019), reflecting thorough and complete use and reuse of these materials.  
878 Choosing a bone, which would dull much more quickly than a stone, as an alternative material  
879 indicates that these humans were ready to exploit a variety of raw material resources and  
880 supplement them altogether when needed. Alternatively, both lithic and bone tools could have  
881 been preferred for hide working, perhaps representing different phases of the process.

882 Indirect percussion on different materials is also evident at Bacho Kiro Cave, as recognizable  
883 from a number of worked and unworked bone and antler intermediate tools along with splintered  
884 lithic pieces (Kozłowski, 1982; Tsanova, 2008, 2012). Unworked intermediate bone tools have  
885 not been commonly reported from Paleolithic sites, especially from old collections. This may be  
886 due to their informal nature making them difficult to recognize as tools. If recognized, these  
887 objects may be difficult to distinguish from intentionally flaked or knapped bones. Because they  
888 are not formally modified tools but simple long bone diaphyseal fragments, these objects are  
889 extremely variable and only recognizable by their use alterations such as splinter removals and  
890 crushing at their opposing extremities (Tartar, 2012; Tejero et al., 2012; Baumann et al., 2020).

891 Intermediate bone tools have been identified in the Middle and Late Pleistocene (Burke and  
892 d'Errico, 2008; Mozota Holgueras, 2012; Tartar, 2012; Tejero et al., 2012; Julien et al., 2015;  
893 Baumann et al., 2020; Villa et al., 2021), and have been found in the IUP (Kozlikin et al., 2020),  
894 including in the previously excavated material at Bacho Kiro Cave (Guadelli, 2011). A variety of

895 uses have been proposed for this bone tool type, including wood or antler working, wedging for  
896 splitting, and hide processing (Semenov, 1964; Stordeur, 1980; Camps-Fabrer et al., 1998;  
897 Rigaud, 2007; Tartar, 2009, 2012; Tejero et al., 2012). Interestingly, many of the osseous  
898 intermediate tools at Bacho Kiro Cave, both formal and informal, have been modified through  
899 indirect percussion, often with lithic (i.e., splintered pieces or ‘pièces esquillées’) or possibly  
900 other osseous intermediate tools. Experimental work has demonstrated the efficiency of using  
901 antler intermediate tools to work other antler blocks. Like intermediate lithic pieces, antler  
902 wedges also produce small distinct fractures, notches, and compressed areas along the lateral  
903 fracture plane of the worked osseous pieces (Tejero et al., 2012). The Bacho Kiro Cave  
904 assemblage includes a number of bone and antler artifacts with small notches associated with  
905 transversal or oblique striations across the bone or antler fracture plane demonstrating the use of  
906 intermediate pieces on these objects. Lithic splintered pieces have also been identified in the  
907 same layers as these bone objects. Preliminary use-wear analysis of these stone tools has shown  
908 macro- and microwear traces of hard material working such as bone (Marreiros et al., 2019).  
909 These include bifacial and bidirectional superimposed negatives and microwear polish  
910 characterized by a compact mesh and homogeneous smooth surface texture, located at the  
911 termination of the edge fracture scars. Using indirect percussion to fracture hard animal tissues  
912 allows for more control during the fracturing process and is a crucial method in the development  
913 of osseous technologies (Tejero et al., 2012; Horta et al., 2019). While these humans utilized  
914 grooving techniques for pendants and notched pieces, there is little evidence that they grooved  
915 bone prior to inserting a wedge for splitting. The use of this technique on and with varying  
916 materials at Bacho Kiro Cave indicates that this was an important component of their



technological repertoire. Further research is necessary to assess whether these similar tools made on bone, antler, and stone were used for processing similar materials or for differing purposes. Formal bone working at Bacho Kiro Cave is demonstrated by several objects of varying forms. One of these types is the smoothers, which are made from ribs using formal techniques such as scraping. The three objects are interpreted as being used for working animal skins based on features such as invasive polish as well as micro-pitting and multidirectional striations (Christidou and Legrand, 2005; Legrand, 2007). Smoothers, or lissoirs, are one of the oldest formally worked bone types recognized in Europe (Soressi et al., 2013), and have been found in a number of assemblages associated with Neanderthals (Martin, 1909; Mozota Holgueras, 2012; Stepanchuk et al., 2017; Julien et al., 2019; Baumann et al., 2020; Martisius et al., 2020a; Martisius et al., 2020b). Similar to the specimens from the IUP of Bacho Kiro Cave, the majority of the MP artifacts that could be identified to taxa are made on large herbivore ribs (Martin, 1909; Martisius et al., 2020a). Though the Neanderthal-made tools are highly fragmented, at least two large fragments from Abri Peyrony and Axlör and a complete example from La Quina, were made from unsplit ribs (Martin, 1909; Mozota Holgueras, 2012; Soressi et al., 2013). This differs from the complete object from Bacho Kiro Cave, which is partially split and extensively modified at the working end. This trend continued later into the UP where the majority of these tool types were manufactured on highly modified and often entirely split ribs (Tartar, 2009; Martisius, 2019).

Awls are one of the more clearly recognizable osseous artifact types in the Bacho Kiro Cave assemblage. These were made by scraping the bone surface until an acute, pointed distal part was created, while minimally modifying the proximal part. Wear traces indicate that these objects were likely used for piercing animal skins (Campana, 1989; Lemoine, 1994; Griffiths and Bonsall,

2001; Christidou and Legrand, 2005; Buc and Loponte, 2007; Legrand and Radi, 2008). Within the IUP of southwest Asia, awls and other small, pointed objects are the only clearly recognized osseous tool type (Table 6). At Ksâr 'Akil, an awl with regular incisions comes from the IUP Layer XXIII (Newcomer, 1974). Further north at Üçağızlı Cave I in southern Turkey, eight bone tools from the IUP layers F-H date to 45–39 cal bp (Table 6). These objects include awls and small bone points and preserve clear longitudinal scraping traces from the manufacturing process (Kuhn et al., 2009; Stiner et al., 2013), similar to what is found at Bacho Kiro Cave in both the recent and older excavations (Kozłowski, 1982; Guadelli, 2011). Pointed objects are also present within the contemporary Ahmarian Wadi Al-Hasa sites in Jordan (Coinman, 1996). In southeast Europe, an awl was located in Layer 4 of trench I in Temnata Cave (Table 6; Guadelli, 2011). An additional four were found in level VIII and the contact zone of levels VII and VIII (corresponding to the IUP chronology) at Kozarnika Cave (Table 6; Guadelli, 2011). Further, fifteen awls have been located within the subsequent Early Kozarnikian level VII (Guadelli, 2011). Awls are also found in the IUP of north and central Asia (Shunkov et al., 2020), and are ubiquitous among other Eurasian UP and transition period assemblages (e.g., d'Errico et al., 2003; d'Errico et al., 2012; Arrighi et al., 2020). The seemingly sudden appearance of this formal bone tool type from 45 ka in different regions and using similar manufacturing methods could indicate cultural transmission either by population movement and/or stimulus diffusion, albeit a simple technology such as awls could have been invented by differing human groups with similar needs through technological convergence.

The presence of awls together with smoothers, several knapped bone objects likely used as scrapers, and a large portion of objects from the lithic assemblage make up a toolkit for processing animal skins for clothing or other items. Together with the lithic blade sidescrapers,

on which microwear consistent with hide working has been identified, a number of retouched blades with unilateral notches at the distal tip are also associated with similar traces. The presence of micro-polish located on the ventral surface of the notched edge indicates that this feature was also most likely used on animal skins (Marreiros et al., 2019). The different artifacts in the combined bone and lithic skin processing toolkit may have been used during different phases of the process. Lithic tools are sharper and would have been more suitable and efficient for removing the remains of flesh and grease from hide, while bone tools would have been useful at a later phase to finish the tanning process and shape the skin. The bone and lithic items represent an early example of a specialized toolkit where the systematic use of specific objects was employed to produce what likely were durable, protective, and form fitting clothing specifically designed for cold weather (Collard et al., 2016).

Specialized clothing would have been needed for the cold climate and environment around Bacho Kiro Cave as evidenced by the cold-adapted animal taxa found at the site and confirmed by isotopic studies (Pederzani et al., 2021; Smith et al., 2021). Further, this is supported by evidence that these humans sought out and butchered specific animals for their skins. Over the course of the IUP occupation(s), increasing varieties of carnivore species are found in the faunal assemblage, yet carnivore chewing and other modifications are extremely rare (Smith et al., 2021). It is possible that these carnivore remains were brought to the site by humans for their resources including their pelts, while cave bears were likely found or hunted in and around the cave for the same reason, as evidenced by cutmarks on cave bear foot bones and crania. While herbivore skins may have also been processed, the fur of carnivore taxa would have provided additional thermal protection in the cold environment (Collard et al., 2016).

985 Carnivore, especially cave bear, and herbivore teeth were also used as pendants suspended using  
 986 different methods possibly fastened to leather clothing. Some of the manufacturing methods used  
 987 to modify the bone artifacts are also evident on the pendants and beads (e.g., scraping, grinding,  
 988 and grooving), but drilling is unique to the latter. The manufacturing methods recorded for these  
 989 pendants are consistent with those documented from previous excavations at Bacho Kiro Cave,  
 990 which include both pierced and grooved examples (Kozłowski, 1982; Kozłowski, 1992;  
 991 Guadelli, 2011). In the same region within Layer 6/7-level VIII (corresponding to the IUP  
 992 chronology) at Kozarnika cave (Table 6), grooved pendants made from fox teeth are found  
 993 dating to between 49–44 ka (Guadelli et al., 2005; Sirakov et al., 2010; Guadelli, 2011; Tsanova  
 994 et al., 2021). It is worth mentioning that a modified red deer canine was found at Grotte Mandrin  
 995 in France in a layer reported to be IUP and dating to older than 52 ka, but the tooth is not a  
 996 pendant and requires further study (Slimak et al., 2022). Other IUP assemblages in nearby  
 997 regions also preserve ornaments, but those in southwest Asia are almost entirely made from  
 998 marine shell. At Ksâr 'Akil, a large number of both anthropogenically and naturally perforated  
 999 marine gastropod shells appear to be beads (Bosch et al., 2019), and similar shells at Üçağızlı  
 1000 Cave I in addition to a vulture talon were also interpreted as ornaments (Kuhn et al., 2009; Stiner  
 1001 et al., 2013; Table 6). Within north and central Asian IUP sites, various forms of ornaments  
 1002 made from a variety of materials are common (Lbova, 2021). The diversity of ornaments  
 1003 preserved across the IUP in different regions is likely reflective of the locally available raw  
 1004 materials but potentially may have been used to convey similar social information (Kuhn, 2014;  
 1005 Stiner, 2014).  
 1006 Technological flexibility is evident in the wide variety of incised and grooved bone and teeth  
 1007 objects, some of which are undoubtedly functional while others are likely decorative or for other

purposes. At Bacho Kiro Cave, grooving and notching were often used for securing a string or  
 cord as is apparent by the grooved pendants. Similarly, at least one of the notched bones  
 preserves wear traces indicating that a flexible material such as a string was used within the  
 notches. The use of many of the other incised and grooved bones is unclear. Bones with linear  
 markings have been reported from a number of Lower and Middle Paleolithic assemblages (e.g.,  
 Mania and Mania, 1988; Sirakov et al., 2010; Majkić et al., 2017; d’Errico et al., 2018; Majkić et  
 al., 2018; Prévost et al., 2021) and other IUP and early UP assemblages including a notched bone  
 at Kozarnika Cave (Guadelli, 2011), the possible incised awl from Ksâr ’Akil (Newcomer,  
 1974), a notched artifact from Ahmarian contexts in Jordan (Coinman, 1996), or the many  
 artifacts found in north and central Asia (Lbova, 2021). A variety of hypotheses have been  
 proposed for linearly marked objects including as a notation device, tally marks, musical meter,  
 decoration, rasps or scrapers, or as proto-aesthetic behavior, among others (Marshak, 1972; Otte  
 et al., 1982; Huyge, 1990; d’Errico et al., 2018; Hodgson, 2019). The variability of material and  
 technological approach observed on the Bacho Kiro Cave objects suggests that an attempt to  
 assign a single explanation for the phenomenon could be an oversimplification. The presence of  
 a wide variety of incised and notched objects, including those from the previous excavations at  
 Bacho Kiro Cave (Kozłowski, 1982; Guadelli, 2011), demonstrates how these humans adopted  
 one method of bone modification for a number of different utility and/or symbolic purposes  
 (d’Errico and Colagè, 2018). Further, the Bacho Kiro Cave osseous artifact assemblage overall  
 displays a flexibility of technological approaches in osseous material working, a hallmark of the  
 broader UP record (White, 2007), and our study demonstrates that this behavior is well-  
 documented starting with the IUP.

## 5. Conclusions

The large assemblage of osseous artifacts at Bacho Kiro Cave along with the variety of types and methods used to make these objects provides us with an ideal example of technologies and inferred behavioral patterns during this phase of *Homo sapiens*' dispersals. This assemblage indicates that these humans repeated tasks for which a standardized tool type was preferred, but were also flexible, often reshaping and reusing broken objects, and creating expedient bone tools that were used similarly to lithic tools. Many of the expedient or informal objects are on minimally modified long bone diaphyseal fragments, which makes them easy to overlook, especially among formally modified bone, antler, and tooth artifacts. Similar informal tools have been located in earlier Paleolithic assemblages (e.g., Vincent, 1993; Julien et al., 2015; Villa et al., 2021). With continued research on well-preserved and well-documented sites and with an eye towards recognizing these artifacts, it is likely that additional informal bone objects will be shown to be more widespread throughout the Paleolithic. The utilization of informal tools demonstrates the continued importance of expedient tools to conduct quick or simple tasks alongside formally worked bones that appear to function in more specific ways. Interestingly, both unworked and formal artifacts, specifically the intermediate tools, appear to have been used as wedges but it is not clear if they were used on the same materials. Experimental work has demonstrated the efficiency of intermediate tool use for woodworking and splitting antler blocks (Tartar, 2012; Tejero et al., 2012), so these remain distinct possibilities for the Bacho Kiro Cave artifacts. But given that the antler tools would have required additional technological investment including acquisition, extraction, partitioning, and further shaping compared with the bone objects that were likely extracted first for subsistence purposes and then later used as bone tools, it is plausible that the antler objects were more specialized in their usage.

1054 The diversity of materials and techniques represented at Bacho Kiro Cave show that these  
1055 humans manipulated different resources to conduct a wide variety of tasks, some of which  
1056 appear to be part of broader technological systems. By combining different lines of evidence  
1057 including functional inferences, we can propose an array of complex behaviors centered on  
1058 working animal skin for transformation into what was likely cold weather clothing (Collard et  
1059 al., 2016). Animal materials including their bones and skins were extracted, transformed, and  
1060 used in different ways. Due to the variable nature of the objects, both formal and informal, it may  
1061 not be possible to propose one clear systematic process. Both lithic and several of the informal  
1062 bone artifacts appear to be multifunctional and intensively used, often in similar ways. Even one  
1063 formal tool, the complete smoother, exhibits use-wear traces along the edge and end that indicate  
1064 this tool was used for multiple purposes. The overall pattern combined with material properties  
1065 differences indicates that the Bacho Kiro Cave inhabitants likely utilized lithic tools in the early  
1066 stages of skin working and bone tools throughout the process employing a flexible approach that  
1067 exploited different raw materials and supplemented them when needed.

1068 While animal remains were often used for subsistence and technological purposes (as utility  
1069 items), the presence of osseous objects with a symbolic purpose at Bacho Kiro Cave illustrates a  
1070 more complex human-animal relationship. Pendants were made from both herbivore and  
1071 carnivore teeth, with nearly every type of cave bear tooth represented, yet raw material only had  
1072 a minor influence on the pendant manufacturing techniques (e.g., root removal for premolars and  
1073 molars, alteration of herbivore tooth crowns). Various manufacturing methods are observed  
1074 across tooth type with little evidence of standardization and might reflect individual preferences.  
1075 This speaks to the flexibility of the makers' technological approaches, a behavioral pattern found  
1076 later and throughout the UP (White, 2007).

When considering the Bacho Kiro Cave osseous artifact assemblage within broader IUP contexts, similarities are evident including the presence of and the technological traces preserved on formal artifacts such as awls and ornaments made of varying materials. There is a clear divide in the hard animal tissues used for making ornaments with animal teeth most abundant in southeast Europe and marine shell in southwest Asia (Kuhn et al., 2009; Guadelli, 2011; Bosch et al., 2019), a distinction that mirrors the diversity of animal resources found in the differing environmental and climatic regions. If the humans who inhabited different regions shared a cultural background, the difference in raw materials used for ornaments could indicate how these groups adapted a shared cultural trait to the raw material resources found within their local environment. Such flexible behavior would have been beneficial to *Homo sapiens* as they expanded into diverse environments and interacted with other human groups.

The ancestors of the Bacho Kiro Cave individuals had already come in contact with Neanderthals, which is evident from their genetic makeup (Hajdinjak et al., 2021). It is possible that some of the cultural or technological traits used by this IUP group were the result of this interaction. Some MP Neanderthals and *Homo sapiens* share a subset of osseous technologies such as the smoothers or informal bone tools (e.g., Soressi et al., 2013; Baumann et al., 2020), which could provide evidence for shared technological knowledge, though convergence is also possible. Likewise, IUP populations likely influenced the local groups with whom they interacted. Shortly after this migration into Europe, various forms of osseous material culture developed in different regions such as the awls and personal ornaments found further west in Europe, including animal teeth pendants from Châtelperronian contexts with strikingly similar manufacturing methods (e.g., d’Errico et al., 2003; Peresani et al., 2016; Julien et al., 2019; Vanhaeren et al., 2019; Arrighi et al., 2020). The widespread complexity of this time period,



including that exhibited not just by formal tools and ornaments but by informal tools, reflects the pattern of diversified technological behaviors integrated into an increasingly complex and dynamic world of human populations encountering one another. Even more intriguing is the genetic evidence that suggests the Bacho Kiro Cave humans did not leave lasting descendants in Europe (Hajdinjak et al., 2021). Rather, an entirely different group of *Homo sapiens* spread across the European continent using bladelet and blade technologies such as those in Protoaurignacian and, later, Aurignacian contexts, some of which were very similar to the tools made by the IUP groups. The Bacho Kiro Cave humans do have a genetic connection with later Asian populations (Hajdinjak et al., 2021), possibly the result of the expansion of the population bearing IUP technology into different parts of Eurasia. The reconstruction of these cultural and demographic processes is at too coarse a scale, but comprehensive analyses of other IUP sites like Bacho Kiro Cave, as well as integration of osseous artifact, faunal, lithic, and genetic data, should help to assess the role of technology and environment in shaping human behavioral evolution and inter-regional biogeography immediately prior to the UP.

## **Acknowledgments**

This research was funded by the Max Planck Society with additional support to N.L.M. from the Fulbright U.S. Scholar Grant (19-11-04) and the Bulgarian-American Commission for Educational Exchange as well as the NSF-SBE (Award ID: 2004818). G.M.S. received funding from the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101027850. V.A. is funded by FCT grant (PTDC/HAR-ARQ/29606/2017). Recent excavations at Bacho Kiro Cave were conducted by the National Archaeological Institute with Museum, Sofia and the Max Planck Institute for Evolutionary

Anthropology, Leipzig (MPI-EVA). Equipment and facilities provided by the Department of Human Evolution at the MPI-EVA, the Department of Anthropology at the University of California Davis, the Archaeology Department at the New Bulgarian University (Sofia), and the National Museum of Natural History (Sofia). Thank you to the Regional Museum of History in Gabrovo and the History Museum in Dryanovo for their assistance in this project. Special thanks to Pepa Nedelcheva, Rada Kaneva, and Angela Rodel for supporting this research. N.L.M. is grateful to Anna E. Goldfield, Teresa E. Steele, and the UC Davis Steele Lab members for their feedback and discussions of this manuscript.

## References

- Arrighi, S., Moroni, A., Tassoni, L., Boschini, F., Badino, F., Bortolini, E., Boscato, P., Crezzini, J., Figus, C., Forte, M., 2020. Bone tools, ornaments and other unusual objects during the Middle to Upper Palaeolithic transition in Italy. *Quaternary International* 551, 169-187.
- Averbouh, A., 2000. Technologie de la matière osseuse travaillée et implications paléolithiques: l'exemple des chaînes d'exploitation du bois de cervidé chez les Magdaléniens des Pyrénées. Ph.D. Dissertation, Université de Paris I-Panthéon-Sorbonne.
- Backwell, L., d'Errico, F., 2001. Evidence of termite foraging by Swartkrans early hominids. *Proceedings of the National Academy of Sciences of the United States of America* 98, 1358-1363.
- Backwell, L.R., d'Errico, F., 2004. The first use of bone tools: a reappraisal of the evidence from Olduvai Gorge, Tanzania. *Palaeontologia Africana* 40, 95-158.
- Backwell, L., d'Errico, F., 2005. The origin of bone tool technology and the identification of early hominid cultural traditions. In: d'Errico, F., Backwell, L. (Eds.), *From Tools to*

- 1146 Symbols: From Early Hominids to Modern Humans. Wits University Press, Johannesburg,  
1147 pp. 238-275.
- 1148 Bar-Yosef Mayer, D.E., Groman-Yaroslavski, I., Bar-Yosef, O., HersHKovitz, I., Kampen-  
1149 Hasday, A., Vandermeersch, B., Zaidner, Y., Weinstein-Evron, M., 2020. On holes and  
1150 strings: Earliest displays of human adornment in the Middle Palaeolithic. PLoS One 15,  
1151 e0234924.
- 1152 Bar-Yosef, O., 2002. The upper paleolithic revolution. Annual Review of Anthropology 31, 363-  
1153 393.
- 1154 Baumann, M., Plisson, H., Rendu, W., Maury, S., Kolobova, K., Krivoschapkin, A., 2020. The  
1155 Neandertal bone industry at Chagyrskaya cave, Altai Region, Russia. Quaternary International  
1156 559, 68-88.
- 1157 Behrensmeier, A.K., 1978. Taphonomic and ecologic information from bone weathering.  
1158 Paleobiology 4, 150-162.
- 1159 Bergman, C.A., 1987. Hafting and use of bone and antler points from Ksar Akil, Lebanon. La  
1160 Main et l'Outil. Manches et emmanchements préhistoriques. Table Ronde C.N.R.S. tenue à  
1161 lyon du 26 au 29 novembre 1984, sous la direction de D. Stordeur. G.S. Maison de l'Orient  
1162 Méditerranéen, Lyon, pp. 117-126.
- 1163 Binford, L.R., 1979. Organization and formation processes: looking at curated technologies.  
1164 Journal of Anthropological Research 35, 255-273.
- 1165 Binford, L.R., 1981. Bones: Ancient Men and Modern Myths. Academic Press, London.
- 1166 Blumenschine, R.J., Marean, C.W., Capaldo, S.D., 1996. Blind tests of inter-analyst  
1167 correspondence and accuracy in the identification of cut marks, percussion marks, and  
1168 carnivore tooth marks on bone surfaces. Journal of Archaeological Science 23, 493-507.

- 1169 Boaretto, E., Hernandez, M., Goder-Goldberger, M., Aldeias, V., Regev, L., Caracuta, V.,  
 1170 McPherron, S.P., Hublin, J.J., Weiner, S., Barzilai, O., 2021. The absolute chronology of  
 1171 Boker Tachtit (Israel) and implications for the Middle to Upper Paleolithic transition in the  
 1172 Levant. *Proceedings of the National Academy of Sciences of the United States of America*  
 1173 118, e2014657118.
- 1174 Bonnicksen, R., Sorg, M.H. (Eds.), 1989. Bone Modification. Center for the Study of the First  
 1175 Americans, Institute for Quaternary Studies, University of Maine, Orono.
- 1176 Bosch, M.D., Mannino, M.A., Prendergast, A.L., O'Connell, T.C., Demarchi, B., Taylor, S.M.,  
 1177 Niven, L., Van Der Plicht, J., Hublin, J.-J., 2015. New chronology for Ksâr 'Akil (Lebanon)  
 1178 supports Levantine route of modern human dispersal into Europe. *Proceedings of the National*  
 1179 *Academy of Sciences of the United States of America* 112, 7683-7688.
- 1180 Bosch, M.D., Buck, L.T., Strauss, A.M., 2019. Location, location, location: investigating  
 1181 perforation locations in *Tritia gibbosula* shells at Ksâr' Akil (Lebanon) using micro-CT data.  
 1182 *PaleoAnthropology*, 52-63.
- 1183 Bouzouggar, A., Barton, N., Vanhaeren, M., d'Errico, F., Collcutt, S., Higham, T., Hodge, E.,  
 1184 Parfitt, S., Rhodes, E., Schwenninger, J.L., Stringer, C., Turner, E., Ward, S., Moutmir, A.,  
 1185 Stambouli, A., 2007. 82,000-year-old shell beads from North Africa and implications for the  
 1186 origins of modern human behavior. *Proceedings of the National Academy of Sciences of the*  
 1187 *United States of America* 104, 9964-9969.
- 1188 Bouzouggar, A., Humphrey, L.T., Barton, N., Parfitt, S.A., Clark Balzan, L., Schwenninger, J.L.,  
 1189 El Hajraoui, M.A., Nespoulet, R., Bello, S.M., 2018. 90,000 year-old specialised bone  
 1190 technology in the Aterian Middle Stone Age of North Africa. *PLoS One* 13, e0202021.

- 1191 Buc, N., Loponte, D., 2007. Bone tool types and microwear patterns: some examples from the  
 1192 Pampa Region, South America. In: St-Pierre, C.G., Walker, R.B. (Eds.), *Bones as Tools:*  
 1193 *Current Methods and Interpretations in Worked Bone Studies*. BAR International Series,  
 1194 Oxford, pp. 143-157.
- 1195 Buc, N., 2011. Experimental series and use-wear in bone tools. *Journal of Archaeological*  
 1196 *Science* 38, 546-557.
- 1197 Buckley, M., Collins, M., Thomas-Oates, J., Wilson, J.C., 2009. Species identification by  
 1198 analysis of bone collagen using matrix-assisted laser desorption/ionisation time-of-flight mass  
 1199 spectrometry. *Rapid Communications in Mass Spectrometry* 23, 3843-3854.
- 1200 Burke, A., d'Errico, F., 2008. A Middle Palaeolithic bone tool from Crimea (Ukraine). *Antiquity*  
 1201 82, 843-852.
- 1202 Campana, D., 1989. *Natufian and Protoneolithic Bone Tools: the Manufacture and Use of Bone*  
 1203 *Implements in the Zagros and in the Levant*. BAR International Series, Oxford.
- 1204 Camps-Fabrer, H., 1966. *Matière et Art Mobilier dans la Préhistoire Nord- Africaine et*  
 1205 *Saharienne*. Arts et métiers graphique, Paris.
- 1206 Camps-Fabrer, H., Ramseyer, D., Stordeur, D., 1990. *Fiches Typologiques de l'Industrie Osseuse*  
 1207 *Préhistorique*. Cahier III. Poinçons, Pointes, Poignards, Aiguilles, Publications de l'Université  
 1208 de Provence, Aix-en-Provence.
- 1209 Camps-Fabrer, H., Barge-Mahieu, H., 1991. *Fiches Typologiques de l'Industrie Osseuse*  
 1210 *Préhistorique: Cahier 4-Objets de Parure*. Publications de l'Université de Provence, Aix-en-  
 1211 Provence.
- 1212 Camps-Fabrer, H., Cattelain, P., Choï, S.-Y., David, E., Pascual-Benito, J.-L., Provenzano, N.,  
 1213 Ramseyer, D., 1998. *Fiches Typologiques de l'Industrie Osseuse Préhistorique, Cahier VIII:*

- 1214 Biseaux et Tranchants. Commission de nomenclature sur l'industrie osseuse préhistorique,  
1215 Centre d'Etudes et de Documentation Archéologiques, Treignes.
- 1216 Chen, P.Y., Stokes, A.G., McKittrick, J., 2009. Comparison of the structure and mechanical  
1217 properties of bovine femur bone and antler of the North American elk (*Cervus elaphus*  
1218 *canadensis*). *Acta Biomaterialia* 5, 693-706.
- 1219 Choyke, A.M., Bartosiewicz, L. (Eds.), 2001. *Crafting Bone: Skeletal Technologies Through*  
1220 *Time and Space. Proceedings of the 2nd meeting of the (ICAZ) Worked Bone Research*  
1221 *Group Budapest, 31 August – 5 September 1999. BAR International Series 937,*  
1222 *Archaeopress, Oxford.*
- 1223 Christidou, R., 1999. *Outils en os néolithiques du nord de la Grèce: étude technologique. Ph.D.*  
1224 *Dissertation, Université Paris Nanterre.*
- 1225 Christidou, R., Legrand, A., 2005. Hide working and bone tools. Experimentation design and  
1226 applications. In: Luik, H., Choyke, A., Batey, C. and Lougas, L. (Eds.), *From Hooves to*  
1227 *Horns, from Mollusc to Mammoth. Manufacture and Use of Bone Artefacts from Prehistoric*  
1228 *Times to the Present. Proceedings of the 4th Meeting of the ICAZ Worked Bone Research*  
1229 *Group at Tallinn, 26th–31st of August. Tallinn Book Printers Ltd., Tallinn, pp. 385-396.*
- 1230 Coinman, N.R., 1996. Worked bone in the Levantine Upper Paleolithic: rare examples from the  
1231 Wadi Al-Hasa, West-Central Jordan. *Paléorient* 22, 113-121.
- 1232 Collard, M., Tarle, L., Sandgathe, D., Allan, A., 2016. Faunal evidence for a difference in  
1233 clothing use between Neanderthals and early modern humans in Europe. *Journal of*  
1234 *Anthropological Archaeology* 44, 235-246.
- 1235 Costamagno, S., Bourguignon, L., Soulier, M.-C., Meignen, L., Beauval, C., Rendu, W.,  
1236 Mussini, C., Mann, A., Maureille, B., 2018. Bone retouchers and site function in the Quina

- 1237 Mousterian: the case of Les Pradelles (Marillac-le-Franc, France). In: Hutson, J.M., Noack,  
 1238 E.S. (Eds.), *The Origins of Bone Tool Technologies*. Römisch-Germanischen  
 1239 Zentralmuseums, Mainz, pp. 165-196.
- 1240 Cristiani, E., Borić, D., 2012. 8500-year-old Late Mesolithic garment embroidery from Vlasac  
 1241 (Serbia): Technological, use-wear and residue analyses. *Journal of Archaeological Science* 39,  
 1242 3450-3469.
- 1243 Cristiani, E., Dimitrijević, V., Vitezović, S., 2016. Fishing with lure hooks at the Late Neolithic  
 1244 site of Vinča – Belo Brdo, Serbia. *Journal of Archaeological Science* 65, 134-147.
- 1245 Currey, J.D., 2002. *Bones: Structure and Mechanics*. Princeton University Press, Princeton.
- 1246 d'Errico, F., Giacobini, G., Puech, P.F., 1984. Varnish replicas: a new method for the study of  
 1247 worked bone surfaces. *International Journal of Skeletal Research* 9-10, 29-51.
- 1248 d'Errico, F., 1993. La vie sociale de l'art mobilier Paléolithique. Manipulation, transport,  
 1249 suspension des objets on os, bois de cervidés, ivoire. *Oxford Journal of Archaeology* 12, 145-  
 1250 174.
- 1251 d'Errico, F., 1995. A new model and its implications for the origin of writing: the La Marche  
 1252 antler revisited. *Cambridge Archaeological Journal* 5, 163-206.
- 1253 d'Errico, F., Backwell, L.R., 2003. Possible evidence of bone tool shaping by Swartkrans early  
 1254 hominids. *Journal of Archaeological Science* 30, 1559-1576.
- 1255 d'Errico, F., Julien, M., Liolios, D., Vanhaeren, M., Baffier, D., 2003. Many awls in our  
 1256 argument. Bone tool manufacture and use in the Châtelperronian and Aurignacian levels of  
 1257 the Grotte du Renne at Arcy-sur-Cure. In: Zilhão, J., d'Errico, F. (Eds.), *The Chronology of*  
 1258 *the Aurignacian and of the Transitional Technocomplexes: Dating, Stratigraphies, Cultural*  
 1259 *Implications*, 247-270.

- 1260 d'Errico, F., Henshilwood, C.S., 2007. Additional evidence for bone technology in the southern  
1261 African Middle Stone Age. *Journal of Human Evolution* 52, 142-163.
- 1262 d'Errico, F., Vanhaeren, M., Barton, N., Bouzouggar, A., Mienis, H., Richter, D., Hublin, J.-J.,  
1263 McPherron, S.P., Lozouet, P., 2009. Additional evidence on the use of personal ornaments in  
1264 the Middle Paleolithic of North Africa. *Proceedings of the National Academy of Sciences of*  
1265 *the United States of America* 106, 16051-16056.
- 1266 d'Errico, F., Backwell, L.R., Wadley, L., 2012a. Identifying regional variability in Middle Stone  
1267 Age bone technology: The case of Sibudu Cave. *Journal of Archaeological Science* 39, 2479-  
1268 2495.
- 1269 d'Errico, F., Borgia, V., Ronchitelli, A., 2012b. Uluzzian bone technology and its implications  
1270 for the origin of behavioural modernity. *Quaternary International* 259, 59-71.
- 1271 d'Errico, F., Colagè, I., 2018. Cultural exaptation and cultural neural reuse: A mechanism for the  
1272 emergence of modern culture and behavior. *Biological Theory* 13, 213-227.
- 1273 d'Errico, F., Doyon, L., Colagè, I., Queffelec, A., Le Vraux, E., Giacobini, G., Vandermeersch,  
1274 B., Maureille, B., 2018. From number sense to number symbols. An archaeological  
1275 perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences* 373,  
1276 20160518.
- 1277 Daujeard, C., Moncel, M.-H., Fiore, I., Tagliacozzo, A., Bindon, P., Raynal, J.-P., 2014. Middle  
1278 Paleolithic bone retouchers in Southeastern France: Variability and functionality. *Quaternary*  
1279 *International* 326, 492-518.
- 1280 Demars, P.-Y., Laurent, P., 1989. Types d'outils lithiques du Paléolithique supérieur en Europe.  
1281 *Cahiers du Quaternaire*, 1-178.



- 1282 Derevianko, A., Rybin, E., 2003. The earliest representations of symbolic behavior by Paleolithic  
1283 humans in the Altai Mountains. *Archaeology, Ethnology and Anthropology of Eurasia*, 27-50.
- 1284 Dibble, H.L., Aldeias, V., Alvarez-Fernandez, E., Blackwell, B.A., Hallett-Desguez, E., Jacobs,  
1285 Z., Goldberg, P., Lin, S.C., Morala, A., Meyer, M.C., 2012. New excavations at the site of  
1286 Contrebandiers Cave, Morocco. *PaleoAnthropology* 2012, 145-201.
- 1287 Doyon, L., Li, Z., Wang, H., Geis, L., d'Errico, F., 2021. A 115,000-year-old expedient bone  
1288 technology at Lingjing, Henan, China. *PLoS One* 16, e0250156.
- 1289 El Hajraoui, A.M., Debénath, A., 2012. El Mnasra - Chapter XXIV. L'industrie osseuse.  
1290 Préhistoire de la région de Rabat- Témara. In: El Hajraoui, A.M., Nespoulet, R., Debénath,  
1291 A., Dibble, H. (Eds.), *Villes et Sites d'Archéologie Marocaine*, Royaume du Maroc. Ministère  
1292 de la Culture et Institut National des Sciences de l'Archéologie et du Patrimoine, Rabat, pp.  
1293 179–188.
- 1294 Falci, C.G., Cuisin, J., Delpuech, A., Van Gijn, A., Hofman, C.L., 2019. New insights into use-  
1295 wear development in bodily ornaments through the study of ethnographic collections. *Journal*  
1296 *of Archaeological Method and Theory* 26, 755-805.
- 1297 Fernandez-Jalvo, Y., Andrews, P., 2016. *Atlas of taphonomic identifications: 1001+ images of*  
1298 *fossil and recent mammal bone modification*. Springer, Dordrecht.
- 1299 Fewlass, H., Talamo, S., Wacker, L., Kromer, B., Tuna, T., Fagault, Y., Bard, E., McPherron,  
1300 S.P., Aldeias, V., Maria, R., Martisius, N.L., Paskulin, L., Rezek, Z., Sinet-Mathiot, V.,  
1301 Sirakova, S., Smith, G.M., Spasov, R., Welker, F., Tsanova, T., Sirakov, N., Hublin, J.J.,  
1302 2020. A 14 C chronology for the Middle to Upper Palaeolithic transition at Bacho Kiro cave,  
1303 Bulgaria. *Nature Ecology and Evolution* 4, 794-801.

- 1304 Fisher, J.W., 1995. Bone surface modifications in zooarchaeology. *Journal of Archaeological*  
 1305 *Method and Theory* 2, 7-68.
- 1306 Gamble, C., 1998. Palaeolithic society and the release from proximity: a network approach to  
 1307 intimate relations. *World Archaeology* 29, 426-449.
- 1308 Garrod, D., Howe, B., Gaul, J., 1939. Excavations in the cave of Bacho Kiro, north-east  
 1309 Bulgaria. *Bulletin of the American School of Prehistoric Research* 15, 46-76.
- 1310 Gaudzinski, S., 1999. Middle Palaeolithic bone tools from the open-air site Salzgitter-Lebenstedt  
 1311 (Germany). *Journal of Archaeological Science* 26, 125-141.
- 1312 Gilead, I., 1991. The Upper Paleolithic period in the Levant. *Journal of World Prehistory* 5, 105-  
 1313 154.
- 1314 Ginter, B., Kozłowski, J., 1982. Excavation and the stratigraphy of the cave. In: Kozłowski, J.  
 1315 (Ed.), *Excavation in the Bacho Kiro Cave (Bulgaria): Final Report*, Warsaw, pp. 7-12.
- 1316 Granger, J.-M., Lévêque, F., 1997. Parure castelperronienne et aurignacienne: étude de trois  
 1317 séries inédites de dents percées et comparaisons. *Comptes Rendus de l'Académie des*  
 1318 *Sciences-Series IIA-Earth and Planetary Science* 325, 537-543.
- 1319 Griffiths, J., Bonsall, C., 2001. Experimental determination of the function of antler and bone  
 1320 bevel-ended tools' from prehistoric shell middens in Western Scotland. In: Choyke, A.M.,  
 1321 Bartosiewicz, L. (Eds.), *Crafting Bone: Skeletal Technologies Through Time and Space*.  
 1322 *Crafting Bone: Skeletal Technologies Through Time and Space. Proceedings of the 2nd*  
 1323 *meeting of the (ICAZ) Worked Bone Research Group Budapest, 31 August – 5 September*  
 1324 *1999. BAR International Series 937, Archaeopress, Oxford, pp. 207-220.*

- 1325 Guadelli, A., 2011. Kostni artefakti ot paleolita v Bulgaria (Les artefacts en matière dure animale  
1326 du paléolithique Bulgare). Ph.D. Dissertation, National Archaeological Institute with Museum  
1327 of the Bulgarian Academy of Sciences.
- 1328 Guadelli, J.-L., Sirakov, N., Ivanova, S., Sirakova, S., Anastassova, E., Courtaud, P., Dimitrova,  
1329 I., Djabarska, N., Fernandez, P., Ferrier, C., Fontugne, M., Gambier, D., Guadelli, A.,  
1330 Iordanova, D., Kovatcheva, M., Krumov, I., Leblanc, J.-C., Mallye J.-B., Marinska, M.,  
1331 Miteva, V., Popov, V., Spassov, R., Taneva, S., Tisterat-Laborde, N., Tsanova, T., 2005. Une  
1332 séquence du Paléolithique inférieur au Paléolithique récent dans les Balkans: la grotte  
1333 Kozarnika à Orechets (nord-ouest de la Bulgarie). In: Molines, N., Moncel, M.-H., Monnier,  
1334 J.-L. (Eds.), Les Premiers Peuplements en Europe. British Archaeological Reports,  
1335 Archaeopress, Oxford, pp. 87-103.
- 1336 Guérin, C., 1982. Première biozonation du Pléistocène européen, principal résultat  
1337 biostratigraphique de l'étude des Rhinocerotidae (Mammalia, Perissodactyla) du Miocène  
1338 terminal au Pléistocène supérieur d'Europe occidentale. *Geobios* 15, 593-598.
- 1339 Gürbüz, R.B., Lycett, S.J., 2021. Did the use of bone flakes precede the use of knapped stone  
1340 flakes in hominin meat processing and could this be detectable archaeologically? *Journal of*  
1341 *Anthropological Archaeology* 62, 101305.
- 1342 Haddow, S.D., Tsoraki, C., Vasić, M., Dori, I., Knüsel, C.J., Milella, M., 2019. An analysis of  
1343 modified human teeth at Neolithic Çatalhöyük, Turkey. *Journal of Archaeological Science:*  
1344 *Reports* 28, 102058.
- 1345 Hajdinjak, M., Mafessoni, F., Skov, L., Vernot, B., Hübner, A., Fu, Q., Essel, E., Nagel, S.,  
1346 Nickel, B., Richter, J., Moldovan, O.T., Constantin, S., Endarova, E., Zahariev, N., Spassov,  
1347 R., Welker, F., Smith, G.M., Sinet-Mathiot, V., Paskulin, L., Fewlass, H., Talamo, S., Rezek,

- 1348 Z., Sirakova, S., Sirakov, N., McPherron, S.P., Tsanova, T., Hublin, J.-J., Peter, B.M.,  
 1349 Meyer, M., Skoglund, P., Kelso, J., Pääbo, S., 2021. Initial Upper Palaeolithic humans in  
 1350 Europe had recent Neanderthal ancestry. *Nature* 592, 253-257.
- 1351 Hallett, E.Y., Marean, C.W., Steele, T.E., Álvarez-Fernández, E., Jacobs, Z., Cerasoni, J.N.,  
 1352 Aldeias, V., Scerri, E.M., Olszewski, D.I., El Hajraoui, M.A., 2021. A worked bone  
 1353 assemblage from 120,000–90,000 year old deposits at Contrebandiers Cave, Atlantic Coast,  
 1354 Morocco. *iScience*, 102988.
- 1355 Hannus, L.A., Rossum, L., Winham, R.P. (Eds.), 1993. Bone Modification Conference, Hot  
 1356 Springs, South Dakota. Occasional Publication 1, Archeology Laboratory, Augustana  
 1357 College, Sioux Falls.
- 1358 Hardy, M., Bouchard, G.P., Doyon, L., 2014. Un outil en os à usages multiples dans un contexte  
 1359 moustérien. *Bulletin de la Société Préhistorique Française* 111, 741-744.
- 1360 Hayden, B., 1980. Confusion in the bipolar world: bashed pebbles and splintered pieces. *Lithic*  
 1361 *Technology* 9, 2-7.
- 1362 Henshilwood, C.S., d'Errico, F., Marean, C.W., Milo, R.G., Yates, R., 2001. An early bone tool  
 1363 industry from the Middle Stone Age at Blombos Cave, South Africa: implications for the  
 1364 origins of modern human behaviour, symbolism and language. *Journal of Human Evolution*  
 1365 41, 631-678.
- 1366 Hodgson, D., 2019. The origin, significance, and development of the earliest geometric patterns  
 1367 in the archaeological record. *Journal of Archaeological Science: Reports* 24, 588-592.
- 1368 Mozota Holgueras, M., 2012. El hueso como materia prima: El utillaje óseo del final del  
 1369 Musteriense en el sector central del norte de la Península Ibérica. Ph.D. Dissertation,  
 1370 Universidad de Cantabria.

- 1371 Horta, P., Cascalheira, J., Bicho, N., 2019. The role of lithic bipolar technology in Western  
 1372 Iberia's Upper Paleolithic: the case of Vale Boi (Southern Portugal). *Journal of Paleolithic*  
 1373 *Archaeology* 2, 134-159.
- 1374 Hublin, J.-J., 2015. The modern human colonization of western Eurasia: when and where?  
 1375 *Quaternary Science Reviews* 118, 194-210.
- 1376 Hublin, J.J., Sirakov, N., Aldeias, V., Bailey, S., Bard, E., Delvigne, V., Endarova, E., Fagault,  
 1377 Y., Fewlass, H., Hajdinjak, M., Kromer, B., Krumov, I., Marreiros, J., Martisius, N.L.,  
 1378 Paskulin, L., Sinet-Mathiot, V., Meyer, M., Paabo, S., Popov, V., Rezek, Z., Sirakova, S.,  
 1379 Skinner, M.M., Smith, G.M., Spasov, R., Talamo, S., Tuna, T., Wacker, L., Welker, F.,  
 1380 Wilcke, A., Zahariev, N., McPherron, S.P., Tsanova, T., 2020. Initial Upper Palaeolithic  
 1381 *Homo sapiens* from Bacho Kiro Cave, Bulgaria. *Nature* 581, 299-302.
- 1382 Huyge, D. 1990. Mousterian skiffle? Note on a Middle Palaeolithic engraved bone from Schulen,  
 1383 Belgium. *Rock Art Research* 7, 125- 132.
- 1384 Jacobs, Z., Roberts, R.G., Nespoulet, R., El Hajraoui, M.A., Debenath, A., 2012. Single-grain  
 1385 OSL chronologies for Middle Palaeolithic deposits at El Mnasra and El Harhoura 2,  
 1386 Morocco: Implications for Late Pleistocene human-environment interactions along the  
 1387 Atlantic coast of northwest Africa. *Journal of Human Evolution* 62, 377-394.
- 1388 Julien, M., Vanhaeren, M., d'Errico, F., 2019. Armes et outils en matières dures animales. In:  
 1389 Julien, M., David, F., Girard, M., Roblin-Jouve, A. (Eds.), *Le Châtelperronien de la Grotte*  
 1390 *du Renne (Arcy-sur-Cure, Yonne, France). Les Fouilles d'André Leroi-Gourhan (1949-*  
 1391 *1963). Société des Amis du Musée national de Préhistoire et de la Recherche archéologique,*  
 1392 *Les Eyzies-de-Tayac, hal-02412737.*

- 1393 Julien, M.A., Hardy, B., Stahlschmidt, M.C., Urban, B., Serangeli, J., Conard, N.J., 2015.  
 1394 Characterizing the Lower Paleolithic bone industry from Schoningen 12 II: A multi-proxy  
 1395 study. *Journal of Human Evolution* 89, 264-286.
- 1396 Klein, R.G., 2009. *The Human Career: Human biological and cultural origins*, 3rd ed. University  
 1397 of Chicago Press, Chicago.
- 1398 Knecht, H., 1993. Splits and wedges: the techniques and technology of early Aurignacian antler  
 1399 working. In: Knecht, H., Pike-Tay, A., White, R. (Eds.), *Before Lascaux: the Complex*  
 1400 *Record of the Early Upper Palaeolithic*. CRC Press, Boca Raton, pp. 139-162.
- 1401 Kozlikin, M., Rendu, W., Plisson, H., Baumann, M., Shunkov, M., 2020. Unshaped bone tools  
 1402 from Denisova Cave, Altai. *Archaeology, Ethnology and Anthropology of Eurasia* 48, 16-28.
- 1403 Kozłowski, J.K. (Ed.), 1982. *Excavation in the Bacho Kiro Cave (Bulgaria): Final Report*. Polish  
 1404 Scientific Publishers, Warsaw.
- 1405 Kozłowski, J., 1992. The Balkans in the Middle and Upper Palaeolithic: the gate to Europe or a  
 1406 cul-de-sac?, *Proceedings of the Prehistoric Society*. Cambridge University Press, Cambridge,  
 1407 pp. 1-20.
- 1408 Kozłowski, J.K., Otte, M., 2000. The formation of the Aurignacian in Europe. *Journal of*  
 1409 *Anthropological Research* 56, 513-534.
- 1410 Kuhn, S.L., Stiner, M.C., Gulec, E., Ozer, I., Yilmaz, H., Baykara, I., Aciklol, A., Goldberg, P.,  
 1411 Molina, K.M., Unay, E., Suata-Alpaslan, F., 2009. The early Upper Paleolithic occupations at  
 1412 Ucagizli Cave (Hatay, Turkey). *Journal of Human Evolution* 56, 87-113.
- 1413 Kuhn, S.L., 2014. Signaling theory and technologies of communication in the Paleolithic.  
 1414 *Biological Theory* 9, 42-50.

- 1415 Kuhn, S.L., Zwyns, N., 2014. Rethinking the initial upper paleolithic. *Quaternary International*  
 1416 347, 29-38.
- 1417 Kuhn, S.L., 2019. Initial Upper Paleolithic: A (near) global problem and a global opportunity.  
 1418 *Archaeological Research in Asia* 17, 2-8.
- 1419 Lbova, L., 2010. Evidence of modern human behavior in the Baikal zone during the Early Upper  
 1420 Paleolithic period. *Bulletin of the Indo-Pacific Prehistory Association* 30, 9-13.
- 1421 Lbova, L., 2021. Personal ornaments as markers of social behavior, technological development  
 1422 and cultural phenomena in the Siberian early upper Paleolithic. *Quaternary International* 573,  
 1423 4-13.
- 1424 Legrand, A., 2007. *Fabrication et Utilisation de l'Outillage en Matières Osseuses du Néolithique*  
 1425 *de Chypre: Khirokitia et Cap Andreas-Kastros*. BAR International Series, Oxford.
- 1426 Legrand, A., Radi, G., 2008. Manufacture and use of bone points from early Neolithic Colle  
 1427 Santo Stefano, Abruzzo, Italy. *Journal of Field Archaeology* 33, 305-320.
- 1428 Lemoine, G.M., 1994. Use wear on bone and antler tools from the Mackenzie Delta, Northwest-  
 1429 Territories. *American Antiquity* 59, 316-334.
- 1430 MacGregor, A.G., Currey, J.D., 1983. Mechanical properties as conditioning factors in the bone  
 1431 and antler industry of the 3rd to the 13th century AD. *Journal of Archaeological Science* 10,  
 1432 71-77.
- 1433 Majkić, A., Evans, S., Stepanchuk, V., Tsvelykh, A., d'Errico, F., 2017. A decorated raven bone  
 1434 from the Zaskalnaya VI (Kolosovskaya) Neanderthal site, Crimea. *PLoS One* 12, e0173435.
- 1435 Majkić, A., d'Errico, F., Milošević, S., Mihailović, D., Dimitrijević, V., 2018. Sequential  
 1436 incisions on a cave bear bone from the Middle Paleolithic of Pešturina Cave, Serbia. *Journal*  
 1437 *of Archaeological Method and Theory* 25, 69-116.

- 1438 Mania, D., Mania, U., 1988. Deliberate engravings on bone artefacts of *Homo erectus*. Rock Art  
1439 Research 5, 91-107.
- 1440 Mania, D., Mania, U., 2005. The natural and socio-cultural environment of *Homo erectus* at  
1441 Bilzingsleben, Germany. In: Gamble, C., Porr, M. (Eds.), The Hominid Individual in Context:  
1442 Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales and  
1443 Artefacts. Routledge, London, pp. 98-114.
- 1444 Marks, A., Volkman, P., 1983. Changing core reduction strategies: a technological shift from the  
1445 Middle to the Upper Paleolithic in the southern Levant. In: Trinkaus, E. (Ed.), The Mousterian  
1446 Legacy: Human Biocultural Change in the Upper Pleistocene. BAR International Series,  
1447 Oxford, pp. 13-34.
- 1448 Marreiros, J., Martisius, N.L., Tsanova, T., McPherron, S., Sirakov, N., Hublin, J.-J., 2019.  
1449 Functional analysis on the lithic assemblage from Layer I (the Bachokirian) at the onset of  
1450 the Upper Palaeolithic in Bacho Kiro cave, Bulgaria, Paper presented at the 9th Annual  
1451 meeting of the European Society for the study of Human Evolution 19th-21st September,  
1452 2019, abstract book, Liège, Belgium.
- 1453 Marshack, A., 1972. Cognitive aspects of Upper Paleolithic engraving. Current Anthropology  
1454 13, 445- 477.
- 1455 Martin, H., 1909. Recherches sur l'Evolution du Moustérien dans le Gisement de La Quina  
1456 (Charente). Schleicher Frères, Paris.
- 1457 Martisius, N.L., Sidéra, I., Grote, M.N., Steele, T.E., McPherron, S.P., Schulz-Kornas, E., 2018.  
1458 Time wears on: assessing how bone wears using 3D surface texture analysis. PLoS One 13,  
1459 e0206078.



- 1460 Martisius, N.L., 2019. The Middle Paleolithic lissoirs (smoothers) from Abri Peyrony and Pech-  
 1461 de-l'Azé I: investigating Neandertal bone tool material selection, manufacture, and use,  
 1462 Anthropology. Ph.D. Dissertation, University of California, Davis.
- 1463 Martisius, N.L., Welker, F., Dogandzic, T., Grote, M.N., Rendu, W., Sinet-Mathiot, V., Wilcke,  
 1464 A., McPherron, S.J.P., Soressi, M., Steele, T.E., 2020a. Non-destructive ZooMS identification  
 1465 reveals strategic bone tool raw material selection by Neandertals. *Scientific Reports* 10, 7746.
- 1466 Martisius, N.L., McPherron, S.P., Schulz-Kornas, E., Soressi, M., Steele, T.E., 2020b. A method  
 1467 for the taphonomic assessment of bone tools using 3D surface texture analysis of bone  
 1468 microtopography. *Archaeological and Anthropological Sciences* 12, 1-16.
- 1469 Mateo-Lomba, P., Fernández-Marchena, J.L., Ollé, A., Cáceres, I., 2020. Knapped bones used as  
 1470 tools: experimental approach on different activities. *Quaternary International* 569, 51-65.
- 1471 McGrath, K., Rowsell, K., Gates St-Pierre, C., Tedder, A., Foody, G., Roberts, C., Speller, C.,  
 1472 Collins, M., 2019. Identifying archaeological bone via non-destructive ZooMS and the  
 1473 materiality of symbolic expression: examples from Iroquoian bone points. *Scientific Reports*  
 1474 9, 11027.
- 1475 Mellars, P., 1973. The Character of the Middle-up per Paleolithic Transition in south-west  
 1476 France. *The Explanation of Culture Change, Models in Prehistory*, 225-276.
- 1477 Mellars, P., 2005. The impossible coincidence. A single-species model for the origins of modern  
 1478 human behavior in Europe. *Evolutionary Anthropology: Issues, News, and Reviews: Issues,*  
 1479 *News, and Reviews* 14, 12-27.
- 1480 Newcomer, M.H., 1974. Study and replication of bone tools from Ksar Akil (Lebanon). *World*  
 1481 *Archaeology* 6, 138-153.

- 1482 Newcomer, M., Watson, J., 1984. Bone artifacts from Ksar ‘Aqil (Lebanon). *Paléorient* 10, 143-  
1483 147.
- 1484 Olsen, S.L., 1984. Analytical approaches to the manufacture and use of bone artifacts in  
1485 prehistory. Ph.D. Dissertation, University of London.
- 1486 Osipowicz, G., Piličiauskienė, G., Orłowska, J., Piličiauskas, G., 2020. An occasional ornament,  
1487 part of clothes or just a gift for ancestors? The results of traceological studies of teeth  
1488 pendants from the Subneolithic sites in Šventoji, Lithuania. *Journal of Archaeological*  
1489 *Science: Reports* 29, 102130.
- 1490 Otte, M., Gautier, A., Bibuyck, P.H., 1982. Interpretation d’un ossement encoche de la préhistoire  
1491 Syrienne. *Paleorient* 8, 85- 86.
- 1492 Pante, M., Torre, I., d’Errico, F., Njau, J., Blumenschine, R., 2020. Bone tools from Beds II-IV,  
1493 Olduvai Gorge, Tanzania, and implications for the origins and evolution of bone technology.  
1494 *Journal of Human Evolution* 148, 102885.
- 1495 Pedergrana, A., Cristiani, E., Munro, N., Valletta, F., Sharon, G., 2021. Early line and hook  
1496 fishing at the Epipaleolithic site of Jordan River Dureijat (Northern Israel). *PloS One* 16,  
1497 e0257710.
- 1498 Pederzani, S., Britton, K., Aldeias, V., Bourgon, N., Fewlass, H., Lauer, T., McPherron, S.P.,  
1499 Rezek, Z., Sirakov, N., Smith, G.M., Spasov, R., Tran, N.H., Tsanova, T., Hublin, J.J., 2021.  
1500 Subarctic climate for the earliest *Homo sapiens* in Europe. *Scientific Advances* 7, eabi4642.
- 1501 Peresani, M., Cristiani, E., Romandini, M., 2016. The Uluzzian technology of Grotta di Fumane  
1502 and its implication for reconstructing cultural dynamics in the Middle-Upper Palaeolithic  
1503 transition of Western Eurasia. *Journal of Human Evolution* 91, 36-56.

- 1504 Prévost, M., Groman-Yaroslavski, I., Gershtein, K.M.C., Tejero, J.-M., Zaidner, Y., 2021. Early  
 1505 evidence for symbolic behavior in the Levantine Middle Paleolithic: A 120 ka old engraved  
 1506 aurochs bone shaft from the open-air site of Nesher Ramla, Israel. *Quaternary International*.  
 1507 <https://doi.org/10.1016/j.quaint.2021.01.002>
- 1508 Provenzano, N., 1998. Fiche générale des objets à biseau distal. In: Camps-Fabrer, H., Cattelain,  
 1509 P., Choï, S.-Y., David, E., Pascual-Benito, J.-L., Provenzano, N., Ramseier, D. (Eds.),  
 1510 Fiches Typologiques de l'Industrie Osseuse Préhistorique. Cahier VIII: Biseaux et  
 1511 Tranchants. Commission de nomenclature sur l'industrie osseuse préhistorique, Centre  
 1512 d'Etudes et de Documentation Archéologiques, Treignes, pp. 5-16.
- 1513 Radmilli, A., Boschian, G., 1996. Gli Scavi a Castel di Guido. Il Più Antico Giacimento di  
 1514 Cacciatori Nell'Agro Romano. Istituto Italiano di Preistoria e Protostoria, Firenze.
- 1515 Ramsey, C.B., 2009. Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon* 51,  
 1516 1023-1045.
- 1517 Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin,  
 1518 M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I.,  
 1519 Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer,  
 1520 J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R.,  
 1521 Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-  
 1522 Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto,  
 1523 M., Sookdeo, A., Talamo, S., 2020. The IntCal20 Northern Hemisphere Radiocarbon Age  
 1524 Calibration Curve (0–55 cal kBP). *Radiocarbon* 62, 725-757.

- 1525 Richter, D., Tostevin, G., Škrdla, P., Davies, W., 2009. New radiometric ages for the Early  
 1526 Upper Palaeolithic type locality of Brno-Bohunice (Czech Republic): comparison of OSL,  
 1527 IRSL, TL and 14C dating results. *Journal of Archaeological Science* 36, 708-720.
- 1528 Rigaud, A., 2007. Retouchoirs sur éclats diaphysaires ou «affûtoirs» de Labastide (Hautes-  
 1529 Pyrénées). *Du barbarisme scientifique à la rigueur artisanale au travers de l'expérimentation.*  
 1530 *Archéologie des Pyrénées Occidentales et des Landes* 26, 193-200.
- 1531 Rybin, E.P., 2014. Tools, beads, and migrations: Specific cultural traits in the Initial Upper  
 1532 Paleolithic of Southern Siberia and Central Asia. *Quaternary International* 347, 39-52.
- 1533 Sano, K., Beyene, Y., Katoh, S., Koyabu, D., Endo, H., Sasaki, T., Asfaw, B., Suwa, G., 2020. A  
 1534 1.4-million-year-old bone handaxe from Konso, Ethiopia, shows advanced tool technology in  
 1535 the early Acheulean. *Proceedings of the National Academy of Sciences of the United States of*  
 1536 *America* 117, 18393-18400.
- 1537 Sehassseh, E.M., Fernandez, P., Kuhn, S., Stiner, M., Mentzer, S., Colarossi, D., Clark, A.,  
 1538 Lanoe, F., Pailes, M., Hoffmann, D., Benson, A., Rhodes, E., Benmansour, M., Laissaoui, A.,  
 1539 Ziani, I., Vidal-Matutano, P., Morales, J., Djellal, Y., Longet, B., Hublin, J.J., Mouhiddine,  
 1540 M., Rafi, F.Z., Worthey, K.B., Sanchez-Morales, I., Ghayati, N., Bouzouggar, A., 2021. Early  
 1541 Middle Stone Age personal ornaments from Bizmoune Cave, Essaouira, Morocco. *Scientific*  
 1542 *Advances* 7, eabi8620.
- 1543 Semenov, S.A., 1964. *Prehistoric Technology: An Experimental Study of the Oldest Tools and*  
 1544 *Artefacts from Traces of Manufacture and Wear.* Cory, Adams & Mackay, London.
- 1545 Shipman, P., Rose, J.J., 1988. Bone tools: an experimental approach. In: Olsen., S.L. (Ed.),  
 1546 *Scanning Electron Microscopy in Archaeology.* British Archaeological Reports, Oxford, pp.  
 1547 303-335.

- 1548 Shunkov, M.V., Fedorchenko, A.Y., Kozlikin, M.B., Derevianko, A.P., 2020. Initial Upper  
1549 Palaeolithic ornaments and formal bone tools from the East Chamber of Denisova Cave in the  
1550 Russian Altai. *Quaternary International* 559, 47-67.
- 1551 Sidéra, I., 1993. Les assemblages osseux en bassins parisien et rhénan du VI<sup>e</sup> au IV<sup>e</sup> millénaire  
1552 B.C.: Histoire, techno-économie et culture. Ph.D. Dissertation, Université de Paris I-  
1553 Panthéon-Sorbonne.
- 1554 Sirakov, N., Guadelli, J.-L., Ivanova, S., Sirakova, S., Boudadi-Maligne, M., Dimitrova, I., Ph,  
1555 F., Ferrier, C., Guadelli, A., Iordanova, D., Iordanova, N., Kovatcheva, M., Krumov, I.,  
1556 Leblanc, J.-Cl., Miteva, V., Popov, V., Spassov, R., Taneva, S., Tsanova, T., 2010. An ancient  
1557 continuous human presence in the Balkans and the beginnings of human settlement in western  
1558 Eurasia: A Lower Pleistocene example of the Lower Palaeolithic levels in Kozarnika cave  
1559 (North-western Bulgaria). *Quaternary International* 223, 94-106.
- 1560 Slimak, L., Zanolli, C., Higham, T., Frouin, M., Schwenninger, J.-L., Arnold, L.J., Demuro, M.,  
1561 Douka, K., Mercier, N., Guérin, G., Valladas, H., Yvorra, P., Giraud, Y., Seguin-Orlando, A.,  
1562 Orlando, L., Lewis, J.E., Muth, X., Camus, H., Vandevelde, S., Buckley, M., Mallol, C.,  
1563 Stringer, C., Metz, L., 2022. Modern human incursion into Neanderthal territories 54,000  
1564 years ago at Mandrin, France. *Science Advances* 8, eabj9496.
- 1565 Smith, G.M., Spasov, R., Martisius, N.L., Sinet-Mathiot, V., Aldeias, V., Rezek, Z., Ruebens, K.,  
1566 Pederzani, S., McPherron, S.P., Sirakova, S., Sirakov, N., Tsanova, T., Hublin, J.-J., 2021.  
1567 Subsistence behavior during the Initial Upper Paleolithic in Europe: site use, dietary practice,  
1568 and carnivore exploitation at Bacho Kiro Cave (Bulgaria). *Journal of Human Evolution* 161,  
1569 103074.

- 1570 Soressi, M., McPherron, S.P., Lenoir, M., Dogandzic, T., Goldberg, P., Jacobs, Z., Maigrot, Y.,  
 1571 Martisius, N.L., Miller, C.E., Rendu, W., Richards, M., Skinner, M.M., Steele, T.E., Talamo,  
 1572 S., Texier, J.P., 2013. Neandertals made the first specialized bone tools in Europe.  
 1573 Proceedings of the National Academy of Sciences of the United States of America 110,  
 1574 14186-14190.
- 1575 Speth, J.D., Meignen, L., Bar-Yosef, O., Goldberg, P., 2012. Spatial organization of Middle  
 1576 Paleolithic occupation X in Kebara Cave (Israel): concentrations of animal bones. Quaternary  
 1577 International 247, 85-102.
- 1578 Steele, T.E., Álvarez-Fernández, E., Hallet-Desguez, E., 2019. Personal ornaments in early  
 1579 prehistory a review of shells as personal ornamentation during the African Middle Stone Age.  
 1580 PaleoAnthropology 24, 24-51.
- 1581 Stepanchuk, V.N., Vasilyev, S.V., Khaldeeva, N.I., Kharlamova, N.V., Borutskaya, S.B., 2017.  
 1582 The last Neanderthals of Eastern Europe: Micoquian layers IIIa and III of the site of  
 1583 Zaskalnaya VI (Kolosovskaya), anthropological records and context. Quaternary International  
 1584 428, 132-150.
- 1585 Stiner, M.C., Kuhn, S.L., Weiner, S., Bar-Yosef, O., 1995. Differential burning, recrystallization,  
 1586 and fragmentation of archaeological bone. Journal of Archaeological Science 22, 223-237.
- 1587 Stiner, M.C., Kuhn, S.L., Güleç, E., 2013. Early Upper Paleolithic shell beads at Üçağızlı Cave I  
 1588 (Turkey): technology and the socioeconomic context of ornament life-histories. Journal of  
 1589 Human Evolution 64, 380-398.
- 1590 Stiner, M.C., 2014. Finding a common bandwidth: causes of convergence and diversity in  
 1591 paleolithic beads. Biological Theory 9, 51-64.

- 1592 Stone, E.A., 2011. Through the eye of the needle: investigations of ethnographic, experimental,  
1593 and archaeological bone tool use wear from pershiable technologies. Ph.D. Dissertation,  
1594 University of New Mexico.
- 1595 Stordeur, D., 1980. Les derniers objets en os de l'Europe occidentale (résultats d'une enquête de  
1596 1976). Objets En Os, Historiques et Actuels. Première Réunion du Groupe de Travail n°6 sur  
1597 l'Industrie de l'Os, GIS, Lyon, mars 1979. Sous la direction de Danielle Stordeur. Maison de  
1598 l'Orient Méditerranéen, Lyon, pp. 63-73.
- 1599 Tartar, É., 2009. De l'os à l'outil: Caractérisation technique, économique et sociale de l'utilisation  
1600 de l'os à l'Aurignacien ancien: Étude de trois sites: l'Abri Castanet (secteurs nord et sud),  
1601 Brassempouy (Grotte des Hyènes et Abri Dubalen) et Gatzarria. Ph.D. Dissertation,  
1602 Université de Paris I-Panthéon-Sorbonne.
- 1603 Tartar, E., 2012. The recognition of a new type of bone tools in Early Aurignacian assemblages:  
1604 implications for understanding the appearance of osseous technology in Europe. Journal of  
1605 Archaeological Science 39, 2348-2360.
- 1606 Tejero, J.-M., Christensen, M., Bodu, P., 2012. Red deer antler technology and early modern  
1607 humans in Southeast Europe: an experimental study. Journal of Archaeological Science 39,  
1608 332-346.
- 1609 Tejero, J.-M., 2014. Towards complexity in osseous raw material exploitation by the first  
1610 anatomically modern humans in Europe: Aurignacian antler working. Journal of  
1611 Anthropological Archaeology 36, 72-92.
- 1612 Tejero, J.-M., Grimaldi, S., 2015. Assessing bone and antler exploitation at Riparo Mochi (Balzi  
1613 Rossi, Italy): implications for the characterization of the Aurignacian in South-western  
1614 Europe. Journal of Archaeological Science 61, 59-77.

- 1615 Tejero, J.-M., Yeshurun, R., Barzilai, O., Goder-Goldberger, M., HersHKovitz, I., Lavi, R.,  
 1616 Schneller-Pels, N., Marder, O., 2016. The osseous industry from Manot Cave (Western  
 1617 Galilee, Israel): technical and conceptual behaviours of bone and antler exploitation in the  
 1618 Levantine Aurignacian. *Quaternary International* 403, 90-106.
- 1619 Tejero, J.-M., Bar-Oz, G., Bar-Yosef, O., Meshveliani, T., Jakeli, N., Matskevich, Z., Pinhasi,  
 1620 R., Belfer-Cohen, A., 2021a. New insights into the Upper Palaeolithic of the Caucasus  
 1621 through the study of personal ornaments. Teeth and bones pendants from Satsurbliia and  
 1622 Dzudzuana caves (Imereti, Georgia). *PloS One* 16, e0258974.
- 1623 Tejero, J.-M., Rabinovich, R., Yeshurun, R., Abulafia, T., Bar-Yosef, O., Barzilai, O., Goder-  
 1624 Goldberger, M., HersHKovitz, I., Lavi, R., Shemer, M., 2021b. Personal ornaments from  
 1625 Hayonim and Manot caves (Israel) hint at symbolic ties between the Levantine and the  
 1626 European Aurignacian. *Journal of Human Evolution* 160, 102870.
- 1627 Teyssandier, N., 2008. Revolution or evolution: the emergence of the Upper Paleolithic in  
 1628 Europe. *World Archaeology* 40, 493-519.
- 1629 Tsanova, T., Bordes, J.-G., 2003. Contribution au débat sur l'origine de l'Aurignacien: principaux  
 1630 résultats d'une étude technologique de l'industrie lithique de la couche 11 de Bacho Kiro. In:  
 1631 Tsonev, T., Montagnari Kokelj, E. (Eds.), *The Humanized Mineral World: Towards Social  
 1632 and Symbolic Evaluation of Prehistoric Technologies in South Eastern Europe. Proceedings  
 1633 of the ESF workshop, Sofia, 3-6 September 2003. Université de Liège, Service de  
 1634 Préhistoire, Liège, pp. 41-50.*
- 1635 Tsanova, T., 2008. Les Débuts du Paléolithique Supérieur dans l'Est des Balkans. *Réflexion à  
 1636 Partir de l'Étude Taphonomique et Techno-Économique des Ensembles Lithiques des Sites*



- 1637 de Bacho Kiro (couche 11), Temnata (couches VI et 4) et Kozarnika (niveau VII). BAR  
 1638 International Series, Oxford.
- 1639 Tsanova, T., 2012. A diachronic view of flake production from the beginning of the Upper  
 1640 Palaeolithic in the eastern Balkans. In: Pastoors, A., Peresani, M. (Eds.), *Flakes not Blades: The Role of Flake Production at the Onset of the Upper Paleolithic in Europe*. Neanderthal  
 1641 Museum, Mettmann, pp. 215-237.
- 1642
- 1643 Tsanova, T., Sirakov, N., Delvigne, V., Sirakova, S., Marreiros, J., Horta, P., Krumov, I.,  
 1644 Zahariev, N., Nachev, T., Anastassova, E., Rezek, Z., Hublin, J.-J., McPherron, S.P., 2020.  
 1645 The Initial Upper Palaeolithic lithic assemblage from Bacho Kiro Cave (Bulgaria), Paper  
 1646 presented at the 9th Annual meeting of the European Society for the study of Human  
 1647 Evolution, abstract book, virtual meeting, p. 120.
- 1648 Tsanova, T., Veres, D., Hambach, U., Spasov, R., Dimitrova, I., Popov, P., Talamo, S., Sirakova,  
 1649 S., 2021. Upper Palaeolithic layers and Campanian Ignimbrite/Y-5 tephra in Toplitsa cave,  
 1650 Northern Bulgaria. *Journal of Archaeological Science: Reports* 37, 102912.
- 1651 van der Made, J., 2018. Quaternary large-mammal zones. *The Encyclopedia of Archaeological*  
 1652 *Sciences*, 1-4.
- 1653 Vanhaeren, M., d'Errico, F., 2006. Aurignacian ethno-linguistic geography of Europe revealed  
 1654 by personal ornaments. *Journal of Archaeological Science* 33, 1105-1128.
- 1655 Vanhaeren, M., d'Errico, F., Julien, M., Mourer-Chauviré, C., Lozouet, P., 2019. Les objets de  
 1656 parure. In: Julien, M., David, F., Girard, M., Roblin-Jouve, A. (Eds.), *Le Châtelperronien de la grotte du Renne (Arcy-sur-Cure, Yonne, France). Les fouilles d'André Leroi-Gourhan (1949-1963)*. Société des Amis du Musée national de Préhistoire et de la Recherche  
 1657 archéologique, Les Eyzies-de-Tayac, hal-02412704.

- 1660 Villa, P., Mahieu, E., 1991. Breakage patterns of human long bones. *Journal of Human Evolution*  
 1661 21, 27-48.
- 1662 Villa, P., d'Errico, F., 2001. Bone and ivory points in the Lower and Middle Paleolithic of  
 1663 Europe. *Journal of Human Evolution* 41, 69-112.
- 1664 Villa, P., Delagnes, A., Wadley, L., 2005. A late middle stone age artifact assemblage from  
 1665 Sibudu (KwaZulu-Natal): comparisons with the European middle Paleolithic. *Journal of*  
 1666 *Archaeological Science* 32, 399-422.
- 1667 Villa, P., Boschian, G., Pollarolo, L., Sacca, D., Marra, F., Nomade, S., Pereira, A., 2021.  
 1668 Elephant bones for the Middle Pleistocene toolmaker. *PLoS One* 16, e0256090.
- 1669 Vincent, A., 1993. L'outillage osseux au Paléolithique moyen: une nouvelle approche. Ph.D.  
 1670 Dissertation, Université de Paris X.
- 1671 Welker, F., Hajdinjak, M., Talamo, S., Jaouen, K., Dannemann, M., David, F., Julien, M.,  
 1672 Meyer, M., Kelso, J., Barnes, I., Brace, S., Kamminga, P., Fischer, R., Kessler, B.M., Stewart,  
 1673 J.R., Paabo, S., Collins, M.J., Hublin, J.J., 2016. Palaeoproteomic evidence identifies archaic  
 1674 hominins associated with the Chatelperronian at the Grotte du Renne. *Proceedings of the*  
 1675 *National Academy of Sciences of the United States of America* 113, 11162-11167.
- 1676 White, R., 2007. Systems of personal ornamentation in the Early Upper Palaeolithic:  
 1677 Methodological challenges and new observations. In: Mellars, P., Boyle, K., Bar-Yosef, O.,  
 1678 Stringer, C. (Eds.), *Rethinking the human revolution: new behavioural and biological*  
 1679 *perspectives on the origin and dispersal of modern humans*. McDonald Institute for  
 1680 *Archaeological Research*, Cambridge, pp. 287-302.
- 1681 White, R., Normand, C., 2015. Early and archaic Aurignacian personal ornaments from Isturitz  
 1682 cave: technological and regional perspectives. In: White, R., Bourrillon, R., Bon, F. (Eds.),

- 1683 Aurignacian Genius: Art, Technology and Society of the First Modern Humans in Europe,  
 1684 Proceedings of the International Symposium, April 08-10 2013. New York University,  
 1685 P@lethnology 7, pp. 138-164.
- 1686 White, R., Mensan, R., Clark, A.E., Tartar, E., Marquer, L., Bourrillon, R., Goldberg, P., Chiotti,  
 1687 L., Cretin, C., Rendu, W., Pike-Tay, A., Ranlett, S., 2017. Technologies for the control of heat  
 1688 and light in the Vézère Valley Aurignacian. *Current Anthropology* 58, S288-S302.
- 1689 Yellen, J.E., Brooks, A.S., Cornelissen, E., Mehlman, M.J., Stewart, K., 1995. A Middle Stone  
 1690 Age worked bone industry from Katanda, Upper Semliki Valley, Zaire. *Science* 268, 553-556.
- 1691 Zilhão, J., 2013. Neandertal-modern human contact in Western Eurasia: issues of dating,  
 1692 taxonomy, and cultural associations. In: Akazawa, T., Nishiaki, Y., Aoki, K. (Eds.),  
 1693 Dynamics of Learning in Neanderthals and Modern Humans. Volume 1: Cultural  
 1694 Perspectives. Springer, Tokyo, pp. 21-57.
- 1695 Zutovski, K., Barkai, R., 2016. The use of elephant bones for making Acheulian handaxes: a  
 1696 fresh look at old bones. *Quaternary International* 406, 227-238.
- 1697 Zwyns, N., Lbova, L., 2019. The Initial Upper Paleolithic of Kamenka site, Zabaikal region  
 1698 (Siberia): a closer look at the blade technology. *Archaeological Research in Asia* 17, 24-49.
- 1699 Zwyns, N., Paine, C.H., Tsedendorj, B., Talamo, S., Fitzsimmons, K.E., Gantumur, A., Guunii,  
 1700 L., Davakhuu, O., Flas, D., Dogandzic, T., Doerschner, N., Welker, F., Gillam, J.C., Noyer,  
 1701 J.B., Bakhtiary, R.S., Allshouse, A.F., Smith, K.N., Khatsenovich, A.M., Rybin, E.P.,  
 1702 Byambaa, G., Hublin, J.J., 2019. The northern route for human dispersal in Central and  
 1703 Northeast Asia: new evidence from the site of Tolbor-16, Mongolia. *Scientific Reports* 9,  
 1704 11759.
- 1705

## Figure captions

**Figure 1.** Site plan with location of 1970–1975 excavations and recent excavations (2015–2019), Main Sector (top) and Niche 1 (lower left; a). Photograph of cave entrance taken by N. Zahariev (b). Stratigraphic sections of the Niche 1 (c) and Main Sector (d). Location of Initial Upper Paleolithic sites with osseous artifacts in southeast Europe and southwest Asia (e). Figure modified from Hublin et al. (2020).

**Figure 2.** Niche 1 longitudinal East profile (a) and plan view of Layer I (b) with plotted fauna and osseous artifacts distinguished by type. Artifact context information in SOM Table S2. Squares are 1 × 1 meter. Orthophoto of Niche 1 profile is from the 2021 season.

**Figure 3.** Number of osseous artifacts from the Bacho Kiro Cave Initial Upper Paleolithic layers plotted by general artifact type and skeletal element.

**Figure 4.** Awls from Bacho Kiro Cave, Initial Upper Paleolithic Layer I and micrographs showing details of the traces. CC8-1047.3 (a) refits with CC8-1091 (b) and has a smoothed and crushed distal end (c), while the mesial portion has minimal smoothing (d). The distal part of BB7-820 (e) is broken, while the mesial portion exhibits longitudinal scraping (f, g). CC7-381 (h) has a pointed distal extremity with longitudinal scraping (i) and transversal striations overlaying the scraping (j). CC8-1765.1 (k) has transversal striations (l) and a broken distal end showing progressive smoothing overlaying longitudinal scraping (m). BB8-1705 (n) has a pointed distal end with minimal crushing and progressive smoothing (o), transversal striations

1729 overlaying longitudinal scraping (p), oblique grinding (q), and transversal striations and  
 1730 smoothing along edge (r). All artifacts on the same 1 cm scale bar.

1731  
 1732 **Figure 5.** Smoothers (a, e, l) and indeterminate worked item (i) from Bacho Kiro Cave, Initial  
 1733 Upper Paleolithic Layers I (a, e, i) and J (l) with micrographs showing details of the traces. AA8-  
 1734 1434 (a) exhibits polish, smoothing, and fine, longitudinal striations on superior face of distal  
 1735 end (b), longitudinal and oblique striations, smoothing, polish, and flaking damage on inferior  
 1736 face of distal part (c), and fine, transversal striations on broken edge (d). DD7-656 (e) exhibits a  
 1737 rounded distal extremity (f) with a slight bevel (g) and fine striations, polish, and micro-pits (h).  
 1738 CC7-180 (i) has an irregular and convex extremity with transversal and oblique markings across  
 1739 the superior face (j) and longitudinal scraping that ends abruptly at about 5 mm from the distal  
 1740 extremity (k). F6-622 (l) exhibits a concave inferior surface with smoothing, polish, and  
 1741 transversal striations (m), a distal end with polish, striations, and flaking damage (n), and a left  
 1742 edge with smoothing, polish, and transversal striations (o). Artifacts on the same 1 cm scale bar  
 1743 except for the full image of artifact l on a 3 cm scale.

1744  
 1745 **Figure 6.** Beveled objects (formal intermediate tools) from Bacho Kiro Cave, Initial Upper  
 1746 Paleolithic Layers H/I (g), I (a, d, m) and J (j), and micrographs showing details of the traces.  
 1747 BB7-1165.8 (a) is splintered (b) and compressed (c) at the working end. DD8-512 (d) exhibits  
 1748 smoothing and faceting at working end (e, f). DD8-327.3 (g) exhibits crushing and flaking  
 1749 damage at distal extremity (h, i). DD7-1361 (j) exhibits manufacturing traces (k) and is crushed  
 1750 with bone fibers frayed at the proximal extremity (l). BB8-881 (m) exhibits deep transversal  
 1751 marks and splintering at the distal part (n) and oblique scrapes on superior face of the proximal

part (o). Wide arrows illustrate the axis of use as indicated by the damaged extremities (e.g., splinters, crushing). Artifact scale bars, 1 cm.

**Figure 7.** Unworked intermediate tools from Bacho Kiro Cave, Initial Upper Paleolithic Layers H/I (a), I (d, g, j, m), and I/J (p) with micrographs showing details of the traces. AA7-31 (a) exhibits crushing at the distal extremity (b) and striations (indicated by arrows) and polish at the proximal end (c). BB7-439 (d) has polish, smoothing, and irregular splintering on the distal part (e) including oblique striations (indicated by arrows; f). CC6-258.2 (g) exhibits polish, splintering, and crushing at distal extremity (h) with oblique striations and polish (i). A8-543 (j) has splintering and crushing on the inferior (k) and superior faces (l) of the distal extremity. AA7-158 (m), with C14 sample damage on the inferior face, has crushing and fraying of bone fibers at the distal extremity associated with splinters (n) and micro-flaking associated with smoothing and polish on left edge (o). BB8-1896.2 (p) exhibits splinters and striations (indicated by arrows) at the distal end (q) and scored linear markings (r). Wide arrows illustrate the axis of use as indicated by the damaged extremities (e.g., splinters, crushing). Large dots indicate impact scars from direct or indirect percussion. Line of dashes indicates used edge. Artifact scale bars, 1 cm.

**Figure 8.** Utilized tips from Bacho Kiro Cave, Initial Upper Paleolithic Layers I (d, g, k) and J (a) including micrographs showing details of the traces. CC7-2458 (a) exhibits marginal striations (indicated by arrows) and polish at distal extremity (b, c). DD8-1236 (d) has smoothing at right edge of distal part (e) and transversal striations (indicated by arrows) on edge (f). A8-1135 (g) exhibits polish, smoothing, and striations (indicated by arrow) at the distal extremity (h)

1775 and a depression across the broken edge (i) with transversal striations (indicated by arrows) in  
 1776 association (j). BB7-1223 (k) exhibits a wear facet at distal extremity with long, oblique  
 1777 striations (indicated by arrows; l) with smoothing and polish on inferior face (m). Large dots  
 1778 indicate impact scars from direct or indirect percussion. All artifacts on the same 1 cm scale bar.  
 1779

1780 **Figure 9.** Knapped bone tools from Bacho Kiro Cave, Initial Upper Paleolithic Layers I (h), I/J  
 1781 (e), and J (a) including micrographs showing details of the traces. DD7-1397 (a) exhibits  
 1782 smoothed over flake negatives at left edge of distal part (b, c) with smoothing and polish at  
 1783 inferior side (d). DD7-1086 (e) has flaking, polish, and striations (indicated by arrows) at distal  
 1784 extremity (f) with striations (indicated by arrows) and polish on right edge (g). BB8-193 (h) has  
 1785 a retouched, pointed superior distal end (i) with long, oblique traces and smoothing on inferior  
 1786 face (j) and a cluster of oblique marks on edge of split femur (k). Line of dashes indicates  
 1787 extensively used end/edge. Large dots indicate impact scars from direct or indirect percussion.  
 1788 All artifacts on the same 1 cm scale bar at top right of figure.  
 1789

1790 **Figure 10.** Bones with subparallel notches and incisions from Bacho Kiro Cave, Initial Upper  
 1791 Paleolithic Layers I (a, c, e, i, l, n, s), I/J (p), and J (v) with micrographs showing details of the  
 1792 traces. DD7-979.8 (a) refits with DD8-1616 (c) and exhibits notching (b, d). AA8-1951 (e)  
 1793 exhibits clustered incisions (f, h) and a proximal part with polish and smoothing (g). DD7-203 (i)  
 1794 has asymmetrically worn notches (indicated by lines of dashes; j, k). CC7-2222 (l) showing  
 1795 detail of notches (m). DD8-1066 (n) showing detail of incisions (o). DD8-726 (p) exhibits a  
 1796 sequence of incisions with varying characteristics (q) and compression and striations on edge  
 1797 (indicated by arrows) from splitting rib (r). DD8-1124 (s) has smoothing and polish over break

1798 (t) with incisions (u). DD7-1359 (v) has incisions with frayed edges (w) and a cluster of  
 1799 subparallel cuts (x). All artifacts on the same 1 cm scale bar.

1800

1801 **Figure 11.** Pendants, pendant fragments, and beads from Bacho Kiro Cave, Initial Upper  
 1802 Paleolithic Layers H/I, I, I/J, and J. All artifacts on 1 cm scale bar.

1803

1804 **Figure 12.** Beads from Bacho Kiro Cave, Initial Upper Paleolithic Layers H/I (e) and I (a, h)  
 1805 with micrographs showing details of manufacture and use. DD7-719.6 (a) exhibits  
 1806 manufacturing traces covering the bead face with overlain smoothing on the edges (b, d) and  
 1807 grinding on edge (c). AA8-222 (e) has transversal striations (indicated by solid line on edge) in  
 1808 conjunction with deformation of the edge (indicated by dashes and arrow; f, g). AA8-1630.1 (h)  
 1809 exhibits concentric striations within the perforation (i). All beads on the same 5 mm scale bar.

1810

1811 **Figure 13.** Bidirectionally drilled herbivore tooth pendants from Bacho Kiro Cave, Initial Upper  
 1812 Paleolithic Layers H/I (a, m) and I (d, g, j, r) with micrographs showing details of the  
 1813 manufacturing, use, and reworking traces. BB7-147.1 (a) has transversal striations on the lateral  
 1814 edge of the perforation (indicated by arrow; b, c). A8-1138.7 (d) exhibits scraping overlain by  
 1815 drilling of perforation with visible concentric striations (e, f). CC8-1047.1 (g) has grooving on  
 1816 multiple faces after perforation was drilled (h, i). CC8-1496.1 (j) exhibits drilling with large  
 1817 concentric striations and red staining inside perforation (k, l). A7-219.1 (m) has scraping on edge  
 1818 near crown of tooth (n), a groove on lateral face of broken perforation (o), modification to  
 1819 perforation after breakage (p), and a polished perforation rim (q). AA7-1635.1 (r) exhibits  
 1820 localized damage at lateral edge of perforation (s, t), longitudinal scraping at crown of tooth (u,



v), and concentric striations within drilled perforation (w). All artifacts on the same 1 cm scale bar.

**Figure 14.** Pendant typology from the Bacho Kiro Cave Initial Upper Paleolithic layers based on taxa, tooth type, and the differing manufacturing methods. Pendant depictions courtesy of Anna E. Goldfield. Abbreviations: Hb = herbivore; C = carnivore incisor; C(P/M) = carnivore premolar or molar; BD = biconically drilled; SS = scraped to form shelf-like feature; GV = grooved; GO = gouged; PP = partially pierced through unknown method.

**Figure 15.** Number of pendants in each Bacho Kiro Cave Initial Upper Paleolithic layer plotted by pendant and taxa/tooth type. Abbreviations: BD = biconically drilled; SS = scraped to form shelf-like feature; GV = grooved; GO = gouged; PP = partially pierced through unknown method.

**Figure 16.** Cave bear incisor pendants from Bacho Kiro Cave, Initial Upper Paleolithic Layers I (a, m), I/J (i), and J (e) with micrographs showing details of the differing manufacturing and use traces. CC7-314 (a) exhibits a scraped and gouged perforation (b, c) and transversal striations (indicated by arrows; d). CC7-2858 (e) has a grey transversal indentation (indicated by arrow) partially circumscribing the root (f) and a partially pierced root with a small chip and striations (indicated by arrows) emanating from hole (g, h). CC8-1571 (i) exhibits scraping and knob at the apex of the root (j, k) and a non-anthropogenic double perforation (l). AA7-1194 (m) has a drilled perforation widened laterally (n), transversal striations (indicated by arrows) lateral to the

1843 perforation (o), and longitudinal scraping overlain by a drilled perforation (p). All artifacts on the  
1844 same 1 cm scale bar.

1845

1846 **Figure 17.** Cave bear molar and premolar pendants from Bacho Kiro Cave, Initial Upper  
1847 Paleolithic Layers H/I (a) and I (d, h) with micrographs showing details of manufacturing and  
1848 use. DD8-187 (a) exhibits oblique grinding overlain by longitudinal scraping (b, c). DD8-782 (d)  
1849 exhibits scraping and a slight knob at the apex of the root (note small notch on lateral edge; e)  
1850 and a longitudinally scraped root surface with transversal depressions (indicated by arrows)  
1851 encircling the root (f) with fine transversal striations (indicated by arrows) near the larger  
1852 depressions (g). BB8-2302 (h) has well-defined grooves encircling the root with most internal  
1853 striations completely obliterated (i, j) and a flat and regular break of the intentionally removed  
1854 root with high polish and smoothing (k). All artifacts on the same 1 cm scale bar.



Figure 1

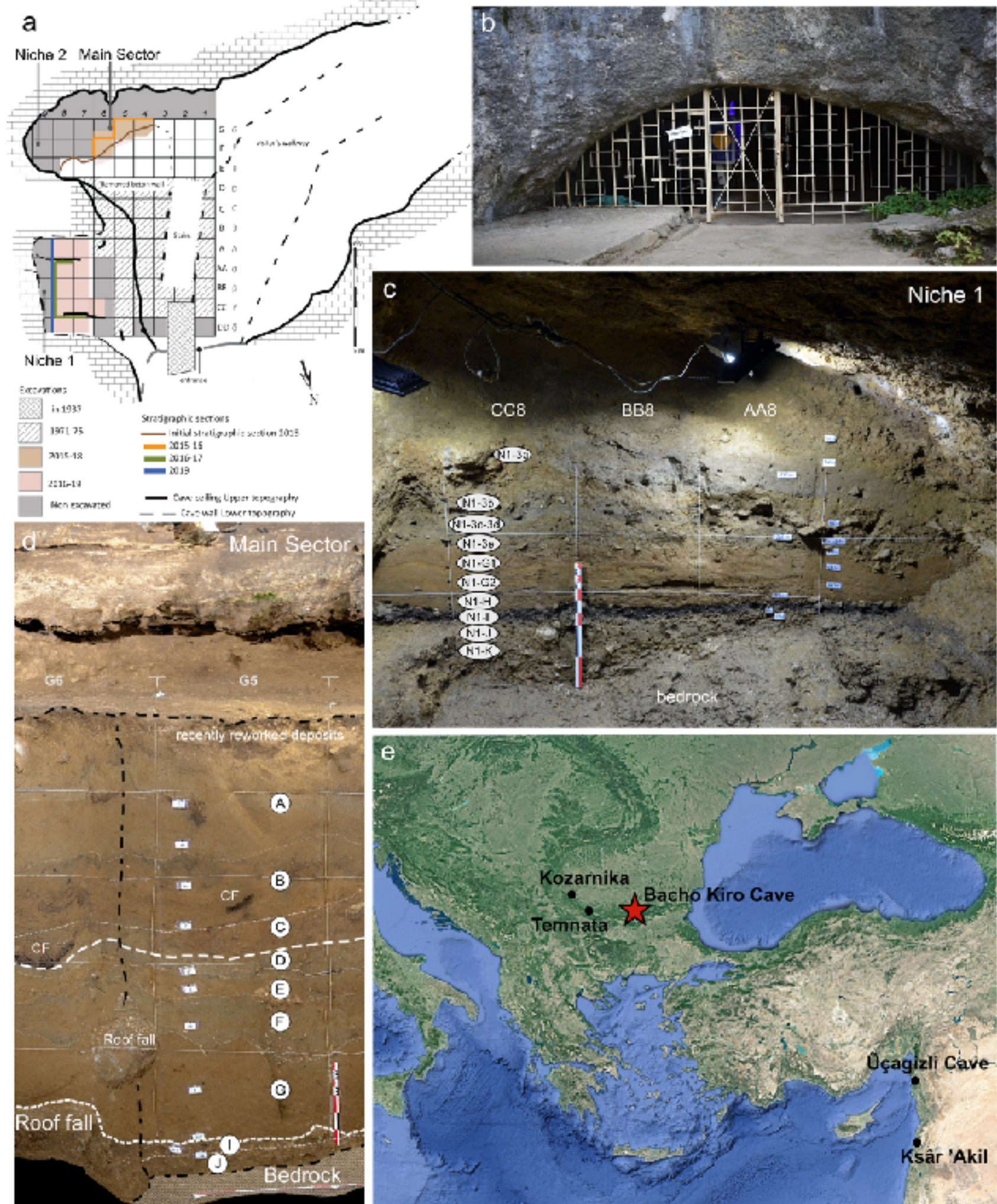




Figure 2

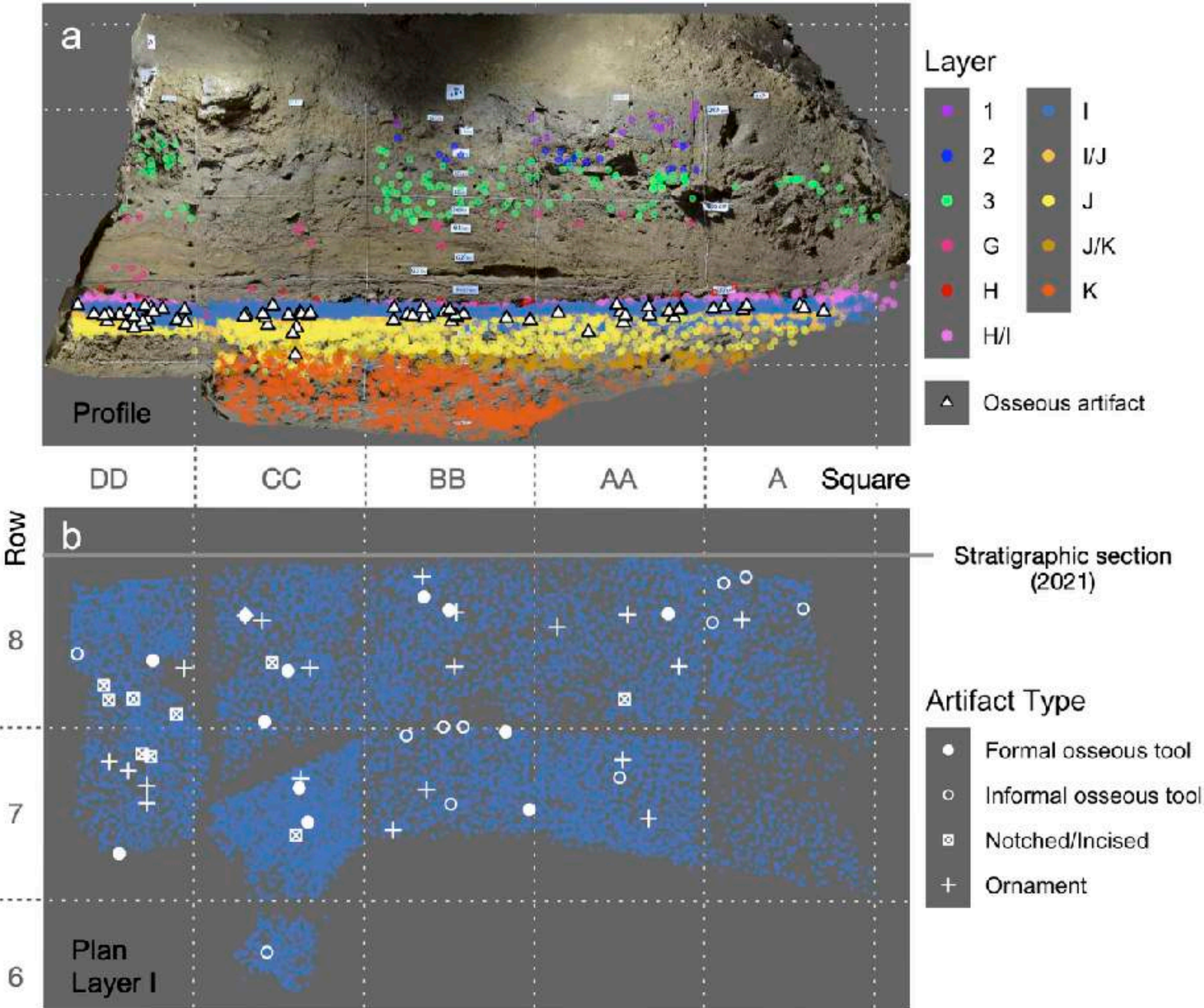


Figure 3

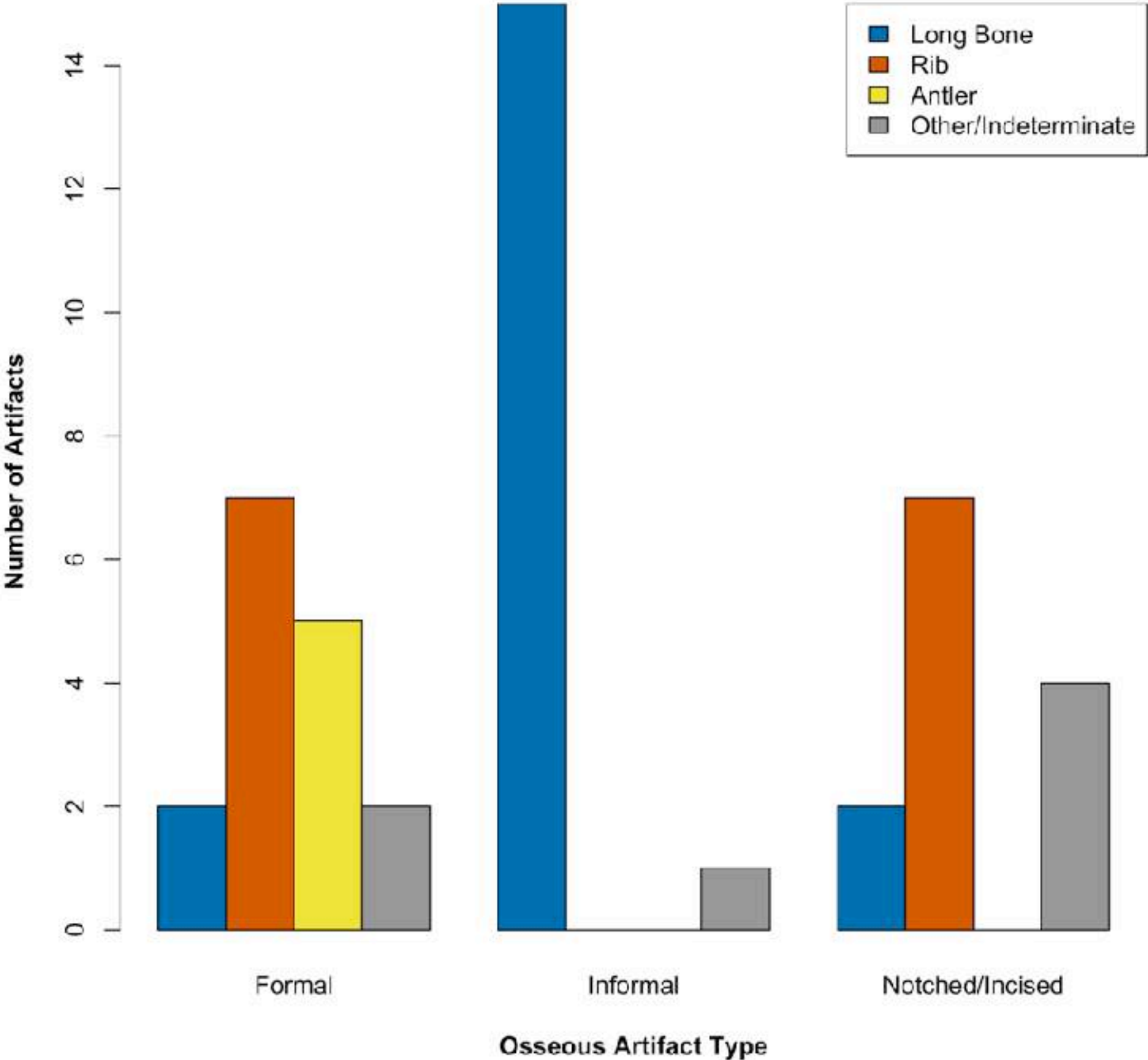




Figure 4





Figure 5





Figure 6





Figure 7

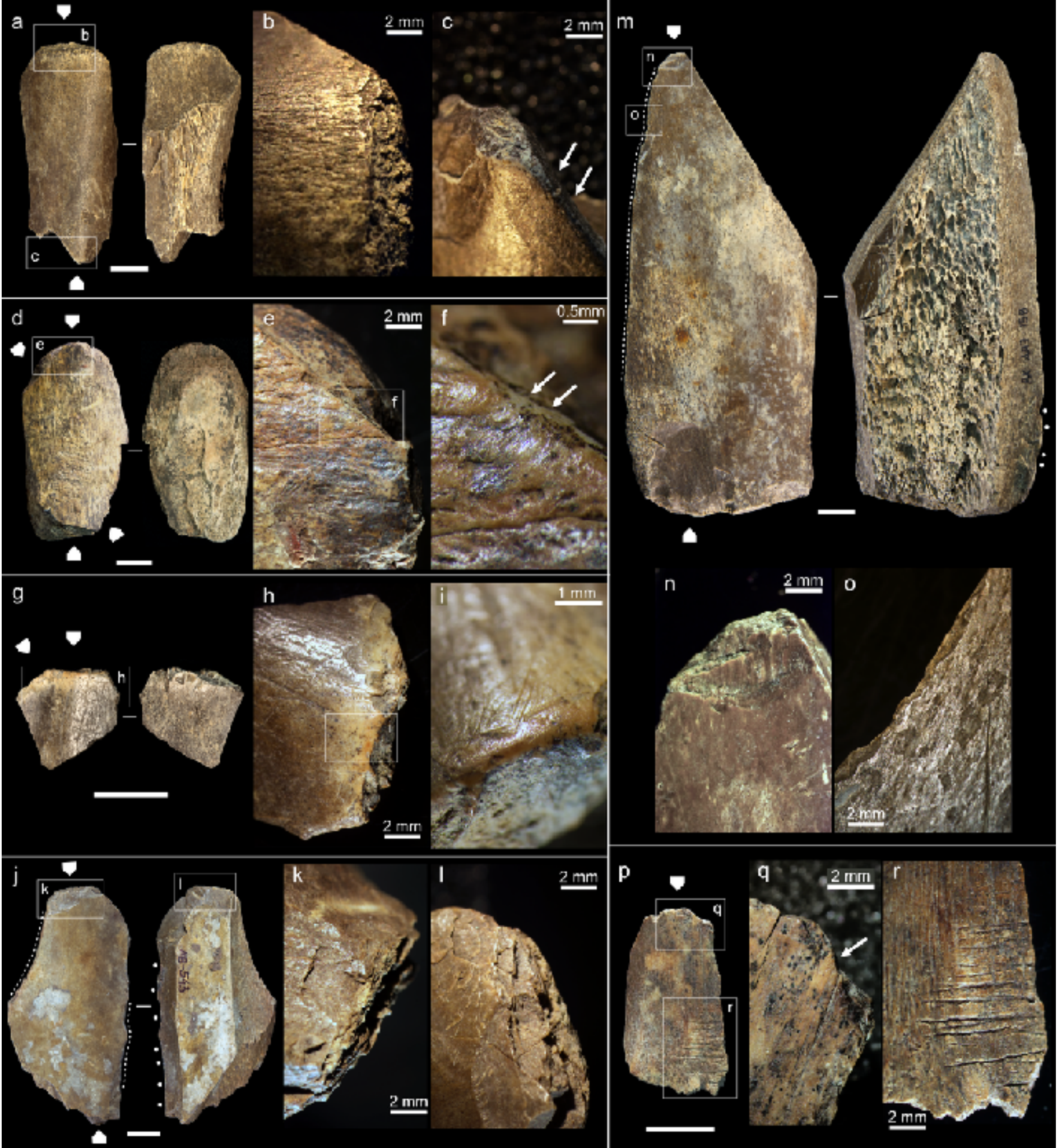




Figure 8





Figure 9





Figure 10





Figure 11

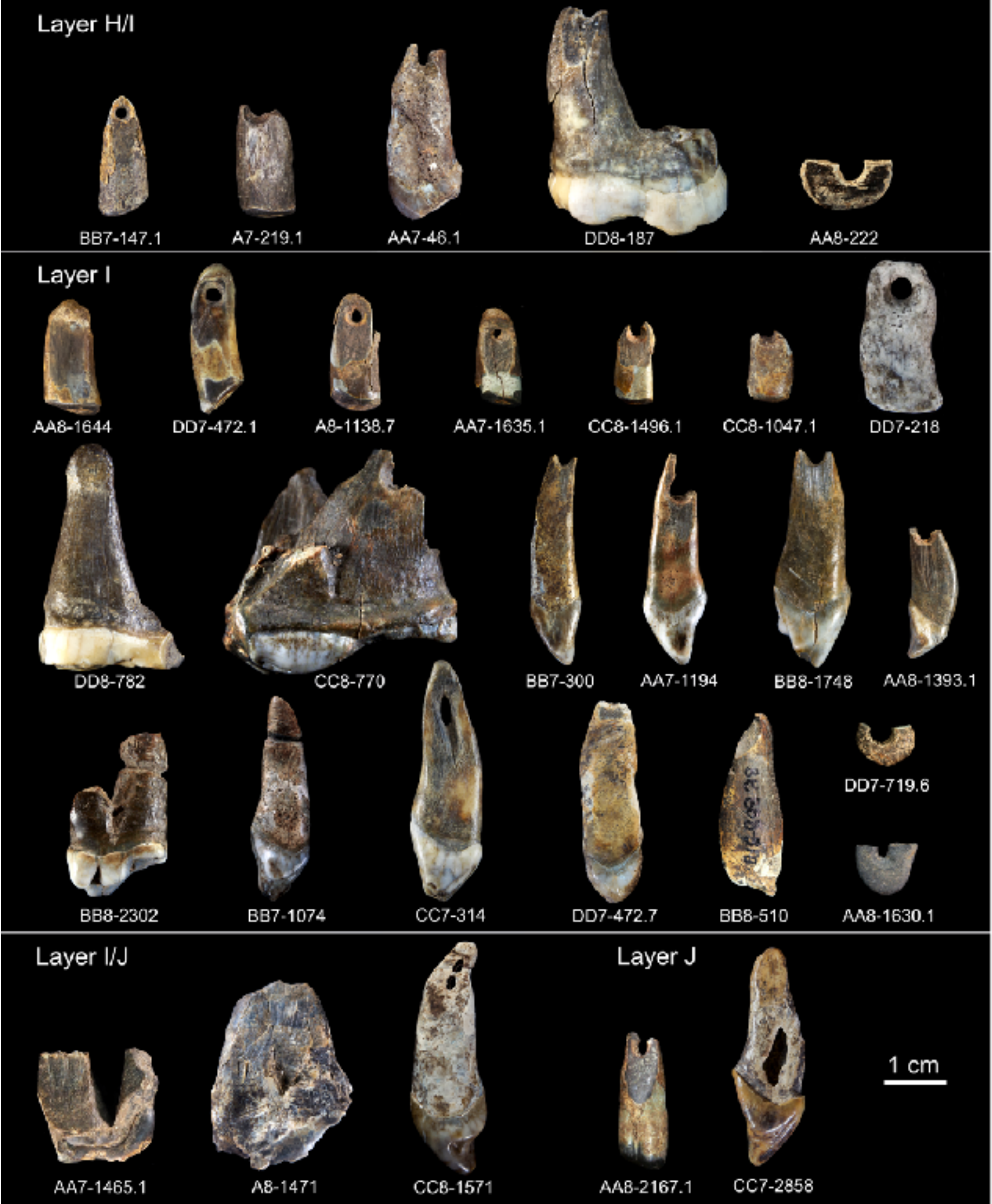




Figure 12

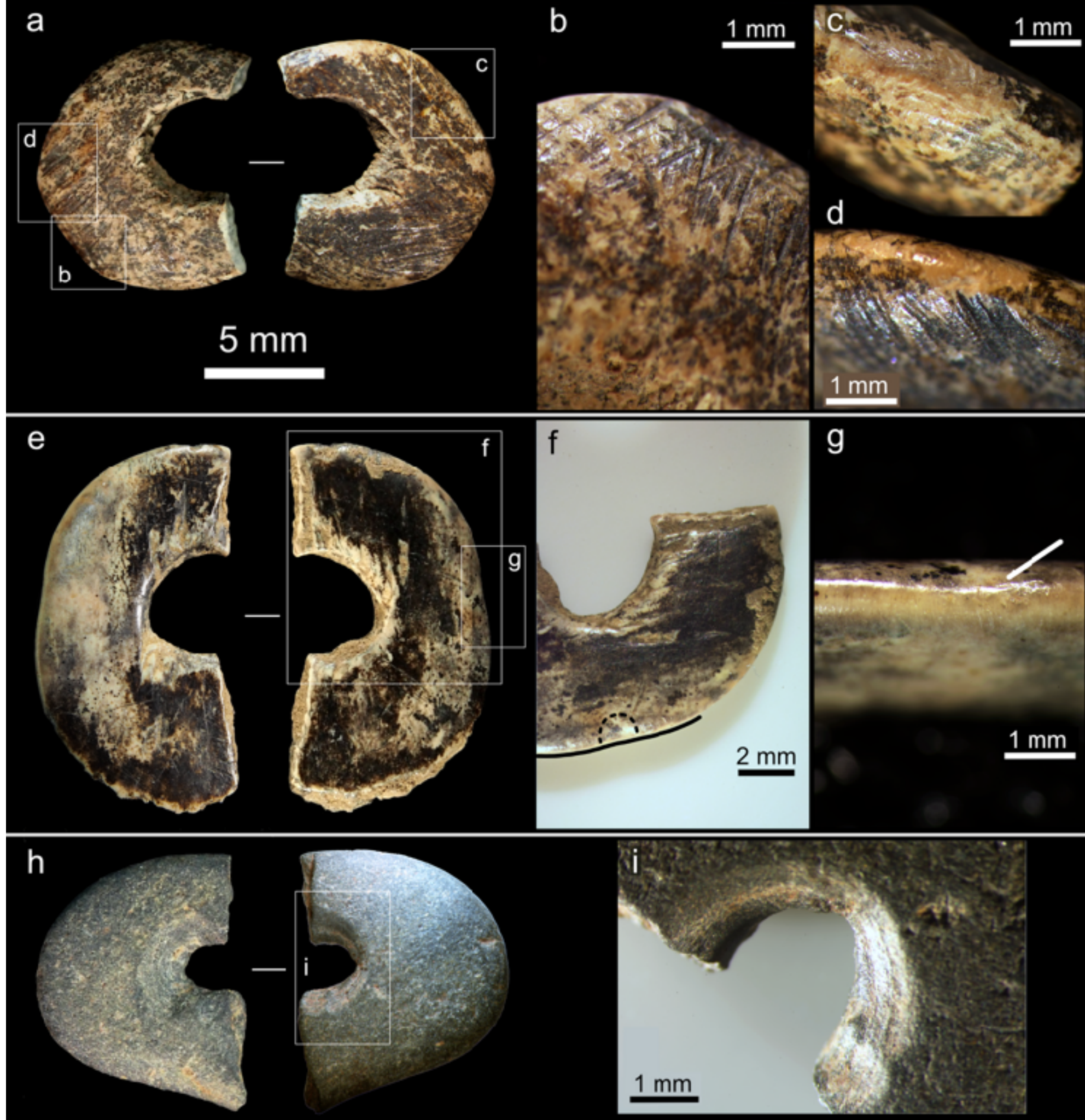




Figure 13



Figure 14 **Taxon**

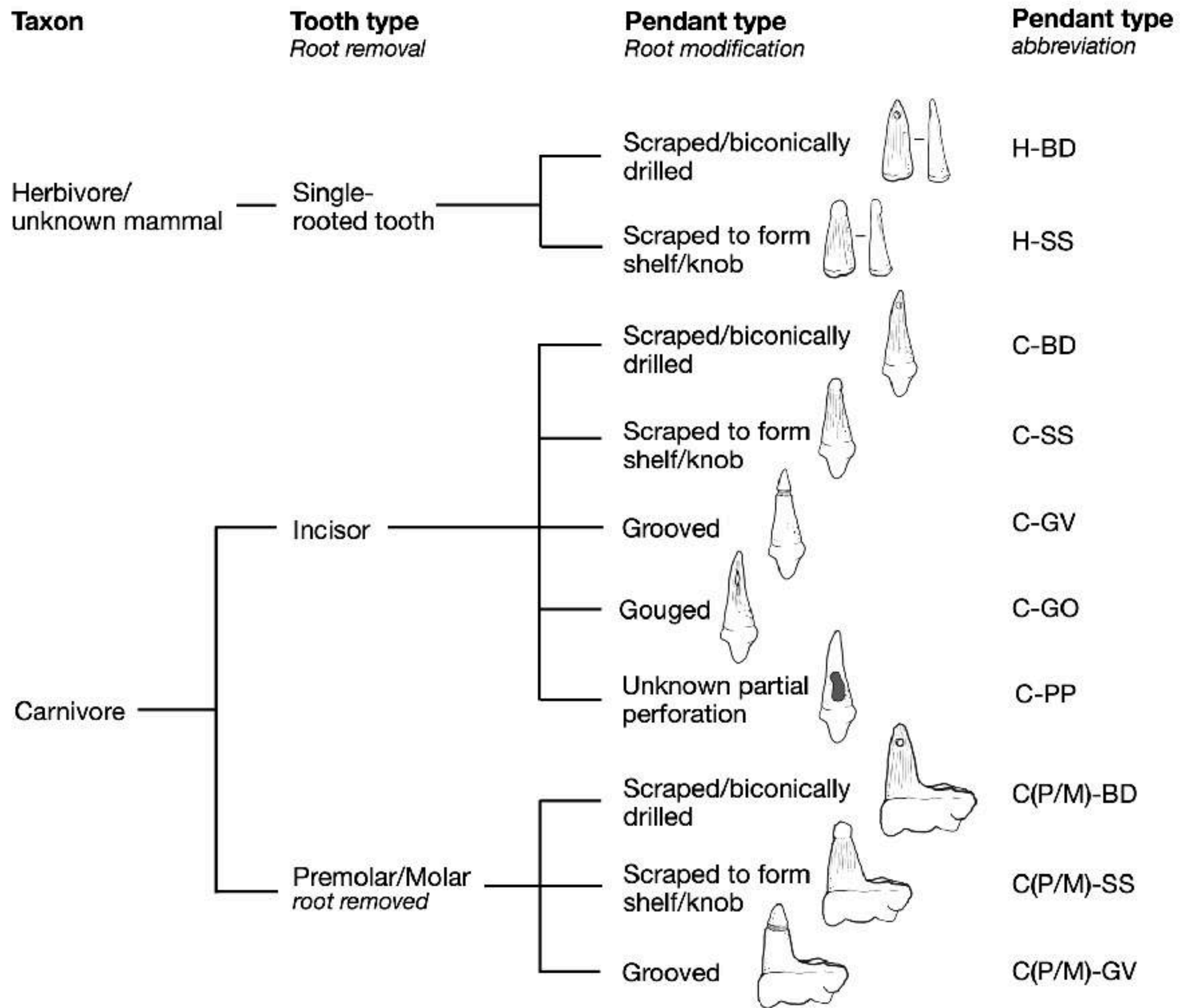




Figure 15

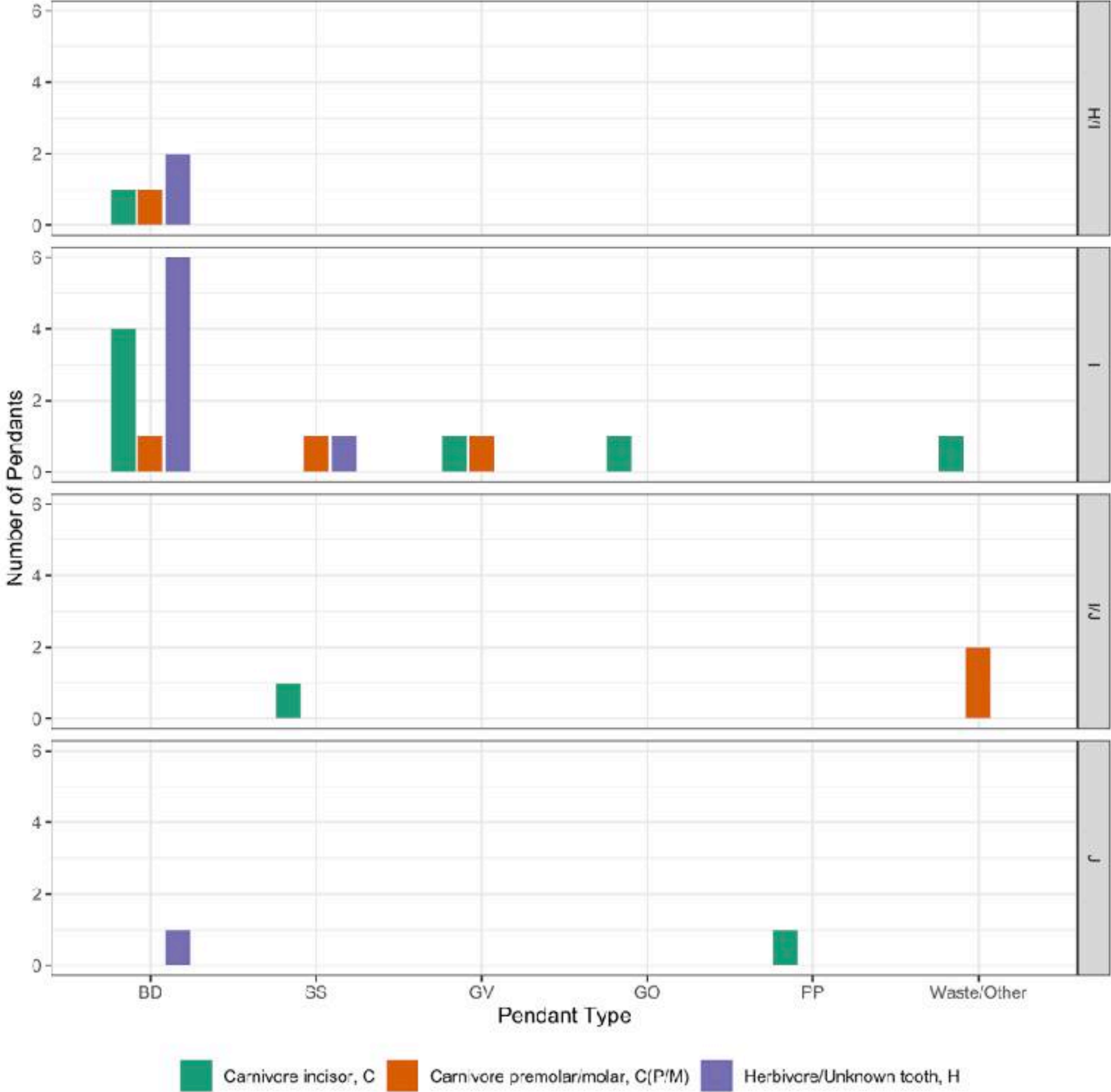
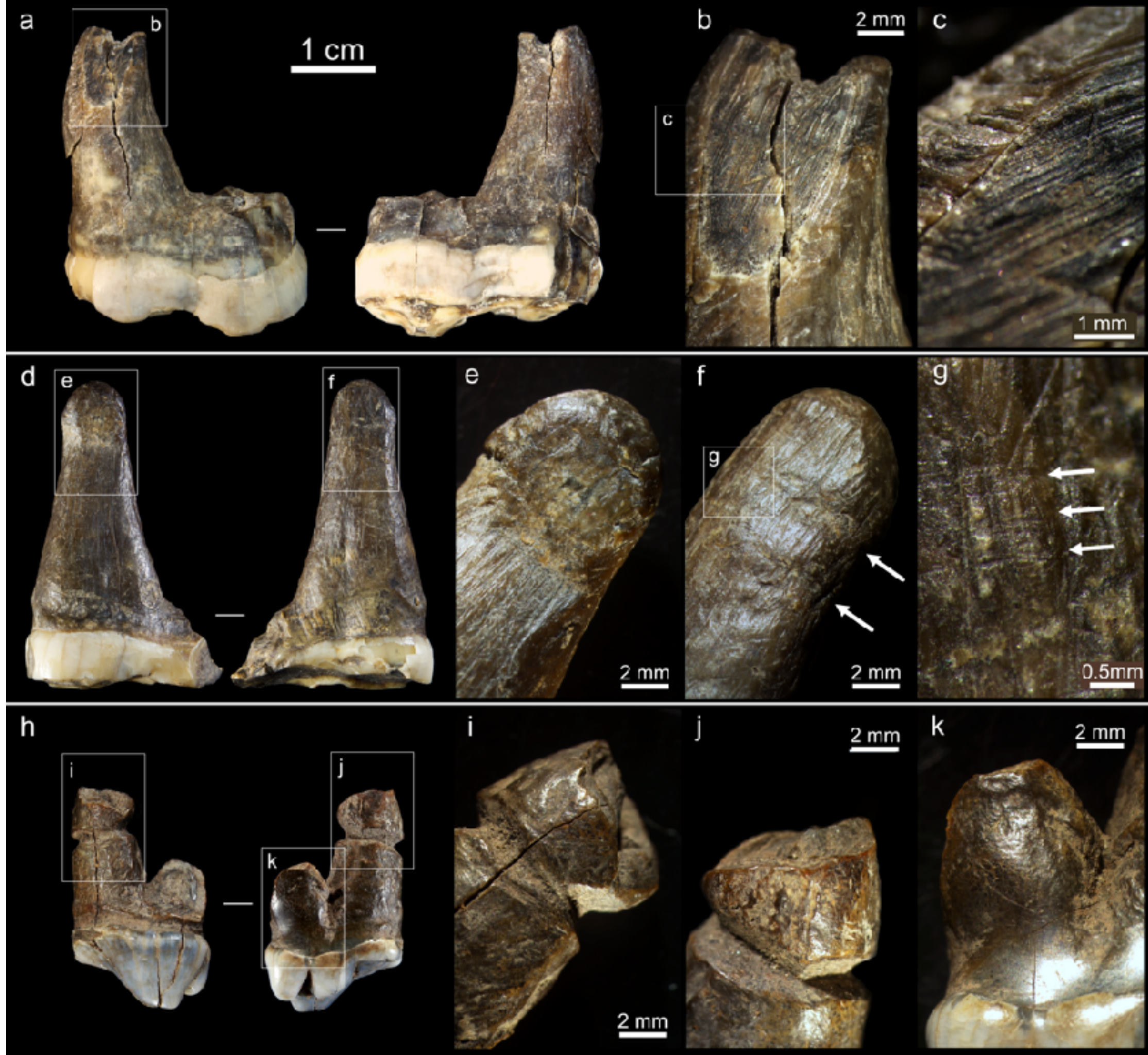


Figure 16





Figure 17



**Table 1**

General classification of the Bacho Kiro Cave osseous artifacts by layer and raw material.

General artifact type	Raw material	J	I/J	I	H/I	Total
Formal osseous tools	Antler	1	1	2	1	5
	Bone	1	0	10	0	11
Informal osseous tools	Bone	2	2	11	1	16
Bones with subparallel notches/incisions	Bone	1	3	9	0	13
Ornaments	Bone	0	0	1	0	1
	Ivory	0	0	0	1	1
	Sandstone	0	0	1	0	1 <sup>a</sup>
	Tooth	2	3	18	4	27

<sup>a</sup> one additional non-osseous bead is included here.

**Table 2**

Typology and counts of bone and antler artifacts at Bacho Kiro Cave by the Initial Upper Paleolithic layers.

General type	Artifact type	J	I/J	I	H/I	Total
Formal osseous artifacts: those shaped using formal techniques such as scraping, grinding, and grooving	Awls: elongated objects with an acute, pointed distal part			6 <sup>a</sup>		6
	Smoothers (lissoirs): elongated objects with a rounded or ogival distal end that exhibits polish	1		2		3
	Beveled objects (formal intermediate tools): elongated objects with a uni- or bifacially beveled distal part	1		3	1	5
	Indeterminate worked items: fragmented objects with traces of manufacturing		1	1		2
Informal osseous artifacts: those minimally modified, sometimes through percussion, prior to use	Unworked intermediate tools: simple splinters with damage at their opposing extremities due to indirect percussion		1	5	1	7
	Utilized tips: simple splinters with a utilized distal end	1		4		5
	Knapped tools: splinters modified by percussion to produce sharp extremities and/or straight edges	1	1	2		4
Bones with subparallel notches/incisions: those intentionally etched with linear markings	Notched: object with multiple subparallel linear grooves deepened using a to-and-fro movement			4 <sup>b</sup>		4
	Incised: object with multiple subparallel linear marks	1	3	5		9

<sup>a,b</sup> indicate two sets of refitted bones.

**Table 3**

Summary information for individual bone and antler artifacts in the Initial Upper Paleolithic layers at Bacho Kiro Cave.

Layer	Find number	Taxon	Element	Type	Modification	Figure number
H/I	DD8-327.3	Cervidae sp.	Antler	Beveled object (intermediate tool)	we, po, uf, cr	6g
	AA7-31	Unknown mammal	Long bone	Unworked intermediate tool	po, uf, cr, st	7a
I	CC8-1091 <sup>a</sup>	Unknown mammal	Rib	Awl	sc, we, po	4b
	CC8-1047.3 <sup>a</sup>	Unknown mammal	Rib	Awl	sc, po, cr	4a
	BB7-820	Sm./Med. herbivore (Cervidae/ <i>Saiga</i> / <i>Capreolus</i> sp. <sup>c</sup> )	Long bone	Awl	sc, po	4e
	CC7-381	Unknown mammal	Indet. bone	Awl	sc, po, cr, st	4h
	CC8-1765.1	Unknown mammal	Indet. bone	Awl	sc, po, st	4k
	BB8-1705	Unknown mammal	Rib	Awl	sc, gr, po, st	4n
	AA8-1434	Med./Lg. herbivore	Rib	Smoother ( <i>lissoir</i> )	sc, gr, po, uf, st	5a
	DD7-656	Lg. herbivore	Rib	Smoother ( <i>lissoir</i> )	sc, gr, po, st	5e
	CC7-180	Med./Lg. herbivore	Rib	Indeterminate worked item	sc, po, st, de	5i
	DD8-512	Cervidae sp.	Antler	Beveled object (intermediate tool)	po, cr	6d

BB7-1165.8	Cervidae sp.	Antler	Beveled object (intermediate tool)	sc, po, uf, cr, st	6a
BB8-881	<i>Megaloceros giganteus</i>	Tibia	Beveled object (intermediate tool)	sc, po, uf, cr, st	6m
BB7-439	Med./Lg. herbivore	Long bone	Unworked intermediate tool	po, uf, cr, st	7d
BB8-207	Med./Lg. herbivore	Femur	Unworked intermediate tool	sc, po, uf, cr, st	Not pictured
AA7-158	<i>Bos/Bison</i> sp. <sup>c</sup>	Long bone	Unworked intermediate tool	po, uf, cr	7m
A8-543	Unknown mammal	Long bone	Unworked intermediate tool	re, po, uf, cr, st	7j
CC6-258.2	Unknown mammal	Long bone	Unworked intermediate tool	po, uf, cr, st	7g
A8-1135	Unknown mammal	Long bone	Utilized tip	po, uf, st, de	8g
A8-715.5	Unknown mammal	Long bone	Utilized tip	sc, po, cr, st, de	Not pictured
BB7-1223	<i>Equus</i> sp.	Tibia	Utilized tip	re, po, cr, st	8k
DD8-1236	Unknown mammal	Long bone	Utilized tip	re, po, uf, cr, st	8d
BB8-193	<i>Ursus</i> sp. <sup>c</sup>	Femur	Knapped tool	re, we, po, st	9h
A8-550	Unknown mammal	Humerus	Knapped tool	re, po	Not pictured
DD8-1124	Medium carnivore	Rib	Incised bone	inc, sc, po, st	10s

	DD8-848	Unknown mammal	Long bone	Incised bone	inc, po	Not pictured
	DD7-203	Unknown mammal	Flat bone	Notched bone	inc, po	10i
	AA8-1951	Unknown mammal	Rib	Incised bone	sc, inc, po	10e
	DD8-1616 <sup>b</sup>	Unknown mammal	Indet. bone	Notched bone	sc, inc, po, st	10c
	DD7-979.8 <sup>b</sup>	Unknown mammal	Indet. bone	Notched bone	sc, inc, po	10a
	CC7-2222	Unknown mammal	Rib	Notched bone	inc	10l
	CC8-266	Lg. herbivore	Cranial- Frontal	Incised bone	inc	Not pictured
	DD8-1066	Unknown mammal	Long bone	Incised bone	inc	10n
I/J	CC6-445.1	Cervidae sp.	Antler	Indeterminate worked item	sc, we	Not pictured
	BB8-1896.2	Unknown mammal	Long bone	Unworked intermediate tool	po, uf, cr, st, inc	7p
	DD7-1086	Unknown mammal	Long bone	Knapped tool	re, po, uf, st	9e
	F5-182	<i>Bos/Bison</i> sp. <sup>c</sup>	Rib	Incised bone	sc, inc, we, po	Fig. 2c in Fewlass et al. (2020)
	DD8-726	Unknown mammal	Rib	Incised bone	inc, we, po, st	10p
	DD7-1232.8	Unknown mammal	Rib	Incised bone	inc	Not pictured
J	F6-622	<i>Bos/Bison</i> sp. <sup>c</sup>	Rib	Smoother ( <i>lissoir</i> )	sc, gr, po, uf, st	5l
	DD7-1361	Cervidae sp.	Antler	Beveled object (intermediate tool)	sc, we, po, uf, cr, st	6j



CC7-2458	<i>Bos/Bison</i> sp.	Indet. bone	Utilized tip	po, st	8a
DD7-1397	Unknown mammal	Long bone	Knapped tool	re, po, st	9a
DD7-1359	Med./Lg. herbivore	Rib	Incised bone	inc, po	10v

---

Abbreviations: Sm. = small; Med. = medium; Lg. = large; Indet. = indeterminate; cr = crushed; de = depressions; gr = ground; inc = incised; po = polished; re = retouched; sc = scraped; st = striations; uf = usage flaked; we = wedging marks.

<sup>a,b</sup> indicate two sets of refitted bones.

<sup>c</sup> denotes species identification through ZooMS. Cervidae/*Saiga* sp. refers to: *Alces alces*, *Megaloceros giganteus*, *Dama dama*, *Cervus elaphus*, *Saiga tatarica*, and *Capreolus capreolus*.

**Table 4**

Summary information for individual beads from Initial Upper Paleolithic layers at Bacho Kiro Cave.

Layer	Find number	Material	Dimensions L × W × T (mm)	Perforation diameter (mm)	Modification	Figure number
H/I	AA8-222	Ivory	15.2 × 6.6 × 1.8	4.1	po, sm, de, st	11, 12e
I	DD7-719.6	Bone	10.1 × 4.5 × 2.4	3.7	gr, po, sm	11, 12a
	AA8-1630.1	Sandstone	10.5 × 6.2 × 1.9	2.0	dr, sm	11, 12h

Abbreviations: de = depression; dr = drilled; gr = ground; po = polished; sm = smoothed; st = striations.

**Table 5**

Summary information for individual pendants in Initial Upper Paleolithic layers at Bacho Kiro Cave. Table ordered following the layout of Fig. 11.

Layer	Find number	Taxon	Tooth	Manufacture	Microwear	Breakage/reworking	Type	Figure number
H/I	BB7-147.1	Med./Lg. herbivore	Single-rooted tooth	sc, dr	sm, st	complete	Hb-BD	11, 13a
	A7-219.1	Med./Lg. herbivore	Single-rooted tooth	sc, gr, dr, gv	po	broken, reworked	Hb-BD	11, 13m
	AA7-46.1	<i>Ursus spelaeus</i>	Left I <sup>2</sup>	sc, dr	sm	broken	C-BD	11
	DD8-187	<i>Ursus spelaeus</i>	Right M <sub>2</sub>	sc, gr, dr	sm	broken	CM-BD	11, 17a
I	AA8-1644	Med./Lg. herbivore	Single-rooted tooth	sc	st, cr	complete	H-SS	11
	DD7-472.1	Med./Lg. herbivore	Single-rooted tooth	sc, dr	po, sm, st	complete	Hb-BD	11
	A8-1138.7	<i>Bos/Bison</i> sp. <sup>a</sup>	Single-rooted tooth	sc, dr	po	complete	Hb-BD	11, 13d
	AA7-1635.1	<i>Bos/Bison</i> sp. <sup>a</sup>	Single-rooted tooth	sc, dr	sm, po, de	complete	Hb-BD	11, 13r
	CC8-1496.1	Med. herbivore (Cervidae/ <i>Saiga sp.</i> <sup>a</sup> )	Single-rooted tooth	sc, dr	sm, st	broken	Hb-BD	11, 13j
	CC8-1047.1	Med./Lg. herbivore	Single-rooted tooth	sc, dr, gv	sm, po	broken, reworked	Hb-BD	11, 13g

DD7-218	Unknown mammal	Single-rooted tooth	sc, dr	st	complete	Hb- BD	11
DD8-782	<i>Ursus spelaeus</i>	Right M <sub>1</sub>	sc	po, st, de, cr	complete	CM- SS	11, 17d
CC8-770	<i>Ursus spelaeus</i>	Right M <sup>2</sup>	sc, dr	sm, po, st	broken	CM- BD	11
BB7-300	<i>Ursus spelaeus</i>	Left I <sub>1</sub>	sc, dr	sm, po, st, de	broken	C- BD	11
AA7-1194	<i>Ursus spelaeus</i>	Left I <sub>1</sub>	sc, dr	sm, po, st	broken	C- BD	11, 16m
BB8-1748	<i>Ursus spelaeus</i>	Right I <sub>3</sub>	sc, dr	sm, po, de	broken	C- BD	11
AA8- 1393.1	<i>Canis lupus</i>	I	sc, dr	sm, po, st	broken	C- BD	11
BB8-2302	<i>Ursus spelaeus</i>	Left P <sub>4</sub>	gv	sm, po, st	broken	CP- GV	11, 17h
BB7-1074	<i>Ursus spelaeus</i>	Left I <sub>2</sub>	gv	sm, st	complete	C- GV	11
CC7-314	<i>Ursus spelaeus</i>	Left I <sub>2</sub>	sc, go	st	complete	C- GO	11, 16a
DD7-472.7	<i>Ursus spelaeus</i>	Right I <sub>1</sub>	sc, gr	sm	broken	unkn own	11
BB8-510	Unknown mammal	Indet. root	sc, gv	---	broken	waste frag ment	11

I/J	AA7-1465.1	<i>Ursus spelaeus</i>	Left P <sub>4</sub>	sc	po, sm	broken	unkn own	11
	A8-1471	<i>Ursus spelaeus</i>	Right M <sub>3</sub> root	sc	po	broken	waste frag ment	11
	CC8-1571	<i>Ursus spelaeus</i>	Right I <sup>2</sup>	sc	sm, cr	broken	C-SS	11, 16i
J	AA8-2167.1	Med./Lg. herbivore	Single-rooted tooth	sc, gr, dr	sm, st	broken	Hb-BD	11
	CC7-2858	<i>Ursus spelaeus</i>	Left I <sub>3</sub>	?	po, st	?	C-PP	11, 16e

---

Abbreviations: Lg. = large; Med. = medium; Indet. = indeterminate; dr = drilled; go = gouged; gr = ground; gv = grooved; sc = scraped; cr = crushed; de = depressions; po = polished; sm = smoothed; st = striations; BD = biconically drilled; SS = scraped to form shelf-like feature; GV = grooved; GO = gouged; PP = partially pierced through unknown method; Hb = herbivore; C = carnivore incisor; C(P/M) = carnivore premolar or molar.

<sup>a</sup> denotes species identification through ZooMS. Cervidae/*Saiga* sp. refers to: *Alces alces*, *Megaloceros giganteus*, *Dama dama*, *Cervus elaphus*, and *Saiga tatarica*.

**Table 6**

Summary information for Initial Upper Paleolithic sites in southeast Europe and southwest Asia discussed in text.

Site	Country	Layer	Age (ka cal BP)	Bone/antler artifact	Ornament	Reference
Backo Kiro Cave (recent excavations)	Bulgaria	H–J	~ 46–43	Awls, smoothers, intermediate tools (beveled and unworked), utilized tips, knapped bones, incised/notched bones, retouchers	Animal teeth pendants, ivory bead, bone bead, sandstone bead	this study; Hublin et al., Fewlass et al. 2020; Tsanova et al., 2021
Backo Kiro Cave (previous excavations)	Bulgaria	8–11	>43–34 <sup>a</sup>	Awls, notched bone, utilized bones, retouchers	Animal teeth pendants, beads	Kozłowski, 1982; Kozłowski, 1992; Guadelli, 2011; Hedges et al., 1994
Temnata	Bulgaria	TD–I 4	~48–41	Awl		Ginter et al., 2000; Guadelli, 2011; Tsanova et al., 2021
Kozarnika	Bulgaria	6–7 (level s VIII and VII/V III)	~49–44	Awls, Notched bone	Animal teeth pendants	Guadelli et al., 2005; Guadelli, 2011; Tsanova et al., 2021

Ksâr 'Akil	Lebanon	XXII – XXIII	>45	Incised awl, worked antler	Marine shell beads	Bosch et al., 2015; Bosch et al., 2019; Newcomer, 1974; Newcomer and Watson 1984
Üçağızlı Cave I	Turkey	F–H	~45–39	Awls, small bone points	Marine shell beads; talon	Kuhn et al., 2009; Douka, 2013; Stiner et al., 2013

---

<sup>a</sup> Uncalibrated dates.