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

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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; Sehasseh 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. Kozlowski 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 Kozlowski, 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; Kozlowski 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 (*Crocuta 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; Bonnichsen 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 (NH_3CO_3, AmBic; 200 µl 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 µl of trypsin (0.5 µg/µl, 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^2) 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^2 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; Griffits 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 intensely, 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).

<u>Beveled objects (formal intermediate tools)</u> 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 facetted 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.

<u>Unworked intermediate tools</u> 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 previous 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; Pedergnana et al., 2021).

<u>Notched bones</u> 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).

<u>Incised bones</u> 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).

<u>Beads</u> 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 facetted 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.

Sixteen of the pendants were made from carnivore teeth based on morphological characteristics of the crown and root shape. One pendant is a wolf (*Canis lupis*) incisor, while the other 15 derive from cave bear (*Ursus spelaeus*) incisors (n = 9), premolars (P; n = 2), and molars (M; n = 4) from both the maxilla and mandible (Fig. 11; Table 5). Given the diversity of teeth pendants preserved, the minimum number of cave bears contributing to the pendants is two based on three different types of teeth (lower left first and second incisors and fourth premolars) represented twice in the pendants (Table 5). All other identified cave bear teeth are unique. Due to preservation issues or anthropogenic modifications, 11 of the 27 teeth could not be identified based on morphological characteristics alone but are most often single-rooted. Three of the artifacts were identified using ZooMS: two as *Bos*/*Bison* sp. and one as Cervidae/*Saiga* sp. (Table 5; SOM Table S1). The remaining eight are from unknown mammals, but based on the size, shape, and similarity of modifications to several of the pendants identified through ZooMS, six of these appear to be produced on herbivore teeth, possibly incisors or vestigial canines (Table 5). Given that large bovids do not form vestigial canines, the teeth identified as *Bos*/*Bison* sp. most likely derive from incisors. Notably, one of the *Bos*/*Bison* sp. artifacts (AA7-1635.1), and two others without ZooMS identifications (A7-219.1 and AA8-1644), preserve scraping traces on and/or adjacent to the crowns of the teeth indicating deliberate alteration of this area (e.g., Fig. 13n, u, v). In addition, it appears that the enamel surfaces of many of the herbivore crowns have been modified through intentional abrasion, a feature observed elsewhere in subsequent UP assemblages (White and Normand, 2015). Modification to the tooth crown is likely unrelated to the method of suspension but rather to the intended shape of the objects. This 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 pigmentatious 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 beneficial for several reasons, not least of which is ease of bundling and storage, which could be supported by their clustered spatial pattern in the Niche 1. Further, a flat rib surface lends itself to easily displayed markings. In the case of the tubular incised artifact, the naturally rounded carnivore rib could have provided a useful shape that similarly required minimal modifications. Interestingly, axial skeletal elements such as ribs (Layer I minimum animal units [MAU] large bovid = 0.38; MAU cervid = 0.27) are under-represented in the Bacho Kiro Cave faunal assemblage when compared with forelimbs (Layer I MAU large bovid humerus = 8 and radius = 7.5; MAU cervid humerus = 6.5 and radius = 7) and hindlimbs (Layer I MAU large bovid femur = 8.5 and tibia = 10; MAU cervid femur = 9.5 and tibia = 9.5), a pattern that has been interpreted to have occurred due to selective transport of skeletal elements into the cave as part of subsistence practices (Smith et al., 2021). The 14 worked rib fragments (Layers I, I/J, and J) likely derive from at least 8 different ribs based on size, curvature, provenience, and taxa, many of which could have easily come from the same animal. With this in mind, and given the overall skeletal part pattern observed at Bacho Kiro Cave, it is possible that ribs were selected during butchery and brought back to the cave for bone working. However, it should be noted that using ribs in calculations of relative abundance is problematic due to their tendency to fragment as well as a dearth of diagnostic features. Further, the modifications on worked ribs may result in entirely unidentifiable fragments, making inferences difficult.

Five artifacts, four of which are beveled objects, are made from antler, an osseous material with a higher fracture toughness than long bone. This material property is the result of its low mineral content and more irregular microcrack propagation pattern compared to long bones making antler more resistant to fracture during flexion (Currey, 2002; Chen et al., 2009). Further, antler working requires a more complex process beginning with beam segmentation followed by longitudinal splitting of the segmented blocks, whereas bone fragments produced during butchery can easily be modified into efficient tools (Tejero et al., 2012; Tejero and Grimaldi, 2015; Tejero et al., 2016). This difference is likely the reason why worked antler is rarely documented prior to and within the Early Upper Paleolithic and only became more regularly exploited after 40 ka during later UP phases, most often for highly modified projectile points (Tejero, 2014). A modified antler fragment was found in the IUP Layer XXII at Ksâr ’Akil (Newcomer and Watson, 1984; Table 6), but there is no indication of antler working within other contemporary or more recent early Eurasia UP assemblages (e.g., Gilead, 1991; Coinman, 1996; Kuhn et al., 2009; d’Errico et al., 2012; Tejero, 2014; Tejero and Grimaldi, 2015; Arrighi et al., 2020). While neither the bone or antler tools at Bacho Kiro Cave exhibit complete transformation of the tool blanks (i.e., large portions of the objects remain un- or minimally modified), the antler artifacts would have required more time and technological investment even for relatively simple beveled objects, a common tool type in later UP assemblages (Provenzano, 1998; Tejero et al., 2012). We can argue that the choice of antler as a raw material was deliberate given its mechanical properties such as fracture resistance during stress and sustained use (MacGregor and Currey, 1983; Currey, 2002; Chen et al., 2009). In fact, worked antler makes up a substantial portion (38%) of total antler fragments (n = 13) in the IUP layers at Bacho Kiro Cave, which further supports the choice of antler as a desirable raw material even if antler is under-represented in the overall faunal assemblage (Smith et al., 2021). The origins of antler working are vague but the objects preserved at Bacho Kiro Cave indicate that these humans had already expanded their use of raw material types. Because the antler tools were all used similarly, this suggests that the selection of different osseous raw materials was tied to function.

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

Percussive methods were used to shape bone into tools throughout the Paleolithic. In these cases, impact fractures occur on various surfaces of a bone and not only within the medullary cavity as is common for marrow extraction. Knapped or flaked bone tools of this type have a long history in the African Early Stone Age (Zutovski and Barkai, 2016; Pante et al., 2020; Sano et al., 2020) and have been preserved in Middle and Late Pleistocene assemblages (e.g., Vincent, 1993; Radmilli and Boschian, 1996; Mania and Mania, 2005; Julien et al., 2015; Baumann et al., 2020; Kozlikin et al., 2020; Doyon et al., 2021; Villa et al., 2021), including those within the MP and UP in southeast Europe (Guadelli, 2011). Both direct and indirect percussive techniques were used on the Bacho Kiro Cave bone tools to produce and shape the bone tool blanks, but also to refine their ends and edges for cutting or other tasks that required a sharp edge. A small number of the knapped bone objects exhibit precise retouch to sharpen and alter their working ends into specific shapes, as is the case for the bone object that appears to mimic lithic end- or sidescrapers. This scraper was fashioned from a long bone, and the method used to shape it was adapted from stone tool manufacture. Further, this bone object and many of the Bacho Kiro Cave IUP lithic artifacts, mainly blade sidescrapers and retouched blades, exhibit microwear traces consistent with hide working (Marreiros et al., 2019). Replication of a tool that substituted bone for lithic as the raw material is likely related to the costs of procuring fine-grained flint from different sources 80–150 km away from the site (Hublin et al., 2020). Most of the lithic artifacts at Bacho Kiro Cave are reshaped and highly fragmented (Tsanova et al., 2020), and show intensive development of microwear, including items used for wood and hide working (Marreiros et al., 2019), reflecting thorough and complete use and reuse of these materials. Choosing a bone, which would dull much more quickly than a stone, as an alternative material indicates that these humans were ready to exploit a variety of raw material resources and supplement them altogether when needed. Alternatively, both lithic and bone tools could have been preferred for hide working, perhaps representing different phases of the process.

Indirect percussion on different materials is also evident at Bacho Kiro Cave, as recognizable from a number of worked and unworked bone and antler intermediate tools along with splintered lithic pieces (Kozłowski, 1982; Tsanova, 2008, 2012). Unworked intermediate bone tools have not been commonly reported from Paleolithic sites, especially from old collections. This may be due to their informal nature making them difficult to recognize as tools. If recognized, these objects may be difficult to distinguish from intentionally flaked or knapped bones. Because they are not formally modified tools but simple long bone diaphyseal fragments, these objects are extremely variable and only recognizable by their use alterations such as splinter removals and crushing at their opposing extremities (Tartar, 2012; Tejero et al., 2012; Baumann et al., 2020). Intermediate bone tools have been identified in the Middle and Late Pleistocene (Burke and d'Errico, 2008; Mozota Holgueras, 2012; Tartar, 2012; Tejero et al., 2012; Julien et al., 2015; Baumann et al., 2020; Villa et al., 2021), and have been found in the IUP (Kozlikin et al., 2020), including in the previously excavated material at Bacho Kiro Cave (Guadelli, 2011). A variety of uses have been proposed for this bone tool type, including wood or antler working, wedging for splitting, and hide processing (Semenov, 1964; Stordeur, 1980; Camps-Fabrer et al., 1998; Rigaud, 2007; Tartar, 2009, 2012; Tejero et al., 2012). Interestingly, many of the osseous intermediate tools at Bacho Kiro Cave, both formal and informal, have been modified through indirect percussion, often with lithic (i.e., splintered pieces or 'pièces esquillées') or possibly other osseous intermediate tools. Experimental work has demonstrated the efficiency of using antler intermediate tools to work other antler blocks. Like intermediate lithic pieces, antler wedges also produce small distinct fractures, notches, and compressed areas along the lateral fracture plane of the worked osseous pieces (Tejero et al., 2012). The Bacho Kiro Cave assemblage includes a number of bone and antler artifacts with small notches associated with transversal or oblique striations across the bone or antler fracture plane demonstrating the use of intermediate pieces on these objects. Lithic splintered pieces have also been identified in the same layers as these bone objects. Preliminary use-wear analysis of these stone tools has shown macro- and microwear traces of hard material working such as bone (Marreiros et al., 2019). These include bifacial and bidirectional superimposed negatives and microwear polish characterized by a compact mesh and homogeneous smooth surface texture, located at the termination of the edge fracture scars. Using indirect percussion to fracture hard animal tissues allows for more control during the fracturing process and is a crucial method in the development of osseous technologies (Tejero et al., 2012; Horta et al., 2019). While these humans utilized grooving techniques for pendants and notched pieces, there is little evidence that they grooved bone prior to inserting a wedge for splitting. The use of this technique on and with varying 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 Axlor 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; Griffits 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).

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

Technological flexibility is evident in the wide variety of incised and grooved bone and teeth 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.

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

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

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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

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

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

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

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

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

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

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

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

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

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

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

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

Figure 1

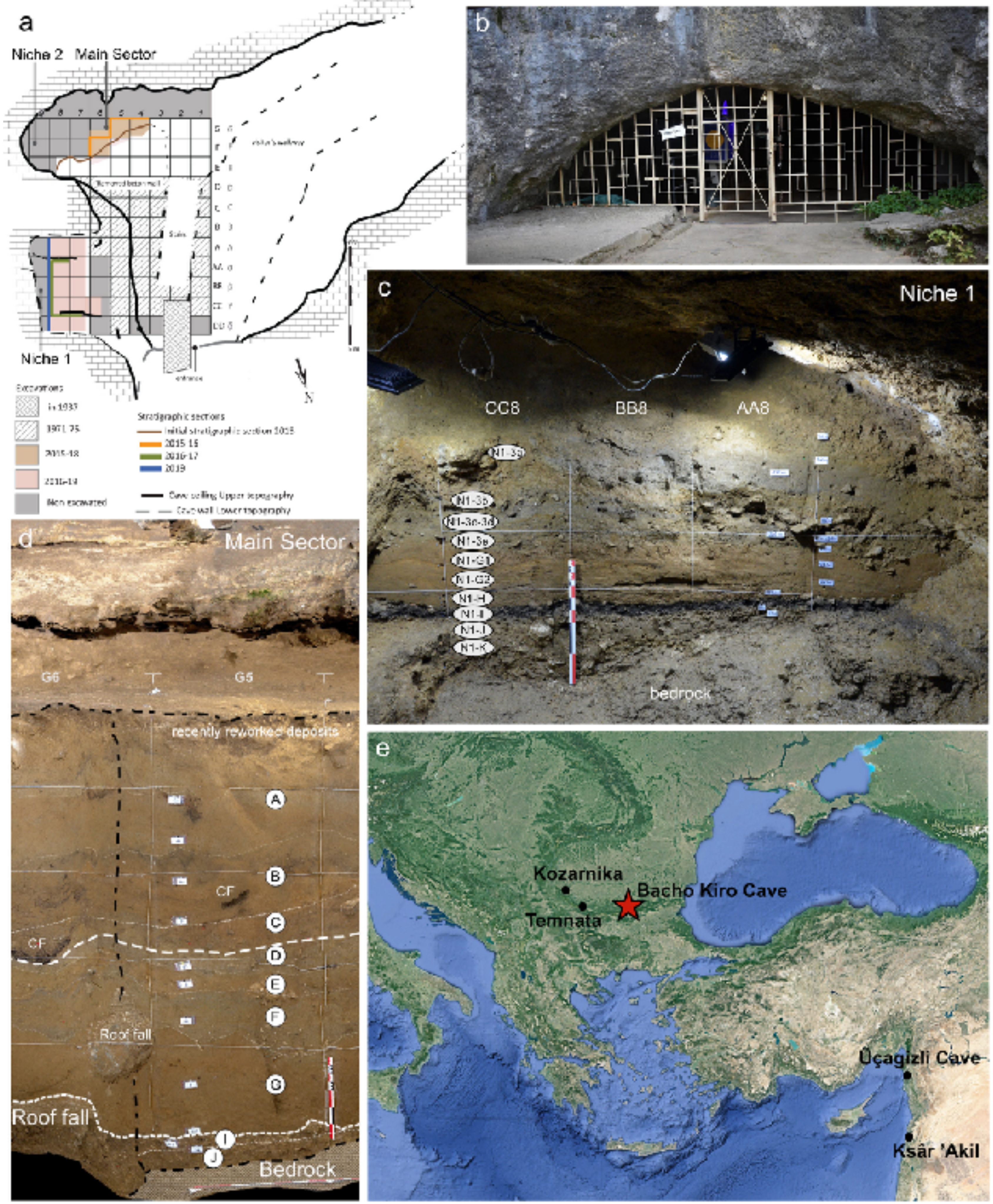
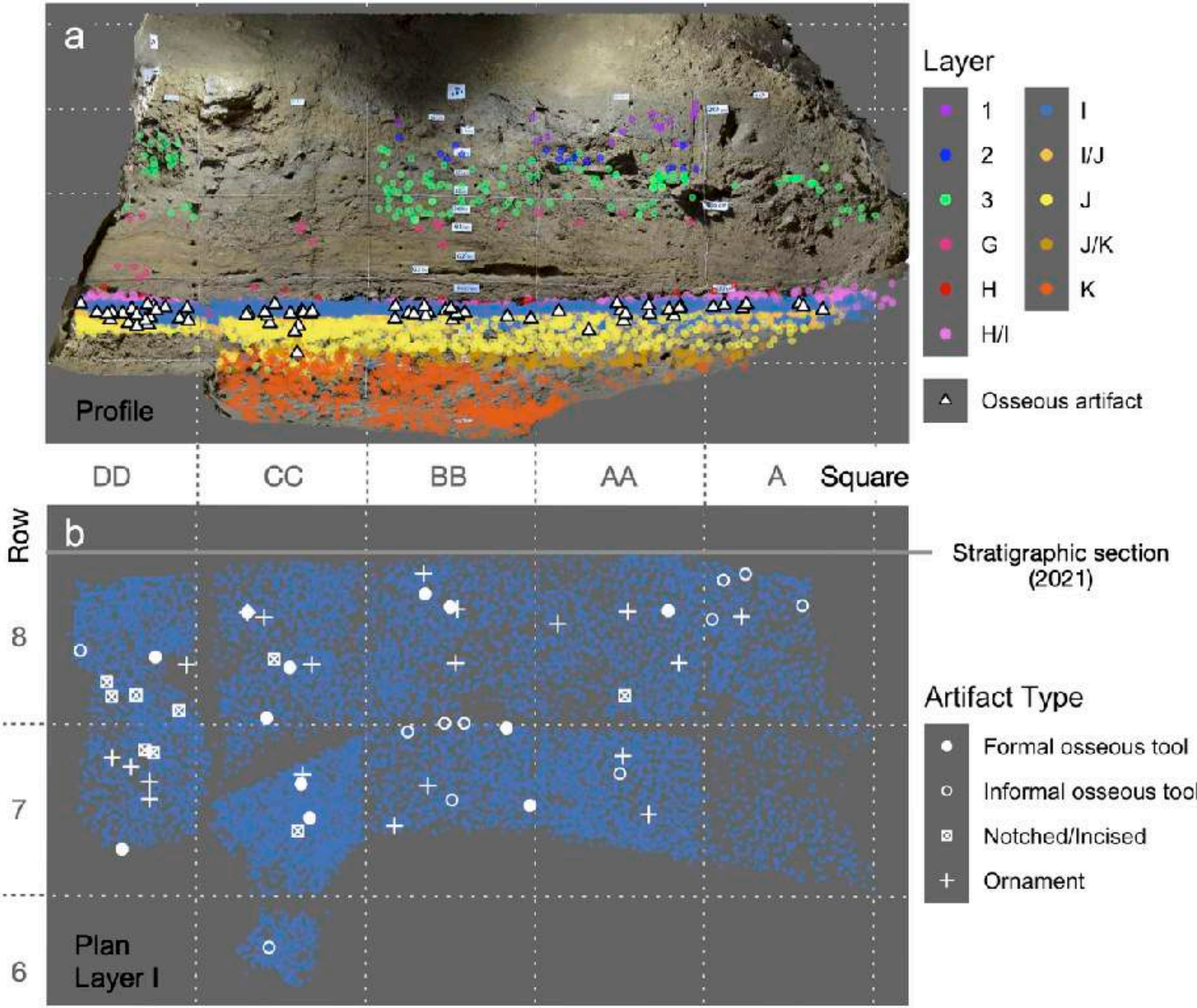

a
Niche 2
Main Sector
Niche 1
b
c
Niche 1
CC8
BB8
AA8
bedrock
d
Main Sector
G6
G5
recently reworked deposits
CF
Roof fall
Bedrock
e
Kozarnika
Bacho Kiro Cave
Temnata
Üçagizli Cave
Ksâr 'Akil

Figure 2



a
Profile
Layer
1
2
3
G
H
H/I
I
I/J
J
J/K
K
Osseous artifact
DD
CC
BB
AA
A
Square
Row
b
Stratigraphic section (2021)
8
7
6
Plan Layer I
Artifact Type
Formal osseous tool
Informal osseous tool
Notched/Incised
Ornament

Figure 3

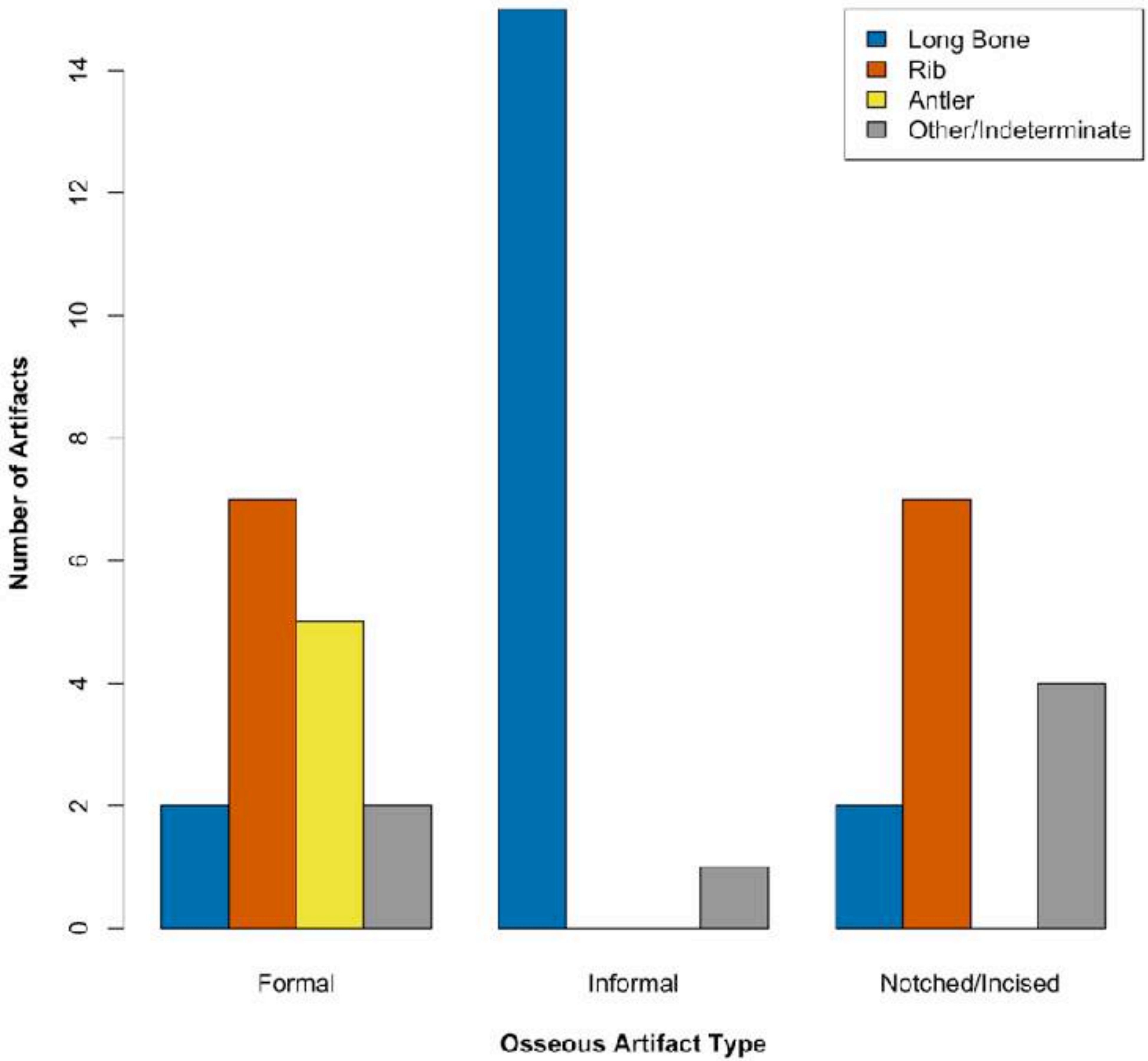

Long Bone
Rib
Antler
Other/Indeterminate
Number of Artifacts
0
2
4
6
8
10
12
14
Formal
Informal
Notched/Incised
Osseous Artifact Type

Figure 4

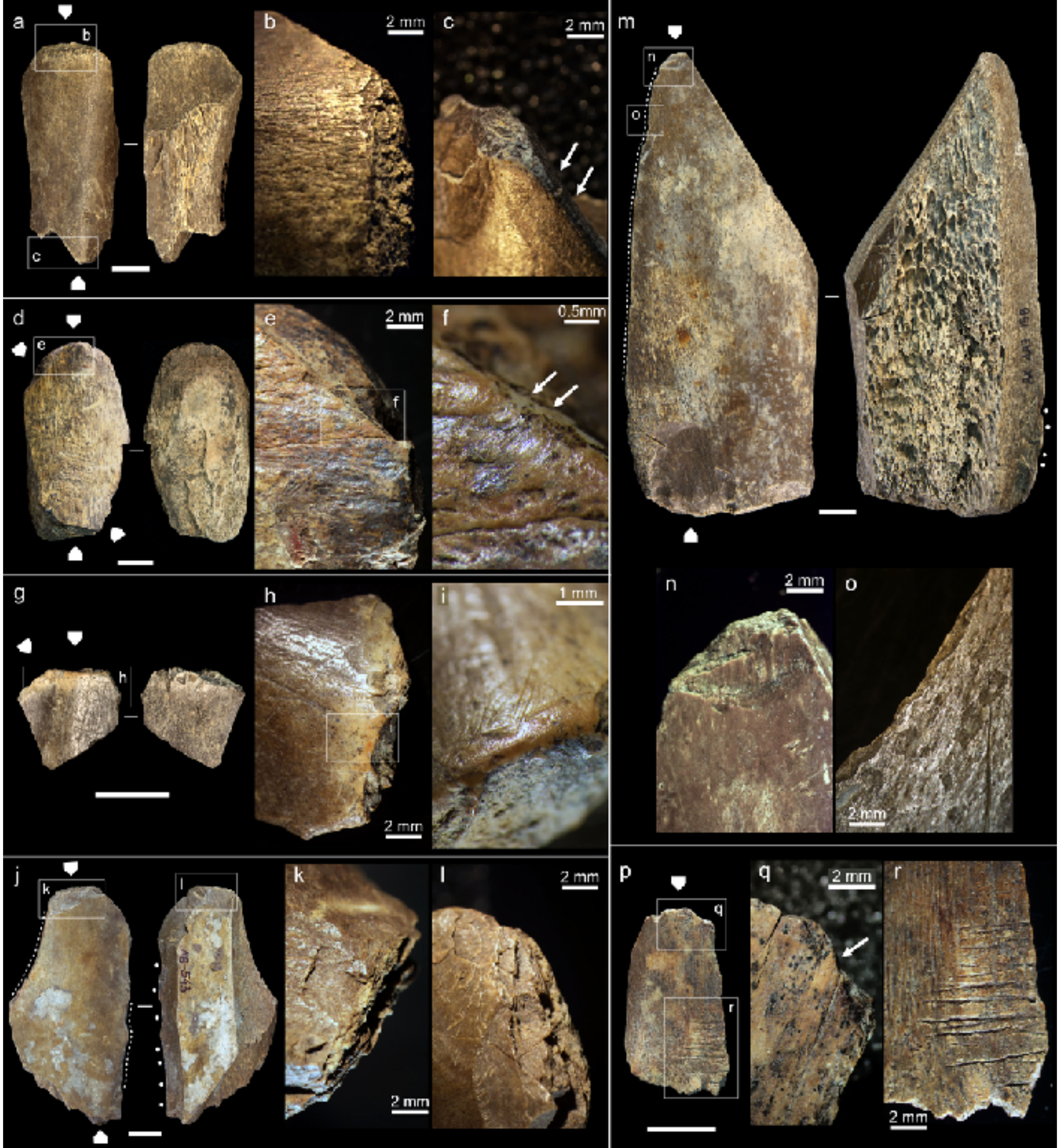
a
c
b
d
c
d
1 mm
1 mm
e
f
g
f
g
2 mm
2 mm
h
i
j
i
j
2 mm
0.5mm
k
l
m
l
m
1 mm
1 mm
n
q
o
r
1 cm
o
p
2 mm
p
q
r
0.5mm
1 mm
0.5mm

Figure 5

Figure 6

a
b
c
b
c
2 mm
2 mm
d
e, f
e
f
2 mm
2 mm
g
h
i
h
i
2 mm
2 mm
j
k
l
k
l
2 mm
2 mm
m
n
o
n
o
2 mm
2 mm

Figure 7



a
b
c
2 mm
2 mm
d
e
f
2 mm
0.5mm
g
h
i
2 mm
1 mm
j
k
l
2 mm
2 mm
m
n
o
2 mm
2 mm
p
q
r
2 mm
2 mm

Figure 8


a
b
b
c
2 mm
c
0.5mm
d
e
e
f
2 mm
f
1 mm
g
h
j
i
h
2 mm
i
2 mm
j
2 mm
k
l
m
1 cm
l
2 mm
m
2 mm

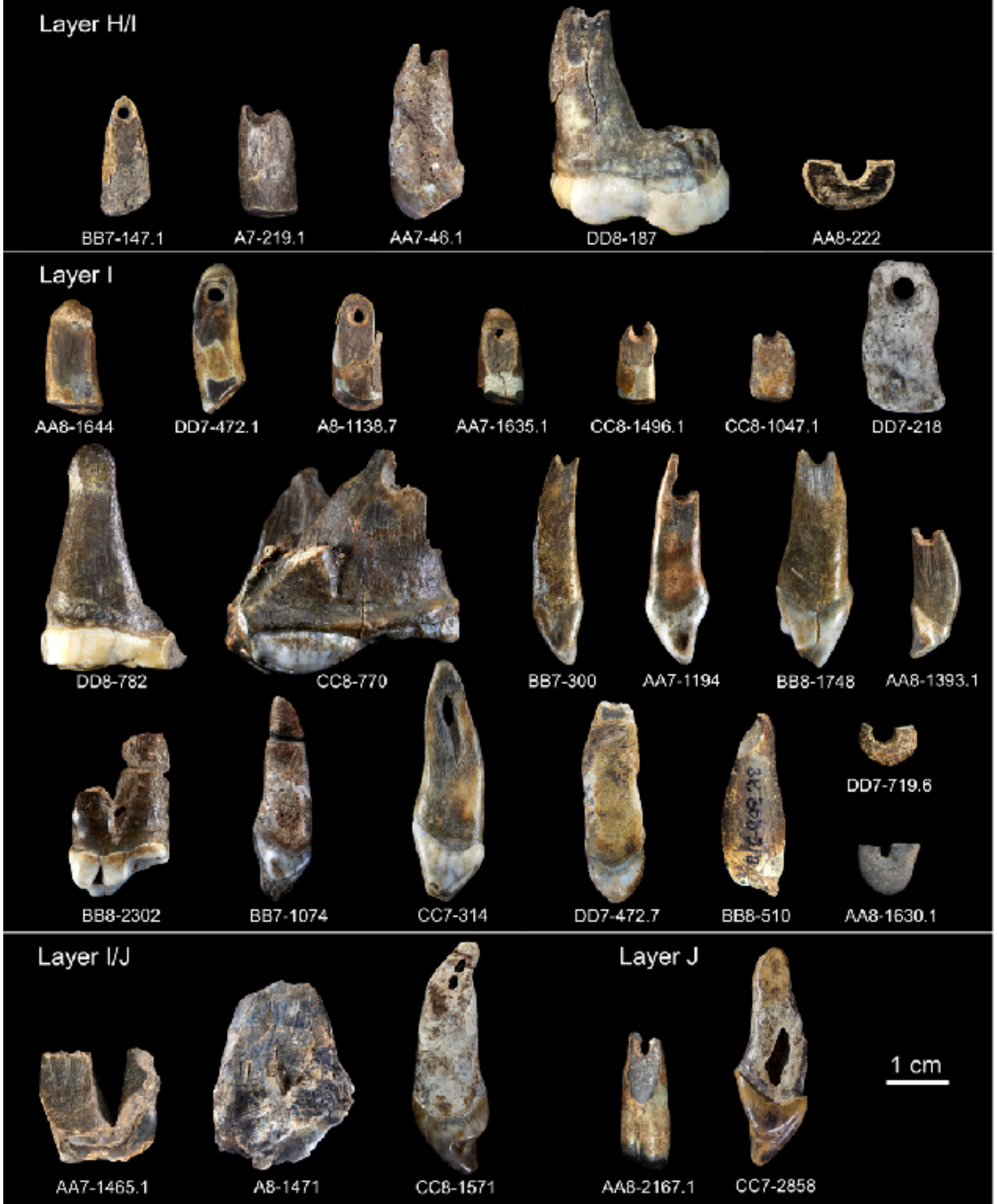
Figure 9

a
b, c
d
007-1297
b
2 mm
c
2 mm
d
2 mm
e
f
g
DD7-1086
f
2 mm
g
2 mm
h
1 cm
i
j
k
Bk
BB8d93
i
2 mm
k
j
2 mm
2 mm

Figure 10

a
b
c
d
1 mm
2 mm
e
f
g
h
2 mm
1 mm
2 mm
i
j
k
2 mm
1 mm
l
m
2 mm
n
o
2 mm
p
q
r
1 cm
2 mm
1 mm
s
t
u
2 mm
1 mm
v
w
x
2 mm
2 mm

Figure 11



Layer H/I
BB7-147.1
A7-219.1
AA7-46.1
DD8-187
AA8-222
Layer I
AA8-1644
DD7-472.1
A8-1138.7
AA7-1635.1
CC8-1496.1
CC8-1047.1
DD7-218
DD8-782
CC8-770
BB7-300
AA7-1194
BB8-1748
AA8-1393.1
BB8-2302
BB7-1074
CC7-314
DD7-472.7
BB8-510
DD7-719.6
AA8-1630.1
Layer I/J
AA7-1465.1
A8-1471
CC8-1571
Layer J
AA8-2167.1
CC7-2858
1 cm

Figure 12

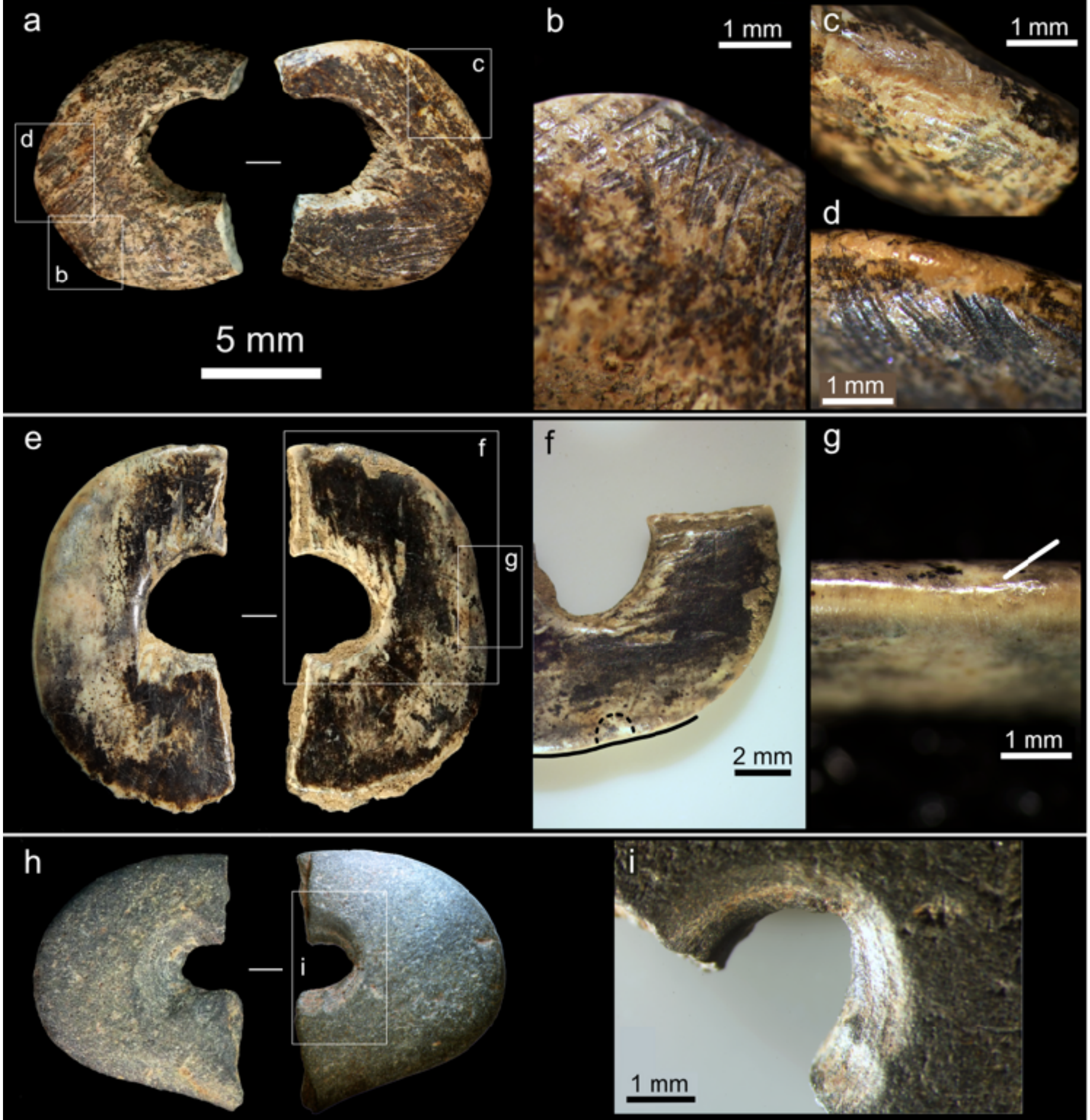


Figure 13

Figure 14

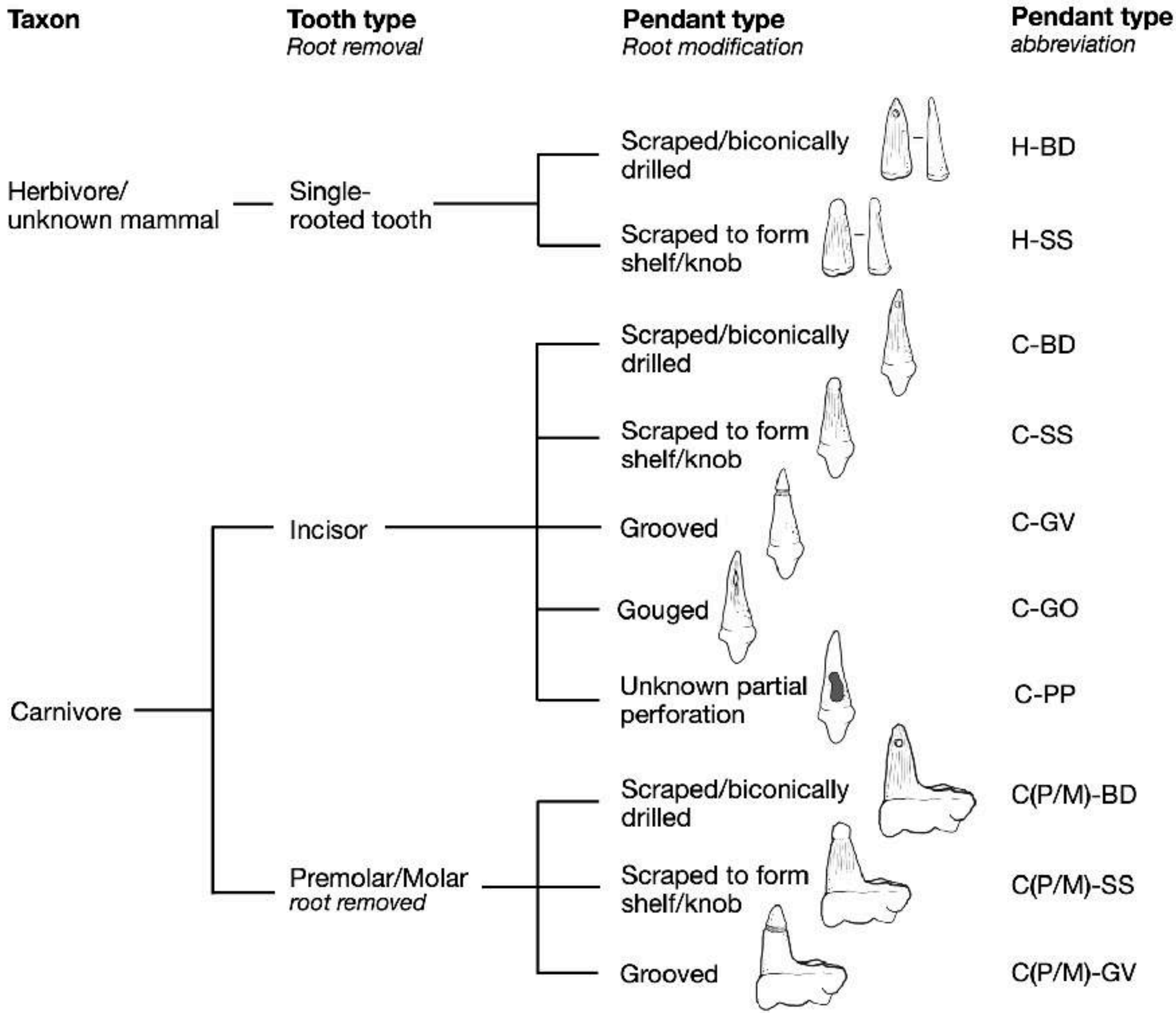
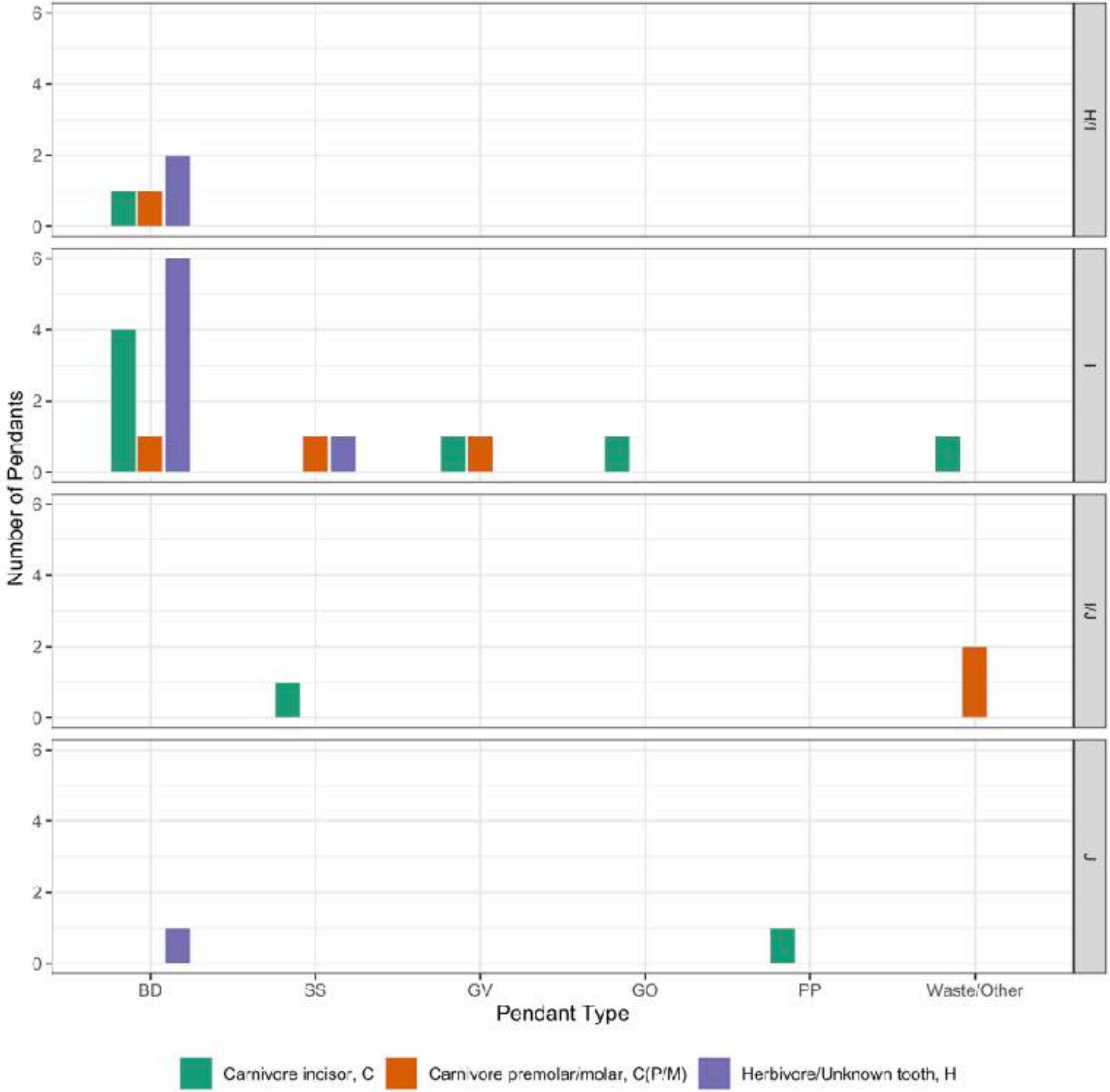
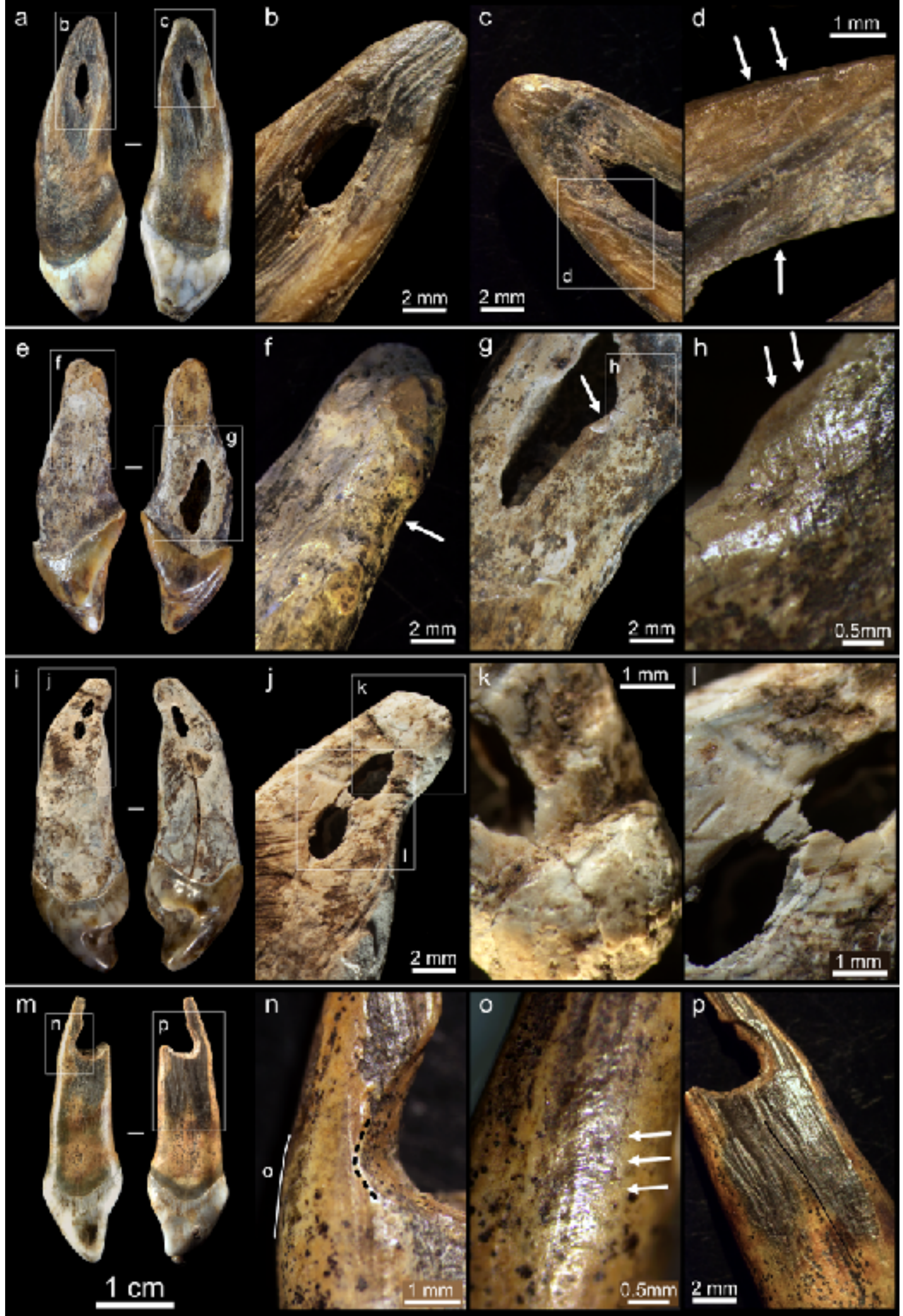

Taxon
Tooth type
Root removal
Pendant type
Root modification
Pendant type
abbreviation
Herbivore/
unknown mammal
Single-
rooted tooth
Scraped/biconically
drilled
H-BD
Scraped to form
shelf/knob
H-SS
Carnivore
Incisor
Scraped/biconically
drilled
C-BD
Scraped to form
shelf/knob
C-SS
Grooved
C-GV
Gouged
C-GO
Unknown partial
perforation
C-PP
Premolar/Molar
root removed
Scraped/biconically
drilled
C(P/M)-BD
Scraped to form
shelf/knob
C(P/M)-SS
Grooved
C(P/M)-GV

Figure 15



Number of Pendants
Pendant Type
BD
SS
GV
GO
FP
Waste/Other
H/I
I
I/J
J
0
2
4
6
Carnivore incisor, C
Carnivore premolar/molar, C(P/M)
Herbivore/Unknown tooth, H

Figure 16



a
b
c
b
2 mm
c
2 mm
d
d
1 mm
e
f
g
f
2 mm
g
h
2 mm
h
0.5mm
i
j
j
k
l
k
1 mm
l
1 mm
2 mm
m
n
p
n
o
1 mm
o
0.5mm
p
2 mm
1 cm

Figure 17

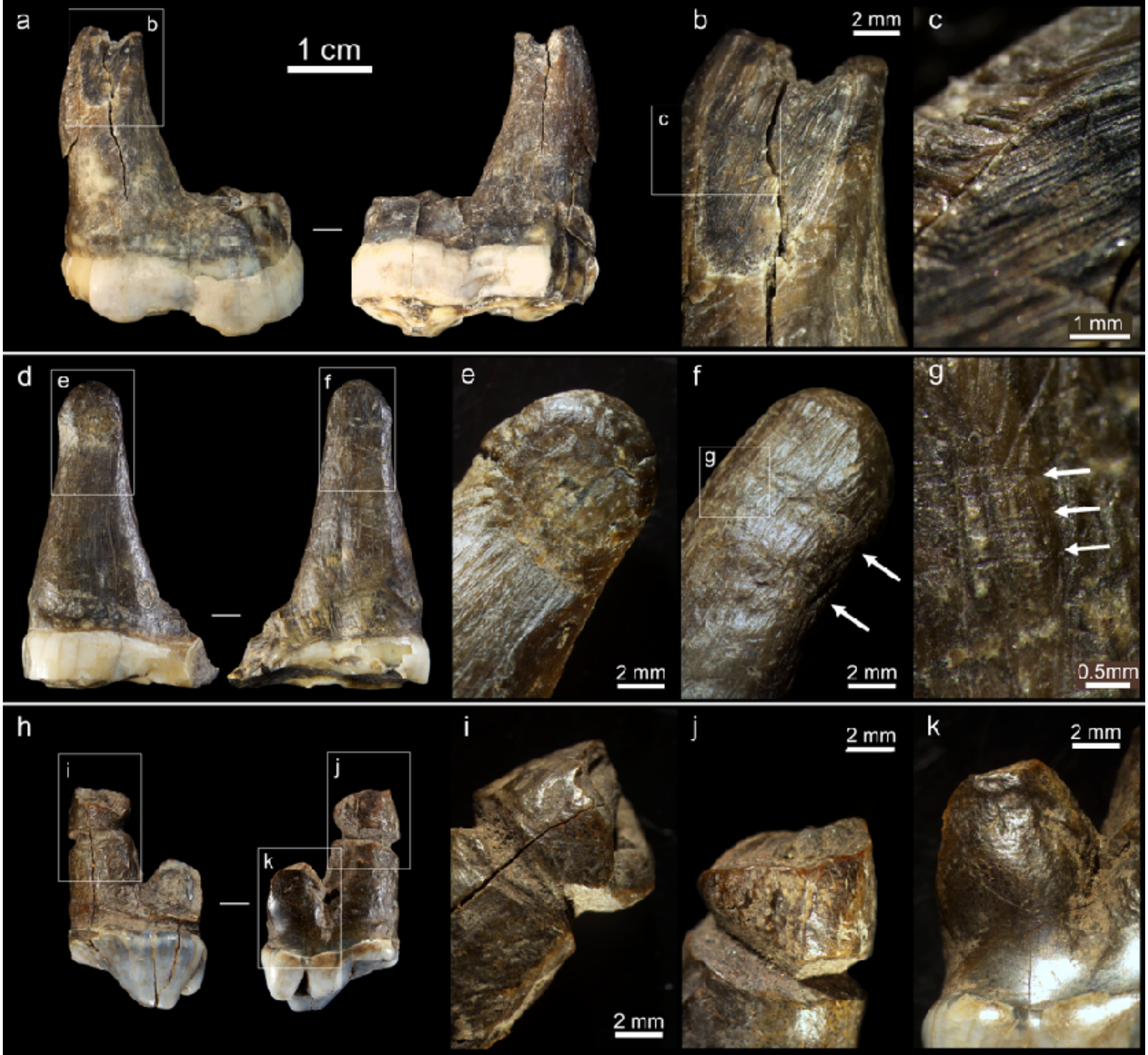


Table 1

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 [a]
	Tooth	2	3	18	4	27

[a] 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[a]		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[b]		4
	Incised: object with multiple subparallel linear marks	1	3	5		9

[a,b] 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[a]	Unknown mammal	Rib	Awl	sc, we, po	4b
	CC8-1047.3[a]	Unknown mammal	Rib	Awl	sc, po, cr	4a
	BB7-820	Sm./Med. herbivore (Cervidae/*Saiga*/ *Capreolus* sp.[c])	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 (*lissoir*)	sc, gr, po, uf, st	5a
	DD7-656	Lg. herbivore	Rib	Smoother (*lissoir*)	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	*Megaloceros giganteus*	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	*Bos*/*Bison* sp.[c]	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	*Equus* 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	*Ursus* sp.[c]	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[b]	Unknown mammal	Indet. bone	Notched bone	sc, inc, po, st	10c
	DD7-979.8[b]	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	*Bos*/*Bison* sp.[c]	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	*Bos*/*Bison* sp.[c]	Rib	Smoother (*lissoir*)	sc, gr, po, uf, st	5l
	DD7-1361	Cervidae sp.	Antler	Beveled object (intermediate tool)	sc, we, po, uf, cr, st	6j

CC7-2458	*Bos*/*Bison* 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.

[a,b] indicate two sets of refitted bones.

[c] 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	*Ursus spelaeus*	Left I^2	sc, dr	sm	broken	C-BD	11
	DD8-187	*Ursus spelaeus*	Right M_2	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	*Bos/Bison* sp.[a]	Single-rooted tooth	sc, dr	po	complete	Hb-BD	11, 13d
	AA7-1635.1	*Bos/Bison* sp.[a]	Single-rooted tooth	sc, dr	sm, po, de	complete	Hb-BD	11, 13r
	CC8-1496.1	Med. herbivore (Cervidae/*Saiga sp.*[a])	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	*Ursus spelaeus*	Right M_1	sc	po, st, de, cr	complete	CM-SS	11, 17d
CC8-770	*Ursus spelaeus*	Right M^2	sc, dr	sm, po, st	broken	CM-BD	11
BB7-300	*Ursus spelaeus*	Left I_1	sc, dr	sm, po, st, de	broken	C-BD	11
AA7-1194	*Ursus spelaeus*	Left I_1	sc, dr	sm, po, st	broken	C-BD	11, 16m
BB8-1748	*Ursus spelaeus*	Right I_3	sc, dr	sm, po, de	broken	C-BD	11
AA8-1393.1	*Canis lupus*	I	sc, dr	sm, po, st	broken	C-BD	11
BB8-2302	*Ursus spelaeus*	Left P_4	gv	sm, po, st	broken	CP-GV	11, 17h
BB7-1074	*Ursus spelaeus*	Left I_2	gv	sm, st	complete	C-GV	11
CC7-314	*Ursus spelaeus*	Left I_2	sc, go	st	complete	C-GO	11, 16a
DD7-472.7	*Ursus spelaeus*	Right I_1	sc, gr	sm	broken	unknown	11
BB8-510	Unknown mammal	Indet. root	sc, gv	---	broken	waste fragment	11

I/J	AA7-1465.1	*Ursus spelaeus*	Left P_4	sc	po, sm	broken	unknown	11
	A8-1471	*Ursus spelaeus*	Right M_3 root	sc	po	broken	waste fragment	11
	CC8-1571	*Ursus spelaeus*	Right I^2	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	*Ursus spelaeus*	Left I_3	?	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.

[a] 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[a]	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 (levels VIII and VII/VIII)	~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

[a] Uncalibrated dates.