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Bevel-ended bone artefacts from Pulli, Estonia: Early Mesolithic debarking tools?

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Abstract:

This paper reports the results of the first attempt of traceological studies (technological and functional) of bone products from the unique Early Mesolithic site of Pulli, Estonia. The analysis covered a group of specific tools made primarily from elk's metapodial bones, referred to as Pulli-type bevel-ended tools. Through microscopic studies, the complete biography of these artefacts was reconstructed, considering all stages of their production and the phases of use and abandonment. Use-wear analysis and studies in the field of experimental archaeology allowed the interpretation of the function of these products, which can be perceived as specialised tools for obtaining bark (debarking). The results of the conducted studies were compared with those of singular technological and functional studies on similar early Holocene bone tools from European contexts.

Keywords: Pulli, Early Mesolithic, bone tools, traceology, tool production and use, debarking, chaîne opératoire

1. Introduction

European Mesolithic sites provide many extremely interesting artefacts made of bone raw materials under suitable depositional conditions. Such artefacts are products of which the method of production and actual purpose cannot be accurately determined, and only from the perspective of our own contemporary cultural conditions do we perceive them as emanations of art (e.g. Płonka 2003), parts of hunting weapons (e.g. Clark 1936; Galiński 1986; Verhart 1988), tools (e.g. Westerby 1927; Mathiassen et al. 1942; Clark, Piggott 1965; Smith 1989) or elements of clothing (Taborin 1993; Álvarez-Fernandez 2009). However, precise research on the method of their production and, above all, their function (which is unfortunately still rare) can sometimes provide new, surprising information that verifies our beliefs and allows us to look differently at the life of hunter-gatherer communities during this stage of prehistory. From the authors' own research, an example is the recently conducted traceological studies on a collection of animal tooth pendants from early and middle Holocene sites in Central and Northeastern Europe, which unexpectedly provided insights into the mobility and intercultural exchange of these human groups (Osipowicz et al. 2024). Another example is the microscopic examination of seal's craniums from the Šventoji site (Lithuania), which showed their probable connection with ritual practices and led to the hypothesis that they served as 'frontlets', analogous to artefacts of this type from Western European sites, such as Star Carr in England (cf. Osipowicz et al. 2020). From the perspective of studies on the function of early Holocene bone artefacts, it is undoubtedly worth mentioning here the recent studies on barbed bone points from the Doggerland, which contributed to the discussion on the connection of some categories of these artefacts with fishing (Aleo et al. 2023).

A specific category (from the point of view of shape and way of preparation of working edge) of Mesolithic bone aretafacts is the so-called bevel-ended tools. These products are defined as simple tools that are made of bones or antlers, the distal part of which has been cut off, creating a single or double bevel (Provenzano 1998). This definition is detailed in the work of Griffiths and Bonsall (2001), who described tools of this type as *(...) made from narrow splinters of red deer antler or bone. One or, less commonly, both ends of the tool are bevelled and/or rounded, the bevelling often occurring on both faces of the tool. The bevelled end is usually convex in plain view.*

Bevel-ended tools were found throughout most of the Mesolithic settlement area in Europe. They were discovered at early Holocene sites in Mullerup 1 in Denmark (David 2005b, 482, PL. 8:2, 3; Leduc 2012), Star Carr in England (Clark 1954, 163, Fig. 72, 73; David 2005b, 543, PL. 69), Bedburg-Königshoven (David 2005b, 557, PL. 83:1) and Friesack 4 (Gramsch, Kloss 1989; David 2005b, 530, PL. 56:1-3; 533, PL:1, 2; 534, PL:60:12) in Germany, Ageröd I: A-H-C in Sweden (David 2005b, 566, PL. 92:5-8), Zvejnieki II settlement part in Latvia (Zagorska 2019, 9, Fig. 6:9-10), La Baume D`Ogens in Switzerland (David 2000; David 2005b, 589, PL. 115:7, 8) or Nizhneye Veretye I (Oshibkina 1989; 408, Fig. 5:10) and Zamostje II (David 2005b, 584, PL. 110:9, 10; Maigrot et al. 2013) in Russia. The vast range of their occurrence testifies to their great importance for the Mesolithic people. However, the fact that they were produced within different technological traditions and used in many, often very different, environmental and economic contexts was clearly reflected in the differences in the methods of their production and use. This is evidenced by even a cursory summary of the existing concepts on the function of this type of artefacts (proposed since the 19th century), where, based on more or less credible premises, they were perceived as chisels (or other types of tools) for working wood (Griffitts and Bonsall 2001; Maigrot et al. 2013; 2014), punches used in flint working, grinding tools for crushing seeds or nuts and multipurpose tools (after Griffitts and Bonsall 2001), tools used in the processing of animal hides (Anderson 1895; Finlayson 1995) or tools used in the collection or processing of limpets (Griffitts and Bonsall 2001). Therefore, understanding how these artefacts were made and, above all, their actual function and the differences in this regard between specimens from different geographical contexts may be an extremely essential step in understanding the economy of the hunter–gatherer–fisher communities of early Holocene Europe.

The studies presented here focused on a group of bone bevel-ended tools that were discovered at the unique Early Mesolithic site of Pulli, Estonia. These artefacts were subjected to precise, microscopic technological and functional studies, the aim of which was to reconstruct the *chaîne opératoire* used in their production and to interpret their actual function. The results of these studies were confronted with current knowledge of this type of tools from other early Holocene European sites.

The following study is the result of the first attempt to conduct a traceological analysis of bone artefacts from Pulli. In addition to the aforementioned primary goals, this research was intended to provide an answer to the question of the possibility of conducting reliable technological and functional analyses of artefacts included in this collection, for which the cognitive potential for knowledge of the European Mesolithic is enormous.

2. The site

The Pulli Mesolithic settlement site is located on the right bank of the Pärnu River near the town of Sindi in southwestern Estonia (Fig. 1A). The site was discovered in 1967 by geologists who noticed a humus strip containing animal bones beneath the sand layers during the investigation of a gravel pit. The settlement was archaeologically investigated in 1968–1973 and 1975–1976, and fieldwork was led by Lembit Jaanits (Jaanits & Jaanits 1975, 1978; Jaanits et al. 1982, 27–33, Figs. 12, 14). The finds are stored in the archaeological research collection of Tallinn University (AI 4476).

At the time of its use, the settlement was probably located on the banks of the Pärnu River, just a few kilometres from the shores of Ancylus Lake (cf. Fig. 1B). Around 10450 BP, the area was first flooded by a river and later, around 10150 BP, by Ancylus Lake, and the area was buried under several-meter-thick sedimentary sands (Jaanits et al. 1982, 27, Fig. 15; Veski et al. 2005, 76, Fig. 1; Kriiska 2020, 51, Fig. 6). The settlement was more than 1000 m^2 in size, and the cultural layer was only 5–15 cm thick. Five fireplaces and the sharpened ends of wooden stakes, which probably came from buildings, were discovered there, but the size and shape of the buildings could not be determined (Kriiska 2020, 62–63). On the basis of the ^{14}C dating of the wood and charcoal found in the cultural layer, the settlement was used for a long period between 10950 and 10500 BP and was probably a seasonal settlement where people stayed during the spring and summer (Veski et al. 2005, 77, Table 2; Kriiska 2020, 52–53).

The materials found consisted mainly of flints and bone and antler objects (Jaanits et al. 1982, 30, Figs. 16–17; David 2005a). Stone and bone arrowheads, bone fish spears and fishing hooks are indicative of hunting and fishing activities (Jaanits et al. 1982, 30, Fig. 16–17; Kriiska 2020, 66–67, 70–71, Fig. 12). Here, 90% of the mammal bones found in the Pulli settlement came from elk (*Alces alces*) and beavers (*Castor fiber*), bones of the brown bear (*Ursus arctos*) and wild boar (*Sus scrofa*) were less numerous, and there were only a few bones from other mammal species (Lõugas 1997, 66; 2017, Table 4.1; Veski et al. 2005, 78, Table 3; Kriiska 2020, 65, Fig. 11). Fish bones, mostly from pikeperch (*Sander lucioperca*), were also recovered (Lõugas 1996, 102, Table 1). Bird bones found come mostly from the divers (*Gaviidae*) (Lõugas 2017, 60).

The bone and antler work material of Pulli includes 134 manufactured items and a similar amount of wastes (David 2005a, Tab. 1).

3. Materials and methods

The subject of the study described in this paper is a collection of 19 bone artefacts from Pulli, of which 16 are bevel-ended tools (Fig. 2), two are probably waste from the manufacture of tools of this type (Fig. 3: 1, 2), and one is a semi-finished product (blank, Fig. 3: 3). The vast majority of tools were most likely preserved in their entirety (Fig. 2: 1-3, 5, 6, 9-11, 14) or have only minor losses resulting from the impact of post-depositional processes (Fig. 2: 4, 7, 8, 12, 13). Only two were preserved in small fragments (Fig. 2: 15, 16). The length of the analysed tools varies and ranges from 29 cm to 185 mm. Their width ranges from 17 to 37 mm.

The author of the first preliminary technological study of these objects is Éva David, who calls them ‘chisels’, distinguishing a number of their types because of the shape of the edge considered to be working (straight, mortise, gouge and notched; cf. David 2005a). In the opinion of the authors of this paper, using terms so strongly marked by functional meaning (such as the word ‘chisel’) before performing a use-wear analysis is unjustified, which is why we decided to use the functionally neutral term ‘Pulli-type bevel-ended tools’ in this work. These products are to some extent formally similar to the Mesolithic tools from the Zamostje site in Russia, which have recently been subjected to traceological studies and defined as (…) *narrow transverse-lateral bevel ended tools with sides invariably composing an angle of 45°* (Maigrot et al. 2014). On the basis of this description and considering the differences in form between the artefacts analysed here and the tools from Zamostje, we propose that the term ‘Pulli-type bevel-ended tools’ should be understood as ‘wide outer-inner bevel-ended tools’, defined as specimens made of bone splinters, where one of the ends of the bone is treated so that its outer and inner (medullary cavity) surfaces form an acute angle with each other (below 45°; cf. Fig. 4). The width of this (working) edge should be at least twice the thickness of the compact bone fragment from which the tool was made. Analogous to the Zamostje artefacts (cf. Maigrot et al. 2014, 523), the ‘upper’ side of the working edge (located at the upper surface of bone), usually prepared (rounded) by means of parallel scraping, is referred to as ‘platform’ and its lower side(located at the inner surface of bone), flattened (bevelled) by means of perpendicular scraping/whittling, is referred to as ‘contra-platform’ (cf. Fig. 4). We consider it necessary to introduce these terms to clearly understand the meaning of concepts related to (1) the anatomical features of the bone (inner and outer surfaces of the bone), (2) technological features of the working edge (platform and contra-platform) and (3) functional features of the working edge (contact and non-contact surface). They do not always mean the same thing.

The artefacts from Pulli included in these studies were subjected to zooarchaeological and traceological analysis (technological and functional), for which additional research in the field of experimental archaeology was performed.

3.1. Traceological studies

The first stage of the traceological analysis (cf. Korobkova 1999) was a macroscopic view and microscopic study of the artefact surfaces using low magnifications. The aim was to assess their state of preservation, the presence of preservatives and other categories of taphonomic modifications (e.g. traces of animal gnawing). In the second stage, technological research was carried out using optical microscopes and low magnifications. These were also used to select areas without preservatives and with clearly legible damage from use. They were analysed in the third research stage using a metallographic microscope. The use-wear traces observed on the tools from Pulli in the second and third stages of the analysis were compared with the damage caused during the experimental tools' use to interpret the prehistoric artefacts' function.

The applied technological terminology is based on osteological nomenclature and studies in this regard reported in the subject literature (e.g. Newcomer 1974; Olsen 1984; David 2004; Évora 2015; Orłowska 2016; Goutas, Christensen 2018; Osipowicz et al. 2018; Orłowska et al. 2022). The criteria for use-wear identification and terminology applied in the traceological (functional) studies were based on the published conceptual system (e.g., Sidéra 1993; Stordeur 1997; Averbouh, Provenzano 1998; Korobkova 1999; Maigrot 2003; Legrand 2007, 2008; Sidera, Legrand 2007; Buc 2011). To characterise the polish (above all, their location and distribution), we also used terminology developed for use-wear studies of stone artefacts (Vaughan 1985; van Gijn 1989; Juel Jensen 1994; Osipowicz 2010). This terminology is more detailed than what has been developed so far for the needs of use-wear studies of bone products.

The traceological analyses were performed using three microscopes. Studies on the state of preservation of the artefacts and the initial analysis of the technological and use-wear traces were performed using a Nikon SMZ-745T microscope (up to 65× magnification) equipped with a Delta Pix Invenio 6EIII camera. The latter was used to obtain the photomicrographs shown in Figs. 5A–C, 6A–E, G–L and 7B–K. Polish observations were conducted using a Motic AE2000MET microscope with up to 50× magnitude (magnification up to 500×) equipped with a Moticam 5+ camera. The photomicrographs shown in Figs. 5D–F and 9E, F were also obtained using this equipment. In addition, verification analyses of the artefacts' working edges were performed using a Zeiss Axioscope 5 microscope equipped with an Axiocam 208 camera. This equipment was also used for the traceological analysis of the experimental tools. The microphotographs shown in Fig. 8, 9A–D, 10, 11 and 12 were produced using this equipment. The photographs of the technological traces shown in Fig. 6F and 7A were captured using a camera Nikon D7100 DSLR camera fitted with a Nikon Nikkor AF Micro 60mm f/2.8D lens.

Traceological studies of the collection of bone artefacts from Pulli were difficult because of the poor state of preservation of many of them (cf. David. 2005a). As a result of the post-depositional processes, some of the specimens had heavily eroded and surfaces cracked (Fig. 5A), and on some of them, remnants of root growth were observed. However, the greatest problem in microscopic analysis (especially the use-wear one) was the method of conservation used in the case of materials from Pulli, i.e. covering the surface of the artefacts with a kind of 'wax'. This substance precisely filled all cracks and roughness on their surface and often made conducting observations very difficult and sometimes even impossible (Fig. 5B, C). This 'wax' could be identified without major problems in places where its layer was thick because of its characteristic yellow colour (cf. Fig. 5B, C). However, after many decades of 'touching' the artefacts, its surface had become polished in many places, which meant that in areas where its layer was thin, it became essentially transparent and extremely difficult or impossible to identify (including observations using an optical and metallographic microscope). In such cases, the structure of the surface covered with 'wax' could easily be confused with the original surface of the bone, which meant that conducting a reliable traceological analysis of these objects was questionable.

However, during testing of various cleaning procedures, it was found that the 'wax' used to preserve the Pulli materials reacted after being wiped with a cloth soaked in alcohol. Its surface became matt and acquired characteristic linearity (linear matting connected with multiple linear traces—Fig. 5E, F), the orientation of which can be freely changed depending on the direction of the wipe. Distinguishing this type of contamination from the natural surface of the bone and from technological and use-wear traces was not a problem (cf. Fig. 5D).

For this reason, it was decided that each of the artefacts would undergo a preliminary qualification procedure before the traceological analysis, consisting of wiping its surface with a cloth with alcohol perpendicularly to the orientation of the linear traces observed on it. If, after this procedure, their orientation and characteristics changed or the cleaned surface acquired the features of a 'waxed' surface, the artefact was excluded from further microscopic examination (removing the preservative was impossible). If the cleaned surface did not change, the artefact was qualified for the next stages of the traceological analysis.

The bevel-ended tools described in this paper were made of hard compact bone with smooth surfaces, which significantly affected the degree to which the preservative was bound to the bone surface. In most cases, no 'wax' was observed on the working edges, which significantly affected the readability of the technological and use-wear traces.

3.2. Experimental archaeology studies

Studies on the function of the analysed tools required planning and implementing a series of archaeological experiments. Before starting to perform the experiments, the traces of use observed on artefacts were compared with the damage of this type visible on experimental bone tools of similar forms, which are part of the reference collection stored at the Institute of Archaeology, Nicolaus Copernicus University in Toruń. Currently, this collection comprises approximately 200 osseous items.

These comparative studies allowed the exclusion of a number of raw materials (e.g. bones, leather, earth and herbaceous plants) and activities (e.g. scraping, sawing and piercing) as potentially performed using the Pulli tools. At the same time, they allowed a preliminary connection of these artefacts with woodworking and an activity resembling chiselling (transverse motion, perpendicular to the cutting edge, with a relatively low working angle). This became the starting point for more precise and focused experimental and traceological studies in this area.

We decided to conduct additional experiments in the field by processing dry and wet wood, including (1) debarking thick branches of dry alder, (2) debarking fresh but already dried thin alder twigs, (3) debarking the trunk of fresh pine, (4) chiselling the wood of fresh pine, (5) debarking fresh willow twigs (bast extraction) and (6) debarking fresh birch branches. The experiments were performed in spring when plants secrete a large amount of sap. The experimental tools were made from the metatarsal bones of red deer (elk bones were not available, as in Poland, this is a protected species). Contemporary tools (angle grinder and modern saws) were used in their production (splitting the red deer metapodials and preliminary shaping), but their surfaces were finished by scraping with flint flakes (in the same way as the artefacts). All experimental tools were hafted in wooden shafts.

4. Results

4.1. Raw materials

All 14 tools for which the taxon was identified were made of elk bones. The remaining five artefacts were assigned to the group of 'large ungulates' (cf. Tab. 1, 2). Most tools (apart from one specimen) for which the taxon was determined were made of metapodial bones, either *Metatarsus* or *Metacarpus*, using their distal and proximal parts to a similar extent. The only tool with an unspecified taxon of large ungulates and in which a different type of bone was used was made of *Tibia*. In the case of the remaining artefacts classified as 'large ungulate', the raw material used was identified using the skeletal element type as a 'long bone'.

4.2. Technological analysis of the archaeological tools

Manufacturing traces resulting from the initial processing of the raw material and its division (reduction) were observed on the tool blanks and finished products.

The first of the aforementioned activities represented the traces of the removal of the bone epiphyses. This process was performed by sawing a perpendicular incision to the depth enabling it to be broken off (Fig. 6J, K). Traces of this technological process were observed on one production waste (distal part of the bone; Fig. 3: 2) and two finished tools, including one made from the proximal part of the bone (Fig. 2:11) and the second made of its part unspecified (Fig. 2: 14).

Another result of the initial shaping of the raw material was, in the case of the analysed artefacts, traces of so-called calibration, i.e. correction of the shape of proximal epiphysis by removing flakes around it using the wedge-splitter technique (Fig. 7A; cf. David 2007). The remains of this process were observed on two artefacts, i.e. tool (Fig. 2:3) and production waste (Fig. 3: 1).

On one of the tools on which the epiphysis was removed (Fig. 2:14), multiple incisions were observed (Fig. 7B). They could have been created as a result of using tranchets or pics. However, it is more likely that they are a result of hitting the bone against a sharp edge to break off the incised epiphysis using a technique that involved breaking by surface percussion against an anvil (Goutas, Christensen 2018). This suggestion is based on the results of experiments that we conducted and the microscopic analysis of the technological traces created during these works.

The methods applied for dividing the raw material lengthwise to its axis are reflected in the traces of the unilateral longitudinal sawing/grooving of the bone shaft (hereinafter diaphyses) to a depth allowing its splitting/breaking off the bone rods and flakes. They are always recognizable only on one of the lateral edges of the artefact (Fig. 6D; Fig. 7I). Irregularities on this surface resulting from the division of the diaphysis (breaking off the uncut part) were smoothed by scraping or possibly by grinding (Fig. 6E; Fig. 7I). The second lateral edge of the artefacts is always fractured naturally (Fig. 6F). Only individual specimens underwent delicate correction by knapping (retouch) observed here (cf. Tab. 1).

On most of the entirely preserved artefacts, there are also visible remains of the process of chipping/breaking off bone fragments, the purpose was to give the tool base a wedge shape (cf. Fig. 6G, H; cf. Fig. 2: 1, 2, 5, 6, 8, 10, 12–14). This procedure was performed by chipping the side edges, usually from the upper surface (cf. Fig. 4). Occasionally, however, there were also hits from the basal end that resembled burin spalls (Fig. 6I). The traces of chiselling/hewing observed on the upper surface of one of the artefacts may also be related to the formation of the tool base (Fig. 7C—partially erased by post-depositional damage). In turn, the result of shaping of the upper end (with the working edge) of the analysed artefacts is the retouch observed on the side edges of one of them, which was performed to narrow this part of the product (Fig. 7D).

The upper and lower surfaces of bevel-ended bone tools from Pulli generally do not bear any manufacturing traces. Scraping remains were observed only on individual products (Fig. 7E). Traces of this activity are, however, typically legible on their working edges. On their upper side (platform), they are always oriented in line with the tool axis (Fig. 6L). Only in one case were obliquely oriented traces found here (Fig. 7F). On the lower side (contra-platform), their orientation is always perpendicular (Fig. 6B). In individual cases, the contra-platform was formed by whittling (Fig. 6C).

Scraping (and possibly whittling) was also used to repair (re-sharpening) working edges, which can be concluded from the fact that the remnants of these activities often destroy the use-wear traces (Fig. 7G).

On the basis of one of the analysed tools, visible incisions are made most likely to facilitate its attachment in the mount using a string (Fig. 7H). Incisions are also visible on the upper side and the lateral surface of the apical part of another product (Fig. 7I). Their purpose in this case is, however, unclear. On the working edge of one of the artefacts, a series of incisions were made, creating a kind of toothed edge (Fig. 7J). Similar but much finer incisions were also observed on a fragment of the working edge of another specimen (Fig. 7K).

4.3. Use-wear analysis

4.3.1. Archaeological artefacts

Despite analytical difficulties resulting from the covering of the artefacts with a preservative substance, most of them showed (more or less legible) use-wear damage (cf. Tab. 1). Their working edges do not show any noticeably developed use retouch. The breakages and removals visible on the working edges are probably, in most cases, the results of post-depositional processes. The cutting edges of the tools are sharp; only at higher magnification can one notice that they are slightly rounded (e.g. Fig. 8D).

The microtraces readable on the analysed artefacts can be classified into two variants. In the first (variant 1), on the platform side of the working edge, a bright polish of medium degree of intrusion (up to approximately 1 mm) was observed, which on the cutting edges largely (in places completely) destroyed the microrelief of the raw material (at least in its highest parts—Fig. 8D, H). Its topography is domed, slightly pitted, usually homogeneous, and the microrelief regular (except for surfaces significantly changed technologically). The high points are rounded. The texture of the polish is smooth (cf. Fig. 8A–I). In the lower areas of the microrelief, the topography becomes grainy, and the texture is much rougher. Linear traces are readable as single, black and filled-in hair-like striations and groves with usually multidirectional orientation and various sizes (usually, however, with a length not exceeding 100 µm—Fig. 8H). Unidirectional striations, which are oriented in line with the tool axis, occur less frequently (Fig. 8A, D, G). Specimens were also identified in which linear traces of the use origin were essentially absent on the platform side of the working edge (Fig. 8I).

On the contra-platform sides of the working edges of tools of this variant, the degree of intrusion of the use-wear traces is invasive, and their most essential feature is a strongly highlighted and clearly visible osteon structure (cf. Fig. 8J–S). The use polish, which to a large extent (completely on the cutting edge) destroys the natural relief of the raw material, has a marginal degree of intrusion (up to approximately 1 mm), which is definitely smaller than the extend of highlighting of the osteon structure. Its topography is slightly domed, in places completely flat and homogeneous. The microrelief of the polished surfaces is regular, and the high points are rounded or completely flat. The texture of the polish is smooth or only slightly rough. The topography becomes grainy only in the lower areas of the microrelief, and the texture is slightly rough. The polish is associated with rare hair-like linear traces of various sizes that are usually relatively short (not exceeding 300 µm in length), oriented in line with the tool axis (Fig. 8P, R).

In the second of the distinguished variants of use-wear traces (variant 2), their general characteristics are similar, but the osteon structure is not so clearly highlighted, and the topography of the polish (more abrasive in this case) is much more often heterogeneous. In addition, the linear traces are definitely more legible (cf. Fig. 9A–D).

On some of the artefacts that were better preserved and less covered with preservatives, hafting traces were also observed (primarily various types of abrasions and linear smoothing—Fig. 9E, F). No damage was recorded, the origin of which could have resulted from direct hitting of the described tools with stone hammers or hammers made of organic materials (cf. Maigrot et al. 2013).

4.3.2. Experimental tools

All tools included in the experimental programme conducted for the purposes of these studies were used for woodworking. Despite this, the traces of use observed on their surfaces differ from each other. Their detailed characteristics are shown in Table 3. By summarising the information contained therein, the following conclusions can be drawn:

1. Clear differences were observed in the use-wear damage occurring on the working edges of bone tools used for work in wet and dry wood. These are contained primarily in the significant highlighting and detailing of the visibility of the osteon structure on the inner surface of the bone in the case of tools used for work in a wet wood.
2. No significant differences in the structure or topography of the polish were observed between the tools used to process wet and dry wood. They are legible but have not been statistically verified enough to draw any further conclusions based on them.
3. Processing (debarking/bast extraction) of thin tree twigs (regardless of whether wet or slightly dry) causes marginal or illegible traces of use to be created on the non-contact sides of tools. Processing thick bark (thick branches and trunks) generates invasive and clearly legible traces on the non-contact sides, although their characteristics can differ in the case of wet (mainly highlighting of the osteons structure) and dry (polish and linear traces) raw materials.
4. No more noticeable differences were observed in the sizes and characteristics of the linear traces resulting from the processing of dry and wet wood. The presence of distinct linear traces oriented perpendicularly to the line of the working edge is a characteristic feature of the contact surfaces of the working edges (although they can also be found on non-contact surfaces when the processed raw material is relatively hard and the working angle is high).
5. Chiselling wood using bone tools with the features described in this paper causes invasive breakages on their working edges. Stress cracks were observed on the working edges of specimens used for chiselling pine (cf. Maigrot et al. 2013; 2014). Traces of this type were not observed on tools used for debarking.
6. There are clear differences in the macro- and microscopic characteristics of the working edges of tools used for processing dry and wet bark. The experimental tool used for working on dry and hard bark was completely dulled after just a few minutes of work. The dulling of the

working edges of tools used for processing wet and fresh bark progresses very slowly. These observations were also confirmed on other bone tools used for working on wood, which are part of the reference database deposited at IA NCU.

5. Discussion

Because they were made primarily from small bone fragments, the analysed artefacts from Pulli are quite specific. However, they found more or less close analogies at many Mesolithic European sites, including the following: Hohen Wiecheln, Horizon A (David 2005b, 507, PL.33:4) and Friesack 4 (David 2005b, 530, PL. 56:1-3) in Germany, La Baume D`Ogens in Switzerland (David 2005b, 589, PL. 115:8), Zamostje II (David 2005b, 584, PL. 110:10) and Nizhneye Veretye I (Oshibkina 1989; 408, Fig. 5:10) in Russia, Mullerup 1 in Denmark (David 2005b, 482, PL. 8:2, 3), Ageröd I: A-H-C in Sweden (David 2005b, 566, PL. 92:5-8) and Zvejnieki II settlement part in Latvia (Zagorska 2019, 9, Fig. 6:9-10). Unfortunately, the products from the cited sites (analogous in form to the Pulli tools) were not subjected to use-wear analysis. Therefore, they cannot be used as a comparative material for the findings made in the course of the studies presented here. Therefore, the observations made below refer mainly directly to the Pulli tools, but as we hope, they will be an impulse to conduct similar studies of other artefacts of this type in the near future.

The studies reported above allowed us to reconstruct the biography of bevel-ended tools from Pulli (cf. Fig. 13). In the first stage, the selection of the raw material for their manufacture was made. The observed preferences in this regard are uniform and highly specific. In all taxonomically defined cases, elk bones were used here, with a clear preference for metapodial bones: *metatarsus* and *metacarpus* (Fig. 13A; cf. Tab. 1, 2).

The process of their treatment to produce the discussed products was also standardised to a large extent and consisted of four basic steps (P1–P4, cf. Fig. 13B). Technological processes typical for them were observed on all Pulli-type tools that were analytical in this respect.

First, the raw material was prepared by removing (cutting and breaking off) or calibrating the epiphysis (P1). In the second step (P2), the bone was divided by sawing/grooving the diaphysis lengthwise and splitting it into several fragments (most of which could probably be used for further processing). In the third step (P3), the tool was formed, i.e. modelled to the required shape. The most common techniques used here were chipping and breaking. At this stage, the shapes of the working edges (in this case preliminarily) and the base of the products were also formed. In the case of those that were to be hafted (the vast majority), the base was very often formed in the shape of a wedge, which facilitated this procedure. Traces of such processing were not observed on one of the two tools, the bases of which show traces of the “saw-and-fracture” method. The last of the activities performed here was flattening (scraping out or possibly grinding) the unevenness of the surfaces cut and split in step P2. The fourth and last step (P4) in the manufacture chain of a tool in question was the final shaping of the working edges, which was performed by means of standardised (in terms of the direction of work) scraping or possibly whittling.

Tools prepared in this way (usually after hafting) were used in the next stage of their biography, i.e. the use phase (U) (cf. Fig. 13B). During this phase, their working edges were subject to reduction (which seems to be quite limited in its scope) due to wear and repairs consisting of secondary scraping (or whittling) primarily of their contra-platform surfaces. Tools were abandoned (stage W) not because they were unsuitable for further work but because of its completion, as indicated by the very good state of preservation of the working edges of the vast majority of the analysed specimens.

The results of the technological analyses made it possible to supplement the initial observations on the method of manufacturing bevel-ended tools from Pulli made by Éva David (2005a). However, the issue of the method used for the initial division of the raw material intended for the production of these tools requires additional comment here. In her work, David indicates the use of the so-called 'Z-method' in Pulli, i.e. (generally speaking) a method assuming the use of bone or stone wedges to split raw material during the production of bone tools (David 2007). Considering the results of the microscopic analyses reported in this paper, the use of this type of wedges can be confirmed indirectly only by examples of the observed epiphyses calibration because (as the conducted experiments have shown) performing this procedure without the use of wedges is rather impossible.

In general, the use of stone and bone wedges for bone splitting generates characteristic technological traces (cf. Osipowicz et al. 2018). From a perspective of the surface where the wedges were driven in, these are negatives of wedges, with an outline corresponding to their cross-section and accompanying cuts/crushes (cf. Fig. 14A–C). From a perspective of the split surface, these are specific linear abrasions in the wedge-drive zone, below which a breakage zone can be observed (cf. Fig. 14D–F). In the work of David et al. (2022), traces of this type are described as *(...) linear feature consisting of one or more 'scratched' or sometimes pointed depressions after the use of a lithic wedge or as a straight, linear feature ending in a step-like shoulder after the use of a bone wedge*.

The vast majority of the analysed Pulli-type bevel-ended tools were made of small, not very regular bone fragments, and their extraction did not require the use of complex techniques. As the experiments conducted have shown, making a cut that weakened the bone structure and hitting the blank with a stone hammer were completely sufficient to produce them. The use of wedges was not necessary. The cut and split surfaces that have been preserved on these artefacts are almost completely cut or were secondary scraped/ground, which means that any traces of the use of wedges are not visible (cf. Fig. 6D, E). The remnants of their use are also not visible on the negatives of retouching correcting the outline of the tool side edges (cf. Fig. 6G) or on the cut and broken off epiphyses (Fig. 6J), where in one case traces of the breaking by percussion against an anvil were probably observed (i.e. a technique that eliminates the need to use wedges; Fig. 7B). Therefore, we could not find any direct arguments for the use of wedges to split the diaphyses and remove the epiphyses, which of course does not mean that they were not used in this case. Perhaps more unequivocal evidence in this regard will be provided by microscopic examinations of other categories of artefacts from the Pulli site, e.g. points.

To sum up the above remarks, it can be stated that the process of manufacturing bevel-ended tools in Pulli did not generally differ from that observed at other sites where the Z-method was used (David 2007). A broader, contextual commentary on the individual technological procedures observed during the analyses is unfortunately impossible because no technological studies of artefacts of similar morphology and chronology using microscopes have been conducted on a larger scale so far. However, it is worth noting here the high standardisation of the technological process of manufacturing the discussed tool forms, which indicates their considerable importance for the users of the camps in Pulli.

As mentioned in the subsection *3.1. Traceological studies*, research on the probable function of the bevel-ended tools from Pulli was not easy because of their conservation method. However, because of the relatively high uniformity of the damages observed on their working edges, it was possible to classify them relatively simply and reliably. Considering the results of the conducted experiments, it is possible to draw the following conclusions:

The working edges of the analysed artefacts are preserved in their entirety (apart from post-depositional fractures), and no stress cracks have been observed on them, which allows us to suggest with a high degree of probability that we are not dealing here with typical wood chisels. As the conducted experiments indicate, the working edges of bone tools used for chiselling wood (and their hammered bases, even if hafted) are subject to retouching and breaking, especially if they are as delicate as in the case of some of the Pulli specimens. A good example documenting this rule is the experimental studies conducted for the functional analysis of bevel-ended artefacts from Zamostje, where retouching and breaking of the working edge were frequent in the case of experimental chiselling/splitting of wood, but were not observed on tools used for debarking (Maigrot et al. 2013; 2014).

Therefore, the characteristics of the working edges of bevel-ended tools from Pulli are definitely more typical for bark processing (or very delicate woodworking) than heavy woodworking. In addition, the cutting edges of these tools are sharp (not rounded), although they often bear very well legible and invasive traces of use. Considering the conducted experimental work, this allowed us to exclude the processing of thick and dry bark from the list of potentially processed materials because as a result of working in such raw material, the blunting of the cutting edges of bone tools progresses very fast.

The basic distinguishing feature of variant 1 of the distinguished use-wear traces legible on the artefacts from Pulli is the clear highlighting and detailing of the osteon structure on the contra-platforms of the working edges (inner sides of the bone). According to the results of the conducted experiments, this is another argument for excluding wood/dry bark processing from the list of potentially performed activities, and to propose a thesis that tools of this variant were used for working in wet wood or wet bark or rather (because of the lack of breakages on the working edges) primarily wet bark. The use-wear traces legible on the described artefacts have an invasive degree of intrusion on both sides of the working edge, which (according to the results of the conducted experimental work) indicates that the subjects of processing were not small twigs but rather thicker branches and trunks.

The processing of this type of raw material is also indirectly supported by the morphological features of the working edges and the technological procedures to which they were subjected. The conducted studies indicate (in cases where such analysis was possible) that the lower (concave) sides of the working edges (contra-platforms) played the role of the contact surfaces on the Pulli tools bearing traces of use of variant 1. This conclusion was drawn based on the arrangement and characteristics of the polished surfaces and linear traces visible on both sides of the tools' working edges, i.e. the presence of a distinct linear polish interfering in an abrasive way with the bone surface relief and distinct and uniformly oriented striations on their contra-platform sides (e.g. Fig. 8R) and a decidedly less developed polish associated with a small number of striations of different characteristics and oriented multidirectional on their platform sides (e.g. Fig. 8H). In the case of tools of this type, the arc shape of the working edge (degree of its concavity in the cross-sectional projection) limits the diameter of the material being processed because it is impossible to effectively debark/chisel branches with a diameter larger than that imposed by the arc shape. The bones used to make the analysed Pulli tools have a fairly standardised diameter, which, when trying to use tools made from fragments covering

1/3 or 1/2 of the circumference of the bone, would allow the effective debarking of branches no larger than approximately 5 cm in diameter. To enable the processing of larger branches, the users of Pulli tools used much narrower bone flakes, which contain a shorter fragment of the bone circumference, and consequently with a lesser concavity of the formed working edge. The purposefulness of such choices is particularly visible in cases where additional retouching of the upper part of the tool was used, aimed at narrowing this part to a width that allowed the production of a working edge of the desired width and the required degree of concavity (Fig. 2:3; 7D). The degree of concavity of the working edges was also reduced by removing a larger amount of material from the extreme, lateral areas of the working edge during the shaping of its lower side. The performance of the above-mentioned procedures clearly indicates a desire to adapt the tools to work with larger diameter material because they would not be necessary when processing small branches. Flattening the outline of the working edge was also essential for work efficiency because, as the experiments demonstrated, it improved the penetration capabilities of the tools when prying up the bark without destroying it (tearing it).

The characteristics of the use-wear traces observed on the Pulli tools also allow preliminary, cautious suggestions regarding the possible type of wood processed using them. One of the characteristic features of the traces of use of the distinguished variant 1 can be considered to be a small number of striations on the contact side of the working edge. It is emphasising the smoothness of the texture and the domed topography of the polished surfaces (cf. Fig. 8A, D, G). During the experiments, a similar effect was obtained only in the case of debarking fresh pine, where the created striations were similar in length to those visible on the archaeological artefacts (cf. Fig. 11C, D, E). Experimental work on different species of deciduous trees (even very wet and fresh ones) generated numerous linear traces, usually of a greater length (cf. e.g. Fig. 12D, E). In addition, in the case of the non-contact surfaces of the working edges of artefacts bearing use-wear traces of variant 1, the damages caused by use were quite analogous to those observed on tools for debarking pine (cf. 7J, M, P and 10F, G, H). As proven by palynological analysis, during the period of the Mesolithic site in Pulli, pine was one of the basic components of the surrounding tree stand (Poska & Veski 1999; Veski et al. 2005, 80, Fig. 4). This lends credence to the above suggestions, although their fully credible argumentation certainly requires statistical verification through additional experiments and traceological analysis.

The use damage visible on the tools of the variant 2 of use-wear traces was identical on both sides of the working edges, and no highlighting of the osteons structure was observed in their case. As indicated by the experimental results, these tools were most likely used for processing (debarking) dry wood (cf. Fig. 9A–D and 10C–F).

The method of using the working edges of the Pulli tools was quite standardised, and the contact surface was usually the lower (inner) side of the bone (contra-platform). However, specimens where the contact surface was its upper (outer) side were also discovered, as evidenced by the presence of well-developed linear traces in this place while maintaining all other features of damage typical of processing wet raw material (Fig. 8A, D).

At this stage of the research, little can be said regarding the significance of the traceological analysis conducted for studies on the function of the Pulli site and other aspects of the functioning of the early Holocene population there. The site was probably a seasonal settlement where people stayed in the spring and summer (Veski et al. 2005, 77, Table 2; Kriiska 2020, 52–53). The results of the studies described above indicating the processing of fresh wet bark using the analysed tools (most likely debarking of trees) seem to be compatible with this hypothesis because such activities were most often performed in spring and early summer when trees release the most sap and work is easiest and most effective (cf. Turner 1998, 153). Tree bark and the bast beneath it were among the most commonly used raw materials by hunter-gatherer-fisher communities of the early Holocene. They were used not only to produce containers (Oshibkina 1989; Gramsch 1993; Burov 1998; Wacnik et al. 2020) or (in the case of bast) cords and wrappings (Körber-Grohne 1995; Miettinen et al. 2008; Gumiński 2005; Lozovski et al. 2014), but they were also used to make less ‘standard’ objects, such as torches (Little et al. 202) or coffins (Marciniak 2001). Therefore, tools associated with the extraction of this raw material must have been common equipment of the people of that period, although their identification is certainly very difficult today for many reasons. One can only hope that the observations in this paper will allow them to be identified much more often in the future because this will enable a better understanding of many issues related to the management of plant raw materials in the Mesolithic.

6. Conclusions

Traceological studies of bone artefacts, especially those conducted to interpret their function, are difficult, and the characteristics of traces of use resulting from the processing of plant materials are influenced by many factors. For this reason, the observations made above, although in our opinion well argued, certainly require verification in some aspects through further experimental studies and microscopic analyses. The traceological studies showed a relatively good state of preservation of manufacture and use-wear traces on bone artefacts from Pulli. They also proved that the applied conservation procedure, although it constitutes a significant obstacle, is not a factor that completely prevents conducting use-wear studies. This is undoubtedly a very good prognosis before starting further traceological analyses of bone artefacts included in the Pulli collection, which are one of the keys to detailed knowledge of this unique archaeological site that is essential for understanding the European Mesolithic archaeological site.

The technological studies reported in this paper have significantly detailed the observations made so far on the production of bevel-ended tools from Pulli and have shown the existence of standardised procedures in this area. Similarly, the functional studies conducted have proven that these are specialised tools associated with processing a single type of raw material and have probably been used for a longer time. From both of these pieces of information, it can be concluded that the function of the site in Pulli most likely went beyond a short-term hunting camp. Therefore, we consider one of the most essential goals set for further studies of archaeological sources from here to be the final definition of the functional profile of the site and the nature of settlement on its territory to clearly determine whether the observed picture of settlements was a result of a cyclical presence of a migrating tribal/family group (foragers), perhaps seasonal expeditions of a small and highly specialised task-based group of hunters (collectors) or perhaps a third option that differs from other suggestions (cf. Binford 1977; 1979; 1980). Traceological studies of bone artefacts may play a key role in this research.

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Captions

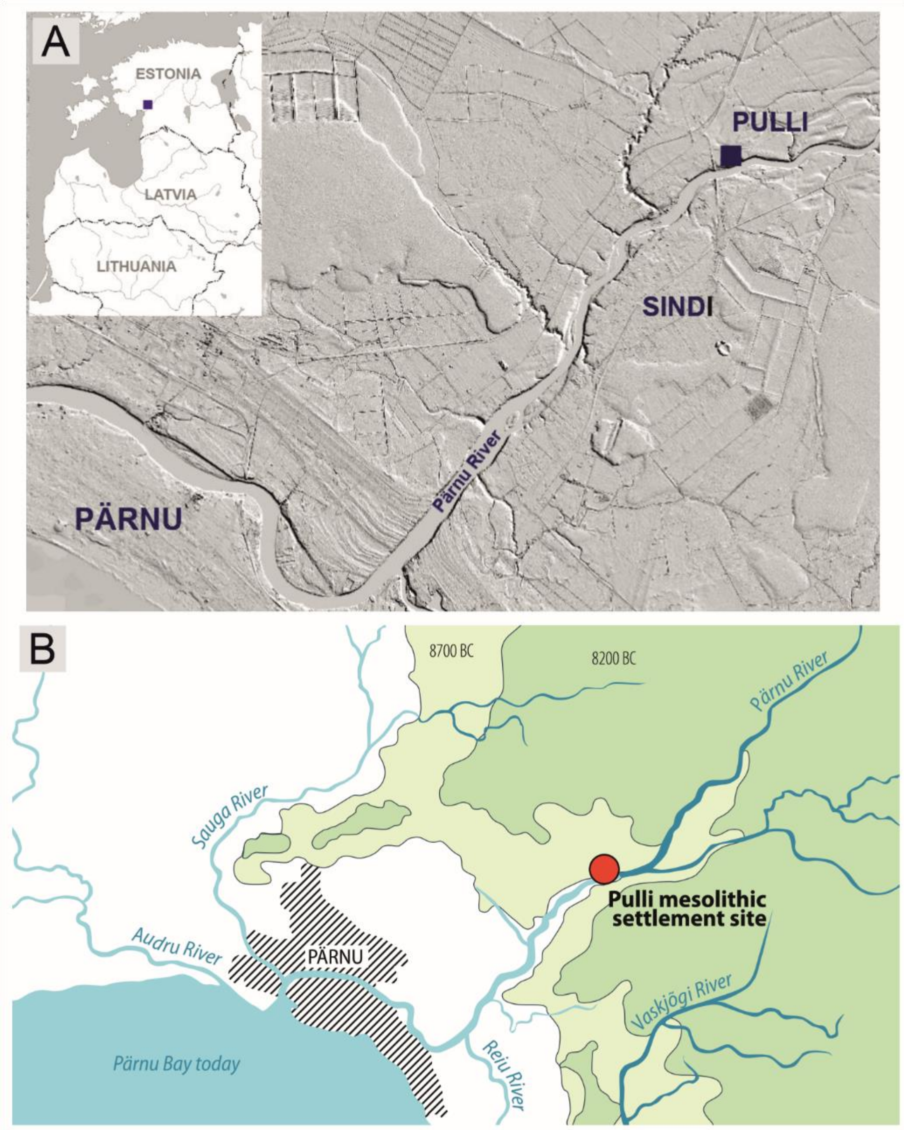


Fig. 1. Location of the Mesolithic site in Pulli: A – location in Estonia and Europe (Base map: Estonian Land Board 2024); B – paleogeographical reconstruction of the lower reaches of the Pärnu River around 10650 years BP and around 10150 years BP. Compiled by Aivar Kriiska, drawn by Jaana Ratas (Kriiska 2020, fig. 6: A).

Fig. 2. Pulli-type bevel-ended tools (with marked location of taking microphotographs presented in the article).

Fig. 3. Pulli-type bevel-ended tools: production wastes (1, 2), and half-finished product (3).

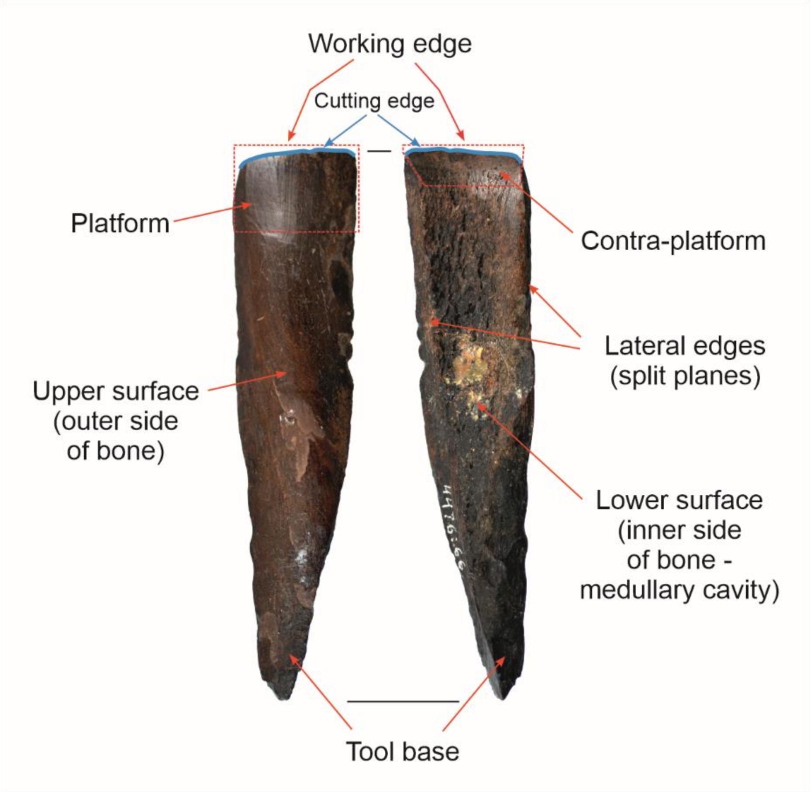


Fig.4. Terminology used in the article

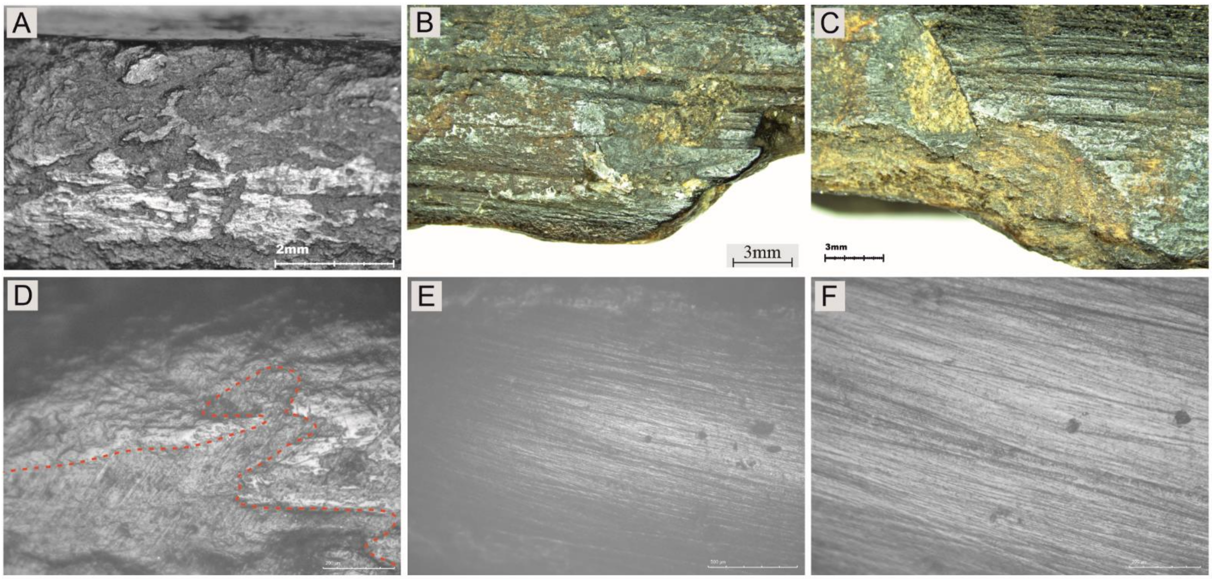


Fig. 5. Taphonomic analysis: A – the example of the surface erosion; B-F – surface contamination with preservatives (“waxy” substance). D – red dotted line show the range of the contamination with preservatives.

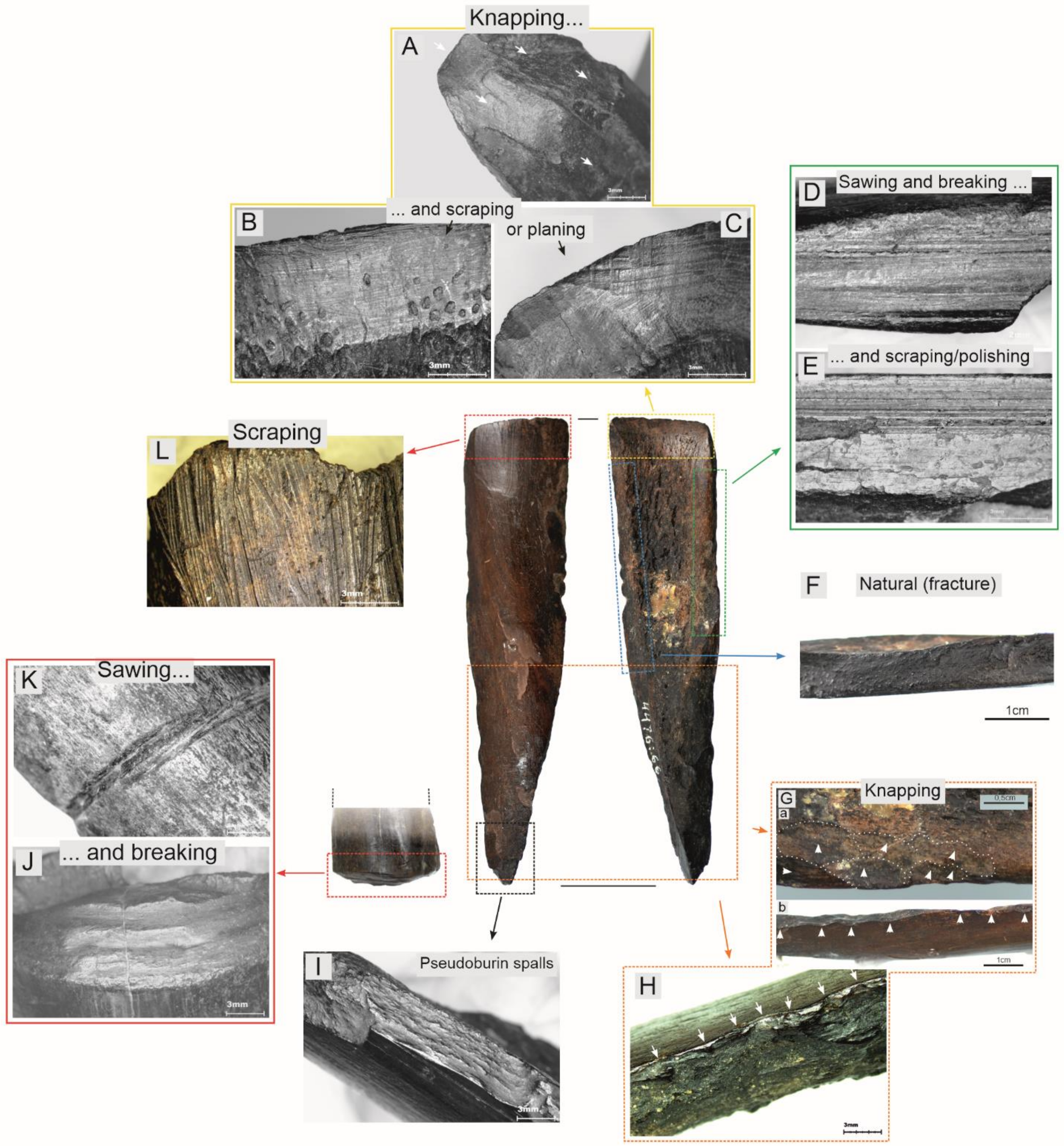


Fig. 6. Pulli-type bevel-ended tools: examples of manufacturing traces observed and their location at the surface of the tool (the scheme; micrographs were taken on different artefacts, for real location, see Table 1 and Fig. 2 and 3. White arrows: A, Ga - direction of the negatives; Gb, H – impact places).

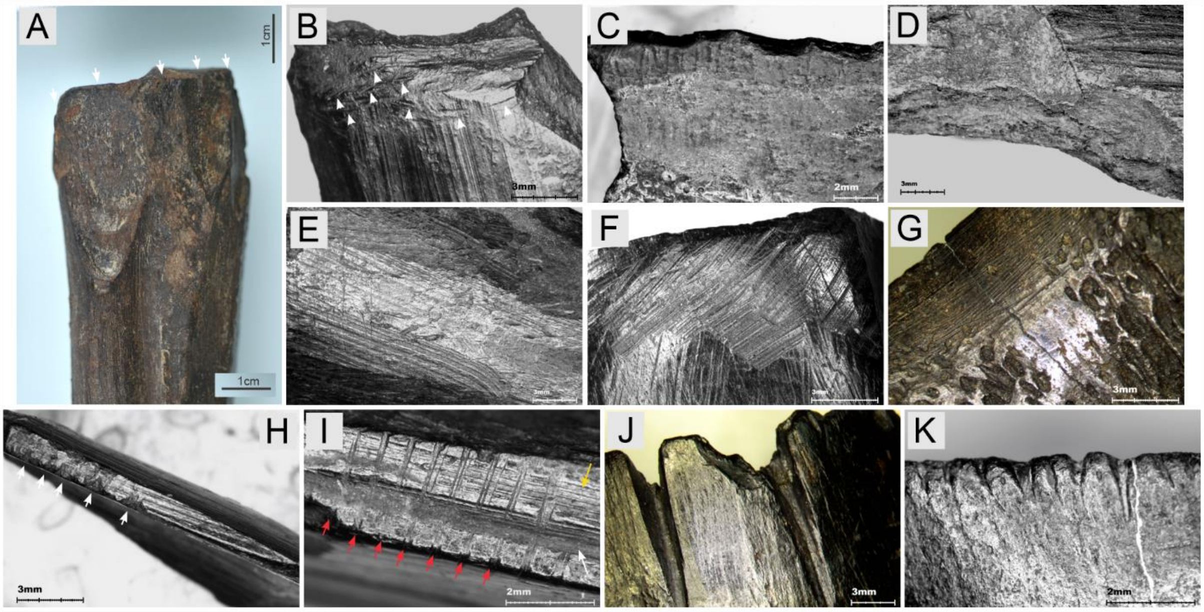


Fig. 7. Pulli-type bevel-ended tools: the examples of manufacturing traces (White arrows: A - impact places, B - incisions, H - cuts, I - sawing traces; Red arrows: I - cuts; Yellow arrow: I - scraping traces).

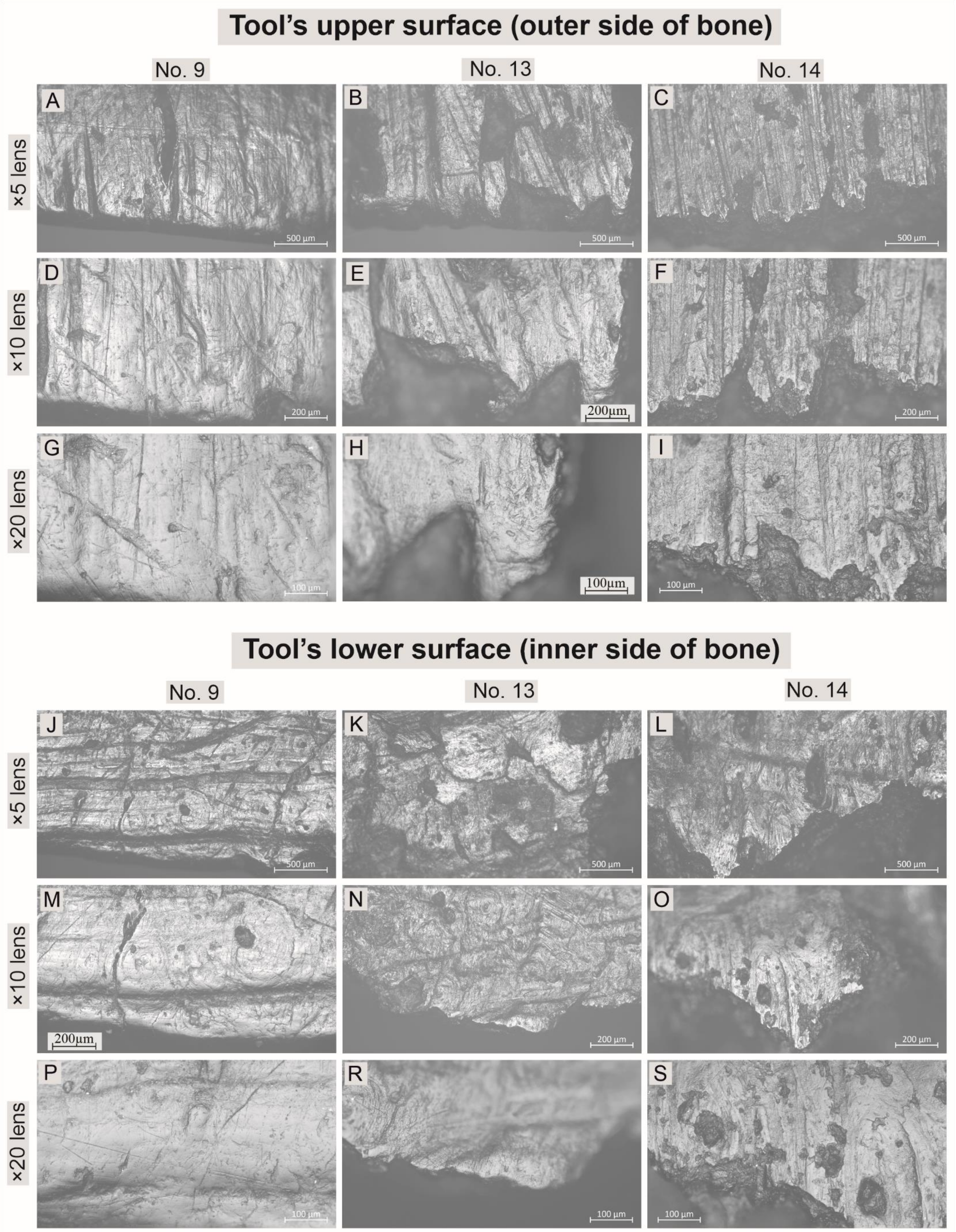


Fig. 8. Pulli-type bevel-ended tools: variant 1 of the use-wear traces.

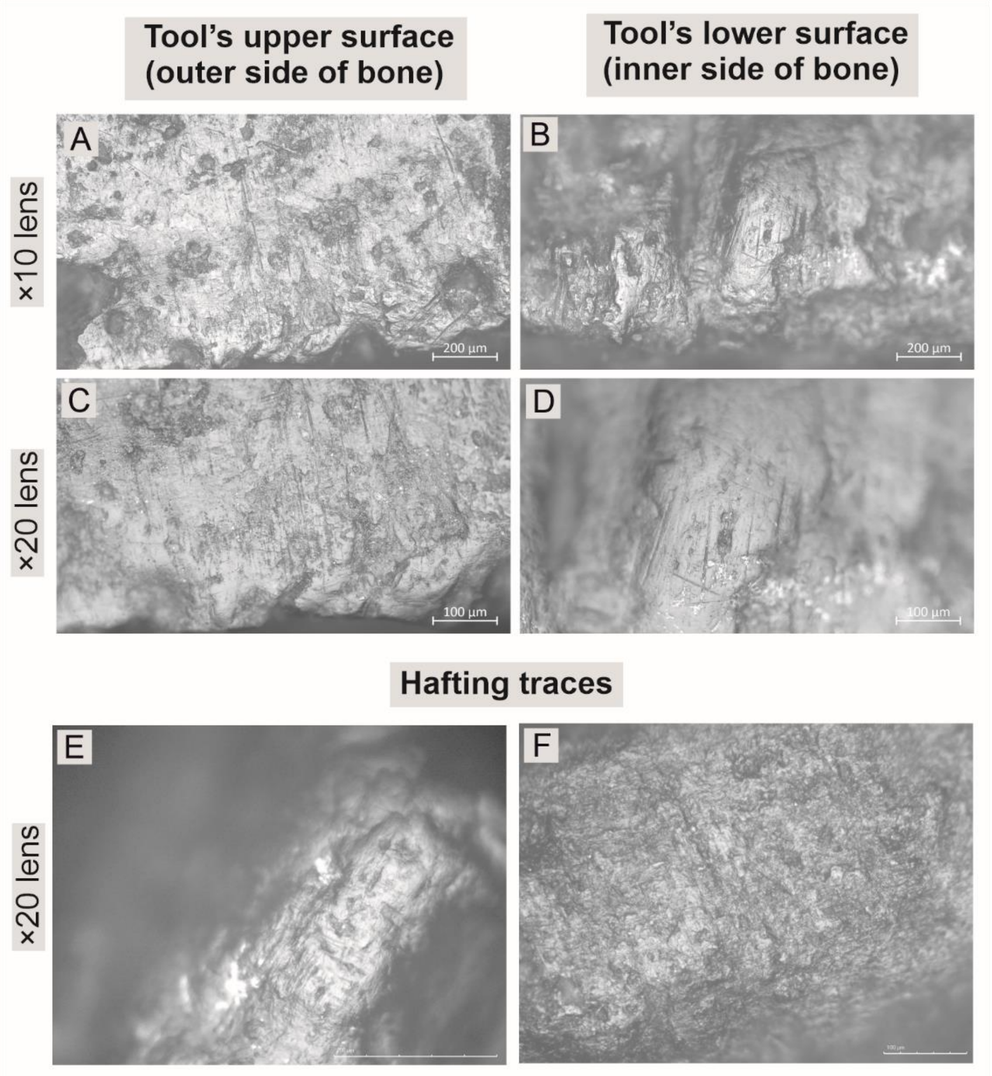


Fig. 9. Pulli-type bevel-ended tools: A-D – variant 2 of the use-wear traces; E, F – the examples of the hafting traces.

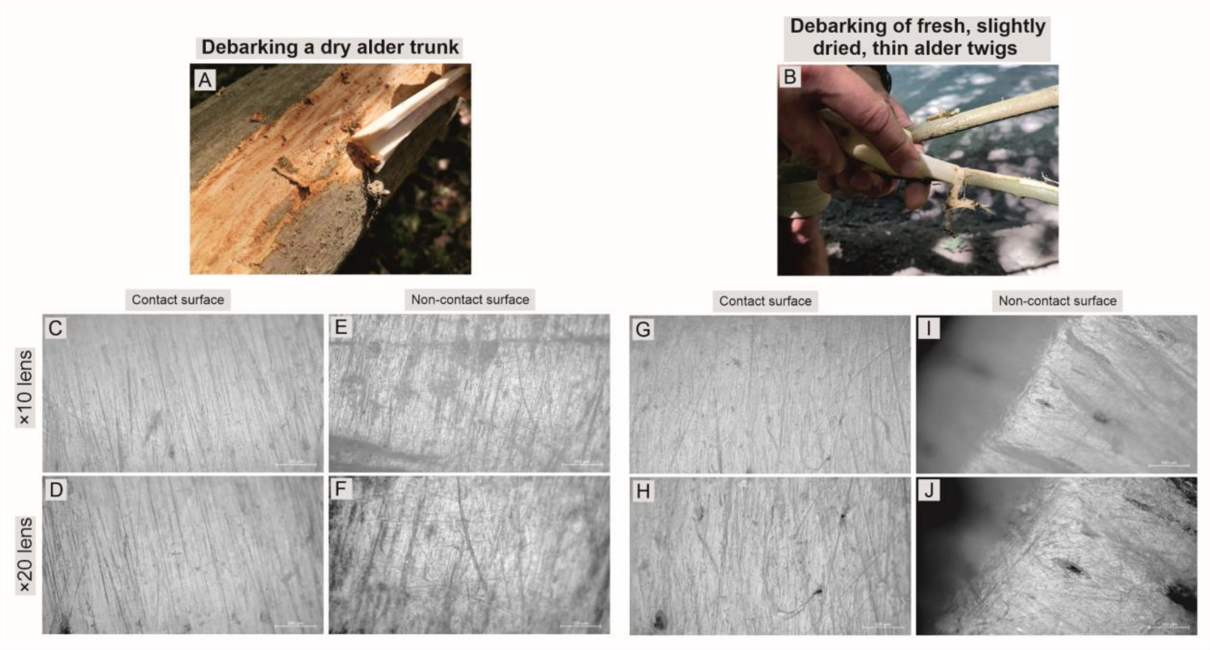


Fig. 10. The examples of the use-wear traces observed on the working edges of the experimental tools (debarking the dry alder trunk, and debarking of fresh alder twigs).

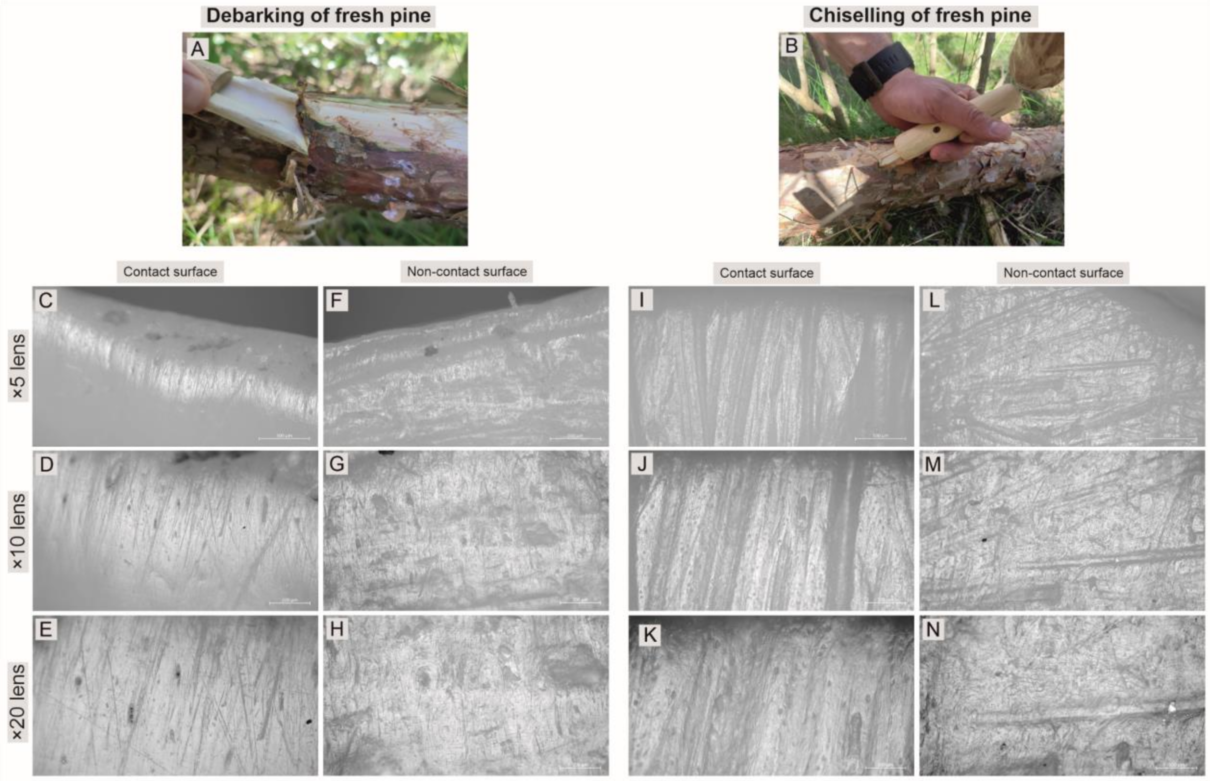


Fig. 11. The examples of the use-wear traces observed on the working edges of the experimental tools (debarking and chiseling of fresh pine).

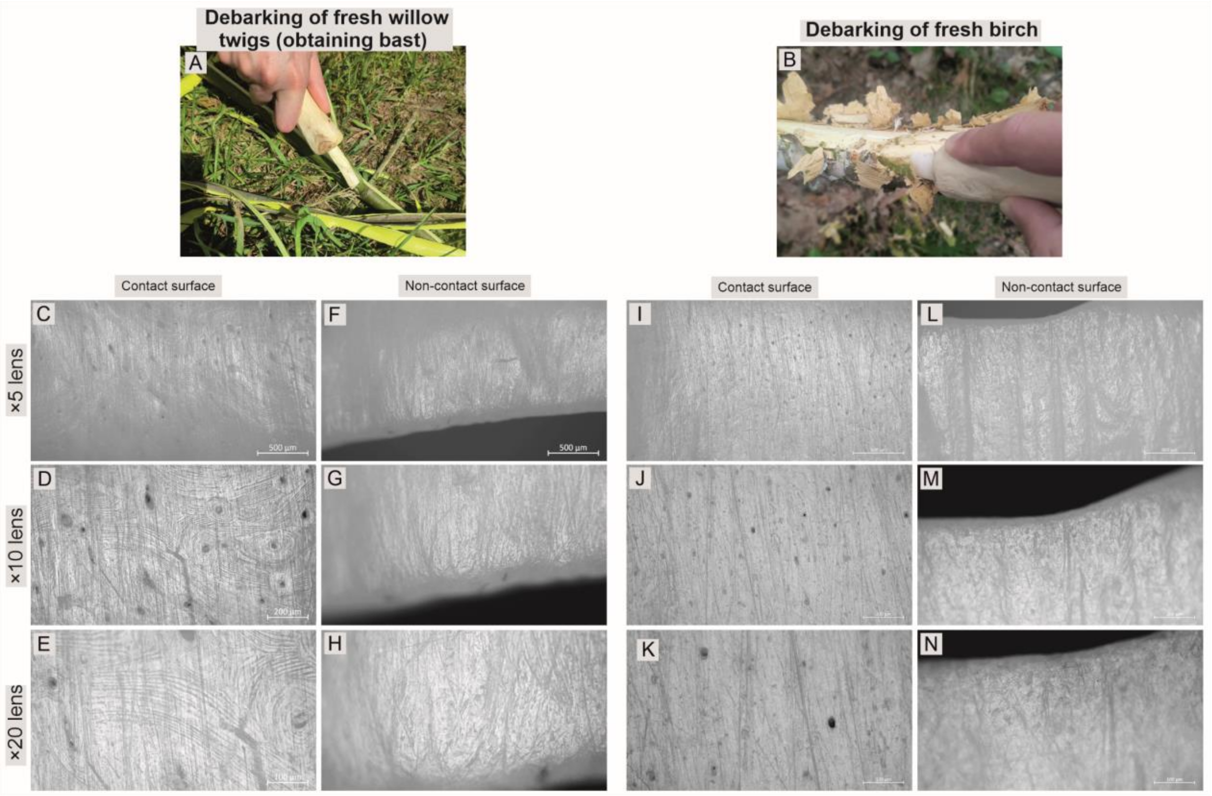
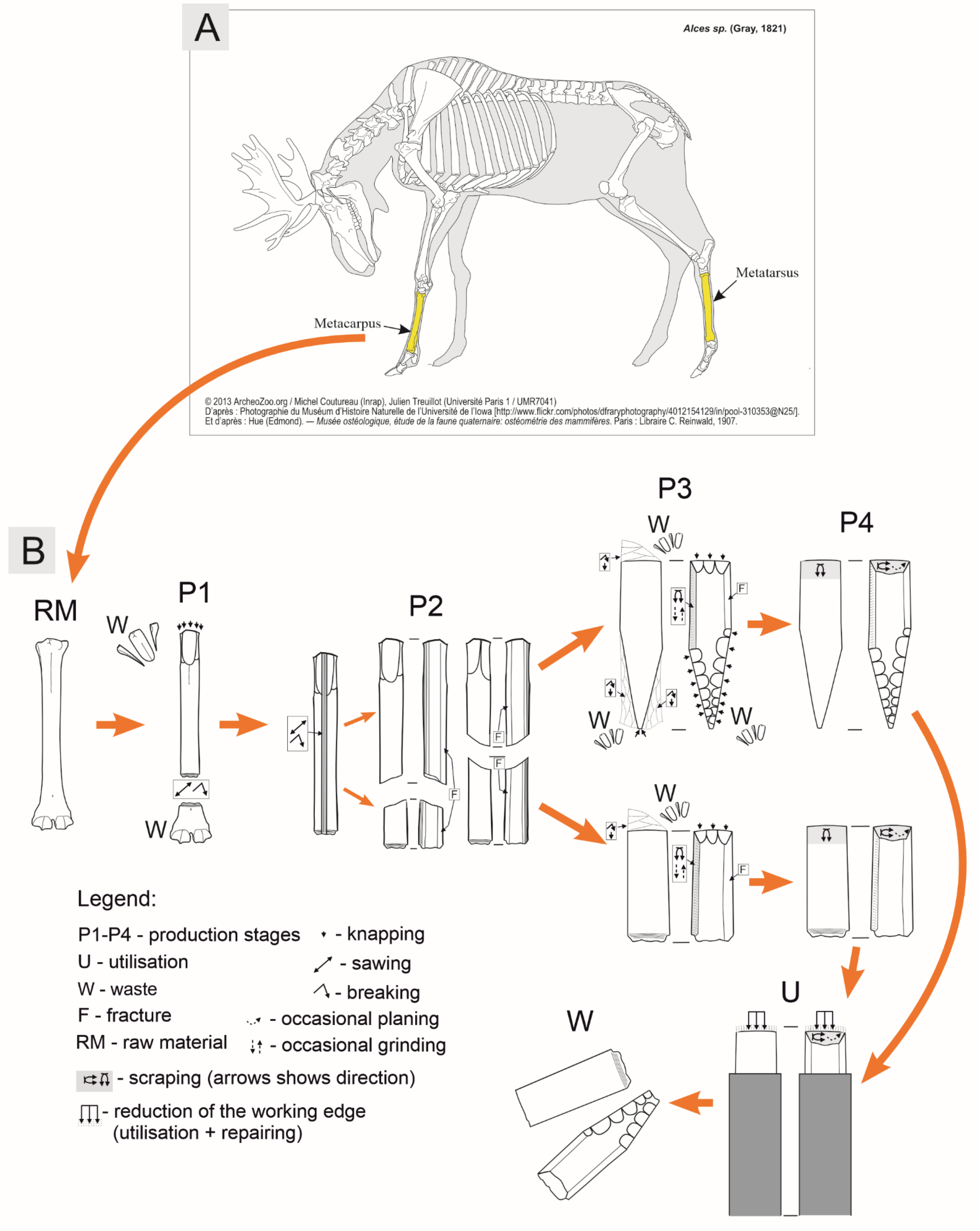


Fig. 12. The examples of the use-wear traces observed on the working edges of the experimental tools (debarking of fresh willow twigs and fresh birch).



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D'après : Photographie du Muséum d'Histoire Naturelle de l'Université de l'Iowa [http://www.flickr.com/photos/dfraryphotography/4012154129/in/pool-310353@N25/].
Et d'après : Hue (Edmond). — *Musée ostéologique, étude de la faune quaternaire: ostéométrie des mammifères.* Paris : Libraire C. Reinwald, 1907.

Fig. 13. Reconstructed biography of the Pulli-type bevel-ended tools.

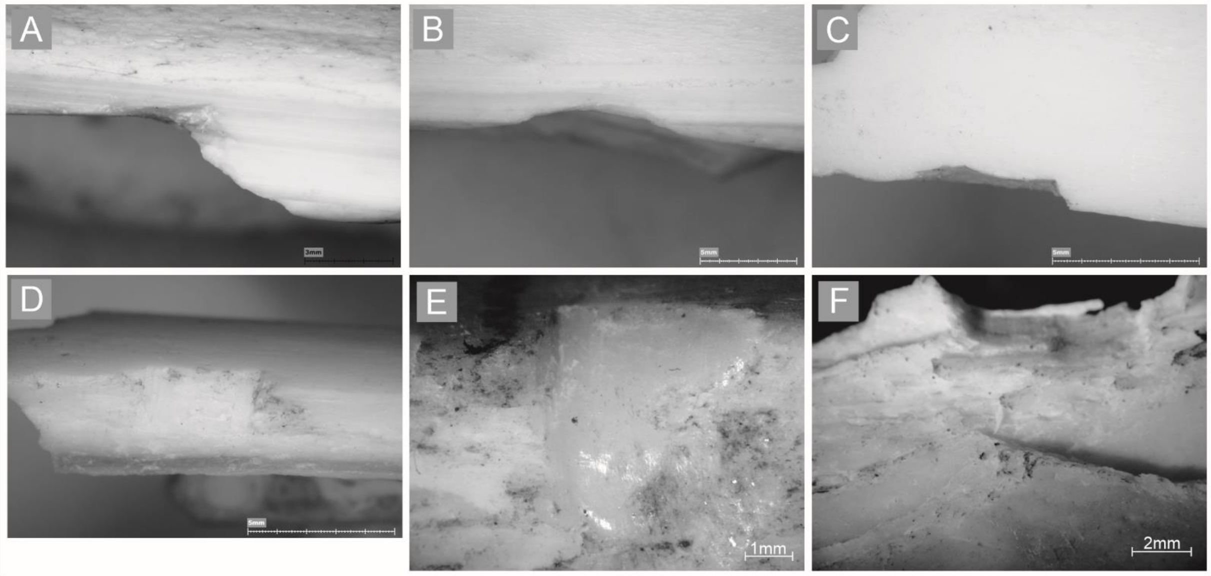

Fig. 14. The examples of the experimental manufacturing traces created by wedges used to split the bone.

Table 1. Pulli-type bevel-ended tools: detailed results of the zooarcheological and traceological (technological and use-wear) analysis.

No.	Inv no.	Species/ anatomical position	Dimensions (mm)	State of preservation	Technological traces	Use-wear traces and residues	Figure	Comments
1	4476:66 (T28)	Large ungulate / Tibia	105×23	Good	Most of the upper surface of the bone, except for the area at the base, was scraped off (Fig. 7E). The left side of the tool (split plane, from the lower side) was formed along most of its length by chipping (Fig. 6G, H). Only a small fragment close the working edge was scraped off and perhaps ground. The tool working edge was formed in a similar manner, by processing only from the lower side (contra-platform). The right side (fracture) of the specimen is natural (fracture). The base was formed into a wedge shape by chipping (Fig. 6G).	On the working edge, minor crushing, mainly on the upper side. There is also a bright polish covering mainly the upper parts of the microrelief, associated with linear traces with an orientation (mainly) consistent with the tool axis, but also multidirectional (especially on the lower, non-contact side). The topography of the polish is strongly domed, heterogeneous, the microrelief regular and the high points rounded. The texture of the polish is smooth (Fig. 9A-D).	2:1	The tool was hafted. On the protruding fragments there is smoothing and polish of the hafting origin (Fig. 9E).
2	4476:129 (T44)	Large ungulate / Long bone	74×22	Very good	The upper surface is natural, scraped only at the working edge. The marrow cavity was not processed. The right side (split plane) is scraped, the left is natural (fracture – Fig. 6F). The working edge was created by whittling (contra-platform – Fig. 6C) and scraping (platform – Fig. 7F). The base was formed into a wedge by splitting.	Delicate breckages on the working edge. Also visible here is a linear polish with a small degree of intrusion, domed, heterogeneous topography, regular microrelief, smooth texture and the high points rounded.	2:2	-

3	4476:198 (T53)	Alces alces/ Metacarpus	185×43	Good	Epiphysis calibrated, legible remnants of removed flakes, covered with traces of rough scraping. The marrow cavity and the outer surface of the bone are basically natural (not treated). Only locally, on the lower side, remnants of scraping used to level the chipped surface were observed. Split planes (and lateral edges) on about half of the length of the artefact from the base side are destroyed post-depositionally. In the remaining fragment, there are legible traces of retouching and scraping made to narrow the tool to make the working edge (Fig. 7D) . The working edge was scraped perpendicularly to the axis of the specimen on a contra-platform.	Minor removals on the working edge. The polish is poorly preserved, due to flaking of the working edge surface and probably the short time of tool use. Where it is visible, it is a bright, linear polish with a domed, rather heterogeneous topography, regular microrelief, smooth texture and the high points rounded. It is accompanied by poorly legible, analogically oriented linear traces.	2:3	-
4	4476:519 (T65)	Large ungulate / Long bone	43×17	Good	On one of the side planes, there are legible traces of sawing the bone to a depth of about 8/10 of its thickness (Fig. 6D), after which it was fractured (split). At the base, there are remains of incisions (chiseling/cutting?), largely destroyed by hafting smoothing (Fig. 7C). The lateral edges of the tool were corrected by means of minor retouching. The working edge of the tool was formed by scraping on the upper side (platform) in line with its axis. On the contra-platform, the working edge was processed in a	Polish badly preserved, domed topography, smooth texture	2: 4	-

					direction perpendicular to the orientation of the specimen, which is, however, already poorly legible due to use-wear smoothing.			
5	4476:785 (T71)	Alces alces/ Metatarsus, prox.	105×25	Very good, maybe broken at the base	The upper side of the bone is natural; in the preserved part of the marrow cavity, there are clear traces of scraping. Remains of this activity (probably performed with an unretouched flake) are also visible on one of the split planes after bone division, but due to the presence of a small step in this place, it should be assumed that it was originally a plane after sawing. The surface of the second split plane is natural (fracture). The working edge, on the upper side (platform) was formed by scraping in line with the tool axis, and the lower (contra-platform) by scraping perpendicularly to it. Here, the manufacturing traces are smoothed by the use-wear traces.	On the lower (contact) side of the working edge, a linear polish is visible, consistent with the orientation of the tool. It has a domed, heterogeneous topography, regular microrelief, slightly rough texture and the high points rounded. On the upper side, "melting" of the microrelief structure and invasive polish were observed with characteristics similar to those described above, but associated with multidirectional linear traces. The polish smoothes out scraping marks on the cutting edge.	2: 5	-
6	4476:601 (T66)	Alces alces/ Metapodium	53×29	Good, surfaces slightly eroded	On one of the side planes, there are remnants of sawing the bone to a depth of about 2/3 of its thickness, and its subsequent splitting (division). This split plane has been ground. The second side split plane is natural (fracture). The base of the specimen was formed into a	There are no usage breakages on the working edge. There is visible smoothing and invasive polish with a slightly domed (almost flat in places), quite homogeneous topography, regular microrelief, slightly rough texture and the high points rounded. It is accompanied by poorly legible, analogically oriented linear traces.	2: 6	-

					wedge by breaking off fragments of the raw material (possibly by chipping). The tool working edge on the platform was scraped in the direction consistent with the orientation of the specimen. Traces of scraping oriented perpendicularly are visible on the contra-platform. Scraping traces are also visible in the marrow cavity.			
7	4476:825 (T68)	Alces alces/ Metacarpus, prox.	88×34	Good, fragment	On the upper surface, singular scraping traces. On the left side plane (split plane) remains of scraping, possibly also grinding; the right one is natural (fracture). Working edge: at the platform side it was formed by scraping in the direction consistent with the tool axis (Fig. 6L); at the contra-platform side, remnants of perpendicular scraping, obliterated by damage from use. Base formed by intentional fracturing and lateral chipping.	Rounding and smoothing with a degree of intrusion of about 1-2 mm on the upper side. On the lower side macroscopically legible striations consistent with the tool axis. On both sides residually preserved bright linear polish rounding the upper parts of the bone microrelief with a smooth texture.	2: 7	-
8	4476:942 (T70)	Alces alces/ Metacarpus, dist.	119×37	Good, surfaces slightly eroded	On one of the side planes, there are remnants of sawing to divide the bone. Both split planes on the preserved fragment are ground. Over 2/3 of the length of the specimen, the split planes were retouched (by chipping) to give the base a wedge shape. The upper surface is natural, there are clear scraping traces in the marrow cavity. The working edge	On the working edge of the tool, from the lower (contact) side, outside the repair scraping zone (where the usage traces are basically illegible), a bright linear polish is visible, consistent with the tool orientation, associated with sparse, hair-like linear traces, mainly black striations. The polish has a domed, heterogeneous topography, regular microrelief, smooth texture and the high points rounded. On the	2: 8	The base shows hafting traces (polish/abrasion and linear traces - Fig. 9F).

					was formed by parallel scraping on the platform, while on the contra-platform by perpendicular scraping (Fig. 6B). In the latter case, we are probably dealing with repair of the working edge of the tool, as scraping removes a heavily polished surface (Fig. 7G).	upper (non-contact) side, there is a polish with quite analogous features, but with a rougher texture. It is non-linear and associated with multidirectional linear traces.		
9	4476:268 (T105)	Alces alces/ Metatarsus, proximal part of diaphyse	45×39	Very good	The upper surface is natural, only in some places scraping traces are visible. Analogical situation can be observed in the marrow chamber. The working edge on the platform is scraped in line with the axis of the artefact, on the lower side (contra-platform) perpendicularly. On one of the side planes of the bone (split plane) there are legible traces of grinding, the second one is natural (fracture).	On the upper side of the working edge, a fairly bright linear polish is visible, oriented in line with the tool axis, with domed, homogenous topography, regular microrelief, smooth texture and the high points slightly rounded. The polish is associated with a relatively large number of hair-like striations (Fig. 8A, D, G). On the lower side of the working edge, polish with similar characteristics was observed, but non-linear and with a small number of multidirectional linear traces. The osteons structure is also well hightlighted here (Fig. 8J, M, P). The degree of intrusion of polish is marginal.	2: 9	-
10	4441: 12 (T73)	Large ungulate / Long bone	60×39	Good	The upper and lower surfaces of the bone and one of the side planes are natural. The nature of the second side plane is illegible due to preservatives. On the tool's base, a perpendicular cut and traces of fracturing are visible, most likely a remnant of separating the epiphysis. Teeth at	Not readable because of the contamination from the preservatives	2:10	Heavily covered with preservatives

					the working edge were cut (Fig. 7J).			
11	4476: 778 (T74)	Alces alces/ Metatarsus, prox.	44×35	Good	On the upper surface of the bone, a smoothed scraping traces are legible. On the lower side (in the marrow cavity), observation was impossible due to preservatives. The working edge on the lower side was scraped perpendicularly to the tool axis. On the base of the tool, traces of removal of the epiphysis (by sawing and breaking) are legible (Fig. 6J). On the tool's working edge, a series of small cuts is visible over a section of about 0.5 cm of unclear origin/purpose (Fig. 7K).	Due to preservatives, legible only on the upper side of the working edge, and even here only fragmentarily due to surface flaking. The observed polish is slightly linear (in line with the tool axis), has a domed, fairly homogeneous topography, regular microrelief, smooth texture and the high points slightly rounded. It is associated with multidirectional linear traces.	2: 11	Heavily covered with preservatives
12	4476:316 (T63)	Alces alces/ Metatarsus, dist.diaph.	46×27	A fragment of the tool	The surface of the marrow cavity and the upper surface of the bone were scraped. The working edge is formed by scraping on a contra-platform, perpendicular to the axis of the specimen (chatter marks are visible). These traces may also be partially/entirely the result of repair (sharpening the specimen's working edge).	Not readable because of the contamination from the preservatives	2: 12	-
13	4476: 882 (T72)	Alces alces/ Metatarsus, dist.	67×28	Damaged (eroded), especially on the working edge	The upper surface of the bone and the marrow cavity are natural (not treated). On the right side plane (split plane) there are legible remains of the division of the raw material (sawing – Fig. 7I, marked with a white arrow) and scraping made to smooth the surface (Fig.	The tool's working edge is badly damaged. On its upper side, there is a visible linear (in line with the tool axis) polish, with a domed, fairly homogeneous topography, regular microrelief, slightly rough (on cutting edge smooth) texture and the high points slightly rounded. Single and	2: 13	-

					7I, marked with a yellow arrow). The left side plane (split plane) is natural (fracture). On the right split plane there is also a series of multiplied perpendicular cuts of unknown purpose (Fig. 7I, red arrows), which pass to the upper surface of the bone. The working edge on the platform side is scraped in accordance with the orientation of the tool, from the contra-platform side perpendicularly. The base of the specimen is shaped in a form of wedge. It was created by fracturing from one side, from which pseudo burin spalls were made along the tool axis (Fig. 6I).	multidirectional linear traces are conected to this polish (Fig. 8B, E, H). On the lower side of the working edge, the osteon structure is highlighted and one can observe a polish, with domed, homogeneous topography, regular microrelief, smooth texture and the high points slightly rounded. It is associated with hair-like linear traces with an orientation perpendicular to the line of the working edge (Fig. 8K, N, R).		
14	4476: 268 (T104)	Large ungulate / Long bone	29×20	Very good, slightly eroded working edge	The upper and lower surfaces of the bone are completely scraped off. On the tool's base, remnants of removing the epiphysis are legible (by sawing and breaking off - Fig. 7B). The large number of incisions visible here does not allow us to exclude the additional use of hewing in this process. It is more likely, however, that these traces were created when breaking off the head, as a result of a percussion against an anvil. The right side plane (split plane) of the specimen is scraped off, the left is natural (fracture). On the right split plane, at the base, cuts were made on a length of about 1 cm (Fig. 6H). It was done probably	The basic feature of the use-wear traces legible on the lower side of the working edge (contra-platform) is the highlighting of the osteons structure. The linear polish is also well legible here, basically without linear traces. It has a domed, fairly homogeneous topography, regular microrelief, smooth texture and the high points slightly rounded (Fig. 8L, O, S). On the platform side of the working edge, the polish is poorly legible, has a domed, homogeneous topography, regular microrelief and smooth texture. It is accompanied by few, multidirectional linear traces (Fig. 8C, F, I).	2: 14	-

					for the purpose of better securing the string holding the specimen in the mount. The working edge on the platform side is scraped in accordance with the orientation of the specimen, on the contra-platform side perpendicularly.			
15	4476:66 (T24)	Alces alces/ Metatarsus (diaphyse)	65×17	Fairly good, fragment of the tool, some surfaces flaked	Remains of one-sided sawing along the bone axis to a depth enabling the flake to be broken off (matrix for tool production). The sawn plane was ground (Fig. 6E), the second side plane (split plane) was processed by chipping (to the medullary cavity side). The working edge of the tool was formed by chipping to the lower side of the bone and locally grinding (Fig. 6A).	On the upper, non-contact side, on the ground surface, a bright polish is visible covering primarily the upper parts of the microrelief. Its topography is domed, heterogeneous, the microrelief regular and the high points rounded. The texture is smooth. On the lower (contact) side, the polish is less developed, has a more pitted topography and a slightly rough texture.	2: 15	-
16	4476:99 (T35)	Large ungulate / Long bone	55×18	A fragment of the tool	There are visible traces of scraping and grinding on the entire surface.	Non-analytical specimen, too small a fragment of the working edge preserved.	2: 16	-
17	4476/2 (T1)	Alces alces/ Metatarsus	155×38	Good	Tool blank. Remains after epiphysis calibration (Fig. 7A) and processing of side planes (split planes) by chipping. Possible preparation of the chipping platforms by scraping.	-	3: 1	-
18	4476:36 (T19)	Alces alces/ Metacarpus, distal part	181×58	The bone surface is quite well preserved; the artefact is fragmentarily preserved	Morphological blank of the tool. Circumferential incision for removing epiphysis (Fig. 6K; illegible on the damaged lower side of the artifact).	Delicate fractures of the perpendicular edge of the bone opposite the bone head. A bright polish covering primarily the upper parts of the microrelief and linear traces oriented in line with the tool axis were also observed here. The topography of the	3: 2	The blank that was used.

						polish is strongly domed, quite homogeneous, the microrelief regular and the high points rounded. The texture of the polish is smooth.		
19	4476: 328 (T121)	Alces alces/ Metacarpus	170×32	Bad, heavily coated with preservatives	A tool blank. On one of the side planes (split planes) there are clear traces of scraping and perhaps grinding. There are also visible traces of splitting the raw material (sawing and braking), unfortunately heavily covered with preservative wax. On one of the tips there are visible remains of chipping on the lower side of bone (creating a base/working edge?).	-	3: 3	-

Table 2. Pulli-type bevel-ended tools. Results of zooarchaeological analysis.

	Metatarsus			Metacarpus			Metapodium	Tibia	Long bone	Total
	Proximal	Distal	N. S.	Proximal	Distal	N. S.				
Alces alces	3	2	3	1	2	2	1	-	-	14
Large ungulate	-	-	-	-	-	-	-	1	4	5
Total	3	2	3	1	2	2	1	1	4	19

Table 3. Experimental program and characteristics of the use-wear traces observed on experimental tools.

Experiment	Duration (minutes)	Conditions and course of the experiment	Use-wear traces	
			Cutting edge and contact surface	Non-contact surface
Debarking a dry alder trunk (Fig. 10A)	5	Thick branch processing. The tool became dull after only 5 minutes of work.	The cutting edge is strongly rounded, with no use-breakage visible. Polish of invasive degree of intrusion, flat, only slightly domed, homogeneous topography, regular	Polish of invasive degree of intrusion, domed, slightly “grainy”, homogeneous topography (in places slightly heterogeneous), regular microrelief and

			microrelief and slightly rounded high points. The texture of the polish is smooth. The observed linear traces are relatively deep, regular, numerous black striations (much less frequently filled in) with orientation perpendicular to the line of cutting edge, with sharp, well-defined edges and length usually of about 400-450 microns, with a width of about 1 μm. They are accompanied by single grooves of the same length and width of about 7-14 μm (Fig. 10C, D).	rounded highest points. The texture of the polish is rough. Linear traces are very numerous. They are black and filled in striations, often with irregular edges. Hair-like striations with a length not exceeding 200 μm (usually 150-200 μm) and a width of about 1.5 μm predominate, next to which bigger, rather irregular grooves with a length of 200-400 μm and a width of 7-12 μm occurred. The orientation of linear traces is mainly perpendicular to the line of the cutting edge. However, many multidirectional striations also occurred (Fig. 10E, F).
Debarking of fresh, thin alder twigs (Fig. 10B)	30	The twigs, already slightly dried out, were held in the hand.	The cutting edge is sharp, and no use-breakage was observed. The polish has an invasive degree of intrusion; its topography is domed, slightly pitted, in the deeper located areas “grainy” and basically homogeneous. The bone microrelief is wholly worn away only in the highest locations. The relief of the polished surfaces is regular, and the high points are rounded. The texture of the polish is smooth/slightly rough. Linear traces are mainly irregular, hair-like filled-in (less often black) striations with rounded, irregular edges. Their length usually does not exceed 100 μm, with a width of about 1 μm. They are accompanied by single larger scratches with a length of 400-600 μm and a width of 4-10 μm. Linear traces very often intersect. In addition to those oriented perpendicularly to the line of the cutting edge, oblique striations also occurred in large numbers (Fig. 10G, H).	The extent of the polish is small. Its topography is domed and quite heterogeneous, and the microrelief is quite irregular, with high points rounded and flat. The texture of the polish is slightly rough. The linear traces have different characteristics but are generally very fine and multidirectional (Fig. 10I, J).

Debarking of fresh pine (Fig. 11A)	25	The tree had been cut down a few days earlier but was still fresh. The upper part of the trunk (diameter about 5-7cm) was processed.	The cutting edge is sharp, and no use-breakage was observed. The Polish has an invasive degree of intrusion, a flat/slightly domed, homogeneous topography. Its microrelief is regular, and the high points are somewhat rounded and flat. The texture is smooth. Linear traces are not very numerous, perpendicularly (sometimes obliquely) oriented, intersecting (mostly) irregular black striations and grooves with uneven edges and various sizes (length about 200-300 µm, width 5-15 µm). The hair-like traces between them are less numerous, 20-50 µm long and about 1 µm wide (Fig. 11C-E).	The range of use-wear traces is invasive. Their most important feature is the highlighted and clearly visible structure of osteons. The polish is bright and has a domed, slightly pitted, in deeper located areas slightly “grainy”, heterogeneous (mostly) topography, irregular micro-relief and rounded high points. The texture of the polish is smooth/slightly rough. The polish is associated with (above all) perpendicular linear traces: hair-like black and filled-in striations, usually 30-100 µm long and 1-2 µm wide. Larger scratches occurred individually (Fig. 11F-H).
Chiselling of fresh pine (Fig. 11B)	25	The tree had been cut down a few days earlier but was still fresh. The lower part of the trunk (diameter about 10-15cm) was processed.	The working edge is sharp; the tool was destroyed due to invasive use-breakage. The observed polish is quite matt and fills the relief structure of the raw material. Its topography is domed, linear and heterogeneous, and the microrelief is irregular, with rounded high points. The texture of the polish is quite rough. Linear traces are filled-in striations perpendicular to the line of the working edge (mainly) with a length of up to about 100 µm and a width of about 1 µm (in principle, this is linear polish - Fig. 11I-K).	The degree of intrusion of use-wear traces is invasive. The characteristic is the highlighting of the osteon structure and strong (stress) cracking of the bone surface (Fig. 11N). The polish has a domed, heterogeneous topography, quite regular microrelief, and slightly rounded high points. The texture of the polish is smooth. Linear traces are very poorly legible. These are mainly minor black scratches 30-40 µm long and 1.5 µm wide with orientation perpendicular to the line of the tool cutting edge (Fig. 11L-N).
Debarking of fresh willow twigs (obtaining bast) (Fig. 12A)	25	Twigs with a maximum diameter of 1 cm.	The working edge is slightly rounded (Fig. 12F-H), and no use-breakage was observed. The range of use-wear traces is invasive. The most characteristic here is the highlighting and very detailed visibility of the osteons structure, associated with a bright polish with a smooth texture and a slightly domed,	The range of usage traces is small. It is mainly a polish covering primarily the upper parts of the microrelief. Its topography is domed and heterogeneous, and the relief is irregular, with high points rounded. Its texture is slightly rough. The polish (slightly linear) is associated with

			wavy and homogeneous topography. Its microrelief is regular, and the high points are rounded. Also characteristic here are numerous linear traces (black and filled-in striations), somehow incorporated (disappearing) in the polish (giving it a slightly wavy topography). They have somewhat irregular edges and a significant length (up to about 1 mm, usually about 400-700 µm), with a width of usually about 1-2 µm. They are oriented perpendicularly to the line of the working edge (Fig. 12C-E).	single striations of various orientations, although mainly perpendicular and oblique to the line of the working edge (most of the perpendicular scratches visible in the photos are manufacturing traces) (Fig. 12F-H).
Debarking of fresh birch (Fig. 12B)	25	The tree had been cut down a few days earlier but was still fresh. Branches with a diameter of 1-5 cm were processed.	The working edge is basically sharp, only slightly rounded. No use-breakage was observed. The range of use traces is invasive. A slight convexity and highlighting of the osteon structure are legible. The polish penetrates the microrelief but covers mainly its upper parts. Its topography is relatively flat, pitted and homogeneous, the relief is regular, and the high points are slightly rounded. The texture is smooth, in places somewhat rough. Linear traces are perpendicular scratches of two types. The first are hairline traces (black and filled-in) 300-500 µm long and 1.3-1.6 µm wide. The second is less numerous larger striations (black) with quite regular edges and a length of 400-700 µm, with a width of 4-7 µm (Fig. 12I-K).	The range of traces of use is minimal. It is mainly a polish covering the upper parts of the microrelief with a domed, “grainy”, heterogeneous topography, irregular relief and high points rounded. Its texture is slightly rough. Linear traces were basically absent (apart from single multidirectional hairline scratches) (Fig. 12L-N).