



Taphonomy of the Kraków Spadzista (Late Gravettian) mammoth killing and butchering site

Piotr Wojtal ^{a,*}, Gary Haynes ^{b,*}, Jarosław Wilczyński ^a, Krzysztof Sobczyk ^{c,1},
Janis Klimowicz ^d

^a Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, Sławkowska 17, 31-016 Kraków, Poland

^b Department of Anthropology, University of Nevada, Reno, United States

^c Institute of Archaeology, Jagiellonian University, Gołębia 11, Kraków, Poland

^d Independent Researcher, Reno, Nevada, United States

ARTICLE INFO

Keywords:

Mammuthus primigenius
Gravettian
Upper Palaeolithic
Taphonomy

ABSTRACT

Kraków Spadzista (Poland) is an important Late Gravettian site that is unusual because of its direct evidence of mammoth hunting, its enormous amount of mammoth remains, and its separate zones of different human activities. Excavations have been conducted at the site from 1968 until the present day. Nearly 400 sq. m. of the site have been studied. Earlier analysis of the archaeological and osteological materials revealed that three distinct activity zones are present as parts of a single large site. These include a camp area where domestic activities were conducted, a workshop and animal processing area, and a large accumulation of mammoth remains. This article presents the results of zooarchaeological and taphonomic studies of all osteological material from all trenches excavated between 1968 and 2017. During the course of the fieldwork a total of ~119,000 mammal remains were discovered, belonging to 16 species (including rodents and other mammals). Some osteological materials were studied for the first time and other materials were subjected to a second round of examination and analysis. The abundant remains of woolly mammoth (*Mammuthus primigenius*) (MNI = 113) and Arctic fox (*Vulpes lagopus*) (MNI = 35) represent a significant majority of the total faunal remains. It is inferred that the mammoths were killed very near or within the area of accumulated bones and teeth, where they were dismembered and butchered. The hunters did not adhere to a strict age-based selection of mammoths for killing and may have opportunistically selected mammoths of varying ages as prey, along with a few individuals of other taxa. Mammoth ribs with embedded lithic fragments presumed to be from weapon points are direct evidence of killing rather than scavenging. The meat-removal and dismembering of carcasses of just killed animals is evidenced by cut marks on various mammoth bones and cut marks on a reindeer tibia. The presence of burned bones suggests the utilisation of mammoth long limb bones as fuel in hearths or cooking fires. Gravettian people did not remain at the site year-round and temporarily left after several weeks or months. After they had departed, the site was visited by animals attracted to scavengeable remains during the spring and summer. Although the mammoth bones likely had been stripped of most meat by Gravettian butchers, carnivores gnawed on remnant soft tissue and the nearly fresh bones. Additionally, the site was utilised by raptors, probably nesting Snowy owls which regurgitated pellets or casts containing remains of rodent prey, which became incorporated into the site sediments.

1. Introduction

1.1. The site

Kraków Spadzista, one of the most important Gravettian sites in

Eurasia, was accidentally discovered more than half a century ago, in 1967. The site is situated on an upland plateau connected to the main summit of Blessed Bronisława Hill very close to the centre of old Kraków (Fig. 1). The site partly overlaps a XIX century Austrian earth fortification about 50 m above the Rudawa River valley (Kozłowski et al., 1974).

* Corresponding authors.

E-mail addresses: wojtal@isrz.pan.krakow.pl (P. Wojtal), gahaynes@unr.edu (G. Haynes).

¹ Deceased.



Fig. 1. (a) and (b): Location of the Kraków Spadzista site; (c): oblique aerial photograph of the site and surroundings in 2019, marked in red. The drone photograph, taken by M. Czarnowicz, is used by permission. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

It is bounded on the north by a rocky cliff edge with a steep dropoff and on the west and east by gentle slopes of a large Pleistocene depression. The area of the site is over 1 ha, and trenches explored in different years cover its entire surface. Archeological materials were discovered in every one of the many excavated trenches, most coming from a layer of tundra gley (layer 6, Late Gravettian) (Lengyel and Wilczyński, 2018), which had developed in a soliflucted clay loam deposited during a moist and harsh climate. Only in this layer was zoological material discovered. This layer was created by repeated visits of hunter-gatherers leaving a local palimpsest. Post depositional processes (e.g. solifluction) transformed the palimpsest into a single cultural level (layer 6), which at trench B + B1 measured 30 to 100 cm in thickness (Kozłowski et al., 1974; van Vliet, 1974; Kalicki et al., 2007). However, some archeological artifacts were found in older sediments – a colluvial or soliflucted calcareous sandy loam (layer 7, Aurignacian) – and also in the bottom of younger loess (layer 5, Epigravettian).

1.2. History of site studies

Field work at the Kraków Spadzista site began in 1968 and continued

with few interruptions until 2017. The site is situated in an area of about 1 ha (~10,000 sq.m.). During the years of work, 21 trenches and test pits designated by letters and Roman numerals were excavated, encompassing 384 sq.m (Fig. 2). Historically trench B was first excavated after the site's discovery in 1967. Field work was conducted regularly there from 1968 to 1973 (trench A refers to older excavations conducted by J. K. Kozłowski at an Aurignacian locus located about 100 m to the south of trench B). Trench B was located in the northern part of the site close to the edge of the steep dropoff. In 1973 work in this area was stopped and results were published in journal papers (e.g. Kozłowski and Kubiać, 1972; Kozłowski et al., 1972, 1975) and a monograph (Kozłowski et al., 1974). Concurrent with the field work at trench B four small test pits a few square meters in size were opened in 1970–1971 (test trenches II, III, IV and V). In 1972 and 1973 trench C was excavated a few dozen meters south of trench B. In 1973 field work at the site was temporarily stopped, but was resumed in 1980 when trench C2 was excavated in the southwest part of the site close to trench C. In 1986–1989 field work was conducted in three trenches: D, E, and F (Fig. 2). Trench D, about 60 m south of trench B, was opened in 1986–1988 (Sobczyk, 1996). In 1987 trench E was excavated, and in 1989 trench F was excavated. These

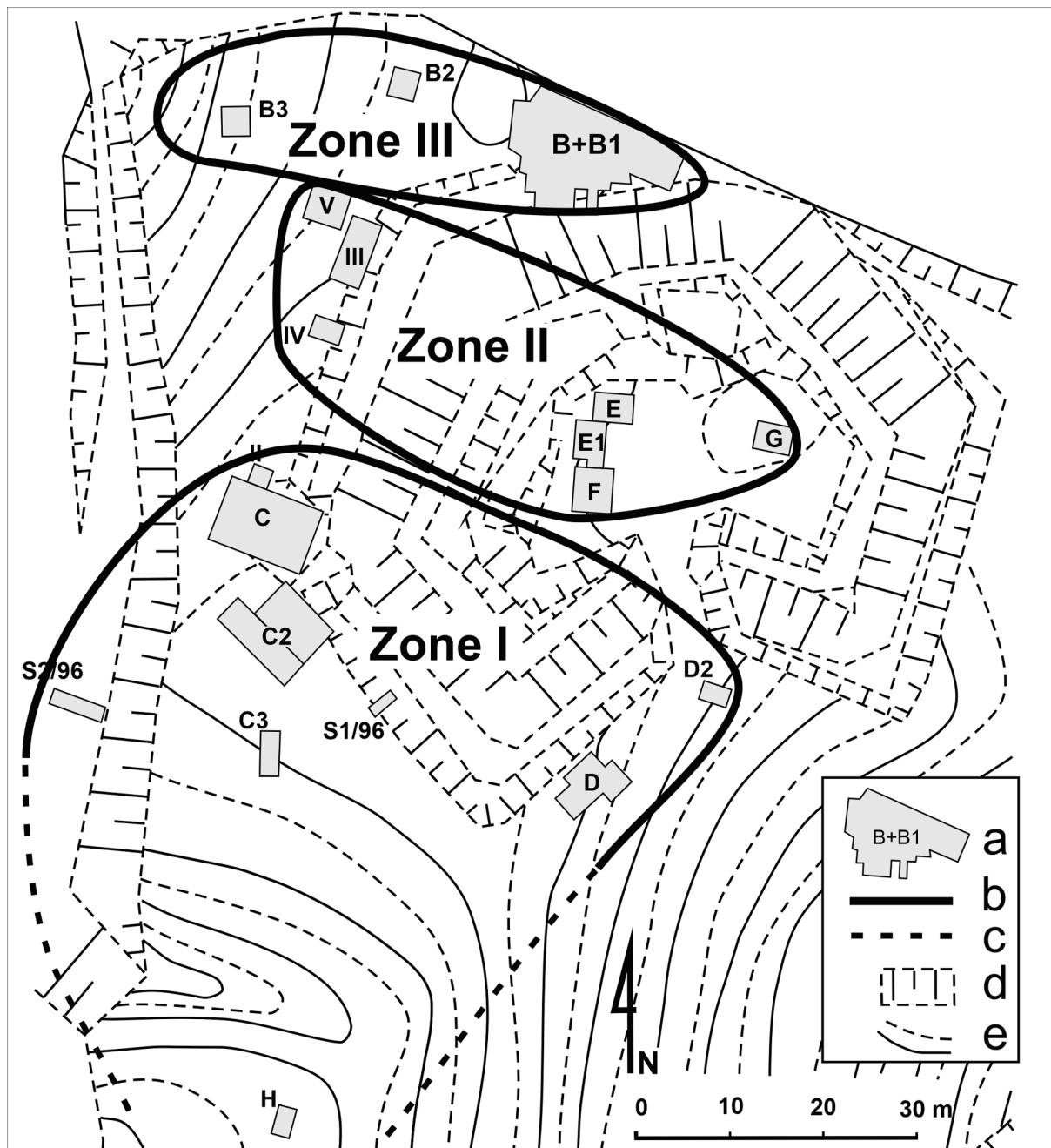


Fig. 2. Plan of the trenches at Kraków Spadzista site and suggested zones of human activity. Zone I – camp area of the site; Zone II – workshop and animal processing area; Zone III – the dump area (large accumulation of mammoth remains) and probably mammoth-kill/processing area. a – archaeological trenches; b – borders of the zones; c – possible border of the Zone I; d – Austrian fortifications; e – ground contours.

trenches are located inside the old Austrian fortification and are next to each other, about 30 m south of trench B. In 1989 excavations were started a few meters south of trench B at a new trench, B1, which was joined to trench B a few years later. Excavations were conducted at trench B + B1 up until 2013. In 1997 trench C3 in the southern part of the site was opened (Fig. 2). After a break in 2011, a new series of excavations was started at the site. In 2011 and 2012 trench C2 was widened and studied (Fig. 2). In 2012 trench E1 was excavated, located between trenches E and F (Fig. 2). In 2016 two small trenches located about 10 m (B2) and 25 m (B3) respectively to the west of trench B + B1 were opened (Fig. 2). In the next year (2017) three last trenches were opened. Trench D2 was located close to trench D, and trench G was located inside the Austrian fortification, about 15 m to the west of

trenches E, E1, and F (Fig. 2). In the same year (2017), small test pit H was opened about 100 m south of trench B + B1 and the rocky cliff edge (Fig. 2). In 2023 the excavation at trench B3 was renewed and the studied area was extended to 20 sq. m.

1.3. Spatial organisation of the site

Until the first decade of the 21st century, the finds in the first separate trenches were interpreted as coming from different sites, an interpretation seen in the titles of monographs and articles (e.g., Kozłowski et al., 1974; Kozłowski and Sobczyk, 1987; Wojtal and Sobczyk, 2005). However, results of archaeological and zooarchaeological studies in the first years of the 2000s, supplemented by a series of

new radiocarbon dates, allowed a revised interpretation of the archaeological and paleontological finds (Wilczyński et al., 2012). The new investigations show that all archaeological trenches were in different parts of a single large site (Wilczyński et al., 2012). The shared presence of a Late Gravettian inventory, the mammalian bones, and the similar stratigraphy indicate that Gravettian occupations occurred on almost the entire area of the promontory, about 1 ha in size, probably extending beyond the apparent edges of the recorded site itself. Now Kraków Spadzista is accepted as one large Late Gravettian site with three distinct activity zones (Fig. 2). Zone I, containing the trenches C, C2, C3, and D, is a camp (domestic activity or home area). Zone II, where trenches E, E1, F, G, III, IV, and V were located, is a workshop and animal processing area. Trenches B + B1, B2, B3, and B “workshop” are situated in the large accumulation of mammoth remains interpreted as discarded bones in a probable mammoth-kill and processing area, designated Zone III.

1.4. Radiocarbon dating

Based on data from more than fifty years of excavations, a series of radiocarbon dates on archaeological and palaeontological finds has been published in recent years (Wojtal et al., 2015; Wilczyński et al., 2020), clearly indicating human occupation during the Late Gravettian cultural period (Lengyel and Wilczyński, 2018), probably between 29 and 27 ka cal BP.

2. Material and methods

The field work at Kraków Spadzista from the beginning was conducted jointly by the Institute of Archaeology of Jagiellonian University and the Institute of Systematics and Evolution of Animals of the Polish Academy of Sciences. The studied osteological materials were collected during archaeological excavations from 1968 until 2017. The methods of collecting and documenting archaeological and palaeontological finds did not change from the 1970s to the 2010s. During excavations in the 1970s (the work done in trenches B and C and in test pits II, III, IV, V) stone artefacts and animal remains were picked up by hand and their positions within a square meter were hand-drawn and depths were measured by optical level. In the 1980s, 1990s, and early 2000s (work done in trenches B1, C2, C3, D, E, F) all finds were also picked up by hand, but their locations inside a trench square meter were recorded by an auto level device, and larger finds were drawn. In the 2010s field work (trenches B1, B2, B3, C2, D2, E1, G, H) all archaeological and paleontological finds were hand picked up and also all sediments in culture-bearing layers were wet-sieved using nesting screens of different mesh size to recover the smallest lithic finds and the remains of smaller animals such as rodents. The position of all the lithic finds and bone and teeth fragments over 2 cm in size was recorded in 3D using a Total Station.

All osteological materials collected during field work in trenches B + B1 (excavations in 1968–1994), C, C2 (excavations in 1980, 2011, 2012), D, E, E1, and F (excavations in 1986–1989, 2012) were taphonomically and zooarchaeologically reexamined and analysed. Mammal remains from trenches B2, B3, D2, G, and H (excavations in 2016 and 2017) were studied for the first time.

The mammal remains were analysed to calculate the standard zooarchaeological counts, namely number of identified specimens (NISP), minimum number of elements (MNE), and the minimum number of individuals (MNI). Those values were calculated on the basis of definitions in Klein and Cruz-Uribe (1984) and Lyman (1994). The MNI was calculated by differentiating paired elements into rights and lefts; the larger number determined how many animals were represented. However, the large number of mammal remains and their often fragmentary condition did not allow pairing of every possible right and left bones because of incomplete size and shape. NISP and MNE values for trenches B and B1 and C2 studied in 1980 and 2011–2012 were calculated together. Field studies from 2011 to 2012 at C2 were only an extension

of the area excavated in 1980: a new area was opened directly on the border of the old trench. A similar set of actions pertains to the osteological materials from trenches E and F from the late 1980s and trench E1 excavated in 2012. Trench E1 was located between trenches E and F (Fig. 2), and therefore all mammal finds from trenches E, E1, F were appropriate to analyse together as coming from a multi-part large trench. Calculating MNE separately for each separate trench excavated in the 1980s, 1990s, and 2000s would artificially increase this value for all taxa, as seen when separate trench calculations were attempted, leading to inflated numbers of elements and individuals.

The mortality profile of Kraków Spadzista mammoths was calculated by analyzing mammoth tooth progression and wear and correlating the data with the tooth progression and wear of modern African elephants for which ontogenetic ages were estimated or documented. This procedure assumes that if the teeth in individuals of the closely related taxa are in similar stages of wear and progression, then the ontogenetic ages are also similar. Individual mammoths in the site assemblage were assigned to 12-yr-long cohorts which are thought to represent important intervals of proboscidean life: 0–12 African elephant equivalent years (AEY) = juvenile, 13–24 AEY = young sexually mature adult, 25–36 AEY = midlife adult, 37–48 AEY = senior adult, 49–60+ AEY = oldest adult. The proportions of animals in the five cohorts were compared to proportions of African elephants in multi-animal death assemblages created by different causes of death.

In the following steps of analyses all skeletal remains were carefully inspected under strong oblique light to discover possible bone surface modifications (BSMs) reflecting human actions such as cutting and chopping. Cut marks were recognised and described according to published criteria (e.g., Olsen and Shipman, 1988; Lyman, 1994; Domínguez-Rodrigo et al., 2009). All marks identified as cut marks were then verified under a Leica microscope zoom. The marks on bones were digitally photographed.

A colour-based scheme (ranging from natural hue to black to white) is the most commonly used method for identifying the intensity of burning on bones (e.g., Buikstra and Swegle, 1989; Lyman, 1994; Shahack-Gross et al., 1997; Stiner et al., 1995; Théry-Parisot, 2002; Villa et al., 2002); we used bone colour to distinguish if bone fragments had been burned. Many counted bone fragments had been affected by fire and their number and colour were noted.

In addition to evidence of human activity, we recorded and noted tooth marks made by carnivores. Feeding activity by large carnivores may have affected bone preservation, potentially influencing bone survival and representation in the assemblage. Characteristic damage caused by the teeth of carnivores have been described by several authors, particularly Binford (1981), Haynes (1980, 1981, 1983), Haynes and Hutson (2020), and Sutcliffe (1970), based on their observations of feeding carnivores. All osteological materials were examined to search for carnivore gnawing marks.

Another factor that affected the preservation of Kraków Spadzista remains is trampling. Trampling typically creates parallel and subparallel marks like scratches visible mainly on cortical bone surfaces of diaphyses. The characteristic location and morphology help distinguish them from cut marks (Domínguez-Rodrigo et al., 2009) which are often near the ends of the bone (Olsen and Shipman, 1988; Fiorillo, 1989) where muscles were severed at tendon attachments to bone.

Weathering changes to bone surfaces were also examined. The weathering stages defined by Behrensmeyer (1978) and Haynes and Wojtal (2023) were used in this analysis. Two other taphonomic factors that could affect the taxonomic identification of the remains and the visibility of human-made marks such as cuts are root etching and calcite precipitation covering bones. The presence of these modifications was noted on the mammal remains.

A 2005 journal article described the taphonomy of remains which had been recovered 1968–1994 from Kraków Spadzista trench B + B1 (Wojtal and Sobczyk, 2005). A later publication (Wilczyński et al., 2012) presented results of zooarchaeological studies of mammal remains from

trenches excavated from the late 1960s to the mid 1990s, specifically B “workshops”, C, C2, C3, D, E, and F. Here we present results of zooarchaeological and taphonomic studies of all osteological material from all trenches excavated from 1968 to 2017 (Fig. 2). All mammal remains discovered in trench B + B1 were restudied. Identification of the remains from this trench was made one more time and all the bones were carefully inspected for BSMs made by humans, animals, and abiotic activity.

Because Kraków Spadzista is one site, we give information on the skeletal representation of the most numerous taxa, woolly mammoth and Arctic fox, (as NISP and MNE) for the whole site, and not for separate trenches. Detailed representations (NISP and MNE) of woolly mammoth and Arctic fox remains in each different zone of the site are presented in Supplementary Tables 1 and 2.

3. Results

As mentioned above, the archaeological trenches were located in different zones of the site (Wilczyński et al., 2012). Our results and discussion of the mammal remains assemblage from Kraków Spadzista are presented in five parts. The first offers the results of taxonomic identification and skeletal representation. The second part describes the age structure of the woolly mammoth population. The third describes traces of human actions visible on the remains. The next part describes

the activity of carnivores, and the final section discusses other signs of modification visible on the remains, namely weathering, root etching, and calcite precipitation.

We note that almost 700 rodent remains were collected during excavations at the site (Table 1). All were collected from wet sieved sediments. Detailed taxonomic and taphonomic analyses will be presented in a separate article. Here we present only basic information on the taxonomy and taphonomy of those remains.

3.1. Mammal taxa and their skeletal representation

During all the field work nearly 119,000 mammal remains belonging to 16 species were discovered (Table 1). Rodent remains were collected only during the most recent excavations (2011–2017) when the sediments of the Gravettian cultural layer were water sieved.

The recovered group of small mammals is typical of Late Pleistocene steppe-tundra species, and includes narrow-skulled vole (*Lasiodipodomys gregalis*) and Arctic lemming (*Dicrostonyx torquatus*) (Table 1). Unfortunately most rodent remains (NISP = 561) were too incomplete to be identified to species level. Only 138 of 456 recovered teeth are identifiable to taxon. Rodent remains from at least 78 individuals of seven taxa were found in all zones of the site. The remains of this group were found in trenches B1, B2, C2, and E1 (Table 1). Erosion from digestion is present on rodent teeth and is evidence the rodents had been consumed

Table 1

The number of identified specimens (NISP) and the number of individuals (MNI) of mammals at various zones in the Kraków Spadzista site.

Taxon	Zone I		Zone II		Zone III		Total	
	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI
<i>Lemmus lemmus</i> (Norway leming)	1	1	—	—	1	1	2	2
<i>Dicrostonyx torquatus</i> (Arctic lemming)	39	20	1	1	16	8	56	29
<i>Arvicola amphibius</i> (Eurasian water vole)	2	1	—	—	1	1	3	2
<i>Lasiodipodomys gregalis</i> (narrow-headed vole)	20	11	2	2	27	15	49	28
<i>Alexandromys oeconomus</i> (tundra vole)	—	—	—	—	2	2	2	2
<i>Microtus agrestis</i> (field vole)	6	3	—	—	8	5	14	8
<i>Microtus arvalis</i> (common vole)	2	1	1	1	9	5	12	7
Arvicolidae	240		16		305		561	
Rodents total	310	37	20	4	369	37	699	78
<i>Lepus</i> sp. (hare)	3	—	1	—	6	—	10	1
<i>Canis lupus</i> (wolf)	12	—	17	—	8	—	37	2
<i>Vulpes lagopus</i> (Arctic fox)	422	7	2,235	27	13	1	2,670	35
<i>Ursus arctos</i> (brown bear)	4	—	12	—	3	—	19	1
<i>Gulo gulo</i> (wolverine)	—	—	1	—	—	—	1	1
<i>Equus ferus</i> (horse)	11	—	9	—	1	—	21	1
<i>Mammuthus primigenius</i> (woolly mammoth)	1,932 (1,165)*	—	1,041 (671)*	—	29,199 (27,407)*	—	32,172 (29,243)*	113
<i>Rangifer tarandus</i> (reindeer)	45	—	5	—	15	—	65	2
Cervidae	2	—	4	—	—	—	6	—
Identifiable non-rodents	2,431	—	3,325	—	29,245	—	35,001	—
Identifiable total	2,741	—	3,344	—	29,603	—	35,700	—
Fox/hare sized mammals	116	—	1,527	—	—	—	1643	—
Reindeer/wolf sized mammals	73	—	26	—	23	—	122	—
Bear/horse sized mammals	28	—	29	—	1	—	58	—
Unidentifiable	28,804	—	49,498	—	2,935	—	81,237	—
Unidentifiable total	29,021	—	51,080	—	2,959	—	83,060	—
TOTAL NISP/MNI	31,762 (30,995)*	—	54,425 (54,054)*	—	32,573 (30,781)*	—	118,760 (115,831)*	266

*In the parentheses are numbers of remains (NISP) without woolly mammoth tusk fragments and teeth fragments.

either by birds of prey which regurgitated remains in pellets, or were eaten by Arctic foxes which defecated the remains. The results of more detailed studies of the remains of this group of mammals will be presented in another paper in preparation.

In the following sections we present the results of research on the mammals whose remains are attributable to Gravettian hunter-gatherers. More than 118,000 (NISP = 118,602) remains of herbivores and carnivores were collected during fieldwork. Bones and teeth were found of nine mammalian taxa very common in Late Pleistocene steppe-tundra environments (Table 1). Two taxa, the woolly mammoth (*Mammuthus primigenius*) and the Arctic fox (*Vulpes lagopus*), are represented by the largest numbers of remains, counted in thousands (Table 1). Other species discovered at the site are represented by far fewer finds, sometimes only one bone (e.g., wolverine) (Table 1). A few dozen specimens were found from each of three species: reindeer (NISP = 65), wolf (NISP = 37) and horse (NISP = 21). However, despite their small numbers, all parts of the skeletons of those three mammals were found. The finds of all body parts support the inference that their carcasses were transported more or less intact to the Kraków Spadzista site. A larger number of reindeer and horse remains were found in Zone I (the camp area) and Zone II (the workshop and animal processing area), respectively: 50 reindeer and 20 horse remains. Wolf bones and teeth were relatively evenly distributed in all three zones of the site (Table 1). Other game animal taxa (hare, brown bear, wolverine, woolly rhinoceros) are represented only by single bones or teeth found in trenches in all zones (Table 1). Mammal remains from Kraków Spadzista were marked by the acronym "Kr Sp" or by an inventory number such as E9 1299. However, we note that the monograph by Kozłowski et al. (1974) lists an anomalous inventory number (SW 138) on a woolly rhino femur, which indicates this specimen was mistakenly added to the Kraków Spadzista mammal assemblage. We have removed woolly rhinoceros (*Coelodonta antiquitatis*) from the list of Kraków Spadzista mammals (Table 1).

3.1.1. Woolly mammoth (*Mammuthus primigenius*)

The largest number of osteological finds from the site belong to the woolly mammoth. More than 32,000 bones, teeth, and their fragments were found in all zones (NISP = 32,172). The vast majority of woolly mammoth remains are concentrated in Zone III (NISP = 29,199), especially in trench B + B1 (NISP = 28,649). In the other zones mammoth remains are much fewer; in Zone I the NISP is 1,932 and in Zone II the NISP is 1,041. However, it should be noted that in all zones and in most of the trenches a large number of very small tusk fragments (<5 cm maximum dimension) and isolated tooth lamellae were collected. Fewer than ten longer tusk fragments (over 1 m) were collected during excavations (Supplementary Table 1). Most of the tusk fragments in this assemblage are small, a few centimetres in length. This high level of fragmentation is the result of poor preservation. Mammoth tusks, like modern elephant tusks, probably weathered rapidly when subaerially exposed (Haynes and Wojtal, 2023). Many tusks must have fallen apart into small fragments due to natural processes of disintegration, and some also were likely broken by solifluction and trampling during Gravettian occupations. In our studies we counted the tusk fragments which were longer than 2 cm. We include the total number of tusk fragments ($n = 1,726$) in the NISP value. Nevertheless, this value could bias the concentration of mammoth remains and interpretation of their presence in certain zones of the site. A similar situation can be observed with tooth fragments (complete lamellae and their fragments; NISP = 1,203). In Table 1 we include two values of woolly mammoth remains. The first includes tusk and tooth fragments, and the second (in the

parentheses) does not include numbers of tusk and tooth fragments. However, even if we exclude the numbers of tusk and tooth fragments, more than 29,000 (NISP = 29,243) woolly mammoth remains were collected during the site excavations. This large number includes almost 6,500 complete teeth and bones (MNE = 6,451), most of them (MNE = 6,204) found in Zone III, especially in trench B + B1 (MNE = 6,098). Taking into account the MNE value, only 106 bones and teeth were found in Zone I and 141 in Zone II.

We strongly underline that all parts of the mammoth skeleton were identified in the Kraków Spadzista site assemblage (Table 2; Supplementary Table 1), including fragile elements such as sesamoid and hyoid bones as well as robust and complete mandibles of adult animals. However, no complete mammoth skulls were found at the site. Nevertheless, identifiable skull fragments (e.g., occipital condyle (MNE = 63), zygomatic arch (MNE = 73), and basilar part of the occipital bone (MNE = 36)) were identified in the osteological material. There were a few examples of upper teeth still rooted in the maxillary bones. Also, a relatively large number of a small hyoid bone (stylohyoid; MNE = 96) was found during excavations. Many unidentifiable woolly mammoth skull fragments (NISP = 2,311) were collected during the excavations (Table 2). The presence of the above mentioned bones is evidence that complete mammoth skulls had been deposited at the Kraków Spadzista site.

Other bones of the mammoth axial skeleton such as vertebrae (from atlas to caudal vertebrae), ribs, scapulae, and innominate bones are well represented. Mammoth limb bones, including long bones and carpal/tarsal bones, were found in large quantities in the assemblage (Table 2). As well, small bones like phalanges (NISP = 462; MNE = 384) and sesamoids (NISP = 231; MNE = 230) are also represented in relatively large numbers.

More than 12,000 (NISP = 12,399) bone fragments lacked characteristic landmarks and features that would allow identification of a bone type. They were identified as mammoth bone fragments on the basis of their dimensions and the thickness of the cortical part of the bone. Among them, we were able to identify more than six hundred ($n = 667$) fragments as parts of limb long bones, and more than one hundred ($n = 145$) as parts of flat bones (Table 2).

3.1.2. Arctic fox (*Vulpes lagopus*)

Arctic fox is the second best represented taxon after woolly mammoth in the bone remains at Kraków Spadzista. More than 2,600 bones and teeth (NISP = 2,670) of this species were found. Most remains (NISP = 2,235) of this taxon were found in trenches in Zone II (Fig. 2; Table 3; Supplementary Table 2). In zone I 422 and in Zone III only 13 Arctic fox bones and teeth were found. In Zones I and II all skeletal parts of this carnivore were collected including larger parts of the skeleton: fragments of the head (e.g., maxillary bones, dentaries), long limb bones (e.g., humerus, ulna, radius, femur, tibia), and flat bones (scapulae and innominate). Wet sieving also allowed us to collect many smaller elements such as vertebrae, including caudal vertebrae, and ribs, carpal and tarsal bones, and phalanges. We note significant differences in NISP between the Arctic fox remains collected in the 1980s (trenches C2, E and F) and those collected in the 2000s (trenches C2 and E1). In the 1980s, 21 specimens of Arctic fox bones and teeth were found during work in the cultural layer of trench C2, and 210 were found in trenches E and F. The more recent (2011–2012) excavations in trench C2 recovered 387 Arctic fox bones and teeth. The most impressive finds, however, came from field work in trench E1 (Fig. 2). Trenches E and F have an area of 32 sq. m., while E1 is smaller at 24 sq. m. but the smaller trench yielded almost ten times more Arctic fox remains (NISP = 1,957) than

Table 2

Woolly mammoth numbers of identified specimens (NISP) and minimum numbers of skeletal elements (MNE) in all zones of the Kraków Spadzista site. ‘dex’ = right side, ‘sin’ = left side, ‘indet.’ = indeterminable.

Skeletal parts	NISP				MNE			
	dex	sin	indet.	Total	dex	sin	indet	Total
Cranial bone	-	-	2,311	2,311				
Occipital condyle (<i>condylus occipitalis</i>)	29	25	18	72	29	25	9	63
Zygomatic arch (<i>arcus zygomaticum</i>)	64	41	23	128	38	27	8	73
Basiocipital (<i>pars basilaris ossis occipitalis</i>)	-	-	36	36	-	-	36	36
Hyoid bone (<i>stylohyoideum</i>)	40	52	30	122	40	52	4	96
Milk tusk	-	-	2	2	-	-	2	2
Tusk fragments	-	-	1,726	1,726	-	-	-	-
Upper isolated cheek teeth	74	82	29	185	68	78	23	169
Mandibular bone	-	-	427	427	-	-	78	78
Lower isolated cheek teeth	61	62	20	143	55	56	14	125
Teeth unidentifiable	-	-	110	110	-	-	110	110
Teeth fragments (lamellae)	-	-	1,203	1,203	-	-	-	-
Sternebra	-	-	14	14	-	-	14	14
Vertebra	Atlas	-	-	140	140	-	-	89
	Axis	-	-	103	103	-	-	51
	Cervicals III-VII	-	-	447	447	-	-	151
	Thoracic	-	-	1,556	1,556	-	-	833
	Lumbar	-	-	175	175	-	-	130
	Sacrum	-	-	130	130	-	-	113
	Caudal	-	-	282	282	-	-	254
	Vertebra indet.	-	-	1,022	1,022	-	-	5
Total vertebrae	-	-	-	3,855	-	-	-	1,626
Ribs	-	-	6,008	6,008	-	-	1,602	1,602
Scapula	73	57	73	203	34	38	1	73
Humerus	45	56	30	131	30	33	2	65
Radius	94	83	9	186	53	58	-	111
Ulna	57	76	28	161	35	45	-	80
Carpals	190	164	3	357	189	164	1	354
Metacarpal I	2	6	-	8	2	6	-	8
Metacarpal II	19	23	-	42	19	23	-	42
Metacarpal III	22	26	-	48	22	26	-	48
Metacarpal IV	19	23	-	42	19	23	-	42
Metacarpal V	18	5	-	23	18	5	-	23
Total metacarpals	80	83	-	163	80	83	-	163
Innominate	92	110	1	203	41	46	1	88
Femur	66	54	92	212	33	32	-	65
Patella	31	32	9	72	31	32	9	72
Tibia	70	79	7	156	33	36	1	70
Fibula	104	91	58	253	62	55	2	119
Calcaneus	33	29	1	63	33	29	-	62
Astragalus	46	38	2	86	46	38	2	86
Tarsals	136	114	8	258	136	114	8	258
Metatarsal I	-	-	-	0	-	-	-	0
Metatarsal II	20	26	-	46	20	26	-	46
Metatarsal III	20	21	-	41	20	21	-	41
Metatarsal IV	23	19	-	42	23	19	-	42
Metatarsal V	13	4	-	17	13	4	-	17
Total metatarsals	76	70	-	146	76	70	-	146
Metapodial indet.	-	-	88	88	-	-	31	31
Metapodial total	-	-	-	397	155	153	32	340
Phalanx I	-	-	285	285	-	-	221	221
Phalanx II	-	-	168	168	-	-	163	163
Phalanx III	-	-	-	0	-	-	-	0
Phalanx	-	-	9	9	-	-	1	1
Phalanx total	-	-	-	462	-	-	-	384
Sesamoids	-	-	231	231	-	-	230	230
Long bone	-	-	667	667	-	-	-	-
Flat bone	-	-	145	145	-	-	-	-
Bone fragment	-	-	11587	11,587	-	-	-	-
TOTAL NISP/MNE				32,172 (29,243)**				6,451

*In the parentheses are numbers of identified specimens (NISP) without woolly mammoth tusk fragments and teeth fragments.

Table 3

Arctic fox numbers of identified specimens (NISP) and minimum numbers of skeletal elements (MNE) in all zones of the Kraków Spadzista site. ‘dex’ = right side, ‘sin’ = left side, ‘indet.’ = indeterminate.

Skeletal parts	NISP				MNE			
	dex	sin	indet	Total	dex	sin	indet	Total
Cranial bone	8	10	5	23			1	1
Maxilla	16	19	0	35	12	11		23
Occipital condyle	5	4	0	9	5	4		9
Upper isolated teeth	85	94	12	191	85	94	12	191
Mandibular bone	43	51	6	100	32	33		65
Lower isolated teeth	60	65	17	142	60	65	16	141
Teeth unidentifiable	—	—	84	84	—	—	65	65
Sternebra	—	—	23	23	—	—	23	23
Vertebra	Atlas	—	—	34	34	—	—	25
	Axis	—	—	21	21	—	—	20
	Cervicals III-VII	—	—	48	48	—	—	48
	Thoracic	—	—	67	67	—	—	66
	Lumbar	—	—	54	54	—	—	52
	Sacrum	—	—	8	8	—	—	8
	Caudal	—	—	106	106	—	—	106
	Vertebra indet.	—	—	3	3	—	—	0
Total vertebrae	—	—	—	341	—	—		325
Ribs	—	—	37	37	—	—	37	37
Scapula	17	20	1	38	17	20		37
Humerus	56	47	3	106	28	21		49
Radius	34	32	8	74	22	20		42
Ulna	32	41	4	77	21	29		50
Carpals	36	40	—	76	36	40		76
Metacarpal I	9	7	7	23	9	7	6	22
Metacarpal II	15	15	—	30	15	15		30
Metacarpal III	14	16	—	30	14	16		30
Metacarpal IV	19	10	—	29	19	10		29
Metacarpal V	10	16	—	26	10	16		26
Total metacarpals	67	64	7	138	67	64	6	137
Innominate	26	32	—	58	16	17		33
Femur	42	41	7	90	20	23		43
Patella	—	—	19	19			19	19
Tibia	47	37		84	27	21		48
Fibula	2	6	2	10	2	6	1	9
Calcaneus	27	21	1	49	27	21		48
Astragalus	15	14	—	29	15	14		29
Tarsals	32	23	5	60	32	23	5	60
Metatarsal I	—	—	—	0				0
Metatarsal II	12	13	—	25	12	13		25
Metatarsal III	14	11	—	25	14	11		25
Metatarsal IV	10	21	1	32	10	21	1	32
Metatarsal V	14	21	—	35	14	21		35
Total metatarsals	50	66	1	117	50	66	1	117
Metapodial indet.	—	—	114	114	—	—	3	3
Metapodial total	—	—	—	369	117	130	10	257
Phalanx I	—	—	263	263	—	—	242	242
Phalanx II	—	—	198	198	—	—	181	181
Phalanx III	—	—	68	68	—	—	68	68
Phalanx total	—	—	—	529	—	—		491
Sesamoids	—	—	17	17	—	—	17	17
Total NISP/MNE				2,670				2,188

were recovered from E and F in the 1980s.

The presence of all parts of Arctic fox skeletons in the camp/home area (Zone I) and the flint workshop (Zone II) is evidence that whole skeletons of this mammal were originally deposited there (Supplementary Table 2).

3.2. Woolly mammoth mortality profile

The mammoth assemblage at Kraków Spadzista is greatly dominated by juveniles. Table 4 shows the age distribution of *M. primigenius* from the site.

Ontogenetic ages were determined for mammoths by applying the method of R. Laws (1966) (also see Jachmann, 1988; Stansfield, 2015) for assigning individuals of *Loxodonta africana* to one of 30 age groups, based on dentition. The Laws system compares the extent of tooth wear and the progression of each emerging tooth in the jaw. Like African

elephants, mammoth had teeth that emerged and wore down through years of use, then were replaced from behind, until the last tooth in the series had been exhausted. The right and left halves of the upper and lower jaws thus had a total of six progressively larger teeth throughout life. The sixth and final tooth was the largest in the series and was in

Table 4

Percentages of different age cohorts of *M. primigenius* at Kraków Spadzista, based on most recent counts of mandibles and isolated teeth. The MNI in this table is 113, which is subject to change as research continues.

Age Cohort	Laws Age Groups*	N	% of N
0 – 12 AEY	I – X	53	46.9
13 – 24 AEY	XI – XVI	38	33.6
25 – 36 AEY	XVII – XXI	9	8.0
37 – 48 AEY	XXII – XXV	10	8.8
49 – 60 + AEY	XXVI – XXX	3	2.7

Note: * Adjusted following Stansfield (2015).

wear for the last 30 or so years of life.

Alternatives to the Laws method for assigning ages are available, such as in Sikes (1966, 1968) where African elephant tooth placement is measured over the mandible's mental foramen during dental progression in the jaw, or by comparing dentitions from *Elephas maximus* (Roth and Shoshani, 1988). The Sikes system was not used in analysis of Kraków Spadzista dentitions because many isolated mammoth teeth from the site cannot be matched to edentulous mandibles. The ages assigned in the Roth & Shoshani system would differ by a few years from ages assigned to the same teeth by the Laws system, but in general both systems would agree on a juvenile-dominated mortality profile.

3.3. Human activity

All collected bone remains were examined for signs of human activity, not only surface modifications associated with hunting (embedded weapon tips) and carcass dismemberment (cut and chop marks), but also modifications associated with the production of tools and ornaments (Supplementary Table 3).

3.3.1. Direct evidence of mammoth hunting: Fragments of lithic points embedded in mammoth bones

The most remarkable and unique finds from Kraków Spadzista are four woolly mammoth ribs with embedded lithic fragments probably from shouldered points or backed blades, the types of weapon tips often found in central European Gravettian lithic assemblages. It is not possible to determine if the four ribs are from a single mammoth or four different individuals, but the latter possibility may be likely in light of the enormous number of mammoths represented at the site. The results of the study of the first lithic specimen were published in 2019 (Wojtal et al., 2019). This specimen is a fragment 5 mm wide and 4 mm long. The implement had penetrated the rib to a depth of 7 mm, chipped off some cortical tissue and reached through cortex to trabecular tissue as observable in Computed Tomography (CT) scans (Fig. 3a) (Wojtal et al., 2019). The second embedded lithic fragment is smaller, 2 mm wide and 3 mm long. Like the first discovered fragment, the second lithic object chipped off some cortical tissue. A Computed Tomography scan revealed that it did not reach trabecular tissue through the cortical layers (Fig. 3b) (Wojtal et al., 2019). The third embedded lithic fragment is very small, not more than 2 mm wide (Fig. 3c). The fourth fragment was

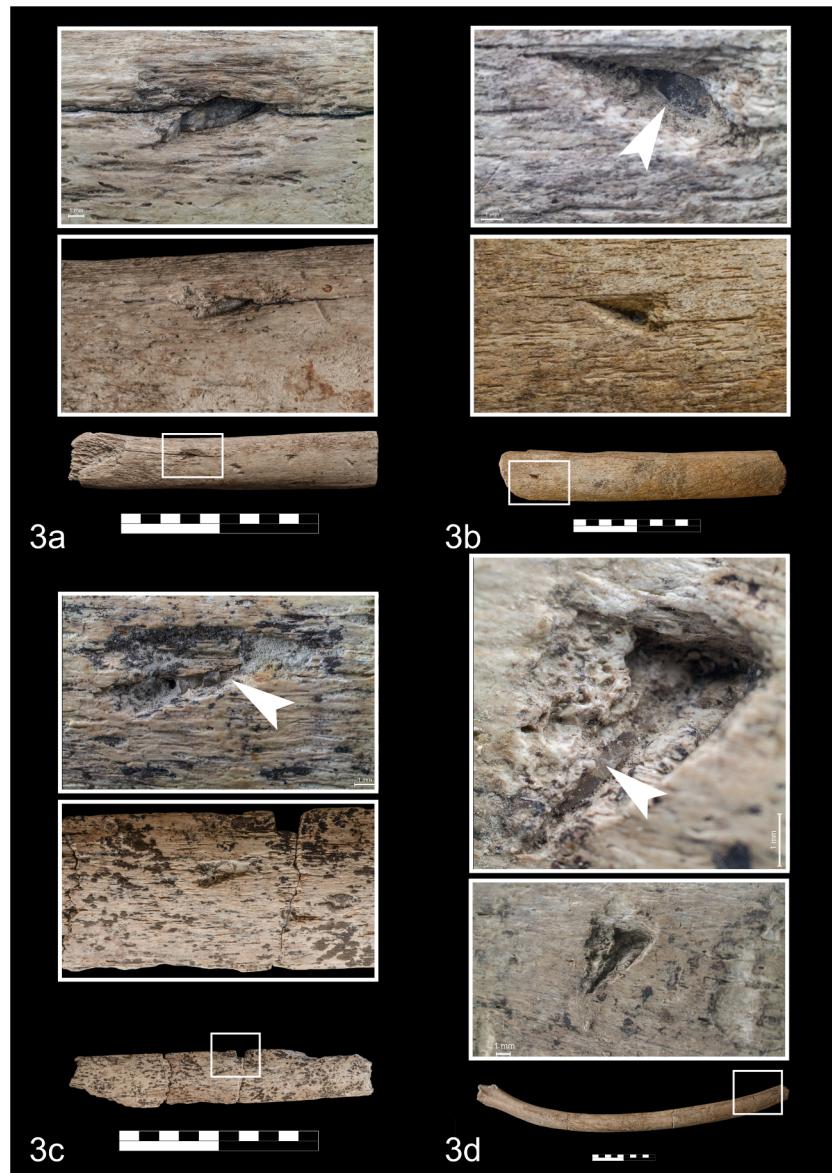


Fig. 3. Fragments of four woolly mammoth ribs (3a-3d) with close-ups of embedded lithic blade fragments (in the white boxes); Trench B + B1 (Zone III).

discovered on an incomplete right rib >50 cm in length. The shape and cross-section of the rib indicate that it may be one of the pair situated between the eighth and fifteenth ribs in the middle part of the rib cage. A very small (2 mm wide) fragment of the lithic object is embedded in the distal part of the bone (Fig. 3d).

In all cases, embedded lithic fragments are on the lateral faces of bones and a fragment of outer cortical bone was broken off when the lithic projectiles struck the ribs. There are no signs of bone healing on the four ribs, indicating that the injuries were perimortem and the mammoths died very soon after being struck by presumed weapon points.

3.3.2. Bone surface modifications: cut marks

In addition to the direct evidence of woolly mammoths being actively hunted, evidence about the processing of killed animals also has been found. Careful examination of all the excavated osteological material from all trenches in all zones of the site revealed marks made on bones by carcass processing activity. Only two bones from animals other than mammoths have these marks (Supplementary Table 3), a reindeer tibia (trench F; Zone II) and a rib fragment of a reindeer/wolf sized mammal (trench C2; Zone I) (Wilczyński et al., 2012; Wojtal and Wilczyński, 2015a).

A large majority of cut marks were found on woolly mammoth bones. In total, 78 bones of this species show signs of stone tool use by

Gravettian hunter-gatherers. Cut marks on mammoth bones were found only on remains collected in trench B + B1. Most marks ($n = 53$) are visible on rib fragments (Figs. 4 and 5) which can not be identified to rib number, but some were also observed on vertebrae, mostly thoracic vertebrae ($n = 9$) (Figs. 6 and 7), although these also are too fragmentary to identify to number. Only one cervical vertebra and one lumbar vertebra have marks made by cutting through soft tissue and marking the bone during carcass processing. A few other cut marks are located on long limb bones (*humerus*, $n = 1$; *radius*, $n = 4$; *ulna*, $n = 2$; *tibia*, $n = 1$) or their fragments ($n = 1$) (Figs. 8–10), and two mandible fragments have been cut. Cut marks were also found on three unidentified mammoth bone fragments. The cut marks on ribs and vertebrae may have been made by stripping meat from a killed mammoth, and cut marks on the long limb bones are probably results of either the dismemberment of a carcass or the stripping of meat.

Despite the large number of long limb bone fragments of mammoth (NISP = 1,766) or whole bones (MNE = 510) in Kraków Spadzista, not a large percentage of fragments or whole bones were cut marked. However, it should be remembered that removing meat would have involved a stone tool first cutting through thick skin, carving through huge muscle masses, and cutting away very tough periosteum before contacting bone. Because of the large size of mammoth bones and the enormous amount of meat on the long limb bones, Gravettian hunters possibly chose to avoid hard contact of stone tool edges against the cortical bone surfaces

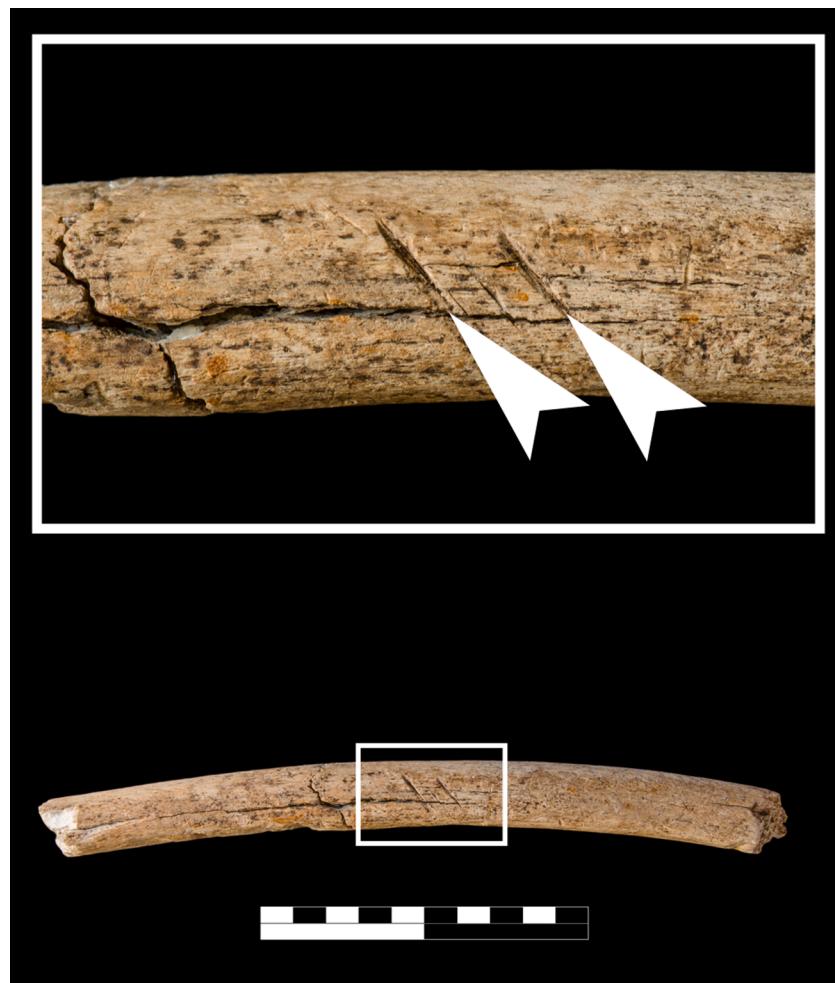


Fig. 4. Fragment of woolly mammoth rib with clear and deep cut marks; Trench B + B1 (Zone III). Scale is 10 cm.



Fig. 5. Fragment of woolly mammoth rib with a cut mark; Trench B + B1 (Zone III). Scale is 10 cm.

when cutting off meat, and did not use tools to scrape off every bit of meat from the long bones, thus avoiding the dulling of tool edges. According to modern observational studies, experienced butchers do not make many cut marks when they strip most of the meat from an elephant carcass (Haynes and Klimowicz, 2015, 2021).

A total of 170 flake-like fragments of periosteal cortical bone were discovered, identified as mostly from long bones: five in trench C2 (Zone I) during 2011–2012, three in trench F (Zone II), and 162 in trench B + B1 (Zone III) (Fig. 11a-c). These might have been incidentally produced during the breaking of bones by chopping or percussion to access marrow or to reduce bones into segments useful as raw material for making artifacts or for hearth fuel. It does not appear that cortical bone was systematically knapped at the site.

3.3.3. Burned bones

Burned bones were discovered in all zones of the site (Supplementary Table 3). Altogether nearly 66,000 bone fragments ($n = 65,981$) were found that have traces of burning. All burned bones are no longer than a few cm in length and unidentifiable to element. There were no signs of fire on identifiable mammoth bones that would suggest roasting of meat on bones.

No well-defined fire features such as hearths were discovered at Kraków Spadzista, possibly because of dispersal through solifluction processes or cleanup by humans, evident throughout the entirety of the site. Other factors such as trampling by animals and humans could have contributed to the destruction of hearths. These activities would have displaced campfire ashes and scattered bones that had been burned as fuel. During excavations, larger fragments of burned bones, primarily those exceeding 1 cm in length, were hand picked up and recorded in three dimensional terms within the trenches. However, the majority of the burned pieces were found during wet sieving of cultural layer sediments. Most of the burned bones were recovered in trenches of Zone I ($n = 22,287$) and Zone II ($n = 43,031$). There are notable disparities in the numbers of burned bones from the excavations of Zones I and II trenches excavated in the 1980s-1990s (Zone I trenches: C, C2, C3, D, test pit II; Zone II trenches: E, F,) and in the 2010s (Zone I trenches: C2, D2; Zone II trenches: E1, G). In the course of previous fieldwork (1980s-1990s) in five trenches of Zone I, a total of 2,385 burned bones fragments were identified. In contrast, during the 2010s excavations, the number of burned bones collected reached nearly 20,000 ($n = 19,902$). A similar pattern can be observed in Zone II. In the 1980s and 1990s, excavations in trenches E and F yielded only 127 burned bones

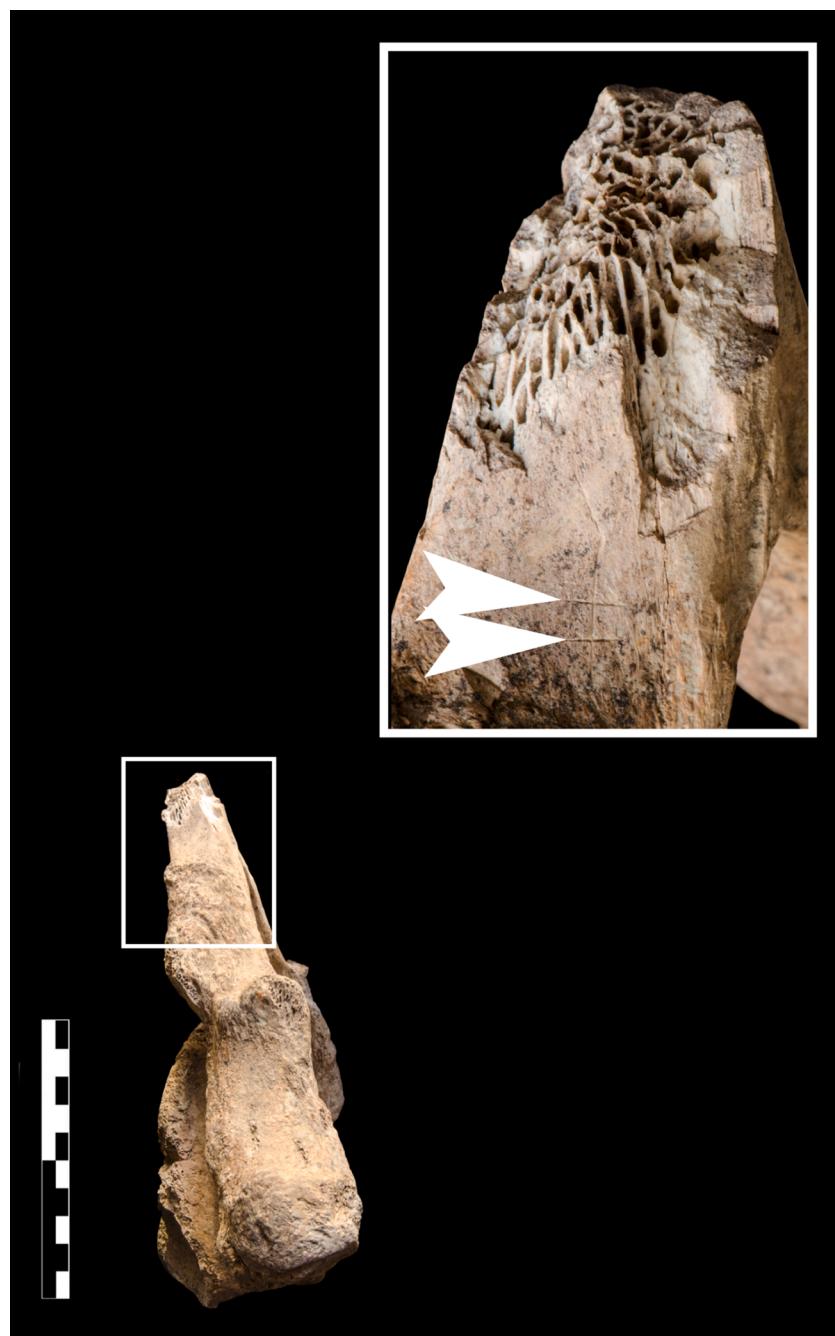


Fig. 6. Woolly mammoth thoracic vertebra with cut marks on the right side of spinous process (*processus spinosus*); Trench B + B1 (Zone III). Scale is 10 cm.

fragments. In contrast, during the 2012 excavation in trench E1, located exactly between the above mentioned trenches E and F, 24,859 burned bones were collected. The discrepancy in the number of burnt bones between the 1980s-1990s and the 2010s excavations is due to the use of new research methods (wet sieving sediments) during the later (2010s) excavations. There is no evidence that this could have been related to any action by Gravettian hunter-gatherers.

The maximum dimensions of burned bone fragments are mostly small, from a few mm to ~1 cm. Larger fragments >1 cm are uncommon

in E1 ($n = 782$) and only 27 specimens have dimensions >4 cm in length; in trench C2 the number >1 cm long is 122; the number of 4–5 cm long burned fragments is 9.

3.3.4. Percussion marks and bone fracturing by Gravettian hunter-gatherers

In addition to the cut marks there were also visible percussion marks on the mammoth bones. The number of such modifications found was very small; only 12 mammoth bones show them. Ten percussion-marked bones were found in trench B + B1 (Zone III) and two were found in



Fig. 7. Spinous process (*processus spinosus*) of woolly mammoth thoracic vertebra with cut marks; Trench B + B1 (Zone III). Scale is 10 cm.

trench C2 excavated in 2011–2012 (Zone I).

A cultural process which affected bone representation was the deliberate breaking of fresh mammoth bones by Gravettian people, suggested by the presence of notched fracture margins appearing to be percussive impact points and by smooth fracture surfaces, typical of green-bone fracturing. The breakage might have been done to extract marrow, to create fragments of useful size for making into implements,

or to reduce bones for burning in hearths (Wojtal and Sobczyk, 2005: 203; Wilczyński et al., 2012: 3632). If mammoth long bones were broken open for marrow extraction, it is possible that a second step was the further breakage of cortical bone fragments to make artifact blanks, as Gürbüz and Lycett (2021) discuss for nonproboscidean bones. Limb bones intended for marrow extraction probably would have been carefully broken to reduce splintering and mixing of trabecular fragments



Fig. 8. Woolly mammoth right humerus with cut mark on posterior part of the bone shaft; Trench B + B1 (Zone III). Scale is 10 cm.

with the exposed marrow. Experiments have shown that an efficient fracturing of proboscidean long limb bones is done by striking with hammerstones the fewest possible times on a convex part of the cortical surface in the center of the diaphyses (Haynes and Krasinski, In Prep.). This would have produced some midshaft fragments with impact notches and usually parts of diaphyses still attached to epiphyses. The cortical bone fragments then could be shaped by percussion, pressure-flaking, or grinding into pieces suitable as raw material (=blanks) for making bone artifacts.

The different fracture angles and fracture surfaces on mammoth bone fragments (such as in Fig. 12) indicates that not all breaks were made on fresh or green bones, and some breaks were made on dry elements, possibly during trampling or cryogenic processes.

The results of hammerstone-breakage are not always clearly distinguishable from the effects of other agents which break or modify bones. We are certain that hard-hammer impacts did affect at least some of the fresher mammoth elements, based especially on sizes of discrete notches and fracture angles, presence of impact marks on bone surfaces, and the relative smoothness of fracture surfaces (a.k.a. fracture planes). Some

fragments of mammoth long bones have variably sized notches on fracture margins; the sizes also vary on single specimens which have multiple notches. Breadths (a.k.a. diameters) of 22 clearly defined notches on different specimens varied from 155.8 mm to 7.8 mm, with a mean of 42.3 mm. Approximately 55 % of the measured notches were <32 mm in breadth. The variability might have resulted from the use of different sized impactors at each loading point during single-event attempts to fragment the bones, which seems unlikely, or from separate notching events after the bones were fragmented, such as from crushing by trampling or pressure from carnivore gnawing. Fracture edges which have collapsed from static pressure also may have the appearance of notching from hard-hammer impact. On some specimens fresh-fracture surfaces with apparent cone-flake scars at notches co-occur with notches having dry-bone/stepped fracture surfaces, suggesting separate events affecting bone when it was green and later when it was dry (Fig. 13c).

Periosteum which connects muscle to bone is tough enough to impede the propagation of fracture if it is not manually removed before green bones are to be broken by hammerstone impact. Some percussive breakage may have been done before periosteum had been completely



Fig. 9. Woolly mammoth left ulna with cut mark on anterior of distal bone shaft; Trench B + B1 (Zone III). Scale is 10 cm.

removed from meat-stripped fresh mammoth elements (Fig. 14), accounting for incomplete fracture propagation.

3.3.5. Bone, ivory, and tooth ornaments & tools

Other manifestations of human activity at Kraków Spadzista are tools and ornaments crafted from bone, ivory, and animal teeth. These artefacts were discovered across the entirety of the site (Supplementary Table 3). More detailed descriptions of these finds were published in Wojtal et al. (2015). Gravettian hunter-gatherers utilised mammoth bones as the primary material for organic artefacts. We note that only two artefacts (one pendant and an awl/point fragment) were made from mammoth ivory. Other artefacts were manufactured from bones and teeth belonging to different mammals. All but the one ivory pendant were made of carnivore teeth (from bear and wolf). There is a considerable number of organic artefacts, but their intended uses are not clear. Six polished bone fragments, some of which have notches, are examples of materials of indeterminate function. Some of the artefacts could be considered decorated objects, such as a part of a mammoth rib with intentional notches at both edges and engraved lines on the medial side (Fig. 15). Another example is an artefact made from part of a long limb



Fig. 10. Woolly mammoth left tibia with cut marks on anterior of distal bone shaft; Trench B + B1 (Zone III). Scale is 10 cm.

bone (probably a femur) of a wolf/reindeer-sized animal, which was cut from both sides and carefully polished and ornamented by seven engraved lines. Most of these artefacts ($n = 13$) were discovered in the C and C2 trenches, which are situated within the camp area (Zone I) where we infer domestic activities took place. It is noteworthy that in the large mammoth bone accumulation (trench B + B1), artefacts also were found that may be decorated objects (e.g., the aforementioned rib with notches; Fig. 15). Additionally, in this trench, an object was discovered that may be a semi-fabricate (unfinished) object (Fig. 16). The fragment is that of a reindeer femur, exhibiting a series of incisions in the mid-shaft region. It is evident that these objects were not mere by-products from processing a killed animal. Another object that appears to be complete but of unknown function or symbolic meaning was found

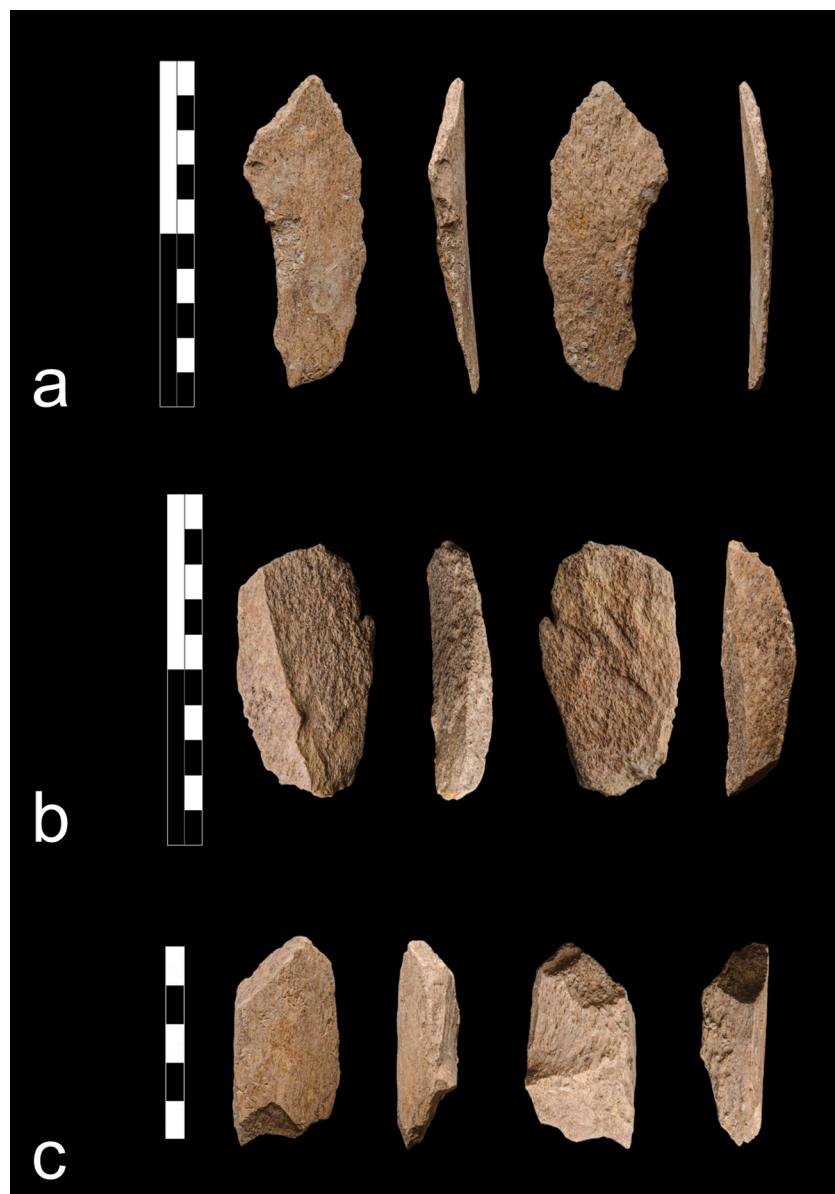


Fig. 11. Four views each of flake-like fragments of woolly mammoth periosteal cortical bone, identified as probably from long bones; Trench B + B1 (Zone III). Scale is 10 cm (a and b), 5 cm (c).

during excavations in trench C2 (Fig. 17).

3.4. Large carnivore activity

The impact of carnivores on the preservation of mammal remains at the Kraków Spadzista site was significant, particularly for mammoth bones. Approximately five hundred bones ($n = 513$) were tooth-marked by gnawing carnivores (Table 5). Only five bones from animals other than mammoth were marked by carnivore teeth – one horse bone, three bone fragments of reindeer/wolf sized mammals, and one unidentifiable bone fragment. The greatest number of specimens with carnivore gnaw traces ($n = 498$) were mammoth bones collected from trench B + B1 (Zone III) (Fig. 2; Table 6). In Zones I and II, only 13 gnawed bones were found. Four were in Zone I (trench C2) and nine were in Zone II

(trenches E, E1, F, and G and test pit III and V).

A relatively detailed pattern of carnivore gnawing of mammoth bones can be discerned on the basis of the findings from trench B + B1 where the majority of the remains exhibiting carnivore gnaw marks were recovered. The 498 woolly mammoth bones with this kind of modification (Table 6) represent 2 % of the total number of bones and their fragments recovered from the B + B1 trench. We excluded small fragments of skulls and tusks and complete teeth and their fragments from our calculation of this percentage. The category of ‘bone fragments’ also has been excluded from the calculation because most are very small (a few cm. long). The possibility that these small fragments were selected for gnawing by carnivores is considered low, and their large number could bias an analysis.

The majority of the tooth marks are located on long limb bones or

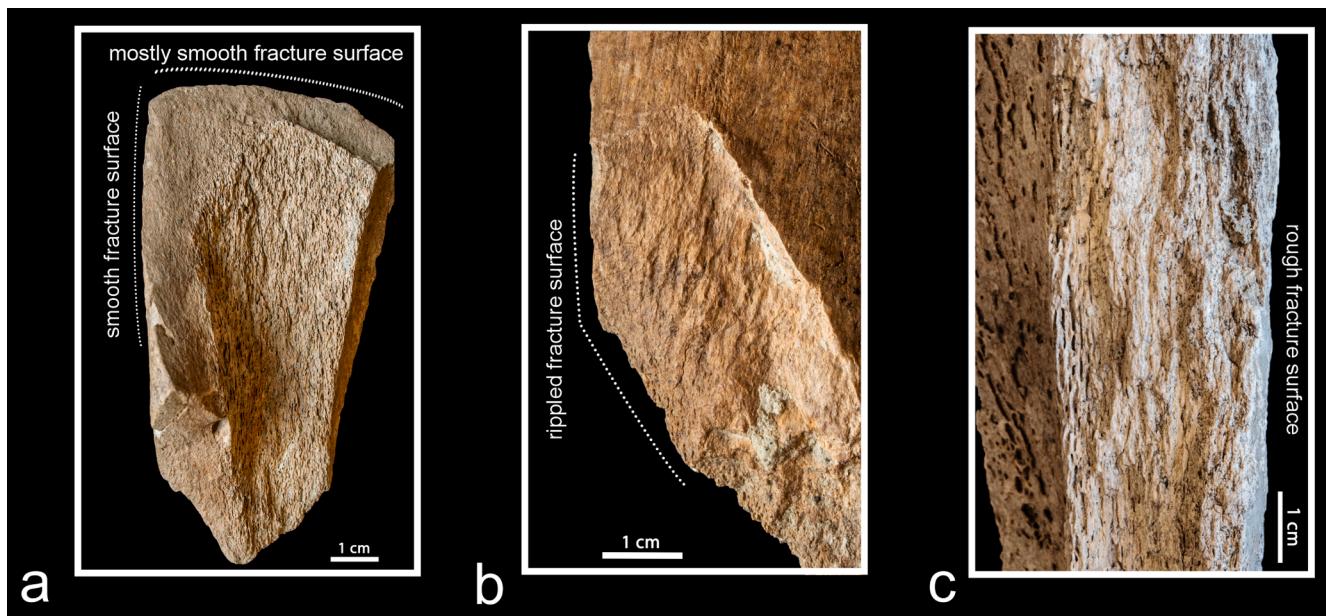


Fig. 12. Fracture surfaces on mammoth long bone fragments from Kraków Spadzista. a and b show specimen I(–2) 2199. Note that the mostly smooth fracture surface on specimen a is partially concave. The fracture surfaces are suggestive of multiple breakage events when the bones were in different states of preservation. c specimen is J(–1) 0109.

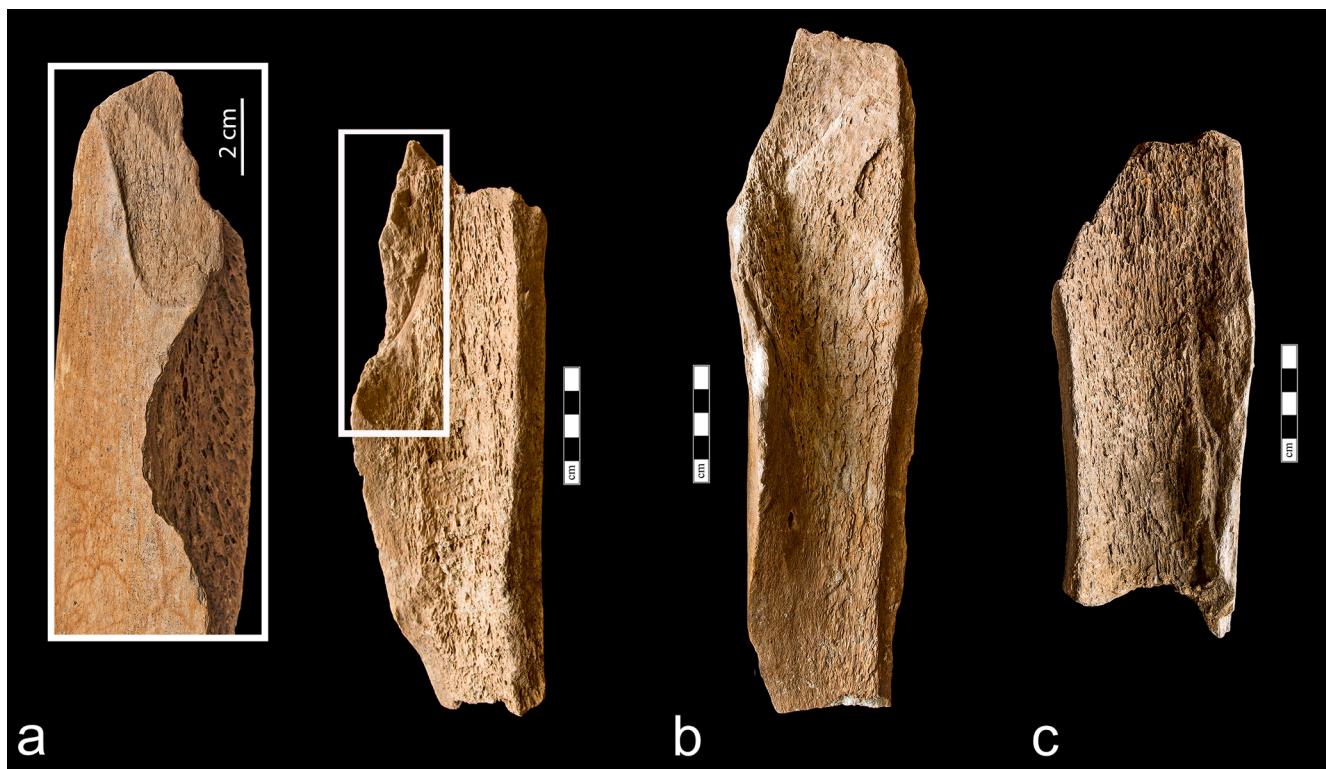


Fig. 13. Fragments of Kraków Spadzista long bones attributed to woolly mammoth, showing morphologies and features typical of bones broken either when green or in low weathering stages. All specimens are in medullary view, except the far left white boxed figure, which is a cortical view of a scalloped-edge notch in specimen (a). The three specimens have evidence which suggests hard hammer impact, such as presence of a notch or cone-flake scar(s), along with curvilinear, longitudinal, and transverse fracture fronts. Specimens (b) and (c) show evidence of multiple impacts or pressure along the upper fracture margins in the photographs. Some breakage might have been due to trampling or cryogenic pressures. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

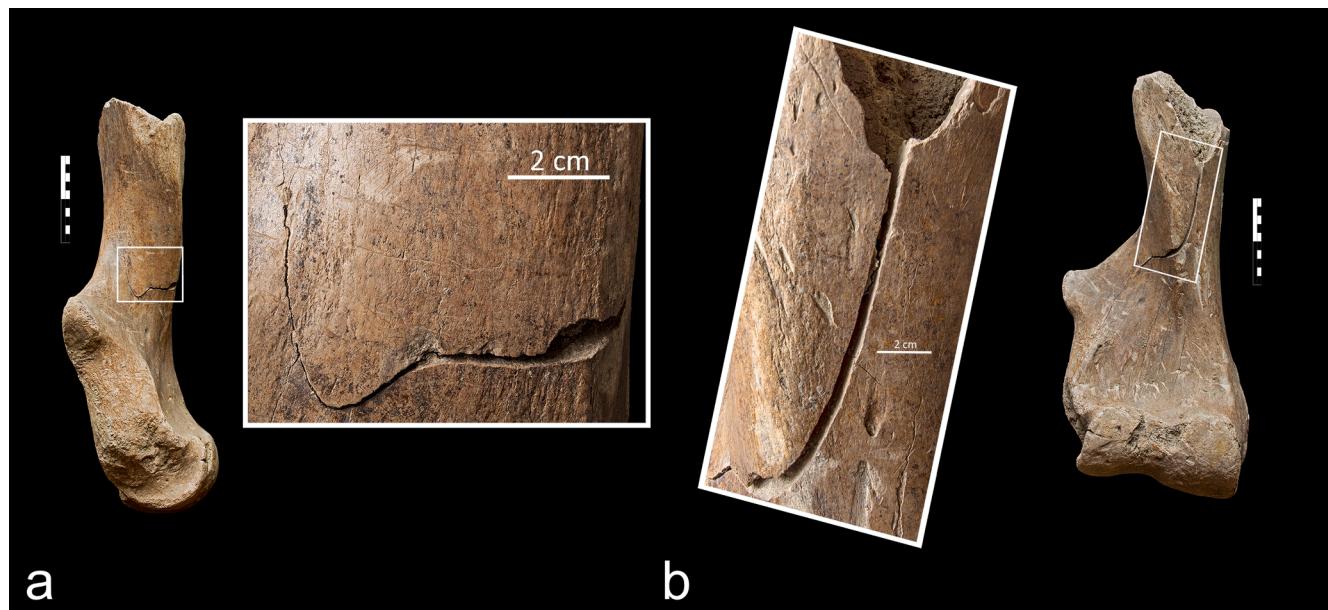


Fig. 14. Two views – lateral (a) and cranial (b) – of a right humerus (specimen E12/13 2106) from a juvenile or very young adult woolly mammoth. The insets are closeups of an incipient spiral fracture that emanates from a notch on the proximo-medial part of the diaphysis, possibly created by hammerstone percussion following incomplete removal of periosteum.

their fragments ($n = 228$), carpals/tarsals ($n = 89$), and metapodials ($n = 54$). Additionally, carnivore gnaw marks were observed on ribs ($n = 39$) and innomates ($n = 36$). Despite the considerable amount of other element fragments, including vertebrae and phalanges, relatively small numbers of them were carnivore-gnawed (Table 6).

The humerus and femur were the most numerous of the long limb elements exhibiting this type of modification (Table 6). Most gnaw marks were observed on the proximal and distal epiphyses of both the humerus and the femur. In the case of the humerus, 76.9 % (20 out of 26) of the preserved proximal epiphyses and 62.1 % (18 out of 29) of the distal epiphyses exhibited carnivore tooth marking (Fig. 18). With regard to the femur, 39.7 % (23 out of 58) of unfused proximal epiphyses and 47 % (24 out of 51) of distal epiphyses exhibited carnivore tooth marks (Figs. 19 and 20). Unfused humerus and femur epiphyses with tooth marks on the undersides were gnawed after they had been detached from diaphyses; the gnawing of elements may have caused the unfused epiphyses to come away from diaphyses of still-growing mammoths. The diaphyses of humeri and femora also exhibit carnivore gnaw marks, both on the proximal and distal parts. Nevertheless, the number of diaphyseal specimens exhibiting such modifications is relatively limited (for humerus, 10 out 68; for femur, 12 out 100).

A comparable pattern of carnivore gnaw marks also is observed on other limb bones, including the ulna. A total of 33 complete or fragmentary ulnae were gnawed by carnivores. Similarly, as previously stated, the ulna diaphyses ($n = 22$) and unfused distal epiphyses ($n = 6$) exhibited visible carnivore tooth marks. Six ulna olecranon fragments were gnawed. Among the 183 complete and fragmentary radius bones, 31 show carnivore gnaw marks. In contrast to the bones described above, only two of the 21 unfused radius epiphyses exhibited carnivore teeth marks. The proximal and distal parts of the diaphyses of radii were gnawed in similar proportions. The proximal parts of 20 specimens exhibited gnaw marks, and the same number of distal parts have

carnivore tooth marks. The last two long bones we describe, the tibia and fibula, were also modified by carnivores but to a lesser extent. In trench B + B1, only 16 tibiae and 7 fibulae or their fragments exhibited such modifications. Among the tibiae, gnaw marks were found mostly on unfused epiphyses ($n = 9$).

Additionally, signs of gnawing by large carnivores are on some foot bones, including carpals, tarsals, and metapodials (Table 6; Fig. 21). In total, approximately 14 % ($n = 146$) of all collected bones from these categories (MNE = 1,050) have carnivore gnaw marks. It is noteworthy that every type of carpal and tarsal bone except the trapezium (*os trapezium*) was gnawed by large carnivores. The number and percentage of the most distal elements modified by carnivores varies considerably. For instance, only one scaphoid (*os scaphoideum*) was modified out of 38, approximately 2,6 % of the total, possibly because in this element's articular position it has no margins extending beyond other bones and would be difficult for a carnivore to reach or extract for gnawing. In contrast, 30,2 % (19 out of 63) of calcaneus bones were modified by carnivores, because the *tuber calcaneus* of this bone in articular position does protrude beyond its enclosing bones. Among metapodials, 17,8 % (57 out of 321) were gnawed by large carnivores. Gnaw marks on metapodials were mostly located on the distal parts of the bone ($n = 51$); teeth marks were also observed less often on the proximal epiphyses ($n = 15$) of metapodials.

The relatively low proportion of recovered distal limb elements (foot bones) hint at a pattern observed with modern *L. africana* carcasses in Africa (Haynes, 1991, and unpublished field notes, 1983 – 1997), which is carnivore removal of the most distal elements from limbs as a 'package' (White and Diedrich, 2012: 293; Haynes and Hutson, 2020).

A greater amount of carnivore gnaw marks was observed on the pelvis ($n = 36$; representing approximately 18,3 % of all bone fragments in this category). Carnivore teeth marks were sometimes observed on different parts of the same innominate bone, e.g., on ilium and ischium.



Fig. 15. Woolly mammoth rib fragment with incised notches on edges. Two fragments of the rib were found in different square meters and both have incisions. Scale is 10 cm. Trench B + B1 (Zone III). Scale is 10 cm.

Carnivore gnaw marks were noted on the 18 ischia, 16 ilia, 3 pubes, and 4 acetabula.

The shape, size, and location of the carnivore gnaw marks indicate they could have been made by the teeth of Cave hyena or wolf. However, the Cave hyena (*Crocuta crocuta spelaea*) was nearly extinct or absent from most of Europe by the time of the Gravettian, disappearing between 40 and 30 ka BP (Stuart and Lister, 2014), and it is likely that wolves were responsible for the tooth marks on many mammal remains.

The tooth marks on some long bone epiphyses are individual furrows ~3–5 mm in breadth and 2–5 cm long, sometimes nearly parallel in alignment, but separated from each other by 5 mm or more (Figs. 18–21), suggesting they were not inflicted by the upper or lower incisor rows of any large carnivore. If incisors had been used to make the irregular tooth scrapes on the mammoth epiphyses, the furrows would be expected to occur in sets of up to six closely spaced parallel marks, each no broader than the greatest width of the wear surface of each



Fig. 16. A reindeer (*Rangifer tarandus*) femur fragment with unusually deep cut marks suggesting an early step in preparation of a tool or art object. Trench B + B1 (Zone III). Scale is 10 cm.



Fig. 17. An artifact made from part of a long limb bone (probably a femur) of a wolf/reindeer-sized mammal; Trench C2 (Zone I). Scale is 2 cm.

incisor in a carnivore jaw. The marks on the mammoth bones instead are separate furrows which often cross each other, most likely made by worn lower or upper cheek teeth.

The extent of carnivore gnaw damage on the identified Kraków Spadzista bones is not severe when compared to the modifications made by modern spotted hyenas to *Loxodonta africana* bones in Africa. The gnaw damage also seems moderate in extent and intensity when compared to records from other Pleistocene multi-mammoth assemblages. Some of those sites have higher frequencies of gnaw-marking and others have lower frequencies than at Kraków Spadzista. A relatively high frequency of gnawed bones, >20 % of NISP, was recorded from a cumulative noncultural assemblage of 35 woolly mammoths from Hofstade in Belgium dated to MIS 3 (a glacial interval, 57 – 29 ka) (Germonpré, 2003: 176). At the time this assemblage was accumulating, Cave hyena was still present in much of Europe. Assemblages created after the disappearance of Cave hyena probably have lower frequencies of gnaw-marked bones, such as at Kraków Spadzista and sector G of the Gravettian archeological site Milovice I, (Czech Republic), dated 30.5 – 28.7 ka, where the reported percentage of carnivore gnaw-marking of

Table 5
Different taphonomic factors affecting mammal remains in the Kraków Spadzista site zones.

	Gnawing (tooth) marks			Trampling marks			Weathering			Calcite precipitations			Root etching													
	Zone			Zone			Zone			Zone			Zone			Total	n	%								
	I	II	III	n	%	I	II	III	n	%	I	II	III	n	%	Total	n	%								
<i>Lepus sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	10									
<i>Canis lupus</i>	-	-	-	-	-	-	-	-	-	-	2	-	3	8.1	-	1	1	2.7								
<i>Vulpes lagopus</i>	-	-	-	-	-	-	-	-	-	-	243	1	275	10.3	1	26	-	27	1.0							
<i>Ursus arctos</i>	-	-	-	-	-	-	-	-	-	-	1	3	4	21	-	1	-	1	5.3							
<i>Gulo gulo</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-								
<i>Equus ferus</i>	-	-	-	-	-	-	-	-	-	-	1	3	4	19	3	-	4	19								
<i>Mammuthus primigenius</i>	4	8	500	512	1.75	-	239	239	0.8	22	24	278	324	1.1	779	304	1,452	2,535	8.7	79	123	640	842	2.88		
<i>Rangifer tarandus</i>	-	-	-	-	-	-	-	-	-	-	10	1	11	16.9	2	-	1	3	4.6							
<i>Cervidae</i>	-	-	-	-	-	-	-	-	-	-	1	-	1	16.7	-	-	-	-	-							
Fox/hare sized mammals	-	-	-	-	-	-	-	-	-	-	5	42	-	47	2.9	2	5	-	7	0.43						
Reindeer/wolf sized mammals	-	1	-	1	1.5	-	1	1	1.5	-	10	8	-	18	14.75	4	5	6	15	12.3						
Bear/horse sized mammals	-	-	-	-	-	-	1	1	-	2	3.44	10	13	-	23	39.6	9	9	-	18	31.0					
Mammoth sized mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
Unidentifiable	4	9	500	513	0.45	1	1	239	241	0.2	23	25	278	326	0.28	638	501	59	1,198	1.5	1	20	17	38	0.05	
TOTAL																	101	192	3.6	1,512	4,119	101	192	664	957	0.83

Table 6

Number of woolly mammoth complete bones and fragments of bones with carnivore gnawing (tooth) marks from Trench B + B1. Unidentifiable skull fragments, tusk fragments, complete teeth and their fragments were not counted and are excluded from the table. % Total = calculated for all remains (dex = right side; sin = left side; indet. = indeterminable).

Skeletal parts	NISP			Total	Gnawing (tooth) marks			Total	% Total
	dex	sin	indet.		dex	sin	indet.		
Occipital condyle	26	25	17	68	—	—	—	—	—
Zygomatic arch	61	39	19	119	—	—	—	—	—
Basioccipital	—	—	36	36	—	—	—	—	—
Hyoid bone	35	50	22	107	—	1	—	1	0.93
Mandible	—	—	—	408	2	1	1	4	0.98
Sternebra	—	—	12	12	—	—	1	1	8.33
Atlas	—	—	135	135	1	—	—	1	0.74
Axis	—	—	101	101	1	—	—	1	0.99
Cervicals III-VII	—	—	426	426	—	—	—	—	—
Thoracic	—	—	1,510	1,510	—	—	14	14	0.93
Lumbar	—	—	164	164	—	—	2	2	1.22
Sacrum	—	—	130	130	—	—	—	—	—
Caudal	—	—	269	269	—	—	—	—	—
Vertebra indet.	—	—	991	991	—	—	—	—	—
Total vertebrae	—	—	—	3,726	—	—	—	18	0.48
Ribs	—	—	5,581	5,581	—	—	39	39	0.70
Scapula	68	55	67	190	3	—	—	3	1.58
Humerus	44	56	28	128	10	19	19	48	37.5
Radius	91	83	9	183	13	18	—	31	16.94
Ulna	56	76	28	160	11	18	4	33	20.63
Carpals	182	155	2	339	22	15	—	37	10.91
Metacarpal I	2	6	—	8	—	—	—	—	—
Metacarpal II	19	22	—	41	3	5	—	8	19.51
Metacarpal III	22	24	—	46	9	7	—	16	34.78
Metacarpal IV	18	22	—	40	5	6	—	11	27.5
Metacarpal V	17	5	—	22	2	1	—	3	13.64
Total metacarpals	78	79	—	157	19	19	—	38	24.2
Innominate	87	110	—	197	17	15	4	36	18.27
Femur	66	52	92	210	17	10	32	59	28.1
Patella	31	32	8	71	2	4	1	7	9.86
Tibia	66	77	6	149	9	7	—	16	10.74
Fibula	102	90	56	248	2	5	—	7	2.82
Calcaneus	33	29	1	63	11	8	—	19	30.16
Astragalus	44	36	1	81	8	2	1	11	13.58
Tarsals	129	113	7	249	11	11	—	22	8.84
Metatarsal I	—	—	—	—	—	—	—	—	—
Metatarsal II	18	24	—	42	1	—	—	1	2.38
Metatarsal III	20	21	—	41	5	4	—	9	21.95
Metatarsal IV	22	19	—	41	3	3	—	6	14.63
Metatarsal V	12	4	—	16	—	—	—	—	—
Total metatarsals	72	68	—	140	9	7	—	16	11.43
Metapodial indet.	—	—	78	78	—	—	3	3	3.85
Metapodial total	—	—	—	375	28	26	3	57	15.2
Phalanx I	—	—	268	268	—	—	5	5	1.87
Phalanx II	—	—	153	153	—	—	1	1	0.65
Phalanx III	—	—	—	0	—	—	—	—	—
Phalanx	—	—	7	7	—	—	—	—	—
Phalanx total	—	—	—	428	—	—	—	6	1.4
Sesamoids	—	—	213	213	—	—	—	—	—
Long bone	—	—	578	578	—	—	34	34	5.88
Flat bone	—	—	112	112	—	—	—	—	—
Bone fragment	—	—	10,706	10,706	—	—	9	9	0.08
Total	—	—	—	24,737	—	—	—	498	2.01



Fig. 18. Two views of a woolly mammoth distal epiphysis of humerus with gnawing marks from a large carnivore; Trench B + B1 (Zone III). Scale is 10 cm.

1,068 *M. primigenius* bones in sector G is low, only 0.7 % (Svoboda et al., 2005), and the gnaw-marked percentage of >61,000 *M. primigenius* bones from all sectors of the site is even lower (0.08 %) (Bosch, 2012:172, table 1). At Langmannersdorf B (Austria), dated 20.5 ka BP, <1 % of the *M. primigenius* bones were identified as modified by carnivores (Bosch, 2012:172, table 1).

If the reported variability in tooth mark frequencies is based on comparable counting methods, it may reflect unique factors at each site, such as the recurring presence of humans at Kraków Spadzista which seasonally reduced scavengers' access to the discarded bones, or simply the presence or absence of certain Pleistocene scavengers such as Cave hyena. The Kraków Spadzista site (including all three zones) did yield skeletal remains of three possible species of bone scavengers: wolverine (*Gulo gulo*) (MNI = 1), bears (*U. arctos*) (MNI = 1), and wolf (*C. lupus*) (MNI = 2).

Wolverine (*Gulo gulo*) has been found in other Upper Pleistocene sites in Poland, Czech Republic, Germany, and elsewhere in Central Europe (e.g., Döppes, 2005; Marciszak et al., 2017). It is a large mustelid, weighing 13 – 25 kg in recent times, and is known to be a powerful scavenger of the carcasses of large mammals such as *Alces alces* (elk in Europe, moose in North America) killed by wolves (Sutcliffe et al., 1985; Magoun, 1985, 1987; van Dijk et al., 2008). Wolverine dentition is robust, adapted to heavy bone-gnawing. Individuals readily switch diets



Fig. 19. Two views of a woolly mammoth proximal epiphysis of femur with large carnivore gnawing marks; Trench B + B1 (Zone III). Scale is 10 cm.

to take advantage of carcass availability (van Dijk et al., 2008). The presence of *Gulo* at Kraków Spadzista (one bone in Zone II) might hint that wolverines had scavenging access to the mammoth bones. Isotopic evidence supports this possibility at the Czech Republic site Předmostí, where analysis of remains of some of the five wolverines found there indicate they "ate significant amounts of mammoth" (Bocherens et al., 2015: 222) which must have been scavenged from carcasses. Wolverine body and tooth sizes were significantly larger in late Pleistocene glacial periods (MIS 5d through MIS 2) than during interglacials (Döppes, 2005; Marciszak et al., 2017), and wolverine may have been capable of fragmenting some mammoth bones such as ribs and tail vertebrae, and also capable of tooth-marking smaller limb bone epiphyses. Some tooth markings on Kraków Spadzista mammoth bones and displacement of bones might have been made by wolverines (see Magoun and Valkenburg, 2001).

Some gnaw marks appear to have been made on the Kraków Spadzista mammoth bones by carnivores smaller than wolverine, possibly by Arctic fox (*Vulpes lagopus*). Arctic fox bones are abundant in the site's animal processing area (Zone II).

The bears found at Krakow Spadzista (19 bones, possibly from one individual) also may have been scavenging the mammoth bones.



Fig. 20. Two views of a woolly mammoth distal epiphysis of femur with large carnivore gnawing marks; Trench B + B1 (Zone III). Scale is 10 cm.

Bocherens et al. (2015: 222) thought there was a “relatively high amount of mammoth in the diet of the [single brown bear found at Předmostí]...as a result of scavenging.” Judging from studies of modern captive and noncaptive counterparts, brown bears can produce abundant tooth marks on limb bone epiphyses of medium to large cervids, equids, and bovids. Tooth marks on Kraków Spadzista mammoth bones are not distinctive enough in size and shapes to assign confidently to bears (see Haynes, 1981; Burke, 2013a, 2013b).

The Pleistocene wolf (*Canis lupus*) is the leading candidate for the scavenger which inflicted most tooth marks on Kraków Spadzista mammoth bones. Pleistocene wolves in Poland and Czech Republic were on average larger than recent specimens, with “broader teeth and more robust postcranial bones” (Marciszak et al., 2017: 4). The larger Pleistocene individuals are sometimes classified as *C. lupus spelaeus*, based mostly on size differences from the modern form. Modern *C. lupus* is gregarious, and prey is hunted by packs which have variable numbers of members, depending upon the body size of available or preferred prey. Modern wolf packs are families, consisting of a pair of breeders and their recent offspring (Mech, 1999), which travel and hunt as units. However, individual offspring may disperse and hunt or scavenge on their own, which was likely also the case in the Pleistocene. Wolf packs may have



Fig. 21. Two views of a woolly mammoth left os lunatum (carpal bone) with very intense large carnivore gnawing marks; Trench B + B1 (Zone III). Scale is 10 cm.

killed some of the smallest mammoths at Kraków Spadzista, and individual wolves may have been frequent scavengers of all mammoth bones at the site. A multi-isotopic study of Předmostí fauna (Bocherens et al., 2015) found that the diet of wolves included mostly equid and mammoth.

Another possible but unlikely scavenger is domesticated dogs (*C. lupus familiaris/C. familiaris*). We note that no dog bones have been found at Kraków Spadzista. Large canids found at Předmostí (Czech Republic) have been interpreted as dogs, but they apparently ate no mammoth meat, according to isotopic analysis (Bocherens et al., 2015: 224). It would have been difficult if not impossible to prevent dogs from eating mammoth at Kraków Spadzista because of the site’s massive accumulation of mammoth bones. Importantly, the gnawing modifications on Kraków Spadzista mammoth bones are not comparable to modern dog-inflicted damage, which is distinguishable from the effects of modern wolf-inflicted modifications (see Haynes, 1980, 1981, 1982, 1983). Few bones of mammals whose body sizes were much smaller than



Fig. 22. Woolly mammoth rib fragment with probable trampling marks; Trench B + B1 (Zone III). Scale is 10 cm.

mammoths were gnawed by large canids at Kraków Spadzista, which is not an expected pattern if domesticated dogs actually had been present. Smaller bones would have been much more modified by dog gnawing. The conspicuously visible damage expected from domesticated dogs is not present in the site's faunal assemblage. Gnawing by modern domesticated canids tends to be persistent and leaves more extensive marking, such as the so-called "kennel pattern" (Haynes, 1981). Domesticated dogs are known to have major effects on animal bones in modern forager camps recorded ethnographically (Hudson, 1993). The extreme effects of gnawing by domesticated dogs can be seen in prehistoric and modern contexts where there is direct evidence dogs were present, such as at pre-Columbian Maya sites (Ley-Lara et al., 2015; Ley-Lara and Götz, 2016) and modern communities in rural Mexico, where dogs for generations have been used to clean up garbage around domestic spaces (Ley Lara, 2018). Also, at European (including Polish) sites dated to the Holocene, signs of dog activity (gnaw marks) are numerous. Over 17 % of animal bones are tooth-marked by dogs in Medieval garbage deposits in central Kraków (Wojtal et al., 2010). In Ojców Castle (southern Poland) carnivore gnaw marks were noted on 13 % to 22 % of remains dating to different phases of castle occupation, from the 14th to the early 19th century (Religa-Sobczyk et al., 2023). Almost 10 % of mammal bones were gnaw marked in the Bronze Age settlement of Asva, Estonia (Wojtal unpublished data).

The relatively modest percentage of tooth marking and gnaw damage on the Kraków Spadzista mammoth epiphyses and the near absence of gnaw damage on smaller species' bones from the site indicate that dogs of any sort, either domesticated or semi-domesticated (called "wolf-dogs" if their relationship to living dogs is unknown, *a la* Shipman, 2015), were not present when the Kraków Spadzista mammoth bones were deposited. True examples of domesticated dogs are present only in post-Gravettian times, in the Magdalenian and Azilian phases in SW France and elsewhere in western Europe (Boudadi-Maligne et al., 2018).

A similar post-Gravettian appearance is also likely for central Europe.

It is important to note that despite water-sieving of sediments from the Gravettian cultural layer in the trenches excavated in 2011 and located in all zones of the Kraków Spadzista site, no digested large-mammal bones or carnivore (or human) coprolites were discovered.

3.5. Trampling

One other factor that affected the persistence of mammal remains at the Kraków Spadzista site was trampling by animals and possibly also by humans. A total of 241 bones with probable trample marks were discovered at the site (Table 5). Almost all these marks were observed on mammoth bones from trench B + B1, with the exception of five mammoth bone fragments from B3 trench and one unidentifiable bone fragment from trench E1. Most often the trample marking was observed on rib fragments ($n = 198$) (Figs. 22 and 23), although marks were also visible on other elements, including cervical vertebrae, long limb bones, and flat bones. Only one foot bone (*astragalus*) had trample marks.

We think that some (perhaps most) trample marking and bone fracturing had been caused by mammoths. This proposal is supported by the evidence of a broken femur belonging to a juvenile or very young adult mammoth. A series of parallel scratches were created during trampling of the diaphysis that resulted in spiral fracturing of the bone (Fig. 24). The cortical thickness of the bone diaphysis is too great for the weight of a human to have caused the fracture. Also, the presence of some bones found in a vertical position in the site sediments may be due to trampling by heavy animals. Trample fracturing possibly explains the high degree of fragmentation of mammoth crania, which is also commonly seen with African elephant skulls in the wild (Haynes et al., 2020). Some mammoth rib fragments were broken by bending, a common effect of trampling by modern African elephants (Fig. 25) and may be evidence for temporary human abandonment of the area that allowed



Fig. 23. Woolly mammoth rib fragment with probable trampling marks next to damage made recently during excavations; Trench B + B1 (Zone III). Scale is 10 cm.

the return of mammoths to the site seeking minerals in the spring water or vegetation different from what grew in the river valleys. Taken together, the marks and breakage from trampling support our inference that mammoths visited the area when human foragers were not present. Another possible reason for the trampling by mammoths may be that hunters sometimes drove mammoths towards the rocky cliff dropoff where bones earlier had been discarded on the site, and the animals could go no farther.

3.6. Weathering

Despite the large quantity of mammoth remains at the site, only 326 bones exhibited signs of weathering (Table 5). The majority of the weathered specimens ($n = 278$) were recovered from trenches B + B1 and B3 within Zone III. The osteological materials from this zone exhibit a range of weathering from light to heavy. The light weathering corresponds to [Behrensmeyer \(1978\)](#) weathering stages 1 and 2, with a total of 146 specimens, while the heavier weathering corresponds to stages 3

and 4, with a total of 122 specimens ([Haynes and Wojtal, 2023:Fig. 10b](#)) ([Fig. 26](#)). The most conspicuous evidence of weathering is on ribs, with less pronounced changes on other skeletal elements such as long limb bones and flat bones. We note that the bones of very young African elephants have been observed to weather more rapidly than those of adults ([Haynes and Wojtal, 2023](#)), which likely also was the case for mammoth bones.

3.7. Calcite precipitation

Calcite coating is present on 4,119 mammalian remains collected across the entire Kraków Spadzista site ([Table 5](#)). In some instances, only a small part of a bone is coated with calcite, whereas in other cases the mineral coating covers the entire bone ([Fig. 27](#)). As a result, it was possible to identify only the shapes of the more encased bones and did not allow documenting other types of surface modification.

Some remains of both large mammals (mammoths) and small ones (Arctic foxes) from trenches C2 and E1 are heavily coated with calcite



Fig. 24. Woolly mammoth femur with probable trampling marks in midshaft; Trench B + B1 (Zone III). Scale is 10 cm.

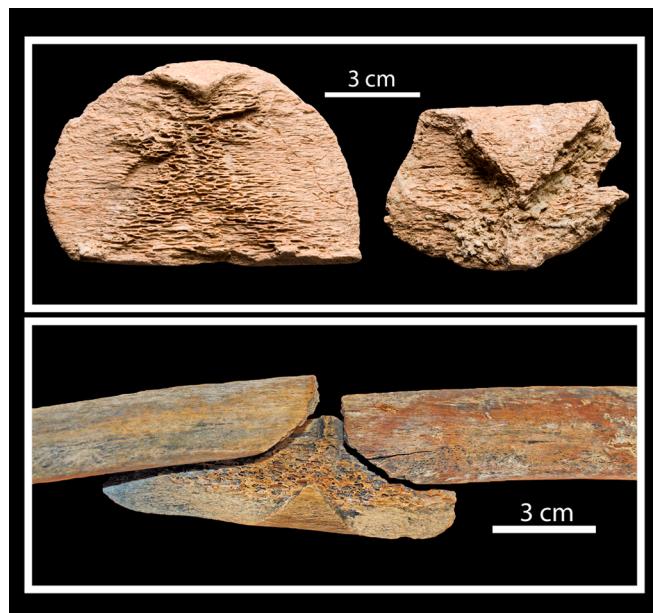


Fig. 25. The top image shows two “butterfly/wedge” fragments of Kraków Spadzista woolly mammoth ribs broken by bending. The bottom image shows three refitted fragments (including a “butterfly/wedge” piece) of a rib from the 24kyr Inglewood (Maryland, USA) Columbian mammoth, broken by bending; note the characteristic V-shape of the margins on the central piece, and its similarity to the shapes of the Kraków Spadzista specimens.

precipitates. (Fig. 28). The calcite cover is particularly challenging to remove; attempted removals resulted in damage to the outer surface of some bones. The calcite coating is also present on mammoth teeth, in some cases covering a significant portion of the tooth, indicating that the unrooted tooth was buried separately from the mandible or maxilla. This is indirect evidence that mammoth skulls were extensively fragmented prior to final burial (Fig. 29).

4. Discussion

Spatial organisation and density of remains

The species whose remains were found in the different zones of the site are limited in number and frequencies. A relatively large number of rodent bones and teeth were collected mainly in Zones I and III (Table 1), but only during 2011–2017 excavations when the sediments of the cultural layer were wet sieved. No rodent bones had been identified during the earlier field work, so we assume that the earlier lack of bones and teeth from small mammals was a result of excavation methods. Rodent remains probably were deposited naturally by raptors – probably Snowy Owl (*Bubo scandiacus*) (Anna Lemanik and Paweł Socha pers. comm.) – although it is also possible some were deposited in Arctic fox scat. Complete taxonomic and taphonomic analysis of these finds are in progress and will be published as soon as possible. The list of mammal species (excluding rodents) from the site is not long – only nine taxa (Table 1). Because of the clear dominance by woolly mammoth we conclude that Late Gravettian hunter-gatherers from Kraków Spadzista were preferential hunters of that taxon. Other Late Pleistocene mammals were only sporadically or opportunistically hunted, with the single exception of Arctic fox, which was probably actively hunted or trapped for its fur and hides. The low diversity of hunted taxa distinguishes Kraków Spadzista from Pavlovian sites in south Moravia (e.g., Dolní Věstonice I, Dolní Věstonice II, Pavlov I), where there was no clear hunting specialisation or focus on only one or two taxa (Wojtal et al., 2012; Wilczyński et al., 2015a, 2015b).

Despite wet sieving sediments from the cultural layer in trenches located in different zones of Kraków Spadzista, no bird remains were found. This is another feature that distinguishes the Late Gravettian Kraków Spadzista site from the Pavlovian sites in south Moravia (Bocheński et al., 2009; Wertz et al., 2016). We reject the possibility that taphonomic factors destroyed fragile bird bones at Kraków Spadzista because the wet sieved sediments did yield many fragile remains of small mammals, specifically Arctic fox and very small rodents.

The density of mammoth remains in the different trenches/Zones of Kraków Spadzista is very distinctive. In the fieldwork from 1968 through 2017, a total of 387 sq. m. were excavated, and in all the trenches 29,243 mammoth remains were found (NISP not including tusk



Fig. 26. Woolly mammoth rib fragment in weathering stage 3; Trench B + B1 (Zone III). Scale is 10 cm.



Fig. 27. Woolly mammoth rib fragment covered by calcite precipitation; Trench C2 (Zone I). Scale is 10 cm.

fragments and small teeth fragments). The mean number of mammoth remains (NISP) per sq. m. was 76. A total of 6,451 (MNE) woolly mammoth bones and teeth were discovered at the site, equating to 17 specimens per sq. m. However, when different zones and trenches of the site are considered, these values are more variable, probably indicating

the influence of hunter-gatherers in the past. In trench B + B1, the largest number of mammoth remains was found – 173 mammoth bones and teeth fragments (NISP) or 37 bones and teeth (MNE) per sq. m. Also at the small (3 sq. m.) trench B3, located in Zone III, 33 mammoth skeletal elements per sq. m. were recovered. A total of 160 mammoth remains (not including small tooth and tusk fragments) have been found in Zone III (the mammoth accumulation), i.e., 36 bones and teeth per sq. m. These values are extremely high compared to other Zones/trenches of the site. In Zone I (the camp area) 10 remains (NISP) were found or only one (MNE) bone/tooth per sq. m. In Zone II (the lithic workshop) the number of remains (NISP) reaches only 6 bone/tooth fragments per sq. m. A more detailed analysis of the frequency of elements in the different zones shows that more than ~93 % of the particular groups of skeletal parts were found in Zone III (Table 7). It should be emphasised that especially vertebrae and foot bones, i.e., non-meaty parts of the skeleton, are poorly represented in Zones I and II (Supplementary Table 1). The presence of most (nearly 94 %) of the mammoth remains in a very small area (trenches in Zone III cover about 170 sq. m.) suggests that Gravettian hunter-gatherers deliberately accumulated the mammoth remains in this zone. Because of this we classify it as a dump area, but, as mentioned, we also think some mammoths were killed and butchered in



Fig. 28. Two views of an Arctic fox first cervical vertebra (*atlas*) covered by calcite precipitation; Trench E1 (Zone II). Scale is 5 cm.



Fig. 29. Two views of a woolly mammoth lower molar partly covered by calcite precipitation; Trench B + B1 (Zone III). Scale is 10 cm.

Table 7

Frequency of woolly mammoth elements in the different zones of Kraków Spadzista site. Forelimb bones are *humerus, ulna, radius*. Forelimb foot bones are carpus bones and metacarpals. Hindlimb bones are *femur, tibia, fibula*. Hindlimb foot bones are tarsus bones and metatarsals. Flat bones are scapula and pelvis.

	Zone I				Zone II				Zone III				Total	
	NISP	% NISP	MNE	% MNE	NISP	% NISP	MNE	% MNE	NISP	% NISP	MNE	% MNE	NISP	MNE
Skull/mandible/teeth	437	12.36	36	4.79	123	3.48	17	2.26	2,976	84.16	699	92.95	3,536	752
Vertebra	33	0.86	17	1.05	56	1.45	30	1.85	3,766	97.69	1579	97.11	3,855	1,626
Ribs	152	2.53	22	1.37	165	2.75	30	1.87	5,691	94.72	1550	96.75	6,008	1,602
Forelimb long bones	2	0.42	2	0.78	2	0.42	2	0.78	474	99.16	252	98.44	478	256
Forelimb foot bones	3	0.58	3	0.58	18	3.46	17	3.29	499	95.96	497	96.13	520	517
Hindlimb long bones	8	1.29	8	3.15	6	0.97	6	2.36	607	97.75	240	94.49	621	254
Hindlimb foot bones	1	0.18	1	0.18	15	2.71	15	2.72	537	97.11	536	97.10	553	552
Flat bones	13	3.20	7	4.35	3	0.74	3	1.86	390	96.06	151	93.79	406	161
Phalanges/sesamoids	12	1.73	10	1.63	21	3.03	18	2.93	660	95.24	586	95.44	693	614
Long bone fragments	40	6.00	—	—	46	6.90	—	—	581	87.11	—	—	667	—
Bone fragments	436	3.76	—	—	208	1.80	—	—	10,943	94.44	—	—	11,587	—

this Zone. Another characteristic is the presence of a high number of long limb bone fragments in Zones I (~6 % of the total) and II (~7 % of the total). In both zones, numerous burned bone fragments were found which could have come from soliflucted hearths where mammoth bones had been used as fuel. The higher proportion of long bone fragments in these parts of the site may indicate that limb elements had been broken to prepare them as hearth fuel. When calculating the density of mammoth remains per sq. m., we did not take into account tusk fragments, isolated tooth lamellae, and their fragments. These skeletal parts are very easily fragmented and including them would misleadingly inflate the counts.

The mammoth mortality profile at Kraków Spadzista: Interpretation and perspectives on multi-proboscidean death sites

As mentioned above in section III.2, the mammoth mortality profile (also known as an age profile) from Kraków Spadzista has been reconstructed from analysis of excavated teeth and mandibles, which are well represented in the assemblage. The MNI based on the dentitions is currently 113 but this calculation may change as analyses continue. The mammoth bone accumulation likely represents a human-made discard or dump area containing the remains of mammoths accumulated over decades to a few centuries, based on radiometric dates with a spread of ~300 calibrated years (Wilczyński et al., 2020). The total time involved in the bone accumulation might have been longer, which would imply that Gravettian people returned to this relatively small site area over and over again for more than three centuries to kill and process mostly mammoths and a few other animals without cultural innovation or stylistic drift in lithic technology.

The recent processes creating multi-elephant death assemblages in Africa (Corfield, 1973; Conybeare and Haynes, 1984; Haynes, 1987, 1988a, 1988b) may be clues to similar death events in the Pleistocene that created multi-mammoth assemblages. These are: (1) serial or single-event mass deaths occurring in certain special resource areas during extreme stress periods, such as drought; (2) serial predation or other non-anthropogenic death events in single localities which lead to accretion of bones from single deaths, as Poole (1992) observed for

elephant bones from single deaths “often in close proximity” in Amboseli National Park (Kenya); and (3) cumulative natural or anthropogenic transport of remains from separate death sites. Process 1) produces the largest accumulations of proboscidean bones, in line with what Voorhies (1969: 59) long ago suspected, that “ordinary, garden-variety catastrophes are responsible for more mass occurrences of vertebrate fossils than is ordinarily supposed.”

The bones of smallest individual animals have the lowest durability to taphonomic destruction, and because small individual mammoths so strongly dominate the mortality profile at Kraków Spadzista, we think representation of different age groups in the assemblage has not been seriously biased by non-anthropogenic taphonomic subtractive processes. The assemblage is thought to fairly reflect the original input of mammoths. The mortality profile appears classically nonselective (or “catastrophic”) (Fig. 30a), similar to what is expected in a healthy living population.

Nearly half of the mammoths (46.9 %) represented by mandibles and teeth were under 12 AEY in age, and ~15–20 % of the total MNI were calves (<4–8 AEY) many of them probably too young to have been fully weaned. This percentage is similar to the estimated proportion of unweaned or recently weaned calves in a large population of free-roaming African elephants (Hanks, 1979; M. Jones pers. comm. to G. Haynes).

Fig. 31 shows several mortality/age profiles recorded or predicted among free-roaming African elephant populations (Haynes, 1991). Type A is typical of many healthy living populations, Type B is a record produced by several drought-caused die-offs, Type C is what is expected from a cumulative assemblage made up mostly of males that had left their natal herd after reaching sexual maturity, and Type D, only a prediction, is without obvious patterning and might be expected in palimpsest deposits containing long-term unrelated deaths. The Kolmogorov-Smirnov nonparametric two sample test is potentially useful for interpreting whether mortality profiles such as these have statistically significant differences. The K-S two-sample test shows no significant difference between Kraków Spadzista and the Type A (nonselective) age profile ($D = 0.083$, $Z = 0.615$).

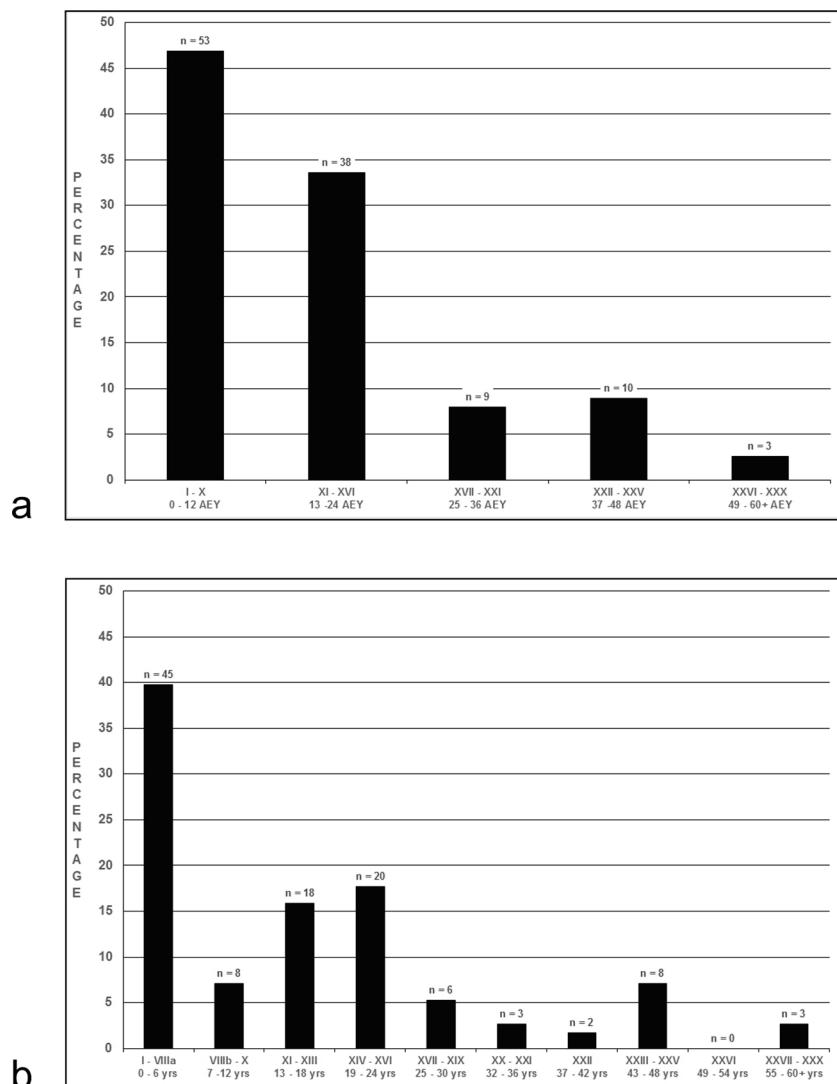


Fig. 30. Mortality profile graphs of 113 mammoths at Kraków Spadzista. Graph (a) shows percentages plotted by cohorts of 12 AEY; graph (b) shows percentages plotted by 6 AEY. The x-axis shows the separate cohorts that include “Laws age groups.”

A more detailed analysis (Fig. 30b) reveals unusual features in the Kraków Spadzista assemblage (also see Haynes and Klimowicz, 2015); namely a high proportion of youngest juveniles in the total (>40 % are < 7 AEY), a substantial representation of young sexually mature adults (>32 % between 13 and 25 AEY), and an apparent shortage of prime/midlife adults (25 – 36 AEY) which are outnumbered by older adults (37 – 60 + AEY).

Wojtal et al. (2015), Wojtal and Wilczyński (2015b), and Haynes and Klimowicz (2015) are certain that the assemblage contains mostly human-killed mammoths, although they concede that some bones might be from natural deaths, perhaps reflecting environmentally mediated die-offs which could have been exploited opportunistically by Gravettian hunter-gatherers. The graph can be interpreted to reflect that some cohorts (e.g., those which died in Laws groups VIIib – X and XVII – XXI) had been depleted in the past when members were at the most vulnerable age (when they were still in Laws groups I – VIIa, <7 AEY, after adjustment following Stansfield, 2015). Here we suggest the relatively large percentage of very youngest individuals in the I – VIIa group shows that the local mammoth population was recovering well after a recent high-mortality period a little over seven years previously. After such high-mortality events, the sexually mature individuals in low-density populations may have had younger primiparous ages and shorter inter-birth intervals, leading to a high birth rate, which is a type

of biological recovery which occurs in recent African elephant populations after a population decline, and possibly also might have occurred in mammoths. This sort of recovery following high mortality periods may be reflected in the Kraków Spadzista mortality graph's irregular percentages of many older age groups, such as the larger percentage of individuals in groups XIV – XVI (18 – 24 AEY) compared to the percentages in the next older group.

This idea of recovery following high mortality is only a suggestion, since we do not know if the extinct proboscidean taxa responded the same ways in different geographic regions and at different times.

Haynes et al. (2018) speculated that adult mammoths in the Kraków Spadzista assemblage were mostly females, based on a sample of limb bones measured to extrapolate shoulder heights. The estimated shoulder heights are ~10–20 % smaller than the shoulder heights estimated for adult male woolly mammoths from other parts of Europe (Garutt, 1964; Lister and Stuart, 2010 Supplementary Table B), and only slightly less than the maximum measured difference between the shoulder heights of adult male and female *L. africana* (e.g., Laws et al., 1970).

To explain the preponderance of female adults, we suggest the social behaviour of mammoths was similar to that of African elephants, in that adult males did not associate for long or in large numbers with mixed herds of females and young. Studies in Zimbabwe (Haynes unpubl. field notes, 1983 – 1987) and other parts of Africa with large protected areas

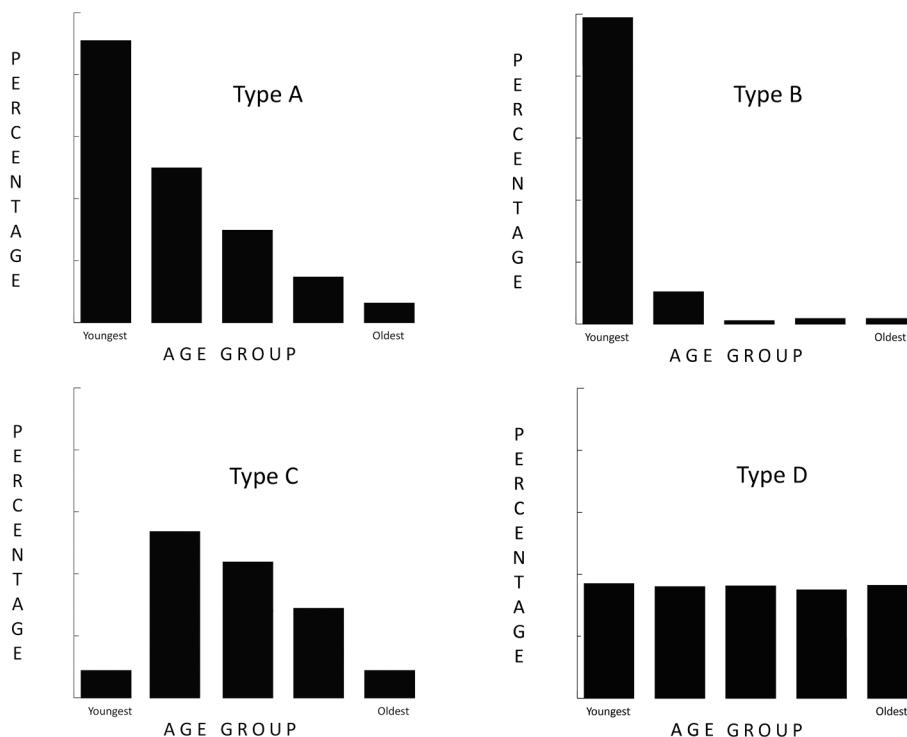


Fig. 31. Types of age/mortality profiles in elephants, resulting from different causes of death (see text).

for free-roaming elephants found that family groups of elephants typically included adult females and their young in company often with no more than one or two adult males. Only the largest elephant groupings such as temporarily coalesced multiple families in Zimbabwe had two or more adult males present. Elephant studies in Africa outside Zimbabwe generally involved smaller elephant populations in smaller areas, so the proportions of adult males with mixed herds may have varied. If mammoth social behaviour was similar to the pattern documented in Zimbabwe, the Kraków Spadzista bone accumulation represents human exploitation exclusively of mixed herds (adult females and young without adult males).

We further suggest the mixed herds were already at the site location on the high ground at Kraków Spadzista when humans hunted them; we do not think they were somehow driven up there by hunters. The location, at the top of a partly steep-sided hill, had mineral-rich springs with more diverse vegetation than what was available below the hill. Adult females of sexually dimorphic large herbivores like elephants tend to stay closer than adult males to dependable water and forage patches (Shannon et al., 2010; Shannon et al., 2013; Lindsay, 2011), and the springs and vegetation on the hill would have attracted female mammoths and young with high nutritional needs. Gravettian hunter-gatherers would have known they might find mammoths on the hilltop, and went there to kill what was encountered, including the vulnerable juveniles and adult females.

The K-S two sample test must be cautiously interpreted when comparing mortality profiles, keeping in mind all the various taphonomic and cultural factors which can affect bone assemblages. Fig. 32 shows mortality profile graphs from two Upper Paleolithic assemblages roughly similar in chronometric age to Kraków Spadzista. One site is Langmannersdorf (Austria), a multi-mammoth archeological assemblage dominated by adults on the graph. The mammoth MNI for the entire site is 27 and MNI is 7 in the bone pile subarea Lagerplatz [campsite] B, ~50 m away from Lagerplatz A (Salcher-Jedrasik, 2012 and references therein; Bosch 2012). Milovice I (Czech Republic) is the second site, also with apparent dominance by adults. The mammoth MNI is either 51 (Brugère and Fontana, 2009) or 46 (Haynes et al. unpubl.) from all areas of Milovice I.

Both assemblages in those sites appear to be different from Kraków Spadzista. Table 8 provides numbers and percentages of mammoths in each age category at Langmannersdorf, Milovice I, and Kraków Spadzista.

K-S two-sample tests suggest the Langmannersdorf mortality profile does not differ significantly from that of Kraków Spadzista ($D = 0.215$, $Z = 1.01$), while the Milovice I mortality profile does differ significantly from that of Kraków Spadzista at the $p = 0.001$ level ($D = 0.318$, $Z = 2.72$). However, a K-S two-sample test suggests the Milovice I profile does not significantly differ from that of the Langmannersdorf (site total, including subarea Lagerplatz B) ($D = 0.201$, $Z = 0.83$). Shipman (2015: 41, Fig. 2b) and Perri et al. (2015: 113, table 1), using the K-S two-sample test, also found no statistically significant differences between Milovice I and Langmannersdorf age distributions, in spite of visual differences on the bar graphs. The sample size from Langmannersdorf (MNI = 27) is less than the 40 recommended for a K-S test (e.g., Klein and Cruz-Uribe, 1984: 213), so the results of K-S tests involving the Langmannersdorf assemblage might be misleading. The tests result in apparently conflicting results that the Langmannersdorf profile is not statistically different from Kraków Spadzista's, while also suggesting its similarity to the profile of Milovice I, which is significantly different from Kraków Spadzista's. As Bosch (2012) pointed out, a subarea of Langmannersdorf (the bone pile of Lagerplatz B) has a higher proportion of juveniles than the site's entire mammoth assemblage (50 % juvenile versus 37 % for the entire assemblage); a graph of Lagerplatz B ages is catastrophic/nonselective, but the MNI is too small for statistical comparison using the K-S test. Bosch (2012) interpreted the Langmannersdorf mammoth assemblage as the result of selective human hunting of prime-age males and females.

Brugère and Fontana (2009) interpreted the combined Milovice I assemblage from all areas of the site as the remains of separate kills made for ivory procurement, implying that the sizes of tusks (which depend on animal age and sex) were the most important factors behind human decisions to kill individual mammoths (see also Halámková, 2009). Bosch (2012) also interpreted Milovice I as a time-averaged accumulation of serial kills made by humans. Bosch (2012) suggested that one subarea at Langmannersdorf was either the result of a

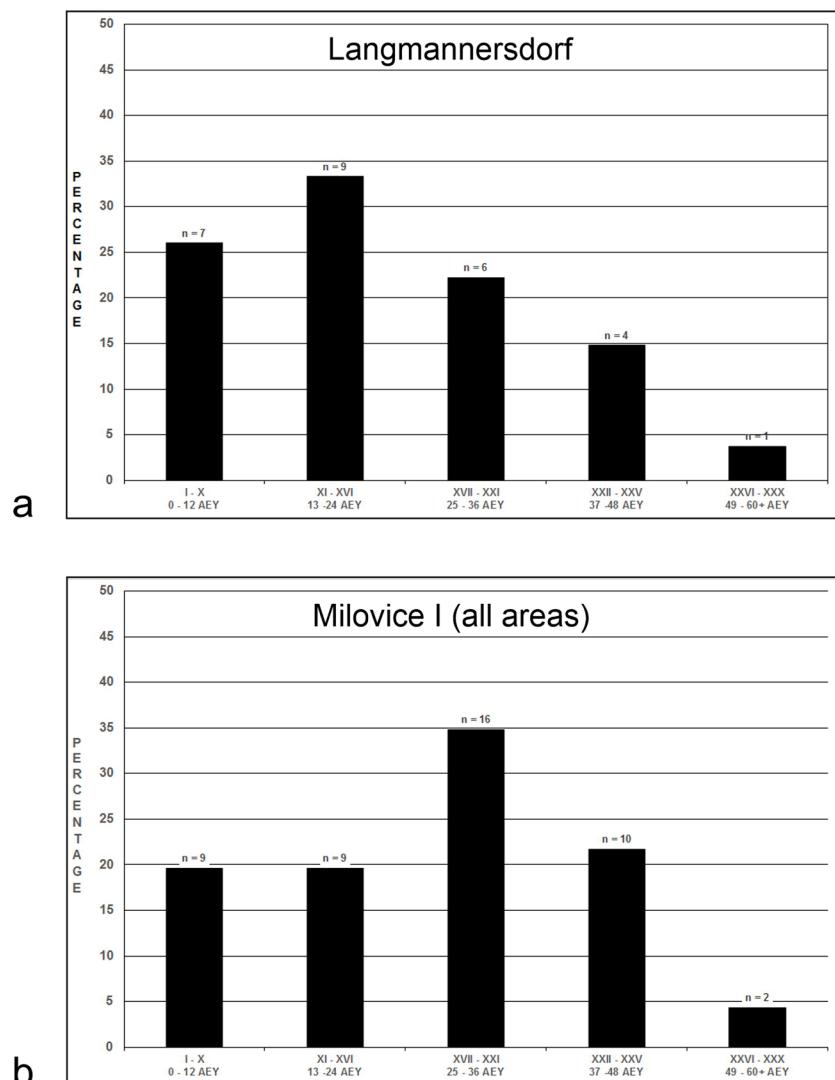


Fig. 32. Percentages and numbers of woolly mammoths in two assemblages. The Langmannersdorf graph has been redrawn from Bosch 2012; the Milovice graph uses data collected in 2019 (Haynes unpublished.), in which the MNI is 46.

Table 8

Numbers (and percentages in parentheses) of woolly mammoth individuals in each age category from two sites (see text). Langmannersdorf data (total site MNI) are from Bosch (2012); Milovice I data are from Haynes et al. (in prep.).

	0-12 AEY	13-24 AEY	25-36 AEY	37-48 AEY	>48 AEY
Langmannersdorf	7 (25.9 %)	9 (33.3 %)	6 (22.2 %)	4 (14.8 %)	1 (3.7 %)
Milovice I	9 (19.6 %)	9 (19.6 %)	16 (34.8 %)	10 (21.7 %)	2 (4.3 %)
Kraków Spadzista	53 (46.9 %)	38 (33.6 %)	9 (8.0 %)	10 (8.8 %)	3 (2.7 %)

single mass death event or several mass deaths close together in time. If these interpretations are correct, it implies that humans at certain times and places did preferentially kill adult mammoths at some sites.

As Bosch (2012) discussed, the variable mortality profiles of multi-mammoth assemblages dating 30 – 20 ka in Europe's middle Danube region may reflect different human behaviors, such as selective hunting for meat, selective hunting for ivory, or human scavenging of already dead mammoths to procure raw materials such as tusks and bones. Other possibilities to explain a preponderance of adults is opportunistic killing by hunters during periods of environmental stress on the mammoths, such as in drought or harsh winter weather. Another possible explanation is that mammoth bones were amassed for public displays of success in the hunting of the “most prestigious game animal” (Oliva, 2009: 304).

Speth et al. (2013) made a similar proposal that North American Paleoindians killed Columbian mammoths (*M. columbi*) to publicly signal their hunting skills and perhaps gain social power; they did not hunt such large mammals as a routine step in provisioning bands or families.

The hunter-gatherers at Kraków Spadzista, Langmannersdorf and Milovice I certainly had a mammoth-hunting focus. At Kraków Spadzista and Langmannersdorf the animals were killed randomly without focusing on one or two age groups. But at Milovice I hunters often killed adult mammoth, so it appears that they were more focused on this category of animals, for reasons unique to that site perhaps. The use of different sized lithic weapon tips for hunting at Kraków Spadzista and Milovice I suggests that the different mammoth hunters had dissimilar strategies for procuring prey (Wilczyński et al., 2019).

These possibilities for variations in mortality profiles mean that using only statistical tests to compare and interpret them can be misleading or contradictory. Comparing fossil site mortality profiles to idealized modern elephant mortality profiles should not be viewed as factual proofs of similarities or differences, but more as only suggestive hints about what the profiles may mean.

Mammoth-hunting directly at the site

Careful inspections of all remains collected from 1968 to 2017 allowed us to find strong evidence that at least some woolly mammoths were hunted and killed at this site. Four partial mammoth ribs were found with embedded fragments of lithic points (Wojtal et al., 2019; Fig. 3a-d). Such direct evidence of woolly mammoth hunting is extremely rare. Up to now very few sites in the world have yielded stone fragments unambiguously embedded in bones from impacting the bones. The finds other than Kraków Spadzista, in central Europe, are known only from northern Asia (Nikolskiy and Pitulko, 2013; Pitulko et al., 2016; Zenin et al., 2006) and eastern Europe (Sinitsyn et al., 2019). As well, the presence of all parts of the mammoth skeleton, including small bones which would have had minimal or no edible tissue – such as hyoids, sesamoids, and phalanges (Table 2) – corroborates that mammoth killing was done directly in the Kraków Spadzista site, and body parts were not transported there from killsites elsewhere. Gravettian hunters were unlikely to transport all the dismembered mammoth body parts from carcasses killed elsewhere, especially whole limbs including feet. Even without soft tissue, proboscidean bones are very heavy. A femur of a modern *Loxodonta africana* may weigh between 15 and 23 kg after meat is removed, and the mandible may weigh between 34 and 65 kg (Haynes and Klimowicz, 2015). Mammoth bones would have weighed more than the bones of comparably sized individual *Loxodonta* and *Elephas*.

Time of site occupation

It is important to note that the site was not occupied year-round, but only seasonally. Research into the mortality season of Arctic foxes (Pryor et al., 2020) and reindeer (Nývltová Fišáková, 2013) indicates that these mammals were preferentially killed during the autumn–winter season. Further evidence of the time of the year when Gravettian hunter-gatherers were present at Kraków Spadzista has been provided through research on the strontium isotopes in mammoth teeth. The research revealed that the mammoths at Kraków Spadzista remained in the site area only during the autumn–winter season, when humans also would have been present at the site. During the summer part of the year, mammoths probably migrated to the north of Poland (Kowalik et al., 2023).

During half or more of the year, the site was probably abandoned by humans, allowing large carnivores free access to the mammoth remains, especially the near-fresh remains accumulated in the northern part of the site, in Zone III. In the trench B + B1 498 bones and their fragments were collected with large carnivore gnawing marks. This is 2 % of all mammoth bones, complete and fragments, from this trench, but if we exclude the small bone fragments (under 12 cm maximum dimension), which large carnivores are unlikely to have selected for gnawing, the percentage of gnawed mammoth bones rises to almost 3,5 %.

5. Conclusions

The site Kraków Spadzista is mainly a Late Gravettian hunting and butchering locus, although other domestic and maintenance activities also took place there. The human occupants were specialised and focused on hunting two taxa – woolly mammoth and Arctic fox. In summary, based on the results of taphonomic and zooarchaeological studies, we can reconstruct the history of the creation of the site. The Gravettian hunter-gatherers actively hunted woolly mammoths during the winter season, which was related to the appearance of herds of mammoths in the Krakow area at this time of year (Kowalik et al., 2023). This activity was repeated over years, probably decades or longer, and more than a hundred mammoths left their bones in the site. The hunters

did not strictly limit their killing to particular ages of mammoths, and they opportunistically chose animals of different ages as victims – the young, adults, and old-age animals. The mammoths were killed near or within the site as delineated today, where they were dismembered and the butchered resources were transported a short distance to the camp zone. The site was cleaned by disposing of most mammoth remains into one area – Zone III – creating a large accumulation of bone waste in the northern part of the site. It is probable that fragments of many long limb bones of the mammoths were used as fuel in campfires. The hunter-gatherers also hunted Arctic foxes. After a few weeks or months at the site, the people temporarily moved elsewhere, and the site area was then visited by different animals during the spring and summer. For the large carnivores – especially wolves – the site was an important place to find easy food. The remains of the mammoths were probably largely devoid of meat but the carnivores gnawed on remnant soft tissue and the epiphyses of the nearly fresh bones. The site was also used by raptors, probably Snowy Owls nesting there and preying on small mammals, whose remains were regurgitated or cast as pellets.

In 1967 this abundant record of Gravettian culture was fortuitously discovered, and it has been a continuously rich source of information about the past ever since then.

CRediT authorship contribution statement

Piotr Wojtal: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Gary Haynes:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Jarosław Wilczyński:** Resources, Writing – original draft, Investigation. **Krzysztof Sobczyk:** Resources. **Janis Klimowicz:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The studies were partly supported by National Science Centre, Poland (grant decisions No. DEC-2011/01/B/ST10/06889 and UMO-2015/17/B/HS3/00165 awarded to P. Wojtal, and grant decision No. DEC-2013/09/D/HS3/04470 and DEC-2015/18/E/HS3/00178 awarded to J. Wilczyński).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2025.105320>.

Data availability

Data will be made available on request.

References

- Behrensmeyer, A.K., 1978. Taphonomic and ecologic information from bone weathering. *Paleobiol.* 4 (2), 150–162.
- Binford, L.R., 1981. Bones: Ancient Men and Modern Myths. Academic Press, New York.
- Bocherens, H., Drucker, D.G., Germonpré, M., Lázničkova-Galetová, M., Naito, Y.I., Wissig, C., Brůžek, J., Oliva, M., 2015. Reconstruction of the Gravettian food-web at Predmostí I using multi-isotopic tracking (13C, 15N, 34S) of bone collagen. *Quat. Int.* 359–360, 211–228.

- Bosch, M.D., 2012. Human-mammoth dynamics in the mid-Upper Palaeolithic of the middle Danube region. *Quat. Int.* 276–77, 170–182. <https://doi.org/10.1016/j.quaint.2012.05.024>.
- Boudadi-Maligne, M., Mallye, J.-B., Castel, J.-C., Ferrie, J.-G., Crepin, L., Kuntz, D., Vercoutere, C., Soulier, M.-C., Costamagno, S., 2018. Loups, chiens et sociétés du Paléolithique supérieur. In: Costamagno, S., Gourichon, L., Dupont, C., Dutour, O., Vialou, D. (Eds.), *Animal symbolisé, animal exploité: du Paléolithique à la Protohistoire*. Paris, Édition électronique du CTHS (Actes des 141e congrès national des sociétés historiques et scientifiques, à Rouen, 2016), pp. 198–213.
- Brugère, A., Fontana, L., 2009. Origin and exploitation patterns of mammoth at Milovice (area G excepted). In: Oliva, M. (Ed.), *Milovice: site of the mammoth people below the Pavlov Hills: the question of mammoth bone structures*. Anthropos: Studies in Anthropology, Palaeoethnology, Palaeontology and Quaternary Geology vol. 27 (N. S. 19). Moravské Zemské Muzeum, Brno, pp. 51–105.
- Buikstra, J.E., Swegle, M., 1989. Bone modification due to burning: experimental evidence. In: Bonnichsen, R., Sorg, M.H. (Eds.), *Bone Modification*. University of Maine Center for the Study of the First Americans, Orono, pp. 247–258.
- Burke, C.C., 2013a. A Study of Carnivore Modification in North American Archaeology: Perspectives on Neotaphonomy, Carnivore Use of Carrion, and Great Plains Bison Bonebeds. Unpublished Ph.D. dissertation in anthropology, University of Nevada, Reno.
- Burke, C.C., 2013b. Neotaphonomic analysis of the feeding behaviors and modification marks produced by north American carnivores. *J. Taphono.* 11 (1), 1–20.
- Conybeare, D., Haynes, G., 1984. Observations on elephant mortality and bones in water holes. *Quat. Res.* 22, 189–200.
- Corfield, T.F., 1973. Elephant mortality in Tsavo National Park, Kenya. *East African Wildlife J.* 11, 339–368.
- Döppes, D., 2005. *Gulo gulo* (Mustelidae, Mammalia) im Ober-Pleistozän Deutschlands. Neues Jahrbuch Für Geologie Und Paläontologie Abh. 235 (3), 411–444. <https://doi.org/10.1127/njpa/235/2005/411>.
- Dominguez-Rodrigo, M., de Juana, S., Galán, A.B., Rodríguez, M., 2009. A new protocol to differentiate trampling marks from butchery cut marks. *J. Archaeol. Sci.* 36 (12), 2643–2654.
- Fiorillo, R.A., 1989. An experimental study of trampling: implications for the fossil record. In: Bonnichsen, R., Sorg, M.H. (Eds.), *Bone Modification*. Center for the Study of the First Americans, University of Maine, Orono, pp. 61–72.
- Garrett, W.E., 1964. Das Mammut *Mammuthus primigenius* (Blumenbach). Stuttgart, Frank'sche Verlagsbuchhandlung Stuttgart, Kosmos-Verlag.
- Germonpré, M., 2003. Mammoth taphonomy of two fluvial sites from the Flemish Valley, Belgium. In: Reumer, J.W.F., De Vos, J., Mol, D. (Eds.), *Advances in Mammoth Research (Proceedings of the Second International Mammoth Conference, Rotterdam, May 16–20, 1999)*. Deinsea 9, pp. 171–183.
- Gürbüz, R.B., Lycett, S.J., 2021. Did the use of bone flakes precede the use of knapped stone flakes in hominin meat processing and could this be detectable archaeologically? *J. Anthropol. Archaeol.* 62, 101305.
- Halámková, L., 2009. Osteometric analysis and mammoth hunting strategies. In: Oliva, M. (Ed.), *Milovice: Site of the Mammoth People Below the Pavlov Hills*. Anthropos: Studies in Anthropology, Palaeoethnology, Palaeontology and Quaternary Geology vol. 27 (N.S. 19). Moravské Zemské Muzeum, Brno, pp. 108–117.
- Hanks, J., 1979. *The Struggle for Survival: The Elephant Problem*. Mayflower Books.
- Haynes, G., 1980. Prey bones and predators: potential ecologic information from analysis of bone sites. *OSSA* 7, 75–97.
- Haynes, G., 1981. Bone Modifications and Skeletal Disturbances by Natural Agencies: Studies in North America. Unpublished Ph.D. dissertation in Anthropology, Catholic University of America.
- Haynes, G., 1982. Utilization and skeletal disturbances of north American prey carcasses. *Arctic* 35 (2), 266–281.
- Haynes, G., 1983. A guide for differentiating mammalian carnivore taxa responsible for gnaw damage to herbivore limb bones. *Paleobiol.* 9 (2), 164–172.
- Haynes, G., 1987. Proboscidean die-offs and die-outs: Age profiles in fossil collections. *J. Archaeol. Sci.* 14, 659–668.
- Haynes, G., 1988a. Longitudinal studies of african elephant death and bone deposits. *J. Archaeol. Sci.* 15, 131–157.
- Haynes, G., 1988b. Mass deaths and serial predation: Comparative taphonomic studies of modern large mammal death sites. *J. Archaeol. Sci.* 15, 219–235.
- Haynes, G., 1991. Mastodons, Mastodonts, and Elephants: Biology, Behavior, and the Fossil Record. Cambridge University Press, Cambridge.
- Haynes, G., Hutson, J., 2020. African elephant bones modified by carnivores: Implications for interpreting fossil proboscidean assemblages. *J. Archaeol. Sci. Rep.* 34, 102596.
- Haynes, G., Klimowicz, J., 2015. The meaning of the mammoth age profile from Kraków Spadzista B+B1. In: Wojtal, P., Wilczyński, J., Haynes, G. (Eds.), *A Gravettian Site in Southern Poland: Kraków Spadzista*. Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, Kraków, pp. 159–187.
- Haynes, G., Klimowicz, J., Wojtal, P., 2018. A comparative study of woolly mammoths from the Gravettian site Kraków Spadzista (Poland), based on estimated shoulder heights, demography, and life conditions. *Quat. Res.* 90 (3), 483–502.
- Haynes, G., Krasinski, K., 2021. Butchering marks on bones of *Loxodonta africana* (african savanna elephant): Implications for interpreting marks on fossil proboscidean bones. *J. Archaeol. Sci. Rep.* 37, 102957.
- Haynes, G., Krasinski, K., Wojtal, P., 2020. Elephant bone breakage and surface marks made by trampling elephants: Implications for interpretations of marked and broken *Mammuthus* spp. bones. *J. Archaeol. Sci. Rep.* 33 102491.
- Haynes, G., Krasinski, K., In Prep. A review of recent experimental fracturing and knapping of proboscidean long bones: Descriptions, shortcomings, results, and recommendations for further research.
- Haynes, G., Wojtal, P., 2023. Weathering stages of proboscidean bones: Relevance for zooarchaeological analysis. *J. Archaeol. Method Theory* 30, 495–535.
- Hudson, J., 1993. The impacts of dogs on bone in forager camps. In: Hudson, J. (Ed.), *From Bones to Behavior: Ethnoarchaeological and Experimental Contributions to the Interpretation of Faunal Remains*. Center for Archaeological Investigations, Carbondale, Illinois.
- Jachmann, H., 1988. Estimating age in african elephants: a revision of Laws' molar evaluation technique. *Afr. J. Ecol.* 26, 51–56.
- Kalicki, T., Kozłowski, J.K., Krzemieńska, A., Sobczyk, K., Wojtal, P., 2007. The formation of mammoth bone accumulation at the Gravettian site Kraków- Spadzista B+B1. *Folia Quat.* 77, 5–30.
- Klein, R.G., Cruz-Uribe, K., 1984. *The Analysis of Animal Bones from Archeological Sites*. University of Chicago Press, Chicago.
- Kowalik, N., Anczkiewicz, R., Müller, W., Spötl, C., Bondioli, L., Nava, A., Wojtal, P., Wilczyński, J., Koziarska, M., Matyszczak, M., 2023. Revealing seasonal woolly mammoth migration with spatially-resolved trace element, Sr and O isotopic records of molar enamel. *Quat. Sci. Rev.* 306, 108036.
- Kozłowski, J.K., Kubiak, H., Sachse-Kozłowska, E., 1972. Pierwsze górnopaleolityczne budowle mieszkane odkryte na stanowisku Kraków Spadzista (B). *Sprawozdania Archeologiczne* 23, 13–32 (In Polish).
- Kozłowski, J.K., Kubiak, H., 1972. Late Paleolithic dwellings made of mammoth bones in south Poland. *Nature* 237, 463–464.
- Kozłowski, J.K., Sobczyk, K., 1987. The upper Paleolithic site Kraków – Spadzista street C2. *Excavations 1980. Praece Archeolog.* 42, 7–68.
- Kozłowski, J.K., Van Vliet, B., Kramarz, K., Drobniiewicz, B., Sachse-Kozłowska, E., Kubiak, H., 1975. Górnopaleolityczne stanowisko Kraków, ul. Spadzista C (badania w latach 1970–1973). *Folia Quat.* 45, 43–71 (In Polish).
- Kozłowski, J.K., van Vliet, B., Sachse-Kozłowska, E., Kubiak, H., Zakrzewska, G., 1974. Upper Paleolithic site with dwellings of mammoth bones – Cracow Spadzista Street B. *Folia Quat.* 44, 1–110.
- Laws, R.M., 1966. Age criteria for the African elephant, *Loxodonta a. africana*. *East African Wildlife J.* 4, 1–37.
- Laws, R.M., Parker, I.S.C., Johnstone, R.C.B., 1970. Elephants and habitats in North Bunyoro, Uganda. *East African Wildlife J.* 8, 163–180.
- Ley Lara, V.M., 2018. Evaluación tafonómica del impacto del perro (*Canis lupus familiaris*) en colecciones arqueofaunísticas de las tierras bajas del Norte. Unpublished thesis in Archeology, Universidad Autónoma de Yucatan.
- Lengyel, G., Wilczyński, J., 2018. The Gravettian and the Epigravettian chronology in eastern central Europe. A comment on Bösken et al. *Palaeogeogr., Palaeoclim., Palaeoecol.* 506, 265–269.
- Ley-Lara, V.M., Götz, C.M., 2016. Dejando huella (Parte II): Implicaciones zoóarqueológicas de la relación entre el perro y e ser humano en el norte del área maya. *AMMVEPE* 27 (4), 93–101.
- Ley-Lara, V.M., Vela-Padilla, D.I., Götz, C.M., 2015. Dejando huella (Parte I): Implicaciones tafonómicas y etnográficas sobre la relación entre el perro y ser humano en el norte del área maya. *AMMVEPE* 26 (6), 157–167.
- Lindsay, K., 2011. Habitat use, diet choice and nutritional status in female and male Amboseli elephants. In: Moss, C.J., Croze, H., Lee, P.C. (Eds.), *The Amboseli Elephants: A Long-Term Perspective on a Long-Lived Animal*. Chicago, University of, pp. 51–73.
- Lister, A.M., Stuart, A.J., 2010. The West Runton mammoth (*Mammuthus trogontherii*) and its evolutionary significance. *Quat. Int.* 228 (1–2), 180–209.
- Lyman, R.L., 1994. *Vertebrate Taphonomy*. Cambridge University Press, Cambridge.
- Magoun, A.J., 1985. Population Characteristics, Ecology and Management of Wolverines in Northwestern Alaska. University of Alaska, Fairbanks. Unpublished Ph.D. thesis.
- Magoun, A.J., 1987. Summer and winter diets of wolverines, *Gulo gulo*, in arctic Alaska. *Can. Field-Nat.* 101 (3), 392–397.
- Magoun, A.J., Valkenburg, P., 2001. Caribou remains at kill sites and the role of scavengers in producing patterned distributions in bone assemblages. In: Gerlach, S. C., Murray, M.S. (Eds.), *People and Wildlife in Northern North America*. BAR International Series 944, pp. 269–299.
- Marciszak, A., Lipecki, G., Gornig, W., Wilczyński, J., 2017. Carnivores from the Borsuka Cave (southern Poland) as an example of changes in carnivore assemblages during MIS 2 and MIS 1. *Acta Zool. Cracov.* 60 (2), 105–146.
- Mech, L.D., 1999. Alpha status, dominance, and division of labor in wolf packs. *Can. J. Zool.* 77, 1196–1203.
- Nikolskiy, P., Pitulko, V., 2013. Evidence from the Yana Paleolithic site, Arctic Siberia, yields clues to the riddle of mammoth hunting. *J. Archaeol. Sci.* 40 (12), 4189–4197.
- Nývítová Fišáková, M., 2013. Seasonality of Gravettian sites in the Middle Danube Region and adjoining areas of Central Europe. *Quat. Int.* 294, 120–134.
- Oliva, M. (Ed.), 2009. Milovice: site of the mammoth people below the Pavlov Hills. Anthropos: Studies in Anthropology, Palaeoethnology, Palaeontology and Quaternary Geology vol. 27 (N.S. 19). Moravské Zemské Muzeum, Brno.
- Olsen, S.L., Shipman, P., 1988. Surface modification on bone: trampling versus butchery. *J. Archaeol. Sci.* 15 (1988), 535–553.
- Perri, A.R., Smith, G.M., Bosch, M.D., 2015. Comment on “how do you kill 86 mammoths? Taphonomic investigations of mammoth megasites” by Pat Shipman. *Quat. Int.* 368 (11), 112–115.
- Pitulko, V.V., Pavlova, E.Y., Basilyan, A.E., 2016. Mass accumulations of mammoth (mammoth ‘graveyards’) with indications of past human activity in the northern Yana-Indighirka lowland, Arctic Siberia. *Quat. Int.* 406 (B), 202–217.
- Poole, J.H., 1992. *Proboscideans Past and Present (review of *Mammoths, Mastodons and Elephants* by G. Haynes*, Cambridge University Press). Trends Ecol. Evol.
- Trends Ecol. Evol.

- Pryor, A.J.E., Pospila, S., Nesnídalová, T., Kowalik, N., Wojtal, P., Wilczyński, J., 2020. Mobility and season of death of the Arctic foxes killed by Gravettian hunters at Kraków Spadzista Poland. *J. Archaeol. Sci.: Reports* 33, 102520.
- Religa-Sobczyk, J., Wertz, K., Lögus, L., Wojenka, M., Lemanik, A., Wojtal, P., 2023. Zooarchaeological evidence from medieval Ojców Castle Lesser Poland. *Heritage* 6 (1), 258–283.
- Roth, V.L., Shoshani, H., 1988. Dental identification and age determination in *Elephas maximus*. *J. Zool.* 214, 567–588.
- Salcher-Jedrasia, T.A., 2012. Mammut, Mensch und große Karnivoren – Die Mensch-Tier-Beziehung im Jungpalolithikum Niederösterreichs. Ph.D. dissertation. Universität Wien, Paläobiologie.
- Shahack-Gross, R., Bar-Yosef, O., Weiner, S., 1997. Blackcoloured bones in Hayonim Cave, Israel: differentiating between burning and oxide staining. *J. Archaeol. Sci.* 24, 439–446.
- Shannon, G., Page, B.R., Duffy, K.J., Slotow, R., 2010. The ranging behavior of a large sexually dimorphic herbivore in response to seasonal and annual environmental variation. *Australian Ecol.* 35, 731–742.
- Shannon, G., Mackey, R.L., Slotow, R., 2013. Diet selection and seasonal dietary switch of a large sexually dimorphic herbivore. *Acta Oecol.* 46, 48–55.
- Shipman, P., 2015. How do you kill 86 mammoths? Taphonomic investigations of mammoth megasites. *Quat. Int.* 359–360, 38–46.
- Sikes, S.K., 1966. The african elephant, *Loxodonta africana*: a field method for the estimation of age. *J. Zool. London* 150, 279–295.
- Sikes, S.K., 1968. The african elephant, *Loxodonta africana*: a field method for estimating age. *J. Zool. London* 154, 235–248.
- Sinitsyn, A.A., Stepanova, K.N., Petrova, E.A., 2019. New direct evidence of mammoth hunting from Kostenki. *Prehistoric. Archaeol. J. Interdiscipl. Stud.* 1, 149–158.
- Sobczyk, K., 1996. Kraków-Spadzista unit D: excavations 1986–1988. *Folia Quarter.* 67, 75–127.
- Speth, J.D., Newlander, K., White, A.A., Lemke, A.K., Anderson, L.E., 2013. Early Paleoindian big-game hunting in North America: provisioning or politics? *Quat. Int.* 285, 111–139.
- Stansfield, F.J., 2015. A novel objective method of estimating the age of mandibles from African elephants (*Loxodonta africana africana*). *PLoS One* 10 (5), e0124980. <https://doi.org/10.1371/journal.pone.0124980>.
- Sinner, M.C., Kuhn, S.L., Weiner, S., Bar-Yosef, O., 1995. Differential burning, recrystallization, and fragmentation of archaeological bone. *J. Archaeol. Sci.* 22, 223–237.
- Stuart, A.J., Lister, A., 2014. New radiocarbon evidence on the extirpation of the Spotted hyaena (*Crocuta crocuta* (Erxld.)) in northern Eurasia. *Quat. Sci. Rev.* 96, 108–116.
- Sutcliffe, A.J., 1970. Spotted hyaena: crusher, gnawer, digester and collector of bones. *Nature* 227, 1110–1113.
- Sutcliffe, A.J., Lord, T.C., Harmon, R.S., Ivanovich, M., Rae, A., Hess, J.W., 1985. Wolverine in northern England at about 83,000 yr B.P.: Faunal evidence for climatic change during Isotope Stage 5. *Quater. Res.* 24, 73–86.
- Svoboda, J., Péan, S., Wojtal, P., 2005. Mammoth bone deposits and subsistence practices during Mid-Upper Palaeolithic in Central Europe: Three cases from Moravia and Poland. *Quat. Int.* 126–128, 209–221.
- Théry-Parisot, I., 2002. Fuel Management (Bone and Wood) during the lower Aurignacian in the Pataud Rock Shelter (lower Palaeolithic, Les Eyzies de Tayac, Dordogne, France). Contribution of Experimentation. *J. Archaeol. Sci.* 29, 1415–1421.
- van Dijk, J., Gustavsen, L., Mysterud, A., May, R., Flagstad, Ø., Brøseth, H., Andersen, R., Andersen, R., Steen, H., Landa, A., 2008. Diet shift of a facultative scavenger, the wolverine, following recolonization of wolves. *J. Anim. Ecol.* 77 (6), 1183–1190.
- van Vliet, B., 1974. Stratigraphic and paleopedologic study. In: Kozłowski, J.K., van Vliet, B., Sachse-Kozłowska, E., Kubiać, H., Zakrzewska, G. (Eds.), *Upper Palaeolithic site with dwellings of mammoth bones – Cracow, Spadzista street B. Folia Quat.*, vol. 44, pp. 17–23.
- Villa, P., Bon, F., Castel, J.C., 2002. Fuel, fire and fireplaces in the Palaeolithic of Western Europe. *Rev. Archaeol.* 23, 33–42.
- Voorhies, M., 1969. Taphonomy and population dynamics of an early Pliocene vertebrate fauna, Knox County, Nebraska. 69 pp. *Contrib. Geol., Spec. Pap.* No. 1. Univ. Wyo. Press; Laramie, Wyoming.
- Wertz, K., Wilczyński, J., Tomek, T., Roblickova, M., Oliva, M., 2016. Bird remains from Dolni Vestonice I and Predmostí I (Pavlovian, the Czech Republic). *Quat. Int.* 421, 190–200.
- White, P.A., Diedrich, C.G., 2012. Taphonomy story of a modern african elephant *Loxodonta africana* carcass on a lakeshore in Zambia (Africa). *Quat. Int.* 276–277, 287–296.
- Wilczyński, J., Goslar, T., Wojtal, P., Oliva, P., Gólich, U.B., Antl-Weiser, W., Ślada, P., Verpoorte, A., Lengyel, G., 2020. New radiocarbon dates for the late Gravettian in Eastern Central Europe. *Radiocarbon* 62 (1), 243–259.
- Wilczyński, J., Wojtal, P., Oliva, M., Sobczyk, K., Haynes, G., Klimowicz, J., Lengyel, G., 2019. Mammoth hunting strategies during the Late Gravettian in Central Europe as determined from case studies of Milovice I (Czech Republic) and Kraków Spadzista (Poland). *Quat. Sci. Rev.* 223, 105919.
- Wilczyński, J., Wojtal, P., Roblickova, M., Oliva, M., 2015a. Mammoth hunter settlement of Dolni Vestonice I. *Quat. Int.* 379, 58–70.
- Wilczyński, J., Wojtal, P., Sobczyk, K., 2012. Spatial organization of the Gravettian mammoth hunters site - Kraków Spadzista (southern Poland). *J. Archaeol. Sci.* 39, 3627–3642.
- Wilczyński, J., Wojtal, P., Sobieraj, D., Sobczyk, K., 2015b. Kraków Spadzista trench C2 - new research and interpretations of Gravettian settlement. *Quat. Int.* 359–360, 96–113.
- Wojtal, P., Haynes, G., Klimowicz, J., Sobczyk, K., Tarasiuk, J., Wroński, S., Wilczyński, J., 2019. The earliest direct evidence of mammoth hunting in Central Europe – the Kraków Spadzista site (Poland). *Quat. Sci. Rev.* 213, 162–166.
- Wojtal, P., Makowiecki, D., Wertz, K., Wilczyński, J., Mieśkina, B., Zabilska, M., 2010. Wstępne wyniki badań zooarcheologicznych szczątków kostnych z wykopalisk prowadzonych na Rynku krakowskim w latach 2007–2011. *Krzesztofory. Zeszyty Naukowe Muzeum Historycznego Miasta Krakowa* 28 (2), 137–151 (In Polish).
- Wojtal, P., Sobczyk, K., 2005. Man and woolly mammoth at the Kraków Spadzista street (B) – taphonomy of the site. *J. Archaeol. Sci.* 32, 193–206.
- Wojtal, P., Wilczyński, J., Bochenek, Z.M., Svoboda, J.A., 2012. The scene of spectacular feasts: Animal remains from Pavlov I south-east, the Czech Republic. *Quat. Int.* 252, 122–141.
- Wojtal, P., Wilczyński, J., 2015a. Zooarchaeological studies of large mammal remains from Kraków Spadzista site-trench C2 and trench E1 (2011–2012 excavations). In: Piotr Wojtal, Jarosław Wilczyński, Gary Haynes (Eds.), *A Gravettian Site in Southern Poland: Kraków Spadzista*. Kraków, pp. 159–187.
- Wojtal, P., Wilczyński, J., 2015b. Hunters of the giants: woolly mammoth hunting during the Gravettian in Central Europe. *Quat. Int.* 379, 71–81.
- Wojtal, P., Sobczyk, K., Wilczyński, J., 2015. A new look at an old site: Studies of the Kraków Spadzista site 1968–2013. In: Sázelová, S., Novák, M., Mizerová, A. (Eds.), *Forgotten times and Spaces: New Perspectives in Paleoanthropological, Paleoethnological and Archeological Studies*. Institute of Archeology of the Czech Academy of Sciences, and Masaryk University, Brno.
- Zenin, V.N., Leshchinskij, S.V., Zolotarev, K.V., Grootes, P.M., Nadeau, M.-J., 2006. Lugovskoe: geoaarchaeology and culture of a Paleolithic site. *Archaeol. Ethnol. Anthropol. Eurasia* 25, 41–53.