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TAPHONOMY OF PLEISTOCENE LARGE MAMMAL REMAINS IN THE DEPOSITS OF RIVER RABA, SOUTHERN POLAND

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Abstract: An assemblage of 120 mammal remains of Pleistocene age has been collected from the fluvial deposits of river Raba at a gravel pit in the village of Targowisko, 30 km east of Kraków, southern Poland. Nearly 100 remains represent woolly mammoth *Mammuthus primigenius*. Other remains belong to four or five such mammal species as horse *Equus ferus*, woolly rhinoceros *Coelodonta antiquitatis,* red deer *Cervus elaphus* and steppe bison *Bison priscus* or aurochs *Bos primigenius*. Pleistocene coarse-grained deposits containing isolated bones, teeth and tusks occur in the lowermost part of the fluvial succession in the open pit, presently inundated by groundwater. The surfaces of the majority of bones and teeth show abrasion damages by fluvial transport, including their rounding and smoothing as well as scratches and grooves. Traces of carnivore activity are visible on mammoth and horse bones. The location, dimension and shape of these marks suggest wolf or cave hyena gnawing.

Key words: Abrasion, bones, *Coelodonta antiquitatis*, fluvial fan, *Mammuthus primigenius*.

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INTRODUCTION

Pleistocene fauna remains found in fluvial sediments in Poland are numerous, but isolated and often with only a single find at a particular site. Most of the finds are from gravel pits, recovered during the excavation process or collected by local residents, and hence are poorly documented and their sedimentological context is usually unclear (Pawłowska, 2015). The site reported on herein abounds in mammoth remains. The latest list of localities with mammoth findings in Poland is given by Pawłowska (2015). The finds of such remains are particularly numerous in the Carpathian and Subcarpathian region, especially in the fluvial deposits of such rivers as Wisła (Vistula), Dunajec, Wisłok and San (Fig. 1A). However, no such finds have previously been reported from the deposits of river Raba, a southern tributary of the Vistula.

The present paper gives a detailed description of the newly found Late Pleistocene bones, tusks and teeth from the fluvial sediments of river Raba. The palaeogeographic and lithostratigraphic context of the osteological material is outlined, whereas a taphonomic analysis of the mammal remains sheds light on the amount of their post-mortem modification by carnivores gnawing and fluvial transport abrasion.

REGIONAL SETTING AND SITE DESCRIPTION

The studied locality is situated in the Subcarpathian region, which encompasses the area of the Carpathian Foredeep (Fig. 1A). The bones were found in coarse-grained clastic deposits of the river Raba, which is a right-side (southern) tributary of the Vistula and drains the Outer Carpathians and a large part of the Carpathian Foredeep. The former region is an orogenic thrust-wedge (*sensu* DeCelles and Giles, 1996), with nappes made predominantly of flysch-type rocks, whereas the latter region consists of Miocene foredeep deposits. The narrow structural Zgłobice Unit of strong deformation (Fig. 1B) is the frontal triangle zone of the orogen thrust-wedge (*sensu* DeCelles and Giles, 1996; see Krzywiec *et al*., 2012). It shows gentle deformation in front of the Gdów Embayment (Fig. 1B) – a tectonic structural re-entrant of the Carpathian front (Krzywiec *et al*., 2012). The tectonic morphology of the Gdów Embayment resulted in a tributive fluvial drainage and forced the river Raba to run along the front of the Carpathians (Fig. 2A). The river transected the least deformed segment of the Zgłobice Unit and, by a lateral shifting, formed a broad distributive fluvial fan (Fig. 2A), or lowlands alluvial fan, at its outlet to the Vistula alluvial plain (Gębica, 1995). The present study

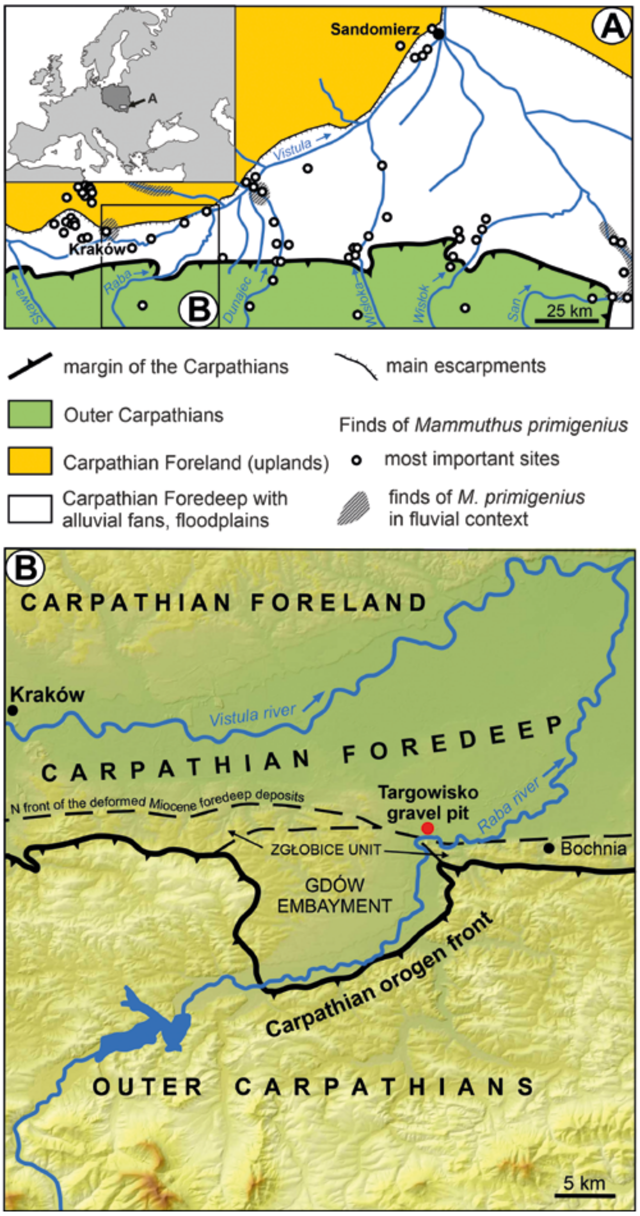

Fig. 1. Location of the Targowisko gravel pit. **A**. Geomorphic map of the Subcarpathian region (after Gębica *et al*., 2015; slightly modified) with the location of the main finds of Pleistocene *Mammuthus primigenius* (after Pawłowska, 2015). **B**. Close-up map of the surroundings of the Targowisko gravel pit.

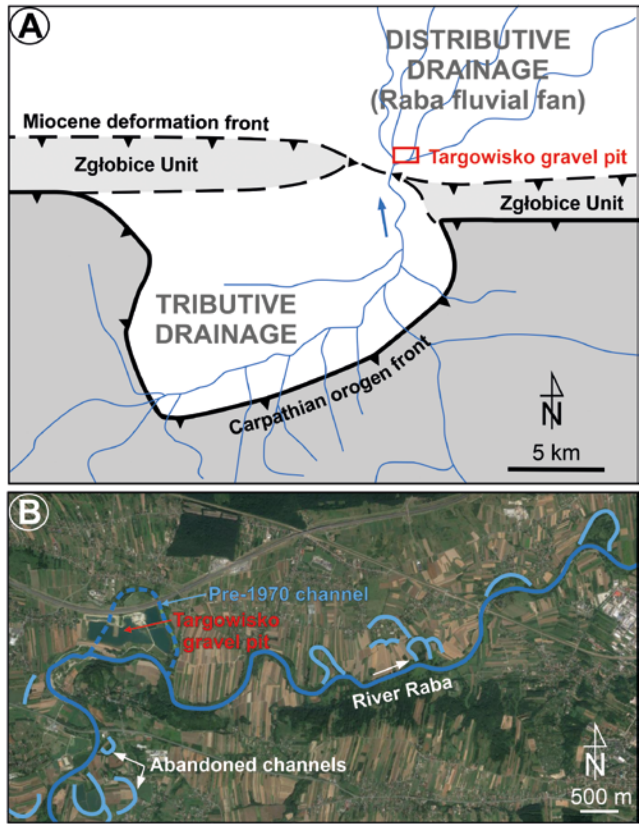

Fig. 2. The Targowisko gravel pit location in the regional context of the Raba river drainage system. **A**. Schematic interpretation of the Quaternary drainage system of river Raba, with a tributive fluvial drainage of the Gdów Embayment breaching the structural barrier of Zgłobice Unit and turning into a distributive drainage of the Raba fluvial fan (lowlands alluvial fan). Note the location of the Targowisko gravel pit in the head zone of the fan. **B**. The present-day course of river Raba in relation to the Targowisko gravel pit, with the river bend post-1970 cut-off by human activity and some of the earlier abandoned Holocene meanders.

site in Targowisko gravel pit is in the head part of this fan (Fig. 2A). It was one of several such fluvial fans formed by rivers draining northwards the Outer Carpathians (Fig. 1A; Gębica *et al*., 2015).

Regional studies of the Quaternary fluvial drainage in the Subcarpathian region (Alexandrowicz and Wyżga, 1992; Gębica, 1995; Gębica *et al*., 2015; Starkel *et al*., 2015) indicate that the Late Glacial drainage in the present study area had changed in the Late Vistulian (Weichselian), around 15–13 ka BP (18.2–15.6 ka cal BP), from a bedload braided pattern into a mixed-load meandering pattern. According to the above-cited authors, the change was accompanied by an increased rate of both lateral channel shifting and depositional aggradation.

Notably, the Raba fluvial fan is located within the range of the maximal advance of the Scandinavian Ice Sheet, which reached the Outer Carpathians and entered some of the Carpathian valleys. The formation of this fan thus clearly postdates the ice-sheet advance, attributed to one of the glaciations of the South Polish Glacial Complex (Wójcik *et al*., 2004; Marks, 2011; Stworzewicz *et al*., 2012). The fan growth marked phases of an intense degradation of the Carpathian mountain slopes, involving solifluction or permafrost creep processes, with the accumulation of fluvial deposits interrupted by incision phases during the Pleistocene (Gębica *et al*., 2015; Starkel *et al*., 2015).

The present study site is about 2 km north of the tectonic edge of the Carpathians and less than 0.5 km from the northern escarpment of the Miocene deformation zone of the Zgłobice Unit. The Pleistocene fauna remains found in the Targowisko gravel pit (Fig. 1B; GPS coordinates 49º58′7.24″N, 20º19′6.84″E) are from a gravelly alluvium underlying the abandoned meander bends of the river Raba (Fig. 3). The osteological material was recovered in the course of gravel mining between 2010 and 2014, when the pit already became inundated by the groundwater (Fig. 3). The fluvial deposits in the pit are 7–9 m thick and show a general fining-upward trend (Fig. 3), with the cross-bedded bar units indicating vertically stacked palaeochannels 1–2 m deep. The bones were found at the base of the lowermost palaeochannels, within coarse gravel pockets probably representing the scour pools of braided river thalweg (cf. Bridge, 2009). The alluvium overlies erosionally the Serravallian (upper Badenian) Grabowiec Beds, a marine post-evaporitic siliciclastic foredeep succession of grey mudstones intercalated with thin sheets of fine-grained sandstones (Alexandrowicz, 1961). The bedrock erosional surface is strewn with erratic cobbles and boulders, up to 150 cm in size, and is locally covered with downstream-elongate patches of muddy matrix-supported gravel containing flysch cobbles and subordinate erratic clasts.

The bone-bearing gravelly deposits are overlain by sandy gravel and sand that contain two distinctive levels with oak tree trunks (Fig. 3). The trunks and hosted subfossil insects *Cerambyx cerdo* were dated to 799–700 BC and 45 BC–AD 554 (Jach *et al*., 2018).

MATERIAL AND METHODS

The mammalian osteological collection from Targowisko gravel pit is presently stored at the Geological Division of the Natural Sciences Education Centre of the Jagiellonian University (institutional code INGUJ257P). The specimen collection was preliminarily catalogued by Drewnicka (2019), with the subsequent identification of bone elements and their assignment to species on the basis of a comparative material of the Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, bone atlases (e.g., Gromova, 1950; Pales and Garcia, 1981a, b) and online digital collections. All bones were carefully examined to recognize their possible post-mortem modification, such as large carnivore gnawing marks and abrasion due to fluvial transport. The bones of woolly mammoth were measured with a measuring tape and slide calliper to the nearest 0.1 mm, following the technique of von den Driesch (1976) and Maschenko (2002). Bones of other mammals were similarly measured with a slide calliper to the closest 0.1 mm, following von den Driesch (1976).

The frequency of skeletal elements and animal individuals in the Targowisko collection was measured in terms of the Number of Identified Specimens (NISP) and Minimum Number of Elements (MNE). NISP is the number of identified specimens in a collection, where identified means ascribed to a taxon. MNE is an estimation of the number of skeletal elements represented by specimens in the assemblage, based on the most common portion of the element considered (Klein and Cruz-Uribe, 1984; Lyman, 1994).

RESULTS

Bone-bearing deposits

The top surface of the substrate marine Grabowiec Beds is sharp and slightly undulating, incised by gravel-filled channels up to 1–1.5 m deep and trending SW–NE. The mammal bones, relatively sparse and isolated, were found only within these palaeochannels (E. Jędrzejek, pers. comm., 2020). The bone-bearing sediment is a coarse gravel composed of the subrounded to well-rounded clasts of Carpathian flysch sandstones, such as quartz arenites, glauconitic quartz arenites, sublithic arenites and greywackes. The gravel contains also rare pebbles of limestones, ca 1 cm across, and locally

Fig. 3. Present-day outcrop of Quaternary fluvial deposits in the Targowisko gravel pit, inundated by a groundwater lake, with a simplified lithological log of the fluvial succession.

subordinate erratic cobbles and boulders. The bone-hosting sediment is preserved within cracks, fractures and hollow spaces in some of the bone specimens.

Skeletal remains

In total, the Targowisko osteological collection comprises 120 specimens of five taxons of large herbivores (Tables 1, 2; Figs 4–12). The measurements of specimens are given in Table 3. The specimens are remains of woolly mammoth (*Mammuthus primigenius* Blumenbach), woolly rhinoceros (*Coelodonta antiquitatis* Blumenbach), horse *(Equus ferus* Boddaert), red deer (*Cervus elaphus* Linnaeus) and steppe bison (*Bison priscus* Bojanus). The lack of diagnostic landmark features in other bovide bones (Table 3; Fig 11) does not allow a precise identification if they belong to aurochs or steppe bison. It cannot be precluded that the overrepresentation of large mammal skeleton fragments is apparent, resulting from a selective collecting of bones during mining.

Woolly mammoth remains are the most numerous, with 99 bones and teeth of this animal. There are cranial bone fragments, including skull, mandible, tusk fragments, complete molars and their fragments. There are also flat bones (scapula and innominate), long limb bones and ribs. Notably, no vertebra and foot bones were found. The collected tusk fragments vary in length from about 10 cm to 130 cm and represent tusk middle parts. Their circumferences suggest adult animals, although their poor preservation does not allow precise measurements and animal age determination. It cannot be precluded that some of the tusk fragments come from the same individual. Much better preserved are teeth, including complete three lower and four upper ones (Fig. 6). Long limb bones indicate adult individuals, on the account on their dimensions and presence of fused epiphyses. Other bone remains are poorly preserved, including long limb bones and their fragments, such as bone shafts and epiphyses (Tables 1, 2; Figs 7, 9, 10).

The flat bones of woolly mammoth are well represented in the osteological collection. There are four scapula fragments (NISP = 4, MNE = 1) and eight innominate fragments (NISP = 8, MNE = 5), as well as eight rib fragments (NISP = 6, MNE = 6), including two identified first ribs (Fig. 10; Tables 1, 2).

Other mammal species are represented by a much smaller number of remains, representing horse (NISP = 8), woolly rhinoceros (NISP = 4), steppe bison (NISP = 1), aurochs/steppe bison (NISP = 4) and red deer (NISP = 1) (see Tables 1, 2; Fig. 11). Their skeletal representation is similar to that of the mammoth bones, with mostly long limb bones (humerus, radius, ulna, femur, tibia, metapodials; MNE = 13) and only one flat bone – a horse innominate (Tables 1, 2; Fig. 11). Among the identified woolly rhinoceros remains was one fragment of lumbar vertebra, one skull fragment with two premolars and one isolated upper premolar.

Post-mortem modification of bones

The preservation degree of mammoth remains is not good. The best preserved are teeth, among them seven are more or less complete and only lightly damaged (Fig. 6B,

Table 1

Summary of the number of identified specimens (NISP) of mammal remains found at the Targowisko gravel pit.

Species and skeletal parts	NISP
***Coelodonta antiquitatis* (woolly rhinoceros)**	4
maxilla fragment with premolars	1
upper molar	1
thoracic vertebra (*vertebrae thoracicae*)	1
femur (*femur*)	1
***Equus ferus* (horse)**	8
humerus (*humerus*)	1
radius (*radius*)	1
ulna (*ulna*)	1
metacarpal (*metacarpus*)	2
innominate (*os coxae*)	1
femur (*femur*)	1
tibia (*tibia*)	1
***Mammuthus primigenius* (woolly mammoth)**	99
cranial bone	1
mandibular bone (*mandibula*)	3
tusk fragments	20
total teeth and teeth fragments	26
ribs	6
scapula (*scapula*)	4
humerus (*humerus*)	2
ulna (*ulna*)	1
innominate (*os coxae*)	9
femur (*femur*)	6
tibia (*tibia*)	3
fibula (*fibula*)	1
flat bones fragments (scapula, innominate)	4
long limb bones fragments (humerus, ulna, radius, femur, tibia, fibula)	12
unidentifiable bone fragments	1
***Bison priscus* (steppe bison)**	1
metacarpal (*metacarpus*)	1
***Bos primigenius/Bos priscus* (aurochs/steppe bison)**	4
humerus (*humerus*)	1
radius (*radius*)	1
ulna (*ulna*)	1
tibia (*tibia*)	1
***Cervus elaphus* (red deer)**	1
antler fragment	1
Unidentified large mammal bone	3
humerus (*humerus*)	1
unidentifiable bone fragment	2

D, E, P–T). Mammoth long limb bones are damaged and only two of them (ulna and tibia; Figs 7K, 9G, H) are preserved almost complete. Other long limb bones of this taxon are preserved only as diaphysis (Figs 8, 9). The innominate specimen (no. INGUJ257P/T118; Fig. 8A) is the only intact flat bone. Other bones from this category, similarly to long limb bones, are more or less damaged and incomplete (Figs 7, 8). The state of preservation of the remains of other taxons is similar to that of the mammoth remains, with teeth and some of the long limb bones quite well preserved.

Notably, some bones and teeth are partly covered with coarse-grained sediment that is diagenetically attached to them (e.g., Figs 6E, 8A, 9K). Most cracks, fractures and hollow spaces within remains are filled with similar clastic sediment (Fig. 5A, F–J). Single bones and tusks show clastic material tightly wedged into the cracks, which are parallel to the bone fiber structure.

Since the osteological material was collected in fluvial deposits, it is not surprising that many bones display abrasive modification due to the transport by flowing water. Clear signs of abrasion by transport in river gravelly bedload are visible on eleven bones (Table 2; Figs 7A, D, F, I, 8D, 9A, I, M, 11F, N, O, R). Mammoth remains show the most distinctive abrasion features, including smoothing and rounding of bone edges, linear V-shaped grooves and multiple parallel or randomly oriented scratches. It is possible that the fragmenting of long-limb diaphysis (e.g., Figs 7J, 10A) and the destruction of long-limb epiphyses are due to the fluvial transportation. Some bones and tusks show cracking and longitudinal splitting resulted from the drying of waterlogged bone.

Large carnivore gnawing marks are visible on the mammal bones. These marks are noticeable mostly on woolly mammoth bones. They are visible on two pelvis fragments (*os ilium*), femur diaphysis and two femur distal epiphyses (Fig. 9C, E, F). Carnivore gnawing marks occur also on horse humerus proximal epiphysis and femur distal epiphysis (Fig. 11E, J). The character of the gnawing marks, with their shape and dimension, suggests cave hyenas or wolves. No traces of bone modification by humans, such as cut marks or percussion marks, have been identified.

DISCUSSION

Taphonomy of the fossil assemblage

Taphonomy of the studied skeletal remains indicates that they were transported and deposited as isolated bones. They become available to fluvial transport by the animal soft-tissue decomposition and skeletonization, accelerated by the action of carnivores. Clastic sediment firmly wedged in bone and tusk cracks indicates periodical wet-state swelling and drying/shrinking of skeletal remains during their fluvial transport (cf. Evans, 2010).

The majority of the osteological material shows moderate to high abrasion indicating episodic higher-flow water transport. According to Behrensmeyer (1982), bones suffer clear abrasion after 1.5 to 3 km of bedload transport, although can also be abraded in-situ by sediment movement. Abrasion of isolated skeletal remains was likely due to the river bedload movement of sand and gravel.

The transport mobility of skeletal remains, much like that of gravel clasts, depends upon their size, shape and specific density (Pante and Blumenschine, 2010). In general, the larger, thicker and heavier bone fragments are less prone to water entrainment and move slower than the smaller, thinner and lighter ones (Voorhies, 1969; Evans, 2014). The smaller bones may move kilometres in suspension with little or no sign of abrasion, while larger ones move less and slower, being prone to an in-situ abrasion.

Voorhies (1969) distinguished three groups of skeletal elements according to their susceptibility to the entrainment and movement by fluvial transport. Group I are skeletal elements readily entrained into motion (e.g., ribs, vertebra); group II are elements that are episodically entrained (e.g., humerus, femur, tibia and pelvis); and group III are bone elements, such as skull and mandible, forming a lag deposit (see also Lyman, 1994). These studies pertained to the disarticulated bones of domestic sheep and coyote, which means animal smaller than the Pleistocene mammals. However, Frison and Todd (1986) made experiments on the fluvial transport of Indian elephant skeletal elements, with the elements classified according to their fluvial transport index (FTI), which means transport mobility potential. The general

Table 2

List of mammal remains from the Targowisko pit analysed in the present study.

Figure number	Collection number	Taxon	Specimen description	Remarks
4A	INGUJ257P/T1	*Mammuthus primigenius*	Tusk, fragment	
4B	INGUJ257P/T2	*Mammuthus primigenius*	Tusk, fragment	
4C	INGUJ257P/T3	*Mammuthus primigenius*	Tusk, fragment	
4D	INGUJ257P/T4	*Mammuthus primigenius*	Tusk, fragment	
4E	INGUJ257P/T5	*Mammuthus primigenius*	Tusk, fragment	
4F	INGUJ257P/T6	*Mammuthus primigenius*	Tusk, fragment	
4G	INGUJ257P/T7	*Mammuthus primigenius*	Tusk, fragment	
4H	INGUJ257P/T8	*Mammuthus primigenius*	Tusk, fragment	

Figure number	Collection number	Taxon	Specimen description	Remarks
4I	INGUJ257P/T9	*Mammuthus primigenius*	Tusk, fragment	
4J	INGUJ257P/T10	*Mammuthus primigenius*	Tusk, fragment	
5A	INGUJ257P/T11	*Mammuthus primigenius*	Tusk, fragment	
5B	INGUJ257P/T12	*Mammuthus primigenius*	Tusk, fragment	Partly filled with sediment
5C	INGUJ257P/T70	*Mammuthus primigenius*	Tusk, fragment	
5D	INGUJ257P/T71 + T72	*Mammuthus primigenius*	Tusk, fragment	
5E	INGUJ257P/T114	*Mammuthus primigenius*	Tusk, fragment	
5F	INGUJ257P/T73	*Mammuthus primigenius*	Tusk, fragment	Partly filled with sediment
5G	INGUJ257P/T74	*Mammuthus primigenius*	Tusk, fragment	Partly filled with sediment
5H	INGUJ257P/T113	*Mammuthus primigenius*	Tusk, fragment	Partly filled with sediment
5I	INGUJ257P/T111	*Mammuthus primigenius*	Tusk, fragment	
5J	INGUJ257P/T112	*Mammuthus primigenius*	Tusk, fragment	Partly filled with sediment
6A	INGUJ257P/T45	*Mammuthus primigenius*	Lower left m6 fragment	Partly damaged; only 17 distal plates preserved
6B	INGUJ257P/T46	*Mammuthus primigenius*	Lower tooth	Heavy worn tooth (9 plates preserved)
6C	INGUJ257P/T48	*Mammuthus primigenius*	Lower right m6	Partly damaged; only 15 distal plates preserved
6D	INGUJ257P/T119	*Mammuthus primigenius*	Lower right tooth	Heavy worn (15 plates preserved)
6E	INGUJ257P/T125	*Mammuthus primigenius*	Lower left tooth	Heavy worn (12 plates); partly covered by gravel
6F	INGUJ257P/T126	*Mammuthus primigenius*	Lower tooth	Heavy worn; partly enveloped by gravel
6G	INGUJ257P/T53	*Mammuthus primigenius*	Lower tooth fragment	Unworn; tooth mesial part with 6 plates preserved
6H	INGUJ257P/T54	*Mammuthus primigenius*	Lower tooth fragment	Preserved 3 plates
6I	INGUJ257P/T56	*Mammuthus primigenius*	Lower tooth fragment	Mesial part, with 4 plates preserved
6J	INGUJ257P/T59	*Mammuthus primigenius*	Lower tooth fragment	Preserved 6 plates
6K	INGUJ257P/ T60 + T61	*Mammuthus primigenius*	Lower tooth fragment	Preserved 5 plates
6L	INGUJ257P/T66	*Mammuthus primigenius*	Lower tooth fragment	Unworn; 5 plates preserved
6N	INGUJ257P/T65	*Mammuthus primigenius*	Lower tooth fragment	Preserved 4 plates
6O	INGUJ257P/T69	*Mammuthus primigenius*	Lower tooth fragment	Mesial part with 7 plates preserved
6P	INGUJ257P/T52	*Mammuthus primigenius*	Upper left tooth	Heavy worn, with 9 plates preserved
6R	INGUJ257P/T57	*Mammuthus primigenius*	Upper left tooth	Heavy worn, with 9 plates preserved
6S	INGUJ257P/T63	*Mammuthus primigenius*	Upper left tooth	Heavy worn, with 10 plates preserved
6T	INGUJ257P/T47 + T49	*Mammuthus primigenius*	Upper tooth	Unworn, with 22 plates preserved
6U	INGUJ257P/T50	*Mammuthus primigenius*	Upper right tooth fragment	Distal part, with 9 plates preserved
6V	INGUJ257P/T51	*Mammuthus primigenius*	Upper tooth fragment	Mesial part, with 5 plates preserved
6W	INGUJ257P/T55	*Mammuthus primigenius*	Tooth fragment	Preserved 4 plates
6X	INGUJ257P/T58	*Mammuthus primigenius*	Upper tooth fragment	Preserved 6 plates
6Y	INGUJ257P/T62	*Mammuthus primigenius*	Upper tooth	Heavy worn, with 5 plates preserved
6Z	INGUJ257P/T64	*Mammuthus primigenius*	Tooth fragment	Preserved 3 plates
6AA	INGUJ257P/T67	*Mammuthus primigenius*	Upper right tooth fragment	Preserved 5 plates
6AB	INGUJ257P/T68	*Mammuthus primigenius*	Tooth fragment	Preserved 4 plates
7A	INGUJ257P/T104	*Mammuthus primigenius*	Skull fragment	Abrasion on bone surface
7B	INGUJ257P/T105	*Mammuthus primigenius*	Right mandible fragment	
7C	INGUJ257P/T107	*Mammuthus primigenius*	Mandible fragment	Symphysis

Figure number	Collection number	Taxon	Specimen description	Remarks
7D	INGUJ257P/T110	*Mammuthus primigenius*	Mandible fragment	Symphysis; abrasion on surface; partly covered by attached gravel
7E	INGUJ257P/T19	*Mammuthus primigenius*	Left scapula fragment	Articular surface preserved; filled with sediments
7F	INGUJ257P/T123	*Mammuthus primigenius*	Left scapula fragment	Fragment of scapula spine; abrasion on bone surface
7G	INGUJ257P/T23	*Mammuthus primigenius*	Scapula fragment	Fragment of scapula spine
7H	INGUJ257P/T99	*Mammuthus primigenius*	Scapula fragment	
7I	INGUJ257P/T16	*Mammuthus primigenius*	Left humerus	Bone proximal and distal part damaged; abrasion on bone surface
7J	INGUJ257P/T22	*Mammuthus primigenius*	Right humerus fragment	Damaged shaft of the bone; filled with sediment
7K	INGUJ257P/T116	*Mammuthus primigenius*	Left ulna	
7L	INGUJ257P/T20	*Mammuthus primigenius*	Flat bone fragment	
7M	INGUJ257P/T95	*Mammuthus primigenius*	Flat bone fragment	
7N	INGUJ257P/T96	*Mammuthus primigenius*	Flat bone fragment	
7O	INGUJ257P/T100	*Mammuthus primigenius*	Flat bone fragment	
8A	INGUJ257P/T118	*Mammuthus primigenius*	Right innominate	Acetabulum filled with gravel
8B	INGUJ257P/T101	*Mammuthus primigenius*	Right ischium fragment with acetabulum fragment	
8C	INGUJ257P/T106	Mammuthus primigenius	Ischium fragment and acetabulum fragment	
8D	INGUJ257P/T25	*Mammuthus primigenius*	Ilium fragment and acetabulum fragment	Carnivore gnawing marks on iliac crest; abrasion on bone surface; filled with gravel
8E	INGUJ257P/T26	*Mammuthus primigenius*	Ilium fragment and acetabulum fragment	
8F	INGUJ257P/T27	*Mammuthus primigenius*	Right ilium fragment and acetabulum fragment	Carnivore gnawing marks
8G	INGUJ257P/T28	*Mammuthus primigenius*	Ilium fragment and acetabulum fragment	Filled with gravel
8H	INGUJ257P/T29	*Mammuthus primigenius*	Ilium fragment and acetabulum fragment	
8I	INGUJ257P/T94	*Mammuthus primigenius*	Innominate fragment	
8J	INGUJ257P/T103	*Mammuthus primigenius*	Bone fragment	
9A	INGUJ257P/T15	*Mammuthus primigenius*	Left femur	Bone proximal and distal part damaged, with visible abrasion
9B	INGUJ257P/T17	*Mammuthus primigenius*	Left femur	Proximal and distal part damaged; filled with sediment
9C	INGUJ257P/T18	*Mammuthus primigenius*	Left femur	Proximal and distal part damaged and filled with gravel; large carnivore gnawing marks in proximal part
9D	INGUJ257P/T117	*Mammuthus primigenius*	Left femur	Head of femur unfused; greater trocheanter fused; distal part damaged and filled with gravel
9E	INGUJ257P/T115	*Mammuthus primigenius*	Right femur distal epiphysis fragment	Large carnivore gnawing marks
9F	INGUJ257P/T124	*Mammuthus primigenius*	Right femur distal epiphysis	Large carnivore gnawing marks
9G, H	INGUJ257P/T13 + T108	*Mammuthus primigenius*	Left tibia	Proximal epiphysis fused; distal epiphysis unfused
9I	INGUJ257P/T14	*Mammuthus primigenius*	Left tibia	Proximal part damaged; distal epiphysis fused; abrasion on bone surface
9J	INGUJ257P/T40	*Mammuthus primigenius*	Right fibula	Proximal and distal part of shaft damaged
9K	INGUJ257P/T37	*Mammuthus primigenius*	Long limb bone fragment	Probably fragment of femur

Figure number	Collection number	Taxon	Specimen description	Remarks
9L	INGUJ257P/T21	*Mammuthus primigenius*	Long limb bone fragment	Probably fragment of femur
9M	INGUJ257P/T82	*Mammuthus primigenius*	Long limb bone fragment	Probably fragment of femur; abrasion on bone surface
10A	INGUJ257P/T24	*Mammuthus primigenius*	Long limb bone fragment	
10B	INGUJ257P/T38	Large mammal	Long limb bone fragment	
10C	INGUJ257P/T81	*Mammuthus primigenius*	Long limb bone fragment	
10D	INGUJ257P/T83	*Mammuthus primigenius*	Long limb bone fragment	
10E	INGUJ257P/T88	*Mammuthus primigenius*	Long limb bone fragment	
10F	INGUJ257P/T84 + T85 + T86 + T87	*Mammuthus primigenius*	Rib fragment	
10G	INGUJ257P/T89	*Mammuthus primigenius*	Long limb bone fragment	
10H	INGUJ257P/T90	*Mammuthus primigenius*	Long limb bone fragment	
10I	INGUJ257P/T91	*Mammuthus primigenius*	Long limb bone fragment	
10J	INGUJ257P/T92	*Mammuthus primigenius*	Long limb bone fragment	
10K	INGUJ257P/T93	Large mammal	Long limb bone fragment	
10L	INGUJ257P/T102	*Mammuthus primigenius*	Long limb bone fragment	
10M, N	INGUJ257P/T75 + T76	*Mammuthus primigenius*	Rib fragment	
10O, P	INGUJ257P/T77 + T78	*Mammuthus primigenius*	Rib fragment	
10R	INGUJ257P/T79	*Mammuthus primigenius*	Rib fragment	
10S	INGUJ257P/T80	*Mammuthus primigenius*	First rib fragment	
10T	INGUJ257P/T98	*Mammuthus primigenius*	First rib	
11A	INGUJ257P/T121	*Coelodonta antiquitatis*	Right maxilla with premolars P2 and P3	
11B	INGUJ257P/T127	*Coelodonta antiquitatis*	Right upper molar M2	
11C	INGUJ257P/T109	*Coelodonta antiquitatis*	Thoracic vertebra	Centre covered by gravel
11D	INGUJ257P/T120	*Coelodonta antiquitatis*	Right femur	Diaphysis
11E	INGUJ257P/T35	*Equus ferus*	Left humerus	Proximal part damaged; large carnivore gnawing marks on proximal part of bone
11F	INGUJ257P/T34	*Equus ferus*	Right radius and ulna	Distal part of radius damaged; ulna olecranon is missing; abrasion on bones surface
11G	INGUJ257P/T39	*Equus ferus*	Metacarpus	Proximal part of bone damaged
11H	INGUJ257P/T97	*Equus ferus*	Metacarpus	Shaft
11I	INGUJ257P/T43	*Equus ferus*	Left innominate	
11J	INGUJ257P/T36	*Equus ferus*	Femur	Distal part of bone; large carnivore gnawing marks on distal epiphysis
11K	INGUJ257P/T31	*Equus ferus*	Left tibia	
11L	INGUJ257P/T44	*Cervus elaphus*	Antler fragment	Shed antler
11M	INGUJ257P/T32	*Bison priscus*/ *Bos primigenius*	Left humerus	Proximal epiphysis damaged; shaft filled with gravel
11N, O	INGUJ257P/T33 + T42	*Bison priscus*/ *Bos primigenius*	Right radius (T33) and ulna (T42)	From the same individual; abrasion on bone surface
11P	INGUJ257P/T30	*Bison priscus*/ *Bos primigenius*	Left tibia fragment	Proximal epiphysis damaged; shaft filled with gravel; abrasion on bone surface
11R	INGUJ257P/T122	*Bison priscus*	Left metacarpus	
11S	INGUJ257P/T41	Large mammal	Left humerus	Distal part of the bone

Table 3

Taxonomy of mammal bone specimens from the Targowisko pit, with their measurements and collection numbers. Explanation of measurement letter symbols: BD – breadth of distal end; BP – breadth of proximal end; CD – smallest circumference of diaphysis; GL – greatest length; SD – smallest breadth of diaphysis.

Taxon	Specimen description	Measurements in cm	Collection number	Figure number
Mammuthus primigenius	Tusk, fragment	Length = 65; circumference = 32	INGUJ257P/T1	4A
Mammuthus primigenius	Tusk, fragment	Length = 60; circumference = 39	INGUJ257P/T2	4B
Mammuthus primigenius	Tusk, fragment	Length = 56; circumference = 29	INGUJ257P/T3	4C
Mammuthus primigenius	Tusk, fragment	Length = 52; circumference = 26	INGUJ257P/T4	4D
Mammuthus primigenius	Tusk, fragment	Length = 58; circumference = 19	INGUJ257P/T5	4E
Mammuthus primigenius	Tusk, fragment	Length = 85; circumference = 34	INGUJ257P/T6	4F
Mammuthus primigenius	Tusk, fragment	Length = 70; circumference = 70	INGUJ257P/T7	4G
Mammuthus primigenius	Tusk, fragment	Length = 59; circumference = 44	INGUJ257P/T8	4H
Mammuthus primigenius	Tusk, fragment	Length = 75; circumference = 51	INGUJ257P/T9	4I
Mammuthus primigenius	Tusk, fragment	Length = 72; circumference = 25	INGUJ257P/T10	4J
Mammuthus primigenius	Tusk, fragment	Length = 50; circumference = 47	INGUJ257P/T11	5A
Mammuthus primigenius	Tusk, fragment	Length = 130; circumference = 51	INGUJ257P/T12	5B
Mammuthus primigenius	Tusk, fragment	Length = 52; circumference = 52	INGUJ257P/T70	5C
Mammuthus primigenius	Tusk, fragment	Length = 39; circumference = 21	INGUJ257P/T71+T72	5D
Mammuthus primigenius	Tusk, fragment	Length = 65.5; circumference = 48.5	INGUJ257P/T114	5E
Mammuthus primigenius	Tusk, fragment	Length = 17; circumference = 32	INGUJ257P/T73	5F
Mammuthus primigenius	Tusk, fragment	Length = 21; circumference = 36	INGUJ257P/T74	5G
Mammuthus primigenius	Tusk, fragment	Length = 20.5; circumference = 37.5	INGUJ257P/T113	5H
Mammuthus primigenius	Tusk, fragment	Length = 19; circumference = 18	INGUJ257P/T111	5I
Mammuthus primigenius	Tusk, fragment	Length = 8.5; circumference = 16.5	INGUJ257P/T112	5J
Mammuthus primigenius	Left humerus	CD = 29.8; SD = 9.2	INGUJ257P/T16	7I
Mammuthus primigenius	Left ulna	CD = 27.5; SD = 9.3; GL = 59.5; BP = 21.7; BD = 14.2	INGUJ257P/T116	7K
Mammuthus primigenius	Left femur	CD = 31.6; SD = 12.5	INGUJ257P/T15	9A
Mammuthus primigenius	Left femur	CD = 29.4 cm; SD = 10.4	INGUJ257P/T17	9B
Mammuthus primigenius	Left femur	CD = 37; SD = 13.6; BD = 19.1	INGUJ257P/T18	9C
Mammuthus primigenius	Left femur	CD = 36.1; SD = 13.4	INGUJ257P/T117	9D
Mammuthus primigenius	Left tibia	GL = 46.6; CD = 27.5; SD = 9.3; BP = 17.3; BD = 13.2	INGUJ257P/T13+T108	9G, H
Mammuthus primigenius	Left tibia	CD = 33.2; SD = 11.2; BD = 17.6	INGUJ257P/T14	9I
Equus ferus	Left humerus	CD = 13.9; SD = 3.9; BD = 8.9	INGUJ257P/T35	11E
Equus ferus	Right radius and ulna	Radius CD = 13.4; SD = 4.6; BP = 8.5	INGUJ257P/T34	11F
Equus ferus	Left tibia	GL = 37.6; CD = 12.2; SD = 4.2; BP = 9.4; BD = 7.6	INGUJ257P/T31	11K
Bison priscus/*Bos primigenius*	Left humerus	BD = 8.2	INGUJ257P/T32	11M
Bison priscus/*Bos primigenius*	Right radius (T33) and ulna (T42)	Radius GL = 41.0; CD = 13.5; SD = 4.6; BP = 7.5BD = 6.9	INGUJ257P/T33+T42	11N, O
Bison priscus/*Bos primigenius*	Left tibia without proximal part	CD = 18.1; SD = 6.5; BD = 8.7	INGUJ257P/T30	11P
Bison priscus	Left metacarpus	GL = 24.5; BP = 9.0; BD = 8.9	INGUJ257P/T122	11R


A
B
C
D
E
10 cm
F
G
H
I
J
10 cm

Fig. 5. Tusk fragments of woolly mammoth (*Mammuthus primigenius*) from the Targowisko gravel pit. For detailed characteristic, see Tables 2 and 3.

Fig. 4. Tusk fragments of woolly mammoth (*Mammuthus primigenius*) from the Targowisko gravel pit. For detailed characteristic, see Tables 2 and 3.

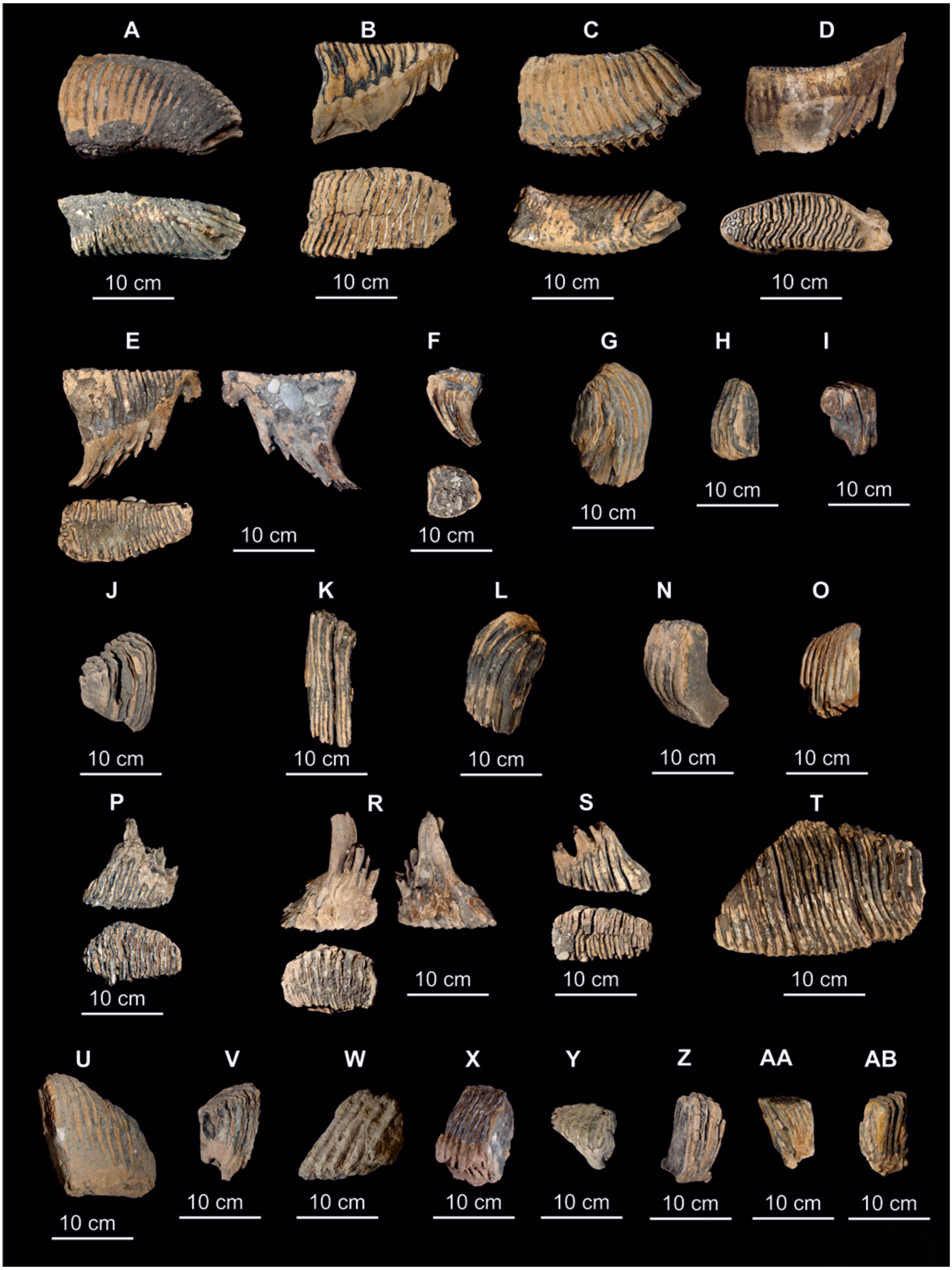

Fig. 6. Woolly mammoth (*Mammuthus primigenius*) remains from the Targowisko gravel pit. **A–F**. Complete lower teeth (upper row – buccal/lingual view; lower row – occlusal view). **G–O**. Fragments of lower teeth. **P–T**. Complete upper teeth (P, R, S: upper row – buccal/lingual view; lower row – occlusal view). **U–AB**. Fragments of upper teeth. For detailed characteristic, see Table 2.

Fig. 7. Woolly mammoth (*Mammuthus primigenius*) remains from the Targowisko gravel pit. **A**. Skull fragment. **B–D**. Mandible fragments. **E–H**. Scapula fragments. **I**. Humerus fragment. **J**. Humerus fragment (bone surface view and damaged bone part view). **K**. Complete ulna. **L–O**. Flat bone fragments. For detailed characteristic, see Tables 2 and 3.

Fig. 8. Woolly mammoth (*Mammuthus primigenius*) remains from the Targowisko gravel pit. **A**. Complete right innominate part (ventral and lateral view). **B**–**J**. Innominate fragments. **K**. Bone fragment. For detailed characteristic, see Table 2.

Fig. 9. Woolly mammoth (*Mammuthus primigenius*) remains from the Targowisko gravel pit. **A**–**D**. Complete femur. **E**, **F**. Femur distal epiphysis. **G**–**I**. Complete tibia. **J**. Fibula fragment. **K**–**M**. Long limb bone fragments. For detailed characteristic, see Tables 2 and 3.

Fig. 10. Woolly mammoth (*Mammuthus primigenius*) remains from the Targowisko gravel pit. **A–L**. Long limb bone fragments. **M–R**. Rib fragments. **S**, **T**. First rib fragments. For detailed characteristic, see Table 2.

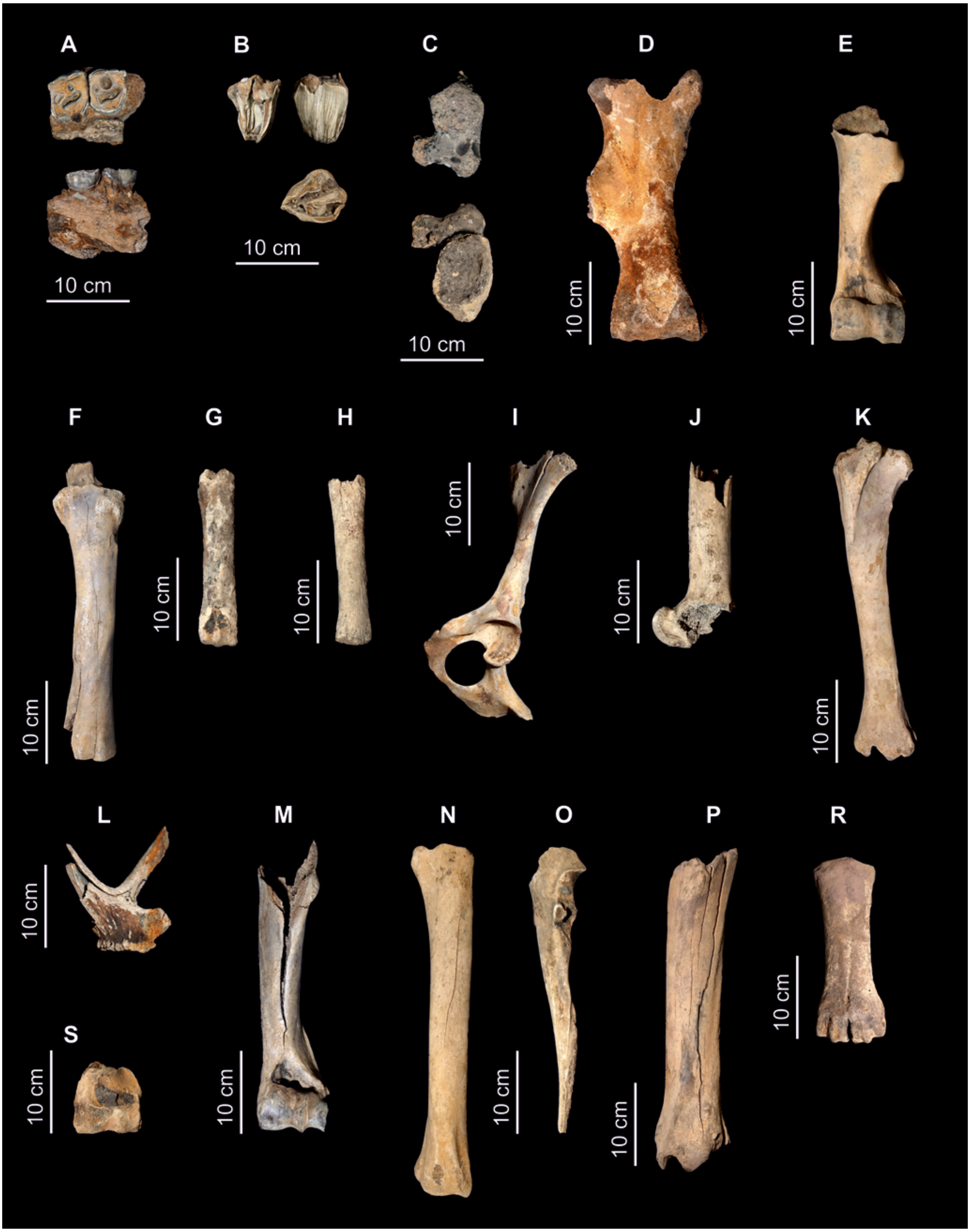

Fig. 11. Woolly rhinoceros (*Coelodonta anitiquitatis*), horse (*Equus ferus*), red deer (*Cervus elaphus*) and steppe bison/aurochs (*Bison priscus/Bos primigenius*) remains from the Targowisko gravel pit. **A**. Maxilla fragments with premolars; woolly rhinoceros (upper – occlusal view; lower buccal view). **B**. Upper second molar; woolly rhinoceros (upper mesial and lingual view; lower occlusal view). **C**. Thoracic vertebra; woolly rhinoceros. **D**. Femur fragment; woolly rhinoceros. **E**. Complete humerus; horse. **F**. Complete radius and ulna; horse. **G**, **H**. Metacarpus; horse. **I**. Complete left innominate; horse. **J**. Femur fragment; horse. **K**. Complete tibia; horse. **L**. Antler fragment; red deer. **M**. Humerus fragment; steppe bison/aurochs. **N**, **O**. Complete radius (N) and ulna (O); steppe bison/aurochs. **P**. Tibia fragment; steppe bison/aurochs. **R**. Complete metacarpus; steppe bison. **S**. Humerus fragment; large mammal. For details, see Tables 2 and 3.

Fig. 12. Post-mortem modification marks in woolly mammoth (*Mammuthus primigenius*) remains from the Targowisko gravel pit. **A**. Left tibia (specimen no. INGUJ257P/T14) with abrasion in bone distal part. **B**. Close-up detail of the bone abrasion damage. **C**. Left femur (specimen no. INGUJ257P/T117) with heavily gnawed distal part of diaphysis. **D**. Right distal epiphysis (specimen no. INGUJ257P/T115) with large carnivore gnawing marks (arrows). **E**. Right distal epiphysis (specimen no. INGUJ257P/T124) with large carnivore gnawing marks (arrows). Specimen numbers as in Table 2.

pattern of elephant bone transport appeared to be similar to that predicted by Voorhies (1969). The elephant elements with high FTI values are sacrum and all vertebra, except for atlas, patella, astragalus and calcaneus. Group I of Voorhies (1969) included sacrum, vertebrae and ribs, but the elephant ribs – with scapulae, humeri, tibiae and metacarpals – have intermediate FTI values and fall into Voorhies's group II. Elephant skeletal elements with low FTI values (atlas, pelvis, radius-ulna and femur) correspond to Voorhies's group III. The skeletal elements collected at the Targowisko gravel pit, mainly long limb bones and ribs, belong to Voorhies's groups II and III. This may suggest that the lighter parts of mammal skeletons were selectively winnowed out and carried further over longer distances by fluvial transport (cf. Voorhies, 1969). This notion is supported by the damages on the surface of relatively light bones, such as the smoothing and rounding of bone edges and the abrasive exposure of trabecular bone along the edges.

It is worth noting that the studied skeletal assemblage is dominated by mammoth remains, mostly tusks that were moderately moved and easily accumulated, whereas the smaller, lighter bones were easily destroyed by carnivores and their fragments transported farther away, winnowed by the river flow (cf. Aslan and Behrensmeyer, 1996; Evans, 2010). The bigger and heavier skeletal remains of woolly mammoth clearly dominate the bone assemblage (Tables 1, 2), whereas the smaller and lighter fragments of other grazing mammal remains (steppe bison/aurochs, horses, woolly rhinoceros and red deer) are less common.

The preservation state of the Targowisko bone assemblage indicates that not only fluvial transport abrasion but also animal body destruction by large carnivores played a significant role. It should be pointed out that the woolly mammoth long limb bones are sparse in epiphyses, whereas the epiphyses and diaphyses cases bear large carnivore gnawing marks (Fig. 12C–E), mainly on pelvis bones (Table 2). According to Haynes and Hutson (2020), carnivores in groups of three or more are able to consume most of the flesh of small elephant carcasses within hours and those of adult elephant within three to 16 days. It should also be kept in mind that the large carnivores utilized carcasses in a predictable sequence (Haynes 1983; Haynes and Hutson, 2020). The damage made by carnivores on mammoth bones in the Targowisko collection (gnawing marks on ilium crest and on femur distal condyle; Fig. 12C–E) indicates an advanced stage 2 (Haynes and Hutson, 2020) of carnivores gnawing on mammal corpses. This means that muscle masses of mammoth bones were consumed and access to the bones was made. Direct carnivore gnawing marks are absent in the case of humerus bones. However, the lack of epiphyses and presence of sediment-filled diaphysis among the specimens may suggest also higher stages of carnivore gnawing activity (stages 2 and 3 according to Haynes and Hutson, 2020). One can assume that fluvial abrasion was preceded by carnivore gnawing and that the bones were primarily damaged by cave hyenas and/or wolves.

Another feature of the Targowisko osteological collection is the lack of mammoth foot bones (metapodials and phalanges). These might have been overlooked in the mining process, although other small fragments of bones and teeth were found. The lack of phalanges and metapodials is more likely an effect of carnivore activity. Haynes and Hutson (2020) point out that the elephant foot bones at recent sites are widely scattered or removed by scavengers even when other parts of the carcass are little affected, with the implication that foot bones at fossil sites visited by scavengers should expectedly be rare.

Ecological and burial conditions

The bone-bearing part of the fluvial succession in the Targowisko gravel pit is presently inundated by groundwater (Fig. 3) and hence inaccessible to a detailed sedimentological investigation. The pit mining history reports on the occurrence of bones in coarse-gravel pockets within fluvial palaeochannels, presumably peak-flood thalweg scour lags. The osteological material represents a taphocoenosis, as indicated by: (1) the low diversity of skeletal remains, representing exclusively large grazing mammals and no carnivores; and (2) the abundance of isolated, abraded and fractured larger bones with carnivore-gnawing marks, scattered over a small area in fluvial deposits and hence indicating gradual accumulation over a long period of time. The osteological material is herbivore-dominated and represents a population of mammals that were grazing and dying on the grassland flanks of river Raba (cf. Kahlke, 1994). Their decomposing carcasses were probably exposed for some time and the bones were gnawed by carnivores before being swept by river floods. The isolated skeletal remains were flushed down the river and buried by the gravel bedload in channel thalweg local scour pools. The river floods were episodic, perhaps seasonal. The fluvial transport modified further the bones by abrasion, fragmentation, fracturing and sorting (cf. Cox and Nibourel, 2015). Cyclic fluvial episodes of erosion and short-distance redeposition cannot be precluded.

The abrasion state of skeletal remains is generally influenced by a number of variables, including the size, shape and specific density of bone fragments and the river flow power, and hence does not correlate strictly with the transport distance (Aslan and Behrensmeyer, 1996; Nawrocki *et al*., 1997; Germonpré, 2003). Therefore, the transport distance of bones in the present case is difficult to assess, albeit the domination and preservation state of large bones indicate a short transport, in the order of several kilometres. Comparable taphonomic studies of mammoth remains in Finland and Sweden have indicated transport distances of less than 50 km (Ukkonen *et al*., 2007) and commonly less than 10 km (Ukkonen *et al*., 1999).

In the regional drainage scenario, seasonal floods would make the Carpathian tributaries of the Raba river sweep large amounts of water and coarse sediment (Fig. 1A; Gębica *et al*., 2015). The river flow power would decline upon entering the wide and relatively flat Vistula plain, where thalweg scouring would be followed by rapid deposition of the coarse gravelly bedload, including the transported mammal bones.

The time of the deposition cannot be precisely estimated. During the Marine Isotope Stages 3 and 2 (Interpleniglacial and Late Pleniglacial, 57–14 ka BP), the Carpathian Foredeep area recorded phases of fluvial sediment accumulation interrupted by short phases of river incision (Gębica *et al.*, 2015; Starkel *et al.*, 2015). These changes are attributed to short-term regional climatic fluctuations with warmer and cooler phases. One can presume that the mammals dwelled in the Raba tributive drainage zone (Fig. 2A) at the same time as analogous animals in the Subcarpathian Basin. The dating of woolly mammoth remains in this latter region ranges from ca. 54 to 12.6 cal. ka (Nadachowski *et al.*, 2011; Ukkonen *et al.*, 2011), with no evidence of mammoth remains in three stratigraphic intervals: from 43.2 to 40.6 cal. ka, from ca. 34.8 to 32.6 cal. ka and from ca. 24 to 18 cal. ka. The Targowisko area of bone burial was in the head zone of the Raba fluvial fan (Fig. 2A), where deposition inevitably alternated with erosion and where it is thus difficult to specify the exact time of bone-bearing gravel deposition. The maximum upper time bracket for their deposition would be the age of the oak tree trunks found in the overlying meandering river deposits dated to 799–700 BC (Fig. 3).

CONCLUSIONS

The study has documented a previously unknown occurrence of Pleistocene large mammal remains in the fluvial deposits of river Raba at the Targowisko gravel pit in southern Poland. The bone assemblage contains mainly remains of woolly mammoth *Mammuthus primigenius* and less frequent remains of horse *Equus ferus*, woolly rhinoceros *Coelodonta antiquitatis*, red deer *Cervus elaphus* and steppe bison *Bison priscus* or aurochs *Bos primigenius.* The mammal remains represent an ecological taphocoenosis.

Taphonomic indices suggest that the animal corpses first underwent a stage of soft-tissue decomposition and skeletonization in subaerial setting, a process accelerated by carnivores. The bone remains were subsequently swept from grassland river flanks by floods and buried isolated in fluvial channel scour pools. The mammal bones and teeth show abrasion damages typical for bedload fluvial transport, presumably over short distances in the order of several kilometres.

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