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Late Quaternary woolly mammoth (*Mammuthus primigenius* Blum) remains from southern Transdanubia, Hungary

*Restes de mammouth laineux (*Mammuthus primigenius *Blum) du Quaternaire tardif de la Transdanubie méridionale, Hongrie*

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ABSTRACT

Six samples of subfossil tusk, bone and tooth remains from the woolly mammoth (*Mammuthus primigenius* Blum) were discovered in south-western Hungary. The remains are relatively well preserved in a Late Pleistocene loess deposit. The samples have been radiocarbon dated (AMS) and are of Late Weichselian (MIS 2) age (21.8–24.1 ka cal BP). The skull fragments, the tusks and maxillary teeth are in close proximity to associated postcranial remains, indicating that the mammoth died where it was found. The size and characteristics of skeletal elements have allowed us to determine that this was a mature male of about 38 years of age.

Mots clés :
Proboscidea
Mammuthus primigenius
Pléistocène tardif
Taxonomie
Taphonomie
Paléo-environnement
Hongrie

RÉSUMÉ

Six échantillons de restes de défense, de dent et d'os de mammouth laineux (*Mammuthus primigenius* Blum) ont été découverts dans le Sud-Ouest de la Hongrie. Ces restes sont relativement bien conservés dans un dépôt loessique du Pléistocène tardif. Les échantillons ont été datés au radicarbonne (AMS) et sont du Wechsélien tardif (MIS 2), d'âge 21,8 à 24,1 ka cal BP. Les fragments de crâne, les défenses et les dents maxillaires sont très proches de restes post-craniaux associés, indiquant que le mammouth est mort là où il a été trouvé. La taille et les caractéristiques des éléments du squelette nous ont permis de déterminer qu'il s'agissait d'un mâle mature, d'environ 38 ans.

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1. Abbreviations

AA	AMS Laboratory, Tucson, Arizona, USA
DEB	Laboratory of Environmental Studies, Institute of Nuclear Research (Hungarian Academy of Sciences), Debrecen, Hungary
UP	University of Pécs, Hungary
PURAM	Public Agency for Radioactive Waste Management, Hungary
M3	upper molars
HI	hypsodonty index
CDJ	cementum-dentin junction
OASA	optical analysis of the Schreger angles
ZM	Zók Mammoth
AEY	African Elephant Years

2. Introduction and geological setting

The woolly mammoth *Mammuthus primigenius* (Blumenbach, 1799) is the most important representative of the Eurasian Late Pleistocene megafaunal assemblage (Kuzmin and Orlova, 2004). The study of mammoth extinction patterns is crucial for understanding the impact of global environmental changes on the mammalian populations at the end of the Pleistocene (Kuzmin and Orlova, 2004). Typical, the woolly mammoth is best known from the Weichselian (Last) glaciation (*c.* 100–10 ka). During the Last Cold Stage, the woolly mammoth occurred widely across northern Eurasia, including nearly all of Europe, mostly in association with regional treeless steppe-tundra vegetation (Allen and Huntley, 2000; Gheerbrant and Tassy, 2009; Lister and Sher, 2001; Lister et al., 2005; Pazonyi, 2004; Svoboda et al., 2005; Wojtal and Sobczyk, 2005).

Fossil remains of *Mammuthus primigenius* are common in Hungary; *c.* 400 specimens have been recovered; among these are five complete skeletons (Főzy and Szente, 2007; Gasparik, 2001; Vörös, 1981). A woolly mammoth, was excavated by students in a vineyard near the city of Pécs (Zók), located in a loess road cut (Fig. 1). The locality occurs on a hillslope 10 km from Pécs. The mammoth occurred at a depth of *c.* 70 cm within a leached, yellow loess unit (Fig. 2). Total loess thickness at the site is ~18 m, with yellow silt being ~12 m thick and the underlying yellow-grey, fine sand ~4 m thick (Sebe et al., 2008). The upper 4 m thick layer is rich in terrestrial Mollusks (*Cochlicopa lubrica, Vallonia costata, Zonitoides nitidus, Arianta arbustorum, Trichia*

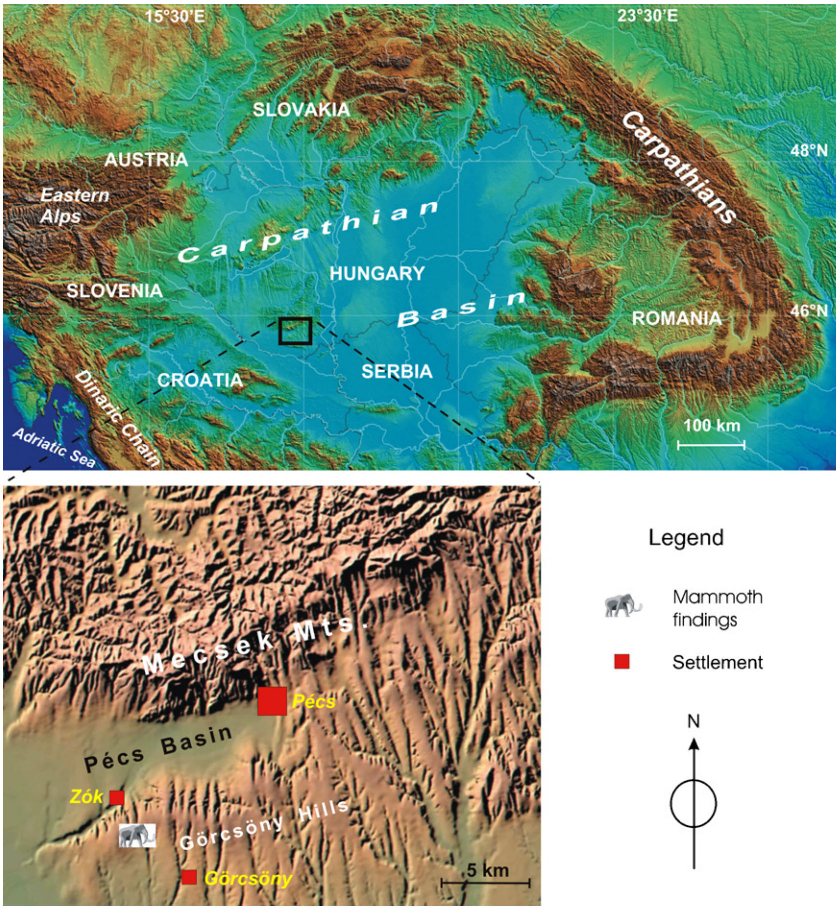

Fig. 1. Location of the mammoth remains in southern Transdanubia, Hungary (map is modified after Horvath and Bada, 2005).

Fig. 1. Localisation des restes de mammouth en Transdanubie méridionale, Hongrie (carte modifiée d'après Horvath and Bada, 2005).

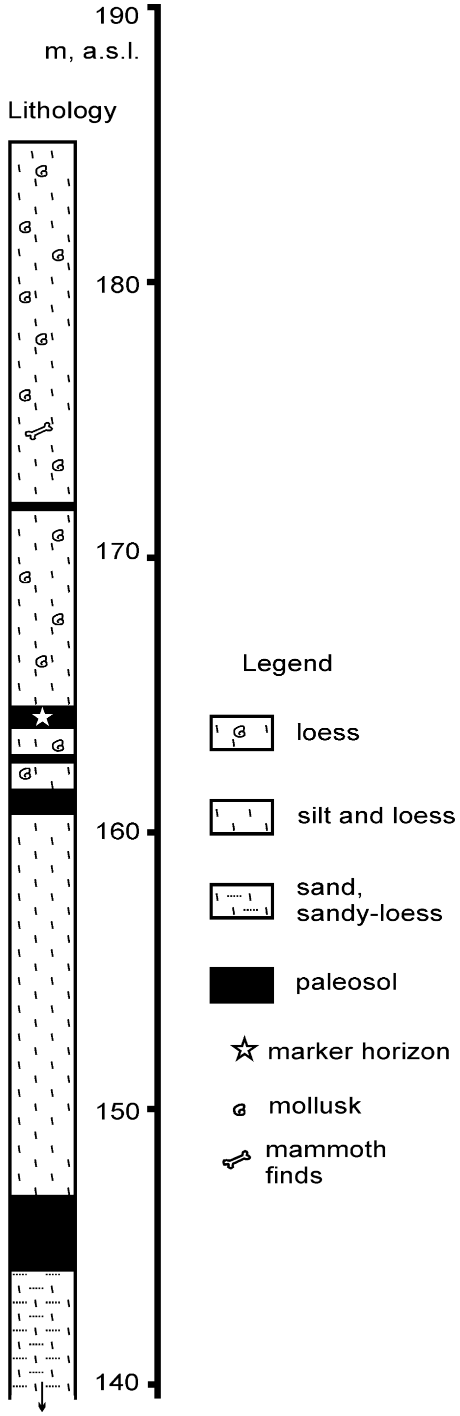

Fig. 2. Simplified sedimentary log near Zók.
Fig. 2. Log sédimentaire simplifié près de Zók (Fig. 1).

hispida, Nesovitrea hammonis). Among these, *Arianta arbustorum* is the dominant species in the mammoth bearing layer.

Thick Quaternary sequences have long been known in the southern foreland of the Mecsek Mountains (Pécsi, 1993; Újvári et al., 2008). However, their distribution, facies and thickness are highly variable. Plio-Quaternary sediments form a continuous sheet in the area between the Mecsek Mts. and the Görcsöny Hills and at certain places their thickness exceeds 100 m. The pediment is covered by loess-palaeosol succession, which thickens towards the south. On the Pécs Basin southern margin, the dip of palaeosols in the loess – approximately 1 to 3° to the south – is clearly visible in several exposures and this dip is syndepositional, i.e. it shows the slope of the palaeosurface. In Görcsöny village, a particular palaeosol layer (marker horizon) is 2–3 m lower than in the excavation site near Zók (Kovács et al., 2007a; Sebe et al., 2008). According to aminostratigraphic studies conducted by Oches and McCoy (Oches and McCoy, 1995), this palaesol formed during the Middle Pleistocene. The Pécs Basin began to appear morphologically contemporaneously with loess deposition.

3. Methods

For the taphonomic analysis of the available material, we counted the isolated skeletal elements and articulated skeletal parts and considered the breakage, weathering, abrasion, and plant root traces on the bone material. The palaeobiological analysis considered the gender of the remains using the tusks and postcranial material as a basis; we determined the age distribution on the basis of the dentition and tusks. Age was determined from dental progression and wear comparisons to modern African elephants (Haynes, 1991; Laws, 1966). According to Haynes (Haynes, 1991), most modern paleontologists use Maglio's (Maglio, 1973) dental nomenclature, which is used herein as well. The method is based on values of enamel thickness, plate (lamellar) frequency and plate length of last generation of mammoth molars (M3). The method of measurements has been described in detail by Lister (Lister, 1996). Measurements were taken on molars and skeletal elements using sliding metal calipers. The tusks were studied by OASA as described by Theodorou and Agiadi (Theodorou and Agiadi, 2001). The broken, flat surface of the tusk, as a transverse section was photographed in high-resolution, and the images were processed with a photo-processing program. The Schreger angles were then measured at high magnification. The tusk of ZM has been radiometrically dated at DEB by conventional radiocarbon dating method (gas proportional counting system). A ^{14}C cross-check (AMS) has been run in AA.

The specimens are kept in the Department of Geology, UP, Hungary.

3.1. *Radiocarbon dating*

Two samples of tusk were sent to DEB and AA, for ^{14}C dating. Radiocarbon ages are quoted uncalibrated and in calendar years, calibrated using CalPal-2007 software (http://calpal.de). The results are in Table 1. Average value of these measurements: *c.* 19,130 ± 850 yrs BP which calibrates into *c.* around 22,973 ± 1160 calendar years ago from today. Calibration gives a 68.2% age probability of 24,105 to 21,806 cal yr BP.

Table 1
Radiocarbon dating results of the Zók Mammoth.
Tableau 1
Résultats de la datation radiocarbone du mammouth de Zók.

Field number	Sample	Laboratory code	δ^{13}C (PDB) [‰] (±0.1‰)	Conventional ^{14}C age (BP)	Calendar age 1σ (68.3%) (cal BP)
Zók-m1	Tusk	DEB-14677	−20.75	20,500 ± 1500	24,700 ± 1870
Zók-m1	Tusk	AA-80678	−21.20	17,760 ± 200	21,250 ± 450

4. Systematics

Order: *Proboscidea* Illiger, 1811.
Family: *Elephantidae* Gray, 1821.
Genus: *Mammuthus* Brookes, 1828.
Species: *Mammuthus primigenius* Blumenbach, 1799.

4.1. Material

ZOK-1 (left tusk), ZOK-2 (right tusk), M3 upper molars, cranial fragments and rib fragments.

4.2. Locality

Village of Zók, Baranya county, southern Hungary (45°59′N and 18°06′E) (Fig. 1).

4.3. Description

The tusks are incomplete; the proximal (root) and distal (tip) ends are unevenly broken (Fig. 2). ZOK-1 is approximately 193.5 cm in length along the outside curve, and 154 cm along the inside curve (Fig. 3C). The diameter of the tusk is approximately 160 mm near the proximal end, and 130 mm near the distal end (Table 2). The coloration of the ivory is light brown on the exterior and becomes progressively lighter into the interior. The cross-section is subcircular (Fig. 4). ZOK-2 is about 120 cm long and its minimum and maximum diameters are 100 mm (dist.) and 130 mm (prox.) (Fig. 3B). Both specimens exhibit moderate curvature and moderate torsion. The Schreger pattern (Ábelová, 2008; Palombo and Villa, 2001; Trapani and Fisher, 2003) is clearly visible on the section surface of both specimens, mainly near the periphery (Fig. 4). The angle measurements were near the CDJ (where the dentine turns to cementum), around 2 cm from the tusk surface (Ábelová, 2008; Espinoza and Mann, 1993; Palombo and Villa, 2001; Trapani and Fisher, 2003). The Schreger outer angles range from 77° to 86°, while near the tooth axis the angles are considerably more acute.

Table 2
Dental measurement of mammoth tusks.
Tableau 2
Mesures dentaires des défenses de mammouth.

Measurements of the tusks (cm)	Incisivus sinistral	Incisivus dextral
Maximum length, measured along the outer curvature	193.5	120.0
Maximum length, measured along the inner curvature	154.0	105.5
Maximum circumference at the end of alveolus	51.0	38.0
Maximum diameter at the end of the alveolus	16.0	13.0

Molars (Figs. 3A 5B): The teeth taper posteriorly, so they have been determined to be M3. These molars show 14 to 12 plates in wear (grinding surface). The whole enamel loops are wide (10 mm) in mesiodistal direction, and mesial and distal parts of the enamel loops are parallel to each other. Molars (M3) of this mammoth are large and hyp-

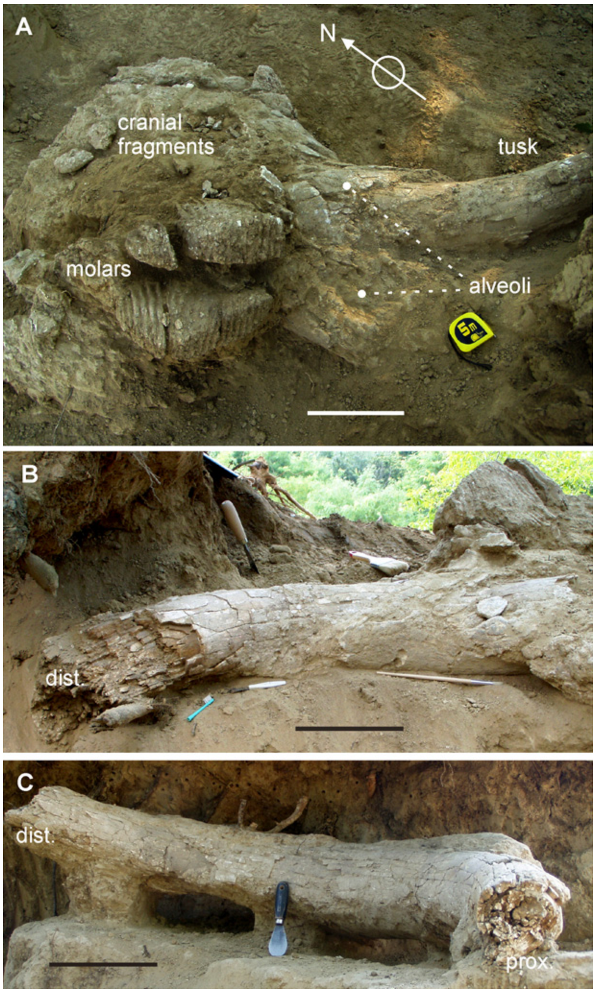

Fig. 3. Major skeletal elements of the ZM in the excavation site. **A.** Two upper M3 s and cranial fragments with right tusk (plan view, the skull is on its left side). **B.** Right tusk (horizontal position). **C.** Left tusk (horizontal position). Scale: 20 cm. (dist.: distal; prox.: proximal end).

Fig. 3. Principaux éléments du mammouth de Zók (ZM) dans le site de fouille. **A.** Deux molaires supérieures M3 s et fragment de crâne avec défense droite (vue en plan, le crâne est sur son côté gauche). **B.** Défense droite (position horizontale). **C.** Défense gauche (position horizontale). Barre d'échelle : 20 cm (dist. : extrémité distale ; prox. : extrémité proximale).

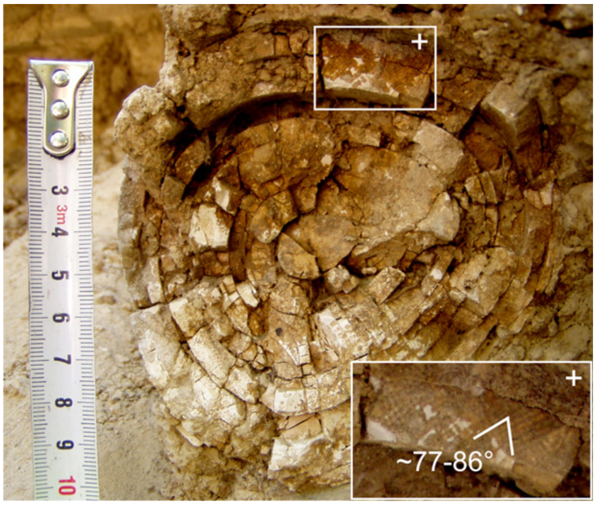

Fig. 4. Section of the tusk showing the Schreger pattern.

Fig. 4. Coupe de la défense montrant le diagramme de Schreger.

sodont (HI – 1.8), having wide and high crown. Length of the upper molars varies between 276 and 288 mm, width varies between 88 and 90 mm, and height (unworn true maximum) varies between 160 and 165 mm. Measurement of crown length and height includes estimated cement thickness. The quantity of plates is 24 including talons. The angle of molar eruption is 43° on both molars. The enamel is thin (1.6–1.8 mm), and enamel folding is visible in the whole occlusal surface of the molars. Plate frequency is 7 to 7.5. Plate frequency is the number of plates on 100 mm of crown. The index is an average based on measurements taken in the middle part of the lateral and medial surfaces of a crown (Lister, 1996; Lister and Sher, 2001). The anterior talon has been lost by other reasons than normal abrasion from the upper right molar. The first root (length: 105 mm) is preserved at the front of left M3. Measurements of the specimen are given in Table 3.

4.4. *Skull*

The whole posterior part of the skull is missing. The frontal portion is fragmented. The pneumatic structure is visible on the praemaxillary fragment (Fig. 5C). The alveolar part of the praemaxilla (Fig. 5A) is straight and long (34 cm). The tusk alveoli are broken.

Table 3
Dental measurements of the upper molars.
Tableau 3
Mesures dentaires des molaires supérieures.

Measurements	M^3 dextral (mm)	M^3 sinistral (mm)
Occlusal length	276	288
Crown width	88	90
Crown length	200	220
Height (unworn true maximum)	160	165
Plate width	8–10	8–11
Enamel thickness	1.7	1.75
Cement width between plates	6–8	6–8
Plate formula (lamellae)	−19×	×22×
Plates in use	12	14
Angle of eruption	43°	43°
Hypsodonty index (HI)	1.81	1.83
Plate (lamellar) frequency	6.5	7

4.5. *Ribs*

One corpus fragment (preserved length ~52 cm) is bilaterally compressed and represents the second to fifth rib (Fig. 5D). The rib fragment, without proximal and distal ends, is medially flat and laterally slightly convex, thus having an ovoid cross-section.

The preserved proboscidean tusks are good for identification. The strongly curved and twisted tusks are typical of all *Mammuthus*, but more data are valuable for a generic attribution: The study of the internal structure of ivory has been enhanced recently, providing good criteria for the identification of the proboscidean tusks, based on the Schreger pattern (Ábelová, 2008; Palombo and Villa, 2001; Trapani and Fisher, 2003). The Schreger pattern is a characteristic feature of proboscidean dentine, usually visible in tusk cross sections as intersecting spiral lines (Fig. 4). The morphology of these lines differs among proboscidean taxa, offering a useful discriminating character. The angles formed by the intersecting lines near the periphery of the cross-section are most often used for this purpose. The acute-to-right angles formed by the Schreger lines near the CDJ in the studied tusk fragments suggest an attribution to *Mammuthus*. In Elephas (including *E. [Palaeoloxodon] antiquus*), these angles are obtuse; in *Mammuthus*, they reach their maximum values of more than 100° about halfway between the pulp cavity and the CDJ (Ábelová, 2008; Palombo and Villa, 2001; Trapani and Fisher, 2003). Considering the above morphological data, the proboscidean tusks from Zók certainly represent a *Mammuthus*.

Typical *M. primigenius* is characterized by its strongly curved tusks, M3 with x20x–x27x plates (average x24x), and an average lamellar frequency of eight. Enamel thickness in M3 is usually less than 2.3 to 2.5 mm (Lister, 1996; Lister and Sher, 2001; Palombo and Ferretti, 2005).

The Zók mammoth has only moderately curved tusks, two plates less than the average, and a slightly lower than average plate frequency in M3. The enamel is thinner than average as well. But the differences are small and the taxonomic attribution of individual recovered from periglacial loess deposits is primarily to *M. primigenius*.

5. Age determination and gender

The third molars in the maxillae (M3, left and right) are preserved. The anterior parts of both molars are almost worn to the base of the crown. The stage of eruption and wear of the M3 (and extrapolating from these to the lower molars that are not available) is equivalent to Laws' (Laws, 1966) Age Group XXII, which means that the Zók Mammoth had an age of approximately 37 to 38 AEY, according to the scale of Craig (in Haynes, 1991) at the time of its death. This age determination is based on comparing the tooth eruption/wear of the mammoth with observed tooth eruption/wear in African elephants of known ages.

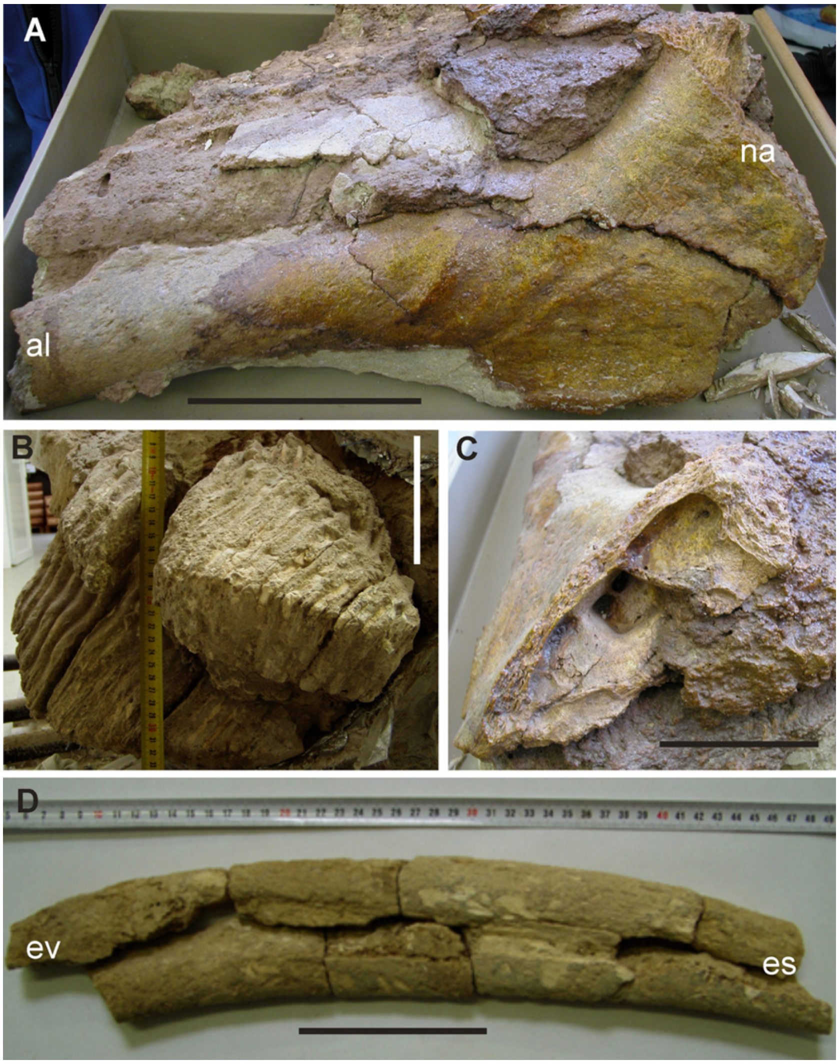

Fig. 5. Cranial and postcranial elements of the ZM. **A**. Praemaxillary fragment (dextral) in frontal view. **B**. The upper M3s in occlusal and lateral view. **C**. Pneumatic structure of the cranium. **D**. Fragments of corpus costa (facies externa). Scale: 10 cm. Al: alveolar; na: nasal aperture; ev: extremitas ventralis; es: extremitas sternalis.

Fig. 5. Éléments craniens et post-craniens de ZM: **A**. Fragment prémaxillaire (droit) en vue frontale. **B**. Molaire supérieure M3 s en vues occlusale et latérale. **C**. Structure pneumatique du crâne. **D**. Fragments du corpus costa (faciès externe). Barre d'échelle : 10 cm. Alv : alvéolaire ; n : extrémité nasale ; ev : extremitas ventralis ; es : extremitas sternalis.

Tusk diameter in *M. primigenius* is strongly sexually dimorphic. Female woolly mammoths have relatively slender, straight and gracile tusks (Averianov, 1996). For females reported by Averianov (Averianov, 1996), the diameter near the ends of the alveoli are less than 90 mm and the tusks turn only slightly medially. Conversely, the tusks of male woolly mammoths are more massive, with a diameter at the end of the alveoli of up to 200 mm and possess very strong medial curvature. The recovered left tusk of the ZM is ~2 m in length. The tusk diameter, measured slightly closer to the proximal end of the tusk, is 160 mm. This measurement is almost double the maximum for females reported by Averianov (Averianov, 1996) for Russian woolly mammoth and thus points to the likelihood of the ZM being a male.

6. Taphonomy

The incomplete skull, including retention of ZOK-2 tusks and upper third molars (Fig. 6), together with the horizontal orientation of the slightly dissociated postcranial remains (mainly fragments), indicate that the mammoth was buried where he died. Fractured edges of broken bones are sharp and exhibit no traces of rounding. Traces of gnaw-marks are absent on the bones. Especially intriguing regarding the taphonomic history of the individual is its left tusk. The skull, as noted, retained only the right tusk and maxillary teeth, but the left tusk had been rotated, pointing in a caudal direction. This is an unusual natural postmortem orientation, suggesting the intervention of an unknown but competent agent. The disarticulated left

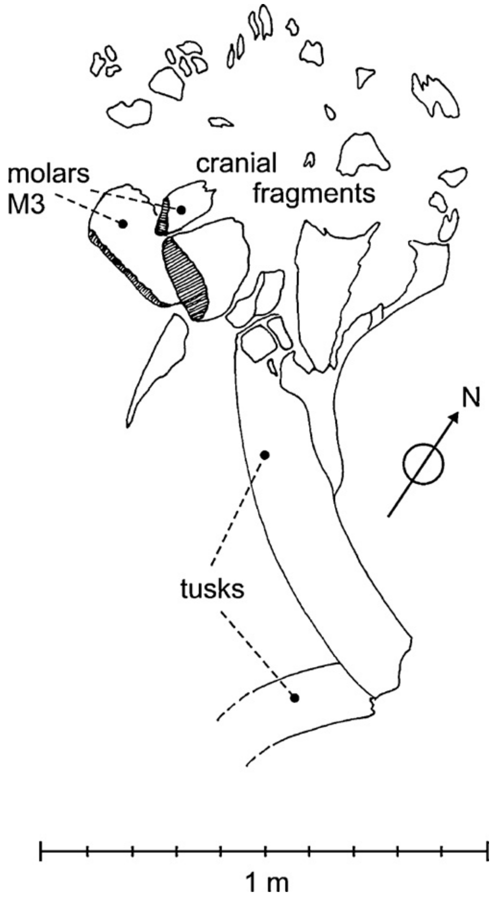

Fig. 6. Map of bones.
Fig. 6. Croquis des os.

tusk and rib fragments were found behind and under the skull, indicating that they had been moved. Stratigraphic and geomorphologic studies indicate that the bones were deposited in a very low energy environment and are in their primary context, with no significant post depositional movement. The major postcranial elements are missing, probably, as that part of the skeleton is in a valley direction, so removed by erosion. The fact that only one animal was found and it is indicated to be a male equates well with the analogous behavior of unattached or lone African elephants. However, there is no evidence of human processing of the mammoth remains, even although an important Palaeolithic (Gravettian) "mammoth hunter" settlement was discovered in the region (Dobosi, 2005). The intervention of a predator or a living mammoth is more likely.

7. Discussions and conclusion

The pattern of the Schreger bands in the tusk dentine of *M. trogontherii* (Pohlig, 1885) is similar to that in *M. primigenius* (Palombo and Villa, 2001). Average plate number of steppe mammoth is less (x19x) than woolly mammoth (Lister, 1996). Lamellar frequency of ZM (7) is more than the average of *M. trogontherii*. Enamel thickness is less (1.75 mm) than the mean of steppe mammoth (2.3 mm). The M3 s present in the ZM possess x22x plates, which is at the edge of the range for *M. trogontherii* but well within that of *M. primigenius*.

Tusks of *Elephas (Palaeoloxodon) antiquus* (Falconer and Cautley, 1847) are large, and weakly curved opposite to specimens of ZM. The molars of straight-tusked elephant are hypsodont (HI 1.8–2.0 in M3, similar to that of ZM), with a relatively narrow crown, characteristically wrinkled enamel with a mean thickness of 2.6 to 2.7 mm in M3 opposite to that of ZM. M3 possess an average of x16x plates with a maximum at x19x–x20x, which is less than the average of ZM. The praemaxilla of *E. antiquus* is fan shaped and extremely wide distally. The praemaxilla of ZM is straight, long, and parallel. The enamel loops on the occlusal surface of M3 of ZM are different to that of straight-tusked elephant.

Based on these results, this specimen is ascribed to *Mammuthus primigenius*.

Since early studies, it has been accepted that mammoths existed under conditions of cold, dry climate and preferred open steppes, locally with trees and bushes (Lister and Sher, 2001; Sher, 1997; Velichko and Zelikson, 2005; Velichko et al., 2002).

During the glacial stages of the Pleistocene, the Carpathian Basin was subject to a cryogenic environment that produced a variety of periglacial features (Kovács et al., 2007b). The particularly cold climate during these glacial periods results from the basin's unique geomorphological setting, which is surrounded by the Carpathians, creating an almost closed climatic system. The loess snail findings (*Arianta arbustorum* dominant) from the mammoth bearing layer are subhygrophilic/hygrophilic, cold-resistant, steppe fauna (Hertelendi et al., 1992; Sümegi and Krolopp, 2002). Based on these data, the landscape in the Carpathian Basin was: extremely continental arid climate with a small amount of solid precipitation; firm soil; dominance of open plant communities (herb, grass and low shrubs), locally with trees. This kind of environment in the Carpathian Basin was still favourable for the mammoth's existence even close to the Last Glacial Maximum.

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