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A Late Pleistocene woolly mammoth from Lower Silesia, SW Poland

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Abstract. The well-preserved remains (74 bones) of a woolly mammoth *Mammuthus primigenius* were discovered in Vistulian (Weichselian) sediments in the vicinity of Zastruże near Żarów, Lower Silesia, Poland. The mammoth female, ~18-50 years old, died from unknown reason on a muddy slope of a periglacial valley and was quickly buried in sediments of ~24 ka age. The results of the stable oxygen isotope analyses of bone phosphates indicate that more than one individual might have been buried at this site. The calculated stable oxygen isotope composition of water drunk by the Zastruże mammoth/s during its/their lifetime was -10.8±0.4‰, reflecting an approximate annual mean air temperature around 6.6±0.8°C

Key words: Vistulian, woolly mammoth, radiocarbon dating, stable oxygen isotope composition, Lower Silesia.

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I. INTRODUCTION

The woolly mammoth *Mammuthus primigenius* BLUMENBACH, 1799 is one of the best known Pleistocene mammals; it has even become a symbol of the Ice Age. It evolved probably ~750 ka from the steppe mammoth *Mammuthus trogontherii* POHLIG, 1885. The earliest findings suggesting this evolutionary pathway are known from Siberia, but the typical woolly mammoth appeared ~400 ka, and it was present in Europe since ~150 ka (LISTER & BAHN 2007). Remains of this species are common in Poland (KOWALSKI 1959; KUBIAK 1965). However, usually these are casual findings of single bones, tusks or molars without confirmed archaeological or geological position. Most of these specimens have been collected from gravel pits and currently are deposited in museums, e.g., Polish Geological Institute (Warsaw), the Museum of Earth of the Polish Academy of Sciences (Warsaw) and other institutions (KUBIAK 1965).

Sites in which several bones of one or more individuals have been found in situ are very rare, and therefore of special importance. The only Polish site with a large assemblage of remains (>8000) of 86 individuals is the Kraków Spadzista Street (B) site in Kraków (KUBIAK & ZAKRZEWSKA 1974; WOJTAL 2007; WOJTAL & SOBCZYK 2005; KALICKI et al. 2007). From other sites such as Skaratki (CHMIELEWSKI & KUBIAK 1962), Niedzica (KULCZYCKI 1955), Warszawa (JAKUBOWSKI 1973) or Kraków Nowa Huta (KOZŁOWSKI et al. 1970) only remains of single individuals are known. From the Lower Silesian region, remains of mammoth found within a well-recognised stratigraphical context are known only from three sites. They are represented by bones from site 1 at Hallera Av., Wrocław (Complex A/B), site A2 (layer 10), and Jordanowska St. in Wrocław Oporów (Fig. 1; WISZNIOWSKA et al. 2003; WIŚNIEWSKI 2005, 2006; WIŚNIEWSKI et al. 2003).

Taking into account the large number of bones situated in a well-recognized stratigraphical context, the Zastruże site represents a unique finding. Moreover, the bones were radiocarbon dated and the stable oxygen isotope composition of bone phosphate was analyzed. Therefore the Zastruże mammoth bones can be recognized as a regional palaeoclimatic benchmark. In order to fully explore the importance of this finding, we report the details of the palaeozoological and geochemical evidence, including determination of sex and individual age of the Zastruże woolly mammoth.

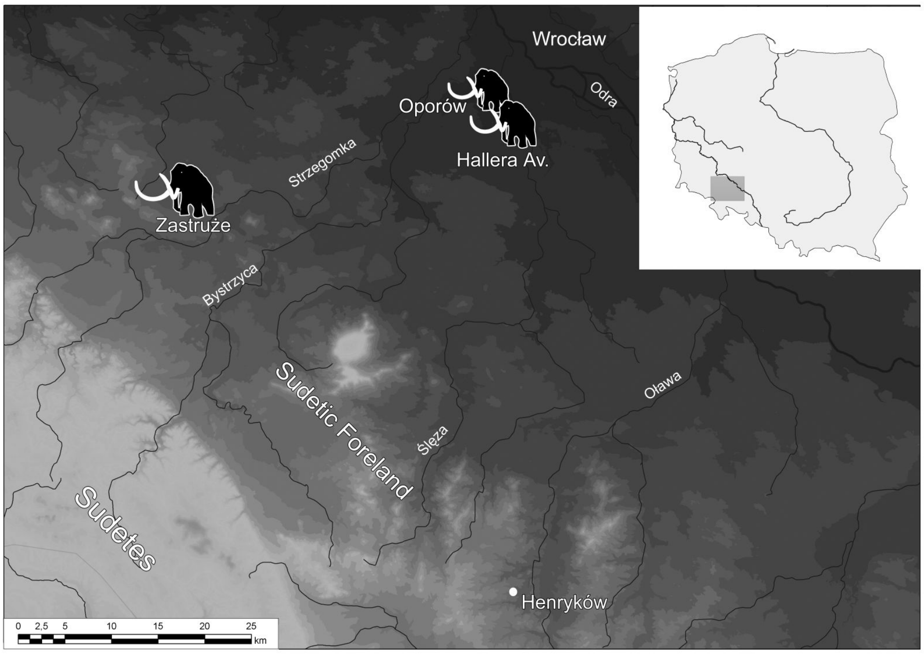

Fig. 1. Location of Zastruże and other sites from Lower Silesia mentioned in the text.

Site location and geological setting

The woolly mammoth remains were accidentally discovered in spring 2005 in a gravel pit known as the Mielęcin site located near the village Zastruże, about 40 km southwest of Wrocław (SW Poland). The gravel pit is located within a northern slope of a small valley situated between Żarów and Zastruże on the eastern part of the Strzegom Hills (WOJEWODA et al. 1995; CZERWONKA & KRZYSZKOWSKI 2001; KRZYSZKOWSKI et al. 2001; WIŚNIEWSKI et al. 2009).

The bedrock consists of crystalline rock covered by Miocene clay and alluvial strata of the Gozdnica series (KRZYSZKOWSKI 2001). The stratigraphy and sedimentology at the site were studied based on profiles and cross-sections accessed from two trenches: 1/2005 – 13.5 m^2 and 1/2007 – 6 m^2, and the walls of the gravel pit and two sedimentological complexes have been distinguished (Fig. 2). The older one which builds the core of the elevation, within which the gravel pit is local-

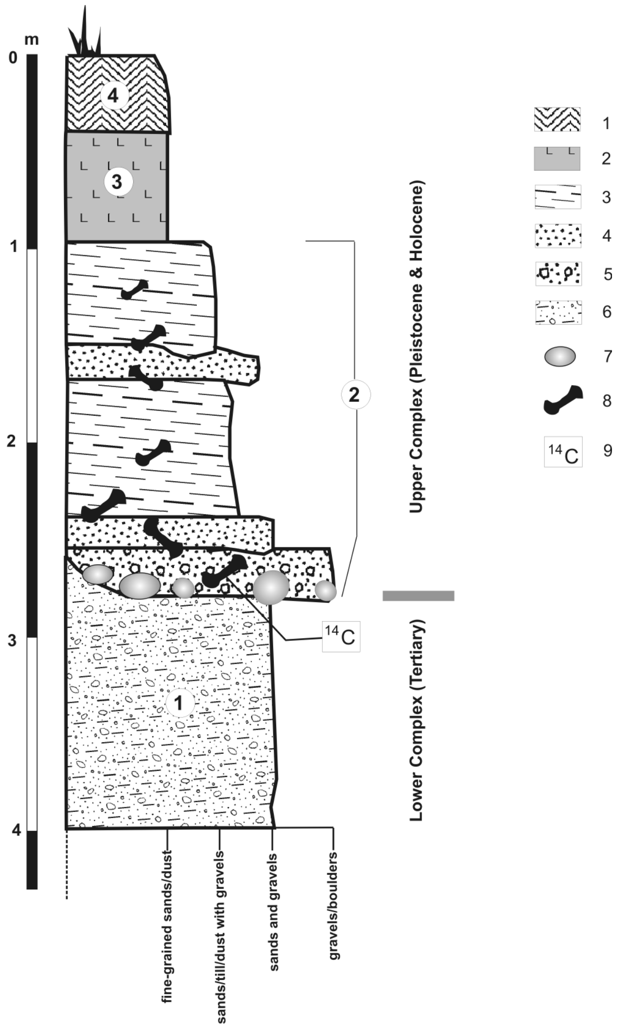

Fig. 2. Stratigraphy of the Zastruże site: 1 – Recent soil; 2 – loess; 3 – sand, till, dust and gravel, 4 – slope sand and gravel, 5 – gravel with stone pavement; 6 – alluvial sand and gravel, 7 – boulders, 8 – woolly mammoth bones, 9 – radiocarbon dating. Lower series: 1; upper series: 2-4. According to J. BADURA, B. PRZYBYLSKI (personal communication), drawing by A. WIŚNIEWSKI.

ized, comprises Pliocene alluvial sediments (KRZYSZKOWSKI 2001). The younger complex which had originated during the Pleistocene, fills an erosional depression within the valley slope. This complex is 2 m thick and 15 m wide. In the southern section of the gravel pit the depression is split into two channels. The bone remains were found within one of them, in the western part of the pit. The lowest part of the depression, comprising a pavement of Scandinavian boulders, contacts alluvial sediments of the lower complex. The pavement is covered with fine-grained slope sediment in the lower part, composed of dusty sand with gravel. Uphill, the bed changes into dusty sand interstratified with a coarse-grained sand with an admixture of gravel. In the upper part of the succession disturbances are visible, indicating the downward movement of solifluction lobes. The entire filling of the depression can be described as rhythmically stratified periglacial slope sediments. However, within the top of the filling isolated cryoturbations occur; the biggest one is 1 m high. The uppermost part of the section consists of a strongly reduced layer of loess with recent soil (Fig. 2, layers: 3-4).

II. RESULTS

Distribution and preservation of bones

At the Zastruże site 74 woolly mammoth bones have been found. These include: shoulder blades (NISP=2, MNE=2), pelvis bones (NISP=2, MNE=2), vertebrae (NISP=11, MNE=6), ribs (NISP=8, MNE=1) and limb bones (NISP=8, MNE=1). The bones assemblage (NISP=31) from trench 1/2005 likely constitutes one mammoth postcranial skeleton (Table I).

In trench 1/2005 the mammoth bones were scattered across a relatively small area of 2.7 m^2 (Fig. 3). Stratigraphically, they were situated in a few colluvial layers. The vertical distribution of bones had a maximum dispersion of 1.83 m. Due to short-distance relocation along the slope, the bones lost the anatomical order. However, the type and position of all mammoth bones suggest that they belong to the skeleton of one individual. Unfortunately, many of the skeleton parts (cranium, jaw, molars, other vertebrae, ribs and some limb bones) are missing. Their absence may suggest that they are still present in the unexplored part of the gravel pit or were removed during the mining operation. In trench 1/2007 neither mammoth nor other animal remains have been found.

During field work in 2008 a total of 43 woolly mammoth bones were found (Table I) in earth heaps located next to the walls of the gravel pit. The heaps were composed of colluvial sediments similar to the filling of the erosional depression. The stratigraphical position of the bones is uncertain but their preservation and the character of the sediments which cover them confirm that they could have accumulated during the same time. However, we cannot exclude that the bones found in the trench 1/2005 and in the earth heap may belong to different individuals.

In general, most of the bones are very well-preserved, however the first stage of alterations have affected their surface. The uppermost remains show weathering which fits the first stage according to Behrensmeyer scale (BEHRENSMEYER 1978; LYMAN 1994). Superficial cracks resulting from weathering were observed on the pelvis (trench 1/2005). Similar cracks were also observed on the scapula found in the heap (Fig. 4a). This indicates that the bones must have been exposed for a longer time – from a few months to a few years. A better state of preservation characterizes bones and their fragments from lower horizons, from which the pelvis bones (middle and lower layers), spinous process and one vertebral body of a thoracic vertebrae (lowest layer) were found, among others.

Moreover, scratches and breakages suggesting relocation were noticed on single bones. No gnawing marks made by large carnivores or rodents are visible. This evidence suggests that the carcass derived from trench 1/2005 was covered by the sediment soon after the animal death (HAYNES 1991). Some of the bones bear traces of root etching (Fig. 4b). On the basis of this evidence we con-

Table I

Inventory of the excavated mammoth bones during field work in 2005 and 2008. Measurements of mammoth *tibia* and *femur* were taken according to MASCHENKO 2002

Location	Year of excavation	Bone	NISP	Comments
Trench 1/2005	2005	tusk	1	fragment, length = 28.6 cm (K10: Fig. 3)
		thoracic vertebrae	4	four vertebrae; (K19, K20, K21: Fig. 3) two vertebrae are the subsequent vertebrae of one individual
		thoracic vertebra	1	only spinous process
		thoracic vertebra	1	only vertebral body
		lumbar vertebra	1	
		sacrum	2	four sacral vertebrae fused and the fifth one is unfused; (Fig. 7)
		caudal vertebra	1	(K9: Fig. 3)
		vertebra	1	only fragment of vertebral body
		scapula right	1	
		pelvis bones – right and left	2	the maximum width of the pelvic canal = 50.5 cm (Fig 5, "a") the width between midpoints of the acetabula = 54.3 cm (Fig. 5, "b") the thickness of the *ilium* at the point of maximum width of the birth canal = 15.7 cm (Fig 5, "c"); (Fig. 6)
		tibia right	1	shaft length: 46.5 cm, greatest length GL = 53.5 cm, smallest circumference of the diaphysis CD = 9.7 cm; smallest breadth of the diaphysis SD = 28.4 cm, greatest breadth of the proximal end Bp = 19.7 cm, greatest breadth of the distal end Bd = 15.3 cm)
		carpal bone	1	left *capitatum* (K8: Fig. 3)
		tarsal bones	4	right *astragalus* (K7: Fig. 3), right *calcaneus* (K3: Fig. 3), right *cuboideum* (K20: Fig. 3) and left internal *cuneiforme* (K6: Fig. 3)
		unidentified fragments of bones	10	
Earth heap at gravel pit/ uncertain stratigraphic position	2008	tusk	2	fragments
		scapula left	1	
		femur right	1	the ends of the bone are destroyed and it is not visible whether the epiphysis were fused (smallest circumference of the diaphysis CD = 33.4 cm; smallest breadth of the diaphysis SD = 12.6 cm)
		fibula	1	fragment of the shaft, length = 12.5 cm
		ribs	10	fragments
		unidentified frag-ments of bones	28	
Total NISP			74	

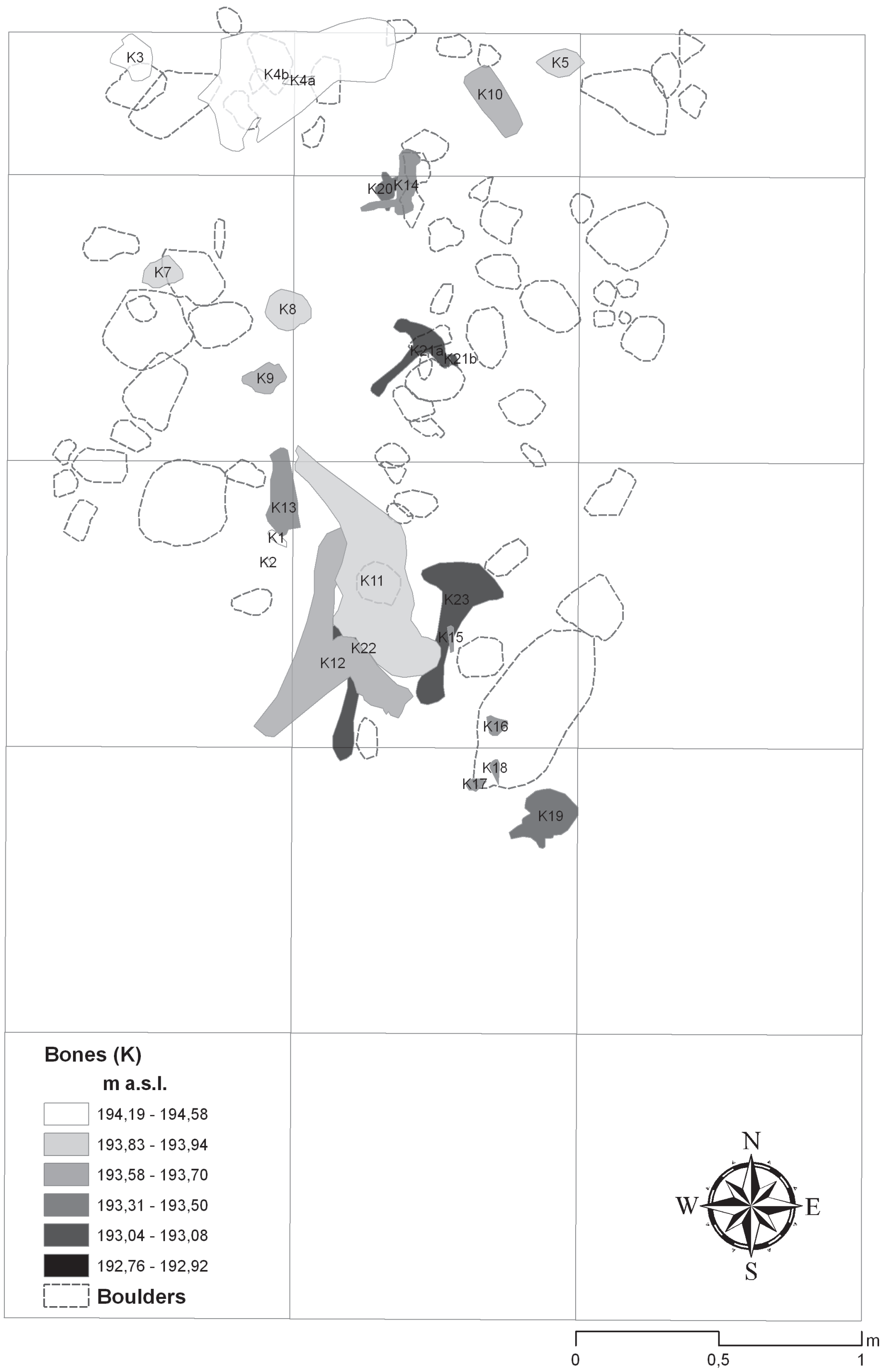

Fig. 3. Spatial distribution of bones (K) and boulders (dotted line) in 1/2005 trench. Drawing by A. MIKOŁAJCZYK.

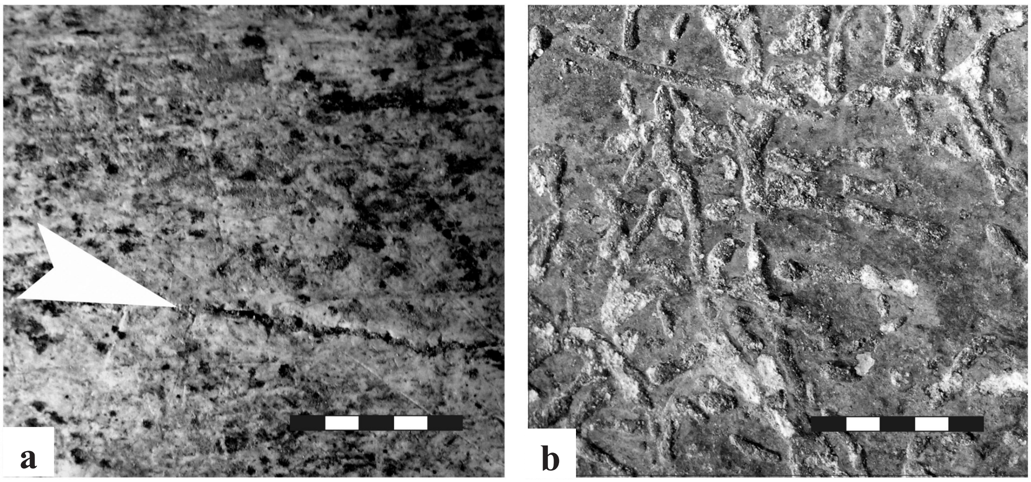

Fig. 4. Microscopic photographs of alterations observed on the surface of bones: a – scratches; b – root etching. Scale: 5 mm. Photo by B. KUFEL.

clude that the bones were redeposited together with colluvial sediments within this depression as a result of intensive slope processes.

Beside the mammoth remains, two well-preserved horse bones belonging to one individual (*Equus* sp.: radius and ulna) were found within the quarry. Their stratigraphical position is uncertain, therefore the chronological link between horse and mammoth bones remains unknown.

Dating of the mammoth bones

One bone (K14, trench 1/2005; Fig. 3) found above the boulder pavement building the bottom of the depression has been selected for the AMS radiocarbon dating. The good preservation of this bone was confirmed by the high content of collagen (6.1%). The radiocarbon age of the bone, about 24 ka (No Poz-16042: 23790±160 years BP), and the stratigraphical position of the overlying horizon of loess suggest that the mammoth died probably before the deposition of aeolian sediments during the Main Pleniglacial (the Leszno stadial).

Determination of the animal age

The most precise method of age determination in elephants and mammoths is based on the stage of molar replacement and wear (LAWS 1966; JACHMANN 1988; ROTH & SHOSHANI 1988; HAYNES 1991). Unfortunately, at the Zastruże site no molars or other cranial elements, with the exception of three tusk fragments, were found. It is not possible to assess the exact age of the animal at the moment of death. However, an alternative method of woolly mammoth individual age determination can be applied based on the epiphyseal fusion sequence of long limb bones, innominate bones, on the fusion of sacrum bones and their fusion to the pelvis. The long-bone epiphyses of the mammoth were fusing, as in extant elephants, over an extended period of time and different epiphyses and bones of the skeleton fused at a different age of the animal (HAYNES 1991; LISTER 1999).

The only complete long bone that was found in the Zastruże site is the tibia, with both epiphyses fused to the diaphysis. According to HAYNES (1991) mammoth females had proximal tibia epiphysis fused to the diaphysis at the age of 18-24 and distal epiphysis fused at the age of 19, while males had both epiphysis fused before they were 32 years old. Taking into account the above data we conclude that mammoth from Zastruże must have been at least 18 years old. The sacrum was not fused to the pelvis bones, therefore it could not be older than 50. On the basis of the aforementioned results we can only state that the mammoth remains found in trench 1/2005 at the Zastruże site belong to an adult individual aged 18-50 years.

Although various pathological changes are known in mammoth bones, especially in older individuals (e.g. KRZEMIŃSKA 2008, 2009, unpublished data), no such changes are recognizable on bones from the Zastruże site.

Sex determination

Mammoths showed a great deal of sexual dimorphism. In general, males were larger than females, therefore the sex of an animal can be determined based on anatomical measurements (HAYNES 1991). It is also possible to distinguish males from females based on the pelvic proportions (Fig. 5). Females had a relatively wider birth canal and thinner ilium (HAYNES 1991; LISTER & BAHN 2007; LISTER 2009). According to HAYNES (1991) the differences of innominate proportions are similar for mammoth *Mammuthus*, mastodon *Mammut* and extant African elephant *Loxodonta*. In *Loxodonta* the maximum width of the pelvic canal is similar in both sexes (about 40 cm for adult individuals) (Fig 5, "a"). In female skeletons it is equal to the width between midpoints of the acetabula, while in males this width is greater (about 50 cm) (Fig. 5, "b"). Also the thickness of the ilium at the point of the maximum width of the birth canal is greater in males than in females (Fig. 5, "c"). In females it never exceeds 16 cm, while in males over the age of twelve years it is rarely less than 16 cm.

At Zastruże one complete pelvis of the 18-50 year old individual was found (Fig. 6). In this individual the maximum width of the pelvic canal (Fig 5, "a") is 50.5 cm and the width between midpoints of the acetabula (Fig. 5, "b") is 54.3 cm, thus they are almost equal. These values fit within the known interindividual variation. The thickness of the ilium at the point of maximum width of the birth canal (Fig. 5, "c") is 15.7 cm, which is close to the upper extreme value in females and to the lower extreme in males (HAYNES 1991).

In woolly mammoth males the pelvic canal is relatively smaller, and the thickness of the ilium is wider than in females. Therefore, the sexes can be distinguished by the ratio between these two measurements, which is always higher for females. According to LISTER (2009) the ratio for females is 2.63-2.86 (for a sample of four woolly mammoth females) and for males 1.92-2.38 (for a sample of ten males). The ratio for mammoth from Zastruże site is 3.22, which is very high and therefore indicates a female.

Summarizing, these data indicate that the Zastruże skeleton from trench 1/2005 probably represents a rather large female.

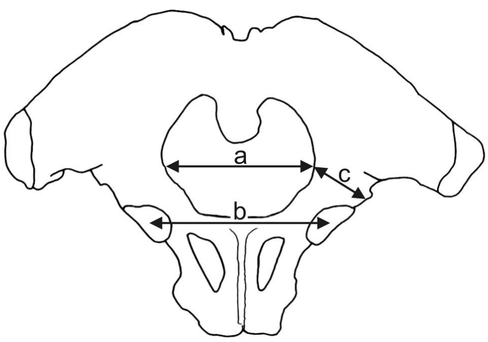

Fig. 5. Measurements of the woolly mammoth innominate after HAYNES (1991): a – maximum width of the pelvic canal, b – the innominate width between midpoints of acetabula, c – the thickness of the ilium at the point where measurement "a" was taken, measured perpendicular to the long axis of the ilium.

Fig. 6. Innominate and sacrum bones of woolly mammoth from Zastruże. Scale is 10 cm (originally published in WIŚNIEWSKI et al. 2009).

Possible human factor in the mammoth's death

The radiocarbon age of the mammoth bones from Zastruże links them with the younger phase of the Gravettian complex. The closest remains of a Gravettian hunters camp are known from the Henryków 15 site, situated 50 km south-east of the Zastruże site (Fig. 1; PŁONKA & WIŚNIEWSKI 2004). However, the TL dating and archaeological evaluation suggests that they are probably older than the remains from Zastruże (personal communication of Andrzej WIŚNIEWSKI). Very similar dates, about 23-24 ka, were obtained for the Kraków Spadzista Street (B) site, where a few dozen woolly mammoths had been killed and butchered by Gravettian hunters (WOJTAL 2007; WOJTAL & SOBCZYK 2005).

The bones from Zastruże were examined for the stone tool cut marks and green bone fractures characteristic of human activity, but without a positive result. Although recent ethnoarchaeological experiments show that it is possible to dismember an elephant body with stone tools without leaving any marks on bones (FRISON & TODD 1986; HAYNES 2006), the possibility that the mammoth from Zastruże was killed and butchered by Palaeolithic hunters can probably be excluded. This assumption is based on the fact that at the Zastruże site only a single stone artefact, a flint blade with unknown stratigraphic position was found and it is not possible to state with certainty whether it comes from the same layer as the bones. Moreover, archaeological field surveys conducted around the site in 2007 did not yield any Palaeolithic artefacts.

Stable isotope study

For stable oxygen isotope analysis four samples from well-preserved but highly fragmented woolly mammoth bones were collected. All four samples were taken from undetermined bone fragments found within the excavation during the operation of the gravel pit in 2008. The best-preserved sections of bones were crushed manually and then powdered. Phosphates were chemically extracted in the form of silver phosphate (STEPHAN 2000; using a buffer as per WIEDEMANN-BIDLACK et al. 2008) and the stable oxygen isotope composition ($\delta^{18}O_P$) of Ag_3PO_4 was analyzed utilizing a TC/EA coupled to a Thermo Finnigan DeltaPlus XL, with precision over 0.3‰. The raw values were reduced to the international VSMOW scale using multipoints normalization techniques (PAUL et al. 2007) based on standards provided by the International Atomic Energy Agency (IAEA): IAEA601, IAEA602, IAEA CH6, and IAEA C3. The quality of the obtained results was verified using the NBS 120c standard treated in the same way as the samples. The bone carbonates were analyzed using a Thermo Finnigan Gasbench II coupled with a Thermo Finnigan DeltaPlus XL mass spectrometer (SKRZYPEK & PAUL 2006), following purification procedure. The raw δ-values were reduced to the international VPDB scale using a multipoints (L-SVEC, NBS19 and NBS18) normalization technique (PAUL et al. 2007). The obtained $\delta^{18}O_C$ values were recalculated to the VSMOW scale. The external reproducibility for the stable carbon isotope composition was better than 0.1‰ and the stable oxygen isotope composition better than 0.2‰. Good preservation of original stable isotope composition was confirmed in three of four analyzed samples following LECUYER et al.'s (2010) cross-checking procedure $\delta^{18}O_P$ of phosphates against $\delta^{18}O_C$ carbonates.

The obtained $\delta^{18}O_P$ values of three unaltered samples are 12.7, 13.3 and 13.5‰ (for all stable isotope results see the Table II). These results suggest that the analyzed fragments of bones likely belonged to two different individuals living during two periods characterized by different temperature. It must also be borne in mind that the samples were obtained from bones derived from the destroyed part of the depression. In this context it cannot be excluded that skeletons of some other mammoth individuals were present in this part of the site.

Table II

The stable oxygen isotope composition of bone phosphates and carbonates for the woolly mammoth. The stable oxygen isotope composition of environmental water calculated using the equation by AYLIFFE et al. (1992). The annual mean air temperature calculated based on the relationship between the stable oxygen isotope composition of precipitation and air temperature for Kraków and for all of continental Europe GNIP/IAEA stations, respectively

Sample ID	$\delta^{18}O_P$ phosphates [‰, VSMOW]	$\delta^{13}C_C$ carbonates [‰, VPDB]	$\delta^{18}O_C$ carbonates [‰, VSMOW]	$\delta^{18}O_W$ env water [‰, VSMOW]	Temperature MAT [°C] Kraków /PL	Temperature MAT [°C] Europe	Comments
UWR 33 (B22/2008)	12.7	-12.7	19.5	-11.3	5.7	5.7	fair preservation
UWR 34 (B35/2008)	13.3	-11.3	20.9	-10.6	6.8	6.6	good preservation
UWR 35 (B36/2008)	13.5	-11.4	20.7	-10.4	7.2	6.9	good preservation
UWR 36 (B37/2008)	14.8	-13.0	20.1	–	–	–	isotope composition alerted
mean ± SD	13.6 ± 0.9	-12.1 ± 0.9	20.3 ± 0.6	-10.8 ± 0.4	6.6 ± 0.8	6.4 ± 0.6	

Fig. 7. Sacrum and caudal vertebra of woolly mammoth from Zastruże. Scale is 10 cm.

The stable oxygen isotope composition of mammal bone phosphate reflects the stable isotope composition of drinking water (LONGINELLI 1984). The main source of drinking water for animals are surface waters. In moderate climates, the stable isotope composition surface water is directly linked with the isotope composition of precipitation. The $\delta^{18}O$ value of precipitation is governed by several environmental factors such as origin of water vapor, altitude, distance from coast, etc. (RÓŻAŃSKI et al. 1993). However, in a particular location, air temperature during precipitation plays a greater role. Therefore, the $\delta^{18}O$ of bone phosphates can be successfully utilized for palaeo-reconstructions of annual mean air temperature (MAT) during the animal's lifetime (e.g. TÜTKEN et al. 2007).

The metabolic rate of animals influencing the stable oxygen isotope composition differs between species and depends mainly on body mass and type of activity. According to AYLIFFE et al. (1992), the environmental water $\delta^{18}O_W$ can be calculated based on mammoth bones utilizing the equation $\delta^{18}O_W = (\delta^{18}O_P - 23.3)/0.94$ obtained during experimental studies on the Elephantidae. Accordingly, the environmental water available for these animals had $\delta^{18}O_W$ values equaling -10.4, -10.6 and -11.3‰. The current annual mean $\delta^{18}O$ value of precipitation in the Polish lowlands is around -9‰. Values above -10 and -11‰ are characteristic for central Sweden or Finland (BOWEN 2010; BOWEN & WILKINSON 2002).

The calculated $\delta^{18}O_W$ value can be used for estimation of the annual mean air temperature (MAT); however, the relationship between $\delta^{18}O_W$ and T_{air} has to been known for a particular location and a stable and similar to current meteorological circulation has to be assumed for past periods. The closest monitoring station is located in Kraków (GNIP/IAEA 1975-2002, DULIŃSKI et al. 2001), about 300 km east from Zastruże. The utilization of the equation calculated for Kraków ($T_{air} = 1.80\times \delta^{18}O_W + 26.02$) allows the calculation of MAT at 5.7, 6.8 and 7.2°C. Very similar results are obtained when the general equation ($T_{air} = 1.41\times \delta^{18}O_W + 21.6$) describing the T_{air} - $\delta^{18}O_W$

relationship for all of continental Europe based on all GNIP/IAEA stations is used: 6.6, 6.9 and 5.7°C, respectively. In view of these results the estimated MAT temperature based on the analyzed animal remains and GNIP data for Kraków varied around 6.6±0.8°C for the studied period.

III. CONCLUSIONS

The Zastruże woolly mammoth remains belong to a 18-50 year old female which lived about 24,000 years ago. The skeleton is not complete; however many bones are very well preserved including shoulder blades, pelvis bones, vertebrae and limb bones. The very good preservation can be attributed to quick burial of the animal remains after death and short-distance transport, due to favourable geological conditions on the valley slope. The dating of the mammoth bones and the stratigraphical position of the overlying horizon of loess suggests that the mammoth died probably before the deposition of aeolian sediments during the Main Pleniglacial (Leszno stadial). However, the reason for death remains uncertain. In the light of the isotopic study it can be concluded that this assemblage comprises remains of more than one individual. The average stable oxygen isotope composition of water drunk by the Zastruże mammoths during their whole lifetime was -10.8± 0.4‰, reflecting an approximate annual mean air temperature about +6.6±0.8°C.

The discovery from Zastruże belongs to a complex of sites characterized by a considerable number of remains represented by at least one individual of mammoth found within the stratigraphical context. Nevertheless, sites with a well-recognized stratigraphical position are still scarce in Poland. Therefore, Zastruże can be considered as a regional palaeoclimate benchmark.

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REFERENCES

AYLIFFE L. K., LISTER A. M., CHIVAS A. R. 1992. The preservation of glacial-interglacial climatic signatures in the oxygen isotopes of elephant skeletal phosphate. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **99**: 179-191.

BEHRENSMEYER A. K. 1978. Taphonomic and ecologic information from bone weathering. *Paleobiology*, **4**(2): 150-162.

BOWEN G. J. 2010. The Online Isotopes in Precipitation Calculator, version 2.2. http://www.waterisotopes.org

BOWEN G. J., WILKINSON B. 2002. Spatial distribution of $\delta^{18}O$ in meteoric precipitation. *Geology*, **30**: 315-318.

CHMIELEWSKI W., KUBIAK H. 1962. The find of mammoth bones at Skaratki in the Łowicz district. *Folia Quternaria*, **10**: 1-45.

CZERWONKA J. A., KRZYSZKOWSKI D. 2001. Preglacial (Pliocene - Early Middle Pleistocene) deposits in southwestern Poland: lithostratigraphy and reconstruction of drainage pattern. [In:] D. KRZYSZKOWSKI (ed.) – Late Cainozoic Stratigraphy and Palaeogeography of the Sudetic Foreland. WIND J. Wojewoda: 147-195, Wrocław.

DULIŃSKI M., FLORKOWSKI T., GRABCZAK J., RÓŻAŃSKI K. 2001. Twenty-five years of systematic measurements of isotopic composition of precipitation in Poland. *Przegląd Geologiczny*, **49**: 250-256.

FRISON G. C., TODD L. C. 1986. The Colby Mammoth Site: Taphonomy and Archaeology of a Clovis Kills in Northern Wyoming. Albuquerque, 238 pp.

HAYNES G. 1991. Mammoths, Mastodonts and Elephants: Biology, Behavior, and the Fossil Record. Cambridge University Press, 413 pp.

HAYNES G. 2006. Mammoth landscapes: good country for hunter-gatherers. *Quaternary International*, **142-143**: 20-29.

IAEA/WMO 2006. Global Network of Isotopes in Precipitation. The GNIP Database. http://isohis.iaea.org; and The WISER database http://nds121.iaea.org/wiser

JACHMANN H. 1988. Estimating age in African elephants: a revision of Law's molar evaluation technique. *African Journal of Ecology*, **26**: 51-56.

JAKUBOWSKI G. 1973. Znalezisko kości mamuta w Warszawie. *Przegląd Geologiczny*, **8-9**: 476-479.

KALICKI T., KOZŁOWSKI J. K., KRZEMIŃSKA A., SOBCZYK K., WOJTAL P. 2007. The formation of mammoth bone accumulation at the Gravettian site Kraków-Spadzista B+B1. *Folia Quaternaria*, **77**: 5-30.

KOWALSKI K. 1959. Katalog Ssaków Plejstocenu Polski. Państwowe Wydawnictwo Naukowe. Warszawa, 267 pp.

KOZŁOWSKI J. K, KUBIAK H., WELC A. 1970. A Palaeolithic site with mammoth remains at Nowa Huta (Cracow, Poland). *Folia Quaternaria*, **36**: 1-20.

KRZEMIŃSKA A. 2008. Preliminary characteristics of pathologies found in the skeletons of mammoths at the Kraków Spadzista Street (B) site. *Veterinarija ir zootechnika*, **43**(65): 52-57.

KRZEMIŃSKA A. 2009. Pathologies of mammoth bones from Milovice Site. [In:] M. OLIVA (ed.) – Milovice: Site of the mammoth people below the Pavlov Hills. *Studies in Anthropology, Palaeoethnology, Palaeontology and Quaternary Geology*, Vol. 27, N.S. 19. Moravske Zemske Muzeum, Brno, Pp: 118-125.

KRZYSZKOWSKI D. 2001. Neogene and pleistocene stratigraphy and paleogeography of the northern foreland of the Strzegom Hills, Sudetic Foreland, Southwestern Poland. [In]: KRZYSZKOWSKI D. (ed.) – Late Cainozoic Stratigraphy and Palaeogeography of the Sudetic Foreland. WIND J. Wojewoda: 25-47; Wrocław.

KRZYSZKOWSKI D., ALEXANDROWICZ W. P., BLUSZCZ A., CHOMA-MORYL K., GOSLAR T., HERCMAN H., JĘDRYSEK M., NAWROCKI J., PAZDUR A. 2001. Middle and Late Weichselian stratigraphy and palaeoenvironments at Jaroszów, Southwestern Poland. [In]: D. KRZYSZKOWSKI (ed.) – Late Cainozoic stratigraphy and palaeogeography of the Sudetic Foreland. WIND J. Wojewoda: 49-72Wrocław.

KUBIAK H. 1965. Słonie kopalne Polski południowej. *Folia Quaternaria*, **19**: 1-43.

KUBIAK H., ZAKRZEWSKA G. 1974. Fossil mammals. [In:] KOZŁOWSKI J. K., KUBIAK H., SACHSE-KOZŁOWSKA E., VAN VLLIET B., ZAKRZEWSKA G. Upper Paleolithic site with dwellings of mammoth bones-Cracow, Spadzista Street B. *Folia Quaternaria*, **44**: 77-95.

KULCZYCKI J. 1955. Les ossements des mammouths. *Palaeontologia Polonica*, **7**: 1-65.

LAWS R. M. 1966. Age criteria for the African elephant, *Loxodonta a. africana*. *East African Wildlife Journal*, **4**.

LECUYER C., BALTER V., MARTINEAU F., FOUREL F., BERNARD A., AMIOT R., GARDIEN V., OTERO O., LEGENDRE S., PANCZER G., SIMON L., MARTINI R. 2010. Oxygen isotope fractionation between apatite-bound carbonate and water determined from controlled experiments with synthetic apatites precipitated at 10-37°C. *Geochimica et Cosmochimica Acta*, **74**: 2072-2081.

LISTER A. M. 1999. Epiphyseal fusion and postcranial age determination in the woolly mammoth *Mammuthus primigenius*. *Deinsea*, **6**: 79-87.

LISTER A. M. 2009. Late-glacial mammoth skeletons (*Mammuthus primigenius*) from Condover (Shropshire, UK): anatomy, pathology, taphonomy and chronological significance. *Geological Journal*, **44**: 447-479.

LISTER A. M., BAHN P. G. 2007. Mammoths, Giants of the Ice Age. Frances Lincoln Limited Publishers, London, 192 pp.

LONGINELLI A. 1984. Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research? *Geochimica et Cosmochimica Acta*, **48**: 385-390.

LYMAN R. L. 1994. Vertebrae Taphonomy. Cambridge: Cambridge University Press, 524 pp.

MASCHENKO E. N. 2002. Individual development, biology and evolution of the wooly mammoth *Mammuthus primigenius* (BLUMENBACH, 1799). *Cranium*, **19**(1), 120pp.

PAUL D., SKRZYPEK G., FORIZS I. 2007. Normalization of measured stable isotope composition to isotope reference scale – a review. *Rapid Communications in Mass Spectrometry*, **21**: 3006-3014.

PŁONKA T., WIŚNIEWSKI A. 2004. New Gravettian Site in Lower Silesia (SW Poland). [In]: J. SVOBODA, L. SEDLÁČKOVÁ (eds) – The Gravettian along the Danube. *The Dolní Věstonice Studies*, **10**: 164-179.

ROTH V. L., SHOSHANI J. 1988. Dental identification and age determination in *Elephas maximus*. *Journal of Zoology*, **214**: 567-588.

RÓŻAŃSKI K., ARAGUAS-ARAGUAS L., GONFIANTINI R. 1993. Isotopic patterns in modern global precipitaion. In: Climate Change in continental isotopic records. [In:] SWART P. K, LOHMANN K. C, MCKENZIE J., SAVIN S., SCHURCH M., KOZEL R., SCHOTTERER U., TRIPET J.-P. 2003. Observation of Isotopes in the Water Cycle – the Swiss National Network (NISOT). *Environmental Geology*, **45**: 1-11.

SKRZYPEK G., PAUL D. 2006. d^{13}C Analyses of Calcium Carbonate: Comparison between the GasBench and Elemental Analyzer Techniques. *Rapid Communications in Mass Spectrometry*, **20**: 2915-2920.

STEPHAN E. 2000. Oxygen Isotope Analysis of Animal Bone Phosphate: Method Refinement, Influence of Consolidants, and Reconstruction of Palaeotemperatures for Holocene Sites. *Journal of Archaeological Science*, **27**: 523-535.

TÜTKEN T., FURRER H., VENNEMANN T. W. 2007. Stable isotope compositions of mammoth teeth from Niederweningen, Switzerland: implications for the Late Pleistocene climate, environment and diet. *Quaternary International*, **164-165**: 139-150.

WIEDEMANN-BIDLACK F. B, COLMAN A. S., FOGEL M. L. 2008. Phosphate oxygen isotope analysis on microsamples of bioapatite: removal of organic contamination and minimization of sample size, *Rapid Communications in Mass Spectrometry*, **22**: 1807-1816.

WISZNIOWSKA T., SOCHA P., STEFANIAK K. 2003. Szczątki kostne zwierząt plejstoceńskich i holoceńskich z Wrocławia Oporowa. [In:] A. WIŚNIEWSKI, J. WINNICKI, A. SZYNKIEWICZ, A. TRACZYK, T. KUSZELL, W. PYSZYŃSKI, S. BRAŃSKI, T. WISZNIOWSKA, P. SOCHA, K. STEFANIAK, Z. JARY, C. KABAŁA,

A. BLUSZCZ, A. PAZDUR, R. KRZYMINIEWSKI, M. WENCKA, J. BRONOWICKI – Wrocław Oporów. Najstarsze ślady osadnictwa i środowisko przyrodnicze. *Studia Archeologiczne*, **33**: 119-140.

WIŚNIEWSKI A. 2005. The oldest settlement in Odra Valley (SW Poland). [In:] N. MOLINES, M.-H. MONCEL, J.-L. MONNIER (eds) – Les premiers peuplements en Europe: colloque international, Rennes, 22-25 septembre 2003. Oxford, John and Erica Hedges Ltd: 349-359.

WIŚNIEWSKI A. 2006. Środkowy paleolit w dolinie Odry. Wydawnictwo Uniwersytetu Wrocławskiego, Wrocław, 260 pp.

WIŚNIEWSKI A., WINNICKI J., SZYNKIEWICZ A., TRACZYK A., KUSZELL T., PYSZYŃSKI W., BRAŃSKI S., WISZNIOWSKA T., SOCHA P., STEFANIAK K., JARY Z., KABAŁA C., BLUSZCZ A., PAZDUR A., KRZYMINIEWSKI R., WENCKA M., BRONOWICKI J. 2003. Wrocław Oporów. Najstarsze ślady osadnictwa i środowisko przyrodnicze, *Studia Archeologiczne* **33**.

WIŚNIEWSKI A., WOJTAL P., KRZEMIŃSKA A., ZYCH J., PRZYBYLSKI B., BADURA J., CISZEK D. 2009. Unikalne stanowisko szczątków mamuta na Dolnym Śląsku, *Przegląd Geologiczny*, **57**: 234-242.

WOJEWODA J., MIGOŃ P., KRZYSZKOWSKI D. 1995. Rozwój rzeźby i środowisk sedymentacji w młodszym trzeciorzędzie i starszym plejstocenie na obszarze środkowej części bloku przedsudeckiego: wybrane fragmenty. Przewodnik 66 Zjazdu PTG, Wrocław, pp. 315-331.

WOJTAL P. 2007. Zooarchaeological studies of the late Pleistocene sites in Poland. Institute of Systematics and Evolution of Animals of the Polish Academy of Sciences, Kraków, 189 pp.

WOJTAL P., SOBCZYK K. 2005. Man and woolly mammoth at the Kraków Spadzista Street (B) – taphonomy of the site. *Journal of Archaeological Science*, **32**: 193-206.