



On the hindfoot bones of *Mammuthus trogontherii* from Shanshenmiaozi in Nihewan Basin, China



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ABSTRACT

Shanshenmiaozi is an open-air fossil site of Early Pleistocene age in Nihewan Basin, China. During 2006–2011, nearly 100 fossil specimens of *Mammuthus trogontherii* were unearthed, including some series of tarsal, metatarsal and phalange bones of immature individuals, which represent the first discovery of hindfoot bones of immature *M. trogontherii*. Morphologically, the new tarsals are intermediate between those of *Mammuthus meridionalis* and *Mammuthus primigenius*. However, they have some possible differences from those of *Palaeoloxodon antiquus*: the relatively quadrangled plantar surface of the astragalus; the relatively flat cuboid facet on calcaneum; and the special configuration of the distal facets on ectocuneiform. With reference to the age determination by teeth, the footbone remains can be categorized into three age groups: newborn calf, juvenile, and subadult, approximately corresponding to one month old, 6–7 years old, and 10–20 years old individuals, respectively. The ontogenetic changes of the hindfoot bones can be detected in their size, morphology, compact layer, and epiphyseal fusion. There are possibilities of proximal epiphyses on metatarsals and distal epiphyses on phalanges, which is unusual in other mammals, but reasonable in elephants because of their lengthy growth period.

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1. Introduction

In the evolution of mammoth lineage, *Mammuthus trogontherii* is an intermediate species between the *Mammuthus meridionalis* and *Mammuthus primigenius* (Lister, 1993, 1996; Lister et al., 2005). The Nihewan Basin, which is located in the upland bordering the North China Plain, has attracted special attention for the origin of *M. trogontherii* (Wei et al., 2010). In Nihewan Basin the fossils from Majuangou site represent the earliest record of *M. trogontherii* in the world, dated back to 1.66 Ma (Wei et al., 2003; Zhu et al., 2004). During 2006–2011, the excavations at the Shanshenmiaozi site provided more abundant material of *M. trogontherii*, especially specimens of calf individuals (Tong, 2012; Tong and Chen, 2016). In 2011 some immature hindfoot bones which had never been found in the world were unearthed from Shanshenmiaozi. They could be

attributed to the *M. trogontherii* as the only identified elephant in Shanshenmiaozi. In this paper we describe these rare hindfoot bones and investigate their morphological and ontogenetic significance.

The Shanshenmiaozi site lies at the core area of Nihewan Basin, surrounded by a series of Early Paleolithic sites (Hou and Zhao, 2010; Keates, 2010; Dennell, 2013). The fossils were unearthed from a 1-m thick sand-silt bed (Tong et al., 2011), which belongs to the fluvio-lacustrine sedimentary sequence of Nihewan Bed. The paleomagnetic age of the fossil layer is 1.2 Ma (Liu et al., 2016). The mammalian fauna includes *Lepus* sp., *Ochotona* sp., *Canis chihliensis*, Felidae gen. et sp. indet., *Pachycrocuta* sp., *M. trogontherii*, *Coelodonta nihewanensis*, *Elasmotherium peii*, *Probo-scidipparion* sp., *Equus sanmeniensis*, *Sus* sp., *Eucladoceros* sp., *Spi-rocerus wongi*, *Gazella sinensis* and *Bison palaeosinensis* (Tong et al., 2011).

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2. Methods and abbreviations

2.1. Methods

The measurements follow the methods described by Göhlich (1998), Von den Driesch (1976), and Ziegler (2001). The measurements of the bones were taken with sliding calipers or measuring box and are given in millimeters. “Breadth” stands for the medio-lateral diameter; “length” stands for the proximodistal diameter;

3.1. Studied material

A total of 24 foot bones are included in this study (Table 1). These bones can be classified to 3 size-groups. The bones of each size-group are scattered in a particular square inside the excavation area, but most of the elements could match with one another when brought together. Based on their size and morphology, we correlate these 3 size-groups with the newborn calf, juvenile and subadult age groups, respectively.

Table 1

Fossil material of *M. trogontherii* studied in this paper.

Specimen	Field number	Catalog number	Square and horizon	Side	Ontogenetic stage
Astragalus	N-11-107	V18010.26	G21-8	Sin	II
Astragalus	N-11-171-c	V18010.27	H20-9	Dex	III
Astragalus	N-11-134-1	V18010.28	G24-8	Sin	III
Calcaneum	N-11-216	V18010.29	H20-9	Dex	I
Calcaneum	N-11-094	V18010.30	F20-8	Sin	II
Calcaneum	N-11-171-d	V18010.31	H20-9	Dex	III
Calcaneum	N-06-235	V18010.32	D11-6	Dex	III
Calcaneum	N-11-134-2	V18010.33	G24-8	Sin	III
Navicular	N-11-258	V18010.34	H20-10	Dex	I
Navicular	N-11-226	V18010.35	H21-9	Sin	II
Navicular	N-11-171-a	V18010.36	H20-9	Dex	III
Entocuneiform	N-11-219-3	V18010.37	H20-9	Dex	III
Mesocuneiform	N-11-219-2	V18010.38	H20-9	Dex	III
Ectocuneiform	N-11-219-1	V18010.39	H20-9	Dex	III
Cuboid	N-11-171-b	V18010.40	H20-9	Dex	III
Mt II	N-11-233	V18010.41	H20-10	Sin	I
Mt II	N-11-117	V18010.42	G21-8	Dex	II
Mt III	N-11-217	V18010.43	H20-9	Sin	I
Mt III	N-11-109	V18010.44	F21-8	Dex	II
Mt III	N-11-173	V18010.45	H20-9	Sin	III
Mt IV	H20-9-b	V18010.46	H20-9	Sin	I
Mt IV	N-11-198;	V18010.47	G21-9	Dex	II
Phalanx	n-11-274	V18010.48	H22-9	Sin?	I
Phalanx	n-11-145	V18010.49	H22-8	Dex?	II

and “depth” stands for the dorsoplantar diameter. The CT image was taken with the 225 kV micro-computerized tomography of IVPP.

The ontogenetic stages follow the age categorizations provided by Sikes (1971) for *L. africana*, which includes the following age groups: calf (0–5 years old), juvenile (5–10 years old), subadult (10–20 years old), prime adult (20–40 years old), and senior adult (>40 years old).

2.2. Abbreviations

CKT: Chou-kou-tien (=Zhoukoudian) locality, China; **DEX:** dexter (right); **IVPP:** Institute of Vertebrate Paleontology and Paleoanthropology; **KIZ:** Kunming Institute of Zoology; **Loc:** locality; **Mt:** metatarsal; **SIN:** sinister (left); **SSMZ:** Shanshenmiaozui Locality; **V:** Catalog-Number-Prefix in IVPP.

3. Systematic paleontology

Class Mammalia Linnaeus, 1758

Order Proboscidea Illiger, 1811

Suborder Elephantiformes Tassy, 1988

Superfamily Elephantoidae Gray, 1821

Family Elephantidae Gray, 1821

Genus Mammuthus Brookes, 1828

Mammuthus trogontherii (Pohlig, 1885)

3.2. Compared materials

Comparative data are from the following sources: *M. trogontherii* from such sites as Untermassfeld (Dubrovo, 2001), West Runton (Lister and Stuart, 2010), Loussika (Athanassiou, 2012), Azovland AzovII (Baygusheva et al., 2012) and Kostolac (Lister et al., 2012); *M. meridionalis* from Leu (Popescu, 2011) and Rodionovo (Maschenko et al., 2011); *M. primigenius* from Rottweil (Ziegler, 2001); *Palaeoloxodon antiquus* from Upnor (Andrews and Cooper, 1928) and CKT Loc.9 (Teilhard de Chardin, 1936); *Elephas maximus*: KIZ-1, 20–30 h old and KIZ-2, 2–3 years old.

3.3. Locality

Shanshenmiaozui, Yangyuan, Hebei, China.

3.4. Horizon

Lower Pleistocene, around 1.2 Ma.

The strata are consisted of the eolian loess and fluvio-lacustrine Nihewan Bed, with a thickness of 72 m. The fossiliferous layer is 1-m thick sand-silt bed, near to the bottom of Nihewan Bed.

3.5. Descriptions

3.5.1. Astragalus

No: V18010.26, juvenile (Fig. 1A; Table 2). This bone is perfectly preserved. Despite the neck and sulcus, the surface is full of

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