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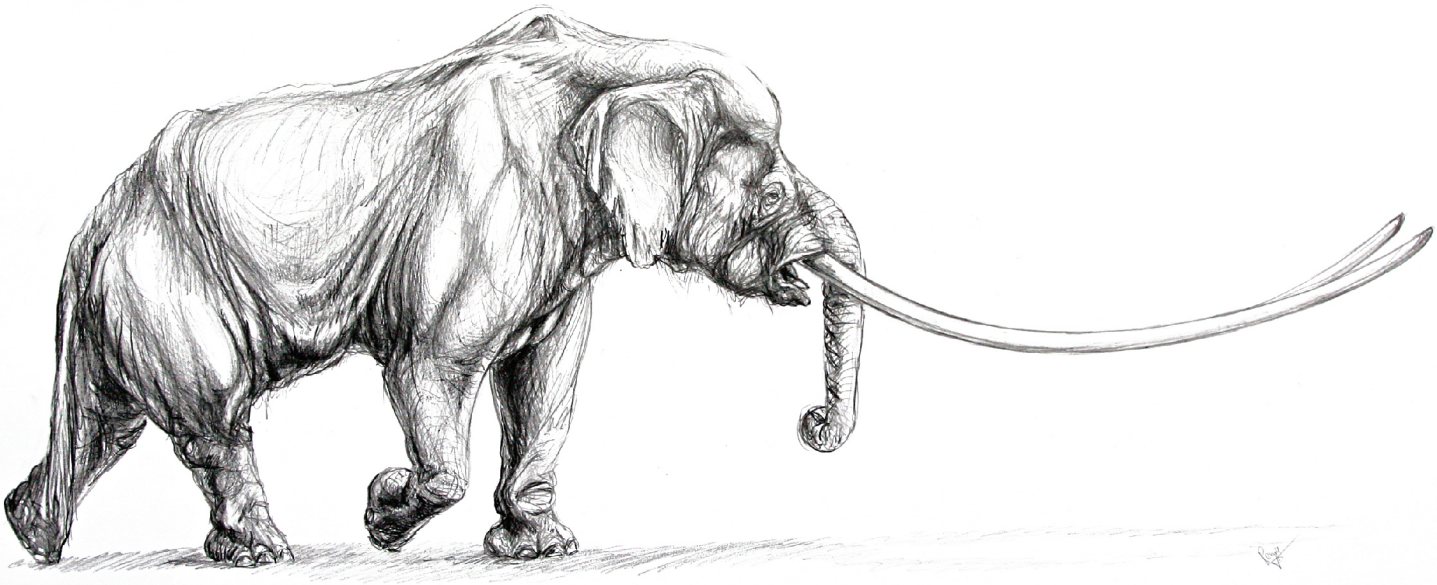

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ABSTRACT BOOK

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Preserved brain of the woolly mammoth *Mammuthus primigenius* (Blum. 1799) from the Yakutian Permafrost

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The mummified carcass of a Woolly mammoth (*Mammuthus primigenius* (Blumenbach 1799)) nicknamed "Yuka" was found in August 2010 in nothern Yakutia, Russia (for details see Maschenko et al. 2012). It was dated by 14C at 39,440 - 38,850 cal. BP (Boeskorov et al. 2013). This specimen represents an individual 6-9 years old and is unique in possessing a preserved brain with well-defined gross anatomical features. We provide data on Yuka's brain morphology obtained with computed tomography (CT), magnetic resonance imaging (MRI), and classical anatomical methods.

Yuka's brain was revealed by a CT scan of the whole cranium done in Yakutsk in May 2012. The brain was then fixed with formalin solution inside the cranium. We applied the "flowing fixation" method over the course of three weeks during February 2013. The brain with meninges was removed from the neurocranium at the end of February 2013. A second CT

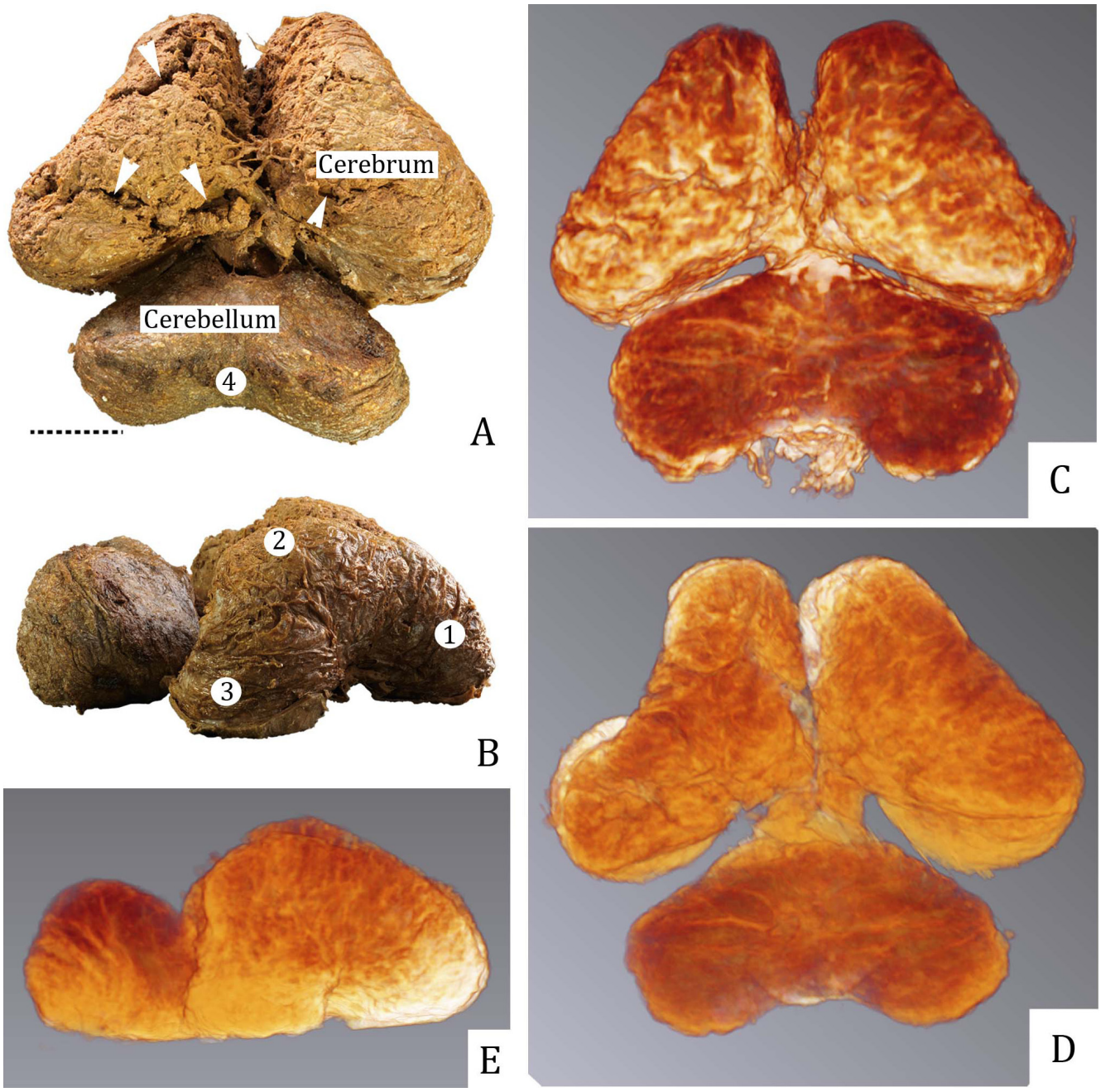

Fig. 1. **A-B**, The Yuka's brain from dorsal (bar=5cm), and lateral view. The 3D reconstructions of the Yuka's brain from dorsal view according to Yakutsk CT (**C**) and Moscow CT (**D**) and from lateral view (**E**, Moscow CT). The damages of the cerebrum surface: the left hemisphere had two large splits and right hemisphere had small one (arrows).

1, *lobus frontalis telencephali*; **2**, *lobus parietalis telencephali*; **3**, *lobus temporalis telencephali*; **4**, *cerebellar vermis*.

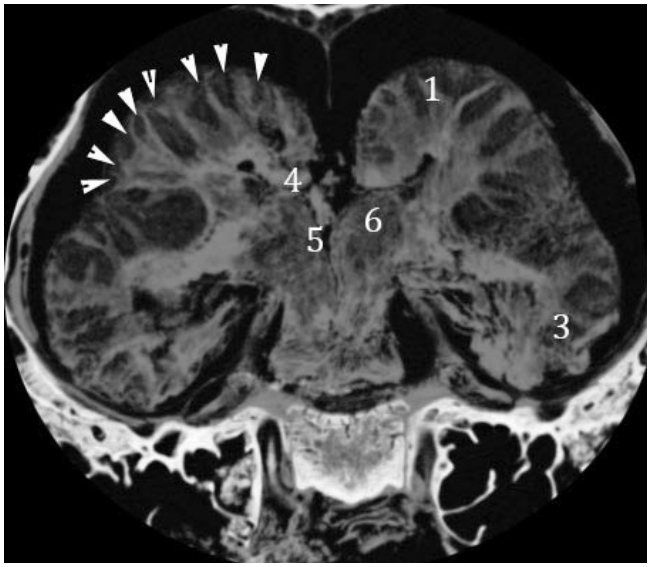

Fig. 2. The frontal (coronal) CT-scan (Yakutsk CT): structure of the white-gray matter reflects the gyri and sulci patterns of the cerebrum, as a result the position of sulcus can be reconstructed (arrows).

1, *lobus frontalis telencephali*; **3**, *lobus temporalis telensephali*; **4**, *corpus callosum* (damaged); **5**, *ventriculus tertius*; **6**, *thalamus*.

and the MRI were performed in March 2013, in Moscow. After all noninvasive data collection, the dura matter was removed, and the brain was anatomically sliced. Yuka's brain was preserved as a whole morphological structure (Fig. 1A-B) but was in poor condition due to shrinkage and oxidation processes. The caudal part of the brainstem including the medulla oblongata was not preserved. The cerebrum had several surface ruptures (Fig. 1A). The olfactory region, including the olfactory bulbs, was also partly damaged. The remnants of the basal part of the olfactory bulbs and the olfactory nerves remained in the bulbus olfactorius cavity above the lamina cribrosa after the brain was removed.

The external morphology of Yuka's brain was described. The general brain morphology of this specimen resembles that observed in modern elephants. Data suitable for anatomical description of internal brain structures and for volumetric procedures were obtained with CT and MRI. A three-dimentional model of Yuka's brain was made (Fig. 1C-E). The detailed structure of the gyri and sulci of the cerebrum was not clear in external view but was reconstructed manually from serial CT scans (Fig. 2).

The volume of Yuka's brain is 2755.42 cm3 (the volume of the cerebellum was 812.28 cm3) based on the Yakutsk CT. Yuka's brain volume as calculated from the Moscow CT appeared to be 25% smaller. In the same manner, the difference in volume under the dura mater, between the Yakutsk and Moscow CT scans, was 23%. This volume difference is caused by the fixation procedure. Formalin fixation causes initial tissue swelling and subsequent shrinkage (Bahr et al. 1957). Formalin solution with added mercuric chloride causes additional shrinkage of the tissue (Romeis 1948). Yuka's brain also might have shrunk somewhat during multiple thawing and freezing cycles. The research team is aware of at least three thawing episodes to which the brain was exposed before the Yakutsk CT was done.

Yuka's brain also shrank due to the long-term mummification process. The brain volume measured from the Yakutsk CT

Table 1. Brain volumes for Yuka and modern elephants.

Volume/ Specimen	Brain	Cerebellum	Intact brain
M. primigenius (Yuka)	**2755** (Yakutsk)/ **2060** (Moscow) cm^3	**812** (Yakutsk)/ **630** (Moscow) cm^3	**4674 - 4774** cm^3 (appr. from endocast)
L. africana[1, 2]	**3886.7** cm^3	**946.6** cm^3	**4091 – 4319** cm^3
E. maximus (Iki)[3]	**4569** l		
E. maximus (Tulsa)[3]	**4900** l		

1, from Hakeem et al. 2005; 2, approximation of the intact brain volume was corrected for long-term formalin fixation shrinkage (storing time unknown); 3, from Shoshani et al. 1982.

is 45% smaller than the endocast volume (5025.4 cm3). In the same manner, the volume under the dura mater was 19% smaller. Volumetric data for modern elephant brains are available for three specimens. Volume of a formalin-fixed brain of an adult female African elephant (*Loxodonta africana*) was measured using an MRI-scan. Two other brain volumes (adult female, *Elephas maximus*) were measured by the the method of water displacement (Table 1).

Histology research on Yuka's brain was performed. Tissue sampled from deep parts of the cerebrum and cerebellum differs from tissues sampled from the surface due to the preservational condition of the samples. In spite of the cell nucleus remnants being revealed, The condition of the Yuka's brain is acceptable for anatomical study, but despite the presence of remnants of some cell nuclei, its condition is not adequate for standard histology and cytology.

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