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Conservation of the Gusinsky mammoth skeleton: A case study

Ekaterina A. Petrova*, Andrey A. Grigoriev, Dmitry V. Dedov & Alexey N. Tikhonov

ABSTRACT. In 2019, the skeleton of a woolly mammoth *Mammuthus primigenius* (Blumenbach, 1799) was recovered from alluvial deposits on the Gusinaya River, Taymyr Peninsula, Russia. This find is of considerable significance for two reasons. First, the skeleton is almost complete and belonged to a relatively young individual, estimated to be 30–40 years old. Second, it is one of the few known *M. primigenius* skeletons dating from the terminal Late Pleistocene, with an age of 13 100–12 690 cal BP. The bones were severely weathered and consequently mechanically weak, friable and highly vulnerable once excavated. This paper describes a conservation process specifically designed to stabilise the bones while preserving them in a condition as close as possible to their original state, without reconstructing losses, fractures or other natural alterations. This approach ensures that the bones remain available for a wide range of current and future investigations, including morphological, morphometric, palaeogenomic, isotopic, radiocarbon and taphonomic studies, without obscuring natural post-mortem damage or the original state of the bones and epiphyses at the time of death.

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KEY WORDS: *Mammuthus primigenius*, skeleton, conservation, polyvinyl butyral.

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Новый скелет Гусинского мамонта: опыт консервации костей

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РЕЗЮМЕ. В 2019 г. в аллювиальных отложениях реки Гусиная на полуострове Таймыр (Россия) был обнаружен скелет шерстистого мамонта *Mammuthus primigenius* (Blumenbach, 1799). Эта находка имеет большое значение по двум причинам. Во-первых, скелет практически полный и принадлежал относительно молодому (30–40 лет) животному. Во-вторых, это один из немногих известных скелетов *M. primigenius*, датируемых концом позднего плейстоцена, возрастом 13100–12690 cal BP. Кости мамонта были сильно выветрены, что сделало их механически слабыми, хрупкими и крайне уязвимыми после раскопок. В данной статье описывается процесс консервации скелета, специально разработанный для стабилизации костей и сохранения их в состоянии, максимально приближенном к исходному, без восстановления утрат, переломов или других естественных изменений. Такой подход гарантирует, что кости останутся пригодными для широкого спектра текущих и будущих исследований, включая морфологические, морфометрические, палеогеномные, изотопные, радиоуглеродные и тафономические исследования, не скрывая при этом естественные посмертные повреждения или первоначальное состояние костей и их эпифизов на момент смерти.

КЛЮЧЕВЫЕ СЛОВА: *Mammuthus primigenius*, скелет, консервация, поливинилбутираль.

Introduction

The Zoological Institute of the Russian Academy of Sciences (ZIN), Saint Petersburg, possesses an extensive collection of Late Pleistocene mammals. Some of these specimens are on display in the public exposition of the Institute's Zoological Museum, including the well-known Lena (Adams) mammoth, the Berezovka mammoth, the Taymyr mammoth and the baby mammoths Dima and Masha (Slepkova & Bublichenko, 2019). Assembly of this collection began in the early XVIII century and continues to this day (Pugachev *et al*., 2008; Slepkova & Bublichenko, 2019). Over the years, carcasses and complete skeletons of mammoths

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and other Pleistocene mammals with intact soft tissues have been discovered in Siberia and were delivered to the museum (Adams, 1807; Tilesius, 1812; Herz, 1903; Pfizenmayer, 1926; Vereshchagin, 1981). Preserving these unique specimens, which are of great scientific value, in good condition for further research and museum exhibition has always been a priority. Consequently, at different times preparators and taxidermists have developed appropriate preservation and conservation methods for each new find (Pfizenmayer, 1907; Zaslavsky, 1981, 1995; Starikov, 1999; Starikov & Petrova, 2016).

Discoveries of mammoth skeletons and carcasses have been well documented in numerous publications (Adams, 1807; Tilesius, 1812; Herz, 1903; Nasonov, 1908; Kutomanov, 1914; Vollosovich, 1914; Pfizenmayer, 1926; Pavlovsky, 1950; Portenko *et al*., 1951; Vereshchagin, 1981). Below, we briefly outline how and by whom some of the unique specimens in the Zoological Museum were preserved and mounted.

In 1799, a complete mammoth skeleton was found in the Lena River delta, on the Bykovsky Peninsula. In 1806, the botanist Mikhail I. Adams, then working for the Academy of Sciences and based in Yakutsk, organised its excavation (Adams, 1807). The skeleton was found in permafrost deposits, and the bones were therefore well preserved. Soft tissues remained on some elements, but they were removed and the bones were boiled to extract grease. Only the skull preserved with the skin attached, the right forelimb and both hind feet with soft tissues were left in their original state (Adams, 1807). The skeleton was subsequently delivered to Saint Petersburg, where Adams mounted it. During this process, he had to supplement missing bones with plaster and wooden models. He also extended the sawn-off bases of the tusks using fragments from another mammoth (Zalenskiy, 1903; Dubinin & Garutt, 1954). Notably, the left tusk was installed in place of the right, and vice versa (Dubinin & Garutt, 1954). When the collections were moved to the museum's current building in 1896, the skeleton was remounted and the tusks were correctly positioned (Dubinin & Garutt, 1954).

In 1901, the carcass of the Berezovka mammoth was discovered and transported to Saint Petersburg. Work on this specimen marked the first instance of taxidermy being used to preserve and reconstruct the external appearance of an extinct animal. Over the course of two years, Eugen W. Pfizenmayer, Sergey K. Prikhodko and Mikhail A. Kolin used the straw-stuffing method to create the stuffed Berezovka mammoth (Zaslavsky, 1995). They reconstructed the animal in the seated posture with its hind legs stretched out beneath its belly in which it had been found on the Berezovka River. A skeleton was also mounted in the museum under Pfizenmayer's direction (Pfizenmayer, 1907; Garutt, 1964). Photographs in Zalenskiy (1903: plates XXIV, XXV) show that the skeleton was supplemented with missing ribs and a right tusk. Furthermore, the skin, hair, soft tissues, tongue, stomach, penis, blood and fat were preserved and studied in several publications (Byalynitsky-Birulya, 1903, 1909; Maliev, 1903; Zalenskiy, 1909a,b; Shestakov, 1914; Sukachev, 1914). The main methods used to preserve the skin, soft tissues and internal and external organs at that time appear to have been salting or preservation in 95% alcohol or formaldehyde [CH_2O] (Byalynitsky-Birulya, 1903, 1909; Maliev, 1903; Kutomanov, 1914).

The trunk, soft-tissue fragments, pieces of skin, tufts of hair and bones with soft tissues from the Sanga-Yuryakh mammoth (discovered in 1908), as well as several other mammoths and Late Pleistocene animals found later (e.g. the Mokhovsky and Khatanga mammoths, the Selerikan horse and the wolverine mummy from the Berelekh River), were all preserved in a similar way (Nasonov, 1908; Kutomanov, 1914; Vereshchagin, 1977; Vereshchagin & Lazarev, 1977; Vereshchagin & Nikolaev, 1982). After treatment with preservative solutions, some of these specimens were dried and used for display in the museum's exhibition.

The skeleton of the Taymyr mammoth, discovered in 1949, deserves special mention. Vadim E. Garutt and Vsevolod B. Dubinin processed and mounted it, with the active participation of preparator Mikhail A. Zaslavsky (Garutt & Dubinin, 1951). The skeleton was mounted with careful consideration of the anatomical structure of the vertebrae, limb bones and skull with tusks, in order to avoid the anatomical errors noted in previous mounts (Garutt & Dubinin, 1951). Under their leadership, the skeleton of *Mammuthus meridionalis* (Nesti, 1825), which was found in 1941 in the city of Primorsk on the shore of the Sea of Azov, was also assembled in 1951 (Naumov, 1980: 94). Information about the conservation and mounting of this skeleton is not available.

In 1977, the carcass of a baby mammoth was discovered in the upper reaches of the Kolyma River, Magadan Region (Vereshchagin, 1981). This specimen had well-preserved body parts, skin, musculature, skeleton and internal organs. Some internal organs and soft tissues with bones from the fore and hind limbs were fixed in formaldehyde. However, creating a traditionally mounted body was not feasible due to the poor condition of the skin on the head. Therefore, the carcass was embalmed using paraffin (Zaslavsky, 1971, 1981). Four moulds were made from plaster to produce casts of the mammoth calf prior to paraffin embalming (Starikov, 1999). Later, silicone negative moulds were created to allow the production of higher-quality copies capable of replicating fine details (Starikov, 1999).

In 1988, a second baby mammoth carcass was found on the bank of the Yuribeche-Yakha River, Yamal Peninsula (Tikhonov & Khrabryi, 1988). This carcass was less well preserved than the Magadan calf: the trunk and tail were missing, and the skin on the neck and left shoulder was severely torn. Upon arrival in Saint Petersburg, the carcass was placed in a freezer. Primary dissection was then carried out: some bones were extracted from the body and a quantity of soft tissues was fixed in formaldehyde. Thereafter, the entire body was placed in formaldehyde. Subsequently, the

mummified calf was dried in a polyethylene cover for four months (Sergei O. Mamonov, pers. comm.).

A new series of Late Pleistocene animal carcasses was discovered in Siberia in the 2000s (Fisher *et al*., 2012; Maschenko *et al*., 2012, 2013, 2017; Grigoriev *et al*., 2017). Some of these specimens, including the baby mammoth Lyuba and the Sopochnaya Karga mammoth, were studied at our institute (Fisher *et al*., 2012; Maschenko *et al*., 2017). Unique conservation and restoration work was performed on the Lyuba and Sopochnaya Karga mammoths in the Laboratory of Experimental Taxidermy under the leadership of Yury V. Starikov (Starikov, 2011; Starikov & Petrova, 2016). After thawing and dissection, the excellently preserved Lyuba carcass was placed in an ethanol–formaldehyde solution containing nipagin (methylparaben, $C_8H_8O_3$) and was subsequently dried (2009–2010). This conservation method enables the specimen to be stored dry at room temperature (Starikov, 2011). Over a period of two and a half years (2013–2015), extensive work was carried out on the Sopochnaya Karga mammoth remains, resulting in the creation of a mounted specimen lying on its left side, mounting of the skeleton and production of a series of dry anatomical preparations (Starikov & Petrova, 2016). Starikov & Petrova (2016) provide a detailed description of the Sopochnaya Karga mammoth conservation and restoration processes. Notably, special attention was paid to preserving and restoring the bones, some of which were in poor condition. To strengthen them, the bones were impregnated twice with a polyvinyl butyral [PVB, $(C_8H_{14}O_2)n$] solution in ethanol of increasing concentration. Restoration of damaged bones was carried out using polyester putty and an Apoxie Sculpt compound, and replicas of missing bones were made from polyester putty.

These examples demonstrate that several generations of taxidermists at the Zoological Museum of the Zoological Institute RAS have accumulated unique expertise in the preservation and conservation of Late Pleistocene animal carcasses. It is important to emphasise that the bones with which they worked were usually well preserved, having been recovered from permafrost; as a result, they often did not require specialised stabilisation treatment.

This article describes the conservation process applied to a mammoth skeleton discovered in 2019 in alluvial deposits on the Gusinaya River, Taymyr Peninsula, Russia. This find is of considerable importance for two reasons. First, the skeleton is nearly complete and belongs to a relatively young individual, estimated to

Fig. 1. Excavation of the Gusinsky mammoth on the right bank of the Gusinaya River in 2019 (Taymyr Peninsula, Russia). A — Bones partially exposed on the surface (indicated by white arrows). B — Hind limb bones preserved in anatomical connection. C — General view of the skeleton in situ, with geologist Dmitry Kostin for scale.

be 30–40 years old. Second, it is one of the few known skeletons of *Mammuthus primigenius* (Blumenbach, 1799) from the terminal Late Pleistocene, dated to 13 100–12 690 cal BP (LU-979). Very few complete mammoth skeletons of this age and geological period are known (Petrova *et al*., 2017, 2023). The bone surfaces were severely weathered, necessitating conservation to stabilize the specimen and ensure its long-term preservation.

History of the Gusinsky mammoth discovery

On 27 July 2019, while conducting a geological survey of the area, geologists Petr Gromov, Dmitry Kostin and Vasily Saltanov from the Russian Geological Research Institute (Saint Petersburg) discovered a mammoth skeleton on the right bank of the Gusinaya River. Having identified partially exposed scapular, pelvic and hind limb bones protruding above the sediment (Fig. 1), the researchers proceeded to excavate the remains. Over the course of three days, they uncovered a nearly complete skeleton; however, the skull, tusks and mandible were missing. In addition to the bones, fragments of skin, soft tissue and hair were also recovered. No conservation work was carried out in the field. Following completion of the fieldwork in autumn 2019, the skeleton was transported to Saint Petersburg, where it is now kept in the Zoological Institute of the Russian Academy of Sciences (catalogue number ZIN 39241). For a list of the skeletal elements, see the supplementary materials (Appendix 1).

Condition of the bones

The majority of the skeletal elements (n = 99) were complete, while some (n = 66) were incomplete. Several bones were recovered as multiple fragments. Due to weathering during burial and subsequent post-sedimentary processes, the bone surfaces were mechanically weakened and highly vulnerable to breakage. Most specimens showed flaking of the outer bone layers (Fig. 2). The outermost concentric thin layers of bone were flaking, a process usually associated with cracks. Where these cracks occurred, the bone edges tended to separate and flake, leading to gradual loss of the bone. Furthermore, the bones were extensively cracked, with fissures often penetrating into large marrow cavities, reducing their mechanical strength (Fig. 2).

Description of the conservation process

Sediment adhering to the bone surfaces from the fossiliferous layers was preserved in places. These contaminants were removed using a soft brush (Fig. 3A). Bone conservation is often achieved through the surface application of consolidants or glues. However, given the observed delamination of the outer bone layers and the presence of long, longitudinal cracks penetrating the marrow cavities, it was decided to immerse the bones fully in a consolidant solution (Figs 2, 3E). A solution of PVB in ethanol was used as the consolidant. The impregnating solution was prepared using 96% ethanol and PVB at two concentrations: 3–5% and 7–10% (weight/volume). The required volumes

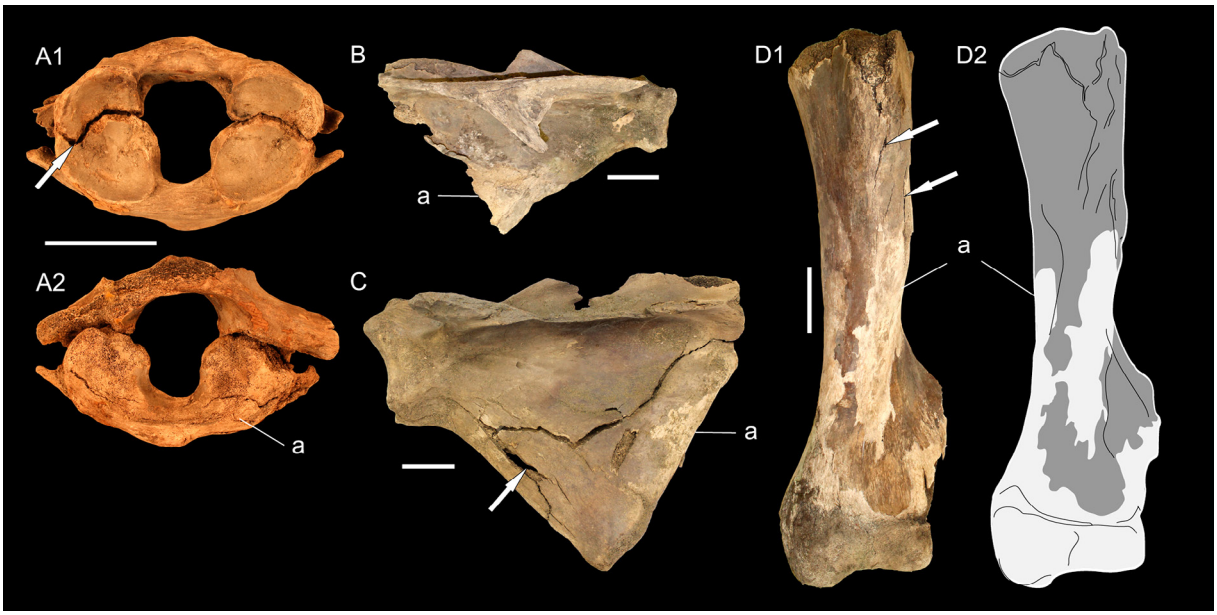

Fig. 2. Condition of the Gusinsky mammoth bones. A1 — Atlas in cranial view, ZIN 39241/1. A2 — *ibid*., in caudal view. B — Right scapula in lateral view, ZIN 39241/77. C — Left scapula in lateral view, ZIN 39241/126. D1 — Left humerus in cranial view, ZIN 39241/83. D2 — *ibid*., explanatory drawing. a — flaking of outer bone layers. The white arrows point to the cracks. Scale bars are 100 mm.

Fig. 3. Conservation process of the Gusinsky mammoth bones. A — Removing sediments from the bone surface. B — Making of the custom-sized boxes from foam board. C — Preparing of the polyethylene 'bag' for the bone conservation. D — Preparing the impregnating solution. E — Pouring the impregnating solution into the box. F — The preparators use ballast to raise the level of the impregnating solution, in background view. The femur after impregnation in a 3–5% PVB-ethanol solution, in foreground view (photographs by Andrey Grigoriev; Andrey Grigoriev [red] and Dmitry Dedov are shown on the plate).

were mixed in plastic containers using a construction mixer (Fig. 3D).

Because the limb bones of the mammoth are large, custom-sized boxes were made from foam board to accommodate them (Fig. 3B). A 2 mm-thick polyethylene sheet was placed inside these boxes to form a 'bag', into which the PVB-ethanol solution was poured and the bone immersed (Fig. 3C). The bag was then tightly sealed. One advantage of this system is that the level of the impregnating solution can be easily adjusted by placing cloth or ballast around the bone inside the box. This ensures that all parts of the bone are treated effectively, as the thickness, height and shape of bones can vary, preventing complete coverage by a simple bath. It also allows economical use of the consolidant (Fig. 3F). Smaller bones (e.g. bones of the manus and pes, vertebrae and unfused epiphyses) were impregnated in lidded plastic containers. Nearly all bones were stabilised (n = 135); only a small number (Appendix 2) were deliberately left untreated so that 'clean', unconsolidated samples would remain available for future analytical work.

The impregnation process consisted of two stages. First, the bone was immersed in a 3–5% PVB-ethanol solution. A substantial release of air bubbles from the bone was observed, indicating good penetration of the solution into the bone matrix. The bone remained in this solution for several days, after which it was re-

moved and allowed to drain (Fig. 3F). It was then immersed in a 7–10% PVB-ethanol solution and the same procedure was repeated. All stages of the process were conducted with constant room ventilation and an operational fume hood, following standard good practice for solvent-based conservation work. Small bones were subsequently dried in sealable polyethylene bags, while large bones were wrapped in polyethylene sheeting to allow slow, controlled drying. Bones exhibiting large surface cracks and damaged areas were consolidated with a concentrated PVB solution and then tightly bound with stretch film, which prevented rapid desiccation and the expansion of cracks during drying. Following this, the bones secured in this manner were wrapped in polyethylene sheeting to ensure the specimens dried slowly. Drying was carried out at room temperature, with the condition of the bones being regularly monitored through visual inspection.

The vertebrae were found with unfused epiphyses of the centra, and the limb bones with unfused proximal and distal epiphyses. It was therefore necessary to reattach these separate elements of each bone (Fig. 4). Consolidation was carried out after impregnation. For this purpose, the synthetic, reversible ethyl methacrylate copolymer Paraloid B-72 was used as an adhesive. In this case, the elements were held in position during setting using clamps and elastic bands.

Storage

Following conservation, the bones were digitised using a 3D scanner (Fig. 5). These 3D models can be used for various non-destructive analyses, thereby enhancing the preservation of the original material by reducing the need for direct handling of the bones.

To maintain the specimens in a stable condition, the bones are stored in cardboard boxes, plastic containers and wooden crates. At present, lidded plastic containers with airtight seals (RoxBox) are a convenient and versatile storage option and are used most frequently. Their advantages include low weight, durability, and protection from moisture, light and dust; moreover, containers fitted with wheels can be readily removed from shelving. Long limb bones are stored in lidded wooden crates manufactured to the dimensions of each element.

The bases of plastic containers and wooden crates are lined with cushioning materials to provide shock absorption (e.g. polyester wadding, cotton wool, paper, or bubble wrap). Additional padding is placed on top of the specimens to prevent movement during storage and handling. To ensure good long-term preservation, stable environmental conditions must be maintained in the storage area, with minimal fluctuations, at approximately 18°C and a relative humidity of 50±5%. Regu-

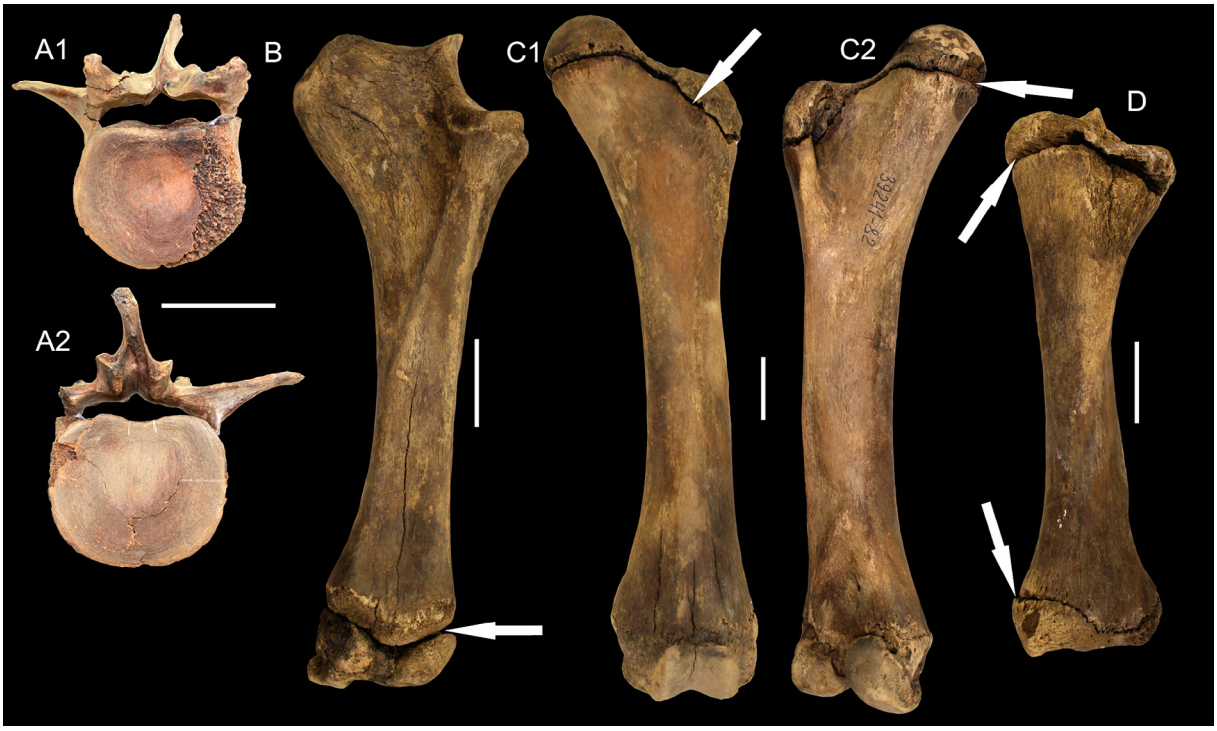

Fig. 4. Bones of the Gusinsky mammoth after conservation. A1 — Lumbar vertebra in cranial view, ZIN 39241/24. A2 — *ibid*., in caudal view. B — Right ulna in lateral view, ZIN 39241/129. C1 — Left femur, in cranial view, ZIN 39241/82. C2 — *ibid*., in caudal view. D — Left tibia in cranial view, ZIN 39241/128. The white arrows point that gap between proximal/distal epiphyses of the limb bone diaphyses were not filled with restoration material. This conservation approach shows the natural stage of epiphyseal fusion. Scale bars are 100 mm.

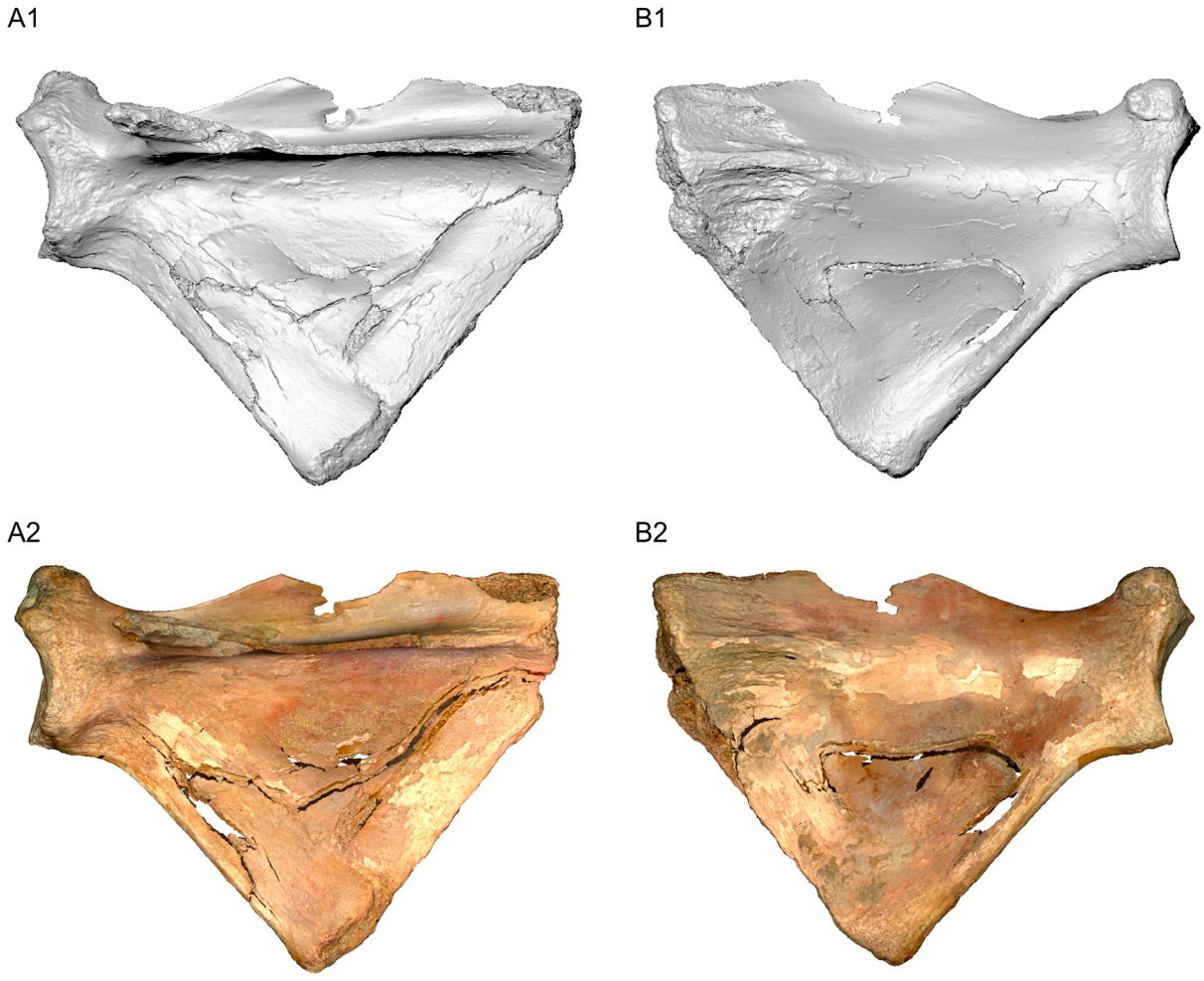

Fig. 5. The 3D model of left scapula of the Gusinsky mammoth, ZIN 39241/126. A1 — the bone in lateral view, without a texture; A2 — *ibid*., 3D model with texture (file in OBJ format); B1 — the bone in medial view, without a texture; B2 — *ibid*., 3D model with texture.

lar visual inspection and photographic documentation are also required, and environmental sensors (data loggers) should be used to monitor storage conditions.

Discussion

It is frequently emphasised in the conservation literature that material from palaeontological and archaeological excavations should undergo only minimal treatment with consolidants, glues and gap-fillers, since invasive methods can hinder future research, such as molecular, isotopic, radiocarbon and taphonomic studies (Larkin, 2010). Nevertheless, conservation and restoration can be critically necessary to recover, stabilise and preserve material, and it is not always possible to avoid these treatments entirely. Accordingly, there are no fixed protocols or rigid rules that must be followed when preserving a specimen; instead, specific procedures are developed for each case individually (López-Polín, 2012, 2015).

In the case of the Gusinsky mammoth skeleton, the decision to apply consolidant was determined by the poor state of preservation of the bones, which were mechanically weak, friable and vulnerable, and by the presence of deep longitudinal cracks in the long limb bones. The bones were therefore immersed in a PVB-ethanol solution (Fig. 3). This treatment method allows the consolidant to penetrate pores and cracks, filling them and binding loose material. Once dry, the solvent evaporates and the consolidant hardens within the bone, thereby strengthening it. Furthermore, the consolidant forms a thin protective layer on the surface, helping to buffer the specimen against fluctuations in humidity in the storage environment. PVB was selected because it is widely used in bone conservation and restoration, and has stable and reversible properties (López-Polín, 2012). Current research indicates that, as methods for cleaning samples of various contaminants continue to improve, reversible consolidants do not necessarily af-

fect the results of certain analyses (e.g. molecular, isotopic, radiocarbon) (López-Polín, 2012). Despite this, several bones of the Gusinsky mammoth were deliberately left untreated with PVB so that 'clean' samples, free of consolidant, would be available for future analytical studies.

Many bones of the Gusinsky mammoth appeared incomplete because epiphyses had separated from vertebral centra or from the diaphyses of long bones, likely owing to the initial stages of ossification. To determine an individual's age, sex, size and other characteristics, it is generally necessary to measure and describe complete bones. Therefore, the unfused vertebral epiphyses and limb-bone epiphyses were reattached to restore the original bone morphology and enable accurate measurements. Importantly, the gaps between the cranial/caudal epiphyses and vertebral centra, and between the proximal/distal epiphyses and limb-bone diaphyses, were not completely filled with restoration material (Fig. 4). This approach preserves the visibility of the natural stage of epiphyseal fusion. Three stages of epiphyseal fusion are typically distinguished in mammoths: 0 = unfused; (f) = fused with a visible suture line; and f = fully fused with an indistinct suture (Lister, 1999; Petrova *et al*., 2017). These stages are used to determine individual age. However, assessing the stage of epiphyseal fusion can be challenging because some mammoth skeletons have been restored for museum display and their epiphyseal sutures are concealed by restoration materials. This practice results in the loss of highly informative age- and growth-related data for subsequent researchers.

In the present case, restoration of distortions, fractures and other modifications of the Gusinsky mammoth bones was deliberately not undertaken, because the information contained in their broken and deformed state is essential for taphonomic analysis (Fig. 2). Taphonomic studies examine the post-mortem changes undergone by bones in order to reconstruct the history of the organism from the time of death and to interpret the processes involved in the formation of the deposit.

Currently, approximately thirty complete woolly mammoth skeletons are known worldwide, nine of which are housed in the Zoological Institute (Zalenskiy, 1903; Dietrich, 1912; Felix, 1912; Pontier, 1913; Toepfer, 1957; Siegfried, 1959; Garutt, 1964, 1992; Weidmann, 1969; Dubrovo, 1982; Koenigswald, 1989; Averianov, 1992, 1994; Ziegler, 1994, 2001; Tikhonov, 1996; Lister, 2009; Petrova, 2009; Kirillova *et al*., 2012; Maschenko *et al*., 2017; Grigoriev *et al*., 2017; Petrova *et al*., 2015, 2017, 2023). While all have been studied to varying degrees and hold significant scientific and historical value, detailed research on them — particularly those mounted for display in museums — can be constrained. Mounting restricts comprehensive description, measurement, photography, scanning and certain types of analysis of individual elements, such as microscopic and histological studies. Furthermore, the mounted mammoth skeletons in the Zoological Museum of the Zoological Institute RAS — specifically the Lena (Adams), Berezovka and Taymyr mammoths — have been repeatedly treated with a polyvinyl acetate [PVA, $(C_4H_6O_2)n$] emulsion to maintain their stability (Sergei O. Mamonov, pers. comm.). Crucially, 'clean' samples for future analytical studies were not usually collected from these specimens prior to treatment. Finally, to prepare these mounted skeletons for exhibition, all natural distortions, fractures and other bone modifications were repeatedly restored, resulting in irreversible loss of information.

By contrast, the conservation strategy for the Gusinsky mammoth combined necessary remedial stabilisation with a deliberately minimal, reversible intervention philosophy, closely aligned with current best practice in the conservation of sub-fossil vertebrate remains (e.g. Larkin, 2010; López-Polín, 2012, 2015).

Conclusions

This paper presents a bespoke conservation protocol for the skeletal elements of the distinctive Gusinaya River mammoth discovery. The conservation process combines international best practice with methodological and conceptual approaches developed by specialists at the Zoological Institute through decades of work with mammoth carcasses and skeletons. Conservation of the Gusinsky mammoth has significantly strengthened the bones, thereby ensuring the long-term preservation of the specimen.

By maintaining the skeleton in a state close to that in which it was recovered — specifically by avoiding the restoration of natural fractures, losses and distortions — we have kept it available for a wide range of future analytical studies.

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Appendix 1. List of the Gusinsky mammoth's bones processed.

(1) Atlas: ZIN 39241/1 (*n* = 1);
(2) cervical vertebrae: ZIN 39241/131–135 (*n* = 5), ZIN 39241/140 (*n*=1);
(3) thoracic vertebrae: ZIN 39241/2–21 (*n* = 19), ZIN 39241/139 *(n*=1);
(4) lumbar vertebrae: ZIN 39241/22–25 (*n* = 4), ZIN 39241/137–138 *(n*=2);
(5) sacrum: ZIN 39241/26 *(n* = 1);
(6) caudal vertebrae: ZIN 39241/27–39 *(n* = 13);
(7) right ribs: ZIN 39241/43, 44, 47, 49, 51–53, 56–59, 70–74 *(n* = 17); left ribs: ZIN 39241/40–42, 45, 46, 48, 50, 54, 55, 60–68, 75, 76 *(n* = 20);
(8) scapula: right ZIN 39241/77, left ZIN 39241/126 and ZIN 39241/141;
(9) humerus: right ZIN 39241/78, left ZIN 39241/83;
(10) ulna: right ZIN 39241/129, left ZIN 39241/80;
(11) radius: right ZIN 39241/79;
(12) lunatum: right ZIN 39241/111;
(13) triangular: right ZIN 39241/109;
(14) pisiform: right ZIN 39241/114;
(15) capitate: right ZIN 39241/107;
(16) hamate: right ZIN 39241/110;
(17) right metacarpals *(n* = 5): Mc 1, ZIN 39241/116; Mc 2, ZIN 39241/108; Mc 3, ZIN 39241/106; Mc 4, ZIN 39241/112; Mc 5, ZIN 39241/113;
(18) pelvis: ZIN 39241/130; ZIN 39241/143 *(n*=5);
(19) femur: right ZIN 39241/81, left ZIN 39241/82;
(20) tibia: right ZIN 39241/127, left ZIN 39241/128;
(21) fibula: right ZIN 39241/85, left ZIN 39241/84;
(22) patella: right ZIN 39241/87, left ZIN 39241/86;
(23) calcaneus: right ZIN 39241/95, left ZIN 39241/88;
(24) astragalus: right ZIN 39241/96, left ZIN 39241/90;
(25) navicular: right ZIN 39241/98, left ZIN 39241/93;
(26) intermedium cuneiform: right ZIN 39241/94, left ZIN 39241/105;
(27) lateral cuneiform: left ZIN 39241/103;
(28) cuboid: right ZIN 39241/97, left ZIN 39241/89;
(29) 1 phalanx *(n* = 5): ZIN 39241/115, 119, 118, 122, 120;
(30) 3 phalanx *(n* = 2): ZIN 39241/123, 121;
(31) right metatarsals *(n* = 4): Mt 2, ZIN 39241/99; Mt 3, ZIN 39241/101; Mt 4, ZIN 39241/100; Mt 5, ZIN 39241/104; left metatarsals *(n* = 3): Mt 2, ZIN 39241/92; Mt 4, ZIN 39241/91; Mt 5, ZIN 39241/102;
(32) sesamoid bone: ZIN 39241/124, 125.
(33) vertebra (fragments): ZIN 39241/136 *(n*=1), ZIN 39241/147 *(n*=3), ZIN 39241/148 *(n*=7);
(34) skull (fragments): ZIN 39241/142 *(n*=7);
(35) indet. bone (fragment): ZIN 39241/144-146.

Appendix 2. Untreated bones of Gusinsky mammoth.

(1) vertebra (fragment): ZIN 39241/136 *(n*=1);
(2) lumbar vertebra (fragments): ZIN 39241/137 *(n*=2), ZIN 39241/138 *(n*=1);
(3) thoracic vertebra (fragment of the transverse costal process): ZIN 39241/139 *(n*=1);
(4) cervical vertebra (fragment): ZIN 39241/140 *(n*=1);
(5) spine of the left scapula: ZIN 39241/141 *(n*=1);
(6) skull (fragments): ZIN 39241/142 *(n*=7);
(7) fragment of the pelvic epiphysis: ZIN 39241/143 *(n*=5);
(8) indeterminable bones: ZIN 39241/144-146 *(n*=3);
(9) vertebra (fragments): ZIN 39241/147 *(n*=3), ZIN 39241/148 *(n*=7).