Preparation and Transportation of a Complete Mammoth Skull from Channel Islands National Park, California, U.S.A.

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ABSTRACT

The Larramendy Mammoth skull was recovered from Santa Rosa Island, Channel Islands National Park (CHIS), California in September 2016. The specimen is dated to approximately 13,393 ± 80 cal BP, and is the best preserved mammoth skull recovered from CHIS to date. The skull has both tusks intact and is missing only its right jugal, which was separated along the suture lines. The skull was buried in a thick layer of gravel, and though some minor deformation has occurred, the overall shape of the skull is well preserved. Sinus cavities in the nasal, frontal, parietal, and occipital regions of the skull, as well as the pulp cavities of the tusks, were never infilled with sediment and remain hollow. The extreme fragility of the occipital and parietal regions necessitated a delicate approach to preparation. To prevent collapse during preparation, exterior bone around the hollow sinuses had to be consolidated prior to cleaning away sediment. Temporary Japanese paper bandages were applied to reinforce cracks around the hollow areas. Consolidated sediment was then removed from adjacent surfaces using acetone and small, soft brushes. Paraloid B-72 in acetone was used for all consolidation of the specimen and adhesion of paper. Initial preparation was begun by the primary author at the Santa Barbara Museum of Natural History in Santa Barbara, California in 2017. The skull was later moved to The Mammoth Site (MS) in Hot Springs, SD to continue preparation and research. Potential collapse of the hollow areas during transport was a significant concern. To prevent damage in transit, all exposed surfaces of the skull were consolidated, including visible interior surfaces of the sinus cavities, by using long, flexible bottle tips to access difficult to reach areas and undercuts. All exposed exterior surfaces were covered with a layer of Japanese paper applied as thin, overlapping strips. The paper acted as reinforcement for the bone, and to aid in reconstruction should any breaks or collapse of hollow areas occur as a result of unpredictable road conditions. The skull was then rejacketed, and secured inside a plywood crate using wooden braces and expanding foam. The crate was placed on rubber anti-fatigue floor mats in a moving truck and driven nearly 1400 miles to MS. The move was completed successfully with no damage to the specimen sustained during travel.

BACKGROUND

The Larramendy Mammoth Skull was collected from northwest corner of Santa Rosa Island, Channel Islands National Park (CHIS) off the coast of southern California (Fig 1). The skull was found in a gravel lens near the base of a 40ft cliff of Pleistocene alluvial sediments (Figs 2 and 3). The skull was completely enclosed in a single gravel lens, indicating rapid burial in a high-energy depositional environment. The lack of visible surface abrasion or other signs of pre-depositional weathering suggests the skull was likely buried shortly after death. However, only one thoracic vertebra was recovered from the same gravel lens, indicating at least enough decay time for disarticulation. Charcoal from the layer immediately above the skull was dated to 13,393 ± 80 cal BP, providing a minimum date for the specimen (Wilkins 2017).

Figure 1. Map of the four Northern California Channel Islands

Figure 2. The skull during excavation.

Two types of mammoths were present on the Channel Islands during the Late Pleistocene: the Columbian mammoth (*Mammuthus columbi*), which was the larger mainland form, and the pygmy mammoth (*M. exilis*), the endemic dwarfed form, which was presumably descended from *M. columbi* (Agenbroad 2012). The timing and number of migrations of mainland mammoths to the Channel Islands remains unresolved, though pygmy mammoth material has been dated to at least 80,000 years ago (Pigati et al. 2016). Both *M. columbi* and *M. exilis* were present on the Islands at end of the last ice age, but it is not known if the *M. columbi* persisted as a relict population, or if they were the result of later migrations (Agenbroad 2005).

The Larramendy skull is intermediate in size between *M. columbi* and *M. exilis*. The length, width, and curvature of its tusks indicate the individual was an adult male that was likely full grown, or close to full grown, ruling out the possibility that it represents a juvenile *M. columbi*. The teeth are currently buried within the jacket, so a more exact dental age cannot yet be determined. The intermediate size of the skull could represent an individual who was along the size continuum of the dwarfing process, or it could potentially represent a hybrid individual between the larger and smaller forms of island mammoth.

Figure 3. The crated skull being airlifted from the base of the cliff by helicopter.

The skull was excavated in September 2016. It was extracted from the field locality via helicopter (Fig 3), and was then transported to the mainland by boat. The skull initially went to Santa Barbara Museum of Natural History (SBMNH) in Santa Barbara, CA, the official repository for CHIS. SBMNH lacked a preparator, so the primary author (MB) traveled from The Mammoth Site of Hot Springs, SD (MS) to Santa Barbara to begin the preparation process. Once the complexity of the project and associated time requirements became clear, the decision was made to temporarily transfer the skull to MS to complete preparation and research. The specimen will eventually return to SBMNH for permanent storage.

A HOLLOW SKULL

The skull, while in generally good condition, has numerous cracks and some mild deformation concentrated along the nuchal crest and in the sinestral parietal/temporal region (Fig 4). Mammoth skulls, like modern elephants (Fig 8), are largely made of sinus cavities which are separated by very thin, delicate bone. Mammoth skulls from CHIS and elsewhere are often found with occipital, parietal, and/or temporal regions damaged or missing due their fragility. During excavation, several fragments of the nuchal crest fell through into the sinus cavities below, which had never in-filled with sediments. Further preparation at SBMNH demonstrated that sinus cavities throughout the occipital, parietal, frontal, and nasal regions also remain hollow, as well as the tusk pulp cavities. The brain cavity was likely at least partially in-filled with sediments through the foramen magnum, but the large size of the gravel and rapid deposition may have prevented complete filling.

Preserving the cranial morphology of this specimen, which could represent a rare intermediate or hybrid individual, is paramount. The foremost concern during preparation and transportation of the skull was the potential of the hollow areas to collapse. In the field, McGean B-15 in acetone was used sparingly to tack loose fragments in place. All post-excavation preparation was done using Paraloid B-72 in acetone as both a consolidant and adhesive, and all further mentions of consolidant or adhesive in this poster refer to Paraloid B -72 in acetone.

The cracks and holes exposing the interior of the sinus cavities were exploited to aim consolidant directly to the interior surfaces of the skull. The weight of wet consolidant on some areas was enough to cause fragmentation or collapse of fragile bone, so consolidant had to be precisely aimed and judiciously applied. Small 2oz bottles with long, flexible tips were used to consolidate in and around the openings of sinus cavities (Figs 5 and 6). This allowed for precision, and also a deep reach into the sinus cavities and cracks. Most sinus cavities beneath the parietal and frontal are vertically oriented as long, narrow chambers (Fig 8), so the horizontal extent of effective consolidation was limited to areas directly beneath cracks or holes.

Several areas have been targeted for potential aDNA sampling (the tusks, teeth, and petrosal) and will be left unconsolidated, or sampled prior to consolidation if necessary:.

Clockwise from top left: **Figure 4.** Deformation of the sinestral parietal/temporal. **Figure 5.** Consolidating the inside of the hollow sinuses. **Figure 6.** 2oz consolidant bottles with long flexible tips used to consolidate inside the sinus cavities to reach undercuts. **Figure 7.** Initial preparation at SBMNH.

Prior to packaging for transport, the decision was made to apply Japanese kozo paper to the surface of the skull (see next section). This served a dual purpose: 1) to add strength to fragile areas to prevent damage, and 2) to aid reconstruction the skull should damage or collapse occur. If the back end of the skull had collapsed, the hope was that the exterior bone would remain glued to the kozo paper and the orientation of the pieces would be preserved, allowing for quicker and more accurate reconstruction of the exterior surfaces. Fortunately, no damage occurred during transport, so the efficacy of the second point remained untested.

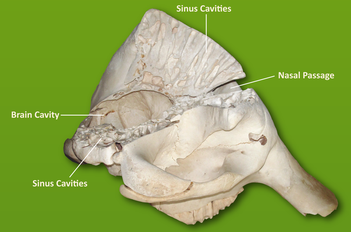


Figure 8. A modern African elephant (*Loxodonta africana*) skull with the top right quarter of the cranium removed, exposing extensive sinus cavities.

KOZO PAPER REINFORCEMENT: APPLICATION AND REMOVAL

After consolidation, Japanese kozo paper (13g/m2) was applied to all exposed surfaces of the skull covering sinus cavities and other fragile areas. Only the tusk alveoli, which were more robust and stable than the rest of the skull, were left free of paper reinforcement. The kozo paper was applied in overlapping thin strips about 1-2cm wide, to form a continuous sheet across the skull. Lengths varied from roughly 5-15cm based on the underlying skull morphology where each strip was to be applied. The paper was glued to the surface using Paraloid B-72 in acetone at various concentrations (Fig 9). The thickness of the consolidant was dependent on the texture or roughness of the bone surface. More rough, porous, or irregular areas required thicker glue to obtain good adhesion. Paper strips on smooth areas could be successfully adhered at lower concentrations. To apply the strip, a coat of consolidant was applied to the surface, and then the paper was laid over top while still tacky. A second coat of Paraloid was added to the top to help seal the paper into place. The strips were tamped in place while drying using a wooden knitting needle to ensure good adhesion.

After successful transport to MS, the paper was removed using small paintbrushes with soft natural bristles. Acetone was applied the surface of the paper to soften the consolidant, then paintbrushes dipped in acetone were used to lift excess consolidant from the surface of the paper. An edge of the paper strip would then be lifted using tweezers or fingers, and gently pulled back while an acetone-soaked brush was worked back and forth at the junction of bone and paper to loosen the bonds of the consolidant. Any loose paper fibers that remained glued to the bone surface were lifted with acetone and brushes, and the bone surface was then reconsolidated. Care had to be taken to soften only the surficial layer consolidant, and not the bone behind it, especially over the delicate sinus cavities. If the bone began to soften, or fragment loosen, the process was suspended until the bone dried and re-hardened. Sometimes more consolidant was added to the bone to strengthen it before continuing the removal process. On smoother areas, like the parietals (Fig 10), paper was able to be removed in large sections, over more delicate areas (Fig 17d) it had to be removed strip by strip.

Figure 9. Applying kozo paper strips to the bone surface.

Figure 10. Removing kozo paper from the skull.

TRANSPORTING THE SKULL

The packing and shipping of the skull was done under tight time constraints, but the process was organized to give the skull multiple levels of protection:

1) Consolidation
2) Japanese kozo paper reinforcement
3) Padding inside the jacket
4) Jacketing
5) Insulation foam to stabilize the jacket
6) Plywood crate and braces
7) Anti-fatigue mats
8) Straps to hold the crate inside the truck

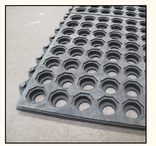
Figure 11 (top). The skull before jacketing, with delicate areas of the nasals, sinestral parietal/temporal and nuchal crest exposed and undercut. **Figure 12 (bottom).** Undercut areas filled with plastic shopping bag pads.

During the initial phase of preparation at SBMNH, sediment had been removed from around several cracked and hollow areas of the skull creating undercuts (Fig 11). Undercuts were filled prior to jacketing using plastic grocery bags which were balled up and formed into semi-solid pads (Fig 12). The crumpled bags were shaped to fit each undercut area using electrical tape. The result was a slightly malleable pad that could be gently squashed into place. The pads were separated from the skull with paper towels to prevent the bags from catching on sharp corners of bone or consolidated kozo paper. As the jacket was applied, the plaster was held taught and slightly pressed into place over top of the pads to help wedge them solidly into place inside the jacket. The bags also provided a large buffer area to safely cut the jacket after transport to MS.

After jacketing, spray insulation foam that was added around the entire base of the jacket to prevent rocking during transport (Fig 13). A crate was built around the skull and the jacket was braced against the sides using wooden supports and padded with moving blankets (Fig 14). The crate was loaded into a moving truck and set on two layers of anti-fatigue floor mats, rubber mats designed to be slightly springy to absorb vibration (Fig 15). The crate was strapped down inside the moving truck, then driven 1400 miles from SBMNH to MS.

Upon arriving at MS, the skull was unloaded from the truck (Fig 16) and the jacket was inspected for signs of external damage; none were found. The jacket was reopened, and the skull inspected for damage, and again no visible signs of damage sustained during travel were noted. The possibility exists that some internal fracturing occurred, especially to the fragile sinus cavity bones, but if so, the damage did not manifest externally. Preparation recommenced, and the project is still currently in progress.

Clockwise from top left: **Figure 13.** Insulation foam around the base of the skull jacket. **Figure 14** The crate being built around the skull. **Figure 15.** Anti-fatigue floor mat used to cushion the crate in the moving truck. **Figure 16.** Removing the skull form the moving truck at MS.



STAGES OF PREPARATION: THE NUCHAL CREST AND DEXTRAL OCCIPITAL

Both the nuchal crest (Fig 17) and dextral occipital region (Fig 18) presented challenges for preparation. The bone was fractured and unsupported by the hollow interior of the skull. In some cases the weight of the consolidant was enough to dislodge fragments from vertical orientation on the occipital, or cause them to drop down into the sinus cavities beneath the nuchal crest. A successful result was achieved through multiple stages of consolidation of both bone and sediment and cleaning away consolidated sediment.

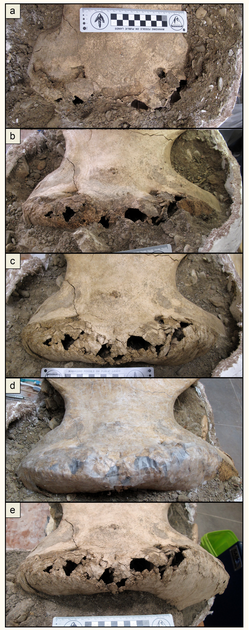


Figure 17. The nuchal crest during five stages of the preparation process. **Fig 17a.** The nuchal crest after the original field jacket was removed, with some fragments collapsed inwards exposing hollow sinus cavities. **Fig 17b.** The initial stages of cleaning and stabilization. Some sediment was consolidated to the surface, while the bulk of the sediment has been removed. **Fig 17c.** The sediment was then gently cleaned from the surface of the bone using acetone and small soft natural bristle paint brushes to soften consolidated sediment and lift it from the surface. **Fig 17d.** In preparation for transport, the bone was reconsolidated and kozo paper was applied to the entire nuchal crest in overlapping layers covering the holes to the sinus cavities. **Fig 17e.** The current state of the nuchal crest. The Japanese paper was removed using acetone and soft brushes and the surfaces were cleaned and reconsolidated.

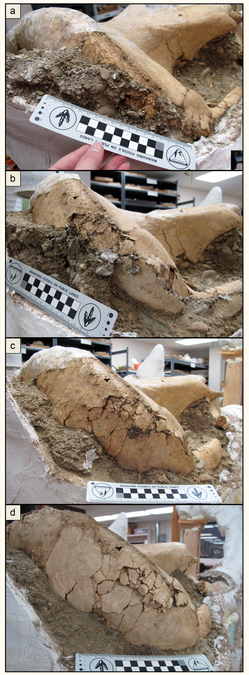


Figure 18. The dextral occipital region during four stages of the preparation process. This area was not exposed prior to transport to MS, and so was not covered with kozo paper. **Fig 18a.** The initial stage of the process, loose gravel fell away from near vertical sections of bone exposing cracked, indented bone. **Fig 18b.** Sediment was selectively glued to the surface in an effort to stabilize the bone beneath. **Fig 18c.** The bulk of the sediment was removed using acetone to soften the consolidant. **Fig 18d.** The bone surfaces were gently cleaned using small, soft, natural bristle brushes dipped in acetone. The cleaned bone was reconsolidated and the cracks reinforced with thick Paraloid B-72 in acetone.

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