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Digging Through Plaster, Wax and Celluloid:
The Second Excavation of an Ancient Mesopotamian Bull

Abstract

From 1922 to 1934, the British Museum and the University of Pennsylvania Museum of Archaeology and Anthropology (Penn Museum) embarked on a joint expedition of Mesopotamian sites in present-day southern Iraq. This expedition was led by archaeologist Sir Leonard Woolley, who was renowned for his innovative on-site stabilization treatments. The subject of this paper is a copper alloy relief of a bull from Tell al-Ubaid, which is now in the collection of Penn Museum. It comes from a frieze on the façade of the temple of Ninhursag, which dates to the First Dynasty of Ur (3100-2460 BCE). The object was mounted in a plaster support and wrapped with adhesive-soaked bandages, but it was unclear when these materials were applied. It was sent to Winterthur for treatment with the goals of removing modern materials and stabilizing the object. There were a dozen other fragmented bull figures from the same frieze, which are housed at Penn Museum, British Museum and the National Museum of Iraq; x-radiographs suggest that this figure is the most complete of its kind.

There is little technical information published on the objects from the First Dynasty of Ur, and less still on how Woolley's treatments of these objects have fared over time. This paper covers the research and technical analysis of this object, which elucidated both its archaeological context and treatment history. The object was studied with ultraviolet light, x-radiography, energy dispersive x-ray fluorescence, Fourier transform infrared spectroscopy, Raman spectroscopy, metallurgical cross section analysis, scanning electron microscopy with energy dispersive spectroscopy, secondary electron imaging and gas chromatography-mass spectrometry. This study revealed materials and evidence of manufacture consistent with the method of construction proposed by Woolley. Furthermore, elemental analysis suggested that the object was an intentionally alloyed copper, thereby supplementing evidence for deliberate metal alloying in ancient Mesopotamia. The identification of extensive atacamite corrosion products in the copper sheet, as well as the characterization of modern materials present on the object have guided treatment to inhibit corrosion and to remove foreign materials as gently as possible. The paper describes the first stage of treatment, which employed a commercially available expanding silicate, Dexpan, to break up and remove plaster. The project is expected to be a useful case study, both for treating archaeological reliefs and for removing comparatively robust conservation materials from fragile, partially mineralized metal objects.

The object examined in this study is a Mesopotamian metal relief of a recumbent bull. Dating from 3100-2460 BCE, it was excavated in 1923 during the joint expedition between the British Museum and the University of Pennsylvania Museum of Anthropology and Archaeology (Penn Museum). Part of the permanent collection of Penn Museum, it was selected for treatment and analysis due to its curious and somewhat mysterious state: the work was mounted in a plaster base and wrapped in adhesive-soaked bandages, which concealed bull's entire body. This treatment had no record in the curatorial or conservation files. The object was sent to the Winterthur/University of Delaware Program in Art Conservation, where the authors of this paper undertook its treatment. Since little analysis had been performed on contemporary Mesopotamian objects, the object also underwent a technical study. As well as adding to the body of knowledge surrounding ancient Mesopotamian sculpture, results of the analysis would also inform the treatment, which aimed to remove the modern materials from the archaeological object.

Figure 1: Bull relief, front. 24 $^{1}/_{2}$ x 11 $^{3}/_{4}$ x 7 $^{1}/_{4}$ inches. acc# ACP 1343 b

Tell al-Ubaid is an archaeological site in what is now southern Iraq (Fig. 2). From 1922 to 1934, Sir Leonard Woolley directed the excavation of this site and the neighboring site of Ur (Hall and Woolley 1927, 2). Renowned for public outreach and thorough documentation, Woolley is widely considered one of the first "modern" archaeologists. He recorded his methods for excavating fragile objects, which often involved consolidating them with molten wax, bandages, Celluloid (a cellulose nitrate consolidant) and/or plaster (Woolley 1924, Greene 2003, Schauensee 1998). Similar materials had been applied to the subject of this study, but it was uncertain whether this was done exclusively by Woolley or also by staff at the British and Penn Museums.

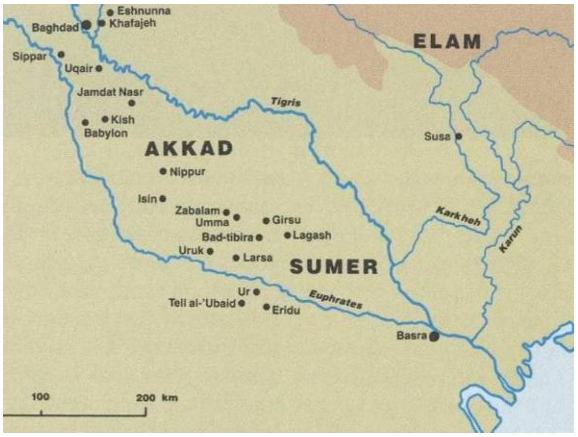


Figure 2: Map of Mesopotamia showing selected ancient cities, included Tell al-Ubaid; Figure 3: reconstruction of temple façade of the temple of Nihursag (Reed 1991)

The object was one of a dozen repeated recumbent bulls believed to come from the façade of a temple (circled in Fig. 3). Decorated elaborately with hammered reliefs, the temple served not only as an example of ancient al-Ubaid's architecture, but also of its metalworking technology. By about 3000 BCE, Mesopotamians had learned to reduce copper from the ore, and to manipulate it with a wide range of techniques (Levey 1959, 196). In addition to hammered work, metal objects from this site included repoussé, chasing, engraving, granulated work, filigree, and casting (Woolley 1935, 75).

According to Woolley's notes, the recumbent bulls' heads were cast in the round and their bodies were hammered over a wooden form coated with a thin layer of bitumen. This technique was apparently applied throughout the façade on the temple, and has been reiterated in articles such as Maryon and Plenderleith's "Fine Metal-work" of 1954, as well as in a treatment of a bull sculpture from the same site (Abbe 2005, 15). Woolley also wrote that the object included two curved copper rods, or "holdfasts," which, as he explains, were used to mount the relief into the mud brick structure of the temple (Hall and Woolley 1927). One of these holdfasts could be seen on the reverse of the object where it protruded from the plaster backing (Fig. 4).

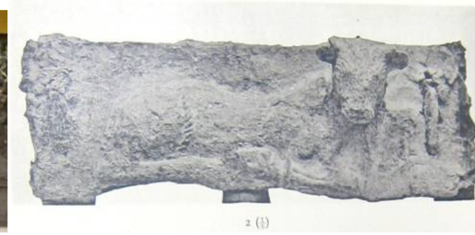
Figure 4: Back of bull relief with PR holdfast circled

These first attempts were made by Dr. Henry Hall, an Egyptologist from British Museum who led the initial phase of the expedition. Hall complained that the hard soil of the site did not facilitate the task: “we were working in a stiff clay beneath stiffer crudebrick, that needed hard work to dig it” (Hall 1930, 240). Several finds collapsed into a heap of green powder shortly after they were excavated. Forewarned by Hall’s experience, Woolley took extra precautions in excavating copper sheet objects. For fragments of the recumbent bull frieze that were found facing upwards, Woolley would mechanically clean the surface, then consolidate it by applying a facing of Paraffin wax and cotton bandages. This would render it stable enough to be lifted out of the ground and flipped. The back would then be “treated with celluloid (a cellulose nitrate consolidant) and the relief filled in directly with plaster” (Hall and Woolley 1927, 87). For fragments found facing downwards, the back had to be treated first and the face was left untreated.

After the finds were stabilized on-site in Ubaid, they went to the British Museum Laboratory, where some underwent conservation treatments. This included consolidation, loss compensation and chemical treatment, the last of which is illustrated by the different coloration of the disembodied bulls’ heads in Figure 3 (Abbe 2005, 11; Scott 1923, 2).

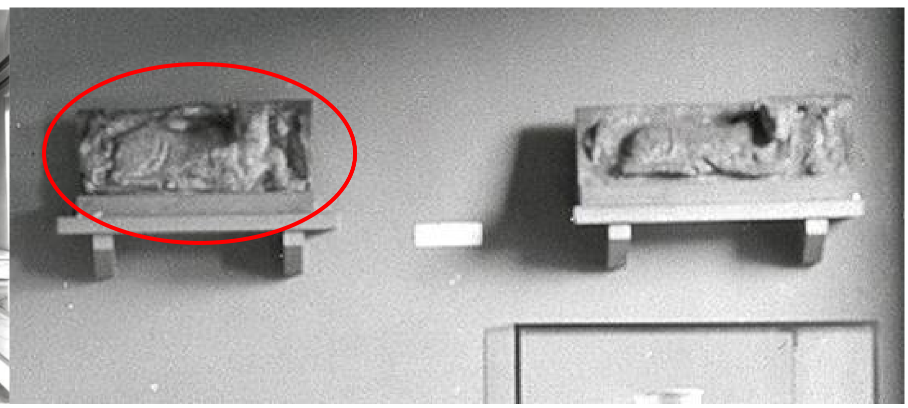
Figure 5: Three Penn Museum cast bull heads from the recumbent bull frieze with different treatment histories. From left to right, 1) “stripped,” electrochemical treatment, 2) sodium sesquicarbonate treatment 3) uncleaned with original consolidation wax and burial accretions. (Photo: M. Abbe, Penn Museum, 2004).

The finds were then were divided between the British, Penn and Iraq Museums in 1926. Most of the bulls are fragmented today, with the heavy cast heads separated from the hammered sheet bodies. To the authors’ knowledge only four of the extant bulls still have heads joined to their bodies, and this is only made feasible with mounting systems (Fig. 5). When Woolley uncovered the subject of this study, its head and body were separated. Believing they came from the same figure, he “restored them as such” and catalogued them under the same number, TO 294 (Hall and Woolley 1927, 88).


From left to right, Figure 6: relief at Penn Museum (with reconstructed bottom half) in plaster mount; Figure 7: relief at the National Museum of Iraq; and Figure 8: relief at British Museum, both with three-part, stone “Woolley mounts.”

The bull was outfitted with a horizontal, painted plaster mount that appeared to have had been designed for display purposes. Though there was no record of when this mount was introduced, a comparison with other bulls in different institutions demonstrated that its style was unique to Penn Museum. One bull at the British Museum has a three-part stone mount, which was installed under Woolley’s supervision (see Fig. 6-8) (Pearce 2010). It can thus be concluded that the painted plaster mount was installed after the object arrived at Penn Museum in 1926.

Left, Figure 9: Image of Near East Galleries at Penn Museum from the 1940s; right, Figure 10: detail showing two bull reliefs, left B15895, the subject of this report, (Penn Museum Archives).

Most of the front of the object was hidden by the woven bandages that were wrapped around it, likely intended as a temporary stabilization treatment. Transparent adhesive was applied on top of these bandages and permeated through them, holding them to the object’s surface. A photo from Penn Museum’s Archives shows the object on display, without bandages, ca. 1940 (Fig. 9-10). The bandages were therefore added after this date at Penn Museum, and not by Woolley or British Museum conservators.

By examining the object and comparing it to photos and other examples, one can thus construct a skeletal treatment timeline: the field stabilization in 1923, the mounting for exhibition after its arrival to Penn Museum in 1926, and the bandage facing applied sometime after the 1940s.

Study and Treatment Objectives

The goals of the 2011-2012 treatment (currently in progress) are to remove the obscuring and potentially damaging modern materials from the object and to stabilize the metal. A technical analysis was carried out to inform the treatment, as well as elucidate the object's construction and history. It is hoped that information gained about its materials and methods of manufacture will inform the study of similar metal objects dating to the First Dynasty of Ur. There is little technical information in the literature about metal objects from Tell al-Ubaid. In the 1920s Alexander Scott analyzed a copper ingot from the site, finding 4.4% lead (Woolley, 1954). The question of whether copper alloys like this one – potentially dating to 3100 B.C.E. – were alloyed intentionally is still debated (Moorey 1999, 248; Charvalt 2002, 149). Tin has also been found to be present in Mesopotamian copper alloys dating after the mid 3rd millennium B.C.E., and since tin has limited occurrence in the Near East, it has been argued that its inclusion is deliberate (Moorey *et al* 1988, 47). As well as the composition of its alloys, this study would provide primary evidence of the object's assembly, which would confirm or refute Woolley's and literature accounts mentioned above.

The study would also guide treatment. Characterizing corrosion products and determining their extent would dictate whether inhibition or stabilization was required. Characterize the restoration materials present on the object would help to reconstruct its treatment history, and that of other objects from the same site now in the collections of three museums.

Technical Study

The object was x-rayed to reveal what lay beneath the bandages. The x-radiograph (Fig. 11) showed that the body of the bull to be intact and complete. Compared to other bulls from the same frieze (Fig. 6-8), this bull had probably received little loss compensation in the 20th century. It was highly fragmented though, as about a half-dozen hairline cracks ran across the body, especially along concave contours which probably received the most hammering (e.g. the crack that runs along inner edge of the back haunch in Figure 6). The relative densities of the metal components confirmed that the head and holdfast are made of significantly thicker – or denser – metal than the body. The variation in density throughout the body suggested that some areas are more corroded than others; indeed, some may be completely corroded and devoid of a metal core. This could reflect varying degrees of cold working – which decreases grain size and thus expedites corrosion – throughout the work.

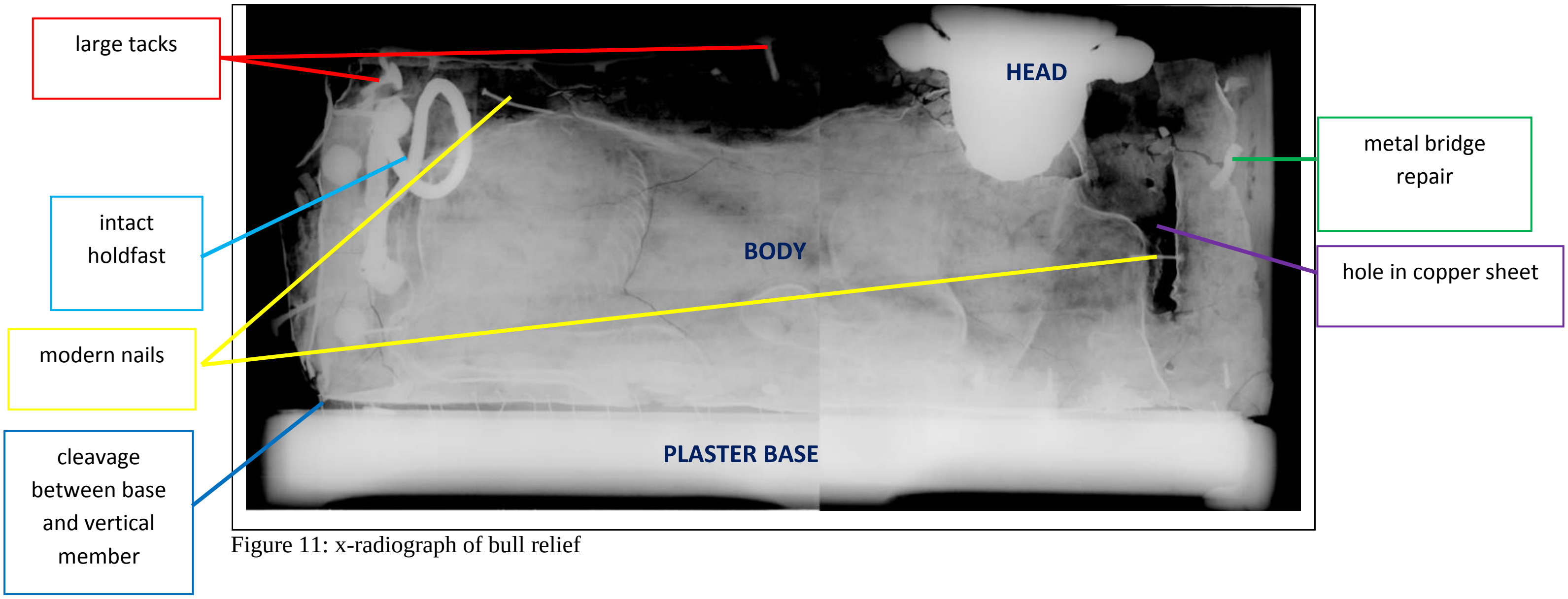


Figure 11: x-radiograph of bull relief

The x-radiograph also revealed numerous nails of a variety of shapes and sizes throughout the work. It was unclear if any of the nails were contemporary with the bull's manufacture; some of the larger forms appeared to be ancient tacks. Many of the fasteners were certainly added later (in repairs) as several modern forms were present, including twenty-nine nails that secured the vertical support to the base. To the proper left of the bull's head, a thick strip of metal bridged a fissure in the copper relief. Though it was uncertain when this new hardware was introduced (whether on site immediately after excavation or later at the British or Penn Museums) its presence indicated that the relief required stabilization post excavation. The x-radiograph suggested, therefore, that the metal sheet was fragile: mineralized copper is brittle and evidence of previous stabilization campaigns indicates physical vulnerability. One diagonal and two horizontal bars of less density ran across the bull's body. These were likely wooden planks added to the plaster backing to lighten it and increase its structural integrity.

Elemental analysis of the hammered sheet and cast head (Figure 12) showed strong copper peaks, which confirmed the hypothesis based on green corrosion products, and correspond to the analysis done on metal objects from the same temple at the British Museum in the 1920s (Hall and Woolley 1927, 37). Arsenic was also detected in both the sheet and head, which implied that the relief was made of arsenical copper, a common metal found in antiquity, which occurred naturally throughout the Near East (Moorey 1994, 250). Another strong XRF line generated by the head, and not the body, was lead (Figure 12A). This difference in elemental make up implies intentional alloying, which, in the case of the head, would lower the melting point of the metal and make it softer and therefore easier to chase after casting. This analysis contributes to the small amount of data supporting intentional alloying in Mesopotamia in the 3rd millennium BCE.

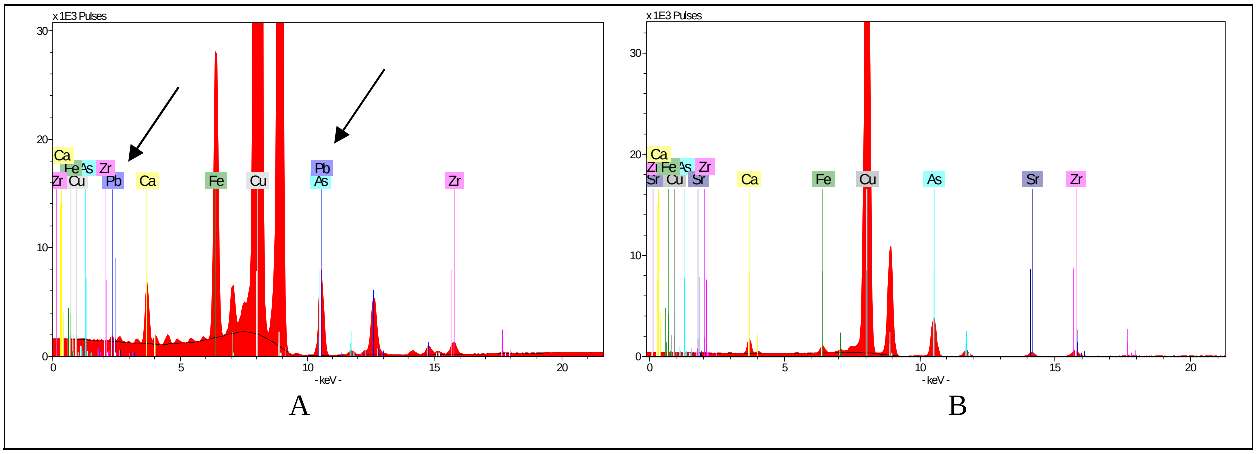


Figure 12: A) spectra of XRF-D, on bull's cast head with arrows pointing towards the lead peaks B) spectra of XRF-E, on bull's hammered body

FTIR analysis of the front surface of the copper sheet gave characteristic spectra for wax, which matched best with the library spectra for paraffin. Obtained by distilling shale oil, lignite and petroleum, paraffin wax was commercially available in the 1920s, at the same time Woolley was consolidating objects in the field (Gettens and Stout 1966, 47). This could very well be the wax he applied to the front of the bull, though it could also have been applied in a later surface consolidation treatment. The spectra of the adhesive used to hold the bandages to the object was a match for cellulose nitrate (Fig. 13). Cellulose nitrate would have been available in the 1920s, and continued to be used in restoration campaigns throughout the 20^{th} century. The spectrum exhibited a broad peak at 3498 cm^{-1}, which indicates the presence of camphor, a common plasticizing agent for cellulose nitrate. Both wax and cellulose nitrate may be damaging to the object as they have been known to form corrosion-catalyzing metal soaps and nitric acid, respectively (Paterakis 2003).

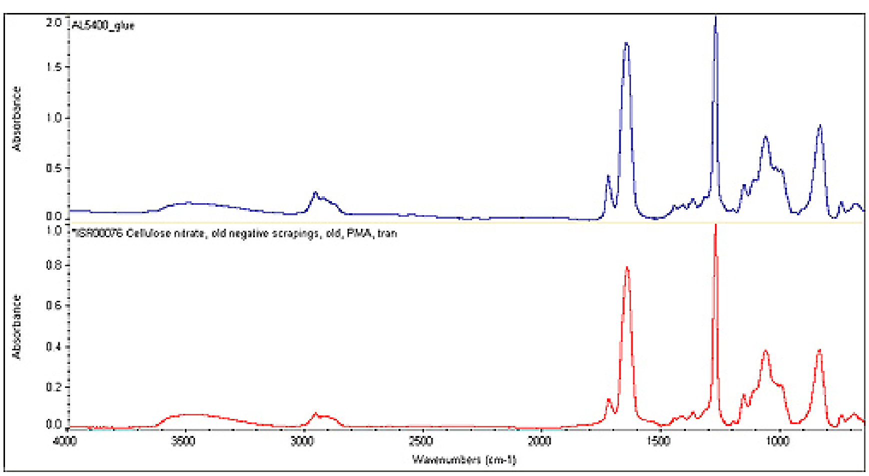
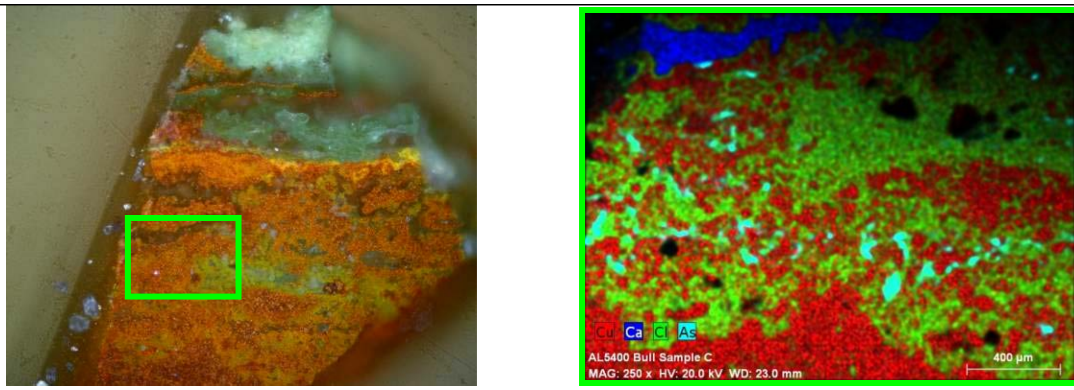


Figure 13: FTIR spectra for the adhesive on the bull (blue) and cellulose nitrate (red)

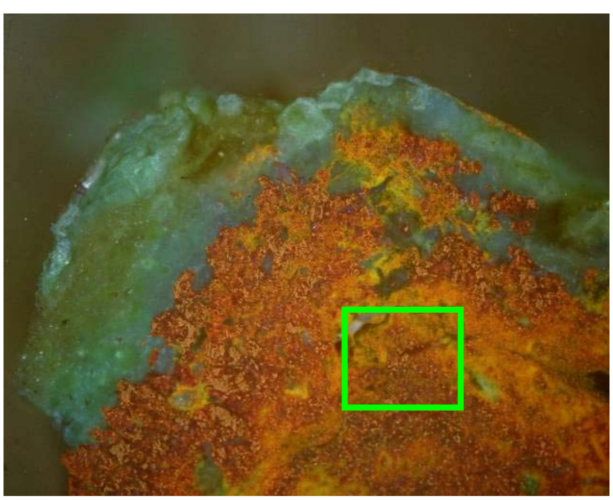
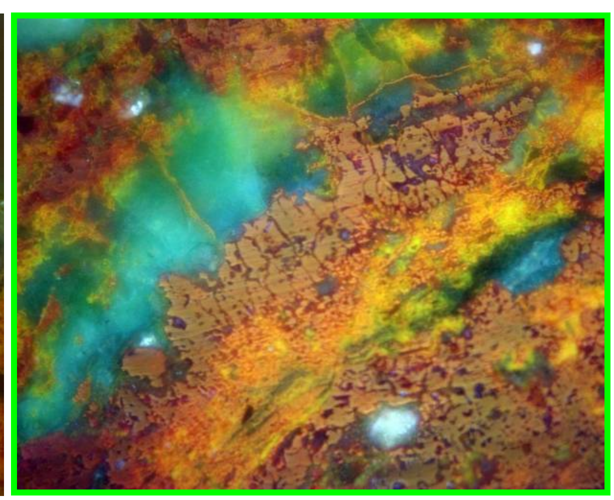
Cross sections showed the metal sheet to be nearly entirely mineralized and elemental maps revealed that the chlorides span the thickness of the sheet (Figure 14). FTIR and Raman spectra of corrosion products exhibited bands matching those of the library reference for atacamite, a form of bronze disease, which is a cyclic corrosion reaction that remains active until no metal remains (Scott 2002, 122). Though corrosion is present throughout the cross sections, they retained a small amount of metallic core with discernible grain structure (Fig. 15-16). These grains were very small, indicating that the metal was cold worked and annealed, which is a technique described by the literature on reliefs from Tell al-Ubaid (Hall and Woolley 1927; Maryon and Plenderlieth 1954, 639).



A **B**

Figure 14: A) cross section from metal sheet 100x unetched, in polarized light B) 250x elemental map showing Cu, Ca, Cl and As. The presence of green throughout indicates extensive chloride corrosion.

The fact that some metal remained meant that the copper sheet had not reached its maximum embrittlement: though very fragile relative to its integrity when it was first manufactured, the copper sheet likely retained a small amount of strength and flexibility. It also meant that the bronze disease was active, and thus should be inhibited in treatment. The presence of bronze disease had further ramifications for storage and display conditions, namely a low relative humidity should be maintained, as moisture expedites bronze disease (Scott 2002, 41).

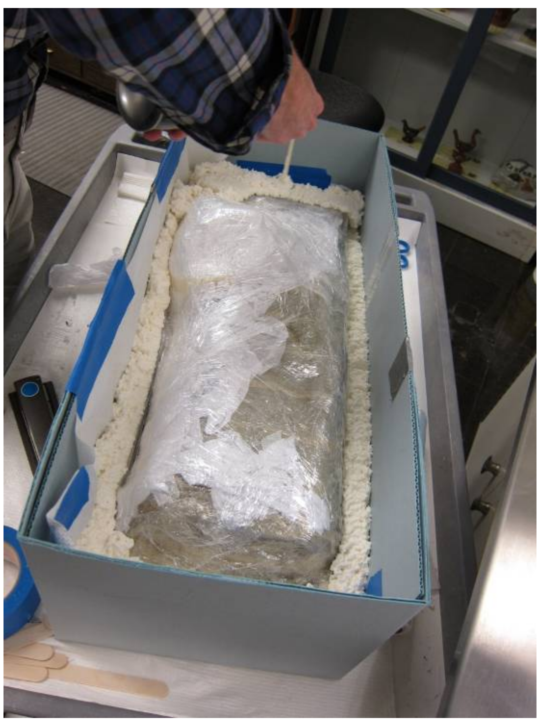
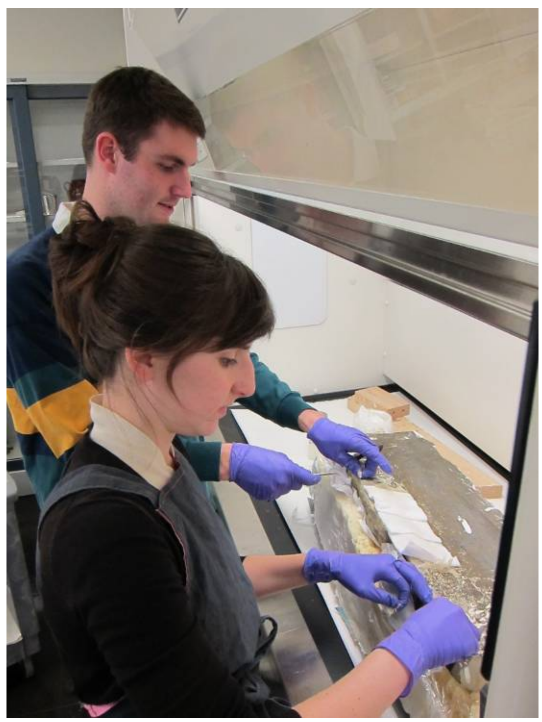



Left, Figure 15: 200x unetched cross section of metal sheet in polarized light; right, Figure 16: 400x unetched in polarized light with grain structure visible.

Treatment

Since the bandages were well-adhered to the front of the relief it was decided to leave them in place as a facing while plaster was removed from behind. The horizontal plaster base was removed first so that the relief could lie flat. As demonstrated by the x-radiograph, the base was held in place by vertical nails, and cleavage was present between it and the vertical support. This gap allowed for a safe mechanical removal with a chisel and wooden mallet. The nails introduced points of weakness, which assisted in removing the base piece by piece.

To turn the object over, it was necessary to support its irregular surface uniformly from the front. Great Stuff Gap Filler, a commercial polyurethane that expands when exposed to oxygen, was applied to the front after the surface was isolated with tissue paper and shrink wrap (Fig 17). The expansion foam was applied in layers to assuage heat generated by the exothermic curing reaction. A box was built around the object to constrain the lateral expansion and rigid weights were placed on top of the last layer of foam to attain a smooth base. The bull was then flipped onto its expansion foam support, and the bandages folded over the back were removed with acetone (Fig. 18).

Left, Figure 17: applying expansion foam to front of object; right, Figure 18: removing bandages from back

The challenge of removing the plaster remained. The technique to remove such a thick, robust material from such a delicate substrate had to fall within certain parameters. First, it had to be efficient, as allotted treatment time was limited. Second, moisture contact with the metal needed to be avoided, as it would expedite corrosion. Heat was also undesirable, as it would drive moisture out of certain materials in contact with the metal like wax and plaster. Finally, and most obviously, the treatment needed to avoid physical forces that might crack the brittle mineralized copper sheet.

The first possibility considered was chemical. Using a chelator with a strong affinity for calcium, it would be possible to dissolve the plaster without introducing stress to the object below. EGTA was applied in a test area and rinsed with water, which was alkalized to prevent corrosion promotion. However this approach proved to be too slow to penetrate such a thick passage: it took about an hour to remove a cubic ½ inch. It was decided that this technique might be effective for the last stages of plaster removal, but a more efficient method was required to eliminate the bulk.

Though briefly considered, mechanical options were quickly eliminated due to the inability to control the impact and vibrations they would introduce. With options dwindling, the authors consulted scientist (and problem-solving guru), Richard Wolbers. Wolbers suggested trying Dexpan, an expanding salt that is marketed as a non-explosive blasting demolition agent. Similar to soluble salts found in stone and ceramics, Dexpan contains silicates that take up more space in their crystalline form than when they are hydrated. When mixed with water and poured into drilled holes of stone or concrete, Dexpan gradually expands as it dries, exerting force on the walls of the hole until cracks form around it. By strategically placing holes, it is possible to guide the cracks, as they will always form where there is the least amount of resistance.

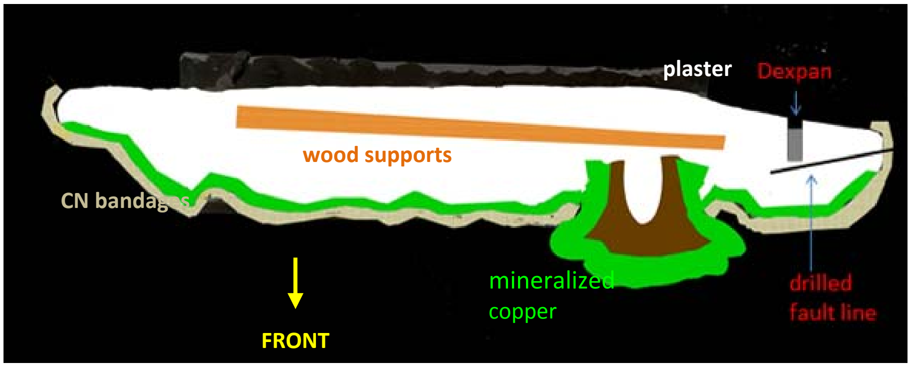
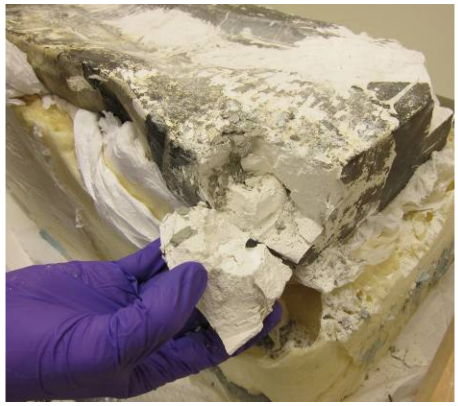


Figure 19: bird's eye schematic of object showing placement of fault line below "expanding hole" with Dexpan

A concern with introducing cracks into the backing was that they would exert stress on the mineralized copper below, causing it to crack, as well. To prevent this, fault lines were drilled below the expanding holes, allowing for a controlled demolition: chunks of plaster were removed at a pre-determined depth (Fig. 19).

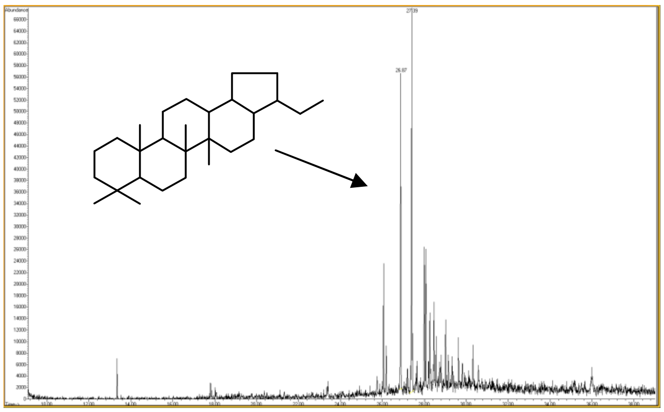



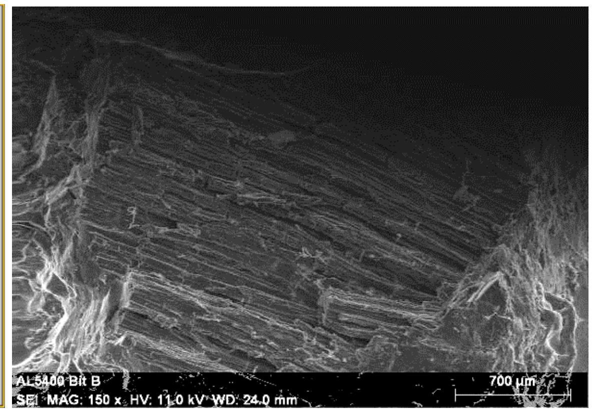

From left to right, Figure 20: filling expanding hole with Dexpan water slurry, Figure 21: first chunk of plaster removed; Figure 22: plaster removal in progress

Working in from the sides, two inches of plaster were removed from the top, exposing the top-most wooden plank. Expanding holes and fault lines were strategically placed around the wood to loosen the surrounding plaster and allow for extraction. The process was continued until the metal sheet was uncovered, which was performed without the use of a chelator as the plaster was not bonded to the metal surface. This poor bond was likely what necessitate the bandage facing. By the end of the semester, about ninety percent of the back surface was uncovered. The plaster left behind was either tenaciously attached to the surface or mechanically trapped by curving metal sheet.

Figure 23: back of object with approximately 90% of plaster removed

Both dirt from burial and a black substance were found adhered to the back of the object. The FTIR spectrum of the black substance on had bands at 1464 cm^{-1} and 1373cm^{-1}, which were characteristic of asphalt. GC-MS showed it to contain hopane structures (Figure 24). Both of these characterizations pointed to bitumen, which supported the method of manufacture Woolley proposed: that the copper sheet was hammered over a wooden form coated with a thin layer of bitumen. Secondary electron images of the bitumen further support this theory, as they exhibited impressions of wood grain, as well as fibers whose parallel vascular bundles and cellular structure resembled wood (Figure 25).





Left, Figure 24: GC-MS spectrum of black substance showing peaks for hopane structures; right, Figure 25: SEI image showing impressions in bitumen

Further Research and Treatment

Further research should be undertaken as treatment progresses. Metallurgical examination of the cast head, which is currently still covered from behind, may further illuminate its manufacture. The grain structure, for example, might light on the casting method. And the extent and characterization of corrosion layers in the cast elements would tell us more about their condition.

The chemical composition of the bitumen could be studied further. As Caroline Roberts notes in her unpublished 2010 study of a bitumen boat from Ur, it is possible to deduce the original source of the bitumen by calculating the ratios of its structures. This would require identifying all of the ring structures and quantifying the steranes and termpanes present (Roberts, 2010; Connan, 1999). There is also more to be discovered about the wooden core. This would likely require a larger passage of impressed bitumen than what has been uncovered so far. The pattern of grain structure might tell us the cut of the wooden form, and possibly the species.

After completing analysis of the exposed backside of the object, future Winterthur students will remove remaining conservation materials, apply a corrosion inhibitor to the metal surfaces and stabilize the fragments. An appropriate mount should be constructed, perhaps drawing from the design of mounts used at the British Museum for bulls from the same frieze. These mounts are structurally sound, visually unobtrusive and chemically stable: at the very least less hygroscopic and more reversible than plaster.

Historical treatments like the ones this bull underwent are easy to criticize today. These materials are unsightly, potentially damaging to the object and difficult to reverse. However they have managed to keep the object intact for nearly ninety years. It is fortunate that materials added after excavation were in keeping with those Woolley had introduced, as this certainly simplified removing them. This may well have been a conscious decision on the part of Penn Museum conservators. Woolley himself seemed aware that his field methods, pioneering as they were, might, in due time, receive criticism.

He writes:

> "Our methods had to be adapted to the particular circumstances, and they were of course limited by the materials at our disposal…On the whole we were I think remarkably successful in salvaging antiquities whose condition seemed at first desperate, and though our methods might of course be improved upon, they may nonetheless prove a useful guide to other diggers." (Hall and Woolley 1927, 79).

This paper is presented in the same spirit of collegiality, in hopes that conservators can use this case study as a reference for similar objects in their collections. It is this sharing of information – combined, of course, with thorough documentation and the use of reversible materials – that offsets the likelihood that our treatments will become outdated. Which is, after all, an inherent reality of a field that is constantly evolving.

Acknowledgements

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