**[title]The Cleveland *Apollo*: Recent Research and Revelations**

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[A-head]Abstract

[abstract]

The Cleveland *Apollo* (Cleveland Museum of Art, inv. 2004.30) has continued to be the subject of extensive research since just prior to its acquisition in 2004. The life-size (H 150 cm or 59 in.) artwork depicts a youthful god of the *sauroktonos* type, including a small, serpent-like creature, now detached. The sculpture is nearly complete, missing only parts of both arms and the accompanying tree. This paper details the most recent research conducted in 2014 and, incorporating data from previous studies, provides a preliminary interpretation of the results. Research included extensive visual analysis, X-radiography, X-ray fluorescence spectrometry, metallography, and lead-isotope analysis of the bronze. These analyses had three primary goals. The first was to better understand the original manufacture, including how the indirect lost-wax bronze was cast, patched, and finished. The second aim was to reconstruct the history of the object before, during, and after burial. This included furthering the understanding of the bronze’s corrosion layers and remaining traces of archaeological materials, and also determining when and how the figure had been exposed to fire. Lastly, this research endeavored to elucidate decades of post-excavation display and interventions, including joining the sculpture to a bronze sheet as a display base, and reconstruction using modern materials.

[A-head] Introduction and Pre-accession Investigation

[main text]

The only life-size bronze version of the sculptural type traditionally known as *Apollo Sauroktonos* (*Apollo the Lizard-Slayer*), now re-named *Apollo the Python-Slayer* and attributed to Praxiteles, is part of the permanent collection of the Cleveland Museum of Art (inv. 2004.30; **fig. 40.1a–d**).[[1]](#endnote-1) There are approximately twenty other known sculptures of this type that exist, all in marble with one reduced-scale bronze copy.[[2]](#endnote-2)

The Cleveland bronze was carefully studied before its acquisition in 2004, and initial visual examinations noted the inlaid copper lips and nipples, the inlaid stone eyes (the right is original), and the separately cast and welded-on front half of the right foot. Numerous rectangular patches and square chaplet holes were noted as evidence of original manufacture. The head had been joined to the neck and the lower left leg joined to the calf in a recent restoration, as evidenced by the use of modern adhesives and a modern internal armature. Most surfaces had been mechanically cleaned except for areas of the hair that retained layers of corrosion and dirt. A dent on the right leg exhibited fracturing and appeared to be something that had occurred post-excavation. Clumps of metal on the back and legs seemed to be related, at least in part, to the tree, now missing. The openings at the arms and feet revealed wax manipulation marks in locations not obscured by modern resin repairs, indicating that the sculpture had been created by the indirect casting process. The bronze plate serving as a base appeared to have been added, as it could never have supported the sculpture on its own, but it was sufficiently corroded to have been in place for some time.

Radiographs clarified areas of modern repair, such as plaster and resin fills around the neck and shoulders, demonstrating that the figure was nearly complete. Also noted were the thick walls (about half a centimeter in many locations) and large individually cast sections of bronze. The radiographs taken at that time did not appear to show that the head was joined at the jawline, and, despite much damage to the neck, written reports concluded that the head was likely cast to the mid-neck (**fig. 40.2**). This visual analysis and radiography provided important basic information about the figure, yet many questions about *Apollo*’s original manufacture, subsequent excavation, and display remained.

In 2004, two of the authors, Peter Northover and Ernst Pernicka, were invited to collaborate. This earlier phase of research is summarized briefly here so that the focus of the paper can remain on the most recent analysis. Three samples of bronze were selected from the detached hand, the right shoulder, and the base. Northover analyzed the samples by electron probe microanalysis with wavelength dispersive spectrometry, and afterward the samples were also examined metallographically in both polished and etched states. It was concluded that the hand and shoulder belonged to the same object and were thoroughly corroded, with almost all the lead having been replaced by corrosion products. In contrast the base was found to be barely corroded at all. What corrosion was present on the base was natural but different in character, suggesting that the base dated from a more recent remounting; based on the known history of the artifact, a date between the seventeenth and the nineteenth century is suggested (**fig. 40.3**). In addition, the corrosion products excluded the possibility that the sculpture had been buried in a marine environment. The lizard (now identified as a “python”) was subsequently sampled in 2006, taking pieces from the front proper left leg and rear proper left leg, to compare either side of the central join.[[3]](#endnote-3)

The compositional analysis of the five samples showed the torso and python belonged together, but the base had a different history. The corrosion products on the figure were consistent with an object that was buried for an extended time and then re-exposed to atmospheric corrosion and precipitation. Interestingly, analysis indicated that early in its history the figure was exposed to extreme heat, while the base did not show evidence of having been in a fire. The two halves of the python seemed to have been cast from the same melt, with some differences in composition due to segregation of lead. The alloy was found to be a low- to medium-tin bronze with 6.7–7.6% tin and 8.6–16.3% lead and was related to the main figure, which had similar tin and lead contents. At that time, it was not possible to determine whether the hand was related, with only one extensively corroded sample having been examined.

Pernicka tested four samples of lead solder in order to determine how the baseplate might relate to the figure: three from the proper right foot that was separately cast and one sample from the body of the figure. They were analyzed by energy dispersive x-ray fluorescence (EDXRF), and the sample from the figure was additionally analyzed by neutron activation analysis, essentially confirming the electron microprobe analyses. Two solder samples were tested for a radioactive signal of 210Pb (see below for test description.). One sample did not yield a usable result and was inconclusive. Another showed measurable radioactivity, which would indicate that the lead and tin were produced within the last hundred years.

[A-head]Recent Testing: Bronze Compositional Analyses

In 2013 a Cleveland Museum of Art focus exhibition on *Apollo* provided an opportunity to continue analysis of the sculpture, and Northover and Pernicka traveled to Cleveland for study and sampling. Additional cross-sections were taken from numerous areas of the figure, the detached forearm and hand, and the python. Seventeen samples in all were carefully selected for location and accessibility, with the goal of obtaining as much information from as few samples as possible, and these were mechanically removed from the bronze. As many as 11 areas on every sample (30 x 50 µm) were analyzed with wavelength dispersive spectrometry and electron probe microanalysis, and 16 elements were recorded as individual compositions of each sample in weight percent. Electron probe microanalysis of the samples verified that the figure was composed of a high-lead, low-tin bronze, as found in earlier analyses (see **table 40.1** for percentages).[[4]](#endnote-4) After analysis the mounted samples were studied in both polished and etched states. The results of the metallographic analysis are consistent with the figure, hand, and python being ancient, as they all have thick corrosion crusts and deep penetration that developed during burial and subsequent outdoor exposure. In fact, some samples were too corroded to be etched and could only be examined as polished.

In order to ascertain whether parts of the figure derived from the same casting or the same raw metal source, multiple small samples from locations throughout the figure were obtained with a steel drill bit to be analyzed with inductively-coupled plasma mass spectrometry (ICP-MS) and EDXRF. This combination of analyses confirmed that the bronze samples had a uniform composition with the exception of the baseplate, which had more lead and less tin than the rest of the figure.[[5]](#endnote-5) The uniformity of the figure, the left hand, the forearm, and the python was further confirmed by lead-isotope ratios, with only the lead solder on the baseplate having a clearly different lead isotope signature.

[A-head]Evidence of a Fire

In addition, parts of the figure’s body, especially the right arm and shoulder, appear at some point in their history to have been exposed to a high-temperature oxidizing atmosphere, such as in a fire. The evidence for this is a band of cuprite particles beneath the metal surface, which was formed by the inward diffusion of oxygen at high temperature (internal oxidation) (**fig. 40.4a–b**). Another sign of exposure to a high temperature environment is the lump on the back of the left thigh (**fig. 40.5**). While previously believed to be fractured supports for the missing tree, these amorphous bits of metal attached to the figure are now known to have solidified from an oxygen-rich melt, as demonstrated by the presence of cassiterite crystals in cross sections.[[6]](#endnote-6)

[A-head]Analysis of the Baseplate

The irregularly cut bronze plate now serving as a base required additional research, as most ancient bronze statue bases are made of stone. Moreover, the few extant bronze bases, such as that of the Croatian Apoxymenos, are considerably larger. The thin bronze plate used to secure *Apollo*, together with the remains of an applied solder on the top surface, was not likely to function on its own as the original base. Analysis of the baseplate indicated that though it was composed of high-lead, low-tin bronze, the composition was markedly different than that of the figure, the detached hand and forearm, and the python.[[7]](#endnote-7)

Unlike the rest of the figure, the baseplate shows no sign of exposure to fire. The relative lack of corrosion on the baseplate further indicates that it was not the original base. Where the plate has not been protected by the solder, the corrosion layer is thin and of a generally uniform depth (about 50µm), with no deeper penetration of the interdendritic lead. By contrast, the samples from the figure are very deeply corroded with interdendritic and intergranular corrosion extending to a depth of several millimeters, while the corrosion products are stratified in such a way as to suggest a significant change in environment at some point in the figure’s history. The plate has been exposed to the environment for long enough that some fine-scale transgranular corrosion has developed; this could be expected from exposure to the elements since the eighteenth or nineteenth century.

Interpreting the history of the solder use on the figure and baseplate is a challenge because there has been little compositional analysis of ancient solders. All the solders identified in this study are tin-based. Pure tin was used as a soft solder in the ancient world since the seventh century BC, but the original solder on *Apollo* would most likely have been a lead-tin mixture.[[8]](#endnote-8) When molten tin comes into contact with a bronze surface, a bi-layer of the epsilon and eta phases of the copper-tin system forms very rapidly, with the epsilon phase bonded to the bronze; above the eta phase will be a layer of unreacted tin. This tin corrodes quite rapidly, and within the thick layer of solder remaining on the baseplate it has largely disappeared. The eta phase is preserved on the baseplate but is missing in the other locations of solder. Substantial remains of the epsilon phase survive on the feet of the python, and this is consistent with it having been re-attached to the tree when the statue was first displayed ~~after excavation~~. Conversely, only a thin layer of the epsilon phase remains in the solder under the little toe of *Apollo*’s left foot, separated from the heavily corroded bronze by up to 100µm of corrosion product. Since bronze must have initially been adjacent to the solder for the epsilon phase to form, and the thickness of corrosion seems greater than what might form during two centuries of exposure to an inclement European climate, it has been concluded that the solder on the foot is ancient. In turn, it follows that the toe was once attached to a piece of metal, suggesting that we must now reconsider how the statue was displayed in antiquity.

[A-head]Lead Isotope Analyses

Additional samples of the solder on the baseplate, as well as samples of the bronze alloys of the baseplate and right foot of the statue, were also analyzed by alpha spectrometry to determine if the radioactive nuclide 210Pb was present. This test for the authenticity of metal artifacts is based on the disturbance of the radiochemical equilibrium of the 238U decay chain during the smelting process. Ores and minerals accompanying the ore usually contain small amounts of uranium. In the decay chain of uranium, elements with different geochemical and metallurgical behavior occur. While lithophile trace elements like uranium, thorium, and radium remain in the slag, chalcophile and siderophile elements, like bismuth and lead, are taken up by the metal phase. Thus the short-lived radionuclide 210Pb (half-life = 22.3 years) is efficiently separated from its long-lived ancestors 238U (half-life = 4.4 x 109 years) and 226Ra (half-life = 1,600 years). The concentration of 210Pb in the metal depends on the origin of the ore and the manufacturing process, so it cannot be used for dating. The 210Pb in the metal then decays with its own half-life of 22.3 years and as a result of the disrupted decay chain it cannot be renewed. This means that radioactivity is usually only measurable in metals younger than about 110 years (relating to five half-lives of the nuclide).[[9]](#endnote-9) Since no measurable activity was detected in the *Apollo* samples, it was concluded that not only the lead in the solder but also the lead in the bronze of the baseplate and the cast-on front half of the right foot are all older than about 110 years.[[10]](#endnote-10) It should be noted that in principle old metal could have been used to produce the objects in modern times. However, this is quite unlikely in this case considering the amounts and types of corrosion products present.

The relation of the bronze baseplate to the figure had puzzled scholars since the acquisition, and questions had persisted about whether it was a recent addition. However, recent results point to it having been attached to the figure in the eighteenth or nineteenth century, based on a few key facts. Compared with the corrosion of the solder remnants on *Apollo*’s foot and on the python, the solder on the baseplate is much less corroded, with the eta phase still preserved. In addition, the composition of the soft solder on the baseplate is inappropriate for an ancient solder.[[11]](#endnote-11)

However, most unexpected of all was the finding that the stable lead-isotope ratios of the plate were consistent with the other parts of the sculpture. In fact, all bronze parts of the statue are isotopically virtually indistinguishable, although one could argue that the two samples of the python and the sample from the cast-on right foot are slightly different from the remaining samples (**fig. 40.6**). This may indicate that the same batch of lead was used but there were two different casting charges. Only the lead solder on the feet and baseplate has a clearly different lead-isotope signature. All of this information may suggest that perhaps the baseplate was reused or recast from the original sculptural assemblage, which would also be consistent with the 210Pb result.

Lead-isotope ratios can also be used to determine the provenance of the lead in the alloy, because much data is available for lead deposits in the Aegean region, in southeastern Europe, and in the eastern Mediterranean.[[12]](#endnote-12) The lead isotope ratios of both the statue and the solder exclude a geological provenance of the lead from the Aegean and therefore Laurium, the largest source of Aegean lead in antiquity. There are not many lead ore deposits that would match the *Apollo*. The Cevennes in France and the Balkans are two possibilities (**fig. 40.7**).[[13]](#endnote-13)

[A-head]Interpretation of Results and Conclusion

Recent analyses of *Apollo* have successfully resolved several questions that have persisted since its acquisition by the Cleveland Museum of Art over ten years ago. All of the reassembled bronze fragments of the figure, hand and forearm, and python belong together and were cast from the same melt, confirmed by metal composition, lead-isotope ratios, and corrosion history. In addition, the corrosion seems to support the figure’s purported history of use, suggesting that it was exposed to an exterior atmosphere for an extended time after excavation. The figure also displays evidence of having been in a fire, which appears to have happened after its excavation; this may be partially responsible for some of the damage that is now evident on the right side. The recent testing was also successful in revealing more information about the baseplate, which does not appear to be entirely original. Though the baseplate’s corrosion differs from that of the remainder of the figure, it shares a lead-isotope signature, leading to the conclusion that the base may be a repurposed part of the original sculptural assemblage. The lead-tin solder used to attach the sculpture to the baseplate has tested as over 110 years old, and it appears to have been done around the eighteenth or nineteenth centuries. An incised line cut into the baseplate to follow the contour of the right foot is corroded over but not sufficiently corroded to indicate that the join is ancient, further supporting this claim.

As for the fire that may have damaged *Apollo*, an attempt was recently made to explore when that occurred. Two samples of charcoal were obtained from the edge of the separated forearm for carbon dating, but the results produced dates that were substantially older than the Greek or Roman periods (see fig. 40.7). One possible explanation for this is contamination of the samples with modern, oil-based materials used during previous restoration efforts. These restorations have also made it difficult to document evidence of manufacture, such as wax-to-wax joins, drips, and tool marks often seen on the interior of bronzes. Recently, CT scans were obtained in an effort to better document features that may lie beneath the plaster, wire mesh, and modern resins used to reassemble the figure over the years. However, the high lead content has made imaging a challenge. A few scans of the detached hand and python have been obtained, but more work is necessary to improve the clarity of the images. In fact, the attempt to image *Apollo* is exemplary of the multiple efforts over a dozen years to better understand the figure; each step forward in obtaining more information leads to additional questions. While we have certainly advanced our understanding of the sculpture, it is clear that the Cleveland *Apollo* will continue to provide new opportunities for research for years to come.

[A-head]Acknowledgments

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1. Bennett 2013. [↑](#endnote-ref-1)
2. Preisshofen 2002. [↑](#endnote-ref-2)
3. Bennett 2013, 80. [↑](#endnote-ref-3)
4. Metallography of the figure, detached hand and forearm, lizard, and baseplate was performed by Peter Northover in early 2014 with a report submitted on March 31, 2014. These analyses were compared with published compositional analyses of classical sculpture, including Craddock 1985; Mattusch 1996. For standardization between methods of analyses, see Mattusch 1996 and Northover and Rychner 1998. [↑](#endnote-ref-4)
5. Eight samples were selected and removed with a stainless steel drill bit and analyzed by Ernst Pernicka in the spring and summer of 2014. The final report of these analyses was submitted August 28, 2014. The samples were first cleaned mechanically under magnification to remove corrosion and nonmetallic material before analyzing with EDXRF. The lead-isotope ratios were determined with a multicollector-inductively coupled plasma mass spectrometer (MC-ICP-MS) after chemical separation of the lead. [↑](#endnote-ref-5)
6. A bronze melt sufficiently rich in oxygen will solidify as a mixture of copper, cuprite, and cassiterite; it is possible that fragments of building debris or ash are also included, and this may make the lump more of a slag. In nonequilibrium conditions, cassiterite can exist in contact with bronze. The temperature suggested by this lump is approaching 1000ºC. [↑](#endnote-ref-6)
7. Refer to table 40.4 for percentages. The first sample taken from the base, no. R2320, had 3.4% tin and 19.5% lead, and the alloy was confirmed by the second cross-section obtained in 2013, no. R4780. [↑](#endnote-ref-7)
8. Only a few quantitative analyses of ancient solder have been undertaken, but these suggest that lead-tin solder was regularly used from the late first millennium BC onward: Drescher 1959; Fasnacht and Northover 1991; Wolters 1996. [↑](#endnote-ref-8)
9. Further details of the method are published in Pernicka et al. 2008. [↑](#endnote-ref-9)
10. The seeming inconsistency with the first measurement of 210Pb is probably due to the very small sample size (less than 5 mg) that was first submitted and may have been taken from the surface of the object where it could have been contaminated with 210Pb from the environment. Furthermore, this sample had a rather unusual and different composition from the other solder samples. The sample was described in an earlier conservation report as “Apollo figure: from the base, proper right foot, instep near the toes,” but no further detailed documentation is available. [↑](#endnote-ref-10)
11. All samples of solder that were mechanically removed from both the top and bottom of the baseplate consist of a lead-tin alloy with about 30–40% tin. [↑](#endnote-ref-11)
12. Pernicka et al. 1984; Stos-Gale, Gale, and Annetts 1996; Gale et al. 1997; Pernicka et al. 1997. [↑](#endnote-ref-12)
13. Bode, Hauptmann, and Mezger 2009 and unpublished data from the Balkans. [↑](#endnote-ref-13)