



Article: Deciphering the puzzle: The examination and analysis of an Eastern Han Dynasty money tree

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DECIPHERING THE PUZZLE: THE EXAMINATION AND ANALYSIS OF AN EASTERN HAN DYNASTY MONEY TREE

John Steele, Leon Stodulski and Karen Trentelman

1. Introduction

The focus of this paper is a Chinese artifact of the Eastern Han Dynasty identified as a money tree or *yaoqianshu* (Erickson 1994). Money trees are so named by modern scholars because of their most prominent feature: cast bronze branches laden with images of coins. In addition to the coins the branches also contain mythological figures and objects important to Han beliefs.

Currently there are only four known money trees outside of China, one of which the Detroit Institute of Arts (DIA) acquired in 1996. The other trees belong to the Royal Ontario Museum in Toronto, Canada, the Asian Art Museum in San Francisco and a dealer in New York City. In China there are perhaps eighty fragments of trees from excavated tombs but because of the fragility of the bronze branches, only a few trees have survived to an extent that permits reconstruction (Erickson 1994).

The DIA's money tree stands 58 inches (147 cm) high and consists of thirty-four branches, a finial and a trunk which fits into a ceramic base (Figure 1). The branches are very thin and fragile, and upon initial investigation it was apparent that the base and many of the branches had undergone prior restoration. Based on a stylistic analysis of the branches, Laurie Barnes, DIA Associate Curator of Asian Art, suspected that branches from at least five different money trees had been brought together to make this one complete tree.

Acquiring the money tree afforded us the opportunity to thoroughly examine and analyze the component parts of one of these rare objects which, to our knowledge, has not been done before. The purpose of our study was to unravel the complex treatment history as well as the origins of the DIA's tree, and to provide a source of data for comparison to other trees when they are eventually analyzed.

In this paper the context and meaning of money trees will be briefly discussed. The examination and condition of the DIA's money tree will be described and a technical study of two of the bronze branches will be presented.

2. Money Trees: Context and Meaning

Money trees were produced during the Eastern Han Dynasty (about 25 to 220 A.D.) in and around an area that is now the modern province of Sichuan, in the People's Republic of China (Erickson 1994). Money trees were created to be placed in the tombs of wealthy individuals to

provide them with an unending source of funds in the afterlife. However, the composition and iconography of money trees, with their ceramic bases and elaborately decorated hanging bronze branches, are thought to also represent the Han dynasty conception of the journey from earth to the heavenly realm and the quest for immortality (Erickson 1994). This journey is described in a Han text as follows:

He who climbs the Chilly Wind Peak of Kunlun will achieve deathlessness; he who climbs twice as high onto the hanging garden will become a spirit and will be able to make wind and rain; he who climbs twice as high again will reach heaven and become a god. (Liu An, 2nd century A.D.)

The bases of many money trees are often mountain-shaped like the mythical Mount Kunlun. This mountain is important in Han mythology because it is the home of Xiwangmu, the Queen Mother of the West, a major Daoist deity who possessed the elixir of immortality and is said to have ruled the land of immortals from the top Mt. Kunlun. The bases frequently are topped by auspicious animals, such as rams, whose function it is to convey the deceased upward toward heaven (Erickson 1994).

The branches of a money tree can be considered to be a stylized representation of the hanging garden described above. In addition to coins, the most prominent image in the branches is Xiwangmu. She is typically depicted enthroned on her dais and flanked by the dragon of the east and the tiger of the west, symbols of her power over the world. Also found in the branches are images of the makers and partakers of the elixir of immortality, such as toads and Daoist immortals as well as other celebrants in the heavenly realm. The top of a money tree is usually crowned by an elaborate finial incorporating the image of Xiwangmu or an auspicious creature such as the sun bird or phoenix, an omen of world peace (Erickson 1994).

3. The DIA Money Tree: Examination and Condition

The initial examination of the ceramic base and the metal trunk, branches and finial of the DIA's money tree was carried out with the aid of x-radiography, x-ray fluorescence (XRF), and thermoluminescence (TL) dating.

3.1 The Base

The terra cotta base, in the shape of a ram surmounted by a rider, is hollow and covered with an iridescent light green and brown glaze. The base was probably made from two molds, evidenced by the fact that the two halves are out of register (one side of the ram is about 3/4" higher than the other). The base had been broken into approximately twelve pieces and was reassembled in a previous restoration with an unknown adhesive.

Two sites from the interior of the base were sampled for TL dating and the results were consistent with the dates of the Eastern Han Dynasty (25-220 A.D.). Following TL analysis, the glaze was analyzed using XRF and found to contain lead, typical of Eastern Han ceramics.

3.2 The Trunk

The trunk, which fits into a hole in the top of the base, has rings mounted to it at regular intervals along its length. A hook at one end of each branch affords a way to attach the branch to the trunk. An authentic money tree trunk, according to the curator's research, would have been a bronze, oval-shaped tube. The trunk of the DIA's money tree is a solid rod which was shown by XRF analysis to be composed of brass. Therefore, we conclude the trunk is a reproduction.

3.3 The Branches

Money tree branches traditionally would have been cast in a ceramic piece mold using a bronze alloy (Chase 1994). The form of the branches is thought, in part, to have been inspired from the molds for Chinese coins. Coin molds of the period show a branched or channeled construction, with smaller channels radiating from a central one, each channel terminating in a coin (Erickson 1994). The cast from such a mold would have had multiple coins attached to a branched structure, not unlike a simple, unadorned money tree branch.

The thirty-four branches of the DIA's money tree can be divided into two groups according to their size: there are twenty large and fourteen small branches. This study concentrated on the examination and analysis of the large branches. Analysis of the small branches is reserved for a later date.

Initial visual examination of the DIA's money tree indicated that some of the branches are particularly thin casts and that corrosion has made them even thinner and more fragile. In fact, seven of the branches were broken in shipping from the dealer to the DIA because of their fragility. Fortunately, most breaks occurred at the site of old repairs.

Following visual examination, each branch was x-radiographed¹. The x-radiographs reveal repaired breaks in the branches as well as areas of replacement or repair using materials other than bronze. In many instances, the repairs were very skillfully disguised on the surface and would have been undetectable without x-radiography.

The x-radiographs also aided the stylistic analysis of the branches by revealing surface details that had been obscured by layers of corrosion. The branches were divided into five stylistic groups named according to a characteristic feature within each group. The groups thus named are: "Kneeling Immortals," "Moon Toad," "Blue Queen Mother," "Brown Queen Mother," and

"Cricket." Two branches from each of these five style groups are shown in Figure 2.

3.3.1 "Kneeling Immortals"

The "Kneeling Immortals" group contains four branches which are named for the kneeling figures present along the top of each of the branches. The Immortals, who became so by drinking the elixir of immortality, are characterized by big ears, double top knots and wings or feathered bodies (Erickson 1994). These branches are very thin casts with finely detailed surfaces and are perhaps the most stylistically refined of the five groups. The corrosion layer is relatively thin and compact and ranges from light green to blue in color.

Because of their inherent fragility, these branches had been heavily repaired. All have had sections replaced, which appear in the x-radiographs as brighter, less detailed regions (see Figure 3). Using XRF analysis, the replacement sections were determined to be composed of a lead-tin alloy (approximately 1:1 Pb:Sn). The replacement sections were most likely cast from a mold taken from an existing original section. They were soldered into place and then artificially patinated to match the corrosion on the bronze. Another skilled method of repair observed within this group was the use of metal pins and solder to repair breaks in the branches.

3.3.2 "Moon Toad"

The "Moon Toad" group consists of two branches and is named for the toad figures found on the branches. In Han mythology, the elixir of immortality was stolen by a beautiful woman, Chang'e, who fled to the moon where she was transformed into a toad as punishment for stealing. The branches of the "Moon Toad" group are thin, detailed casts, and along with those of the "Kneeling Immortals" group, are the most stylistically refined of the five groups. The corrosion layer is dark green, glassy, and compact in appearance. The branches are fragile and contain numerous repairs: metal pins to repair breaks in both branches and replacement sections of lead-tin alloy on one of the branches. In addition, the hooked ends of the branches, which originally would have been cast integrally as part of the branch, have been skillfully replaced with copper. The new hooks were installed with small tongues of copper extending from the tip into the center of the bronze stem, as shown in the x-radiograph in Figure 4.

3.3.3 "Blue Queen Mother"

The "Blue Queen Mother" group consists of six branches and is named for the heavy layer of blue/green corrosion present on the branches and the figure of the Queen Mother of the West at the top of each branch. These branches are thicker and less refined casts than those in the other style groups, and four of the branches have small sections replaced with lead-tin alloy. In general,

there are fewer repairs here compared to the other groups. However, as seen in the "Moon Toad" group, the hooked ends of four of the branches have been replaced with copper or brass.

3.3.4 "Brown Queen Mother"

The "Brown Queen Mother" group consists of four branches and, again, is named for the color of the branches and the presence of the Queen Mother of the West at the top of each branch. All four branches are thin, fragile casts and have a very thin, brown corrosion layer on the surface. However, XRF analysis revealed that two of the branches are a brass alloy and therefore probably are copies. The two bronze branches show numerous repairs while the brass ones show very few. The repair materials found on the two bronze branches include lead-tin solder, grey putty, and clear resin. Also of note in this group is the absence of lead-tin alloy replacement sections on any of the four branches.

3.3.5 "Cricket"

The last style group, the "Cricket" group, consists of two branches and is named for the small insect found on the outer edge of the branches. In the *Shijing* (the *Classic of Poetry* compiled by Confucius in 551-479 B.C.), the migration of the cricket to areas of warmth are described. The cricket on the money tree represents the journey from the chilly peak below to the warmer celestial garden above. These branches are thin casts and are more stylistically refined than both the blue and brown "Queen Mother" groups, but not as refined and detailed as the "Kneeling Immortals" or "Moon Toad" group. Replacement sections of lead-tin alloy were found on one of the two branches, and both have numerous breaks repaired with lead-tin solder and pigmented resins.

3.3.6 The Finial

The tree is topped by a finial depicting Xiwangmu, Queen Mother of the West. The authenticity of the finial was initially in doubt. Finials from excavated trees have a metal pin or dowel at the bottom which slides inside the hollow oval tube which forms the trunk. The finial from the DIA's money tree has a cap on the bottom which fits over (not inside) the solid (not hollow) tip of the brass trunk, known to be a replacement (see Section 3.2). Additionally, the finial from the DIA's money tree very closely resembles a finial from the archaeological site Hejiashan, Mianyan, Sichuan (*Wenwu* 1991), even to the extent that the same losses are present in both finials. XRF analysis confirmed that the DIA finial is made of a lead-tin alloy and thus is most certainly a copy of the excavated finial.

3.4 The DIA Money Tree: Conclusions from Examination

The examination and study of the DIA money tree confirmed that its ceramic base is of an age consistent with the Han dynasty (25-220 A.D.). The variety of repair methods and materials on the branches show that numerous restoration efforts have taken place. Branches in four of the groups show replacement sections made of a lead-tin alloy while most of the hooked ends of the branches have been replaced with copper or brass. The two most stylistically refined groups, the "Kneeling Immortals" and the "Moon Toad", have more extensive repairs using techniques requiring greater skill, such as the use of metal pins to repair breaks. All of the groups have some traces of pigmented resins or putty on them indicating recent restoration efforts using modern repair materials. Finally, the finial, the trunk, and the two brass leaves were reproduced in order to complete the tree. Establishing a chronology of the repairs would help in determining when the various branches were brought together; further study and analysis of the repair materials is ongoing.

4. Technical Study of Two Bronze Branches

The main questions addressed in the technical study of the branches of the DIA's money tree were:

- a) what is the composition of the alloy in which the branches were cast?
- b) what corrosion processes have the branches undergone?
- c) is there any correlation between alloy composition, corrosion processes and style grouping?

Although branches from all five stylistic groups were studied, the analytical results from only two branches from the DIA's money tree will be discussed here: a branch with a matte, green patina from the "Kneeling Immortals" style group will be compared to a branch with a glassy, brown patina from the "Cricket" group. The composition of the original alloys, the thickness, composition and nature of the corrosion layers and the resulting colors and surface appearances of these two branches are discussed.

4.1 Experimental

To determine the composition of the bronze alloy and the nature and depth of the corrosion layers, small pieces of the branches were removed for the preparation of cross-sections. The tiny pieces (approximately 1-2 mm across and 3-4 mm long) were removed using a jeweler's saw fitted with a 000 blade. The samples were embedded in a cold-setting polyester resin (Bio-Plastic, Ward's Scientific), and were sectioned using an ultramicrotome (LKB Ultramicrotome III Model

8801A) fitted with a glass knife. In order to avoid introducing any foreign substances which might influence the subsequent elemental analysis, no polishing or chemical etching of the sections was performed.

The sections were coated with a thin layer of elemental carbon for examination under a scanning electron microscope (SEM). All SEM images were obtained using a CamScan Series 4 SEM (LaB₆ emitter operated at 20 kV) equipped with a Noran Voyager 4 energy dispersive spectrometer (Pioneer detector with Norvar window) for elemental analysis. The SEM images presented in this paper are backscatter electron images (BEI), in which the intensity is proportional to the average atomic number of an area (e.g. heavy elements such as lead will appear white while low average atomic number compounds, such as the carbon-based polymers of the mounting resin, will appear black).

4.2 Results and Discussion

4.2.1 Section from "Kneeling Immortals" Branch

The visible reflected-light photomicrograph of the cross-section from the "Kneeling Immortals" branch (Figure 5, top) shows three distinct regions of interest: KI-1, a core of uncorroded alloy surrounded by KI-2, a pale green corrosion layer with a few red inclusions (unfortunately not visible in this black and white photograph), on top of which lies KI-3, a fragmentary layer of darker green material. The light and dark bands visible within region KI-2 are not additional layers but are artifacts produced by light scattered off the rough surface in this region. The backscatter electron image (BEI) in figure 5 (bottom) clearly shows that there are only three regions present in this section. The BEI is not affected by surface roughness, and therefore provides a better means of judging the uniformity and width of region KI-2 than the visible reflected-light photomicrograph.

Elemental analysis by energy dispersive spectroscopy (EDS) of the uncorroded metallic core (KI-1) yielded an average overall composition² of 72% Cu, 16% Sn and 10% Pb. SEM and EDS analysis of the microstructure evident in this region revealed the as-cast structure of the alloy: dendrites of α phase Cu-Sn alloy (the first phase to solidify upon cooling, which can contain up to 15.8% Sn) surrounded by $\alpha\delta$ eutectoid (an intimate mixture of α and the more Sn-rich δ phase (Cu₃₁Sn₈) which can contain between 15.8 and 32.6% Sn) (Hanson and Pell-Walpole 1951). That portion of the lead which does not form a solid solution with the Cu and Sn is the last component to solidify after casting, and segregates into globules which become trapped in the $\alpha\delta$ eutectoid regions; these globules are visible as white spots in region KI-1 in the BEI image.

In the pale green corrosion layer (KI-2), the as-cast phase structure of the Cu-Sn alloy is still evident, but the α and $\alpha\delta$ phases (and the Pb globules) have undergone corrosion. Close inspection of the boundary between the uncorroded metallic core and the first corrosion layer

(KI-2) indicates that the Cu-rich α phase undergoes corrosion before the Sn-rich $\alpha\delta$ eutectoid. Elemental analysis of this layer reveals it is depleted in Cu and enriched in Sn relative to the metallic core, with O and C also present, supporting the observation of preferential corrosion of the Cu-rich α phase. The visual appearance of the red inclusions within this layer suggest they might be cuprite, Cu_2O ; this identification was confirmed by energy dispersive spectroscopy (EDS). The inclusions of cuprite appear to have formed within the spaces originally occupied by the globules of unalloyed lead. The lead, which undergoes oxidation, migrates to the surface where it may remain as a layer of oxide or carbonate or spall off.

Elemental analysis of the topmost darker green corrosion layer (KI-3) indicates that only Cu, O and C are present. A small sample of this layer was removed and isolated, and was identified by x-ray diffraction (XRD) as the basic copper (II) carbonate, malachite ($\text{CuCO}_3\cdot\text{Cu}(\text{OH})_2$). The characteristic habit of malachite, forming in tufts of long prismatic or needle-like crystals (Palache et al. 1951) can easily be seen in the magnified view of this region shown in Figure 5. The presence of a malachite layer suggests that the original surface of the branch lies directly under this layer, that is, at the boundary between regions KI-2 and KI-3. The pale green corrosion layer (KI-2) appears to have progressed from the original surface towards the interior of the bronze with the corrosion of the α and $\alpha\delta$ phase regions as described above, while malachite grew outwards from that surface.

A corrosion mechanism which is consistent with these observations is as follows: preferential corrosion of the Cu-rich α phase and migration of Cu ions to the surface (where they combine with CO_2 to form malachite) leaving behind the Sn-rich $\alpha\delta$ eutectoid which subsequently oxidizes to SnO_2 . Although pure SnO_2 is white, it is easily stained by metal ions (Gettens 1969); Cu ions present in the first corrosion layer (KI-2) may thus account for the pale green coloration of this layer. The corrosion of the lead globules can be treated as a separate but parallel process: lead is oxidized and migrates towards the surface. Eventually, the spaces originally occupied by globules of lead are filled with cuprite (which may undergo further corrosion to form copper carbonates).

4.2.2 Section from "Cricket" Branch

The visible, reflected-light photomicrograph of the cross-section from the "Cricket" branch (Figure 6, top) reveals three general regions of interest: C-1, an uncorroded metallic core, surrounded by C-2, a blue-gray corrosion layer, on top of which lies C-3, a golden tan corrosion layer. Interestingly, the two colored corrosion layers C-2 and C-3 are not evident in the BEI shown in Figure 6 (bottom); only a single corrosion layer is evident. Since backscatter electron images indicate average atomic number, this suggests that the blue-grey and golden tan materials have similar average atomic numbers.

Elemental analysis of the uncorroded metallic core (C-1) by EDS yielded an overall average composition of 75% Cu, 17% Sn and 8% Pb, similar to that found in the section from the

"Kneeling Immortals" branch. Not surprisingly, a similar as-cast microstructure was also observed: dendrites of α phase Cu-Sn alloy surrounded by $\alpha\delta$ eutectoid with globules of unalloyed lead in the $\alpha\delta$ eutectoid regions. However, the dendritic structure is larger and more defined in this section than that from the "Kneeling Immortals" branch, suggesting that this branch cooled more slowly after casting. The inset in Figure 6 (bottom) shows a magnified portion of the cross section: a dendrite of uncorroded α phase is visible as a line of dark gray spots.

As with the section from the "Kneeling Immortals" branch, the as-cast phase structure of the Cu-Sn alloy is still evident in the corrosion layers. The magnified inset in Figure 6 (bottom) shows the leading edge of the corrosion. Dendrites of corroded α (black in the BEI) are surrounded by uncorroded $\alpha\delta$ eutectoid. Therefore, as before, corrosion apparently occurs initially in the α phase and subsequently proceeds to the $\alpha\delta$ phase. Elemental analysis reveals that the corrosion layer(s) are depleted in Cu and enriched in Sn relative to the uncorroded core, with O and C also present in significant amounts, exactly analogous to the results from the section from the "Kneeling Immortals" branch. However, elemental mapping shows Fe is present in the outermost 1/3 of the corrosion layers: this corresponds to the thickness of the golden tan layer at the surface. Since there is no iron present in the metallic core, we must assume that the iron has penetrated *into* the corrosion layer from the outside.

Therefore, we propose a slightly different corrosion process for this branch: as before, preferential corrosion of the Cu-rich α phase and migration of Cu ions to the surface created a Sn rich corrosion region which eventually was oxidized to SnO₂. However, in this branch the Cu ions did not form malachite at the surface, but rather were "washed" away by the surrounding matrix of water/earth. However, some Cu ions remained and stained the SnO₂ producing the blue-gray color observed for C-2. Either subsequently or simultaneously, Fe ions from the surrounding matrix migrated into the porous corrosion layer, staining the SnO₂ brown creating the golden tan layer, C-3. The corrosion of the lead globules appears to proceed by a similar mechanism as the previous section: lead oxides are subsequently displaced by copper oxides and carbonates.

4.3 Conclusions from Analytical Study

In this study, the examination of branches from two different stylistic groups have been shown to have a similar alloy composition with approximately 15-20% Sn and 10% Pb. This relatively high amount of Sn would produce an alloy which melted easily and the large amount of Pb would facilitate the flow of the molten metal into the narrow and intricate forms of the branches. The resulting cast would be relatively brittle (Reeve *et al.* 1953), but this would not be of particular concern in a non-utilitarian piece such as a money tree. The high Sn content would also increase the corrosion resistance of the bronze. Compositions and corrosion processes similar to what we have found here been documented for other ancient Chinese bronze ritual vessels (Barnard 1961; Chase 1994; Gettens 1969). The corrosion processes we have proposed are based on the theories of Robbiola (1990) regarding the migration of ions during corrosion. These mechanisms are

consistent with our observations and can account for the differences in the surfaces on the two branches discussed here. Unfortunately, no published analyses of money tree branches are available for comparison.

Although the two branches investigated here belong to different stylistic groups, they have comparable alloy compositions. Thus, the environment under which they corroded must have been different, as evidenced by the formation of an outer layer of malachite on the branch from the "Kneeling Immortals" group and the lack of this layer on the branch from the "Cricket" group, which instead shows an influx of iron into the corrosion layer. This suggests that the branch from the "Kneeling Immortals" group was most likely in a relatively dry and aerated environment while the branch from the "Cricket" group was exposed to a wetter environment for at least some period of time (Schweizer 1994).

5. Summary

The examination and analysis of a complex object such as the DIA's money tree necessarily must draw upon many different fields in order to develop a complete picture of the history and composition of the object. In this study we have used numerous techniques ranging from stylistic and historical analysis of the object as a whole to scanning electron microscopic investigations of the most minute details.

Our results have confirmed that the ceramic base is of an age consistent with the Eastern Han Dynasty. The bronze composition as well as the nature and extent of the corrosion seen on the branches is also consistent with the currently available data on ancient Chinese bronzes. In the two branches discussed in detail here, we appear to have examples of the products of two different corrosion environments, wet versus dry, on bronzes with similar composition. Additionally, the variety of repair materials found throughout the object contains clues to the repair history of the individual pieces. Technical, iconographic and historical analyses of branches from all five style groups, the base, trunk and finial is continuing and we hope that the combined results will enable us to develop a better understanding of the manufacture, corrosion, prior repair and chronology of assembly of the component pieces of this money tree.

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radiography and photography and Carol Forsythe, senior objects conservator, DIA, for helpful discussions.

Endnotes

1. The x-radiographs were done at 70kV and 5 mA.
2. Compositions are calculated from the x-ray emission peak intensities using a standardless analysis. The percentages are constrained to total 100% for all elements used in the calculation (trace amounts of Si and O were often detected, thus the percentages of Cu, Sn and Pb may not sum to 100%). Using known bronze standards, we determined that the error associated with these calculations is 5% or less.

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Wenwu. 1991 no. 3. 9-19, fig 29.4.

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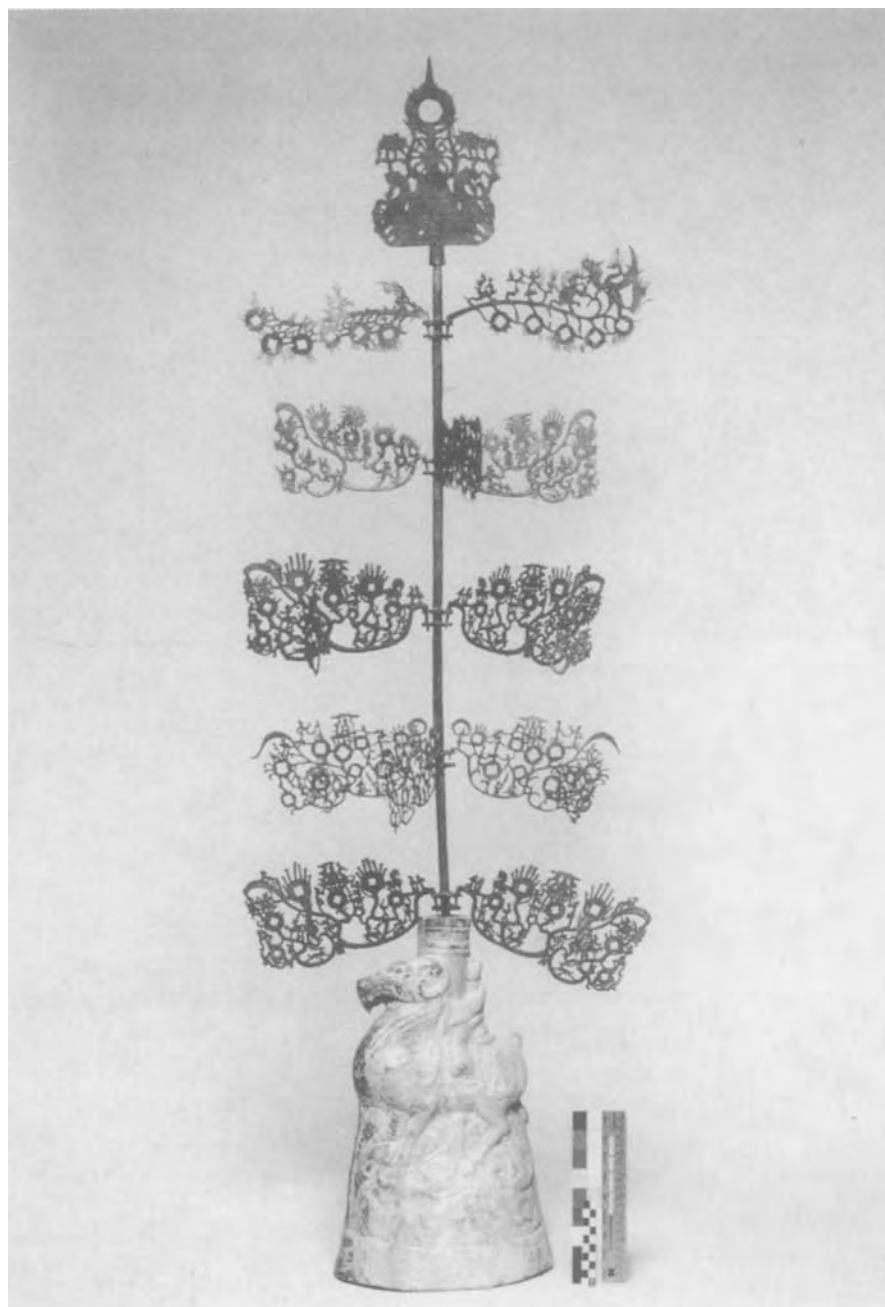


Figure 1. The Detroit Institute of Arts Money Tree, DIA 1996.29, partially assembled for photography.

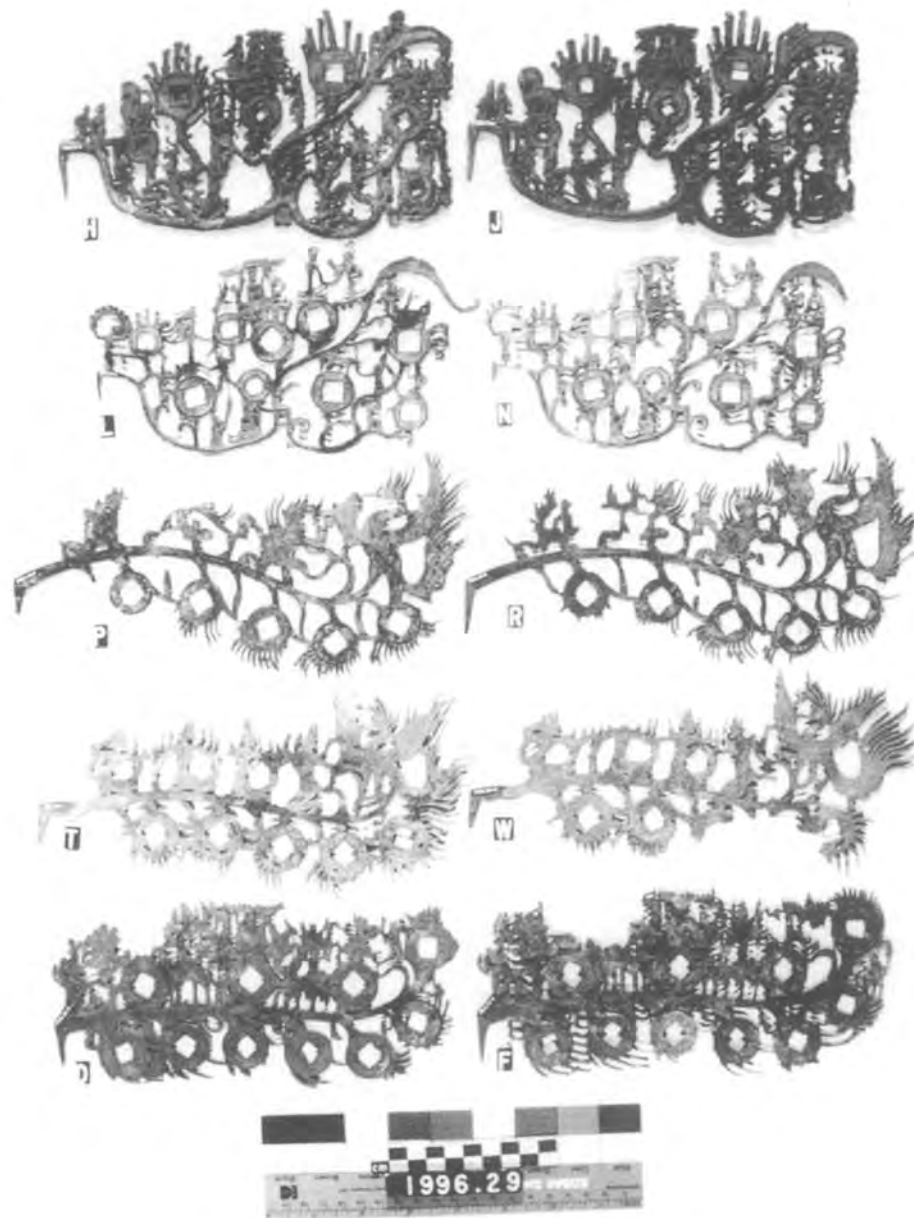


Figure 2. Two branches from each of the five style groups (from top to bottom): "Blue Queen Mother," "Brown Queen Mother," "Moon Toad," "Kneeling Immortals" and "Cricket."

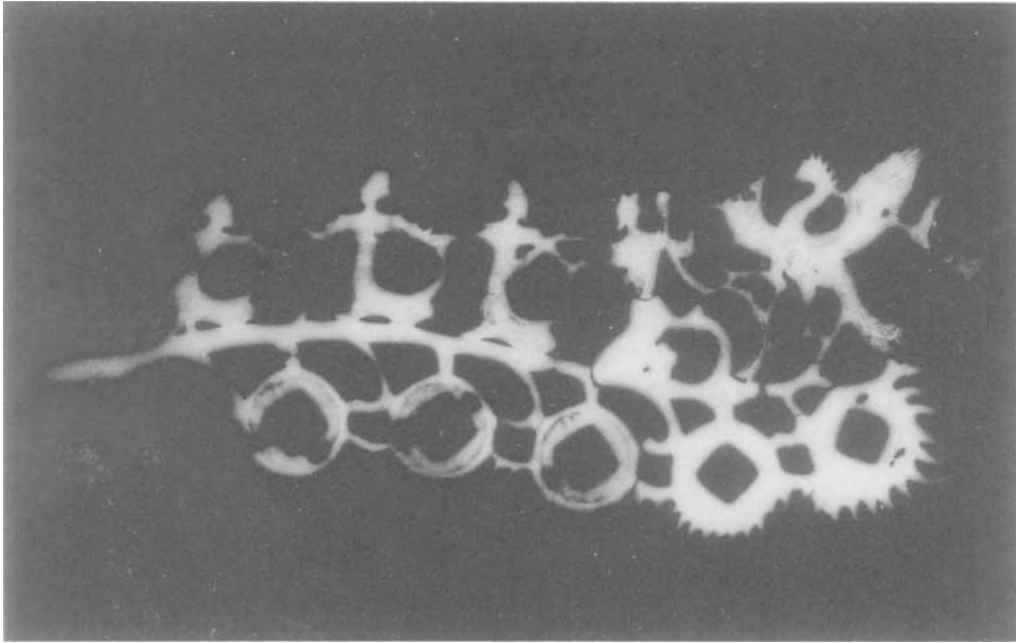


Figure 3. X-radiograph of a branch from the "Kneeling Immortals" group showing a replacement section (in bright white) of lead-tin alloy in the lower right end of the branch.

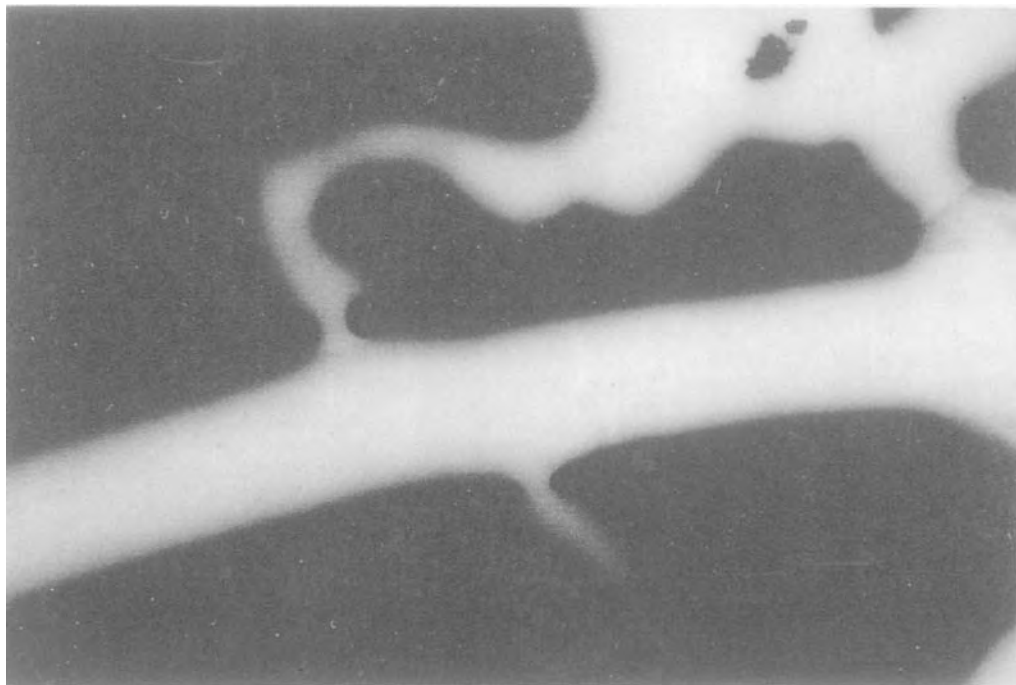


Figure 4. Close-up of an x-radiograph of a branch from the "Moon Toad" group showing the join between the copper hook on the left (a replacement) and the bronze branch on the right.

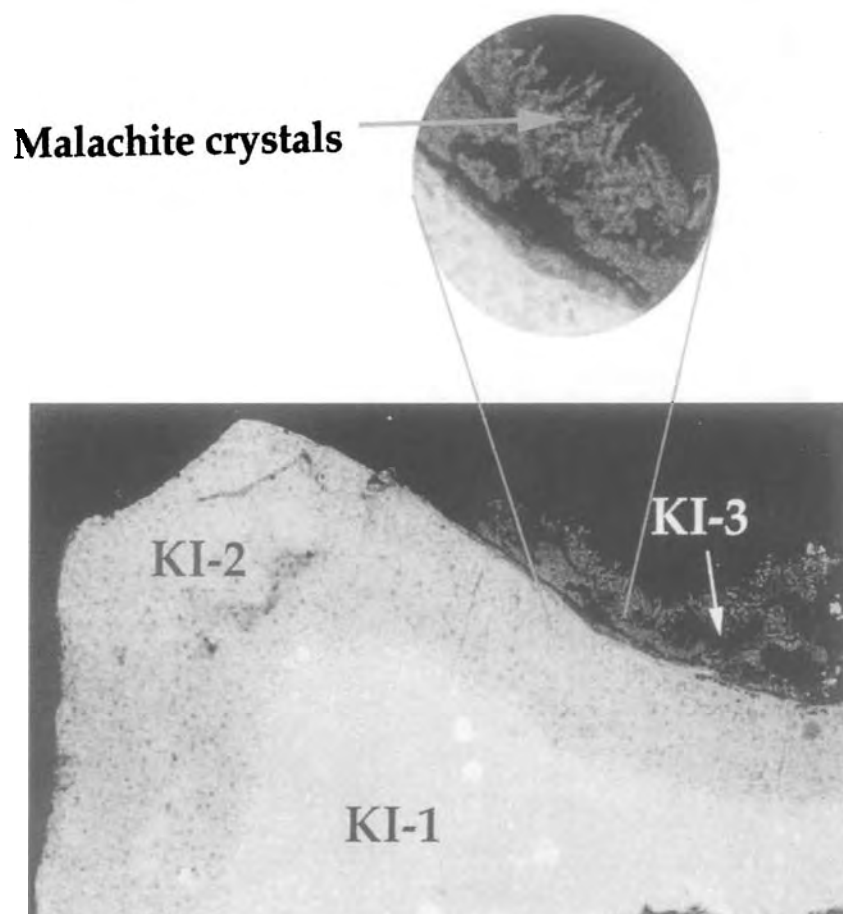
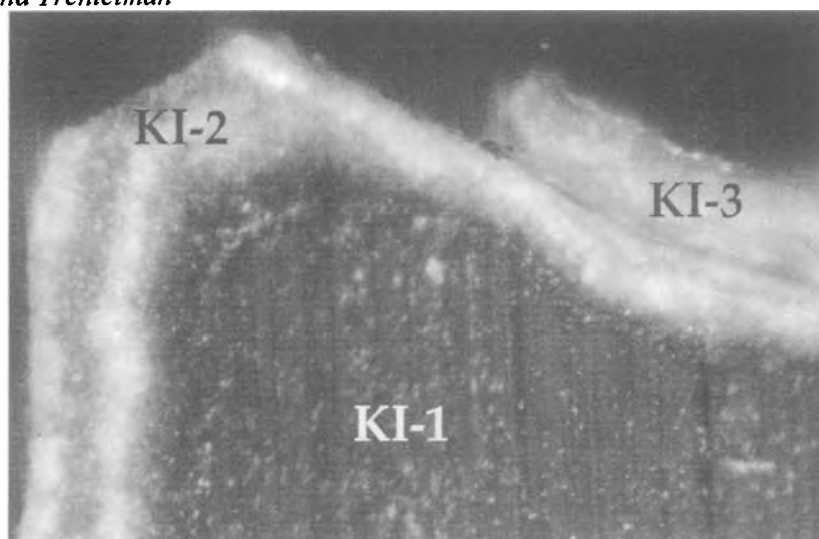


Figure 5. Section from the "Kneeling Immortals" branch. Top: visible reflected light photomicrograph. Bottom: backscatter electron image; a region of the outer layer of malachite is magnified to show the crystal habit.

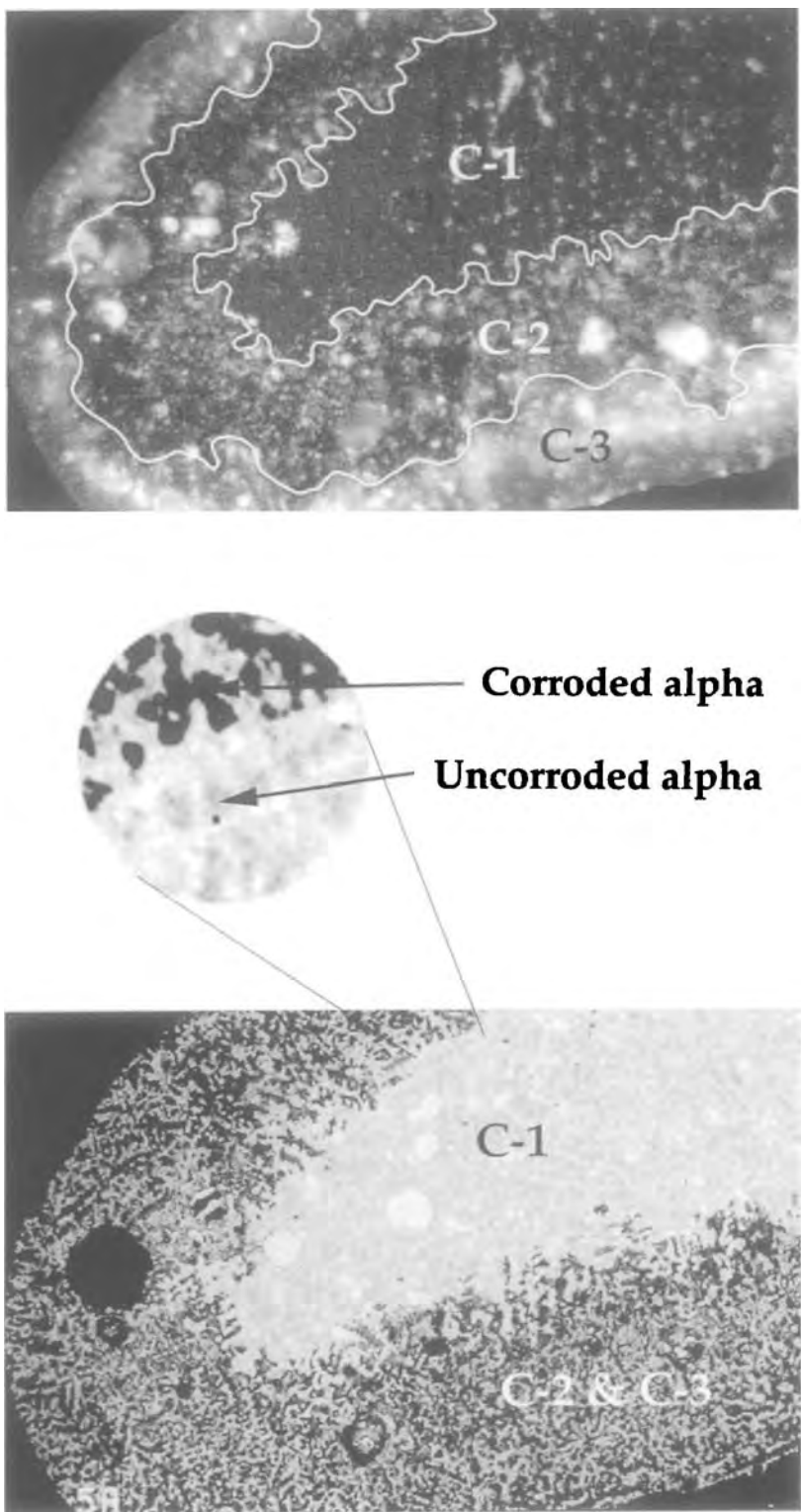


Figure 6. Section from the "Cricket" branch. Top: visible reflected light photomicrograph. Bottom: backscatter electron image; a portion of the figure has been magnified to show the edge of the corrosion layer.