Bronze Age Metal Objects from East Crete, Greece

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The excavations of Bronze Age settlement sites in eastern Crete have yielded a large corpus of metal objects. These habitation contexts tend to date to the Late Bronze Age (ca. 1600–1100 BC). The artifacts are mostly comprised of small toiletry items, small weapons such as daggers and knives, and tools for utilitarian purposes such as axes, chisels, vessels, hooks, needles, and knives. A minority of the excavated pieces has been scientifically analyzed using a range of methods such as Laser-Induced Breakdown Spectroscopy (LIBS), energy dispersive X-ray fluorescence (ED XRF), X-ray fluorescence (XRF) spectrometry, and Lead Isotope (LI) analysis. These techniques assist in determining elemental composition and give insight into local metallurgical traditions, which were significantly active since the Final Neolithic period in eastern Crete. Patterns emerge when comparing the results of various scientific analyses among many different types of metal objects and between different sites.

KEY WORDS: bronze; tin; copper; arsenic; Crete; Minoan.

1. Introduction

For this analytical project, many copper-based objects excavated from the Minoan town of Gournia in eastern Crete were analyzed with XRF at the Penn Museum in Philadelphia, PA, USA (for a selection, see Fig. 1). Ingots and other metal objects from the local workshop of this Late Minoan (LM) IB (ca. 1525–1450 BC) settlement have been analyzed in the past.1) All of these objects are housed in the Mediterranean Section of the Penn Museum. The ingots were excavated in the early 20th century from Rooms Ea and Cg where some tools also had been found.2)

Stone moulds and apparently also slag were discovered in Room Fh, but they were not published. Only two objects—a fragment of a needle and a twisted strip—were analysed in 1978.1) The analyses resulting from a scanning electron microscope (SEM/EDS) showed that the ingots were made of very pure copper with 98–99% purity (meaning mass%), with some copper sulphide and copper oxide inclusions. The pin and the strip exhibited traces of tin in a very pure copper matrix. The authors concluded that the traces of tin could have been due to scrap metal and that very pure copper ingots, similar to the ones analysed, must have been used in the Minoan workshop.

In more recent years several ingots from Bronze Age Crete, including a few from Gournia and another LM IB Minoan town called Mochlos, have been examined by lead isotope analysis (LIA) to establish the provenance of the copper. All have been determined, by Zofia A. Stos-Gale, as copper ingots from the Apliki mine in Cyprus, while the lead pieces examined all come from the mines of Lavrion.3,4) Furthermore, Stos-Gale carried out XRF analyses on several metal objects from the metal workshop in the Artisans’ Quarter at Mochlos.3)

Between 2010 and 2012, several additional groups of

Fig. 1. Selection of metal objects from Gournia that were analyzed with XRF spectroscopy.
objects from Gournia\(^5\) and Mochlos\(^6\) have been studied and analysed by the authors.

All of the metal artifacts analysed until now belong to several classes and can be considered representative of all kinds of alloys employed during the Late Bronze Age in the workshops of the Minoan towns. They consist of tools, weapons, decorative objects, vessels, utilitarian objects of better quality such as tweezers and weaving hooks, small everyday objects, and small functional pieces of lesser quality. Finally, among the metal finds were also special objects for ceremonial use, such as a sistrum and tin ingot from Mochlos\(^6,7\) that will be discussed separately below.

2. Analysis Results

Our most recent XRF analyses include approximately 90 measurements on the materials from Gournia (Table 1).\(^8\) Not all of them will be discussed in this paper, but the general outlines of the results will be given in relation to the analyses of metal objects from the Artisans’ Quarter at Mochlos.\(^3\)

Many of the finds were made of unalloyed copper or of copper with very low contents of other elements. At Gournia, approximately 50% of the copper-based finds were produced with unalloyed copper. Also, many of these objects are simple types of everyday artifacts. Pieces made of arsenical copper and others that contain tin, and often also arsenic, come from both sites.

Arsenical copper has been employed since the Early Bronze Age, both in the Middle East and in Europe.\(^9\)–\(^12\) In the Middle Bronze Age, a long period of evolution starts with the introduction of tin followed by the use of both alloying elements, together or alone, until the final prevalence of tin and the disappearance of arsenic from copper alloys.\(^13,14\)

The histogram illustrating the arsenic content of the objects from Gournia (Fig. 2) shows that the As content can go up to almost 4.0%. The mean content of As is approximately 1.3% (standard deviation [hereafter, st. dev.] 0.98). The maximum As content determined in the finds is that of the chisels (inventory numbers [hereafter, inv. nos.] MS4178, MS4180–MS4182, MS4199) with almost 4% of As. The objects from Gournia seem to be in the transition phase between the use of arsenical copper and bronze, with about 10% of the objects containing both elements. The presence of both As and Sn in the alloys can be due to recycling, but it perhaps also could result from the desire to exploit the advantages of both elements. In relation to this, it is important to note that the remains of a tin ingot have been recovered from the LM IB settlement of Mochlos (see below).\(^15\) It is the only tin ingot excavated from Bronze Age Crete.

The histogram illustrating the frequency of tin in the finds from Gournia (Fig. 3) demonstrates that around 20% of the objects contain tin (the mean is 2.87% Sn, st. dev. 2.3) that is more evenly distributed in the lower regions, while only a few pieces contain higher amounts or percentages of this metal. The objects with measurable tin content make up about two-thirds of the entire group. A dagger (MS4186) contains the highest tin content at 9.4% Sn. A total of 34 copper-based objects from the Artisans’ Quarter at Mochlos were analyzed, revealing seven objects containing Sn. Two bronze bowls contain 6.4% and 8.6% Sn, respectively (Soles and Stos-Gale 2004, table 1; CA 18, CA 19).\(^3\)

In this period, lead was not employed as a deliberate addition to the alloys, and only very few objects contain traces of lead. A chisel (MS4199) was the only object from Gournia in which more lead was identified (3.5%). The Artisans’ Quarter at Mochlos produced only one artifact with measurable lead (0.7%), but it also contains 1.9% zinc. Furthermore, two lead weights were also analyzed and are consistent with the LIA pattern of the Lavrion mines.\(^3\)

The alloys employed for the different classes of objects show that the artisans were skilled and able to choose their alloys by considering their properties. The results of the analyses of the different classes of objects from Gournia will be discussed in greater detail below.

2.1. Tools

The composition of the tools from Gournia is generally less carefully controlled than those of more representative objects. Many are made of unalloyed Cu or Cu with very low amounts of Sn and As. For example, the alloys employed for the 5 chisels are all different: arsenical Cu, Cu containing 2–3% of Sn, and unalloyed Cu. Chisel MS4180 is made of well purified Cu. The copper of chisel MS4181 shows traces of Sn, Pb, Sb, and As. This fact indicates that scrap metal was used. The shapes and sizes of the chisels are different, and it is clear that they were employed to work on different materials. This also means that they required a different hardness, and this partly explains the diversity of composition. Nevertheless, the metal employed for this class of object seems less carefully prepared than that, for example, of the blades. Among the tools, a small saw (MS4191) was made of arsenical Cu (1.6% As). The As content confers hardness to the teeth for them to stay sharp. The teeth were produced possibly with a sharp piece of flint, which is a stone that is hard enough to be used as a tool on copper-based alloys.

2.2. Small Implements

Several needles have been found at Gournia, and they are mainly made of unalloyed copper (MS4746D, MS4201, MS4743). On the other hand, needle MS4741 is made of a bronze alloy with 2.2% tin, but it also contains 1% arsenic. Unalloyed Cu can be hardened and shaped to a sharp point by hammering and repeatedly annealing it. All examples, with one exception, were made by twisting a strip of metal so that the strip doubled at the top and formed the eye of the needle. The shaft of needle MS4201 is broken and shows the two parts twisted together. The shaft was hammered and then carefully polished with abrasives, so that now the item is covered by a thin and compact patina, and the helicoidal seams are almost invisible. Needle MS4743 represents an exception, because its eye was made by piercing the thin strip of unalloyed copper at a suitable spot before twisting it. The microscopy examination showed that the shaft of the needle was produced by twisting, hammering and polishing the strip to obtain a smooth surface and a very regular structure. One end of “pin” MS4742A is missing, but this item was most probably also a needle similar to MS4743. The material is again unalloyed Cu, and the structure is the same.
Table 1. Results of XRF analyses on metal objects from Gournia. Italicized text means the results are semiquantitative only. MS = Mediterranean Section, Penn Museum, Philadelphia, PA. Tr. = trace amount. Frg. = fragment.

| Object Type | Museum Inv. No. | Part | Cu   | Sn  | Pb  | As  | Sb  | Fe  | Ni  | Ag  | Zn  | Co  | Mn  | Au  |
|-------------|----------------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Dagger      | MS4183         | Blade| 94.2 | 1.3 | 1.8 | 0.2 | 0.9 | Tr. |     |     |     |     |     |     |
| Dagger      | MS4183         | Rivet 1 | 90.9 | 2.1 | 1.2 |     |     |     |     |     |     |     |     |     |
| Dagger      | MS4183         | Rivet 2 | 95.7 | 1.3 | 0.3 | 1.4 | 1.1 |     |     |     |     |     |     |     |
| Dagger      | MS4184         | Blade | 92.6 | 3.2 | 2.3 | Tr. | 1.8 | Tr. |     |     |     |     |     |     |
| Dagger      | MS4184         | Rivet 1 | 93.8 | Tr. | 0.5 | Tr. | 1.9 | 2.3 |     |     |     |     |     |     |
| Dagger      | MS4184         | Rivet 2 | 92.7 | Tr. | Tr. | 2.2 | 5.5 |     |     |     |     |     |     |     |
| Dagger      | MS4186         | Blade | 88.6 | 9.4 | 0.6 |     |     |     |     |     |     |     |     |     |
| Dagger      | MS4186         | Rivet 1 | 96.2 |     | 2.4 |     |     |     |     |     |     |     |     |     |
| Dagger      | MS4186         | Rivet 2 | 97.1 | Tr. | 1.3 |     |     |     |     |     |     |     |     |     |
| Dagger      | MS4186         | Rivet 3 | 93.8 |     | 2.1 | Tr. | 3.8 | Tr. |     |     |     |     |     |     |
| Dagger      | MS4187         | Blade | 95.2 | 0.4 |     |     |     |     |     |     |     |     |     |     |
| Dagger      | MS4187         | Rivet 1 | 97.6 |     |     |     |     |     |     |     |     |     |     |     |
| Dagger      | MS4187         | Rivet 2 | 95.5 |     | 1.7 | Tr. | 2.5 | Tr. |     |     |     |     |     |     |
| Dagger      | MS4187         | Rivet 3 | 94.4 |     |     |     |     |     |     |     |     |     |     |     |
| Sickle      | MS4185         | Blade | 96.9 |     | 1.4 |     |     |     |     |     |     |     |     |     |
| Axe         | MS4188         | Blade | 97.3 |     |     | 0.6 |     |     |     |     |     | 1.8 |     |     |
| Ingot       | MS4563B        | Cut   | 99.1 |     |     | 0.2 |     |     |     |     |     |     |     | 0.4 |
| Ingot       | MS4563A        | Cut   | 99.8 |     |     |     |     |     |     |     |     |     |     |     |
| Ingot       | MS4563C        | Cut   | 99.9 |     |     |     |     |     |     |     |     |     |     |     |
| Ingot       | MS4563D        | Cut   | 99.7 |     |     |     | 0.2 |     |     |     |     |     |     |     |
| Chisel      | MS4182         | Blade | 93.9 |     | 3.9 |     | 1.9 | Tr. |     |     |     |     |     |     |
| Chisel      | MS4181         | Blade | 94.8 |     |     | 2.9 |     | 2.7 |     |     |     |     |     |     |
| Chisel      | MS4180         | Blade | 99.9 |     |     |     | 0.1 |     |     |     |     |     |     |     |
| Chisel      | MS4178         | Blade | 97.1 | 1.8 |     | 0.8 |     | 0.6 |     |     |     |     |     |     |
| Chisel      | MS4199         | Blade | 84.2 | 2.7 | 3.5 |     | 0.3 |     |     |     |     |     |     |     |
| Axe         | MS4189         | Blade | 98.8 |     | 0.7 |     | 0.5 |     |     |     |     |     |     |     |
| Blade       | MS4190         | Blade | 93.3 | 0.9 |     |     | 1.3 |     |     |     |     |     |     |     |
| Blade       | MS4190         | Rivet 1 | 92.0 |     |     | 0.5 |     |     |     |     |     |     |     |     |
| Blade       | MS4190         | Rivet 2 | 91.6 |     |     | 2.4 |     |     |     |     |     |     |     |     |
| Cauldron    | MS4718         | Leg   | 91.4 | 5.2 | 1.5 |     | 1.8 |     |     |     |     |     |     |     |
| Cauldron    | MS4718         | Rivet | 97.2 |     | 0.5 |     | 2.3 |     |     |     |     |     |     |     |
| Cauldron    | MS4746A        | Handle | 96.9 |     |     |     | 2.6 |     |     |     |     |     |     |     |
| Cauldron    | MS4746A        | Wall frg. | 93.5 | 3.7 |     | 0.5 |     | 2.4 |     |     |     |     |     |     |
| Cauldron    | MS4746A        | Rivet | 93.2 | 1.6 |     |     | 0.6 |     |     |     |     |     |     |     |
| Cauldron    | MS4746A        | Wall frg. 2 | 96.5 | 2.2 |     | 0.8 |     | 0.4 |     |     |     |     |     |     |
| Cauldron    | MS4746A        | Rivet | 96.8 |     | 1.9 |     | 1.1 |     |     |     |     |     |     |     |
| Sheet       | MS4745         |       | 98.7 |     |     |     | 1.2 |     |     |     |     |     |     |     |
| Blank 1     | MS4746-A       |       | 98.6 |     | 0.4 | 0.3 |     |     |     |     |     |     |     |     |
| Blank 2     | MS4746-A       |       | 90.1 |     |     | Tr. | 1.4 |     |     |     |     |     |     |     |
| Blank 3     | MS4746-A       |       | 97.7 |     | 0.5 |     | 0.4 |     |     |     |     |     |     | 1.3 |
| Blade       | MS4746-A       |       | 99.9 |     |     |     |     |     |     |     |     |     |     |     |
| Scale       | MS4193         |       | 99.6 |     |     |     | 0.3 |     |     |     |     |     |     |     |
| Scale       | MS4195         |       | 99.0 |     |     |     | 0.9 |     |     |     |     |     |     |     |
| Lead strip  | MS4747         |       | 96.8 |     | 0.3 |     |     |     |     |     |     |     |     |     |

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Fragment MS4749 has a sharp point and contains both Sn and As. “Wire” MS4742B is also made of unalloyed Cu and was produced by twisting a thin strip of metal.

An awl (MS4179) from Gournia is rather interesting because its characteristics aid in understanding the production technique of these small implements. It has a square...
section and a rough heel. The shaft shows some shallow lines that are different from the helicoidal seams previously mentioned. The shaft was not produced by twisting strips of metal, but by twisting a blank instead. The lines are in this case much more irregular and wider. They seem to be the remains of the corrugated upper part on the as-cast blanks (see below in the section Workshop remains). The corrugated lines are always on the bent side of the blanks and are certainly due to the rapid cooling of the metal in an open mould. In this case, it is obvious that the awl was produced by using such castings. The copper alloy contains 3.5% Sn and some As.

This class of objects also contains a large fish hook (MS4192). The piece has been carefully shaped with a sharp point, and it originally bore a hole at the top through which a fishing line could have been inserted and fixed. The material of the fish hook is bronze with a low amount of Sn. Apparently, special care was taken in the manufacture of this small implement.

As in the case of the tools, the alloys employed for small implements also are not homogeneous, and their arsenic and tin contents are irregular. The analysis results of the two classes of objects therefore can be considered together in the same histogram (Fig. 4): many tools and small implements were made of unalloyed copper, but more specialised pieces were made from copper alloyed with higher arsenic and tin contents.

2.3. Tweezers and Scrapers

Tweezers could be grouped with the small implements, but their composition shows that tweezers were a special kind of object and that their alloy was very carefully prepared with well purified copper and by adding higher amounts of tin. Most of them contain 2–3% tin. These tweezers comprised one of the largest classes of metal objects from Gournia. It is also important to note that they were accurately finished.

Some examples show that they were carefully repaired after damage instead of being melted for recycling (see MS4196). This suggests that the tweezers had a special meaning and value to the Minoans. Perhaps they were worn at the belt or even as a pendant, as was done in later times in other contexts, so that they may have functioned as small personal ornaments. The composition of the tweezers can indeed be compared to that of ornaments. Apparently, only one of the tweezers (MS4746K) contains only traces of Sn and higher arsenic (2.4%). Tweezers made of this alloy are just as functional as the ones made of bronze, and also their colour would be noticeably lighter. In this case, however, the piece is in poor condition, therefore the data must be considered only indicative.

Along with the tweezers, this group includes two scrapers. The small “scraper” MS4198 was provided with a loop as a handle. The alloy employed for its production is comparable to that of the tweezers, and perhaps this item was used as a cosmetic scraper and also was worn as a personal ornament.

Another small implement with a flaring blade (MS 4190)—probably a scraper for cosmetic use—contains low traces of Sn and no measurable As. The rivets are made of unalloyed Cu with some traces of other elements, i.e., the copper was not thoroughly purified. Nevertheless the blade is carefully finished, and the cutting edge shows traces of intensive use and re-working.

2.4. Decorative Objects of Personal Use: Pins and Bracelets

Personal ornaments, such as pins and bracelets, can be considered prestige items and commonly show a better quality than everyday objects and tools.

One of the pins, characterised by a spatula-shaped head (MS4200) is made of unalloyed Cu. This simple ornament was cast as a small bar and then hammered into shape. Another pin (MS4744) is more interesting, as its head has a composition that is different from that of the shaft. The head
seems to have been cast on the shaft by using a less purified Cu, but it is possible that the differences in composition were induced by the use of a different production technique. The shaft was first cast and then hammered and polished, while the head was left in as-cast condition. Possibly the arsenic originally present in the alloy was driven off by the intensive hammering and annealing that was carried out to shape, sharpen and harden the shaft, thus inducing a loss of As from the alloy.

In this group, four hook-shaped pins (MS4203–MS4205, MS4740) are made of alloys containing relatively high Sn (2–5%) and, in some of the pieces, also measurable arsenic. They have been produced by using different techniques. While two of them are characterised by a square section and therefore seem to be simple castings, two other hooks (MS4203, MS4205) have a round section that were most probably hammered into shape. Hook MS4203 was produced with a third technique by twisting together two pieces of wire. The helicoidal seam from twisting the artifact is visible under the microscope. The shaft was then hammered and polished.

A fragmented bracelet (MS4719), made of unalloyed but very well purified copper, shows an incised decoration with a simple zigzag line. In the group of finds, a second bracelet (MS4194) bears the same zigzag decoration, however this example was wrapped in thin fibre, the pattern of which is still preserved in the corrosion layer. The area for the XRF measurement was cleaned by the conservator of the museum. The alloy used for this bracelet is copper that contains low amounts of Sn and As. This alloy must have been selected to belong to a slightly different metallurgical tradition or, simply, more care was taken in its manufacture.

The only ring analysed is made of Cu with approximately 2% Sn and 1% As. This alloy must have been selected because of its colour, which is lighter than that of unalloyed copper. The ring is open, and the ends have been flattened next to each other to form a kind of bezel.

2.5. Daggers and Sickle

As previous analyses of Bronze Age materials from very different contexts have shown, the blades are commonly the objects for which the best refined copper and the highest contents of tin and arsenic were used. An excellent example is dagger MS4186 mentioned above, which has the highest Sn value at 9.4%. It is possible that the corrosion present in the blade might have enhanced the tin results, but the copper employed for this dagger is clearly better refined than that employed for other daggers. For example, the arsenic contents are under the measurable percentage both in the blade and also in the rivets. Possibly this particular piece belongs to a slightly different metallurgical tradition or, simply, more care was taken in its manufacture.

The sickle (MS4185) is made of copper with around 1.5% As and no measurable tin. This was a common tool, and the properties conferred by the arsenic were deemed sufficient for the tasks this item had to perform.

The small blade MS4746A (one of 16 pieces catalogued together in the museum collection) is made of unalloyed Cu with only slight traces of As and Ag. At Gournia, the alloys used for the blades are not standardized, as they contain variable amounts of tin and arsenic (Fig. 5). However, also in this context, these alloys were prepared with the highest contents of tin and arsenic. The metal artisans tried to use their best quality alloys for the weapons. The only exception is a small blade made of unalloyed Cu, but this object should be perhaps considered a tool and not a real blade.

2.6. Miscellaneous Objects

Among the finds from Gournia are remains of vessels. The most impressive example is a heavy cast leg of a cauldron (MS4718) that contains over 5% Sn and 1.5% As. The rivet is made of unalloyed Cu. The higher tin and arsenic contents lower the melting point and increase the fluidity of the metal, which can fill all parts of the mould more easily without the formation of casting faults. The presence of both metals also changes the colour to a lighter and more golden hue that was certainly appreciated by the customers of the metal merchants. A cast cauldron handle (MS4746A) bears some remains of the vessel walls still attached by the rivets. In this case, it therefore is possible to determine the composition of the entire vessel. All parts contain different amounts of Sn, no measurable As, low traces of Sb, and a relatively high Ag content. The copper employed for this
vessel is characterised by its high silver content, and it is therefore different from that of the other objects. The caudron walls contain more Sn than the other parts, but no As. The alloy is more malleable because of the higher Sn content (almost 4%) that improves its workability.

Several fragments of a small cup (MS4748) have been recovered from the excavation. The alloy is bronze with ca. 4.5% Sn and traces of As, Sb, and Ag. The composition is suitable for use as a cup, as it can be cast and then hammered and repeatedly annealed to shape the metal as required.

Axes MS4188 and MS4189 are cast and made of Cu containing 0.6% and 0.7% As, respectively. In the case of axe MS4188, some traces of shrinking during the cooling process are visible on the upper part. This is where the mould was open and where a cylinder (possibly made of stone) was inserted to produce the shaft-hole.

Two scale discs (MS4193, MS4195) of very thin sheet are made of well purified unalloyed Cu, which is softer and easier to hammer into the required thinness compared to bronze or arsenical copper, but it must be properly annealed to keep it malleable.

2.7. Workshop Remains

The small ingots MS4563A–D from Gournia, sampled in the past for optical and scanning electron microscopy (OEM and SEM),17 also have been selected for the current program of XRF analyses. They are made of well purified, unalloyed Cu, and they were most probably the metal stock from which the artisans prepared their alloys.

Furthermore, four of the many thin metal strips (MS4746J) from Gournia have been analysed. A total of 111 pieces are present in the Penn Museum collection. They are ca. 5–7 cm long and 0.7 cm wide, and they were cut from a sheet with a sharp and hardened blade. The metal is a well purified unalloyed Cu (see also Betancourt et al. 1978).17

This kind of strip can be used in the production of many small and larger objects because they can be part of a large object, they can be used in the production of needles (see for example MS4743), or they can become thin wire. These strips must have been cut with a blade from a large piece of sheet similar to MS4745, which is a large and relatively thin sheet made of purified and unalloyed copper and still in excellent condition.

Moreover, 16 blanks (MS4746A) have been found at Gournia. These rods measure ca. 7 cm in length and ca. 5 mm in thickness. They all exhibit a shrunk line caused by the fast cooling of the metal in an open mould. Their curved shape is due to the tension caused by the fast cooling only on one side, while the rest of the metal cooled slowly, developing a different structure on the opposite side. After extraction from the mould, they immediately assumed a curved U-shaped form. All of them have flat ends. As already mentioned, the shrinking line can still be recognised on several objects from Gournia.

2.8. Prestige Objects

The analyses have shown that a few copper-based objects from Gournia discussed above were actually prestige goods because the alloys contain particular component metals in certain amounts (one of which is a precious metal) to convey the color and status of silver and gold.

As is the case with the tweezers and the cosmetic scraper mentioned above, the composition of the alloys employed and the careful production technique for the hook-shaped pins (MS4203–MS4205, MS4740) are similar to those of more prestigious, decorative objects. The hook-shaped pins have been interpreted either as jewellery pieces20 or as a utilitarian tool such as weaving hooks. Several examples from Crete have been called jewellery and are made of bronze.21 The use of XRF in our program of analyses proves that the surprisingly high level of tin, sometimes in combination with arsenic, would have given the alloy a much lighter colour. As a parallel, a total of 10 ivory pins were excavated at Mochlos along with an ivory box filled with amethyst, carnelian, and lapis lazuli beads.22 The entire set must have belonged to a very important lady, perhaps one like those depicted in the Miniature Grandstand Fresco of Knossos,23 two of which wear hook-shaped pins in their hair, or like the “injured adorant” in the Xeste 3 wall paintings whose hair is adorned with a hook-shaped pin ending in the form of an iris.24 This demonstrates that hook-shaped pins must have been more than simple tools, and that they must have had a special social meaning. Perhaps they had multiple uses: as ornament, status symbol, and as weaving hook.

In the case of four daggers (MS4183, MS4184, MS4186, MS4187), clear traces of Ag (1–5%) have been determined on the head of the rivets, while no traces of silver could be detected on the blades. The rivets are mostly quite corroded, but it is safe to conclude that the rivets were originally Ag-plated. The corrosion processes of the heavily hammered rivets caused the loss of the silver sheet, so that only traces of silver remained in the corrosion. Silver-plated rivets are found in contemporary contexts in Crete on a dagger from Pseira25 and on many weapons from the mainland of Greece at Mycenae in Grave Circles A and B.21,22

Three special metal finds from Mochlos should also be interpreted as prestige goods. A copper-based trident and the remains of a tin ingot were buried together in a foundation deposit in Building B.2, which probably had a special ceremonial function.26 The tin was uncovered as a whitish-gray powdery substance that was identified with Laser-Induced Breakdown Spectroscopy.27 During the Late Bronze Age, tin was a rare and expensive commodity that had to be imported from still unknown distant lands.22 This special deposit at Mochlos emphasizes the extraordinary character of tin, which was worthy of being an offering to the divinity. Further-more, a large copper-based sistrum was also uncovered at Mochlos in the so-called Merchant’s Hoard,23,24 which appeared to be a cache of artifacts ready for trade. Most of the objects in the hoard were tools of serial production; however the sistrum was a significant musical instrument in the Minoan culture.25 XRF analyses revealed significant tin and silver contents in both the cross-pins (8% Ag, 5% Sn) and disks (5% Ag, 5% Sn), which combined to create the percussive musical sound of the instrument.26 Notably, the other parts of the sistrum did not contain silver, and only the handle contained a minor amount of tin, ca. 2%.26
3. Conclusions

In the two contemporary Late Minoan settlements of Gournia and Mochlos in eastern Crete metal workshops have been documented. Ingots, raw metal, and tools among other objects have been recovered and analysed. They give insight into the local prehistoric metallurgical production and techniques. The skilled local artisans prepared specific metal alloys for crafting many different types of everyday objects, tools, decorative items of personal use, and other prestige goods.

The XRF analyses of Minoan metal objects from Gournia and Mochlos are ongoing and continue to reveal significant details about the composition and manufacture of copper-based artifacts. This systematic and diachronic scientific research can be compared and contrasted among different archaeological sites. The results disclose the evolution of Minoan metallurgical technology through time.

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