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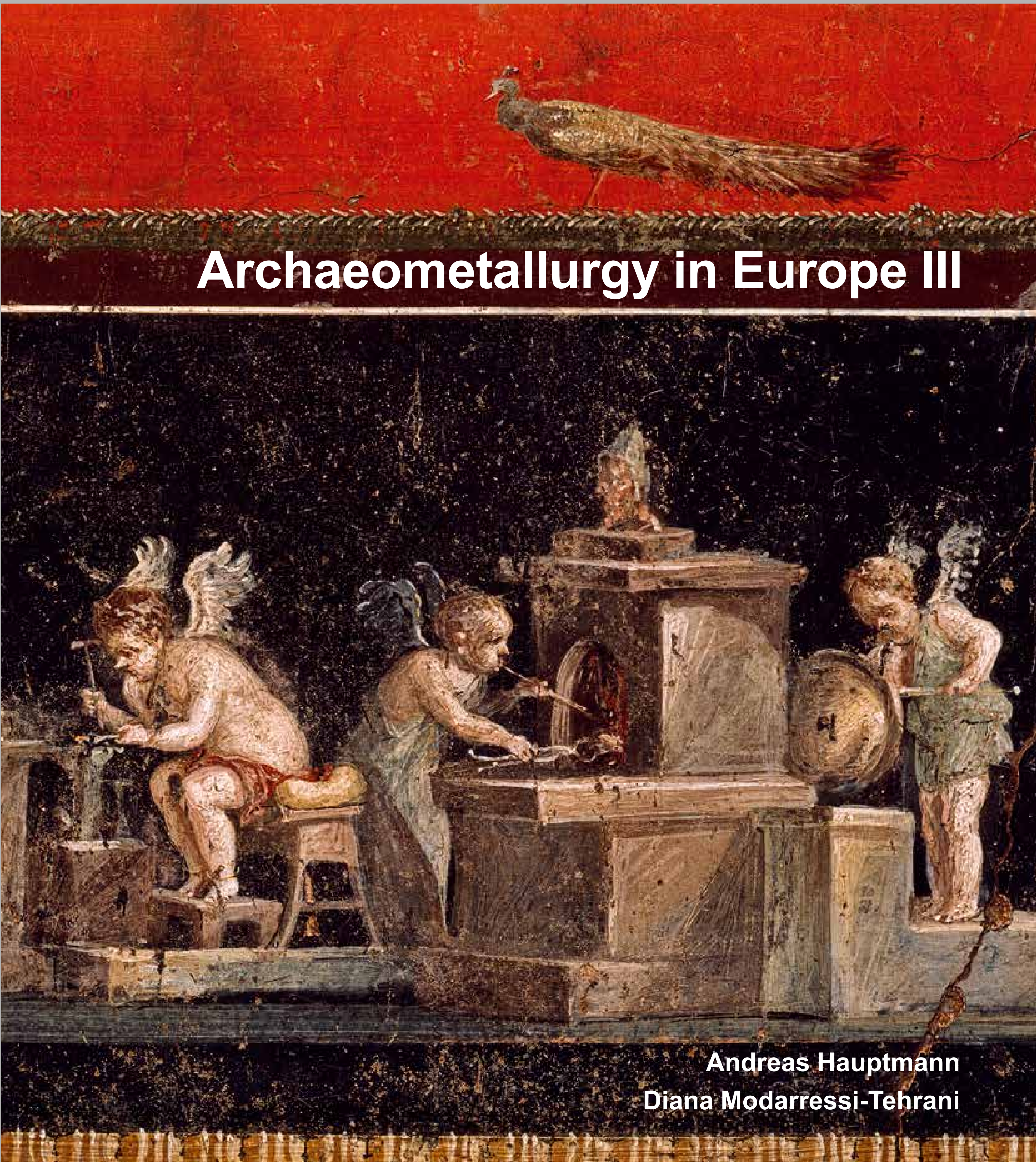

Archaeometallurgy in Europe III

Andreas Hauptmann
Diana Modarressi-Tehrani

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Andreas Hauptmann
Diana Modarressi-Tehrani

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Cover

Domus Vettiorum / Casa dei Vettii, Pompeii (Campania, Italy, 63-79 BC), which was excavated in 1894. Section of a Pompeii-style scenic fresco showing Erotes and Psyches in a gold assay laboratory. In the left corner, scales for weighing gold are put on a table. Next to it, one of the Erotes is working with a small hammer on an anvil. On the right side, an assay furnace is shown. Another of the Erotes is holding a small crucible with pincers with the right hand while using a blowpipe with his left hand, supplying the fire with air. The large bellow for the assay furnace is driven by the third of the Erotes.

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Archaeometallurgy in Europe III

Editorial

This volume comprises a range of articles, which were submitted and selected from all the presentations given on the International Conference ”Archaeometallurgy in Europe III”, held from the 29th of June to 1st of July 2011 at the Deutsches Bergbau-Museum Bochum, Germany.

The present volume is the third in the series “Archaeometallurgy in Europe” , capturing the spirit of the successful series of international conferences on this special theme of research. The first conference “Archaeometallurgy in Europe” had been organized by the Associazione Italiana di Metallurgia and took place in Milano, Italy, from the 24th to the 26th of September 2003. The second conference was held in Aquileia, Italy, from the 17th to the 21st of June 2007. It was also organized by the Associazione Italiana di Metallurgia.

The splendid idea to launch this conference series, a scientific series of meetings limited to the countries of Europe, came from the late Prof. Dr. Walter Nicodemi, formerly President of the Assoziazione Metallurgia di Italia. Thanks to the efforts of Dr. Alessandra Giumlia-Mair, Merano, these conferences have developed into increasingly productive events with a high scholarly quality. Since then three conferences have taken place and the fourth meeting is at an advanced stage of preparation and will take place in Madrid, Spain, from the 1st to the 3rd June 2015.

The title of the conference series covers a research field which is a distinctive part of archaeometry, and which so far was usually included as one of the topics in the program of the “International Symposium on Archaeometry” (ISA), organized every third year at different locations in Europe and in the United States. However it is our opinion, that in the last decade archaeometallurgy has developed as a very important research field, and we are observing a large number of scholarly activities all over the world. We are convinced that such an important topic needs to be organised and presented in conferences specifically dedicated to this field. Therefore the topic of this conference is the history of metals and metallurgy primarily in Europe, but it also includes other regions of the Old World.

The future prospects of the conference series are promising, especially because “Archaeometallurgy in Europe” constitutes an extremely useful broadening and a regional counterpoint to the well-established and successful conference series “The Beginnings of the Use of Metals and Alloys” (BUMA), which was launched in 1981 by Professors Tsun Ko, Beijing, China, and Robert Maddin, then Philadelphia, USA. The focus of the eight BUMA conferences held so far (the last one was held in Nara, Japan, in 2013) lays on the development of metallurgy in South-East Asia and the Pacific Rim. We firmly belief that the two conferences complement each other very effectively and should therefore continue to exist side by side.

With this special volume of *Der Anschnitt*, we are delighted to publish a selection of the lectures presented at the conference at the Deutsches Bergbau-Museum Bochum in 2011. Many of the authors contributed with very instructive and informative papers, which finally resulted in this volume.

We are very much obliged to all these authors who, with patience and persistence, cooperated with us and helped to shape this volume. We would also like to thank the reviewers who decisively contributed in the improvement of the scientific level of this volume.

Our thanks go first to all those colleagues and friends who helped to organize the conference in 2011. The former director of the Deutsches Bergbau-Museum, Prof. Dr. Rainer Slotta, and the present director, Prof. Dr. Stefan Brüggerhoff encouraged and promoted our efforts to organize this scholarly meeting. Dr. Michael Bode, Dr. Michael Prange, and Prof. Dr. Ünsal Yalçın supported the conference planning and realization in every aspect. Many colleagues of the staff of the Deutsches Bergbau-Museum, and many of the students working in our research laboratory offered their assistance and help.

Finally, our thanks go to Mrs. Karina Schwunk and Mrs. Angelika Wiebe-Friedrich who performed the editorial work, design, and layout for this volume.

Andreas Hauptmann
Diana Modarressi-Tehrani

Contemporaneously to the conference in 2011 a volume with abstracts on every lecture given and every poster presented was published:

2011 HAUPTMANN, Andreas, MODARRESSI-TEHRANI, Diana & PRANGE, Michael (eds.), Archaeometallurgy in Europe III. Abstracts. METALLA, Sonderheft 4, 2011.

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Early mining and metallurgical innovation stages in Europe

Regional studies in Europe and beyond

Reconstructing ancient technologies

Alessandra Giumlia-Mair, Susan C. Ferrence & Philip P. Betancourt

Metallurgy of the copper-based objects from Gournia, east Crete

Summary

The copper-based finds from the Late Minoan town of Gournia in eastern Crete were excavated over 100 years ago by Harriet Boyd Hawes. A selection of the artifacts belongs to the University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, PA. Most of these objects can be assigned to Late Minoan I, but because exact contexts were seldom recorded, a few may be earlier or later in date. For this project about 90 measurements were carried out on 70 different objects, including their various parts. The finds have been analyzed by X-ray Fluorescence Spectrometry (XRF). The aim was to use a non-destructive method to gain insight into the local metallurgical tradition, to identify the alloys employed in this period, and to determine the production technology of the finds. Until now very little systematic analytical work has been published on the metal finds of this period from Crete, nor from other contemporary sites in the Mediterranean.

In this paper the copper-based alloys and the production methods used by the local artisans will be discussed. The production techniques and the finishing processes have been investigated and allow for the reconstruction of the fabrication processes and the stages of production. The classes of objects are representative of diverse techniques and include finds, such as weapons (like daggers, knives, and axes), tools (like chisels, saws, and small blades), ornaments (like rings, pins, and bracelets), vessels, and objects of personal use (such as tweezers and cosmetics scrapers). Furthermore, small ingots, strips, pieces of wire, and blanks give a good general idea of the manufacturing processes employed in this period.

Introduction

This paper presents the analyses of the Cu-based finds from the Late Minoan (LM) site of Gournia in eastern Crete and gives insight into the local metallurgical tradition. Relatively little systematic analytical or technical work has been published on the metal finds of this period from Crete (Betancourt et al. 1978), and studies on comparable materials from other Mediterranean sites are very few. The objects were excavated more than one century ago by Harriet Boyd Hawes (Boyd 1904; Boyd Hawes et al. 1908) and now belong to the collections of the University of Pennsylvania Museum of Archaeology and Anthropology (hereafter, Penn Museum) in Philadelphia, PA, USA. An unspecified number of finds from Boyd Hawes' excavation is in the Museum of Heraklion.

Most of these objects can be assigned to LM I (1625–1450 BCE), based on the context of their deposition (Betancourt 1979; Betancourt and Silverman 1991; Fotou 1993; Soles 1991). Metal objects tend to have a long lifespan, however, so they may have been manufactured many years prior to their deposition, possibly decades or even centuries earlier.

In the present work, the range of alloys and techniques used by the local artisans will be discussed. The production technique and the finishing processes of the artifacts have been investigated and allow clarification of hypotheses regarding the fabrication of the pieces. The various classes of objects are representative of diverse techniques and include a range of weapons, tools, ornaments, vessels and vessel fragments, and objects of personal use. Additionally, small ingots, strips, pieces of wire, and blanks give a good general idea of the alloys and of the manufacturing techniques that were employed in this period.

Scientific Analyses

All objects from Gournia in the Penn Museum were first autoptically examined with various magnification devices and viewed under a microscope to determine the conservation conditions and to find the best area for performing the analytical measurements. For the scientific analyses, it was decided to use a non-destructive method, therefore a transportable X-ray fluorescence analyzer—specially developed for the analysis of cultural heritage objects—was brought to the Penn Museum. It consisted of an X-ray source, a transformer, a tripod, and a laptop computer with dedicated software for the analysis of ancient metals. In the cases in which the items were covered by a rough or thick patina, a small area of the altered layer was removed by the chief conservator Lynn Grant.

The XRF measurements were performed by illuminating a flat, cleaned area on the object with X-rays for a short time (typically 15 minutes). If the analysed spot is very small, the measurement time can be longer. The irradiated area has a diameter of approximately 1.5–2.0 mm, but the analysed spot can be smaller or larger as required by the size of the object and the surface texture. The measurements are accomplished at a fixed angle and a fixed distance from the sample. At least three XRF readings were obtained for confirmation in case of unclear results, due, for example, to the small size of the objects or to vibrations from inconsistent positioning of the items.

A wide range of elements – and particularly metals and alloys – can be quantified simultaneously with a high degree of precision if proper standards and some caution are used (cf. Hahn-Weinheimer et al. 1995; Lutz et al. 1996). Detection limits vary depending on the element. Here results under 0.2 % have been considered as traces. Blank spaces in the table of results mean "not detected". The comparison of previous analyses, carried out by AAS and XRF on the same samples, demonstrated that over 90 % of the XRF results were well within ± 20 % of the corresponding AAS results. The calculated correlations for Sn and Pb, two of the most important alloying elements, range from 0.84 to 0.97.

The different standards of various composition employed during the measurements have been produced by AGM Archeoanalisi for the analysis of ancient metal alloys. They represent an important tool in the evaluation of the results and were run every day at the beginning of the measurements, whenever the equipment was switched off, and at regular intervals during the entire project. Drift and particular interference effects therefore could be monitored exactly and taken into account while evaluating the results. This methodology helps to retain the standard of analytical precision and guarantees reliable results.

Discussion of Results

About 90 analytical measurements were performed on all objects from Gournia in the Penn Museum (approx. 70 items; see also Fig. 1) and on their different parts. As shown by the table of results (table 1), about half of the measurements indicated that the objects are made of unalloyed Cu or at least Cu with very low As, Sn, and Pb contents, while around 10 % of the analysed finds are made of arsenical Cu.

Over 20 % of the objects are made of bronze, i.e., a Cu-Sn alloy, however, about 10% of objects in the group of finds from Gournia contain both low amounts of Sn and As. The pieces with a measurable Sn content therefore are one-third of all finds.

Measurable As is present in ca. 25 % of the finds, but many more objects contain traces of this element. The maximum As content determined in the entire group was found in the chisels (inv. nos. MS4178, MS4180–MS4182, MS4199) in which the As increases to almost 4 %. The mean content in the objects with measurable As is 1.3 % (st. dev. 0.98). Several blades and tools contain around 2 % of As, while many more contain very low percentages, and 29 pieces contain only traces of this element. This indicates that As was a common impurity in the raw Cu employed for the production of the pieces. In many cases traces of Sb also were determined.

Omitting the strip of almost pure Pb, the highest Pb content is 3.5 % in one of the chisels (MS4199). This is the only instance with such a high Pb content, and it is certainly not a deliberate addition. In all other objects Pb was found only at trace levels.

The maximum Sn content determined in the objects is 9.4 % in the blade of a dagger (MS4186). Several items, in particular tools, contain Sn percentages of around 3–4 %; the mean is 2.87 % Sn (st. dev. 2.3). Low traces of Sn were determined in nine of the analysed objects.

Composition of Daggers and Sickle

As the analyses show, blades of different composition are represented in the group of analysed finds. Two daggers (MS4183, MS4184) have low contents of both Sn and As, however Sn is present in the blades only, while As is found also in rivets. While the Sn is a deliberate addition, it therefore seems that As, often accompanied by traces of Sb, was one of the original components of the Cu. The smiths must have taken care in choosing As-rich Cu, especially for objects like weapons, which needed to be hard and keep a proper cutting edge.

The blade of dagger MS4186 has the highest Sn values, with 9.4 %. The Sn results may have been enhanced partly because of the presence of corrosion, however the As is under the measurable percentage in the blade and even in the rivets. The Cu employed for this dagger was better refined than that of other pieces, or perhaps this object belongs to a metallurgical tradition slightly different from that of the previously discussed examples. Dagger MS4187 has a different shape and was not alloyed with Sn. The blade does not contain As, however rather high As is present in two of the rivets. Because of the presence of corrosion, though, in this case the results must be considered indicative, and we hypothesize that the As content of the blade was originally higher.

Traces of Ag (1–5 %) have been determined on the rather corroded head of the rivets in four daggers (MS4183,

Table 1: Metal objects from Gournia that were analyzed with XRF. Italicized text means that the results must be considered semiquantitative only. MS = Mediterranean Section, Penn Museum, Philadelphia, PA. Tr. = trace. Frg. = fragment. Blank space = not detected

Object Type	Museum Inv. No.	Part	Cu	Sn	Pb	As	Sb	Fe	Ni	Ag	Zn	Co	Mn	Au
Chisel	MS4178	Blade	97,1	1,8		0,8	Tr.	0,6		Tr.				
Awl	MS4179		95,5	3,5		0,5		0,4						
Chisel	MS4180	Blade	99,9				Tr.	0,1		Tr.				
Chisel	MS4181	Blade	94,8	Tr.	Tr.	2,9	Tr.	2,7						
Chisel	MS4182	Blade	93,9			3,9		1,9	Tr.				Tr.	
Dagger	MS4183	Blade	94,2	1,3		1,8	0,2	0,9					Tr.	
Dagger	MS4183	Rivet 1	90,9			2,1		1,2		5,7				
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				
Sickle	MS4185	Blade	96,9			1,4		1,7						
Dagger	MS4186	Blade	88,6	9,4		0,6		0,8						
Dagger	MS4186	Rivet 1	96,2					2,4		1,3				
Dagger	MS4186	Rivet 2	97,1				Tr.	1,3		1,7				
Dagger	MS4186	Rivet 3	93,8					2,1	Tr.	3,8		Tr.		
Dagger	MS4187	Blade	95,2			0,4		3,8						
Dagger	MS4187	Rivet 1	97,6					2,3						
Dagger	MS4187	Rivet 2	95,5			1,7	Tr.	2,5		Tr.				
Dagger	MS4187	Rivet 3	94,4					1,6		Tr.				
Axe	MS4188	Blade	97,3		Tr.	0,6		1,8						
Axe	MS4189	Blade	98,8			0,7	Tr.	0,5		Tr.				
Blade	MS4190	Blade	93,3	0,9				1,3		Tr.	4,6			
Blade	MS4190	Rivet 1	92		Tr.	Tr.	Tr.	1,7			5,8			
Blade	MS4190	Rivet 2	91,6	Tr.		Tr.		2,4		Tr.	5,5			
Saw	MS4191		95			1,6		1,2		Tr.	3,2			
Fish hook	MS4192		94,6	0,9	0,2			1,5			2,5	Tr.		
Scale	MS4193		99,6			Tr.		0,3		Tr.				
Bracelet	MS4194		98,7	0,5		Tr.		0,3				Tr.	Tr.	
Scale	MS4195		99			Tr.		0,9		Tr.				
Tweezers	MS4196	Blade	96,7	2,1	Tr.	Tr.		1,5		Tr.				
Tweezers	MS4196	Repair	95,6	1,8		Tr.		2,4		Tr.				Tr.
Tweezers	MS4197		96,4	2,3		0,3		0,7		0,2				
Scraper	MS4198		94,7	3,2	0,3		Tr.	1,7						
Chisel	MS4199	Blade	84,2	2,7	3,5			0,3		Tr.	7,4			
Spatula	MS4200		99,1			Tr.		0,7						
Needle	MS4201		99,7			Tr.				0,2				
Needle	MS4201	Bis	99,3			Tr.		0,4		0,2				
Hook	MS4203		93,6	5		0,4		0,8		0,5				
Hook	MS4204		95,6	2,3		1,2	Tr.	1,3		Tr.				
Hook	MS4205		94,2	4,2	0,3			1,2					Tr.	
Ingot	MS4563A	Cut	99,8				Tr.	Tr.		Tr.				Tr.

Table 1 ff.

Object Type	Museum Inv. No.	Part	Cu	Sn	Pb	As	Sb	Fe	Ni	Ag	Zn	Co	Mn	Au
Ingot	MS4563B	Cut	99,1		0,2		Tr.	0,4						
Ingot	MS4563C	Cut	99,9					Tr.		Tr.				Tr.
Ingot	MS4563D	Cut	99,7			Tr.	0,2	Tr.						
Cauldron	MS4718	Leg	91,4	5,2		1,5		1,8		Tr.				
Cauldron	MS4718	Rivet	97,2	Tr.		0,5		2,3						Tr.
Bracelet	MS4719		99,3					0,6		Tr.				
Ring	MS4739	Ring	96,5	2,4		0,8		0,3						
Ring	MS4739	Bezel	97	1,9		0,8		0,3						Tr.
Hook	MS4740		93,6	3,8		Tr.	Tr.	2,2		0,2				Tr.
Needle	MS4741		95,3	2,2		1,1		1,3						
Pin	MS4742A		99,5			Tr.		Tr.		0,4				Tr.
Wire	MS4742B		99,9			Tr.		Tr.						
Needle	MS4743		96,8			2,8		0,3						
Pin	MS4744	Shaft	98,2	Tr.				Tr.		0,9				
Pin	MS4744	Head	97,9	Tr.	Tr.	Tr.	0,7	Tr.		1,3				
Sheet	MS4745		98,7					1,2						
Blank 1	MS4746-A		98,6	0,4	Tr.	0,3	Tr.	0,3		Tr.				
Blank 2	MS4746-A		90,1	Tr.		Tr.		1,4			8,2			
Blank 3	MS4746-A		97,7	0,5		Tr.		0,4		Tr.	1,3			
Blade	MS4746-A		99,9			Tr.				Tr.				
Cauldron	MS4746A	Handle	96,9	Tr.		Tr.		2,6		Tr.				
Cauldron	MS4746A	Wall Frg.	93,5	3,7				0,5		2,4				
Cauldron	MS4746A	Rivet	93,2	1,6			Tr.	0,6		0,5				
Cauldron	MS4746A	Wall Frg. 2	96,5	2,2			Tr.	0,8		0,4				
Cauldron	MS4746A	Rivet	96,8	1,9			Tr.	1,1						
Cauldron	MS4746A		95,6	1,9	Tr.	Tr.		2,3		Tr.				
Blank 5	MS4746A5		98,9			0,3		0,7		Tr.				
Blank 6	MS4746A6		98,6			0,5		0,9						
Blank 7	MS4746A7		99,1			0,2		0,7		Tr.				
Blank 8	MS4746A8		99,2			Tr.		0,6		Tr.				
Blank 9	MS4746A9		99,1			Tr.		0,5		0,2	Tr.			
Awl	MS4746C		97,9			Tr.		1,9						
Needle	MS4746D		99,9			Tr.		Tr.		Tr.				
Tweezers	MS4746F	Frg.	99,8					Tr.						
Tweezers	MS4746G	Frg.	98,9	0,7		0,3	Tr.	Tr.		Tr.				
Tweezers	MS4746H	Half	97,4	2,5	Tr.					Tr.				Tr.
Strip	MS4746J1		99,4		Tr.	Tr.		0,5						
Strip	MS4746J2		98,6		Tr.	Tr.		1,2		Tr.				
Strip	MS4746J3		98,9			0,3		0,8						
Strip	MS4746J4		99		Tr.	Tr.		0,9		Tr.				
Tweezers	MS4746K	Frg.	97,2	Tr.		2,4	Tr.	0,3						
Dagger	MS4746L		95,7			3,7		0,5		Tr.		Tr.		Tr.
Lead strip	MS4747		Tr.		99,6		Tr.	Tr.		0,3				Tr.
Cup	MS4748	Frg.	95,4	4,4		Tr.	Tr.	Tr.		Tr.				
Point	MS4749		95,2	1,5		1,8		1,4						

MS4184, MS4186, MS4187). The presence of Ag traces on the rivet heads, but not on the blade, suggests that the rivets were originally Ag-plated. The corrosion must have detached the Ag sheet leaving only some trace of Ag in the corrosion layer. Ag-plated rivets on contemporary daggers are well known in Crete.

Dagger MS4746L shows a very different shape, and the upper part is now missing. The Cu contains 3.7% As. The As content of the bulk is probably lower: it is well known that the eutectoid with approximately 29% As is pushed to the surface during the cooling phase of the metal and forms a silvery layer on the surface.

The sickle consists of Cu with only ca. 1.5 % of As. Apparently the bronze workers did not wish to waste precious Sn for this common tool and employed an As-rich Cu instead.

Object MS4190 is a carefully finished small cutting implement with a flaring blade. The cutting edge shows traces of intensive use and re-working. The blade contains only low traces of Sn and no measurable As, while the rivets are made of less well refined, unalloyed Cu. A further simple small blade (MS4746A) was produced with unalloyed Cu with only slight traces of As and Ag.

In the Bronze Age, swords, daggers, and blades in general were the most carefully worked class of objects for which the best controlled alloys were employed. In this period, the alloys used for the blades from Gournia, however, cannot be defined as "controlled": we have demonstrated that Cu containing variable amounts of both Sn and As was employed. Nevertheless the analysis has shown that also at Gournia the alloys with the highest Sn content belong to this class of objects and that Cu with high As content was also chosen for the blades. We therefore can say that at Gournia the most expensive alloys were kept for this class of objects. The only exception is the small blade made of unalloyed Cu, but this small item belongs to the class of tools more than to that of blades.

Decorative Objects of Personal Use: Pins and Bracelets

Metallic personal ornaments were a socially important class of objects during the Bronze Age. This class commonly shows a better quality than everyday objects and tools.

A decorative pin (MS4744) has a rather different composition in the shaft compared to the head, which indicates that the head is cast on the shaft with a less purified Cu. The differences in composition might be due to different working methods. The shaft was hammered and polished, while the head was left in as-cast condition. Intensive working by repeatedly hammering and annealing an As-rich Cu can induce a loss of As from the alloy.

The pin with a spatula-shaped head (MS4200) is made of unalloyed Cu and seems to have been cast as a small bar and then hammered into shape.

The group of four hook-shaped pins (MS4203–MS4205, MS4740) is characterised by relatively high Sn content (2–5 %) and noticeable As in some of the specimens. Two of the pins show a square section and seem to have been cast in this shape, while the other two hooks (MS4203, MS4205) have a round section. Hook MS4203 has been produced by twisting two pieces of wire together, as demonstrated by the seam visible under the microscope. The shaft has been hammered and smoothed with an abrasive material.

The hook-shaped pins have been interpreted as weaving hooks, however their composition and production technique are more similar to that of decorative objects than to those of tools. Furthermore, there also are parallel examples of similar objects made of Au and Ag. The use as personal ornament therefore seems to be more probable than that as weaving hooks. It is possible, however, that small personal tools were made of more expensive metal to also be used as decorative ornaments; multiple uses certainly should not be excluded.

A fragmented bracelet (MS4719) is decorated with a simple incised zigzag line and is made of well purified, unalloyed Cu. A second bracelet (MS4194) has the same zigzag decoration and seems to have been wrapped in thin fibre, possibly linen, the pattern of which is still preserved in the corrosion layer. The XRF measurement was taken on an area cleaned by the conservator of the museum. The metal is Cu containing low amounts of Sn and As.

Among the personal ornaments, a ring was made of Cu containing ca. 2 % of Sn and 1 % of As. The difference in colour from unalloyed Cu must have been quite noticeable. The ring is open, and the ends have been flattened next to each other to form a bezel.

Tweezers

One of the largest classes of objects among the metal finds of Gournia at the Penn Museum is that of the tweezers. These objects show compositions (2–3% Sn), which are quite similar to those of the ornaments. The alloys are generally made of well refined Cu, containing noticeable amounts of Sn and some As. The objects were carefully finished and repaired when broken (e.g., MS4196). This seems to suggest that the tweezers were considered special objects of some value. They might have been worn at the belt or even as a pendant.

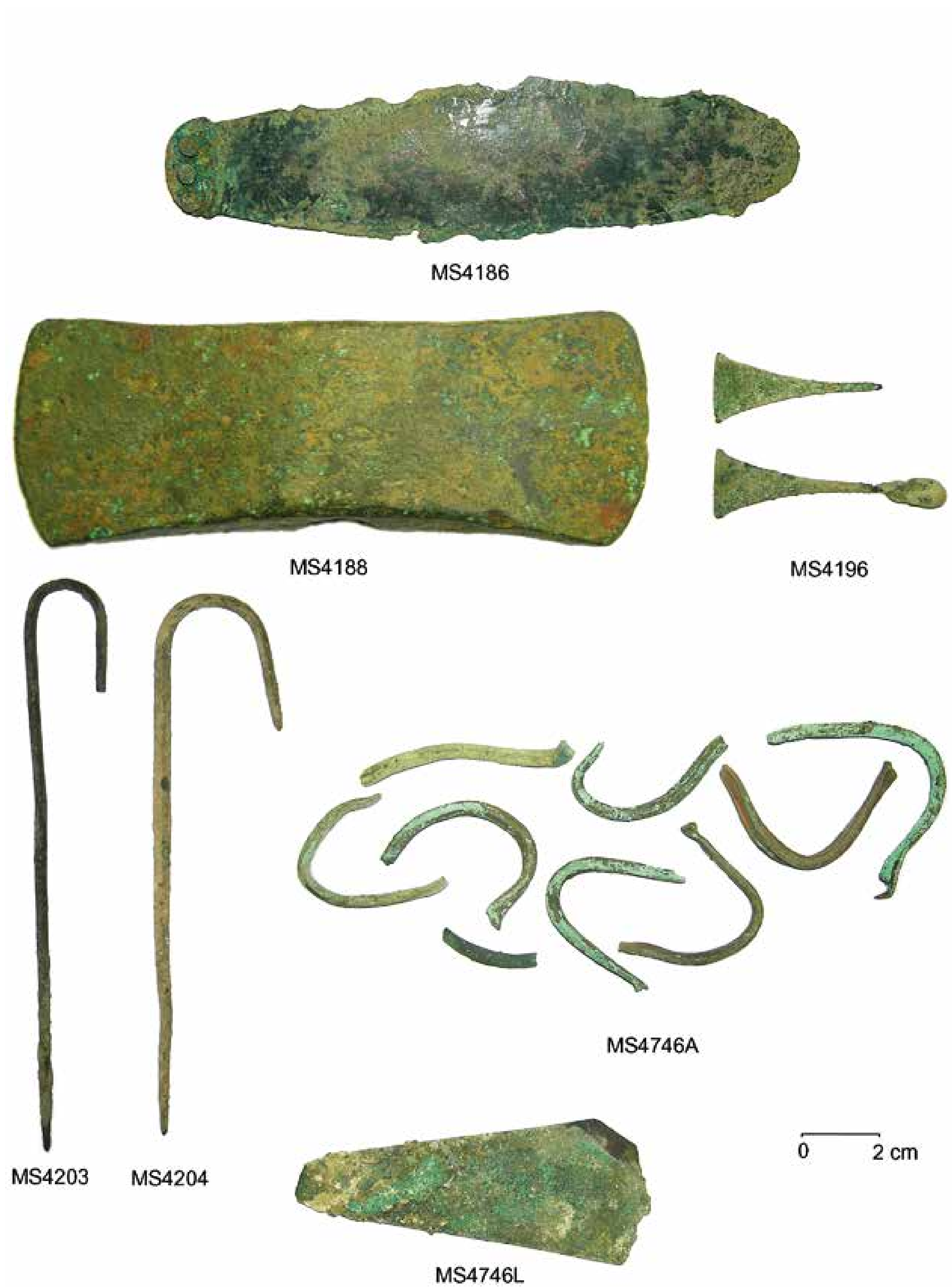

Fig. 1: Selection of objects discussed in the text: dagger, axe, tweezers, hook-pins, blanks and dagger fragment (compare table of results). Photo by authors.

Only one of the tweezers (MS4746K) contains traces of Sn and 2.4 % of As. This kind of composition allows for the production of a functional and aesthetic tool. In this case, however, the piece is in poor condition, therefore the data must be considered only indicative.

The small “scraper” provided with a loop as a handle (MS4198) shows the same kind of composition. This object may have been used as a cosmetic scraper and also could have been worn as a personal ornament, as suggested for the tweezers.

Miscellaneous Objects

Two scale discs (MS4193, MS4195) are made of a very thin sheet of well purified unalloyed Cu. Apparently the smiths felt more confident in hammering unalloyed Cu into thin sheet and preferred to use it instead of arsenical Cu or bronze. This is due to the fact that, even if it needs more annealing, unalloyed Cu is softer and can be more easily thinned down to sheet.

Axes MS4188 and MS4189 are both heavy castings made of Cu containing 0.6 % and 0.7 % of As respectively. On one side of axe MS4188, shrinking traces were left when the metal cooled in a matrix open on one side into which a cylinder (possibly made of stone) was inserted to produce the shaft-hole.

The leg of a cauldron (MS4718) contains over 5 % of Sn and 1.5 % of As, while its rivet is made of unalloyed Cu. The higher Sn content of the large casting not only turns the colour to a more golden hue, but, together with the As, it also lowers the melting point and improves the fluidity of the metal.

A heavy cast cauldron handle (MS4746A) still preserves the remains of the vessel walls where the handle was attached with rivets. All parts contain different amounts of Sn, no measurable As, low traces of Sb, and a relatively high Ag content. The Cu used for this object seems to be slightly different from that employed for the other objects. The high Ag content stands out. The alloy employed for the cauldron walls contains more Sn than the other parts, but no As. The higher Sn content (almost 4 %) improves the workability of the alloy by making it more malleable.

The small fragmentary cup (MS4748) is a carefully worked object made of bronze with ca. 4.5 % of Sn and traces of As, Sb, and Ag. This alloy is malleable and quite suitable for casting and hammering to obtain a cup.

Tools

Aside from the previously mentioned special groups of blades, tweezers, and pins, several additional groups of small tools come from Gournia, such as needles, chisels, awls, a fish hook, and a saw. Their composition is generally less carefully controlled than, for example, those of the blades and ornaments. They embody many instances of unalloyed Cu and/or of Cu with very low amounts of Sn and As.

This can be illustrated very well by the group of five chisels that are all made of alloys of different composition: arsenical Cu, Cu containing 2–3 % of Sn, and unalloyed Cu. In the case of chisel MS4180, a well purified Cu has been employed, while chisel MS4181 exhibits traces of Sn, Pb, Sb, and As, suggesting the recycling of mixed scrap. The chisels were manufactured into different shapes and sizes, certainly for employment with various materials, requiring different hardness and performance. This partly explains the very inhomogeneous compositions, however they also reflect the fact that less care was taken in the production of everyday tools.

Small implements such as needles must work efficiently to be employed as tools in everyday life, and can give a good idea of the bronze workers’ skill in manufacturing everyday items.

Needle MS4201 was twisted from a strip of unalloyed Cu, and the eye was shaped by doubling the strip. A fracture on the shaft shows the two parts twisted together. After hammering, the shaft was polished with abrasives, so now the thin and compact patina perfectly conceals the seams. Needles MS4741 and MS4746D were produced in the same way. The former was made of an alloy containing 2.2 % of Sn and over 1 % of As, while the latter example was created from well purified and unalloyed Cu. Needle MS4743 was also made of unalloyed Cu, but it is different because the eye of the needle has been produced by piercing the thin Cu strip at a suitable spot on the flattened end. The helicoidal seam shows how the strip was twisted to obtain the shaft. In this way, a very regular structure was created.

“Pin” MS4742A is also made of unalloyed Cu, and has been produced in the same way. One end is missing, but this item possibly was a needle similar to MS4743. Unalloyed Cu can be hardened and shaped to a sharp point by hammering and repeatedly annealing it. As microscopy has shown, the sharply pointed fragment MS4749, which contains both Sn and As, and “wire” MS4742B, of unalloyed Cu, have also been manufactured by twisting a thin strip of metal.

The fragment of a small saw (MS4191) is made of arsenical Cu (1.6 % As). The teeth were shaped by scratching the edge of the blade with a very hard instrument, perhaps a sharp piece of flint.

The large fish hook (MS4192) was made of bronze with a low amount of Sn, and it was very skilfully worked.

Originally the hook was provided with a hole for the fishing line or net.

Awls also belong to this class of object: specimen MS4179 is made of bronze with 3.5 % of Sn, and some As, and its details give a clear idea of its production technique. The piece is characterised by a square section and a rough heel. The shallow lines on the flattened surfaces do not seem to come from twisting as in the case of the needles, but they are much wider and more irregular. A comparison with the cast blanks found at Gournia indicates that the lines on the sides of the awl must be the remains of the casting seams, which are visible on the as-cast blanks (see below).

Workshop Remains

From a technical point of view, the most interesting finds from Gournia are the workshop remains such as small ingots, strips and sheets of metal, and the blanks mentioned above. Their study, coupled with that of the finished objects, gives a good general idea of the various alloys and manufacturing processes that were employed in LM I Crete.

The small ingots (MS4563A–D) from Gournia, now in the Penn Museum, have been sampled in the past for optical and scanning electron microscopy (OEM and SEM; Betancourt et al. 1978) and Pb isotope analysis (Gale, in prep.). The XRF analyses on these ingots show that the metal is a well purified unalloyed Cu. With all probability they represent the metal stock that the smiths kept ready in their workshops to be used for better quality items.

Many thin metal strips (MS4746J, 111 pieces), ca. 5–7 cm long and 0.7 cm wide, were cut from a sheet with a sharp and hardened blade. Four of the strips have been analysed and found to be made of good quality unalloyed Cu (see also Betancourt et al. 1978). Thin strips of metal of this kind can be employed for a myriad of objects, both as rough material to be cut into thinner strips for twisting to produce wire, and also as part of larger objects. The thin strips of unalloyed Cu may have been cut from a larger piece of sheet, similar to specimen MS4745, which is a large and rather thin metal sheet in excellent condition, made of well refined, unalloyed Cu.

During the excavations at Gournia a noticeable number of blanks (MS4746A, 16 pieces) came to light. They are ca. 7-cm-long and ca. 5-mm-thick curved bars, which still bear the traces of casting in an open mould. All of them have flat ends and are curled up on the side, which shows the traces of shrinking of the metal in air during the cooling phase. They were cast in simple open moulds. The shrinking line from the casting can be recognised on several objects from Gournia, and it is quite apparent that they have been manufactured from this kind of small blank.

Conclusions

This research has shown that several kinds of alloys were in use in LM I Crete. Beside the arsenical Cu objects, which would have been in use in earlier periods, bronzes also have been identified. Many of the objects, however, contain both As and Sn. This seems to indicate that Sn was still a rare and expensive commodity and that recycling and the use of scrap metal were rather common. The XRF analytical results and the microscopy study have demonstrated that the smiths were able to perfectly purify their Cu whenever it was needed.

It is quite clear, however, that for some classes of everyday objects a thorough purification of the Cu was not deemed necessary, and rather impure Cu was employed. Depending on the impurities present, impure Cu could present some advantages, such as a lower melting point and higher fluidity in the molten state.

It is also evident that, as heritage of the empirical experiences gathered in the previous millennium, the metal workers were able to recognise and choose As-rich Cu, certainly because of its paler colour. They deliberately employed it in the production of objects that needed an alloy more resistant and harder than Cu. This fact is especially noticeable in the case of the blades, but also in chisels and other tools.

Only very little Pb is present in the objects, and it was certainly not used as a deliberate addition to Cu.

The shrinkage traces observed on several objects suggest that, at least in some cases, open moulds were used. This has been observed particularly on axes and in the production of blanks for small items. Carefully purified Cu was preferentially employed to produce thin metal sheets. These could be cut into strips of different sizes to obtain wire or small objects like pins and needles. The examination of details of the finds and of the patina by microscopy indicates the use of abrasive materials like pumice stone and sand. These abrasives would have been utilised for the removal of the casting skin, for smoothing the traces of hammering, and for the polishing of metal.

For several classes of objects the manufacturing process could be reconstructed from the alloy preparation to the last finishing phases.

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