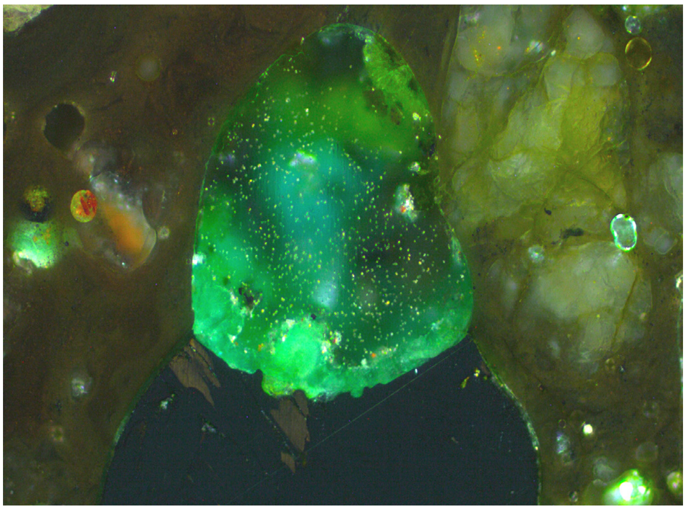
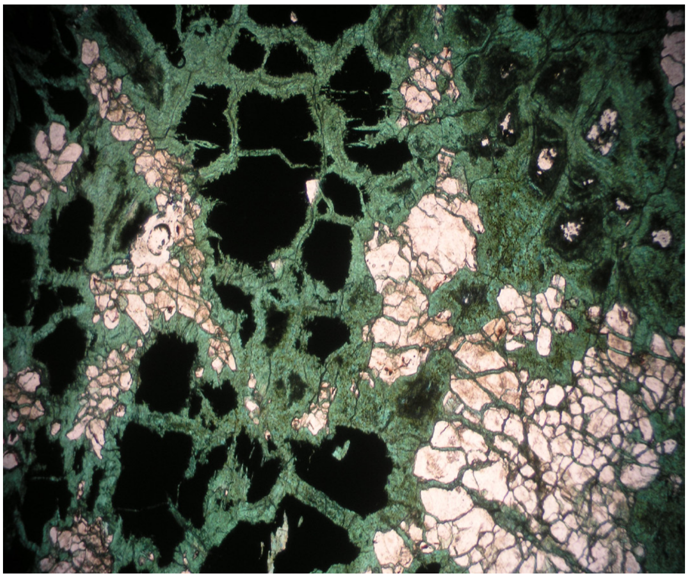
# THE CRUCIBLE

Historical Metallurgy Society News
Issue 99 Winter 2018





## Inside The Crucible



The Historical Metallurgy Society

## From the chairman

*Visit to Rievaulx Abbey during the "Royalty, Religion and Rust!" conference and AGM meeting held in Helmsley, 4th-5th June 2011*

It is with pride and excitement that I greet all of you as the new chair of the Historical Metallurgy Society. First of all, I would like to thank the other members of Council for their trust in me by electing me to this opportunity. Also, I would like to express my gratitude to all the people who dedicate substantial amounts of their time to the working of the Society. This not only means the people behind the visible products of our Society, such as its publications and meetings, but also those keeping track of membership, looking after our collections, safeguarding our finances and so much more.

I am proud of this new position as I consider it an honour to be able to contribute to the work of an institution such as the Historical Metallurgy Society. It is easily forgotten how rare societies such as ours are, where people with an amateur interest in the history of metal production can work side-by-side with some of the foremost academics in their field. In most places and research fields this simply does not happen. Also, while other historical interest groups tend to focus on a specific, chronologically-defined topic, the Historical Metallurgy Society encompasses the interaction of humans with about one tenth of the period table, globally and without time constraint. I shall never forget the first time I attended a meeting by the Historical Metallurgy Society, in Bradford in 2009 to celebrate the contributions made by Gerry McDonnell. Not only were the people present responsible for about half of my Master's thesis bibliography entries but there were talks ranging from chalcolithic copper production to twentieth century steel. There were representatives from a community project working on lead and iron production in Yorkshire to a presentation on iron production in prehistoric Thailand.

I am also very excited for the future of the Society and its research field. Because of the extent of the study area and the often required specialized knowledge needed to understand both the literature and the remains, the history of metals and their production has lagged behind many other topics. This is the time of year I am asked for my Christmas list, which nearly always consists solely of books. This invariably includes books giving sweeping overviews of the global history of a single material, be it organic or inorganic. And while there are comprehensive histories of glass, tea, honey, pigments and wood, overviews of the production and especially use of metals have yet to be written, except, perhaps understandably, of gold. I do believe we are nearing the point when we can look forward to the publications on the histories of iron, copper, lead and other metals. And when these publications become available I expect many of the references to point to publications by you, our members.

In the space that remains, I would like to wish all the best for the festive period to you and yours and hope to continue our adventure in metals in the new year.

*Paul Rondelez*

## Historical Metallurgy:

### A note from the editor

I must first of all apologise to all our members and subscribers for the backlog that has built up in publishing our journal, Historical Metallurgy. The new arrangements we have made for editing the journal are beginning to pay off, and are allowing us to maintain its high quality whilst providing a faster turnaround time on the papers we publish. The good news is that although we are still behind where we should be, you will already have received two issues earlier this year, the next issue is now being set and will be with the printer in November (and hopefully with you by the end of the year), while the following issue is at an advanced stage and should be published fairly early in the New Year.

The Editors believe that they can catch up by the end of 2019, but to do so we need more papers as the current accelerated production is using all the papers we have in hand. This is where you come in: now is the time to finish writing the paper you've been planning to submit to us as at the moment we can guarantee a fast track to publication. Please send papers to **submissions@hist-met.org**; any other comments or queries should be sent to me at **editor@hist-met.org**

*Justine Bayley*

## HMS Workshop

HMS is looking into the possibility of running seminars/workshops on aspects of archaeometallurgy.

The first of these would be on X-Ray Fluorescence (XRF) aimed at all users from the curious, to novice to expert.

This will be a hands on practical approach to the technique.

To gauge demand for this first seminar would anyone who may be interested in attending please contact

**mike@mikedobby.com** for further information.

**FUTURE INTERVIEWS**

*Who would you like us to interview for the next issue of* **The Cruicible**?

*Please let us know at* **thecrucible@hist-met.org**

**FUTURE COVER IMAGES**

*Do you have any intresting pictures that you like to share with the community on the front of The Crucible?*

*Please send them to us at* **thecrucible@hist-met.org**

## Slag standards for XRF

The ACC-HMS (Archives & Collections Committee) has become aware that a few people need standards for analysing ancient slags, especially those from iron smelting.

Do any HMS members

a) know of suitable standards,

b) also have a need for similar material or

c) would like to collaborate in the production of suitable standards?

Comments and wish-lists will be received gratefully at **ACCchair@hist-met.org**.

**Front cover images:**

**Top:** Bloomery iron-smelting event (see page 14)

**Middle left:** Copper sulphide prill and green gas bubble

**Bottom left**: Malachite thin section

**Submissions**

Submissions to ***The Crucible*** are welcome at any time, but deadlines for each issue are 1st March, 1st July and 1st November every year. Contributions can be sent in any format, but we prefer digital if possible. Images should be sent as high resolution jpeg or tiff files.

For consistency, we tend to use contributor's names without affiliations and email contacts. Anyone wishing to contact a contributor not known to them is welcome to forward a message in the first instance to the editors who will facilitate the contact.

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## Obituary

### Henry Cleere

Henry Cleere sadly passed away on the 24th August this year at the age of 91. Henry was the last surviving founding member of the Historical Metallurgy Society. An honorary member and also serving as an assistant editor designing the layout of the *Historical Metallurgy* Journal when it moved from a duplicated typescript at the same time as he was editing at the Iron and Steel Institute. Henry and David Crossley founded the Wealden Iron Research Group and jointly wrote T*he Iron Industry of the Weald* (Cleere, H. Crossley, D. 1995 eds. Hodgkinson, J. Merton Priory Press, Cardiff).

Gaining his PhD at UCL in the Department of Archaeology in 1980, his research took him across the globe from Sussex to Oman and he became internationally renowned for his work. Throughout his life, Henry was awarded many honours around the world including an Honorary Doctorate from Sussex University in 1993, an OBE in 2002 and the European Heritage Award in 2002.

Henry's contribution to archaeometallurgy will be greatly appreciated by generations to come and he will be sorely missed within the community.

*Amy Flynn*

## Supported Projects

*Figure 1. Burghmote horn in the care of Folkestone Town Council*

### Burghmote Copper Alloy Horns

I am carrying out research into the metal alloys of medieval 'brass' wind musical instruments, in particular Burghmote or moot horns. For my PhD (Bacon 2003), I studied the metallurgy of 'brass' wind instruments from 1651 to 1867, where I examined instruments by dated known makers. I found that the 17th century 'brass' instruments I examined were made of a ternary alloy of copper, tin and zinc. Beyond my PhD I am examining instruments from earlier centuries to see if this is an English trait as evidence shows that in Europe instruments were generally being made of brass (copper and zinc).

Ten Burghmote horns still exist mainly in the towns of the Cinque Ports, South East England, the earliest dating from possibly the 13th century. Traditionally the horn was blown by the Town Sergeant, usually to summon the citizens of the town on the election of a new Mayor, or to call the town or borough council to a meeting – hence 'Burgh' town and 'mote' meet. This tradition continues today where, in many of the towns, the horn is still blown at the election of a new Mayor or on a special occasion such as Armistice Day (Figure 1).

Lists of existing horns have been made by Crane (1972), Bridges (1905) and Galpin (1965) to name a few publications. Winchester Museum, now part of Hampshire Cultural Trust, has also had their horn investigated and analysed by Peter Northover (Crummy et al. 2008).

Analysis of the metal has shown them to be either of bronze or brass, and only two to be ternary alloys of copper, tin and zinc. They exhibit a variety of repairs, some botched, some refined, some tantalisingly strange, some adapted to enable playing, and one has even had a piece of music written for it. Also intriguing is that some appear to have been cast, whereas others are made from sheet metal, which is the common method of manufacture.

I am now at the stage where I am preparing to write up the research for publication. The pXRF work has been carried out, the data needs to be scrutinised and a lot of social history and archival research needs to be done.

The Kent County Archive holds the ancient records for the Cinque Ports, some of which go back to the 12th century.

I am very grateful to have had two grants from the HMS. For my PhD I had a grant towards the cost of carrying out XRF analysis. Some years later, I am now carrying out the research into the Burghmote horns. In this instance I have had a grant from the HMS towards travel and archival research and I have also been fortunate to have received a grant from the Institute Archaeometallurgy Studies (I.A.M.S) towards radiography of several of the horns.

*Louise Bacon*

**References**

Bacon, L. 2003. *A Technical Study of the alloy compositions of 'brass'* wind musical instruments (1651-1867) utilizing non-destructive X-ray fluorescence. University of London

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Crummy, N., C., J and N, Peter. 2008. The Winchester Moot Horn. *Medieval Archaeology*

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## ODONG – BLACK-PATINATED INLAID BRONZES FROM KOREA

The ninth BUMA conference was held in November 2017 at Busan in South Korea. After the conference Alessandra Giumlia-Mair and I took the opportunity to investigate the production of odong wares in present day Korea and obtain a small collection of material for the British Museum. Black-patinated inlaid bronzes containing a small percentage of precious metals in the alloy and inlaid with precious metals now have a well established history stretching back over four thousand years and from the Middle East and Egypt through Mycenaean Greece and Classical Rome, and from there to the Far East (Craddock and Giumlia-Mair 1993). The patinated irogane metals of Japan, particularly shakudo are probably the most familiar and well researched of these prestige metal items. These have tended to overshadow recognition of similar traditions of patinated copper alloys elsewhere in the Far East which are thus relatively unknown and certainly under researched (Craddock et al. 2009). Although there is some publication of the local technique in some of the countries that have produced these materials in the past there have been no overall syntheses, each producing area in apparent ignorance of their neighbours.


*Figure 1. Last of his kind? Gi Bo Hwang, Intangible Cultural Property No. 65, holding one of his odong pipes*

Production was quite widespread throughout the region well into the 20th century, but now seem to have ceased almost everywhere except in South Korea, although even here production is very limited, restricted to a few elderly practitioners who have no apprentices (Hyun et al. 2016). We visited one of these craftsmen, Gi Bo Hwang, Intangible Cultural Property No. 65, in Namwon city in Jeonbuk province, and recorded the process (Figure 1). The Korean technique is highly individual, but probably derived from the corresponding Chinese inlaid and patinated metalwork, known as wu tong (lit. black copper, and from which the name, odong, is derived) (Wayman and Craddock 1993). In both regions the material was principally used for tobacco pipes in the latter days of the process (Figure 2). The treatment of the component parts and their assembly is highly complex. In Korea the main bowl of the pipes are of cupro-nickel, similar to the Chinese wu tong pipes where the indigenous cupro-nickel paitong alloy was used, but the stem is often of bamboo Figures 1 & 3). The chequer-patterned central tubular section is made as follows. Squares of pure silver and of the odong alloy, copper with about 5% of gold, are soldered to a base plate of silver or copper (Figure 4). Decorative designs are then chased into the squares. Odong is hammered into the silver squares and a special silver alloy with a very low melting point (70% Ag, 20% Cu & 10% Zn; M.P. approximately 8000 C) is melted over the whole surface of the heated plate. This alloy has to be used otherwise the whole soldered assembly would fall apart and so very careful heating is necessary (Figure 5).

*Figure 2. Fine tobacco pipes. The stem and bowl are handmade of cupro-nickel but the central section is of silver inlaid with odong*

The assembled plate is then filed to remove the surplus special silver alloy from the surface leaving it only in the chased areas of the odong plates (Figure 6). After this the plate is hammered around a mandrel to form a tube and soldered. After further polishing and cleaning the patina is developed by treating with the urine of a male child that has been left to stand for about three months, during which time the pH rises from between four and five to between seven and eight.

*Figure 5. The square light coloured plate in the centre of the charcoal hearth is carefully heated and the special silver alloy melted over it*

The use of urine is also reported from China to develop the patina on the wu tong, and recalls the 'soil collected from beneath old walls' in India for the patination of the zinc-copper alloy bidri wares (Stronge 1986; Craddock 2005). All are basically an alkaline urea and ammonical solution with sodium, potassium, chloride and nitrate ions. This was applied in a poultice of mud in the case of bidri, and paper for the odong. The tube to be patinated is wrapped in hand-made Korean paper and then soaked in the urine and kept for several days at a temperature of about 600C, during which time the fine purple-black colour develops on the odong elements (Figures 2 & 3). As with all these special patinated metals in the Far East odong apparently has a quite short history in comparison with the Bronze Age origins of the technique in the occidental Old World.

Even the Japanese shakudo is difficult to trace before the 16th century. As noted above, the closest parallel to odong is the Chinese wu tong, the manufacture of which is believed to have begun in the 17th century. Korean sources suggest odong began to be produced in the early Joseon period, probably in 16th century. After flourishing for several hundred years it now seems likely that the production of odong will soon cease, unless there is greater awareness of this sophisticated technique from the remote past.

*Paul Craddock*

*Figure 3. A piece made by Young Bo Hwang for us, incompletely patinated. The main white square is of pure silver inlaid with dark odong, which has itself been inlaid with the low melting silver alloy. The dark square is of odong inlaid with the low melting silvery alloy*

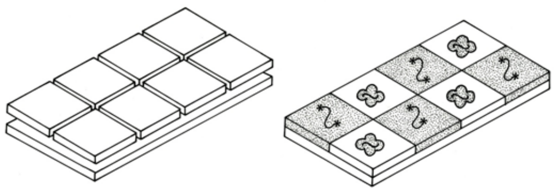

*Figure 4 . Sketch of the chequer pattern of alternate pure silver and odong squares soldered to a base plate (left) and then chased (right) (Drawn by Brenda Craddock)*

*Figure 6. The plate is filed to remove the low melting silver alloy from the surface leaving it only in the chased designs*


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## UNDERSTANDING THE LOST WAX TECHNIQUE THROUGH ETHNOGRAPHIC STUDY

The tradition of lost wax model in India goes back to Harappan cultural times and the finest example is the dancing girl (Figure 1). The tradition is still continued even today in various parts of India such as Tamil Nadu, Kerala, and West Bengal. Traditional and the modern ways (used in industries termed as investing casting) now co-exist with one another. To understand the lost wax technique the author has selected Manner in Kerala since they use the traditional method. Even though in some parts of India, like west Bengal and Tamil Nadu, the artisans are melting the metal in modern crucibles made up of iron and sand, the craftsmen of Manner still use a clay crucible to melt the metal (Figure 2). My aim is to study the lost wax technique through ethnography which will help to understand the probable technique followed by the Harappan metal craftsmen. The methodologies adopted for this article are to review archaeological and literary sources as well as ethnographic investigations.

Lost wax casting (also called "investment casting", "precision casting" or Cire Perdue in French) is the process by which a duplicate metal sculpture (often silver, gold, brass or bronze and copper) is cast from an original sculpture. Dependent on the sculptor's skills, intricate works can be achieved by this method. The method of manufacturing an object starts when the artisan designs a desired shape for an object.

The steps are

• Making a replica of the object with wax (bees wax)

• Adding clay to the wax model (three to four layers of clay are usually added)

• Moulds are reused in the sense that if the moulds are broken those broken parts are recycled. Broken parts are ground to fine powder and coated on to the wax model

*Figure 1. The famous Dancing girl of Harappan*

• The next step is sticking the pot shreds to the model. This is to support the clay to hold along the mould.

• The mould is then heated for almost an hour;

• Next is melting of the brass/bronze in a crucible and then a pit is dug and the mould is covered with the soil only keeping runners and raisers outside;

• Molten brass is poured into the mould;

• The mould is taken out from the pit next day;

• Finally the object goes for chiselling, making designs and polishing.

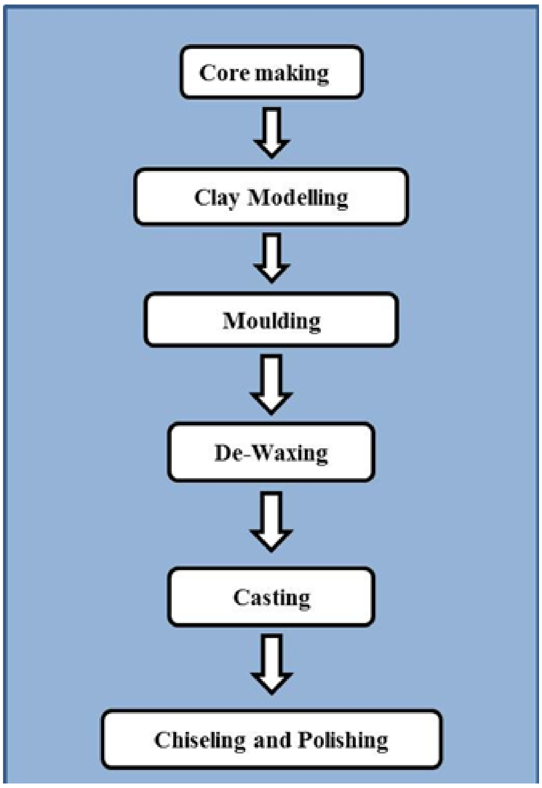



*Figure 2. A craftsman from Manner*

## Textile Textured Silver Ingots: A technical investigation into how these textures came to be on some Viking hoard ingots

*Figure 1 Texured ingot form West Coast Cumbria Hoard*

The ‘West Coast Cumbria’ hoard, discovered in 2014, is a late ninth/early tenth-century Viking silver hoard, housed at the Beacon Museum, Whitehaven, UK. It is composed of 20 Viking silver objects: bar-shaped ingots and ornaments, in various stages of fragmentation (PAS ‘Find-ID’ LANCUM-FA14C8). One, complete ingot (museum no. 2016.162.5) bears coarse cloth-impressions on its upper surface i.e. the face that was in direct contact with the mould. How such textile imprints were acquired is somewhat of a mystery. Close study of textile imprints preserved on five silver ingots from the Cuerdale, Lancashire, hoard revealed that the imprints were in the negative, meaning that the textile had been in direct contact with the metal. The presence of dendritic formations surrounding the impressions confirms that silver had been in direct contact with the fabric when it was cast i.e. the molten silver was poured onto fabric placed in the mould (Graham-Campbell 2011, 82). However, earlier experimental casting of silver ingots revealed that pouring molten silver directly onto fabric caused the fabric to ignite and left no physical trace on the finished ingot (Kruse et al. 1988). I therefore approached David Meyers to see if further experimental casting could shed light on two key questions: 1) how were textile impressions acquired by ingots during the casting process? and 2) what purpose did the fabric serve?

In conversation with Dr. Jane Kershaw, Institute of Archaeology, University of Oxford, she asked if I could investigate the possible causes for the textile texture found on a silver ingot from the West Coast Cumbria hoard shown in Figures 1 and 2. Similar textured ingots were found in the Cuerdale, Lancashire, Hoard, deposited c. 905-10 AD (Graham-Campbell 2011, 82). The pictures and technical information presented here are an investigation into how these textures may have gotten onto the surfaces of a poured silver ingot. The experiment was limited to pouring molten sterling silver into trenches carved in a piece of construction lumber (Figure 3).

*Figure 2 Notches cut into a pine wood board with a chisel approximately 2"x ½" x 3/8" deep*


*Figure 3 A dishtowel was selected for its pronounced and varied weave pattern impregnated with different media*

The carved out spaces (moulds) were each lined with a piece of coarsely woven cloth (Figure 4). My experiment included three mould preparations to see if there was any difference in the finished ingot (Figure 5). My three mould treatments included a trench lined with dry cloth, a trench lined with animal fat coated cloth and a trench lined with clay coated cloth. The clay was allowed to dry before the silver was poured into it.

I poured molten silver into the cloth lined mould first. Just as I finished pouring the ingot it began to violently erupt and spit silver. The second ingot was poured into the mould prepared with animal fat. This was less violent than the first although it did flare up somewhat. The third mould that had clay applied to the cloth poured well (Figure 6). Figure 7 shows the moulds and ingots after pouring.

Looking at the resulting ingots we can see:

The wood and cloth mould shows that the shape of the ingot mimics the charring of the wood trench (Figure 8).

The middle mould with the cloth saturated in animal fat is distorted in shape, but has one small patch imprinted with the weave pattern.

The ingot poured into the clay saturated cloth mould had substantial texturing on one side matching the weave of the cloth (Figure 4).

From these experiments it is easy to see that the cloth and clay performed the best and gave the closest texture results. Analysis of the West Coast Cumbria hoard ingot shows that the textile pattern goes only part way around it. The ingot made in the clay and cloth mould look quite similar. I believe the discontinuities in the ingot in Figure 1 may have been caused by charcoal getting from the fire into the crucible and ultimately into the ingot mould during the pour. I have experienced these discontinuities myself.

For comparison, I show the underside texture of two sterling silver ingots poured into a steel mould. The ingot surface is pitted but it is otherwise smooth and not granular like the ingots poured unto the cloth and wood moulds.I wonder if the use of cloth was to expedite the process or was a desperate measure for some unknown reason?

I questioned a scenario where a piece of cloth is smeared with mud or clay, a quick trench is carved into the dirt, the cloth placed over and the metal poured. Moisture and hot liquid metal are a bad combination; the metal in contact with moisture usually has explosive results.

*David Meyers*

*Figure 4 Texture of clay ingot*

**References**

Graham-Campbell, J. 2011. *The Cuerdale Hoard and related Viking-Age silver and gold from Britain and Ireland in the British Museum*. London, British Museum Press

Kruse, S.E., R.D. Smith & K. Starling. 1988. *'Experimental Casting of Viking Age silver ingots'*. Historical Metallurgy 22:2

For the PAS (Portable Antiquities Scheme), see **www.finds.org.uk**


My research has focused on prehistoric archaeometallurgy at various locations across Eurasia with major, current emphasis on Thailand in Mainland Southeast Asia. Specifically, my interests lie in the origins, transmission and societal impact of metallurgy across the greater region. Recent research suggests connections linking the transmission of tin-bronze metallurgy across Eurasia with that developing ultimately in Southeast Asia. It is in this context that I have focused on the embedded interactions of prehistoric technology and culture.

Interest in Southeast Asia comes from a decade of fieldwork by the Thailand Archaeometallurgy Project (TAP), which I co-directed with my Thai colleague Surapol Natapintu. This fieldwork was conducted under the auspices of the Thai Fine Arts Dept. and the University of Pennsylvania Museum. Our excavations focused on a prehistoric copper mine in the northeast and, later, three other related sites in the central region revealed there a major prehistoric copper production center. This research yielded among the earliest and most extensive archaeological evidence for early copper production in Southeast Asia, and both the technology and its chronology link developments in Thailand to ancient China and the Eurasian Steppes. My research into the origins and development of metallurgy began with my Ph.D. dissertation at Penn that focused on early iron metallurgy in Southwest Asia, esp. in ancient Iran.

Subsequently, I was employed at the Penn Museum's Applied Science Center for Archaelogy (MASCA) as a Senior Research Scientist focused on archaeometallurgy and, later, I served also as the Museum's Associate Director. Upon moving to London, I joined University College London's Institute of Archaeology as a Visiting Professor and was affiliated with its Archaeological Materials and Technology Group.

After returning to the US I remain affiliated with the Asian Section of the Penn Museum as a Consulting Scholar, and also with New York University's Institute for the Study of the Ancient World (ISAW), and with NYU's Dept. of Anthropology's Center for the Study of Human Origins (CSHO). I am also a Fellow of the Society of Antiquaries, London, and now reside in Santa Fe, New Mexico where I continue my research and publication.

**THE CRUCIBLE: Can you summarise your career in a couple of sentences?**

Over the course of my career my research has been focused in the Asian Old World, in particular in Southwest and Southeast Asia with some points in between. This research has been a combination of site survey, excavation and the analysis of metallurgical artifacts in the laboratory working to answer questions of some archaeological import.

**THE CRUCIBLE: What is your most memorable professional moment?**

One memorable moment occurred during excavations in Thailand at the prehistoric Non Pa Wai, a 5 hectare copper smelting site. I had gone to town one morning to get the weekly workers' payroll. At my return to the site one of the excavation team came to me excitedly and told me she was working on a burial with very unusual artefacts. I did not know what to expect as I climbed down into her trench and was there taken aback by the remarkable finds in this burial. It was a supine male individual, arms at his sides, and in each open hand was a fragment of a ceramic bivalve casting mould for a large socketed axe. Other fragments of what comprised single mould pair were distributed around the body in some sort of burial ritual. Not long after this find, a second burial nearby revealed another skeleton with a similar pair of moulds, these intact, sandwiched together between its knees. Seeing the first burial was a truly thrilling moment for me. Here was the metalworker, one among generations of workers, who had lived and worked creating overtime this massive industrial site.

**THE CRUCIBLE: Who has been your most influential colleague, and why?**

Over the years I have counted many as mentors: Bob Maddin, Jim Muhly, Tamara Stech, Ted Wertime, Mike Notis and Bill Rostoker, to name but a few. But I would single out the eminent materials scientist Cyril Stanley Smith from MIT, whom I was fortunate enough to meet early in my graduate career. He had a strong interest in ancient Iran and its evidence for early copper/bronze and iron metallurgy, both focal points of interest of mine at that point. At that time he was devoting much of his scholarly effort to the study of ancient metallurgy and, in particular, its origins. His premise that technological innovation often proceeds from experimentation or playing with materials for decorative effect, a kind of aesthetic innovation, was especially insightful. He is a scholar whose influence has pervaded much of my thinking and writing over the course of my career.

**THE CRUCIBLE: What is your main current project?**

Most of my current efforts are devoted to post-excavation research and publication following the fieldwork by TAP. Presently my team and I are involved in a major, new AMS dating project in an effort to refine our working chronology for central Thailand and to more specifically date the arrival of copper-base metallurgy in the greater region. We are also engaged in a comparative analysis of several classes of technical ceramics (crucibles, moulds, furnace fragments) from our excavations as well as the study of levels of copper contamination in soils at central Thai sites. Other team members are also researching, under my direction, ceramic, faunal, archaeobotanical and bioarchaeological assemblages, all of which derive from heavily metallurgical site contexts.

Also, given that I have conducted fieldwork and research at both ends of Eurasia, in Southwest and Southeast Asia, I maintain also a strong working interest in the prehistoric transmission of tin-bronze metallurgy between these two regions across Inner Asia.

**THE CRUCIBLE: What multi-million project would you like to develop?**

Create a Center for the Study of Southeast Asian Archeometallurgy.

- Purpose: to engage students and scholars in the study of Southeast Asian archaeometallurgy through fieldwork and research on subjects including:
- site surveys dedicated to documenting ore bodies and mines exploited in prehistory in relation to regional settlement patterns
- long-term excavation projects dedicated to sites found on survey
- the study of site-based, archaeometallurgical chaînes opératoires
- from mines to finished products to their ultimate dispositions
- the evidence for and the chronology of the adoption of various metallurgical technologies
- the economics and social implications of metal production including evidence for widespread metal trade networks
- the cultural, chronological and metallurgical links of early metalworking in Southeast Asia to neighbouring regions such as China and those further afield including the Eurasian Steppes
- the laboratory analysis of archaeometallurgical remains from across the greater region

The Center would serve as a central focus of collaboration on archaeometallurgical research for the region and would have a permanent, fully dedicated research staff. It would be a place where scholars from various disciplines could come together to work on common research themes. Along with a dedicated analytical laboratory, it would also offer internships for students from Southeast Asia and beyond.

**THE CRUCIBLE: Which publication should every HMS member read?**

Cyril Stanley Smith's 1981, A Search For Structure – Selected Essays on Science, Art and History. MIT Press.

**THE CRUCIBLE: Have you got any advice for young students interested in archaeological and historical metallurgy?**

Understand that you are straddling two disciplines. While the study of material science is the foundation, it is essential also to train in archaeology and/or history. Understanding the methods and theories of both disciplines allows for a more critical understanding, more nuanced interpretations, and better cross-disciplinary communication and collaboration.

**THE CRUCIBLE: I would like to tell every reader of The Crucible that…**

I am indeed incredibly fortunate to have spent a career in archaeometallurgy. It is work of constant discovery. Most importantly, it is a collaborative work. Learning and understanding comes from experiences shared with remarkable colleagues and students.

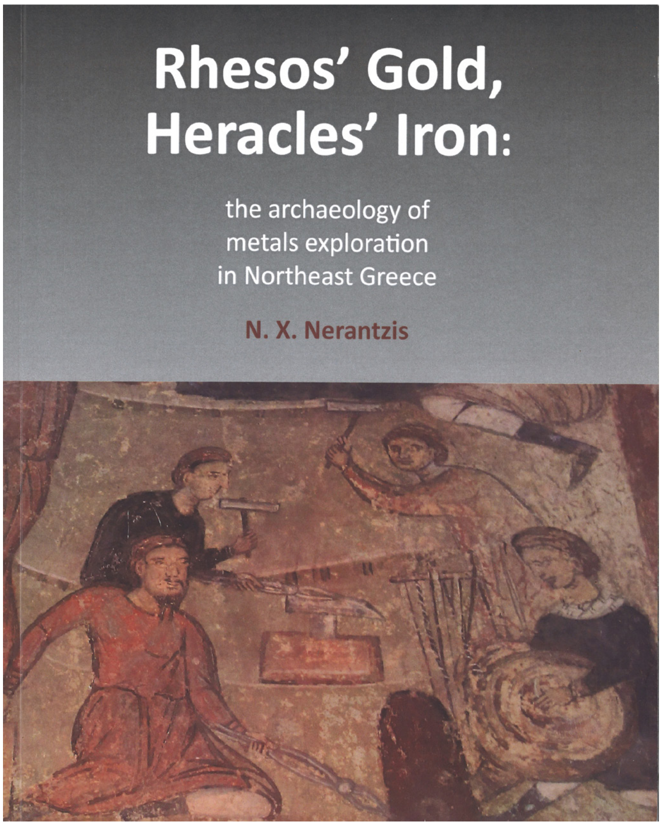

My interests in history and metallurgy started very early. I grew up in the Forest of Dean, Gloucestershire, an area famed for its ancient iron industry. As a child I used to play at Dark Hill, the site of the ironworks founded in 1810 by David Mushet, often finding small pieces of slag and clinker. At Puzzlewood and Clearwell Caves I was able to see the marks that Roman miners had left in their search for iron ore. The undulating craggy landscape of this area is called scowles, features that were once thought to have been made during the mining of iron ore. The Forest is now a much quieter place but it always fascinated me how 2000 years of industrial usage shaped the landscape there today.

I went to London for university in 2003 but I first came across HMS in 2010 after I started my masters in the Technology and Analysis of Archaeological Materials at UCL. My initial HMS outing was as a volunteer at the Experimental Iron Smelting Conference held at West Dean College, West Sussex organised by David Dungworth and Roger Doonan. It proved to be a very tiring but rewarding 5 days of ore and charcoal crushing, clay mixing, wood chopping, furnace building and bellowing. The weather was sunny, the people very friendly, and the smelts themselves were amazing. There were multiple furnaces run by various local and international groups from WIRG (Wealden Iron Research Group) to an American team headed by Lee Sauder. Until then I had never seen slag streaming from an opened furnace or a glowing bloom hammered into shape. After that I was hooked and have been increasingly involved in the activities of the society ever since.

After my masters I worked on a 6-month placement at the English Heritage Laboratory in Portsmouth as an Archaeomaterials Analyst and was able to work on iron working remains from Roman sites and 18th century Downside Mill, Cobham, before starting my PhD in 2012 at UCL in the analysis of Islamic glass. In 2012 I helped to organise a well-attended HMS conference held at the SS Great Britain in Bristol. As well as the excellent papers, my highlight was the trip to the wonderfully restored Saltford Brass Mill, a project started by Joan Day a long-time HMS member. In 2013 HMS held their 50th anniversary conference in London of which I was able to help behind the scenes, and in that year I became a sub-editor with the UCL team under Marcos Martinón-Torres of the newly rebranded newsletter: The Crucible. A role which I continued until 2017. I was then elected to Council and since then have been on the Web Team.

My interests in metallurgy continued during my PhD. In 2012 I helped organise an iron smelt with David Dungworth using Forest of Dean ore at Clearwell Caves in the Forest of Dean. I actually got the chance to mine my own ore from the mines, an amazing experience, even if dragging it all to the surface was rather hard work! At UCL I ran the copper casting and smelting for Primtech – the undergraduate experimental archaeology weekend – and also helped in the yearly iron smelting trip overseen by Jake Keen with the Archaeology masters students. In my recent work, I was lucky enough to conduct the analysis of the Roman jewellery from the Colchester Hoard. The remarkable material consisted of gold rings set with emeralds, gold bracelets and earrings. This is soon to be published. I also conducted freelance slag work, mainly on Roman and Medieval slag from London and surrounding region. Most recently I became an accountant (I do have to somehow pay my rent in London!) but I do still long to look at archaeology and I still wonder about how our industrial past shaped our now.

The web team, where I am now, continues to develop the website and increase its functionality. Future plans include a members-only area where subscriptions can be checked and renewed. We also aim, one day, to have the back catalogue of journals freely available for all members online.




**N.X. Nerantzis, 2015, Rhesos' Gold, Herakles' Iron: the archaeology of metals exploration in Northeast Greece. Glasgow: Potingair Press. ISBN 978-0-9568240-2-8. pp185. The book is fully illustrated.**

Eastern Macedonia in northern Greece has rich deposits of gold and silver as well as copper and iron ores. The gold and silver were important to Classical Athens and even more so to Alexander the Great and the Hellenistic world. Copper was extracted as early as the Late Neolithic and iron was worked from the Iron Age to Ottoman times. The same range of mineral deposits also occurs on the archaeologically important island of Thasos, lying close to the coast of Macedonia. Bringing to life the essential background to this wealth derived from metals, this book, much of it arising from the author's PhD research (at Sheffield University), presents an up-to-date account of the archaeological and archaeometallurgical evidence for the mining and processing of the ores and extraction of metals.

However, the book also encourages the reader to visit the region to appreciate the 'silent landscapes' of this part of Macedonia where so much took place at different times of the past up until the last century and moreover where nature has now taken over the remains of buildings, installations and slag heaps. This part of the book is in effect a guide book: itineraries describe in a practical fashion the many localities where metallurgical activity occurred, placing them in their natural environment and explaining their metallurgical and historical contexts.

The book's title refers on the one hand to the Thracian tribes ruled by the mythical king, Rhesos, who was fully aware of the region's richness in precious metals. One of the tribes, the Bisaltes, was among the first in the Greek world to issue silver coins (Fig. 2). Elsewhere, there is Herakles' connection with the Thracian tribes and their interest in iron as reflected in the archaeological record of Thasos. This mythical background is explored in Chapter 1. The following chapter deals with the region's physical environment and geological setting, with reference to the relevant archaeological literature. Chapter 3 sketches the prehistory and history of the region. Of most interest to Crucible readers may be Chapter 4 which outlines the technologies involved in the various extractive processes and details the information gained from characterising the iron slag and other residues by laboratory analysis. In the final chapter a theoretical framework is established to investigate the changing practical and ideological priorities that drove the metals industries over time.

The first itinerary takes the visitor north of modern Kavala to the sites of ancient gold and silver extraction in the Lekani Mountains, including the enigmatic Skapte Hyle referred to by Herodotus and others. Settlements established by Thasos, Classical towns, the major Hellenistic and Roman urban centre of Philippoi and Ottoman-period workings all feature in this itinerary. Moving west up the River Strymon, Itinerary 2 covers a similarly wide chronological range of metallurgical and settlement sites, the main focus being the eastern end of Mt Pangaion, renowned for its gold and silver. Setting off from the modern town of Drama in the north of the region, Itinerary 3 explores the Byzantine-Ottoman bloomeries and the abundant polymetallic deposits that supplied lead and silver in the Byzantine period. The final itinerary takes in the medieval gold and iron production centres in the area dominated by modern Serres, ranging from gold panning in the River Strymon to bloomery iron making near the Bulgarian border.

*Effie Photos-Jones*


**THOMAS Nicolas et DANDRIDGE Pete (ed), Cuivre, bronzes et laitons médiévaux : Histoire, archéologie et archéométrie des productions en laiton, bronze et autres alliages à base de cuivre dans l'Europe médiévale (12e-16e siècles).**

Medieval copper, bronze and brass: History, archaeology and archaeometry of the production of brass, bronze and other copper alloy objects in medieval Europe (12th-16th centuries) [Actes du colloque de Dinant et Namur, 15-17 mai 2014. Proceedings of the symposium of Dinant and Namur, 15-17 May 2014]. Namur: Agence wallonne du Patrimoine, 2018, (Études et documents, Archéologie 39). A4, 416pp, colour illustrations, ISBN 978-2-39038-016-0, 40 €. This volume includes 34 papers (18 in English, 16 in French, all with bilingual abstracts) by archaeologists, historians, conservators, art historians, metallurgists and chemists, divided into four sections: Raw materials and supplies, Craftsmen and workshops, Techniques, and Products, trade and exchange. Collectively, they show the range of approaches being taken to copper and its alloys in the material culture of medieval and post-medieval Europe. In the late Middle Ages there was a gradual increase in the use of copper and its alloys for making everyday objects such as dress accessories or household vessels. In contrast to these common objects fabricated in serial or mass production, were those satisfying the needs of the aristocracy and church. Such made-to-order masterpieces might include aquamanilia, candelabra or lecterns. Additionally, copper alloys were used for more colossal works of art such as doors, funeral monuments and bells. Copper was also used for artillery, musical instruments and coinage. A full review will appear in a future issue of Historical Metallurgy.

*Justine Bayley*

## BLOOMERY IRON-SMELTING FESTIVAL

Last August, a bloomery iron-smelting event was held in the village of Woodford in Co. Galway. The Furnace Festival was organized by the Sliabh Aughty Furnace Project, an initiative that carries out research on the 17th- and 18th-century blast furnace industry in the area. A HMS fieldtrip to the area took place in the Spring of 2014. Woodford was chosen as this village had developed around a blast furnace built there in 1681.

The Festival consisted of two parts. From Monday 20 till Friday 24 August, Lee Sauder (Virginia, USA) trained up six Irish people in the art of bloomery iron smelting. On the following Saturday and Sunday, 10 teams from all over Europe and the US ran furnaces varying from an Irish slag-pit furnace (Tim Young's team) to a Catalan furnace (Jesus Hernadez/Owen Bush). The newly trained Irish teams also did their first independent smelts. Only Irish bog iron ore and locally made charcoal were used. On the Sunday, Irish blacksmiths were invited to get to know the newly made Irish iron.

The results were very good indeed. In total, about 150kg of iron was made and each furnace made a bloom, although in some the carbon content was high enough to be considered cast iron. Exceptional results were had by the two German teams: Robert Seller's, that managed to smelt a 26kg bloom out of 60kg of ore, and Bill Trainer's, that produced a bloom of steel while using only local turf as fuel.

The reaction locally was very positive and the Festival even made national prime time television (https://www.rte.ie/player/ie/show/nationwide-21/10954384/). Plans are already been made for next year's event and it is hoped this will be a recurring event. Watch out for next editions of the Woodford Furnace Festival.

*Paul Rondelez*

## BRONZE AGE AXES IN ACTION

Student and researchers from Newcastle University are testing the efficiency of Bronze Age axes in a multidisciplinary project combining archaeological field tests, engineering laboratory tests, and the use-wear analysis of archaeological and replica axeheads. The Bronze Age Tree-felling and Woodworking Experimental Project (BATWEP) investigates if changes in axe design during the 2nd millennium BC may be motivated by increased efficiency in blade shape and hafting technology. To test this hypothesis we cast replicas of an early Bronze Age flat axehead, a middle Bronze Age 'palstave' (a type of prehistoric axehead with two wings and a stop ridge) and a late Bronze Age socketed axehead, and hafted them with seasoned ash handles. We then used the three axes in controlled field experiments involving the felling and sectioning of birch trees, a species native to the British Isles. Efficiency was measured based on two parameters: time taken to fell and section the trees with the three axes and energy expenditure (as revealed by the woodworker's heart rate). Dental casts were taken at regular intervals during the field tests and later analysed for wear marks in the Wolfson Archaeology laboratory, using a Huvitz HSZ stereomicroscope. Thirty Bronze Age axeheads (ten per type) from the Great North Museum collections, Newcastle, were also analysed to see if our tree-felling tests reflected actual prehistoric uses of the tools as revealed by microscopic wear marks. Subsequently, the three experimental axes were mounted on a purpose-built rig and tested for performance in the School of Engineering laboratories, under the supervision of Professor Thomas Joyce. The rig tests aimed to subject the axes to greater mechanical stress than we could generated in the field by dropping them on a sand bed 1200 times each. Efficiency was measured in terms of changes in blade hardness and roughness, as well as blade volumetric loss, during the tests. Overall, the experiments have generated a large amount of data, which we are still digesting and interpreting. We do not seem to have statistically significant improvements in tool efficiency over time, but further tests and data modelling may well change this early result.

*Andrea Dolfini*

*Figure 1. The analysed assemblage of Early Dynastic and Old Kingdom artefacts from the Egyptian Museum of Leipzig University (photo by J. Kmošek)*

As Belgian colleagues informed in the previous issue of Crucible (98/Summer 2018), our Prague team is also trying to contribute to deeper knowledge of ancient Egyptian metallurgy. In previous years, we have focused on the late end of the chaîne opératoire, on the finished artefacts, most of them from the documented archaeological contexts. The work was financed largely in the framework of the student projects of Charles University, Prague. Egyptological and archaeological aspects are being covered by Martin Odler (Czech Institute of Egyptology, Faculty of Arts, Charles University, Prague) and the archaeometallurgical aspects by Jiří Kmošek (Department of Chemical Technology, Faculty of Restoration, University of Pardubice). The first phase of the research and first student project resulted in a publication of a monograph Old Kingdom Copper Tools and Model Tools (Odler 2016). The Old Kingdom of Egypt (Dynasties 4–6, c. 2600–2180 BC) is famous as the period that saw the building of the largest Egyptian pyramids. Generally, it has been accepted that only humble remains of copper alloy tools are preserved from this era. Old Kingdom evidence shows in great detail the extent to which the range of artefacts available for study by archaeology today is influenced or even biased by a selection made by the past culture.

Had it not been for the custom of depositing copper model tools in the burial equipment (and in the richest assemblages, there are altogether more than a thousand tools preserved from the whole period), we would have almost nothing preserved from metal tools used in the era. Iconographic sources indicate the use of other metal artefacts that were not even fragmentarily preserved from the Old Kingdom (such as metal blades of weapons). Scattered finds from Old Kingdom settlements provide artefacts which were included neither in the burial equipment (or very rarely) nor in the iconography (e.g. needles). Harpoons and fish-hooks have their firm place in Old Kingdom iconography, yet their specimens in the Old Kingdom material culture are rather rare.

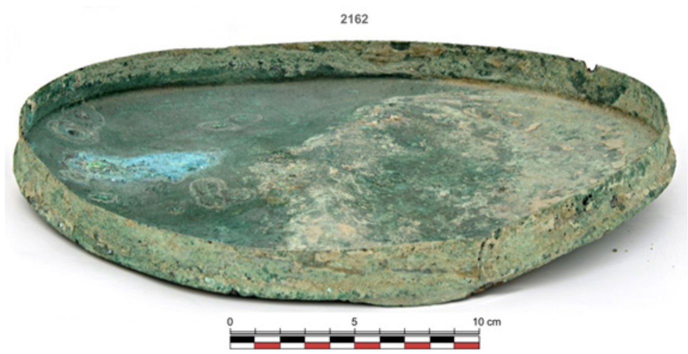



*Figure 2. The Dynasty-1 bowl from Abusir (ÄMUL 2162; photo by J. Kmošek)*

*Figure 3. Sampling of the objects by J. Kmošek (photo M. Odler)*

Old Kingdom Egyptians were using arsenical copper as the main practical alloy, typical for the whole Ancient Near East in the Early Bronze Age. Already, in the Early Dynastic Period, Egyptians certainly knew bronze as the oldest securely-dated bronze objects, spouted jar and wash basin, have been found in the tomb of King Khasekhemwy, built and furnished at the end of Dynasty 2.

The long-standing division in the Egyptological literature between full-size tools and model tools was questioned. One of the most important arguments is that the traces of tools on objects are actually very close to the size of some bigger so-called "model tools". Also the objects from the settlements can be rather small, comparable in their size to the "models". Moreover, not everything that was found in a tomb, with a burial, must be a model tool. The typology alone and use of the preserved textual and iconographic sources are not sufficient for the correct understanding of Old Kingdom material culture. Typological studies can be enriched by the use of geometric morphometry (Odler – Dupej 2016), further vital knowledge can be provided by the archaeometallurgical study of the objects.

The understandable next step in the research of ancient Egyptian metallurgy was thorough examination of the metal objects themselves. The cooperation involves until the present day Ägyptisches Museum – Georg Steindorff – der Universität Leipzig (ÄMUL) in Germany and Kunsthistorisches Museum Wien in Austria, both holding important collections of ancient Egyptian and Nubian artefacts.

In case of the museum in Leipzig, we were allowed to take samples from the objects and thus it enabled us to look in more detail at the production techniques and the metals themselves.

*Figure 4. Objects in the workshop of the museum in Leipzig (photo by D. Chmelíková)*

ÄMUL a holds modest, but significant collection of ancient Egyptian and Nubian artefacts, as they are coming predominantly from documented sampled archaeological contexts. The 86 artefacts sampled represent the development of ancient Egyptian metallurgy over more than one and a half millennia, from Dynasty 1 (ca. 3100–2900 BC) until almost the end of the New Kingdom (ca. 1200 BC). The most important assemblages are from the (Early Bronze Age) Dynasty 1 Abusir, Dynasty 2 Tomb of King Khasekhemwy at Abydos, the Old Kingdom cemetery at Giza, and the largest sampled corpus is from the Nubian site Aniba, from the Middle Bronze Age Nubian C-Group Cemetery N and from the Late Bronze Age New Kingdom Cemetery S. The sampled artefacts can be divided into several morphological categories: full-size tools, model tools, full-size vessels, mirrors and other metal objects (hardware, e.g. bolts, nails). A range of methods was selected to study in detail the chemical composition and technology applied for the production of metal artefacts. X-Ray radiography and X-Ray CT tomography was used for the visualization of the construction details and mechanical state of the artefacts. were more frequent

The artefacts with metal core present were selected for sampling, consisting of drilling of metallic material in the amount of 60–100 mg (for chemical composition and lead isotope analysis) and sawing of 1×2×2 mm samples (for optical microscopy).

To understand the technology used for the production of artefacts, we needed to apply optical microscopy which can identify metallic structures (31 artefacts). The most frequent artefact structures were formed by recrystallized or wrought grains with non-metallic inclusions in different states of deformation. These structures correspond to different thermomechanical techniques of metal processing, especially casting, annealing and hammering (technology in detail discussed in Kmošek – Odler et al. 2016). In most cases, the structures were formed by a single-phase solid solution of copper and arsenic or copper and tin.

Vickers microhardness testing was used for the analysis of mechanical properties, for the testing of the hardness of artefacts, providing another set of the proxy data for the practical usability of objects (22 specimens). The microhardness of the tested arsenical copper alloys ranges between 80 and 160 Vickers hardness units. The results, compared with the chemical composition, clearly indicate that microhardness depended more on hammering and annealing of the artefacts than on the content of arsenic and its alloying effect. The hardness of artefacts with wrought structures and low concentration of arsenic is much higher than that of recrystallized structures with a high portion of arsenic. Energy dispersive X-Ray fluorescence spectrometry was applied for the quantitative chemical analysis of the base composition of all 92 sampled artefacts. The copper alloys used for the production of the analysed artefacts can be divided into several groups.

*Figure 5. X-ray image of the axe blade ÄMUL 4698 in its original sheath made of palm leafs, C-Group of Nubia, mid 2nd millennium BC (photo by J. Kmošek, A. König)*

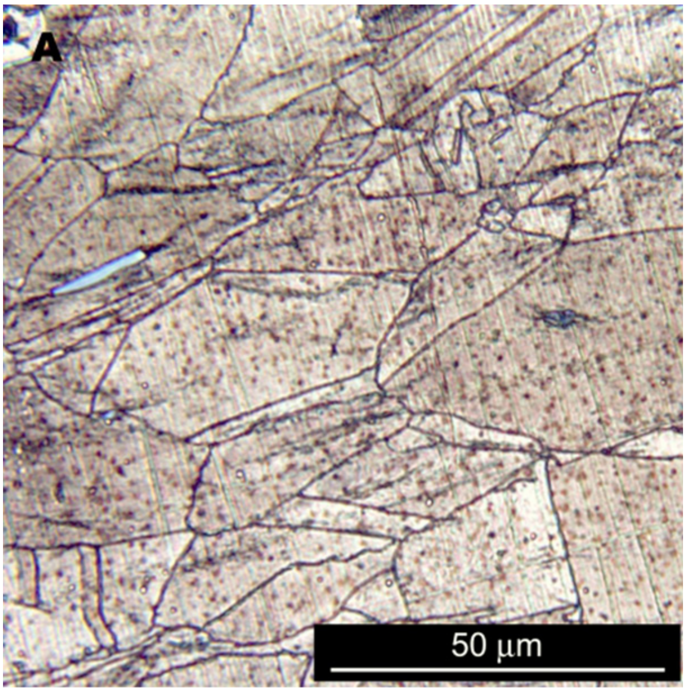



*Figure 6. Metallic microstructure after etching on optical microscopy images, recrystallized irregular grains of α-Cu phase with elongated sulphidic inclusions, vessel ÄMUL 2162*

The majority of artefacts from 2nd millennium BC were made of a tin bronze alloy, for the 3rd millennium BC an arsenical copper alloy or copper with admixtures of arsenic, iron and lead were more frequent. Arsenic was intentionally used for the alloying of copper at least from the Early Dynastic period.

Neutron activation analysis of all samples, done at the Institute of Nuclear Physics of the Academy of Sciences of Czech Republic, by Marek Fikrle, confirmed his initial observations of alloy composition, done by XRF. However, now it is possible to study in the detail trace elemental composition, alongside the lead isotope analysis. This was done at the Czech Geological Survey by Yulia Kochergina. Archaeological institutes of the Charles University in Prague are not well equipped regarding archaeological science, yet a cooperation among institutions can help in obtaining results.

A final interpretation of Early Dynastic and Old Kingdom objects was published recently (Kmošek et al. 2018). The paper contains an in-depth analysis of 22 ancient Egyptian artefacts. The biggest surprise was that a metal vessel deposited in a tomb at the Egyptian site, Abusir, 5,000 years ago was made of a material that was used concurrently in distant Anatolia.

The ore coming from the Sinai Peninsula was expected and confirmed, as it was the most frequent target of ancient Egyptian expeditions with many ancient Egyptian mining expedition inscriptions. An amount of ore, not at all negligible, originated from the Eastern Desert of Egypt.

There are not many inscriptions in particular areas where copper ore was being mined (malachite, but also chalcopyrite and others), but archaeological research of the past two decades has identified many mining sites, and analyses have now confirmed that the ore was indeed used by ancient Egyptians. In both cases, however, it needs to be stressed that these areas were outside of ancient Egypt proper, they were never a part of the Egyptian nome structure, nor did any permanent settlements. The ore here was mined by mining and often also military expeditions.

As mentioned, the greatest surprise was a large bowl from a Dynasty-1 tomb at Abusir (Fig. 2). It is peculiar for its contents of arsenic (1.4 %) and nickel (4.8 %), unusual for that period in Egypt. The lead isotope ratios match Anatolian ores and are similar to contemporary Early Bronze Age Anatolian artefacts, in a distance more than 1,500 kilometres. The vessel was most probably made in Egypt, but the ore or metal ingot must have travelled from far away. Although this is most probably not an evidence of direct contact between the two regions, special metals had circulated around the ancient Near East earlier than previously thought.

The project will continue with the evaluation and publication of data from the later examined corpus: bronze artefacts from the Second Intermediate Period and the New Kingdom site Aniba in Nubia. In case of the Kunsthistorisches Museum Wien (KHM), a selection of 15 artefacts was studies from the Egyptological and archaeological point of view by Martin Odler, Scientific laboratory of KHM done an X-ray fluorescence study of the objects. Although the objects were published as bronzes in the literature, they were made either from copper with impurities or an arsenical copper. Thus also data from Vienna confirm the use of arsenical copper in Egypt and Nubia until the middle of 2nd millennium BC (Odler – Uhlir et al. in press).

Our research continues. We are modestly successful in contacting other museum curators, trying to persuade them that sampling does not harm objects and can increase their scientific value in reconstructing the past. The French Institute of the Oriental Archaeology in Cairo also supported our project, aimed for analytical work on the selected objects, currently found in Egypt. We hope we can inform the readers in further issues of *The Crucible* about the progress of our projects.

*Martin Odler and Jiří Kmošek*

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# FORTHCOMING EVENTS

| conference, date and locations | Desciption | websites, emails and prices |
|---|---|---|
| 10/04/2019-14/04/2019 Albuquerque, USA | Society for American Archaeology | http://www.saa.org/ |
| 24/04/2019-26/04/2019 Manchester, UK | United Kingdom Archaeological Sciences | https://ukas2019.com/ |
| 13/05/2019 Uncasville, USA | American Istitute for Conservation's Annual Meeting 2019 | https://icon.org.uk/events/american-institute-for-conservation-annual-meeting-2019 |
| 17/05/2019-18/05/2019 London, UK | Trial by Fire Conference | trialbyfiretean.com |
| 06/06/2019-09/06/2019 Marguette, Michigan, USA | Mining History Association Annual Conference | https://mininghistoryassociation.org/MarguetteMichigan |
| 19/06/2019-21/06/2019 Miskolc, Hungary | Archaeometallurgy in Europe | http://www.aie2019.argum.hu/ |
| 04/07/2019-08/07/2019 llanafan, Ceredigion Wales, UK | National Association of Mining History Organisations Conference 2019 | https://www.namho.org/conference_2019.php |
| 04/08/2019-09/08/2019 Norfolk, UK | Archaeometallurgy Experimental Course | https://www.sharp.org.uk/ |
| 09/11/2019-10/11/2019 Edimburgh, UK | "Where are we going? Reconsidering migrations in the Metal Ages CFP- Metal Ages in Europe Scientific Commision Conference | https://ww.ed.ac.uk/history-classics-archaelogy/news-events/events/cfp-vissp-2019 |