THE CRUCIBLE

Historical Metallurgy Society News
Issue 104 Summer 2020

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Chrysocolla (page 15)

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Inside The Crucible

The HISTORICAL METALLURGY Society

From the Chair

Dear cherished members,

Undoubtedly, the current pandemic has strongly influenced your life, hopefully not in very adverse way.

The Society also has had to adapt, from a Council meeting in April which needed to be conducted online at short notice instead of the planned physical get together to topics now routinely being discussed via Zoom or similar platforms. In fact, this newly acquired proficiency with online peer-to-peer platforms by many can be seen as one of the few silver linings around this dark-grey cloud of the current reality and is likely to greatly influence future conduct within the Society.

Some of the changes which can be envisaged are an increased participation of international members in Council, something previously strived for but never really successfully implemented. The nature of Council meetings themselves are likely to change, with discussions and decisions largely moving online and reserving the physical meetings for more informal and enjoyable occasions.

There is also preliminary talk of the Historical Metallurgy organising virtual conferences, podcasts and producing other online content.

But, while meeting through the internet does provide for excellent opportunities for reaching those faraway using relatively little resources, the current situation has also shown us the immeasurable value of in-person interaction and, once this horror is behind us, it is hoped that the Society can organise, more so than before, meetings and outings where we can meet each other face-to-face.

Until then, please stay safe,

Paul Rondelez

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. We accept a maximum of 5 Harvard-style references per article only.

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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FUTURE INTERVIEWS

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

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

BRIAN HENRY READ (1940 - 2020)

It is with great sadness that we report the death of Brian Read from Covid-19 on Easter Sunday.

Brian was born on the 23rd of October 1940 in Cheltenham. He grew up on the outskirts of London, mainly Mitcham and Croydon, where he and his brother, Peter, spent their time visiting different museums. From these visits, Brian developed a love for history.

In 1959, Brian met Bernice and they married in August 1962. Brian continued to study chemistry as his family grew. Once he attained his qualifications, he was offered a position as an analytical chemist with the Railway Technical Centre in Derby. So, he, Bernice and their two young daughters moved 'North'. Whilst living in Richmond, both he and Bernice developed a love for boating. They purchased their first boat, Periander, followed by the Wild Goose in 1972. The family enjoyed many years sailing and crisscrossing through the canals and waterways.

Brian retired from work at British Rail in 1994. Subsequently, he and Bernice moved to Darley Abbey where they enjoyed walking with their dog and grandchildren through the wonderful countryside. Brian always made sure to make the most of the British Rail passes. They enjoyed many holidays in the Scottish Highlands and Islands, in Dorset and many other parts of the UK.

Brian had a long-term interest in the history of hand tools and the trades which used them. He was a founding member of the Tools and Trades History Society (TATHS) and was one of the Vice Presidents. He served on their committee and for many years was the editor of their magazine. This interest led to him joining the Historical Metallurgy Society around the Autumn of 1986; Brian was keen to learn about the metals used for making these tools.

Brian organized the HMS AGM in Derby in 1988 and a joint meeting with TATHS in 1989. He also attended several other HMS conferences, enjoying the company of fellow members (Fig. 1). He served on HMS Council at least twice, and was a member of the Archives and Collection Committee (ACC) and the Membership Publicity and Programme (MPP) committee. Brian handled the sales of back issues and special publications, until 2016, he even had to reinforce his loft in order to safely store the copies. He was made an Honorary Member of HMS by the Council in 2016. In conjunction with being a member of the TATHS, Brian researched and co-authored their publication on "Natural Sharpening Stones and Hones".

Brian was always a kind and exceedingly passionate man. He leaves behind wonderful memories for his family, friends and colleagues as well as the wider community.

Fig. 1 Brian (second from right) with HMS council members

Our thanks are extended to Bernice and his family for sharing this information about Brian's life. Our sincerest condolences to them for their loss.

Lesley-Ann Cowell

Membership Secretary

A Letter From ... the NRI

The Needham Research Institute

For those readers not so familiar with the Needham Research Institute it houses the East Asian History of Science Library and provides a base to continue the legacy of Dr. Joseph Needham and support research on the history of science, technology and medicine in East Asia. It is the home of the *Science and Civilisation in China* (SCC) series of books, of which 25 volumes have been published by Cambridge University Press since 1954.

Dr. Needham's first encounter with metal working in China was on 3rd May 1943, when he photographed men at work by the bellows at the back of the cupola furnace in the Central Machine Works in Chengdu (Fig. 1). Through the friendship and generosity of scientists, archaeologists and historians, such as Ke Jun (Tsun Ko) 柯俊, Li Ji 李濟and Li Jinghua 李京華, he was able over the following decades to develop probably the most comprehensive, and certainly the most convenient to access, collection in Europe on the history of metallurgy in China. This includes books (in many languages), as well as copious numbers of offprints and photographs. His energies, however, were largely focused on writing about subjects other than mining and metallurgy for SCC. Having published a few short monographs in the 1950s-1960s on iron and steel in China, he passed on the mantle of writing about mining and metallurgy to other scholars. Professor Peter Golas accepted Needham's invitation in 1977 to work on the SCC mining volume and it was finally completed and published in 1999. Dr. Donald Wagner's SCC volume on iron and steel came out in 2008, and over the years Don also contributed more books and especially many interesting offprints and photographs to our collection, the most recent of which is a copy of Tegengren's marvellous atlas that accompanies his *The Iron Ores and Iron Industry of China* (Peking, 1923) (Fig. 2). Since the 1990's we have continued to keep up with relevant publications from China and beyond, as well as developing our holdings on metallurgy in wider East Asia, with many more donations also coming from colleagues in China. Our Librarian, Mr. John Moffett also takes advantage of his regular trips to China to root out interesting locally published materials, for instance, about the iron oxen found near Puzhou 蒲州 (now Yongji city) in Shanxi province (Fig. 3). So, once times return to something approaching normal, if you think there may be material here of interest for your research, do get in touch.

Of course, Dr. Needham planned to have a chapter (which grew in concept to a volume) on non-ferrous metallurgy in *SCC*, and this is now the responsibility of our Director, Professor Jianjun Mei and a group of scholars. Research work on this has been making steady progress in recent years, and here are a few highlights.

Fig. 1 Men at work at a cupola furnace in the Central Machine Works in Chengdu, SW China, May 1943 (Photograph: Joseph Needham).

Fig. 2 A page from Tegengren's atlas The Iron Ores and Iron Industry of China (Peking,1923)

First, Professor Mei and his colleagues, Dr. Wang Lu and Professor Kunlong Chen, of the University of Science and Technology Beijing (USTB) have completed a systematic scientific examination of hundreds of copper and bronze objects recovered at the Mogou cemetery site in Lintan, Gansu province, that are dated to mid-second millennium BC and comprise largely implements (such as knives) and ornaments (such as buttons, earrings, tubes, torques, armbands and beads). The examination reveals that tin bronze is the most important alloy for making the ornaments and copper for manufacturing the implements, while other alloy materials, such as Cu-As, Cu-Pb, Cu-Sn-Pb and Cu-Sn-As were also in use. The ornaments were mostly manufactured by forging and annealing, while the implements were mainly cast, with cold-working being applied at the final stage of shaping. These results have thrown new light on the development of early copper and bronze metallurgy during the mid-second millennium BC in north-western China.

The second is further research work on bronze metallurgy during the Shang dynasty. Professor Mei and Professor Kunlong Chen have been working on hundreds of Shang-period bronzes recovered in the Hanzhong basin, southern Shaanxi Province, and they argue for the existence of indigenous metallurgical production in the region. They have recently proposed that the Qinling area should be considered as a potential region of origin for the metals containing highly radiogenic lead, which was used by several contemporaneous but culturally/politically distinct entities across a vast territory within and beyond the Shang Kingdom during the second half of the second millennium BC.

The third significant area of progress is work on the development of forging technology during the Eastern Zhou period (8th to 3rd centuries BCE). Professor Mei and his colleagues at the USTB have carried out a research project entitled '*Forging and the Use of Tin: New Exploration of Pre-Qin Metal Technology*', revealing extensive evidence for the employment of forging technology for manufacturing exotic metalwork during the Eastern Zhou period (Fig. 4). Of special interest are the armour plaques covered with decorative gold and tin foils unearthed from the two tombs in Dangyang, Hubei province, dated to c.5th century BC, since these forged tin foils are the earliest found so far in China.

Any realistic date for the publication of the non-ferrous metallurgy volume is still quite some way off, but we shall be sure to let readers know more about our research as the volume comes to fruition.

Jianjun Mei

John Moffett

Fig. 3 Looking up at one of the iron oxen found near Puzhou in Shanxi province, China. The photo was taken by John Moffett in 2006, prior to the "encasement" of the oxen in a newly constructed museum.

Fig. 4 Professor Jianjin Mei and his colleague, Dr. Yongbin Yu, examining bronze bells of the Western Zhou period (11th-8th centuries BC) at Yichang Museum in Hubei province, China in 2012.

Rachel Cubitt

Rachel became a member of HMS after studying archaeometallurgy at the University of Bradford, where her Masters' dissertation saw her analysing medieval arrowheads from the Wars of the Roses battlefield at Tewkesbury. The results of this work were published in HM vol. 48 (2014). When studying objects, she is particularly interested in unlocking how they were produced, what their intended uses were, and who the manufacturers were. When lucky enough to do a blacksmithing course a couple of year ago, she was under no illusion that future archaeologists will be able to identify that the items she made were from the hands of a beginner!

As an artefact specialist working in commercial archaeology, Rachel often examines objects but also assesses and reports on the waste by-products produced in manufacturing processes. Her recent work includes fired clay moulds from East Yorkshire and Roman ironworking slag from Catterick, North Yorkshire. One of the things Rachel really enjoys about her specialism is that one is always encountering different objects and learning something new, even if that does mean occasionally being presented with some unfathomable items.

Rachel is interested in all periods, up to and including the present day and the things we see around us. Street furniture is one of her particular interests, and now she was one of the organisers of the 2015 Celebrating Street Furniture conference. As well as being a member of the Council, she is part of the Archives and Collections Committee to which she has been able to bring her curatorial knowledge. She currently manages the post-excavation process at Northern Archaeological Associates, based in County Durham.

Vasco La Salvia

A member of the Editorial Board of the Journal Post Classical Archaeologies (PCA) since January 2011, and an executive member since March 2012 of the Board of the Società degli Archeologi Medievisti Italiani–Society of Medieval Italian Archaeologists, of which he became managing secretary during 2018, Vasco gained his PhD in 2006 under the supervision of Professors J. Laszlovszky and I. Boná at the Department of Medieval Studies of the Central European University (Budapest, Hungary). He has led numerous archaeological excavations and survey missions in Italy: in Corfinio – Aquila province and Palombaro – Chieti province in Abruzzi; and in Armenia too, in the Shirak region: Bjni castle (region of Kotaik) and in the Village of Yeghegis (region of Vayots' Dzor). His main research interests include the passage between Late Antiquity and the early Middle Ages, technology in transition, Rome and the Others, the medieval commercial network. In this context he began his research on India and Kerala in order to reconstruct the commercial relationships and network and the strategies of technology transfer during Late Antiquity and the Middle Ages. On this very topic he has already delivered papers at international conferences held at the RUB of Bochum (Germany) during March 2013, in Maday (Kannur, Kerala) in April 2017, and again in Bochum (Germany) in May 2017, focusing on the Archaeology of Production and medieval commercial networking.

He has participated in various collaborations for the catalogues of very important archaeological exhibitions such as 'Longobardi, un popolo che cambia la Storia' (The Lombards, a people that changes History) held at the Museo Civico Archeologico di Pavia, Museo Archeologico Nazionale di Napoli, Hermitage S. Pietroburgo and that on the A Cavallnel Tempo (The Horse through time) held at Giardin di Boboli, Galleria degli Uffizi, Firenze, Italy. Among his main publications are two monographs (2007, Iron Making during the Migration Period. The Case of the Lombards, Oxford: Archaeopress (BAR IS 1715); 1998, Archaeometallurgy of Lombard Swords. From artifacts to a History of craftsmanship, Florence: All'Insegna del Giglio) and many other articles on scholarly Journals.

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

No, I cannot … but I am happy to be an archaeologist working mainly on ancient fire-based production technologies. I started as a freelance professional in the field, during the middle of the '90s of last century and, only after about 10 years, I started my academic career.

THE CRUCIBLE: What is your most memorable professional moment?

Still has to come ...

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

I was so lucky to have the opportunity to start working together with R. Francovich (among the first to start archaeometallurgical investigations in Italy) and to have met, during my academic life, many other exceptionally qualified colleagues (I. Bona, L. Mihok, M. Valenti, P. Arthur). But the academicians who totally changed the direction of my scientific life were A.M. Cirese and G. Stabile, respectively Professors of Cultural Anthropology and of the History of Science at the University of Roma 'La Sapienza.' They sponsored my interest for the study of Material Culture.

THE CRUCIBLE: What is your main current project?

My main project at the moment is "Mission Madayi," the Italian archaeological mission of "Gabriele D'Annunzio" University, Chieti-Pescara (UDA), born in 2018 which I am directing in Kerala, Southern India. Ours is a diachronic multidisciplinary project, focusing on archaeology and ethno-anthropology as well. We boast a team from all over the world, since our co-workers and partners are from U.S.A, Scotland (UK) and, of course, India. Our purpose is to study and retrace trades from and to India through the centuries and how the rich and thriving territory -the Malabar coast- has changed from antiquity to the current period, and also to establish friendly relationship between our two countries.

Vasco working at the Miranduolo site

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

A database of the (iron) early medieval agricultural tools of Europe, providing a large scale program of archaeometallurgical analyses on these objects in order to have a better understanding of the technology in transition during the passage between Late from Late Antiquity to the early Middle Ages.

THE CRUCIBLE: Which publication should every HMS member read?

Tylecote and Pleiner. Everything, concerning Archaeometallurgy, is already in their scholarly publications.

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

Fieldwork is crucial. A good and sound base in archaeological methods and theory is more than necessary. After that, you need to have working knowledge of geology (Chemistry and Physics) and History of Science and Technology.

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

Life is wonderful but Archaeometallurgy is better !!!!

The AMG Superalloys UK Rotherham Technical Archive

Historically valuable company records are often lost when a company moves premises or closes. Records may be destroyed by the very people who generated them as they become technically outdated. The work described here was not an attempt to save a technical archive, but rather to make its eventual survival into a local or national archive a little more likely.

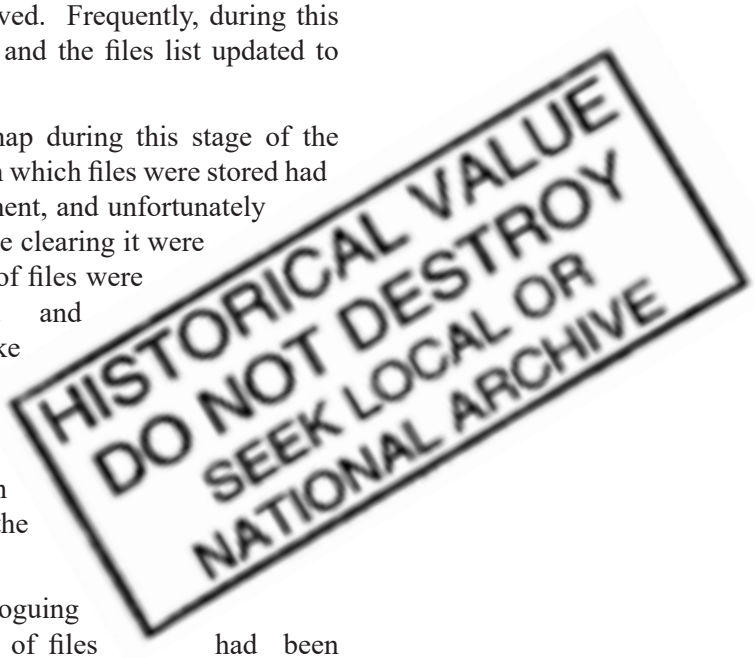
Having retired from the former London & Scandinavian Metallurgical Company (LSM), now incorporated into the Advanced Metallurgical Group (AMG), I knew that with the advent of computer records the paper technical archive was no longer added to, but was well housed and used fairly regularly. In addition, files gathered by a number of managers had been retained but not incorporated into the catalogued archive, and were dispersed around the Rotherham manufacturing site.

Since the company's product range was (and is) diverse, and in some cases unique within the UK, I asked the then Managing Director, Itamar Resende, whether I might voluntarily bring the paper archives together, and do what I could to make them more likely to survive in the long term.

He agreed, and designated a manager to liaise with me during the project. Any paper I took to be of special historical interest would be marked with a rubber stamp.

During the sorting, duplicate files that had been saved by different people were removed. Frequently, during this stage, files were combined and the files list updated to reflect the changes.

There was one major mishap during this stage of the project. One of the rooms in which files were stored had to be cleared for refurbishment, and unfortunately the instructions to the people clearing it were misunderstood. A number of files were unintentionally discarded and destroyed before the mistake was discovered. While of course this was a blow to morale, it reinforced the need for the work if such an archive was to survive in the long term.



When the sorting and cataloguing was complete, the number of files had been reduced to about 2200. These files were labelled showing where they belonged in the archive, their file title and category, and a note of my assessment of their priority category for long term preservation. A number of laminated sheets were distributed through the archived collection, suggesting it be presented to a local or industrial archive if the company eventually decided it was no longer needed.

I'd encourage any retired reader to volunteer to do something similar to help their company archives survive. As I said before, the work described above does not ensure archive survival, but it does make its loss a little less likely. If enough people do something like this a few more company archives should be available to future historians.

I'll finish with a story which I had never heard during my thirty years with LSM, and which only came to light during the project. The company was founded in 1938 by German refugees, at around 1943 the directors wanted to use a process covered by a German patent for making materials needed for the British war effort. They asked their solicitor to get a permit from the British authority which controlled the use of such patents. His advice, however, was that the application would be unlikely to succeed as technically they were enemy aliens.

My thanks to Paul Cooper, Dave Burniston, and the security staff at AMG Rotherham for help and support during this project.

Eddie Birch

THE "EURODAG" PROJECT

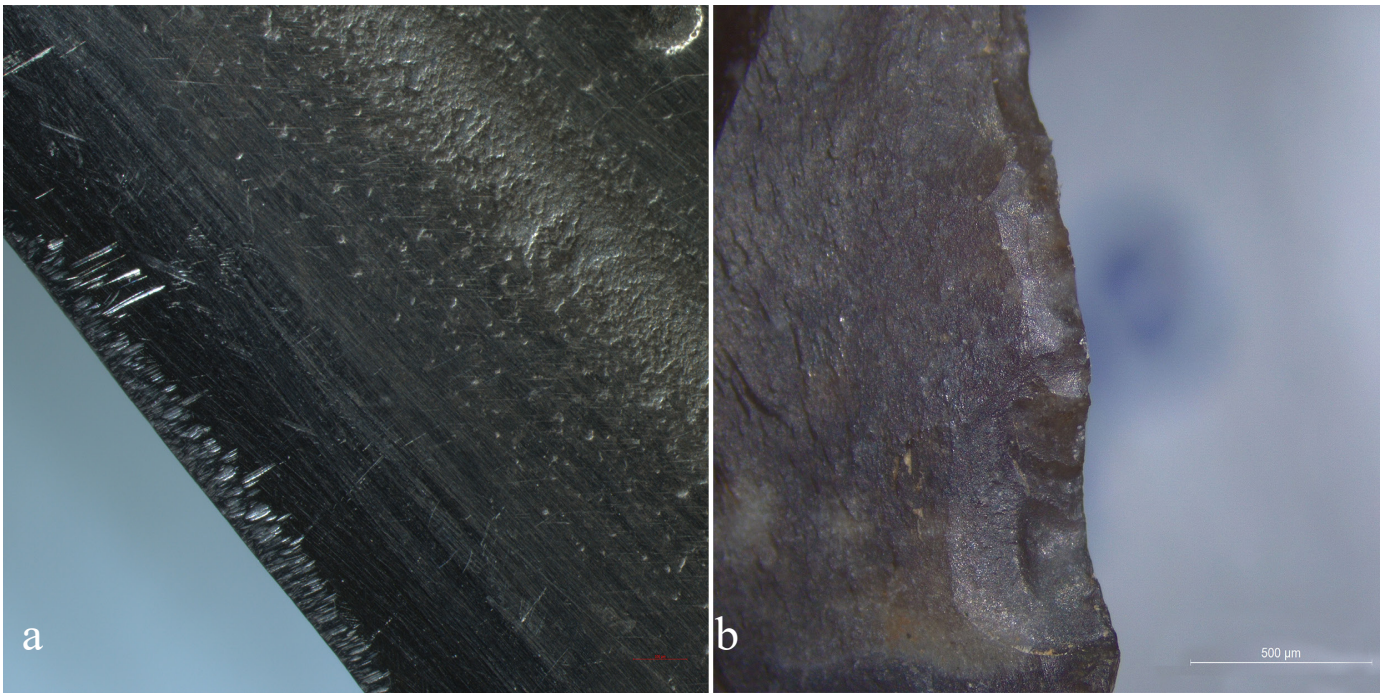


Fig. 1 Experimental use-wear (striations, negatives of scars) on a) metal and b) flint daggers.

The "EuroDag" project, "The first European daggers: function, meaning, and social significance" is the first ever comparative study of the function of early European stone and metal daggers, c. 3800-1500 BC (from Neolithic to the Bronze Age). The project is funded by the Marie Sklodowska-Curie Fellowship, and carried out at Newcastle University.

The EuroDag project aims to understand how early daggers were used, for what purposes, and in which social contexts, while also exploring whether meaningful functional differences might be discerned amongst this broad class of objects based on manufacturing technology, chronology, typology, or regional distribution. The research problem will be addressed through an original combination of microwear analysis (to be conducted on prehistoric flint and copper-alloy daggers from Italy) and functional experiments with purpose-built replica objects.

Fig. 2 Experimental phase of production of stone daggers; a) carving of the dagger and b) final completed dagger

Fig. 3 Experimental a) smelting and b) production of metal daggers

Microwear analysis involves the observation, by optical and electronic microscopy, of the macro- and microscopic use-wear (e.g. striations, negatives of scars and polishes) found on the surfaces of archaeological objects; these are interpreted by comparison with experimentally developed traces (Fig. 1a & b).

The experimental protocol made it possible to reproduce replicas of stone (Fig. 2a & b) and metal daggers (Fig. 3a & b). These have been replicated thanks to two expert craftsmen who use production methods similar to the ancient ones

Replicas have been tested in various activities, such as harvesting (Fig. 4a & b), slaughtering, bone and wood processing; there is also an experiment that includes combat.

Finally, the experimental protocol made it possible to obtain significant data on the use-wear on Prehistoric daggers, on how they were used and in what specific activities.

Isabella Caricola

Andrea Dolfini

Fig. 4 Cutting of Triticum Monococcum *using a) stone and b) metal dagger*

COPPER FOR THE NAVY

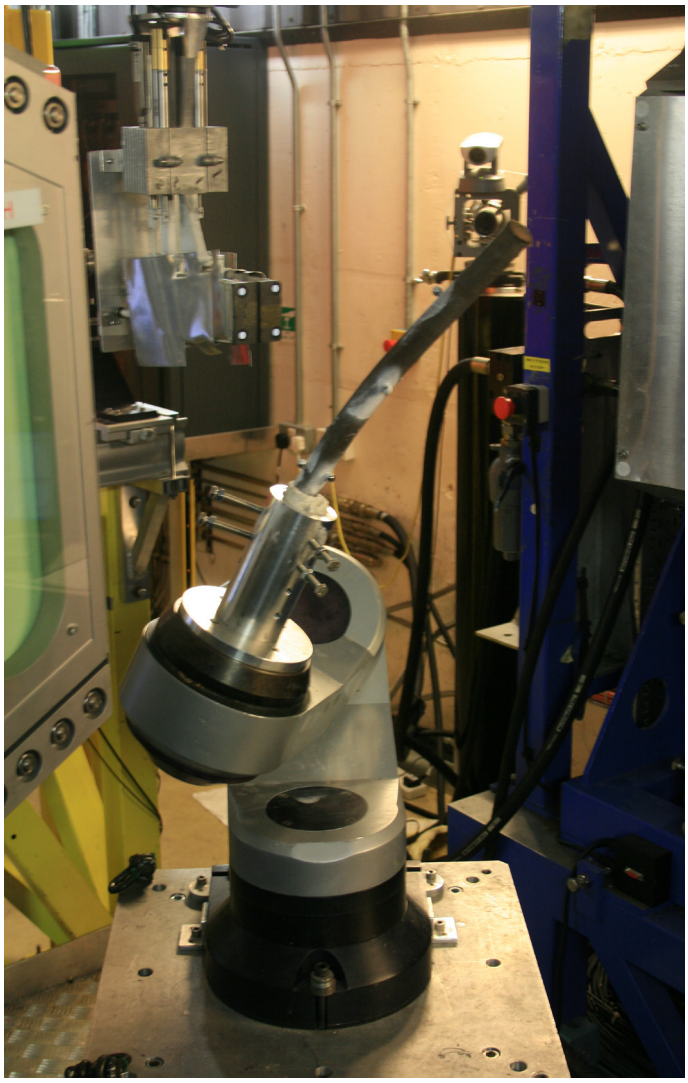


Fig. 1 Analysis in progress

This project has a long prehistory. It all began 20 years ago when the producers of the TV series "The Wreck Detectives" telephoned Peter to ask whether it was possible to determine whether two large sections of shipwreck, believed to be from HMS Pomone, found on the floor of Alum Bay were part of the same ship. The response was that nobody had ever looked but it was worth a try. Bolts from another contemporary wreck were provided for comparison, and all the copper bolts proved to have much the same composition and microstructure. Subsequent post-excavation studies of wrecks and an MEng dissertation at Oxford by Nick Wilcox, which included more shipwreck material and contemporary copper coinage, showed the uniformity of the composition of British copper, whether from Cornish or Anglesey ores. The principal impurities were a pattern of arsenic, bismuth, lead, and silver; all of the bismuth and some of the arsenic being present as oxides due to the oxidative refining of the Swansea process, as a means to avoid the deleterious effects of bismuth in copper.

Besides analysing their composition, all the samples were examined metallographically. Many were hardness tested, and axial samples from a couple of bolts were also tensile tested. Coupled with documentary research, it became clear that there was considerable potential for improving our understanding of the Royal Navy's adoption of copper sheathing and copper fastenings for wooden vessels. Two developments then greatly increased this potential and meant that the history could be corrected and re-written. The first was following up a bolt from HMS Impregnable, the first line-of-battle ship to be switched, in 1783, from iron to copper bolts. In 1783 three patents were taken out for using grooved rolls to produce copper bolts, the first being by William Forbes, a major copper contractor to the Navy, and the Impregnable bolt had a FORBES works stamp. An online search for "William Forbes coppersmith" yielded the finding aid for Forbes entire business archive, located at Callendar House, Falkirk, the mansion he built for his retirement.

This was a pure treasure trove and it appears no naval historian or metallurgist had ever looked at it. In combination with Admiralty records at The National Archives, it was possible to establish a complete paper trail from the Navy Board's minute authorising the work, through Forbes' ledgers and invoices, the record of the copper leaving his works, to objects from wrecks with a FORBES stamp.

There is much, much more, such as his payroll, his furnace notebooks showing each charge of metal going into his furnaces and the weight taken out, inventories of tools, and correspondence from the works manager recording the day to day operating problems.

Fig. 2 Copper bolt from HMS Pomone

Fig. 3 Close up of stamp on HMS Impregnable bolt

Perhaps of even greater significance were records of the evolution of copper bolts from the first order Forbes received at the end of 1776, when the bolts were made with a tilt hammer and a swage, a history that was effectively unknown.

The other development came from Shirley's suggestion that electron backscatter diffraction (EBSD) could help solve a metallographic problem where some copper bolt samples were showing deformed grain boundaries even where no slip traces or deformation twins could be etched. During this study, a bolt from Pomone produced a remarkable result when Shirley asked why a half-inch diameter copper bar should have a wire texture. The answer was that William Collins, another of the patentees in 1783, used grooved rolls to grip a copper bar to pull it through a massive drawplate.

The patent had been produced under the auspices of Thomas Williams and the Parys Mines Company, another major supplier of copper to the Navy. Since most bolts do not have factory stamps this raised the possibility that texture analysis can help map the supply chain. We have gone further and used neutron diffraction methods on ENGIN-X at the ISIS neutron source to determine texture in complete bolts. Since rolled bolts could be case hardened by forging, we are also using spatially resolved texture analysis to elucidate more of the manufacturing process, with promising results.

Where next? From 1805, the Navy established the Metal Mill at Portsmouth Dockyard for recycling copper from ships in dock and after a few years became self-sufficient. We need to explore this process through well dated wrecks, especially in relation to the heated dispute with the main commercial supplier over whose copper was best.

Much of this is recorded in the Simon Goodrich archive in the Science Museum Library: Goodrich was effectively chief mechanical engineer for the Dockyards and made careful records of the trials. We are also going back to the beginning to look at forged bolts through material from HMS Crocodile—one of the first copper-fastened ships to be ordered in 1777. As data accumulates, we can contribute to other post-excavation projects such as the wreck of the Neva at Sitka, Alaska, in 1813, and the examination of materials related to the search for Sir John Franklin from 1848 onwards.

Peter and Shirley Northover

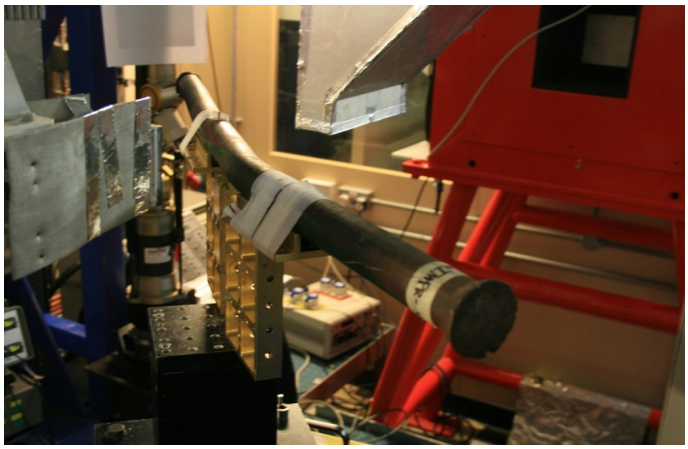


Fig. 4 Copper bolt from HMS Impregnable at ENGIN-X

PROJECT INKACOPPER (2020-2023)

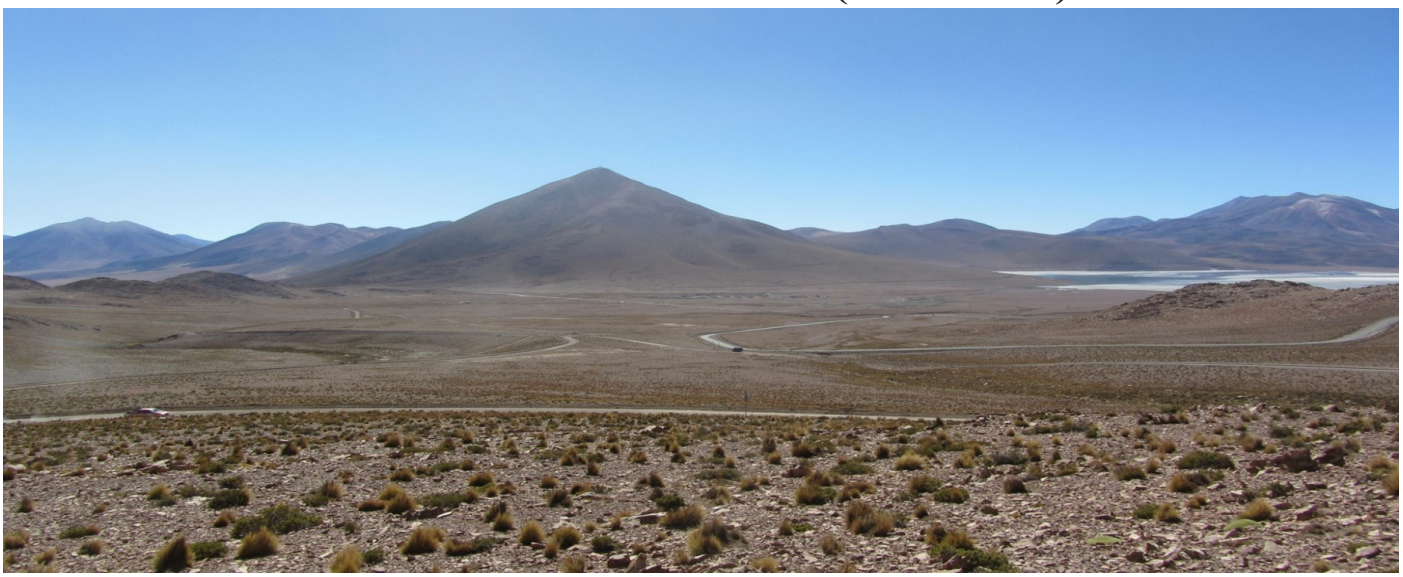


Fig. 1 The Collahuasi metallurgical and mining district (Atacama desert, Chile), © V. Figueroa, IIAM

Recent research has indicated that copper production during the Inca period (14th C. AD) strongly increased from the previous period: was this due to simple reorganization or changes and innovations in the metallurgical and mining techniques? In 2012, Chilean and French archaeologists, archaeometallurgists and geologists discovered at Collahuasi, a location in the Atacama Desert in the north of Chile, the most important site of pre-Hispanic copper production known (Mille et al, 2013, Figueroa et al, 2018). It was discovered that chrysocolla ($Cu_2H_2Si_2O_5(OH)_4 \cdot nH_2O$) was the main mineral sought and mined there.

The first objective of INKACOPPER will be to reconstruct the ancient smelting process used in the Collahuasi district through the archaeometallurgical study of slags and furnaces remains.

The second objective of the project will be to determine the geochemical signature of the copper, in order to identify its use in finished objects, and therefore better evaluate the importance of the Collahuasi source during Inca times. We are currently beginning the research by studying "chrysocolla" (see front page). Reference chrysocolla from known sources (Katanga, Peru, USA, Russia) are compared to the Collahuasi sample: composition, structure and behaviour during heating (PIXE analysis, XRD, Raman, Thermogravimetry/Differential Thermal Analysis) (Figs 2 & 3). More to follow when we study the slags!

Sibylle Manya; Benoît Mille;
Valentina Figueroa Larre; Thierry Bataille;
Jean-Baptiste d'espinose de La Caillerie; Laurent Le Polles

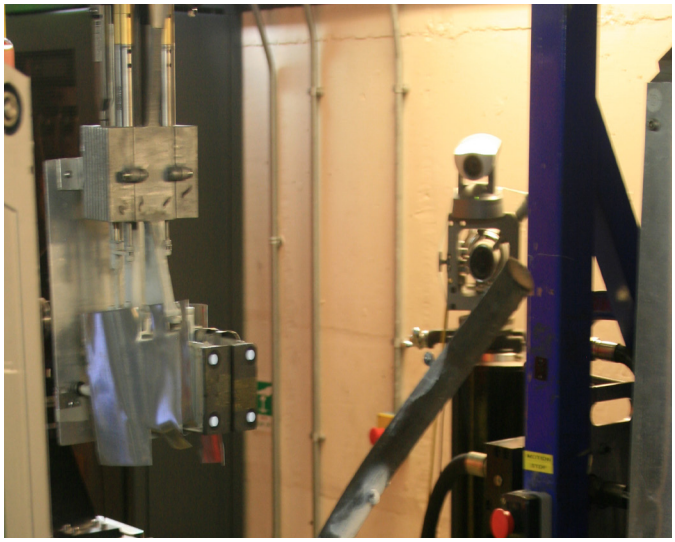


Fig. 2 Centimetric pieces of Chrysocolla (Peru), © S. Manya, C2RMF

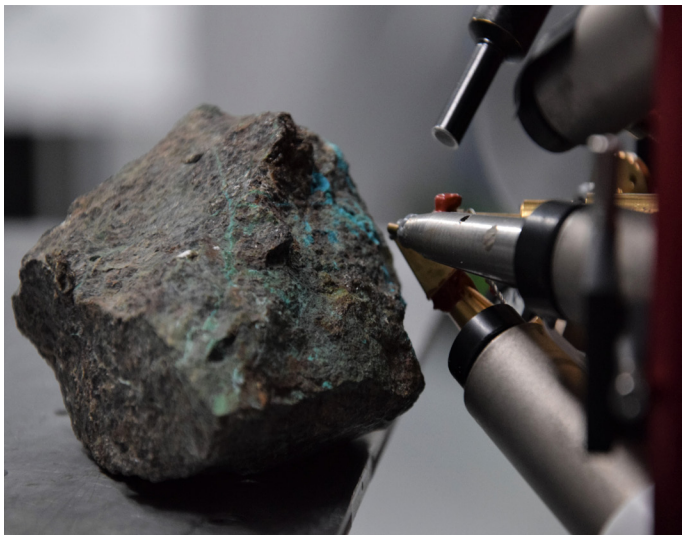


Fig. 3 PIXE analysis of a chrysocolla veinlet, © S. Manya, C2RMF

HAMMERING OF COPPER AND COPPER ALLOYS IN ANGKOR: AN ARCHAEOLOGICAL AND TECHNOLOGICAL STUDY

(9TH-15TH CENTURY AD)

Fig. 1 Plastic deformation by hammering technique used to create Big vessel from Angkor Thom (1996, Angkor Conservation).

HAMMERING OF COPPER AND ITS ALLOYS: A NEW VISION OF ANGKORIAN CRAFT

Widely known for its monumental architecture and stone sculpture between the 9th-15th centuries AD, the ancient Khmer kingdom of Angkor also produced many large images and ritual artefacts made of metal (gold, silver, copper and copper alloys). Although studies of Khmer bronzes were initiated a century ago, research has limited its interest on objects made by casting, more precisely, using the technique of lost wax casting (Ieng 1972, Vincent 2012). However, within the framework of metallurgy and copper-based alloys, another forming technique from the Angkor period is also attested: plastic deformation by hammering (Fig. 1).

To date hammering and its related products have attracted less attention from researchers and this subject is the focus of this study. More specifically, in order to document copper hammering and the copper-based alloys of Angkor, two complimentary approaches are planned. The first approach will consider the technical and economical aspects (the supply of raw materials, technical knowledge and actions, type, quantity, organization of production, and the distribution of the finished products). The second approach will focus on the social aspect (the transmission and diffusion of ritual and technical knowledge, the social position of artisans, and their interactions with sponsors and commissioners).

Ritual and decorative objects

Even if Angkorian hammered copper alloys have been known since the end of 19th century AD, most examples are recent discoveries from archaeological excavations at Angkor and across the ancient Khmer Empire (Cambodia and its neighboring countries). Hammered copper-based artefacts are preserved in many heritage institutions in Cambodia (National Museum of Cambodia, Monastery Museum of Wat Reach Bo, Angkor Conservation, Apsara National Authority), at several foreign institutions (National Museum of Thailand, Guimet National Museum of Asian Arts), and within private collections. The first appraisal of artifacts has attributed them to different categories and/or functions, for example ritual objects (vessels) and the architectural elements (foundation deposits and decorations) (Fig. 2). Hammered architectural elements have been studied from typological and stylistical points a view with some preliminary technical observations.

By assembling an inventory of these collections (description of condition, measurement and weight, photography and photogrammetry) with a synthetic database, this PhD will produce a typology of hammered copper to understand the various objects used during the Angkorian period. Moreover, in continuity with the work of Dominique Soutif dedicated to the lists of *devadravya*, *biens de divinités*, or "goods of divinity" in ancient Cambodian epigraphy, this thesis will collect archaeological data on the series of products mentioned by the inscriptions, in old Khmer and in Sanskrit. Notably it will consider the usage context of those products and their significance to identify sponsors (Kings, the court, and dignitaries).

Fig. 2 Hammered copper-based artefact

From excavation to laboratory: restoring the technical processes of hammering

Furthermore, our work will characterize the techniques of hammering. Different methods of examination and analyses will be conducted: visual and microscopic examination, metallography and elemental analyses (XRF, PIXE, LA-ICP-MS). Experimental simulation might be used as well.

This study will hopefully include artefacts originating from the ongoing excavations of the royal foundry (copper plates, hammering waste, fragments of hammered objects, and technical ceramics). This site of manufacture with no equivalence was established in the center of Angkor's capital close to the Royal Palace, and utilized actively between at least the middle of 11th century and the beginning of 12th century AD (Polkinghorne *et al.* 2014) (Fig. 3).

Finally, to complete the study, an ethnographic survey will focus on silver and hammered copper handcrafts in early modern, modern, and contemporary Cambodia (16th - 21st century AD), particularly around the ancient capital of Oudong (including the active villages of Kompong Luang and Koh Chen, Kong 2009), and the present capital of Phnom Penh (various master craftsmen and the *École des arts cambodgiens)*. This approach, used to great effect in former university research includes surveys, photography, and videography, and will seek to document the tools of hammering to identify potential cases of technological continuity (Fig. 4).

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Fig. 3 A display of hammered copper

Selected bibliography

IENG, Soeung (អៀង សឿង), 1972, អំពីការសិតអ៊ីរូបនឹងវត្ថុផ្សងៗ *[Aṃbī kārsit dhvoe rūp niṅ vatthu phseṅ phseṅ] [Sur la fonte de divers statues et objets]*, Manuscrit non publié, Paris, École française d'Extrême-Orient, Fonds Madeleine Giteau.

KONG, Vireak (គង់ វីរៈ), 2009, ក្បឿងបុរាក់ខ្មែរ *[Grīoeṅ prāk' khmaer]*, Phnom Penh, UNESCO & Reyum, 114 p.
- 2009, *Khmer silverwares*, Phnom Penh, UNESCO & Reyum.

MEAS, Sreyneath (មាស សុរីនាគ), 2016, សិប្បកម្មចងរុកង់ភូមិផ្សារដែកលឿ ឃុំផ្សារដែកលឿ ស្រុកពញ្ញាឮ ខេត្តកណ្តាល *[Sippakamm caṅkraṅ' bhūmi Phsār Daek Loe ghuṃ Phsār Daek sruk Bañā lu khett Kantāl] [L'artisanat des grelots* caṅkraṅ*', village de Phsar Daek Leu, khum de Phsar Daek, srok de Ponhea Lu, province de Kandal]*, Mémoire de fin de licence en Archéologie, Phnom Penh, Université royale des Beaux-Arts, Faculté d'Archéologie.

POLKINGHORNE, Martin, Brice VINCENT, Nicolas THOMAS et David BOURGARIT, 2014, "Casting for the King: the Royal Palace bronze workshop of Angkor Thom", *Bulletin de l'École française d'Extrême-Orient*, 100.

VINCENT, Brice, David BOURGARIT et Paul JETT, 2012, "Khmer bronze metallurgy during the Angkorian period (twelfth to thirteenth Centuries): technical investigation of a new selected corpus of artifacts from the National Museum of Cambodia, Phnom Penh", in P. Jett, B. McCarthy et J. G. Douglas (éd.), *Scientific research on ancient Asian metallurgy: Proceedings of the Fifth Forbes Symposium at the Freer Gallery of Art*, London, Archetype Publications.

A NOTE ON STYRIAN STEELMAKING

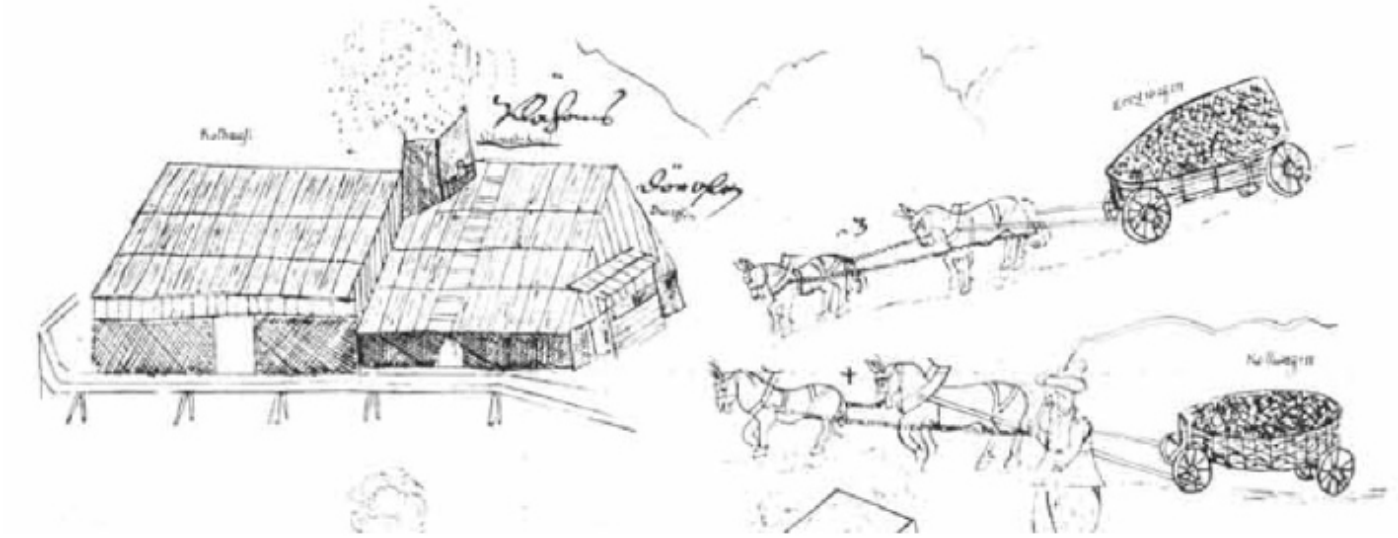
Some years ago, an article by Köstler (1986) showed an interesting drawing of a high bloomery. This was one of a series of drawings illustrating steelmaking in Styria.

An earlier article had shown all of them (Kurzel-Runtscheiner, 1949), but in a somewhat obscure publication. These drawings had remained unknown in the MS 1041 of the archives of Steyr –Lamberg from the year 1613. They seem to have belonged to the Wasserbaumeister Hans Gasteiger.

They were published to accompany an exhibition in the Oberösterreichischen Landesmuseum organised by the Oberarchivrat Dr. A.Hoffmann.

These drawings consisted of views of the town of Eisenerz, this town with the mountain of iron ore called the Erzberg, a wooden barrier for a weir, and, most interesting, drawings of the production of blooms of iron/steel. These last are in four rows with annotations .

Row 1. The furnace, and to the right, two carts each pulled by two horses, labelled Ertzwagen & Kollwagen (ore wagon & charcoal wagon).

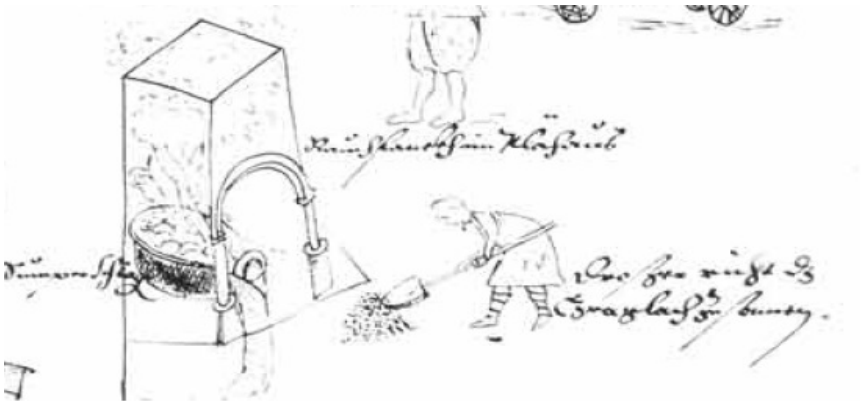


Kolhaus
charcoal store

Blähhaus
blowing house (= blast furnace)

Düroffen
drying (= ore-roasting?) oven

Row 2. An outline of the furnace, beside which there is a detail, drawn at a larger scale, of a workman at the base of the furnace, apparently removing slag.



Sumpferschlag
drain for slag

Rauchfandh im Blähhaus
chimney of the furnace

Droszger häuft das Graglach auf
the slag-man scrapes out the mass of slag

.

Row 3. A waterwheel drives a shaft with rotating cams which operate a pair of long bellows, feeding air to the base of the furnace, the perspective of which is not very clear.

Die 2 groszen Bälg
a pair of large bellows

A wheel (presumably the same) hauls on a long chain which pulls the (apparently still glowing) contents out of the base of the furnace.

Da würt die Mäsz aus dem Blähhaus gezogen .This is how the mass (of metal) is extracted from the furnace.

Row 4. A lump of metal being split by 2 men and another (larger one) by 3 men.

Kholschreiber & Gradler Schradten die Mäsz

The charcoal-clerk and the grader

bend (= beat out ?) the mass

Kholschreiber = charcoal-clerk, (so the person in charge of the fuel) was the one who recorded all deliveries of charcoal, and the use thereof. In some coal mines he also had one set of keys to the cashbox, so was a trusted and relatively senior member of staff.

Diese lauchen mit dem Schlögl die ganze Mäsz,

die genent werden, die Blähoszmülner,

Gradler und Droszger.

Gradler = grader, but exactly what he graded is unclear.

Droszger = slag-man These people (who are known as the furnace-millhand, the grader and the slag-man) divide the whole mass with hammers and wedges.

Products of the furnace

From these drawings it seems that the furnace was twice the height of a man. So one may wonder why did it not produce cast iron? The simplest answer is probably that steel, if it could be consistently produced, would have been a much more valuable product.

Styrian steel was exported across Europe, locally to the Imperial Armoury at Innsbruck (which from 1509 received 8 mule-loads (about 140 kg) of steel plate (*harnischblech*) each month), the armour-making centre of production at Graz (Williams, 1997), and as far north as the Royal Armoury at Greenwich (Dillon, 1888).

Armour of any quality was generally made of steel in the 16th & 17th centuries, but there remained a substantial market for infantry armour, evidently of the lowest quality, made of iron. For instance, in 1539, the English Government bought (carriage paid) 1200 armours from Köln for £454 and 2700 more at Antwerp for £630. These would have each cost the equivalent of between 6 and 10 days wages, so it may be assumed that the cheapest possible metal was employed; presumably finery iron. Even the armour-producing town of Graz was known to import infantry armour from Nürnberg in 1578 when pressed by the prospect of war .

The method of operation must have been skilfully developed, so that the bloom never quite melted. Such a valuable insight would certainly have remained a trade secret. For a similar reason the Brescian steelmakers did not tell Biringuccio how they made steel. They showed him a lot of furnace activity, but not their trade secrets. What he described was probably a finery (Williams, 2003).

Alan Williams

Postscript

Some years ago Peter Pratt (Professor of Crystal Physics at Imperial College, London) did attempt to reproduce Biringuccio's method of "steelmaking", but was surprised to find that it was not successful in making steel. Only a thin outer carburised layer was formed on the iron bar. The author has so far been unable to find a published description of these experiments.

References:

Dillon, H. "A letter of Sir Henry Lee" Archaeologia, 1888, 51, 167-172. Sir Henry Lee, the Master of the Armouries, tested armour made from this steel with pistol shots.

H. J. Köstler, "Der Übergang vom Stuckofen zum Flossofen aus metallurgischer Sicht" Ferrum 57 (Schaffhausen, 1986) 28 –31.

E. Kurzel-Runtscheiner, "Vier unbekannte Darstellungen zur Geschichte des österreichischen Eisenwesens", Oberösterreichische Heimatblätter, 3, 206-211 (Linz, 1949).

Williams, A. "Analyses of armour from Graz" in "War and Society in the Eastern Mediterranean" Y.Lev. 1997, 384.

Williams, A. "Biringuccio and the metallurgy of Italian armour" Archaeometallurgy in Europe (Milan, 2003) I, 143-151.

Calcutta's Street Ordely Bin

Fig. 1 Street orderly bin outside the High Court Building (India)

I recently took a two-hour 'virtual walk' around Kolkata's Dalhousie Square with Heritage Walk Calcutta (https://www.heritagewalkcalcutta.com/). We 'visited' the majestic buildings of the British East India Company that were erected during the early colonial period, and heard about the city's founders, specifically Job Charnock after whom the dark granitic rock called charnockite, that I encountered long ago during jungle surveys in Sri Lanka, is named after. But what attracted my attention was the street orderly bin on the pavement outside the High Court building (Fig. 1). This cast iron feature was manufactured by Whitworth and Co. of Manchester and its purpose was to provide a handy repository for street rubbish, in particular horse manure. Interestingly, we learned that the bin was not originally designed as a static 'bin' but was in fact part of a Whitworth's patent sweeping machine which had been imported at great expense in 1852. It was used for one year, only to find that the local labour did a better and quicker job, at lower cost. According to municipality records, parts of the retired machine were then 'repurposed'. Later, other street orderly bins were imported from Glasgow and placed one on every street corner. These have all now disappeared and only this bin remains in use today. *GJ*

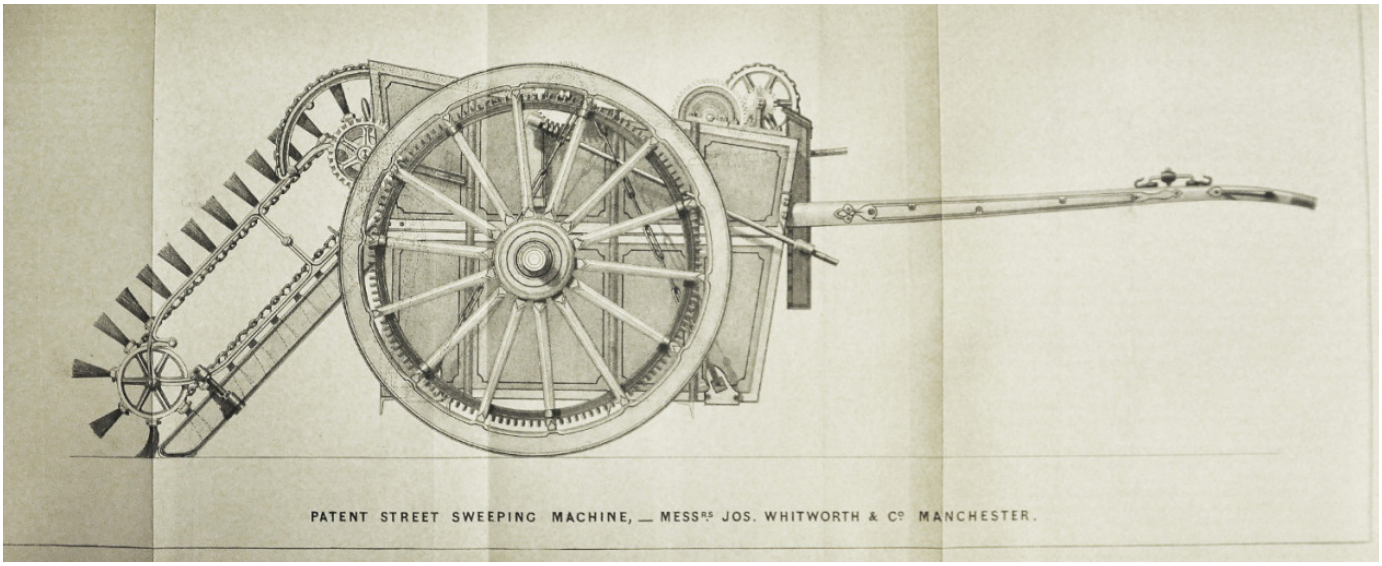


Fig. 2 Whitworth's patent street sweeping machine

Shovel Ready - Furnace Dismantling

Cross section of the WIRG experimental large furnace during demolition after 16 smelts over nine years. Hearth dimensions: 700 x 600mm, Height 1.5m, shaft tapering to 300mm at top, based on an excavated Wealden Romano-British furnace. The furnace is being replaced with a smaller straight shaft furnace of 280mm diameter based on a Wealden Roman excavated furnace in order that these charges will allow a greater number of smelts each season. *Tim Smith*

But is it cricket!

Reconstructed **Indian Bloomery** photographed by Dr Henry Cleere. Henry, who was then the Assistant Editor of Journal Iron & Steel Institute, visited Jamshedpur in 1963 with members of ISI when the bloomery smelting re-enactment is believed to have taken place. During the visit, the group played cricket against an Indian side captained by Tata MD Sir Jehangir Ghandy. The British team was captained by Jim Russell, Editor of the 'British Steelmaker' and one of the team members, Dr Jack H Chesters, had a finger broken during the match. Britain scraped a win – with the help of the 12th man – Richard Lyttelton, the umpire of the match! *Tim Smith*

Conference, date & locations	Description	Website, emails and prices
7th Balkan Symposium on Archaeometry 22/09/2020-25/09/2020 University of West Attica, Athens	The main theme of the Symposium is: "Science and Heritage" and it will focus on interdisciplinary research projects on cultural heritage of the Balkan countries.	https://bsa7.uniwa.gr Email: bsa7th@gmail.com
ICANMR 2021: 15. International Conference on Archaeometallurgy and Non-Metallurgical Residues 15/02/2021-16/02/2021 Dubai, United Arab Emirates	This conference aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results on all aspects of Archaeometallurgy and Non-Metallurgical Residues, as well as practical challenges encountered and solutions adopted.	https://waset.org/archaeometallurgy-and-non-metallurgical-residues-conference-in-february-2021-in-dubai
12th Experimental Archaeology Conference 29/03/2021 - 31/03/2021 Exeter	We at EXARC and the Dept. of Archaeology at Exeter University invite you to come to Exeter and celebrate where we are now and map out the future developments. We plan to make this a memorable bringing together of all of the diverse interest groups that contribute to the field.	https://exarc.net/meetings/eac12 Email: info@exarc.net
3RD Perspective on Balkan Archaeology- PeBA 2021 International Conference May 2021 (TBC) Ohrid, Republic of North Macedonia	The theme of this conference is centred on "the mechanism of power in bronze and iron ages in south-eastern Europe"	https://pebasite.wordpress.com/peba-2020/ Email: pebaconference@gmail.com
43rd International Symposium on Archaeometry ISAS2020 10/05/2021 - 14/05/2021 Lisbon, Portugal	The symposium aims to promote the engagement in the use of scientific techniques to improve the extraction of archaeological and historical information from historical sites.	https://www.isa2020-lisboa.pt Email: isa2020@isa2020-lisboa.pt
Accidental and Experimental Archaeometallurgy 2.1 04/06/2021- 06106/2021	To celebrate the 10th anniversary of the hugely successful experimental conference at West Dean in 2010, and the subsequent volume of the same name, the Historical Metallurgy Society would like to invite submissions for both practical metallurgical experiments and oral presentations to be held over a two-and-a-half-day event at the Ancient Technology Centre in Dorset in June 2020.	https://exarc.net/events/accidental-and-experimental-archaeometallurgy-21
Iron in Archaeology 29/06/2021-2/07/2021 Fribourg, Switzerland	For all things iron in archaeometallurgy, hosted by the CPSA Comité pour la Sidérurgie Ancienne – the Committee for Ancient Ironworking.	

Virtual Content

Program	Description	Website
Behind the Scenes: Metalworking at an Anglo-Saxon Palace 05/10/2020	Eleanor Blakelock gives us a glimpse into the metalworking at Rendlesham with her analysis of copper alloys and precious metal objects.	https://www.eventbrite.co.uk/e/behind-the-scenes-metalworking-at-an-anglo-saxon-palace-registration-115210092488