ARCHAEOMETALLURGY: EMERGING PRACTICES

Martha Goodway

ABSTRACT

There has been a recent shift in archaeometallurgy from the longstanding emphasis on metal objects, workshops, and documents, to a process orientation with an emphasis on the interpretaion, both scientific and archaeological, of byproducts. These byproducts are usually abundant as waste material, but their recognition and analysis are requiring different approaches and a closer collaboration between archaeologist and archaeometallurgist.

Introduction

Archaeometallurgy, as a term, has come into general use within the last ten years to identify a discipline that previously has been known as historical and archaeological metallurgy. With the change in terminology came a change in focus, from the technological examination of metal objects and the determination of furnace site plans, to the comprehensive study of the surviving materials on these sites where processing byproducts such as slag, matte, furnace linings and furnace bottoms, crucibles, molds, cupels and tuyeres are more abundant than metal. Thus the field of study has been enlarged beyond metallurgy to include that of materials science.

Simultaneously with this shift of focus has come the application of recently developed instrumentation whose expanded capabilities, including greatly increased sensitivities, has supported a parallel shift in methodology from one emphasizing chemical analysis and optical micrographs to one of sophisticated materials identification. Materials characterization, especially as applied to byproducts, is aimed mainly toward the reconstruction of processes rather than the technical examination of individual products. In moving from objects to technology, the locus of attention has also moved from the museum to the field.

The shift of focus is bringing about changes in practice. By its nature it engages the archaeologist and the archaeometallurgist in direct and more active cooperation. It is becoming accepted practice for archaeometallurgists to select samples for study at the site; by so doing they become sensitive to the context, to the effects of the local environment, and to the practical difficulties of recognition and recovery of the materials they wish to examine. The changes in practice also have brought with them a climate which fosters significant efforts of reinterpretation.

Early Work on Ancient Metals

Archaeometallurgy as a term seems first to have been used in English by Beno Rothenberg in 1972 when he established his Institute of Archaeo-Metallurgical Studies (IAMS), which now has offices at the Institute of Archaeology in London University. The word is still too arcane to be included in the latest edition of the Oxford English Dictionary. It appeared in print in 1980 when IAMS published its first newsletter.

The earliest scientific literature relating to ancient metals was published in the late 18th century, by Klaproth in Berlin in 1795, Pearson in London in 1796, and Thomson in Paris in 1809, and was of chemical analyses. One must remember that metallurgy at that period was a craft, and not a recognized scientific discipline as chemistry was. Metallurgy was not a full-fledged science until the introduction of x-ray diffraction early in the 20th century allowed proof of the crystalline nature of metals.

During the early 19th century - roughly 1815 to 1850 - the publications on ancient metals continued to be of chemical analyses, chiefly of coins, bronzes, and also of corrosion products (Caley 1951). Their purpose was aimed ultimately toward authentication.

In 1853 the first scientific appendix of any kind in an excavation report was the study of metals contributed by the distinguished English metallurgist, Dr. John

Percy, to Layard's *Nineveh*. In 1878 Percy contributed a similar appendix to Schliemann's *Mycenae*. Despite Percy's example, the emphasis in studying ancient metallurgy remained almost entirely on the composition of the ancient metal itself.

Meetings

The existing literature up to 1964 was cited in Professor Earle R. Caley's book, the *Analysis of Ancient Metals*. He also organized the first meeting where scientific methods had been applied in aid of archaeology, a Symposium on Archaeological Chemistry, in Philadelphia in 1950. Oxford's Research Laboratory for Archaeology and the History of Art was established by E. T. Hall shortly thereafter and began a series of international symposia in Archaeometry that still continues.

Beginning in 1965, William J. Young inaugurated a series of international seminars at the Museum of Fine Arts in Boston whose proceedings, under the title of *Application of Science in Examination of Works of Art*, became standard texts (Young 1959, 1967, 1973). These meetings tended to have a strong orientation toward museum objects and museum problems.

Metallurgists

What did archaeologists of the time do when they wanted metallurgical examination of their materials? At the Smithsonian, excavated objects occasionally were sent to commercial laboratories who treated them in the same way as they did materials in modern commerce. Typically, they would remove all external corrosion layers before beginning study, making recovery of the initial surface impossible and risking possible loss of information, such as the pseudomorphic replacement of the microstructure by corrosion products, a strong possibility in early alloys such as bronze. When I arrived at the Conservation Analytical Laboratory at the Smithsonian in 1970 I was the first metallurgist employed by a museum laboratory in the United States.

Museum scientists had all been chemists. Several of these, however, had trained themselves to do metallography to a very high standard. One of these was Pieter Meyers, then at the Metropolitan Museum in New York. In 1974 he arranged for a week's training in the metallographic interpretation of ancient metals under the guidance of Professor Cyril Stanley Smith at MIT. At that time a small group consisting of everyone working in archaeometallurgy in North America gathered in Cambridge. In this group there was only one other metallurgist present besides Professor Smith and myself, Professor Ursula Franklin. Professor Franklin was later to establish the Collegium Archaeometricum at the University of Toronto.

Objects and Documents

Rutherford John Gettens, then chemist at the Fogg Art Museum of Harvard University, and Cyril Stanley Smith met while working at Los Alamos, where Gettens' skill in the analysis of very small samples and Smith's in metallurgy were needed in the development of the atom bomb. Gettens' study of the materials of painting interested Smith in the study of the museum objects of metal. In addition to his many papers on this subject Cyril Smith has made an important contribution by his ability to inspire others. One was Theodore Wertime, who wrote *The Coming of the Age of Steel* (Wertime 1962) and edited *The Coming of the Age of Iron*, a festschrift for Cyril Smith (Wertime & Muhly 1980). Directly after the war Cyril Smith founded the Institute of Metals at the University of Chicago, where Radomir Pleiner was one of this graduate students. After returning home to Czechoslovakia, Pleiner established the Comité pour la Sidérurgie of the International Union of Pre- and Protohistoric Sciences, whose meetings are of importance to those interested in the technology of early iron making.

Cyril Smith also produced a number of technically competent translations into English of metallurgical classics, a tradition that began with Ashbee's 1888 translation of Cellini's *Treatise on Gold-Smithing* and was continued by President Herbert Hoover and his wife, Lou Henry Hoover, when they translated the 16th century text by Agricola, *De Re Metallica* (Hoover & Hoover 1950). Cyril Smith has been responsible for translations of Biringuccio's *Pyrotechnica* (Smith & Gnudi 1959), the 12th century treatise *On Diverse Arts* by Theophilus (Hawthorne & Smith 1963), the 12th century Latin manuscript *Mappa Clavicula* (Smith & Hawthorne 1974), the illustrated book on Japanese copper smelting by Masuda Tsuna, *Kodo Zoruku* (Shirakawa & Smith 1983), and so on.

One can sense the influence of his thought in popular literature such as Bronowski's television series *The Ascent of Man*, and in the Time-Life volume on *The Metalsmiths*, as well as more philosophical discussions of technology and its human import (Bronowski 1974, Knauth 1974). But for our purposes, the body of this work collected in the volume *The Search for Structure* is perhaps the most useful, consisting chiefly of many careful and thoughtful studies of museum objects (Smith 1981).

The Beginnings of Archaeometallurgy

This emphasis on the object and the document was not followed everywhere else. In England a different tradition was being established. The metal finds made at Ur between the wars by Leonard Wooley led to their study by the Sumerian Copper Committee of the Royal Anthropological Society. Close cooperation between archaeologist and metallurgist was already a fact when the Historical Metallurgy Society was founded in 1963 and began publishing the journal *Historical Metallurgy*. The editor until his death in 1990 was Professor Ronald Tylecote of the Institute of Archaeology, University of London.

In 1962 Tylecote began publishing the extraordinary series of books on archaeometallurgy that have become the textbooks of the field. The first was *Metallurgy in Archaeology* (1962), followed by *A History of Metallurgy* in 1976. Upon revision the first book became two: *The Prehistory of Metallurgy in the British Isles* (1986), and *The early history of metallurgy in Europe* (1987). A revised edition of *A History of Metallurgy* was near completion at his death. His research addressed important questions of archaeometallurgical interpretation, such as the possibility of smelting in crucibles and the processes indicated by various slags.

The Shift to Materials

Thus by the 80s a sound basis had been prepared for what became a major shift in the focus of archaeometallurgical studies. In 1982 Paul Craddock and Michael Hughes organized a symposium at the British Museum Research Laboratory on the subject of *Furnaces and Smelting Technology in Antiquity* (Craddock & Hughes 1985). Rather than yet another discussion of furnace design and operation, quite spontaneously discussion centered on what they were made of and what sorts of materials were left behind in the archaeological record.

This meeting represents to me a very important turning point in archaeometallurgy. A shift of attention had occurred, from the study of objects to the study of processes, from metals to materials. The archaeologist will recognize this shift as one which parallels those in other areas such as the study of debitage. Whole installations were now being studied in material as well as in plan.

Waste products

One archaeometallurgical site whose materials have been studied at the Conservation Analytical Laboratory is the Athenian silver mining site of Laurion. There the ore was mined and processed, the silver smelted and then refined by cupellation. The ore processing in particular required large amounts of water, and this in a region of scanty rainfall. Dams and cisterns as well as washing floors are part of this installation. There was an elaborate water conservation and recirculating system that depended upon an impermeable cement manufactured in part from the waste products of silver smelting (Mishara 1989). Cisterns that were lined with this cement still hold water 25 centuries later.

Another archaeometallurgical site whose materials are under study at the Conservation Analytical Laboratory is Kestel, an Early Bronze Age tin mine located in the Taurus mountains of south central Turkey (Yener et al. 1989). The discovery was serendipitous. Dr. K. Aslihan Yener was prospecting for lead and silver ores, intending to match their lead-isotope ratios with those from objects from Troy and elsewhere in the early Near East, when she located mine openings directly above a stream where the Turkish Geological Survey had panned small but significant amounts of cassiterite.

What was not obvious was the extent of open pit mining at the site, since natural processes as well as cultivation had obliterated much of the evidence. What remains is grass covered with a surface contour the English describe as "gruffy ground". This may be familiar to the archaeometallurgist who has seen gruffy ground in places such as the Mendips, Derbyshire, where lead has been mined since Roman times, but it is not well known to geologists. At sites like Kestel where both open pit and underground mining took place, estimates based solely on the amount of ore mined from underground galleries cannot give a correct idea of the scale of operations.

Also adding to the difficulties of this site is the general problem of recognizing tin slag. Replication tin smelting experiments by Brian Earl in Cornwall produced slags of several types, including one that looked very much like sand (Earl 1985, 1986). This complicates the interpretation of any supposed tin smelting site, as does the very real possibility - easily confirmed in the laboratory - that bronze was initially alloyed by adding cassiterite (tin oxide) to molten copper in a cementation process, rather than smelting it to tin first (Yener & Goodway 1991). The question then becomes one of determining whether tin smelting took place at all and, if so, what the appearance of the residues might be.

This is not the difficulty we expect to have with slags. In 1981 I had the opportunity to visit Khirbet en-Nahas and Wadi Feinan in the southern desert of Jordan, a copper smelting area that was subsequently studied by Andreas Hauptmann and his colleagues at the German

Mining Museum at Bochum (Hauptmann et al. 1989). The slag is obvious. It is black, in the form of large plates, i.e., tap slag, and there are an estimated 150,000 to 200,000 tons of it in and around Feinan. It marks the largest early copper producing area between Cyprus and Oman.

Recycling of Waste Products

It is understandable that a waste product so durable and so easily formed as tap slag would be put to use in a number of ways, including the casting of building blocks. The most attractive examples I know of are in Sweden, where iron slag in shades of green and blue has been used in this way, at Engelsbergs Bruk for example. Similarly in India, at Zawar in the Rajastan desert, ceramic retorts used in the traditional distillation of zinc were recycled as building material for walls, where they were first recognized.

Excavation at Zawar in 1984 immediately located furnaces (Craddock 1987). Nearby there was a heap of what from its appearance might have been quartz sand; it was free of vegetation. It was suggested to me at the time that this was probably a supply of flux. Later, systematic analysis of all the different materials present at the site showed that this was not flux but a spoil heap. It had high levels of cadmium, a common and very toxic byproduct of smelting zinc ores - hence the lack of vegetation.

Replication and Recognition

Here we have another example of detritus that was not recognized in the field because it did not have a customary appearance. Replication experiments using known inputs under known conditions, which have been used simply to verify the possibility of operating a particular process, are now also being conducted with the express purpose of producing materials diagnostic of the methods employed.

Firesetting experiments have been conducted recently with this end in mind by Simon Timberlake, by Andrew Lewis, and by Peter Crew (Crew & Crew 1990). A further development extends replication to the study of the effect of natural processes on archaeometallurgical installations. Peter and Susan Crew are studying the effects of weathering from season to season on replicate iron hearths in Wales, monitoring the rate at which the hearth and its detritus alter in amount and character.

This is a very different orientation toward the study of archaeological and historical metallurgy when compared with studies of metal artifacts and literary documents. It may begin there but the new orientation demands that archaeometallurgists go to the field, survey sites and in collaboration with the archaeologist collect the samples they will work on.

Collaboration

If there is a prediction that I would be willing to make about the future of archaeometallurgy it is the need for collaboration between archaeologists and materials scientists, not just metallurgists. The interpretation of crucibles, furnace linings and the like, for example, requires the expertise of a ceramics engineer who is well versed in ancient technology. And so on.

A great deal of patience and mutual respect is required by the collaboration of people who have been trained in very different fields. In working with anthropologists I have learned, for example, that a four-digit population figure absolutely must have a comma. I still do not understand this convention but I respect it, and I have been fortunate that my collaborators have been equally tolerant of the tribal customs of my own field.

What is hopeful about the new orientation toward materials and processes is that out of closer collaboration will come new questions and new interpretations that neither archaeologist nor archaeometallurgist alone could have made.

References

Ashbee, C.R. (translator) 1888 *The Treatises of Benvenuto Cellini on Goldsmithing and Sculpture.* London, reprinted by Dover, New York 1967.

Bronowski, J. 1974 *The Ascent of Man.* Boston.

Caley, E.R. 1951 *Journal of Chemical Education* 28, 63.

Caley, E.R. 1964 *The Analysis of Ancient Metals.* New York.

Craddock, P.T. 1987 The early history of zinc. *Endeavour*, New Series 11:4, 183-191.

Craddock, P.T. & Hughes, M.J. (eds.) 1985 *Furnace and Smelting Technology in Antiquity.* British Museum Occasional Paper 48. London.

Crew, P. & S. (eds.) 1990 *Early Mining in the British Isles*, proceedings of the Early Mining Workshop at Plas Tan y Bwlch, Snodonia National Park Study Centre, 17-19 November 1989, Plas Tan y Bwlch Occasional Paper No 1. Plas Tan y Bwlch, Wales.

Earl, B. 1985 " Melting tin" in the West of England: a study of an old art. *Historical Metallurgy*, The Journal of the Historical Metallurgical Society, 19:2, 153-161.

Earl, B. 1986 Melting tin in the West of England: part 2. *Historical Metallurgy*, The Journal of the Historical Metallurgical Society, 20:1, 17-32.

Hauptmann, A., Weisgerber, G. & Bachmann, H-

G. 1989 Ancient copper production in the area of Feinan, Khirbet en-Nahas, and Wadi el-Jariye, Wadi Arabah, Jordan. In S.J. Fleming & H.R. Schenk (eds.): *MASCA Research Papers in Science and Archaeology* 6, History of technology: the role of metals. Philadelphia.

Hawthorne, J.G. & Smith, C.S. (translators) 1963 Theophilus, *On Diverse Arts*, The foremost medieval treatise on painting, glassmaking and metalwork. Chicago, reprinted by Dover, New York 1979.

Hoover, H.C. & Hoover, L.H. (translators) 1950 Georgius Agricola, *De Re Metallica*. Translated from the first latin editon of 1556. New York.

Knauth, P. 1974 *The Metalsmiths*. New York.

Mishara, J. 1989 The plasters of the ore washing structures at Laurion. In Y. Manitas (ed.): *Archaeometry*, Proceedings of the 25th International Symposium, 191-205. Amsterdam.

Shirakawa, Z. (translator) & **Smith, C.S.** (ed.) 1983 *Kodo Zuroku*, illustrated book on the smelting of copper by Masuda Tsuna, Norwalk, Connecticut, USA.

Smith, C.S. 1981 *The Search for Structure*, selected essays on science, art, and history. MIT Press, Cambridge MA.

Smith, C.S. & Gnudi, M.T. (translators) 1959 *The Pyrotechnia of Vannoccio Biringuccio*. The Collector's Series in Science. New York.

Smith, C.S. & Hawthorne, J.G. 1974 *Mappae Clavivula*, a little key to the world of medieval techniques. *Transactions of the American Philosophical Society*, new series 64:4.

Tylecote, R.F. 1962 *Metallurgy in Archaeology*, A Prehistory of Metallurgy in the British Isles. London.

Tylecote, R.F. 1976 *A History of Metallurgy*. London.

Tylecote, R.F. 1986 *The Prehistory of Metallurgy in the British Isles*. London.

Tylecote, R.F. 1987 *The early history of metallurgy in Europe*. London and New York.

Wertime, T.A. 1962 *The Coming of the Age of Steel*. University of Chicago Press. Chicago.

Wertime, T.A. & Muhly, J.D. (eds.) 1980 *The Coming of the Age of Iron*. Yale University Press. New York and London.

Yener, K.A. & Goodway, M. 1992 Response to Mark E. Hall and Sharon R. Steadman, "Tin and Anatolia: another look". *Journal of Mediterranean Archaeology* 5:1, 77-90.

Yener, K.A., Ozbal, H., Kaptan, E., Pehlivan, N.A. & Goodway, M. 1989 Kestel: an Early Bronze Age source of tin ore in the Taurus Mountains, Turkey. *Science* 244, pp 200-204.

Young, W.J. (ed.) 1959 *The Application of Science in the Examination of Works of Art*, Proceeding of the Seminar: September 15-18, 1958, Museum of Fine Arts, Boston.

Young, W.J. (ed.) 1967 *Application of Science in the Examination of Works of Art*, Proceedings of the Seminar: September 7-15, 1965, Museum of Fine Arts, Boston.

Young, W.J. (ed.) 1973 *Application of Science in the Examination of Works of Art*, Proceedings of the Seminar: June 14-19, 1970, Museum of Fine Arts, Boston.