Late Neolithic Copper Smelting in the Arabah

'Tubal-Cain, instructor of every artificer in copper and iron' (Genesis 4:22)

The very beginning of extractive metallurgy, when man realized for the first time that he could turn rock into metal, was one of the most revolutionary events in the intellectual and material history of mankind. However, the location, date and circumstances of this 'creative moment' will probably remain forever unfathomable to science. It is highly interesting that we find the very beginnings of metallurgy deeply engraved in the early Biblical genealogy of Genesis 4 (19-22). The material background of the Cain and Abel story with its emphasis on the 'tiller of the ground' and the 'keeper of sheep' clearly reflects the socio-cultural Neolithic environment.

The continuation of the list of descendants of Cain, as the 'fathers' of crafts and arts, leads to the figure of 'Tubal the smith', that eponymous ancestor of metalworkers. The association of iron with Tubal in Genesis 4:22 is certainly not part of the Neolithic environment, but small numbers of metallic objects made from native copper and lead have been excavated and dated to the Late Neolithic (Heskel, 1983). There are even a few small pieces of metallurgical slag from some sites, but to what extent should copper smelting be viewed as one of numerous 'crafts' of the Late Neolithic?

For a great many years, archaeometallurgists have tried to identify workshops of the earliest extractive metallurgy, but nothing representing such an incipient technological phase of copper smelting could hitherto be identified with certainty. For this reason, Chalcolithic copper smelting (see Rothenberg, 1990; Rothenberg, Tylecote and Boydell, 1978; Hauptmann, 1989, 1992) dated to the 4th millennium BC, was so far understood to be the earliest identifiable and datable beginnings of the metal making story in the Southern Levant.

Recent investigations by the present authors are taking the metal story a significant step further, showing that finds in the copper mining region of Timna (South Arabah, Israel) and Sinai, and in the Feinan mining region (North Arabah, Jordan), apparently represent copper smelting already at a late phase of the Neolithic Period. Based on recent excavations along the Nahal (Wadi) Besor, near Qatif (southern Gaza strip) by Gilead and Alon (1988), these finds can now be related to the 6th-5th millennium BC 'Qatifian' Pottery Neolithic culture (Gilead, 1990; Goren, 1990) and represent the first, incipient, step to the extractive metallurgy of copper. Based on our current scientific investigation of the metallurgical remains, we now propose a model of this earliest phase of smelting copper ore to metallic copper. Our identification of a Late Neolithic phase of extractive metallurgy in the region of the Arabah, closes a gap which seemed to have existed in the Levant, compared with developments in the Northern Fertile Crescent. Furthermore, Site F2 – and perhaps also the find spot of the early slag at Site Fidan 4 – is the earliest proper extractive metallurgical workshop identified anywhere.

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The identification of Qatifian copper smelting adds about one millennium to the history of metal in the Levant.

1. A 'Qatifian' Neolithic smelter in the Timna mining area
The Timna Valley (Fig. 1) lies alongside the Arabah, some 30 km north of the Gulf of Eilat-Aqaba. Its ancient copper mines were mainly located in the Late Cretaceous sandstone formation along the foot of the Timna Cliffs, whilst the copper smelting took place well outside the mining area, in the centre of the Timna Valley, at its eastern fringes and in the adjacent region of the Arabah.

The location of the smelters in relation to the mines, reflects mainly logistical problems in the different periods of metallurgical activities in Timna (Fig. 1). Most of the Chalcolithic to Early Bronze Age IV (4th to 3rd millennium BC) smelting sites were located at or near settle-
ments, as near as possible to the sources of water and firewood, i.e. in the nearby Arabah Valley and at the fringes of the Timna Valley. Some smelting also took place at a prehistoric camping site and shrine along the foot of 'King Solomon's Pillars' (around Site 112 and underneath the Egyptian Temple at Site 200).

Reflecting a very efficient and quite different logistic system of supplies, and perhaps also aspects of security, the Egyptian New Kingdom smelting camps were set up in a close group west of Mt Timna, also well outside the mining region.

Fig. 2. Site F2 with, in the background, the Timna mines.

1.1 Site F2
No smelting of any kind or time had been found in the actual mining area of Timna until 1976, during our survey of a 'Model area' (Fig. 1), we discovered a small smelting site, which was named 'Site F2', deep in the mining area at the far west of the Timna Valley. Site F2 consisted of a concentration of small slag lumps (estimated at about 5 kg) and copper ore nodules, around a group of stone tools for crushing (Fig. 2). In its centre was a deep mortar (Fig. 3) of a type we had not seen before at Timna, but the type was well-known from other prehistoric sites in Sinai. There was no architecture of any kind.

The slag of Site F2 (Fig. 4) was extremely inhomogeneous in appearance, suggesting a very primitive smelting technology and most of it was in very irregular, rough, porous lumps. However, some surfaces were observed to be very smooth and sinuous whilst some fragments seemed very solid and dense and contained copper prills. From the collection of samples at Site F2, the general impression is that the slag was very diverse.

Fig. 3. Large coarse grain granite stone mortar used for crushing ores and slag.

Fig. 4. Typical 'nodular' slag from Site F2.

Among the finds of slag were also slagged lumps of sandy soil, suggesting that smelting took place in a very shallow hole in the ground, without the use of stones or furnace lining: the earliest type of furnace discussed by Tylecote (1962: Fig. 3b). There were also a few fragments of small tuyeres (Fig. 5), apparently made by simply attaching a handful of sandy clay mortar to the nozzle of the bellows for protection against the fire and heat of the 'furnace'. These tuyeres (outer diameter 5-6 cm, length c. 4 cm, air hole diameter c. 1.5 cm) were the smallest ever seen in the Arabah.

Fig. 5. Restored tuyere from Timna site F2.
In our survey of 1976, we found at Site F2, about 20 fragile, poorly fired ceramic sherds of a type not previously seen in the Arabah. These were mainly body sherds, but there were also fragments of simple rims of a crude bowl or hohomouth jar, and the thick flat base of a large vessel, probably from the same hohomouth jar. Petrographic studies of the sherds by J. Glass showed a coarse arkosic ware with abundant vegetal temper, indicative of the earliest pottery of the region (Glass and Ordenthall, in press).

Considering the pottery as well as the character of the few flint objects found at Site F2, and especially the small quantity of heterogeneous slag at the site, we began to interpret these remains as representing some of the very earliest encountered in our many years of archaeometalurgical surveying. The fact that Site F2 was located next to a quite extensive area of primitive pit-mining (Model Survey Areas A and G in Conrad and Rothenberg, 1980: Abb. 44–6), completed the so far unique picture of a coherent prehistoric mining and smelting enterprise, as yet found nowhere else. However, the unusual location of Site F2, the character of its pottery, flints and primitive metallurgy, left the chronological and cultural context and the extractive technology of Site F2 as an enigma in the overall picture of the copper industries of the Arabah and Sinai — and indeed the Levant — and as a challenge for further research.

We started this new line of inquiry by rechecking the archaeological records and find boxes of our Arabah and Sinai surveys of the 1960’s and 1970’s for any other pottery, flints and slag lumps similar to the specimens from Site F2. The result was the realisation that there seems to be a thin spread of similar assemblages of material from sites in the Southern Arabah and South Sinai, to be understood as evidence that the ‘F2 Phenomena’ — now proposed to belong to the ‘Qatian Neo- lithic’ Period (see below) — was indeed a fairly widespread development of considerable culture-historical significance.

1.2 The ‘Qatian’ Late Neolithic culture and the beginnings of metallurgy in the Arabah

Excavations by Gilead and Alon (1988) in the Nahal (Wadi) Besor area, in the southern Gaza strip near Qatif, identified a distinct ‘Qatian’ Late Pottery Neolithic culture (Gilead, 1990). Calibrated C14 determinations date the Qatian culture from the middle of the 6th millennium to most of the 5th millennium BC.

One uncalibrated C14 date for a Qatian site (Qatif Y-3) 4090 ± 89 b.c. (Gilead and Alon 1988: 129), and several uncalibrated dates from pre-Ghassulian, apparently Qatian, layers of Tellat Ghassul, excavated by Hennessy (1989) from 4600 to 4400 b.c. (Goren, 1900: 104–6), when calibrated cover part of the 6th and much of the 5th millennium BC, which seems to us the right chronological range for the Qatian Neo-lithic phase.

The calibrated C14 date of 5500–5270 BC for a ‘Pottery Neolithic’ site in Wadi Feinan (Northern Arabah, Jordan) recently published by Hauptmann (1989: 119) is well in line with the Qatian dates quoted above.

In recent papers, Gilead (1990) and Goren (1990) outlined the characteristics of the Qatian artifacts and the place of the Qatian Neolithic culture in the culture-historical developments of the Negev and Sinai and its transition to the Chalcolithic period. The most conspicuous element of the Qatian, of decisive relevance for the smelters of the Arabah and Sinai, is the pottery and petrography of its pottery. Gilead and Goren listed a rather limited range of pottery types, mainly bowls, jars and hohomouth vessels with thick bases and flaring loop handles, as criteria of the Qatian pottery. Goren (1990: 101, 103) states, ‘The pottery is of low quality and very crumbly. All vessels were made by hand using coils, the traces of which can still be seen. The clay used for producing these vessels was mixed with large amounts of straw and coarse grits, which causes the surface of the vessel to be porous and rough… All the pottery … is characterized by a dark core, due to poor firing and a high content of vegetal components in the raw materials’. The pottery of the Qatian Late Neolithic culture is quite distinct from any other early pottery of the region and its characteristics are evidently of chronological significance.

The typology and petrography of the pottery of Site F2 established its great similarity to the Qatian ware, though the matrix of the latter was of course different from the local Arabah ware. Considering the incipient copper metallurgy of Site F2, together with the distinct Qatian pottery characteristics and stone tools, Site F2 evidently belongs to the Qatian Pottery Neolithic culture of the 6th–5th millennium BC, representing the Neolithic beginnings of extractive metallurgy in the Levant.

2. Qatian Neolithic copper smelting in the Feinan mining region (Northern Arabah, Jordan)

The earliest metallurgy from the ancient mining region of Feinan, represented by finds from Site Fidan 4 (Hauptmann, 1991: 411), was dated by pottery to the Chalcolithic Period (Raikes, 1980: 55; Weisgerber in Hauptmann et al. 1985: 185–8; Hauptmann 1989: 132). Hauptmann closely correlated Fidan 4 to the Late Chalcolithic Ghassul-Bearsheba copper working sites and considered this correlation as a supporting dating evidence for Fidan 4 (Hauptmann, 1989: 122, 126).

Based on this dating and his detailed studies of the metallurgical finds, Hauptmann proposed a new model of Chalcolithic copper smelting involving ‘solid state’ smelting of copper ore and perhaps even a ‘slagless metallurgy’ (Hauptmann, 1991: 403; 1989: 123–6).

2.1 Qatian at Fidan 4 and Site F2

Site Fidan 4 was discovered in 1976 by T. D. Raikes (1980: 55, marked ‘Fidan E’) who also reported some slag at an unspecified location at the site. By comparison with pottery collected at Tell Magass-Aqaba, Raikes dated the site to the Chalcolithic period. This date was recently confirmed by Hauptmann (1991: 401) based on pottery collected at Fidan 4 (Hauptmann et al. 1985; Khalil, 1988).

Unfortunately, neither Raikes nor Hauptmann provided complete archaeological information about the correlation between the pottery, flint and slag finds and the actual (unexcavated) settlement at Fidan 4. This site was reported by Raikes as ‘a small town… possibly about 4 acres’, with numerous flints and much pottery, but the find circumstances of the metallurgical remains are not mentioned. Hauptmann (1989: 122) wrote: ‘… relics of Chalcolithic copper production such as ores, slags and copper prills were discovered in a settlement on top of a plateau’. Since Raikes and Hauptmann refer only to surface finds among the ruins of an unexcavated settlement, we must keep in mind that surface finds of slag are not necessarily dated by the ruins and the finds of the Fidan 4 settlement. We therefore refer here only to
the pottery published by Hauptmann (1986) in relation to the slag finds at Fidan, assuming both were found in the same archaeological context.

1. Gilead of Ben Gurion University, Beer Sheva, was offered the opportunity to inspect the finds from Fidan and other pottery finds from the Feinan region at the Deutsches Bergbau Museum at Bochum. His recent assessment of the pottery from Fidan 4, which has now been published (Gilead, 1990: 60) is that the Wadi Fidan 4 pottery is ‘...undoubtedly a local version of the Qatif-P14 tradition... the archaeological entity that prevailed in the northern Negev at the turn of the fifth millennium B.C.’

We did not at first relate the change of identification and dating of the Fidan 4 pottery – from Late Chalcolithic to Qatifian Pottery Neolithic – to our finds at Site F2. It was only after the recent completion of the petrographic investigation of the Arabah and Sinai pottery by J. Glass, discussed above, the comprehensive publications by Gilead (1988; 1990), and especially the petrographic study by Goren (1990: 102–5) of pottery from Wadi Fidan, Khirbet e-Nakhas and Feinan, that it became clear that, together with Fidan 4, Site F2 has to be identified as a Qatifian Pottery Neolithic site. The new identification of Wadi Fidan 4 with copper smelting as a Qatifian Pottery Neolithic site, apparently one of several in the Feinan region (Hauptmann, 1991: 401; Goren 1990: 102) and the rather unusual characteristics of their metallurgical slag, also apparent at Site F2, now strongly support our identification of Site F2 as a Qatifian Late Neolithic copper smelter.

3. The Qatifian Neolithic extractive metallurgy at Site F2

Slag samples from Site F2 were investigated using the new JEOL Superprobe (Electron Probe Microanalysis) facility at the Wolfson Archaeological Science Laboratory at the Institute of Archaeology, University College London. Microanalysis has been used to investigate a random selection of twelve samples of the distinctive slag from the earliest archaeological context at Site F2. Each sample has had up to 10 separate, microscopic points analyzed. The following elements are quantitatively at each point: Cu, Fe, Mn, Mg, Al, Si, As, S, Ca, Ni, Pb, Zn, P, Ti and Ba. In contrast to bulk chemical analysis and phase analyses of metallurgical slag, this microanalytical approach is quite different in that microscopic mixtures of individual phases in the slag can be identified. This is very important for the early, heterogeneous slag samples because fragments of ore entrapped in the slag can be analyzed. Thus, it is possible to determine what ores were actually charged into the smelting furnace. Photographs of the microstructures, along with the point analyses, document the relationships between ore reduction, slag formation and metal product compositions. From these randomly selected samples of slag it is possible to infer a rather primitive or unsophisticated technology which appears to be at a stage near the threshold of iron ore flux utilization in copper smelting.

From the microanalytical investigation, two types of slag from Site F2 have been identified and simply classified as either glassy or crystalline. This distinction in microstructure, however, is not readily apparent in the outward appearance of the small, irregular lumps of slag from the site. Although the glassy slag compositions with about 10–15% calcium, 20–25% iron, 20–25% silica would approximate pyroxene in composition, there are no actual crystals of pyroxene (for example, hedenbergite, CaFeSiO₄). Nevertheless, all of the slag samples do have variable concentrations of iron. Through microanalysis (Fig. 6) it is possible to document numerous entrapped grains of copper ore as well as copper prills in the glassy slag. There are also numerous grains of unreacted quartz clustered in the copper ore fragments. Point analyses of the copper ore fragments indicate about 20% copper and 40% silica. Several of the glassy slag samples are attached to ceramic which is interpreted as furnace remains. In laboratory remelting experiments under carbon, the glassy slag melts at about 1250°C.

Alternatively, the second type of slag is crystalline with crystals of fayalite (Fe₅SiO₄) in approximately the same matrix of pyroxene-glass. In a laboratory furnace, the crystalline slag is observed to melt at 1100–1150°C. Bulk analysis of one slag sample was done with Inductively Coupled Plasma Emission Spectroscopy (ICP). The major constituents were 36.7% Fe, 3.17% CaO and 22.0% SiO₂. The copper was low at 0.72% reflecting the inferred low viscosity due to the high iron composition of this slag specimen. Appropriate additions of iron ore flux, along with the copper ore characteristically found at Timna, represents the fundamental step toward increasing the small quantities of metal recoverable as prills from the slag by crushing.

Microanalysis of the crystalline slag revealed distinct fragments of iron oxides which are interpreted as reacting flux. Away from these iron oxide inclusions, the fayalite crystals diminish in quantity as the composition in a single lump of slag can grade into areas of glassy composition with higher melting temperatures. Figure 6 illustrates a good example of heterogeneous slag of variable compositions which can be directly related to the reaction of iron oxides in specific areas. The whole furnace charge was not molten, due to the variable slag compositions. For a meaningful increase in copper production, the slag should be of a composition which would allow the microscopic, disseminated copper prills to merge into larger sizes for recovery by hand from the crushed slag.

Whether iron ore had actually been added deliberately or not is still in question. While there are distinct fragments of iron oxides in the crystalline slag samples, there are also fragments of mixtures of copper and iron phases in other entrapped ore inclusions. At Timna, most ore nodules are distinctively green in colour, but
some examples have quite recognizable combinations of the green malachite (CuCO₃•Cu(OH)₂) with the red-coloured hematite (Fe₂O₃). The 'ores' charged into the smelting furnace at Site F2 do not seem to have been adequately sorted. This mixture of copper ore, iron ore and mixed copper/iron ore is interpreted as somewhat 'accidental', more representative of the available 'ores' at Timna. Due to the presence of significant concentrations of iron in all twelve of the analyzed slag samples, the documentation of entrapped iron oxides, as well as numerous fayalite crystals in four of the twelve slag samples, iron ore was definitely added with copper ore. This could represent an early attempt to produce an appropriate copper ore-to-flux ratio. Nevertheless, iron ore was not added sufficiently or consistently along with the copper ore. Our overall impression is that the mixtures of 'ores' are accidental and not controlled.

Visible copper prills with diameters greater than about 1mm in the crystalline slag represent the only recoverable product from smelting at Site F2. Numerous prills of various sizes entrapped in the slag have been analyzed. The iron concentrations in the copper prills range up to about 3%. Lead is also present in minor concentrations. One piece of copper metal weighing several grammes collected from the site was analyzed. The results from microanalysis for this spil of metal were 95% copper, 3.5% iron, 0.3% lead and 0.1% arsenic. These concentrations would be appropriate for local metal. Previous analytical work by Craddock (1988) on a pin found at the site reported higher levels of arsenic and antimony. This pin is interpreted as an imported, finished object.

This stage of Late Neolithic or Qatfin extractive metallurgy seems far less advanced than that represented at Timna Site 39 dated to the Late Chalcolithic. Bachmann (1978: 21) reported that the slag from Timna 39 always had fayalite associated with oxides of the spinel type, such as magnetite. Although some 'trial-and-error' nature of the Chalcolithic smelting process is apparent, there seems much more consistent use of iron ore flux. This is not so at Site F2 where the concentrations of iron and calcium are more variable and the slag melting temperatures higher with the pyroxene-type compositions. Often the contributions of calcium in slag have been attributed to calcium in the ore or deliberate fluxing but, based on the low calcium concentrations of the entrapped ore compositions from the slag, this is unlikely. Smelting experiments by Merkel (1990) suggest fuel ash alone is sufficient to account for most of the calcium in the slag. As with quartz gangue in the copper ore, excess calcium from fuel ash also required additional flux to achieve appropriate lower melting temperature slag compositions. Excess calcium from fuel ash suggests very inexperienced workers using too much fuel trying to smelt copper.

Our current research into the process metallurgy of the prehistoric periods, even back into the Late Neolithic, indicates that there were specific technological achievements in copper smelting which occurred in a step-wise manner. The exact point of departure for each advance will be difficult to establish, but the effects of the developing use of flux and other process-related parameters in copper smelting are discernible in various sites. There will be chronological as well as geographic differences. The essential point is that as more prehistoric copper smelting sites are investigated, we continue to find more diversity which thus allows more technological detail to be placed into perspective. Metallurgical developments must be understood in terms of their archaeological context. Thus, the Late Neolithic context should now be discussed with the inclusion of the very beginnings of copper smelting along with the other more recognized arts and crafts.

Beno Rothenberg and John Merkel

Notes
1. After total removal of all surface finds during the initial survey, we returned to Site F2 in the autumn of 1976 and excavated most of the c.20m-long ridge down to bedrock. This excavation was supervised by Paul Craddock and produced additional slag, pottery and flints, but no architectural remains. At the far end of the ridge at F2, a small circular stone setting of a fireplace, containing mainly wood ash, was uncovered. Stratigraphically, this stone setting was clearly intrusive, and in fact was dated by C14 to the Egyptian New Kingdom. A preliminary review of F2 was included in Rothenberg (1990: 6-9). Site F2 will be published in full by B. Rothenberg and J. Merkel, The Prehistory of Copper in the Arabah: The earliest steps to copper metallurgy, from its prehistoric beginnings to inceptindustrial copper production, IAMS Monograph 2 (forthcoming).

2. Because of the indigenous character of the local population in the semi-arid region of the Arabah and Sinai, we propose to use a more suitable chronological terminology put forward by Rothenberg and Glass (1992) for the regional technological and cultural developments. The Sinai-Arabah Copper Age - Early Phase (late Neolithic to Early Bronze I), Middle Phase (Early Bronze II to Early Bronze III), Late Phase (Early Bronze IV and later). The petrographic investigations showed Site F2 to be the key site for the beginning of the Early Phase. See also Rothenberg (1990) for F2 as the earliest site of extractive metallurgy in Timna.

3. Our IAMS Prehistoric Metallurgy Project had been established early in 1994, when we recognized the significance of the Qatfin Neolithic remains for the prehistory of metallurgy. We expect to conclude this research project and its publication in 1995. We would like to express here our gratitude to Mr Felix Posen, London, for his encouragement and generous support of this project and its forthcoming publication (IAMS Monograph 2).

4. Since the totally different environments of Nahal Besor and the arid region of the Arabah and Sinai must have required a different assemblage or 'tool kit' of flints, we shall not deal in the present paper with the Qatfin flint assemblage in relation to our finds in the Arabah and Sinai. One diagnostic element in the Nahal Besor coastal area was a typical sickle blade – which would, of course, be out of place in Timna or South Sinai.

5. It seems rather difficult by definition to consider simultaneously a 'solid state' smelting process as well as 'slagless copper smelting' as has been recently proposed. Solid state reduction is, of course, possible for copper ores. However, experiments have shown that the metallic product would be very finely dispersed, and thus difficult to recover by crushing and hand-sorting. Furthermore, there are many examples of heterogeneous slag where at least part of the mass has been molten. Appropriate slag compositions enable the recovery by hand of copper prills (>0.5mm). Based on published evidence, we do not accept models for 'solid state' smelting of copper ores. 'Slagless smelting' of copper ore, as proposed by Craddock and Meeks (1987: 202) seems to us a misconception deriving from a lack of slag finds where such finds would have been expected. Even the smelting of the highest grade copper oxide ores leaves slag residue due to the fuel ash, high temperatures and poor quality refractory materials used as crucibles or furnaces. The residue from small-scale copper smelting does occur. Site F2 is exemplary.

References
Sophisticated Roman Recovery Techniques for Gold

In his *Naturalis Historia*, Pliny the Elder has told us much about the state of science and technology at his time, i.e. the first century AD. The industrious author was well aware of the writings of his contemporaries, though he very rarely acknowledged them. For the wealth of material he wanted to communicate, he not only had access to what can only be termed a data base in the form of elaborately filed notes and quotations, but also to scores of scribes to whom he could dictate his books. Translations of Pliny's *Naturalis Historia* are numerous. However, some sentences are difficult to understand, others are even unintelligible. Therefore, a study group in Germany, consisting of linguists, scientists, technicians and historians has been engaged for more than 15 years in retranslating and reinterpreting Pliny's texts on metals.

When Pliny wrote about gold mining and beneficiation, he wrote with some authority. After all, he was procurator in Hispania Tarraconensis from AD 72 to 74. Iberia was once one of the main sources of gold for the Roman Empire, though not the only one. Bird (1984) discusses references which Pliny made to several gold mining and extraction techniques. These include hushing, sluicing and the unique 'arrugia'-practice which is the systematic preparation of whole mountains by tunnelling for subsequent erosion by man-made floods from gigantic water reservoirs. Not mentioned by Bird (ibid) are Pliny's remarks that, for purification purposes, gold has to be 'cooked' (i.e. smelted) with lead. According to H. Rackham, this passage (*Nat. Hist. XXXV, 60*) is translated in English as '...for the purpose of purifying it is roasted with lead'. Furthermore, some gold ores have to be crushed and washed, as well as roasted and the smelting of the ore with lead produces a silver-colour alloy. This alloy would be considered a lead bullion in modern terminology. According to Pliny, the slag has to be crushed and returned (recycled) to the furnace. Using the Rackham translation again, this passage (*Nat. Hist. XXXV, 69*) is extremely interesting:

"The substance dug out is crushed, washed, fired and ground to a soft powder. The powder from the mortar is called the "scudae" and the silver that comes out from the furnace is the "sweat"; the dirt thrown out of the smelting furnace in the case of every metal is called "scoria", slag. In the case of gold the scoria is pounded and fired a second time; the crucibles for this are made of "tasconium", which is a white earth resembling clay. No other earth can stand the blast of air, the fire, or the intensely hot material.

Fig. 1. Adits to Roman open cast gold mine. Três Minas, Portugal.
Surely these procedures do not apply to free or native gold from alluvial deposits, but point to hard-rock polymetallic gold ores in which at least part of the precious metal is associated with a variety of base metals and other elements, like sulphur, arsenic, etc., defying the simple process of 'panning', i.e. gravity separation.

Actively involved in the Pliny Study Group, I was invited to visit the unique Roman open-cast gold mines called 'Três Minas' located in the county of Trás-os-Montes in Northern Portugal (Fig. 1). These mines have been known for a long time, but only fairly recently have they attracted the devoted attention of the German archaeologist J. Wahl (1988). He became intrigued by finding pointing to a process technology hitherto unknown in the many Roman gold mines in the Iberian peninsula, and asked for scientific support and advice. Wahl found hundreds of prismatic stone slabs with cup-shaped depressions on all four sides (Fig. 2). These proved to be discarded crushing stones of Roman stamp mills. They are preserved in the modern villages, serving as construction material for gates and foundations. Circular mill-stones, also discovered in the vicinity, point to the next step of Roman gold ore treatment: grinding after crushing (Fig. 3). The existence of slag heaps near the mining area was at first not seen as something bearing any immediate relation to the metallurgy of precious metals but, after analysis, these slags were identified as waste typical of a smelting process in which lead acted as collector for precious metals. Already Harrison (1931) had noticed the slag heaps near Três Minas. He came to the conclusion that the slag had something to do with

Roman gold metallurgy. He wrote of a 'lithargine process' in which litharge (lead oxide) had played a part in gold recovery and which apparently was practised here during Roman times. The process of smelting with lead can be carried out either with metallic lead or lead oxide.

Fig. 3. Roman mill stone from ore/slag processing at Três Minas.

Fig. 4. Schematic flow sheet for gold ore processing at Três Minas.
The reducing atmosphere in the furnace will in either case provide lead metal as collector for the precious metals.

Though the Roman mines have been completely exhausted, we do have a reliable indication of the types of ore mined in antiquity. A modern, small gold mine nearby—perhaps the last one in Portugal—had been in operation until quite recently. The type of ore mined here was a mixture of arsenopyrite, pyrite and galena, with some sphalerite, stibnite, etc. and quartz as the main gangue mineral. Gold was present either as native gold or intimately intergrown with other minerals, notably arsenopyrite. The gold concentrations varied between 5 and 25 grams/ton. Silver content from silver-rich galena as well as from alloys with gold could reach 200 grams/ton and more. We have good reason to assume that the ore mined during Roman times was similar in composition and precious metal content.

Taking Pliny's remarks at face value, Roman gold ore beneficiation from Três Minas could have been carried out in a sequence of steps illustrated in the flow chart (Fig. 4). This schematic diagram leaves an option for the recovery of native gold prior to the treatment of the gold-containing complex ore. As the deposit is rich in silver as well, the separation of the precious metals, after cupellation, was probably the final metallurgical step, either performed on site or in a special refinery. Refined gold (aurum obliatum) was mandatory for the minting of Roman gold coins.

Contrasting the ancient descriptions of Pliny along with modern principles of process metallurgy serves to understand better an ancient, technologically-advanced metallurgical process for the recovery of precious metals. The metallurgical flow chart will assist as a model for further archaeological excavations of the various industrial, gold-processing sites at Três Minas. It is ample proof of the interdisciplinary nature of archaeometallurgical research.

Hans-Gert Bachmann

References

Romano-British coins from Richborough, Kent

During the excavation of the Roman Saxon Shore Fort at Richborough in Kent, a small hoard of coins (Fig. 1) was discovered which were thoroughly corroded together. The find was published in the coin report for Richborough (Reece, 1968) where a date of the second quarter of the fourth century AD was suggested. The only visible feature on any of the legible coins on the surface of the hoard was a PROVIDENTIA AVGG reverse type of Constantine I (AD 306–337) which would have been issued between 324 and 326.

This group offered a rare chance to investigate a hoard of coins where the individual coins are still stacked in original positions. The idea was to see if the compositions of the coins change relative to their position and degree of corrosion within a hoard. This project was part of my doctoral research, supervised by Drs Richard Reece and John Merkel, at the Institute of Archaeology, University College London. Usually, the degree of corrosion on coins from the exterior of a hoard is worse than in the centre. It was decided to investigate the range of compositional variation between apparently identical coins in relation to the position of each coin within the Richborough hoard. This information would also be used in conjunction with the analyses of numismatically comparable issues discovered at Tingrith (Deacon, 1990). Using the same issue of coins practically as test blanks of the same composition buried in different environments, enables the post-depositional modification suffered by these coins to be assessed over a period of some 1,668 years.

In order to accomplish this task, it was first necessary to record accurately the relative position of each coin within the corroded hoard in three dimensions. Various possible methods of doing this were considered, ranging in complexity from simple cardboard models up to sophisticated photogrammetric imaging techniques. It was eventually decided to use a computer-aided design (CAD) programme called Microstation (Intergraph Corporation, 1991). This was chosen mainly because of its ability to interface directly with database programmes as well as providing a relatively user-friendly interface.

Although primarily intended as a design programme for architects and engineers, Microstation also has the ability to draw simple standard shapes from sets of Cartesian co-ordinates. In this case it was necessary to reduce each coin in the hoard to a set of three co-ordinates relating to three arbitrarily selected points along the edge of each coin. This was done using a Reflex Metograph in the Department of Photogrammetry.
UCL. This measuring microscope is capable of recording the position of a given point in three dimensions and writing the information to disk as an ASCII file. The coordinates in the file were then read into dBase III plus, one of the data base programmes with which Microstation can be linked. A user command programme was written which instructed Microstation to read the coordinates from the data base and use the data to draw a series of circles corresponding to the coins in the hoard, each coin being given a unique number.

Once the relative coin positions in the hoard were accurately recorded (Fig. 2), the concretion was carefully dismantled. The cleaning and dismantling of the corroded hoard was accomplished mechanically, using a scalpel. The coins were given a quick cleaning in order to enable an exact identification against the assumption that all of the coins were the same issue. It was apparent that the degree of corrosion differed quite considerably from area to area. Some of the coins around what, for convenience sake, may be termed the 'top-front' of the hoard were visibly more corroded than those elsewhere. The original orientation of the hoard was not recorded by the excavator (Cunliffe, 1968).

Each coin was sampled by drilling two or three small (0.8 mm) holes into the cylindrical edge and collecting the metal. The first millimetre or so was discarded to avoid the corrosion products on the surface. The degree of corrosion varied: one of the coins was totally mineralized whilst others were affected by intergranular corrosion to a considerable depth, despite being clearly identifiable. Those coins which were positioned to the exterior of the hoard were more corroded than those which had only a small segment of the edge exposed. Many of the coins retained some of the white-metal (silver) coating which had covered them when new. This coating was usually found in the corrosion products surrounding the coins, having been lifted from the coin's surface by the corrosion.

Drilled examples from 73 coins were analyzed by atomic absorption spectroscopy. Routine methods were used for the determination of copper, lead, tin, zinc, silver, iron, nickel, arsenic, gold and antimony (see Hughes et al. 1976). The analyses were conducted in three batches which were run consecutively. The same sets of standard solutions and standard reference materials were employed for each batch to improve analytical consistency. Antimony and cobalt levels were found to be too low at the initial dilution (10 mg to 25 ml), to achieve the desired accuracy for this study. Consequently, these two elements were run again using fresh solutions of a higher concentration (10 mg to 10 ml).

The compositional results were broadly consistent with the previously gravimetric analyses of these issues reported by Cope (1972). However, statistical methods revealed significant differences between the compositions of the Richborough coins and identical issues from the Tintagl hoard. A total of 20 coins of the same issue also were analyzed from Tintagl. To establish whether the compositional differences were statistically significant, standard t-tests were conducted. The results show significant differences in compositions between the Richborough and Tintagl hoard for the following elements: nickel, lead, gold and silver. The concentrations of tin, zinc, iron and arsenic were similar. The size of the sample population and the limited number of elements allows the use of t-tests without encountering problems asso-

Fig. 2. This three-dimensional computer model of the hoard of coins was made before cleaning and dismantling of the corroded hoard.

ciated with 'multiple comparisons' (Miller, 1966). The observed statistical differences are not spurious. The t-test comparisons were also applied to coins from the Tintagl hoard which were not the identical issue to those in the Richborough hoard. It was unexpected that the compositions were again not significantly different. As a control, t-tests were also conducted on two random samples taken from the Richborough hoard alone. The results did not show significant differences in composition.

Together with the data base feature, the three-dimensional computer image (Fig. 2) was used to identify similar compositional data. For example, coins with silver concentrations over 0.7% could be highlighted and the image rotated to examine relative positions of these coins in the hoard to study the effects of differential corrosion relative to coin positions and elemental compositions.

In summary, this brief report proposes a potentially routine technique for the recording of three-dimensional objects. Microstation proved very powerful as a documentation and research tool for technical studies of ancient coins. The compositional data were studied in relation to the positional data for the coins in the Richborough hoard. This is a new approach. There is considerable potential for exploiting this approach for technical studies of coins as well as documentation of three-dimensional objects for archaeological conservation.

Matthew Ponting

References
Pre-Dynastic Iron Beads from Gerzeh, Egypt

Sir Flinders Petrie (1914/5) and G. A. Wainwright (1932) described two groups of 'Iron Beads' that had been found in Pre-Dynastic graves at Gerzeh, 70km south of Cairo. Both authors claimed that the beads were of Pre-Dynastic date (about 3000 BC) and that, at the time the beads were discovered, they were the most ancient iron artefacts ever recorded. A technical study of several examples of the beads revealed only that the composition was entirely of limonite (a hydrated iron oxide). There was no remaining metallic iron.

All of the 'iron beads' from this collection, now at the Petrie Museum at University College London, are thoroughly corroded (Fig. 1). Only three beads remain; Nos. 10,738 through 10,740. Their dimensions are roughly 15–16mm in length and variable in diameter with 12mm, 5.5mm and 3mm. The weights are approximately 1 gramme. Reportedly, these beads formed part of a necklace in which metallic iron cylinders had originally alternated with precious and semi-precious stones. Petrie (1914/5) claimed that these beads were made by 'flattening' small pieces of metallic iron which were then bent into cylindrical shapes. Gowland and Bannister (1927) agreed. Based upon folds, or creases, observed along the cylindrical axis, the beads appear originally to have been metallic iron (Fig. 1). This phenomenon is characteristic of folding metallic iron and not drilling through a mineral specimen of brittle, inflexible limonite.

In an early metallurgical study of the beads, Gowland (1927) reported that an analyzed bead consisted of 78.7% of ferric oxide and 21.3% combined water. However, Desch (1929) reported that another one of the beads contained 92.5% iron and 7.5% nickel. Such a composition would be typical for meteoric iron. Wainwright (1932) emphasized this to be 'proof positive' of the meteoritic origin of the iron metal. Nevertheless, Desch (1929) did not give any indication of the analytical method used, nor did he describe the corrosion state of his sample. These results, presented as weight percentages of iron and nickel, are presumably normalized from analysis of the remaining corrosion products. The meteoric origin of the iron used for these beads is accepted as plausible by Buchwald (1975) based upon corrosion models suggesting greater loss of nickel than iron under such burial conditions. Reworked meteoric iron is the interpretation usually accepted today as the explanation for the occurrence of metallic iron artifacts from such early archaeological sites. A rare alternative source of native metallic iron in Egypt is very unlikely indeed.

Due to the archaeometallurgical significance of these corroded iron beads, small samples, up to about 0.5mm, were scraped from the surface of the smallest of the beads and mounted for electron probe microanalysis (EPMA) in the Department of Mineral Resources and Engineering at Imperial College, University of London. Microscopy documented that the corrosion products taken from the surface consisted mainly of porous, hydrated iron oxide (limonite). This mineral encloses small, rounded sand (quartz) grains (Fig. 2). These identifications were confirmed with EPMA. Despite careful search, no metallic iron or common slag minerals were observed. The rounded quartz grains most likely derive from the burial environment having been incorporated into the greater volume of the corrosion products.

Numerous microanalyses of small areas, measuring about 20 x 20 microns, were made on the polished section of the corrosion products. These areas were selected to characterize the iron oxide corrosion products, without inclusion of the quartz grains. The weight percent range of elemental compositions based upon eleven analyses are as follows:

51–59% Fe
0.0–0.2% Ni
0.03–0.5% Cu
2.0–4.0% Si
0.1–5.0% Ca
0.0–0.5% Na
0.0–0.3% P
0.0–0.2% K
0.1–2.2% Cl

Traces of Ti, Ag and Au were also noted. The concentra-

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Fig. 1. Three 'iron' beads from the Pre-Dynastic grave at Gerzeh now in the Petrie Museum collections. The narrowest bead shows clear indications of having been bent into a cylindrical shape. (Actual size)

Fig. 2. Photomicrograph from the electron microprobe of the corrosion products from the analyzed bead. The image shows the quartz grains surrounded in the matrix of iron corrosion products.
tions of iron, along with the low totals, are characteristic of limonite. The ranges for Ni and Cu are most significant.

The concentration range for nickel is much lower than that indicated from the earlier analyses by Desch (1929). While the new analytical results would not completely rule out the possibility of meteoric origin (Photos, 1989), the lower concentrations below 0.2% Ni do certainly decrease the strength of the argument. Although both sets of analyses were done on corrosion products, the earlier set by Desch did include a larger sample; most likely the whole bead. To resolve this matter, a new metallographic section across one of the remaining beads would be required. This could confirm or reject the hypothesis that the bead was originally metallic. Microanalysis may also discover any remaining metallic iron within the corrosion products.

It is important to establish the origin of this Pre-Dynastic iron metal and this is where the observed copper range in the corrosion products is important. It is uncertain whether any copper or copper alloy artefacts were also in the same grave with the beads. If the copper is, indeed, a component of the original iron metal, then the implication would be that the iron may be a by-product from copper smelting. Again, a section would be necessary to establish the distribution of copper within the iron corrosion products. Investigations of copper in corroded iron artefacts from Timna by Gale et al. (1990), simply report the presence of copper based upon X-ray fluorescence analysis (XRF). Chronologically, these 'iron beads' from Pre-Dynastic Egypt would be comparable to the Late Chalcolithic or Early Phase of metallurgical activities in Rothenberg's (1990) table for the Sinai-Arabah. At this time, copper smelting was conducted using iron ore flux, which could be the actual source of the smelted iron.

References


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Analytical Investigation of Crucible Steel Production at Merv, Turkmenistan

According to the early Islamic texts, three methods are described for indirect production of steel (fulad) as discussed by Allan (1979) and al-Hassan and Hill (1986). The most common, traditional method is solid state carburization of wrought iron. There are many variations on this method. It is also known as 'case hardening' or in other instances 'cementation'. This is a diffusion process in which wrought iron is packed in crucibles or a hearth with charcoal, then heated to promote diffusion of carbon into the iron to produce steel. Alternatively, another indirect method uses wrought iron and cast iron. Although there has been some uncertainty on the translation of the word dana in Islamic texts, the cast iron interpretation is generally accepted (Allan, 1979). In this process, wrought iron and cast iron may be heated together in a crucible to produce steel by 'fusion'. This is also called a 'viscous liquid diffusion process' (Needham, 1958) and may operate below the melting point of true cast steel (Smith, 1960). A third indirect method to produce steel is partial decarburization of cast iron or a high carbon steel bloom. Again, there are variations of this method, but generally it is considered very difficult to control (see Rostoker and Bronson, 1990). Outside the Islamic textual evidence, inadvertent direct production of steel during bloomery iron smelting represents another possibility, but it is not considered here in the context of an indirect or multi-stage process to routine production of steel. A detailed account of the many variations is presented by Rostoker and Bronson (1990). It is against these three main methods for indirect steel production, this preliminary report concerns the archaeometallurgical evidence and its interpretations for early Islamic times at Merv, Turkmenistan.

The archaeometallurgical investigations at the Islamic site of Merv represent only one aspect of an international collaborative project under the direction of Dr Georgina Herrmann and Dr K. Kurbansakhatov. The organizations involved in the International Merv Project are the Institute of Archaeology, University College London, YuTAKE (the South Turkmenistan Multi-Disciplinary Archaeological Expedition), Turkmen Academy of Sciences, Ashgabat, and the Institute for the History of Material Culture, St Petersburg.

During the 1993 season at Merv, two areas with surface concentrations of crucible fragments, green 'glass' fragments and slagged furnace fragments have been located in the survey in area MGK 7.F.II. The scatter of pottery around and within the archaeometallurgical remains in MGK 7.F.II at Merv is predominantly dated as Early Islamic, perhaps 8th or 9th century AD, by the archaeological team. A small-scale excavation was conducted in the 1994 season (Fig. 1) by Dr K. Kurbansakhatov, D. Connolly, St. J. Simpson, Ann Feuerbach and other members of the International Merv Project.

Fragments of crucibles, furnace walls and tuyeres, as well as the glassy slag, were collected from the metallurgical dumps by Dr J. Merkel for technical investigation in the Wolfson Archaeological Science Laboratory at the Institute of Archaeology, UCL. The analytical work is undertaken, in part, as supervised M.Sc. research in archaeometallurgy by Ann Feuerbach. The metallurgical
process has now been identified as crucible steel production, based foremost upon the presence of abundant carbon steel droplets in the glassy green slag adhering to the inner surface of crucible fragments collected from the two areas. The steel is identified using etched metallographic sections and microhardness measurements (Hv 140–320). Against metallographic standards, the carbon concentrations of the steel droplets seem to range from <0.1–0.8%. The structures are characteristically variable proportions of pearlite and ferrite. Microanalysis also detected silicon and sulphur in the iron droplets. The droplets range in diameter up to approximately 0.3mm, but most droplets are too small for microhardness and adequate etching for microstructure identification. Quantitative microanalysis of the steel droplets for phosphorous and other possible alloying elements will follow. The Merv oasis is alluvial and without local iron ore deposits, so iron smelting locally is very unlikely. Steel production at Merv was probably based upon recycled wrought iron scrap.

Qualitative compositional analysis (SEM/EDS) of the associated green ‘slag’ adhering to the interior surface of a crucible fragment (Fig. 2) identified silicon, aluminium, calcium, iron, manganese, magnesium and potassium. The ‘slag’ does not have a crystalline structure; it is a glass with a variable composition. Concentrations for calcium, potassium and aluminium from the SEM/EDS, however, are quite different from those typical for glass. Fragments of the glassy green slag are observed to melt under reducing conditions in an electric furnace at a temperature of about 1250°C. This is a temperature below the melting point of true cast steel (Smith, 1960). Several glassy slag fragments exhibit viscous flow patterns which will be investigated. Some crucible fragments indicate the upper level of the molten crucible contents as a ‘fin’ of glassy green slag (Fig. 2). It is this slag which contains abundant steel droplets. Above this ‘fin’ of slag, the adhering pattern of corroded iron is interpreted as ‘splashes’ onto the upper crucible wall. Of course, these forms will be investigated in detail for relict structures in the corrosion products. Below the ‘fin’ appears a honeycomb pattern in the glassy slag on the inner surface which appears similar to that on the inner surface of other crucible base fragments. Similarities in descriptions of a characteristic honeycomb pattern in the slag (see Percy, 1864) as well as striations in some glassy green slag fragments suggest incomplete fusion (see Smith, 1960).

Crucible fragments are variable in thickness and condition, but appear to represent a single type. Wall
thickness ranges from 0.5–2.5cm. Fragmented circular segments with a reconstructed outer diameter of 6–8cm and a thickness of about 0.5cm are interpreted as crucible lids. These fragments have a central perforation of about 1cm in diameter and the outer edges exhibit evidence of a clay seal to a crucible wall. The use of a luted, perforated lid is a variation in accounts of traditional steel making in crucibles during the 19th century (see Rostoker and Bronson, 1990). The thinner fragments and lids are interpreted as having been fired at high temperatures under reducing conditions. The thickest fragments have a light-coloured core and dark, reduction fired surfaces. Investigations of the refractory properties of the crucible fragments and furnace wall fragments will be undertaken in order to characterize the materials relative to their performance at high temperatures and to estimate the duration of firing. These would be important considerations for steel production.

Fragments of furnace wall consist of the local mud brick, but lined with crucible fragments on the interior. The inner surface is covered with a black, adhering layer of slag arising from high furnace temperature and fuel ash which has not yet been investigated. The furnace wall fragments were about 5–10cm in length and 5–10cm in height. Several are interpreted as representing corner fragments. There are examples of crucible base fragments slagged onto a lower ceramic support (Fig. 3) which was placed on the furnace bottom. During the excavations in the summer of 1994, the remains of two furnaces were discovered. The internal diameters of the circular furnaces are about 70cm, so it is estimated that a maximum of some 40 crucibles could be packed into each furnace. Part of one furnace wall was lifted from the site for technical study, currently in progress. Slag remains from melting brass were also present in the archaeologi cal layers with the furnaces. The context for the furnaces is interpreted as a metallurgical workshop involved with several different metallurgical processes.

While these archaeometallurgical samples are attributed to crucible steel production, there remain many questions and lines of evidence to investigate and many samples still to section and analyze. Distinction between the three possible indirect methods (cementation, fusion or decarburization) for crucible steel production at Merv would depend upon further discovery of minute fragments of raw materials in the glassy green slag or adhering to the crucible walls. Raw materials might include wrought iron with elongated slag inclusions, carbon impressions or components (such as rice husks in the later Indian examples presented by Lowe et al. 1991) or perhaps even cast iron coatings on wrought iron droplets. Final products such as ingots or fragments may not necessarily be conclusive enough to distinguish between fusion or cementation. For the interpretation of these archaeometallurgical specimens from Merv, the most salient observations relate to the abundant steel prills of variable carbon content in a relatively small amount of glassy green slag with a melting temperature of approximately 1250°C adhering to the inner wall of crucible fragments. Further excavations of the archaeometallurgical remains are anticipated.

We would like to acknowledge the valuable advice of Dr G. Herrmann, Dr I. Freestone, T. Lowe, Dr B. Gilmour, Professor H-G. Bachmann and others on the investigation of these remains.

John Merkel, Ann Feuerbach and Dafydd Griffiths

References

From the Director’s Desk

It is with a deep sense of sorrow that we have to announce to our readers the death, early in 1994 of Sir Alistair Frame, Trustee of IAMS since the late 70’s. Since IAMS was founded in 1973 on the initiative of Sir Val Duncan, Chairman of the mining group Rio Tinto Zinc (RTZ), a tradition developed through Sir Mark Turner, the next Chairman, that the RTZ chairman takes an active interest in our research and teaching activities and joins the IAMS Board of Trustees. In the early 1970’s as technical director of RTZ, Sir Alistair became involved in our archaeo-metallurgical survey in the ‘copper belt’ of south-west Spain. When Sir Alistair became chief executive and deputy chairman of RTZ, he initiated one of IAMS’ major research projects: the systematic, large scale excavations in the mining region of Rio Tinto (Huelva). Sir Alistair’s steadfast support as Chairman of RTZ and wise council, and his often-needed active intervention, made it possible to successfully conclude our work in Rio Tinto, despite the difficult local political conditions which arose after closing-down copper production at Rio Tinto.

The volume Early Rio Tinto, the publication of our almost 15 years of archaeo-metallurgical fieldwork in the Rio Tinto region, which is now in preparation, will present a major new chapter in the prehistory and ancient history of metals of Western Europe. We intend to dedicate this volume to the memory of Sir Alistair Frame since this important project would not have succeeded without his keen interest.

Sir Alistair’s shrewd judgement, constructive imagination and initiative, and, foremost, his kindness and friendship, are being missed by us all.

The Department of Material and Data Science was recently established at the Institute of Archaeology, University College London, to facilitate closer collaboration of science-related research and teaching of specialist staff working on technological studies of archaeological inorganic materials. This new development will provide a new research focus and a base for international scientific collaboration. A great deal of work has already been in progress, including IAMS research projects. The new JEOL Electron Probe Microanalysis facilities at the Wolfson Laboratory for Archaeological Science, housed at the Institute of Archaeology, makes it possible to develop archaeometallurgical research to a new level of technological sophistication. The impact of the JEOL microprobe is apparent in the leading article on Neolithic copper smelting in this issue of the IAMS journal, as well as the continuing work by Dr John Merkel and Dr Dafydd Griffiths on the precious metal artifacts from the Sican burial at Batan Grande, Peru.

We welcome Professor El-sayed El-Gayar, our new Scientific Visitor from Suez Canal University, Egypt. Professor El-Gayar has for several years carried out metallurgical research at the Department of Mineral Resources Engineering, Imperial College of Science and Technology, London, and published papers on ancient Egyptian iron. He is now taking part in a IAMS research project on ancient Egyptian metallurgy, working on early iron objects and copper-working relics from Egypt in the Petrie Museum of University College London, as well as the IAMS teaching collection at the Institute of Archaeology. We also wish Professor El-Gayar much success in his endeavour to establish an archaeo-metallurgical research institute in Egypt.

An international conference on ‘Ancient Egyptian Mining, Metallurgy and Conservation of Metallic Artefacts’ took place in Cairo between 10–12 April 1995. The sponsors of the conference were the Egyptian Ministry of Culture, the Supreme Council of Antiquities (S.C.A.) Egypt and the Institute for Archaeo-Metallurgical Studies (IAMS). The Conference Patron was Mr Farouk Hosni, Minister of Culture, and the Conference President Professor Abd El Halim Nour El Din, Secretary General of S.C.A. Many members of IAMS participated in this major conference on so many aspects of Ancient Egyptian metals. Dr Kamal Barakat was the Administratve Organizer.

The paper on Neolithic Copper Smelting in the Arabah published above is intended to form the ‘platform’ for a professional discussion of the issues involved. We would particularly welcome comments by our colleagues about the culture-historical ‘location’ of the sites and the process model proposed and any information of comparative sites elsewhere.

Our excavations, since 1965, of a series of prehistoric smelting sites and mines in the Southern Arabah, produced a unique series of archaeo-metallurgical samples, representing the basic steps, through some 3000 years of metals processing developments, toward the optimal Late Bronze Age extractive copper technology. To our knowledge, this is a unique research situation, which made it possible for the first time to follow in detail the impact of the basic parameters of the copper smelting process, as and when they first appeared in the development of copper smelting. This current IAMS research project will be published by Beno Rothenberg and John Merkel as The Prehistory of Copper in the Arabah. It will be number two in the IAMS Monograph Series.

Since we have had a number of inquiries from colleagues and students about the publication dates of Researches in the Arabah, Volumes 3 and 4, the final reports on our excavations in the mines and smelting sites of the Western Arabah, we would like to inform our readers about a major editorial change causing some delay of the publication. Because of the unique nature of the Arabah Project, systematically excavating for 30 years in the prehistoric to medieval mines and smelting sites of the Western Arabah, the IAMS Editorial Board proposes to publish this extensive project as an integrated, comprehensive history of copper in the Arabah. This new ‘format’ will make it possible to reconstruct the story of complete copper industries, including also their organisation, layout of workshops, logistics and environmental and socio-economic parameters, from the mine to the smelters and to the finished metal objects, for each recognized archaeological period from the Neolithic beginnings of copper production in the 6th millennium BC to the Islamic Period. We intend to publish Volume 3 of Researches in the Arabah, The Ancient Mines and Smelters of the Western Arabah, as a two-part set in 1995–6.

Milton Ward, Chairman, President and Chief Executive Officer of Cyprus Amaz Minerals Co. and a IAMS Trustee, has been named the Copper Man of the Year by the Copper Club, New York. The award to Milton Ward was announced at the annual festive dinner of the Copper Club in New York City. The Trustees of IAMS and its Scientific Committee congratulate Milton Ward on this prestigious Copper Club Award.
Review


The publisher launched this book on 24 March 1994 in London in the rooms of the international magazine Metal Bulletin. The date was the 500th birthday of Georgius Agricola and had been deliberately chosen for the publication of the book in homage by an expert journalist to the founder of modern metal mining. We are indebted to Arthur Wilson for several books and his writings on mining, as well as biographies of some of its outstanding representatives. Regrettably, he died just a month before publication.

After all his previous publications, one might have high expectations of this book with its ambitious subtitle of "The story of metals since earliest times and their impact on developing civilization". During the past years a lot has been written about the beginnings of mining and early metal production. The more metal mining became a thing of the past in Europe, the more keenly and eagerly it was studied. However, this publication is based on different motivations. When a journalist, completely in command of his profession and who has been acting as press officer for international mining concerns for a long time, writes about it, higher expectations and demands are made upon him. The book is convincing by way of profound knowledge of the subject matter and succinct wording.

Selected chapter headings incite interest in the book: 'Mediterranean Merry-go-round' (i.e. metal production and trade in the Mediterranean from pre- and early historic times to antiquity), 'The Ships of Tarshish', 'What the Romans did', 'Renaissance', 'After Agricola', 'Mining by the sword' (The conquest of South and Middle America driven by obsession for precious metals), 'Gone to the diggings!' (Gold rush as a sign of the times in the 19th century) and so on. Every one of the twenty chapters in the book stands for an era or period in history and the metals dominating in each period.

It is the course of history primarily which provides the framework for mining, discoveries, new techniques, economy and metal based developments in culture and civilization. Great, world changing events merge with details of local happenings into a kaleidoscope. The author's experience and know-how is yet again shown by how supremely well the contexts are recognized, defined and made plausible to the reader. It is not the well-known facts and events contained in every history book which are used here to bring history and the role of metals to life in this popular book but the inclusion of new, recent research results showing that the author has, throughout his life, maintained contact with scientists in this field and visited many archaeological excavation sites himself.

Arthur Wilson's activities in industry and experience gained in the metal business have enabled him to combine new conclusions about the beginning of mining and metal production with the mining economy of today. The transition from antiquity via the early New Age up to our age is seamless and the book well indicates Wilson's talents as an intermediary and communicator. His earlier, exciting reports in books and articles on large mining concerns of the 19th and 20th century and unconventional, often inspiring, personalities from the mining world were taken from his direct professional environment. The breadth of this latest book crowns all his earlier writings. It is a very personal review of the history of metal by a professional journalist. We are grateful to Arthur Wilson for his legacy. His name will always be linked with metal with respect and recognition.

Professor H.-G. Bachmann

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