Chalcolithic, 5th Millennium BC, Copper Smelting at Timna

New radiocarbon dating evidence for Timna Site 39

The earliest copper smelting furnace and workshop found up to date - Site 39 in the Southern Arabah (Israel) - and the copper smelting technology it represented (at the time of its discovery the earliest known anywhere), was dated by diagnostic archaeological finds to the Chalcolithic Period (5th-4th millennium BC). This date was of fundamental importance for the history of metallurgy - and became the subject of repeated controversies mainly based on the lack of scientific confirmation by C14 (see IAMS No. 15/16, 1990, 9-12). A recently obtained radiocarbon date of an ash sample from the excavation of Site 39 by the Oxford University Acceleration Unit was (calibrated) 4460 BC (95.4% confidence) 4240 BC, which fully confirmed the archaeological date proposed at the time by the excavators of Site 39. Site 39 is the earliest Chalcolithic smelting site recorded in the Near East.

Contents

Professor Beno Rothenberg and Dr J. Merkel

Professors B. Rothenberg, C. T. Shaw, F. Hassan and A. A. A. Hussein
Renaissance Survey of Ancient Mining and Metallurgy in the Mersa Alam Region, Eastern Desert of Egypt, p. 4

D. Levene
Expedition to Atika, p. 10

Dr C. Merideth
A Western Cretan Cassiterite Survey 1992-96, p. 14

Dr S. Srinivasan and Dr I. Glover
High-Tin Mirrors of Kerala, South India, p. 15

From the Director's Desk p. 17

Professor H-G. Bachmann
A Note on 'free-silica slags', p. 18

Reviews: The Sounds and Color of Power: The Sacred Technology of Ancient West Mexico, by Dorothy Hosler; and Early Metal Mining and Production, by Paul T. Craddock, reviewed by Professor H-G. Bachmann, p. 19

The archaeology of Site 39

Site 39, located in the Wadi Nehustan in the Arabah Valley, at the entrance to the modern Timna Mines Co, is one of many prehistoric copper smelting sites on the foothills along the western fringe of the southern Arabah Valley. Discovered by Rothenberg in 1960 (Rothenberg 1962, 58-60), it was excavated in 1965 (Rothenberg, Tylecote and Boydell 1978; Rothenberg ed. 1990, 4-8). The site (Fig. 1) consisted of an oval-shaped, enclosure-like, line-up of small working places (29x23m) and three ruined buildings, one of which was excavated in 1965 (Site 39A). From this workshop a well-trodden ancient path led up the adjacent hill and here, right above the workshop, a concentration of small slag lumps, ore nodules, charred, slagged rocks, stone mortars and pestles indicated the smelting location of Site 39 (Site 39B). A number of diagnostic flint objects were found on the surface of Site 39A and B during the survey, before the excavation of the site.

Site 39A: Already before the excavation, the finds at the actual work locations (forming the oval 'enclosure') - crushing tools, nodular copper ore, flint implements and a quantity of small, crushed slag lumps - indicated metallurgical activities, though there was no evidence for actual smelting at Site 39A. Ephraim Yevin dated the flint tools to the Chalcolithic period, a date later confirmed by Professor M. Stekelis,
primitive smelting 'installation' found anywhere, especially if compared with the advanced Egyptian New Kingdom smelting furnaces of the Timna sites nearby. Slagged and sintered pieces of unlined furnace wall were found scattered around the furnace together with some slagged rocks from the superstructure. Many small, crushed or broken pieces of slag were found dispersed around the furnace but also over much of the hill top, indicating that there must have been more than one furnace operating at Site 39B, so far undetected.

The viscous, non-tapped slag contained a lot of metallic copper pellets and was obviously raked out of the furnace at the end of the smelting process and crushed to small fragments in order to mechanically recover the entrapped metallic copper. The analysis of the slag proved that fluxing with iron oxide was already known at Site 39, though it was still lacking the proper control of the smelting charge and other process parameters. As such, the slag of Site 39 represented a distinct type, characteristic for the first step in the Chalcolithic period towards advanced copper smelting (Rothenberg and Merkel in press). On the hard surface around the furnace a number of archaeological finds were found: flint implements (Fig. 4) and a few sherds, besides many small lumps of crushed slag. It is important to point out that this hard surface went right up to the kerb of the furnace and was evidently the actual working floor of the furnace and the finds on it were in situ. The flint tools found on this floor, the same as all the flint implements found at Site 39A+B, date to the Chalcolithic period.²

Site 39B: The copper smelting furnace found in the excavation (Fig. 3) was a simple, bowl-shaped hole-in-the-ground (about 25-40cm in diameter and 40cm deep), with a low superstructure of small rocks (Rothenberg et al. 1978, 6-7). It was the most

Fig. 2 The excavated habitation of Site 39A. At the right lower corner near the entrance, the cooking stove (source of the ash sample for the new C14 dating).

Director of the Department of Prehistory, Hebrew University, Jerusalem (Rothenberg 1962, 8: chapter III).

The building excavated at Site 39A (Fig. 2) was an oval structure, 4.5x5.5m, about 1.5m high, which apparently had served as the enclosure of a hut-like structure of wood, skin or cloth. It had a circular pebble floor in its centre and next to it a small pit full of dark ashes, apparently a fire place. This structure must have served as a habitation as no signs of any other use were found. The archaeological finds inside this structure included numerous flint tools and flakes, some pottery, several simple hammerstones and animal bones. Right next to the entrance to this building was a small cooking stove, found still full of ashes. The ash sample for the new, recent C14 dating originated from this stove.²

Site 2: The copper smelting furnace found in the excavation (Fig. 3) was a simple, bowl-shaped hole-in-the-ground (about 25-40cm in diameter and 40cm deep), with a low superstructure of small rocks (Rothenberg et al. 1978, 6-7). It was the most

Fig. 3 Site 39B: the smelting installation.

Fig. 4 Typical Chalcolithic flint axes from Site 39.

Dating Site 39: The smelting technology of Site 39, with its typical rather primitive furnace and slag, represents an important step in the development of copper metallurgy (Rothenberg, ed., 1990; Rothenberg and Merkel in press) and its secure dating is, therefore, of considerable importance for archaeo-metallurgy.

In the recent excavation at the late Chalcolithic site of Abu Matar, near the town of Beersheba (Gilead et al. 1992), crushed slag pieces, pieces of copper ore and crucible and smelting furnace fragments were found which, for the first time, proved that not only metallic copper was worked at this settlement but that copper was also smelted there from imported ore. Most of the slag of Abu Matar and other Ghassulian-Beersheba culture sites in the Beersheba region, looked very similar to the slag of Site
The 'controversy' about the date of Site 39

In 1973, J.D. Muñly voiced his doubt about any site in Timna dating to a period before Early Bronze II, although at that time the archaeological finds of Site 39 had not been published and Muñly could not have seen them without our knowledge in the store of the Arabah Expedition. Muñly argued: 'While little of the early material has been published thus far, it seems doubtful that anything at Timna is really earlier than EBIII (Early Bronze II - 2850-2650 BC). In his 'review' of our Timna research in 1984 - i.e. after the publication of our monograph about Site 39 and Barocvic's paper on the date of the flint finds (Rothenberg et al. 1978) - Muñly (1984) goes even further: 'I know of nothing found at any of the mining or smelting sites at Timna that need to be dated earlier than the later part of the Egyptian New Kingdom...Rothenberg has never published any hard evidence in support of the Chalcolithic dating of Site 39.' Muñly (1984) even suggested that the flint objects of Site 39 may be as recent as the Iron Age. At first, several prehistorians and, especially, archaeo-metallurgists dealing with the region had accepted the Chalcolithic character and date of Site 39 (Bachmann 1978, 22; Tylecote 1962, 25-29; 1976, 6-7; 1978, 28-29), it did not make much sense to enter into an argument with Muñly, who is a historian and not a metallurgist or archaeologist, about the lithic industries of the Arabah and Sinai or about prehistoric extractive metallurgy. However, since Muñly was repeatedly quoted as the expert for the date of the metallurgical sites of Timna and Sinai, one of the present authors (B.R.) published what he considered to be convincing arguments against Muñly's opinionated views, hoping that this would bring an end to this rather futile situation (Rothenberg 1987, 1-7; 1990a, 9-12). Since Muñly's views about the date of Site 39 and its metal technology are still being quoted as factual evidence when considered convenient (e.g. Adams and Genz 1995 19 n.4), we once more mention this 'controversy', which now, after we have obtained a C14 date for Site 39, seems even more out of place.

A new C14 date for Site 39

As mentioned above, a sample of ash from the cooking stove of Site 39A was recently located among the findboxes of the excavation and dated by the Acceleration Unit of the Research Laboratory for Archaeology and the History of Art, Oxford University:

Timna Site 39, Israel

OxA-7632 Timna 39, 15, charcoal, ? ash 5485 ± 45 BP
Calibrated (M. Stuiver and R.S.Kra eds. Radiocarbon 28 (2B): 805-1030, we receive the date: 4460 BC (95.4% confidence) 4240 BC.

The new C14 date of Site 39 in the 5th millennium BC provides significant support for the concept of several metallurgical developmental phases within the Chalcolithic period, towards the end of which stands the Ghassulian-Beersheba metallurgy as found at Abu Matar. Site 39 evidently represents a very early, perhaps even the earliest step towards proper copper smelting technology and as such has a secure place in the history of metal.

Beno Rothenberg and John Merkel

Notes:

1. The earliest smelting workshop found to date is Site F2 in the Timna Valley, which is dated Late Pottery Neolithic - see IAM 1995.

2. The (late) archaeologist Ephraim Yeivin was in charge of the excavation of the workshop, whilst Rothenberg was excavating the furnace on the hill above. Because of sudden illness, Ms Yeivin left the excavation at the end of its first week. The finds during this week were recorded by Ms Yeivin, boxed and stored. The ash sample recently radiocarbon dated in Oxford was one of these few early samples and had been overlooked. Luckily, it was noticed by its mark "for C14" when all the finds from Site 39 were taken over for permanent storage by the Israel Antiquity Authorities.

3. Right after the excavation in 1965, ash samples from inside the habitation were sent to the British Museum for C14 dating but there was not enough carbon left to date the samples. The sample of ash recently dated by the Oxford Accelerator Unit was one of the first samples taken by Ephraim Yeivin.

4. The flint objects from the excavation of Site 39 were published by A. Barocvic (in Rothenberg et al. 1978) and dated to the Chalcolithic period with similarities to the Ghassul and Beersheba flint industrieties of the late 4th millennium BC. However, no traces of the Ghassulian-Beersheba culture have ever been found in the Arabah mining regions, not at Fenan or at Timna, and the flints of Site 39 do in fact belong to a local, almost pure flake industry and in spite of some similarities to the Ghassulian, is, according to our surveys in the Arabah and Sinai, of a much wider chronological range, i.e. the 5th to 4th millennium BC. See also Rothenberg and Glass 1992.

5. See Rothenberg, 1990a, 9-12, for a previous review of the dating controversy on Site 39.

6. Adam and Genz (1995) published their excavation of Fidan 4 as "A Chalcolithic village complex" in the Fenan region. According to the character of the archaeological finds from this excavation, the lack of any pottery and flint typical for the Ghassulian-Beersheba culture of the northern Negev, as well as the late 4th millennium C14 date quoted by the authors, we would relate the site of Fidan 4 to Early Bronze I and not to the Chalcolithic period.

References


- 1990a. The Chalcolithic Copper Smelting Furnace in the Timna Valley - its discovery and the strange argument surrounding its dating, IAM 15/16, 9-12.


- 1978. Experiments on Copper Smelting based on furnaces found at Timna, in Rothenberg et al.1978.
Reconnaissance Survey of Ancient Mining and Metallurgy in the Mersa Alam Region
Eastern Desert of Egypt

Introduction

1. Following the International Conference on Archaeo-metallurgy held in Cairo in April 1995, initiated and co-sponsored by IAMS London, the first steps were taken to set up an Egyptian Centre of Archaeo-metallurgy. It was decided to centre this organisation around a major, long-term archaeo-metallurgical field research project, which will also become a 'training ground' for students in field research methodology and the scientific processing and conservation of metal-related archaeological finds. For this purpose, the Egyptian authorities, represented by the Supreme Council of Antiquities (SCA) Egypt and the Egyptian Geological Survey and Mining Authority (EGSMA), in collaboration with the Tabbin Institute for Metallurgical Studies Helwan, (Tabbin), the Institute of Archaeology (IA), University College London, the Institute for Archaeo-Metallurgical Studies (IAMS), University College London and The Royal School of Mines (RSM), Imperial College of Science, Technology and Medicine, London, formed an international working group consisting of Professor C. Tim Shaw (RSM), Professor Beno Rothenberg (IAMS), Professor Fekri A. Hassan (IA), Dr Abdel Aziz A. Hussein (EGSMA), Professor Dr Sayid Khalil (Tabbin), Dr Kamal Barakat (SCA), Professor Dr Kamal Hussein (Tabbin), Dr Mohammed el Huwari (EGSMA), Mr Attiya Makhlouf (EGSMA).

2. The ancient Egyptians are known to have exploited a variety of mineral resources since prehistoric times. Copper and gold in particular were already used during Predynastic times, before 4000 BC, and were in wide use since the Old Kingdom. Gold mines, dating to the Predynastic and the Pharaonic periods and up to medieval times, have been located in a variety of areas of the Eastern Desert. Since the early years of this century and especially since the 80s, a fair number of geological reports have been written by the Egyptian Geological Survey and others about gold deposits and mining in the Eastern Desert (e.g. Jenkins 1925; Kochin and Bassiuni 1986; Gabra 1986) but only in recent years was systematic field research of ancient gold extraction in the Eastern Desert undertaken as a collaborative project of the Geological and Egyptological Institutes of Munich University and the Egyptian Geological Survey and Mining Authorities (EGSMA), with due emphasis on the geological, mining technological and – of particular significance – archaeological aspects. During the years 1989-93, about 150 ancient gold mines were identified (Klemm 1995; 1994; also recently Cairo Conference reports 1995; Hawary; Takia and Hussein; Osman; Tahaw; Klemm).

However, many very early, Predynastic gold mining sites showed quite extensive copper mineralisation – believed to have been the means of identifying the associate gold by the earliest miners (Klemm 1994:194) – which therefore represent for the archaeo-metallurgists a so far unsolved 'enigma': What was actually mined at these sites in Predynastic times – gold or copper or both? What were the mining techniques of these copper-gold mines and what is their chronology and culture-historical context? Recent excavations at such a site, Wadi Dara in the northern part of the Eastern Desert (Tawab et al. 1990), showed that copper was the mineral mined and smelted at this site in Predynastic times and that gold was only mined in Early Islamic times (9th century AD). Yet, although this may be correct at Dara, according to the evidence available so far, this is certainly not the whole story of gold – and copper – in the Eastern Desert and will need much further detailed investigations.

Extensive copper mineralisation in several regions of the Sinai peninsula, with about 100,000 tons of Middle to New Kingdom smelting slag of a very advanced metallurgical
character alone in one huge slag heap at Bir Nasib, was a major source of copper of Pharaonic Egypt (Rothenberg 1979, 1987). In the Timna Valley (Wadi Meneiyeh) of the southern Arabah, on the eastern fringe of Sinai, operated large-scale Pharaonic, New Kingdom (19th-20th Dynasties) copper industries (Rothenberg 1990; 1988; 1972; Conrad and Rothenberg 1980) with sophisticated mining and smelting technologies as well as a highly organised industrial organisation. These provided convincing evidence for the exceptionally high standard of development of ancient Egyptian extractive metallurgy. Although there was also earlier, evidently indigenous, pre- and early-dynastic (Late Pottery Neolithic to the end of the Early Bronze Age (Rothenberg and Merkel 1995; Rothenberg and Shaw 1990)) copper smelting in Sinai and in the Timna Valley – and presumably also in the Eastern Desert – the ultimate origin of the Egyptian New Kingdom (Late Bronze Age–Early Iron Age) peak of extractive metallurgy has not yet been traced; indeed, it is one of the unresolved riddles of early metal-related history.

Again, during the 22nd Dynasty, probably during the campaign by Pharaoh Sheshonk I in post-Solomonic Palestine (c. 920 BC), the Egyptian copper industry at Timna was revived for a short period of time. The copper smelting technique of this time, using a still more advanced furnace and tuyere type, unique slag tapping arrangements, with the sole use of manganese as (a much more efficient) flux, produced the most advanced tapped slag (containing almost no metallic copper) found so far anywhere (except also in the New Kingdom smelters of Sinai) before modern times (Rothenberg 1990: 44-57). The metallic copper produced here was of extraordinary quality and contained no iron and very little other impurities – quite exceptional for this period. A very similar smelting technology was again found at the later copper smelting sites of Edomite (Jordan, 8th to 6th centuries BC), Feinan, south-east of the Dead Sea (Bachmann and Hauptmann 1984), and seems to have reached this region from Sinai, perhaps by way of Egyptian 22nd Dynasty Timna. But where was this advanced Pharaonic metallurgy developed? It is also for this reason that it is so vital for the history of metallurgy to search for these steps in the development of Egyptian extractive metallurgy ‘closer at home’, i.e. in the mines of the Eastern Desert.

3. Tin, that vital ingredient of proper bronze, had never been found in the Near East but the presence of cassiterite deposits in the area of Wadi Muelia in the Eastern Desert (noted following a visit to the area in 1976 by Wettmer, Muhly and Rapp) was unfortunately not followed up by mining experts and has only recently been brought to the attention of archaeo-metallurgists (Rothe 1995). The cassiterite deposits were mined during the first half of this century, which most probably destroyed most of the evidence of any ancient mining. In any case, if the ancients ever worked the tin deposits of Wadi Muelia, it is most likely that they would have picked their ore from the wadi alluvium, instead of working the difficult granite, and this ‘mining’ would have left very few traces. The tin mining region was included in the survey by our group in order to establish its potential for future mining research. It should, however, be noted that a great deal of archaeo-metallurgical work has already been done in the area by a team from Minnesota University, directed by Professors R. Rapp (Rothe 1995; Rothe and Rapp 1995), including field surveys and analytical and experimental studies, and the study of the numerous hieroglyphic inscriptions of the region and beyond.

Muelia

Travelling along the Wadi Muelia, we turned into an unnamed tributary of that wadi where tin mineralisation had been exploited up to recent times. About one km from the wadi junction we came first to some Bedouin petroglyphs of camels and, more important, wasm (traditional Bedouin symbols) indicating that water could be dug there. A little further on the same outcrop of dolerite we found to a group of hieroglyphic inscriptions (recently published in a PhD thesis by R. D. Rothe, Minnesota, 1995). These inscriptions are dated to the Old Kingdom, especially to Pharaoh Neferkare Pepi II (2278-2184 BC, Sixth Dynasty), and imply that during his reign water wells were dug in this wadi (Fig. 2). The inscriptions mention several high ranking functionaries, like the ‘King’s Noble, overseer of the foreign gang’, the ‘Sealbeaar’, the ‘Chamberlain and overseer of the scribes of the crew’ and several inscriptions mentioning a ‘Ship Captain’. These inscriptions clearly indicate the presence nearby of a large working force, for which water was naturally a basic requirement. Water may also have been a basic requirement for the gold extraction process. These Old Kingdom inscriptions fit very well the assumption of large scale mining operations – the tin mines of Muelia – as early as Old Kingdom times. The actual mining area is located about three km north of the inscriptions.

Obviously the ancient miners would have exploited the placer deposits in the area. The tin weathering from the quartz veins in the area produces coarse cassiterite grains while the granites produce fine grained cassiterite. We assume that these were mined in antiquity, but since it was alluvial it was not possible during our short visit to identify any old mine workings.

Upon returning from the tin mining area down the Wadi Muelia, about 2-3 km from the wadi junction, in a small side arm of the wadi, a group of ring-shaped, stone-built tombs, with standing slabs surrounding the base, were identified. There were at least seven tombs, approximately 4m in diameter, 80cm high, with walls ranging in thickness from a metre to 60cm. Our preliminary observations suggest that these are Predynastic tombs and require further archaeological investigation.

About 4 to 5km from the wadi junction leading to the Muelia mine, we encountered an archaeological site referred to by the local Bedouins as the ‘Roman City’. This is a large area of rectangular stone-built houses or workshops, now in a state of disrepair. There were a lot of Roman potsherds, but some sherds seemed to be as early as Pharaonic. One of the buildings was on top of a small knoll and was probably a lookout or defensive building of some kind. At some distance from the main group of Roman buildings, along the foot of an adjacent hill, were some rougher stone structures which appeared to be earlier than the Roman buildings. We also found many grinding stones, some obviously in situ, so either they were grinding some ore, or they were making grinding stones for use elsewhere. There are no known mines of any sort in the immediate vicinity.
Hamash

Hamash is mainly known as an ancient gold mine and is recorded as such on the latest official map 1:50,000, Bir Umm Qubur sheet (see also Klemm 1994: 221), but copper mining has also been mentioned (Rothe 1995: 174-6). In the Hamash area are several locations with ancient mine workings and building remains (Area W, Area E, Um Hagalik, Um Tundub). We visited Hamash-West, the site with the largest known complex of ancient buildings. These building remains are situated along the foot of a hill where mine workings are located.

At the north end of the site are several simple stone enclosures, probably remains of workers' huts. Further south stands a group of rectangular, uniform buildings, similar to Early Islamic army stations in the South Arabah and Sinai. Right next to these buildings, a large, multi-room structure showed several phases of construction (or re-construction), some even relatively recent. In what appeared to be a forecourt of this building, heavily burnt, ashy 'installations' indicated metallurgical activities. Similar 'ash heaps' are also to be found in the other sections of the site, perhaps from roasting of ores.

Dispersed among the buildings were pieces of broken slag 'cakes' as well as lumps of rough, viscous furnace slag and many slagged stone furnace fragments. Obviously, smelting had taken place all over the site. A heap of several tons of particularly dense and homogeneous tapped slag was located right next to the large multi-room building, indicating that major smelting activities must have taken place there.

As much as could be established by visual inspection of the metallurgical debris, there seemed to be evidence for various extractive processes having taken place at Hamash, perhaps also at different times. Much of the slag was very dense, dark black and very homogeneous, and showed no metallic inclusions; other pieces of tapped slag showed corroded copper prills on their surface. Furthermore, some of the slag was rough and viscous, obviously not tapped, and seemed to have been raked out of the furnace at the end of the smelt. However, most of the slag was tapped slag, showing on the surface the typical ripples of such a slag, and had obviously been tapped into a pre-prepared roundish tapping pit. The diameter of such a complete slag 'cake' was 40-50cm. and its maximum thickness 4 to 5cm. The smelting furnace fragments, found together with this slag but also at other sections of the site, indicated a furnace diameter of about 35-40cm.

No clay tuyeres of any kind were found at the site, a fact of considerable significance taken in consideration that at all Pharaonic smelting sites in the Arabah and the Sinai, numerous clay tuyeres were found — but none in the smelters of the Roman, the Early Islamic and later periods (Rothenberg 1990). We assume that during these later periods the bellows tube was made of iron. The same applies to stone working tools. No such tools were found at Hamash-West — the same as at the Roman-Early Islamic smelting sites in the Southern Arabah and Sinai (Rothenberg 1972: 212-23; see corrected date Rothenberg 1988).

Some plain pottery was collected on the site, seemingly later than Roman. However, we shall have to rely on C14
dating of charcoal entrapped in the slag, before we cannot say anything definitive about the chronology of the slag and the extractive operations of Hamash. However, tentatively, we suggest an Early Islamic and or later date for the Hamash-West smelting operations.

It was quite unexpected that the analysis of the slag established that at Hamash-West iron as well as copper was produced. Several slag samples from the slag heaps of Hamash have been analysed by the Tabbin Institute for Metallurgical Studies, Cairo, and were found to be iron smelting slag. Since this is the first time that ancient iron slag has been identified in the Eastern Desert, we publish these results in Table 1, below. The slag was of the fayalite-rich olivine type with a spinel phase, sometimes also with small amounts of pyroxene.

The fact that no stone tools of any kind were found at Hamash-West — neither at the site of the buildings or the smelting operation, nor at the mine on top of the adjacent hill — seems to indicate that no gold was extracted at this site in ancient times, though traces of gold may be present in the mine workings on top of the hill. Gold may have been extracted here in modern times. Copper minerals were identified both at the smelting site and within the mine up on the hill, though the main mineralisation at this mine was, according to Abdel Aziz Hussein (EGSMA), arsenopyrite and haematite. There are, however, several copper-ribbon mines in the vicinity and these would have provided the ore for the copper smelter. The haematite of the mine above would of course provide the ore for the iron smelter.

On top of the hill there were a number of possible 'plates' (the surface evidence of filled ancient mine shafts) associated with some very old looking spoil heaps. There was also access to the ancient mines, but as these had been made by modern prospecting and had been left in an unsafe state, we did not go far into these workings. Furthermore, whatever traces and tool marks the original miners had left had been destroyed. We searched for mining tools but failed to find any. We are therefore unable to say anything other than that this is apparently an ancient mining site but further research on the mining activities in the area is required before any opinion as to technology and date could be developed.

Sikeit Emerald Mines

Up the Wadi Nugrus, a tributary of Wadi Gimel, is the Wadi Sikeit, where emerald mines are located. We visited one of the several 'mining towns' of the area, which is located where the wadi widens out to form a large, oval-shaped valley. At its southern entrance, the mining temple of Sikeit is located (Fig. 3), whilst all around the valley stand the ruins of a huge complex of workers' habitations and other very large buildings, with buildings also climbing the steep slopes of the enclosing hills. The mining temple was cut into the rock face and had numerous inscriptions in Greek on it. The whole temple was carved, like Abu Simbel, into the rock but, unlike the latter, this one is falling apart. There is another small rock-carved shrine on the hill above and to the right of the main temple.

The site was littered with large quantities of Roman, perhaps also Potemalic, pottery and the number of amphora fragments was astonishing considering the location of the

Table 1 (%w)

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Cu</th>
<th>CaO</th>
<th>MnO</th>
<th>Al₂O₃</th>
<th>Pb</th>
<th>Zn</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>FeO</th>
<th>Ni</th>
<th>Cr</th>
<th>TiO₂</th>
<th>V</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>32.0</td>
<td>0.01</td>
<td>4.7</td>
<td>0.70</td>
<td>4.5</td>
<td>0.03</td>
<td>0.01</td>
<td>0.60</td>
<td>0.30</td>
<td>50.9</td>
<td>0.03</td>
<td>0.02</td>
<td>0.21</td>
<td>0.03</td>
<td>1.17</td>
</tr>
<tr>
<td>1/2</td>
<td>30.9</td>
<td>0.01</td>
<td>7.2</td>
<td>0.50</td>
<td>4.5</td>
<td>0.01</td>
<td>0.01</td>
<td>0.90</td>
<td>0.43</td>
<td>53.9</td>
<td>0.02</td>
<td>0.02</td>
<td>0.18</td>
<td>0.05</td>
<td>0.63</td>
</tr>
<tr>
<td>1/3</td>
<td>27.9</td>
<td>0.01</td>
<td>4.7</td>
<td>1.10</td>
<td>3.3</td>
<td>0.03</td>
<td>0.01</td>
<td>0.63</td>
<td>0.30</td>
<td>59.3</td>
<td>0.015</td>
<td>0.02</td>
<td>0.15</td>
<td>0.02</td>
<td>-</td>
</tr>
<tr>
<td>1/4</td>
<td>32.2</td>
<td>0.01</td>
<td>8.1</td>
<td>0.83</td>
<td>5.1</td>
<td>0.04</td>
<td>0.01</td>
<td>0.82</td>
<td>0.40</td>
<td>47.1</td>
<td>-</td>
<td>0.01</td>
<td>0.18</td>
<td>0.03</td>
<td>9.29</td>
</tr>
<tr>
<td>1/5</td>
<td>36.2</td>
<td>0.01</td>
<td>5.2</td>
<td>0.98</td>
<td>2.7</td>
<td>0.01</td>
<td>0.01</td>
<td>0.74</td>
<td>0.35</td>
<td>50.3</td>
<td>0.01</td>
<td>0.01</td>
<td>0.04</td>
<td>0.01</td>
<td>1.19</td>
</tr>
</tbody>
</table>
makes Bakari a unique site for the history of gold mining world-wide.

At the northern end of the site, there was a group of primitive, semi-detached, round, stone fences, seemingly of the Old Kingdom (Site 1), with numerous small stone hammers and stone anvils dispersed inside the structures, many of which were still in situ. According to the shallow dent marks, these were simple crushing tools, used as locally found, others showed striation marks and were obviously used as grinding tools.

On the hill to the west, at a mining site (Site 2), we found grooved hammer stones, none of which were found in any of the working camps of any period. On the slope below the mine (Site 2) we found a workshop for the preparation of such grooved hammers from dolerite pebbles of various sizes, brought here from somewhere in the vicinity. These grooved hammers represent the earliest ore mining tools anywhere in the world and have been found at fifth and fourth millennium BC mines in Timna (Arabah), at Rudna Glava (Yugoslavia), in the ancient ‘copper belt’ of south-west Spain, at Mt Gabriel in Ireland, in fact everywhere where mining at a prehistoric, Late Neolithic-Chalcolithic, technical horizon has been identified. There is a very strong likelihood that these grooved hammers identify Bakari as an early Rhodesian mining site.

The mine on top of the hill was found more or less undisturbed. It could be entered and a few hammer peck marks could be identified as the typical mining tool marks. Next to it there was another open mine, but this was a vertical opening with smooth sides and very deep, and it was decided not to enter it without climbing equipment. The find of the grooved hammers next to mine workings certainly makes this site important for further investigation into early mining methods.

Further south, a large group of New Kingdom architectural remains were located (Site 3). The New Kingdom architecture as found here, represents a very flimsy building of irregular stone fences, which seems rather unusual for New Kingdom working camps in view of the rather well-built Egyptian miners camps in Sinai and Timna (Petrie 1906; Rothenberg 1972). It therefore seems most likely, that the structures found by us are what was left after the Ptolemaic and/or Early Islamic miners dismantled the New Kingdom buildings and removed the stones for the building of their own settlements further to the south.

In the New Kingdom workshops there were essentially four types of stone tools, the functional interrelation of which is a matter for further detailed research. The size of the stone tools were from 30 to 100cm and there was a very large number of tools spread right through all the New Kingdom buildings. One tool type is a squarish, unworked rock with a flat anvil-type upper surface, which shows shallow cup marks from rough mineral crushing activities. The second tool type is an oblong rock which shows a long groove and striation traces created by a grinding tool moving up and down. The third tool type, which clearly represents the final stage of the gold extraction, shows evidence for a concentric movement, grinding the ore to fines. This type of tool has a large cup mark in the centre showing striation of concentric working around it. The fourth type of New Kingdom tool was a crescent-shaped, heavy, trough-like stone grinder of large size (up to one metre long), which was found together with a unique, heavy, grinding or rubbing tool with outcropping ‘handles’ for moving it back and forth along the lower trough-like part of this grinding installation. Some of the New Kingdom (and also Ptolemaic/Early Islamic – see below) tools showed two or more of the above types of working, often on top of each other, indicating a change of function or secondary use of a tool which had become
unservicable for its original purpose, or was taken from an earlier workshop.

On the hill above this site there are a number of mine openings. They were not enterable having been largely filled with sand over time. It was not possible to identify the mining techniques used in these mines and further clearing and investigation will be needed to establish the methods used.

Further south, there was a large complex of a Ptolemaic and Early Islamic mining settlement (Site 4). Here one can distinguish between multi-room habitations, solid, monumental stone buildings and low, fence-like workshop structures. One of the typical workshops within a low fence was 10 x 7 metres and contained in situ ten rotary mills of granitic rock, their diameter about 50cm. This is a typical tool for finishing the crushing and grinding process, as it will result in very finely ground mineral. In the Ptolemaic-Early Islamic workshops were also other types of crushing and grinding tools the function of which, and their interrelations, will be a very interesting subject for detailed study related to the reconstruction of the extraction technique of these periods of major mining activities at Bakari.

We also identified water-laid fine-grained tailings below a stonemuff platform suggesting that water was used for separating the gold from the fines produced at the workshops.

It is interesting to notice that within the habitation areas, a number of small granitic 'saddle-backed' quarries were found, used perhaps for grinding grain and not for ore dressing. However, in the courtyards of the big buildings were also crushing tools and it was quite obvious that a large number of people had been constantly working on this part of the extractive process.

Once again the mines were up the hill above the working and habitation area, but here most of the openings had been disturbed by recent (British) prospecting. However, there is part of an old open pit left up on top of the hill, and investigation. There were also sites at the top of the hill to which ore had been taken for preliminary crushing. The reason why this ore was taken there for crushing requires further study.

A mining component in the western part of the site (Site 5) consists of several New Kingdom houses and, at some distance from them, a mining area of quartz veins and a crushing site, as well as an elaborate water collecting system. There are also rock mortars developed in the bedrock. Grooved hammers were found at this site, as was an extremely weathered quern. Klemm reported from here the rock drawing of a ship (Klemm 1994: Abb.11).

According to our observations, the progress from a primitive stone hammer and anvil to really sophisticated specialised stone tools designed for each stage of the gold extraction process can be followed at Bakari. This makes Bakari unique and therefore most important for the study of the history of gold mining in Egypt from earliest times to the Early Islamic Period.

**Kanayis Temple**
A temple on the Mersa Alam-Idfu road known as the Kanayis (Churches) Temple was visited on the return trip to Luxor. The temple was excavated in part in the rock with an outside built facade. Rock carvings, mostly ships, were identified on the cliff face above the temple. It is suspected that the temple, which may have been a mining temple, was built next to a Pre-historic rock shelter.

**Discussion and Conclusions**
1. Although important field surveys have recently been undertaken by the Munich University (R. and D.D. Klemm) and Minnesota University (R.Rapp and R.D.Rothe), in collaboration with EGSMa, their main objective was the identification and surface investigation of gold and tin mining sites in the Eastern Desert. Copper mining and smelting sites in the Eastern Desert have not yet been systematically investigated, in fact no survey concerned especially with ancient copper has yet been undertaken.

So far we know only about some small scale, Predynastic copper mining sites because of their coincidence with gold mining, but even these sites have not been excavated and their archaeological stratigraphy, i.e. culture-historical chronology, is so far unclear. The only exception are the sites of G. Mongul-South and Wadi Dara in the northern Eastern Desert the excavation of which produced evidence for Predynastic copper smelting as the earliest metal extraction at these sites, with gold mining only in the Early Islamic (9th century AD) period (Tawab et al. 1990). Although a number of copper deposits and copper mining sites have been identified in the south as well as in the north of the Eastern Desert – like Hamash – these sites still await systematical archaeo-metallurgical study. So far not a single Pharaonic copper production site has been identified in the Eastern Desert and it seems imperative for Egypt's metal-historic, and archaeo-metallurgy in general, to give priority to a proper survey of copper mining and smelting as the first part of a major archaeo-metallurgical research project in the Eastern Desert.

However, it should be remembered that surface surveys, even if done very meticulously, will only provide tentative results, pending proper archaeological excavations (see note 7). We would like to point out in this connection the systematic survey of the copper mining region of the Southern Arabah (Rothenberg 1962), the results of which had to be fundamentally changed after a series of systematic archaeological excavations in the copper mines and smelting camps (Rothenberg 1972; 1988: 1-18; 1993: 1475-86; Conrad and Rothenberg ed. 1980: Rothenberg and Shaw 1990). It was only due to proper archaeological excavations of sites found during the initial surface survey that the chronology and culture-historical context of the Arabah sites could be established – identifying in the Timna (Wadi Meneiyeh) Valley the largest Egyptian New Kingdom copper industries known to date – and only by meticulous scientific follow up of the excavations could the complete picture of the origin and development of copper metallurgy throughout the ages be worked out (Rothenberg 1990; Rothenberg and Merkel 1995).

**2. In the light of these consideration we shall shortly discuss the four key sites visited during our reconnaissance survey.**

**Mueilha:** The source of tin has been for long one of the fundamental problems of the ancient Near East and the tin mine at Mueilha is for that reason a very significant discovery. Mueilha is the core of an ongoing field and laboratory research project in the Eastern Desert by R. Rapp and R. D. Rothe, Minnesota University. We tend to agree with Rothe (1995: 171-4) that modern mining operations have most probably destroyed whatever traces of ancient mining had been preserved at Mueilha, especially as the ancients probably simply collected the tin nuggets from the natural placer in the wadis, which would have left very little recognisable traces.

From the find of metallic tin droplets in the small casting workshop of the New Kingdom mining temple at Timna (Rothenberg 1988: 202; Craddock 1988: 180, Table 4) we learned that metallic tin was indeed carried by the Egyptians to their workshops and it would be most interesting to prove that this tin originated from the Mueilha mine. Perhaps this approach could be widened out to a search for tin in Egyptian excavations and museums, and their systematic analytical study.
Hamash: According to the prospectus of our survey and other sources, there are several copper mines in the Hamash region, seemingly also of different times. We would recommend a special visit to the Hamash area to properly survey all its ancient sites, since the Hamash region could be a good place for systematic excavations which would also take care of the (perhaps first) appearance of iron smelting in the Eastern Desert. However, we would strongly recommend a season of archaeological surveying in other parts of the Eastern Desert, where other sites are known as copper mining and smelting sites, such as Semiuiki, in the south, or Abu Seyal in Wadi Allaki, before the final decision is made where to start a long-range archaeo-metallurgical research project. There are of course also other considerations, like logistics and communication, to be taken in account.

Bakari: The survey of Bakari has shown this site to provide a unique opportunity for a systematic archaeological and mining-historical study of gold extraction technology from Predynastic times to Early Islam with the exception of the Roman-Byzantine period. Since all aspects of gold extraction are reasonably well-preserved, including the mines, installations for the separation of the gold with the help of water, the whole range of working tools and the architecture of workshops and habitations, there is no doubt that the systematic excavation of Bakari would be of great importance for mining history.

Sikeit: From the archaeo-metallurgical point of view, the emerald mines—though highly interesting also because of the huge size of this operation and the fine state of preservation of its buildings—are not considered a priority for archaeo-metallurgy.

To sum up: There are unique research potentials for archaeo-metallurgy and culture-history in the Eastern Desert and we would suggest priority be given to a copper region, Hamash or another suitable site, and also excavate the site of Bakari. These sites, properly excavated and partly reconstructed, could also serve as a unique ‘Mining Park’, a rare attraction for ‘alternative tourism’.

Beno Rothenberg (IAMS) Fekri A. Hassan (IA) C.Tim Shaw (RSM) Abdel Aziz A. Hussein (EGSMA)

Acknowledgement
The working group extends its gratitude and thanks to Geologist Guber Naum, Chairman of EGSMA, and Professor Abdel Halim Nour el Din for their support of this mission. The group is also most grateful to the supporting staff of the EGSMA and the Tabbin Institute.

Notes
1Quoted from Klemm 1994:189.
2According to the guide prepared for our survey by EGSMA.
3Without excavation it was not possible to establish the quantity of slag at the site and the quantity mentioned is only a rough approximation. However, compared with the large slag heaps seen in Sinai, the slag heap of Hamash indicates a relatively medium scale operation.
4Rothe (1995: 174) reported having found Roman pottery at Hamash. The sherds we found at the site seemed much later but will have to be re-investigated in the light of Rothe's identification. This issue is of some importance because Rothe builds his identification of the architecture and the chronology and the kind of metal extracted at different times at Hamash, on the Roman date of the pottery.
5If the British extracted gold at Hamash-West, as suggested by Klemm (1994) and Rothe (1995), surely there must be records available also concerning extraction methods and processing. No clear evidence of gold mining was discernible at the mine in the hill.
6Bakari was mapped, and its components dated, by Klemm (1994), but the pottery and working tools found at the site remain so far unpublished. The sequence of stone tools, as recorded in our survey, should be considered still tentative until confirmed by excavation. It is quite possible that stone tools of one period, left behind in a workshop, will be found in a workshop of another period in secondary use. The definitive typology of the stone tools will have to await proper stratigraphic excavations (see below).
7We have already put our Timna samples at the disposal of Rip Rapp and Russell Rotha, including some high tin bronze samples from the same Egyptian workshop.
8We wish to thank Rosemarie Klemm for passing on to us valuable information on copper in the Eastern Desert and for her valuable observations on this subject.
9The Klemms' map of Bakari (1994:Abb. 11) was very helpful in dating the different miners, settlements and workshops. Unfortunately, the Klemms' survey report of Bakari is still unpublished. We accepted Klemm's exclusion of Roman-Byzantine from the long history of Bakari gold mining (1994:217) as based on the study of the pottery of the site.

References
Rothe, R.D. and Rapp, G.R. 1995. Trace-Element Analysis of Egyptian Eastern Desert Tin and its Importance to Egyptian Archaeology, Ph. D. Egypt-Italian Seminar on Geoscience and Archaeology in the Mediterranean Countries, Cairo 1993; 229-44.
Tawab, M.M.A. et al. 1990. Archéo-Géologie des anciennes mines de cuivre et d’or des région el-Urf (Mongul-Sad et Dana-Quest, in BIFAO 90: 359-64.)
Expedition to Atika

In his book Timna Rothenberg cites a section of text from Papyrus Harris (Pap. Harris I 78: 1-5), a document which in its entirety is a recounting of the benefactions to gods and people which Ramesses III made during his reign (of 31 years). Here there is a rare reference to copper mines, which he suggests could be an allusion to Timna.

For reasons that will become clear I have chosen to include in my translation a further couple of lines (Pap. Harris I 78: 6-8) which are in my opinion relevant to the understanding of this passage.

'I sent my agents to the foreign land Atika [the word 'agents' denotes only the fact that these people were sent in some official capacity, their titles and ranks are not implied in the expression used] to the great copper mines which are in that place. While their ships were filled with them, others went overland on donkeys. It was not heard before since [the] kingship [began]. Their mines were found full of copper which was loaded like tens of thousands to their ships. Ordering them to Egypt, arriving safely, carrying what they made in heaps under the canopied shrine as many copper ingots like hundreds of thousands. They were of the appearance of gold of number 3. I caused that everyone should see them like marvells.'

'I sent butlers and officials to the mekat country [the translation 'butlers and officials' is used here for convenience, the words in the text are official titles which do not necessarily denote a specific post] to my mother, Hathor, mistress of the mekat. Presented to her was silver, gold, royal linen, and many things into her presence, like sand. There were brought for me wonders of real mekat in numerous bags presented before me. It had not been seen brought back since kingship.' [The word maat translated here as 'real' is taken to indicate the authenticity of the mineral as opposed to any imitations].

We know from the work of Rothenberg and the Arabah expedition team that the Egyptians were involved in copper mining and smelting activities, especially during the Middle and New Kingdoms. The two most important sites relating to copper are Timna in the Arabah and Bir Nasib in the north-west of Sinai. The first includes a little temple for the goddess Hathor which was originally built by Sethi I (1291-1278, XIXth dynasty) rebuilt by Ramesses II (1279-1212) and later reconstructed by Ramesses III (1182-1151). Above this shrine there is a stela carved in the rock face depicting Ramesses III giving offerings to Hathor. The second site is well described by Professor H. G. Bächtman: 'Bir Nasib, the largest smelting site in Sinai, is also a place of copper ore and turquoise mining ... The small adits visible in the sandstone cliffs surrounding the smelting area ... show green lenses consisting of malachite, paratacamite and quartz ... The whole district, extending as far as Um Bogma and Gebel Um Rinna ... is rich in copper mineralisation, all within the Nubian sandstone. Bir Nasib should rather be considered the centre of an ancient copper mining district instead of an individual mine.' The slag heap at this site, which was noticed by Petrie, is estimated by Bächtman to be the waste product of the manufacture of 5000 tons of copper.

Rothenberg points to line 3 of the text which reads 'While their ships were filled with them, others went overland on donkeys', as a possible indication that the location of Atika is Timna. The mention of access to the mines by land and water fits this location well. It is implied in the text that the people on ships came directly from Egypt, yet where these 'others' on donkeys came from is not implicit. What is implied is that the arrival of both these groups was simultaneous. Who then were these others on donkeys and where might they have come from? We are reminded of the great numbers of donkeys brought on expeditions which are mentioned on various of the Sinai stelae (110, 137, 114, etc.) as well as the images of the 'Prince of Retenu' the Asiatic illustrated on his donkey (Fig. 1). Is this an allusion to another people? Finds in the temple of Timna have led Rothenberg to the conclusion that: 'In Timna, according to the evidence in the temple, the Midianites and the Amelekites, the indigenous inhabitants of the area, seem to have become some kind of 'partners' not only in work but also in the worship of Hathor.' (Timna p. 183). This evidence is strengthened by finds of two contemporaneous but distinct furnace technologies which appear side by side during the New Kingdom, a situation which might reflect two ethnic groups working together. Were other peoples of the area apart from Egyptians summoned to get on their donkeys and join a re-vitalised industry?

It is interesting to note that what is loaded on the ships is khemet, 'copper' where as what ends up in a pile in Egypt are debeht khemet, 'coppers' whose appearance was that of 'gold of number 3'. The terms n sp2. (4 n sp3.) are terms confined to Pap. Harris; the Woerterbuch and J. R. Harris both consider these to do with the grading of the quality of copper. In the same papyrus there is another copper related product khemet kemet literally 'black copper'. There is no consensus as yet as to the precise nature of this copper product. One suggestion is that it refers to the plano-convex bun ingots which were the product of one stage of refinement; another suggestion is that this name refers to a special copper and gold alloy that produces a particular black patina. Whatever the precise meanings of these terms they are never the less evidence to the recognition of different types of copper alloy.

The second extract of text (lines 6-8) is interesting as it presents something of a contrast in relation to the section which preceeds it. Here the king sends 'Butlers and officials' as opposed to messengers, and these are sent with a task of giving tribute to Hathor Lady of mekat, whereas in the first section the objective is taking. Hathor Lady of mekat was the chief deity of the whole of the mining region consisting of Sinai and the Southern Arabah, to whom both the Serabit and Timna temples were dedicated. Whether the 'Butlers and officials' are going to Timna or Serabit is impossible to say; however, both sites are located in the Egyptian mind within the 'mekat country' which is Hathor's domain. Atika on the other hand appears to be a specific place-name to which the king's 'messengers' were sent. The only things brought back from the second trip were bags of 'true mekat'. Presuming Rothenberg is right about the location of Atika, an area which is covered by Hathor Lady of mekat, it seems natural that a narrative of
acquisition should be followed immediately by one of voyage to the mekat country the object of which was returning tribute to this very goddess.

What is mekat which Hathor is the goddess of and which was so highly prized?

Champollion took mekat to be green copper ore. He backed his opinion with a drawing that appears in the tomb of Rekhmire (Fig. 2), a depiction of a bowl containing some green substance above which is the caption mekat. Since then there has been a considerable amount of debate concerning the precise meaning of this word. In Harris’ eyes however it was Loret who finalised the debate stating that mekat could only be ‘turquoise’. All the same, this is a status-quo rather than a conclusion as Harris himself concedes that there are still problems, as although ‘... the meaning of mekat is clearly established as turquoise and nothing else. It is, not, however, always possible to determine whether the word refers to precious stone, or to faience or glass imitation which bore the same name, though there are clear indications of both.’ These varieties of mekat were explained by him in reference to mekat maat (‘true mekat’), a term which most commonly appears in formal lists of precious substances. It was his opinion that this term in itself suggests that all other varieties were just imitations of the ‘real’ thing. In the Introduction to The inscriptions of Sinai it is stated that: ‘If mekat meant Malachite, as used to be thought, it seems strange that so few malachite objects have been found and that there should be no mention at all in the Egyptian texts of the frequently recurring turquoise.’ It might add to this comment that it is just as strange that in all the textual evidence from Sinai and the Arabah it is the mineral mekat which is mentioned, while the word for copper surprisingly appears only three times. This is all the more puzzling in light of the fact that this area became increasingly orientated towards copper from the Middle Kingdom onwards. The confusion and disagreement about the meaning of mekat in itself attests to a state of incompatibility between the Ancient Egyptian concept which is invested in this word and our own modern way of thinking, which has so far been loath to accommodate a single word or set of words that would fulfil the range of meanings which mekat seems to project in its various contexts. Since Harris’ publication in 1961 considerable work has been done in Sinai which has shed light on the mining and copper smelting industries there. It is now therefore possible to map more accurately the location, nature and development of the Ancient Egyptians’ enterprise in Sinai and the Arabah and assess how this information correlates with the development of related terms in the Ancient Egyptian language.

From Pre-dynastic times right through to the New Kingdom period the three main minerals sought after in Sinai and the Arabah were Malachite Cu2(OH)CO2 Paratacamite Cu2(OH)4Cl and Turquoise (Cu, Zn)Al(OH)(PO4)2H2O. All are copper ores, the turquoise being the exception in that metal cannot be extracted from it. Around these mining areas there grew an industry of copper smelting the history of which was determined by two main factors: 1. Periods of lull, due to political changes and availability of relevant supplies. 2. The development of new mining and smelting techniques. The shift in the focus of this industry coincided with the advances made by the ancient smiths at their craft, a process which culminated in their mastery of it. A long evolution of furnace design, slag tapping and experiments with different charges culminated in a technology that achieved optimal separation of copper from all the other minerals present in the ore. Much of the evidence for this is to be found in the waste product left behind, namely the slag. Characteristically, the Egyptian industry expanded and reached a peak in the New Kingdom. Rothenberg’s comment that ‘Although the Pharaohs of the New Kingdom contin-

About the general nature of Sinai’s mining stelae texts

Expeditions to foreign and often hostile places in search of minerals and other precious, rare or otherwise unavailable goods were considered by the Egyptians as heroic. The size of the expedition party, its arrival in full force, obstacles faced, unprecedented success and reference to some ceremonial dedication are all part and parcel of the heroic narrative, grand explorations akin to warfare. Despite the rather formulaic structure of such texts their owners were particularly fond, if possible, to express the uniqueness of their own actions, usually by such statements as ‘it has not been seen since kingship’ or ‘the like was not done since kingship’. Unfortunately texts that describe technical processes are rare; it might be that there was no interest in writing such texts, yet it is also possible that none as yet have been unearthed. Even though the texts on the Sinai stelae generally adhere to form they still use some specialised vocabulary which alludes specifically to mining and its related activities. Although it is not obviously manifest in the texts we now know that during the Middle Kingdom the technology of smelting was developing, and quite naturally mining activities expanded accordingly. In antiquity this kind of progress might well have been viewed as heroic. For us, however, all that is left from these great innovations are only a collection of ancient inscriptions and the scant ruins of great mining sites, workers camps and slag heaps.

Before going back to the texts in the Sinai itself where mekat comes in narrative contexts let us look at some of the forms in which it appears in lists of products or as a simile in poetic or religious texts.

Products of mekat

In the illustration from Rekhmire’s tomb we observed mekat stored with other particularly precious substances, just as in the texts it appears in formulaic sequence with some of these very same materials.
A good example of this standard phraseology is in the Harris Papyrus:

'gold, silver, true lapis, true mefkat, every true stone, copper, cloth...' This is a fairly typical statement which would often precede a fuller inventory of goods. The qualifying maat 'true' refers always, as in this case, to stone minerals rather than metals. Objects are usually not made of 'true mefkat' as can be seen in the varieties of mefkat amulets, scarabs, rings and glass where it comes without the qualifying maat. In Harris Papyrus\textsuperscript{26} 'wonders of true mefkat (maat) in numerous bags' were presented to the king on the officials return from the 'mefkat country'.

An object of particular interest cited in the same Papyrus is \textit{mefkat wedjekh (wsd)}\textsuperscript{a}, translated in the \textit{Wörterbuch} as 'glass'. The reference here must be to the substance which was used to colour the glass, i.e. fine quality copper ore.\textsuperscript{27} We know that high grade malachite was used also in the manufacture of faience,\textsuperscript{28} a reference of which is in a love song from Tell el Amarna 805:\textit{its leaves are like unto mefkat and are like glass (tawmdhet=nhtm)}\textsuperscript{a}. It is of interest to note that the word \textit{tchekhenn, 'gleaming'}, is related to the word used for faience \textit{tchekhenet}, and is the very same word used in Sinai 26 to describe an aspect of the quality of the mineral. Another adjective used with mefkat is \textit{akh (3h), 'shining'}. The green colour of mefkat is illustrated in Rekhmire's tomb and in objects such as \textit{wsbyt wadj im nt mefkat (wsbyt wsd im nt mfk3't)}\textsuperscript{a} 'green beads'.\textsuperscript{29} In the Book of the Dead mefkat is used as a metaphor for the colour of water and sycamore trees.

**Mefkat in the Sinai stelae texts**

The expression \textit{khetu mefkat (sxw mfk3't)}\textsuperscript{a} 'terraces of mefkat' \textsuperscript{a} is found in three Old Kingdom inscriptions, two from Maghara in Sinai (13 and 17), a third on the Palermo Stone. In Akhtoy's tomb\textsuperscript{b} from the Late First Intermediate or Early Middle Kingdom this expression appears in the text together with 'When I was in Bia (bi3) \textit{Hr}\textsuperscript{2}}. Terraces of mefkat', which has been thought by some to be specifically Wadi Maghara, does not appear after the Old Kingdom in any inscription in Sinai. Bia the 'mining country' does it. Appears in eight\textsuperscript{c} texts, all of which are Middle Kingdom. In inscription 141 it is spelled thus \textit{Hr}\textsuperscript{2} and in 90 it is spelled \textit{Hr}\textsuperscript{2}, both forms are reminiscent of the writing for 'bronze' \textsuperscript{32} \textit{Hr}\textsuperscript{2} or \textit{Hr}\textsuperscript{2} and the writing for 'mineral' \textit{Hr}\textsuperscript{2}. The word for iron is also \textit{bia}. Harris maintains that the expression '\textit{bia n pt (bi3 n pt)} (iron from heaven), first occurs in the 19th dynasty...\textsuperscript{a} (Harris, op. cit. n. 12, p. 59). He was of course not aware in 1961 when he published his \textit{Lectographic Studies} of evidence from Timna and Bir Nasib which has since proved that iron was extracted as a by-product of copper smelting in Sinai already in the Middle Kingdom and possibly even earlier. Sinai stela No 127 from the Middle Kingdom has a small (unfortunately disjointed) passage which reads \textit{r=n pt n bi3 \textit{Hr}\textsuperscript{2}} 'he made heaven of iron (bi3)'. Harris also states that 'In no instance is any of the common determinatives of bia used to write the word for copper (\textit{Hr}\textsuperscript{2}), nor is any of the old copper ideograms applied as a determinative to bia.' (ibid. p. 61). If this is the case then Sinai 182 (Hatshespst, 1498-1483), a New Kingdom stela, has both 'copper' and \textit{\textit{Hr}\textsuperscript{2}} 'iron' mentioned in it. We have here two explicit textual references to iron in Sinai which are consistent with the fact that this metal was being extracted there. The connection between the word for iron and the word which begins to be used for the mining area of Sinai in the Middle Kingdom is not surprising in light of the fact that this is the first place where iron was produced by the Egyptians.

The change of use from the term 'Terraces of mefkat' to Bia

lands'. Eventually in the New Kingdom it assumes a shorter form of the word with just the mineral determinative _, or _.

There are many Middle Kingdom stelae from the reign of Amenemhet III (1842-1797) in Sinai, not least of which is the one on the ridge above the great slag heap at Bir Nasib (Sinai 46) dated to his 20th year. Although the contents of this text do not elaborate much beyond his title its importance is the enormous slag heap in situ which connects him with copper mining and smelting. It is not surprising that Rothenberg described him as 'the first great "copper king" of the Egyptians'.\textsuperscript{34} The same combination of minerals found at Bir Nasib is resident in Wadi Maghara, though the turquoise mines in the latter appear to be more prominent. It is in Wadi Maghara, however, that we find stela no. 23 dated to the second year of the same Amenemhet III where we are informed that the said expedition 'was sent to fetch \textit{\textit{Hr}\textsuperscript{2}, \textit{Mr}\textsuperscript{2}, mefkat khemyt (hmtty) or bia (bi3)}', which can read either 'mefkat and copper' or 'mefkat, more precisely, copper' (Fig. 3). Whichever is the case, this inscription is of particular importance as it is the only text in Sinai which explicitly states as one of its aims the acquisition of 'copper'. This literal specification that a combination of minerals was sought after is important as it reflects the mining reality described by the archaeologists; it is, however, surprising in its uniqueness. But is it unique in this respect or are there other allusions to the complex of minerals they were exploiting? At Serabit there are three inscriptions of particular interest to our investigation, two of which are from Amenemhet III's reign (1842-1797), the third is Middle Kingdom, reign unknown, nos 53 (year 44), 90 (year 6) and 141. I will deal with each in turn. Stela no. 53 which is located by one of the pits (pit B) does not specify in its narrative the quarry which is sought. There is a nice description of the opening of a gallery, \textit{khetet (hts)},\textsuperscript{a} considered to be a mine shaft. In line 10 is written rather poetically: "The mountains produce that which is in them; the mountains and deserts bring their offerings." This statement makes sense considering the whole area was a hive of diverse mining and smelting activities. No. 90, the famous stela of Hawara, sheds a little more light on the subject. Lines 9-12 read: "There is mefkat in the mountain forever it is its character which is sought in this season, we have already heard the like before ore has come at this time, however it's the character which is missing completely in this difficult season of summer'. Many others have discussed this passage; suffice it to note that it strongly

Fig. 3. Wadi Maghara, Sinai 23. Amenemhet III, year 2. Middle Kingdom.
ly implies varieties of ore. Haweere’s implicit description of mineral prospecting is consistent with a complex Sinaic industry where both turquoise and the various grades of malachite (for cosmetic, glass and faience colouring, soldering) and, of course, copper smelting) were sought. This multiplicity is natural for the Egyptians who were not in the habit of ignoring anything they could exploit. Inscription 141 tells another story, here it says: ‘I ordered the work which I was going to do

Fig. 4. Serabit, Sinai 72, Middle Kingdom. ‘...he offers cones of mekafet for the majesty of this god.’

and I assessed a delivery of 25 hekat of mekafet daily, of best quality’. This would amount to about 7.57 litres of best quality mekafet per person per day. It is curious that the measure here is one of volume used usually for grain, suggesting that the best quality mekafet was at least as fine. This description of mekafet is reminiscent of ‘the wonders of true mekafet in numerous bags’ mentioned earlier in Papyrus Harris, as well as finds of powdered malachite which are common in graves ranging from Predynastic Badarian times till the XIXth dynasty.

As for the shape of mekafet there is, apart from the bowl in Rekhmire’s tomb, a textual reference accompanied with an illustration in the Middle Kingdom Sinai inscription no. 72. It reads ‘... he offers cones of mekafet for the majesty of this god’. The little cones in the man’s hand might be the natural shape of a pile of crushed ore, an image which appears several times in Sinai (Fig.4).

Conclusion

This review of the evidence shows that although it is in some instances tempting to use mekafet as purely turquoise, it is in a wider sense inappropriate. Although I cannot suggest a single word to replace turquoise, considering the evidence, I believe mekafet to be a substance which had symbolic as well as practical value, most likely a generic even ideal term for the purest form of the family of copper ores the Egyptians went to fetch in Sinai and the Arabah. It is indisputable that the reference is in many cases to turquoise, but that parachamite and especially the malachite in all its varieties were ignored is unlikely and contrary to the evidence. It is important to bear in mind that where copper was concerned it was not the metal which was extracted from the ground but the rock ore. The recovery of the metal was achieved by a sophisticated pyrotechnological process in consequence of which the original mineral was totally transformed and any relation to its original form was lost. We take for granted our understanding of this process via the modern concept of chemistry. For the Ancient Egyptian a different rationale was appropriate; it is possible that their concept of the nature of copper bearing ores from the Sinai is preserved in the word mekafet $\text{mekafet}$

Dan Levene

Notes

1 Rothenberg 1972.
2 The nature of this document is still a matter of discussion. For further reference see: Gottinger Miscellen Vol. 123 (1991), pp. 57-90.
3 The translation used was the one published by J. H. Breasted in 1906.
4 Rothenberg 1987.
7 Rothenberg 1990.
8 Personal communication Dr J. Merkel.
9 Classification of metal alloys in antiquity is also attested from the Pedinao archives found at Ebla.
10 A. H. Gardner et al., 1955, p. 10.
11 Sinai 23 - Middle Kingdom 12th dynasty, Sinai 127 - Middle Kingdom, 19 - 19 of the metal of copper', Sinai 182 - New Kingdom (of this particular form there is only the one example).
12 Harris 1961.
14 The combination of crushed ore with fuel and flux prepared for loading in a smelting furnace.
15 Rothenberg 1979, p. 166.
16 178; 5-8.
19 Matt. a. Kind 1.1, Middle Kingdom.
20 Gardner 1917.
21 Sinai 53: 3; 90:2, 3, 9, 13; 106: N1; 115: W5; 141: W5; 167: 409: 4; 56: 3, 56.
23 Sinai 90, and 53 where it appears as $\text{mekafet}$.
24 Rothenberg 1979, p. 164.
25 See also Akhty’s tomb (Gardner 1917) in which there is mention of the opening of a khekr within ‘this mountain of the house of Horus of the mekafet terrace’.
26 ‘To bow down to everybody, not to hide the face from a starving man: “The helping hand is what is beloved.” That is (inn) Character.’ U.C. 14333. A neglected Wisdom Text. H. Goodenich. JE 48 1962-3 (I would like to thank J. Clayton for bringing my attention to this parallel).
28 Faulkner, op. cit., in note 22.

Acknowledgements.

I would like to thank Dr John F. Merkel for his encouragement, Professor John Tait for his comments and M. A. Lawler for her support. I would also like to thank The Committee of the Egypt Exploration Society for giving me permission to use their illustrations of the Sinai stelae.

Bibliography.


Beit Arich Ishaq. 1980. A Chalcolithic site near Serabit el-Khadim. Tel Aviv 7, numbers 1-2, pp. 45-64.


A Western Iberian Cassiterite Survey
1992-96

This article is a short review of the archaeo-metallurgical survey work which formed the basis of my PhD thesis presented at the Institute of Archaeology, University College London in January 1996.

I decided on tin as the subject for my PhD field survey work in 1992 since tin was a metal used in antiquity which had not been properly dealt with compared to the amount of research and fieldwork that had been invested in the provenance and production techniques for gold, silver, lead, copper and iron within the Iberian Peninsula.

The geographical and geological region I chose to work in was Mid-Central Western Iberia, including cassiterite ore sites in Spain in the provinces of Badajoz, Caceres and Salamanca and ore sites in Portugal in the provinces of Beira Alta, Beira Baixa and Upper Alentejo.

Cassiterite, the major tin ore used in antiquity in the Iberian Peninsula, appears almost exclusively within the Centro-Iberian Zone granites. The Centro-Iberian Zone granites run in a curved arch from the north-west corner of the Iberian Massif in the province of Galicia down to the Andalusian province of Jaen. The Central-Iberian granite zone contains important mineralizations of Sn, W, U, Cu, P, Li, Zn, Sb, and Au. The major deposits of Iberian cassiterite ores appear mostly within the central and northern regions of the granites. The field survey work which I undertook included only the central region granites.

A total of 42 sites were visited, some of the sites were visited only once, others were revisited each year as the survey work progressed.

A reference for choosing sites to visit was the geological listing of cassiterite mines that were still working or had recently ceased to work (Dallmeyer, Garcia, eds, 212-19). I visited primary vein mines where possible since alluvial worked sites would not really provide much identifiable archaeo-metallurgical surface evidence.

During the survey, I soon realised that it would be very difficult to locate some of the mines as they had not been worked for years and local knowledge of the location of what were very small mine workings was very meagre.

The sites were visited with the hope of locating remains of cassiterite ore veins or fragments of ore samples, archaeo-metallurgical surface remains such as mining or crushing implements, furnaces, casting or mould fragments, metal objects or fragments, slags and pottery.

The most important sites were:
No 4. El Cerro de San Cristobal, Logrosan, proved to be the most rewarding of all the sites visited, for both its archaeo-metallurgical and Late Bronze Age settlement remains. Vicente Sos Baynet, a geologist working in the Logrosan area in 1950 to 1960, made a collection of archaeological artefacts which he presented to the National Roman Museum, Merida. Some of these artefacts strongly infer that El Cerro de San Cristobal was also settled in the Iberian Copper Age approximately 2000 BC.

No 42. La Mina de Berrocal, also was a site with numerous probable mining surface remains (hammers and crushers) and Copper Age settlement pottery.

No 16. Mina Golpejas produced a mineral containing both Cu and Sn. In a series of laboratory experiments I was

Fig. 1. View of Torre Romana Centumcellas, Belmonte, Portugal, looking south-west. The Roman tin slag, 1st to 3rd century AD, both surface and excavated, was found where vehicle is parked. Site No. 20.

Fig. 2. El Cerro de San Cristobal, site No. 4. Casting mould fragment, part of Sos Baynet collection, found in the 1950s-60s. National Roman Museum, Merida. Bronze chisel, surface find by Anthony Bridgeman, 1995. The chisel fits perfectly into the casting mould. Scale 1:1.
able to melt this unique mineral into a very small natural bronze prill. A Spanish geologist (Felix Garcia, Minas de Rio Tinto) informed me that small ore veins of mixed copper/tin minerals were quite common in the past at the western side of the Iberian Peninsula. The majority of these deposits would most probably have been worked out in antiquity.

No 20. Torre Romana Centumcellas produced a small amount (about 15 pieces of surface and excavated Roman tin slag dated 1st to 3rd centuries AD). Iron slag fragments were also collected and analysed. The excavated tin slag of Torre Romana Centumcellas is only the third example of ancient tin slag that has been found and recorded within a archaeological context.

The Torre Romana Centumcellas tin slag, analysed in the laboratory of the Institute of Archaeology (SEM/EDS) not only contained tin in amounts varying from 2.2% to 20%, but also contained varying percentages of the elements Niobium (Nb), Titanium (Ti), and Tantalum (Ta). These three minerals appear almost always with or alongside cassiterite in the granites of the central Iberian Peninsula.

The settlement and mining area of El Cerro de San Cristobal was planned (features and contours, 1:500 scale) during the 1994-95 survey seasons. It is hoped in the near future to enlarge the Logrosan planning survey to include the worked out mines on the lower north side of the Cerro and to plot in greater detail the cassiterite veins, mining shafts and galleries within the Late Bronze Age settlement area of the west Cerro.

The Extremadura tin survey project will be an on-going project involving the Prehistoric Department of the University of Caceres and it is hoped in the near future it will be possible to make some small excavation trenches at El Cerro de San Cristobal and at Mina de Berrocal.

References

High-Tin Bronze Mirrors of Kerala, South India

High-tin bronze (copper with 20-30% tin) has been used in various ancient cultures to make mirrors. This alloy, also known as speculum, has a bright reflective surface when polished. In Ancient China, decorated mirrors were widely made from the Chou dynasty onwards for cosmetic, decorative and other uses. Typical Han Chinese mirrors were often cast from leaded high-tin bronze with about 25% tin and 5% lead (Meeks, 1993). There are examples of mirrors from the Roman world which were also leaded high-tin bronze. A variation during Roman times utilized low-tin bronze alloys, but with a tin coating on the reflective surface. Mirrors in antiquity represent a special class of metal object requiring specific metallic properties. In addition to technical studies of ancient mirrors, observations of traditional metallurgical crafts may also be used to increase our understanding of mirror production using high-tin bronze alloys.

A distinctive traditional process for making cast, high-tin bronze mirrors exists in several small villages in South India. The process received little attention from archaeologists, anthropologists or metallurgists, until the first publication of the process by Mukherjee (1978). There are, however, many aspects of this specialized traditional craft which were not considered at that time. As this traditional craft may yet vanish, the opportunity was taken to observe and document the process recently in the Allepey district of Kerala. There still remain several small, specialised groups of metals craftsmen utilizing the distinctive material properties of high-tin bronze to produce mirrors as well as bells, musical instruments and wrought vessels. Such utilitarian objects of high-tin bronze also appear to have been commonly used in Ancient India, so study of the traditional craft adds an additional perspective for the archaeological mirrors.

The metals craftsmen at the village of Aramula in the Allepey District of Kerala, about 15 km from Changanur on the banks of the Pamba river, were visited on several occasions in 1992-93. Most helpful was a Mr A. Gopalkrishnan (Fig. 1), one of the few artisans who still carries on this traditional craft, which he claims has been in danger of dying out altogether. Economically, it was the interest of foreign tourists at a nearby ashram (religious commune) which has helped revive the craft. Mr Gopalkrishnan makes polished high-tin bronze mirrors mounted in brass handles. The high-tin bronze mirrors,
unlike modern coated glass mirrors, have the property of point image due to absence of refraction and although planar in form, the very slight natural convexity of the mirrors' surfaces are sufficient to give a somewhat reduced image. Some of the details of the process seemed guarded "secrets", but visits to the workshops, along with technical studies, helped better to establish certain properties of the mirrors. Mr Gopalakrishnan said the mirror compositions were "... pure copper with a high percentage of tin." The exact composition of which he would not say, but he indicated it could be close to 50%. Other workers also mentioned a similar composition. Samples of the mirror alloy provided by the craftsmen for analysis were actually not over 35% tin. Further samples were collected on a subsequent trip to Kerala. Another traditional metals craftsman, Mr M.S. Janardhanan Achary, from the nearby village of Malakkara in the Pathanamthitta District of Kerala, sold off some of his stock-in-trade. From these samples of alloys, moulds, and intermediate blanks, along with visits to the workshops, it is possible to document the steps of the process.

To make the mould for casting, two oval, fine clay disc moulds about the size of the mirror were prepared and fired. The two disc moulds for each face of the mirror are spaced apart using three small cut pieces of the alloy. These alloy spacers would later melt into the cast metal and leave little trace in the finished mirror surface. The positioned discs are then covered with further layers of alluvial clay and bound with iron wire for strength. A plug of wax maintained a channel from the void between the discs to a cup-shaped cavity in the neck of the mould. These features are all evident in an X-radiograph made of an unfired mould with the wax still intact. Alloy fragments, sufficient to make the mirror, were then placed into the neck cavity and sealed with more clay to form a closed crucible attached to the mould. The whole assemblage was then put in a shallow pit filled with charcoal and kept vertical with the crucible downwards (Fig. 2). A small hand-cranked blower was used to achieve the required temperatures to melt the high-tin bronze alloy. The alloy would melt at about 750°C. When the crucible was observed to be red hot, the crucible-mould assemblage was turned over quickly so that the molten metal would flow through the neck cavity into the void between the two discs of the mould. After cooling, the mould was carefully broken to obtain the cast mirror blank. The use of the closed crucible-mould assemblage decreases oxidation and unnecessary loss of tin during casting. The ceramic discs could be carefully removed and reused.

The mirror blank was then mounted with wax onto a thick rectangular wooden polishing block with a rear handle. The blank was then carefully polished with even pressure against a hessian cloth placed on a wooden board, using coarse and fine polishing powders consisting of burnt mound material mixed with powdered mirror alloy and oil for lubrication. The polishing took several days. Final polishing was given with finely crushed red oxide (hematite) which is also used to clean the mirror face from time to time when it tarnishes. The oval mirror was then polished from the polishing block by melting the wax. The polished mirror was fitted, using wax, into a handle frame made of brass. Mr Gopalakrishnan of Aranmula advised that to prevent tarnishing, the mirror should be given a polish occasionally using red oxide or vermilion, while grease was to be cleaned off by rubbing the surface with solidified coconut oil.

Metallographic sections of a finished mirror from Aranmula and an as-cast alloy fragment from Malakkara were examined using optical microscopy and the JEOL electron probe microanalysis (EPMA) in the Wolfson Archaeological Science Laboratory at the Institute of Archaeology, UCL. Structures of both show predominantly delta phase with the eutectoid matrix of alpha plus delta. EPMA confirmed the identification of delta phase with 32-34% tin, while the eutectoid had lower concentrations of tin. The microhardness ranged between 390-440 VPN. The high-tin alloy has a typical silver-white colour and it is hard, brittle and relatively corrosion resistant. When polished, it has optical effects which are responsible for the catoptric or mirror-like properties. It is noteworthy that craftsmen from both villages used approximately the same alloy compositions with 32-34% tin.

The contemporary mirror makers of Aranmula believe that their technique has indigenous local origins. Mr Gopalakrishnan said that his trade had a history of at least five hundred years passed down through generations, practiced only by acharis (master craftsmen) who had the status of Brahmins. Reportedly, they had migrated from Sankarakoil in Thiruvallur, Tamil Nadu, to Kerala about 700 years ago. These acharis claimed Pandyan decent. Mr Gopalakrishnan said that the local technique for mirror casting had been divined by his ancestors through a vision of the Goddess.

There is a legend about the origin of the Aranmula mirrors which was told by Mr Janardhana Achary of Malakkara. In the 16th century, the Raja of Aranmula brought to the village some bronze craftsmen from Tamil Nadu in order to make ornaments and musical instruments for the temple. Growing fat and lazy on the products of the land granted to them, the

---

**Fig. 1.** Mr Gopalakrishnan makes and sells high-tin bronze mirrors in the village of Aranmula in the Alleppey District of Kerala. His foundry is one of the few remaining that make mirrors using traditional techniques.

**Figure 2.** The mould and crucible are attached allowing the molten metal to be cast simply by inverting the assemblage. The mould may be seen above the crucible which is covered by burning charcoal in the front centre of the photograph.
Raja threatened to withdraw their privileges and evict them from his territory. After prayers and discussion, a widow Smt Parvathy Ammal had a dream in which Lord Parthasarathy revealed to her the secret of combining copper and tin in the right proportions to make a shining metal with a reflective crystal surface. They made a crown of this material for the Raja who relented and encouraged them to use the metal for Vallkannadi (mirrors), one of eight articles in the Ashtamangalya sets. Traditionally this type of mirror was used only by royalty and brahmins because of its ritual associations and also in tantric worship in shrines such as Sabarimalai.

Metal mirrors were also one of the asthamangalaya or eight auspicious items which were important for the prosperity of each household. Mirrors were also one of the asthamangalaya which formed the wedding trousseau of Namburthi and Nair brides of Kerala. Mirrors as an item in the asthamangalaya as described by the acharis are depicted as early as the Kushan period in a Jain votive tablet of the 1st-2nd centuries AD (Czuma, 1985).

Different types of mirrors are also commonly depicted in Indian sculpture as being held by deities, celestial maidsens and dancers from the early historic periods into the medieval period in North and South India. Stone sculptural panels and friezes depicting such mirrors include the Sunga Yaksi from Barhut (3rd century BC), the Kushan Yaksi or Tree Goddess from Sanchi (1st century AD) and several from the medieval period such as a Hoysala dancer and a deity from Konarak and two apsaras (celestial maidsens) from Khajuraho (Keay, 1981). A few archaeological finds of mirrors are reported from widely separated contexts such as the tanged planar mirrors from the Indus valley civilisation (c. 3000 BC), others from the Nilgiri megaliths (mid to late 1st millennium BC) in southern India, and from Satavahana hoards (1st century BC - 2nd century AD). However, scarcely any analytical work is reported, except for two mirrors from the Gandharan grave culture of the 1st millennium BC found at the important archaeological site of Taxila. The reported compositions of the two mirrors are 22% and 24.8% tin (Marshall, 1951).

One suspects that the use of high-tin bronze has a long history in the Indian subcontinent, particularly in Southern India, to make wrought and quenched bowls, gongs, cymbals, coinage, mirrors and other items. The accounts by traditional craftsmen agree that mirror making from Arannula has certainly some local antiquity. The numerous iconographic representations of mirrors in Indian art represent use and associations of distinctive metal products. When viewed from a metallurgical perspective, however, the investigation of high-tin bronze mirrors reveals fascinating insights into technical accomplishments and fine craftsmanship.

Sharada Srinivasan and Ian Glover

References
Gopalakrishnan, A. 1992, personal communication.
Janardhanan Achary, M.S. 1992, personal communication.

From the Director's Desk

The Director and the Trustees of IAMS welcome our new Trustee, Professor Peter Ucko, the recently-appointed Director of the Institute of Archaeology, University College London.

In the light of the changes in the *IAMS Newsletter*, which in the past concentrated on work done within our research group, members of the Scientific Committee of IAMS proposed to widen the orbit of IAMS to become a refereed journal of archaemetallurgy starting with the next issue, No. 21. IAMS will publish compact reports on ongoing research and we are inviting our colleagues to contribute papers. Peter Clayton and John Merkel will continue to be the editors of IAMS, assisted by members of the Scientific Committee.

Subscriptions will be invited for Volume 3 (parts 1 and 2) of *Researches in the Arabah: The Ancient Copper Mining and Smelting in the Western Arabah*, edited by Beno Rothenberg and C. Tim Shaw, which is now going to press. These volumes will contain the final reports of all excavations carried out by IAMS between the years 1964 to 1990 on the mine and smelting sites, dating from the Late Neolithic period to medieval times, of the south-western Arabah. These reports also contain numerous specialist reports on all the finds, plus hundreds of photographs, drawings and maps. Subscriptions received for Vol. 3 (parts 1 and 2) before the date of publication will entitle the purchaser to a 50% price reduction, and for a similar reduction for Vol. 1 *The Timna Mining Temple, 1988* and/or Vol. 2 *The Ancient Metallurgy of Copper, 1990*.

During the past few years, IAMS has been involved in cooperative projects with the Supreme Council of Antiquities (SCA) and Cairo University in Egypt. Along with the SCA, in April 1995 IAMS co-sponsored the first International Conference on Ancient Egyptian Mining and Metallurgy and Conservation of Metallic Artefacts. In the following summer, IAMS presented a summer course in archaemetallurgy at the El Tabbin Institute of Metallurgical Studies (TIMS). In the summer of 1996, along with conservation staff from the SCA and Cairo University, the Institute of Archaeology at UCL presented a summer programme on archaeological conservation at the Tabbin Institute. Dr Merkel lectured on the conservation of metallic artefacts. The second conference on Ancient Mining and Metallurgy and Conservation took place on 14-16 April 1998. IAMS was again a co-sponsor for the conference. The Institute of Archaeology UCL and the Royal School of Mines, Imperial College, were also sponsors from the UK.
A note on ‘free-silica slags’

Over the last years, the term ‘free-silica slags’ has been employed frequently to characterise certain types of slag. These are smelting residues with inclusions of crystallised silica (quartz and/or cristobalite). They rarely exhibit flow textures. Their generally heterogeneous nature is indicative of furnace slags, i.e. slags which remained inside the reactor (furnace, hearth, crucible) at the end of the process. The silica inclusions in these slags vary in size from less than one millimetre to centimetres in diameter.

The explanations given for the genesis of ‘free-silica slags’ are not convincing (Kassianidou et al., 1995). The inclusions of quartz etc. are interpreted as relics of gangue or fluxes which have not reacted nor reached their melting point. How does this explain the often relatively large inclusions? Components of furnace charges (ores, fluxes) are crushed to small sizes prior to charging in order to increase their surface and thus help to promote reaction. Large fragments of gangue would most likely have been removed from the charge during beneficiation of the ore. The assumption that quartz had been added to the molten slag as ‘stiffener’ to increase its viscosity and thereby aid in the liquidation of metals with low melting points, e.g. lead (Tylecote 1987, p. 306f.) refers to a routine used in lead smelting still practised in England and Scotland during the 19th century (Percy 1870, p. 238f.). Limestone was added to the slag in order to make it ‘stiff’ and prevent its flowing out of the hearth; only molten lead was tapped into the fore hearth. Quartz would have been the most unstable substance to add, because lead and silica react vigorously to form lead silicates with melting points from up to 700°C. If quartz had been employed for this purpose, the reaction would have resulted in severe losses of lead. During the smelting of copper ores, the ‘stiffening’ of slags with quartz, etc. would have made no sense either, because the metallurgists’ intention is and was the optimal separation of metal and impurities, which is best achieved through formation of low viscosity tap slags.

In August 1997, the author witnessed smelting experiments at ValliPres near Aubusson in Central France, carried out by members of the Institute for Industrial Furnace Construction/Technical University Aix-la-Chapelle/Germany. The construction of the experimental furnace was based upon archaeological evidence for Bronze Age copper smelting furnaces in the Austrian Alps, e.g. Mitterberg near Salzburg. Its height was about 50cm, the internal dimensions 45 x 30cm. Air was blown into the furnace front through two tuyeres (diameter c. 3cm) with a controlled flow rate of c. 40 to 60 l/min. The charge consisted of a petrified synthetic ore (grain size 5mm) with the following composition: CuO = 16%, FeO = 50%, SiO₂ = 18% and CaCO₃ = 16% (Woelk and Woelk 1997). The first experiments with CO/CO₂-ratios insufficient for complete reduction produced inhomogeneous, porous furnace slags with charcoal fragments and large white opaque SiO₂-inclusions, some of them more than a centimetre in size. They consist of quartz and cristobalite (Hauptmann 1997). The silica necessary for the formation of these inclusions was supplied by the ore, the furnace walls and the charcoal ashes. At the start of the experiment the charge was completely free from any visible quartz crystals or fragments. Thus, genesis and growth of quartz-cristobalite inclusions was the result of reactions in the semi-molten state or of solid-state reaction. They can be explained as follows:

Under reaction conditions in the heating zone of the furnace which are not completely reducing, the FeO₂-content of the ore is only converted to magnetite, Fe₃O₄ instead of to FeO. Reaction of magnetite with SiO₂ under the prevailing temperatures (ca. 1100°C) is extremely slow or totally absent. Only at temperatures above 1375°C does SiO₂ react with magnetite to form Fe₂O₃ and fayalite slag respectively:

\[ 2 \text{Fe}_3\text{O}_4 + \text{SiO}_2 \rightarrow 4 \text{Fe}_2\text{O}_3 + 2 \text{Fe}_2\text{SiO}_4 \]

Silica is thus ‘withdrawn’ from reaction with iron oxide and can therefore form the polymorphic crystalline phases quartz and/or cristobalite (Tafel 1953, 257f.). According to Bauder (1853, 158f.) other metal oxides, like hammer scale as well as other slag phases will promote crystallisation and transition of SiO₂-modifications and presumably their crystal growth as well.

In later smelting experiments, using the same furnace and the same type of synthetic ore, the conditions for reduction were optimised. This resulted in the formation of homogeneous fayalite tap slag, completely free from inclusions, and metallic copper (with only little adhering slag particles).

The occurrence of ‘free-silica’ slags’ is apparently not restricted to base-metal smelting. It was also observed in the direct production of iron (blowmery process). In September 1997, Swedish magnetite ore was tentatively smelted in an experimental furnace built at Plas Tan y Bwch/Snowdonia National Park. The experiment did not produce a proper bloom, but only a lump of very heterogeneous furnace slag with scattered white inclusions, obviously of crystalline silica.

Based on these observations, it is postulated that ‘free-silica slags’ are indicative of magnetite formation (or conservation) within the furnace charge. Magnetite does not react readily with silica— at least not within the temperature range characteristic in early smelting practice. Silica molecules tend to form crystals which, under the influence of mineralising agents, can grow to considerable size. Further investigations, e.g. determination of magnetite contents in ‘free-silica slags’ are suggested and recommended to verify my hypothesis.

Hans-Gerti Bachmann

References:
Reviews


The mysterious and also promising title of this book is an invitation to read it. Already the outer appearance of this publication is tempting: excellent print, yellow cloth binding, unconventional square size, etc. Thus, the expectations for its contents are high. The author is more than fulfilling them! Dorothy Hosler is a student of Cyril Stanley Smith, the eminent scientist, who has taught us new insights to interpret and understand works of art by resorting to metallurgy and metallography. This book follows along the same line in an impressive, convincing manner. Dorothy Hosler addresses her readers directly in the first person singular, which is unusual in scientific publications. The reader virtually listens to what the author has to communicate. Professor Hosler (profiteri (Lat.) = to confess) dedicates her work to Cyril S. Smith and her father: ‘...who in his own style shares Cyril’s intellect, creativity, imagination, and craft, and who showed me that work and play could be one and the same.’ We are presented thus with the lifelong endeavours and engagement of her research, opening up a new chapter in the understanding of the position and evaluation of metals in Meso-American societies and cultures.

 Artefacts from several museums and their thorough characterisation form the foundation for explanations of a technology which – according to the book’s subtitle – has to be called ‘sacred’. During the time-span from 600 to 700 AD, the societies of Mexico acquired a knowledge and experience in the production and working of metals which were hitherto unknown to them. Influences and impulses probably came via sea routes from the Andean civilisations. An autochthonous origin of metallurgy in Central America is not very likely. As in earlier millennia in the Old World, metal objects demonstrated social status and symbolised power and glory of gods and deities. In those phases of the cultural assimilation of metals, there was as yet no use for articles of daily use (tools, weapons). How true this was of ancient Mexico is best revealed by Dorothy Hosler’s own words: ‘These societies defined metal as a material whose principal use was for objects that communicated sacred power – through sound and through color – and for objects used in ceremony and worn by the elites.’ When speaking of sound, she refers in particular to the unique tiny bells – often smaller than a centimetre – which were cast with great skill and must have played (together with rattles) a paramount role in religious services. The colour of metal objects is conveyed by choosing an appropriate alloy. The ambitious (and convincingly successful) research project of the author has resulted in synthesising the regional technologies and their products with their implementation in religion and cult.

The introductory chapters are devoted to general statements on metal cultures and the geological prerequisites in the sense of availability and exploitation of mineral deposits. Most of the written sources referred to were compiled after the Spanish conquest. They are useful and informative also for the pre-conquest times. The region of Western Mexico apparently could supply all the ores and metals that made smelting and alloying – though perhaps on a rather limited scale – possible. The book’s central chapters are reserved for the two main periods of West Mexican metal technologies, i.e. Period 1 from 600 to 1200/1300 AD and Period 2 from 1200/1300 AD to the time of the Conquistadores. For each period a vast assemblage of dated and documented artefacts is characterised in detail (chemical analyses, metallographic examination of polished sections, and occasionally finite element analysis for the mathematical determination of critical parameters – such as dimension, composition, manufacturing technique – in order to understand the actual functioning of objects, for example tweezers which were important attributes of priests). The excellent photographs of polished sections would do credit to any text-book on metallography. The articles’ descriptions are augmented by accurate line drawings. Many maps help to find the localities cited in the text.

The following metals/alloys are present among the objects: copper, gold, silver, copper-arsenic, copper-arsenic-silver, copper-arsenic-tin, copper-gold, copper-silver, copper-silver-gold and copper-tin. The catalogue of artefact types includes: fish-hooks, awls, bells (smooth-walled and decorated with wire work), needles, rings, tweezers (of beam and shell design), axes, axe-monies and a variety of sheet metal ornaments. Manufacturing methods practised are: annealing, cold work from an initial cast blank, lost wax casting and hot work.

In addition to the numerous publications on South American metallurgy by Heather Lechtman, Dorothy Hosler’s book on Meso-America will be one more milestone in our knowledge and understanding of the role of metals in the New World, which is in many aspects so intriguingly different from what we know from the Old World. The authors has to be congratulated. She has achieved a masterly synopsis between critical and meticulous scientific research on one side and a highly sensitive mental immersion into the transcendental and emotional worlds of past, lost cultures and societies.

Hans-Gert Bachmann


To review a book written by an esteemed colleague is likely to turn into a compromise between loyalties: uncritical praise is easily understood as an act of biased friendship; emphasising the short-comings (and which publication is without them?) will only too readily be misinterpreted as an act of small revenge for past disharmonies between author and reviewer. However, Paul Craddock is too important in the field of archaeometallurgy, and in particular the author’s role in it is too significant, to let this publication remain unreviewed.

Paul T. Craddock, a scientist working at the British Museum’s Research Laboratory for more than 25 years, is by training an analytical chemist. He had already made a name for himself by analysing numerous objects from the BM by the then new method of atomic absorption spectroscopy. Important monographs signify this phase of his career. Thus, it is only too understandable that one day the author was drawn to the countries from where the artefacts came that he had so diligently analysed. Once at the scenes of early mining and metallurgy, he became fascinated by the insights as well as the problems these sites revealed. There are hardly any places of early exploitation and extractive metallurgy he has not seen, described and investigated. Among other contributions, we owe Paul Craddock special credit for his thorough and pioneering research on zinc production in India. Occasionally, his publications anticipated the reports of colleagues he had visited in the field.

Craddock’s bibliography is indeed impressive. It reads like a catalogue of current activities in the whole field of archaeometallurgy. He certainly is a scientist in the front line of these interdisciplinary approaches, particularly after R. F. Tylecote died in 1990. This book is an up-to-date companion to
Tylecote’s volumes. In the author’s words (cf. Introduction, p.1): ‘There is little attempt here to integrate the metal technologies into the overall social or economic life of the communities that used them.’ This modesty and restraint has to be respected and is 63.021 to be regretted. In my opinion, it is the interdependence between material remains and the cultural as well as socio-economic environment of a civilisation or ethnic group that raises archaeometallurgy to its interdisciplinary rank. To restrict the scientist’s role to mere fact collecting and data listing is certainly contra-productive to the shared responsibilities between science and humanities. Only the joint endeavours of dual approaches are likely to present answers to essential questions of cultural developments.

The content of the book is a vast summary of material evidences, a storehouse of information for the specialist in this field. The initiated reader can not only resort to the text of the book itself, but is also guided to 775 references, taken not only from English sources! He will no doubt get an B jour-overview of early metal mining and metallurgy from this publication. We, therefore, have to praise the author’s efforts and industry to relate all this relevant information to us. He certainly has benefitted from his position and the easy access to the British Library. Together with illustrations (some photographs are admittedly of rather poor printing quality), the text provides a very useful compendium for the advanced research fellow. I hesitate to recommend it for beginners, because a ‘leading thread’ is hard to discern.

About the book’s contents: the introduction is followed by a chapter on ‘The Development of Early Mining Technology’, continued by ‘Native Metals and their Treatment’. The important chapter on ‘The Inception and Development of Metal Smelting’ is but a compilation of scattered archaeological case studies rather than a more fundamental, general approach. Why not explain to the reader what processes and reactions are possible and which are not by introducing and explaining the basic laws of thermodynamics and reaction kinetics in metallurgy? The author is, after all, a scientist, and the laws of nature have not changed in the course of time. In the nearly 50 pages devoted to ‘The Smelting Process’, I was irritated to find here an excursion on roasting, which I would have expected under a heading ‘treatment prior to smelting’ or the like. In this same chapter, an unexpected paragraph on ‘Charcoal Production’ turns up and the already confused reader is suddenly confronted with the Ellingham diagram (free-energy relations of metal-oxide systems) in minute print. This most important graphic key to the fundamental understanding of metal oxide reduction equilibria is in this context rather out of place, particularly as not a word of explanation is given. What to make of JG? (only in the figure caption of this diagram)? After these general chapters, the author proceeds in the following order to ‘Lead and Silver’, ‘Iron and Steel’, and finally to ‘The Production of Volatile Metals and their Alloys’, i.e. arsenical copper, brass, zinc, etc. The sequence of this arrangement is rather unusual, to say the least.

To summarise: one has to admit that the author has done his best to present to his colleagues (and more to these, than to anyone looking for an introductory text-book) an up-to-date compilation of current research in the complex fields of early mining and extractive metallurgy. The abundant list of references is very useful and reliable. Paul Craddock has given us free access to his extensive filing cabinet and database. But, no doubt, he had more in mind when writing his book. As a modern introduction to the wide and fascinating field of Metallurgy in Archaeology (to quote the title of Tylecote’s unsurpassed ‘classic’, which first appeared in 1962) I hesitate to make a recommendation, but for the ‘fellows-in-arms’, the volume certainly serves its purpose.

Hans-Gert Bachmann