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News from the Institute

Thilo Rehren, Acting Director

There has been a serious delay in producing this issue; initially planned for Spring 2004 it finally was completed in December 2005. This delay reflects much of the life at the Institute during the last two years, and some of the more remarkable events from 2004 I would like to mention here.

The Spring and Summer of 2004 were dominated by the building works in the basement of the Institute of Archaeology, where most of the archaeo-metallurgy laboratories are situated. The works were triggered by the much needed new building for UCL's Department of Anthropology, right next to the Institute on a former car park and immediately above our labs (Fig 1). In order to lay the foundations for the new five-storey building, we had to vacate almost the entire Wolfson Archaeological Science Laboratories and move the equipment into new accommodation. This involved finding suitable new permanent space within the basement for the equipment, then preparing this space with the necessary power supplies, air conditioning, chiller units etc., and finally moving the four electron microscopes and the electron microprobe into this new space. The planning and building phase took about half a year, and wasn't free of surprises. The actual move of the equipment took about four weeks during which the labs had to be closed; to minimise the impact on ongoing teaching and research activities, this was scheduled for the Easter period, before the peak in demand in Summer when the Masters' students have to produce the data for their theses.

Soon after the completion of this first phase of the building works, during the IAMS Summer School 2004, we learnt that we had been awarded a major grant by the European Commission Framework Programme 6 under the Marie Curie Action, to host over the next four years a total of 40 Early Stage Researchers (EU speak for graduate students in Masters' and PhD programmes). The aim of the programme is to provide Early Stage Training ('EST') in the fields of materials science, conservation, and GIS applied to archaeology. The total number of trainees includes 15 one-year fellowships for students in Masters' programmes, up to nine two- and three-year fellowships for PhD students, and 16 short-term fellowships (three to six months) for individual training. The programme had to start in October 2004, and the necessary detailed negotiations both with Brussels and within UCL's grant administration to implement this £1.4M programme took most of the summer. Details of the programme are to be found on page 35 of this issue.

In August, after that year's Masters' students had finished preparing their samples for analysis and were busy in the new analytical lab and then writing up for submission day in mid September, the sample prep labs had to be moved out of their traditional space into temporary accommodation, taking up half of the former Student Common Room. This second phase was technically less complicated than the move of the analytical equipment, but still required a lot of planning to keep the downtime of the labs to an absolute minimum, and demanded extra work and patience from everyone involved. So still no time to finish *iams* 24, although by now most of the papers had been refereed, corrected and some even sent to the copy editor.



Fig 1. View of our former car park being prepared to take the foundations for the new building of the Department of Anthropology. The opening in the centre is where our former micro-analytical laboratory was situated. The sample preparation labs were below the opening visible in the lower left hand corner. Picture taken 3 December 2004.

Towards the end of 2004 then, four of our PhD students prepared to submit their theses, while at the same time four new ones started their research, including the first three funded under the new Marie Curie EST programme. This required much reading of final drafts for Marcos Martinon-Torres, whose research was on the role of triangular crucibles in Renaissance chemistry and metallurgy, Myrto Georgakopoulou who had studied Early Bronze Age copper smelting on the Aegean island of Seriphos, Shadreck Chirikure who had investigated change and development of Iron Age iron smelting in northern Zimbabwe, and Xander Veldhuijzen, whose topic had been the earliest iron smelting in the Levant, from the early first millennium BC in northern Jordan. Parallel to this, the research plans and training of Lorna Anguilano, Claire Cohen, Fatma Marii, and Aude Mongiatti had to be set up. So the plan was to finish *iams* 24 early in 2005. However, the building works which were meant to be completed, at least in the basement, before Easter 2005 continued throughout the year with frequent disruptions of our work, through constant noise, repeated dust ingress, two major and several smaller floodings, affecting both the new analytical laboratory and a dozen PhD students in one of our research rooms. They had been given temporary accommodation in a neighbouring building until January 2005, when their original room was supposed to be available again. As I write this in December 2005, they are still in temporary accommodation, after an Odyssey which at times bordered onto the farcical.

However, I want to finish this report for 2004 on a more positive note. Following on from the substantial increase over the last five years in student numbers in archaeo-metallurgy and related areas, and the success with the Marie Curie application, the Institute of Archaeology agreed in late 2004 to establish an additional lectureship in Archaeological Materials. We interviewed four shortlisted applicants, and a few days before College closed for the Christmas break Marcos Martinon-Torres accepted our offer for this lectureship, to start in January 2005 and on the condition that he finishes his PhD within six months from taking up his appointment. Did he succeed? How did he and the other finishing PhD students fare in their *viva voce* examinations in 2005? What about the fieldwork in Uzbekistan and Bolivia originally scheduled for 2004? This and more in next year's news!

Examination of copper slags from the Early Bronze Age site of Daskaleio-Kavos on the island of Keros (Cyclades, Greece)

Myrto Georgakopoulou

Introduction

The earliest metal artefacts known at present from the Cyclades (*Figure 1*) date to the Final Neolithic (FN: c. late 5th millennium-late 4th millennium) with examples from the Zas Cave on Naxos (Zachos 1996; Zachos and Douzougli 1999), Phtelia on Mykonos (Maxwell 2002), and Strophilas on Andros (Televantou in press). From the same period come the earliest finds of slag and metallurgical ceramics associated with copper production from the settlement of Kephala on Kea (Coleman 1977). The evidence for indigenous Cycladic metallurgy during the Final Neolithic is still limited but this previously little documented period is rapidly becoming better understood through a number of recent excavations in this region. Future examination and publication of the emerging data promise a much more informed picture of Final Neolithic Cycladic metallurgy.



Figure 1. Map of the Cyclades showing the sites mentioned in the text (adapted with changes from Broodbank 2000b: 325)

In the ensuing Early Bronze Age (EBA) both the metal artefacts and the metallurgical remains increase substantially in the archaeological record. A remarkable boost in the visibility of metallic artefacts is attested during the EBII period (c. 2700-2200 BC), which was characteristically assigned the term *Metallschock* (Renfrew 1972: 338). Metallurgy was seen as one of the prime stimulants for the important social changes observed in the Cyclades during the EBII (Branigan 1974, 1977; Renfrew 1967, 1972), although this direct association has been challenged by Nakou (1995), who stresses the possibility of a change in depositional patterns rather than, or as well as, a sudden increase in metal production and usage, particularly as the majority of these finds have been recovered from burial contexts. In terms of metallurgical activities on the other hand, developments in archaeometallurgical research in this region during the last two decades leave no doubt that by the Early Bronze Age copper, lead and silver were produced locally in the Cyclades. Several slag heaps or scatters have been reported for example on Kea (Caskey et al. 1988; Papastamataki 1998), Kythnos (Bassiakos and Philaniotou in press; Gale et al. 1985; Hadjianastasiou 1998; Hadjianastasiou and MacGillivray 1988; Stos-Gale 1998; Stos-Gale et al. 1988), Seriphos (Gale et al. 1985), and Siphnos (Wagner and Weisgerber 1985) although the degree to which these have been studied varies considerably and many remain undated. Among them the most well-known examples are the lead/silver mining and smelting site of Ayios Sostis on Siphnos (Wagner et al. 1980; Wagner and Weisgerber 1985) and the copper smelting site of Skouries on Kythnos (Gale et al.

> 1985; Hadjianastasiou and MacGillivray 1988; Stos-Gale *et al.* 1988), which have both provided conclusive evidence for EBA metal production. The role of these islands in early metallurgy is additionally supported by the results of an extensive lead isotope analysis programme, through which a large number of Aegean metallic artefacts were analysed and compared to potential Cycladic ore sources and production remains (see for example Gale and Stos-Gale 2002; Stos-Gale 2000 and references within).

> The metal production sites studied so far in the Cyclades are typically relatively large slag heaps in close proximity to potential ore sources, but are all located at a distance from any known EBA settlements. Evidence for the metalworking stages that follow smelting, such as melting and casting, has not been identified in the near vicinity of these heaps, leading to suggestions that the metal was most likely transported to settlements for further processing and artefact manufacture (Barber 1987: 112; Broodbank 2000a: 293-7). Metallurgical remains have indeed been recovered from a number of EBA settlements, albeit in contrast to the

western Cycladic slag heaps, their quantities are considerably smaller in these cases, usually only a few handfuls. Slag, metallurgical ceramic fragments, and/or litharge have been reported from Kastri on Syros (Bossert 1967; Stos-Gale *et al.* 1984; Tsountas 1899), Ayia Irini on Kea (Stos-Gale 1989; Wilson 1999), Provatsa on Makronissos (Lambert 1973; Spitaels 1982) and close to the EBA cemetery of Avyssos on Paros (Tsountas 1898). With the exception of a small number of lead isotope analyses no further analytical examination of such material had been undertaken to date. As the slag and ceramic specimens may in principle be associated with either smelting or melting, the absence of appropriate studies inhibits a clear distinction between the two possibilities.

A collaborative fieldwork project between the Universities of Athens, Ioannina and Cambridge and the Ephorate of Prehistoric and Classical Antiquities of the Cyclades (*Annual* Report 1986-7; Whitelaw 2003), carried out on the EBA site of Daskaleio-Kavos on the island of Keros in 1987, brought to light among numerous other finds, a small collection of metallurgical remains. Within the context outlined above, this material presented an excellent opportunity for a comprehensive technological investigation that would not only clarify the types of activities undertaken on the site but also contribute to the overall assessment of the organisation of metallurgy in EBA Cyclades. The collection included small fragments of slag, metallurgical ceramics, copper and lead metal, iron minerals and a single litharge specimen. The finds were all small, while the total weight of slag recovered did not exceed 300 g. Samples from all the different types of material were selected for analysis. Laboratory examination has been completed and a comprehensive presentation of the results is currently under preparation by the present author for publication in the forthcoming volume on the 1987 project on Daskaleio-Kavos (editors Renfrew et al.). This paper will present a shorter overview of the results only from the slag analyses, which represent the main type of material examined.

The site

Kavos lies at the western edge of Keros island, facing Daskaleio islet a few metres off the coast (*Figure 2*). A recent geoarchaeological study concluded that the EBA shoreline of this area was 2.5-5 m below modern sea-level, suggesting that Daskaleio was at that time possibly connected to Kavos by a low thin stretch of land (Bassiakos and Doumas 1998).

Archaeological interest was drawn to Daskaleio-Kavos following extensive looting in the 1950's and 1960's. The looting activities concentrated mainly on a 'special deposit' at the northern end of Kavos and resulted in severe destruction of its structural features and unrecoverable loss of priceless material. Subsequent sanctioned excavations recovered hundreds of fragments of broken marble anthropomorphic figurines and vessels, which appeared to have been deliberately broken in antiquity, as well as other lithics, pottery and metal finds establishing the 'special deposit' as the richest accumulation of prestige material known from an EBA Cycladic context (Doumas 1964; Renfrew 1972: 531-2; Hadji-Vallianou 1975; Zapheiropoulou 1967, 1968, 1975). The nature of the 'special deposit' has given rise to intense controversy among Aegean prehistorians. The wealth and intriguing nature of the finds, in combination with the catastrophic damage to its structural features caused by looting, have left behind a puzzling image, with suggestions divided between a funerary or ritual character (Bassiakos and Doumas 1998; Broodbank 2000b; Doumas 1964, 1990; Renfrew 1984, 1991).

In the south-central part of Kavos, habitation is testified both by the excavation of a house (Doumas 1964) and the abundance of domestic pottery (Broodbank 2000b). Settlement remains have also been noted on the islet of Daskaleio (Doumas 1972). Unfortunately the preoccupation with the role of the 'special deposit' has undermined research into the remaining areas of the site and fieldwork has been limited. On the basis of the pottery the site is dated to the Early Bronze Age II period (EBII: c. 2700-2200 BC), with very little evidence for earlier or later use (Broodbank 2000b;



Figure 2. Plan of the site and the surveyed area (Broodbank 2000a: 224). Reprinted with permission from C. Broodbank and T. Whitelaw.

Doumas 1964, 1972). The variability in the pottery shapes and fabrics (Broodbank 2000b) together with the wealth of other apparently imported material, portray a widely connected site. In his recent treatise of the EBA Cyclades, Broodbank (2000a) attributes the high influx of materials on Daskaleio-Kavos to the nodal position of the site within a wider inter-island maritime communication and trade network.

The 1987 fieldwork project involved systematic gridded surface collection over the entire Kavos area and excavation in the special deposit. Surface collection was additionally carried out on a low exposed promontory slightly to the north of Kavos, known as Kavos North *(Figure 2)*. The project did not expand to the islet of Daskaleio. The finds presented in this paper were all collected during the surface survey from south-central Kavos (samples labelled KK) and Kavos North (samples labelled KKN).

Analytical methodology

Samples were cut from each specimen and mounted in resin to prepare polished sections. Initial examination under the optical microscope was supplemented by analysis of individual phases and inclusions using the attached Energy Dispersive X-ray facilities on a Scanning Electron Microscope (SEM: JEOL JSM-35CF). Bulk composition measurements of the slag and metallurgical ceramic fragments were carried out on the electron microprobe with an attached wavelength dispersive X-ray spectrometer (WDS-EPMA: JEOL Superprobe JXA-8600). Ten to fifteen areas (c. 0.02 mm² each) were analysed in each case. The results presented here are averages of the measurements for each sample, normalised to 100 % to compensate for porosity. The following elements were analysed for1: Na, Mg, Al, Si, S, K, Ca, Ti, Mn, Fe, Co, Ni, Cu, As, Sn, Sb, Pb, Bi, expressed as oxides, and Cl. Metal prills in the slags were analysed using point measurements on the electron microprobe searching for S, Cl, Fe, Co, Ni, Cu, Zn, As, Ag, Sn, Sb, Au, Pb, Bi.

Results of the analytical examination of slag samples

Fourteen slag samples were examined. With the exception of one (sample KKN3 discussed separately below), they were classified into two groups on the basis of both macroscopic and analytical differences.

Group 1

Macroscopic characteristics

A total of nine slag samples were attributed to this group. Their size is small, reaching a maximum of 5 cm in their largest dimension *(Figure 3)*. They are all grey-black in colour with little or no external green staining. A ropey-flow texture is visible on the upper surface of some of the specimens. With the exception of a couple of samples that showed a little magnetism, the majority did not respond to a handheld magnet.



Figure 3. Examples of Group 1 samples.

Bulk and phase composition

Bulk composition measurements given in *Table 1* showed that silica (36-46 %) and iron oxide (33-42 %) are the main constituents, followed by calcium oxide (10-19 %) and smaller amounts of other gangue elements. Copper contents are relatively low ranging between 0.4-0.8 % (estimated as CuO). The low copper and high iron content of these slags immediately suggests a smelting rather than melting origin.

Additional evidence for an association with smelting stems from the microstructure of these specimens. Overall, despite variations in the size and distribution of the different phases both within and between sections, a common pattern is observed with reference to the nature of phases present and

Table 1. EPMA results (weight %) of bulk analyses on all the slag samples. Top: Group 1, Middle: Group 2 Results have been normalised to 100% to compensate for porosity, while the measured totals are given in the last column labelled MT. Note: Elements consistently measuring below the detection limits of the method (c.0.05%) have not been included in these tables.

	Na ₂ O	MgO	Al_2O_3	SiO ₂	SO ₃	Cl	K ₂ O	CaO	TiO ₂	MnO	FeO	CoO	NiO	CuO	As_2O_3	SnO ₂	Sb ₂ O ₃	PbO	MT
KKN1	0.5	4.1	2.7	39.7	0.1	0.1	0.2	14.9	0.1	0.2	37.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	93.1
KKN4	0.4	4.3	2.6	40.8	0.5	0.0	0.2	12.0	0.1	0.2	38.6	0.0	0.0	0.4	0.0	0.0	0.0	0.0	93.5
KKN5	0.3	4.5	1.9	40.0	0.1	0.0	0.1	13.9	0.1	0.2	38.5	0.0	0.0	0.4	0.0	0.0	0.0	0.0	95.3
KKN8	0.2	3.7	2.1	41.4	0.7	0.1	0.0	11.3	0.1	0.2	39.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	95.1
KKN9	1.0	4.5	3.1	46.0	1.3	0.1	0.8	10.0	0.1	0.2	32.5	0.0	0.0	0.4	0.0	0.0	0.0	0.0	95.8
KKN1	0 0.4	5.3	2.1	45.5	0.2	0.0	0.1	11.9	0.1	0.2	33.6	0.0	0.0	0.5	0.0	0.0	0.0	0.0	94.3
KK1	0.7	3.6	3.3	35.8	0.5	0.1	0.3	18.6	0.1	0.2	36.1	0.0	0.0	0.8	0.0	0.0	0.0	0.0	96.5
KK10	0.3	4.0	1.8	39.4	0.5	0.1	0.0	11.2	0.1	0.2	41.9	0.0	0.0	0.6	0.0	0.0	0.0	0.0	95.5
KK11	0.6	3.6	2.9	38.9	0.4	0.1	0.2	13.3	0.1	0.2	39.1	0.0	0.0	0.6	0.0	0.0	0.0	0.0	97.7
KKN2	1.3	2.7	7.9	30.1	0.0	0.5	0.9	5.6	0.3	0.4	39.7	0.1	0.2	2.6	0.1	0.0	0.0	7.5	93.8
KKN7	0.8	0.9	4.9	23.4	0.0	0.0	0.3	4.2	0.2	0.0	48.4	0.0	0.5	9.6	2.2	0.0	0.0	4.5	98.7
KK3	0.7	0.8	3.3	18.8	0.1	1.9	0.1	1.4	0.1	0.4	43.8	0.0	0.2	10.1	7.4	0.4	0.1	10.2	90.4
KK12	0.6	0.8	8.0	25.3	0.5	0.1	0.7	3.6	0.4	0.0	53.9	0.0	0.0	2.8	2.5	0.0	0.0	0.8	87.8
KKN3	0.0	0.3	0.0	5.6	0.0	2.5	0.0	0.2	0.0	0.0	59.9	0.0	0.0	31.4	0.0	0.0	0.0	0.0	86.4

their relative abundance. In most samples the dominant phase is fayalite (Fe_2SiO_4), surrounded by a glassy matrix, while fine and dispersed magnetite (Fe_3O_4) crystals are also present in most cases (*Figure 4*). Fayalite crystals (*Table 2*)



Figure 4. Reflected light photograph of the microstructure of sample KKN8, showing fayalite (medium grey), magnetite (light grey), glass (dark grey), and porosity (black) (scale: 50 µm).

in these samples usually accommodate significant amounts of magnesia (8-9 %) and lower quantities of calcium (2-5 %) and manganese (0.2-0.3 %) oxides. In sample KK1 the iron silicate crystals are much richer in calcium with an atomic ratio of approximately 1:1 between iron oxide, silica, and calcium oxide. The composition is more consistent with the mineral kirschsteinite (CaFeSiO₄), while small amounts of magnesium oxide were also noted. The crystallisation of these calcium-rich phases in this sample are not surprising given the comparatively high calcium contents detected in the bulk analysis of KK1.

Table 2. SEM analyses (weight %) of individual phases in Group 1 slags, normalised to 100% (Fe-Si: iron silicates; magn.: magnetites; MT: measured total).

The slags are virtually free of any unreacted or partially reacted primary materials, as are typically observed in early (usually pre-EBA) copper production slags (see for example Hauptmann 1989, 2003). The predominance of fayalite indicates reducing conditions, with oxygen pressures below 10^{-8} atm (Moesta and Schlick 1989), while the overall microstructure of these specimens suggests that the primary materials fully reacted to form a relatively homogeneous melt. Low copper losses are attested from the bulk composition measurements.

Entrapped prills in the Group 1 slags are mostly mixed copper and iron sulphides (matte). In the larger ones, different phases of the Cu-Fe-S system can be discerned within individual prills (*Figure 5*). Analyses of several matte prills from each sample were carried out on the electron microprobe but no other elements apart from copper, iron, and sulphur were detected. In addition to the matte, minute prills that resembled copper metal were also identified in the optical micro-



Figure 5. Reflected light photograph of the microstructure of sample *KK1*, showing kirschsteinite (medium grey), magnetite (light grey), glass (dark grey), and a large matte prill in the centre with a lamellar texture (scale: 10μ m).

Fe-Si	MgO	SiO ₂	CaO	MnO	FeO	MT					
KK1	5.3	31	22	0.3	42	88					
KKN1	9.5	31	3.5	0.2	56	89					
KKN4	7.9	31	2.3	0.3	59	87					
KKN5	8.3	31	4.5	0.3	55	88					
MAGN.	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	Fe ₃ O ₄	MT				
KK1	0.9	1.9	0.4	0.6	0.5	93	95				
KKN1	0.3	1.4	1.0	0.4	0.4	93	95				
KKN4	b.d.l.	1.4	2.4	0.8	0.5	92	96				
GLASS	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	SO ₃	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃	CuO	МТ
KK1	0.7	2.4	4.9	40	0.3	0.5	20	0.2	29	b.d.l.	90
KKN1	b.d.l.	4.0	1.8	45	0.1	b.d.l.	23	b.d.l.	24	b.d.l.	92
KKN4	b.d.l.	2.1	2.3	42	b.d.1.	b.d.l.	20	b.d.l.	30	b.d.l.	90
KKN5	b.d.l.	2.4	1.8	42	0.2	b.d.1.	20	b.d.l.	30	0.2	91

scope, but these were too small and could not be analysed further.

The presence of matte testifies to the addition of sulphidic minerals in the furnace charge. Several independent studies using different methodologies have concluded that from the early stages of metallurgy sulphidic copper ores could be smelted in processes that did not require particularly strongly reducing conditions or elaborate treatment as was the case for the matte smelting process carried out in later periods (Hauptmann *et al.* 2003; Moesta and Schlick 1989; Rostoker *et al.* 1989; Zwicker *et al.* 1985). In these case studies the sulphidic minerals entered the charge either as minor accessory components to a mainly oxidic ore (co-smelting), or formed the bulk of ore used. The resulting microstructure of the slags is frequently very similar, showing the same broad characteristics as the Group 1 slags from Kavos (cf Moesta and Schlick 1989; Zwicker *et al.* 1985). In the absence of remains of undecomposed ore in the slags, or discarded fragments on the site, it is difficult to decide with certainty the exact nature of the raw materials with reference to use of primary or secondary minerals.

Group 2

Macroscopic characteristics

Three out of the four slags attributed to this group show very similar external characteristics (*Figure 6*). They are greyblack in colour, with iron oxide and green copper oxide staining on their outer surface, the latter being particularly intense in and around the pores observed upon sectioning. They are very small, their largest dimension reaching a maximum of 1.5 cm, and magnetic. A very characteristic feature of these samples is the appearance of several tiny (c. 0.1 cm) green prills, which protrude on the outer surface.



Figure 6. Group 2 samples (top: sample KK12).

Sample KK12 is somewhat different macroscopially, but was included in this group mainly because of analytical similarities. This black slag reaches nearly 3 cm in length, is largely covered externally by a thin (~0.1 cm) solid green corrosion layer and also shows red-brown iron oxide staining on one side. External green prills were not visible and the sectioned surface did not show the intense green staining observed in the other samples.

Bulk and phase composition

The bulk analyses of Group 2 samples (*Table 1*) differ significantly between samples, due to the internal heterogeneity within each sample in terms of frequency, size, and distribution of phases (see below). Compared to Group 1, these samples show higher iron oxide contents (40-54 %), which predominates over silica (19-30 %), higher alumina (3-8 %) and lower calcium oxide (1-6 %). The copper contents are also much higher (CuO: 3-10 %), while particularly characteristic is the presence of other base metals, the most common being lead (PbO: 0.8-10 %), arsenic (As_2O_3 : 0.1-7.4 %)¹, and to a lesser extent nickel (NiO: 0-0.5 %).

The microstructure of these slags is generally very heterogeneous and also differs between the four samples. The frequency, size and distribution of the different phase components varies between each section. All the samples are rich in magnetite embedded in a glass matrix (see Table 3 for analyses of these phases). Sample KK3 shows a particularly high concentration of magnetite, with little glass, which is in agreement with the lower percentages of silica and other gangue elements measured in the bulk analyses of this section (Table 1). Fayalite crystals are only present in two samples (KKN2, KK12) (Figure 7). Analyses showed that these also incorporate small amounts of magnesia and calcium oxide (*Table 3*). A concentration of iron oxides in the shape of wüstite (FeO) was observed in sample KKN2, although the presence of this phase is limited to one area of the sample, the remaining being dominated by magnetite.



Figure 7. Reflected light photograph of the microstructure of sample KK12, showing magnetite crystals and large magnetite aggregate (light grey), fayalite (medium grey), and glass (dark grey) (scale: 100μ m)

Inclusions of unreacted or partially reacted raw materials are also common. Magnetite is often observed in large and irregularly shaped aggregates, which usually include within them distinct copper prills (*Figure 7*). These formations are interpreted as the remains of the partially reacted limonitic part of mixed copper and iron ores (Hauptmann *et al.* 2003). A few quartz fragments were also discerned. Analysis of these on the SEM showed that they usually contain small amounts of iron, copper, lead, and/ or nickel, possibly indicating a geological association between the quartz and the iron and base metal-bearing minerals.

The Group 2 samples are all very rich in copper prills, which vary significantly in size, the largest being visible macroscopically in the cut sections. Electron microprobe point analyses showed that these are arsenical copper prills, usually incorporating distinct lead metal inclusions (*Table 4*)². The distribution of arsenic in these prills is uneven with arsenic enriched zones appearing within a matrix of lower or even negligible arsenic contents, as is typically encoun-

Fe-Si	MgO	SiO ₂	CaO	MnO	FeO	Total								
KKN2	7.8	30	2.1	1.0	59	83								
KK12	2.8	28	2.6	0.0	66	92								
MAGN.	MgO	Al ₂ O ₃	TiO ₂	MnO	Fe ₃ O ₄	NiO	MT							
KK3	1.9	1.4	b.d.l.	0.7	96	0.8	96							
KK12	0.2	4.4	0.3	0.0	95	b.d.l.	98							
KKN2	2.1	3.1	0.3	0.5	94	0.6	92							
GLASS	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	SO ₃	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	CuO	As ₂ O ₃	PbO	MT
KK3	1.8	0.4	5.4	53	0.0	0.7	2.9	0.0	0.3	20	4.5	3.2	7.8	73
KK12	1.6	0.0	10.9	43	0.1	3.3	13	0.0	0.0	28	0.1	0.0	0.0	89
KKN2	2.5	0.4	9.1	36	0.0	2.0	13	0.1	0.4	29	0.2	0.0	7.0	89
KKN7	0.8	1.6	6.9	41	0.0	1.5	10	0.2	0.0	26	2.2	0.9	8.5	88

Table 3. SEM analyses (weight %) of individual phases in Group 2 slags, normalised to 100% (Fe-Si: iron silicates; magn.: magnetites; MT: measured total).

tered even in low arsenic copper alloys (Budd and Ottaway 1991; Northover 1989). The separation of lead in copper is not surprising given the almost complete immiscibility of the two metals in the solid state (Hansen and Anderko 1958: 610). Tiny lead prills were also identified, either distinct or attached to copper prills. Lower levels of several other elements were detected during electron microprobe analysis, the main being iron, nickel, and antimony.

In addition to copper prills, sample KK12 also bears separate matte prills. As can be seen from the analyses in Table 4, these generally show lower arsenic contents than the copper prills from the same sample. The observation agrees with the results of Yazawa (1980), who proposed that during copper smelting, arsenic impurities tend to concentrate in the metal phase rather than the slag or the matte.

The chemical composition and microstructure of the Group 2 slags indicate that these are the by-products of arsenical

copper production. The identification of partially decomposed starting materials, the presence of fayalite in two samples, and the relatively significant concentrations of silica and other gangue elements in the bulk all point to a smelting origin for these specimens. The predominance of magnetite indicates only slightly reducing conditions (Moesta and Schlick 1989), while the presence of fayalite and possibly also wüstite in some samples together with their overall heterogeneity show that the operating conditions are likely to have fluctuated considerably during the process. Despite the observed inclusions of partially decomposed materials, the formation of fayalite suggests that at least part of the mixture reacted forming a melt. Relatively high copper losses are attested in the bulk analyses.

Production of arsenical copper alloys can be achieved via several pathways depending on the nature of the starting materials (see for example Budd *et al.* 1992; Lechtman 1991, 1996; Lechtman and Klein 1999; Pollard *et al.* 1991; Rostoker and Dvorak 1991). Although arsenical copper alloys

Table 4. EPMA point analysis of copper and matte prills in Group 2 samples (weight %). Analyses KKN7I and KKN7J were carried out on the same prill analysing arsenic poor and arsenic rich zones respectively, although their small size does not allow complete separation of the two. Low totals, where observed are due to the small size of the prills, while totals above 100% usually result from the unavoidable simultaneous measurement of two adiacent phases.

	S	Fe	Ni	Cu	As	Ag	Sn	Sb	Pb	Bi	Total
KKN2A	0.0	3.1	3.7	88.0	0.1	0.0	0.0	1.8	0.1	n.a.	96.8
KKN2B	0.0	1.0	2.0	90.0	0.5	0.0	0.0	2.2	0.1	n.a.	95.9
KKN2D	0.0	0.0	0.9	89.6	2.3	0.0	0.0	0.4	2.6	n.a.	95.8
KKN2G	0.0	2.0	3.7	89.1	1.5	0.0	0.0	0.5	0.1	n.a.	97.0
KKN2H	0.0	0.4	2.3	95.8	0.0	0.0	0.0	0.3	0.6	n.a.	99.6
KKN7A	0.1	2.4	1.3	77.3	14.4	0.0	0.2	0.3	4.3	n.a.	100.2
KKN7C	0.0	2.1	0.1	90.8	5.6	0.0	0.0	0.1	0.0	n.a.	98.7
KKN7I	0.0	0.0	0.0	93.5	4.3	0.1	0.0	0.0	0.0	n.a.	97.9
KKN7J	0.1	0.0	0.0	71.7	28.0	0.1	0.0	0.4	0.0	n.a.	100.3
KKN7O	0.0	0.2	0.4	92.1	6.7	0.0	0.1	0.1	0.1	0.0	99.7
KK3D	0.0	2.2	0.5	75.7	16.3	0.0	0.0	0.7	1.7	0.0	97.2
KK12A	0.0	2.8	1.4	94.0	1.8	0.1	0.0	0.0	0.0	0.1	100.2
KK12B	21.1	7.3	0.0	67.6	0.1	0.0	0.0	0.0	0.0	0.0	96.1
KK12D	0.0	2.1	1.3	90.4	6.6	0.1	0.0	0.0	0.0	0.0	100.3
KK12E	0.4	6.7	0.5	70.5	21.1	0.0	0.0	0.1	0.2	0.1	99.5
KK12F	18.8	11.0	0.5	65.4	1.4	0.0	0.0	0.0	0.0	0.0	97.1
KK12G	0.0	3.6	1.6	91.3	4.7	0.0	0.0	0.0	0.0	0.0	101.3

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are common among EBA Cycladic metal artefacts, little is known about their production. To date only a few of the slags from the large smelting site of Skouries on Kythnos were found to contain appreciable amounts of arsenic in the entrapped copper prills (Gale et al. 1985), while the majority of material analysed so far does not agree with production of alloyed copper (Bassiakos and Philaniotou in press). The commonly held view that in the broader Aegean the alloy was produced 'accidentally' by smelting arsenical-copper ores (Gale and Stos-Gale 1989), has been challenged by recent finds from the sites of Chrysokamino (Catapotis et al. 2004) and Poros (Doonan et al. 2004) on the island of Crete. Mixing of arsenic and copper ores is suggested for Chrysokamino, while addition of arsenical minerals to copper metal is proposed for Poros.

The absence of associated ore fragments in the Kavos collection does not allow a clear conclusion to be drawn regarding the route followed for the production of arsenical copper on this site. The identification of quartz crystals with traces of copper found within the slags suggests that copper most likely entered the charge as a mineral rather than in its metallic form. The presence of other base metals in the slag in addition to arsenic such as lead, antimony, and nickel suggest the use of polymetallic ores, but whether these elements co-existed in the ore or whether different minerals were deliberately mixed in the furnace charge remains at present uncertain.

A remark should also be made concerning the surprisingly high levels of lead in some of the bulk analyses of the Group 2 samples, which in sample KKN2 in particular, appear to be higher than the copper contents. It should, however, be noted that during bulk analyses, areas exceptionally rich in copper prills were avoided. This practise would result in a lower copper to lead ratio in the measurements than may be true in reality, as the former mainly appears as distinct prills, while the latter is also present in significant quantities in the glass. Still, the overall lead composition in these samples is usually notably high. Although low levels of lead in copper smelting slags are not uncommon in the Old World (see for example Hauptmann 1989), these do not usually exceed 1 %. Examples of copper smelting slags with lead contents comparable to the Group 2 samples have not been found in the literature examined so far.

Sample KKN3

Macroscopic characteristics

The external appearance of sample KKN3 is very similar to the Group 2 slags. The sample is small (<2 cm in length), very magnetic, black with limited green staining and tiny green prills on its outer surface. Despite this resemblance KKN3 showed markedly different compositional and microscopic features, which necessitated a separate classification.

Bulk and phase composition

Bulk analysis of KKN3 showed that the sample mainly consists of iron (FeO: 60 %) and copper oxides (CuO: 31 %). Silica and the other gangue oxides are surprisingly low (Table 1), while other base metals, as identified in the Group 2 slags, are not present above the detection limits of the analytical method used.

The bulk composition is clearly reflected in the microstructure of this sample. Magnetite crystals predominate, often surrounded by a thin band of delafossite (CuFeO₂), while separate thin elongated delafossite crystals are also present in parts of the section (*Figure 8*). The glass phase is very limited. Circular copper chlorides are frequent in this section, possibly formed from the re-deposition of leached salts. Copper prills are commonly seen within the magnetite crystals. Analyses of these prills only detected copper and iron. Arsenic, lead and other base metals noted in the Group 2 slags are all below detection limits in these prills.

Sample KKN3 shows unique characteristics different than the other samples analysed from the collection. The absence of other base metals, characteristic in Group 2 slags, makes an association with these specimens unlikely, despite the similarities in external characteristics. The phase composi-



Figure 8. Reflected light photograph of the microstructure of sample KKN3, showing magnetite (light grey) and delafossite (white, elongated). Dark grey inclusions are copper chlorides (scale: 50 µm).

tion of sample KKN3, mainly composed of magnetite and delafossite, indicates relatively oxidising conditions and probably short reaction times (Bachmann 1982; Hauptmann 2000: 556; Moesta and Schlick 1989). It is likely that the material represents partially reacted dross, spilled from the reacting mixture at the early stages of smelting.

An alternative proposal may be envisaged based on the results of Moesta and Schlick (1989) on the Bronze Age copper smelting furnaces of Mitterberg. The authors suggested a two-step smelting sequence of copper from sulphidic ores, which involved initial formation of matte and subsequent oxidation to copper metal in the same furnace. The microstructure of the relevant slags is similar to the Group 1 slags from Daskaleio-Kavos for the first step, while a slag rich in magnetite and delafossite was formed from the oxidising process. Needless to say such an association cannot be deduced at this stage but the possibility should be considered if further similar material is recovered. As at this stage the sample is unique in the collection it has to be considered as an accidental by-product.

Discussion

The results of the analytical examination of the slags from Daskaleio-Kavos challenge to some extent the previously held model, which proposed a spatial separation of metallurgical activities in the EBA Cyclades, with smelting carried out on the western Cycladic slag heap sites and further metalworking in the settlements (Barber 1987: 112; Broodbank 2000a: 293-7). Admittedly, the scale of production appears to be much smaller in this case.

Particularly interesting are the indications for variability in the metallurgical processes on Daskaleio-Kavos. Evidence for processing of at least two different types of copper was brought forward, while a single litharge specimen identified in the collection (see Georgakopoulou in prep.) raises the possibility that lead-silver metallurgy was also practised on the site. Specimens conclusively associated with metalworking have not been identified, but as the material was all produced from surface investigations and excavation has not been carried out, absence of evidence should not be regarded as evidence for absence.

Several interesting questions now arise. The first is the provenance of the ores used on Daskaleio-Kavos. Was the material local or was it brought to the island from elsewhere? To date systematic search for potential prehistoric ore sources has not been carried out on Keros. Bassiakos and Doumas (1998) report a weak iron-copper mineralization on the island, but this is very limited and it is not clear whether it could have been a source even for small-scale production. On the other hand, the use of at least two different types of ore and the accepted high influx of other imported materials on Daskaleio-Kavos appear to favour the suggestion of an external source. Final interpretation will, however, need to await further study, using appropriate methodology targeted specifically at addressing the question of provenance.

Another issue that needs to be considered is whether the two processes are strictly contemporaneous or whether they reflect a shift in the use of different materials in the period when the site was inhabited. The implications are interesting in terms of assessing the organisation of metallurgy on the site, proposing reasons for the selection of different sources, and comparing the technological details of each process. The Group 2 slags, for example, appear to be associated with a less sophisticated process, with higher metal losses and incomplete reaction of the primary materials, although the small number of samples available for analysis at this stage inhibits a direct comparison. Do the observed differences mirror technological advancements or are they associated with intentional or unintentional adaptation of the operating conditions to the use of different materials? Excavation of stratified material will be necessary in order to examine whether further refinement of the chronological association between the two processes can be made.

In closing, it should be stressed that the nature of metallurgical processes carried out on Daskaleio-Kavos should not necessarily be expected to be similar to those practised on other contemporaneous Cycladic settlement sites. On the contrary it is the identification of potential similarities or differences (whether in working only specific metals, carrying out only some steps of the production sequence, or using different sources) that is necessary in order to obtain a more complete picture of the organisation of metallurgy in EBA Cyclades.

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Notes

- l In order to discriminate between the lead and arsenic contents of the sample on the WDS spectrometer, lead was measured on the M α line and arsenic on the L β line.
- 2 Analyses presented in Table 4 are point measurements and, given the heterogeneity of the arsenical copper prills, should not be taken as representative of the metal's composition.

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Experiential and experimental archaeology with examples in iron processing

Daniel Jeffery

Introduction

Experimental archaeology has experienced a great deal of attention in recent years from both professionals and lay people. As is usual with a rapid growth in interest, misunderstandings abound. In order to clarify the principles of experimental archaeology a distinction will be drawn from closely associated experiential archaeology and then some excellent examples of well informed experimental archaeology related to iron processing will be reviewed. The intention is to clarify by explanation and example a simple definition of experimental archaeology.

Experiential and Experimental

Experimental Archaeology is a term that is used so frequently and so variedly, with different meaning and scope by different sources, that it is almost worthless as a descriptor. Over time progressive attempts have been made to define the term. Looking at them diachronically a clear maturing of the definition of experimental archaeology can be seen; it can be said to be 'coming into focus'.

The most recent work reviewed for this paper was that of Mathieu (2002), wherein he lays out a fairly detailed typology for categories of experimental research. His description allows for the categorization and understanding of a very broad range of experiment types to test different hypotheses within archaeology and is very useful in giving a perspective on the scope and usefulness of the experimental approach to archaeological interpretations.

Mathieu and the majority of the sources reviewed also sought to define clearly what makes experimental archaeology different from other approaches to understanding and interpreting material culture. This difference between true archaeological experimentation and other activities can be difficult to see without looking closely at some of the related activities and comparing them in light of their purposes, procedures and results. In conducting the overview, the work of Reynolds (1999) will be heavily drawn upon as it is of a similar scope and the divisions he suggests agree well with this author's own way of looking at the matter. Two closely related, often even intertwined, groups of activities commonly fall under the general label of experimental archaeology. Partially borrowing from Reynolds (1999), they will be labelled 'experiential' and 'experimental'.

Experiential Archaeology

Experiential archaeology is concerned with realistically performing tasks in the manner in which they were performed in the past. As such, this 'archaeology by experience' is quite commonly confused with experimental archaeology by the lay person and even the professional. Experiential archaeology can, for example, give insight into the difficulty of manoeuvring large timbers and blocks of stone or the labour required to plant a field and grind grain. Such experiences are very valuable in discovering for oneself the workings of ancient technologies and understanding their application to everyday problems. However, there remains a major difference between experience doing a thing and true experimentation.

Experimental Archaeology

The critical element separating experiential projects from experimental ones is that experimental projects contain welldefined hypotheses that are to be tested and then either accepted or rejected through clearly defined procedures and reasoning. Kelterborn (1987) provided an outline of two key issues in proper experimental archaeology:

KEY ISSUE 1: STATE OF THE ART: When does an experiment agree with today's accepted scientific standards? When it is:

- 1.1 Clearly goal oriented.
- 1.2 Measurable.
- 1.3 Repeatable.
- 1.4 Professionally planned and supervised.
- 1.5 Executed with expert manual skill.

KEY ISSUE 2: BASIC ACTIVITIES: What is common to all complete experimental projects?

- 2.1 Study, conceive and plan the project
- 2.2 Procure, analyze, and exploit the existing data base and make the logical conclusions with regard to the project. The data base includes literature, archaeological originals and opinion of experts.
- 2.3 Prepare and equip the infrastructure and the location of the experiment (lab or field).
- 2.4 Supply all original or substitute raw materials.
- 2.5 Make or buy tools, instruments, fixtures and gadgets.
- 2.6 Conduct the experiment, analyze, evaluate and draw conclusions.
- 2.7 Document, store, report.

The first key issue makes very clear the elements necessary for a true experiment. Point 1.1 necessarily implies a hypothesis to be tested by means of the experiment and succinctly states the need for the experiment to be focused and oriented toward a very specific and explicitly understood end. 1.2 is very important to recognize since a major difficulty in experimentation upon archaeological materials comes from the large number of variables and unknowns that must somehow be controlled for, or at least acknowledged. This brings 1.3 - 1.5 to the forefront since, in order to be repeatable, the measurements and variables that were present must be known and accounted for in the literature. This in turn requires a skilled staff, who not only know how to effectively operate the experimental and analytical equipment, but also a staff that has the manual skill to simulate that of humans in the past.

The points in key issue 2 serve to illustrate with details that a true experiment is not taken lightly or embarked upon just to experience an ancient way of doing something. Of particular relevance is 2.2, which points out the vital importance of drawing on all available resources and research. In order for an experiment to be meaningful it must be done in the context of what is known about the process it investigates, the culture and the other research that has already been conducted.

A third grouping was also proposed by Reynolds (1999): education. However, both experiential and experimental projects are educational in nature. Archaeology, which is normally publicly funded, owes a special obligation to relay its discoveries back to the general public and experiential and sometimes experimental archaeological projects are often a very effective way of giving back. This is very apparent in the area of public archaeology where experiential projects play a major role in most curricula.

While the distinction between experiential and experimental archaeology should be clear, it is quite common for a project to fulfil both purposes at the same time, possibly creating some confusion. This seems to be what has led to the confusion that exists today wherein any group that attempts activities done in the past may refer to themselves as doing experimental archaeology (e.g. Lothene Experimental Archaeology Group in Scotland). Additionally, the word 'experiment' is closely associated with science and as such gives a sense of authority to activities associated with it. This would seem to be at least part of the reason for the prolific use of the term by groups only marginally involved with experimentation. Even within archaeology we find confusion as in the 1981 edition of the Bulletin of Experimental Archaeology (1981) wherein is stated, "It is our belief that practical experiments in archaeology, responsibly conducted, can be an important educational experience both in schools and in adult education." The author then goes on to reference a teaching pack for schools on using a Roman sundial and measuring rod. While this is indeed an excellent example of experiential archaeology and could conceivably be conducted in such a way to make it experimental, as an experiment it is likely to be unwieldy and less effective for teaching. An experimental project is distinct in that it requires a rigorous scientific experiment intended to help determine the validity of a given hypothesis.

Projects such as the West Stow Saxon Village, the exhibitions in historic martial arts at the Royal Armouries or the Higgins Armory Museum and any number of battle re-enactments throughout the world are all examples of what is sometimes called historic sites or public archaeology. Other projects such as experiential projects at the Butser Ancient Farm and most of the experimental archaeology week at the Institute of Archaeology, UCL are examples blurring the boundaries with scientific experimentation because they do some recording of data and some experimental variation in their procedures. While these activities undoubtedly have shown us something of the nature of construction of ancient buildings, historic martial arts and grain grinding, they are normally not experimental in the scientific sense of carefully controlled and documented hypothesis testing. A symbiotic relationship, however, could exist as worthwhile experiential projects are informed by and serve as impetus for experimental projects, as is indeed increasingly the case with the Institute's experimental archaeology week.

Experimental projects

A large number of 'experiments' in different areas were examined during the research for this paper. Several examples directly related to charcoal production, iron smelting and crucible steel production were selected to highlight the characteristics of well designed experimental archaeology projects and in so doing to underscore the difficulties encountered within a related context.

Charcoal Production

Traditional charcoal production requires a great deal of skill to achieve good results and therefore poses a serious challenge to the experimental archaeologist. Charcoal production is still practiced in many parts of the world and so it is frequently studied on-site with the experiment conducted by professionals who still derive their living from charcoal production. This form of ethnographic experiment poses its own unique set of problems, however. As has been discussed, careful analysis and quantification of the individual variables involved is vital in a good experimental project. The quantification of charcoal production is entirely feasible and has been easily done within industrial settings, but when the project is moved to a remote third-world location where wood has just been cut to be charred, it is extremely difficult to implement the needed tools.

In the study of charcoal production effectiveness the most significant measurement of efficiency is charcoal yield. This is a calculation of the weight percent of charcoal generated from a given weight of wood. The average charcoal yield using the common mound kiln is generally estimated at about 15-20% (Rehder 1999: 310; Armstrong 1978: 74). Horne (1982: 11) cites 14% in an experiment in Iran although stating that European data (no source or timeframe is given) indicates 20-30% yields. While Horne and Armstrong's yield percentages seem quite similar, Rehder and especially Schenkel and co-workers (1998: 509) point out that there will be a dramatic variation in weight percent yield depending on the initial level of moisture in the wood and the type of wood being charred. Based on the research of Schenkel and co-workers using anhydrous measurements the charcoal yield in a skilfully operated mound kiln today in Africa can reach 25-30%. This is comparable to that obtained in modern kilns (Schenkel et al 1998: 515; Emmerich & Luengo 1996: 43). Although the data of Schenkel and coworkers at first seems to contradict that of other researchers, it is important to note that they are measuring the actual mass yield based on an anhydrous measurement from before charring. It seems likely that the experimental burns which Armstrong (1978) recounts need to be qualified according to the skill of the operator and calibrated for water content in the pre-burn weight. The data may then turn out to be very similar to those reported by Schenkel and co-workers. An interesting conclusion is that modern methods of charcoal production may not have improved the yield over that achievable by a skilled burner in antiquity, although they have dramatically reduced the time and the amount of human labour and skill required.

A very important issue apparent in the above studies is that of measurement on location. Schenkel and co-worker's method requires an adiabatic calorimeter, a tool not conducive to use in third-world forest areas. Rehder (1999: 310) deals with the problem of calibrating for weight before and after burning by analyzing the energy produced in the furnace from charcoal in comparison to that of the same uncharred wood, measuring the change in energy to quantify the yield rather than the change in weight. This technique poses a similar problem to the adiabatic calorimeter in that it requires very exact measurement of temperatures in the furnace, which are virtually unattainable outside of a highly specialised laboratory.

As recorded by Kelterborn (1987) in key issue 1.5 above, the skill of the burner must not be neglected. When analyzing superficially comparable yield percentages it must be remembered that charcoal making is a craft that requires considerable skill and that therefore reliable and consistent data can only be gained from a project involving a skilled charcoal burner.

From the work reviewed, it is clear that data reported without careful quantification before and after may be anecdotal and interesting, but cannot accurately tell how effective a technique of charcoal production is. More careful experimentation needs to be done by skilled burners using absolute techniques, such as the anhydrous weight as proposed by Schenkel and co-workers (1998), to get a true picture of charcoal yield. This necessarily means either devising a way to take the analytical equipment to the burn or to bring the professional burner to a location where the procedure can be recorded. The situation can be even more complex in some of the projects considered below.

Iron Smelting

The work of Peter Crew (e.g. 1991) in experimental smelting with a low shaft furnace (see front page) is one of the best, most well-developed and well-documented experimental archaeology projects to be found. Looking at his work within the framework of the key issues above, the clear overall goal has been to determine the parameters of Iron Age and Medieval bog iron smelting in northern Wales.

Crew started from experiments already conducted by Tylecote (1971) and Cleere (1970) and the archaeological evidence local to the area. Thanks to Tylecote and Cleere, Crew started with some previous experimental data, but the archaeological record showed very little evidence as to height and wall thickness of the furnace. This necessarily required that Crew develop his own interpretation of the furnace construction and thickness.

In conducting his experiments, Crew has maintained detailed records and set clear purposes for each experiment, stating precisely which variables have been altered, forming hypotheses for expected results, revising them based on evidence and evaluating the results for further experiments.

One important factor that Crew and his predecessors identified was the control of airflow into the furnace. Changes in airflow will dramatically affect the condition of the smelt and a controlled and known volume of air is important as a variable in the smelting operation. Initially Crew attempted to use different types of hand bellows to deliver air to the furnace, but the rate of flow was so variable that a large range of temperatures and conditions would exist in the furnace, making it very difficult to keep constant, or even quantify, furnace conditions. In order to achieve a controllable and measurable airflow into the furnace he also tried using electric blowers, but airflow was still difficult to quantify and too fierce an airflow was generated. Finally, a specialized piston bellows was developed, which allowed Crew to measure and control the volume of air delivered to the furnace. So, while the furnace itself was made from local clay and stocked with local ore, a mechanical bellows was used to provide the air at a realistic and consistent rate, while providing a pulsed air flow very similar to that expected of a hand bellows. This is an excellent example of the way that a truly experimental project considers the elements of an operation that must be maintained exactly as they were in antiquity and the elements that are better handled using a modern technique that will allow for more precise control, while still maintaining an acceptable degree of adherence to the ancient process.

Crew's work has continued with variations to test different variables and he has now conducted over 90 smelts, making him possibly the most experienced bloomery iron smelter alive today. One element clearly shown by the extensive work of Crew is the paramount importance of repeated experimentation and experienced operators. Somewhat in contrast to this are some of the experimental smelting projects presented by the Historical-Archaeological Experimental Centre at Lejre in Denmark. There, at the centre, a series of individual smelts have been conducted to answer specific archaeological questions such as the type of slag and bloom retrieved from a magnetite ore (Hjarthner-Holdar et al 1997) or the use of straw within pit furnaces to support the ore (Mikkelsen 1997). As an example, the Mikkelsen experiment has a clear hypothesis and method, but since it is only a single experimental smelt conducted by Mikkelsen, who apparently has no previous experience, the conclusions drawn must be held as indicative or qualitative only, pending further experimentation.

An issue raised by Reynolds (1999), closely tied to Kelterborn's point 1.5 (1987), is the publication of the length of time required to accomplish tasks. Since there are few experts in bloomery iron smelting alive, suggesting a length of time for the task based on experimental evidence may be very deceptive. In the context of Crew's work, a shortening of smelting times as the operators' own understanding of the process increases is reported and a plateau was observed as the times became more consistent after a significant number of smelts. This data, as with all experimental data, is indicative only of the results of one possible method by which smelting may have been accomplished in the past. Reynolds' concern was that no sweeping claims about societal dynamics should be made based on the process durations, especially when the experiment may have been conducted by those inexpert in the technology under consideration.

Crucible Steel Production

A very interesting series of papers by Verhoeven and coworkers (1987, 1987, 1990, 1992, 1992, 1993, 1996, 1998, 2001, 2002) and Wadsworth and Sherby (1982, 1983, 1985, 1992), illustrate another issue in experimental archaeology not as readily apparent in the iron smelting projects discussed above. In the study of crucible Damascus steel, both parties used ultra-high carbon steels (around 1.4% C) and more or less agree on the cause of Damascus steel patterning and even to a large part on the methodology. Procedural differences separate them, however. They are both agreed, and have provided quite substantial evidence, that patterned crucible steel is produced when steel reaches a liquid state and cools very slowly. Wadsworth and Sherby use a warm rolling machine in a steam bath in order to process pieces of steel within a very controlled temperature range. They then analyze the resulting material for patterning similar to that of known crucible Damascus steel. The tightly controlled temperature and processing allow for precision in method, but applicability is called into question. Although this modern method and the patterns it produces show similarities to ancient artefacts made of patterned crucible steel, there are also marked differences. One significant difference is that all of the visible banding is in line with the direction in which the steel was rolled. Wadsworth and Sherby claim that this is simply an artefact of the production method, but no further processing has been done to prove that their method could produce the appropriate banding if it were forged.

Verhoeven, on the other hand, has worked with a number of other scientists and skilled smiths in his research. These smiths actually forge the metal into blades and then polish and etch it to determine whether they can produce the Damascus patterns. The results are nearly identical to surviving historical examples, but the processing temperatures and working method are much less controlled. The real strength in Verhoeven's approach is that they have continued to make procedural and compositional variations in processing billets of steel, thus developing a solid experimental database. Both of these groups decry the other's methods as not applicable enough to be useful, but the reality would seem to be that both approaches have given us very valuable information. Taken together, they can illustrate the value of both modern and historical methods used in synthesis for helping to understand ancient technologies.

Conclusion

The confusion around the term experimental archaeology is unfortunate because a clearer understanding would allow better interaction between the experiential and experimental communities and create a symbiotic relationship in which the two would be better able to aid one another, and reach the public. It is hoped that the definition of experiential and experimental archaeology offered above and then illustrated by quality experimental efforts has helped to create a clearer understanding in the mind of the reader. The examples of experimental work exemplified by Schenkel and coworkers, Rehder, Crew, Blair, Wadsworth and Sherby and Verhoeven and co-workers should demonstrate some of the varied problems of scientific experimentation in exploring the workings of ancient iron technology and differentiate it from experiential undertakings. Further efforts need to be made to inform both archaeologists and the public as to the distinction between and value of experience and experimentation in archaeology and how they can work together to enhance our understanding of the past.

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Late Neolithic and Chalcolithic copper smelting at the Yotvata oasis (south-west Arabah)

Beno Rothenberg, Irina Segal and Hamoudi Khalaily

Site 44 at Yotvata, its discovery and excavation

Yotvata is the modern name of an oasis located in the Arabah rift valley (G.R.155.923), about 40 km north of the Gulf of Eilat/Aqabah (*Fig. 1*). At the time of the first visit at the site



Fig. 1. Map of the Arabah and adjacent regions

by Beno Rothenberg in the early 1950s, the oasis was still called 'Ein Ghadyan¹, a name presumably derived from the nearby Roman station ad-Dianam (Tabula Iteneraria Peutingeriana, Segm.IX, Miller 1962). The oasis consisted of several shallow wells, a grove of date palms and an extensive area of tamarisks. The newly founded Kibbutz settlement was called 'Yotvata', due to the proposed identification of this oasis with "Jotbath, a region with running brooks", Deuteronomy 10:7, (JPS 1999), which finally became the official name of the oasis. Already during this first visit, numerous ancient sites were observed in and around Yotvata, some of which had already been reported by previous explorers (for references cf. Meshel 1993: 1517 and Rothenberg 1967: 139-140). The large number of ancient sites was obviously due to 'Ein Ghadyan being the most important source of water in the southern Arabah as well as an ancient major crossroads. However, its particular importance for us was due to the fact that it was, since early prehistoric times, the only major source of water and fuel for the often largescale mining and smelting activities in the region, especially in the Timna Valley, the Wadi Amram and on numerous hillsites along the mineralized mountain range of the southwestern Arabah, one of which, Site 44, was located at Yotvata itself (Rothenberg 1999).

Site 44 (G.R.15529234), located on top of a hill next to the Kibbutz settlement, was first recorded by Rothenberg in 1956 (*Fig. 2*) and again investigated by Rothenberg's 'Arabah Expedition' in 1960² and in 2001³. The architecture of this site (*Fig. 3*), and its location on a steep, high cliff overlooking the oasis, indicated that it was a stronghold to guard this rich source of water and wood. Related to the architec-



Fig. 2. Hill site 44 at Yotvata



Fig. 3. Architectural features (1960) on the hilltop

tural features of the site (see below, on Meshel's excavation), there was pottery very similar to the pottery found at the copper production sites at Timna, which is dated to Egyptian New Kingdom. There were also some Roman and Nabatean sherds, presumably related to tombs of this period on the hill⁴.

On the flat hilltop, mainly on its east side, many small lumps of slag were found dispersed - estimated 30 kg5 - evidently indicating copper smelting at the site. Flint tools and pottery, found among the slag, were at the time dated to the Chalcolithic period (Rothenberg 1967: 141; Rothenberg & Glass 1992: 152; Meshel 1993: 1517). Recent re-investigation of the finds also identified Late Pottery Neolithic sherds and flints⁶ (see below). However, since the slag, flints and the finds were mostly found within the fortified area of the hilltop, dated to the 19th and 20th Dynasties of the Egyptian New Kingdom, it remained difficult to be sure about the date of the metallurgical activities, and whether there was one or several different periods of copper smelting at the site. This problem remained essentially unsolved even after the stratigraphic excavation by Meshel (Meshel 1993), who assumed that some of the metallurgical remains found inside the casemate fortress may indicate local smelting by the Egyptian New Kingdom inhabitants of the fortress (Meshel 1993: 1518). The solution of this problem was one of the main objectives of our visit at the site in 2001 and, foremost, the recent metallurgical investigations reported in the following.

Site 44 was excavated in 1976 by Zeev Meshel, Tel Aviv University (Meshel 1993: 1518-1519; 1990: 37-39). This excavation produced important stratigraphic information and a clear picture of the architectural remains (*Fig. 4*). The summit of the hill, isolated on three sides by steep cliffs, was only fortified on its western side, protecting the easy approach from the adjacent hills by a casemate wall, with rooms of irregular size (1.9-2.4 m) and varying length. The casemate wall's foundation, about one meter high, was built of undressed stones, topped by sun-dried mud bricks. It was built onto the flat surface of the site, without any foundation trenches. Bedrock or a leveled earthen fill comprised the floor inside the rooms.

About 75 m west of the casemate fortress, an earth-build fence enclosed more of the hill's summit, which the excava-



Fig. 4. Plan of the Yotvata hill site after excavation (Meshel 1990)

tor suggested to be possibly of Chalcolithic date (Meshel 1993: 1517). A number of burials of the Classical periods were identified at the site, including a double tomb containing a skeleton and an empty cedar coffin, dated by pottery to the 1st century AD. Some metal jewellery was found with the skeleton⁷.

The excavation of the casemate wall produced a considerable quantity of pottery, including wheel-made storage jars, crude, handmade cooking pots (Negev Ware) and several Midianite sherds. Since the whole pottery assemblage, especially the Midianite ware, was most similar to the pottery found in the Egyptian New Kingdom copper industry of Timna (Rothenberg & Glass 1983: 65-124), the excavator related the "Yotvata fortress ... to the zenith of copper production at Timna" (Meshel 1993: 1518), *i.e.* from the late 14th century to the middle of the 12th century BC.

However, the dating problem of the metallurgical activities at Site 44 became more acute after Meshel's excavation, because the metallurgical remains8 were found whilst clearing the "floors" inside the casemate rooms and because "in sections cut in the fortress's courtyard a layer of ashes and slag was found against the casemate wall". Meshel accepted these stratigraphic details as evidence for copper smelting by the New Kingdom inhabitants of the casemate fortress (Meshel 1993: 1518). This stratigraphic problem was re-investigated at the site by our team in 2001 and we now suggest another interpretation of this surface against the outside of the casemate wall: the casemate wall was built partly on bedrock and partly on the sandy surface of the hill top. This sandy surface is only a shallow layer of loose sand, covered by very soft wind-blown loess. The heavy wall would obviously settle into the soft surface, and the surface outside the casemate wall appeared to touch the wall at a higher level, *i.e.* appeared, wrongly, to be a floor of stratigraphic significance. We have met a similar situation in excavations in the loess-covered desert region of the Arabah and the Southern Negev.

Already during our earlier surveys at the site, we noticed that the rough slag of Site 44 was totally different from the tapped slag of the New Kingdom smelters at Timna (cf. Rothenberg 1990: 69) and that the stone tools dispersed on the surface of Site 44 were also not of the type common at New Kingdom Timna (cf. Rothenberg 1972: figs. 23-25). Obviously, there was need for closer study of the archaeological situation and, foremost, of the metallurgical remains. From the archaeological point of view it seemed to us that the casemate rooms had been built on top of earlier metallurgical activities, without any previous clearing of the surface. According to Meshel's report, the NK builders took earth from the near vicinity in order to level the floors of their rooms, and we assume that this fill contained earlier remains. In fact, Meshel's excavation report provided the archaeological evidence for this conclusion: "a thin layer of ash9 that was found in several places in pockets in the bedrock beneath the walls and floors of the later fortress's casemate rooms. An unusual find was a deposit of about twenty grinding stones of different sizes, mostly made of granite, that were hidden in a sealed pit under the later fortress wall". Evidently, these finds are evidence for pre-New Kingdom activities at the site - also assumed by Meshel - but they do not exclude the possibility that also during the New Kingdom copper was produced or worked at the site. We, therefore, undertook the investigation of the metallurgical remains found at the site and their comparison with other sites of well-dated copper metallurgy in the Arabah.

Besides the dating of the metallurgical activities, the main objective of our investigations was to establish the metallurgical technologies used at Yotvata, whatever the date. During our inspections of the site10 and also during Meshel's excavation, no smelting installation of any kind was found. In fact, in the excavated casemate rooms no remains or traces of any metallurgical activities in situ were identified. We assume that somewhere on the hilltop smelting took place in a simple hole in the ground, as we know from other prehistoric smelting sites in the Arabah, as f.i. Late Neolithic Site F2 (Rothenberg & Merkel 1995; Segal et al. 1998) and Chalcolithic Site 39 of Timna (Rothenberg & Merkel 1998; Merkel & Rothenberg 1999). The Chalcolithic 'smelting furnace' at Site 39b, excavated by Rothenberg in 1965 (Rothenberg et al. 1978: 13, fig. 15), and lately ¹⁴C-dated to the 5th millennium BC (Rothenberg & Merkel 1998), was such a simple hole in the ground, and produced the same type of porous, viscous furnace slag, as found at Yotvata.

Pottery and flint assemblage of Site 44, the archaeological dating evidence

During the survey of Site 44 in the early sixties, pottery and flint were collected on the surface of the site. The flint assemblage comprises 35 artefacts. The knapper used homogenous, fine-grained raw material that varied in colour from light grey to dark brown. However, the majority sustain patina which covers most of the debitage surfaces.

Waste

Within the waste material, flakes and blades appeared in equal numbers (8 each). There are also two chips. The blades are mostly large blanks, probably produced from large cores, while the flakes vary in size and include large as well as small flakes. Three cores were identified: A flake core, a broken blade core and one amorphous core (*Fig. 5:1*).

Tools

Tools (15) make up 43% of the entire assemblage: The three borers identified are on thick flakes (*Fig. 5:4*).





Fig. 5. Flints from Site 44



Their working edges were formed by a large notch on one side and a simple retouch on the other.

The five retouched blades were subdivided into two types, three of them are simple retouched blades, the other two are backed blades (*Fig. 6:8*). The two backed blades are made on wide blanks, over 22 mm, their cross sections triangular in shape.

Two sickle segments were identified, both were shaped on wide blanks (average 1.8 cm). One has a trapezoid cross-section and was backed by semi abrupt retouch. Its distal end is truncated while the proximal is natural (*Fig. 5:3*). Sickle gloss is visible on the working edge. The second sickle (*Fig. 5:2*) is rectangular in shape and relatively thick. Semi abrupt retouch shaped its back and the truncation. The working edge shows irregular retouch.

One of the two scrapers was made of a thick flake, the scraping retouch covers the distal end as well as one of the laterals (*Fig. 6:5*). The second scraper is a broken piece of what could be a fan scraper (*Fig. 6:6*). This identification is based not only on the morphological shape, but also on the lightbrown raw material which is not common in this region and was probably brought from the western Negev area.

Pottery

The pottery collected comprises mainly body sherds. However, several rims and one base were among the collection. The pottery was manufactured of local clay tempered by small to medium black and white grits, part of them probably of magmatic origin.

The three sherds that could be defined consist of one bowl, one holemouth jar and one thick base, probably of a storage jar. The bowl (*Fig. 7:1*) is of a V-shaped type. This type of bowls was frequent in the Late Pottery Neolithic as well as in the Chalcolithic assemblage of the region. They occurred in a variety of shapes and sizes, but all have straight walls and a rim diameter almost twice their base diameter.



The Holemouth jar (*Fig.* 7:2) is of a wide opening variant, which is very common in the Late Pottery Neolithic assemblages, and is characterized by cut rims and a wide opening, even broader than the base diameter. Most of these vessels have washed surfaces and no traces of decoration. Larger Holemouth jars are usually hand made and have a thick base (*Fig.* 7.1.3:3). This type of Holemouth jar is characteristic for the Wadi Rabah assemblages of the southern Levant (Garfinkle 1992: 1999).

Based on the nature of the pottery and the composition of the inclusions, it is possible to identified two ceramic cultures: Several sherds are Chalcolithic, but the majority are pre-Chalcolithic, *i.e.* Late Pottery Neolithic.

The early chronology of Site 44

The flint assemblage from Site 44 is rather small and lacks diagnostic types, but the presence of wide sickle blades among the tools indicates their chrono-cultural assignment. This type of sickle blades has been identified in Late Pottery Neolithic assemblages (Gopher & Gophna 1993), probably close to the transition to the Chalcolithic.

The Neolithic pottery from Yotvata consists of a limited repertoire of types. Notable is the presence of several diagnostic forms that are among the hallmarks of the pre-Chalcolithic cultures and are frequent in such assemblages. Among the types represented at Yotvata are the jars with a wide opening and the deep bowls. The majority of the vessels were manufactured of light clay, ranging in colour from beige to light grey. The surface was treated before firing, and the temper includes small to medium, dark, magmatic and chalky grits. Notably, the chalky grits mostly disappeared due to weathering. A similar material culture was found also in the Uvda valley, in the nearby mountain range west of Timna (Site 124.17, Avner 1990), dated by the excavator to the Neolithic period (Avner *et al.* 1994).

Metallurgical samples and analytical methods

By visual inspection, at Site 44 there was no tapped slag or related 'furnace slag' of the type common at New Kingdom Timna (Rothenberg 1990: 43-45), but only rough, viscous, crushed slag lumps as found previously at the prehistoric smelting sites of the Arabah, like Sites F2, N2, 39a, 39b, 189A and others (Rothenberg 1990: 5-6. table 1; Segal *et al.* 1998; Merkel & Rothenberg 1999).

Visually, the Yotvata slag samples could be divided into three groups (Table 1). Group 1: very small (0.5 - 2 cm), black, with metallic luster, very dense, without holes or pores; Group 2: small (1.5 - 3 cm), internally black, green on the surface and porous. Group 3: larger slag lumps (5 - 8 cm),

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black and porous (*Fig. 8*). Slag of Group 3 contained copper prills, visible with the naked eye on freshly broken surfaces. Three samples of Group 1 [samples 1-112S, 29-169 and 44-3], four of Group 2 [samples 15-159, 3-111, 44-1 and 44-2] and six of Group 3 [samples 15-155, 10-113S, 118 G.S., 18-139, 118(1) G.S. and 18-139,140] were selected for analytical characterization.



Fig. 8. Slag 118 and 18-139,140 found at Yotvata.



Besides slag, four pieces of nodular copper ore and two copper ingots (*Fig. 9*), found in the excavation by Meshel (*cf. Table 1*), were examined. First the samples were cut, then the sections were mounted in resin, ground and polished. Additional pieces were drilled or crushed and powdered for chemical and mineralogical investigations.

Chemical analyses of slag and copper ingots were made by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES with a Jobine Yvon JY-48 polychromator). Some of the trace elements (cadmium, arsenic, silver, tin, antimony, cerium, thorium and uranium) in slag were analyzed using a Perkin Elmer Sciex Elan 6000 Inductively Coupled Plasma Mass Spectrometer (ICP-MS), equipped with Fig. 9. Copper ingot 12-148 found at Yotvata.



Table 1. Description of finds from Yotvata

Identity	Size, cm	Description
Ores		
9-116	3	black, green surface
10-113 O	2	green
1-112 O		
9-116a		
Slag		
1-112 S	0.5	black, sub-metallic luster
29-169	2	black, sub-metallic luster
44-3	1.5	black, sub-metallic luster
15-159	2	black, green surface
3-111	1.5	black, green surface
44-1	2-3	black, green surface
44-2	3	black, green surface, white inclusions
15-155	5	black, white inclusions
10-113 S	5	black, attached to crucible?
118 G.S.	7	black, Cu inclusions
18-139	8	black
118(1) G.S.	6	black
18-139,140	6	black
Metal		
12-148	9x7x1.5	Ingot
16-201	5x4	Ingot

flow injection system for sample introduction. Operating procedures for slag analysis are described by Beyth *et al.* (1988) and of metal analysis by Segal *et al.* (1994). The precision or relative standard deviation (RSD) of the analyses is as follows: 1% for major elements, 3% for minor constituents and about 10% for traces.

The mineralogical composition of the slag was examined using a Philips X-ray powder diffraction spectrometer (XRD). Detailed micro-petrographic and mineral chemistry studies were carried out with a Scanning Electron Microscope (JEOL 840), equipped with an Oxford Energy Dispersive Spectrometer (SEM-EDS) and Back Scattered Electron Detector (BEI).

Results

Ores

Only the four ore samples found in Meshel's excavation were analyzed, and these, according to Amit Segev¹¹ (verbal information), are a type of ore not common in the Timna Valley, but common in the Wadi Amram (south of Timna) and, especially, in Jordan.

Chemical analyses and phase compositions of the ore samples are summarized in Table 2. The high-grade ores with copper contents in the range of 14 to 48% are ideally suited for a direct reduction process. The dominant copper mineral in the ore is atacamite, Cu₂(OH)₃Cl, followed by cuprite, Cu₂O, and malachite, Cu₂(OH)₂(CO₃). Haematite, alpha-Fe₂O₃, and quartz, SiO₂, were identified as gangue minerals. The ores are low in silica (2 to 4 %), with variable Fe_2O_3 contents (2 to 53%) and very low MnO (< 0.06%). Ore sample 10-113O could have been reduced to copper metal without additional flux (due to its high copper content and low percentage of impurities); the other samples represent a type of ore which would have required the addition of silica to the smelting charge, in order to remove the admixed gangue components by slagging. As will be discussed below, there is, however, no need to conclude, based on the analytical data alone, that silica, *i.e.* quartz, was deliberately added to the charge as a flux.

Ores 10-113O and 1-112O contain sulphur. Petrographic examination showed remnants of chalcocite, Cu₂S. Oxidic ores with minor additions of sulphides are fairly widespread both at Timna (Shlomovich *et al.* 1994; Segev *et al.* 1992: 26) and Feinan (Hauptmann *et al.* 1992). These minor contents of sulphide did not affect the smelting process specific for oxidic ores. There was definitely no need for any preliminary roasting of the ore.

Slag

In the following interpretation of the analytical study of the slag, the ore samples in *Table 2* are seen as representing at least some of the ore used by the Yotvata smelters. With sand of the 'furnace wall'¹², and available oxides (MeO = FeO, MnO, MgO, CaO), slag silicates of pyroxene and/or olivine types could have been formed (ratio MeO/SiO₂ for pyroxenes is 1 and for olivines 2). However, non-equilibrium conditions (reaction time, temperature changes, CO/CO₂-ratio inside the 'furnace' etc.) during the smelting process resulted in the formation of heterogeneous slag. Several of the slag samples on *Table 3* are clearly indicative for the use of ore from the local Timna ore deposits and these are equally heterogeneous¹³.

As shown in *Table 3*, the crystalline phases in the slag nearly always include oxides (spinels) in addition to silicates. Apart from the slag minerals that can be determined by Xray diffraction, non-crystalline glass ("matrix") is most likely also present. Slag with a high content of spinels tends to be viscous, typical for prehistoric smelting. Therefore, since segregation is inhibited, much copper remains "trapped" in the slag and has to be manually separated. The slag sample 118(1) G.S. with the lowest Cu-content analyzed (1.3%), and magnetite as the only crystalline phase identified, has to be interpreted as rapidly cooled slag in which all the silicates apparently solidified as amorphous glass. Table 2. Chemical composition of ores found at Yotvata.

								Wt %														ppm						
Identity	SiO ₂	Al ₂ O ₃	CaO	MgO	Fe ₂ O ₃	TiO ₂	$P_{2}O_{5}$	SO ₃	Cu	Mn	Pb	Co	Ni	Ba	Cr	V	Sr	Cd	Be	As	Ag	Sn	Sb	Ce	Mo	Th	U	Phase composition
9-116	2.0	0.3	0.7	0.2	27.8	0.03	1.8	0.6	38.0	0.002	0.03	0.01	0.01	0.004	< 0.001	< 0.01	0.01	<1	<1	70	<1	<1	1	2	10	3	1	Atacamite,
																												cuprite, haematite
10-1130	1.6	0.1	0.9	0.1	1.5	0.01	3.0	2.5	46.3	0.059	2.00	0.03	0.03	0.001	< 0.001	< 0.01	0.07	<1	<1	90	<1	2	<1	3	20	2	1	Atacamite,
																												malachite, quartz
1-1120	3.6	0.4	0.3	0.2	53.4	0.02	0.8	3.1	13.7	0.044	0.04	0.02	0.04	0.011	0.001	< 0.01	0.02	<1	2	340	15	220	12	7	60	3	5	Atacamite,
																												cuprite, haematite
9-116a	2.8	0.3	1.0	0.2	13.2	0.03	2.1	0.4	48.4	0.010	0.03	0.01	0.02	0.004	0.001	< 0.01	0.01	<1	<1	60	10	6	2	4	9	2	1	Atacamite,
																												cuprite,
																												haematite, quartz

Table 3. Chemical (ICP-AES and MS)* and phase composition (XRD and SEM-EDS) of slag from Yotvata.

								Wt %														ppm						
Identity	SiO ₂	Al_2O_3	CaO	MgO	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	SO3	Cu	Mn	Pb	Co	Ni	Ba	Cr	V	Sr	Cd	Be	As	Ag	Sn	Sb	Ce	Mo	Th	U	Phase composition
1-1128	28.2	1.6	10.5	1.1	49.7	0.08	0.4	0.7	4.4	0.03	0.25	0.02	0.02	0.05	0.02	0.05	0.16	1	13	47	3	<1	4	12	140	3	32	Magnetite, fayalite.
29-169	39.2	1.6	7.8	0.1	36.9	0.11	0.7	0.6	2.0	3.04	0.15	0.04	0.03	0.07	0.04	0.18	0.07	<1	11	24	<1	2	3	21	92	7	34	Knebelite,
																												(Cu, Mn)-spinels
44-3	42.1	2.6	4.1	< 0.1	28.2	0.14	0.6	0.4	2.8	7.55	0.33	0.02	0.03	0.96	0.05	0.03	0.08	<1	18	20	<1	2	4	33	127	8	36	Knebelite, spinels.
15-159	39.4	1.1	11.5	1.0	32.7	0.09	0.4	0.5	8.9	0.04	0.26	0.02	0.02	0.06	0.01	0.05	0.08	1	10	65	6	1	9	14	70	5	36	Magnetite, cuprite.
3-111	28.1	0.9	4.5	0.6	57.1	0.06	0.3	0.5	3.7	0.02	0.93	0.03	0.03	0.02	0.01	0.04	0.06	2	20	95	2	1	6	11	160	4	55	Magnetite, fayalite.
44-1	37.9	1.0	8.1	0.2	42.1	0.09	0.3	1.1	3.3	0.09	0.39	0.03	0.03	0.02	0.03	0.06	0.07	1	13	38	<1	2	5	19	110	7	51	Fayalite, magnetite
44-2	36.4	1.1	18.0	1.1	24.2	0.10	0.8	4.6	10.5	0.09	0.04	0.01	0.01	0.03	0.02	0.02	0.12	<1	7	34	30	1	7	15	60	5	40	Fayalite, Cu2S,
																												Cu, wollastonite.
15-155	33.9	1.7	9.7	1.1	31.8	0.10	0.5	1.1	2.3	10	0.13	0.03	0.01	0.66	0.01	0.07	0.16	<1	12	14	3	<1	1	18	70	5	47	Spinel, knebelite.
10-1138	34.3	2.1	9.4	0.8	47.5	0.11	1.2	0.8	2.5	0.46	0.22	0.01	0.01	0.04	0.01	0.02	0.11	<1	30	11	5	2	2	16	50	3	44	Si min**, fayalite,
																												traces of knebelite.
118 G.S.	37.8	1.4	9.8	1.3	24.4	0.10	0.8	0.6	16.7	0.01	0.33	0.02	0.01	0.05	0.01	0.07	0.10	1	10	76	2	2	8	13	50	5	30	Si min, delafossite,
																												many cuprite.
18-139	39.0	1.2	10.1	0.9	20.0	0.09	0.7	1.0	17.5	0.03	0.20	0.01	0.02	0.01	0.01	0.04	0.12	ns*	ns	ns	ns	ns	ns	ns	ns	ns	ns	Delafossite, cuprite.
118(1)																												
G.S.	42.5	1.0	7.9	0.3	42.5	0.13	0.4	0.9	1.3	0.08	0.04	0.01	0.01	0.03	0.02	0.07	0.07	0	15	10	<1	2	2	25	120	8	63	Magnetite.
18-139,																												
140	44.2	1.7	11.5	0.2	25.3	0.18	0.6	0.9	8.1	0.08	0.27	0.03	0.03	0.03	0.03	0.06	0.06	<1	11	72	<1	3	12	26	77	11	66	Magnetite, cuprite.
																												2 / 1

* ns - not sought. ** Si-rich mineral.

Group 1¹⁴: The knebelite-spinel slag (Table 3: 29-169, 44-3, 15-155) may be understood as indicating the use of a copper-manganese type of ore, to be found in the Shehoret Formation (Segev *et al.* 1992: 9-11) in the area of Har Michrot and Wadi Mangan, south of Yotvata. Elongated knebelite crystals (*Fig. 10*) and tiny spinels between them (*Fig. 11*) can be seen in sample 15-155. In this particular slag, copper occurs as rare sulphide prills. The copper content in this type of slag is relatively low.

Although manganese was intentionally used in Timna as the main flux for an advanced smelting practice at New Kingdom Site 2 and at late New Kingdom Site 30, Stratum I, (Rothenberg 1990: Table 3-4), producing high quality tapped slag, it appears that Cu-Mn ore of the Shehoret Formation (with relatively low Mn) was used in the hole-in-the-ground-furnace of the smelters of Yotvata. If this interpretation of samples 29-169, 44-3 is correct, it would also imply iron oxide flux being used at Yotvata for the smelting of this Timna copper ore. Intentional fluxing with iron oxide was already known in the Arabah since the early Chalcolithic (Site 39a and others, Rothenberg & Merkel 1998: 2).



Fig. 10. Knebelite slag 15-155. Elongated, partly dissolved knebelites are seen in the matrix. White round inclusions consist of copper sulphide.



Fig. 11. Same as in Fig. 10 with large magnification. Dendrites of magnetite are dispersed between the knebelite crystals.



Fig. 13. Structure of magnetite slag 15-159. Tiny magnetites and large copper oxides (white) are dispersed through the slag. Note presence of cracked quartz inclusions.

Group 2: The typical structure of a magnetite-fayalite slag is shown in Fig. 12, with polygonal crystals and dendrites of magnetite and elongated fayalite. Here, copper occurs as small metallic prills and veinlets. Despite the formation of fayalite, metal-slag separation was inefficient and copper content in the slag is relatively high. In magnetite-rich slags 15-159 and 18-139, 140, tiny magnetite and cracked quartz crystals can be seen (Fig. 13). Quartz was not melted and undecomposed ore (haematite together with cuprite) remained almost unaltered in the slag (Fig. 14). Large (0.25 mm) copper oxide prills were also observed in these samples (Fig. 15). It would appear that this slag was produced from the ore of Table 2, reaching only a low temperature (below c. 1100 C) inside the hole-in-the-ground-furnace, combined with an insufficient, short period of smelting and was a product of the earliest smelting attempts at Yotvata.



Fig. 12. Magnetite-fayalite slag 1-112S. Numerous polygonal magnetite crystals and darker elongated fayalites are distributed randomly in the matrix. Copper veins intersect the slag (all the photos are SEM-BSE images).

Fig. 14. Remnants of non-decomposed ore within the slag 15-159. Grey polygonal minerals are haematites and white - cuprite. ▼



Group 3: Two samples of larger slag lumps (118 G.S. and 18-139) exhibit delafossite crystals with many large (0.3 mm) cuprite inclusions (*Fig. 16*). Under large magnification also numerous dendrites of copper oxide are visible (*Fig. 17*). Delafossite, CuFeO₂, an oxygen-rich mineral formation, is presumably the result of primitive smelting with insufficient reduction.

Some of the slag show copper prills of various sizes (up to 0.3 mm), containing about 2-5% iron. It appears that smelting took place in two stages: 1) decomposition of ore and other oxides from gangue etc. and 2) oxide reduction to metallic copper. In other slag, only copper sulphide inclusions, containing 2-10 % Fe, were observed. Slag 44-2, for example, contains Cu_2S prills up to 2 mm (SO₃-content in bulk analysis is about 5 %). This suggests the use of oxidic ores with some admixture of copper sulphides, typical for the oxidic ore of the Arabah.



Fig. 15. Structure of magnetite slag 18-139,140. Dendrites of magnetite and large copper oxide inclusions and veins are distributed in the matrix.

Fig.16. Slag 18-139. Needle-like delafossites and white copper oxide inclusions present in this slag.▼



Fig. 17. Same as in Fig. 16 with large magnification. Dendrites of cuprite between delafossite crystals. ▼



Ingots

As chemical analyses show (*Table 4*), the copper ingots¹⁵ contain up to 6.4 % Fe. SEM-EDS examination of polished sections revealed that the ingots are very inhomogeneous (*Fig. 18*). They contain iron and copper-iron oxides (*Fig. 19*), similar to those found in the smelting slag of Yotvata. Furthermore, several copper sulphide inclusions are randomly distributed. The sulfur content in the bulk analysis of different parts of the ingots varies between 0.4 - 3 %. The chemical composition of the ingots is similar to those of the prills

Table 4. Chemical composition of ingots from Yotvata, wt %*.

Identity	Cu	Zn	Fe	Pb	Ag	As	Sb	Ni	Co	Mn	Sn	S
12-148	78.4	0.18	3.8	0.4	0.003	0.01	0.03	0.031	0.013	0.001	nd	0.5
16-201	78.7	0.07	6.4	0.6	0.040	nd	nd	0.025	0.019	0.001	nd	0.2

nd - not determined



Fig. 18. Structure of the ingot 12-148 showing its inhomogeneity. Dark grey inclusions are magnetite remnants, round light grey - copper sulphide.



Fig. 19. Iron (dark grey) and iron-copper oxide inclusions near the planar surface of the ingot No.12-148.

in the Yotvata slag, including high iron content (*Table 5*). This indicates that the ingots are indeed a major part of the smelting product which formed below the slag at the bottom of the

Slag	Cu-prills	Fe, %	Quantity + size of prills
10-113	Cu	3-4	rare
29-169	Cu_2S	10	rare, small
15-159	Cu	1	many, large
18-139, 140	Cu	2-3	many, large
44-1	Cu	5	rare, small
44-2	Cu_2S	2-6	many, large
44-3	Cu	1-2	rare, large
1-112	Cu	6	rare, small
15-155	Cu_2S	3	rare, medium

Table 5. Fe in Cu prills in Yotvata slags

In ingots there is 4-6% Fe and sulfur content is 0.4-4%

Chalcolithic 'furnace', the other part being the entrapped prills in the slag, which had to be manually extracted. This also explains the somewhat 'plano-convex' shape of the ingots. Comparing the Yotvata ingots with (later) ingots from Timna (Roman 1990), it seems most likely that the Yotvata ingots were produced from the local oxidic ore of nearby Timna.

Discussion and Conclusions

Meshel's excavation established the stratigraphy of the hillsite of Yotvata. Based on the pottery finds and their similarity to Timna pottery, the casemate stronghold could be dated to the 19th-20th dynasties of the Egyptian New Kingdom. There was no trace of any New Kingdom metallurgy or any sign of metal working inside the casemate structure. However, all over the hilltop, and also underneath the casemate walls, a variety of metallurgical remains were found. These could be dated to the Late Pottery Neolithic (6th-5th millennium BC) as well as the Chalcolithic period (5th-4th millennium BC)¹⁶ by Rothenberg's archaeological finds (of the 1950s and 60s, and again recently): flint objects, prehistoric pottery, its typology and comparative petrography, and by the type of metallurgy as established by the present investigation. There was no architecture or installation of any kind related to the prehistoric activities at the site, besides, perhaps, the earthen fence mentioned above.

Archaeological typology of the finds at Site 44 established a Late Pottery Neolithic as well as a Chalcolithic date for the smelting activities at the site. The technological characteristics of the slag indicated that Group 1 of the slag is of Chalcolithic date, whilst Groups 2 and 3 are Late Pottery Neolithic. Although this dating of the slag groups is somewhat tentative, based on the available evidence and comparisons with other sites in the region, these dates seem the most appropriate.

The establishment of the Late Pottery Neolithic as well as Chalcolithic date of the metallurgical activities on this hilltop site is of considerable significance for archaeo-metallurgy as well as for the history of the Arabah. Similar metallurgical activities, indicated by concentrations of slag of a primitive type, took place on top of many of the foothills along the mountain range of the South-western Arabah, which were difficult to identify and date because of lack of diagnostic archaeological remains. The results of the Yotvata investigations will now help to form a comprehensive picture of prehistoric copper in the Arabah and adjacent areas. The Late Pottery Neolithic and Chalcolithic copper producers of the Southern Arabah obviously belonged to the clusters of settlements of these periods, located in the Southern Arabah as well as in the nearby Uvdat Valley, in the Eilat Mountains. It is important to mention here that the Chalcolithic settlement/culture of this region does not show any traces of the Chalcolithic Beersheba-Ghassulian culture of Israel, which is also substantially different in its metallurgy¹⁷.

Smelting the ore found at Yotvata needed additional silica for the slagging of its gangue. We assume that the source of the silica was the sand from the sides of the hole-in-the-ground smelting 'furnace' and not intentionally added silica. Although intentional addition of iron oxide ore, seemingly a vaguely understood, irregular kind of fluxing, was already practiced by early Chalcolithic smelters of the region, there is no evidence anywhere for intentional fluxing with silica in prehistoric times.

According to the analyses of the slag samples, the nodular oxidic copper ore of Timna, as well as copper-manganese ore from the region of the manganese deposits north of Timna, were used by the prehistoric smelters of Yotvata, besides the imported ore. Iron oxide flux, as used at Site 39 and, perhaps, also at other Chalcolithic sites, was widely available in close proximity to the copper ore of the region.

It is quite difficult to distinguish between Late Pottery Neolithic and Chalcolithic slag, because inefficient or unsuccessful smelting of any period may appear to belong to a more primitive, earlier phase of smelting technology. Nevertheless, since it is clearly possible to distinguish between compositions, phase mineralogy and quantities of Late Pottery Neolithic / Chalcolithic slag and slag of the Late Bronze Age / Egyptian New Kingdom, technological characteristics can obviously be used for tentative dating. However, it is not possible to date slag by its chemistry alone, which is also reflecting heterogeneous furnace operations. Furthermore, in many cases, not all representative samples of the smelting products are preserved and such 'missing links' also make it often difficult to identify technological developments and characteristics. Problems are also caused by the fact that we are dealing with small-scale activities, which took place for relatively very short periods between the 6th and the 4th millennium BC. Nevertheless, comparisons with the slag/technology of previously investigated prehistoric sites in the Arabah, and their distinct types of extractive metallurgical remains, dated by archaeological evidence, provided very useful chronological indications.

The analyses of the slag showed great heterogeneity, typical for prehistoric smelting. The differences of the slag phases: magnetite, fayalite, knebelite, delafossite and spinels, can be explained by the use of different ores and varying efficiency of the smelting process. High contents of spinels means very viscous slag, apparently typical for early prehistoric smelting, with much of the metallic copper entrapped in the slag as prills of different sizes, which have to be manually separated. Although fayalite was formed, metal-from-slag separation was still very inefficient, probably also because of the primitive hole-in-the-ground smelting installation. Tapping of the slag was unknown; at the end of the smelting process, after cooling down, the contents of the 'furnace' had to be removed, the ingot(s)¹⁸ at the bottom (when present)

collected and the copper prills manually separated from the slag.

The small copper ingots found at Yotvata, which, according to their shape, were formed at the bottom of a furnace, are probably of Chalcolithic date, although no comparable finds are known from elsewhere. Their chemical composition is similar to that of the copper prills in the slag, including also some copper sulphide prills, which clearly indicates that the ingots were produced from local oxidic ore nodules with a chalcocitic core. Thus Yotvata is providing the evidence that already in Chalcolithic smelting enough metal segregation took place to form a lump of copper, a rough 'ingot', below the slag at the bottom of the 'furnace'¹⁹. The ingots as well as the copper prills in the Yotvata slag contain a high percentage of iron, again an indication that both are the result of primary copper smelting at the site.

The fact that no copper ingots were ever found at a smelting site of the Chalcolithic period before the excavation at Yotvata, should be followed by reconsideration of earlier research of prehistoric copper metallurgy. Is it possible that such ingots of rather rough, irregular shape, were actually produced in many Chalcolithic and other prehistoric smelters, but not identified or reported by the excavators. There is often prehistoric slag with very low copper content, smelted from very high-grade copper ore - we have to ask: where remained the copper? It seems most likely that ingots were indeed produced and removed, leaving only the slag behind.

The high iron contents of the ingots and of the copper prills in the slag of Site 44 seems to need some consideration, since high iron in copper has lately been taken to indicate a much later smelting process, using in effect the iron contents in copper as a chronological criterion (Craddock and Meeks 1987: 190)²⁰. Based on "thousands of analyses of bronzes" and some copper objects of the British Museum's collection, Craddock uses the iron contents as indicator for the date of the original smelting process - low iron early, high iron much later "probably coincident with the improved smelting technology". These conclusions regarding copper smelting conditions and chronology, drawn from analyses of finished metal objects, do not seem acceptable to us for the interpretation of smelting remains, taking in consideration the many metallurgical changing parameters from the smelters to the finished tools, including of course the ever occurring recycling and related refining.

The copper prills with high iron content in smelting slag of Site 44 (cf. Table 5) are well dated by flint, pottery and comparative technology to the Chalcolithic period. In this connection there is important chronological evidence in the fact that the copper prills in furnace slag of Chalcolithic Abu Matar contained iron up to 4.12% (average 0.97%, Shugar 2000: 207). In their seminal paper on iron in ancient copper, Cooke and Aschenbrenner (1975: 253) list Chalcolithic copper objects from India with 2.57 % and 6.48 % iron, as well as a 12th dynasty (ca. 2000 BC) copper ingot from Sinai with 5.9 % iron. These authors do not use iron in copper as a chronological criterion but as an indicator for different smelting technologies in different regions of the ancient world. There is no doubt that iron in copper as such can not serve as a criterion for the date of the smelting of copper.

26

We propose to distinguish between some typical technological characteristics of Late Pottery Neolithic and Chalcolithic smelting processes at Site 44:

Late Pottery Neolithic: the LP Neolithic slag is extremely heterogeneous. Delafossite is probably a typical phase of LP Neolithic slag. Due to the high viscosity of the slag, there was no segregation and, therefore, all the copper produced in the hole-in-the-ground smelter remained in the slag, only part of which could be manually recovered. Consequently, the slag analysis show a very high copper content, mainly as small copper prills, veinlets and dendrites, as well as copper oxide prills.

Chalcolithic: Chalcolithic slag, though still heterogeneous, shows some common characteristics, which also assist in dating the slag. Due to intentional, though not well controlled, fluxing and improved process technology, like higher temperature and better reducing atmosphere, the slag was less viscous and segregation considerably improved. Comparing the Chalcolithic slag with the LP Neolithic slag of Yotvata, but also with the 5th millennium BC Chalcolithic slag of Site 39²¹, the quantity of copper prills entrapped in the Chalcolithic Yotvata slag is quite low. Improved segregation caused the merging of the small copper prills in the slag into larger prills, manually easier to recover, but apparently much of the copper formed ingots below the slag, at the bottom of the furnace.

So far we have no close absolute date for the start of the production of ingots at the furnace bottom, but this significant development in the prehistory of extractive metallurgy was probably related to the introduction of improved fluxing, *i.e.* a better balanced smelting charge, at some time in the later Chalcolithic period.

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Notes

- 1 Ein el-Ghidyan is the previous Arabaic name of the oasis, cf. Palestine Survey map 1939/44.
- 2 Cf. Rothenberg 1967a, attached map; *idem*, 1972: 11. The first plan of Site 44 was published in Rothenberg 1967: 286.
- 3 We visited Site 44 again in 2001 in order to clear up some stratigraphic/chronological problems which arose at the excavation of the site (see below).
- 4 At the time of the early Arabah Survey, before the discovery of the Hathor Temple in Timna, *i.e.* before the recognition that Timna was mainly an Egyptian New Kingdom copper industry of the late 14th to mid-12th centuries BC (Rothenberg 1972; 1988), the main activities in the mines and smelters of Timna were dated to Iron Age I. This date should now be corrected to 'Egyptian (Ramesside) New Kingdom', or Late Bronze Age IIA to Iron Age IA. The Classical pottery of the hill site was dated by M. Gichon (in preparation).
- 5 It is difficult to estimate the total quantity of slag dispersed on Site 44 since these slag fragments have been exposed on the surface for thou-

sands of years and much of the slag was probably washed down the slopes by the occasionally very heavy rain of the region. Our team found a quantity of slag at the bottom of the slopes of the site. Our estimation of 30 kg is meant to indicate the scale of production, compared with later smelting sites in the region, where many hundreds of kilograms to many thousands of tons of slag were found.

- 6 Hamoudi Khalaily, Israel Antiquities Authority, in July 2001 identified Late Pottery Neolithic as well as Chalcolithic pottery amongst the finds of our 1956 and 1960 surveys at Site 44.
- 7 We shall not deal in this paper with the metal objects of the NK and the Roman period found in the excavation of Meshel. These will be published in his final excavation report.
- 8 We chose the samples from the excavation for our investigation, rather than those collected during our surveys, since the metallurgical debris on the surface of the site were exposed for thousands of years and may now be quite different from the debris at the time of production. This is a common problem of archaeo-metallurgy and should be more taken into consideration.
- 9 There was no ash at all at the site as typical for smelting sites and we assume that Meshel noticed charcoal dust.
- 10 We inspected the site again in June 2001. Many hours of meticulous search on the hill as well as on the slopes below, produced only very few finds. As we were told by members of the nearby Kibbutz, Site 44 has been for very long a common "hunting ground" for nice stones, sherds, stone tools and other antiquities by the children of the Kibbutz.
- 11 Amit Segev, Israel Geological Survey, is a specialist of the geology of the Timna valley (Segev *et al.* 1992). H.G. Bachmann (verbal com.) found samples of this type of ore in the region of the Timna mines.
- 12 The whole process of slag formation is, to a degree, self-regulating. If, for instance, there is too much iron in the ore or charge, the slag simply forms with silica from the 'furnace wall' and (additional) CaO from the fuel (charcoal) ash (cf. Merkel 1990: 113)
- 13 The very low Mn in the four ore samples found at Site 44 (Table 2), compared with some of the slag analyses (knebelite-spinel slag, Table 3), is evidently an indication for the use of different types of ore at Yotvata.
- 14 The groups of slag reported in the following are not fully identical with the visually established "groups" of slag, described above, though the typology of these groups are certainly related to the different smelting characteristics.
- 15 We are using here the term 'ingot' to indicate that we are not dealing with metal objects or parts thereof. The two metal samples ('ingots') on Table 4 are in fact quite irregular copper lumps, of rather vaguely planoconvex shape.
- 16 So far it was not possible to establish closer, absolute dates within these period of about 3000 years. Efforts are now being made to establish absolute dates for our site.
- 17 Cf A. Shugar 2000. Based on new excavations at Abu Matar (Beersheva) by I. Gilead, Shugar could reconstruct the Chalcolithic Beersheva-Ghassul metallurgy, including copper smelting in clay-lined furnaces and melting/casting in crucibles. Some of the ore probably originated from Feinan (Jordan), but there was also a different ore imported probably from Anatolia.
- 18 Ingots, *i.e.* rough, irregular lumps of copper, form on the bottom below the tuyere. When several tuyeres are used, there may be a separate ingot below each tuyere, sometimes, depending on the quantity of copper produced and on its temperature, merging into one ingot. This interpretation is based on results of smelting experiments (Merkel 1990) and on the fact that these flat lumps of copper (our 'ingots') are totally different from the typical plano-convex, 1-2 kg Late Bronze Age ingots (Roman 1990).
- 19 For the formation of 'ingots' inside the furnace see Merkel (1990).
- 20 Craddock's conclusions, relating to the iron contents in copper, are based on his assumption (Craddock & Meeks 1987: 187-193) "that the low iron content regularly found in metalwork of the European Bronze Age implies a simple non-slagging process and explains why so few remains of smelting, as compared with mining, have been identified in Europe. The evidence is not lost but probably never existed".... "the low iron content in copper indicates a smelting process without slag formation can perhaps explain the apparent absence of smelting sites in most of Western Europe in prehistory..... Slag heaps are not found associated with the prehistoric mine workings quite simply because they never existed." Craddock's theory of prehistoric 'slag-less copper smelting', based on the fact that no slag heaps of this period have been reported, is total-

ly unacceptable. First, what happened to the gangue, ash from the fuel etc. of the smelting charge? Even if the quantity is minute, the term 'slagless smelting' is obviously a contradictio in adjecto. Second, the main reason why almost no prehistoric slag was found until rather recently next to the prehistoric mines identified in Western Europe, is simply because nobody looked for the slag. In the 1970s, my team undertook the first ever archaeo-metallurgical survey in the 'copper belt' of the Huelva province, SW Spain, where the local geologists had noticed ancient workings and numerous prehistoric mining tools, next to 19th century mines - but nothing else. We found and recorded numerous prehistoric mines all over the province (Rothenberg and Blanco-Freijeiro 1981) - later on also in the province of Almeria (Rothenberg 1988, 1989) - and near each of them, looking at the suitable spot in the rugged landscape, we found a concentration (flat heap) of primitive slag, often with crushing tools and diagnostic flint and pottery. We did not locate a single mine without a smelting site nearby - often near a group of megalithic structures of the same date ('dolmen'). These slag 'concentrations' indicated very small scale working, but quite comparable with the scale of prehistoric smelting sites in the Levant, including the sites reported in this publication.

21 We would propose to date Chalcolithic Yotvata to the first half of the 4th millennium BC.

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The Wertime Pyrotechnological Expedition of 1968

Roya Arab & Thilo Rehren

Introduction

The 1950s and 60s saw a major increase in interest in scientific and technological issues in archaeology, particularly in metal and ceramic production, the origin of raw materials, and the development and spread of technologies. In 1958, the Research Laboratory for Archaeology and the History of Art at Oxford began publishing its Bulletin, which later developed into the journal Archaeometry; the Historical Metallurgy Society was founded in 1962 by Ronald Tylecote and others, soon publishing the journal Historical Metallurgy. Beno Rothenberg begun his series of archaeo-metallurgical surveys in the Arabah and systematic excavations in the smelting camps of Timna, which eventually led to the formal foundation of IAMS in the early 1970s. In the United States, Cyril Stanley Smith in 1961 moved to MIT to become a professor between the departments of humanities and metallurgy in order to encourage the scientific investigation of the material record of the past (Goodway 1992).

In this academic climate, Theodore Wertime set out to explore in Western and Central Asia the beginnings of the use of fire, starting with a series of expeditions in Iran, and culminating in the survey of 1968, covering Afghanistan, Iran and Turkey. These countries were already known for their prominent role in the early development of pyrotechnology, from plaster to ceramic and metals. Wertime wrote in 1966, "Forty years ago a number of European countries were vying to be known as the original home of the blast furnace - today the competition has moved in space to the Middle East and in time to the much earlier beginnings of the smelting of ores and metals." (Wertime 1968: 927). In effect, archaeology was becoming more scientific and downto-earth, starting to look beyond the palaces and grander people, in an attempt to find out more about the lives of ordinary people and addressing questions of early farming, urbanisation and the various technologies that gave rise to civilisations. This region, however, was by no means a virgin land waiting to be explored by innocent archaeologists. Clearly the Middle East had much to offer to Europeans searching for their cultural origins, whose sense of ancient history was taken largely from the Bible and classical authors; and from the early 20th century onwards, archaeological research in the region increased significantly. Politically and economically, however, the region had already been of great interest to Western nations for some time before that. The Indian Ocean had been largely a Muslim trading lake until the Portuguese took over control in the 15th century, soon followed by the Dutch, British and others, securing highly lucrative trade routes to India and China. More recently, the discovery of oil in the Middle East in the 1930s added a totally new facet to the economic interests, quickly changing it from a mere transit region to the riches of the East into a core area of strategic interest in its own right. This was further exacerbated by the geopolitical developments following the ideological and power struggles in Europe, resulting inter alia in the foundation of the state of Israel, the Soviet expansion after the Second World War and US-American attempts to contain and roll back this advance. Political, economic and archaeological interests thus overlapped each other for a broad swath of land, extending from the eastern Mediterranean littoral through Mesopotamia and Iran into Afghanistan. This overlap of interests becomes almost dramatically manifest within the microcosm of the last of the pyrotechnological surveys led by Theodore Wertime, in 1968. It is this complex pattern of disparate but interconnected pursuits which really makes this expedition so remarkable.

Before the 1968 Expedition

Wertime had already been active in the region for several years, both in his professional capacity as Cultural Attaché at the embassies of the USA in Iran and Greece, and in his very own quest for the birth place of 'pyrotechnology' as he called it. In 1961, along with the Iran Ministry of Mines, he had made a metallurgical reconnaissance of archaeological sites in the North, followed by a trip in 1962, together with Cyril Stanley Smith, which included some experimental archaeology in Yazd (Wertime, A2)1. In 1966, a survey covering 'The Great Persian Desert' was carried out as an adjunct to the excavations by Caldwell at Tal-i-Iblis. The group then included Theodore Wertime, Radomir Pleiner, Cyril Stanley Smith and G. H. Vossoughzadeh. They did a rapid and wide-ranging survey of old mining and smelting sites in Iran, with the intention of looking for archaeological evidence, traditional lore and pattern of settlement (Smith et al. 1967; Wertime 1967, A1). A further reconnaissance in 1967 was not attached to any particular excavations, but was coordinated with Lamberg-Karlovsky's field survey of 1967, this time looking for gold, lead, silver, copper and iron, and pursuing the mystery of tin in the river basins of the Albourz and Zagros mountains (Wertime 1967, A1). Thus, Wertime had already gained some experience in the region, and visited many archaeological sites. The 1968 survey, however, was going to be the largest and most ambitious of them all, funded by the Smithsonian Institution and the National Geographic Society in the USA, and headed by Theodore Wertime who had invited a host of experts from a range of different disciplines to accompany him.



Fig. 1: Ancient kiln at Maghiz, 28 August 1968.

The team

Formal planning for this survey began in 1967, when Wertime started to approach various specialists to build his team. Having secured funding, he went about inviting a carefully selected group of experts. In a letter from Wertime to Braidwood, who himself was involved in ground breaking work in the region, Wertime mentions the planned survey and names of seven people he was sounding out (Wertime 1967, B1):

Dr. Ebrahim Shekarchi, chief Middle Eastern specialist for the US Bureau of Mines.

Dr. R.F. Tylecote, archaeo-metallurgist at the university of Newcastle upon Tyne.

Dr. Beno Rothenberg, archaeo-metallurgist from Tel Aviv.

Dr. Radomir Pleiner, archaeo-metallurgist at the Archaeo-logical Institute in Prague.

Dr. Fred Matson, archaeologist at Penn State University. Dr. Robert Brill, research scientist at the Corning Museum

of Glass.

Dr. Carl Lamberg-Karlovsky, archaeologist at the Peabody Museum.



Fig. 2: Persepolis, 31 August 1968.

Not all of those mentioned did eventually travel, and other scholars were included in the expedition. Shekarchi for example, who had travelled with Wertime in the 1967 expedition, was mentioned, but due to other commitments was only able to establish the route for the 1968 survey and then handed the job over to Fred Klinger (Klinger 2003, D1).

The final team then included, in alphabetical order, Sam Bingham as the team's photographer; Robert Brill, interested in ancient glass, glazes and metals, from Corning, New York; Fred Klinger as the geologist; Fred Matson, a ceramicist from Philadelphia, Pennsylvania; Ezat Neghahban, an eminent Iranian archaeologist; three archaeometallurgists, Radomir Pleiner from Prague; Beno Rothenberg from Tel Aviv, and Ronald Tylecote from Newcastle-upon-Tyne; and finally John Wertime, one of Theodore's sons.

Not all of the members were present at all the sites, nor did they all take the same route. But even allowing for this degree of independence, it would seem that with ten specialists travelling there was cause for some interesting dynamics. Not all members felt that their needs were met in



Fig 4: Slag heaps and furnace remains at Meskani, 3 September 1968.

terms of choice of sites, "the various expertises of our expedition members were beyond mutual reconciliation", as Wertime himself put it (Wertime 1976: 491).

This discrepancy in interests becomes apparent from how different members of the group described at the time the aims of the expedition:

- "For a wrap up look at the region of the birth of Pyrotechnology" (Wertime A1, p2)
- "Reconnaissance to locate and examine early metallurgical and other sites that have contributed to the Ancient Middle Eastern civilizations" (Tylecote 1970: 285)
- "Quick survey of a large number of early pyrotechnological sites, and to bring together in the field, persons from various appropriate disciplines" (Brill 1968, A6)
- "Determine whether tin was present in amounts indicative of sources for tin ores used in antiquity...... but also afforded chemical and mineralogical data that were interpretable in the context of regional potential for other elements of current industrial use" (Domenico *et al.* 1978, abstract)

Theodore Wertime was clearly the facilitator and leader in this team. He was a powerful character who achieved most of his goals in life (Wertime 2000). During his time as Cultural Attaché to the US embassies in Tehran and Athens in the 1960s and 70s, he had managed to carve out, according to his son, a "parallel career as a serious historian of metallurgy" (Wertime 2000: 35). This he managed probably not just due to his love of ancient technology, but also for his excellent choice of fellow travellers on all his expeditions. He was, it seems, a travelling student choosing those who had lessons to offer he wanted to learn, and whose wisdom he sought to explain the places he, in his capacity as a diplomat, was able to arrange for them to go. He never took an active part in professional discussions of the team, at the sites as well as whilst travelling, but took notes during discussions of sites visited; indeed, some years later Cyril Smith told Beno Rothenberg whatever Wertime published after the 1968 trip were indeed views voiced by the professionals during their trip (Rothenberg pers. comm. 2004).

Bob Brill, who always felt treated well by Wertime, in a recent email mentions that "Ted was a difficult person with

a dark side - a complex and flawed individual" (Brill 2003, F2). In an email from Sam Bingham there is clear indication of some of the problems the team had. He speaks of moving fast, using a route that had 'independent determinants', with Wertime's passion leading the way, and the interests of the other members taking a back seat. He recalls friction leading to fascinating debates, partly caused by other team members feeling Wertime was "not qualified to be as egocentric as he was" (Bingham 2003, F4). Sam Bingham describes himself as "tacked on at the last minute (grossly under-qualified) as photographer and camp cook" (Bingham 2003, F4), having just lost an eye in Vietnam where he had been a freelance journalist. Beno Rothenberg remembers being told that the National Geographic had sent Sam Bingham, whose photographs he later was never able to locate in the society's archive.

So here we had ten individuals, with varying degrees of specialist knowledge, led by a difficult but dynamic character. From the outset, the undertaking was clear to be far from a smooth running; Wertime himself mentions this in a letter he had written to Braidwood in 1967. Regarding his choice of expedition members for the survey of 1968, he says "I hope the Turks don't choke over this." (Wertime 1967, B1). It may have been his very nature that helped him procure funds for so many expeditions; however, it was probably that very nature that also meant that this particular expedition did not get the academic attention it deserved when the dust of fieldwork had settled.

Sites and sampling

As mentioned, not all the sites were visited by all the members and some members visited other sites alone; further-



Fig 5: Ancient furnace remains at Tamarish, 3 September 1968.

Fig 6: Slag heap near Isfahan, 4 September 1968. more, no decision was taken as to the name and spelling of the site names. Beno Rothenberg was not present in Afghanistan and Radomir Pleiner did not visit Turkey. The survey began in Afghanistan in August 1968, covering the following sites:

Kara Murad Beg, Estalif, Bamian, Farinjal, Pandshir Valley, Zar Kashan, Mirzaka, Karystu Valley, Askar Kot, Tepe Mundigak, Herat. By August 12th, the members had reached Tehran / Iran, from where they went on to: Uzbeg Kuh, Deyhook, Tepe Yahya, Deh-i- Sard, Sechah, Tal-i-Iblis, Qatru, Kuh-i- Sorgh, Istebanat, Persepolis, Zar Tsheshmeh, Pasargadae, Hannasq, Talmessi, Meskani; all names in this section have been taken from Pleiner (1968, A11).

After Meskani further visits were made to Talmessi, before moving on to Sialk, and finally Ahaer in Iran. The expedition then moved into Turkey on September 16th covering: Trebizond, Tirebolu, Ergani-Maden Mine, Geyduk, Kultepe, Catal Hoyuk and Acem Hoyuk (Tylecote 1968, A3).

Two published maps exist from the survey, one in the geological report (Domenico *et al.* 1978), and the other in a short piece written by Tylecote about the journey for *Metals and Matter* (Tylecote 1970).

Early on Rothenberg and Tylecote had realised the lack of professionalism in the setup of the expedition; there were no proper maps, so that Rothenberg had to get a simple tourist map from the petrol station; he further recalls not doing any surveying in the archaeological sense, but visits to published sites and modern mines; the latter were assumed to have antique activities, and in their vicinity smelting sites were discovered at times. The geologist Klinger did not travel with the group but with Iranian geologists, sometimes joining the rest of the group in the evenings. The rest of the group never knew where the geologists went and what they did, and Rothenberg assumed they were doing a job of their own and only used the Wertime trip as a convenience. Wertime had fixed the route of the trip, and as his son was working on a PhD on early mosques of Iran a lot of mosques were visited; Rothenberg felt at times that the route was actually more determined by visits to mosques than to ancient mines (Rothenberg pers. com. 2004). He suggested that the team use a common system of recording and give numbers to the sites, to be written on the sample bags (Rothenberg pers. com. 2004), which they used alongside various members' reports to name the sites.

No co-ordinated sampling was conducted by the group; as far as we could establish from the participants, several members of the group collected material according to their own briefs and interests. Klinger accumulated a systematic collection of rock and soil samples for his geological prospection work; Matson collected sherds of archaeological ceramics. Wertime did not collect any samples. The three archaeometallurgists collected slags, ores, furnace remains and other metallurgy-related material. The majority of sites visited were archaeological in nature; however, some of the recorded site numbers represent modern cities, local bazaars, museums and modern production centres. The lack of coordination between the members and their field notes made it difficult to associate the samples with their proper place names of origin when cataloguing the artefacts from the survey, some 35 years later. Thankfully samples were given site

numbers, which could be used in association with note books and reports to establish their provenance (Arab 2003). This confusion was already felt at the time by the members of the expedition themselves; Tylecote and Pleiner discuss this in personal correspondence after the survey. They discuss their eagerness to start analysis, and the issue of site names, with Tylecote finally suggesting that Wertime should decide what site names to use (Pleiner & Tylecote 1968, B6).

Clearly, the tight schedule did not allow the group to survey the vast lands they travelled in any detail; however, they tried to tap into the knowledge of the local people. Sam Bingham mentions visits to markets, and wherever an audience could be found, there was a display put on of the kind of material the team was interested in, with the curious invited to comment and mention where they had seen any of the materials being displayed (Bingham 2003, F4). This reflexive manner was also supported by ethnographic work (Matson 1968, A5). These approaches were modern for their time and show a real effort to address questions of past technologies, though in this instance there seem to have been too many questions.

After the expedition

Both Klinger and Matson took their collections to the United States, where the geological material finally was analysed (Domenico et al. 1978), and the ceramics are now at the Matson Museum at Penn State University (Matson pers. comm. 2003). The archaeo-metallurgical collection first was held in Turkey, due to the antiquity laws of the country. The samples should have been recorded on entry to the country to enable later export; Rothenberg also felt that Wertime as a diplomat should have sorted out the problem (Rothenberg pers. comm. 2004). Wertime, however, apparently was not at all interested in the finds which only the professional team could handle and publish (for this reason there was no plan or budget for analytical or other work on these samples). Eventually, Rothenberg managed to meet the Turkish minister of mining who granted him an export permit. Tylecote took some samples with him to England for study, and the rest were left in Rothenberg's store in Tel Aviv for safe keeping, though he had no interest in dealing with these samples. When Tylecote later asked for funding to work on the samples Wertime had not been interested. Rothenberg waited for



Fig 7: Old mine entrance in Tabriz-Ahar, 13 September 1968

a long time to hear from Wertime as he had taken lots of photographs and kept a record of the site numbers and the collection; he expected Wertime wanted to publish a report together with the team members (Rothenberg pers. comm. 2004). In fact, no joint publication was prepared. "We never took any useful decisions regarding publication and Ted said do it if you want to", Tylecote writes in 1973 in a letter to Klinger (Tylecote 1973, B12). Klinger in turn had other worries, not having analysed the samples collected on the 1968 survey, and blaming this on his pride in wanting to do the work himself and a fire that held back work at his laboratories (Klinger 1973, B12).

It seems quite clear that Theodore Wertime, who was the instigator of this expedition, lost interest in the work and was not being supportive enough after the expedition. We may assume that he was aware of this issue; in a letter to some of the members of the expedition of 1968, Wertime says, when speaking of another project in the region, that "this time we should institutionalise relationships in the area...As a beginner what are the chances Beno would invite some Iranian, Turkish and Greek archaeologists at his digs in Negev or Sinai?" (Wertime 1969, B7). However, no further expedition followed from this one, and its participants went on with their individual lives. Very few publications ever referred to it, until a chance meeting between Beno Rothenberg and a student in 2002 prompted his decision to transfer the archaeometallurgical collection to the Institute of Archaeology UCL for future curation and use in teaching and research. This collection is now fully catalogued, documented and archived at the IoA and accessible to use for interested scholars (Arab 2003).

Politics of archaeology

Archaeology deals with the past, a commodity that raises interest in claims of ownership of cultural heritage, the right of permission of excavation and interpretation of past remains, and - in its most extreme - ownership of land. We may be looking at the past, and collecting material to represent and explain the past, but we do so with the permission of governments today, funded today, and in the social and academic climate of today. The modern world witnessed developments that saw the use of archaeologists in the World Wars for reading of maps, as well as an archaeology that makes use of developments in other fields to enhance its reading of the past; archaeologist being called into murder scenes with their understanding of stratigraphy and incomplete evidence; an archaeology whose tales of the past are being increasingly accepted by the general public as well as being used by interested parties to construct identities and claims of ownership; an archaeology that by now should accept its deeply political nature. We must therefore look at the political element that exists implicitly and explicitly within archaeology, and increasingly at the role of archaeology in the political arena.

The Middle East not only has a rich past but also a potentially rich future, which has not yet been fully realised. There were several known incidents of archaeologists using their work for other purposes in the last century, for example T.E. Lawrence, of Arabia-fame, whose intelligence activities in the Middle East were sometimes hidden by archaeology, illustrated by his involvement in excavations at the site of Carchemish with Sir Leonard Wooley. Wendell Phillips in the 1950s had to leave Yemen hastily with fellow expedition members in an atmosphere of suspicion and fear, having been accused of having interests other than archaeology (Phillips 1955). Dr Todd Whitelaw (pers. comm. 2003) mentioned a geographical survey in the 1960s done by Loy and how he, Whitelaw, had been intrigued by the fact that the US office of naval research funded the geographical survey in the Peloponnesus (Loy 1970). It is apparently always useful to be aware of the geography and geology of other nations, and this attitude was nothing new. Cortes, arriving in Mesoamerica in the 16th century, saw fit to detain tribute collectors (Smith 2003), who have been a great source of information for the origin of gold, silver and other riches the Spanish so eagerly sought.

At the time that this survey took place roads were built in Afghanistan mile for mile by the Americans and the Russians, in their attempts to win favour with the government. Wertime mentioned to Brill that the Russians had constructed a tunnel that happened to be wide enough to accommodate two passing columns of the largest Soviet tanks (Brill 2003, F2). When not busy exporting wars there are all the other products of modern culture. Matson mentions the replacements of many pottery forms with plastic substitutes. He goes on to comment on the life ways encountered on the journey "Entering Turkey you can see modernisation but still evidence of older ways....with Iran under the Shah less oriented towards western ways" (Matson 1968: 9). The exportation of democracy is changing ancient life ways, which inadvertently make one a potential consumer in the global market, be it through the purchase of plastics, ammunition or suits to wear to the big boys' tables and be heard. At the same time in the West ceramics become again cutting edge of technology, organic foods increase in value, old life ways become more attractive again, questioning the logic of massproduced industrial products which the West exports with increasing aggression, with us all affected by their profit driven ways.

The survey of 1968 was clearly done by a mixed group. We were trying to establish which member may have been interested in more than the ancient world. As we collected more documents, the story became more and more interesting. Various members both in the past and present voiced their suspicions of the interests of different members, in letters and communications archived at the IoA (Arab 2003).

Theodore Wertime was the Cultural Attaché to Iran in the early 1960s. It is in his son's Richard memoirs that we get a hint of Wertime's other interests. His son Charlie on a trip to India had discovered a book written in English and published in China entitled '*Who's who in the American CIA'*, with one Theodore Allen Wertime mentioned (Wertime 2000: 4). This has never been proven, but is of interest to us (Arab 2003). In a conversation in 2003 with Professor Matson on the subject of spying, he said he was unaware of Wertime having links with the US intelligence service, but went on to say that he (Professor Matson) made a point of never giving names of persons he met abroad. It would seem Professor Matson was well aware of his government's interest in other nations and their structures and systems.

It is intriguing that Wertime, during his time as cultural attaché in Iran in pursuit of his scholarly interest (which are in no doubt), managed to survey a large part of the country. It would seem in the 1968 survey that Klinger was the unintentional 'spy', not so much because of his intent but that of the US Geological Survey, who paid for the most conclusive report to come out of this pyrotechnological survey. After the pyrotechnological survey, the only funding available for analysis happened to be for the geological report, which covers potential for minerals used in antiquity "and of use in the present development of the economies of the three countries" (Domenico et al. 1978: 5). Presently the US government is ensuring that certain countries do not achieve nuclear capability; meanwhile the Russians are helping to build a nuclear power station in Iran. The geological report happens to also mention sources for uranium, which is presently being extracted at one of the sites covered in this survey and is no longer accessible to archaeologists.

In the last few years, the USA has attacked Afghanistan where the Taliban were intentionally destroying major parts of the country's heritage until they were bombed out of the government; by invading Iraq, archaeological sites and museums were made vulnerable to destruction and inaccessible through the collapse of the government. How convoluted is the relationship of archaeology and society at large. What a dilemma we face, even if data are collected for innocent use, it is impossible to control how the information is



Fig 8: Mine entrance in Ergani Maden, 21 September 1968.

used. Archaeologists need to address the inherent politics in the discipline and examine closely its role in the political arena. European scholars have often followed their governments into foreign countries. Whether in the Americas, Africa, or parts of Asia, European institutions seemed to have left varying scars after up to 500 years of interference, with perhaps China with its long lived wall and boundaries retained if not increased since antiquity, as the only place relatively untouched. It is time for Western scholars to think about their role in all this and about how they can help redress the imbalances caused by their governments. The scientifically minded archaeologists in their attempts at being objective are often particularly reluctant to consider the socio-political aspects of the discipline. Archaeology is a discipline that needs groups and teams of people, there is very little meaningful work that can be done by one person alone. Archaeology being made up of so many specialists from different fields needs to address the interpersonal aspect of the discipline to avoid conflicts of 'great minds'. The travellers involved in the survey of 1968 seemed to have had different interests which meant that the artefacts they so carefully collected were left without the necessary full documentation, had little attention paid to them and, had they not been stored by Beno Rothenberg, would have been lost in the mist of time.

Collection and Documentation

The bulk of the pyrotechnological material assembled during the expedition in 1968 was transferred in 2002 to the IoA collections. It has since been repacked, re-labelled and catalogued, and given a full photographic documentation and an appendix of supporting texts, field notes and field photographs for future research (Arab 2003). The majority of the physical material is ferrous and non-ferrous slags and ores from Iran and Turkey, and technical ceramics such as tuyere, crucible and furnace fragments; remains of some metallic artefacts are also present. Access to the collection for study and analysis is available on request (th.rehren@ucl.ac.uk), and is governed by the IoA procedures for access to its collections. The related documentation comprises:

- Professor Pleiner's collection of preliminary reports and results of analysis undertaken on samples from the 1968 Survey by various members of the expedition.
- Professor Tylecote's notes from the British Museum, including copies of his field note book, letters and documents of interest, received from Dr Paul Craddock in 2002.
- Professor Rothenberg's field note book and photographs from the 1968 survey, and a taped conversation in 2002.
- Fred Klinger's geological report of the 1968 survey (Domenico *et al.* 1978) and correspondence in 2003.
- Several published reports and articles relevant to the survey of 1968.
- Correspondence relating to the survey of 1968, with varied peoples in 2002/2003, including a copy of the book published by Wertime's son Richard Wertime.
- Finally a basic report of the sites and their location on modern maps provided by Mr. Riyazi in 2002, with sites according to Professor Rothenberg's notebook.

Acknowledgements

Our thanks go first and foremost to Beno Rothenberg for looking after the collection for more than thirty years, and to Radomir Pleiner for his impeccable collection and curation of unpublished reports and his generosity in sharing these with us. Robert Brill, Fred Klinger and Sam Bingham kindly provided information and shared some of their personal memories with us, for which we are very grateful; the contextualisation of this information, however, reflects our own interpretation of events. Paul Craddock of the British Museum is thanked for allowing us to photocopy Ronald Tylecote's original notes, and Martha Goodway for information and reports held at the Smithonian Institution in Washington. The transferral of the collection to the Institute of Archaeology UCL was generously sponsored by IAMS. The curation of the collection and the research into its history were done by Roya Arab in partial fulfilment of the requirements of the degree of BA in Archaeology of the University of London.

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Marie Curie EST Project Science, Conservation and Archaeology

The project aims to train students to become full-time academic researchers and teachers in material science-based archaeology. The Institute of Archaeology UCL has a unique range of analytical scientific instruments which enables it to train young European archaeologists in the application of scientific methods to archaeological materials.

EST fellows can choose from one of six master programmes, selected from the current range of master degrees offered at the Institute. These programmes were chosen for their interdisciplinary combination of scientific methods within an archaeological research agenda.

An existing network of European and overseas co-operations will enable the fellows to gain a European perspective on modern science-based research in archaeology, and to contribute to the development of similar programmes in their home countries.

What Fellowships are available?

Three different types of fellowships are available: short-term visits of three months, one-year fellowships for taught Masters programmes, and two-year fellowships for MPhil / PhD research students.

All fellowships are aimed at training students to become academic researchers and teachers in material-science based archaeology. Fellows will be trained to use scientific instrumental methods for an archaeological research agenda, with particular emphasis being placed on using the Institute's facilities available in the Wolfson Archaeological Science Laboratory and the GIS Laboratory.

The positions offered for the 2006-2007 programme are as follows:

- Four three-months fellowships, specifically aimed at students in existing PhD programmes elsewhere who would benefit from the additional training and research experience available at the Institute.
- Four one-year Masters fellowships for one of the following Masters programmes: MA in Artefact Studies; MA in Principles of Conservation; MSc in Conservation for Archaeology and Museums (which is a 2 year programme); MSc in GIS and Spatial Analysis in Archaeology; MSc in Technology and Analysis of Archaeological Materials; and MA in Research Methods for the Humanities.
- Two two-year MPhil/PhD Fellowships beginning in October 2006. Research topics may be suggested by the applicant or proposed by the Institute. A specific research proposal is currently available for a two-year fellowship:

Coin minting since the Late Middle Ages: a comparative analytical perspective

Who is eligible?

The programme aims at emerging researchers with less than four years of research experience and prior to obtaining their PhD. The action aims to promote transnational mobility within the EU as well as to attract the best students from outside the EU. Fellows should not have lived more than twelve months during the previous four years in the UK, and should be EU citizens. A certain number of non-EU applicants can be funded under the rules of FP6.

What does the funding cover?

Funding is in accordance with EST rules and includes a monthly living allowance in excess of _ 1,400, plus a monthly mobility allowance of _ 500. In addition, a one-off travel allowance will be available, and a further allowance for fellows staying 12 months or more. UCL UK/EU fees is also likely to be part of the fellowship.

Application procedures

There is no set application form for these fellowships. However, all applicants will have to set out in writing (mail or email, including cv) their eligibility and their research plans and interests.

- Applicants for the three-months fellowships should explain how this will benefit their training and research programme.
- Applicants for the degree programmes need to apply separately to UCL for a place in one of the eligible programmes before

applying for funding. The covering letter should contain the application for the Marie Curie funding and state how their planned research (in the case of MPhil/PhD fellowships) or their research interests and career plans (for Masters fellowships) match the aims of this particular EST action.

Selection criteria

Fellows will be selected on the basis of academic merit and the suitability of their planned research and training for the EST programme, as well as the availability of appropriate facilities and expertise at the Institute of Archaeology UCL.

Deadlines

The deadline for applications for the 2006-2007 degree programmes is **30th June 2006**, but applicants are encouraged to express their interest in EST funding before this date. Note that applications for funding will only be considered once the applicant has been offered a place in the academic programme by UCL. For short-term visiting fellows, the next application deadlines are **30th June 2006** and **15th December 2006**.

The project will be running at least until 2007-2008.

Contacts

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Instructions for authors

We welcome submissions of papers from the field of archaeo-metallurgy in its widest sense. They should be in English, not normally be more than about 5,000 words, and not exceed a maximum of two to three images per thousand words of text.

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All texts will be reviewed by the editor and at least one external referee; to facilitate editorial handling, we encourage submissions of compuscripts as word or pdf files by email (th.rehren@ucl.ac.uk). The editor will communicate suggested changes to the author(s); the final decision about acceptance or rejection will be based on the revised paper, and an invitation to re-submit a revised paper does not guarantee eventual acceptance. Copy-edited proofs will be checked internally, The journal appears at present once per annum with only a limited number of pages, and we can not guarantee publication of accepted papers in a particular issue.

Organisation of the text

Please organise your draft text according to papers in the most recent issue of the journal; particular attention should be given to accurate referencing, correct spelling of names and non-English words, and provision of full bibliographical details in the list of References. Please do not abbreviate journal names, and give full titles of papers in journals or edited books, and provide first and last page numbers. Please try to avoid end notes, and provide a clear abstract as well as concluding section. When discussing analytical work, please make sure to provide all necessary methodological detail of the instruments used, and the full data required to follow your conclusions.

Illustrations and Tables

All photographs, maps, line drawings, diagrammes etc. should be numbered consecutively as they appear in the text as Figures. Tables should be numbered separately in their own order. Both figures and tables will be placed within the text in appropriate positions.

We prefer to receive illustrations in high resolution electronic files; please bear in mind that we can only print in half-tone (black and white and grey shades), but not colour. In future, pdf files of published papers will have illustrations in colour if provided as such. Captions for figures and tables should be listed at the end of the compuscript. Please indicate the preferred approximate position of figures and tables in your final text.

MSc in the Technology and Analysis of Archaeological Materials

Programme Co-ordinator: Professor Thilo Rehren FSA Further details: th.rehren@ucl.ac.uk

The Programme

This one-year taught masters programme offers students an introduction to the scientific study of a broad range of materials typically found in archaeological excavations and museum collections. It is designed for graduates in archaeology with a strong interest in scientific methods. It is also suitable for conservators and others concerend with archaeological collections, and for science graduates who have, or are willing to aquire, a good understanding of archaeology.

The programme provides an overview of the role of materials in past societies, enabling the student to understand and interpret scientific data derived from the investigation of these materials. It gives students the opportunity to analyse real archaeological materials from the group they have chosen to specialize in (see options), using the Institute's own analytical equipment and related facilities (such as optical and electron microscopy; X-ray radiography; image processing; quantitative bulk and spot chemical analysis by X-ray fluorescence and electron microprobe; phase identification by XRD and FTIR; data handling, interpretation and presentation).

Students are required to take the core course and a total of two full optional elements (see below for details) during the two teaching terms (October to March). They then write a dissertation of around 15,000 words, preferably based on their own analytical work.

The Core Course

This course will introduce students to the social aspects of technology and materials as well as providing a broad introduction to the theoretical foundations of common analytical methods, relevant laboratory skills, and the development of a research design.

Options

The programme offers a range of half element options, allowing for individual specialization. These include routinely: Archaeometallurgy I: Mining and Extractive Metallurgy; Archaeometallurgy II: Metallic Artefacts; Advanced Topics in Lithic Analysis; Plaster & Ceramics; Interpreting Pottery; Glass, Glazes, Pigments and Beads; Archaeological Computing and Statistics. In addition, students can after consultation with their degree co-ordinator chose from the full range of other elements offered within the Institute. This is particularly relevant for science-based graduates who want to expand their archaeological background.

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- Examination and Analysis of Late Bronze Age Egyptian Glass from Timna, Israel.
- Hellenistic Gilded Wreaths found in Magnesia, Greece: Materials Study and Conservation.
- The Technology of Brass Production in Central Europe from the 10th to the 16th Century: Archaeometry and History.
- Metals and Metalworking from Kastri-Kythera at the Late Bronze Age, Classical and Late Roman periods.
- An Analysis of the Experimental Smelts XP90 and XP91 from Plas Tan Y Bwlch utilising Reflected Light Microscopy and XRF Analysis.
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