Early Islamic Copper Smelting – and Worship – at Beer Ora, Southern Arabah (Israel)

The smelting site at Beer Ora (Site 28 on our Survey map) was discovered by the author in 1959 during his archaeological exploration of the Arabah Valley from the Dead Sea to the Red Sea.¹ It is located about 25km. north of modern Eilat, one km. from an ancient well, still used today by a small settlement, and consists of two very large slag heaps surrounded by smaller heaps (Fig. 1).

Most of the slag pieces were broken off large circular slag plates, 50–80cm. in diameter and c. 7cm. thick. There were also complete slag plates, most of which had a small ‘cast in’ hole in the centre. This ring-shaped slag was obviously tapped, very heavy, solid and black, with very few copper inclusions, and obviously the product of an advanced smelting technique (Fig. 2).

Unlike all the other smelting sites of the Arabah, it was surprising that at Site 28 no stone-built structures were visible anywhere; indeed, there were no structures whatsoever. We assumed at the time that the workers’ habitation may have been somewhere near the ancient well or in a nearby wadi, where some structural remains and Roman sherds had been found by our Survey.

Only a handful of apparently Roman sherds were found during our surface survey of the slag heaps, most
of which could be dated to the second century A.D., while some others remained difficult to define.

In 1969 we excavated at Beer Ora. The most important find was a group of smelting furnaces in a fairly good stage of preservation. The smelting hearth was a mortar-lined pit, dug into the ground without any stone support and with a slag-pit attached to it. There were tuyère fragments but none as found in situ. One of the smelting furnaces had been refelted with mortar lining after a previous run – and abandoned unused (Fig. 3).

Although the furnaces at Beer Ora seemed to be of much less sophisticated construction than the earlier Egyptian New Kingdom smelters of the Timna Valley, the smelting technique appeared to be rather similar. There were, however, characteristic differences which only became apparent during the subsequent metallurgical study of the slag – Pyroxene type of slag instead of Fayalite and Knebelite types – but these were basically connected with the fluxes used and not the result of a different smelting technology.

Upon excavation, the smaller slag heaps turned out to be collapsed buildings constructed of slag plates standing on edge. Most of these rather small structures were used as stores but some were also habitations. One had a small kitchen attached to it, where remains of cooking utensils were found (Fig. 4).

Right in the centre of the smelting site we noticed a curious arrangement of slag plates which had been inserted into the ground, standing on edge, to form a rectangular ground plan, 7.5 × 5.5m. with an ‘apse’ at its south side (Fig. 5). Excavation showed that these slag plates had been carefully set into narrow, triangular foundation trenches and the ‘apse’ was constructed with particular care by using a double row of smaller slag pieces. The method of construction suggested that the lines of slag could only have been intended as the demarcation of a plot by a kind of symbolic fence. Clearing the inside down to a hard trodden surface, c. 10cm. below the present surface, some sherds and traces of a fireplace or two were found, but nothing to indicate the function of the structure.

In the first publication of Beer Ora in 1972, based on the dating at that time of the pottery found to the Roman period, it was suggested that this enigmatic structure could be a ‘symbolic’ early Christian church. Reference was made to the observations in Sinai of Bedouin ‘mosques’, which are, in fact, only segregated plots, marked out simply by a line of stones or shells, with an ‘apse’ indicated as the mihrab.

In 1982 we excavated a rock-cut smelting furnace at Site 2 in the Timna Valley, reported in IAMS Newsletter No. 5. This furnace (Fu Z) was dated by pottery and the general context of the site to the Egyptian New Kingdom, like most of the smelting camps of Timna. It therefore came as a great surprise that a charcoal sample taken from the very bottom of this furnace at the end of our excavation, produced a radiocarbon date of A.D. 740, i.e. Early Islamic. The implications of such a late date for Fu Z, which was of the same type as most of the New Kingdom smelting furnaces at Site 2, and also showed the same ring-shaped tapped slag, made it imperative to systematically re-investigate many of the Arabah and Timna sites and installations. This renewed investigation included the systematic collection of a large series of charcoal samples from all slag heaps in Timna and the Arabah which contained mainly ring-shaped slag, including the large slag heap of Beer Ora.

The radiocarbon dating of these samples proved that the Timna furnaces in question were indeed of a New Kingdom date, but at several sites there was also evidence for a later, secondary use of New Kingdom installations.

The large slag heap of Beer Ora had already been sectioned in our previous excavation and we could therefore obtain well-stratified charcoal samples from the top of the heap to its bottom. All these turned out to date to the Early Islamic Period, the bottom sample to A.D. 640.

Parallel to these scientific investigations there were also new developments on the archaeological front. As part of our preparations for the final publication of our Arabah and Timna research – the first two volumes of
which are due for publication in 1988 – Professor M. Gichon re-investigated the pottery of the Classical periods found at our Arabah sites in order to update the reports prepared many years ago. Since a number of Early Islamic sites have been excavated within the last ten years, in the Arabah as well as in Arabia, much new comparative material became available. One of the important results of these recent ceramic studies was the re-dating to Early Islamic of a number of sherds which had previously been considered ‘Late Byzantine or later’.

C14 dating, as well as the new pottery identification and dating of Beer Ora, established that the history of this site was rather more complicated than has been assumed so far. At the beginning, during the Roman Period, it was a copper smelter close to a Roman well and station. During the Early Islamic Period, when the southern Arabah was occupied by Muslim invaders, copper mining and smelting was restarted in the whole area. Beer Ora, probably because of its rich water source, and the proximity of a rich copper mining area at the nearby southern fringe of Timna, became the major Early Islamic smelter of the Southern Arabah.

Tracing each of the Early Islamic sherds to its exact stratigraphic context made it evident that the smelting furnaces of Beer Ora, previously published as Roman installations, and the related characteristic Pyroxene-type ring slag, must now be re-dated to the Early Islamic Period. This re-dating may also explain the fact that the Beer Ora slag showed fluxing with limestone, a fact which was quite difficult to accept for the Roman Period in the Arabah. Although the use of limestone as flux in a smelting charge in the Early Islamic Period still seems rather early, it appears now to be well estab

lished by Bachmann’s phase studies of the Beer Ora slag.

We now have the first reliably identified Early Islamic copper industry in the Arabah, using quite advanced extractive metallurgical production methods, and this new information adds a further chapter to the long history of copper mining and smelting in the Arabah.

In the light of these new and important re-interpretations, we can now ascertain the function of the
enigmatic slag structure among the slag heaps of Beer Ora. It is not a 'symbolic church' but a mosque built by the seventh century A.D. Islamic metallurgists of the Arabah. This, of course, also explains why the 'apse', i.e. the mihrab, was orientated south, towards Mecca.

The age-old tradition of erecting places of worship in the centre of mining and smelting regions, still adhered to in modern times, and well documented by our Arabah expeditions from the fifth millennium B.C. beginnings of metallurgy to the fourteenth-twelfth centuries B.C. Egyptian mining temple of Timna, can now be followed through to the seventh century A.D. at Beer Ora – a total of about 6000 years of mining and metallurgy and metal-related worship.

Beno Rothenberg

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1 Rothenberg, B. Ancient Copper Industries in the Western Arabah, Palestine Exploration Quarterly, 1962, 5-71; idem, Negev Archaeology in the Negeb and the Arabah. Tel Aviv, 1969.
7 Pta 4117, bottom of slag heap: 1390±50 B.P.; cal. date 640 A.D. (Courtesy Dr. J. Vogel, Pretoria).

Arsenical Copper Smelting at Batán Grande, Peru

The Sicán Archaeological Project, under the direction of Professor Izumi Shimada (Harvard University), is a long-term interdisciplinary study carried out to date over nine seasons (1978–86). A primary research aim is an understanding of both cultural and technological aspects of Sicán copper production. John Merkel, who recently took a doctoral degree in archaeo-metallurgy on an IAMS Fellowship at London University, is collaborating with Dr. Stuart Fleming (MASCA, University of Pennsylvania) on the analytical programme of the Sicán Archaeological Project. Dr. Merkel (currently at Harvard, but shortly to join the staff of the Institute of Archaeology, University College London) is on the Scientific Committee of IAMS. The project is supported by grants from the National Geographic Society, the National Science Foundation and Harvard University.

Starting with the Middle Sicán Period, A.D. 900–1100, copper-arsenic alloys definitely replace unalloyed copper to become the mainstay of the North Peruvian metallurgical tradition. At the sites around Batán Grande (Fig. 1), indigenous copper production ended with the Spanish conquest at A.D. 1532–5. This brief report will discuss new evidence from technical investigations of the ores, slag, speiss, copper and furnaces, including copper smelting experiments conducted on site.

Based on work to date, it appears that Batán Grande represents part of an extensive, regional network of copper production sites. Six prehistoric mines and three smelting sites have been identified and, in part excavated in the Batán Grande area. The earliest remains of copper smelting furnaces date from c. A.D. 900–1000. At the site of Huaca del Pueblo, Batán Grande, five rows of small bowl-shaped furnaces have been excavated (Fig. 2). More than fifty examples of such furnaces have been examined altogether in the three

Fig. 1. Relevant archaeological sites in the Batán Grande region of North Coast Peru.
known smelting sites. Based upon furnace volumes and slag density estimates, each furnace could have held 5 to 10kg. of molten slag and copper (Fig. 3). Tuyères, also abundant at the smelting sites, were presumably positioned pointing into the open front of the furnace directed toward the bottom. The ceramic tuyères (Fig. 4) were connected to blow pipes. No remains of bellows have ever been found and ethno-historical documents clearly note their absence in Pre Hispanic South America. Copper production was based upon a 'prill extraction' technique; furnace slag containing entrapped metallic copper prills was crushed on large stable anvils, called ‘batanes’, with a heavy rocking stone in order to separate the copper prills for subsequent collection by hand. Small copper ingots, weighing 300-600g., were produced by remelting copper prills.

There has been much speculation concerning the ancient production of copper-arsenic alloys. Based upon laboratory analyses of finished objects, some scholars have argued that the alloy may have been produced from smelting deliberately mixed ores. At Batán Grande, there is new archaeo-metallurgical evidence which supports this theory.

Proton induced X-ray emissions (PIXE) analyses of ore specimens recovered from excavation of smelting sites indicate that the dominant copper mineral was malachite. It is significant that of over 40 samples of copper ores from the smelting site of Huaca del Pueblo, only four had concentrations of arsenic over 0.05%. Two specimens had about 0.2% arsenic, but there were also two with high concentrations of 6% and 11% arsenic. These two specimens were also different in colour than the 'best' grade copper ore specimens from the site. This suggests that arsenic-rich ores were recognized as being different from the usually smelted ores at Huaca del Pueblo. Available fluxes, also collected at the smelting site, included hematite and limonite. Six samples of iron ore flux were analyzed, only one had 4% arsenic, the others were below 0.05% arsenic.

Copper ore collected for the smelting experiments from nearby surface deposits at Cerro Blanco did not have arsenic concentrations above 0.05%. However, iron ore used as flux in the experiments also collected at Cerro Blanco contained up to 0.5% arsenic. In the mining survey of the immediate area, at a large, shallow ancient mine, called Cerro Meiliso, arsenopyrite (FeAsS) and scorodite (FeAsO₄·2H₂O) were identified. (Scorodite is a common weathering product of arsenopyrite.) PIXE results for one of the specimens were 38% Fe, 49% As and 12% S. Results were confirmed by electron probe microanalysis (EPMA) and the phases identified by X-ray diffraction (XRD) and petrographic techniques. The absolute date when this local mine was utilized for its arsenic-rich ores is still somewhat uncertain. Outside the mine are Pre-Hispanic ceramics and wall foundations with standardized room dimensions. The mine was cut with stone tools. It most probably predates Spanish contact. Thus, surface deposits of arsenic-rich mineralization are present in the Batán Grande area.

Slag specimens and crushed slag samples collected from around the smelting furnaces at Huaca del Pueblo, would be termed 'furnace-type, spinel-type', following Professor H-G. Bachmann’s 1980 classification. Typical ranges for slag-forming constituents are 35-60% FeO, 10-35% SiO₂, 2-10% Al₂O₃, 5-20% CaO, and 2-10% Cu. The slag is characteristically
heterogeneous. Such slag compositions have estimated free running temperatures often well above 1150°C. Copper prills of varying sizes are entrapped throughout practically every slag sample. ‘Droplets’ of matte (CuFeS) have also been identified in the slag. Copper losses were considerable, despite crushing and hand sorting of the prills from the furnace slag.

Another discovery among the excavated material collected from around the furnaces is the presence of speiss. These specimens have weathered surfaces of iron oxides. Average composition for the speiss is about 56% Fe, 41% As and 4% Cu.

The compositions of copper prills entrapped in the slag (Fig. 5) provide essential data for reconstructing the smelting process at Batán Grande. Using EPMA, our average concentration of arsenic in the copper prills is about 6%. Arsenic has been found to range typically from 1–20% in the entrapped copper prills in the slag at Huaca del Pueblo. Values above the solid solubility of about 7% arsenic are common. Some compositions of inclusions and two phase regions in prills were measured with up to 40% arsenic. These high-arsenic copper prills entrapped in the smelting slag, along with the presence of speiss at the smelting site, indicate some necessary additional input of arsenic in the furnace charge in excess of that from the available copper ore and flux. The ore compositions from the smelting sites, along with the identification of distinct mine locations for arsenic-rich ores, suggest that three separate ore components were recognized and mixed in the smelting charges at Huaca del Pueblo. Based upon mass balance estimates, the low levels of arsenic in the majority of copper ore and iron ore samples would not account satisfactorily for the observed products. A few ‘erratic’ ore specimens included accidentally in a smelting charge could produce occasional copper-arsenic alloys. However, accidental inclusions would not sustain a tradition or ‘industry’ based upon predominant use of copper-arsenic alloys.

We believe that the Batán Grande evidence best supports a model for alloy production using deliberate additions of local (perhaps supplemented by some imported) arsenic-rich ores in smelting charges. Considerable variability in arsenic concentrations and the speiss products suggest rather poor control over ore sorting and charge preparation. It is possible that mixing or ‘blending’ of complex prills from high-arsenic smelting runs was undertaken, to counteract refining losses, in a further attempt to control final alloys for finished objects. At Batán Grande there is no evidence at present to recommend an alternative theory for deliberate secondary alloying in a separate step after smelting.

Fig. 5. Photomicrograph (×80) copper prills entrapped in slag from Cerro Huaringa.

Experimental smelting reconstructions were conducted at Batán Grande to test several aspects of furnace operation and product compositions. In the final experiment, an ancient furnace was re-used after some 500 years of abandonment (Fig. 6). It was determined in the preliminary experiments that these furnaces incurred very little damage with each smelting run because the charcoal bed protected the furnace walls from slaggery. Based upon our observations, these small furnaces were not filled with molten slag at any given time during smelting. Using blow tubes, maximum temperatures over 1200°C were frequently measured during the experiments, but only in a relatively small zone directly in front of each tuyère. With three or four tuyères (the maximum number that could practically fit into the open furnace front) and the use of ceramic sherds covering the front of the furnace to contain heat (evidence for which is also abundant at the Batán Grande smelting sites), we could not get the entire furnace charge to melt at any one time. We were rotating blowers and trying to operate at maximum airflow and burning rates. Under these restraints, one possible way which was tested to operate the furnace was to start with small charges (under 100g. of mixed ore and flux) placed slowly on top of the burning charcoal in the back of the preheated furnace. With continued blowing, temperatures of small charges would quickly reach 1100 to 1200°C. However, with each subsequent small charge, the temperature measurements would quickly fall below 1100°C. It does not seem possible to achieve a thermal balance between charcoal and small ore charges based upon observation alone. As continued small charges first melted and then cooled and solidified, a solid mass was slowly accumulated, building toward the front until the furnace was

Fig. 6. Reconstruction copper smelting experiment at Cerro Huaringa using a 500-year-old furnace. Three local workmen shown using cane pipes and ceramic tuyères.
filled. Operating volumes were less than expected due to slag-coated unburned charcoal remaining in the furnace. Clearly, variable low burning rates at only about 2kg. charcoal per hour, relative to heat losses, were limiting factors. Nevertheless, the smelting products were comparable in many respects (expect for arsenic) to the Sicán products.

In the experiment with the 500-year-old furnace, from 775g. furnace slag only about 30g. of copper prills were collected after crushing (Fig. 7). The slag was 44% FeO, 34% SiO₂, 3% Al₂O₃, 8% CaO and 6% Cu. The concentrations of arsenic in the prills were especially interesting. The copper ore (31% Cu) had less than 0.05% As, but the iron ore selected for the experiments had up to 0.5% As, as noted above for Cerro Blanco. From smelting a 1 : 1 ratio of ore to flux, the copper prills resulted with about 1% arsenic. Such levels of arsenic in the flux clearly represent accidental inputs in the smelting charges. These figures give some further indication as to the partitioning of arsenic into the copper prills in smelting under 'primitive' conditions, such as documented previously in other simulation smelting experiments.

Fig. 7. Copper prills collected from crushed slag produced in the reconstruction copper smelting experiment.

In conclusion, since the concentrations of arsenic in the majority of ore and flux samples collected from the Huaca del Pueblo smelting site were at least an order of magnitude lower (below 0.05% As), the results of these experimental smelting reconstructions underscore the necessity of seeking an additional, separate arsenic input to the smelting charge. 'Accidental' inclusions of arsenic-rich ore or flux cannot account for the production scale utilizing high-arsenic prills and alloys that characterize the period from A.D. 900 to the Spanish conquest. Full documentation of the analytical results and broader cultural interpretation of Sicán metallurgy will be published in a forthcoming volume of Sicán Archaeo-Metallurgy.

John Merkel and Izumi Shimada

Peter Wincierz
4 May 1930 – 22 April 1988

It is with a deep sense of sorrow that we have to announce the sudden death of Prof. Dr.-Ing. Peter Wincierz, Frankfurt/M.

From the very beginnings of IAMs, in the early '70s, Peter was one of the central members of our archaeo-metallurgical research group and he also took part in our fieldwork in the Arabah and Sinai. His major contribution to our research projects was in the field of theoretical as well as applied extractive metallurgy.

In the last few years, in spite of his heavy responsibilities as Director of the Metal-Laboratory of Metallgesellschaft AG Frankfurt/M, Peter spent many of his rare off-duty hours working together with his IAMs colleagues on the very exciting development of new experimental and theoretical models of copper smelting.

Shortly, before his untimely death, Peter completed his part of the final version of 'Mathematical Modeling of Late Bronze Age/Iron Age Smelting of Oxide Copper Ore', published, posthumously, in the May issue of Metall, Internationale Zeitschrift für Technik und Wirtschaft, Berlin/Heidelberg.

It is with great sadness, but also with a deep sense of gratitude, that we turn the pages of the voluminous manuscript Ancient Smelting of Oxide Copper Ores, written by Peter Wincierz and M. Bamberger for the forthcoming second volume of Researches in the Arabah, which reached us almost together with the Job's message of Peter's death.

Peter has left his mark not only on the development of new archaeo-metallurgical research methods but also, and in many ways, on his research partners and colleagues who will greatly miss his unique expertise, his unbending professional integrity and, most of all, his unfailing loyal friendship.

B.R.
The Egyptian Mining Temple at Timna
Researches in the Arabah 1959–1984: Vol. 1
Beno Rothenberg

Twenty-five years of intensive fieldwork and research in the Arabah have produced an unprecedented amount of information about the past history of the Arabah and the adjacent areas of Sinai, North-western Arabia and the Negev. This volume is the first of four which will fully present the findings of the Arabah Expedition, throwing new light on the archaeo-metallurgical history of this area of extreme importance for the early history of mining and metal technology.

The discovery of the Ramesside mining temple, dedicated to the Egyptian goddess Hathor, was a turning point in the history of the Arabah research. The identification through this discovery of the large scale copper mining and smelting operations in the Arabah as Egyptian industries, where Egyptian mining expeditions worked together with local inhabitants, the Midianites from North-western Arabia and the Amalekites from the Negev mountains, has meant fundamental changes in the culture-historical concepts concerning the areas adjacent to the Gulf of Eilat-Aqaba.

The old ideas of King Solomon's Mines and the Solomonic copper smelters on the shores of the Red Sea have had to be completely changed in the light of this new archaeological evidence which proves that the south-western Arabah came into the sphere of influence of the Pharaohs of New Kingdom Egypt.

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