Metalworking Technology at the End of the Early Bronze Age in the Southern Levant

This paper concerns a complex period once considered a ‘Dark Age’ in the history of the Levant, from about 2200-2000 B.C. It has been known alternatively as Middle Bronze I, Intermediate Early Bronze-Middle Bronze, and Early Bronze IV. According to Dame Kathleen Kenyon (1979), it was associated with a great invasion by a group of nomadic people known as ‘Amorites’, a name that has associations with descriptions in the Biblical Books of Numbers and Joshua. These invasions are believed to have led to the collapse of the Early Bronze Age city states and to the First Intermediate Period in Egypt. However, many new archaeological discoveries have changed our understanding of this period. Foremost amongst them is the archive of cuneiform inscribed tablets from a large urban site in Syria recognised as ancient ‘Ebla’. Additionally, archaeo-metallurgical research now contributes new evidence of trade in metal, particularly from the south.

In the southern Levant, metalwork from the final phase of the Early Bronze Age (the so-called EB IV Period, c. 2200-2000 B.C.) is characterised, in part, by an increase in the use of bronze for weapons and other implements. Copper-tin alloys are seen to begin replacing the earlier, wide spread use of unalloyed copper as well as copper-arsenic alloys. Most of the EB IV metalwork from the Jordan Valley, north-eastern Negev and Hebron Hills has been recovered from burials, such as the cemeteries at Jericho and Jebel Qa’aqir (Fig. 1). Daggers, javelins and pins are the prevalent metal objects from the tombs.

From the archaeological evidence, it was assumed that the EB IV life-style in the southern Levant was pastoralist and nomadic with a local tradition of metalworking. Bar ingots (Fig. 2) are distinctive for the period and seem to indicate local production of copper implements. In contrast, large urban sites, such as ancient Ebla (Mardikh), dominate in this period to the north (Fig. 3). Based upon information from the Ebla archives of cuneiform inscribed clay tablets, it is now known that the large urban sites were involved in an extensive and far-reaching trade in copper (Waetzoldt and Bachmann, 1984). As metal implements are investigated from additional sites, especially remote EB IV sites in the south such as Jebel Qa’aqir, it is possible to achieve a better understanding, both chronologically and geographically, of the introduction of bronze into this southern area. While there is still little progress toward identification of distant tin and arsenic sources, there are several new lines of investigation (conducted by several members of the IAMS Scientific Committee and other research teams) which together significantly improve our knowledge of this complex, regional trade in copper and the production of alloys for the late third millennium B.C.

The archaeological site of Jebel Qa’aqir is representative of the EB IV Period in the southern Levant. It was excavated by W. G. Dever (1972) and has been the subject of other specialist studies (London, 1987). From a total of 25 copper-based objects recovered from the Jebel Qa’aqir tombs, eleven daggers and seven javelins were selected for archaeo-metallurgical study. The daggers have been conveniently divided into three general types, primarily on characteristics of shape

Fig. 1. Entrance to an EB IV tomb at Jebel Qa’aqir.
(Fig. 4). Due to the destructive analytical techniques involved, it was decided to exclude (and thus fully preserve) seven of the 'best' examples of metal weapons and pins from this study.

Metallographic examination of the daggers and javelins from the EB IV Period indicated a competent level of metalworking skill utilising casting, coldworking, and annealing. For example, production of dagger Q408 involved these standard steps in production. In metallographic section (Fig. 5), non-metallic inclusions appear elongated especially at the cutting edge of the dagger indicating the degree of coldwork. In the final step of production, only the cutting edge of the dagger was preferentially coldworked, i.e. deliberately worked-hardened. Note in section, how the deformation decreases away from the edge. Toward the central midrib, the dagger was left in a recrystallised state with a correspondingly lower hardness. From EB IV Jericho, only one flat, blunt dagger was found that may be interpreted as a cast blank ready for working into a final form. The other daggers and javelins at Jebel Qa’aqir were produced by the same metalworking techniques, in a qualitative sense, but the edges of the javelins were not coldworked to the same degree. These microstructures indicate that the metalworkers exercised basic control over the properties of annealing and work-hardening. Similar conclusions have been published for metal weapons from other EB IV sites.

In comparison to the uniform application of standard metalworking techniques like casting, coldworking and annealing, the compositional data also suggest deliberate alloy selection based upon concentrations of tin and arsenic. The compositional data may reflect local socioeconomic conditions during the EB IV period, when tin was only just beginning to be used. In the two Type 3 bronze daggers from Jebel Qa’aqir, except for tin, the concentrations of arsenic, zinc, lead, iron and nickel are all within the ranges determined for the unalloyed objects. On this evidence, we conclude that tin was added deliberately to available copper. The low tin concentrations in some of the other weapons at about 0.1% and 0.2% are believed to represent recycling and mixing of bronze scrap, rather than tin impurities resulting from the copper ore, or use of iron ore flux in smelting. Furthermore, although these Type 3 daggers are only rarely found in the EB IV of the southern Levant, they are rather common in archaeological deposits at Byblos, Ugarit and elsewhere. Since many of the unlooted tombs had few or no grave goods it has been suggested that Jebel Qa’aqir was a relatively poor site. The less frequent occurrence of bronze at Jebel Qa’aqir (about 10% of the objects analysed) in contrast to other sites such as Jericho (with 25% bronze) reflects in part the remoteness of the site, a lower general wealth and poorer trade connections. Tin was a valuable commodity and thus generally used wisely when
available. The observation that composition and object types are occasionally related (but not always as at Jericho) may indicate an intermittent supply of tin and re-use of bronze during this period of several hundred years. The evidence from Jebel Qa’aqir, as well as other sites, suggests that the trade in tin and copper were not necessarily linked at this time.

The association of bar ingots with metal objects in hoards found in the Negev (at Beer Resisim and Har Yeruham) suggests that the apparently local metalworking involved itinerant copper-smiths. In a technical study of EB IV bar ingots, Maddin and Stech Wheeler (1976) concluded that the bar ingots were secondary castings. Recent compositional analysis has shown that these ingots are not alloyed with either arsenic or tin. Thus, the ingots were smelted and refined metal intended for alloying, and not recycled available scrap with low, dilute concentrations of arsenic or tin. These results attest to secondary, deliberate alloying as well as casting and finishing having taken place at the remote sites.

One of these bar ingots (No. 64-883) was also analysed for lead isotopes by R. H. Brill and I. L. Barnes (1988). Since EB IV mining and smelting sites have been found at Timna and Feinan in the Arabah, it is not unexpected that these lead isotope ratios for the EB IV bar ingot plot in the field for Timna, published by N. Gale and Z. Stos-Gale (1984; their graph is reproduced again here, Fig. 6). Although only one bar ingot has so far been analysed for lead isotope ratios, there is sufficient correspondence between the trace element patterns for this ingot and the others, to recognise Timna and Feinan as the source for, at least, a portion of the copper used at the time. We are hoping to proceed with further investigations of bar ingots and metal implements from the EB IV period relating to this interesting trade from the south. The recent find of a hoard of EB IV bar ingots (being investigated by IAMS) in a settlement of this period at Ain Ziq, alongside the ancient route from the south (Timna) to the central Negev, may indicate the actual road of the copper trade from the mines to the settlements of the Negev.

The dominant proportion of the metal in the southern Levant is still believed to have come by trade through the large urban sites in the Levant. From the Ebla tablets, H. Waetzoldt and H. G. Bachmann (1984) discussed the ancient technical terms referring to copper and copper alloys for the EB IV Period in Syria. For example, among the various terms is one interpreted as meaning 'pure copper for alloying'. The bar ingots from the Negev could thus serve as an illustration for this technical term. From Ebla there are also directions for the proportions of copper and tin to be mixed for bronze objects (Pettinato 1981). Due to the general correspondence of the dates, along with trade connections, the local metalworking tradition in the remote southern sites may be viewed as an extension of the regional metal industry evidenced from the Ebla clay tablets.

In conclusion, at Jebel Qa’aqir the foremost question concerns the deliberate selection of available copper-arsenic alloys for metalworking, and not deliberate production from smelting. Non-urban, remote EB IV sites in the south were certainly not primary markets or destinations for metals smelted in Anatolia or elsewhere and traded through the urban sites; the quality of metal available at any one time in the southern Levant was the result of many factors: social, economic and technological. Surely copper from many ore sources was available for use or alloying as these conditions varied. Observed metal compositions have both foreign and local components. Although EB IV workshops with mould and crucible fragments have not been discovered yet, it does not necessarily follow that all finished copper-based objects were imported or ultimately derive from Syria. The technology involved in the production is straightforward and easily reconstructed (Fig. 7). While Syrian influence is clear for some metal types, such as the daggers, it cannot account for all metal types and variants found in the southern Levant. Hoards of bar ingots and scrap metal from southern EB IV sites (which we intend to analyse in the near future) suggest the activity of local metalworkers. The uniformity and skill of standard metalworking, with annealing and coldworking techniques, seem to represent a local tradition present before the introduction of tin bronze. The low concentrations of arsenic and tin in copper-
based objects from Jebel Qa'aqr, and other sites like Jericho, are understood to reflect 'homogenisation' as the result of local recycling. Deliberate selection of arsenic-rich copper seems to have taken place for some of the daggers. The introduction and supply of tin for alloying was intermittent during the EB IV period, which accounts for the apparent relationship between composition and object type. There are clear local characteristics of the EB IV metalworking tradition. Copper containing high concentrations of arsenic was obviously the result of long distance trade; no such arsenic-rich ores are known to exist in the southern Levant. However, it is important to emphasise that during its transport and use, this material underwent considerable secondary selection, refining, mixing, alloying and recycling.

J. F. Merkel and W. G. Dever

References
Gale, N. and Stos-Gale, Z. Mystery of Timna’s iron solved by lead isotope ‘fingerprinting,’ IAMS Newsletter, No. 6, 1984, 6-7.

The Enigmatic Iron Object from the Great Pyramid – re-investigated

An iron plate was found by an excavation team in the Great Pyramid at Gizeh, Egypt, in 1837. This plate was said to have been found partly blocking an air passage high up on the south flank of the pyramid, but located within an undisturbed portion of the structure (Fig. 1).

The plate was not examined in any detail at the time and it has since been in the safe keeping of the British Museum in London. A small fragment of the plate has now been subjected to detailed examination by modern metallographic techniques. These techniques have shown, conclusively, that the plate consists of numerous laminates of wrought iron that have been inexpertly welded together by hammering (Fig. 2). The various laminates differ from each other in their grain sizes, carbon contents, non-metallic inclusions, and thicknesses. Some of the non-metallic inclusions consist of un-reacted (or incompletely reacted) fragments of the iron ore that was used to produce the iron metal. Other iron oxide ‘inclusions’ consist of the iron ‘scale’ that had formed between the inexpertly welded laminates. Yet other non-metallic inclusions are sodium- and potassium-rich ‘ashy’ remnants of the charcoal fuel.

The iron grains in all the laminates are equi-axial whilst the inclusions within the metal are all markedly elongated. These features show that the welding process was carried out at modest temperatures that allowed only the iron grains to recrystallise. It is signifi-
It is significant that the examined specimen contains no siliceous, slaggy inclusions, nor does it contain more than a small trace of copper. Thus, it is most unlikely that the iron was produced as a by-product of a copper smelting operation.

The outer layers of the iron have been badly corroded and now form banded iron oxides. Significant proportions of gold were found in one of the oxidised layers and the plate may, originally, have been gold-plated.

The new data, coupled with the original, archaeological information, strongly suggest that the iron plate is contemporary with the building of the pyramid and that it is, therefore, one of the oldest known pieces of iron.

M. P. Jones (Imperial College, London) and El-Sayed El Gayer (Suez Canal University)

[The Great Pyramid of Gizeh was built by the pharaoh Cheops (Khufu) of the Fourth Dynasty, c. 2560 BC. A fuller report of this investigation is to appear in The Journal of the Historical Metallurgy Society, vol. 23, pt. 2 (1989). Editor.]

Crucible smelting in Prehistoric Thailand

In the neighbourhood of Khao Phu Kha mountain, an ancient copper mine near Lopburi town, in Central Thailand, there are extensive mounds of ancient slag at Non Mak La (NML), Non Pawai (NP), Nil Kam Haeng (NKH), Tha Khae (TK) and Khao Sam Yoi (KSY) (Fig. 1). These were visited in 1984 and 1985 in order to assemble samples of past metallurgical activities.

Although only a very small amount of copper metal was recovered from any of the smelting sites investigated, the large quantities of slag indicated that the area around Lopburi had been an important industrial complex and that smelting had been carried out on a large scale.

The metallurgists were using an efficient and standardised process, employing a crucible smelting technology rather than the more usual method of smelting in shaft and bowl furnaces. Large numbers of fragments of thick-walled, organically tempered crucibles were recovered at the smelting sites of Non Mak La and Non Pawai. Unfortunately, no complete crucibles were found and the fragments were all quite small, often only 10% of the rim remained. Because of the absence of complete profiles the proportions of the crucibles cannot be established with any degree of certainty, but the internal diameter seems usually to have been between 12 and 24cms. The thickness varied from about one centimetre at the rim, through 1–1.5cm. for the wall, to 4cm. at the base, and while the rim thicknesses could be accurately assessed, considerable thinning had occurred in some wall and base areas due to the internal

Fig. 1. Map of the prehistoric copper casting and smelting sites in the neighbourhood of Khao Phu Kha mountain.

Fig. 2. Cross section of the iron plate (×13) found in The Great Pyramid of Gizeh. It shows a number of laminae that have been inexpertly welded together. The grain sizes, carbon contents and non-metallic inclusions are different in each laminate.
dissolution during use. For example, one base fragment with an original thickness of at least 3.6 cm had been reduced in parts to 1.6 cm.

The fact that the crucibles were used for smelting is demonstrated by the bulk chemical composition of the slag lining the inner surfaces of the fragments, which is similar to that of slag cakes found at the sites. Petrographic and electron microprobe analysis showed that the slag lining, unlike the cakes of slag, contained appreciable amounts of magnetite, resulting from oxidation of the thin layer of molten slag by air entering the crucible during the pouring process. None of the crucible fragments showed any evidence of holes which might have been used for inserting tuyères, or for tapping off slag. It seems likely, therefore, that these were externally heated, and the slag and metal removed by pouring at the end of the process. While there is no evidence of the intentional use of the roasting reaction, the mineralogy is such that this would have occurred naturally to a certain extent, and would thus have contributed to the heat requirements of the charge.

No evidence of the heating process survives but, in the absence of any tuyères (the few fragments of tuyères which were found at Non Mak La were associated with iron smithing there), it is probable that the crucibles were supported on fires blown either by a channelled natural draft or by bellows feeding through a perishable organic material such as bamboo. However this was done, it seems inescapable that the ancient metallurgists of the Lopburi area were able to achieve temperatures of 1200°C in these crucibles using a technology not previously encountered elsewhere.

The pouring operation is similarly unclear. Many of the rim fragments show evidence of slag being poured out (Fig. 2), and slag lumps were found of approximately the same size and shape as the cup moulds found on these sites (Fig. 3). These moulds, unlike the crucibles, show no evidence of direct heating, and some have a projecting foot which would possibly allow them to be held in a stand or frame. Fragments of heavy clay rings were found, slightly larger in internal diameter than the crucibles themselves, and these could have been used to protect the crucibles from damage while being gripped with green bamboo for pouring.

Clearly an important further step in the investigations of copper smelting in this area would be to build such a crucible and operate it under simulations of conceivable field methods.

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References
Arsenic copper ore in the newly discovered Copper-Age mine ALS2 in Almeria, South-east Andalusia (Spain) – a correction

The discovery by our IAMS survey team in September 1988 of a prehistoric copper mine and smelter (ALS2 = Almeria Survey Site No. 2), probably related to nearby Los Millares, the important Copper-Age key site of the ‘Millaran culture’ and the beginnings of metallurgy in South Iberia, was an event of considerable interest to archaeo-metallurgy. As explained in our previous report (Newsletter No. 13), among the major objectives of our Almerian Archaeo-Metallurgical Survey is the solution of some of the basic problems of Millaran metallurgy: the appearance of arsenical copper as the copper alloy in common use already at this very early phase (late 4th-early 3rd millennium BC) of metalworking.

To emphasise the importance of the ores found at ALS2, and their correct identification, we re-state here the pertinent question: Was the arsenical copper, used by the early prehistoric metalworkers of Andalusia, the product of a metallurgical process involving the intentional addition of arsenic to copper to improve its metallurgical properties and applications, or was it an ingredient of the original copper ore as mined? In other words: was arsenical copper a ‘natural alloy’, the appearance of which in metal history is but a fortuitous ‘accident’ of mining history, or was arsenic ore brought to the copper-smelters or the workshops to be used as an intentional additive to the copper ore or the metallic copper in order to make ‘arsenical bronze’? This question is of considerable importance for the understanding of prehistoric metalworking technology not only of Southern Iberia but also of the Near East and many other areas of the Old World where in prehistoric times arsenical copper was commonly used for the manufacture of working tools, weapons, jewellery and cult objects.

The problem of the early appearance of arsenical copper in Southern Iberia has been previously discussed in Beno Rothenberg, et al., Studies in Ancient Mining and Metallurgy in South-West Spain (Metal in History Vol. 1, 1981). Based on the mining situation in the Huelva Province it was suggested that the answer to the question of arsenical copper is to be found in the mines and not in the smelters, i.e. the arsenic was contained in the copper ore as mined in the secondary enrichment zone of the pyrite ore deposits of Southern Iberia and also in the ores from complex ore deposits which were also mined in prehistoric times. The fortuitous production of an alloy of such complexity seemed the only acceptable explanation considering the still rather primitive technological horizon of the Copper Age.

It must be mentioned here that recent investigations of arsenical copper smelting in Peru (John Merkel and Izumi Shimada, Arsenical Copper Smelting at Batan Grande, Peru, IAMS Newsletter, No. 12, 1988, 4–7), showed that arsenic-rich minerals were intentionally added to oxidised copper ore in order to produce arsenical copper. Although the smelting site in Peru is dated to the period between AD 900 and the Spanish Conquest, i.e. rather late for comparison with European and Near Eastern prehistoric metal production, it presents proof that the process of mixed ore smelting (oxidised copper ore together with arsenic-rich minerals) was indeed practised in societies functioning at a ‘prehistoric’ level. This evidence, though arriving from a very different archaeo-metallurgical time and space, has to be taken into consideration in any discussion of arsenical copper production and use. It will also be an important guideline for our future archaeo-metallurgical surveys.

Considering the previous conclusions of our surveys in the south-west of Andalusia, the identification of the copper ores found at the mine and with the ancient slag at site ALS2, (published in IAMS Newsletter No. 13, 1988), as chalcocite, chrysocolla as well as malachite and azurite, was rather disappointing. We had hoped that we would be able to establish a similar situation – arsenical copper ore in the original ore deposit – also for south-east Spain and in a Millaran context.

The evaluation of site ALS2 and its place in the metallurgy of Los Millares has now been radically changed through the recent re-identification of the ores and minerals collected there by our team. A small group of our samples was recently sent to Noel Gale, Oxford University, for lead isotope provenance studies and he identified the substantial presence of arsenical ores: ‘Azurite and malachite are both present in these ores, but so apparently are fauhlerz ores, probably mainly tennantite. There are certainly major amounts of arsenic present’. Gale also pointed out the presence of sulphur as a major component of most of the minerals (not azurite or malachite).

The precise and detailed identification of the minerals of site ALS2 must await XRD studies, but already at this preliminary stage of these investigations, the presence of arsenical ores as a major component of the mining geology of site ALS2 establishes the basic fact that the arsenical copper of Los Millares was apparently the result of the mining situation, just as the arsenical copper in the Huelva province.

The probable role of the fahlo-type ores from ALS2 in Millaran metallurgy, especially in the metallurgical workshops uncovered at Los Millares by the Granada group, directed by Fernando Molina, is now being studied by members of the IAMS Iberian Archaeo-metallurgy Project.

Beno Rothenberg
From the Director’s Desk

USA Copper Club Scholarship
The IAMS-sponsored course in Archaeo-mettallurgy at the Institute of Archaeology, University College London, is a unique post-graduate teaching programme which for a number of years has been drawing an ever-increasing number of postgraduate students from many countries of Europe, the Near and Far East, and the USA. We wish to express our sincere gratitude to the USA Copper Club and its President, Tom Kennedy, for the pledge of a full scholarship for this course which will enable IAMS to offer facilities for a Ph.D. research programme in archaeo-mettallurgy.

A previous grant had made it possible to invite a USA student to carry out a full scale experimental study of ancient copper smelting of oxidised copper ores, which produced the technological story of the beginning of metal production, to be published in the forthcoming volume ‘The Ancient Metallurgy of Copper’ (ed. B. Rothenberg). The present programme, supported by the scholarship of the Copper Club, will deal with the experimental study of the processing of complex ores – the next chapter in the history of metallurgy.

The Director and the members of the Scientific Committee of IAMS wish to take this opportunity to thank our USA Trustees, Tom Kennedy, Simon Strauss, and Patricia Walker, for their continuing support.

Dr John Merkel – newly appointed Chairman of our Scientific Committee
Many years ago, John Merkel, a student of Minnesota University, approached the Director of IAMS with a request for metallurgical samples from his excavations at Timna to be used for an M.Sc. research programme. The quality of this research work greatly impressed the members of our Scientific Committee and we subsequently offered him a scholarship for our archaeo-metallurgy course and for a Ph.D. research programme concerned mainly with the ancient copper smelting technology of Timna. Merkel’s experimental work on copper smelting can be considered as one of the most important recent contributions to archaeo-metallurgy.

Dr Merkel, after graduation, returned to the USA where he continued his archaeo-metallurgical research work at Harvard University. In 1988 Dr Merkel returned to London and joined the staff of the Institute of Archaeology as the lecturer in charge of archaeo-metallurgical teaching and research.

The Trustees of IAMS are very pleased that Dr Merkel recently agreed to serve as the new Chairman of its Scientific Committee. The Committee will now be reorganised to become the active centre of all ongoing IAMS research projects and also as the professional body to direct new research initiatives. The first of our future undertakings, the study of the extractive archaeo-metallurgy of south-west England, is now under active consideration, to be directed by Dr Merkel with the participation of Professor R. F. Tylecote.

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