An offprint from

Metallurgy in the Early Bronze Age Aegean

Edited by

Peter M. Day and Roger C. P. Doonan

ISBN 978-1-84217-293-3

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Lame Excuses for Emerging Complexity in Early Bronze Age Crete: the Metallurgical Finds from Poros Katsambas and their Context

Roger C. P. Doonan, Peter M. Day and Nota Dimopoulou-Rethemiotaki

Introduction

This paper discusses recent metallurgical finds from Poros Katsambas, located on the north coast of Crete (see Dimopoulou *et al.* this volume). Along with a consideration of the technical aspects of the assemblage, we suggest ways in which those engaged in metallurgical practices were bound up in recursive relationships which centred on somatic concerns, technical skill, and identity. Specifically, we address the social and material factors which could be drawn upon in the construction of identity and how certain identities might have emerged for those with access to metal and technical *savoire faire.* We have attempted to understand how the performance of metallurgy (Dobres 2000) could have been conducive to the institutionalisation of power in EBI/II. Finally, a consideration of the political context of the so-called EBII *metallschock* (Renfrew 1972) attempts to elucidate the circumstances that allowed the renegotiation of power as metallurgical practice and resource control became separate domains of concern.

Traditional studies of early metallurgy are permeated with diffusionist concerns (e.g. Wertime 1964) and a preoccupation with industrial orthodoxy and rational economy (Taylor 1999). Hence, the study of early metallurgy has tended to be either scoped at a continental scale or developed from a regional perspective which seeks to understand affinities between artefacts, technical practice and adjacent regions. Naturally, such concerns have favoured approaches which have emphasised '*trade*' through provenance studies, technological characterisation and typological schemes. The Aegean is a good example where regional studies have focussed on such concerns and have been used as a means to understand the relationship (or sometimes lack of it) between Aegean communities and their neighbours. Studies have been specific in their subject matter: there are few papers on Aegean Bronze Age metallurgy that cannot be categorised as typologies (e.g. aspects of Branigan 1974), provenance investigations (e.g. Gale and Stos-Gale 1989) or technical studies (e.g. Tylecote 1987). It has been common to demonstrate the affinities of Aegean metalwork and its practice with other regions, as a way to explain the inception of metallurgy and its subsequent innovation in the Aegean (see Doonan and Day this volume). Whilst typological studies have identified stylistic links between the Aegean and adjacent regions, provenance studies have emphasised the scale of metal circulation sometimes even on a Europe-wide scale. Likewise, technical studies have tended to describe a single trajectory of rational technological development beginning in Anatolia/Middle-East and diffusing across Europe (Pernicka 1999: 168). The common and collective aim of all these studies has been to document the evolution of metals technology and to demonstrate causal links with social evolution.

This relationship between technical and social development has been important for understanding social change in the Aegean region and constitutes essential foundations to any work addressing metallurgy in the Mediterranean basin. However, with rather few notable exceptions (e.g. Nakou 1995) there is a dearth of studies that attempt to understand how the inception of metallurgy transformed those who actually *practiced* this fiery art and the relationships within which identities were forged.

Metallurgical Traditions

Metallurgy in the Aegean

Much of what we know of Bronze Age metallurgy in the Aegean comes from either scientific analyses of ores, slags and ingots or stylistic studies of artefacts (e.g. Stos-Gale 1998; Branigan 1968). There are too few studies of the actual *practice* of metallurgy, be it mining, primary smelting, alloying or final working. Instead, there is a prevalence of studies that concentrate on aspects of exchange or 'trade'. This preoccupation with exchange and circulation has rarely been questioned (but see Nakou 1995) and suggests that there is a tacitly acknowledged consensus amongst scholars, that the appropriate study of metals in the Bronze Age is of exchange networks and the definition of interregional contacts, so as to explain change. After all, it is these 'networks' that are held to be the cultural highways along which new ideologies, practices, and social strategies are transported at the end of the Neolithic.

With such assumptions underpinning most studies of Bronze Age metallurgy, it is clear why exchange and provenance studies have dominated at the expense of those that aim to understand the organisation of production at the local level. It seems to us wrongheaded to postulate extensive exchange networks when our understanding of production contexts is still at an embryonic stage. In light of the various problems that have dogged circulation and exchange studies, often because of technology being treated as a 'black box' (Dobres 2000), it seems timely to pursue a study which aims to understand the implications of the spatial and technical organisation of metallurgical practice (see Catapotis this volume).

The sources of copper minerals in the Early Bronze Age Aegean are well understood, with Lavrion and Kythnos appearing to be the predominant sources for the Cyclades (Stos-Gale 1989). However, our current understanding of the organisation of mining, beneficiation and smelting in the Aegean is complex and may run counter to intuitive 'rules' concerning technological efficacy (c.f. Rothenberg 1990). Rather than smelting sites being located in the immediate proximity of copper mineral sources, (e.g. Broodbank 2000: 310), evidence from the Aegean suggests that in some contexts other concerns were more important (see Catapotis this volume). For instance, copper smelting at Kythnos (Hadjianastasiou and MacGillivray 1988) involved the use of ore charges that comprised not only Kythnian ores, but also those from elsewhere (Gale and Stos-Gale 1985), whilst at Chrysokamino on Crete smelting was located away from the occurrence of any copper ores (Betancourt 2006).

Metallurgy on Crete

There are two key strands of evidence to consider in any study of Early Bronze Age metallurgy on Crete. Firstly, material culture data from studies such as that compiled by Branigan (1974), and secondly, production evidence for mining, smelting, and final working (Gale and Stos-Gale 1989; Gale *et al*. 1985; Betancourt and Floyd 1999; Betancourt 2006; Catapotis this volume).

The precise nature of copper sources on Crete has been the subject of much debate. Faure (1966) and Wheeler *et al.* (1975) reported several potential deposits of copper minerals on Crete, but many have been discounted by Muhly and Rapp in their 1974 survey (Stos-Gale 1993: 119). Convincing evidence for copper mineralisation appears to be restricted to western and southern Crete with no evidence noted in the east. Although the identification of ancient ore sources is often contentious (Ixer 1999: 44) the clearest evidence on Crete comes from Chrysostomos on the edge of the Mesara (Branigan 1971: 14; Stos-Gale 1993: 119). Here there are outcrops of azurite and malachite within a ferruginous matrix. In West Crete, Sklavopoulou exhibits near-surface evidence for copper mineralization, associated with open cast mining. At Myrtos Fournou Korifi copper bearing pebbles were reported adjacent to the EMII settlement (Hood *et al.* 1964; Branigan 1971: 10).

More convincing evidence for copper smelting comes from the site of Chrysokamino located on the Gulf of Mirabello (Mosso 1910; Stos-Gale 1989; Betancourt and Floyd 1999; Betancourt 2006; Catapotis *et al.* this volume). Although not located in the vicinity of any ore sources, this site has produced significant and convincing evidence of copper smelting dated to the end of the Early Bronze Age. The many fragments of furnace wall recovered suggest that they belong to a perforated, truncated cone similar to those from Kythnos (Catapotis and Bassiakos this volume; Betancourt 2006: 184).

The limited evidence for primary production during EMI–EMIIA contrasts with our understanding of EM artefacts. Whilst the Final Neolithic period has been characterised by 'trinket' metallurgy, by EBII there is a shift towards tools capable of useful work and toilet implements (Pare 2000; Nakou 1995). Crete seems to be particularly prolific in the manufacture of tweezers and/or toilet scrapers, some being very similar to those found in the Levant (Pare 2000). Whilst the focus on toilet implements suggests that the modified presentation of the body has become a concern by EBII, the parallel development of the dagger has been associated by some with masculinity (Muhly 1985) and conspicuous display.

Branigan identifies two centres of metallurgy in the Aegean, one centred on the Troad and one in the southern Aegean. Emphasising the high degree of regional variation in the early phase of the Bronze Age, he notes two distinct types of Cretan dagger (Branigan 1967), the so-called long dagger and the quintessentially Cretan triangular dagger. The distribution of long daggers Types I and II, which are essentially ellipsoid in cross-section without any cast or raised central rib, is focussed in the southern Aegean. Although this might suggest that the '..north is lagging behind the south' (Branigan 1967: 214), this impression is corrected by the proportion of long daggers of Type III and IV in the north, which are characterised by a mid-rib raised by working. Daggers with a true cast single mid-rib are classed as Type V to XIII and are an insular development in either Crete or the Cyclades. It is critical to our understanding of the material presented below that there appears to be no chronological separation between the worked, raised mid-rib and the cast mid-rib. It is tempting to see raised ridge forms as being more 'primitive' than cast rib forms, and thus to assume that the cast version follows the raised version chronologically. However this is to miss an important point. Branigan (1967: 227) shows clearly that, whereas it is impossible to say for sure whether any daggers can be attributed firmly to the EMI period, it is clear that raised ridge daggers and cast mid-rib daggers existed simultaneously in EMIIA.

Consideration of the Aghia Photia cemetery material (Day *et al.* 1998) also suggests that the killed, cast mid-rib daggers from this site can be attributed to the end of the EMI period. Although raised ridge daggers continue into the MM period, it seems that true cast mid-rib daggers are the norm by EMIIB. This transition should not be seen necessarily as representing technological evolution. Since it is not possible to confirm the mechanical superiority of the cast technique without detailed metallographic study and hardness testing, it remains possible that the raised ridge weapons benefit from the working process in terms of rigidity and toughness. Equally, the raised ridge represents a significant input of labour in comparison with the cast mid-rib and accordingly may have signified a superior weapon in terms of both function and status.

The distribution of the Cretan triangular daggers is also worthy of note. In Branigan's study (1967: 230), ninety percent of triangular daggers are derived from the Mesara, nearly half of these coming from Aghia Triadha. Branigan divides them into seven groups. Apart from Type VI and VII, all are of an ellipsoid cross-section. Types VI and VII differ, in that Type VI is characterised by a raised ridge and Type VII by a presumably cast rectangular section mid-rib. Outside of Crete, few comparable examples exist for the triangular daggers, confirming their identity as an insular Cretan development. Branigan does draw attention to examples from Egypt, but these are of flint, while other examples from El Amrah seem more akin to long daggers. If Egypt was the source of inspiration, then Branigan sees this as coming in the form of lithic objects rather than copper.

Alloying Agents

Interest in Bronze Age sources of tin was rekindled over thirty years ago by two key publications. Firstly, after the radiocarbon revolution (Renfrew 1973) it was realised than Stonehenge was not the result of Mycenaean prospectors trying to secure access to Cornish tin and secondly with the publication of James Muhly's 'Copper and Tin' (1973) serious questions were raised about our understanding of the exchange of metals, both in terms of resources and technology. The search for tin sources accessible to Aegean societies has since occupied a central role in many studies (Penhallurick 1986; Charles 1967; Yener and Özbal 1987). The commoditisation of tin in Aegean studies has meant that its role has perhaps been overemphasised, especially in the southern Aegean, where it was only in the later Bronze Age that it became the mainstay of the metallurgical tradition (Gale and Stos-Gale 1985; Pernicka 1999; Pare 2000).

Since copper and tin minerals rarely occur together, the intentionality of tin bronze is not contentious. The introduction of tin bronze is thus seen as signifying an important technological horizon with humans understanding the benefits of alloying. Such clarity does not surround the intentionality of arsenic-copper alloys (Pare 2000: 2; Harding 2000: 202; Craddock 1995: 289; Budd *et al*. 1992; Tylecote 1987; Charles 1967). Because arsenic occurs in association with many copper minerals, it is possible to produce arsenic-copper alloys unintentionally when smelting minerals containing low levels of arsenic (Pernicka 1999). However, in the Aegean Renfrew (1973) suggested that copper-arsenic alloys were intentional, based on the correlation between composition and artefact function. In terms of circulation and as an index of interregional contact, Muhly (1973) suggested that the rapid spread of arsenic-copper alloys at the beginning of the third millennium represented a "truly international age of metallurgy". These assertions produced a flurry of investigation into the problem of intentionality in arsenic-copper alloys: an issue which has broad implications when their presence is used as indicators of increasingly complex exchange networks, levels of technological 'achievement' or evidence of fortuitous, insular production. In the absence of direct, conclusive evidence for the production of copper-arsenic alloys, scholarly opinion has varied on what constitutes intentionality. Some have suggested arbitrarily that alloys containing above 1% arsenic constitute an intentional alloy (e.g. Lechtman 1981), whereas others have suggested that Cu-As alloys were the accidental product of smelting As-rich ores, even though the enriched product may well have been recognised (Budd *et al.* 1992).

By the later Bronze Age the apparent preference for tin bronze over arsenic-copper alloy is often explained as a preference for enhanced mechanical properties. Although an enticing argument, such explanations do not acknowledge several studies which indicate that the mechanical properties of tin bronze are not necessarily sufficient by themselves to warrant a change in technological choice (Charles 1967; Lechtman and Klein 1999). Arsenic-copper alloys are in fact superior for hot-working and offer considerable advantages with their deoxidising properties. Charles (1967) has suggested that rather than the mechanical advantages supposedly offered by tin bronze, a more valid reason for the replacement of arsenic is its toxicity (see also Harper 1987).

The evidence for the distribution of tin-bronze in the Early Bronze Age Mediterranean and Near East is not uniform. Tin bronze is absent or scarcely represented in Egypt, Palestine, Crete and mainland Greece whilst it comprises almost 25% of analysed metal from north-west Iran, central Anatolia, the Troad and the Cyclades (Eaton and McKerrell 1976). More recent data has been forthcoming, although the image established by Eaton and McKerrell still holds true. Arsenic-copper alloys were widespread in Syria, Iran, the Cyclades, Crete and mainland Greece. They represent over 60% of all analysed metal (Mangou and Ioannou 1998; Kayafa *et al*. 2000). It was only in the Troad that the use of tin eclipsed arsenic in the Early Bronze Age and only in the later Bronze Age that tin became the dominant alloying agent. Highlighting the evidence of high arsenic concentrations in knives in comparison with low concentrations in other items, Eaton and McKerrell (1976) imply that the alloying of copper and arsenic to form arsenic bronze was deliberate and intentional. Other scholars have argued that such data could simply indicate recognition and selection of alloys rather than wilful creation (Gale and Stos-Gale 1985: 156). However, the presence of discrete arsenic coatings on Egyptian mirrors along with the arsenic 'plated' Bayindirkou dagger from Corum-Merzifon (Eaton and McKerrell 1976) suggests that Bronze Age metalworkers were familiar with how to manipulate arsenic bearing minerals.

Evidence from Poros

Overview

Excavations at Poros-Katsambas produced a metallurgical assemblage that is exceptional in terms of its date, technical origin, and completeness. Although chronology is beyond the scope of this present paper (See Dimopoulou *et al.* this volume) the material discussed here need not be considered later than EMIIA and some is from clear EMI contexts. What follows is a brief account of some of the more critical elements of the metallurgical assemblage. It represents early evidence for the casting of mid-rib daggers on Crete and is made more significant by the completeness of the assemblage. The Poros material contains virtually every element that a complete metallurgical assemblage might well be expected to contain.

Crucibles

Twenty two crucible fragments of various dimensions were recovered. Wall thicknesses vary between 7–28mm, whilst their estimated internal diameters range from 45–140mm. The larger crucibles may have held about 500g of molten copper alloy, sufficient to cast virtually any artefact encountered in the EMI–IIA period in a single pour. No socketed crucibles were identified such as those from Aghia Photia (Tsipopoulou this volume), Thermi, Troy, Chalandriani and Sesklo (Branigan 1974:70), nor was there evidence for them being seated on an integral pedestal such as those recovered from Aghia Photia (Betancourt and Muhly this volume). Numerous fragments exhibited oxidising scorch marks suggesting that they sat on hot charcoal, but the heavily vitrified internal surfaces show that these crucibles were heated from above, the fuel and metal being in intimate association. Many crucibles had evidence of an extra layer of silty clay having been applied to the outer surface (c.f. Bayley 1992), presumably to insulate the crucible and to guard against catastrophic failure as a result of thermal shock.

The ceramic fabric is a buff, calcareous clay with frequent small quartz inclusions. All examples have a characteristic void structure reminiscent of burnt-out organic temper. The type of clay used is most likely derived from local Neogene deposits which are widespread in the Herakleion area. In thin section, the frequent voids are clearly visible and suggest that the burnt-out vegetal temper was most likely dung. Slag fragments were noted within the ceramic body and, although rare, are important as they provide an insight into how the production of metallurgical paraphernalia was organised. The slag inclusions indicate that crucibles were manufactured in the same context as metalworking rather than being brought from elsewhere.

Over eighty percent of the crucibles were slagged on the internal surface. Slag thickness varied but occurred up to 24mm thick. The slag was dense and black, with green staining characteristic of copper corrosion compounds (Figure 6.1). Thick black slag is not typically found on crucibles associated simply with the melting of copper alloy. Microstructural analysis of twelve crucible fragments found fayalitic laths in a glassy Fe-Ca-Al silicate matrix, accompanied by localised concentrations of globular iron oxides, delafossite, and magnetite spinels. Such mineral assemblages suggest that the process varied between reducing to mildly oxidising and is what would be expected for a technology employing cyclic air

Figure 6.1. Slagged crucible fragments from Poros Katsambas.

blasts using human lung power or bellows. Inclusions of copper alloy were common ranging in size from 10µm to 3mm. Analyses of the prills by SEM-EDS detected the presence of arsenic ranging in concentration from ~0.5% to 52%.

Other Refractory Material

Excavation recovered sixty-four fragments of refractory material of which approximately 25% were believed to be eroded crucible fragments, although the lack of original surfaces prevents their certain identification. Approximately 60% of refractory material had one surface covered in slag. The morphology of the void structures in the refractory material suggested that it was once tempered with an organic filler such as animal dung. The majority of refractory material appeared similar to the crucible fabrics, a buff calcareous fabric with occasional scorch marks. Chemical and microstructural analyses of adhering slag suggest that this material comprises two distinct groups. Group One contains localised concentrations of copper prills and is iron rich. In Group Two the 'adherent slag' is low in iron and copper prills are absent. It is probable that Group One represents eroded crucibles and the Group Two fragments of furnace lining or hearth superstructure.

Metal Artefacts (including spillages and miscasts)

A number of copper alloy artefacts were recovered from EM levels and included fragments of copper alloy sheet, spillages, small tools and a possible ingot fragment. Small fragments of copper sheet weighing less than 1g were poorly preserved and offer little hope for analytical studies. Whether this sheet represents a sheet fabrication technology such as would be encountered in the manufacture of vessels (see Nakou 1995) or simply casting flash from other artefacts remains unclear.

One fragment of copper alloy (Figure 6.2), triangular in cross-section, is interpreted as an ingot fragment with a strong resemblance to EBA Levantine ingots (c.f. Denver and Tadmor 1976; Maddin and Stech 1976). The surface is

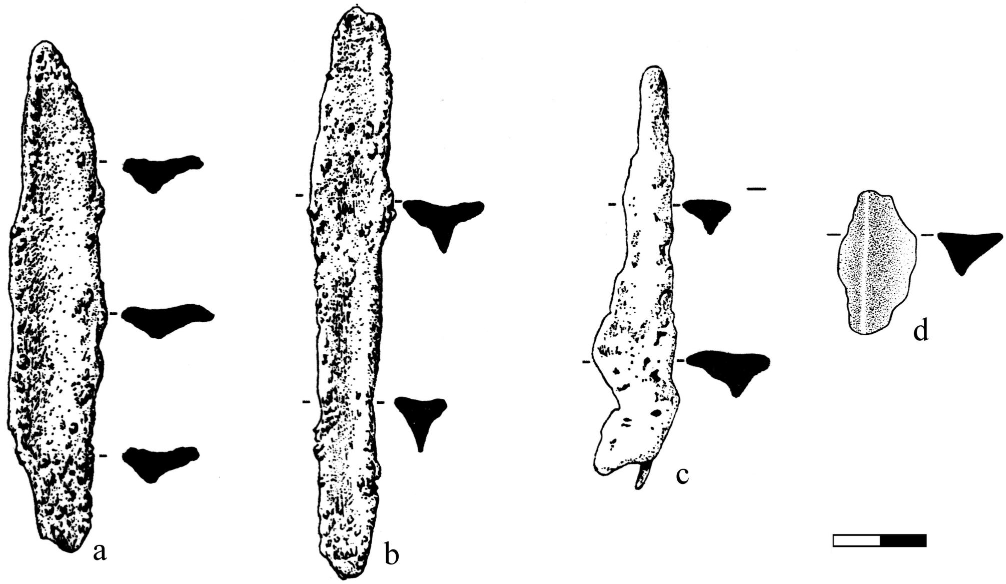

Figure 6.2. a–c: Ingot fragments from the Levant (redrawn from Vandiver and Stech 1986). d: Ingot fragment for Poros Katsambas.

covered in corrosion products, although the state of preservation remains good. Microstructural analysis revealed an as-cast structure, with frequent isolated inclusions of lead. Repeated analysis of large areas by SEM-EDS determined the composition to be 95.2% Cu, 3.7% Pb and 1.1% Fe, again comparable with the Levantine ingots referred to above. A programme of lead isotope analysis is currently underway to investigate this find more fully.

Other recognizable artefacts include a copper alloy rivet and two awls. Microstructural examination of the awls revealed localized concentrations of copper-copper oxide eutectic suggesting the possibility that the tool was cast in an open mould or that it was melted in barely reducing conditions. Compositional analyses of one awl using SEM-EDS identified the alloy as arsenical copper with 1.9% arsenic and 3.6% Ni with a trace of Fe. This elevated level of Ni is not typical for the Poros assemblage but such compositions have been noted in Crete, specifically in the Mesara in the form of triangular daggers (Branigan 1967).

Slag and Dross

The Poros assemblage contained samples of both slag and dross. Dross was defined as any fused conglomeration which is green/red-purple in colour and consists predominantly of copper alloy, copper oxides, and copper corrosion products. Dross is formed during the melting of copper alloy when oxidized copper is scraped from the surface of the melt and discarded. Slag differs from dross by virtue of its elevated iron and silicon concentration. Slag is black and is normally considered to be the fused product of refractory material, impurities, flux, and fuel ashes.

Only four fragments of dross were identified amongst the assemblage. It was dense with adherent copper corrosion products, metallographic and SEM-EDS analysis revealed an intergrowth of copper and iron oxides. Where metallic copper did survive its composition was normally in excess of 99% copper with less than 1% of As.

Thirty slag fragments were recovered which ranged in colour from black to grey-black. They were predominantly crystalline, although one sample exhibited a glassy texture. On the basis of physical appearance, slags could be divided into two groups; plate slags and nodular slags. Plate slags were black and dense, with rare vesicles and frequent inclusions of copper prills. Nodular slags ranged from grey-black to black and were vesicular with less frequent inclusion of copper prills. Nodular slags varied in composition, some rich in iron and silicon, others high in aluminium, potassium and silicon, suggesting that they were more vitrified ceramics than true metallurgical slags. For both groups it was rare to encounter a slag greater than $2cm^3$ in volume. The fragmentary nature of the slag and crucible fragments may suggest that any slag formed was routinely broken to remove any significant copper prills.

Microstructural analysis showed that most slags had little structure. Most comprised a glassy matrix (Ca-Al-Fe silicate) with isolated concentrations of iron oxides; dendritic wustite, magnetite spinels and globular iron oxides going into solution. Arsenic concentrations in copper-alloy prills ranged from 1.2–7.4%. Occasionally localised concentrations of fayalite were encountered. These mineral suites suggest that hearth conditions varied from quite reducing to mildly oxidising, such as would be expected with a low built hearth powered by a cyclic air supply.

Moulds

Nine fragments of ceramic mould were found, representing both open and bivalve casting techniques. Open moulds were of a buff calcareous fabric similar to crucibles and again had evidence of organic temper having been added. Grey reduced areas on the interior of the mould testify to them having been used. One fragment appears to be from the terminal of a blunt ended tool, another comprises an 'L' shape, which could not be attributed to any specific artefact.

Six fragments of bivalve moulds relate to the manufacture of daggers (Figure 6.3, 6.4). Four of the six show clear evidence of a mid-rib which would appear comparable with Branigan's Type V or VI. Branigan sees both these types as being present in EMIIA and probably in EMI (Branigan 1967). Two mould fragments exhibited no evidence of a mid-rib and are best compared with any of

Figure 6.3. Fragment from mid-ribbed dagger mould.

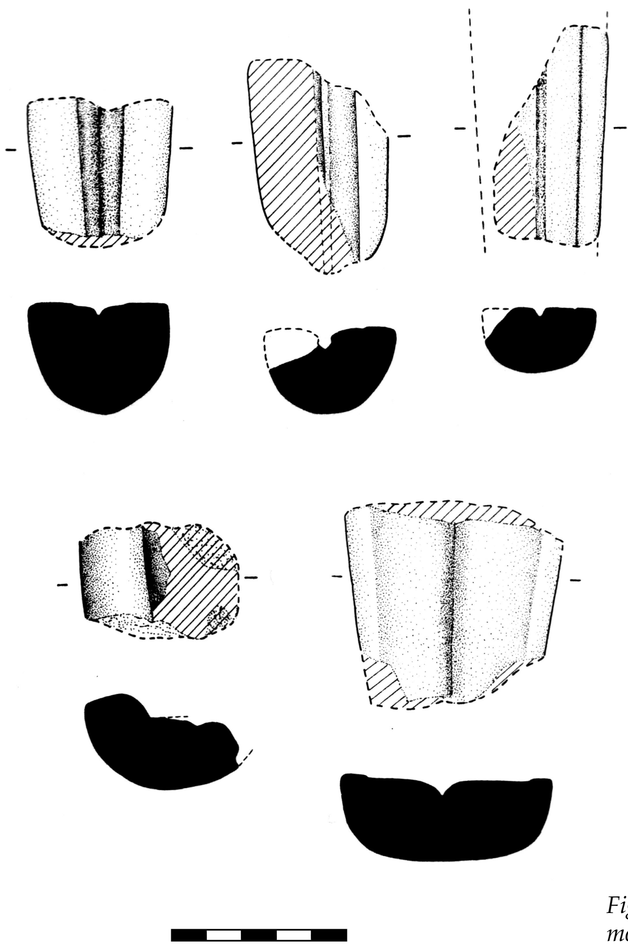

Figure 6.4. Examples of mid-ribbed dagger moulds recovered from Poros Katsambas.

Branigan's Types I–IV. Although intuition may suggest that Type I–IV daggers are probably derived from an open mould these two fragments suggest that even daggers of apparently simple form were cast in 'more complex' bivalve moulds prior to further working.

Minerals

A mineral fragment resembling iron pan was identified as a heat-altered fragment of iron-arsenide. Reflected light microscopy identified an unaltered highly reflective central core surrounded by concentric bands of iron arsenate accompanied by disseminated iron oxides (confirmed by SEM-EDS) (Figure 6.5). There is evidence of a heat-altered eutectic structure at the interface between the central core and the oxide banding. Repeated analysis by SEM-EDS of the central core has identified it as iron arsenide (52.8%Fe, 39.0%As, 3.1%O by SEM-EDS), most likely Loellingite.

The absence of any detectable copper in this mineral sample suggests that, whatever the reason for it being selected and taken to Poros, it was not because of any copper content. Other possibilities for its selection may have been for use as a pigment, but iron arsenide is not known for this. The mineral fragment was most likely involved in the metallurgical processes and it seems probable that its wilful selection and heat alteration results from the deliberate creation of arsenic-copper alloys.

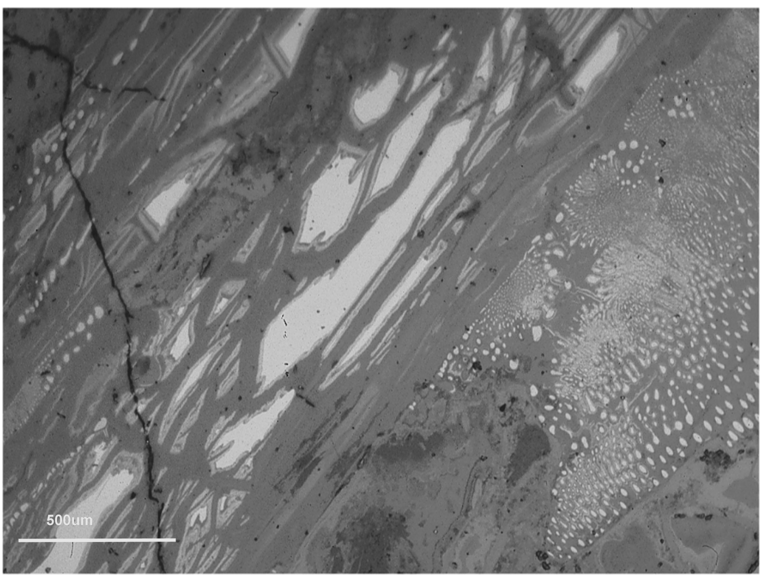

Figure 6.5. Optical micrograph of arsenide mineral, note heat altered structure.

Figure 6.6. Tuyère from Poros Katsambas.

Tuyères

Two tuyères were recovered, one virtually complete (Figure 6.6). The best preserved tuyère had a terminal aperture of 7mm and a wall thickness of 6mm. It was most likely fixed to the end of a portable tube which was used to conduct human breath into the hearth. Such tuyères may be associated with work that requires careful localised heating. The other example was a larger tuyère with a terminal aperture of 44mm and a thickness of 19mm, suggesting it was used for less delicate work. Both tuyères exhibited evidence of vitrification on the terminal.

The Significance of the Poros Assemblage

Chronologically, the Poros assemblage is significant, as it represents the earliest evidence for metal artefact production, especially daggers, on Crete. The finding of mid-ribbed dagger moulds is challenging, as this style has been presumed to be definitively Cycladic. The Poros moulds suggest unequivocally that such daggers were made on Crete. Finally, the presence of arsenical minerals in association with crucibles demonstrates the facility with which early metallurgists employed diverse mineral resources.

Chronology

The finding of mid-ribbed daggers in EMI/EMIIA contexts is important for our understanding of the spatial and temporal origin of these artefacts. The Early Bronze Age is a key moment in the development of Bronze Age metallurgy and its association with emerging elite has been widely reported (i.e. Renfrew 1972; Nakou 1995). For Renfrew, the arrival of the dagger and a redirection of metallurgical skills from trinket metallurgy towards objects associated with combat and status is representative of the so-called *metallshock* which characterises this transition. It is clear that the Poros material is of EMI/EMIIA date (see Dimopoulou *et al*. this volume) and it is worth indicating that the stylistic affinities of both the ECI and EMI pottery from Poros and the parallels of the EMIIA Poros material with the West Court House at Knossos (EMIIA earliest phase) suggest that the EMI material from the Sanoudakis Plot is late in that phase (Wilson and Day 2000).

The evidence from Poros, therefore, suggests that all the necessary elements that characterise the EBII intensification of metallurgical practice were already in place in EMI, or at latest very early EMIIA. Therefore, it seems more likely that it is the scale and organisation of production and depositional practice that changes significantly in EBII rather than the transfer of technology or specific technical innovations (Nakou 1995). Despite their limited extent, excavations at Poros to date have produced evidence for crafts such as obsidian working and such traces are believed to extend over a wide area. The remarkable wealth of evidence for craft may be simply fortuitous or it may bear witness to an intensity of production at Poros that is greater than has previously been thought plausible for the beginning of the Early Bronze Age.

Intentional Arsenical Copper Alloys

The metalworking assemblage provides the first *direct* evidence from the Old World for the wilful manipulation of arsenic-rich minerals and the intentional production of arsenic-copper alloys. The ubiquitous presence of arsenic-copper prills in slagged crucibles, the identification of prills with very high arsenic concentrations (52%), the high concentration of arsenic in crucible slags, the iron-rich nature of the crucible slags, and the identification of heat-altered iron-arsenide mineral all contribute to support the claim of intentional alloying.

The majority of copper prill inclusions in crucible slags were found to contain between 1 and 6% arsenic, yet these analyses alone do not provide compelling evidence for deliberate alloying since accidentally produced alloys would also produce such concentrations, if melted in a crucible. However, analyses of prills in crucible slags also found arsenic concentrations of up to 52%. These are elevated levels which are unlikely to occur through the melting down of a copper arsenic alloy. Rather, it seems that a rich source of arsenic had been purposefully added to the crucible to adjust the arsenic concentration of the alloy.

The slag adhering to the crucible fragments was unusual and unlike a normal crucible slag. Crucible slags are normally rich in basic metal oxides, silica and copper, with low levels of iron oxide (Bachmann 1982). This is because they are normally the product of vitrified crucible fabric mixed with copper alloy and fuel ashes. The normal product of melting and casting is a dross (see above) which is chiefly composed of metal oxides and metallic phases. The high level of iron in the slagged crucible fragments from Poros is more like a refining slag which is produced when removing iron from black copper (Craddock 1995: 203).

The thick black slags adhering to crucibles contained significant concentrations of arsenic (up to 23%) which are unlikely to have been produced by the simple melting down of arsenical copper alloys containing ~5% arsenic. The discovery of heat-altered arsenide minerals alongside metalworking evidence suggests that these concentrations were due to the purposeful admixing of arsenic-rich minerals to the copper melt.

Creating arsenical copper alloys is not as simple as adding an arsenic-rich mineral to molten copper. Iron arsenide will readily dissolve in molten copper but, as it does, the iron concentration increases along with the level of arsenic. The subsequent removal of the iron would require oxidative refining, which would in turn reduce the arsenic concentration of the melt. The challenge to early smiths would have been to elevate arsenic concentrations in the copper whilst keeping iron concentrations low. The presence of crucibles with thick iron-rich slags and the heat altered structure of the iron arsenide mineral give valuable clues as to how this was achieved.

The banded structure around the iron arsenide core comprised mixed iron arsenates and iron oxides, suggesting that the original arsenide was subject to a slow heating regime in mildly oxidising conditions. Initially it was suspected that the mineral sample was an altered form of arsenopyrite but Clark (1960a, 1960b) has shown the difficulty involved in transforming Arsenopyrite into Loellingite. Clark only managed to achieve this by sealing a sample in a glass tube and heating it for 30 days at elevated pressures. The difficulty of converting arsenopyrite to an arsenate is further demonstrated by laboratory-based roasting experiments. Arsenopyrite ignited easily and sustained combustion. Analysis of the roasted mineral found that arsenic was depleted with only some sulphur remaining. Together Clark's work and laboratory experiments strongly suggest that the mineral from Poros was originally an arsenide and not arsenopyrite.

This transformation of arsenide to arsenate is important for controlling how the mineral interacts with the copper melt. Once roasted, the treated mineral can be admixed with molten copper. High concentrations of arsenates will establish a favourable solubility co-efficient for the arsenic to enter the metal phase. Iron oxides remain in the oxide form and preferentially move to the slag phase (Tylecote *et al*. 1977) thus keeping it from entering into the copper melt. Such a process would account for the high concentration of arsenic in the crucible slag and the unusually thick, iron-rich crucible slags.

The evidence for intentional arsenical copper production is compelling and rests not on indirect evidence of artefact composition or ambiguous textual evidence but on several interconnected strands of material evidence including slags, minerals and metal alloy inclusions found within a wider context of arsenic-copper forming the mainstay of the Cretan metallurgical tradition. The process of roasting and careful admixing of arsenide minerals is not simple and in terms of technical complexity might be compared with the smelting and alloying of tin. Since it is well established that tin offers no significant advantage over arsenic in mechanical terms (Charles 1967; Lechtmann 1996) and is inferior in terms of working properties, especially hot forging, we are forced to ask why tin bronzes replaced arsenical copper.

We have suggested that arsenical copper production relies upon the complex roasting and admixing of minerals. The maintenance of consistent arsenic concentrations in the copper melt is difficult since arsenic is prone to volatilisation. Therefore, this process demands considerable skill and attention and it could well be the *complexity* of the process that encouraged the uptake of tin alloying despite its hot working properties being inferior. This transition occurs in a period when exchange was becoming increasingly important and *intensification* of production seems more of a concern than the *quality* of production. It seems probable that the move to tin bronze was more a socio-political act, relating more to the organisation and intensity of production than simply technology developing along functionalist lines. Acknowledging arsenical copper alloys as intentional products demands that we rethink the context within which tin bronze was received. Rather than seeing the adoption of tin bronze as representing a dramatic shift in metallurgical ability and widening exchange possibilities, it should be seen as a material which allowed existing skills to be employed on a new material, in order to permit an intensification of production.

Dagger Production at Poros

The discovery of mould fragments, crucibles, spillages, dross and slag all support the proposition of Poros being a production centre where mid-rib daggers were cast. Alongside the evidence for mid-rib dagger production comes evidence for the production of long daggers of Branigan Types I–IV. The variation in dagger form may equally relate to identity and group affiliation as it might to function. We have already stated that the different technological choices necessary to raise a ridge on types I–IV may have afforded the artefact different meaning to the daggers produced by casting

This perhaps becomes a more persuasive argument in light of the reasons for adopting tin as an alloying agent. If tin eclipsed arsenic because it was a simpler, more reliable process, which allowed increases in the scale of production then the shift towards cast mid-ribs could be rooted in the same concerns. The casting of a mid-rib would involve a lot less work and time than the gradual raising of a ridge by hammering. Whether the final artefact was in fact functionally better remains contentious until a program of metallographic and replication work is undertaken. There is little doubt however that the casting technology offers a better strategy by which to intensify production and hence exchange. A final point of interest is that the adoption of the mid-rib type may well suggest an increased emphasis on the dagger as an artefact of single use in combat and for display. The incorporation of the mid-rib, especially the developed examples in Type VII and VIII, would inhibit certain uses such as slicing deep rigid materials and in whittling-type actions. The non-ribbed dagger can thus be seen as a more flexible tool with a greater utility outside the domain of combat.

Mid-rib daggers are well documented on Crete (Branigan 1967) but are not considered Cretan *per se,* as are the triangular daggers of southern Crete. In fact, mid-ribbed daggers have, as mentioned above, been held to represent increasing Cycladic influence (Renfrew 1973) in Crete. This Cycladic association is difficult to sustain in light of the number of daggers found on Crete (Alexiou 1975; Branigan 1974; Day *et al*. 1998; Betancourt this volume) with the discovery of the Poros moulds bringing this association further into question.

The distribution and contemporary use of various dagger styles on Crete, coupled with their local production challenges us in two ways. Firstly we should perhaps begin to explain this patterning in ways other than technical evolution with certain forms being presumed functionally superior. The concepts of 'life course' and identity seem obvious approaches to adopt here. Secondly it challenges us to reconsider how we conceptualise the geography of the Early Bronze Age. Clearly Crete shows an undeniable heterogeneity in this period, with noticeable regional styles emerging, but we continue to talk of Crete as a unit of space worthy of study. Without maps and objectified concepts of space and territory this would have been very different for the inhabitants of the Early Bronze Age. It is useful to remind ourselves that the Aegean is not a body of water that encompasses and defines continuous land masses as islands but more a territory which permits specific means of transport that facilitates movement between certain places by tidal currents and seasonal winds (see Broodbank 2000). In light of this, speaking of Cretan metallurgy or style, may be a former convenience that is now of questionable worth.

Private Practice and Public Identities

The inception of metallurgy in the Aegean has been understood as a problem which needs to be addressed in terms of identifying specific influences from surrounding regions. Traditional typological and scientific provenance studies have assumed centre-stage in identifying the extent of these 'connections'. The prevalence of burial excavations and other contexts of consumption have largely been responsible for creating a body of data that lends itself to such approaches. Most work which addresses the role of metals in the Aegean and its implications for the emergence of elite groups has concentrated on status afforded by the display of finished artefacts and their consumption in mortuary contexts. While such studies are important, refocusing on contexts of production allows us the opportunity to approach metals and metallurgy from a different perspective. As the possession and display of metalwork has been argued as a central resource in the construction of elite identity, an intriguing avenue to explore would be how identities were constructed for those engaged in the activity of production.

It is of course the *context of production* which actually witnesses the significant changes in the organisation of metallurgy in the Aegean. Of course, artefacts can precede local production, but the study of artefacts is not necessarily the study of metallurgical practice. The study of production, then, is the study of an arena where choice, practice and control converge in the creation of objects that are held central in the emergence of complexity in the Aegean (Renfrew 1972). Metallurgy is a dramatic process than unfolds through time. A technological liturgy where certain acts, for instance bellows being pumped, minerals being transformed by fire, and metal being poured, need precise choreography in order to be successful, however that might be judged. Metallurgical performances are surrounded with a sense of anticipation towards the emergence of a final object, and completion itself is uncertain and hence adorned in risk. A strategy to minimise this risk, or what we might call failure, may have been to allow the act associated with production to serve other social purposes which are as important as the metallic product itself (see Avery *et al.* 1988). In such ways technological 'failure' need not go hand in hand with the fragmentation of social relations which have been founded on the ability to undertake such acts.

In developing an understanding of Aegean metallurgy, a prime consideration is the kind of technology that is in use; a point that has received little attention but seems critical for our investigation of the technology's first incarnations. Skouries on Kythnos (Bassiakos and Philaniotou this volume) and Chrysokamino (Betancourt 2006; Catapotis and Bassiakos this volume) on Crete document evidence of primary smelting and allow us to attempt a tentative reconstruction of the technology employed. Judging by the quantity of slag recovered from both sites it is apparent that the process was a high-temperature slagging process. The type of furnace employed is a perforated ceramic chimney in the form of a truncated cone. A survey of smelting evidence in the vicinity of the Cyclades and Crete indicates that this technology is apparently unique and specific to the Aegean. Evidence from Egypt (Rothenberg 1990), Cyprus (Knapp *et al.* 2001), the Alps (Anguilano *et al.* 2002; Höppner *et al.* 2005), Central Europe (Nosek *et al.* 1991: 103, Chernykh 1992), Ireland (O'Brien 2004), France (Bourgarit and Mille 2001), Yugoslavia (Tringham and Krstić 1990), the Levant (Shugar 2003) and Jordan (Hauptmann *et al.* 1989) have all produced evidence for smelting that shows no technological similarities with the Aegean, save for the process being a high temperature one. From this we are forced to conclude that the technological choices made in copper smelting in the Aegean were ultimately Aegean innovations.

Characteristic of the Aegean process is the geographically dispersed organisation of production. Each stage was separated in space and time, perhaps an attempt to alienate or make exotic the product of such practices. Such organisation not only affects the products but also those charged with the responsibility of producing them. It is a matter of contention how we decide to view specialisation in EMI/IIA, but there seems no compelling reason to suggest that those mining, amalgamating ores, beneficiating, voyaging, smelting, alloying, casting and working were different persons. All stages in the process require some knowledge of the adjacent ones whilst they all draw upon a common body of *savoir faire* and motor skills relating to the recognition, procurement, and manipulation of minerals, ceramics, charcoal and fire. It seems sensible, and not just for reasons of process and quality control, that a single group was involved in all stages of production, voyaging between mine smelting place and artefact production zones. Evidence from Chrysokamino (Betancourt and Floyd 1999; Betancourt 2006) suggests that smelters favoured isolated windy promontories whilst artefact production, such as that witnessed at Poros, takes place in more public locations. This combination of isolation and advertisement (Broodbank 2000) gives us the impression of ambiguous figures who seek to obscure the specifics of the process yet advertise the general act. In mining and smelting, it seems that smiths are obscured, isolated and hence secretive. When producing artefacts, such as at Poros, they are centrally located and probably public, if not for the act itself, at least when arriving at the location for casting and at its conclusion at the moment of exchange.

This reinforces the idea of ambiguous figures merging in and out of isolation and publicity. The segmented nature of the process and the procurement of other metals and minerals (i.e. tin, silver, arsenic) emphasises the voyaging aspect of these individuals, thus their isolation is not restricted to fiery arts acted out on windy promontories but also periods in canoes in the Aegean sea. Such voyages may allow the accumulation of news or stories whilst also providing a rich cultural knowledge to draw upon in other social encounters. At landfall such individuals may appear rather cosmopolitan, being messengers with news and fantastic tales.

Simultaneously cosmopolitan and insular, those who controlled the production of metallurgy would be seen as exotic as the goods they produced. With their wide-ranging geographic and cultural knowledge they would have been seen as powerful people who could pass on such traits through the exchange of metalwork. The arena of production would have witnessed more than acts of material production. Even today, the act of smithing with its sparks, flames and frightening crackles still has the ability to entrance a crowd, the skill of a craft worker complementing this display. Marshalling these skills and materials in a final performance provides metalworkers with the resources to draw crowds to witness their abilities, whilst simultaneously listening to stories of far-off lands and tales related to the procurement of metal used for that artefact. Perhaps then as the metalworkers engaged in the performance of artefact production, biographies of material, artefact and artificer were woven together constructing powerful identities for both producer and consumer.

The Cycladic style of much of the EBI pottery at Poros supports a general picture of Cycladic movement in the Aegean to key locations on the north coast of Crete. Early Bronze Age metalsmiths were individuals who travelled, skilfully manipulated materials, controlled key materials essential for the construction of elite identities and in turn had the power to construct those identities in others.

The frequency of metal daggers in burial contexts and the finding of crucibles in EMI contexts at Aghia Photia (Betancourt this volume) suggest that the practice of metallurgy may well have been held as a sacred act, because "…sacred things …..provide an inexhaustible source of power, capable of producing effects which are infinitely special and infinitely varied" (Mauss 2001: 10). Metalsmiths by association could draw on their bodily skills and knowledge of resources and geography in the construction of a powerful identity.

Forging Identities: A Footnote

The metallurgical process is a dramatic one, it needs to unfold precisely through time in order to be productive; a kind of techno-liturgics is necessary in order to act effectively (Boyd 1993). Generally technological acts are routine social practices which are in every sense a practical drama. If the negotiation of social relations centred on metallurgical acts, then such acts have the essential elements of ritual. Any act of creation and especially metallurgical ones, hold the potential to both reference and, to be referenced by, new ideologies seen to emerge in Early Bronze Age Aegean. It is not difficult to see how numerous natural events can be woven into a metallurgical metaphor, including death, birth, reincarnation, ancestry, control of wind and sun, light and fire, but it is perhaps not wise to speculate too freely at present. If those who practiced metallurgy in EMI and IIA were afforded a special status by those making sense of their worlds in a particular way, then there must be both a time and means whereby this act became dislocated from the power associated with it, as it seems that by late EBII elites are less concerned with acting out production but more concerned with the reorganisation and administration of production. Evidence for the use of seals in EBII seems to suggest an increase in such strategies (Pullen 1994; Bennet 1992) whilst in the Mesara, Renfrew (1972: 388) sees an association between daggers, sealstones and male identity. It seems that events from EMIIA onwards may amount to a familiar story of administration eclipsing practice which is largely complete by EMIII. A plausible explanation which links the changing power relations associated with metal production and the procurement and alloying of arsenic relates to increasing concerns with the presentation of the body. The increasing visibility of artefacts associated with personal body maintenance during EMII, some of which are seen as an explicitly Cretan innovation (Branigan 1974), suggests that the appropriate presentation of the body was becoming an increasingly important concern.

If identity is, in part, contingent on the presentation of the body and ideas of corporeal aesthetics then the deleterious effects of working with arsenic become significant. The control of arsenic in molten copper is difficult since mildly oxidising conditions allow arsenic to escape as arsenic trioxide vapour. This arsenic compound is a well-known poison, acquiring the name 'inheritance powder' in the 19th century (Blyth 1885: 35–71), and is particularly toxic when inhaled as a finely divided powder. Arsenic trioxide poisoning would have affected the mobility, dexterity and appearance of metalsmiths. The classic symptoms of prolonged low-level arsenic exposure are skin ulcerations and neuropathy of the sensory and motor neurones, specifically in the extremities (Harper 1987; Gorby 1988). Bearing in mind the apparent emphasis on the effective presentation of the body in the Early Bronze Age, it seems that the very act which provided resources with which to construct elite identities would in time cause their marginalisation because of accrued deformities. It seems logical, then, that as the effects of metallurgy and arsenic on the body were realised, those with access to metallurgical spheres would have positioned themselves away from the arena of practice and into one of control.

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