# 1. AEGEAN METALLURGY IN THE BRONZE AGE: RECENT DEVELOPMENTS

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**Some initial assumptions**

In November 2004, Philip Betancourt, summarising the work of a conference on Aegean Metallurgy in the Bronze Age held at the University of Crete, ended his address with the phrase "this is really a Bronze Age". He thus linked the production and use of bronze artefacts with the definition of a period, aligning the achievement and dissemination of copper alloys with its name. This conventional periodisation, which has been used since the very beginnings of research into prehistory, may still serve at the beginning of the 21st century as a starting point for the investigation of its historical reality.[1]

This identification is sometimes challenged: not in terms of the appropriateness of the name, but on account of the awareness that changes are not sudden, but long drawn out and partly retrogressive, and that technology is not invariably connected with historical changes – or least that this is a theory that has yet to be proved. The transition to the generalised use of metals is uneven in terms of the length time required and its geographical distribution.

The definition of periods on the basis of the raw material used for tools (already attempted by Lucretius (98-55 B.C.)) has proved highly successful, since after dozens of other attempted definitions it still survives: it classifies the past by establishing notional boundaries based on identical criteria, though often purely conventional. The danger here is that these boundaries, despite being purely conventional, may imply that the point at which the modern division is drawn is also the point at which the change took place, which has repeatedly been proved to be wrong.[2] History, like technology, is a continuum, even in its regressions.

These considerations, however, though eliminating a certain schematisation by drawing attention to the implications of defining periods in this way, have not done away with either the name or the overwhelming importance of metallurgy in the definition of the period. Above all, they have not invalidated the idea of connecting a period with the new modes of production attendant on new materials. We may summarise the arguments: if the heart of archaeological and historical studies is the interpretation of changes, and if these changes are associated with innovations, then in principle, metals cannot but play a strategic role. Metal tools and weapons are cutting-edge technology, a field of innovation in every period and certainly not only in ancient times. Possession of raw materials and technical know-how gives an advantage in both war and peacetime. Metallurgy, as a technology of strategic importance, plays its role in the creation and fortunes of social formations, as well as of political forms. It is therefore one of the crucial elements in historical developments. The answer to the question whether metals and their technology constitute the basic difference that can bring about a universal cultural and historical change has therefore always been a resounding yes.[3]

The schematic nature of this view too, however, is gradually becoming clear. There is much evidence to suggest that this version should be regarded as only relative. The societies of the Bronze Age are complex and varied. The adop-

1. Similar concerns may be found in C.F. PARE "Bronze and the Bronze Age" in C.F. PARE (ed.) *Metals Make the World Go Round* (2000) 1-38, pp. 1, 3.

2. B.G. TRIGGER, *A History of Archaeological Thought* (1989) 59-60.

3. These ideas are best expressed in A. Leroi-Gourhan, *Milieu et Techniques* [1973 (1945)] especially chapter VIII.

tion of innovative technology presupposes the corresponding presence of interactive factors, and a favourable social context, in the sense that in a community that generates or is subjected to innovations, there are, or can be discerned, needs which cause an imbalance in the existing relationships, and that this imbalance supplies an impulse to new trials involving the adoption of new methods, at least by a part of the community. These new methods include new, more effective tools or weapons. This kind of global approach to the forms of metallurgy in the Aegean set in the general context of social phenomena was taken by Colin Renfrew, establishing thus the terms and context for subsequent research.[4]

Few would disagree with this *a priori* view of the scope and importance of metals. However, to use the terminology of Leroi-Gourhan, this is only a tendency not a fact. When we investigate the actual situation, actual archaeological data, or specific technical events, the picture that emerges is invariably more complex than the oversimplification of a technical tendency.[5] It is becoming ever clearer that the above assumptions simply establish the basis for the argument, the starting point for a syllogism. Specific research is now required. What were the routes followed by the raw material? How was the technical know-how disseminated? How did the composition of alloys develop? There are, for example, areas like the Iberian peninsula or parts of central Europe with large ore deposits, whose potential was exploited in the context of quite different social formations.[6] These questions, and other more specialised ones, lend substance to the original evolutionist construction of a technical tendency by expounding on the different conditions under which innovations were adopted. This trend is reflected in the assessment made by Todd Whitelaw in *The Emergence of Civilization Revisited*: that Renfrew's general view of social change is oversimplifying and homogenising, in that it takes the existence of common currents for granted and thereby underestimates differences and discourages the study of distinctive features.[7] It is, however, precisely these differences, the many unexpected distinctive features, that cloak generalisation in a specific historical reality. And it is only through this reality that the generalisation has any validity.

Perhaps the conference held on November 2004 in Rethymnon and the resulting collection of papers that are published in this volume, are to be seen as part of a trend which blends the general with the particular, the theoretical generalisation with the actual event. Not that such a blend was a conscious or deliberate choice. It is simply that in 2004 and 2006, when the studies were completed, these positions were well established among scholars interested in questions relating to metal technology and efforts were directed more to furthering particular issues. The attempt to assign them to their social context was a given fact.

Professor Jim Muhly was kind enough to prepare, by way of an introduction, a summary of the studies on archaeometallurgy which reveals not only the major landmarks in research (the large database of chemical analyses known by the abbreviation SAM – *Studien zu den Anfängen der Metallurgie* – the analysis of lead isotopes, and the investigation of the provenance of metals) but also the new excavations and finds (Chrysokamino, Cyprus). In current research, as in recent decades, there is a clear shift from analysis of typology to analysis of techniques, metallurgy, ores, and production. In 1996, H. Sangmeister, in assessing the SAM project, expressed the view that the main contribution made by this major project was that the chemical composition of the metal has now

4. Especially in his classic work on the Cyclades: C. RENFREW, *The Emergence of Civilisation. The Cyclades and the Aegean in the Third Millennium B.C.* (1972) 308-338.
5. LEROI-GOURHAN (*supra* n. 3) 336-340.
6. PARE (*supra* n. 1) 18-24. M. DIAZ-ANDREU and I. MONTERO "Metallurgy and Social Dynamics in the later Prehistory of Mediterranean Spain" in C. PARE, (ed.) *Metals Make the World Go Round* (2000) 116-132.
7. T. WHITELAW, "Alternative Pathways to Complexity in the Southern Aegean," in J.C. BARRETT and P. HALSTEAD (eds) *The Emergence of Civilisation Revisited* (2004) 232-256.

been added to typology as a criterion for the classification and archaeological assessment of an object.[8]

What needs to be stressed, both as a general trend and on the evidence of the papers in this volume, is that it is becoming increasingly clear that the development was non-linear and uneven, with many centres and a veritable mosaic of techniques. Particularly with regard to duration. Developments in metallurgy sometimes proceed slowly, with experimentation involving the gradual replacement of the techniques and material of stone tools, while retaining their form (see the paper by Karimali, which deals systematically with the crucial question of the replacement of stone tools by bronze ones), and sometimes relatively quickly, as in the case of the adoption of new forms and new kinds of tools, alloys and weapons, and later even more rapidly, with the adoption of iron.

**The first steps. Copper**

The gradual adoption of new materials – silver, gold, bronze, lead – in the final millennia of the Neolithic (roughly speaking from the end of the 6$^{th}$ millennium to 3000 B.C.), was a very slow process. Initially it may be said to have involved small objects, experiments with no obvious purpose, probably ornaments whose significance was rather symbolic. The adoption of copper, in particular, despite the overwhelming importance of this metal later, was at first diffident and simply involved the use of native copper in the Middle East, the Balkans and the Iberian peninsula, where it was melted and forged to give it shape. It only later moved on to the working of ore deposits and more advanced smelting and casting techniques.[9] As in most parts of Europe, the copper used in the majority of artefacts in the Aegean and particularly in mainland Greece, exhibits a high degree of purity and may not have been produced by smelting but have been native copper – that is, it may have come from areas in which native copper was to be found.[10] The new evidence for metallurgy in the Aegean reveals that in the Final Neolithic even though there was less copper available than in the northern countries, metallurgy and metalworking showed remarkable dynamism. Alongside the well-known artefacts from Sesklo, Knossos, Ayia Photia near Ierapetra, mentioned by Mosso (Muhly, introduction, this volume), Kea, Attica, and recently from the cave of Zas on Naxos,[11] new evidence for bronze metallurgy has emerged, mainly from Petras on Crete. According to the paper by N. Papadatos, which is not included here, there is clear evidence for smelting during the Final Neolithic occupation of the site, which is also the earliest evidence for metallurgy on Crete. Smelting is considered to be a more advanced stage than simply melting, because it requires a corresponding advance in pyrotechnology. It is also sometimes thought that the adoption of smelting in the early phases (usually in the Final Neolithic) was the result of a scarcity of native copper. This obliged societies and their craftsmen to turn to ore deposits, which de-

8. H. SANGMEISTER, "Metallanalysen in der Archäologie: Erfahrungen aus 45 Jahren Forschung," in C. MORDENT, M. PERNOT and V. RYCHNER (eds) *L' Atelier du Bronzier en Europe du XXe au VIIIe siècle avant notre ère* (t. I), (1998) 9-18.

9. The large numbers of ordinary copper objects found in settlements and cemeteries in Europe from the 5th millennium onwards, possibly for social (ornaments, ostentation) rather than functional reasons, is discussed by T. CHAMPION, C. GAMBLE, S. SHENNAN and A. WHITTLE *Prehistoric Europe* (1984) 137-151. The subject was debated anew on the occasion of the discovery of the by now famous calendar disc from Nebra. For an introduction to the question of metallurgy in Central Europe, see the articles in the volume that accompanied the exhibition on this subject: H. MELLER (ed.) *Der geschmiedete Himmel. Die weite Welt im Herzen Europas vor 3600 Jahren* (2004).

10. PARE (*supra* n. 1) 5. However, the difficulties involved in distinguishing native copper have repeatedly been stressed, see the summary in PARE (*supra* n. 1) 5 and R. MADDIN, J.D. MUHLY and T. WHEELER, "Distinguishing artefacts of native copper," *Journal of Archaeological Science* 7 (1980) 211-225.

11. For a summary of metallurgy in the Neolithic period, see K. ZACHOS "Metallurgy" in G. PAPATHANASOPOULOS (ed.), *Neolithic Culture in Greece* (1996) 140-143. For more on the finds from the cave of Zas and questions of chronology, see K. ZACHOS and A. DOUZOUGLI " Aegean Metallurgy: How Early and How Independent? " in *Meletemata. Studies in Aegean Archaeology presented to Malcolm H. Wiener as he enters his 65$^{th}$ year*, *Aegaeum* 20 (1999) III, 959-968.

manded a more complex technology. Smelting techniques generally make their appearance first in areas in which both a knowledge of the potential of the metals and a knowledge of the properties of a number of nearby ores are to be found (such as Ai-Bunar in Bulgaria and Rudna Glava in Serbia, where the ore was extracted through galleries). Another prerequisite was a social and technical context that allowed new techniques to be invented for new needs, or for innovations to be tested.[12] According to the existing evidence, such a context appears to have existed in the Aegean, also with the transfer of technical expertise and materials, albeit in smaller quantities.

**Silver**

Evidence for the early working of other metals (gold, silver) is also to be found in the Aegean, either in the form of end products, or in the form of workshop waste from the process of manufacture.[13] In the case of silver, in particular, there is significant recent evidence even from the late phases of the Neolithic and the early phases of the Bronze Age. Specifically, excavation data from the Final Neolithic, Early Bronze Age I and Early Bronze Age II down to Middle Bronze Age in the area of Koropi, Attica, attest to the intensive working of silver. Significant quantities of litharge, a by-product of the extraction of silver from argentiferous lead (through the process of cupellation) have been found in the area of Koropi, where, according to the available evidence, the earliest workshop for processing silver has been found. The litharges are in good condition, making it possible to investigate the technical details of cupellation (Kakavoyanni, Douni and Nezeri, this volume). The large quantities of litharge, and above all its standardisation, point to organised and technically consolidated production in the metalliferous region of Lavrion, despite the fact that the specific areas in which the ore deposits were located have not yet been identified. Cupellation, a technique also known in the Near East (Habuba Kabira, Syria) has left remains in other parts of Greece, too, particularly at Limenaria on Thasos (Papadopoulos, this volume). It is perhaps no coincidence that the map of early silver-production in the Aegean is starting to be filled in first near the areas known to have produced silver in Classical times.

At the same time, it is possible to trace the presence of silver through the presence of the end products in settlements, and above all in cemeteries, dating from the Final Neolithic and Early Bronze Age. There is an unexpected abundance of these objects.[14] For Crete, the silver artefacts from the Final Neolithic to the New Palace period are gathered together in the present volume by A. Vasilakis. Their presence, however, acquires greater significance through comparison with the much more numerous artefacts made of gold in Pre-Palatial Crete. Crete is traditionally regarded as an area in which there are more gold artefacts (e.g. the cemetery at Mochlos and tombs in the Mesara) and fewer silver ones, while the Cyclades, in contrast, are pre-eminently an area of silver artefacts, with large quantities of jewellery found in tombs.[15] The presence of silver artefacts in tombs of Early Minoan Crete, which are by no means inconsiderable in absolute numbers, is regarded as the result of Cycladic influence. This subject is highlighted by Muhly in his article in the present volume, *Hagia Photia and the Cycladic Element in Early Minoan Metallurgy*. Muhly refers to finds both from the cemetery at Ayia Photia and from the cemetery of Gournes.[16] A. Vasilakis in his work on gold and silver in Early

12. An evolutionary scheme of this kind appears to be suggested by Muhly in J.D. MUHLY "The Beginnings of Metallurgy in the Old World," in R. MADDIN (ed.) *The Beginning of the use of Metals and Alloys. Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21-26 October 1986* (1988) 2-20, p. 9.

13. See the summary in ZACHOS (*supra* n. 11).

14. J. MARAN, "Das agaische Chalkolithikum und das erste Silber in Europa," in *Studien zur Religion und Kultur Kleinasiens und das ägäischen Bereiches: Festschrift Baki Ögun. Asia Minor Studien* 39 (2000) 179-193.

15. N.H. GALE and Z.A. STOS-GALE, "Cycladic Lead and Silver metallurgy," *BSA* 76 (1981) 169-224.

16. A similar paper was read by Yannis Bassiakos at the recent 10th Cretological conference (2007).

Bronze Age Crete, draws an interesting comparison: the silver and gold diadems in Crete and the Cyclades have the same typology but are made of different materials.[17]

This data gives rise to an interesting geographical distribution in the Aegean, at least for the Early Bronze Age: in Crete gold is predominant, while in the Cyclades it is silver and lead. In the North-east Aegean (Troy and Poliochni) gold is indisputably superior, both in terms of quantity and – above all – in technique, since the jewellery techniques are the most advanced in this area, and far more advanced than Minoan techniques. In mainland Greece and the Peloponnese, in contrast, artefacts made of silver or gold are very few.[18] Is this geographical distribution connected with the existence and exploitation of ore deposits? At present, our evidence is confined to silver: Siphnos[19] and Lavrion[20] are regarded as probable sources. For gold we can only make conjectures on the basis of evidence from Classical times, and the provenance of the gold of both Minoan Crete and Mycenae in the Late Bronze Age remains unknown. There is an enormous geographical and chronological gap between these gold artefacts of the Early Bronze Age and the Neolithic gold cutouts from the cemeteries at Varna on the one hand and the finds from Arabessos on the other. The gold cutout from the cave of Zas bridges the gap to some extent, at least in geographical terms, since it is close both morphologically and chronologically to the Neolithic finds from Varna.[21]

**Arsenical copper or arsenical bronze?**

The significance of arsenical bronze, the main compound in Branigan's 'metallurgical explosion' of Early Bronze Age II, which took precedence over tin bronze in the Aegean, at least in terms of quantity, was long ago analysed by Renfrew and Charles in two important articles.[22] Its advantages, particularly its hardness, were also analysed in the same articles. However, in his article on Ayia Photia in the present volume, Muhly reminds us that the first analyses to reveal the importance of arsenical bronze in early Aegean metallurgy were made much earlier, in 1903, by Konstantinos Zeigelis, professor of chemistry at Athens Technical University. At the Fifth International Conference of Classical Archaeology, Zeigelis clarified the properties of arsenical bronze on the basis of analyses of objects in the National Archaeological Museum of Athens. It is he, in fact, who is the father of modern Aegean archaeometallurgy.

The considerable presence of arsenical bronze in the Aegean during the Early Bronze Age, after a scarcity of evidence with regard to metals which may point to certain difficulties of supply, comes as no surprise. The same phenomenon has been observed in all areas of South-east Europe, the Middle East as far as the Indus, and Central and North Europe as far as Britain (see Muhly's introduction, this volume). It is a technical phenomenon which is attested over a wide geographical area that forms a very broad technological zone. The details are missing, however, and it is these that we are attempting to identify in the Aegean.

When, how, and why did arsenical bronze replace the use of pure copper, at least in quantitative terms? Was it the result of experimentation due to the lack of available ore?[23] Did it happen because, whether by chance or not, the metallurgists and users became aware of the advantages of the alloy (better endurance

17. A. VASILAKIS, Ο *χρυσός και ο άργυρος στην Κρήτη κατά την Πρώιμη περίοδο του Χαλκού* [*Gold and Silver in Crete during the Early Bronze Age*] (1996) 124-127.
18. VASILAKIS (*supra* n. 17) 221-236.
19. G.A. WAGNER and G. WEISBERGER "Silber, Blei und Gold auf Siphnos: Prähistorische und antike Metallproduktion," *Der Anschnitt* 3 (1985).
20. GALE and STOS-GALE (*supra* n. 14) 211-212; Z.A. STOS-GALE and C.F. MACDONALD, "Sources of Metals and Trade in the Bronze Age Aegean," in N.H. GALE (ed.) *Bronze Age Trade in the Mediterranean* (1991) 249-288, pp. 270-271.
21. K. ZACHOS and A. DOUZOUGLI (*supra* n. 11) 965.
22. C. RENFREW, "Cycladic Metallurgy and the Aegean Early Bronze Age," *AJA* 71 (1967) 1-20; J. A. CHARLES, "Early Arsenical Bronzes – A Metallurgical View," *AJA* 71 (1967) 21-26.
23. J. MUHLY (*supra* n. 9) 9.

and ductility)?[24] Is there a hiatus between the use of pure copper and the dissemination of arsenical bronze, as seems to be the case in the north Balkans and Europe? If so, to what is this due? [25] For the Aegean and the surrounding areas, the detailed metallurgical tradition and sequence has not been fully established and is at present geographically rather disconnected and fragmented. Nevertheless the presence of arsenical bronze from the end of the Neolithic period in the East (Nahal Mishmar cave, early 4th millennium), the Balkans and also the Aegean (Petromagoula in Thessaly: Final Neolithic, Tharrounia on Euboea: Late Neolithic II) is evidence, albeit isolated and in need of analysis, but nonetheless evidence, that although the early phases of the use of arsenical bronze are not very clear and lack any firmly attested sequence, thereby justifying the view that there was a gap, they are nonetheless much earlier then Early Bronze Age II. It is for this very reason that the objects made of arsenical bronze from the cemetery at Ayia Photia, Siteia, which is dated a little earlier, towards the end of Early Minoan I, are of such great importance, irrespective of whether the artefacts were manufactured on the spot or not. The subject is discussed by Muhly in his article on Ayia Photia in the present volume. In an earlier article, Muhly cited the arguments for the presence of arsenical bronze in the Cyclades as early as Early Minoan I, based on the slags from Kephala on Kea dated to the Final Neolithic (though not of certain date),[26] and more recently the same author has convincingly assembled the evidence in support of a significant presence of metallurgy on Crete as early as Early Bronze Age I (Krasi, Pyrgos cave, Trapeza cave).[27]

Arsenical bronze can have differing arsenic content. When this is very small, below 1%, the addition is not thought to be deliberate, its presence being due to the nature of the ore. In contrast, when it is over 1% and nearer 2% it is probably a deliberate alloy and is classed as arsenical bronze.[28] The difference is not always clear and there are differing views as to the level of the value above which the addition should be regarded as deliberate (Papadimitriou this volume). It does mean, however, that two different processes were followed. Either the ore was selected because of the natural presence of arsenic, that is, it was simply smelted and used as arsenical copper, or two different ores were combined during smelting or after re-melting, and in this way a higher quantity of arsenic was achieved, producing arsenical bronze. Something of this kind appears to have taken place in the installation at Chrysokamino, where there is evidence for the hypothesis that a second ore was deliberately added in order to create arsenical bronze (Betancourt this volume).

At the beginning of this introduction it was suggested that the presence of large quantities of copper-based objects is an index of social change, either as cause or result. The presence of arsenical bronze is associated with three important social phenomena archaeologically attested. The first is the dramatic increase in the quantity of bronze artefacts, to the point where the term 'metallurgical explosion' is justified. As a result of the scale of production and the increased effectiveness of the end products, the scale of production itself becomes a factor that

24. J.P. NORTHOVER, "Properties and Use of Arsenic-Copper Alloys," *Archäometallurgie der Alten Welt, Beiheft* 7 (1989) 111-118; U. ZWICKER, "Natural Copper-arsenic Alloys and Smelted Arsenic Bronzes in Early Metal Production," in J.-P. MOHEN (ed.) *Découverte du métal* (1991) 331-340. For recent discoveries of arsenical bronze in South-east Europe, see also D. BUDD and B.S. OTTAWAY, "Eneolithic Arsenical Copper: Chance or Choice," in P. PETROVIC and S. DURDEKANOVIC *Ancient Mining and Metallurgy in Southern Europe* (1995) 95-102.

25. See the summary of the arguments on the hiatus in the use of pure copper and arsenical bronze in PARE (*supra* n. 1) 2.

26. J.D. MUHLY, "Beyond Typology: Aegean Metallurgy in its Historical Context." in N.C. WILKIE and W.D.E. COULSON (eds) *Contributions to Aegean Archaeology: Studies in Honor of William A. McDonald* (1985) 109-141, p. 118.

27. J.D. MUHLY "Chrysokamino and the Beginnings of Metal Technology on Crete and in the Aegean," in L. PRESTON DAY, M. MOOK and J.D. MUHLY, (eds) *Crete Beyond the Palaces: Proceedings of the Crete 2000 Conference* (2004) 283-289.

28. For the level of arsenic in the bronze, and the extent to which it is deliberately added, see BUDD and OTTAWAY (*supra* n. 24).

can bring about – or dynamically contribute to – important cultural and social changes.[29] This dramatic increase in the archaeological record may also be due to the fact that copper-based (like other metal) objects were withdrawn from circulation and placed in tombs giving them greater archaeological visibility. The majority are connected to symbolic issues and the picture we have is therefore filtered through human behavioural patterns.[30]

The second is the different kinds of copper-based objects. Alongside the imitation of earlier stone tools – a common practice during the adoption of bronze tools (Karimali, this volume) – new types were also produced. More advanced tools were now created using double or single moulds: longer and thinner, and possibly more effective, shaft-hole axes and flat axes, probably with better hafting and with a more complex form. They were probably multifunctional tools, although it is thought that they were connected with carpentry. Above all many types of weapons were created, such as triangular daggers and ribbed swords whose very existence points to situations of conflict. This differentiation is due to the greater endurance and ductility of arsenical bronze; later (and sometimes at the same time) tin bronze was to offer even greater possibilities. The chronological and geographical relationship between these two types of alloy is an open question for the Early Bronze Age. To what degree the latter displaced the former or whether they existed alongside each other from the start has not been established due to difficulties of access to sources of tin, the difference being only in quantities (Muhly, Tselios and Papadimitriou, this volume).[31]

The third issue, which was debated intensely at the 2004 conference and to which several articles in the present volume are devoted (Betancourt, Gale, Kayafa and Zofia A. Stos-Gale, Papadopoulos, Catapotis, Pryce and Bassiakos), is the important evidence for the techniques of smelting, a method of extracting metal by melting it at high temperatures in a furnace, which is an essential precondition for the larger quantities of metal found in Early Bronze Age II. It is this that gives the investigation of the metallurgical installation at Chrysokamino its enormous significance (Betancourt this volume). The detailed excavation, recording, analysis, and reconstructing of the smelting process, and the fact that it was possible to form an idea of the entire process (*chaîne opératoire*), has made this site a reference point for the interpretation of similar finds in other areas. The smelting process consisted of heating small perforated furnaces with a natural draft and with the help of pot bellows. Then the surface was broken up, and the resulting slag and prills of copper were removed. The numerous perforated sherds scattered all around bear witness to the operation. With this standard model as a parallel, similar metallurgical installations have been identified at various sites in the Aegean. Corresponding techniques were used on other islands (Skouries on Kythnos, Avessalos on Siphnos, see the article by Catapotis in this volume). Theocharis's finds at Raphina have been reinterpreted, and it appears that there was a corresponding technique there, too (see the article by Gale). The same is true at Limenaria on Thasos (Papadopoulos this volume). It is thus clear that this technique of smelting small quantities of bronze to serve local needs, which is probably a seasonal activity, is found all over the Aegean, from Crete to Thasos, while in contrast it is not recorded at present outside this area. It appears to be a local tradition that was maintained for at least 1000 years (Final Neolithic to Early Minoan III). Special mention should be made here of the work by M. Catapotis, Pryce and Bassiakos who organised and carried out the experiments that led to a bet-

29. Metallurgy is one of the factors invoked by Renfrew to explain the changes in the Early Bronze Age Aegean. See RENFREW (*supra* n. 4) 308-338.

30. G. NAKOU, "The Cutting Edge: A New Look at Early Aegean Metallurgy," *Journal of Mediterranean Archaeology 8.2* (1995) 1-32.

31. The presence of tin bronze in Early Minoan I artefacts provides another parameter. S. N. MARINATOS, "Πρωτομινωϊκός θολωτός τάφος παρά το χωρίον Κράσι Πεδιάδος [Early Minoan Tholos Tomb near the village of Krasi Pediados]," *ArchDelt* 12 (1929) 102-141.

ter understanding of how functioned the metal furnaces at Chrysokamino. They made detailed records of their efforts to reconstruct smelting experimentally at all its stages, and at the same time checked and corrected these hypotheses and trials. Their work has shown the enormous possibilities of such experiments in checking views formed on the basis of the archaeological record and analyses: the temperatures that can be achieved, the endurance of the walls of the furnaces, some calculations of quantities, and the role and kind of fluxes. The installation at Chrysokamino is fairly small and seasonal and served the needs of the surrounding area for centuries. An important feature is that, according to the conclusions of Betancourt, the unworked ore was brought from elsewhere and only the smelting took place at Chrysokamino. The metalworking processes did not take place there, and presumably were carried out near the settlements at which these products were consumed.[32]

At the end of the Early Bronze Age (2300-2200 B.C.), in Aegina (Kolonna) we encounter a more advanced form of furnace, which is the only one of its kind so far known in the Aegean. It is a fixed, built structure almost two metres high, with ventilation ducts and a channel along which the molten ore flowed and was collected. Bronze seems to have been produced more frequently and in greater quantities in such fixed structures, but it is not clear whether this is due to increased demand or simply to a different technological tradition.[33]

After smelting, the metallurgical processes that followed included re-melting, casting in moulds, hammering, and possibly annealing and re-hammering, which took place near or in the settlements. "Workshops" – special places for production – are known.[34] The article by Thomas Tselios deals with the techniques by which the final products were formed. It is based on metallographic examination of samples taken from selected Pre-palatial tools and weapons, mainly from the Mesara, though also from other sites (Mochlos). For the investigation of the metallography of the objects, the relevant article by Northover and Evely, based on samples from the Ashmolean in 1995,[35] continues to be of seminal importance. Their line is followed in the article by Tselios, which presents similar analyses of objects from Prepalatial Minoan Crete for the first time on such a scale. Metallographic examination is used to deduce the ways in which tools and weapons were manufactured through successive annealing and hammering. The clarification of this sequence, combined with the chemical analyses and also with evidence derived from typology permits conclusions to be drawn about the needs served by an object, and also possible local technological traditions and preferences. This leads to some interesting conclusions, such as the existence of a workshop at Ayia Triada, in which the use of arsenical bronze continued (whereas at other surrounding centres tin bronze was used), and which specialised in triangular daggers.

In a series of recent studies, the abundance of bronze and particularly bronze weapons in Early Bronze Age II is associated with social differentiation. The deposition of these objects in tombs may be related to the display of wealth and power of elite groups, and through it, the establishment and consolidation of their position as leaders.[36] However, there may be other explanations of the presence of weapons in tombs (as of artefacts made of other metals). It undoubtedly points to their actual and symbolic value, but at the same time the fact that

32. For the importance of Chrysokamino, see also J. MUHLY (*supra* n. 27). See also, recently P.P. BETANCOURT *The Chrysokamino Metallurgy Workshop and its Territory*, Hesperia Special Volume (2006).

33. H. WALTER, *Die Leute im alten Ägina. 3000-1000 v. Chr.* (1983) 59-63.

34. NAKOU (*supra* n. 30) considers that this entire process may assume exaggerated dimensions: that is, that there is a collective pride that finds expression in the manufacturing of weapons. This can be seen also in the ancient Greek tradition (see, e.g., the arms of Achilles in Homer).

35. P. NORTHOVER and D. EVELY "Towards an Appreciation of Minoan Metallurgical Techniques: Information provided by Copper Alloy Tools from the Ashmolean Museum, Oxford," *BSA* 90 (1995) 83-105.

36. NAKOU (*supra* n. 29).

they were put out of circulation can only mean that there were adequate quantities in circulation. There are many other ways of interpreting these deposits that are consistent with the rest of the archaeological record. For it should not be forgotten that, despite the efforts that have been made, no convincing evidence has emerged for social differentiation in the corresponding settlements of this period.[37] I believe that essentially the only indisputable fact that emerges from the deposition of weapons in tombs of the South Aegean in the Early Bronze Age is the context of conflicts, for at least one phase. The matter should perhaps be studied in combination with the fortified settlements of the Aegean, though even this leaves us with many question marks. The curious find of crucibles in the tombs at Ayia Photia (Muhly, this volume), and also in an Middle Bronze Age tomb at Pyrgos *Mavroraki* on Cyprus (Kassianidou, this volume) are of greater interest, in my view, for the status of metalworking and of the metal workers, and also for their personal – and proud – relationship with the tools they took with them when they departed life. Pride of ownership versus pride of craft?

There is however a parallel for this phenomenon that may shed light on these finds and possibly assign them to a European tradition. This involves the so-called 'burials of metalworkers', a fairly widespread phenomenon throughout Europe (mainly in Eastern Europe, though also in Czechia, Germany, the Netherlands, France and Spain). These burials are from different cultural cycles, but chronologically they all belong to the period between 2500 and 1700 B.C. – that is, they correspond with the Early and Middle Bronze Age in the Aegean. They involve the interment of men, normally accompanied by depositions of tools connected with metalworking: crucibles, tuyères, hammers and anvils, as well as moulds, though the finished objects are usually missing. They are thought to be the tombs of craftsmen, people who were important for the community but not outstanding.[38]

**The Petralona Hoard**

There is one particular find that has not been mentioned at the conference, but to which I feel it is useful to refer, partly because it is not very well known, and partly because it is of relevance for almost all the subjects discussed in this volume. This is the Petralona Hoard, a group of bronze objects found near the site in west Chalkidiki known after the cave of Petralona, though the hoard itself is not connected with this cave.[39] The question of what is meant by the term hoard, and whether it is appropriate (collection of similar or analogous metal objects, or concealment, or symbolical deposit) has been analysed at great length, though a certain lack of clarity remains.[40] Under whatever name, however, the group is important for its similarity with and differences from the bronze artefacts of south Greece, and also because its geographical position – near the north border of the Aegean, with influences both from the

37. T.M. WHITELAW, "The settlement at Fournou Korifi, Myrtos and Aspects of Early Minoan Social Organisation," in O. KRZYSZKOVSKA and L. NIXON (eds) *Minoan Society* (1983) 324-345. See also the arguments in L. VANCE WATROUS, D. HADZI-VALLIANOU and H. BLITZER *The Plain of Phaistos. Cycles of Social Complexity in the Mesara Region of Crete* (2004) 233-238.

38. J.-P. MOHEN, "Les sépultures des metallurgistes du début des âges des métaux en Europe," in J.-P. MOHEN (ed.) *Découverte du métal* (1991) 131-142.

39. D.B. GRAMMENOS, I. TZACHILI and E. MANGOU "Ο θησαυρός των Πετραλώνων της Χαλκιδικής και άλλα χάλκινα εργαλεία της ΠΕΧ από την ευρύτερη περιοχή [The Petralona Hoard and other EBA Copper Tools from the Neighbouring Region]," *Archaiologiki Ephemeris* (1994) 75-116.

40. For an analysis of the phenomenon known as the hoard, with its economic and symbolic coordinates, see A.B. KNAPP, J.D. MUHLY and P. MUHLY, "To Hoard is Human: Late Bronze Age Metal Deposits in Cyprus and the Aegean," *Report of the Department of Antiquities, Cyprus 1* (1988) 233-263, 235-237. For a classification and analysis of hoards in the Aegean during the Early and Middle Bronze Age, see K. BRANIGAN, "Early Aegean Hoards of Metalwork," *BSA* 64 (1969) 1-11. For the abuse of the term, see R. LAFFINEUR, "Les trésors en archéologie égéenne: réalité ou manie?" in P. DARCQUE, M. FOTIADIS and O. POLYCHRONOPOULOU (eds) *Mythos. La préhistoire égéenne du XIX au XXI siècle après J.-V. BCH Supplément 46* (2006) 37-46. J. MUHLY gives a brief overview of the phenomenon in his review of the volume *Metals Make the World Go Round* (2003) 291-293. For Minoan Hoards see Hakulin, this volume n. 28.

*Fig. 1 The Petralona hoard: flat axes. Thessaloniki, Archaeological Museum.*

*Fig. 2 The Petralona hoard: flat axes. Athens, National Archaeological Museum.*

South Aegean and from the Balkans – suggests further possibilities for interpretation. It may therefore be useful to refer to a number of details and then engage in an archaeological assessment.

The Petralona hoard is a group of 42 tools, 37 flat axes, 4 shaft-hole axes and a chisel-wedge (Figs 1-3). It is the product of antiquities theft and for this reason is now in two museums, the National Archaeological Museum of Athens and the Archaeological Museum of Thessaloniki. The fact that the objects come from the same group, which was divided into two, is clear both from the information relating to the acquisition of the part that is in the National Archaeological Museum in Athens, and from macroscopic and chemical examination.

The tools are preserved in excellent condition, virtually without corrosion, on account of the low quantity of iron in their composition. It is by far the largest and most homogeneous group from the Early Bronze Age in the Aegean. By comparison we may note that the Naxos (formerly Kythnos) hoard consists of thirteen pieces: the Petralona find, that is to say, is two and a half times larger.[41] The Petralona hoard, like two other hoards from mainland Greece (Eutresis and Thebes), consists exclusively of tools and contains no weapons.

The objects have been dated to Early Bronze Age II on the basis of typological criteria alone. The flat axes – a common, versatile tool in Early Bronze Age II – also known from the Late Neolithic and present throughout the entire Bronze Age – find closest typological parallels are the axes from the Poliochni hoard, though similar axes are to be found throughout the Aegean. For the shaft-hole axes, too, the closest Aegean parallels are the axes from the Poliochni hoard (that is to say, all the objects found together at Vano 829), the axe from the Thebes hoard,[42]

41. After Fitton's study, the hoard was united with similar artefacts in the Museum of Copenhagen: J.L. FITTON, "Esse Quam Videri: A Reconsideration of the Kythnos Hoard of Early Cycladic Tools," *AJA* 93 (1989) 31-39.

42. J. MARAN, "Die Schaftlochaxt aus dem Depotfund von Theben (Mittelgriechenland) und ihre Stellung im Rahmen der bronzezeitlichen Äxte Südosteuropas," *Archäologisches*

a series of other axes – chance surface finds – found in the area around Thessaloniki,[43] and especially that from Mandalo, a settlement in Central Macedonia, which comes from a clearly defined archaeological level and is securely dated.[44]

So far all the axes of this type come from mainland Greece, with the majority of them from Chalkidiki and Central Macedonia. They are not isolated finds, however. Shaft-hole axes in large numbers and with a wide geographical spread (Bulgaria, Romania and the area around the Black Sea) are a common find in the Early and Middle Bronze Age in southeast Europe and have the same morphology and composition (arsenical bronze) as similar finds in mainland Greece.[45]

According to information relating to the circumstances in which they were discovered, the Petralona tools were found in a pithos. When, several years later, archaeologists were shown the find spot near the modern village of the same name, it was noted that there were no traces of habitation in the surrounding area, nor was there a cemetery.[46] It seemed to be a genuine hoard, as though someone had concealed the tools in the middle of nowhere and had never returned to collect them. Of course this picture

***Fig. 3*** *The Petralona hoard: shaft hole axes. Thessaloniki, Archaeological Museum.*

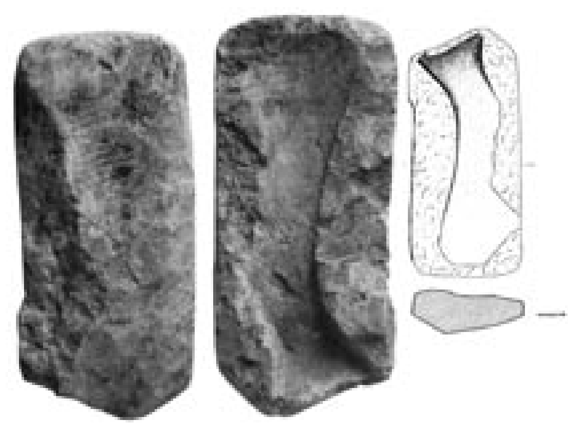

***Fig. 4*** *Stone mould from Toumba Mesimeriou. Thessaloniki, Archaeological Museum.*

*Korrespondenzblatt* 19 (1989) 129-136.

43. GRAMMENOS *et al*. (*supra* n. 39), 89-90.

44. A. PILALI-PAPASTERIOU and A. PAPAEUTHIMIOU-PAPANTHIMOU “Νέες ανασκαφικές έρευνες στο Μάνδαλο 1985-1986 [New excavations in Mandalo],” *Egnatia* 1 (1989) 15-28, Fig. 6. For the absolute dates of phase III, in which the axe was found, see K. KOTSAKIS, A. PAPANTHIMOU-PAPAEUTHIMIOU, A. PILALI-PAPASTERIOU, T. SAVOPOULOU, Y. MANIATIS and B. KROMER, “Carbon 14 Dates from Mandalo,” *Archaeometry, International Symposium, Athens 1985* (1989) 679-685. Phase III is dated in absolute terms between 2950 and 2200 B.C. The chronological spectrum is therefore very wide, but the term of use of a tool of this kind is also very long.

45. For these finds, two works should be consulted. For Romania, A. VULPE *Die Äxte und Beile in Rumänien I* (Prähistorische Bronzefunde IX/2) (1970); For Bulgaria, the monumental work by E.N. CHERNYKH *Gornoe delo I metallurgiya v drevneyskey Bolgarii* (1978) which classifies and analyses copper-based tools, taking into account both typology and composition. No similar endeavour has yet been made for the Aegean. For a recent synthesis of the evidence for this geographical region, see PARE (*supra* n. 1) 12-16.

46. GRAMMENOS *et al*. (*supra* n. 39) 75.

could easily be due to the fact that no excavation ever took place. It is true, however, that the assemblage consists only of tools, that they were found all together, and that they do not come from tombs. Additionally, their chemical composition is similar, the technique by which they were made is the same, and both the axes and above all the flat axes are impressively of the same size. All of them, therefore, come from the same zone of manufacture and use. Moreover, a stone mould for casting shaft-hole axes was found nearby, at Mesimeriani Toumba, again in Chalkidiki, and it may therefore be asserted confidently that metalworking was carried out in the surrounding area (fig. 4).[47]

There are many more tools than would be needed by one man, so they should be seen rather as community goods. There is no reference either to a use context. They had probably been assembled and temporarily put out of use for some unknown reason. They are all used, and some of them are broken but not useless. They were not a scrap assemblage intended to be re-melted in order to make new tools. From the composition of the group it seems that they were probably gathered together for other reasons. There is nothing to preclude the possibility that some person or persons concealed them in order to use them or to distribute them at a later date, or that this was a symbolic deposition, like the countless similar ones known from the same period in the Carpathians and neighbouring areas (Early Bronze Age), and a little later in Central Europe.[48] It is worth emphasising that despite the extensive investigation of the European hoards, and despite the efforts made to establish their geographical distribution and composition, no definitive conclusion has been reached as to the causes of such depositions.[49] Whatever the reason (concealment for later use or symbolic deposition), a hoard objectively represents the putting out of circulation of a significant number of artefacts and a significant quantity of copper. It presupposes that there is an adequate number of other tools in use and that the raw material is not scarce. It may be assumed either that they were the merchandise of an itinerant merchant-craftsman who had assembled tools in order to sharpen and repair them and who left them somewhere and never returned to collect them (as might be conjectured on the basis of later examples), or that we are dealing with the collective movement of a group (a group of craftsmen, or an entire community?) who put them temporarily out of circulation for unknown reasons, with the intention of collecting them later. The latter is possibly suggested by the large number of tools (implying that more then one individual had contributed) and by the fact that they had been carefully placed in a vessel – that is, an attempt had been made to keep them in good condition. In any case, as human behaviour this is very different from the depositions of metal objects in tombs in the Cyclades. If the Petralona hoard is a symbolic deposition, the questions concerning the reasons and practices must be similar to those all over Central and Eastern Europe.

The chemical analyses of the composition of the alloy are also important. Two have been undertaken: the earliest analysis was carried out on objects in the Archaeological Museum of Thessaloniki and is included in SAM,[50] while the most recent analysis was carried out in 1992 by Eleni Mangou, a chemist and archaeometalurgist at the National Archaeological Museum of Athens.[51] The latter, which involved objects

47. GRAMMENOS *et al.* (*supra* n. 39) 90, no 48, fig. 13.

48. For the phenomenon of hoards in Central Europe and the attempts to account for it, see T. CHAMPION, C. GAMBLE and A. WHITTLE *Prehistoric Europe* (1984) 203, 217, 218, 271.

49. C. MORDENT, M. PERNOT, V. RYCHNER (eds) *L' Atelier du Bronzier en Europe du XXe au VIIIe siècle avant notre ère; t. III, Production, circulation et consommation des bronzes* (1998). Almost all the studies in this volume deal with the phenomenon of hoards in Europe.

50. S. JUNGHANS, E. SAGMEISTER and M. SCHRÖDER, *Kupfer und Bronze in der frühen Metallzeit Europas. Studien zu den Anfängen der Metallurgie* (1968) Vol 2, 13 nos 9333-9355.

51. GRAMMENOS *et al.* (*supra* n. 39) 109-114. For sources of copper and arsenic in Greece, see recently G.R. RAPP Jr., "Copper, Tin and Arsenic Sources in the Aegean Bronze Age," in P.P. BETANCOURT, V. KARAGEORGHIS, R. LAFFINEUR and W.-D. NIEMEIER, *Meletemata. Studies in Aegean Archaeology presented to Malcolm H. Wiener as he enters his 65th Year III*, *Aegaeum* 20 (1999) 699-704.

from both museums, revealed the similarities of their composition and demonstrated beyond any doubt that they form a group. The copper contains 1.07% to 4% arsenic, and is therefore a deliberate alloy. Eleni Mangou, considered it very important that bismuth was found in large concentrations in the copper. Interestingly, the search in the area for ores containing copper, arsenical lead and bismuth has produced positive results. Ores of this kind are to be found in Chalkidiki, in the prefecture of Thessaloniki, and near Kilkis. It is possible, therefore, that these objects were manufactured from deposits that are not far from the place where the artefacts were found.[52]

Consequently the assemblage of copper-based artefacts from Petralona is a find which is large in terms of quantity, which, according to the existing evidence, was not inside a settlement or in a cemetery, which lacks features that would define its use or the reason for its deposition, but which might have been manufactured from local ores. Tools that are typologically entirely similar have also been found in the surrounding area of Thessaloniki as chance surface finds, which points to their being common.[53] It is also significant that all the similar assemblages of bronze artefacts, all the hoards from mainland Greece, are invariably composed of tools and not weapons. The depositional behaviour does not exhibit any similarities with the South Aegean, despite the morphological similarity of the flat axes.

Without wishing to exaggerate the importance of the finds from Chalkidiki and Central Macedonia, it may reasonably be asserted that they point to the existence of a metallurgical and a metalworking centre in Central Macedonia similar to those of the South Aegean, the North-East Aegean and Crete. This centre lies on the geographical border between the Aegean and the Balkans and its products are technologically similar to those of both these areas, which in any case belong to the same broad technological zone. With regard to the depositional behaviour, however, cultural differences can be detected, though they are difficult to interpret. Chalkidiki and Central Macedonia lie close to metalliferous areas and there is an attested affinity of the metal of the final products to the ore deposits in the area. There is also evidence for a considerable metalworking output. Nevertheless, the social circumstances are completely different from those of the South Aegean. Most importantly, there are no proto-urban settlements like those of the Aegean and of southern mainland Greece in Early Bronze Age II and III, which are accompanied by a network of exchanges, advanced techniques, and elaborate symbolic systems. Metallurgy has been regarded as one of the causes and results of proto-urban settlements, and as one of the main features of the phenomenon of the proto-urbanisation in the Aegean. Yet here, in Central Macedonia, where an intensive production and use of copper-based artefacts is attested, close to natural sources of ores, this phenomenon is not observed. There are no proto-urban settlements. The development of technology does not interact with other social phenomena to produce changes of the type observed in South Greece. It seems that technological development in a field does not necessarily bring about mobility and general changes, and in any case whatever differentiation does take place does not always follow the same course. The evolution is different in the South Aegean where, in many places there is abundant evidence of metallurgy and metalworking from that in Macedonia where again there is strong evidence of metallurgy and metalworking.

## Tin and the great period of Aegean Metalworking

The question of tin cannot be omitted from any debate on Aegean or European metalworking. The present volume includes an article devoted to a pilot program on the investigation of matters related to tin (Carole Gillis and Robin Clayton). This raises a number of problems that have troubled scholars, though no definitive solution has been advanced in most cases. The bibliog-

52. GRAMMENOS *et al.* (*supra* n. 39) 89-91.
53. GRAMMENOS *et al.* (*supra* n. 39) 89-91.

raphy on the presence of tin in the Aegean is impressive (Gillis's article includes an exhaustive bibliography). In recent decades, great and possibly excessive emphasis has been placed on the importance of bronze for the construction of increasingly complex or efficient objects (mainly weapons), throwing into even greater relief just how little is known of a metal that has acquired almost mythical dimensions. The debate focuses mainly on the question of the sources of tin, since the known sources are largely to be found in Western Europe. The debate also turns to other matters, however, such as the routes followed by tin to the Aegean, the ways in which it was transported, how it was distributed, and who controlled this distribution.

Technical matters, too, are not completely clear. It is not apparent, how and at what phase alloys began to be made, and it appears that symbolic issues were also involved, relating in particular to the colour. Tin is to be found sporadically in the Aegean from Early Bronze Age, while in Middle Bronze Age arsenical bronze has been displaced virtually everywhere and tin bronze is the only copper alloy to be found. This, however, does not imply an abundance or even an adequate supply. Curiously, alongside the objects made of tin bronze there are also large quantities made of pure copper (see the articles by Soles and La Marle), which is possibly to be accounted for by the small quantities of tin available, though possibly also by the fact that pure copper can be used for some artefacts that are not subjected to great stress. There is abundant evidence for the presence of tin in Late Bronze Age III, though very little is known as to its circulation and sources. In an attempt to circumvent the problem of defining the sources, the programme on tin mentioned above has investigated how far isotope analysis can supply answers. A methodology has been devised and a number of pilot analyses have been carried out. This preliminary investigation has shown that there are possibilities, but a huge collection of samples is required.

Important evidence on this subject has been provided by the new finds from Mochlos, where it seems that the metalworking carried out inside the settlement included melting with tin in order to create a compound. Two important facts have emerged from the finds discovered at Mochlos in 2004. One is that it proved possible to restore the form of a tin ingot despite the fact that it was pulverised. Its form was rather like those found in the Uluburun shipwreck. Second, the archaeological context makes it possible to interpret the find as a foundation deposit.

Hubert La Marle has made an attempt to trace the changes observed in the composition of bronze in the Linear A inscriptions, through shifts of meanings and related terms. Using the frequency of references, the manner of incision and the dates, he reaches the conclusion that slight differences in a series of inscriptions relating to metals may suggest copper with a higher tin content. And he locates a probable word for tin in inscriptions dating from LM IB at Ayia Triada and Zakros.

Traces of tin have been found in the majority of the objects analysed by the LIBS and EDXRF methods (see the articles by Anglos *et al*. and Kallithrakas-Kontos and Maravelaki-Kalaitzaki). There were smaller quantities of tin in the majority of the bronze objects from the cave of Ayios Charalambos (probably of the Middle Minoan period), which is accounted for as being the result of the recycling of bronze objects. In contrast, the objects analysed from the cemetery at Armenoi dating from the LM IIICa and b period included a bead and other indeterminate objects made of pure tin. The available evidence thus suggests that the presence of tin increased towards the end of the Mycenaean period on Crete, as in the whole of the Aegean, and possibly also the whole of the Mediterranean and Europe.

With regard to the symbolic value of tin, it is significant that it was used in the LM III period for jewellery, as is clear from the evidence from the cemetery at Armenoi and also from the fact that it was used to embellish a number of vases, which were tin-plated, like the ones from Asine (Gillis and Clayton, this volume) - an entirely 'useless' function which nonetheless points to a relative abundance of tin at this period, at which all the bronze objects appear to be of tin bronze.

In any case, the fact that tin is not found as an ore in many of the areas which have a metal-working tradition, but was a nonetheless essential and desirable element, made the creation of exchange networks necessary. Its very presence presupposes their existence. Such networks are attested in the Middle East by written sources, and in the Eastern Mediterranean by the finds from shipwrecks.[54] They will certainly not have operated solely for metals, but for a wide spectrum of products, with one functioning as a means of exchange for the other. It is possibly worth commenting that, given the present stage of our knowledge, the most important sources of tin are in Central Europe, the Iberian peninsula, Cornwall, and Italy, with less certain sources in the East: its presence in the Aegean and elsewhere, therefore, can only be accounted for by the functioning of these networks.[55] The general adoption of tin bronze in the whole of Europe and the East during the second millennium can be due only to exchange.

It is also worth noting that the powerful state formations of the Aegean (Minoan Crete and also Mycenae), despite their refined administrations and the exchange networks that they maintained, do not necessarily coincide with a particularly large presence of copper or tin bronze. Neither copper as a raw material nor bronze objects are particularly numerous compared with the corresponding quantities and numbers of objects from Central Europe. On the other hand, such state formations are not found in some areas that have considerable mineral wealth and a large number of bronze artefacts, such as the Iberian peninsula, Central Europe and the countries along the Black Sea.

**The Minoan Metallurgical Tradition**

Three of the studies in this volume refer to the great Minoan metallurgical tradition, at the time of its zenith from MM III to LM IB, which coincides with the zenith of Minoan civilisation. It is perhaps no coincidence that two of these articles deal with finds from Mochlos, a harbour-town in Eastern Crete that probably occupied a key position with regard to exchange (Soles, Brogan, this volume). These two articles are connected both by subject and by area. Taken together, the two shed light both on aspects of the operation of the metallurgical work on the site of the settlement (Brogan), and the presence of metal artefacts and raw material on the site (Soles). We may say that we have a good picture of the practice of metalworking *in situ*.

Everyone who attended the conference in Rethymnon in November 2004 will remember the enthusiasm that greeted the new finds presented by Soles in his paper. The reader of this paper will, I believe, form the same impression. Impressive finds paraded before us one after the other, the treatment of which relates *de facto* to some of the major questions of Minoan metallurgy at its zenith. Soles analyses the ten hoards, that is the ten assemblages, found in the town, and classifies them according to their function, which he deduces from their composition, as foundry hoards for re-melting the metal, as merchant hoards (objects that were traded) and finally as ritual hoards, which include foundation deposits.

The information derived from the new finds at Mochlos sheds light on a variety of topics. I refer to a few, selectively. A few questions relating to the origins of ingots are clarified on the basis of the Lead Isotope Analysis. The ingots from Mochlos come either from the Anatolia or from Cyprus (which is significant, since the majority of the ingots on Crete are not from Cyprus), and it has proved possible, indeed, to identify the specific areas from which they

54. For a detailed bibliography on the distribution of tin in the Eastern Mediterranean, see the article by Gillis and Clayton in this volume.

55. PARE (*supra* n. 1) 25. However, some recent analyses suggest that the tin came from Afghanistan, see the article by Soles in this volume. See also RAPP (*supra* n. 51).

come.[56] This is important information, given the confusion prevailing as to the beginning of the extraction and distribution of Cypriot copper (Kassianidou, this volume). The secure dating of the ingots to LM IB is also significant in establishing a chronological sequence for the commercial routes of the Mediterranean.

In order to animate this evidence, Soles reconstructs the imaginary but completely convincing voyage of a ship that brought such products, together with its route and the trading posts and ports at which it called long before the one wrecked at Uluburun.[57] Special mention may be made of two 'exotic' finds, the sistrum from Egypt and the trident from the Syrian Coast.

Furthermore, although we have many ingots (30 complete ones from Crete) and are well acquainted with the form in which copper was transported, the finds from Mochlos provide evidence for how it was used. They were broken into pieces and re-melted, while constant care was taken to fragment them in regular shapes so as to maintain a standard weight. They were kept in sacks which have left their imprints on the metal.

Metalworking at Mochlos acquires a broader perspective from the finds from the Artisans' quarters (Brogan, this volume). Evidence is provided by a series of crucibles and moulds for a series of metalworking tasks such as hammering and casting, and also for the more advanced, lost-wax technique. Casting waste or spill has also been found, showing that re-melting took place. This gives us the opportunity to clarify a number of gaps and to enrich our knowledge with a range of details such as the role played by crucibles in relation to their size, and the significance of a series of other tools apart from stone ones, such as pieces of pumice. The role played by metalworking in the town is also illuminated by the spatial distribution both of the workshop evidence and of the raw materials and artefacts. The chronological and spatial differences by period can thus be seen: in LM Ia, the work was more decentralised within the settlement, since the remains are scattered and not concentrated on one neighbourhood, as appears to be the case in the Artisans' quarters in LM IB. What might this difference mean? Greater specialisation in LM IB or, on the contrary, a contraction of output?

With regard to the general organisation of the metalworking output, including questions relating to the distribution of the raw material and products, the general body of evidence from Mochlos points rather to decentralised production based on the Minoan town and its port, on which the processing and trading of the metal within a certain radius was focused. The finds do not point to any external administration that would have functioned as a superior agent of the production and trading of metal products.

The article by G. Papasavvas affords an opportunity to cast a glance at art, the great art of gold finger-rings. Starting with an outstanding example from Symi Viannou, a finger-ring with a depiction of a Minoan runner, his article explores how rings were constructed, how the gold leaf was attached, and how the representation was engraved – that is to say, the techniques which illuminate more then anything else the craft of the artisan that underlies the aesthetic result. Through his minute analysis of the technique of the finger-ring from Symi, all these features acquire specific substance, from the successive stages of manufacture, and tools, to the exploitation of the potential of the metals. And between the lines can be read the enormous technical expertise behind the end product. Of course, it is possible to enjoy a representation, admire its lines, and the abstraction that leads to the capturing of a unique movement, without having any idea as to how this was

56. See also J. SOLES and Z. STOS-GALE, "The Metal Finds and their Geological Sources," in *Mochlos I C, Period III, Neopalatial Settlement on the Coast: The Artisans' Quarters and the Farmhouse at Chalinomouri* (2004) 45-59; A Cypriot origin for the Chania ingot fragment is claimed by S. STOS-GALE, N.H. GALE and D. EVELY, "An Interpretation of the Metal Finds, using Lead Isotope and Chemical Analytical Procedures," in E. HALLAGER and B.P. HALLAGER (eds), *The Greek-Swedish Excavation at the Agia Aikaterini Square Kastelli, Khania 1970-1987* (2000) vol. II, 209-212.

57. J.S. SOLES, "From Ugarit to Mochlos, Remnants of an Ancient Voyage," in R. LAFFINEUR and E. GRECO (eds) *Emporia, Aegeans in the Central and Eastern Mediterranean Aegaeum* 25 (2005) 429-442.

achieved. When we do have this knowledge, however, it changes our approach. The secrets behind it, when they are no longer secret, add a depth of recognition, a familiarity above and beyond scientific knowledge, a kind of proximity. As if we are not simply watching the hand of the master craftsman behind the tool, but actually anticipating his next move.

The written sources for metals, particularly the Linear A inscriptions are dealt with by Hubert La Marle. In his analysis of the references to metals, he concentrates mainly on frequencies, chronological differences, and the kind of objects on which the inscription is found. He makes a careful series of distinctions in the corpus of inscriptions connected with metals. He distinguishes between inscriptions on metals and inscriptions on clay. The former are divided into relatively long inscriptions on votive axes and on jewellery, while the latter, which are on ingots and consists of one or two signs, are probably arithmograms. He thus builds up the argument that one series of references distinct from another series of references refer to objects made of tin bronze. His article is of interest, *inter alia*, for its very fine observations such as the fact that Linear A inscriptions on metals are first found when Linear A inscriptions began to be used at Knossos, that in general Linear A on metals is found in the period at which there was more intensive use of tin, and that inscriptions on clay relating to metals tend to be concentrated at the end of the period of use of Linear A. Finally, the geographical distribution of references to metals, which he exploits in combination with the archaeological record, is very useful. When this article is combined with information from other papers (Soles, Muhly, Hakulin), more or less the same picture emerges as the one given by the archaeological data, that is to say, a lack of arsenical bronze and the widespread existence at the same time of both tin bronze and pure copper, a picture that can also be detected, albeit with great difficulty, in the written sources.

With Hakulin's article we remain in Minoan Crete, but move to a different level. In contrast with other studies in this volume, Hakulin's analysis may be said to be macroscopic. Her subject is the overall presence of copper, the overall production, movement and geographical distribution of bronze artefacts in Crete in the Late Bronze Age. Her treatment is global, in keeping with her title. With the aid of a database she calculates the quantity of bronze objects by kind and by type, and establishes their distribution and the composition and quantity of copper. This global approach makes it possible to compare and assess the actual extent of metalworking in society during a period of prosperity, such as LM IA, and also in a period of change, such as LM IB, and therefore to establish – potentially – the role it played in any social developments. It also makes it possible to assess the proportions of the various bronze artefacts – for example, the ratio between weapons and tools, as well as various details, such as the significant presence of pure copper alongside tin bronze, particularly in tools.[58]

**Quantitative Assessments**

Hakulin's article brings us to a second important matter which is the quantitative assessment of the volume of copper in circulation. The significance of this is decisive for an assessment of the place of metalworking in society, and whether or not it should be regarded as a decisive element in the material base of Minoan societies in Late Bronze Age. Hakulin attempts to achieve this by taking weight into account. She assembles the evidence for the weight of objects, where of course this is possible, and tots it up.

There are serious obstacles in the way of an enterprise of this nature. The most important is that we do not know what proportion of the output of bronze artefacts has survived to the

58. The presence of pure copper in (usually small) tools can be traced at Akrotiri on Thera, as in a small saw. See A. MICHAILIDOU, "Η Τεχνολογία του μετάλλου στην προϊστορική κοινωνία του Ακρωτηρίου Θήρας [Metallurgy in the prehistoric society of Akrotiri, Thera]," *Αρχαία Ελληνική Τεχνολογία, Πρακτικά 1ου Διεθνούς Συνεδρίου* [Ancient Greek Technology. Proceedings of the 1st International Symposium Thessaloniki] (1997) 645-541.

present day. Most of the bronze at our disposal today, the bronze that can be recognised in all the ways described in the present volume, is that which was withdrawn from use (in tombs or hoards). It is the result of deliberate social behaviour. The rest which seems to have been the larger part was probably re-melted. Its volume will be forever unknown. The second category of finds that have survived are 'chance' discoveries whose presence in the archaeological record is due to conjunctures hostile to their users, and probably also due to hostile historical circumstances. They are all bronze objects that were abandoned by mistake, as a result of an unfortunate social or personal situation, or simply out of neglect, in ruined places. No one returned to collect them, either because they did not know where they were or were not able or no longer interested in doing so. These 'chance' finds are also the result of behaviour, but not of deliberate behaviour, such as ritual deposits. Nevertheless, in a fairly large statistical sample, even if it is not possible to approach the overall magnitude, the element of 'chance' leads to a fairly reliable proportion both of the kind of objects (artefacts and raw materials or ingots) and of techniques or alloys. We can arrive at a statistical generalisation, that reflects in general terms an actual situation. Apart, of course, from the crucial matter of the original quantities. In the case of the first category of finds, however, – bronze objects which were withdrawn from circulation and placed in tombs or hoards as a result of deliberate behaviour, and therefore on the basis of choice – chance does not intervene. Or at least the element of chance relates to the possibilities of recovery and preservation and not to the deposition, which is determined by the depositional pattern.[59] However, even in this case, the original quantities are unknown.

Reference may be made to two other factors that influence the quantitative assessment. The overall assessments relate to a long period of time. We do not know the volume of bronze in circulation over a smaller given period of time, in a reasonable range of time, and we cannot, therefore, assess the effects on society and its members in the short term, which is of significance for the circulation of goods in the social life of individuals or of the group. The statistical counts refer to very long periods of time, which exceeds any reasonable interval – say, a generation. The circulation of goods that form part of, and maintain the exchange networks in the absence of coinage, and the use of these goods, are of significance only over a limited period of time. The longer interval provides us with the development of the use, but not with the situation in a brief slice of time, which is of critical importance for an assessment of the impact of bronze to a given society, to its fortunes or misfortunes.

Finally, we are largely unaware of another, equally decisive, factor: demography. How can we assess the quantity of metals and their significance for society when we are unaware, or at least have only a rough idea of the magnitudes of the population? We cannot understand the distribution or non-distribution pattern when we do not know of the number of people to whom the bronze artefacts were or were not distributed, and whose life and social status is supposed to have been affected by them. [60]

Within these restrictions, the work of Maria Kayafa is characteristic of the kind, quantity and limitations of the information that can be gained from quantitative analysis. Despite the reservations she herself expresses, this evidence is important and useful. The chronological spectrum she chooses, the Final Neolithic and the whole of the Bronze Age in the Peloponnese allows her to follow the fluctuations of bronze artefacts at different periods with relative ease. As is to be expected, the greatest increase is observed at the time when Mycenae was at its zenith, while there is a radical decrease at the end

59. For a combination of deliberate forms of deposition and the chance parameter see M.B. SCHIFFER, *Formation Processes of the Archaeological Record* (1996) 1-11.

60. For recent attempts to estimate the population around Knossos see T. WHITELAW "Estimating the Population of Neopalatial Knossos," in G. CADOGAN, E. HATZAKI and A. VASILAKIS (eds) *Knossos: Palace, City, State* (2004) 147-158.

of LH III. There are other, equally interesting, features, such as the ratio of objects from settlements to those from tombs. Those from tombs are, of course, greater in number (deliberate deposition), but there is also an increase in the number of bronze objects found in settlements in the Late Mycenaean period, due to the presence of hoards, mainly in citadels and particularly in mainland Greece, as was also the case in EBA (again deliberate withdrawal).[61] The geographical distribution of the finds is also very interesting, with those from the Argolid and Messenia being overwhelmingly greater in numbers then those from other areas. Many different readings and interpretations can be drawn from these quantitative records, as the author herself states in her conclusions, despite the limitations.

A brief reference to other quantitative data, this time from the written sources – the Mycenaean archives – may be useful. Here too, there are similar concerns about the possible distortion of reality due to the fragmentary preservation of the evidence. What proportion of the total number of tablets is preserved? What did the central administration choose to record out of the total production? Is this proportion characteristic of the whole? Given that the evidence of the tablets relates to a single year, we can at least approach what we earlier called the short term perspective, that is to say the evidence for production, consumption and distribution of bronze and bronze objects in a single year. The evidence is, of course, set in the context of a central administration, and we are therefore unaware of the geographical area it covers, or the proportion of the whole.[62] I shall cite just two examples, one from Knossos and one from Pylos. At Knossos such ingots are mentioned in KN Oa 730.[63] Their number is sixty. In all, therefore, a quantity just over 1,560 kilograms. When one considers that thirty ingots have been found intact on Crete and almost as many again in fragments (see the article by Hakulin), the difference is not great. The ingots do not seem to have been stored for a long time in this form: they were used in metalworking, goods were produced from them, and care was taken to acquire a further supply. In both cases, the quantities are not large, which also seems to be true in comparison with similar quantities in Europe and generally in the Aegean.[64]

The quantities also appear not to have been particularly large at Pylos, where the evidence again relates to a single year. In the Jn series, there is reference to the delivery of copper to coppersmiths through the ta-ra-si-ja system. There are 170 coppersmiths (though on other calculations there could have been 293) and the amount of copper delivered to them ranges from 1.5 kilos to 12 kilos with an average of 3.5 kilos. Reference is also made to 81 coppersmiths who do not receive copper.[65] The quantities are again considered small, though the large number of coppersmiths scattered over the province is impressive. What most scholars agree on is that there was probably a shortage of raw material, an issue to which we shall return.[66]

The impression one gains of the Aegean in the Late Bronze Age (as indeed in the Middle Bronze Age[67]) is that metallurgy was practised on a small scale and was dispersed. Everywhere over a wide geographical area, tools, and possibly also weapons, were manufactured and repaired. This was not a centralised industry

61. E. BORGNA,"I ripostigli delle acropolis micenee e la circolazione di bronzo alla fine dell'età palaziale," *Studi Micenei ed Egeo-Anatolici* 35 (1995) 7-55. See also MUHLY (2003, *supra* n. 40).

62. For ways of estimating the proportions in the Knossos tablets, see I. TZACHILI, "Counting and Recording Textiles in the Mycenaean Archives of Knossos," in A. MICHAILIDOU (ed.) *Manufacture and Measurement. Counting, Measuring and Recording Craft Items in Early Aegean Societies* (2001) 177-193, 177-180.

63. The details of the proportions of the metals are taken from the article by A. MICHAILIDOU "Recording Quantities of Metal in Bronze Age Societies," in MICHAILIDOU (*supra* n. 62) 87-88.

64. PARE (*supra* n. 1).

65. For more details, see J. SMITH, "The Pylos Jn Series," *Minos* 27-28 (1992-1993), 167-259; Y. DUHOUX, *Aspects du vocabulaire économique mycenien* (1976) 102-109.

66. J. CHADWICK, *The Mycenaean World* (1976) 139-142.

67. For the limited production of bronze artefacts at Malia in MM II, see J.-C. POURSAT and M. LOUBET, "Métallurgie et contacts exterieurs a Malia au MMII," in R. LAFFINEUR and E. GRECO (eds) *Emporia. Aegeans in the Central and Eastern Mediterranean*, *Aegaeum 25* (2005) 117-122.

under the control of an administration – a phenomenon attested to some extent, but not overall. There were groups of coppersmiths, possibly organised in some form of guild, which carried out the work and perhaps also undertook some of the distribution. These groups were traditionally independent of the central administration, which nevertheless sought to control them through taxation, in the form of obligatory labour (ta-ra-si-ja), perhaps some form of *corvée*. This picture takes into account the archaeological and epigraphic evidence. The objects made of metal registered in the tablets are those collected by the administration as tax.

**The wider Mediterranean context: sources, trade and exchanges**

It is impossible to deal with metallurgy in the Aegean, far less metallurgy in the Mediterranean, without referring to Cyprus. In her article on the formation of Cypriot bronze metallurgy Lina Kassianidou undertakes a substantial review of this subject, and poses the basic questions that arise from the re-examination of the exploitation of the ore deposits resulting from recent finds. She begins with a question that is hotly debated, mainly as a result of the views of Hector Catling: the question of the date of the beginning of metallurgy in Cyprus, the beginning of the extraction of copper.[68] Traces of metallurgy on Cyprus are apparently to be found from the end of the third millennium, and become even more frequent in the first half of the second millennium, as is attested by data from surface surveys conducted in the Troodos mountain, from the re-examination of earlier finds, and from the new finds from Katydata. This development continued in the Late Bronze Age, as cause and effect simultaneously, while throughout the Central, Western, and Eastern Mediterranean, networks that traded copper in the form of ingots were formed and operated. Not all the copper of these ingots came from Cyprus, of course, though undoubtedly the island was the source of a large quantity of it. The extraction of the ore on Cyprus, the processing of it and the production of the ingots were all part of this enormous enterprise. How? Where? With what technology? By whom? Questions like these increase in number as the position occupied by Cyprus, both as a place of extraction, and in general trade (e.g. from signs in the Cypro-Minoan script found on some ingots that are not made of Cypriot copper) becomes clearer. Some answers are provided by the finds from the excavation at Politiko *Phorades*, where a Late Bronze Age smelting site has been excavated. Much evidence of great importance has been identified. One such piece of evidence was connected with technology. The ways in which smelting was carried out are now known quite well, because furnaces have been found and the form in which they were operated has been understood, while tuyères and bellows have also been discovered. The study by Hein and Kilikoglou in the present volume undertakes a technical analysis of the furnaces on the basis of the pottery fragments, and attempts to establish their temperatures. Study of the slags has shown that the product was matte, which means that further processing was required to make the copper ready for metalworking; this processing was not carried out on the spot. Kassianidou makes an assessment of the data from this excavation, and draws attention to its comparative significance. The copper produced is reckoned from the slag to have been about 350 kilos: this was therefore a small installation and we should imagine many such small extraction sites at the ore deposits (which is also evident from the analysis of the finds from Mochlos: Soles this volume). The further processing of the metal probably took place at other points. In order to establish the way in which the ore was

68. In a famous article, H.W. CATLING, "Copper in Cyprus, Bronze in Crete. Some Economic Problems" *in Acts of the International Archaeological Symposium. The Relations between Cyprus and Crete ca. 2000-500 B.C.* (1969) 69-75 expressed a view that subsequently became known as Catling's paradox. Cyprus worked its ore deposits and exported copper from the end of the Bronze Age, while, before the Neopalatial period, Minoan metallurgy flourished without the source of its copper being known. For the debate on this 'paradox', see mainly A.B. KNAPP "Cyprus, Crete and Copper: a Comment on Catling's Paradox" *Report of the Department of Antiquities, Cyprus* (1990) 55-63.

safely moved to the ports of the island such as Enkomi or Toumba tou Skourou, the probable communication routes are investigated. Sometimes the security required in transporting the copper from the centre of the island to Enkomi is associated with a series of forts (Nitovikla, Nikoklidhes and Ayios Sozomenos).[69]

In her conclusions, Kassianidou raises an issue that has perhaps not been discussed adequately: the question of the relationship of the script to metalworking. Finally, reference should be made to the question that has been central to the debate for the last thirty years: was Cypriot copper transported to Crete? And from what date? It is a fact that it was not transported in great quantities during the New Palace period. Until recently the answer was negative, because the ingots from Ayia Triada and Zakros do not come from Cyprus. Nevertheless recent analyses from Gournia, Mochlos and Chania.[70] have revealed the Cypriot origins of at least some of the copper of New Palace Crete. Even more interestingly, recent analyses of bronze artefacts from Malia as early as MM II reveal that some of the copper probably comes from Cyprus.[71]

This brings us to the huge question of the transportation and distribution of oxhide copper ingots. Ingots is the name given to plaques of pure copper of rectangular shape with slightly curved sides, which are thought to imitate oxhides. This was the form in which copper was traded in the Late Bronze Age from the 16th to the 12th century. Whole ingots or fragments have been found all over the Mediterranean (particularly in the Uluburun shipwreck, in which dozens were found), invariably in specific shapes with roughly the same content of pure copper and of a corresponding weight. Ingots of this kind from the Black Sea, Aegean, Syria and Palestine, Crete, Mycenae, Sicily, Sardinia, Corsica, and recently Southern France, reveal the breadth and cohesion of the commercial networks that distributed them.[72]

The article by Lo Schiavo in this volume affords an opportunity to trace the presence and dissemination of ingots in the Central and Western Mediterranean, and also to learn something of the network that brought them here. Special mention should be made of Sardinia, where whole ingots or fragments have been found at no fewer than 36 sites, frequently along with evidence for metallurgy. In her article, Lo Schiavo identifies the evidence that points to relations with Cyprus, a question discussed extensively,[73] and dwells at length on the ways in which they were distributed. Was there perhaps a combination of routes, with different ships travelling from different ports, and possibly also from Sardinia? Farinetti has designed a database which has provided not only a useful tool but also a rational classification of the all issues surrounding ingots.

A network as large as this needs continuous and steady supply. For over 3 centuries, from the 16th until at least the 12th, it must have received constant attention from many people, in more than one city or state formation. Collaboration was required between many partners, from many geographical centres. The distribution networks functioned successfully for a long period, balancing needs with supply. The distribution of copper ingots certainly did not take place in isolation. We should imagine the ingots being traded along with a large number of other goods, textiles, perfumes, precious vessels, or rare raw materials such as tin. We have in any case a (partial) picture of the merchandise carried on a ship, thanks to the Uluburun

69. E. PELTENBURG, "From Isolation to State Formation in Cyprus c. 3500-1500 B.C.," in V. KARAGEORGHIS and D. MICHAELIDES (eds), *The Development of the Cypriot Economy from the Prehistoric Period to the Present Day* (1996) 17-43, p. 35.
70. STOS-GALE, GALE and EVELY (*supra* n. 56).
71. POURSAT and LOUBET (*supra* n. 67).
72. See recently C. PASCHALIDES, "The Aegean and the Black Sea in the LBA," in I. GALANAKI, H. TOMAS, Y. GALANAKIS and R. LAFFINEUR (eds) *Between the Aegean and Baltic Seas. Prehistory across borders*. *Aegaeum* 27 (2007) 433-445.
73. The possibility that ingots were produced on Sardinia, and the relationship between the metallurgy of this island with Cyprus, as well as issues related to recycling are discussed in the article by P. BUDD *et al.*, "Oxhide Ingots, Recycling and the Mediterranean Metals Trade," *Journal of Mediterranean Archaeology* 8.1 (1995) 1-32.

shipwreck. We know what it was carrying, and also its 'multinational' character.[74] Inside the ship there were Mycenaean, Canaanite, Cypriot, Egyptian, Cassite, Mitannite, and Syrian cultural goods. What was the scale of values that formed the basis for such varied exchanges? Was there such a scale? Was it uniform? For the ingots, at least, there must have been a standard scale, since they were distributed in a standardised form for such a long period of time. Against what were they traded? Presumably for portable goods, that were transportable and easily stored - possibly textiles? Metals, like textiles, formed a stock that was potentially convertible, which could be used and exchanged again on a different occasion and in different circumstances, possibly at a different port every time.[75]

The picture that emerges from the data is a situation familiar in the Mediterranean until very recently. That is, short commercial voyages ('cabotage'), continuous short hauls from port to port, sailing along the coast, with numerous stops of longer or shorter duration, possibly involving changes of ships and sailors and the reloading of the cargo. Goods changed hands, some left and others arrived, in bustling harbours where large crowds passed and watched, trying to communicate in different languages.[76] This is a suitable context for the small Sardinian boats which Lo Schiavo invokes, and in which she considers that raw materials and metalworking products were transported from and to Sardinia.

A great impulse was given to the debate on the distribution of ingots by investigation of the sources of metal by lead isotope analysis. In many cases the source of origin of the metal has been identified in this way: metal on Thera, for example, has been shown to have come from Lavrion (see article by Gale, Kayafa and Stos-Gale in the present volume). In addition to the information itself, the identification of the source of the ore entails a further body of evidence: distribution routes may be revealed, for example, and possibly also the middlemen, as part of the general relations and influences.[77] This method, however, has been strongly challenged in the last decade, on the grounds that possible recycling to create new ingots would influence the results and thus the source cannot be established with certainty.[78] On this occasion, the arguments on both sides have been set out, useful assessments have been made, and there has been discussion of the complex relationship between archaeology and the natural sciences, to which I shall turn below.

Nevertheless, despite the vast number of studies of Mediterranean trade based on ingots, despite the evidence that has been accumulated and the relevant theoretical elaborations, the knowledge provided by the material remains alone is scant and only partial. It should not be forgotten that we are at total loss as to the general context of the exchanges. We know nothing of the human relations that governed them, the social values that surrounded them, and the people who carried out this work. We know

74. Lo Schiavo's article contains a detailed bibliography for this shipwreck. For a general overview, see G. BASS, "Evidence of Trade from Bronze Age Shipwrecks," in N.H. GALE (ed.) *Bronze Age Trade in the Mediterranean* (1991) 69-82.

75. For a general discussion of trade in the Mediterranean and its parameters, see the article by Andrew and Susan SHERRATT, "From Luxuries to Commodities. The Nature of Mediterranean Bronze Age Trading Systems," in N.H. GALE (ed.) *Bronze Age Trade in the Mediterranean* (1991) 351-384. For Crete in particular, see M.H. WIENER, "The Nature and Control of Minoan Foreign Trade," in N.H. GALE (ed.) *Bronze Age Trade in the Mediterranean* (1991) 325-350.

76. A description of these small, manoeuverable sailing ships and their high levels of performance is to be found, albeit for other centuries, but for the same natural environment, in the classic work on the Mediterranean by F. BRAUDEL, *La Méditerranée et le monde Méditerranéen à l époque de Philippe II* (1987 [1949]) t. 1, 271-286.

77. For a general view of the provenance of metals in the Mediterranean, see the useful articles by S. STOS-GALE, "Trade in Metals in the Bronze Age Mediterranean: an Overview of Lead Isotope Data for Provenance Studies," in C.F. PARE (ed.) *Metals Make the World Go Round* (2000) 56-69 and N.H. GALE "Copper Oxhide Ingots: their Origin and their Place in the Bronze Age Metal Trade in the Mediterranean," in N.H. GALE (ed.) *Bronze Age Trade in the Mediterranean* (1991) 197-239.

78. See BUDD *et al.* (*supra* n. 73), where the arguments are set out. A very useful discussion has also been published with the arguments for both sides. Particular mention should be made of the contribution by Muhly, who attempts to make a detached presentation of the state of scholarship by setting out the pros and cons of all the arguments.

nothing of the special place of gifts. Knowledge of the material base is not in itself sufficient: many crucial questions relating to trade, such as the institutions, values, practices, the collaboration between large numbers of people, and the presence of many languages, cannot be resolved through the material evidence. And we should not forget the threat of violence – piracy, looting – that loomed over those who travelled by sea, as echoed in the Homeric poems. For the highly complex forms of exchanges, both in the Middle Eastern communities, for which there is some evidence, thanks to written texts and archives, and in the Aegean, as known from Homer and the Linear B tablets, a different approach would be needed, involving a combination of archaeological evidence and written sources.[79]

**Technological questions**

One of the intentions of the 2004 conference in Rethymnon was that the archaeologists should formulate questions of a kind that could be answered by chemical and other analyses in such a way as to allow the resolution of archaeological concerns. Or, conversely, that information on the potential of laboratory work and modern methods should furnish an impulse to the formulation of such archaeological and historical questions, in which these expert analyses might be of assistance.

We should not expect simple answers. The majority of the papers in this volume are certainly the expression of this collaboration, which on both sides is constantly under review. It may be useful, however, to undertake a brief review of relations between archaeologists and archaeometallurgists, which have passed through difficult times, frequently involving misunderstanding.[80] In brief, one might distinguish the following stages.

The first is the stage of general suspicion. In the 1960s and 1970s, some archaeologists espoused the new possibilities while others were suspicious, despite the enormous influence of the writings of Colin Renfrew on Aegean metallurgy based on archaeometallurgical studies.[81] The implicit objection was that even if we learn the chemical composition of a dagger, this will tell us nothing of its cultural features, nor will it provide any historical information. There was as yet no awareness that the chemical composition and manufacturing methods belong also to cultural traditions.

The second stage is characterised by the complete and now enthusiastic espousal by archaeology of the methods of the natural sciences. We are now in the 1980s. Books on archaeometric investigation appeared one after the other, and societies and journals were founded. For a short time, we archaeologists could bid farewell, with some relief, to the relativity of the human sciences.

The third stage may be called the phase of perplexity, the 1990s. At some point, the period of happy trust came to an end. We archaeologists, too, became aware of the relativity of scientific results. We became aware that, as for us, so for the natural scientist, the result depended on the question asked and on the method used. That here there is a choice: all objective measurements conceal a methodological choice which is not the same for everyone. What were we do to when different laboratories gave us divergent results? Invariably with methods used by the natural sciences. Invariably in search of the objective. Everything seemed to be on the verge of being debated and disputed again.

The fourth phase began in the middle of the 1990s and was consolidated recently, after 2000. We might call this phase the age of maturity, the age of constant dialogue. All of us, archaeologists and archaeometallurgists alike, became aware that in order to be able to debate, a flow of information was needed on both sides.

79. For the complexity of the subject, I believe that the study by E. BENVENISTE "Un métier sans nom: le commerce," in *Le vocabulaire des institutions Indo-européennes 1. économie, parenté, société* (1969) 139-147 is useful. It shows, through the tortuous semiology of the names, the difficulty experienced by ancient societies in accepting and assimilating commercial processes.

80. Debates of this kind have been published in recent years. See the discussion on LIBS in the *Journal of Mediterranean Archaeology* (1995) and in the *Journal of European Archaeology* (2001).

81. RENFREW (*supra* n. 4 and n. 22).

Nothing would happen automatically. We could not avoid making the effort to understand the analytical methods of the other side, and we had to accept all their doubts.

The majority of the articles in this volume are the fruit of this phase, the phase of collaboration. A special contribution has perhaps been made to these concerns by the largely archaeometallurgical articles by Papadimitriou, Kallithrakas-Kontos and Maravelaki, Anglos and his colleagues and Kilikoglou and Hein. I shall attempt a brief analysis of these investigations mainly in order to demonstrate how they tie in with the concerns of the other articles in the volume.

The article by G. Papadimitriou may be regarded as in introduction to archaeometallurgical matters, especially in the prehistoric Aegean. It sets out systematically the advantages and disadvantages of various alloys, the series of tasks in the process, and the potential of different alloys for different uses. The major alloys by period are also recorded on the basis of laboratory analysis. It is followed by two articles devoted to the investigation of the composition of metal artefacts. Both methods proposed are non-destructive. The article by D. Anglos and the ITE-Forthnet group attempts to determine the composition of the objects on the basis of the LIBS (Laser Induced Breakdown Spectroscopy) method, which is analysed. The analysis of the composition is very quick and simple and involves a portable device. The examples given are analyses carried out on metal objects from the cave of Ayios Charalambos in Eastern Crete. The analyses presented are of objects made of bronze with tin, iron, and lead (therefore probably the products of recycling) or with gold and silver. The importance of this method resides in the fact that, given that the analysis is easy and accessible, it can be carried out relatively quickly on large groups of metal objects and simultaneously with archaeological field research. This will provide us with statistics – provisional, of course, since we do not yet know the final proportion of each constituent in the overall metal composition of the object, only its presence, but statistics that can be suitably processed. That is to say we can easily and quickly acquire a credible initial picture, that will be constantly improved.

The second method, EDXRF, is also non-destructive and was presented by Professor Kallithrakas-Kontos and N. Maravelaki-Kalaitzaki. The analysis was carried out on objects from the Mycenaean cemetery at Armenoi. The advantages of the method are that in addition to the analysis of the composition of the metal, it also analyses the corrosion products, and this is of help in conservation, an issue which is said to be one of the objectives of any analysis. The majority of the objects analysed are rings. The composition of the bronze objects again reveals a slight presence of tin, corresponding with those analysed from the cave of Ayios Charalambos, and again probably due to recycling. The interesting feature is the existence of a bead and other indeterminate artefacts made of pure tin, which probably means that there was a greater abundance of this valuable material at the end of the LM III period, as can also be seen from mainland Greece and Europe (see above).[82]

The study by Hein and Kilikoglou deals with the properties of ceramics connected with metallurgical work and consequently of heat-resistant ceramics. Starting with finds from Politiko *Phorades* on Cyprus (for the significance of the site, see the article by Kassianidou) they describe the furnaces, tuyères and pot bellows. Above all, they investigate the question of heat transfer in ceramics and the level of the temperatures a matter of decisive significance in revealing the details of the smelting process.

**Epilogue. Is the evolutionary model useful?**

The jigsaw puzzle of the metallurgy and metalworking of the Aegean is slowly being completed. It is being filled in by new finds, new methods, and analyses that point to new possibilities. The pieces of the puzzle are still difficult to assemble: our knowledge is frequently fragmented, both geographically and chrono-

82. PARE (*supra* n. 1) 29-31.

logically. It consists of fragments of knowledge, rather like areas of knowledge. Nevertheless, even though the information lends itself only to an empirical approach, I believe that certain generalisations can be made over and above the highly general comments with which this introduction began – that is, the connection with the social developments. Despite the fact that the information now at our disposal is fragmented, we can be more specific and closer to the technical events. It is now possible to arrive carefully at a minimum series of technical events in a chronological and geographical sequence, not just a sequence of abstract technological development and not merely following the concept of a continuous and linear development. The effort that is being made is directed rather to plotting the evidence in chronological, technical and geographical correspondence, albeit with a number of gaps, or regressions and delays. What really makes this possible, however, is the knowledge already acquired from other parts of Europe or the East.[83] This is the context for the metallurgy of the Aegean during the Bronze Age.

A large metallurgical zone can be detected in West and Central Europe, in the areas on the Black Sea and in the Middle East. This zone is uniform despite its variations (mainly in smelting techniques); it possibly has some chronological discontinuities, but there are significant correspondences at the level of technological choices, such as the generalised use of arsenical bronze and later of tin. The question of a technologically privileged zone that followed the geography of farming innovations was raised as early as 1945 by Leroi-Gourhan.[84] Within this broad geographical zone, an overall approach of this kind was made in 1960 in the substantial work by Jean Deshayes, *Les outils de bronze de l'Indus au Danube*, in which, on the basis of morphological and functional similarities, he studied and classified all the bronze tools in this wide zone, which largely coincides geographically with the technological metallurgical zone defined and studied later.[85] It is perhaps worth recalling that Deshayes' work was written at the same period as another massive project on metallurgy, SAM, to which much reference has been made (Muhly, introduction). No attempt has been made, however, to combine the typological and metallurgical studies. Such studies, covering a large geographical area in South Russia and the Balkans, were mainly the work of Chernykh in the 1970s and the 1980s, who combined metallurgical and typological analyses.[86] With the adoption of bronze, Europe of the second millennium was a 'large metallurgical province', in Chernykh's phrase, which was adopted by Pare and may be applied also to the technological features of the Aegean.[87]

Europe and the East appear to be a unit not only as far as technological features are concerned, but also with regard to distribution. The distribution of metals functioned as a lever for exchanges, as a kind of coinage, whether this took the form of bronze torques in third-millennium Europe or of ingots in the second-millennium Mediterranean, or simply a recyclable form of broken tools and weapons at the end of the second millennium.[88]

83. An attempt of this kind was made by PARE (*supra* n. 1), who dealt with metallurgy throughout Europe and the Middle East for the entire Bronze Age.
84. LEROI-GOURHAN (supra n. 4) 309-310.

85. J. DESHAYES, *Les outils de bronze de l' Indus au Danube (IVe au IIe millénaire)* (1960).
86. E.N. CHERNYKH, *Gornoe delo i metallurgiya v drevneyskey Bolgarii*, (1978); E.N. CHERNYKH *Ancient Metallurgy in the USSR* (1992). As far as I know, CHERNYKH is the first, and probably the only one for such a large geographical region, to combine chemical, metallurgical and typological analyses with a statistical treatment.
87. PARE (*supra* 1) 25-27.
88. For the Ösenhalsring that served as ingots in Europe and the Near East during the Early Bronze Age, see P. KRAUSE and E. PERNICKA, "The Function of Ingot Torques and their Relation with the EBA Copper Trade," in C. MORDENT, M. PERNOT, V. RYCHNER (eds) *L' Atelier du Bronzier en Europe du XXe au VIIIe siècle avant notre ère* (t. II), (1998) 219-226. For the corresponding type of Ösenhalsring found at Ras-Shamra see C. F.-A. SCHAEFFER "Porteurs des Torques," *Ugaritica* 2 (1949) 49-120; C. F.-A. SCHAEFFER "Ex occidente Ars," *Ugaritica* 7 (1949) 475-552. For ingots as a precondition and result of trade and as a form of coinage with its potentially varied uses, see A. SHERRATT, "What would a Bronze-Age World System look like? Relations between temperate Europe and the Mediterranean in Later Prehistory," *Journal of European*

It is perhaps worth noting that the situation is different with regard to precious metals such as silver and gold. Here, in contrast to the relatively constant presence of bronze, there are great fluctuations, rapid increases and decreases in quantities, and techniques that emerge in developed form in many places, and are less developed in others, which sometimes disappear. No overall study of these fluctuations in the Aegean has yet been undertaken. All of this is presumably connected with the availability of metals, though mainly with values, with the real and the symbolic values of a society, and with the methods of exchange within and between communities. These 'useless' metals are probably much more sensitive to historical fortunes and reversals than are the 'useful' metals, bronze and iron. They may be said to belong to the short rather than the long term. They do not give rise to developments, but set their seal on them. A general examination of this kind, using technological and statistical evidence in the Aegean, would show the presence – or absence – of these metals in association with social and political formations.[89]

When projected against this screen, the metallurgy of the Aegean can be seen more clearly as a general technological and social phenomenon that has a distinctive character. The presence of metals is rather humble in terms both of volume and of technological performance. When compared with the important achievements of the Aegean societies in other spheres – in urban formations and the attendant sophistication of ways of life, in state formations and the complex administrative system, in scripts and the composite character of cultural achievements – the significance of metals is no less nor more than in other societies that are much less complex at the social and political level. The emergence of the powerful civilisations in the second millennium Aegean appears to be due mainly to a combination of multiple factors, not to the great advantages offered by better tools and better weapons. The social situations, therefore, that gave rise to administrative and political formations, as well as the human potential, with its techniques and inventions, functioned in combination, thus giving rise to the well known and completely distinct Aegean civilisations of the Bronze Age. Metallurgy was not absent: it played its part but this part does not seem decisive: it is just one amongst others. Where it does seem to have been predominant is in the manufacture of prestige objects, decorated vases, jewellery made of various materials, and elaborate weapons, which, however much they may give prominence to their owners, do not form the main technical body of a society, nor its strategic cutting edge. (We may call to mind much more important techniques, such as ship-building and sea-faring.)

Generally speaking the articles in this volume do not adopt a diffusionist view; nor do they take the opposite position, involving numerous centres of creation and development, in the terms in which it was expressed in the past, and also more recently on the occasion of the publication of the second volume of Sitagroi a Bronze Age settlement in Eastern Macedonia.[90] This issue does not lie at the centre of the interests of scholars, and this too is a choice, though of course not a deliberate one. This possibly chimes with the observation that Aegean metallurgy in all its variations, was formed and func-

*Archaeology* 1/2 (1993) 1-57; PARE (*supra* 1) 27-29. For the abandonment of ingots in the bronze trade, see Susan SHERRATT, "Circulation of Metals and the End of Bronze Age in the Eastern Mediterranean," in C.F. PARE (ed.) *Metals Make the World Go Round* (2000) 82-95.

89. An article by Chernykh may be regarded as an example of such a 'holistic' approach: E.N. Chernykh "Ancient Gold in the Circumpontic Area," in J.-P. MOHEN (ed.) *Découverte du métal* (1991) 387-396.

90. C. RENFREW and E. SLATER, "Metal Artifacts and Metallurgy," in E.S. ELSTER, C. RENFREW, *Prehistoric Sitagroi: Excavations in Northeast Greece, 1968-1970.* Volume 2: The Final Report (2003) 301-319. See also J. Muhly's reaction in his review of the book in the *Bryn Mawr Classical Review* (2004). Retrieved from http://ccat.sas.upenn.edu.bmcr/2004/2004-06-21.html. The view that there were numerous centres is also advanced by P.T. CRADDOCK "Copper Production in Bronze Age Britain," in J.-P. MOHEN (ed.) *Découverte du métal* (1991) 197-212. The majority of the articles in the volume in question emphasise the importance of local ore deposits for peripheral metal technologies (e.g. Southern France).

tioned in the context of a wider geographical technical zone.

In conclusion, the question should perhaps be raised here, albeit allusively, as to what happened later, after about 1200 B.C. and the end of the Late Bronze Age in the Aegean. Metallurgy does not seem to have shared in the collapse of the political formations in the Aegean. Rather, the opposite occurred. After this date, with the appearance and rapid adoption of iron, societies embarked upon a new round of the adoption of innovations. Iron, given its abundance, is considered to be a more 'democratic' metal, that was more widely disseminated.[91] There is a continuation, that is, of the same trend to the 'democratisation' of the ownership and use of metals at the end of the Bronze Age, with the clear abundance noted by Sherratt after the collapse of the bronze trade in the form of ingots.[92]

91. J.D. MUHLY, "Texts and Technology. The Beginnings of Iron metallurgy in the Eastern Mediterranean," in Αρχαία Ελληνική Τεχνολογία, 2ο Διεθνές Συνέδριο [Ancient Greek Technology, 2nd International Conference] (2006) 19-31.

92. Susan SHERRATT (*supra* n. 88).

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