

Aegean Metallurgy in the Bronze Age

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19. THE FORMATIVE YEARS OF THE CYPRIOT COPPER INDUSTRY

Vasiliki Kassianidou

Hector Catling in 1979 published a paper about copper production in Cyprus, in which he presented a 'paradox'. Namely, although great quantities of copper are used in Neopalatial Crete, which some presumed to have been imported from Cyprus, according to the archaeological evidence available at the time, metal activity on Cyprus was rather limited in this period and furthermore, trading relations between the two islands did not seem to be very strong. The situation appears radically different in the following period during which the Cypriot copper industry thrived, and great quantities of Mycenaean pottery were imported on the island. Yet according to Catling, and this is wherein lies the paradox, Crete and the Mainland, at the same time seemed to have been experiencing a shortage of metal. A number of scholars addressed the problem raised by Catling, and some have in fact questioned whether such a shortage really existed.

The purpose of this paper is to focus on another issue raised by Catling, namely the early stages of the Cypriot copper industry. Over the past twenty-five years, much new evidence has come to light regarding the role of Cyprus as a copper producer and exporter during the later part of the Bronze Age. Excavations of practically all Late Cypriot sites have revealed remnants of metallurgical workshops. Lead Isotope Analysis on oxhide and other ingots found throughout the Mediterranean, shows that most have an isotopic profile, which is consistent with that of the Cypriot ore deposits. Finally, Alashiya, the name by which Cyprus was known at the time, appears in texts from the Near East and Egypt as the copper exporter par excellence.

It is only, however, over the last decade that we have finally a better understanding of the early stages of the Cypriot copper industry and the development of smelting technology through the Bronze Age. This is due to the discovery and excavation of a number of Bronze Age sites where evidence for the extraction of copper from sulphide ores was uncovered.

One of the most important is that of Politiko Phorades, which was discovered in 1996 and subsequently excavated by a joint team from the University of Glasgow and the University of Cyprus, under the direction of A.B. Knapp and V. Kassianidou. The excavations have uncovered an impressive amount of metallurgical debris. The geological setting, the pottery and several C14 dates place the Phorades workshop in the beginning of the Late Bronze Age, making it the earliest primary smelting workshop ever excavated on Cyprus.

Introduction

In 1979 Hector Catling published a paper entitled 'Copper Production in Cyprus, Bronze in Crete: Some Economic Problems', in which he questioned whether Cyprus was indeed the principal source of copper for Crete in the Neopalatial period, during which great quantities of copper were being used.¹ His doubts were

based on three arguments: first, according to the archaeological evidence available at the time, metal activity on Cyprus was rather limited in this period, second, Cypriot society did not seem to be sophisticated enough to have been involved in long-distance trade and third, trading relations between the two islands did not seem to be very strong as Minoan finds on Cyprus were limited, as were Cypriots finds on Crete. The situation appeared radically different in the subsequent period, during which the Cypriot copper industry was thriving, and great

1. 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.* (1979) 69-75 p. 69.

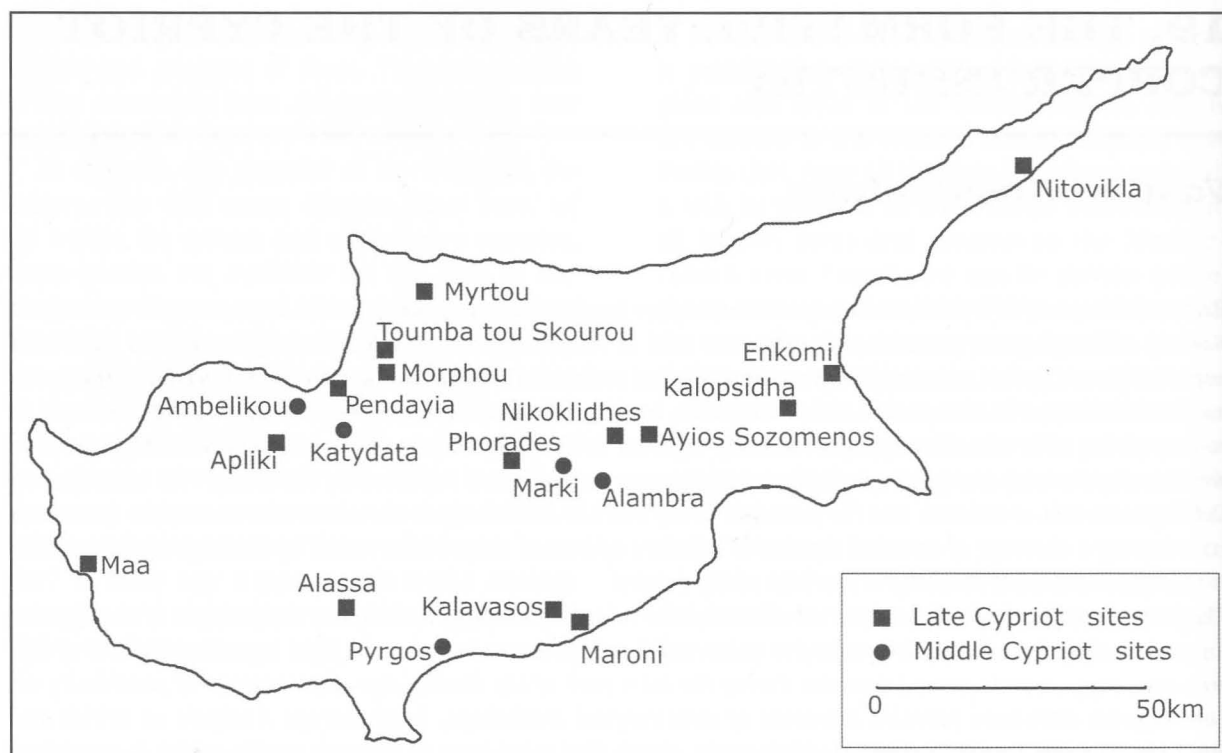


Fig. 1 Map showing Middle Cypriot and Late Cypriot sites mentioned in the text.

quantities of Mycenaean pottery were imported to the island. Yet according to Catling, paradoxically Crete and the mainland at the same time seemed to have been experiencing a shortage of metal.² A number of scholars addressed this so-called paradox and some have in fact questioned whether such a shortage really existed.³

The purpose of this paper is to address Catling's question regarding the importation of Cypriot copper into Crete in the Neopalatial period, and more specifically to present new evidence which counters his first argument. I will try and draw an up-to-date picture of the Cypriot copper industry, during its formative years, in other words in the first half of the second millennium. In archaeological terms this cor-

responds to the Middle Cypriot (ca. 1900-1600 B.C.) and to the beginning of the Late Cypriot period (LC I dates from ca. 1600-1450 B.C.). To be fair, it should be pointed out that, at the time of Catling's publication the evidence available regarding copper production on Cyprus in this period, which he called Industrial Phase I, was rather scanty, as it basically consisted of finds from two sites only, Ambelikou-Aletti and Enkomi, both of which will be discussed in more detail below.⁴ Had it not been for a number of texts from the archives of Mari, dating to the first half of the eighteenth century, which mention copper and bronze from Alashiya, the name by which Cyprus was known to its eastern neighbours, the logical conclusion deriving from the available archaeological evidence at the time would be that the production of Cypriot copper had barely started and that the metal was not exported before well into the

2. H.W. CATLING, *Cyprus and the West 1600-1050 B.C.*, *Ian Sanders Memorial Lecture* (1980) 19.

3. E.g., A.B. KNAPP *Cyprus, Crete and Copper: a Comment on Catling's Paradox*, *RDAC* (1990) 55-63; A.B. KNAPP, J.D. MUHLY and P. MUHLY, "To Hoard is Human: LBA Metal Deposits in Cyprus and the Aegean," *RDAC* (1988) 233-262, p. 257.

4. CATLING (*supra* n. 1) 69.

Late Bronze Age.⁵ However, a number of new excavations and discoveries made over the last ten years show that this is not the case. This new evidence will be presented here in an effort to argue that the technology for extracting metal from Troodos' rich copper sulphide deposits was already highly developed at this early stage of the Cypriot copper industry and that copper was being produced in some quantity. It is, therefore, possible that some of this copper would have been exported to Crete.

The Cypriot copper industry in the early stages of the Bronze Age

Perhaps the most interesting recent finds, relating to the very beginnings of metallurgy in Cyprus, are two stone moulds which were found incorporated in a Philia facies wall at the settlement of *Marki-Alonia*.⁶ Philia is a distinctive archaeological culture which appears on the island at the beginning of the Early Bronze Age, and dates from ca. 2400-2300 B.C.⁷ The moulds were used to cast boat and tongue-shaped ingots and flat axes with perforated butts which are also believed to have been used as ingots.⁸ They are, therefore, extremely important, as they indicate that metal was already cast into standard shapes for, presumably, the purpose of exchange, whether in a local or a foreign market. It is intriguing that apart from these moulds and a handful of metallic artefacts, no other finds relating to metallurgy, such as slag or refractory ceramics, have been uncovered in the excavated part of the site, which lies at a short distance from the Troodos foothills and

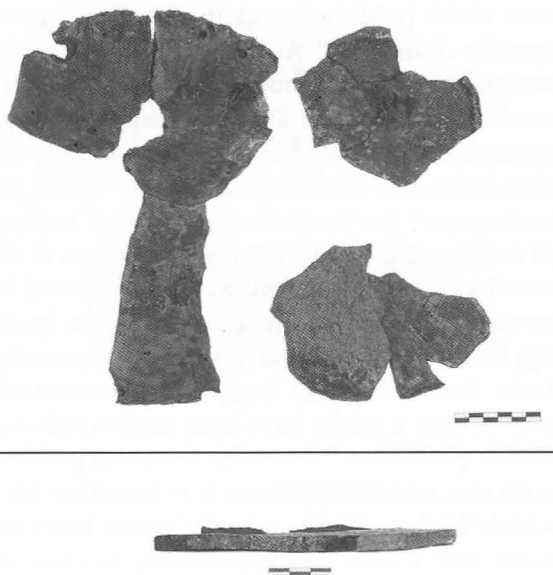


Fig. 2 Slag from Katydata dating to the Middle Cypriot Period.

the copper ore deposits. Furthermore, there is no other archaeometallurgical evidence such as slag or refractory ceramics or metallurgical installations from any other contemporary or Early Bronze Age site to show that copper smelting was taking place on the island already at this period.

Direct evidence for Bronze Age mining first came to light in 1942 at Ambelikou in the north-western foothills of the Troodos (Fig. 1), where miners discovered pottery and stone tools inside ancient shafts.⁹ The sherds come from Red Polished III pithoi and jugs, of the Middle Cypriot I period, which dates to the 19th century B.C.¹⁰ In the same year, the Department of Antiquities conducted rescue excavations at a contemporary settlement nearby, Ambelikou *Aletri*, which must clearly have been associated with the mine. Although the significance of the site was

5. J.D. MUHLY, "The Land of Alashiya: References to Alashiya in the Texts of the Second Millennium B.C. and the History of Cyprus in the Late Bronze Age," in V. KARAGEORGHIS and A. CHRISTODOULOU (eds), *Acts of the First International Congress of Cyprological Studies* (1972) 201-219, p. 20.

6. D. FRANKEL and J.M. WEBB, "Excavations at Marki-Alonia, 2000," *RDAC* (2001) 15-43, p. 35.

7. J. M. WEBB and D. FRANKEL, "Characterising the Philia Facies. Material Culture, Chronology and the Origin of the Bronze Age in Cyprus," *AJA* 103 (1999) 3-43.

8. FRANKEL and WEBB (*supra* n. 6) 35; W. FASNACHT and N. KÜNZLER WAGNER, "Appendix I. Stone Casting Moulds from Marki-Alonia," in D. FRANKEL and J.M. WEBB (*supra* n. 6) 38-40.

9. P. DIKAIOS, "A New Chapter in the Long History of Cyprus: Wartime Discoveries of the Earliest Copper Age," *Illustrated London News* 208/5576 (1946) 244-245; R.S. MERRILLEES, "Ambelikou *Aletri*: A Preliminary Report," *RDAC* (1984) 1-13.

10. MERRILLEES (*supra* n. 9) 7.

recognised, a detailed report of the excavation was never published and the site was subsequently destroyed.¹¹ Among the finds from the settlement were stone tools, ores, a double-sided terracotta mould and a crucible made of coarse grained ceramic, all of which attested to the fact that there was metallurgical activity within the settlement.¹² On the basis of qualitative analysis of a slag sample from the interior surface of the crucible, it was suggested that this was used for re-melting copper prills, produced in a smelting furnace.¹³ Tylecote also studied the crucible from Ambelikou and suggested a reconstruction of how it might have been used which was widely published.¹⁴ However, there is a problem with this reconstruction, as it is based on finds which in fact do not actually come from the same site! I take this opportunity to clear up a misconception that has become well established in the literature. Tylecote teamed up the crucible with a D-shaped tuyère, which he described as coming from Ambelikou *Aletri*. This tuyère would then be the earliest known tuyère from Cyprus. It was first discussed in 1971¹⁵ and then illustrated and discussed numerous times in Tylecote's papers and books,¹⁶ together with other tuyères which Tylecote studied in the Cyprus Museum, from Enkomi and Apliki *Karamallos*, the miners' village dating to the

Late Cypriot IIC, which roughly corresponds to the 13th century B.C., excavated in 1938.¹⁷ In the caption of the illustration, the tuyères with an inventory number starting with AK are said to come from Ambelikou, while those with inventory numbers starting with A are said to come from Apliki *Karamallos*. I was intrigued by this find and the reconstruction, as no other Middle Cypriot site where metallurgical debris has been recovered has produced any tuyères. Furthermore, the tuyère is not mentioned in either of the publications on Ambelikou, which only list the crucible and the double-sided terracotta mould. I asked both Robert Merrillées and Anne Elizabeth Vaturi who are now in charge of publishing Dikaïos excavation and neither of them has any knowledge of such a tuyère coming from Ambelikou, as it is not listed among the finds in Dikaïos inventory.

Having studied the stone tools from the later miners' settlement of Apliki *Karamallos*, I knew that the excavator of that site, Joan Du Plat Taylor, had used both AK and A as a prefix for the finds. Thanks to Prof. Jim Muhly and Barbara Kling, who are in charge of publishing that excavation, I had access to Du Plat Taylor's diary and inventory and thus I could actually check whether, as I suspected, the D-shaped tuyère with the inventory number AK RZ14 came from Apliki. Indeed this is the case: the tuyère comes from House A, room 2 (clearly Tylecote mistook number 2 to be the letter Z) and is fourteenth on the list of finds from this room. In his reconstruction, Tylecote is using a Middle Bronze Age crucible together with a Late Bronze Age tuyère! In fact, to date, no tuyères have been found in any of the excavated Middle Cypriot sites. The use of tuyères in Cyprus seems to be a technological advance of the Late Bronze Age.

Metallurgical remains were also uncovered at the Middle Bronze Age settlement of Alampra.

11. DIKAIOS (*supra* n. 9) 245.

12. MERRILLEES (*supra* n. 9) 7.

13. U. ZWICKER, G. CONSTANTINO, H.G. BUCHOLZ and V. KARAGEORGHIS, "Investigation of an Ore, Flux and Crucible Slag from Prehistoric Copper Smelting at Ambelikou, Cyprus," *Revue d'Archéométrie. Supplément 1981 Actes du XX Symposium International d'Archéométrie*, Paris 1980 (1981) 331-340 p. 338; U. ZWICKER, "Bronze Age Metallurgy at Ambelikou – Aletri and Arsenical Copper in a Crucible from Episkopi – Phaneromeni," in J.D. MUHLY, R. MADDIN and V. KARAGEORGHIS (eds), *Early Metallurgy in Cyprus, 4000-500 B.C.* (1982) 63-68, p. 63.

14. R.F. TYLECOTE, "Observations on Cypriot Copper Smelting," *RDAC* (1971) 53-58, p. 56; R.F. TYLECOTE, "From Pot Bellows to Tuyères," *Levant* 13 (1981) 107-118, p. 111; R.F. TYLECOTE, "The Late Bronze Age: Copper and Bronze Metallurgy at Enkomi and Kition," in MUHLY *et al.* (eds), (*supra* n. 13, 1982) 81-100, pp. 93-94; R.F. TYLECOTE, *A History of Metallurgy* (1992) 22.

15. TYLECOTE 1971 (*supra* n. 14) 55.

16. TYLECOTE 1981 (*supra* n. 14) 115; TYLECOTE 1982 (*supra* n. 14) 94; R.F. TYLECOTE *The Early History of Metallurgy in Europe* (1987) 119.

17. J.T. DU PLAT, "A Late Bronze Age Settlement at Apliki, Cyprus," *The Antiquaries Journal* 32 (1952) 133-167; J.D. MUHLY, "The Organisation of the Copper Industry in Late Bronze Age Cyprus," in E. PELTENBURG (ed.), *Early Society in Cyprus* (1989) 298-314, pp. 306-309.

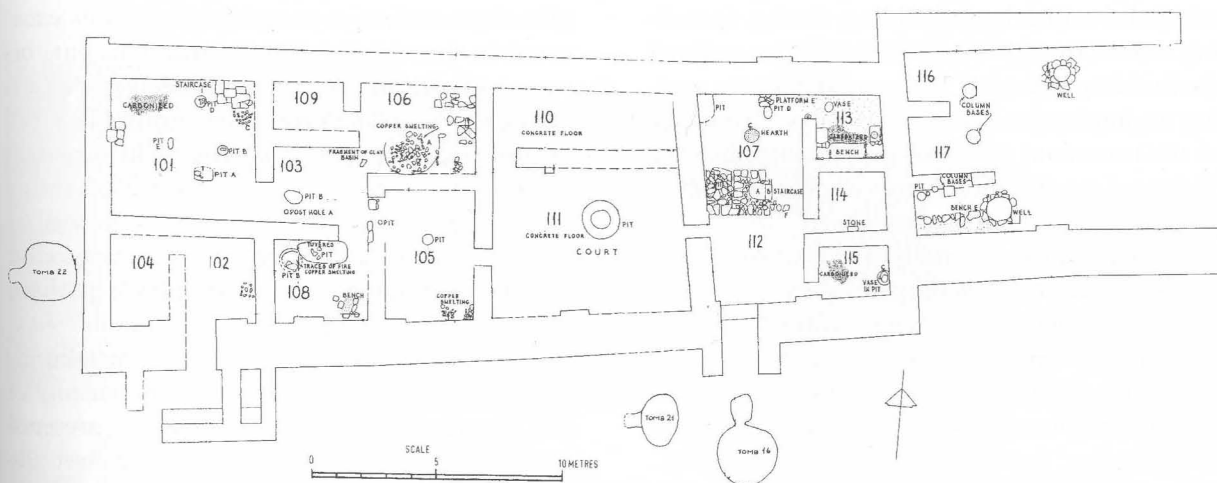


Fig. 3 Plan of the Fortress, located in Enkomi's Area III, during the LC I (ca. 1600-1450 B.C.) (Dikaios 1969).

According to radiocarbon dating, the site was occupied between 1900 and 1800 B.C.¹⁸ During the excavations, small quantities of mineral samples, pieces of slag and crucibles were collected.¹⁹ Chemical and mineralogical analysis showed that the slag was the product of a smelting process. The fact that no matte or other copper sulphide inclusions were detected in the analysed samples led to the conclusion that at Alambra copper extraction was not based on the exploitation of copper sulphides.²⁰ It is surprising, therefore, that the bronze artefacts from the same site were found to contain significant amounts of iron and small amounts of sulphur, while microscopic analysis detected a number of copper sulphide inclusions interspersed in the metal phase.²¹ These objects were clearly manufactured from metal extracted from sulphide ores! Among the finds were two fragmentary moulds used to produce bar ingots and indi-

cating the standardised form in which metal would have circulated during this period.²²

A small amount of slag was found during the excavation of a settlement at Kalopsidha, which becomes an important site in the later phases of the Middle Bronze Age.²³ Although a limited number of metallurgical finds was found (and some may be related to the later, Late Cypriot I, phase of the site), it clearly shows some metallurgical activity.²⁴ Once again, however, a preliminary report on the analysis of these slag samples could not state conclusively that they were derived from smelting sulphide ores.²⁵

More evidence of Middle Bronze Age copper smelting has come recently from the settlement of Pyrgos *Mavroraki*.²⁶ Excavations under the direction of Maria Rosaria Belgiorno have un-

18. J.E. COLEMAN, J.A. BARLOW, M.K. MOGELONSKY and K.W. SCHAAR, *Alambra, A Middle Bronze Age Settlement in Cyprus. Archaeological Investigations by Cornell University 1974 - 1985* (1996) 335.

19. N.H. GALE, S. STOS-GALE and W. FASNACHT, "Metal and Metalworking," in J.E. COLEMAN *et al.* (eds) (*supra* n. 18), 129-142, p. 139.

20. N.H. GALE, S. STOS-GALE and W. FASNACHT, "Copper and Copper Working at Alambra," in J.E. COLEMAN, *et al.* (eds), (*supra* n. 18) 359-426, p. 390.

21. GALE *et al.*, (*supra* n. 20) 379.

22. GALE *et al.* (*supra* n. 19) 135-136.

23. P. ÅSTRÖM, *Excavations at Kalopsidha and Ayios Iakovos in Cyprus*, (1966) 138.

24. T.F. WATKINS, "Metal Finds," in P. ÅSTRÖM (ed.), (*supra* n. 23) 113-115.

25. H.G. BACHMANN, "Copper Slag Preliminary Report," in P. ÅSTRÖM, D.M. BAILEY and V. KARAGEORGHIS (eds), *Hala Sultan Tekke I Excavations 1897-1971*, (1976) 127-128.

26. M.R. BELGIORNO, "Preliminary Report on Pyrgos Excavations 1996, 1997," *RDAC* (1999) 71-80; M.R. BELGIORNO, "Project Pyrame 1998-1999: Archaeological, Metallurgical, and Historical Evidence at Pyrgos (Limassol)," *RDAC* (2000) 1-17; M.R. BELGIORNO, *Pyrgos-Mavroraki Advanced Technology in Bronze Age Cyprus* (2004).

covered a rather large building, dating, according to C14 from 1900-1850 B.C.²⁷ The walls of the building collapsed after an earthquake, sealing an impressive array of artefacts. According to the excavator, this was an industrial quarter dedicated to the production of olive and perfume oil, textiles and copper.²⁸

Although in the initial published excavation reports of this site smelting installations are described in some detail, these should be treated with great caution.²⁹ The so-called smelting furnaces are circular depressions lined with plaster.³⁰ Plaster is a non-refractory material which disintegrates in temperatures above 900°C, and, therefore, not an appropriate choice for the construction of a smelting furnace, which would operate well above this limit. This, together with the fact that there is no evidence of slagging on the lining of the pits, which are often filled with ash, which does not survive in a smelting furnace as it is incorporated in the slag³¹ and their recorded size (according to Belgiorno³² one of them had a diameter of 1m!) argues against their identification as smelting installations. Giardino suggests that they may have been 'furnaces used to anneal the metal objects produced in the workshop'.³³ Equally possible is that they are, in fact, pot stands, known from other sites of this period, and indeed in some of them complete ceramic vessels, destroyed *in situ*, were found.

Although the excavator mentions the presence of numerous crucible fragments among the finds from these buildings, only one undiagnostic fragment is described.³⁴ A well-preserved, unused crucible was among the burial

gifts deposited in a contemporary tomb excavated in the vicinity of the settlement, but this was clearly meant for melting metal to be cast, rather than for smelting.³⁵ An impressive array of grinding stones and pestles were found at the site, but these may have been used in the processing of plants such as cereals, as well as copper ores or slag. A large stone anvil found in one of the rooms of this complex is perhaps the only clearly metallurgical stone tool.³⁶

The most obvious indication that metallurgical activities were taking place in the vicinity of this so-called industrial quarter is the presence of slag, which is found scattered all over the excavated area.³⁷ It is in the form of small irregular-shaped pieces, which are often covered with heavy incrustations of copper carbonates, clearly demonstrating that they are rich in metal.³⁸ Their small size, irregular shape and copper incrustations show that the smiths achieved neither a high enough temperature nor the right mixture of ore and flux needed to produce a 'good' slag: in other words, a slag with a low melting point and low viscosity which easily separates from the metal. As a result, the two phases had to be mechanically separated using stone tools, perhaps of the type found at the site.³⁹ Chemical and microscopic analysis of the slag shows that the ore smelted was a copper sulphide.⁴⁰ It is very hard to calculate the scale of the production at Pyrgos, as none of the excavation reports gives exact information as to the total mass of slag collected: Belgiorno mentions thousands of pieces weighing from 350g-1g.⁴¹ Nevertheless, in general this site has produced the largest amount of slag from Cyprus

27. BELGIORNO 2004 (*supra* n. 26) 21.

28. BELGIORNO 2004 (*supra* n. 26) 22-23.

29. BELGIORNO 1999 (*supra* n. 26) 76; BELGIORNO 2000 (*supra* n. 26) 8-10.

30. BELGIORNO 2004 (*supra* n. 26) 34.

31. R.F. TYLECOTE, H.A. GHAZANI and P.J. BOYDELL, "Partitioning of Trace Elements between Ores, Fluxes, Slags and Metal During the Smelting of Copper," *Journal of Archaeological Science*, 4 (1977) 305-333, p. 307.

32. BELGIORNO 2000 (*supra* n. 26) 8.

33. C. GIARDINO, "Prehistoric Copper Activity at Pyrgos," *RDAC* (2000) 18-32, p. 27.

34. BELGIORNO 2000 (*supra* n. 26) 34; GIARDINO (*supra* n. 33) 27.

35. M.R. BELGIORNO, "A Coppersmith Tomb of Early-Middle Bronze Age in Pyrgos (Limassol)," *RDAC* (1997) 119-146; BELGIORNO 2004 (*supra* n. 26) 66; GIARDINO 2000 (*supra* n. 33) 27; C. GIARDINO, G.E. GIGANTE and S. RIDOLFI, "Archaeometallurgical Investigations on the Early-Middle Bronze Age Finds from the Area of Pyrgos (Limassol)," *RDAC* (2002) 33-49, p. 37.

36. BELGIORNO 2004 (*supra* n. 26) 32-33.

37. BELGIORNO 2004 (*supra* n. 26) 30.

38. BELGIORNO 2004 (*supra* n. 26) 31; GIARDINO 2000 (*supra* n. 33) 21.

39. GIARDINO 2000 (*supra* n. 33) 25.

40. GIARDINO 2000 (*supra* n. 33) 23.

41. BELGIORNO 2004 (*supra* n. 26) 31.



Fig. 4 View of the site of Politiko-Phorades.

dating from the Middle Bronze Age and, therefore, it is very important. Although we may still not be certain of the type of installations used, it is clear from the slag that the smelting process was not yet very efficient and a significant amount of metal was lost.

An even more recent discovery published here for the first time shows that towards the end of the Middle Bronze Age smelting technology may in fact not have been so primitive after all. From 2001-2003, the Troodos Archaeological and Environmental Survey Project (or TAESP), an interdisciplinary program under the direction of Michael Given, Bernard Knapp, Jay Noller and the author systematically surveyed a wide area located along the north-western foothills of the Troodos.⁴² One of

the main purposes of the project was to record all archaeometallurgical sites within the survey area and, it was hoped, to discover some that date from the Bronze Age. Much of our attention was focused around the region of the mine of Skouriotissa, where one of the largest copper ore deposits of the island was once located, but now has been largely mined away, and the location of some of the most impressive remains of the ancient Cypriot copper industry. The landscape is marked by enormous slag heaps measuring hundreds of metres in length, standing over 20m in height and dating mainly from the Roman period, but we were hoping to find workshops dating from earlier periods as well. After all, just a few kilometres away

42. For more information on the project see M. GIVEN and A.B. KNAPP, "Troodos Archaeological and Environmental Survey Project: First Preliminary Report (June-July 2000)," *RDAC* (2001) 425-440; M. GIVEN, V. KASSIANIDOU, A.B.

KNAPP and J. NOLLER, "Troodos Archaeological and Environmental Survey Project, Cyprus: Report on the 2001 Season," *Levant* 34 (2002) 25-38; A. BOUTIN, A.B. KNAPP, I. BANKS, M. GIVEN and M. HOROWITZ, "Settlement and Cemetery in and Around Katydata Village: from Prehistory to the Roman Era," *RDAC* (2003) 335-349.

from Skouriotissa is the mine of Apliki, where in 1938 remains of a miners' village, dating from the 13th century B.C., was partially excavated before the site was destroyed by the modern mining operations.⁴³ Furthermore, in 1915, Menelaos Markides, an archaeologist working for the Department of Antiquities, excavated a number of tombs in the vicinity of Skouriotissa ranging from the Middle Bronze Age down to the Iron Age.⁴⁴ Within the village of Katydata, which is at a distance of less than a kilometre from the mine, Markides excavated nine tombs dating from the Late Cypriot Period.⁴⁵ Unfortunately, the location of the Late Bronze Age settlement with which these tombs would have been associated is not known. As much as we had hoped to and tried, I am sorry to say that we did not find a Bronze Age smelting site or any archaeometallurgical finds dating from periods prior to the Roman era, but as luck would have it, someone else did.

The Cyprus Water Authority, while opening a long trench in one of the roads in Katydata village, uncovered a series of Bronze Age tombs. Giorgos Georgiou was the archaeological officer in charge of the rescue excavations and I would like to thank him for allowing me to mention here what he uncovered. Two of the tombs were excavated and produced an array of pottery, which dates from the MCII period (1800 - 1725 B.C.). What is extraordinary, however, is that among the finds that came out of this trench was a small quantity of slag. It is unclear whether the slag was inside or outside the tombs but it is assumed that it is contemporary with the cemetery. If it did come from the tombs, then it will be the first time that we have clear evidence of slag being deposited together with other funerary gifts. Unfortunately, the excavation was not extended and these questions will remain for the moment unanswered. What does the slag look like? The fragments come

from flat circular cakes of a very small thickness (Fig. 2). The slag is very homogeneous and, therefore, very different from that found on the other two MC sites. In fact, as far as I know, it is different from anything else we know from Cyprus. It is to be hoped that chemical and microscopic analysis, now under way, will enable us to know more about the technology that produced it.

To summarise: although still rather limited, over the last ten years a number of discoveries have shown that Middle Cypriot was indeed a period during which the foundations for the Cypriot copper industry were established. The information derived from the analysis of the slag shows that copper was extracted from copper sulphide ores and that although in most cases the technology seems rather primitive, the finds from one site, that of Katydata, show that there was some progress which anticipates what was to follow in the subsequent period. Clearly the production of copper had already commenced and if we accept the written documents, so had the exportation of copper, at least in small quantities, to the East.

The Cypriot copper industry in the Late Bronze Age

However, according to both the textual⁴⁶ and the archaeological evidence, it is in the Late Bronze Age that both the production and the exportation of copper truly develop, reaching a zenith in the 13th century, during which oxhide ingots made of Cypriot copper, if we accept the results of the Lead Isotope Analysis, were shipped in the hundreds to the East and the West.⁴⁷ Recent

46. MUHLY (*supra* n. 5) 212, 217; A.B. KNAPP, "Alashiya, Caphtor/Keftiu, and Eastern Mediterranean Trade: Recent Studies in Cypriot Archaeology and History," *Journal of Field Archaeology* 12/2 (1985) 231-250, p. 238; A.B. KNAPP, "Introduction," in A.B. KNAPP (ed.), *Sources for the History of Cyprus. Volume II: Near Eastern and Aegean Texts from the Third to the First Millennia B.C.* (1996) 1-13, pp. 3, 8, 11.

47. There is an extensive bibliography regarding the trade in Cypriot copper and oxhide ingots: E.g. N.H. GALE, "Archaeometallurgical Studies of Late Bronze Age Copper Oxhide Ingots from the Mediterranean Region," in A. HAUPTMANN, E. PERNICKA and R. KRAUSE (eds), *Old World Archaeometallurgy* (1989) 247-268; N.H. GALE, "Copper Oxhide Ingots: their Origin and their Place in the Bronze Age

43. DU PLAT (*supra* n. 17) 133-167; MUHLY (*supra* n. 17) 306-309.

44. P. ÅSTRÖM, *Katydata. A Bronze Age Site in Cyprus* (1989) 7.

45. ÅSTRÖM (*supra* n. 44) 9.

discoveries show that oxhide ingots are found as far east as the Kassite palace of Dur-Kurigalzu located near Baghdad,⁴⁸ as far west as Marseille⁴⁹ and as far north as Oberwilfingen in

Metals Trade," in N.H. GALE (ed.), *Bronze Age Trade in the Mediterranean* (1991) 197-239; N.H. GALE, "Lead Isotope Characterization of the Ore Deposits of Cyprus and Sardinia and its Application to the Discovery of the Sources of Copper for Late Bronze Age Oxhide Ingots," in S.M.M. YOUNG, A.M. POLLARD, P. BUDD, and R.A. IXER (eds), *Metals in Antiquity* (1999) 110-121; N.H. GALE and Z.A. STOS-GALE, "Copper Oxhide Ingots and the Aegean Metals Trade. New Perspectives," in P. BETANCOURT, V. KARAGEORGHIS, R. LAFFINEUR and W.-D. NIEMEIER (eds), *Meletemata. Studies in Aegean Archaeology Presented to Malcolm H. Wiener as he Enters his 65th Year*, *Aegaeum* 20 (1999) 267-277; V. KASSIANIDOU, "Cypriot Copper in Sardinia: Yet Another Case of Bringing Coals to Newcastle?," in L. BONFANTE and V. KARAGEORGHIS (eds), *Italy and Cyprus in Antiquity: 1500-450 B.C.* (2001) 97-119; V. KASSIANIDOU, "Η παραγωγή και εξαγωγή Κυπριακού χαλκού κατά την Χαλκοκρατία [The production and export of Cypriot Copper during the Bronze Age]" in A. KYRIATSOULIS (ed.), *Αρχαία Ελληνική Τεχνολογία και Τεχνική* [Ancient Greek Technology and Technique], Σύλλογος για τη Μελέτη και τη Διάδοση της Ελληνικής Ιστορίας (2003) 67-85; A.B. KNAPP, "Alashiya, Caphtor/Keftiu, and Eastern Mediterranean Trade: Recent Studies in Cypriot Archaeology and History," *Journal of Field Archaeology* 12/2 (1985) 231-250; A.B. KNAPP, "Copper Production and Eastern Mediterranean Trade: the Rise of Complex Society on Cyprus," in J. GLEDHILL, B. BENDER and M.T. LARSEN (eds), *State and Society: Emergence and Development of Social Hierarchy and Political Centralisation* (1988) 149-169; A.B. KNAPP, "Archaeology, Science-based Archaeology and the Mediterranean Bronze Age Metals Trade," *European Journal of Archaeology* 3/1 (2000) 31-56; J.D. MUHLY, "The Nature of Trade in the Late Bronze Age Eastern Mediterranean: The Organization of the Metals Trade and the Role of Cyprus," in MUHLY *et al.* (*supra* n. 13) 251 - 269; J.D. MUHLY, "The Role of Cyprus in the Economy of the Eastern Mediterranean," in V. KARAGEORGHIS (ed.), *Acts of the International Symposium Cyprus Between the Orient and the Occident* (1986) 45-60; J.D. MUHLY, "The Significance of Metals in the Late Bronze Age Economy of Cyprus," in V. KARAGEORGHIS and D. MICHAELIDES (eds), *The Development of the Cypriot Economy From the Prehistoric Period to the Present Day* (1996) 45-60; J.D. MUHLY, "Cyprus and Copper for the World," in Ü. YALÇIN (ed.), *Anatolian Metal III* (2005) 137-141; J.D. MUHLY, R. MADDIN and T. STECH, "Cyprus, Crete and Sardinia: Copper Oxhide Ingots and Bronze Age Metals Trade," (1988) 281-298.

48. J.D. MUHLY, "Cypriote Copper: Some Geological and Metallurgical Problems," in *Acts of the International Archaeological Symposium, the Relations Between Cyprus and Crete, ca 2000- 500 B.C.* (1979) 86-100.

49. CL. DOMERGUE and C. RICO, "À propos de deux lingots de cuivre antiques trouvés en mer sur la côte languedocienne," in L. RIVET and M. SCIALLANO (eds), *Vivre, produire et échanger: reflets méditerranéens* (2002) 141-152.



Fig. 5 The slag heap formed against an old river channel's bank.



Fig. 6 Concentration of large furnace fragments.

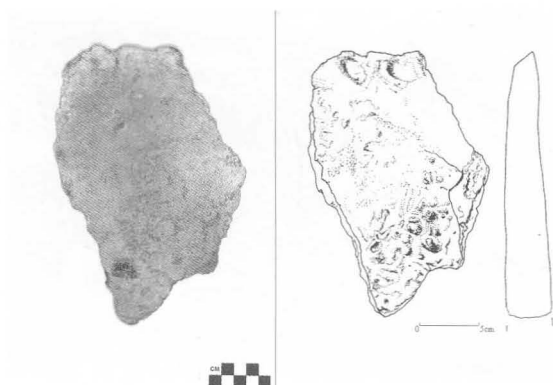


Fig. 7 One of the largest fragments of furnace wall from Phorades. Drawn by Glynnis Fawkes and photographed by Christopher Parks.

Germany.⁵⁰

I will argue that already from the beginning of this period, in other words in the Late Cypriot I (ca. 1600-1450 B.C.), which roughly corresponds to Late Minoan I, the period with which Catling was concerned, smelting technology was already well developed, allowing large quantities of copper to be extracted from the Troodos' sulphide ore deposits. Indeed, Jim Muhly reached the same conclusion 15 years ago, when he presented some of the preliminary results of his study of the archaeometallurgical finds from the Dikaios excavations at Enkomi.⁵¹

Evidence of copper production first appears at Enkomi in the earliest excavated level of Area III, which Dikaios attributed to the MC III (ca. 1725-1600 B.C.) period.⁵² This consisted of two fragments of tuyères, the earliest examples to be found on Cyprus. The use of tuyères may in fact be one of the main technological developments of the Late Bronze Age smelting technology over that of the Middle Bronze Age, for, as I have argued above, no tuyères are known from any Middle Cypriot excavated sites. Improved furnace design and the use of tuyères and bellows led to higher temperatures

and more reducing atmospheres, while the use of fluxing agents lowered the melting point and produced more fluid slags, and led to better separation between the metal and the slag.⁵³

During the beginning of the LC I, a large building, identified as a fortress by Dikaios, was erected in Area III (Fig. 3). Throughout its lifespan, from the LCI to the LCIIIA (in other words ca. 1600-1100 B.C.), this building underwent a number of destructions and reconstructions, often with slight modifications to its ground plan, but some of the rooms, as well as open spaces, are believed to have always been dedicated to metallurgical activities.⁵⁴ This argument is based on the discovery of large numbers of tuyère and crucible fragments, bellows, and slag within the area of this complex.⁵⁵

The question has always been what the exact nature of the metallurgical processes taking place there was.⁵⁶ Dikaios reported a significant slag heap which he found in association with the copper workshops in his Area III.⁵⁷ The presence of slag may be an indication that one of the processes was smelting, although most scholars agreed that this was not a logical location for a primary smelting workshop.⁵⁸ Indeed, slag is also produced in other processes, such as refining and casting, and therefore its presence does not exclusively indicate smelting.⁵⁹ In fact, the discovery of a number of stone moulds for the casting a variety of objects such as daggers⁶⁰ or even beads, presumably of gold⁶¹, shows that casting was also taking place there. The point is that, as important as they are, the finds

p. 141.

50. M. PRIMAS and E. PERNICKA, "Der Depotfund von Oberwilfingen," *Germania* 76 (1998) 25-65, p. 42.

51. MUHLY (*supra* n. 17) 299.

52. P. DIKAIOS, *Enkomi. Excavations 1948-1958, Vol. II* (1971), 500.

53. J.A. CHARLES, "The Coming of Copper and Copper-base Alloys and Iron: a Metallurgical Sequence," in T.A. WERTIME and J.D. MUHLY (eds), *The Coming of the Age of Iron* (1981) 151-182, pp. 164-167.

54. DIKAIOS (*supra* n. 52) 500, 516.

55. DIKAIOS (*supra* n. 52) 505; MUHLY (*supra* n. 17) 299.

56. MUHLY (*supra* n. 17) 302; T. STECH, "Urban Metallurgy in LBA Cyprus," in MUHLY *et al.* (eds), (*supra* n. 13) 105.

57. P. DIKAIOS, *Enkomi. Excavations 1948-1958, Vol. I* (1969) 46.

58. STECH (*supra* n. 56) 102.

59. H.G. BACHMANN, *The Identification of Slags from Archaeological Sites* (1982) 2.

60. Inv. Number 3544/2; DIKAIOS (*supra* n. 52) 635.

61. Inv. 1411; DIKAIOS (*supra* n. 52) 684.

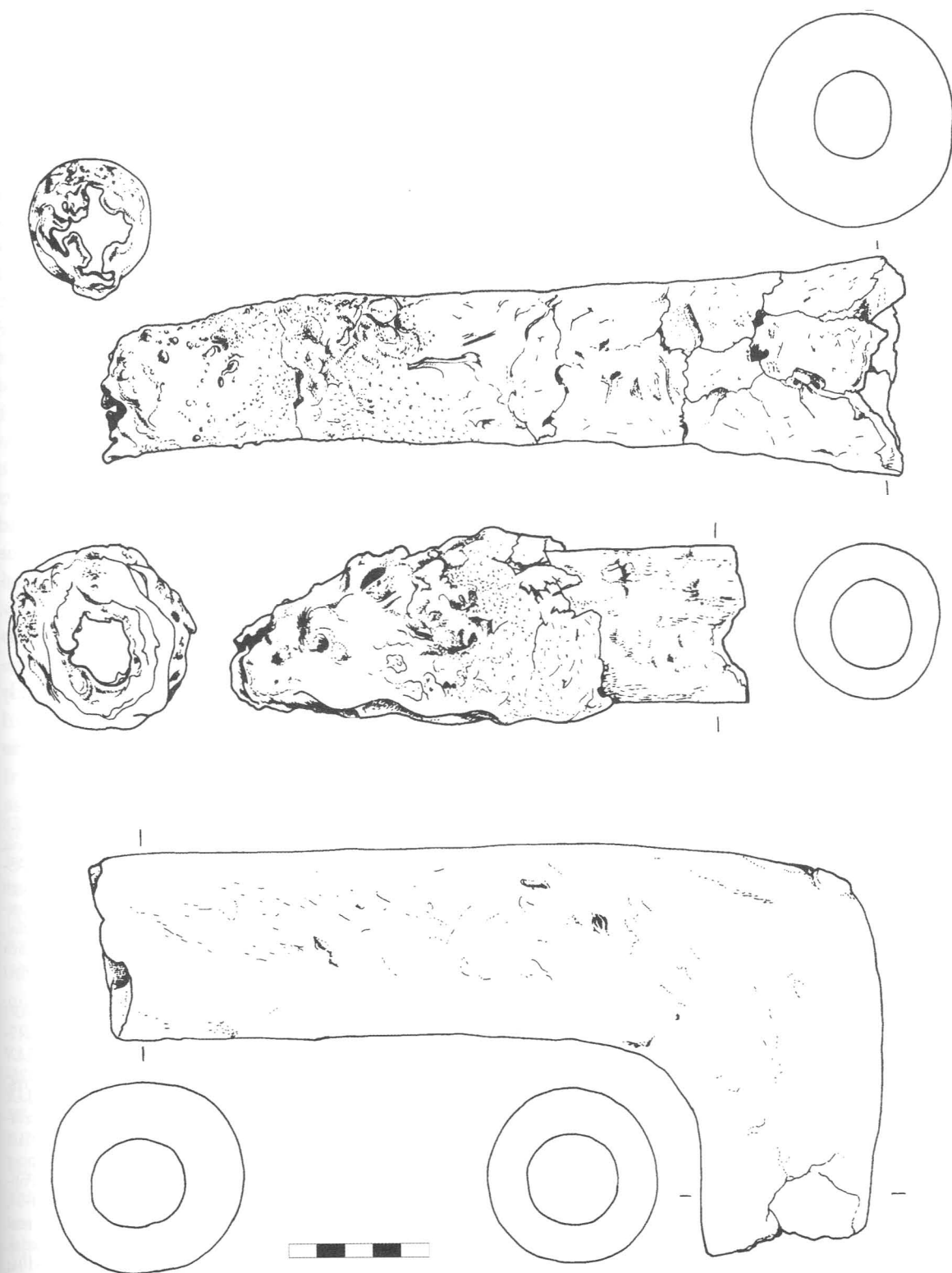


Fig. 8 Types of tuyères from Phorades. Drawn by Glynnis Fawkes.



Fig. 9 Tuyère from Phorades. Photographed by Christopher Parks.

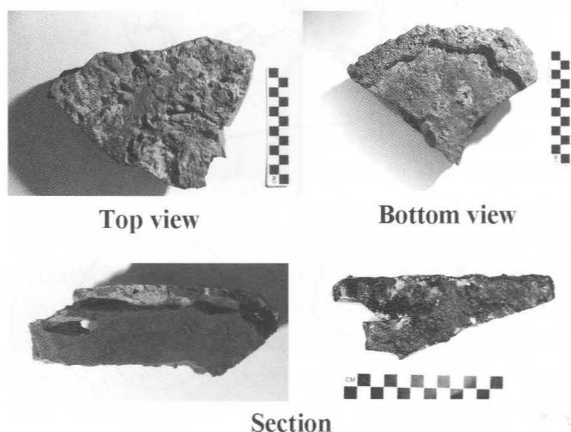


Fig. 10 Slag from Phorades. Photographed by Christopher Parks.

from Enkomi could not clarify basic questions regarding the Late Bronze Age technology of extraction of copper from sulphide ores. For this purpose a primary smelting workshop had to be studied.

The Late Cypriot copper smelting workshop at Politiko-Phorades

Such a workshop was finally discovered on the site of Politiko Phorades during the 1996 field season of the Sydney Cyprus Survey Project. Phorades was excavated by a joint team from the University of Glasgow and the University of Cyprus, under the direction of A.B. Knapp and myself.⁶² A number of preliminary reports have already been published and the final publication is almost complete.⁶³ The discussion which follows is a summary of the specialist reports which will be published in the monograph, and I would like to acknowledge the work of the people who have contributed to the examination and study of the material from Phorades. Michael Donnelly and Paul Duffy were the excavation field directors, while Jay Noller provided a much needed geomorphological study of the site and the surrounding landscape. I studied the archaeometallurgical material from

62. For more information on this project see M. GIVEN and A. B. KNAPP, *The Sydney Cyprus Survey Project: Social Approaches to Regional Archaeological Survey* (2003); V. KASSIANIDOU, "Recording Cyprus Mining History Through Archaeological Survey," in M. IACOVOU (ed.), *Archaeological Field Survey in Cyprus: Past History, Future Potential. Proceedings of a Conference Held by the Archaeological Research Unit of the University of Cyprus 2000*, BSA Studies 11 (2004) 95-104.

63. A.B. KNAPP, M. DONNELLY and V. KASSIANIDOU "Excavations at Politiko Phorades 1997," *RDAC* (1998) 247-268; A.B. KNAPP, V. KASSIANIDOU and M. DONNELLY "Excavations at Politiko Phorades 1998," *RDAC* (1999) 125-146; A.B. KNAPP, V. KASSIANIDOU and M. DONNELLY "Copper Smelting in Late Bronze Age Cyprus. The Excavations at Politiko Phorades," *Near Eastern Archaeology* 64/4 (2001) 204-209; V. KASSIANIDOU, "Bronze Age Copper Smelting Technology in Cyprus - the Evidence from Politiko Phorades," in YOUNG *et al.* (eds) (*supra* n. 47) 91-97; V. KASSIANIDOU, "54 Archaeometallurgical Finds and Analytical Results," in M. GIVEN and A.B. KNAPP (eds), (*supra* n. 62) 214-227; KASSIANIDOU (*supra* n. 62) 95-104; A.B. KNAPP, "The Archaeology of Community on Bronze Age Cyprus: Politiko Phorades in Context," *AJA* 107 (2003) 559-580.

the workshop and was in charge of the chemical and microscopic analysis of the slag and metal finds. The archaeometric analysis of the refractories was undertaken by Anno Hein and Vassilis Kilikoglou of the Archaeometry Laboratory of the Demokritos National Centre for Scientific Research while Costas Xenophontos did the petrography of the ceramic refractories.⁶⁴ The ceramics from *Phorades* were studied by Ellie Ribeiro and Sturt Manning, who was also in charge of the radiocarbon dating. The wood species analysis of the charcoal from the workshop was undertaken by Maria Dinou, and the faunal remains were studied by Paul Croft. Carole McCartney studied the lithics.

The workshop is situated on the bank of an ancient creek bed (Fig. 4). There, using river pebbles, the metalworkers constructed flat working surfaces, on which they operated the smelting furnaces. No architectural remains have been discovered, showing that the work was done in the open air, clearly at a time of the year during which the weather allowed such activities to take place. The slag produced was piled against the creek's bank, eventually forming a small heap (Fig. 5). Just to the east of the slag heap a concentration of very large fragments of furnace wall was found (Fig. 6), as well as a unique, well-preserved elbow tuyère. A couple of possible crushing stones have been found at *Phorades*, but there are no other remains clearly connected with ore beneficiation or the roasting process. Either these steps took place in some part of the site that has not survived, or else they were carried out near the mine. Kokkinorotsos, the likely source of the ores, lies about 500 metres to the north-west.

In the area of the working platforms and around the slag heap we uncovered an admittedly small but clearly Late Cypriot I to early Late Cypriot II ceramic assemblage. In order to confirm the Late Cypriot I date suggested by the ceramic assemblage, we carried out radiocarbon analyses on charcoal trapped within the furnace lining and the slag. Nine samples have

been successfully dated by AMS. The radiocarbon dates suggest a calendar age for the metallurgical activities somewhere from the 16th through the 15th centuries B.C. In other words, consistently with the ceramic assemblage, the radiocarbon dates place the workshop in the Late Cypriot I. *Phorades*, then, is a primary smelting workshop contemporary with the earliest phase of the Enkomi workshops.

Whereas the site itself, and indeed the archaeological finds, are rather unimpressive, the same cannot be said of the archaeometallurgical finds. We have collected more than 6,000 fragments of furnace rims, walls and bases. However, despite this high number of furnace fragments and the fact that at some points of the excavated area concentrations of large diagnostic pieces were found, it has not been possible to reconstruct a complete furnace or even a complete profile. Nevertheless, the finds provide enough information for us to understand how the furnaces were made, to suggest what they looked like and to understand how they operated. All of the furnace fragments derive from free-standing, cylindrical structures with well-defined rims and flat bases, made entirely of coarse refractory clay mixed with chaff (Fig. 7). It is interesting that, according to Carole McCartney, the vast majority of the lithics collected are flakes with a light polish, which may have resulted from their use to shred plant fibres. Their presence, therefore, may be used as indirect evidence that the furnaces were produced *in situ* using local raw materials.

In the majority of the fragments, the thickness of the walls ranges between 2.5cm and 4.5 cm while the thickness of the bases ranges between 4cm and 7.5cm. As we were unable to reconstruct a full profile of a furnace, we are missing one of the crucial dimensions, which is the height of the cylinders. However, some of the rim fragments and the body fragments are large enough to show that the furnaces would have been at least 30cm high. Their diameter is estimated at approximately 42-44cm. Fingerprint impressions on the exterior, usually where the wall joins the base, show how the furnaces

64. Cf. paper in this volume.

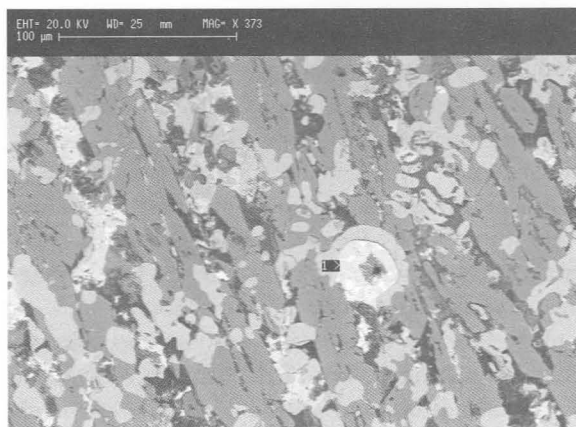


Fig. 11 Micrograph of slag from Phorades showing long fayalite crystals, wüstite globules and a small matte prill, set within a glassy matrix.

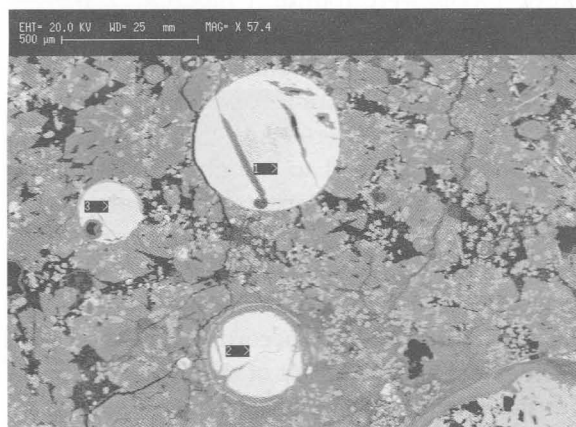


Fig. 12 Micrograph of slag from Phorades showing matte prills.

were constructed: first a thick, flat, circular disk was formed on which the cylindrical body was built with slabs. It is clear that the furnaces were constructed in the round, not in a pit or against a stone wall. Had this been the case, the outer surface would not have been so smooth and finger impressions would have been on the interior surface where the maker would have pushed the clay against the pit or the stone structure (as at Timna⁶⁵ and at Ayia Varvara-Almyras⁶⁶). The best parallel for the *Phorades* furnaces is the well-known 'crucible' from Enkomi,⁶⁷ which Tylecote⁶⁸ defined as a smelting furnace. This was found in Enkomi's Area III where Dikaios excavated a series of copper workshops. The 'crucible' was recovered from the floor of a room of the Level IIB building which Dikaios dated to between 1300 and 1230 B.C.⁶⁹ It is, therefore, later in date than the examples from *Phorades*. Apart from the difference in date, there is also a difference in the size, the one from Enkomi being smaller (the diameter is 30cm and the preserved length is 20cm⁷⁰). This may indicate a different use for the example from Enkomi, such as melting enough copper metal to cast an ingot weighing a talent.

Tuyères formed an integral part of the smelting installations. In an excavated area of approximately 30 square metres, we have collected over 600 fragments and 50 almost complete examples. The majority are cylindrical, while, as stated above, we have a single elbow tuyère and a rare intriguing group of double-walled tuyères (Fig. 8). As none of the tuyères has been found complete, the possibility must be considered that more elbow tuyères did exist.

65. B. ROTHENBERG, "Copper Smelting Furnaces, Tuyères, Slags, Ingot-moulds and Ingots in the Arabah: the Archaeological Data," in B. ROTHENBERG (ed.), *The Ancient Metallurgy of Copper. Researches in the Arabah 1959-1984*, Vol. 2 (1990) 1-74, p. 12 and fig. 25.

66. W. FASNACHT, K. ZUBLER, R.S. MORRIS, D. GERBOTHÉ, V. KASSIANIDOU, A. CONNOLLY and T. REHREN, "Excavations at Ayia Varvara-Almyras. Fourth Preliminary Report," *RDAC* (1992) 60-74, p. 63 and pl. XVII 1.

67. Inv. 1640; DIKAIOS (*supra* n. 57) 58; DIKAIOS (*supra* n. 52) 644.

68. TYLECOTE (*supra* n. 14) 92.

69. DIKAIOS (*supra* n. 52) 452.

70. P. DIKAIOS (*supra* n. 57) 58.

THE FORMATIVE YEARS OF THE CYPRIOT COPPER INDUSTRY

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	TiO ₂	MnO ₂	K ₂ O	P ₂ O ₅	CuO	ZnO	S
23.9	4.8	64.4	1.8	0.4	0.1	0.2	0.3	2.7	0.4	1.2

Table 1: Average values of major and minor elements in slag from *Phorades* determined by XRF.

In the ones where the nozzle is preserved, it is slagged and highly vitrified. There is a fair amount of standardisation in the dimensions of these artefacts: they have an outer diameter ranging between 5-7cm and an airhole, which is rarely perfectly cylindrical, or symmetrically positioned, ranging between 2.5-3.5cm. None of them is preserved to its full length but one of the best examples has a length of ca. 30cm (Fig. 9). Tylecote identified three types of tuyère from Bronze Age sites in Cyprus: the straight cylindrical, the straight 'D' shaped, and the elbow tuyère.⁷¹ In general, the tuyères from *Phorades* conform to this classification and are similar, in shape and material, to those from Apliki⁷² and Enkomi⁷³, although the ones from Apliki are rather more massive in their construction.

The excavations have also revealed examples of a fourth type, previously unknown from Cyprus: the double-walled tuyère. In four well-preserved examples, a layer of clay seems to have been wrapped around what appears to be a used tuyère, identified as such because of its slagged outer surface. This suggests that the purpose behind the design was not to protect the inner tuyère, by a second layer made of more refractory clay, as is the case with the examples from Timna, dating from the New Kingdom, but rather to repair and re-use a tuyère which was somehow damaged but could still be of use.⁷⁴

The fact that this double-walled type is quite wide provides some clues as to the position of tuyères within the furnace structure. Had they been introduced from the side, as shown in Tylecote's well-known reconstruction of LBA furnaces from Kition and Enkomi, we would expect

to find furnace fragments with a curvature or hole that would fit such a wide tuyère⁷⁵. Yet we have not found any fragments of furnace wall with openings for tuyères. This, I believe, indicates that the tuyères were introduced into the structure from the top rather than the side. The length and the extent of the slagging in all the tuyères also seem to support this idea.

Apart from the position of the tuyères, there are other questions relating to the operation of the furnaces. We know both from Egyptian wall-paintings and sites in the Near East,⁷⁶ but more importantly from other sites in Cyprus, namely Enkomi,⁷⁷ Alassa⁷⁸ and Maa⁷⁹ that the tuyères were used together with ceramic bellows. At *Phorades*, we have not found any definite fragments of ceramic bellows. Two small rim sherds made of a very coarse fabric, unknown from other sites, and bearing traces of having been exposed to high temperatures, may have come from such vessels. If so, they are very different from the examples we do know from Enkomi, Maa and Alassa, which are wheel-made. All of those, however, date from the LC IIIA, in other words, they are almost 250 years later than the occupation at *Phorades*. Nevertheless, even if these sherds are dismissed, there still is the possibility that at *Phorades* they used leather bellows.

We know that the ore smelted was a copper sulphide, and, thanks to Maria Dinou, who has studied the charcoal from the site, we know that

71. TYLECOTE (*supra* n. 14) 92-93.

72. DU PLAT (*supra* n. 17) 152, 161.

73. E.g. Inv. Numb. 2336/9P; DIKAIOS (*supra* n. 52) 627.

74. ROTHENBERG (*supra* n. 65) 8.

75. TYLECOTE (*supra* n. 14) 91.

76. C. J. DAVEY, "Some Ancient Near Eastern Pot Bellows," *Levant* (1979) 101-111.

77. Inv. 1640; DIKAIOS (*supra* n. 52) 577.

78. S. HADJISAVVAS, "Alassa, a New Late Cypriote Site," *RDAC* (1986) 62-67, p. 66.

79. U. ZWICKER, "Appendix VIII: Investigations of Material from Maa-Palaeokastro and Copper Ores from the Surrounding Area," in V. KARAGEORGHIS and M. DEMAS (eds), *Excavations at Maa-Palaeokastro, 1979-1986* (1988) 427-448, p. 430.

the fuel used was charcoal produced almost exclusively from *Pinus Brutia*, the pine tree that even today predominates in the landscape.

The furnaces produced metal and slag. It is not surprising, therefore, that the waste product of the process, slag, is the most abundant find from *Phorades*: we have collected over three and a half tons of slag fragments which come from large plano-concave cakes (Fig. 10). The slag is homogeneous, very dense, and magnetic. This is due to the high percentage of iron oxides confirmed both by bulk chemical analysis, using XRF and undertaken by Andreas Karydas of the Demokritos National Centre for Scientific Research, which showed that the slags have an iron content averaging 64.4%, and by micro-analysis (Fig. 11). Although, in section, there are no metallic prills visible to the naked eye, the copper content of the slag averages 2.7%, which is relatively high in comparison to that of slag dating from later periods: for example, in the Roman period, copper concentrations are below 1%.⁸⁰ The average composition of the slag from *Phorades* is shown in Table 1.

The manner in which the cakes are shaped, in particular the concave bottom, suggests that the slag has cooled on top of a layer of molten metal. Long fayalite crystals show that the slag body was able to cool rather slowly (Fig. 11). The fact that in a number of the cakes small river pebbles are found embedded in their edges shows that the contents of the furnace were tapped into a pit, which was sometimes lined with pebbles. There the slag and the metal were left to separate. Indeed very similar slag was produced in smelting experiments, during which, following a technique described by Agricola, the full contents of the furnace were tapped into a sand mould.⁸¹

The slag from *Phorades* is totally different from the slag coming from the Middle Cypriot sites discussed earlier. Clearly it is a 'good' slag, the product of a much more advanced and suc-

cessful smelting technology. The slag also differs in shape from other known slag dating from the Late Cypriot period. In Apliki, for example, there are large cakes of tap slag,⁸² while at Kition some of the slag is plano-convex in shape.⁸³ The fact is that the type was unknown in Cyprus until now.⁸⁴ We need to consider whether the difference is due to the chronological distance between *Phorades* and these other LC sites, or whether this is a technological difference: i.e., is this the type of slag one finds in a primary smelting workshop and the other what one finds in workshops which were involved in secondary processes?

At *Phorades* the metal produced was matte. This statement is based not only on the presence of matte prills within the slag matrix (Fig. 12) but also on the discovery of a small piece of matte. This was found to consist of 73.5% Cu, 2.6% Fe and 23.9% S. Matte is in fact an intermediate product in the smelting process of sulphides ores and, therefore, a usually extremely rare find. It would have had to undergo further treatment before it could be converted into black copper; the latter would then have to be refined, probably several times, in order to produce metal pure enough to be used in casting artefacts. Each of these processes would produce a different type of slag. At *Phorades* we only find the slag which is related to the initial stages of smelting copper sulphide ores into matte, and therefore none of the other processes seems to have been carried out in this workshop. This is an important point as it may explain the findings from the coastal urban centres.

In the past, archaeologists studying the production of Cypriot copper have suggested that in the LBA there still existed a primitive technology in which a material they identified as furnace conglomerate was produced somewhere near the mining districts and then transported to the urban centres for further processing.

80. KASSIANIDOU (*supra* n. 62) 100.

81. M. BAMBERGER and P. WINCIEZ, "Ancient Smelting of Oxide Copper Ore," in B. ROTHENBERG (ed.), *The Ancient Metallurgy of Copper* (1990) 123-157, p. 133.

82. MUHLY (*supra* n. 17) 306.

83. TYLECOTE (*supra* n. 14) 89.

84. For a classification of Cypriot slag see F.L. KOUCKY and A. STEINBERG, "The Ancient Slags of Cyprus," in MUHLY *et al.* (eds), (*supra* n. 13) 117-137.

There it was smelted in small furnaces, forming a pool of copper at the bottom, and prills of copper within the lower, outer portions. It was thus argued that copper was recovered largely through the crushing of slag, and the removal of the copper prills trapped within it, which were then melted together to form a copper ingot.⁸⁵ We now know that the Late Bronze Age smiths had been greatly underestimated. The study of the finds from *Phorades* shows clearly that in the LBA both the design of the smelting installations, which included ceramic tuyères and perhaps bellows, and the use of flux, had been perfected so as to produce two well-separated products: matte and slag. There was no need for the crushing of the slag in order to remove the metal, as was the case for the MBA. However, the matte did have to be further processed and this final stage does not seem to have taken place at the primary smelting workshop. As slag is found on the coastal sites, often containing copper sulphides, it looks as if these secondary smelting and refining stages took place there. Why this would be so is not well understood. Stech suggested that it may have been because of the wish of the ruling class to control the final product of the copper industry, which in state-controlled workshops on the coast would have been turned into standardised ingots for export.⁸⁶

If we assume that for every kilo of slag, roughly 100g of metal would have been extracted, then at *Phorades* an estimated total of 350kg of metal was produced. This is not a huge amount of copper but it is significant. Surely this was one of many such workshops that would have operated in the Troodos mountains. The fact that it lies at some distance from all the large ore bodies, which were extensively exploited in the 20th century, is probably the reason why it survived while so many others have perished. One only needs to look at the extremely altered

landscape around the modern mine of Skouriotissa to realise how lucky we were to find it.

Conclusions

What is known about Cyprus in the Late Cypriot I period? Unfortunately, not very much, as not many settlements dating from this period have been extensively excavated. This is the period during which Enkomi, clearly the most important known LC settlement, was founded, which some believe may have controlled the whole of the island.⁸⁷ The establishment of fortresses such as those at Nitovikla, Nikoklidhes and Ayios Sozomenos and the discovery of mass burials at Morphou, Pendaria and Myrtou along the north coast have been used by some as evidence that this was a time of turmoil and upheaval.⁸⁸ The fact that some of these fortresses are inland seems to show that the threat was an internal rather than an external one.⁸⁹ Peltenburg argued that since some of the fortresses are located along the route linking the mining regions with Enkomi, perhaps they were established by Enkomi to control and protect the transporting of copper from the mines to the coast.⁹⁰ The location of *Phorades* almost at the centre of the island could very well mean that it was under the control of Enkomi. However, almost at an equal distance to the west lies another important settlement dating from this period, Toumba tou Skourou, which could also have received copper produced at *Phorades*.⁹¹ The metal would have been cast into ingots both for local use and for export, although to date no oxhide ingots have been found in LCI deposits in Cyprus. This, of course, may be because apart from the complex in Enkomi's Area III, no metalworking workshops dating

85. T. STECH, R. MADDIN and J.D. MUHLY, "Production at Kition in the Late Bronze Age," in V. KARAGEORGHIS and M. DEMAS (eds), *Excavations at Kition VI: The Pre-Phoenician Levels, Areas I and II, Part I* (1985) 388-402, p. 399; MUHLY (*supra* n. 17) 303.

86. STECH (*supra* n. 56) 112.

87. E.g. MUHLY (*supra* n. 17) 299.

88. R.S. MERRILLEES, "The Early History of Late Cypriot I," *Levant* 3 (1971) 56-79, pp. 75-78.

89. H. W. CATLING, "Patterns of Settlement in Bronze Age Cyprus," *OpAth* 4 (1962) 129-169, p. 141.

90. E. PELTENBURG, "From Isolation to State Formation in Cyprus ca. 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.

91. KNAPP (*supra* n. 63) 574-575.

from this period have been excavated in other urban settlements. It is during the LCI that the Cypro-Minoan script appears on the island and it is perhaps of interest that the earliest known tablet written in this script was found in the copper workshops of Enkomi's Area III.⁹² This is perhaps the best evidence for the emergence of a complex society which, having started trading with its neighbours, had to establish a recording system.

New settlements were established along the coast, marking the beginning of Cyprus's interest and involvement in sea-borne trade.⁹³ For example, an underwater survey of the seabed at the site of Maroni, *Tsaroukas* detected several well-preserved ceramic sherds dating from the Late Bronze Age and recorded 35 stone anchors, of the Cypriot Late Bronze Age type, indicating that this must have been an anchorage during this period.⁹⁴ Among the finds was a variety of LC IA wares, as well as imported ceramics such as Canaanite jars⁹⁵, indicating that the anchorage was used for long-distance trade already from the 17th century B.C.⁹⁶ That Cyprus had established trading relations with its neighbours at this time is evident from the fact that Levantine, Egyptian and Aegean imports start to appear on the island while Cypriot ceramics are found in the Levant, Egypt, Anatolia, and the Aegean, including a few sherds found in LMI deposits at Kommos and Pseira.⁹⁷ Although more difficult to detect, Cypriot copper was most probably also exported at this time. I have argued that both the finds from Enkomi's Area III and especially those from *Phorades* show that at the beginning of the Late Bronze Age the smelting technology was already well-

developed and efficient. There should, therefore, be no doubt that Cyprus was producing large quantities of copper, some of which could have been exported.

The question raised by Catling is whether some of this copper made it to Crete, something which he doubted. Initial Lead Isotope Analysis of the earliest known oxhide ingots, found at Ayia Triada, Tylissos and Kato Zakros, dating from the Late Minoan IA-IB period, seemed to confirm Catling's scepticism, as they were found to be made of a copper deriving from a geologically very old, hitherto unknown, deposit, which could not have been located in Cyprus.⁹⁸ This led Gale to the conclusion that:⁹⁹

'At any rate, Cypriot oxhide ingots were not coming to Crete in the period 1550-1450 B.C.; indeed Cypriot copper was almost certainly not being cast into oxhide ingots as early as this. In this period oxhide ingots were made elsewhere, though we know from our work on the Middle Cypriot site Alambra that Cypriot copper was being used on a small scale as early as about 1800 B.C.'

However, recent analytical data show that this statement now has to be amended. Lead isotope analysis of oxhide ingot fragments from Gournia dating from LM IB showed to be consistent with a copper ore deposit probably located in the NW Troodos.¹⁰⁰ Similarly, all analysed ingot fragments from LM IB levels of Mochlos were found to be consistent with a Cypriot provenance.¹⁰¹ Clearly, then, some Cypriot copper did make it to Crete in the Neopalatial period. Even more fascinating are the recently published LIA analysis of objects from Quartier Mu of Malia which date to the MM IIB.¹⁰² Among the anal-

92. DIKAIOS (*supra* n. 52) 503.

93. CATLING (*supra* n. 89) 134.

94. S.W. MANNING, D.A. SEWELL and E. HERSCHER "Late Cypriote IA Maritime Trade in Action: Underwater Survey at Maroni Tsaroukas and the Contemporary East Mediterranean Trading System," *BSA* 97 (2002) 98-162, p. 114.

95. MANNING (*supra* n. 94) 126-146.

96. MANNING (*supra* n. 94) 159.

97. A.B. KNAPP and J.F. CHERRY, *Provenience Studies and Bronze Age Cyprus: Production, Exchange and Politico-economic Change* (1994) 43-44.

98. GALE (*supra* n. 47) 224; GALE (*supra* n. 47) 119; N.H. GALE and S. STOS-GALE, "Archaeometallurgical Research in the Aegean," in M. BARTELHEIM, E. PERNICKA and R. KRAUSE (eds), *The Beginnings of Metallurgy in the Old World* (2002) 277-301.

99. GALE (*supra* n. 47) 254.

100. GALE (*supra* n. 47) 119.

101. Z.A. STOS-GALE and N.H. GALE, "Lead Isotopic and Other Isotopic Research in the Aegean," in K. P. FOSTER and R. LAFFINEUR (eds), *Metron. Measuring the Aegean Bronze Age, Aegaeum* 24 (2003) 83-101.

102. I owe this information to J.D. Muhly whom I would

ysed objects 4 have a lead isotope composition consistent with the Cypriot copper ores, showing that even in small quantities some Cypriot copper reached Crete even earlier!¹⁰³

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103. J.-C. POURSAT and M. LOUBET, "Métallurgie et Contacts Extérieurs à Malia (Crète) au Minoen Moyen II: Remarques sur une Série d'Analyses Isotopiques du Plomb," in R. LAFFINEUR and E. GRECO (eds), *Emporia. Aegeans in the Central and Eastern Mediterranean*, *Aegaeum* 25 (2005) 117-121.

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