OXHIDE COPPER INGOTS IN CRETE AND CYPRUS AND THE BRONZE AGE METALS TRADE

INTRODUCTION

THE so-called oxhide copper ingots potentially provide a key to the understanding of the Late Bronze Age metals trade in the Mediterranean region. Nevertheless in spite of many investigations, both archaeological[1] and scientific,[2] it has hitherto not been found possible to turn that key to unlock the information certainly held by them. In the preliminary work reported here on some ingots from Cyprus and from Hagia Triadha, Crete, we show how the application of the methods of lead isotope geochemistry bids fair to succeed where other approaches have largely failed.

Oxhide ingots have a wide distribution in the Mediterranean.[3] They are found in corpore from Sardinia[4] and Sicily in the west, through Crete and mainland Greece to Bulgaria,[5] Cyprus, and Anatolia in the east; they are depicted also in an important series of tomb paintings in Egypt.[6] They have been recovered from the sea at Antalya off the coast of Turkey and Kyme off the coast of Euboea. Their importance in reconstructing the ancient trade in the Mediterranean was dramatized by the discovery off the coast of Turkey of the Cape Gelidonya Bronze Age shipwreck which had on board thirty-nine such ingots[7] and has recently been highlighted by the spectacular discovery of the Kaş shipwreck.[8] All extant oxhide ingots appear to belong to the second millennium BC and most to its second half; they clearly represent an important form in which raw copper was transported in the Late Bronze Age. Arguments presented by Bass[9] show that these ingots do not, as formerly suggested,[10] represent an early form of currency and that their shape has nothing to do with the tanned hide of an ox, but the name oxhide ingot is so commonly accepted in the English literature that nothing is to be gained by inventing another.

By and large the ingots display a measure of standardization of shape[11] and weight (at around 29 kg) which was probably intended to guarantee their nature and value to buyers throughout the Mediterranean area. The characteristic shape of the later ingots, with concave sides and protruding corners, would have facilitated their being carried on the shoulders of one man or in the hands of two men. Oxhide ingots are indeed depicted in Egyptian paintings

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[1] Principally H. G. Buchholz, *PZ* 37 (1959) 1-40 and *Schweizer Munzblätter* 16 (1966) 62: G. F. Bass, *Transactions of the American Philosophical Society* 57 (8) (1967) and in *Orient and Occident: Festschrift Cyrus H. Gordon* (Kevelaer 1973) 29-38.

[2] The scientific work on oxhide ingots has chiefly been conducted by R. Maddin, J. D. Muhly, R. F. Tylecote, and U. Zwicker. A complete list of the relevant publications is encompassed in the publications: J. D. Muhly, *Acts of the International Archaeological Symposium 'The Relations Between Cyprus and Crete, ca.2000-500 B.C.'* (Nicosia 1979) 87-100 and in *Early Metallurgy in Cyprus* (Nicosia 1982) 251-69.

[3] See Buchholz, op. cit. and Bass, op. cit. (n. 1 above).

[4] F. Lo Schiavo, *Rend. Linc.* xxxv, fasc. 5-6 (1980) 379-88.

[5] B. Dimitriov, *Int. J. Nautical Archaeology* 8 (1979) 70-9.

[6] See the discussion by Bass (1967), op. cit (n. 1 above).

[7] Bass, op. cit (1967) (see n. 1 above).

[8] G. F. Bass, D. A. Frey, and C. Pulak, *Int. J. Nautical Archaeology* 13 (4) (1984) 271-9.

[9] Bass, op. cit. (1967), (see n. 1 above).

[10] C. Seltman, *Greek Coins* (London 1955) 5 ff.; A. K. Kyrou, *Nomismatika Chronika* 1 (1972) 64-75.

[11] See Buchholz, op. cit. (1959) and Bass, op. cit. (1967) (n. 1 above) for discussions of the variations in both shape and weight.

as being carried on the shoulders of Keftiu or Syrians.[12] When it was required to use copper from an oxhide ingot, the ingot was broken into pieces of a size suitable for melting down in a crucible. The breaking of a copper ingot into pieces to make different objects is described in a Hittite text[13] and archaeological excavations have turned up many ingot fragments, e.g. at Mathiati,[14] Pyla-Kokkinokremos,[15] Skouriotissa, and Ayios Dhimitrios[16] in Cyprus, in Crete at Gournia[17] and Kommos, at Emporio in Chios,[18] at Ayia Irini in Keos,[19] and at many sites in Sardinia.[20]

The Source or Sources of the Oxhide Ingots—Archaeological Evidence

It is clear that copper oxhide ingots have a special connection with Cyprus. Apart from the ingots and ingot fragments found at Enkomi, Mathiati, Skouriotissa, Pyla-Kokkinokremos, Maa, and Ayios Dhimitrios/Kalavassos there are two Cypriot openwork bronze stands which contain offering bearers carrying oxhide ingots.[21] Moreover, there is the bronze statue of an armed, horned god standing on an oxhide ingot which was excavated by Schaeffer[22] at Enkomi from an LC III context (early twelfth century BC), which has now been joined by a twelfth-century BC bronze statuette of a female divinity standing on an oxhide ingot.[23] The armed, horned god is not only associated with the copper mines but is ready to protect them at a time when the copper trade was endangered by troubled conditions in the eastern Mediterranean.[24] Catling has identified the female ingot deity with the goddess who symbolizes the fertility of the copper mines. The religious connection of the oxhide ingots in Cyprus, and of copper metallurgy generally, is emphasized by votive miniature oxhide ingots found at Enkomi[25] and in other evidence from the sites of Kition, Palaeopaphos, and Myrtou-Pigadhes.[26]

It has been generally accepted by Aegean archaeologists that Cyprus was a very important source of copper for the Minoans and the Mycenaeans, and therefore that oxhide ingots found in Crete or Greece were most likely made in Cyprus from Cypriot copper.[27] One strand of the arguments used to support this thesis, apart from the evidence summarized above for a special connection of oxhide ingots with Cyprus, is the commonly accepted identification of Cyprus with Alashiya.[28] There is no doubt from Hittite, Egyptian, Ugaritic, and other texts that a principal export of Alashiya was copper. Though the texts do not suggest that copper was exported from Alashiya to the West, it has been sufficient for most scholars that the accepted equation of Cyprus with Alashiya establishes Cyprus as an exporter of copper in the Late Bronze Age. That copper was produced then in Cyprus is certain from the archaeological

[12] See Bass, op. cit. (1967) (n. 1 above).

[13] A. Kempinski and S. Košak, *Tel Aviv* 4 (1977) 87–93.

[14] H. W. Catling, *Cypriot Bronzework in the Mycenaean World* (Oxford 1964).

[15] V. Karageorghis and M. Dernas, *Pyla-Kokkinokremos* (Nicosia 1984).

[16] A. South-Todd, *Report of the Department of Antiquities Cyprus* (1983).

[17] P. Betancourt, T. S. Wheeler, R. Maddin, and J. D. Muhly, *MASCA Journal* 1 (1978) 7-8.

[18] S. Hood, Excavations in Chios (Oxford 1982) 665.

[19] J. Caskey, *Hesperia XL* (1971) 388 pl. 75*a*.

[20] Lo Schiavo, op. cit. (see n. 4 above).

[21] One from Kourion, now in the British Museum, is described by Catling, op. cit. p. 205 pl. 34 (see n. 14 above); the other was published by A. D. Tushingham, *Archaeology* 32 (4) (1979) 53–5.

[22] C. F. A. Schaeffer, *Antiquity* 39 (1965) 56, pl. xvi*b*, and *Alasia* i (Paris 1971) 505 ff.

[23] Catling, *Alasia* i (Paris 1971) 15–32. The statuette is in the Ashmolean Museum, Oxford.

[24] V. Karageorghis, *Cyprus* (London 1982) 103–4.

[25] Bass, op. cit. (1967 and 1973) (see n. 1 above).

[26] Karageorghis, op. cit. (1982) 104 (see n. 24 above).

[27] The signs impressed or incised into many oxhide ingots have been compared with Cypro-Minoan, Linear A and Linear B, but Bass (1967, op. cit. in n. 1 above) has shown that no group of signs is uniquely related to any one of them. The signs cannot therefore be used to support a Cypriot origin for particular ingots.

[28] The case for the equation Alashiya = Cyprus has recently been forcibly argued by J. D. Muhly, *Proceedings First International Congress of Cypriot Studies* i (Nicosia 1972) 201–10; the case against the equation was ably argued by R. S. Merrillees, ibid. 111–19.

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evidence from such sites as Enkomi, Kition, Hala Sultan Tekke, and Kalavassos/Ayios Dhimitrios. For most Aegean archaeologists the final link in the chain of evidence is the appearance in Cyprus of Mycenaean and Minoan pottery, at its height in the fourteenth and much of the thirteenth centuries BC.[29] It was assumed that this pottery, and its contents, represented the Cypriot end of a trade which, in the opposite direction, had its motivation in the Minoan and Mycenaean procurement of copper from Cyprus. These arguments were reinforced by the observation that, starting at the beginning of the Late Bronze Age, an urban revolution took place in Cyprus with the establishment close to the coast of substantial new settlements[30] which, it had been reasonably assumed, owed their *raison d'être* to foreign trade.

In the absence of other evidence the arguments presented above are reasonable, but it must be stressed that it remained purely an assumption that the objective of Minoan and Mycenaean interest in Cyprus was copper.[31] The failure of minor element chemical analysis as a means of provenancing copper[32] meant that there was no direct proof that Cypriot copper ever came into Minoan or Mycenaean hands. However, Catling had pointed out that both the pottery record and an acceptance of the equation Alashiya = Cyprus revealed that Cyprus had its strongest links with the East, especially Syria-Palestine and Egypt, and had suggested that Cyprus' continental neighbours may well have wished to keep the island's strategic and economic importance free of Western influence.[33] Catling had also pointed to a strong western interest in the Levant, suggesting that there may be about as much Mycenaean III pottery in sites in Syria-Palestine and Egypt as there is in Cyprus.[34] Moreover, Catling had noted a paradox in the assumption that Cyprus was the dominant source of copper for Crete and Greece throughout the period 1650–1200 BC.[35] He had observed that from about 1650 to 1450 BC copper was abundant in Greece and Crete, but that this is the period where the pottery record shows intense Cypriot involvement with Syria-Palestine and Egypt and very limited contact between the Aegean and Cyprus. In contrast, from about 1450 to 1200 BC there is abundant evidence for contact between the Aegean and Cyprus (though also between both the Aegean and Cyprus and Syria-Palestine-Egypt) but in this period Catling avers that there is every sign that the Aegean was faced by a metal shortage that was never solved.

The evidence for a special connection of copper oxhide ingots with Cyprus is in fact confined to the twelfth century BC, whereas Egyptian tomb paintings[36] dating to the early part of the fifteenth century BC already show men of Keftiu bearing oxhide ingots of the early Type 1.[37] In Crete itself the copper oxhide ingots from Zakros date to LM IA (*c.*1550–1500 BC) whilst those from Hagia Triadha date somewhere between late MM III and LM IA. These and other facts have led Catling to argue that:[38]

> The Mycenaean colonisation of Cyprus at the end of the thirteenth century BC brought a revolution in the working and management of the metal industry, including the introduction of the 'ox-hide' ingot as a technical and administrative convenience. Though the final history of this ingot type belongs to Cyprus, there is no proof that it originated there. The idea probably was developed in Crete as an

[29] P. Astrom, *SCE* iv (iD), 709–54 and in *Acts of the International Archaeological Symposium: The Relations Between Cyprus and Crete circa 2000–500 B.C.* (Nicosia 1979) 122–7.

[30] e.g. Enkomi, Hala Sultan Tekke, and Kition.

[31] Tin, which was unavailable anywhere within the Aegean, seems an equally possible source of Western interest in Cyprus, which may have acted as a middleman for supplies coming from much further east, perhaps through Mari. See N. H. Gale and Z. A. Stos-Gale, *Report of the Department of Antiquities Cyprus* (1985) 83–99.

[32] Muhly, op. cit. (1979) (see n. 2 above) 94.

[33] Catling, *Cyprus and the West 1600–1050 B.C.* Ian Sanders Memorial Lecture (Sheffield 1980).

[34] Ibid. 17–19.

[35] Id., in *Acts of the International Archaeological Symposium: The Relations between Cyprus and Crete, circa 2000–500 B.C.* (Nicosia 1979) 69–75.

[36] See, for instance, Bass, op. cit. (1967) 62–7 (n. 1 above), and E. and Y. Sakellarakis, *Skrifter Utgivna av Svenska Institutet i Athen 4°* xxxii (1984) 197–203.

[37] For the typological classification of oxhide ingots, see Buchholz, op. cit. (1959), and Bass, op. cit. (1967) (n. 1 above).

[38] Catling, *CAH*[3] II/2 (Cambridge 1979) 188–216.

administrative measure in the palaces. It will then have been adopted by the Mycenaeans (who borrowed heavily from Minoan metallurgical ideas), who brought it to Cyprus when they fled at the beginning of L.C. III.

Some have gone further, suggesting that the Minoan oxhide ingots were produced on Crete from copper derived from Cretan copper-ore deposits[39] and that Crete was an exporter of copper.[40]

Other Aegean archaeologists, amongst them the excavator of the Zakros ingots,[41] prefer to see Cyprus as the principal source of Minoan copper even as early as LM IA times. Before the recent excavations in the Morphou Bay area, at Toumba tou Skourou[42] and Ayia Irini,[43] no LM I pottery had been found in Cyprus to support this idea. Now the excavations at LC I Toumba tou Skourou have unearthed at least thirteen LM IA painted vases, whilst the LC I cemetery at nearby Ayia Irini yielded three painted cups identified as Myc. I or very early Myc. II and a conical cup of MM or early LM period. Both sites are close to the Troodos copper-ore deposits, as exemplified by those at Skouriotissa, Apliki, and Mavrovouni. Catling has suggested that if the Morphou Bay area was a major source of copper for Neopalatial Crete, perhaps it was here that the early copper-oxhide ingots of the type found in Crete at Hagia Triadha and Zakros were produced, and some sold to the West.[44] It may be worth mentioning here that Platon[45] has published a votive bronze figure from Kato Symi (Biannos), Crete, of uncertain date but which stands on an oxhide ingot.

In summary, it cannot be said that the archaeological evidence, discussed briefly above, provides a very clear picture of the sources of the oxhide ingots or the nature of the Late Bronze Age copper trade. A very recent archaeological discovery has, however, provided certain evidence of the place of manufacture of at least some oxhide ingots. French-Syrian excavations at Ras Ibn Hani,[46] near Ras Shamra in Syria, have uncovered a stone mould which was clearly used for casting copper oxhide ingots of Type 2, which belong chiefly to the fourteenth and thirteenth centuries BC and which Buchholz has attributed to Cyprus.[47] This is not the place to discuss in detail this very important discovery, except to note that copper deposits in Syria itself are scanty, so that we may have to face the possibility that oxhide ingots were not always made where the copper ores were mined.

Copper Sources for Oxhide Ingots—Scientific Evidence

Considerable effort has been devoted to the scientific examination of oxhide ingots from Sardinia,[48] Cyprus,[49] Crete, and Kyme,[50] and the Cape Gelidonya shipwreck.[51] The work has been confined to metallographic examination, minor element bulk chemical analysis by optical

[39] P. Faure, *RAI* (1966) 45–78 and in *Proceedings Second International Congress of Cretan Studies*, ii (Athens 1968) 174–83.

[40] Merrillees, *Trade and Transcendence in the Bronze Age Levant*, SIMA xxxix (Göteborg 1974) 7.

[41] N. Platon, *Acts of the International Archaeological Symposium: The Relations Between Cyprus and Crete ca. 2000–500 B.C.* (Nicosia 1979), 101–10.

[42] E. Vermeule and F. Wolsky, *Proc. Amer. Phil. Soc.* 122 (1978) 294–317 and *Toumba tou Skourou: The Mound of Darkness* (Harvard 1974).

[43] P. E. Pecorella *Le Tombe dell'Età del Bronzo Tardo della Necropoli a Mare di Ayia Irini 'Paleokastro'* (Rome 1977).

[44] Catling, op. cit. 4–8 (see n. 33 above), but later in the same article he inclines to the view that the LM IA pottery found at Toumba tou Skourou may reflect the presence there of refugees from Thera, and may have nothing to do with the copper trade.

[45] Platon, op. cit. pl. ix. 2, (see n. 41 above).

[46] J. Lagarce, E. Lagarce, A. Bounni, and N. Saliby, *C. Rend. Academie des Inscriptions et Belles-Lettres* (1983) 249–90.

[47] In H. G. Buchholz and V. Karageorghis, *Altägäis and Altkypros* (Tübingen 1971) 59.

[48] M. S. Balmuth and R. F. Tylecote, *J. Field Archaeology* 3 (1976) 195–201; U. Zwicker, P. Virdis, and M. L. Ceruti, in *British Museum Occasional Paper* 20 (1980) 135–55.

[49] J. D. Muhly, R. Maddin, and T. S. Wheeler, *Report of the Department of Antiquity* (Cyprus 1980) 84–95.

[50] Wheeler, Maddin, and Muhly, *Expedition* 17 (1975) no. 4, 31–9.

[51] Muhly, Wheeler, and Maddin, *J. Field Archaeology* 4 (1977) 353–62.

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emission spectroscopy, and semi-quantitative micro-chemical analysis of second phase inclusions using the scanning electron microscope (SEM) or the electron microprobe (EMP). It cannot be said that the existing scientific examinations have added much to either the archaeological or technical knowledge of oxhide ingots. Metallographic examination has confirmed the perhaps expected fact that the ingots were cast from molten copper not in a semi-molten or spongy state; together with SEM and EMP analyses it has shown that the majority of second phase particles are of copper sulphide, though some contain also iron, lead, and even tin and copper oxide particles are sometimes present. In some cases it has been suggested that an 'incompletely weathered copper ore'[52] was smelted to provide the copper for particular ingots, the small amount of residual sulphur in the ore largely passing into the smelted copper where, because copper sulphide is almost wholly insoluble in and immiscible with copper metal, it forms second phase particles. In other cases the same evidence of copper sulphide particles in oxhide ingots has apparently been said to be possibly consistent with the use of chalcopyrite ores, 'although sulfur and iron can be introduced into the smelt from other sources such as the fuel and the iron ore flux, if such was used'.[53] It is clear that metallographic and electron-microprobe examinations of the metal produced in controlled experimental smelts of known copper ores are necessary before unambiguous interpretations may be possible of analyses of second phase particles in oxhide ingots.

The bulk minor element chemical analyses have told us little beyond the fact that the full-sized oxhide ingots are made of rather pure copper usually containing 99 per cent or more of copper.[54] An earlier suggestion[55] that 0·2 per cent of cobalt in one of the Cape Gelidonya ingot fragments indicated that its copper came from the Ergani Maden copper mine in Turkey has now been abandoned for good reason.[56] As we shall see later, slightly elevated concentrations of minor elements are a most unreliable guide to the provenance of copper.

Conventional scientific examinations have conspicuously failed to answer one of the most important archaeological questions in relation to the oxhide ingots; which copper-ore deposit or deposits provided the copper metal of which they are composed? Here we may best quote the opinion of those who have been most closely involved in these examinations: (1) 'Nothing can be said about the sources of copper either from metallography or from elemental analysis'[57]; (2) 'Our analytical work on these ingots, involving most of those found in the eastern Mediterranean as well as of a few examples from Sardinia, has produced no evidence for provenance, no grounds for dividing the known ingots into distinct groups. The ingots from Sardinia prove to be identical, in terms of structure and composition, to the ones from Cyprus.'[58]

As Muhly has recently written, it could be argued that the failure to divide the ingots into groups or to separate, say, the Cretan or Sardinian ingots from the Cypriot ones, is that the oxhide ingots had a common source, that they were all made in one place, perhaps Cyprus.[59] Alternatively it may be that the scientific methods of examination hitherto employed have been too coarse to reveal differences which do in fact exist between the ingots, differences which may yet reveal the provenance of the copper. Perhaps analyses of trace elements by neutron

[52] For instance, in Muhly, Wheeler, and Maddin, op. cit. (1977) 355–6, (see n. 51 above), and in Muhly, op. cit. (1979) (see n. 2 above) 94.

[53] Muhly, Maddin, and Wheeler, op. cit. (1980) 94 (see n. 49 above).

[54] One of the Cape Gelidonya oxhide ingot fragments contained 10 per cent of iron; see R. Maddin and J. D. Muhly, *J. Metals* 26 no. 5 (1974) 1–7. The oxhide ingot fragment found in Hattusa has now also proved, from measurements made in Oxford and Erlangen, to contain a large amount of iron.

[55] Maddin and Muhly, op. cit. 4–6 (see n. 54 above).

[56] Muhly, Wheeler, and Maddin, op. cit. (1977) 359 (see n. 51 above).

[57] Muhly, op. cit. (1979) 94 (see n. 2 above).

[58] Id., op. cit. (1982) 255 (see n. 2 above).

[59] Ibid.

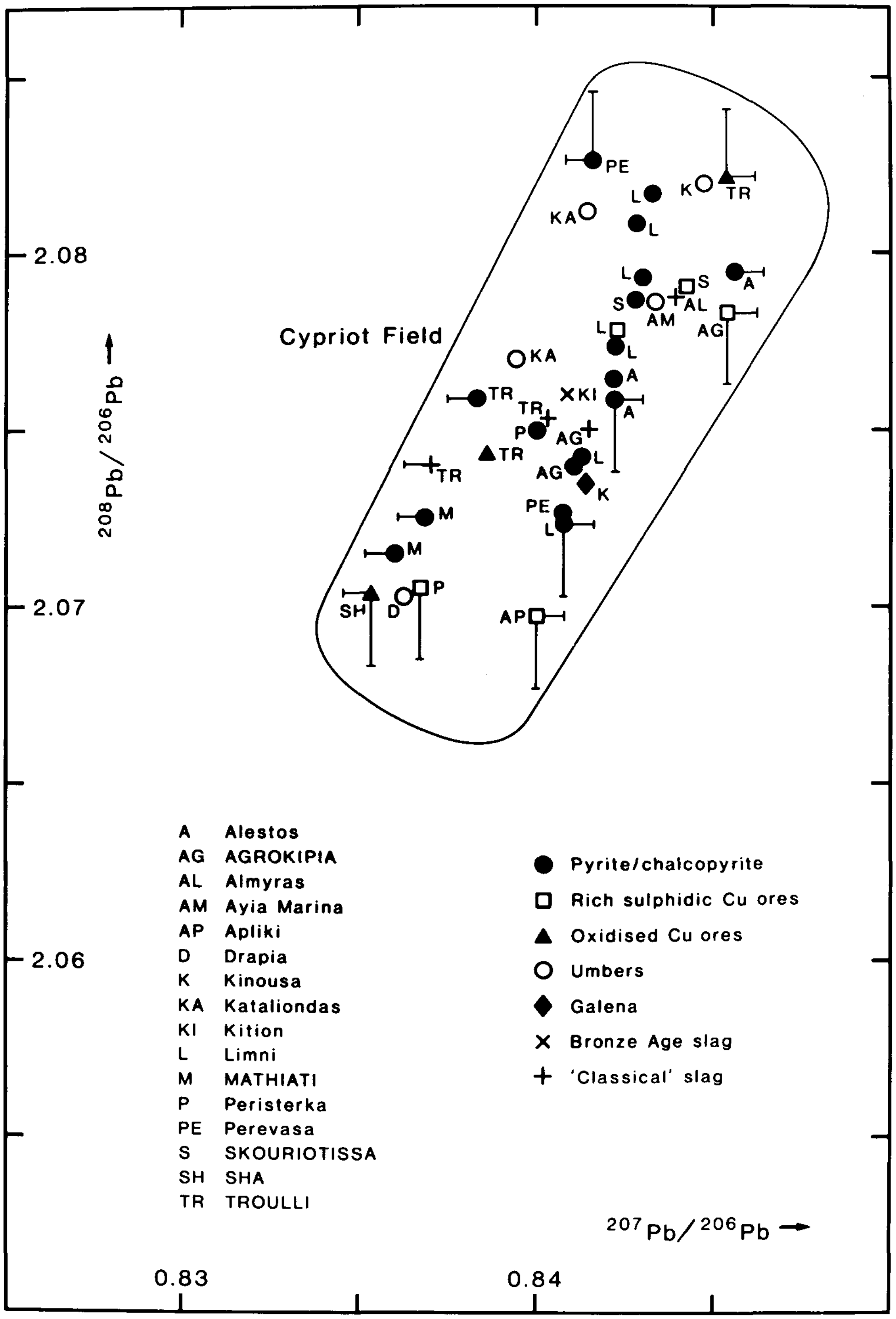

FIG. 1. The principal lead isotope field for Cypriot copper ores

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activation analysis[60] may reveal differences not apparent in the minor element analyses. Much more likely to throw light on the provenance problem is the lead isotope method, recently demonstrated to be of considerable promise for provenancing ancient copper.[61]

Lead Isotope and Neutron Activation Analyses of some Oxhide Ingots from Cyprus and Crete

The basic principles of lead isotope analysis as a means of provenancing metals have been explained in many articles.[62] The application to determining the provenance of the copper in an ancient copper-alloy artefact needs closer examination and has been discussed more recently.[63] Copper oxhide ingots constitute an almost ideal case for the application of lead isotope analysis, since they certainly contain no added tin or arsenic,[64] and are almost certainly free of the mixing problem.[65] About the lead isotope method it suffices to say here that because some lead isotopes are partly radiogenic in origin, coming from the radioactive decay of uranium and thorium isotopes, the proportions of the four isotopes of lead vary in nature and act as a 'fingerprint' of an ore deposit. Comparative isotopic analyses of lead in copper-alloy artefacts and in copper-ore deposits allows the provenance of the copper in the artefacts to be determined. The advantages of the lead isotope method, compared with minor element chemical analysis, are twofold. The minor element concentrations in an ore body often vary considerably, both on an absolute basis and relative to each other;[66] in contrast the isotopic composition of lead in an ore body usually varies only within very small limits.[67] Further, unlike the chemical composition, the lead isotope composition is not fractionated by the processes of smelting, refining, casting, corrosion, etc.

However, because the lead isotope composition of an ore deposit depends to first order on the geological age of that deposit there is the possibility that copper-ore deposits of similar age may have overlapping lead isotope compositions. Consequently one should say strictly that, if the lead isotope composition of an artefact results in an isotope composition which falls within the isotopic field of a particular copper-ore deposit, then the copper of the artefact is *consistent* with having come from that ore deposit.[68] Here trace-element analysis may sometimes help; consequently we now routinely add neutron activation analyses to our lead isotope analyses.

A much more powerful application of lead isotope analysis is that it can make a negative statement with absolute certainty in a way which chemical analysis can rarely hope to do. Having, for instance, established the lead isotope field for Cypriot copper-ore deposits then, if the isotopic composition of, say, an oxhide ingot falls well outside the Cypriot field, it is certain that the artefact was *not* made of Cypriot copper.

[60] For neutron activation analyses of trace elements in ancient copper, see, e.g. G. R. Gilmore, *J. Radioanalytical Chemistry* 39 (1977) 113-20, and G. R. Gilmore and B. S. Ottaway, *J. Archaeological Science* 7 (1980) 241-54.

[61] Gale and Stos-Gale, *Science* 216 (1982) 11-19, see also K. Branigan, *Nature* 296 (1982) 701-2.

[62] See, e.g., R. H. Brill and J. M. Wampler, *AJA* 71 (1967) 63-77; Gale, in *Thera and the Aegean World i* (1978) 529-45.

[63] Gale and Stos-Gale, op. cit (1982) (see n. 61 above) and in *Report of the Department of Antiquities Cyprus* (1985) 83-99.

[64] Tin or arsenic minerals, from an ore source different from the copper-ore source used to produce the copper metal, may rarely carry with them sufficient 'foreign' lead to disturb the signature of the lead characteristic of the copper-ore deposit, though in practice much ancient arsenical copper was probably an accidental product of the smelting of arsenical copper ores.

[65] It was for this very reason, that 'a single ingot was probably made from the ores of a single mine', that the Philadelphia group chose to focus their archaeometallurgical studies on oxhide ingots. See Wheeler, Maddin and Muhly, op. cit. 32 (see n. 50 above).

[66] G. Constantinou, in *Early Metallurgy in Cyprus* (Nicosia 1982) 14-7 fig. 2.

[67] Commonly the ratios $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ vary less than $\pm 0{\cdot}3$ per cent throughout an ore body; sometimes the variation is much less.

[68] A more certain attribution, in the case of overlapping lead isotope ore fields, ideally requires field-work to determine whether the copper deposits were anciently worked, the age of mining, etc.

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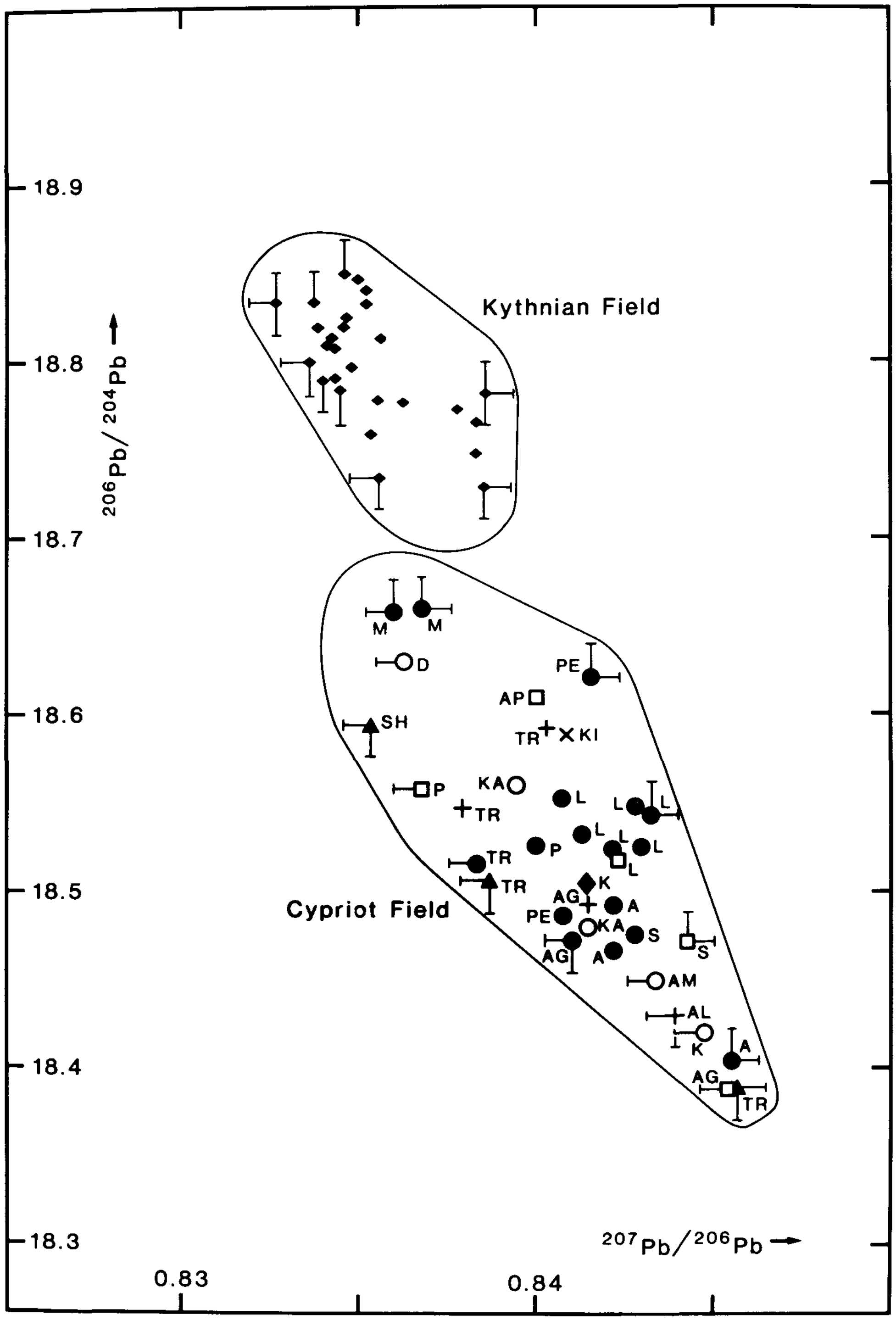

FIG. 2. The alternative lead isotope field for Cypriot copper ores, showing also the separation from the field for the Early Cycladic II Kythnos ore field

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TABLE 1. *Lead isotope compositions for oxhide ingot fragments from Cyprus*

Ingot*	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
Mathiati 1	2.07288	0.83997	18.508
Mathiati 2	2.07267	0.84139	18.492
Mathiati 3	2.07828	0.84218	18.535
Mathiati 4	2.07338	0.84117	18.516
Skouriotissa 7a	2.06911	0.83935	18.528
Skouriotissa 7b	2.07495	0.84130	18.497
Skouriotissa 7d	2.07520	0.84389	18.469

* See Table 3 for an explanation of the museum inventory numbers for these fragments.

Since the question of Cypriot copper sources is central to the oxhide ingot problem we have made extensive lead isotope analyses of Cypriot copper ores to determine the field characteristic of such ores. This investigation is reported in detail elsewhere[69] but the lead isotope fields characteristic of both the Troodos copper deposits and of the Troulli outlier are given in FIGS. 1 and 2.[70] The lead isotope data acquired so far give little promise that the individual Cypriot copper deposits can be distinguished one from another, but the overall fields characteristic of Cypriot copper ores are well-defined.

We began our studies of copper oxhide ingots with some Cypriot examples. We have analysed samples from four different oxhide ingot fragments from the total of eleven fragments found in the Mathiati hoard[71] and samples from four different fragments found at Skouriotissa together with tuyere and crucible fragments. All this material is in the Nicosia Museum, Cyprus. Catling has shown that the Mathiati Hoard may be dated to the twelfth century BC. The fragments include three handle or corner pieces of an ingot, or ingots, of Type III; there are no joins.

The lead isotope data are given in Table 1 and the neutron activation analyses are given in Table 3. FIGURE 3 gives a graphical plot of the lead isotope data in relation to the Cypriot ore field. It is clear that all these ingot fragments have lead isotope compositions which are fully consistent with their copper having been smelted from Cypriot ores. It would indeed have been surprising if any other result had been obtained, in view of the abundant evidence of copper-working at the Late Cypriot sites of Enkomi, Kition, Hala Sultan Tekke, and Kalavassos/Ayios Dhimitrios.

The neutron activation trace-element analyses (Table 3) show that all of these Cypriot oxhide ingot fragments are of rather pure copper, greater than 99 per cent in each case. Arsenic is the major impurity, ranging from about 0.2 per cent to about 0.7 per cent and averaging about 0.45 per cent. Although arsenic is the major impurity, it is at a low level, consistent with the known low level of arsenic in the Cypriot copper ores.[72] Antimony ranges from 90 to 190 p.p.m., averaging 137 p.p.m., whilst silver ranges from 40 to 190 p.p.m., averaging

[69] N. H. Gale, Z. A. Stos-Gale, and U. Zwicker, *Report of the Department of Antiquity* (Cyprus 1986) (in press).

[70] Three isotope ratios can be formed from the isotopic abundances of the four naturally occurring isotopes of lead; these ratios can be combined in pairs to give the two diagrams customarily used in plotting graphically the measured lead isotope compositions.

[71] The Mathiati Hoard, and the eleven oxhide ingot fragments which form part of it, have been published in Catling, op. cit. 268, pl. 49*g* (see n. 14 above).

[72] L. M. Bear, *The Mineral Resources and Mining Industry of Cyprus* (Nicosia 1963) 36; Constantinou, in *Early Metallurgy in Cyprus* (Nicosia 1982) 20.

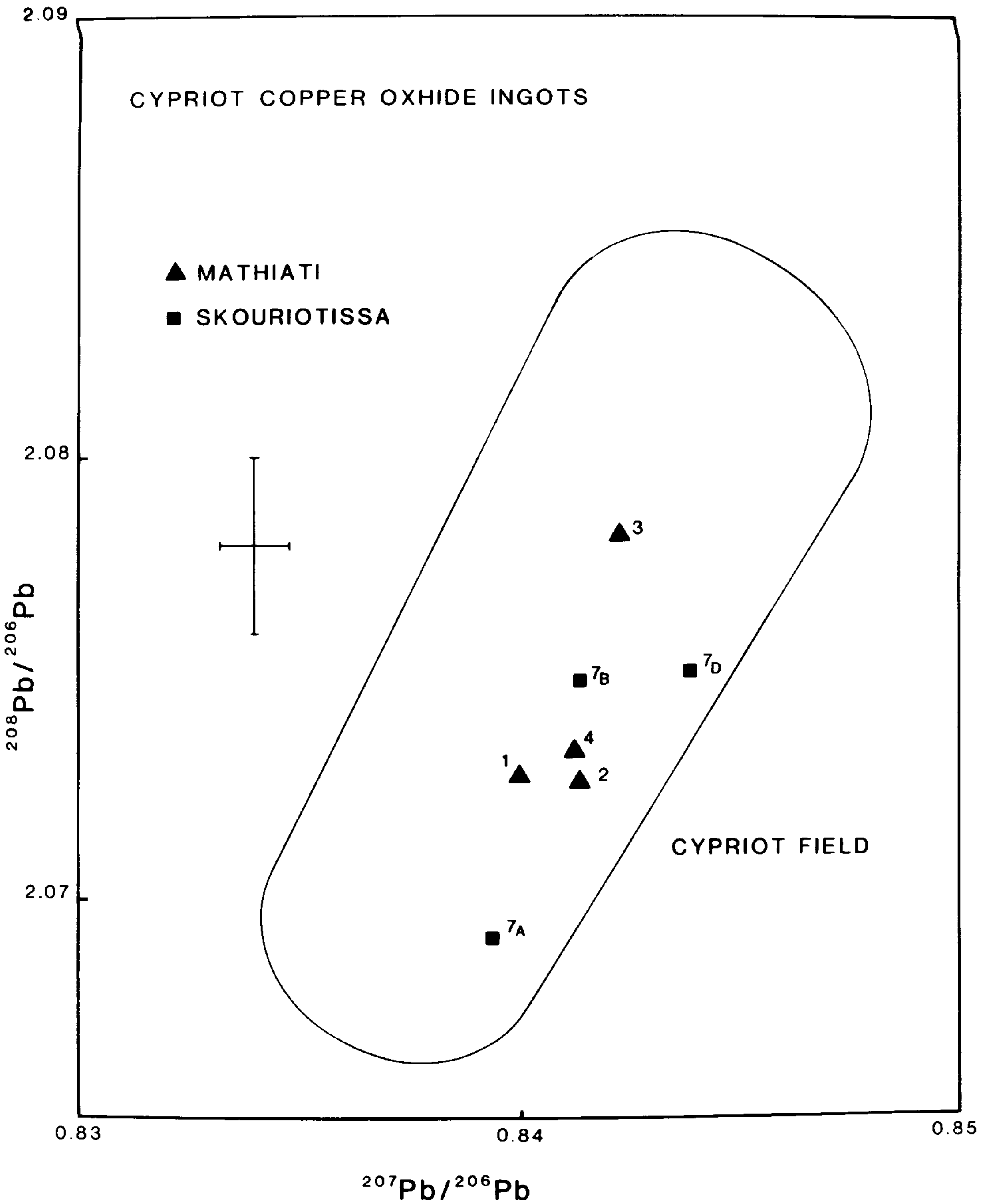

FIG. 3. Lead isotope compositions for oxhide-ingot fragments found at Mathiati and Skouriotissa in Cyprus

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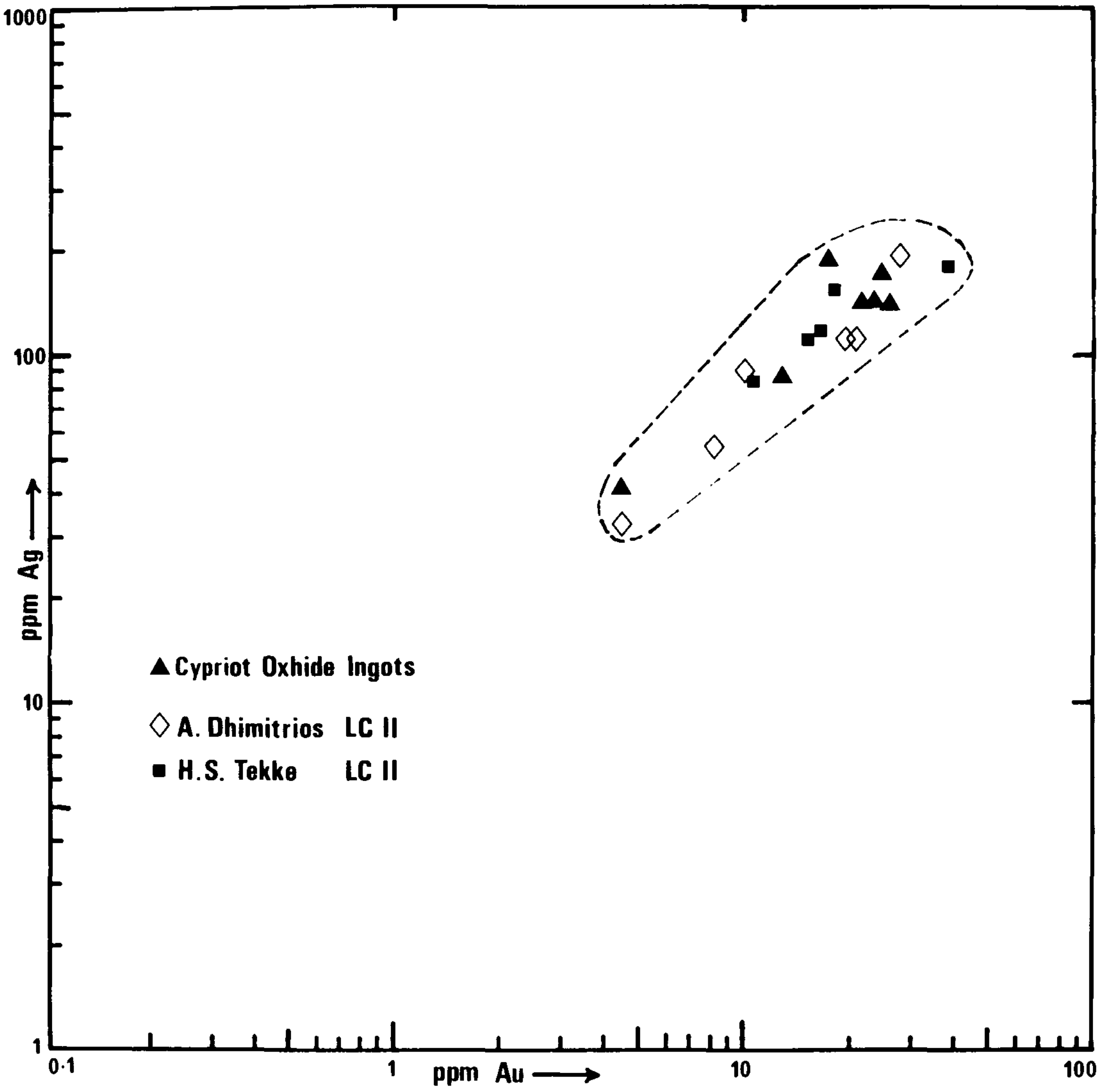

FIG. 4. Gold and silver concentrations for Cypriot oxhide-ingot fragments compared with those for Late Bronze Age copper-alloy artefacts from Ayios Dhimitrios and Hala Sultan Tekke

129 p.p.m. The trace element compositions of the ingot fragments are closely similar to those obtained for Late Cypriot artefacts from the sites of Hala Sultan Tekke and Ayios Dhimitrios.[73] This is true in particular for the elements silver and gold, which Tylecote has suggested might be of use in provenancing ancient copper.[74] Although the concentrations of silver and gold are variable in the Cypriot oxhide ingot fragments and in the Late Cypriot artefacts from Hala Sultan Tekke and Ayios Dhimitrios, nevertheless when plotted in a gold–silver diagram (FIG. 4) the LC artefacts and the ingot fragments fall in a comparatively well-defined 'field'. It is

[73] The analyses are reported by Gale, Stos-Gale, and Zwicker, op. cit. (see n. 69 above).

[74] R. F. Tylecote, H. A. Ghaznavi, and P. J. Boydell, *J. Archaeological Science* 4 (1977) 305–7.

not at present known whether this reflects faithfully the gold and silver concentrations in the Cypriot copper ores used or whether it is a function of the smelting process used. Whatever the cause, it seems at present that the gold-silver diagram may provide another method to characterize Late Cypriot copper, though analyses of Late Cypriot copper artefacts from other sites remain necessary to test this idea thoroughly.

TABLE 2. *Lead isotope compositions for oxhide ingots from Hagia Triadha, Crete*

Ingot*	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
B	2.10081	0.85911	18.267
B (patch)	2.09979	0.86032	18.110
C	2.12248	0.87788	17.698
E	2.12782	0.88180	17.641
F	2.11838	0.87479	17.767
H	2.13086	0.88109	17.742
I	2.12962	0.88594	17.488
J	2.13187	0.88631	17.495
O	2.11965	0.87783	17.674
P	2.12582	0.87842	17.718

* The letter designations for the ingots are those used in FIG. 5. See Table 4 for the relation of these designations with those used by Buchholz.

It is not certain how many different oxhide ingots are represented by the eight fragments which we have analysed. Catling noted that the eleven ingot fragments in the Mathiati Hoard had no joins; this is true also for the fragments for Skouriotissa. Differences in the cobalt, nickel, and selenium contents suggest that the four Mathiati fragments analysed each came from a different ingot and that the four Skouriotissa fragments came from at least three different ingots. Thus our analyses represent at least two, and possibly as many as seven, different Cypriot oxhide ingots. Of course, differentiation between ingots based on trace-element analyses is at present uncertain, because there has been no investigation of possible inhomogeneities in trace-element distribution within such large copper objects. Nevertheless the lead isotope and neutron activation analyses have grouped together from two to seven Cypriot oxhide ingots and have shown that the copper used to make them came from Cypriot ores.

Nineteen oxhide ingots were found together in the Italian excavations at Hagia Triadha.[75] They are of the early Type I and date approximately to late MM III or early LM IA. Sixteen are on display in the Herakleion Museum; here we report the analyses of nine of those.[76] The lead isotope analyses are given in Table 2 and the trace-element analyses in Table 4.

FIGURE 5 gives a graphical plot of the lead isotope data in relation to the lead isotope field for Cypriot copper ores and in relation to preliminary lead isotope data for the Ergani Maden[77]

[75] R. Paribeni, *Rend. Linc.* 12 (1903) 334-5; P. Carratelli, *MA* 40, 434, 455-8; F. Halbherr, E. Stefani, and L. Banti, Ann. 55 (1977) 123-4.

[76] Full analyses of all sixteen ingots, including metallographic and electron microprobe analyses, are in progress and will be reported in due course.

[77] See P. de Jesus, *BAR International Series* 74 (i) (1980) 21-2, 55, 109, 121, 147, 148; for the geology, see W. R. Griffitts, J. P. Albers, and O. Oner, *Economic Geology* 115 (1972) 701-16.

TABLE 3. *Trace-element contents of oxhide ingots found in Cyprus*

	p.p.m.														
Ingot	Sn	Pb*	As	Sb	Co	Ni	Cr	Fe	Au	Ag	Bi	Zn	Se	In	Ir
Mathiati 1	< 2,750	166	6,860	177	1,762	550	< 25	500	25.8	140	< 50	340	50	< 43	0.012
Mathiati 2	< 1,657	155	4,730	190	297	310	< 57	300	17.1	186	< 50	191	114	< 66	0.03
Mathiati 3	< 1,500	207	5,874	170	720	410	< 48	210	27.0	142	< 50	140	78	< 58	0.01
Mathiati 4	< 1,429	64	2,196	89	40	120	< 43	310	10.7	80	< 60	64	440	< 100	< 9
Skouriotissa 6	< 232	nm	5,030	158	1,215	nm	< 41	nm	20.7	128	nm	355	82	< 49	< 0.01
Skouriotissa 7A	< 355	98	5,012	133	296	330	< 52	280	24.9	170	< 60	103	90	< 68	0.01
Skouriotissa 7B	< 1,851	nm	3,758	118	nm	470	< 60	280	23.9	143	< 50	nm	nm	< 45	0.01
Skouriotissa 7D	< 815	26	2,218	59	22	160	< 30	250	4.2	40	< 50	90	242	< 43	< 0.01

* Measured by mass spectrometric isotope dilution. nm = not measured. The Mathiati samples all have the Nicosia Museum prefix 1936/VII-17/9 and come from the Mathiati Hoard mentioned by Catling, *Cypriot Bronzework in the Mycenaean World* (Oxford 1964). The Skouriotissa samples all have the Nicosia museum prefix 1976-I-20.

TABLE 4. *Trace-element contents of the Hagia Triadha oxhide ingots*

	p.p.m.														
Ingot†	Sn	Pb*	As	Sb	Co	Ni	Cr	Fe	Au	Ag	Bi	Zn	Se	In	Ir
B 726_β	< 750	203	468	17	119	30	< 25	100	3.0	9	< 50	3,198	70	< 35	< 0.01
C 721	< 1,400	100	5,650	76	785	6,800	< 44	300	27.2	58	< 50	727	266	< 53	< 0.01
E 726_η	< 820	125	315	7.5	346	100	< 32	500	1.3	13	< 50	3,680	71	< 42	< 0.01
F 723	< 940	nm	1,357	44	201	580	< 30	500	44.7	65	< 50	8,510	34	< 42	< 0.01
H	< 540	306	457	16	80	< 50	< 19	100	1.4	16	< 50	523	170	< 27	< 0.01
I 722	< 590	175	435	20	68	< 50	< 20	700	2.1	14	< 50	216	88	< 30	< 0.01
J	< 300	379	499	14	157	80	< 33	500	2.1	13	< 50	3,548	86	< 42	< 0.01
O	< 530	112	167	3.7	68	< 50	< 18	700	0.8	4	< 50	2,808	77	< 26	< 0.01
P 724	< 1,100	256	873	22	89	100	< 34	400	31.3	63	< 50	10,110	463	< 50	< 0.01

* Measured by mass spectrometric isotope dilution. nm = not measured.

† The capital letter designations for the ingots are those used in FIG. 5. The numerical designations are those given by Platon to Buchholz and published by him, *PZ* 37 (1959) 34. The ingots do not now bear these numbers; therefore it is possible to identify them only where they bear inscriptions or marked hollows.

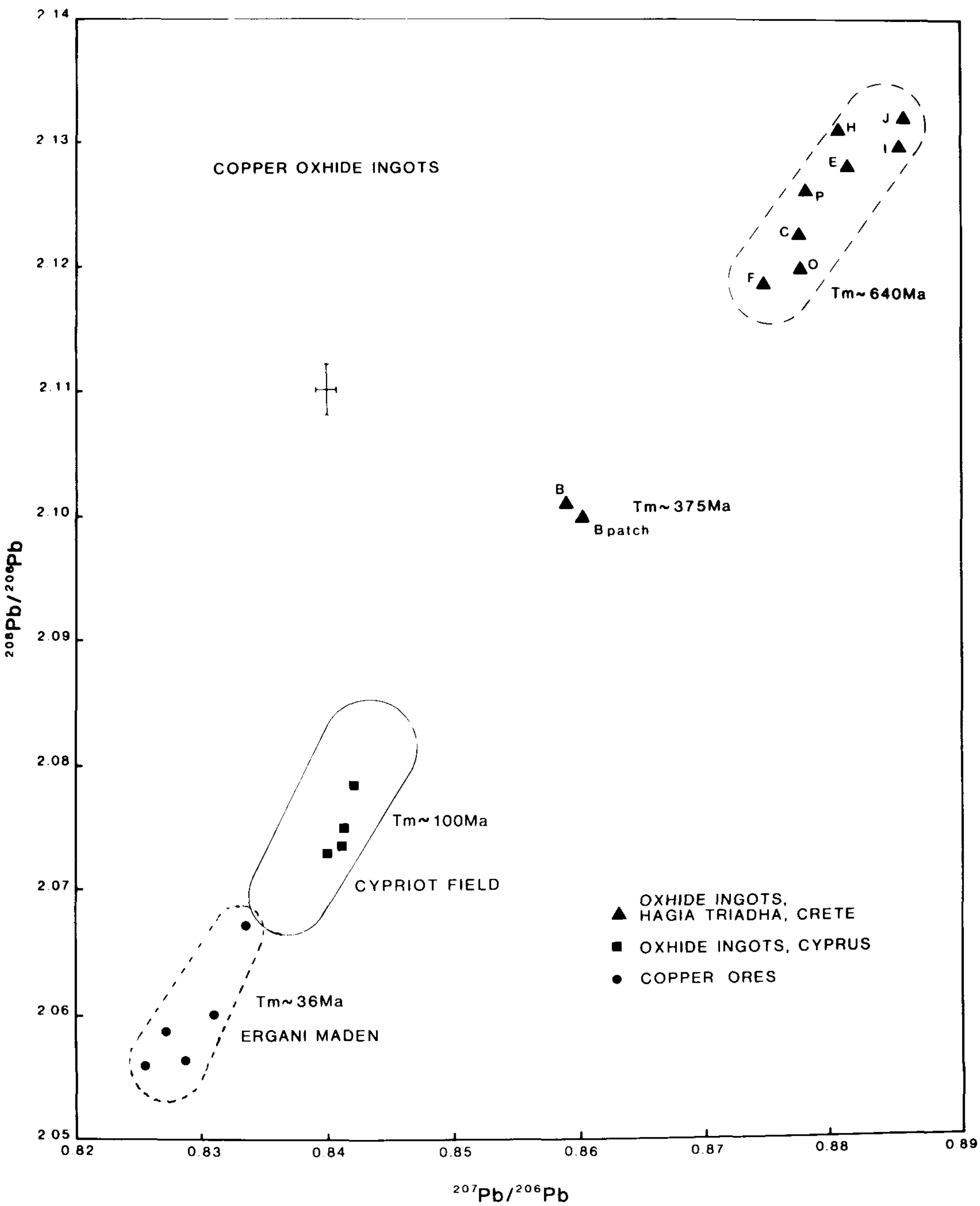

Fig. 5. Lead isotope compositions for oxhide ingots excavated from Hagia Triadha, Crete, compared with the Cypriot field and with copper ores from Ergani Maden, Turkey

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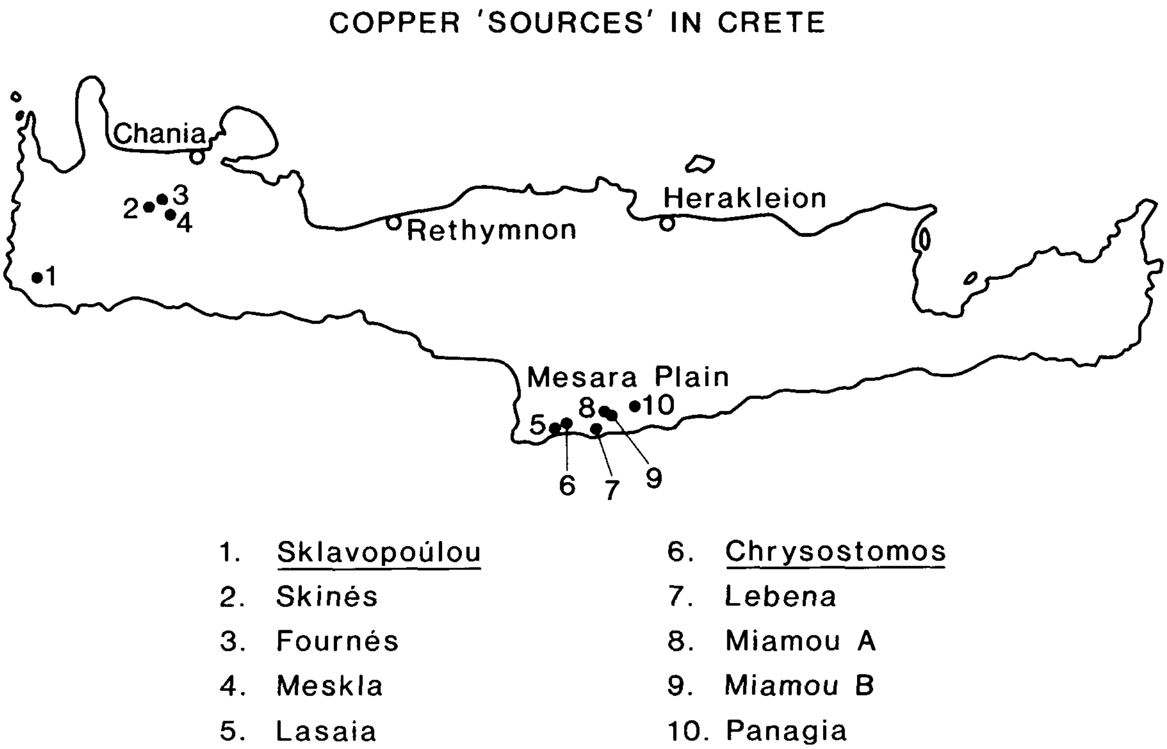

FIG. 6. Map showing the location of copper deposits in Crete. Only the sources at Sklavopoulou and Chrysostomos contained substantial amounts of copper ore

copper mine in Turkey. The dashed curves on this group are intended merely to guide the eye to similar isotopic compositions; at present they have no other significance.

The lead isotope data at once prove that the Hagia Triadha ingots are not made of Cypriot copper, nor are they made of copper from the Ergani Maden mines. The symbols Tm give lead isotope model ages computed using the simple Cumming–Richards Model III;[78] these model ages should correspond approximately with the geological ages of the ore deposits. The model age for the Ergani Maden copper deposit agrees well with the potassium-argon age of 31.5 ± 0.8 Ma which Griffitts *et al.*[79] quote. For the Cypriot copper-ore deposits the model age of about 100 Ma is slightly high when compared with the geochronological age of about 80 Ma recently obtained for the Troodos sheeted dyke complex;[80] but the agreement is acceptable if one considers the simplicity of the lead isotope model.

In contrast the model age calculation suggests that eight of the Hagia Triadha ingots were made of copper coming from a Precambrian ore deposit of about 640 Ma age whilst the ninth ingot[81] came from a different ore deposit with a model age of about 370 Ma. The isotopic composition of the lead in the patch is identical, within errors, with that in the main body of

[78] G. L. Cumming and J. R. Richards, *Earth and Planetary Science Letters* xxviii (1975) 155–71.

[79] Op. cit. (see n. 77 above).

[80] A. Desmet, H. Lapierre, G. Rocci, C. Cagny, J. F. Parrot, and M. Delaloye, *Nature* 273 (1978) 527–30.

[81] The ingot with a patch bearing a sign, Ingot 726B according to Buchholz, op. cit. (1959) (see n. 1 above), who illustrates it on p. 33 pl. 4.3.

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TABLE 5. *Lead isotope compositions of Cretan copper ores*

Sample	Locality	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
CHR2	Chrysostomos	2.07920	0.84348	18.515
CHR3	Chrysostomos	2.07834	0.83913	18.573
CHR5	Chrysostomos	2.08010	0.84480	18.510
CHR4	Chrysostomos	2.08103	0.84077	18.599
SKL1	Sklavopoulou	2.08523	0.84212	18.609
SKL2	Sklavopoulou	2.08624	0.84495	18.485
SKL3	Sklavopoulou	2.08656	0.84632	18.479
LAS1	Lasaia	2.08554	0.84286	18.544
LEB1	Lebena	2.08067	0.84110	18.540
PNG1	Panagia	2.08233	0.84388	18.452
MIA A	Miamou A	2.07618	0.84592	18.323
MIA A2	Miamou A2	2.09126	0.85285	18.249
MES 2	Meskla	2.09862	0.86201	18.054

this ingot, suggesting that the patch was put in place very soon after the ingot was made, using copper from the same batch.

These nine oxhide ingots from Hagia Triadha were clearly not made from copper from Cyprus, Ergani Maden, or, for that matter, from Lavrion. Could they have been made from Cretan copper ores? The geological ages of the structural units of Crete makes that unlikely.[82] We have nevertheless searched hard for copper ores on Crete, but have found most of the so-called copper deposits quoted by Faure,[83] Branigan,[84] and others to be non-existent; they are nothing more then green schist or serpentinite in many cases and mere stains on the rocks in others. Muhly and Rapp independently reached the same conclusion.[85] Nevertheless there are eight places in Crete where there are traces of copper ore, in the form of malachite and azurite (FIG. 6). Only two of these localities, Chrysostomos and Sklavopoulou, have ever contained copper ores in quantities large enough to have been useful even in the Bronze Age. In both cases the amounts are negligible if compared with the quantities of malachite/azurite still remaining in the Lavrion region. Lead isotope analyses of these Cretan copper ores are given in Table 5 and FIG. 7. They plot in the general region of, and partly overlap, the Cypriot copper deposits. Consequently the Hagia Triadha ingots are not made from Cretan copper ores. Our preliminary lead isotope analyses of Sardinian copper ores also prove that they cannot be the source of the eight ingots which cluster together, though they might possibly be consistent with the ingot 726P with a patch.

The trace-element analyses of the Hagia Triadha ingots (given in Table 4) show considerable differences from those for the Cypriot ingots, especially for the elements arsenic, antimony, silver, and zinc. The averaged contents of arsenic, antimony, silver, and zinc in the Hagia Triadha ingots are 1,136, 24, 28, and 3,702 p.p.m. respectively; in the Cypriot ingots the same elements have mean concentrations of 4,459, 137, 129, and 183 respectively. The indication is that the copper-ore source from which the copper metal of the Haghia Triadha ingots was derived is chemically, as well as isotopically, different from the Cypriot copper-ore sources. This difference extends also to the gold–silver diagram. FIGURE 8 shows that in this diagram the Haghia Triadha ingots do not plot in the same region as the Cypriot oxhide ingots. Note, however, that the Hagia Triadha ingots C, F, and P, which all have higher concentrations of

[82] See N. Creutzberg, *Geological Map of Crete, IGME* (Athens 1977).
[83] Op. cit. (see n. 39 above).
[84] Branigan, *BSA* 70 (1975) 18; *BSA* 72 (1977) 66; *Studi Micenei ed Egeo-Anatolici* 13 (1971) 10–14; *Aegean Metallurgy in the Early and Middle Bronze Age* (Oxford 1974).
[85] Op. cit. (see n. 50 above) 32.

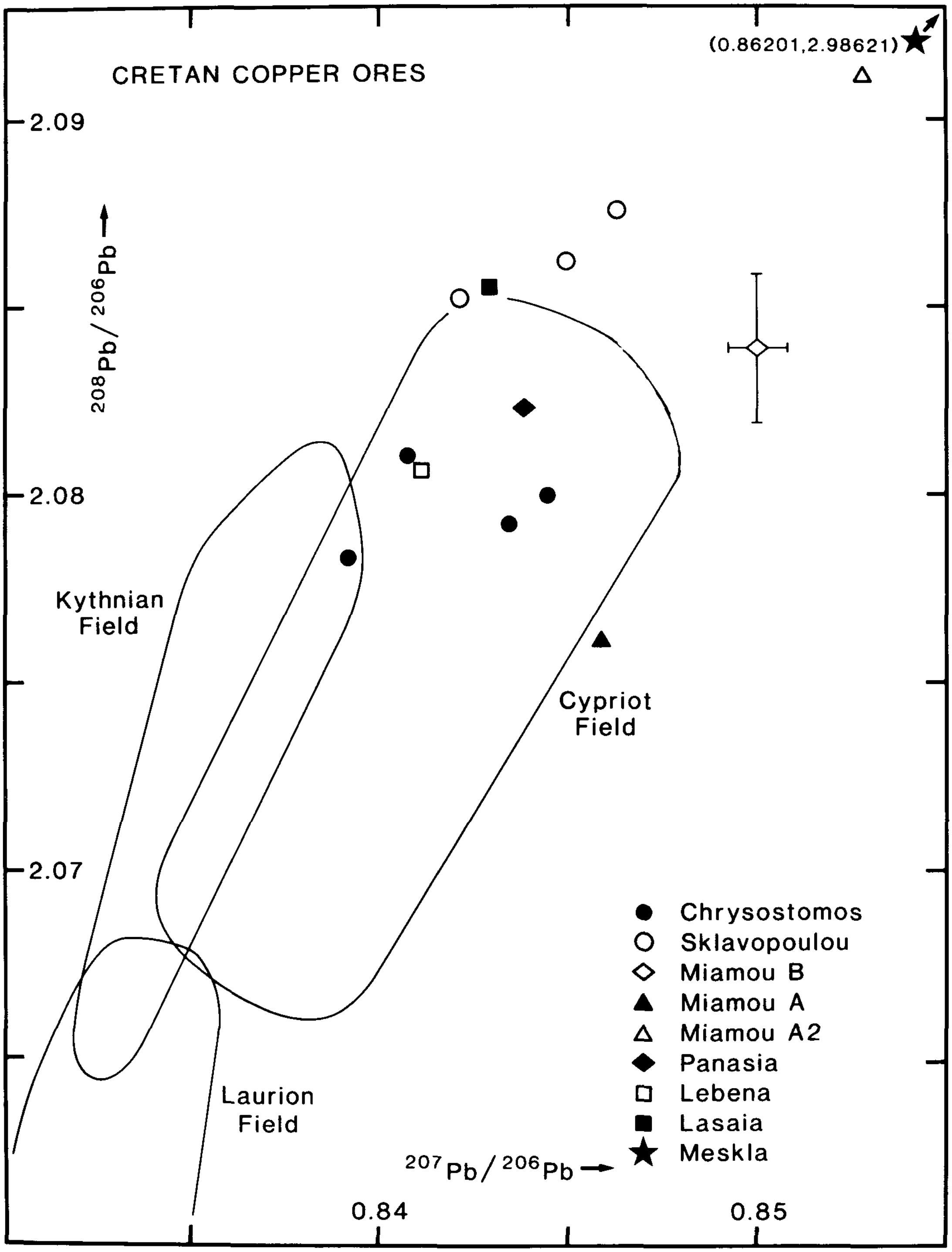

FIG. 7. Lead isotope compositions for Cretan copper ores

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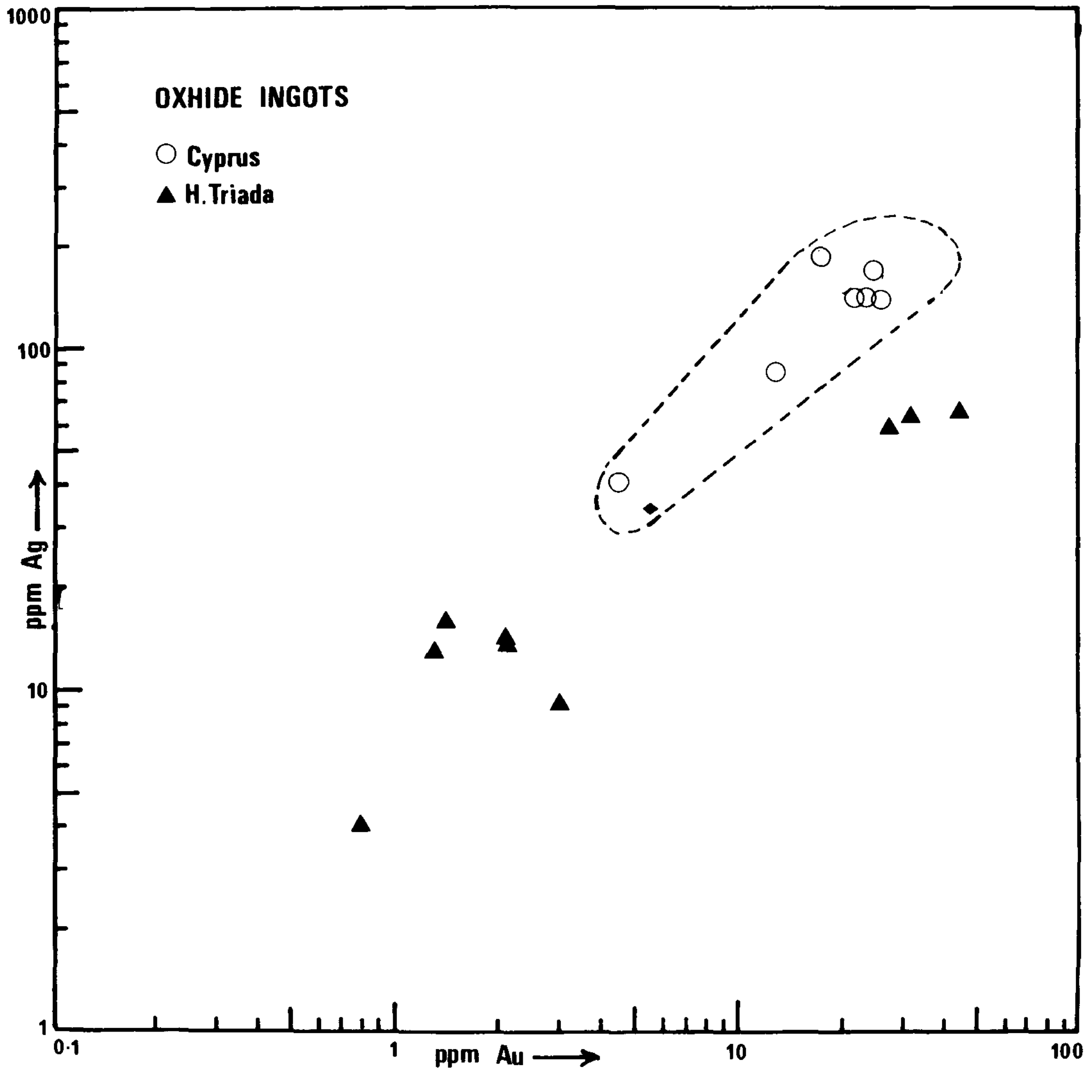

FIG. 8. Gold and silver concentrations for oxhide ingots from Hagia Triadha compared with the 'field' for Late Cypriot copper and bronze objects and with Cypriot oxhide-ingot fragments.

arsenic and gold, nevertheless plot in the same isotopic field as ingot E, H, I, J, and O. The individual trace-element compositions seem clearly to be a less reliable guide to provenance than are the lead isotope compositions. Finally, we note that the optical emission spectrographic analyses[86] failed altogether to discriminate between the oxhide ingots from Crete and from Cyprus. We believe this to be so merely because optical emission spectrography is an insufficiently accurate method of analysis at the low concentration levels typical of such elements as silver, nickel, cobalt, antimony, zinc in oxhide ingots; it cannot at all even detect the low concentrations of gold, selenium, indium, and iridium.

[86] Op. cit. (see nn. 49, 50 above).

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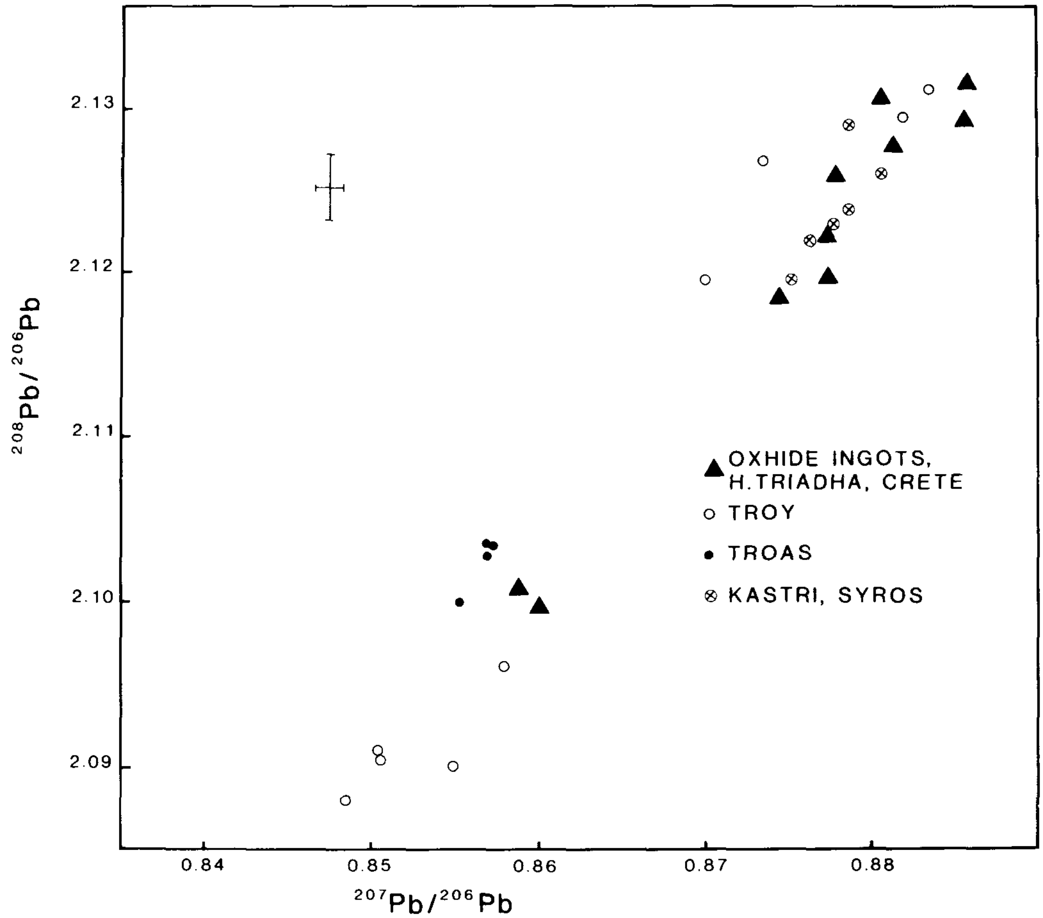

FIG. 9. Lead isotope compositions for oxhide ingots from Hagia Triadha compared with those for bronzes from Troy, the Troas and Kastri on Syros.

We cannot yet identify the copper sources used to make the Hagia Triadha ingots, but they *may* have been located in Anatolia. FIGURE 9 compares the lead isotope data for bronzes from Troy, the Troas and Kastri on Syros[87] with those for the Hagia Triadha ingots; there are clear similarities. On the other hand, the trace-element compositions of these Minoan ingots are considerably different from those of the Anatolian or Cycladic objects. The Trojan and Cycladic objects are at least 500 years older than the oxhide ingots, so that the trace-element differences might reflect the use of different regions in, or different copper ores from, the same general ore deposit. Nevertheless we cannot at present go further than to point out the similarities in lead isotope composition and to recall that there are regions in Anatolia containing copper deposits of the right geological age.[88]

[87] N. H. Gale, Z. A. Stos-Gale, and G. R. Gilmore, *Anatolian Studies* (1985) 143–73, and E. Pernicka, T. C. Seeliger, G. A. Wagner, F. Begemann, S. Schmitt-Strecker, C. Eibner, O. Oztunali, and I. Baranyi, *Jb DR-GZ* (1984) 533–99.

[88] See Gale, Stos-Gale, and Gilmore, op. cit. (n. 87 above).

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Conclusions

Our lead isotope and neutron activation analyses have for the first time clearly differentiated between two groups of oxhide ingots. The Cypriot examples from Mathiati and Skouriotissa were clearly made from copper smelted from Cypriot ore deposits; equally clearly, those from Hagia Triadha were not made from Cypriot copper. The provenance of the oxhide ingots found at Zakro has yet to be established, but the non-Cypriot origin of those from Hagia Triadha weakens Bass's arguments[89] that the conjunction of the evidence from the Cape Gelidonya wreck, the Type 1 ingots found nearby in the Bay of Antalya and LM IA pottery found at Toumba tou Skourou strongly suggests that Type 1 ingots found in Crete are made of Cypriot copper. Perhaps Catling's[90] alternative suggestion for the significance of LM I pottery in the Morphou Bay area of Cyprus deserves serious consideration.

Branigan[91] also believed the Minoan ingots to be of Cypriot origin and that the archaeological evidence supported the hypothesis that the importation of copper from Cyprus to Crete became important in MM III–LM I; our evidence shows matters to be more complicated. Of course our demonstration that at least some of the earlier Type 1 ingots found in Crete were not made of Cypriot copper says nothing about the later Type 2 and Type 3 ingots found in Mycenae, Sardinia, Sicily, and elsewhere. Since the later ingots found in Cyprus itself are now proven to be of Cypriot copper, it remains possible that those found elsewhere will also prove to be of Cypriot copper. The ingot mould found at Ras Ibn Hani shows that oxhide ingots of later type were made also in Syria. It is beginning to appear that the Late Bronze Age copper trade was a more complex affair than previously thought. A great deal more work seems necessary before we shall know enough about it to discuss intelligently its organization. New analytical methods, especially lead isotope analysis, seem, however, to provide a solution to the long-standing problem of the provenance of copper in the ingots, a problem which blocked the path to an understanding of the metal trade.

N. H. Gale
Z. A. Stos-Gale

[89] Bass, op. cit. (see n. 1 above).
[90] Catling, op. cit. (see n. 33 above).
[91] Branigan, in *Early Metallurgy in Cyprus* (Nicosia 1982) 203–12.

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