

COPPER OXIDE INGOTS: THEIR ORIGIN AND THEIR PLACE IN THE BRONZE AGE METALS TRADE IN THE MEDITERRANEAN

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My topic is a rather specialised one. It certainly has to do with the metals trade in the Late Bronze Age Mediterranean, from about 1550 BC until about 1100 BC, but it concerns chiefly a particular part of the trade in copper. This is the origin, source and transport of the so-called copper oxide ingots, formerly called also *talenta* (Seltman 1955, Iakovides 1974), *keftiubarren* (Buchholz 1959) and, for certain special shapes, *kissenbarren* (Buchholz 1959), double axe ingots (Svoronos 1906), etc.

Since I have mentioned the word trade, I should like to begin with an aside about that, because some ancient historians (perhaps principally Finley and the Cambridge school) cast doubt on the very existence of trade (at least in a modern 'commercial' sense) in the ancient world, whilst others have suggested that where it existed it was motivated solely by the need for imports, never exports. This volume contains a most elegant examination of the concept of trade in the ancient world (Snodgrass 1991) which puts the minimalist case with considerable persuasiveness; we are asked to envisage the movement of goods in the Mediterranean Bronze Age largely in terms of profitless ceremonial gift exchange between élitist rulers accompanied by negotiated exchange of necessities and systematic redistribution of goods within Aegean communities.

One example suggests that to concentrate overmuch on that paradigm may be unwise. It concerns the trade, documented in Old Assyrian cuneiform tablets, between northern Mesopotamia and south-central Anatolia in the late 20th and early 19th centuries BC. It was largely controlled by the Assyrian trad-

ing colony of *karum Kanesh*, established on the fringes of the Anatolian city of ancient Kanesh, modern Kultepe (see Figure 1).

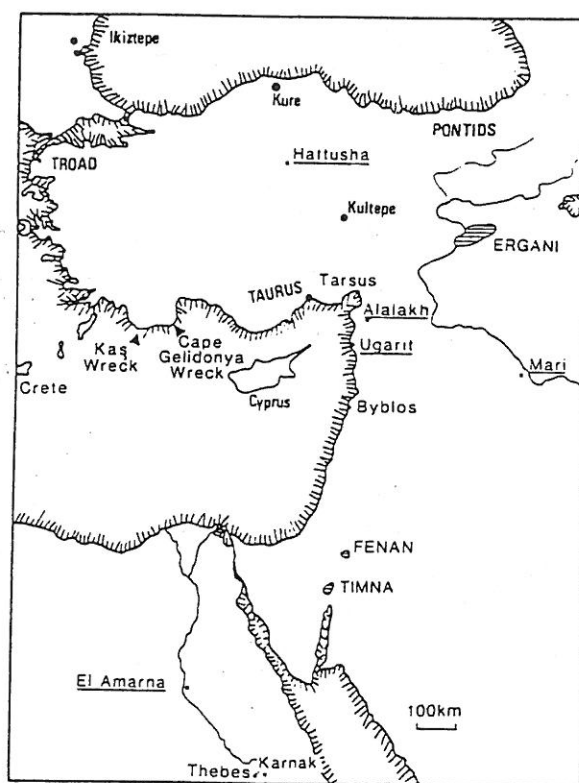


Figure 1. Locations of the Cape Gelidonya and Kas shipwrecks, Kultepe, Mari, etc.

The Assyrian merchants bought tin, textiles, etc., in Assur, brought them by donkey caravan to Kanesh, and sent back to Assyria large amounts of silver and gold in payment. The tablets seem to reveal, on the part of the Assyrian merchants, an example of capitalistic, profit motivated (for both state and private investors), export trade (Veenhof 1972, Veenhof in Hawkins 1977, Finegan 1979, 86). In this volume Bass adds further to our knowledge about the wealth of goods of many types carried on the Bronze Age

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ships wrecked off the coast of Anatolia at around 1350? and 1225? BC near Ulu Burun and Cape Gelidonya. It is difficult to interpret this evidence other than in terms of trade of some sort, and as a trade in the hands of people who were primarily exporters. It is difficult to accept that, for example, the Ulu Burun ship was, as suggested by Snodgrass (1991, 16), sailing at the behest of a single major redistributive centre in the Aegean, for its cargo of copper alone was enough to satisfy the annual demands of Pylos five times over and to equip at a stroke the entire army of a Mycenaean kingdom. We must, of course, take care not to extrapolate from what we know about Assyrian trade and attempt to impose that structure in the Aegean; Snodgrass (1991, 13) is right to deter us from a vain search for a universal model of exchange in the Late Bronze Age Eastern Mediterranean. Nevertheless it might be that at least some part of the goods coming into the Aegean were brought by people familiar with the attitude to the movement of commodities typified by the merchants of Kanesh rather than the redistributive procedures which may have been more typical of the Aegean palaces, *once they had goods in their possession*. These matters are examined more extensively in this volume by Wiener, by Sherratt and Sherratt and by Bass. This paper is more concerned with part of the programme advocated by Catling (1991, 10), viz. the identification of imports and the determination of their places of origin. This is properly the main theme of the British Academy Project since, where so little of this basic information is certainly established, it remains dangerous to erect over-elaborate theoretical constructs on what remain rather shaky foundations.

COPPER OXIDE INGOTS

Let me begin my main theme by giving some facts about copper oxide ingots. The most comprehensive archaeological studies of

these ingots remain those of Buchholz (1959) and Bass (1967).

Copper oxide ingots are basically flat, oblong, ingots of copper from 4 to 6 cm. thick, with lengths varying from about 30 to 60 cm., breadths varying from 20 cm to 45 cm., and weights from about 10 Kg (e.g. some from Kyme, Euboea) to 37 Kg. Even in a closed deposit of ingots, as found on the Cape Gelidonya wreck, the difference in weight between the lightest and the heaviest was 13 Kg. (Bass 1967, 71) whilst the earliest hoard of ingots from Hagia Triadha on Crete varied from 27 to 32 Kg. (Buchholz 1959, 32) in weight. Tablets from Knossos, with depictions of oxide ingots, seem to confirm this variability of weight; Tablet Oa 730 states that sixty ingots weighed 52 2/30 'talents', whilst Tablet Oa 733 gives the weight of ten ingots as six or eight 'talents' (Ventris & Chadwick 1973).

Whilst the lower side of each ingot is relatively smooth, the upper side is always rough and 'bubbly' (see e.g. Selman 1955, Fig. 1, p. 6), due to the release of dissolved oxygen and sulphur dioxide from the surface of the metal as it cools and solidifies from the molten state. Recent examination by the author of the Tyllissos ingots preserved in the Herakleion Museum, Crete, and of the ingot from Antalya? kept in the Metropolitan Museum, New York, show these all to contain small fragments of charcoal entrapped in their upper surfaces, possibly remaining from a covering of charcoal (to prevent oxidation) as they cooled in the mould or even from some attempt at rudimentary 'poling' whilst the metal was still molten (Percy 1961, 325; Gowland 1930, 142).

Quite apart from the variability of weight, oxide ingots come in a number of shapes and sizes, as can be seen from the photographs (Buchholz 1959, Tafel 3, p. 27) of ingots from Crete, Cyprus and Antalya and

(Buchholz 1959, Tafel 5, p. 35) of ingots from Mycenae and Kyme. From the selection of six of the earliest known oxide ingots from Hagia Triadha on Crete (see Buchholz 1959, Tafel 4, p. 33), which date from LMIA, or about 1550 to 1500 BC, it can be seen that they clearly have more or less straight tops and bottoms, with incurving sides.

In complete contrast is the ingot excavated by Tsountas at Mycenae (illustrated by Iakovides 1974, p. 297), with typical long "ears" or handles and dating to about 1400 BC according to Wace (1949, 88).

Similar, but different in detail, are the ingots from Enkomi on Cyprus illustrated by Catling (1964, Plate 49 a-d) which date probably to about 1200 BC or somewhat earlier. On the same Plate (49(h)) is a miniature, votive, ingot from Enkomi? with a Cypro-Minoan inscription. Two ingots (Catling 1964, Plate 49 f, g) are broken into fragments, the ultimate destination of all such ingots prior to melting down for casting objects or for the manufacture of bronze. The breaking of a copper ingot into pieces to make different objects seems to be described in a Hittite text (Kempinski & Kosak 1977).

Oxide ingots are often depicted in Egyptian tomb paintings and reliefs which can be quite precisely dated. Ingots of the earlier type, similar to those excavated at Hagia Triadha on Crete, are depicted in an Egyptian tomb (T. 131) of Useramon at Thebes (illustrated by Wachsmann 1987, Plate XXXIIIA) dating to about 1500 to 1450 BC, whilst an ingot of a later type from the tomb of Huy (dating to about 1370 to 1340 BC) is illustrated by Davies & Gardiner (1926, Plate XIX).

Taking the Egyptian pictorial evidence together with that of dated oxide ingots from archaeological excavations led Buchholz

(1959) to erect a typological classification tied to a chronological development of the shape which shows a broad division into three main types. It does indeed seem quite reasonable that the handles should be a later invention which was aimed at greatly facilitating the handling of ingots which mostly averaged 30 Kg in weight. Certainly the later shape (Type 2) which, by its fortuitous resemblance to the flayed hide of an ox, gave these ingots their name, is a development with a practical purpose.

A much more extensive study of the Egyptian pictorial evidence, which in a few cases seems to show all three types of ingots co-existing, led Bass (1967) to conclude that the three types of ingots cannot always be separated chronologically, but that the appearance of ingots (Type 1) without handles was indeed slightly earlier than the first appearance of those with handles, an opinion which his later studies of ingots from Ulu Burun and of the 13th century BC mould from Ras Ibn Hani have reinforced (Bass 1991, this volume).

All the oxide ingots from the Cape Gelidonya ship, which dates probably to about 1225 BC, are of Buchholz' Type 2, but they could be grouped further into three subtypes, 2a, 2b, and 2c, which allowed Bass to extend the typological classification of Buchholz (Bass 1967, Fig. 55, p. 53).

Many of the Gelidonya ingots are marked with signs, either impressed into the top of the ingot whilst it was still soft, or incised later into the solid ingot (see Bass 1967, Figs. 56-58). As illustrated by Buchholz (1959 Ta. 3, 4, 5; Abb. 12) such impressed signs are found also in ingots from Mycenae, Enkomi, Hagia Triadha and Sardinia; thus such signs are also common on ingots found on land. I shall not dwell on them, since thorough studies by Bass (1967), Buchholz (1959) and others have so far not been able

to ascribe them to Linear A, Linear B, Cyprio-Minoan, or any other contemporary script. Nor do they seem to designate weight, or the destination of the ingots, or the quality of the copper, or, as we shall see, the origin of the copper.

THE COPPER TRADE.

If we are to use the oxhide ingots to contribute to our studies of Bronze Age trade we need to discover where they were made, which copper sources were used, how they were transported, what were their destinations and what were the nationalities of the people who made them, who sold them and who transported them. It will also be interesting to discover how and where they were cast, whether bun and slab ingots formed part of the copper trade at the same time that oxhide ingots were in use, and the relative quality of the copper used for the different types of ingot. Can we also discover the extent to which copper imported as oxhide ingots competed with other sources of copper, local or foreign, at a particular site at a particular period?

DISTRIBUTION OF OXHIDE INGOTS.

Figure 2 shows the distribution of known oxhide ingot find spots around the Mediterranean. For the finds on land, which often consist only of fragments, it is difficult to estimate the number of whole ingots represented, but it is about 130, with about 20 on Cyprus, 37 on Crete, 50 on Sardinia, 22 in Greece (chiefly Mycenae and Kyme) and 1 each in Sicily and Lipari. There were 38 ingots on the Cape Gelidonya wreck and more than 200 on the Ulu Burun wreck, so that about 65 per cent of all known ingots have been found on only two shipwrecks.

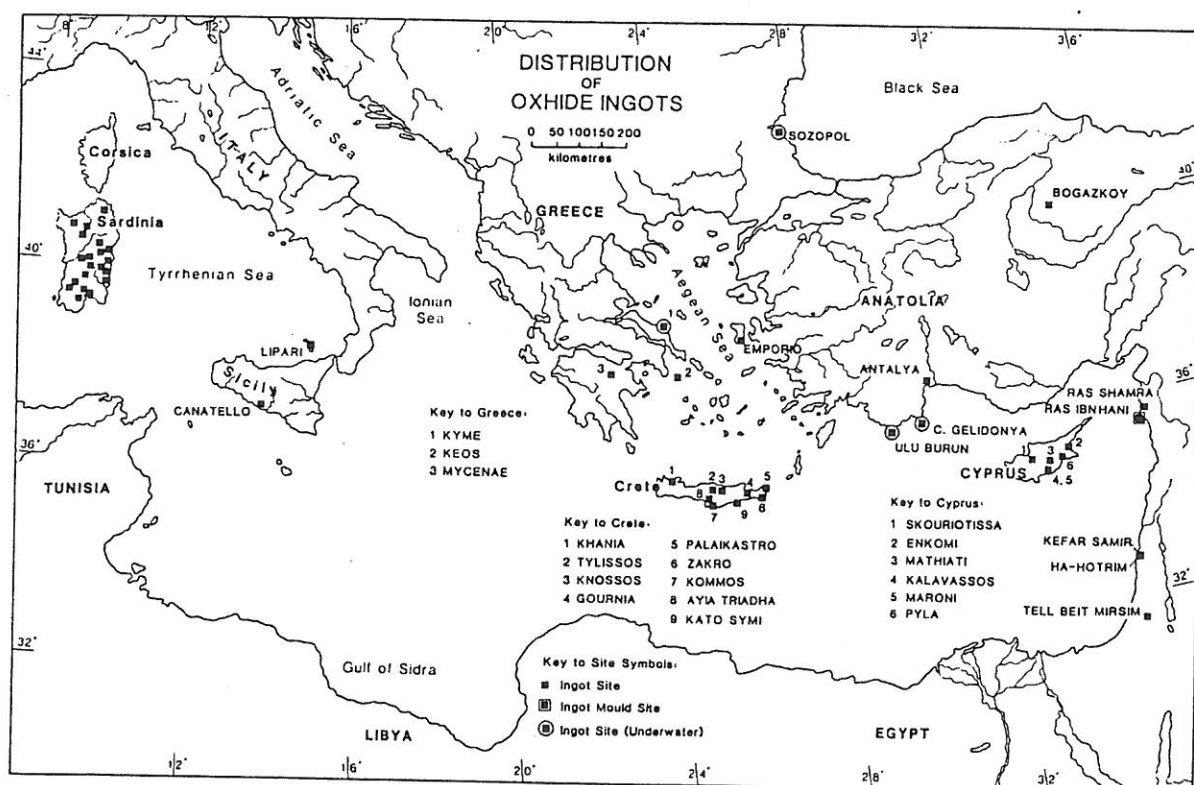
That indicates the scale of the trade in copper in the oxhide ingot form alone (or at least that *intended*; how many ships foundered with their cargoes, how many voyages were successful?), with at least 6 metric tonnes of

copper as oxhide ingots on the Ulu Burun ship alone. The distribution of find spots on land suggests that these ingots were almost exclusively transported by ship. They have been found overwhelmingly either on islands or at mainland sites not far from the sea; sites which in the main have other evidence for international trade.

Only two ingots have so far been reported from far inland. One Type 2 fragment, of 7 Kg mass, was excavated at Bogazköy, the ancient Hittite capital of Hattusha (Müller-Karpe 1980, Abb. 22, p. 304). The other, so far not illustrated, was reported by Brinkman as having been excavated at the Kassite capital of Dur-Kurigalzu, near modern Baghdad, and dates to the 12th century BC. (The ingot from Bogazköy reported by Buchholz (1959, p. 30, No. 9) is not of the oxhide shape, nor does it seem to be a fragment of an oxhide ingot. This ingot, illustrated by Bittel (1957, pp. 25, 32, Plate 21.3) is trapezoidal in shape and is very small, with a thickness of only 0.8 to 1.5 cm., a width of 6.35 cm at one end and 4.5 cm. at the other; it dates to about 1275 to 1250 B.C.).

These two ingots may have something rather special to tell us about some ramifications of the oxhide ingot trade, as may the example (see Gale 1989b, Fig. 29.1) excavated by Dimitrov (1979, Fig. 3, p. 73) from underwater off the Black Sea coast near Sozopol, ancient Apollonia, in Bulgaria. This ingot weighs 29 kilograms and has dimensions L. 58cm; W. 34cm; Th. 4cm; the weight is almost identical with that of ten of the early ingots excavated at Hagia Triadha, Crete, and its shape is similar, though a little longer and thinner.

This Bulgarian oxhide ingot bears a sign similar to that appearing on the later ingot from Enkomi which is now in the British Museum. It seems possible that there is a shipwreck with a cargo of oxhide ingots



waiting to be excavated underwater off Sozopol in the Black Sea. Where did the ship come from, where was it going?

Even more exciting are the two ingots reported to have been found underwater off the coast of Turkey in the Bay of Antalya, of which one is kept in Berlin and the other in the Metropolitan Museum, New York (Richter 1915, No. 1810, 457). Both are of the early type 1, that held in New York weighs 28.1 kilograms with L. 44.5cm; W. 37.5cm; Th. 5.1cm; shape, weight and dimensions are closely comparable with the ingots from Hagia Triadha. Both ingots point to the existence in the Bay of Antalya of a 16th or 15th century BC wreck whose exact location is, I understand, still being sought.

A clear feature of the distribution of oxhide ingot find spots on land is the prominent role played by the three great islands of the Mediterranean, Cyprus, Crete and Sardinia. About 80 per cent of all ingots discovered on land have come from these three islands. The very first oxhide ingots known to archaeology were discovered on Sardinia in 1857 (Spano 1858, Pigorini 1904), followed in the 1890's by the discovery by Tsoumas of the ingot at Mycenae (Svoronos 1906, 1910 Plate II), in 1896 by discoveries at Enkomi on Cyprus (Murray et al. 1900, 15, 17, Plate 1535) and in 1903 by the discovery of the ingots at Hagia Triadha on Crete (Paribeni 1903, 20-21; Carraelli 1945, 433, 455-458; Halbherr, Stefani, Banti 1977).

We can say at once that, as far as copper ore deposits are concerned, they are of course abundant on Cyprus, considerably less so on Sardinia and almost non-existent on Crete. Yet amongst these islands the very earliest oxhide ingots, dating to the late 16th century BC, have so far been found only on Crete. Cyprus and Sardinia have yielded only the later Type 2 and 3 ingots. On Cyprus, long regarded as the predominant source of copper

for the Bronze Age Aegean¹, it is remarkable that, until relatively recent excavations, there was only one complete oxhide ingot found in an excavation, that from Enkomi (from the Turner Expedition of 1897, Murray 1900; see also Matthäus 1985, Plates 123-127A) which forms part of the Enkomi Foundry Hoard and can perhaps be dated to circa 1200BC (Cailing 1964, 278-281; Matthäus and Schumacher-Matthäus 1986; but see Bass in this volume who argues cogently that the Cypriot hoards are to be dated to the 13th rather than the 12th century BC). The other complete oxhide ingots attributed to Enkomi, one in the Nicosia Museum (illustrated in Karageorghis 1982, Fig. 79) and one in the private collection of Henry Mudd, Los Angeles. Neither of these ingots has a secure archaeological context, nor do the fragments of ingots in the Nicosia Museum attributed to find spots in the Mathiati (1936-VII-17) and Skouriotissa (1976-I-20/6, 7) copper mines. There were also at least six oxhide ingot fragments in the Foundry Hoard at Enkomi; they are mentioned by Mühlly in this volume but four of them had already been published by Cailing (1964, 280). Recent excavations have now yielded oxhide copper ingot fragments from secure, well-dated, archaeological contexts from four sites in Cyprus. From secure LCIIIC (about mid 13th century BC) contexts at Kalavassos-Ayios Dhimitrios we have samples from three fragments of oxhide ingots from Room A50 of Building IX (South-Todd 1985, 119). From the Ashlar Building at Maroni-Vournas come four unpublished fragments of oxhide ingots, again from the LCIIIC period (Cadogan 1985: 1987, 83). From Mar-Palaeokastro (Demas 1984) come at least one, perhaps three, oxhide ingot fragments, dating to the end of LCIIIC. From Pyla-Kokkinokremos come two handle fragments of oxhide ingots (Karageorghis and Demas 1984, 38, 57, 100-103, Plate XXVI, 65), also dating to the end of LCIIIC (about 1240-1220 BC).

On Crete a few fragments of Late Bronze Age Type 2 and 3 oxhide ingots have now been found at Kommos (six fragments dating to LMIIIA2-IIIB, see Shaw 1987) and Khania (three fragments dating to LMIIIA1-IIIB, see Haltinger 1987), whilst one LBA fragment has recently been excavated from the Minoan sanctuary at Syme by a team directed by Dr Angelike Lebesse. Oxhide ingots or fragments thereof have now been excavated from nine sites in Crete, the other sites being Hagia Triadha, Zakros, Knossos (Evans 1928, p. 624 describes this fragment as having been found in 1902, in disturbed earth, in the Long Corridor of the Magazines at Knossos), Gournia (Belancourt et al. 1978), Tylioussos (Hazzidakis 1921, p. 57, Fig. 31), Palaikastro (Bosanquet 1977, p. 306, Plate XVI). At Hagia Triadha, Zakros and Tylioussos the ingots or fragments are predominantly of the earlier type; indeed about 75 per cent of the oxhide ingots found on Crete are of the early Type 1 and/or come from 16th to 15th century contexts. These early ingots include the 19 excavated at Hagia Triadha (illustrated *inter alia* by Carraelli 1945, Figs 38-41; Buchholz 1959, Tafel 3, 4; Pigorini 1904, Figs G-H) and six excavated by Platon at Kato Zakros (Platon, 1971).

A puzzle with the ingots from Hagia Triadha is the half ingot of the later Type 2, which Carraelli (1945, Plate XXIII) confidently published as having been found with the others of Type 1. Our photograph (Plate 1) shows it to be in the Herakleion Museum to this day, attributed to Hagia Triadha; is this a correct attribution? Certainly Paribeni (1903, p. 334) reports in 1903 that the Italian Mission found nineteen ingots together in five groups: "Uno di cinque pezzi, tre di quattro e uno di due" (though his notebook dated 31 March 1903, reports the slightly different arrangement of "tre gruppi di cinque lingotti erano lungo la parete sud, un gruppo di tre e un lingotto isolato erano appoggiati al muro nord"). Of these, sixteen complete Type 1 ingots are

on display in Herakleion and two complete specimens of the same type in Rome (Borda 1946, p. 79, Plate LX); in principle this certainly leaves room for the half ingot of Type 2 to be the nineteenth ingot found in the single hoard at Hagia Triadha. Carraelli (1945, Fig. 2), reproduces a drawing of this hoard *in situ* by Stefani, made at the time of excavation, whilst a photograph of the hoard *in situ* appears as Fig. 85 in (Halbherr et al. 1977); the half-ingot can be seen in neither depiction, but it could easily have been obscured behind other, Type 1, ingots. On the other hand a closer reading of Paribeni (1903, p. 334) suggests that there were excavated, in addition to the nineteen Type 1 ingots, two additional fragments, one a half ingot and one a quarter ingot; Paribeni records these two fragmentary ingots as having been found "fra lo strato di suppellettile votiva del piazzale superiore orientale" but perhaps we may be forgiven for suggesting that exactly where these were found in relation to the main hoard of nineteen whole ingots is unclear because of the obscurities in Paribeni's account of the excavation, as discussed by Halbherr et al. (1977, 115ff.). It seems that currently the whereabouts of the excavated quarter ingot and one of the Type 1 ingots are unknown. The Type 2 half ingot must have been deposited prior to the end of LMIIIB, so we may have here a case of contemporary Type 1 and Type 2 ingots similar to that pointed out by Bass in the Egyptian tomb paintings. If such a contemporary difference in ingot shape did exist, it might of course point to the production of ingots of broadly similar shape at quite different centres, possibly using copper from quite different ore deposits.

The Type 1 ingot from Tylioussos (HM11763) published in 1921 by Hazzidakis (1921, pp. 56-57, Fig. 31) is well known and a recent photograph is reproduced in Plate 2a. Less well known is the fact that there are two



Plate 1



Plate 2a



Plate 2b

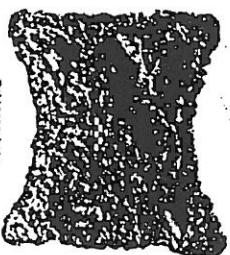


Plate 2c

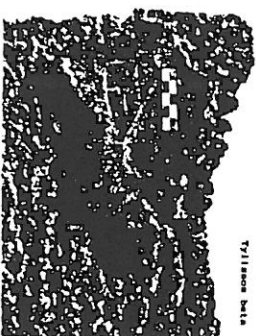


Plate 2d

more unpublished Type 1 oxhide ingots in the scientific collections of the Herakleion Museum which are recorded as having come from Tyliссos. This attribution is probably correct, since the wooden labels attached to each bear old marks which associate with them the same number (1763) as the inventory number for that published by Hazizidakis. Plate 2b and 2c illustrates these two ingots, which I have arbitrarily called Tyliссos alpha and Tyliссos beta. Tyliссos beta is particularly interesting since it bears two patches; one of these is shown enlarged in Plate 2d, and bears an impressed sign.

WHO CONTROLLED THE TRADE?

I shall end the archaeological introduction by saying something very briefly about the possible identity of the people who operated the trade in oxhide ingots. In the past it has been almost universally assumed that such trade was in late Minoan, Mycenaean or at least Aegean (perhaps Cycladic) hands (e.g. Vercoeur 1956, and the general use of the term Kefitiubarren by Buchholz 1959). The careful studies of representational evidence made by George Bass (1967), and recently confirmed by Shelley Wachsmann (1987), throw considerable doubt on that.

Their examination of the Egyptian evidence from tomb paintings and reliefs suggests that it is in only one tomb, that of Rechinire at Thebes, dating to about 1470 to 1410 BC, where oxhide ingots may definitely be associated with Aegeans, from Kefitiu (Bass 1967, 63, Fig. 67). Even here (Bass 1967, 64, Fig. 68) Syrian chiefs present similar ingots, and when the ingots are seen in the hands of porters bringing them to Egyptian bronze workers in the same tomb (Bass 1967, 64, Fig. 70), they are identified as Asiatic copper from Retnu, that is, Syria. Wachsmann (1987, 50) goes as far as to write: 'It would seem, therefore, that in the case of the oxhide ingots of Rechinire's Aegeans they have been transferred from the source scene of Syrian

tribute'. As Bass (1967, 62-67) has written, in eleven other representations we may be certain that the Egyptians considered the ingots to be in the hands of Syrians. An example is from the tomb of Huy at Thebes (Bass 1967, 67, Fig. 82), whilst from the tomb of Amenemhet (Wachsmann 1987, Plate LI(B)) the porters, carrying both copper oxhide and lead ingots, have been identified by Shelley Wachsmann (1987, 50) as an example of hybrid Aegean/Syrians. It is not uncommon in Egyptian art for human figures and objects to be composed by uniting elements originally belonging to two or more separate entities.

However we should note that the Egyptian representations of Syrians bringing oxhide ingots to Egypt date no later than 1350 BC. These records do not by themselves necessarily tell us who traded oxhide ingots to the west, or in whose hands the trade was in later times.

There are at least two pieces of evidence which do seem to indicate a Syrian connection with the production of copper oxhide ingots in later times. The most positive is the excavation by Drs Elisabeth and Jacques Lagarde (Lagarde *et al.* 1983, 277-290; for an illustration see Gale 1989b, Fig. 29, 19), who are with us today, of the only mould for an oxhide ingot yet discovered, from the Late Bronze Age palace at Ras Ibn Hani just south of Ugarit. It was found in atelier 17 of the North Palace and the excavators (1983, 287-289) have noted that this may indicate that the metal working was a royal franchise. Scattered around the ingot were a number of copper metal droplets which presumably splashed out when the mould was used to cast an ingot; we shall see later what the analyses of these droplets have to reveal about the manufacture of oxhide ingots at Ras Ibn Hani. In Ugarit itself two possible oxhide ingot fragments were found by Schaeffer (1936, 99; 1956, 269; 260, Fig. 224:19;

Another, perhaps less certain, piece of evidence linking copper oxide ingots with the Syrians is the well known bronze stand from Kouion in Cyprus (see the illustrations in Catling 1969, Figs. 1 and 17, and Taiton-Brown 1987, 19), now in the British Museum (BM 1920/12-20/1), dating to the twelfth century BC. Scholars debate the ethnic identity of the man carrying the Type 2c ingot, but parallels have been drawn with figures on contemporary North Syrian sculptural reliefs.

Finally we must mention the evidence from the Cape Gelidonya shipwreck. It carried much to associate it with Near Eastern merchants, such as a merchant's seal, religious talismans, Near Eastern weights, stone hammers, mortars, a lamp, and bronzes more than half of whose prototypes are found in the Near East (Bass 1967). It is true that the probable ethnic mix in contemporary Cyprus, making it difficult to distinguish a Syrian from a Cypriot merchantman, does not rule out the possibility that the ship was Cypriot; but it can hardly have been Aegean. These matters are discussed in more detail in the paper by George Bass in this volume.

THE COPPER SOURCES USED TO MAKE THE OXIDE INGOTS.

Archaeological evidence suggests that bulk trade in copper developed in the Levant and Eastern Mediterranean only in the Late Bronze Age; by that time the large-scale bronze industry of Late Minoan Crete (as witnessed by sites such as Knossos, Hagia Triadha, Zakros, Malia, Tylissos, the Arkalochori cave, Gournia, Palaikastro, Armenoi etc.), which depended entirely on imported copper and tin, was in full swing. Indeed the earliest copper oxide ingots are so far attested only at sites in Crete such as Hagia Triadha, Gournia, and Zakros (perhaps all dating to LMIB, though formerly dated to

LMIA) and in Egyptian tomb paintings dating to the reigns of Hatshepsut and Tutmosis III (perhaps 1504-1450, following the 1976 chronology of the Oriental Institute of Chicago). Later depictions of oxide and other ingots occur successively in tombs dating to the reigns of Amenhotep II [1453-1419], Tutmosis IV [1419-1386], Akhenaten [1350-1334] and Ramesses III [1182-1151] (Bass 1967, 62-68) to which we may add the evidence of the ingots on the Ulu Burun ship [circa 1300 BC], the Cape Gelidonya wreck [circa 1240-1200 BC], and the ingots on Cyprus, Crete, Sardinia and the Mycenaean world, discussed earlier. None of this evidence reveals where the ingots came from or the ore deposits which were exploited to provide the copper metal from which they were made.

Clearly, if we are to be able to use the copper oxide ingots to shed some light on the pattern of the Bronze Age Copper trade in the Mediterranean we have to find a way of being able to answer such questions as: were the ingots found on Sardinia imported or were they made on that island from Sardinian copper ores?

The ordinary methods of archaeology are powerless to answer such questions. There has been no progress with attempts to understand the meaning of the signs on some oxide ingots and in any case many bear no signs. Typological classification has given no clue about their place of manufacture, nor have the Egyptian tomb paintings or the evidence from Bronze Age shipwrecks. A considerable effort has been put into trying to find a scientific technique which would enable the provenance of copper or bronze objects to be established. Most of that effort has been put into chemical analysis of objects, with the hope that at least the minor or trace element compositions would solve the problem. Very little effort was put into chemical analyses of ores or into the study of

the relevant ore deposits and their geology. The end result has been a failure to make any progress along these lines with the provenancing problem properly so-called (see Coles 1982), i.e. the linking of copper alloy artefacts with the ore deposits which provided their copper metal (see later for a discussion of the use of trace elements to cluster particular oxide ingots together in groups). Much effort has been put into metallographic studies of oxide ingots (e.g. Zwicker *et al.* 1980; Zwicker *et al.* 1985; Muhly, Stech-Wheeler, Maddin 1977; Muhly, Maddin, Stech-Wheeler 1980; Tylecote *et al.* 1984); this has yielded much of metallurgical interest but has not at all solved the problem of provenance.

The most promising approach (see, e.g., Gale 1989a; Gale and Stos-Gale 1989, 1991), seems to be to use lead isotope analyses backed up by trace element analyses. At the first level of utility one can in this way link oxide ingots together which appear to be made from the same copper metal source.

It is much more important that, by comparing lead isotope analyses of ingots with those of copper ore deposits, one can hope to link both oxide ingots and manufactured bronze objects to the copper ore deposits whence came their copper metal.

Figure 3 shows lead isotope analyses for a few important Mediterranean copper ore deposits whose locations are given by Stos-Gale & Macdonald (this volume, Fig. 1). It should be said at once that this diagram shows the two ordinary diagrams necessary to depict the three lead isotope ratios available (the fields are shown as statistically computed ellipses at the 90% confidence level). It illustrates, by comparison of the two diagrams, that the apparent overlap between some of the fields disappears when all three isotope ratios are used.

The important principle is that if the isotopic composition of the trace of lead in an ingot falls well outside the field of compositions AEGEAN, TUSCAN AND ANATOLIAN ORES

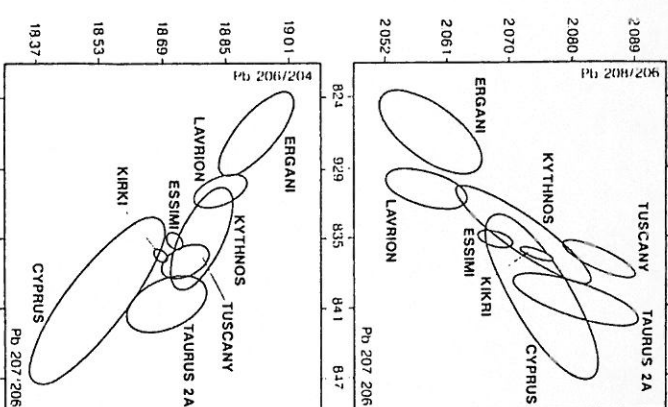


Figure 3. Lead isotope fields for some copper ore deposits of relevance to the Aegean world. The elliptical fields are drawn at the 90% confidence level.

characteristic of a given ore deposit, then the copper used to make that artefact did not come from that ore deposit. Conversely, if the lead isotope composition for an ingot falls within the field for a particular ore deposit, then that ingot is consistent with having been made using copper extracted from those copper ores.

DIAGRAMS, OVERLAP, STATISTICS, ETC.

I need to make a small digression here to

explain just a little about how one can display and analyse lead isotope data, whether it is for artefacts or ore deposits.

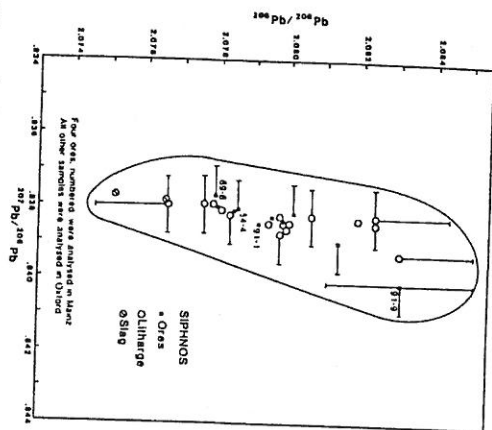


Figure 4. One of the two available ordinary bivariate lead isotope diagrams for the lead-silver ores from the Cycladic island of Siphnos.

The first approach was to adapt the method used by isotope geologists, illustrated in Figure 4 for one of the two bivariate diagrams for the ancient lead-silver sources on the Cycladic island of Siphnos (Gale and Stos-Gale 1981). In Stos-Gale *et al.* (1986, 127, Figs. 2 & 3) appears the field of lead isotope compositions for the copper deposits in Cyprus. They give the lead isotope ratios for a number of samples of copper ores taken throughout the Cypriot copper ore deposits, which they plot in the two possible diagrams resulting from the two combinations of the three measured isotope ratios for each sample.

By plotting also on these diagrams the known reproducibility at the 95% confidence level of plus or minus 0.1% for the lead

isotope ratios, one could construct fields around the measured points, as illustrated for Siphnos in Figure 4.

Sometimes this results in overlapping lead isotope fields for particular ore deposits, as is seen in Figure 3 for the copper deposits of Cyprus, Kythnos and Lavrion. Actually there is good evidence that the copper deposits on Kythnos were used only in Early Cycladic II times (Stos-Gale 1989), and could not therefore have been a source of copper for oxide ingots, which began to be made not earlier than 1600 BC, but one would still like an objective way of separating the lead isotope data for these copper deposits.

In fact, though these three copper deposits all overlap to some extent in one lead isotope diagram, the Kythnian field separates completely from the Cypriot field in the alternative possible diagram (lower part of Figure 3), but there is still some overlap between Lavrion and Kythnos. Of course these two-dimensional diagrams are just arbitrary cross-sections through three dimensional distributions of lead isotope data. If one uses a programme like Macspin (see the paper by Cherry and Knapp in this volume) or Brush and Spin (in the S-Plus statistical software), one can rotate the data, whereupon it is often possible to choose a direction in which there may be no overlap between the three ellipsoids which contain the data.

DISCRIMINANT FUNCTION ANALYSIS

Another, more quantitative, approach is to use multivariate statistics to include all three lead isotope ratios together at the same time. A technique which is ideally suited to situations which focus on a set of two or more groups of data, such as we have with lead isotope data from a number of different copper ore deposits, is discriminant function analysis (see, e.g. Manly 1986), which can

be applied in a stepwise fashion. This method of statistical analysis, which is far superior for our purposes to principal components analysis or factor analysis, investigates how well it is possible to separate several groups of data and provides numerical assessments of the separation between groups, say groups of lead isotope data for different copper ore deposits. It subsequently provides a means of testing whether the lead isotope data of, say, an oxide ingot belongs to one of these groups, and gives an objective assessment of the probability that the ingot belongs to a particular group. This is far superior to cluster

analyses, which do not produce a quantitative measure of the degree of separation between groups, nor result in mathematical functions for classifying new objects to groups with a quantitative measure of group membership. Cluster analysis remains, however, a useful preliminary technique for investigating the grouping of data where one has no *a priori* indication as to what groups should exist; the groups suggested by cluster analysis should always subsequently be assessed by a proper technique of multivariate statistical analysis such as discriminant function analysis.

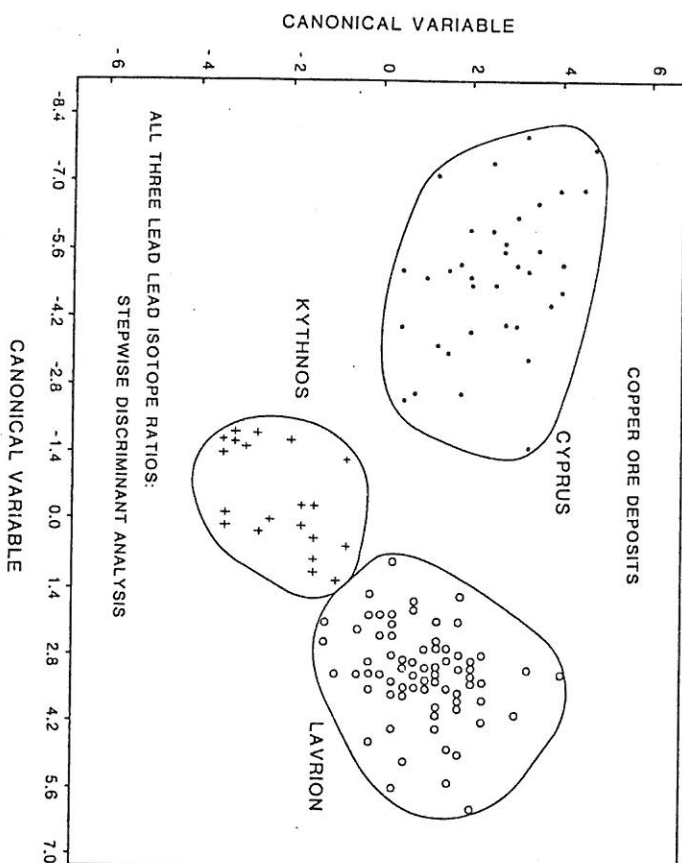


Figure 5. Stepwise discriminant function analysis of all three lead isotope ratios for ore samples from the deposits on Cyprus, Kythnos and in the Lavrion (Attica).

Figure 5 shows that discriminant analysis gives a good separation of the lead isotope

data for the three copper deposits we have been considering, in the scatter diagram for the first two canonical functions which discriminant analysis produces as best separating these three groups. Such a scatter diagram is a useful pictorial summary of a discriminant analysis, but of course it does not tell the whole story. Discriminant analysis software, such as BMDP programme 7M, produces also numerical information. On the one hand group centres are computed together with, for each data point, the Mahalanobis distances to the group centre; if an observation is very significantly far from the centre of its group on the basis of the chi-square distribution, then this brings into question whether that observation really comes from this group. The posterior probabilities of group membership are also computed for each observation. In the present example of grouping the lead isotope data for the three copper deposits of Lavrion,

Cyprus and Kythnos the probabilities for Lavrion ores belonging individually to the Lavrion group are all over 98%; the same is true for the Kythnos ores except that for just one sample the probability drops as low as 81%; for the Cypriot group the probabilities of group membership are all above 99%, save for one ore sample misclassified with Kythnos at a probability of 88%. We shall henceforth use scatterplots for brevity in summarising the results of discriminant function analysis. In such scatterplots, if the data follows a multivariate normal distribution with equal variances and covariances amongst groups, then each scatter of points would be ellipsoidal with approximately the same size and direction of tilt. The dissimilar 'ellipses' in Figure 5 suggest a departure from such assumptions, but the discriminant functions generated still divide the groups quite sharply.

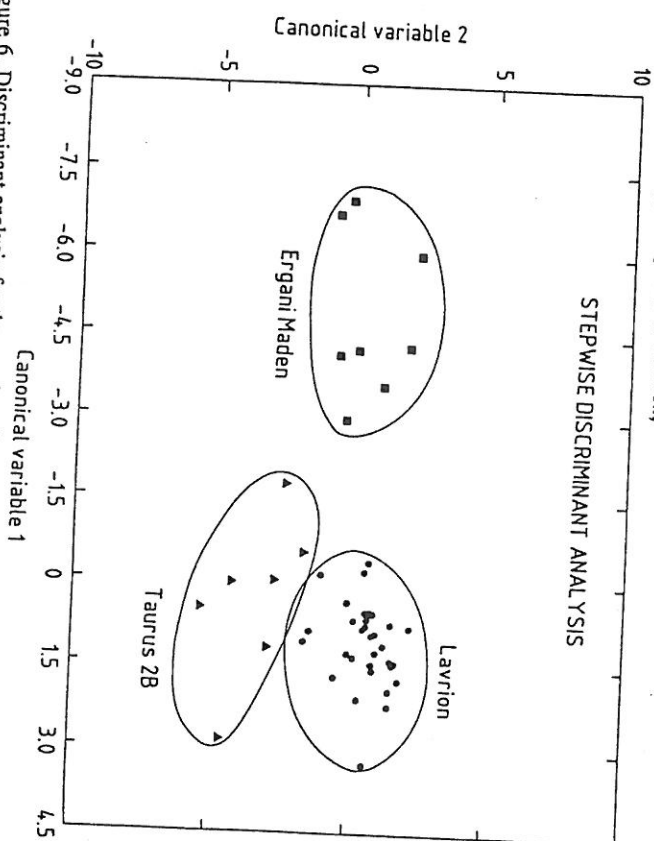


Figure 6. Discriminant analysis for the ore deposits of Ergani Maden, Lavrion and Taurus 2B.

Other apparent overlaps between ore deposit lead isotope data have come from recent work of Asiltan Yener and her colleagues (1991), for ore deposits in the Taurus Mountains in Anatolia, whose location is shown in Figure 1. This sketch map also shows the location of the large copper mine of Ergani Maden (Griffiths et al. 1972, Birgi 1950) in central Anatolia which has often been suggested as an important ancient source of copper (Birgi 1951, Seeliger et al. 1985).

Yener *et al.* (1991) have shown, in an ordinary lead isotope diagram, serious overlap between their Taurus 2B ore source and that of Lavrion, with some minor overlap with Ergani Maden. In contrast stepwise discriminant analysis of all three isotope ratios for Lavrion, Ergani and Taurus 2B, plotted in Figure 6, shows good separation of all of these ore deposits.

STEPWISE DISCRIMINANT ANALYSIS

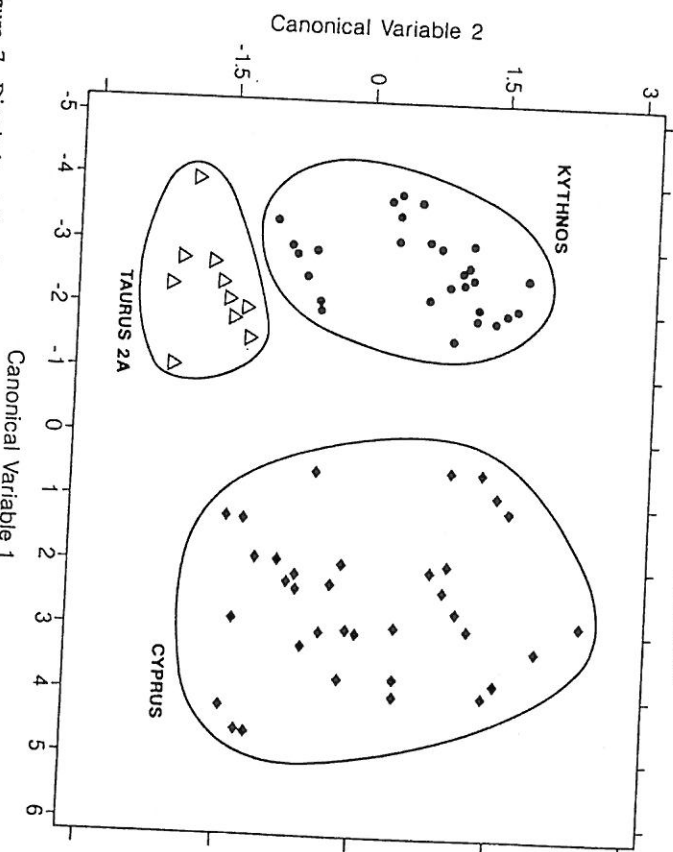


Figure 7. Discriminant function analysis of lead isotope data for ores from Cyprus, the Cycladic island of Kythnos and the Taurus 2A ores of Yener et al. (1991).

Figure 3 depicts in an ordinary bivariate lead isotope diagram another case of partial, but apparently significant, overlap between the Cypriot field and the Taurus 2A field. Again the application of stepwise discriminant analysis to all three isotope ratios completely

separates the lead isotope fields of all three copper ore deposits, as shown in Figure 7.

Gale and Stos-Gale (1991) have investigated many other apparent cases of partial overlap of lead isotope fields for copper deposits in

the Aegean, Anatolia, Tuscany, Sinai, etc. In every case but one discriminant function analysis has been able to resolve the lead isotope fields. The one case where overlap cannot be completely unscrambled by multivariate statistical analysis of all three ratios is for the copper deposits on Thasos

and on Kythnos. Here however, combined analytical and archaeological arguments (Gale and Stos-Gale 1991) show that copper was not exploited on Thasos in the Bronze Age, and could not therefore be a source of copper for the oxhide ingots studied in this paper.

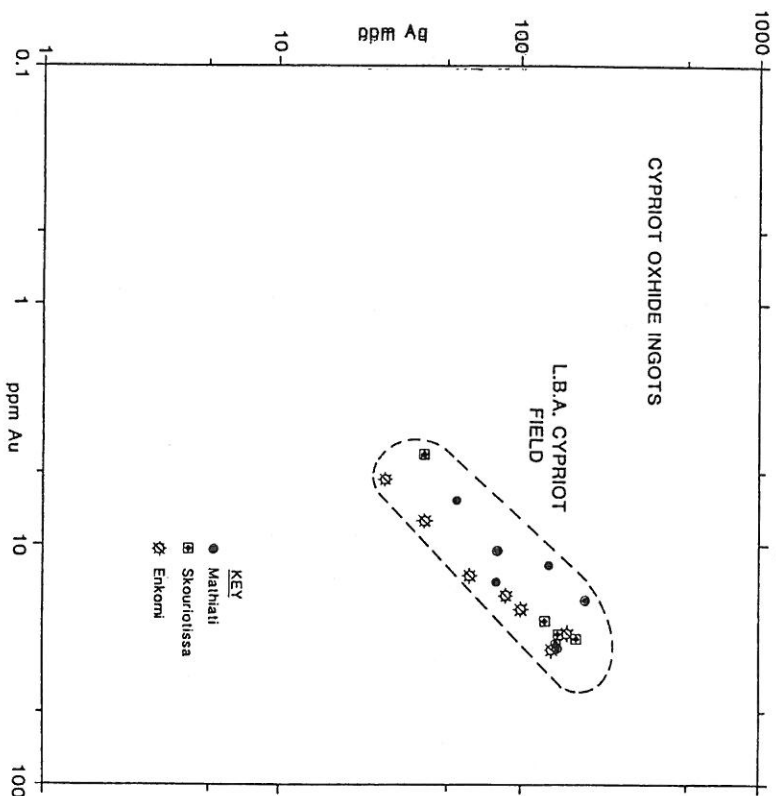


Figure 8. A plot of the concentrations of gold (Au) and silver (Ag) in oxhide ingots from three sites in Cyprus, showing that they fall in a 'field' defined by analyses of Late Cypriot artefacts.

OXHIDE INGOT DATA

We can now turn to the data for lead isotope analyses of copper oxhide ingots. Before we do that I want to say a little about trace element data. There is no space here to

discuss all our trace element data, so I will concentrate on the elements gold (Au) and silver (Ag), since they seem to give us significant extra information for Late Cypriot copper.

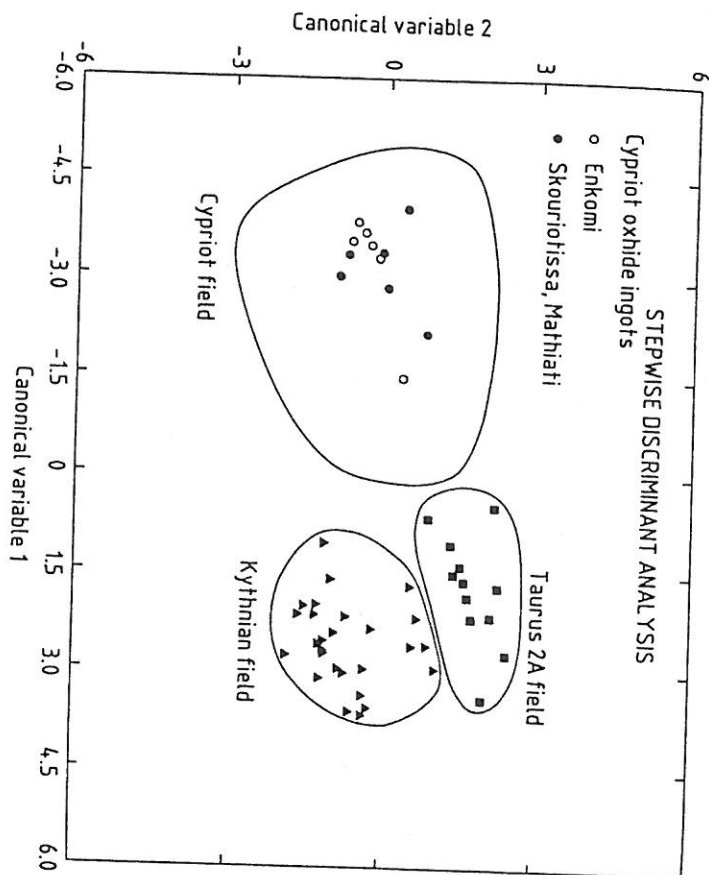
Stos-Gale *et al.* (1986, 131, Fig. 8) showed that, in a plot of their Au and Ag contents, all analysed copper and tin bronze artefacts from the Late Bronze Age sites of Hala Sultan Tekke and Ayios Dhimitrios in Cyprus plotted in a restricted region or 'field' of the Au-Ag diagram. All of these artefacts have lead isotope compositions falling into the field defined by Cypriot copper ores (Stos-Gale *et al.* 1986, 130, Figs. 6 & 7). The sites now included for which this characteristic remains true range in date from Late Cypriot IIC at Kalavassos - Ayios Dhimitrios (e.g. South 1980), that is about 1325 to 1260 BC, to latest LCIIIC at Pyla-Kokkinotremos (Karageorghis and Demas 1984) and at Maa-Palaeokastro (Demas 1984), i.e. about 1230BC. Their geographical position is such that the different sites may well have drawn their copper from different ore deposits around the Troodos, but the Au and Ag contents plot in a well defined field of compositions. This Au/Ag field seems to be a "fingerprint" for Late Cypriot copper. Middle Cypriot copper artefacts from Alambra and elsewhere, and Early Cypriot artefacts from Lapinos or Middle Cypriot artefacts from Alambra etc., do not have Au and Ag contents falling into this field (unpublished data), so that it seems to be a fingerprint only for Late Cypriot copper metal.

Oxhide ingots and fragments have been known from Cyprus for a long time from Enkomi, Skouriotissa and Mathiati. The whole ingot and six fragments from the Enkomi Foundry Hoard, now in the British Museum, probably date from about 1200 BC, though they could be earlier (Knapp *et al.* 1988). These ingots again span sites across Cyprus and perhaps extend to later times, but Figure 8 shows that their gold/silver analyses all fall in the field defined by the Late Cypriot copper alloy artefacts. On this evidence the oxhide ingots found on Cyprus are indeed consistent with having

been made of Cypriot copper. This conclusion is greatly reinforced by the lead isotope data for the oxhide ingots found on Cyprus. Stos-Gale *et al.* (1986, 129, Fig. 5) showed, in an ordinary lead isotope diagram, that the ingot fragments from Skouriotissa and Mathiati fall within the field defined by Cypriot copper ores; they showed also (Stos-Gale *et al.* 1986, 130, Figs. 6 and 7) that the Cypriot ore lead isotope field contains all the Cypriot artefacts from Kalavassos, Pyla and Hala Sultan Tekke whose Au, Ag contents define the Late Cypriot Au-Ag field. Figure 9, a diagram resulting from stepwise discriminant function analysis, shows that the lead isotope data not only for the oxhide ingots from Skouriotissa and Mathiati, but also the data for the whole oxhide ingot and 6 fragments from Enkomi, is all contained within the field defined by Cypriot copper ores. This has the advantage of including all three lead isotope ratios and allows a comparison of the grouping of the ingots with the ore deposits nearest in lead isotope composition to Cyprus, from which they are completely resolved.

There is no doubt that both the lead isotope data and the Au, Ag concentrations support the conclusion that all analysed oxhide ingots and fragments found on Cyprus were made from Cypriot copper ores. Now we know that Cyprus possesses abundant copper ore deposits, and our own lead isotope data proves that Cypriot copper ores were used to make artefacts excavated at Vounous (Stos-Gale *et al.* 1991) which date as early as Early Cypriot IB (about 2,100 BC) and at the LCIIIC (about 1325-1225 BC) sites of Ayios Dhimitrios, Pyla, and Hala Sultan Tekke (Stos-Gale *et al.* 1986).

Consequently it might well be that most oxhide ingots found elsewhere are also made of Cypriot copper, and it has long been the common assumption of Mediterranean archaeologists that this is so. There is one



curious exception for the oxide ingots found in Sardinia in that, though originally assumed to have originated in the Aegean (Pigorini 1904), there is a very recent tendency for a few contemporary scholars to believe that they may have been made in Sardinia from Sardinian copper ores.

In considering the scientific evidence that we have accumulated about copper oxide ingots we must remember one important fact. This is, as discussed above, that we have both a lead isotope and a Au/Ag fingerprint for copper produced from Cypriot copper ores in

the Late Bronze Age, fingerprints which we can use to trace the movement overseas of Cypriot copper in the form *inter alia* of oxide ingots.

SARDINIAN INGOTS

Let us first consider the *ingots* found on Sardinia. I should say at once that our work forms part of a large research programme directed by Fulvia Lo Schiavo which involves also James Muhyi, Tamara Stech and Robert Maddin. I shall limit myself here largely to a brief outline of what has already been published about the Oxford work, but

with an amplification of the archaeological aspects.

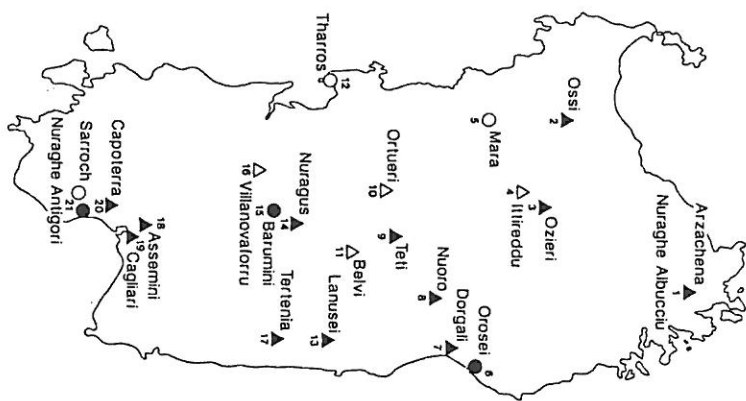


Figure 10. Sketch map showing some of the find spots (solid and open triangles) for oxide ingots in Sardinia.

The sketch map of Figure 10 shows, as solid triangles, some of the more than 20 find spots for oxide ingots now known on Sardinia, which have recently been reviewed by Fulvia Lo Schiavo (1980, 1985).

The most familiar oxide ingots found on Sardinia are the three from Serra Ilixi (Spano 1858). They are conveniently illustrated by Lo Schiavo (1981, Fig. 281), where they are

shown together with fragments of oxidized ingots excavated from the nuraghe Albucciu, Atzarchena (Lo Schiavo 1982, 271-272). The whole ingots have no archaeological context, but the fragments from Albucciu are thought to date to the end of the Italian Late Bronze Age (Ferrarese-Cerni 1985, note 18), which I take to be about 1200-1000 BC according to the chronology of Lilliu (1982). If this is correct, this is amongst the latest known contexts for oxide ingots (others which may be in similar contexts include those from Villanovaforru and Sardaia), though of course these fragments may well be from an oxidized ingot or ingots made rather earlier. In most cases the Sardinian oxide ingots and fragments do not have an archaeological context which allows firm dating, though it has been suggested by Stech (1989) that they begin in the 13th century BC.

Italian archaeologists such as Pigorini, writing in 1904, were convinced that the oxidized ingots found on Sardinia came from the Aegean world, but it has been recently more fashionable to point to the undoubted copper ore deposits on Sardinia and to suggest that the oxide ingots found there were in fact produced from these deposits on Sardinia itself. It has sometimes been suggested that to bring copper oxide ingots from the Eastern Mediterranean to Sardinia is akin to bringing coals to Newcastle, though perhaps one should recall the contemporary imports to Britain of coal from Poland and elsewhere. The analogy is in any case not a good one, since Sardinia is not noted for its reserves of copper, but rather for its deposits of lead. For example, the total production of copper concentrates from Sardinia in the period 1851-1948 was 75,000 tonnes, compared with 3,147,000 tonnes of lead minerals in the same period (Sarda 1949, 59). That the reserves of copper in Cyprus are overwhelmingly larger is shown by the fact that in Cyprus one mine (Mavrovouni) exported 131,093 tons of copper concentrates in the

Frenzel *et al.* 1975), since this dates as young as Tertiary times. The important point is that the range in geological age of the Sardinian copper ore deposits is a positive advantage for the method of characterising ore deposits based on isotopic analysis of contained trace lead.

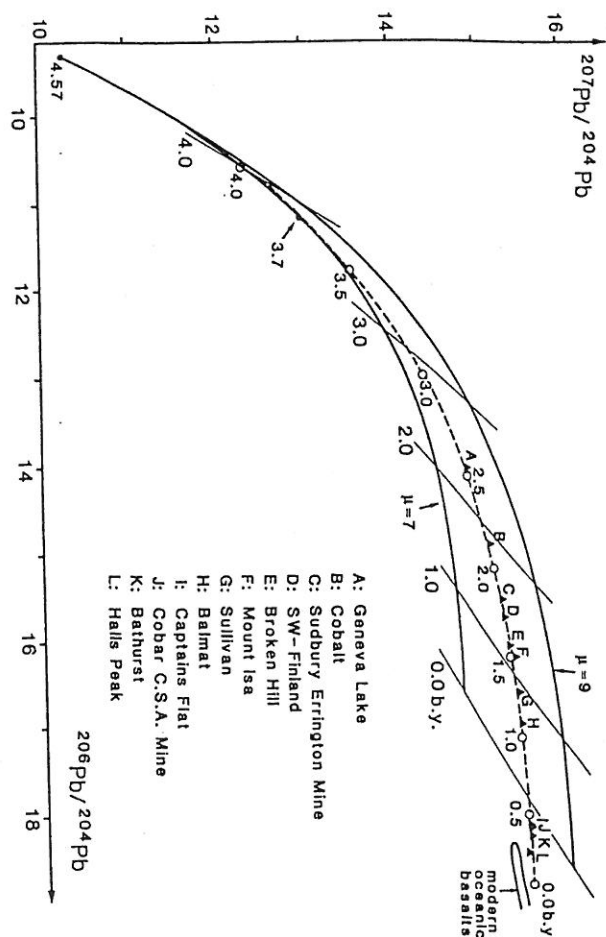


Figure 12. Isotopic analyses of lead from conformable ore deposits, showing that they fall in a regular way along a curve according to the depositional age of the deposit. Time is marked on this diagram in units of billions of years.

The reason is that, as Figure 12 shows, the lead isotope composition of a metallic ore deposit is governed to first order by the geological age of deposition of the ore. On this diagram the age is given in thousand million year units along the curve, on which the ore deposit lead isotope compositions are plotted. (In this diagram the isotopic ratios plotted are those normally used by isotope geologists).

Figure 12 is actually for rather special types of ore deposit, the so-called conformable deposits; nevertheless most ore deposits have lead isotope compositions which fall only a little off the position on this curve which would correspond to their geological age (see Gale 1989a; Gale and Stos-Gale 1989, 1991, for a more detailed discussion of the bases of using lead isotope analyses for provenancing).

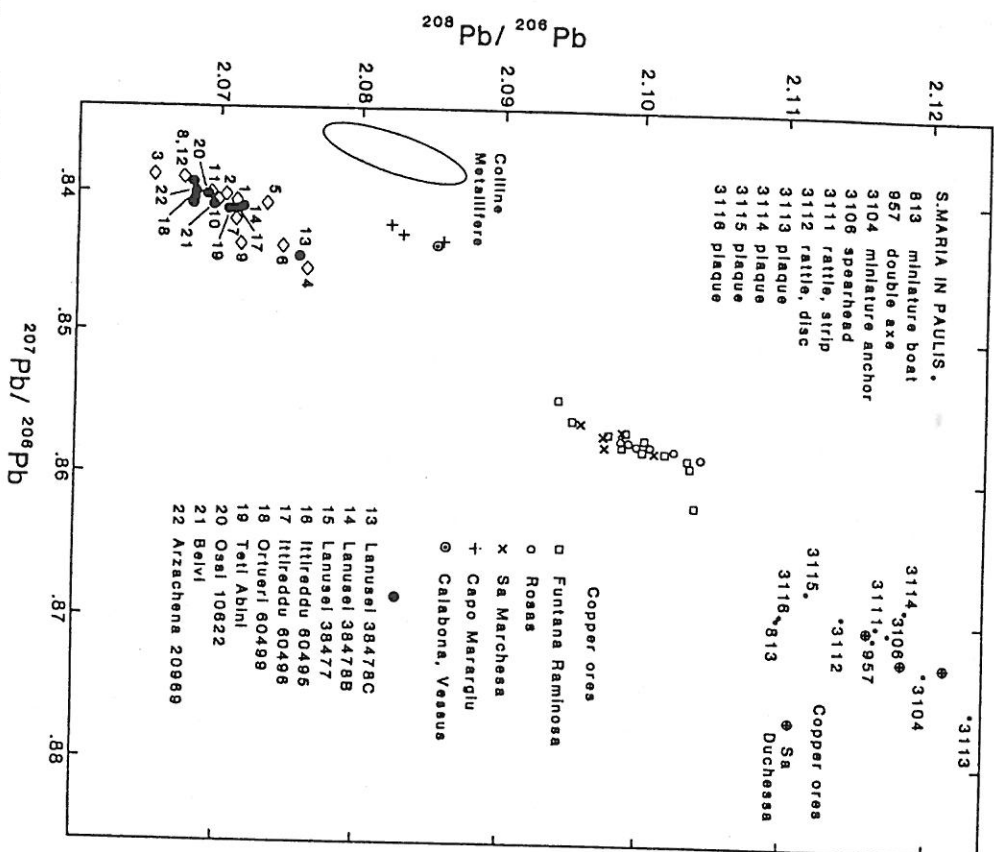


Figure 13. Lead isotopic compositions for nuragic bronzes and oxide ingots found on Sardinia compared with Sardinian copper ore deposits.

Hence we would expect in advance that we should easily be able to distinguish the older Cambrian (about 500 Ma old) Sardinian copper ore deposits from the Late Cretaceous Cypriot ore deposits, which date to about 80

Figure 13 presents lead isotope data for the major Sardinian copper deposits; it shows also the lead isotope data for 22 Sardinian oxide ingots so far analysed, together with the lead isotope data for a number of nuragic copper alloy objects from Santa Maria in Paulis. This hoard of nuragic artefacts dates most probably around the 12th-11th or the 10th-9th centuries BC (Macnamara *et al.* 1984).

It is at once clear from Figure 13 that all 22 of the Sardinian oxide ingots match none of the analysed copper ore deposits from

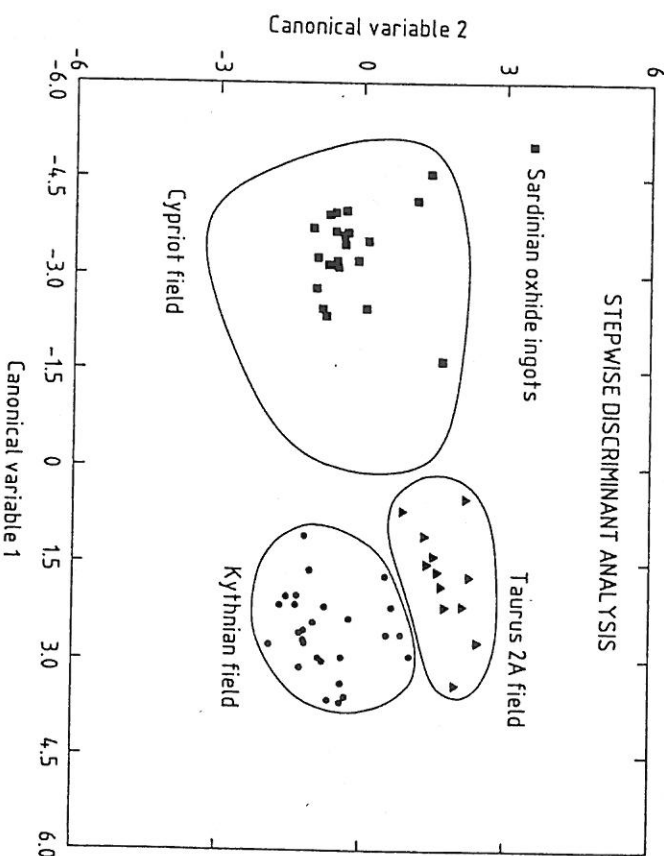


Figure 14. Stepwise discriminant function analysis of the three lead isotopic ratios for twenty-two copper oxide ingots found in Sardinia, showing that they are classified with copper ores from Cyprus.

If a match does not exist with Sardinian copper ores then it is clear that comparison should be made with the Cretaceous copper ores from Cyprus. Gale (1989b, 250, Fig.

29.6) has given the evidence for the field of lead isotope compositions for Cypriot copper ores which derives from stepwise discriminant analysis of all three isotopic ratios for each ore sample. Figure 14 shows that multivariate discriminant function analysis groups the Sardinian oxide ingots firmly in the field of Cypriot copper ores. Here we should mention that Muthy's comment (Muthy and Stech 1990, 203) is misleading in focussing on the fact that, in one of the bivariate lead isotope diagrams (Gale & Stos-Gale 1988, 375, 379, Fig. 17) the Sardinian

ingots lie towards the edge of the Cypriot lead isotope field, "so the relationship (of the Sardinian ingots with Cyprus) cannot be taken as proved". In fact all the lead isotope data for Late Cypriot artefacts and for Cypriot oxide ingots lies in the same position with respect to the Cypriot copper ore field as do the Sardinian oxide ingots in this bivariate plot. Moreover the discriminant analysis of all three isotope ratios allows very high statistical probabilities (over 90%) that the Sardinian oxide ingots belong to the Cypriot field.

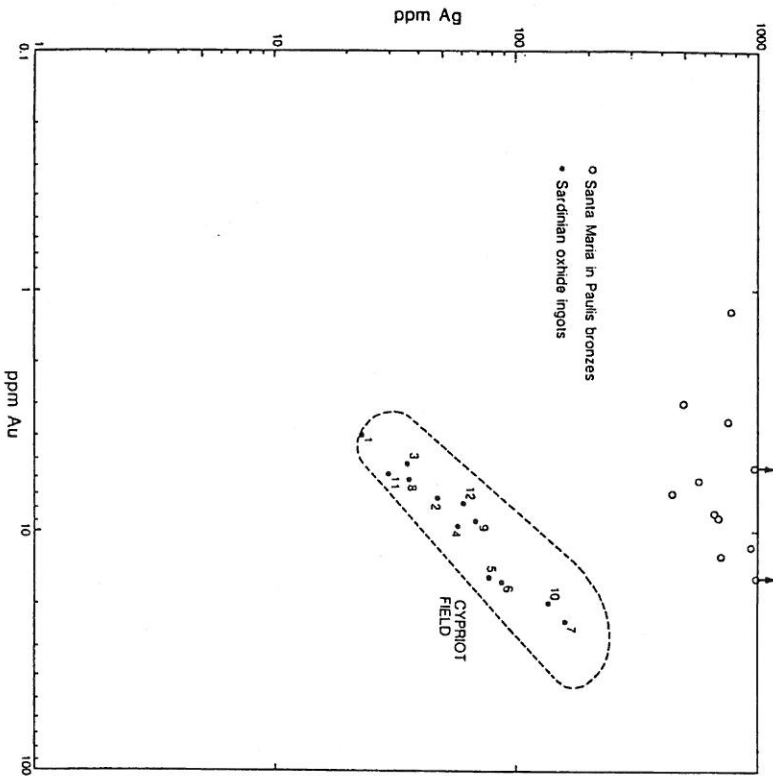


Figure 15. The gold/silver diagram for twelve Sardinian oxide ingots which have lead isotope compositions which fall within the Cypriot field, and for some typically nuragic bronzes.

Figure 15 shows the Au/Ag diagram for the 12 Sardinian oxide ingots so far analysed, in

which the Sardinian oxide ingots group in the field defined by Late Cypriot bronze artefacts and Cypriot oxide ingots. In contrast the nuragic bronze artefacts from Santa Maria in Paulis plot high up in the diagram, quite outside the Cypriot field. This agrees with the evidence from lead isotopic analysis that the nuragic bronzes were made from Sardinian, not Cypriot, ores. Clearly the nuragic bronzes and the oxide ingots found on Sardinia were made from quite different sources of copper.

The result is that two independent lines of evidence are consistent with the Sardinian oxide ingots having been made of Cypriot copper; the gold/silver analyses for the Sardinian oxide ingots show their copper metal to be of the type being produced in LCII - LCIII times on Cyprus.

Here we should comment on remarks by Cherry and Knapp in this volume to the effect that:

'On the other hand, if a series of artefacts or ingots contain isotopic traces of lead of approximately the same age as the lead in the Cypriot ore bodies - as, for instance, a number of oxide ingots from Sardinia - it is only permissible to state that these ingots are consistent with Cypriot ores analysed thus far, and they will of course plot in the field defined for those ores.... The problem remains that other ore sources (e.g. in Spain, in the Negev Desert, or in Oman) may have similar or overlapping ages, and therefore overlapping fields;....'

First, it is by no means certain that lead from an ore deposit of the same age as the Cypriot ores will overlap in isotopic composition with the Cypriot field, though it is likely to be near, since isotopic composition is controlled only to first order by geological age. Second, we have ourselves on many occasions emphasised the point about consistency rather than certainty, and the great power of lead

isotope analyses to exclude ore sources (e.g. Stos-Gale *et al.* 1986, 128; Gale 1989b, 249, 254). Third, for Late Cypriot copper we emphasise yet again that we have two independent fingerprints. One is certainly lead isotopic composition; the other is the gold/silver composition. We emphasise again also that, whilst they retain the lead isotope signature, even Middle to Early Cypriot artefacts do not have the gold/silver signature which is probably telling us something about the copper ores and/or the extractive metallurgical technology used in Cyprus in Late Cypriot times, but not earlier (Gale 1989b, 252). It seems at the least rather unlikely that copper from elsewhere will have both of these characteristics, so that their possession by all the analysed oxide ingots which were found on Sardinia does seem rather compelling. The improbability that copper produced other than in Late Bronze Age Cyprus will have both of these 'fingerprints' argues against the suggestion by Cherry and Knapp (this volume) that copper ore deposits in Spain, in the Negev Desert or in Oman may have been a source of copper for production of the oxide ingots found in Sardinia. For a refutation of a Spanish source, suggested also by Muthy, see later in this article. By the Negev Cherry and Knapp presumably mean the Timna copper mines in the Arabah, since there are no copper deposits in the Negev proper; the lead isotope compositions for the Timna deposits (and for Feran in Jordan) are widely different from those for Cyprus (Gale & Stos-Gale 1985a). For the copper deposits in the ophiolite sequence in Oman (Hauptmann 1985) Gale *et al.* (1981) have shown that their lead isotopic field is again quite distinct from that for Cyprus. The copper deposits in Cyprus and Oman are in fact examples of deposits with similar geological ages having easily separable lead isotopic compositions.

The existing scientific evidence is fully consistent with the view that we should see

the Sardinian ingots as the successful Western extreme of the trade in Cypriot copper exemplified by the ill-fated Cape Gelidonya and Ulu Burun ships. This would not be inconsistent with the Cypriot bronze artefacts found in Sardinia, like those recently published by Lo Schiavo *et al.* (1985), or with the Cypriot, Minoan and Mycenaean pottery recently excavated from Sardinian sites (Ferraresi Cerni *et al.* 1987). These Eastern Mediterranean artefacts, down to the heavy smithing tools, are all represented amongst the cargoes of the Cape Gelidonya and Ulu Burun ships.

Here we would part company with the views expressed in this volume by Muthy about the copper oxide ingots found on Sardinia. First, he finds it difficult to accept that Cypriot copper might be imported into an island like Sardinia, "with its own rich deposits of copper ore". But, as discussed above, the copper deposits on Sardinia are really quite meagre, and are quite insubstantial in comparison with those in Cyprus or even with those closer to hand in Tuscany (especially the large Tuscan copper mine of Montecatini Val di Cecina, see Dessau *et al.* 1975). There is of course no proof that the Tertiary Sardinian copper ores (for the lead isotope analyses firmly exclude, as a source of copper for the oxide ingots, the geologically earlier mines such as Rosas, Sa Duchessa and Funtana Raminosa) were even discovered at the time the oxide ingots were made. Further, can we be sure that the motives driving trade in the Bronze Age were not at least as complex as those today, where some countries choose to conserve their own strategic reserves of certain materials whilst importing the same materials from overseas. Again Wiener (this volume) has written that

"A rational purchaser may elect to maintain a long-term relationship with a higher-cost supplier in order to insure access to a critical resource (such as metal in the Bronze

age) while satisfying any increase in demand from a lower-cost source".

Moreover we know that the Romans carefully distinguished copper from different mines as being of different quality (Pliny, NH. XXXIV.11) which, if it can be extended back into the Late Bronze Age, may add another degree of complexity. But we should also be careful about terminology; even if the oxide ingots in Sardinia truly are made of Cypriot copper it is dangerous to speak of the import of Cypriot copper into Sardinia if by that word we understand a deliberate endeavour on the part of the nuragic people to ensure that shiploads of such copper were to be delivered to Sardinia. It is difficult to see at present why the arrival off the coast of Sardinia of a Bronze Age ship from the eastern Mediterranean could not be a trading venture inspired wholly from the east, carrying copper oxide ingots which were in surplus in the east but which might be welcome somewhere in the western Mediterranean. In that case, the presence of small copper deposits in Sardinia, probably not known in advance to the eastern traders, would be quite irrelevant. Nuragic people, if indeed they knew at the time of arrival of the ship anything at all about mining and smelting their own copper ore sources, might well nevertheless have been glad to receive copper metal in ready state for making tools etc., and might even have been induced to take it as part of a bargain for accompanying decorated pottery, tripods, smithing tools etc., which they may have wanted more. Alternatively it might be that oxide ingots were seen as a status symbol, and desirable just on that account.

In his reluctance to accept the 'importation' of Cypriot copper into Sardinia Muthy (this volume) seems even prepared to accept that copper might have come into Sardinia from Spain or elsewhere in the central or western Mediterranean, though this does not seem

altogether consistent with his objection against copper being imported into copper rich Sardinia. Unfortunately, in his argument that this idea is strengthened by the alleged coincidence of lead isotope composition between the ore deposits of Cyprus and that of the ore deposit of Sierra de Cartagena in Spain Muthy has been badly advised by Pernicka; the coincidence does not exist. The problem derives partly from not plotting a graph of the data but more importantly from the general failure of the Heidelberg/Mainz group to include in their discussions the third lead isotope ratio *viz.* $^{204}\text{Pb}/^{206}\text{Pb}$. The full lead isotope data for Cartagena (Graessner & Friedrich 1970, 368, Table 1) is:

$^{208}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{204}\text{Pb}/^{206}\text{Pb}$
2.0856	0.8387	18.726
2.0767	0.8370	18.754
2.0764	0.8370	18.752
2.0794	0.8373	18.760
2.0792	0.8382	18.748
2.0765	0.8373	18.762

Table 1. Lead isotope data for lead ores from Sierra de Cartagena.

This data is plotted in the two available bivariate diagrams in Figure 16, together with the elliptical lead isotope fields for Cypriot ores. Even in the top diagram, which results from plotting the partial data quoted by Muthy, the overlap is small, but in the lower diagram there is no overlap at all between the lead isotope compositions of the Sierra de Cartagena ores and the field of Cypriot compositions. The point is made even more forcibly by a stepwise discriminant analysis (not figured) of the lead isotope data for the Cypriot ores and the Sierra de Cartagena deposit, using all three ratios; the six data points for the Spanish deposit each have less than a 0.1% probability of belonging to the Cypriot ore group.

Rather than turning to ore deposits in Spain it

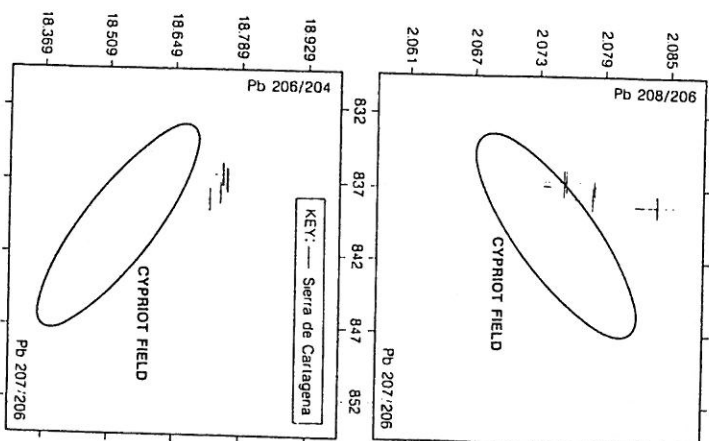


Figure 16. Lead isotope analyses for the Spanish lead-zinc ore deposit of Sierra de Cartagena showing that, *contra* Muthy, there is no overlap with the Cypriot field when all three isotopic ratios are taken into account.

would seem more reasonable to look at the copper ore deposits nearby Sardinia in Tuscany, perhaps especially since it is in this general region that we have the development of the Rinaldone copper using culture which, if it used the local ores, might have led to their use also at later times contemporary with the oxide ingots. We have analysed copper ores from the major copper ore

deposits in Tuscany, whose locations are

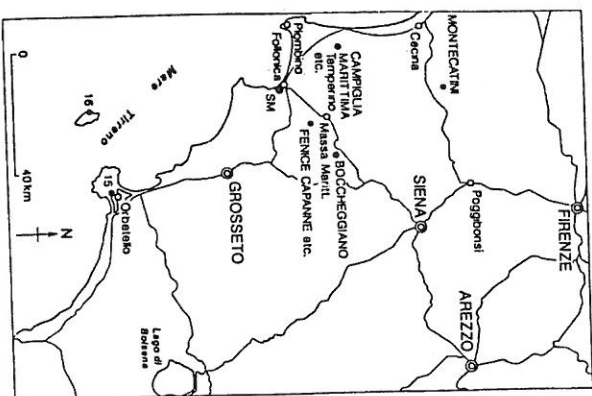


Figure 17. Locations of major copper deposits in Tuscany.

given in Figure 17. In Figure 18 are shown the resulting lead isotope fields of the Tuscan ores, in one of the two available bivariate diagrams, in relation to the Cypriot ore field (The full data will be published elsewhere). We can see that these Tuscan ores are readily discriminated from the Cypriot field, and that the copper oxide ingots found on Sardinia were certainly not made from these Tuscan ores. We should emphasise at this point that, so far, there has been no analysed copper deposit in Greece, Crete, the Cyclades, Anatolia, Sardinia, Italy or Spain which has a lead isotope composition with a major overlap with the Cypriot field; 99% do not overlap at all.

Muhly's argument against a Cypriot origin for the Sardinian ingots, that oxide ingots were in use down to the end of the tenth

century BC in Sardinia whilst they are not

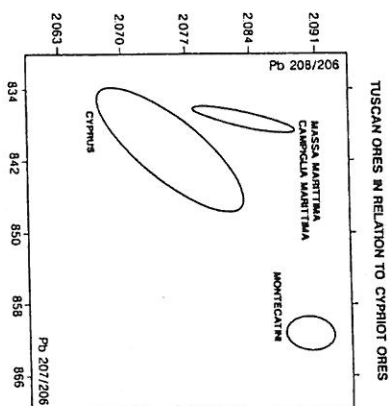


Figure 17. Lead isotopic fields for Tuscan ore deposits.

known in Cyprus after the early 12th century BC, is not only a dangerous argument *ex silentio* but also has other difficulties. First, the absolute dating of the Italian Late Bronze Age (and the relative chronology between Italy and elsewhere in the Mediterranean) is not even on so sound a basis as in Greece or Cyprus, even in the latter there are still differences of opinion (see, e.g. French 1980, 269; Karageorghis and Demas 1984, 68-75; Manning 1988). Second, very few oxide ingots from Sardinia have any sound archaeological context. Third, for those fragments that do the latest can be ascribed only to have been put in place "not later than the end of the Italian Late Bronze Age" (Lo Schiavo 1989, 36). Fourth, this does not necessarily mean that they were made as late as that; they could well have been made much earlier, subsequently broken up, and a few fragments later stored away for a use to which they were never put. One can easily hypothesise circumstances in which this might arise. On Crete, for instance, the 19 whole ingots from Hagia Triadha were stored in a basement room which was twice walled

off from the other three basement rooms: the oxide ingot room was accessible to rooms above only by a wooden ladder (Partheni 1994, 334). If, after the LMIB(?) destructions of Hagia Triadha, the later LMIII inhabitants (Pernier & Banti 1947, 7, 29) had discovered them and broken them up for use but had not used all fragments, leaving some to be excavated to-day from LMIII strata, there would be a roughly 200 year gap between the date of their manufacture and the date of the strata in which the fragments were found.

Muhly writes that

"The presence of heavy smithing tools in Sardinian bronze hoards parallels the situation in Cyprus, indicating that both islands were copper-producing regions whereas Minoan Crete and Mycenaean Greece, without such tools in any of the surviving hoards, were copper importing regions.... Why then would a local Sardinian metal industry be making use of imported Cypriot copper?"

Here the inference does not seem to me by any means to follow from the facts, but rather to be forced upon the facts from the standpoint of a preconceived position. Muhly simply assumes that the heavy smithing tools found in Sardinia were made there from copper extracted from Sardinian copper ores. I hope to show that conventional archaeological arguments lead to a quite different conclusion. First, we know that a sherd of a LHIIIb:1 Cyprio-Mycenaean rhyton has been excavated at nuraghe Antigori in Cyprus (Lo Schiavo *et al.* 1985, 7; Ferraresi-Ceruti 1981, Fig. M4; 1982, Pl. 63,5) and Muhly himself draws attention to the Cypriot pithos sherds (Vagnetti and Lo Schiavo 1989, 221) from the same nuraghe, which scientific analyses (Jones & Day 1987) suggest to have been made at Kalavassos-Ayios Dimitrios or Maroni-Yournes in Cyprus, both being sites with known metallurgical associations

(copper slags at both sites; fragments of copper oxide ingots at Maroni). These Cypriot sherds and other Aegean pottery found at Antigori (Ferraresi-Ceruti *et al.* 1987) would not be out of place amongst the Aegean pottery which was aboard the Cape Gelidonya or Ulu Burun ships, which were of course also carrying oxide ingots. The Ulu Burun ship also carried a sword suggested to have been of Italian or Sicilian manufacture (Vagnetti & Lo Schiavo 1989, 222), which may have been left over from a previously successful voyage to the Western Mediterranean. Moreover it has been concluded that several tripod stands found in or associated with Sardinia were Late Cypriot III in date, of Cypriot manufacture, reaching Sardinia towards the end of the second millennium BC (Lo Schiavo *et al.* 1985, 35-51); a few fragments of Cypriot tripods were found in the Cape Gelidonya wreck (Bass 1967, 107-109). Perhaps most telling is the presence of heavy smithing hammers and shovels (Bass 1967, 84-110) and probably part of a pair of smithing tongs (Catling 1964, 99, 292) on board the Cape Gelidonya ship; thus there seems every reason to suppose that the smithing tools found in Sardinia came from Cyprus together with Aegean pottery. Indeed Lo Schiavo *et al.* (1985, 27-28), in their study of Cypriot imports to Italy, conclude that:

"Concerning the smithing tools as a whole, there must be noticed the association of similar forms in Cyprus and Sardinia, as opposed to the absence of similar forms elsewhere. Sledgehammers, Levantine tongs and charcoal shovels are totally unknown in the Aegean and otherwise in the west; raising hammers and shovels are different from the examples known in Italy and Greece; and in the Levant only 'Levantine' tongs and charcoal shovels are documented. It seems difficult to suggest a contemporary independent invention of the complete set of smithing tools in the two islands, even based on the argument of the mining activity of

both of them. The few but distinctive imports also stand against this interpretation of the archaeological data, stressing, on the contrary, the general framework of imports and influences from Cyprus to the west and mostly to Sardinia.

It seems almost as difficult to see the oxide ingots as an independent invention in both islands. If we are to apply Occam's razor and seek the simplest interpretation of the Cypriot pottery, Cypriot smithing tools, Cypriot tripod stands and oxide copper ingots found in Sardinia we should surely see them as forming a whole which cannot artificially be separated; on this view the whole represents imports from Cyprus to Sardinia, an interpretation which is strengthened by the cargoes of the Cape Gelidonya and Uluburun ships which between them include all of these classes of Cypriot artefacts.

Nevertheless, it would at present be presumptuous to make a final judgment about the origin of the oxide ingots, which should perhaps be reserved until the complete study directed by Fulvia Lo Schiavo is completed. In particular more attention should be given to the copper deposits at Calabona, Alghero, and it is vital to make lead isotope analyses of a much wider range of nuragic bronze objects, of metal objects found on Sardinia but thought to be Cypriot imports (or copies of Cypriot objects), and of a wide range of the bronze objects from the Cape Gelidonya wreck, especially those thought to be of Cypriot manufacture.

HAGIA TRIADHA and TYLISSOS:

The chronological evidence for the oxide ingots found on Sardinia is rather tenuous, but they may well cover the period 1300 BC to 1000 BC, in which case they include the latest examples of this type of ingot found anywhere.

In contrast the ingots from Hagia Triadha, Tyliossos and Zakros in Crete, all of Type I,

date to LMIB (perhaps LMI A), about 1580 to 1500 BC; these are the earliest oxide ingots known *in corpore*. Plate 3(d) is of an unpublished ingot from Tyliossos which, like ingot HM726 (Buchholz 1959, 34) from Hagia Triadha, is an example of an ingot with an added patch of metal bearing a sign.

Do these ingots, 19 at Triadha and 3 at Tyliossos, bear witness to an earlier shipment of copper from Cyprus, on this occasion to Minoan Crete? This has certainly been the most common assumption made by Mediterranean archaeologists.

The scientific evidence for the Triadha ingots and the Tyliossos ingot published by Hazzidakis (1921, 57, Fig. 31) is firmly against these ingots having been made from Cypriot copper.

This is clear from Figure 19 (updated from the diagram published by Gale and Stos-Gale 1986, 94, Fig. 5), which shows that the lead isotope compositions of these Minoan ingots lie far outside the field defined by Cypriot ores. All the data is not yet plotted on this 16 analysed Type I ingots from Hagia Triadha plot well away from the Cypriot field. We do not need discriminant analysis to prove this; one ordinary bivariate lead isotope diagram is quite sufficient.

For the ingot B from Hagia Triadha bearing a large patch the isotopic composition of lead from the patch is identical within error to that from the main body of the ingot; both are almost identical to that of the ingot from Tyliossos, and lie close to the lead isotope compositions of ingots N and G from Hagia Triadha. The lead isotope compositions suggest that the copper for all these ingots was derived from a Devonian copper deposit dating to about 370 Ma; its geographical location is not yet known.

It is clear that most of the Hagia Triadha

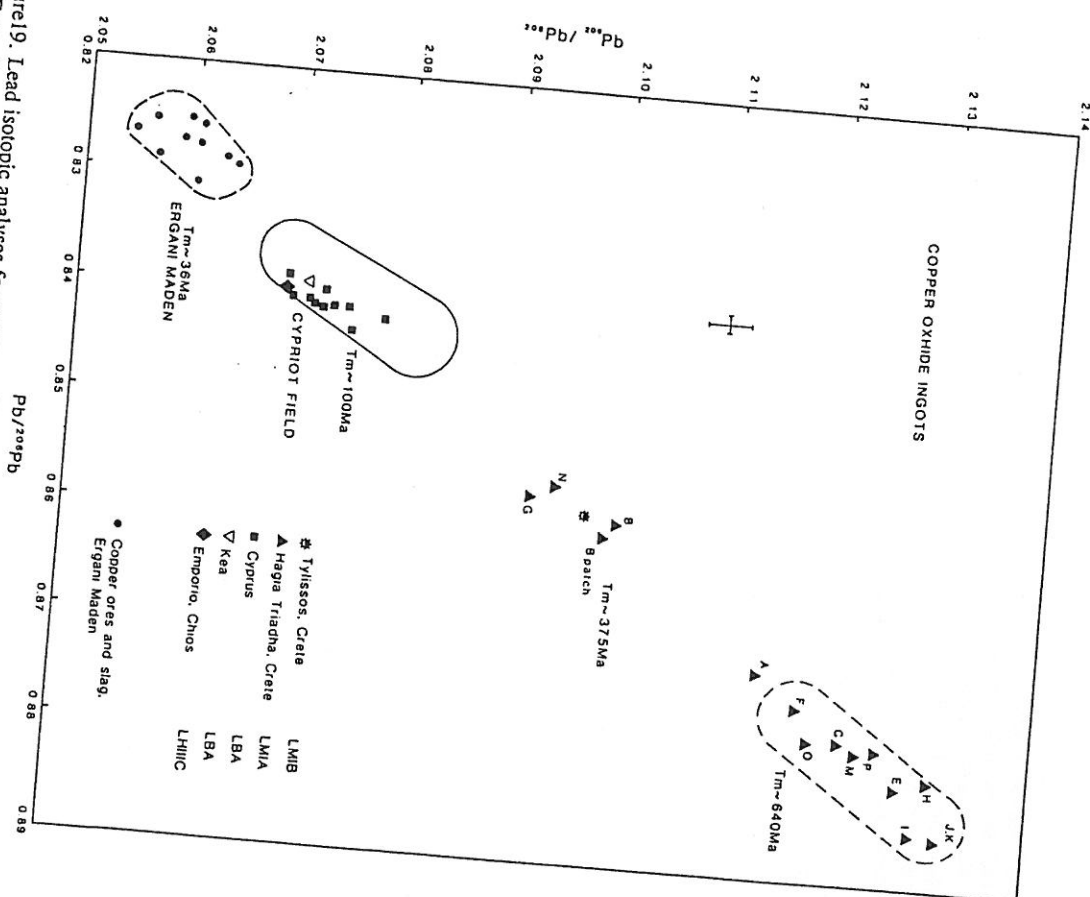


Figure 19. Lead isotope analyses for copper oxide ingots from Hagia Triadha, Tyliossos, Kea and Emporio. T_m = lead isotope model age.

ingots plot together, in another region of the lead isotope diagram which suggests that their copper was derived from a Precambrian ore deposit laid down about 650 Ma ago. Its geographical source is not yet known, but it is not in the Mediterranean region or in Anatolia. This is a similar situation to that

which we had reported before for much earlier bronzes from Early Cycladic II Kasri on Syros and for contemporary bronzes from Schliemann's excavations at Troy (Stos-Gale *et al.* 1984; Gale *et al.* 1985).

In all these cases our best guesses for the

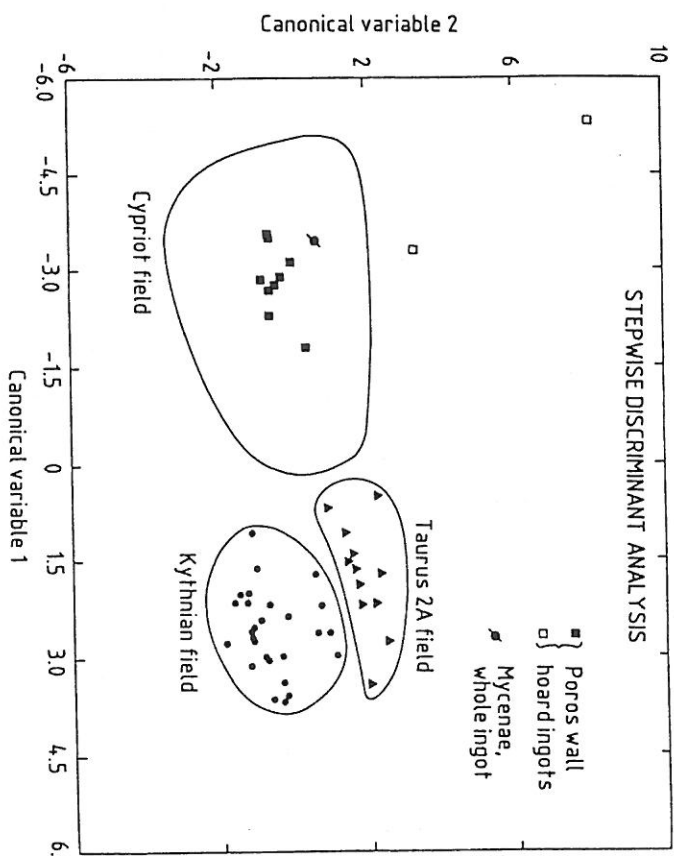


Figure 20. Discriminant function analysis of the lead isotope data for oxide ingots from Mycenae.

location of the copper ores involved are in Precambrian copper deposits in Afghanistan (Berthoud 1977), Iran (Bazin & Hübner 1969) or southern Russia. This may seem rather a long way away but, at least from Late Minoan I times, lapis lazuli (Herrmann 1968) and probably tin (Cleuziou & Berthoud 1982) were apparently coming from Afghanistan, with Mari (see Figure 1) acting as a middleman for supplies of tin to Crete (Dossin 1952, 1970; Malamet 1971). There was also the earlier Assyrian trade in tin between Kultepe and Assur; again the latter must have been a middleman².

MYCENAE
Turning again to later times and the Mycenaean world in Greece itself, if we exclude the Kyme ingots (Buchholz 1959, cat. nos. 38-56, Pl. 5) of uncertain date, there is not all that much evidence for copper oxide ingots in the archaeological record.

At Mycenae itself there is the whole ingot (illustrated by Jakovides 1974, p. 297) which was excavated by Tsountas, the 12 fragments (illustrated by Gale 1989b, p. 254, Fig. 29.15) from the Poros Wall Hoard (Wace 1959) of probable Late Helladic IIIB date (about 1340 to 1200 BC), a LHIIIB-C

fragment mentioned by Mylonas (1962, 406, Pl. 121:2) and a handle fragment recorded by Catling (1964, 269, in the Nauplion Museum). At Ayia Irini on Keos there are a two fragments from Late Bronze Age (one from Period VII) contexts (personal observation at the site), whilst Sinclair Hood (1982) has excavated a fragment in a Mycenaean context (LHIIIC) from Emporio on Chios.

Figure 20 shows the results of discriminant analysis applied to analyses of some of this material. The Tsountas ingot and 10 of the fragments from the Poros Wall Hoard are associated firmly with the Cypriot copper ores; data not included here but shown on Figure 19 associates the fragments from Keos and Emporio also with Cyprus.

Two of the fragments from the Poros Wall Hoard are not of Cypriot copper, and have

lead isotope compositions in the general region of the Tylosos ingot and of three of the ingots from Hagia Triadha, but will not be discussed further in this paper. Nevertheless, the majority of analysed oxide ingots from the Mycenaean world seem to have come from Cyprus.

THE CAPE GELIDONYA AND ULU BURUN WRECKS

I want to turn now to the few initial results of work in collaboration with Professor George Bass on ingots from the Bronze Age wrecks which he has excavated at Cape Gelidonya and Kas, now more usually called Ulu Burun. It is believed that the Cape Gelidonya wreck dates to about 1200 BC or a little before, whilst that of Ulu Burun foundered at about the late 14th/early 13th century BC (about, say, 1300 BC); the dating is discussed further in this volume by Bass.

Ingot No:	Wreck	208Pb/206Pb	207Pb/206Pb	206Pb/204Pb
223	C. Gelidonya	2.07575	0.84176	18.541
350	C. Gelidonya	2.07462	0.84190	18.491
353	C. Gelidonya	2.07071	0.84002	18.523
355	C. Gelidonya	2.07026	0.84076	18.482
356	C. Gelidonya	2.07383	0.84085	18.569
358	C. Gelidonya	2.07996	0.84505	18.439
360	C. Gelidonya	2.07344	0.84115	18.519
361	C. Gelidonya	2.07084	0.84058	18.490
362	C. Gelidonya	2.07555	0.84151	18.543
379	C. Gelidonya	2.07036	0.84062	18.497
423	C. Gelidonya	2.07381	0.84128	18.517
424	C. Gelidonya	2.07242	0.84016	18.572
425	C. Gelidonya	2.07601	0.84253	18.490
433	C. Gelidonya	2.07203	0.84126	18.488

KW 147	Ulu Burun	2.06895	0.83925	18.556
KW 390	Ulu Burun	2.07069	0.83887	18.624
KW 632	Ulu Burun	2.07002	0.83995	18.580

Table 2. Lead isotope data for copper oxide ingots from the Cape Gelidonya and Ulu Burun (Kas) Bronze Age shipwrecks.

We have made lead isotope and trace element analyses of 15 copper oxide ingots from the Cape Gelidonya ship and of 10 assorted ingots from the Ulu Burun ship. The lead isotope analyses are given in Table 2. Figure 21 shows discriminant function analysis of the lead isotope data for the 15 oxide ingots from the Cape Gelidonya ship so far

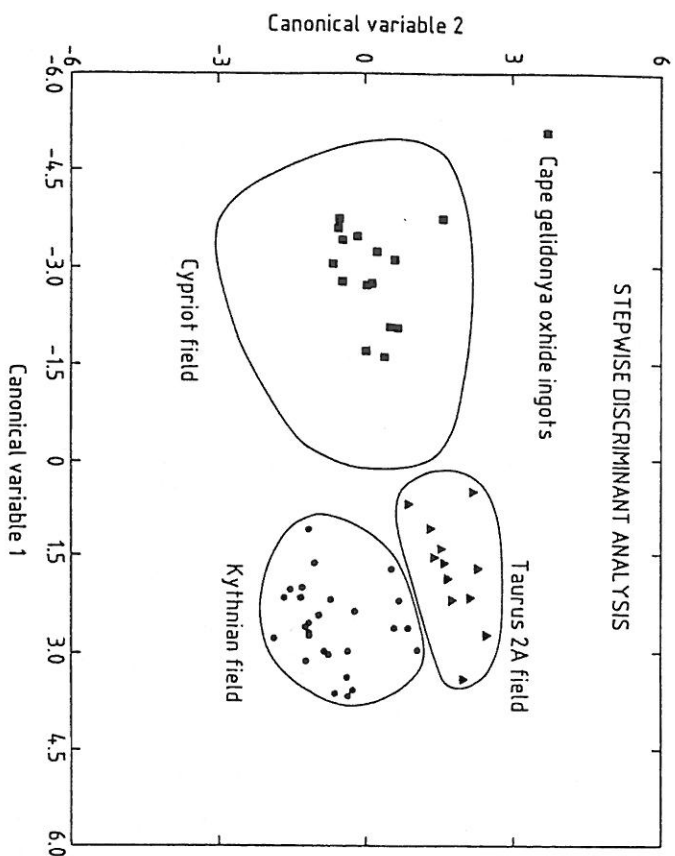


Figure 21. Discriminant function analysis of the lead isotope data for oxide ingots from the Cape Gelidonya shipwreck.

analysed. Clearly they all group very well within the field defined by Cypriot copper ores, within which all the analysed ingots found on Cyprus itself also group.

The clear implication is that these oxide ingots are fully consistent with having been made of copper extracted from Cypriot copper ores. Probably they were loaded onto the Cape Gelidonya ship in Cyprus itself.

We are confident that there is still much more to be learned from the metals, both lead

and copper, on the Cape Gelidonya wreck. Lead isotope and trace element analyses of the lead copper and bronze artefacts and of the copper bun ingots from this ship will eventually tell us very much more about the Bronze Age metals trade.

THE ULU BURUN SHIPWRECK

Our analyses of copper ingots from the Ulu Burun wreck have only just started. So far we have been working on four oxide ingots, five bun (plano-convex) ingots, and one slab ingot for which the lead isotope analyses are

given in Table 2. Figure 22 shows that discriminant function analysis of the lead isotope data for ingots from the Ulu Burun ship connects most of them, whether bun ingots, the single slab ingot, or the copper oxide ingots, with Cyprus. Just one bun ingot is not made of Cypriot copper; its ore source has yet to be located.

Our trace element analyses (to be reported in detail elsewhere) for gold and silver concentrations in the copper ingots from the Cape Gelidonya and Ulu Burun shipwrecks, show that all ingots with Cypriot lead isotope ratios fall into the region in the Au/Ag diagram defined by Late Cypriot bronze artefacts and Cypriot oxide ingots.

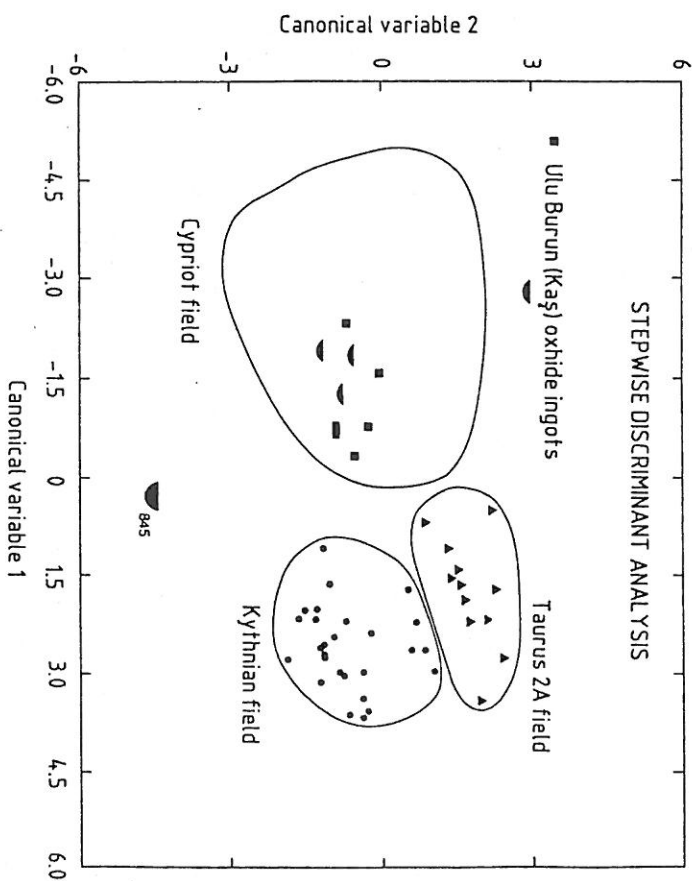


Figure 22. Discriminant function analysis of all three lead isotope ratios for copper oxide, bun and slab ingots from the Ulu Burun shipwreck in relation to the field defined by Cypriot copper ores.

We can conclude that all analysed copper oxide ingots from the Gelidonya and Ulu Burun ships are consistent with having been made from Cypriot copper; the consistency extends not only to the lead isotope

composition but also to the match in gold/silver concentrations. Both ships are at least 150 years later than the Type 1 oxide ingots found on Crete, and so far they have shown no evidence of copper having the

Precambrian ore deposit signature of the earlier Minoan ingots.

It is quite likely that further work on the various ingot types and bronze artefacts found on both ships will reveal more complex cargoes, drawing on copper from two or more different sources. This is already suggested by the non-Cypriot origin of one of the analysed bun ingots from the Ulu Burun ship. Since lead ores are little more than a mineralogical curiosity on Cyprus, the characterisation of lead on these ships will be fascinating. Even more fascinating will be the attempt to use isotopic means to trace the source of the tin found on both ships, even in the oxide ingot form on the Ulu Burun ship.

In this volume Muhly has suggested that current work by the Philadelphia and Oxford groups on the oxide ingots from Sardinia and the Ulu Burun shipwreck illustrates 'dramatically the scholarly differences that still exist'. I have briefly discussed the Sardinian evidence above, but for the ingots on the Ulu Burun ship I believe that misunderstandings rather than disagreements are in question. First, we have analysed only four oxide ingots from the Ulu Burun ship. It is not legitimate for Muhly to extrapolate from their undoubted Cypriot origin to a conclusion that all of the more than 200 oxide ingots (about

6 tonnes) on that ship necessarily derive from Cyprus. Perhaps they do, but this is a question which only more analyses can decide.

Second, Muhly throws doubt on our assignment of four of the Ulu Burun ingots to Cyprus, since he claims that the 16 oxide ingots from Ulu Burun analysed by Maddin (1989, 100, Table 11.1) have an average content of arsenic (0.08%) which is much lower than the average of 0.45% arsenic for the eight analyses of oxide ingots from Cyprus reported by Gale & Stos-Gale (1986, 93, Table 3), and the average of 0.34% arsenic reported by Muhly (this volume) for 22 Cypriot oxide ingot analyses. The first point to make here is that Maddin (1989, Table 11.1) does not report the Ulu Burun site numbers for his analysed ingots, so that we do not know whether they include the four ingots which we analysed and for which the lead isotope analyses are consistent with manufacture from Cypriot copper. It could be that Maddin's ingots are all different from ours, in which case his analyses may hint that some of the Ulu Burun ingots are not made of Cypriot copper and that, as we suggested above might possibly prove to be the case, the cargo is made up of copper from a number of different sources.

Kas No:	Au	As	Sb	Se	Te	Ag	Sc	Sn	Cr	Zn	Co	Ni	Fe
KW147	6.39	2162	53	184	144	42.4	2.5	590	<1	<0	16	142	137
KW517	5.28	2191	62	386	210	27.5	1.0	286	<1	<0	125	280	<100
KW632	7.88	2524	75	338	230	43.2	1.3	229	3	80	176	187	176

Table 3: Trace element compositions of three oxide copper ingots from the Ulu Burun (Kas) wreck. [These analyses are calibrated against parallel analyses of four NBS copper standards.]

Table 3 gives our available trace element analyses (three out of four) which we have made for the four oxide ingots from the Ulu Burun ship which our lead isotope analyses show to derive from Cypriot copper ores. The average arsenic composition is 0.23%, far higher than the average arsenic content of 0.08% reported by Maddin (1989) for the fifteen Ulu Burun ingots which he analysed. It is not considered that the arsenic contents

for our oxide ingots from the Ulu Burun wreck are at all outside the range of arsenic contents which we have measured for other Cypriot copper oxide ingots and for copper objects from Late Cypriot sites such as Ayios Dimitrios and Hala Sultan Tekke. Hence the objection which Muhly raises against the Cypriot origin of the copper for the four oxide ingots from Ulu Burun analysed in Oxford seems to have no basis in fact.

HOW IMPORTANT IS THE OXIDE INGOT TRADE?

I will end on a slightly quizzical note. How important to the Mycenaean and Minoan worlds was the copper trade in the form of oxide or bun ingots of Cypriot copper? Did they rather rely more on their own local sources of copper, perhaps supplementing those by limited recourse to supplies from Cyprus? Here we should note Muhly's remarks in this volume to the effect that we now adopt a new position:

"This is quite a shift from their position in 1988 (Stos-Gale 1991) when they claimed that "there is virtually no direct evidence that Cypriot copper ever came into Minoan or Mycenaean hands".

What had been intended by this introductory passage in this paper (*in fact given in 1987; in press 1991*) was that there was no direct archaeological evidence on this point, but only the sort of indirect inferences referred to by Galling (this volume, p. 2) based on the ceramic evidence, and that an appeal had to be made to lead isotope analyses for hard evidence about this. Stos-Gale (1991) goes on, in the same paper, to demonstrate that some Cypriot copper did come to Mycenaean and Minoan sites. The question remains: was Cyprus a dominant source of copper for the Minoans and the Mycenaeans?

We might expect to learn something about this by making lead isotope and trace element analyses of Mycenaean and Minoan artefacts,

to see what proportion were made of Cypriot copper.

We do not yet have more than preliminary data about this, and chiefly for Mycenaean itself and, in Crete, Late Minoan sites at Knossos and in West Crete.

At Mycenae the Poros Wall Hoard (Wace 1959) contained artefacts as well as ingot fragments, such as a double axe, a cauldron handle, several large chisels, a hammer, a bun ingot, part of a knife, etc. Recently Dr Artemis Onassoglou carried out some rescue analyses of LHIIIB tombs at Mycenae which produced a number of bronzes, including tripods. From 'Iakovides' excavations at Perati and Demakopoulou's excavations at Kokla and from older excavations at Menidi and Tiryns, came a number of bronze artefacts for analysis.

The majority of these bronzes (Demakopoulou *et al.* 1991; Stos-Gale & Macdonald this volume) have lead isotope analyses consistent with their having been made from copper ores in Lavrion. For example, only one object (as opposed to oxide ingot fragments) from the Poros Wall Hoard falls into the Cypriot lead isotope field.

In LHIIIB times Mycenae itself does not seem to have been making many artefacts from Cypriot copper, even though a few Cypriot copper oxide ingots were reaching it; nor, on present evidence, do other Mycenaean sites seem to have been using much Cypriot copper in making objects.

The preliminary data for sites in West Crete such as Armenoi, Pighi, Samonas, etc and for the Unexplored Mansion at Knossos again give very little evidence for the manufacture of artefacts from Cypriot copper. Here we are dealing with periods including Late Minoan II, LMIIIA and LMIIIB. Again the lead isotope composition is consistent with

copper from the Lavrion ore deposits. Though known more for lead, silver and zinc, copper ores certainly do occur in considerable amount in Lavrion (Marinos & Petraschek 1956; Gale & Stos-Gale 1982; 1985a, 93-96).

The extent to which Lavrion dominates Cyprus as a source of copper for the Mycenaean and Minoan manufacture of objects is documented further by Stos-Gale and Macdonald (this volume). However, this is a conclusion based so far on the analysis of rather few objects from rather few sites. At present one must be cautious about making sweeping conclusions; certainly we should wait for more analyses of ingots (both oxide and plano-convex), and of artefacts, from the Gelidonya and Ulu Burun ships, and many more analyses of material from Late Bronze Age Minoan, Mycenaean and Levantine sites. Nevertheless it may be legitimate at least to begin to ask: how important as a commercial resource was the trade in Cypriot oxide ingots to Late Bronze Age Greece and Crete? Should we take another view of their acquisition?

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FOOTNOTES:

1. It may be useful here, in the context of Muhly's remarks (this volume) about the direct evidence from Cypriot slag heaps and mines going back apparently no earlier than Roman times, that there is now good scientific evidence from Zwickler's work which dates some of the slag heaps and mining activities considerably earlier. Zwickler (1986) has reported C-14 dates which he made on timbers from Cypriot mines and charcoal from many of the larger slag heaps. Timbers from different galleries in the Kamibia mines gave calibrated dates of 660, 640 and 460 BC; ancient galleries at the Skouriotissa mines gave dates of 620 and 580 BC and at Limni 275 and 350 AD. Various levels in the Kalavassos slag heap gave calibrated dates from 450 to 225 BC, whilst the Mahiati slag heap gave a date of 270 AD and the Mitsero slag heap a date of 470 AD. Our own lead isotope work on Early Cypriot copper alloy objects from Lapithos and Vounous shows that most of them are made of Cypriot copper, thus pushing back much further still the proof of exploitation of Cypriot copper ores.

2. It is perhaps apposite here to remove a misunderstanding on the part of Muhly et al. (1988, 290) about a paper which first presented our preliminary results for Sardinian oxide ingots at a meeting in Manchester in April 1986 (Gale & Stos-Gale 1988). Muhly et al., relying not on our paper but on an abbreviated preview of the conference at which it was presented (Brice 1986, 170), suggest that we claimed that Crete was importing Sardinian copper in the LMIB period, and imply that we were unaware of the serious chronological difficulties of such a claim. In our paper we were in fact careful to discuss in detail the evidence for the dating of the first contacts between Sardinia and the Eastern Mediterranean to not earlier than the 13th century BC, of the order of two centuries later than LMIB. Moreover the conclusion of our 1986 paper, *contra* Muhly et al. (1988), was that we

could find no evidence of Sardinian copper having come to Crete, even in the later Bronze Age when Minoan pottery is found in Sardinia.

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