ARCHAEOLOGY, SCIENCE-BASED ARCHAEOLOGY AND THE MEDITERRANEAN BRONZE AGE METALS TRADE: A CONTRIBUTION TO THE DEBATE

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Abstract: The current consensus is outlined about the application of lead isotope analyses to metal provenance studies and to the unravelling of the Mediterranean Bronze Age copper trade, with special reference to copper oxhide ingots. Various misconceptions, especially some of those contained in Knapp (1999, 2000), are corrected. It is shown that there is no need to fall back on hypotheses based upon the Mediterranean-wide mixing/recycling of copper metals to explain the lead isotope characteristics of post-1250 BC copper oxhide ingots, since there is a good isotopic coincidence between these ingots and the Apliki region ore deposits in Cyprus. Weaknesses are exposed in the hypotheses of direct or indirect pooling of Cypriot ores, and of the proposed widespread recycling of metals in a Mediterranean-wide *koine,* particularly since there is no evidence for a homogeneity of lead isotope composition in artefacts and no tin in the oxhide ingots.

Keywords: archaeology and science-based archaeology, Cyprus, lead isotope analysis, Mediterranean Bronze Age metals trade, recycling, Sardinia

INTRODUCTION

Yet another article largely based on late Bronze Age Mediterranean copper oxhide ingots and lead isotope analysis may well seem rather too much, and gilding the lily with a vengeance, and that is certainly the view of the author of this article. However Bernard Knapp (2000) has published an interesting article which attempts to connect the thorny subject of the relationship and utility of science-based archaeology to archaeology *per se,* via an interpretation of this very topic that seems at many points to be in such ill accord with the current facts as almost to compel a response. Before examining the wider issues of lead isotope analysis and the Mediterranean Bronze Age, I wish to point out and counter several comments made by Knapp (2000), in which he mistakenly attributes positions to the Oxford group which were never held or which have long been superseded. In reading this discussion, it is important to note that the production of copper oxhide ingots

European Journal of Archaeology Vol. 4(1): 113–130

appears to have changed dramatically around 1250 BC, after which date the evidence is that they were produced solely from the Apliki ore body or its environs on Cyprus. This is an important point of disagreement with Knapp's article (2000).

Detailed critique

Perhaps the most serious misapprehension in Knapp (2000:40) lies in the statement that:

> On the basis of a new suite of lead isotope data, Stos-Gale et al. (1997) have argued for the predominance of the Skouriotissa region and, in particular, the primacy of Apliki *Karamallos*, in the production of all copper oxhide ingots that appear, analytically, to be consistent with production from Cypriot ores.

This misapprehension occurs also in Knapp (1999:106), where the statement that we claimed that 'a large proportion of Bronze Age mining and primary smelting activities were conducted at one site', attributes to the Isotrace Laboratory a claim that we have never made. The site to which he refers, Apliki *Karamallos,* is far too small for us to make such a claim for it. Stos-Gale et al. (1997) clearly state in their abstract that

> The data shows that all oxhide ingots so far analysed, dating to the fourteenth (actually thirteenth) century BC and later, were made of copper consistent isotopically with only one mining region in the geographical north of Cyprus, and especially the Apliki mine.

It is important to distinguish the large Apliki copper *mine and ore deposit* from the small archaeological site of Apliki *Karamallos* (Taylor 1952; Muhly 1989). This distinction we made in 1997; it was repeated by Gale (1999:120) in the following words:

> Finally, Stos-Gale et al. (1997) drew attention to the LCIIC-LCIIIA site of Apliki *Karamallos*, situated in Cyprus near the Apliki deposits. This site produced a large quantity of copper smelting slag in good archaeological contexts and was characterized by Muhly (1989) as a late Bronze Age miners' village. Stos-Gale et al. (1997) mentioned this site only as providing evidence that mining and copper smelting were proceeding at, or very near, the Apliki deposits at the period of the late Bronze Age in which it was known copper oxhide ingots were produced. However, *contra* Knapp (this volume), they did not state or imply that Apliki *Karamallos* was the only, or even a major, site producing copper for oxhide ingots. Instead the lead isotope evidence points to the ore deposits of the Apliki region, perhaps only the Apliki deposit itself, as the source of copper for the post-1250 BC copper oxhide ingots. It is certainly not argued that a major proportion of Bronze Age mining and primary smelting activities was conducted at the one site of Apliki *Karamallos*.

> Indeed, as discussed above, the Oxford lead isotope evidence for Bronze Age Cypriot tools and weapons points to mining and smelting activities at many other sites around the Troodos Mountains.

One such site we now know to be that of Politiko *Phorades* (Knapp et al. 1998, 1999). It is clear, firmly based on lead isotope data (Stos-Gale and Gale 1994), that the position of the Isotrace Laboratory, though maintaining the primacy of the Apliki ore deposit (and perhaps to a lesser extent the relatively nearby copper deposits at Mavrovouni and Skouriotissa) as a source of copper for the post-1250 BC oxhide ingots, is in complete accord with Knapp's position that copper for other purposes came from other deposits and LBA sites all around the Troodos. Consequently it was incorrect to write (Knapp 2000:41) that our position in Stos-Gale et al. (1997):

> contradicts previous interpretations by the Oxford team, which argued for the exploitation of multiple ore deposits around the Troodos (e.g. Gale and Stos-Gale 1992a; Stos-Gale and Gale 1994: 106).

We had already argued, and continue to argue, for the exploitation of multiple copper ore deposits around the Troodos, except that all post-1250 BC copper oxhide ingots appear to have been made of copper from the Apliki ore deposit or its close environs. Recent lead isotope analyses by the Isotrace Laboratory of copper slags from the Bronze Age slag heap at Politiko *Phorades* (Knapp 1999:104–105) prove that the ores being smelted at *Phorades* were not from the Apliki deposit and are not the source of copper for post-1250 BC copper oxhide ingots, though their isotopic composition does match some of the Cypriot artefacts published by Stos-Gale and Gale (1994). Though this is evidence from only one Bronze Age Cypriot copper smelting site, it does accord with the model we have proposed before and recall in the first sentence of this paragraph. It does not support Knapp (2000:41) in his assertion that the evidence from *Phorades* rules out our claim that Apliki was the source of copper used to make all so far analysed post-1250 BC copper oxhide ingots.

It is difficult to understand how Knapp (1999, 2000) could have misunderstood our clearly stated position, and curious that Knapp (2000) omits any reference to Scaife et al. (1999), Knapp (1999), and Gale (1999) in which he could have discovered it. These omissions are puzzling since Knapp (2000) does list a reference to the volume (Young et al. 1999) in which these three articles appear.

We have laboured these points and misapprehensions since they are so crucial to the archaeological interpretation of the lead isotope data, and any light it may cast on the organization of the LBA copper industry in Cyprus. Reminiscent of a criticism by Bass (1973:37) of an article by Muhly (1972), is the statement (Knapp 2000) that:

> When the Oxford team initiated LIA [lead isotope analysis] as a provenance technique for the study of Mediterranean metals they maintained that the only conclusive evidence LIA could provide was negative – i.e. establishing

> that an artefact or ingot could not have come from a particular source (Gale and Stos-Gale 1982a, 1982b).

In fact the Oxford articles quoted by Knapp do not contain such a statement or concept, as independently verified for us by Maria Kayafa.

Moreover Knapp (2000:38) writes:

> (5) finally, it must be pointed out that very few copper or bronze metal artifacts analysed have an isotopic signature which can be correlated with the field established for the copper oxhide ingots [Muhly 1998].

For Cyprus itself, Gale (1999:117), in an article not referenced by Knapp (2000), does indeed mention that only some artefacts are consistent with their copper having been derived from the Apliki mine, but also points to the fact that their lead isotope compositions support instead that the copper for many artefacts derives for the most part from many other ore deposits around the Troodos. We do not insist on the following explanation, but these data could be consistent with the use of the Apliki copper deposit primarily for the production of oxhide ingots destined largely for export, with most artefacts for use in Cyprus being made of copper chiefly, but not exclusively, from a number of other Cypriot ore deposits. It seems possible that we do not yet properly understand the function and significance of the oxhide copper ingots to the people of the Bronze Age. Might it be too simplistic to regard these ingots merely as raw material ultimately destined to be used to make copper-based artefacts such as tools and weapons? Perhaps the more sophisticated interpretations of Lagarce and Lagarce (1996) and Melas (1991) need to be taken seriously.

In a misleading partial quotation taken out of context, Knapp (2000:38) reports that Barnes et al. (1986:2) argue forcefully that:

> . . . [metal] objects from the eastern Mediterranean are notoriously difficult to classify because of the complications arising from the mixing and overlapping effects

However Barnes et al. (1986) were not dealing with the Bronze Age, but chiefly with lead metal or a few leaded bronze objects from the Serce Liman shipwreck, which included both Byzantine and Islamic artefacts, whilst the lead net sinkers which formed the largest group of samples were of mixed and unknown periods. Barnes et al. (1986:2) complete the above quotation by writing:

> By this rather late period of history, large quantities of scrap lead would long since have accumulated for salvage and reuse. . . . The overlapping complication in this instance is that the wreck contained both Byzantine and Islamic finds.'

There is the added complication that Barnes et al. (1986) were using incorrectly defined lead isotope fields for ore deposits which were so much larger than those based solely on ores from the deposit (see Gale 1980:175, Fig. 8) that false overlaps were bound to occur. To illustrate the absurdity of some of their fields, their lead isotope Field E (Barnes et al. 1986) was defined as including leads from European and British sites and also from Constantinople.

In another attempt to press the claims of a now outdated and superseded article, Knapp (2000:39) writes:

> In a re-examination of much of the relevant published data on ores, ingots and artifacts, Budd et al. (1995) suggested that the Mediterranean region contains so many copper deposits of similar geological age, and/or derived from isotopically similar fluid resources, that it is impossible to attain the resolution needed to ascribe or clearly refute a Cypriot, Sardinian or any other origin.

This is again a qualitative argument, but one that is not soundly based, since geological age alone does not fix the lead isotope composition of an ore body except to first order (Gale and Stos-Gale 2000), and there is certainly no consensus about the fluid resources which gave rise to the ore deposits, or about their isotopic character. Even in Cyprus, where the ore deposits are closely similar in geological age and one might have supposed the 'fluid resources' to have been similar, we now know the range of analysed, quantitative, lead isotope compositions between different mines in the island to be quite large (Gale et al. 1997; Gale 1999). Moreover the large lead isotope data banks now available for ores in Sardinia (Stos-Gale et al. 1995) and Cyprus (Gale et al. 1997), together with that for copper oxhide ingots (e.g. Gale 1999 and references within), show that in practice the isotopic resolution for the oxhide ingot provenance question now *is* available. Yet again the qualitative argument fails when confronted with the quantitative data.

Knapp clearly does not accept our claim that the lead isotope analyses for oxhide ingots found on Sardinia prove them to be made of copper from the Apliki region copper deposits in Cyprus, even though trace gold and silver analyses back up this claim (Hall 1995; Pernicka 1995). In trying to throw doubt on this, and referring to Lo Schiavo et al. (1987:182–183), as evidence that they are of separate origins, Knapp (2000:44) notes the consistent quantity of arsenic from 0.16 per cent to 0.54 per cent in the Sardinian ingots, and the claimed absence of arsenic but more erratic presence of iron in the Cypriot ingots (Knapp 2000:44). These comparisons are incorrect. As Gale and Stos-Gale (1987:171, Table 7.9) show, the mean arsenic concentrations in Cypriot oxhide ingots is 0.45 per cent, comparing closely with a mean of 0.46 per cent arsenic in Sardinian oxhide ingots, all analyses having been made using instrumental neutron activation analysis calibrated against NIST standards.

As a last item in this class, consider Knapp (2000:46): 'The problem is that there are no known ingots of ''Laurion copper'', but rather of Cypriot, Anatolian or Sardinian copper.' In fact both Stos-Gale et al. (1998b:117, Fig. 3) and Gale (1999:118, Fig. 13) gave data showing some copper ingots with Laurion lead isotope compositions. It has also to be remembered that very few bun or slab ingots have been made available for analysis from, say, the Greek mainland, Crete or the Cyclades.

INTERPRETATION OF LEAD ISOTOPES

Throughout Knapp (2000), appeals are made to old, superseded, work. If, for example, we consider the lead isotope data for Cypriot ore deposits, it seems incorrect for Knapp (2000:40) even to mention its proposed division by Sayre et al. (1992, 1995:46) into two fields, a division categorized by Budd et al. (1995:73) in these terms: 'It is preposterous for the Smithsonian/Chicago group to continue to suggest that these subdivisions have any meaning.' First, this division was based solely on the application of multivariate statistics which Knapp (2000:38) has himself correctly dismissed as '. . . inappropriate or unnecessary for assessing data generated by lead isotope analysis' (Scaife et al. 1996; Baxter and Gale 1998). Second, Sayre et al. (1992, 1995:46) applied multivariate statistics without considering the ore source of the ores they were treating, with the absurd consequence that ores sampled a few tens of metres apart in the same mine, and having close isotopic compositions, were incorrectly assigned to different fields (Gale and Stos-Gale 1992a:315; Budd et al. 1995:73; Pernicka 1995). Moreover the statement (Knapp 2000:40) that '. . . the five Cypriot fields proposed in Gale and Stos-Gale [1992a, 1992b, 1995:36–37] were later reduced to one' (Stos-Gale and Gale 1994; Stos-Gale et al. 1997) is a misunderstanding. Gale and Stos-Gale (1995:316, Fig. 1) clearly state that the lead isotope data graphed in that note are for only *some* Cypriot ores, and are intended only to show that there is discrimination between the five different mines involved; this did not imply that all the Cypriot ores then analysed could be divided into five fields. Perhaps more important is the fact that Stos-Gale et al. (1997) definitely do not propose one field for the lead isotope composition of Cypriot ores. It is true that in some figures (e.g. Stos-Gale et al. 1997, Fig. 12) the old, discarded, elliptical Cypriot field was depicted, but only as a link with the past. Gale (1999, Fig. 8) graphs on one diagram the considerable range of lead isotope compositions now established (Gale et al. 1997) for Cypriot ore deposits, which fall into discrete (sometimes overlapping) isotopic regions for the different mines, and cannot be and are not described as a single Cypriot field. With the new data of 1997 the idea of a single Cypriot field had to be, and was, abandoned, just as by then we had abandoned the use of multivariate statistics. For provenance purposes comparison must be made on a point-by-point basis between the lead isotope composition of an artefact and of the individual Cypriot ore samples, eschewing statistics.

The evidence which has now built up (Gale and Stos-Gale 1987; Stos-Gale and Gale 1992; Stos-Gale et al. 1995, 1997, 1998b; Gale 1999) demonstrates that there are no overlaps between the lead isotope compositions of ores from Sardinia with those from Cyprus. The statement (Knapp 2000:40) that 'The much greater variation in lead isotope ratios for Sardinian ores, which completely swamps any signal emitted by the Cypriot field' (Budd et al. 1995:16, Fig. 5) makes the grave errors of conflating lead deposits with copper deposits, Palaeozoic with post-Triassic ore deposits, and relying on old articles now superseded by new articles (Stos-Gale et al. 1998a; Gale 1999; Scaife et al. 1999), all known to but not referenced by Knapp (2000), which show this statement to be wholly erroneous.

The same danger of relying on past articles (Budd et al. 1995) now largely retracted even by their authors (Scaife et al. 1999), is evinced in Knapp (2000:40) by the statement that:

> Most significantly, the modified source fields indicate that the lead isotope compositions of several oxhide ingots from Sardinia, the Anatolian shipwrecks, Crete and even Cyprus are inconsistent with the Cypriot field (Budd et al. 1995:11–13, Figs 3–4).

This belief, that many copper oxhide ingots have lead isotope compositions which do not match those of Cypriot ores (or any other Mediterranean copper ore deposit), is important because it led to the casting about for other explanations for the narrow range of lead isotope compositions of post-1250 BC oxhide ingots. However the belief is now known to be wrong for post-1250 BC copper oxhide ingots, as abundantly demonstrated by a series of articles (Stos-Gale et al. 1997, 1998; Gale 1999) which show that all such oxhide ingots match Cypriot ores from the copper deposits in the Apliki region of Cyprus. If Knapp had quoted the article by Scaife et al. (1999:131), he would have noted that even the Bradford group now accepts, albeit grudgingly, the idea that it now seems likely that the Apliki deposit will prove to be the source of LBA oxhide ingots.

It is of course accepted that lead isotope analyses (LIA) have shown that the copper sources for oxhide ingots dating prior to 1250 BC were chiefly not the copper ore deposits in the Apliki region of Cyprus. This is clearly the case for the late Minoan IA-B ingots hoarded at Hagia Triadha in Crete (Gale and Stos-Gale 1986) and seems to be so for the ingots excavated from the Uluburun shipwreck dated to *c.* 1300 BC (Pulak 1998; Gale 1999). In both cases, the corresponding ore deposits remain unknown. Rather than agreeing with Knapp (2000:39) that this exemplifies 'one of the unresolved problems of using LIA', implying that it points to a methodological problem, we regard this as most probably pointing to the fact that the ore deposits in question have not yet been sampled and analysed. For the earliest known oxhide ingots from Crete, it should not yet be excluded that the Minoan sources of this type of ingot may then have been from very far afield. After all Crete has no real sources of copper itself, whilst what there are have been excluded by LIA as the source of the Hagia Triadha ingots. Moreover we know from the eighteenth century BC Mari tablets (Dossin 1970) that tin from the east was collected at Mari, of which a part was sent to a Caphtorite, usually regarded as an inhabitant of Crete (Muhly 1985:282). Moreover it is usually assumed that the Minoans were somehow acquiring lapis lazuli from Afghanistan. It seems difficult to exclude that some copper ingots, though not all copper metal for artefacts, may also have come from far afield to Crete.

MIXING AND RECYCLING

On the basis of what is now known to be the false postulate that post-1250 BC oxhide ingots had lead isotope compositions which matched no ore deposits in Cyprus, nor indeed any deposits in the Mediterranean region, various hypotheses of mixing of ores or metals were advanced. There is in fact no need for these hypotheses now that we have the proven match of isotopic composition with the ores from the Cypriot Apliki copper ore deposit and its environs. Nevertheless it is worth examining further the credibility of these mixing hypotheses. However strong the evidence may be for the recycling of metals in the LBA Mediterranean world, we contend that, whilst this may have been a factor for the production of artefacts, it did not enter into the production of copper oxhide ingots. In this we are supported by the opinions of Pernicka (1995), Sayre et al. (1995), and Kassianidou (Karageorghis and Kassianidou 1999:185) who, on independent metallurgical grounds, do not believe that recycled metals were used to make oxhide ingots. Consequently the use of LIA for provenancing the copper of oxhide ingots is valid.

Knapp (2000:40) writes that Sayre et al. (1995:50) have shown that there exist '. . . at least five isotopically different groups of oxhide ingots which probably came from different sources', with the clear implication that Knapp (2000:40) considers this to be a new finding and a severe problem for our implication of the Apliki mine region as the predominant source of copper for solely the post 1250 BC oxhide ingots all over the Mediterranean. This is an example of muddled thinking. Sayre et al. (1995:50) are actually correct, in that they were not dealing exclusively with post-1250 BC ingots, but also with the LMIA-B ingots from Hagia Triadha and those few then analysed from the Uluburun shipwreck. As mentioned before in this article, our earlier evidence showed clearly that these earlier ingots had different lead isotope ratios from all the clustering together post-1250 BC ingots. Consequently if oxhide ingots from all periods are considered together, as Sayre et al. (1995) did, there is indeed a division into at least three, perhaps four, groups. This does not disprove our demonstration that the isotopic data for post-1250 BC copper oxhide ingots, from all over the Mediterranean region and beyond, cluster closely together in one group with the Cypriot Apliki region copper ore deposits.

A serious defect of much of the recent debate about lead isotope analyses in archaeology, including Knapp (2000), is that much of it has been conducted in qualitative terms. Often a quantitative examination would show that the qualitative idea does not in fact withstand a comparison with numerical data.

Some examples of this have already been mentioned in this article. Another is the idea of pooling ore sources in Cyprus (Knapp 2000:38 [4], 41–42), either by mixing ores or by mixing at coastal sites primary bun (or slab etc.) ingots from different inland origins where they might be melted down, perhaps refined, and cast into oxhide ingots. There is of course no evidence for such processes, whilst we believe there may be serious evidence against them. There is even evidence from experiments by Zwicker, quoted by Gale and Stos-Gale (1995:34), that an oxhide ingot could be produced from smelting one charge of ore in a furnace of the type excavated both at Enkomi and Kition in Cyprus. Tylecote (1971) also discussed these large LBA furnaces from Enkomi and Kition, suggesting that they were used most probably for copper smelting, though his particular furnace reconstructions may not be accurate.

Hypothetically, the smelting charge may have been made up of ores from different sources. Lead isotope analyses of the ores from Cyprus bear directly on this possibility. Figure 1 depicts such analyses, and includes relevant mixing lines, which for first order mixing must lie along straight lines (e.g. lines A, B, C) connecting the isotopic compositions for the ores being mixed as end members. It is clear that for mixing to produce isotopic compositions anywhere near those of the lowest lying Apliki ores in the upper diagram, ores from Kalavassos region mines must have been incorporated into the mixture, but there is no evidence from the isotopic composition of Cypriot artefacts that these ores were ever used in ancient times. Moreover even the extreme mixing lines passing through the Kalavassos region ores cannot account for the isotopic compositions of the major part of the

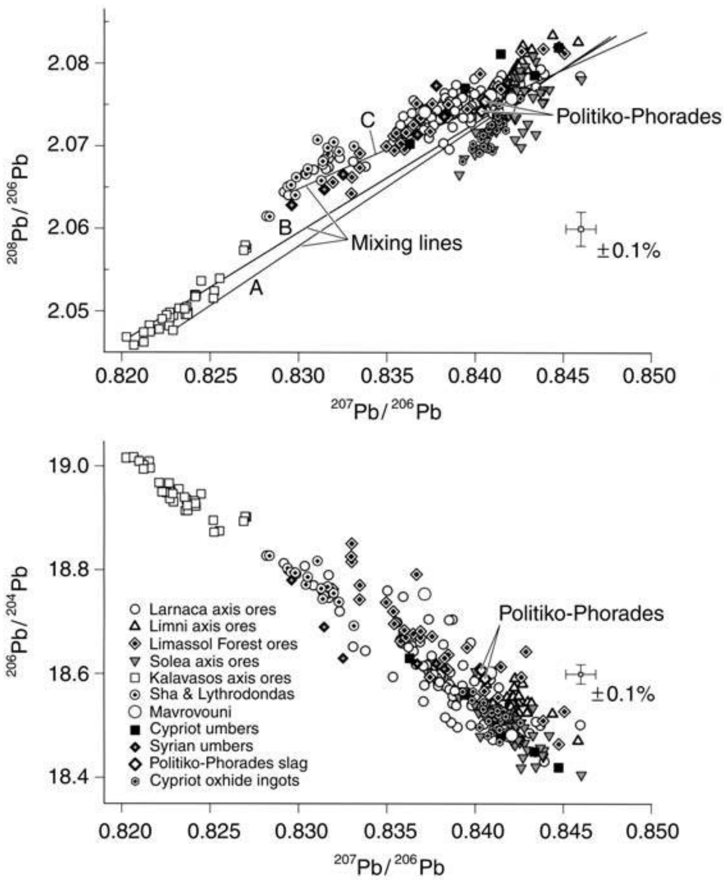

Figure 1. *Lead isotope diagrams for metal ores from Cyprus, with possible single stage mixing lines superimposed.*

Apliki ores. A little reflection shows that more complicated mixing of these Cypriot ores cannot reproduce the isotopic compositions of the major part of the Apliki ores. Recalling that all post-1250 BC copper oxhide ingots have lead isotope compositions lying with the Apliki region ores, we can also reject the idea (Knapp 2000:42) '. . . that black copper – in the form of bun (or slab, or plano-concave) ingots – from *different mines* or smelting workshops were pooled to produce the more pure, copper oxhide ingots'. The examination of possible mixing lines rules this out. Moreover, random mixing of this type, with the mixing of differing proportions of ores (or ingots) from different mines at different times, would result in different batches of oxhide ingots having isotopic compositions spread out along the mixing lines. This is not observed.

Thus the qualitative idea of pooling ores, or copper smelted from them, from a number of different Cypriot ore deposits to produce the particular narrow range of isotopic compositions of the post-1250 BC oxhide ingots is not compatible with the quantitative data for real ore deposits and ingots. We see here the complete negation of the view of Knapp (2000:39), in considering the question whether pooling, recycling and mixing can or cannot be distinguished from copper coming from a single ore source, that:

> Unfortunately LIA cannot help in any way to distinguish between the two. Such a judgement is purely subjective and should be informed by independent archaeological data.

It is true that qualitative consideration of lead isotopes in the abstract cannot resolve this question, but equally true that quantitative consideration of the relevant numerical lead isotope data *can* resolve the issue, as outlined in this article. At this level of discussion and interpretation of lead isotope data, archaeological data has no standing. It is at the next stage, that of interpreting how the provenancing information yielded by lead isotopes alone can validly be interpreted within an archaeological framework, that archaeological data and independent archaeological thinking come into their own. If the lead isotope data indicate something at first sight running counter to prior archaeological assumptions, then scientists must be prepared to re-examine their data and scientific interpretation of it. Equally, archaeologists must be prepared to re-examine their preconceptions, which may well not be so well founded on fact, as distinct from social theory perhaps not so safely applicable to ancient societies, as they had thought. A good example is the lead isotope evidence which led Pernicka et al. (1993) to reject the Eneolithic Serbian mine of Rudna Glava as a significant source of copper for Eneolithic Serbian copper based artefacts.

RECYCLING

> It must be made clear, however, that the same result – the clustering of the oxhide ingots on LIA plots would occur if raw copper from multiple sources were pooled in their production. (Knapp 2000:43).

This was originally postulated by Budd et al. (1995) when insufficient data for the Apliki region ores were available to give a completely convincing demonstration that post-1250 BC oxhide ingots matched them isotopically. Budd et al.'s hypothesis never advanced to an appropriate quantitative examination of the data. As originally developed, Budd et al.'s (1995) model involved production of oxhide ingots by thorough recycling and mixing of scrap copper and tin bronze throughout a Mediterranean *koine* which presumably included Cyprus, Sardinia, Greece and the Near East. Admixture of tin bronze had to be abandoned when it was pointed out that all copper oxhide ingots do not contain tin above the merest traces (e.g. Maddin and Merkel 1990:183; Stos-Gale et al. 1998b). Of course, if true, the recycling model destroyed the possibility of provenancing, through lead isotopes, the true source(s) of copper for oxhide ingots.

In our view, the seeds of the downfall of such a model were built in from its inception. Consider the geographic scale of finds of LBA oxhide ingots with the same lead isotope composition, from Sardinia through Greece, Crete, Cyprus, to Bulgaria, Anatolia, and Qantir in the Nile Delta (a distribution map of the findspots of oxhide ingots through the Mediterranean was given by Gale 1991:201). Consider that the lead isotope composition of copper used for contemporary Nuragic objects in Sardinia (Gale and Stos-Gale 1987:155, Figs. 7–15) is widely different from that of copper artefacts in Greece, Cyprus, Syria, etc., which also differ widely amongst themselves. Where was all this copper coming together, on a scale of at least many tens of tons of metal, to be thoroughly mixed together and cast into oxhide ingots, so as to produce a very tight lead isotope composition? What happened to the tin content? There is evidence that it is not easy to remove Sn and Pb at trace levels (<500 ppm) from a copper based alloy by fire-refining (Merkel 1990:108, Table 15), but apparently direct experimental data is not at present available for fire refining of copper alloys containing these elements at the 1–10 per cent level (Merkel, pers. comm.).

The question is posed: 'is it archaeologically reasonable to contemplate copper coming from all over the Mediterranean to be thoroughly mixed together at one place, consequently to be formed into oxhide ingots which were then re-exported back again to the far corners of the wider Mediterranean?' If it was not mixed together at one place, it is not likely that the batches of copper mixed together at different places will have resulted in a number of thoroughly mixed batches having the same isotopic composition as each other. It is not likely that the different batches of copper coming on different ships to any one locality will have sampled all the Mediterranean copper sources; it seems more likely that different sites will have been brought copper from a different array of copper ore deposits. Should it be envisaged that over time a thorough mixing of copper from all the sources somehow occurred, then it is difficult to avoid the assumption that this took place through recycling scrapped artefacts into oxhide ingots, whereupon the difficulty of the lack of tin in these ingots is again raised.

We may note in this connection the contrast in Figure 2 of the lead isotope compositions of artefacts from the Cape Gelidonya wreck with those for the copper oxhide ingots on the same wreck. The artefacts appear to reflect provenance from

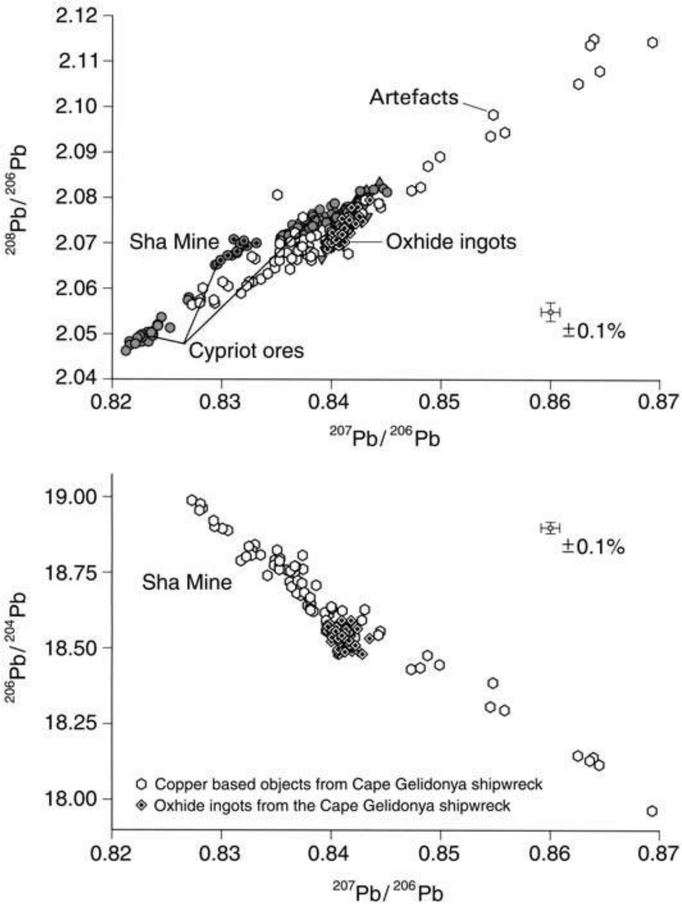

Figure 2. *Lead isotope diagrams for copper oxhide ingots and copper based artefacts from the Cape Gelidonya Bronze Age shipwreck, with data for Cypriot ores.*

a number of different copper ore sources; at any rate they have a broad range of isotopic composition. In contrast the oxhide ingots have a narrow range of isotopic compositions. There is no evidence here for thoroughly mixed, isotopically homogenized, copper characteristic (according to Knapp) of a network. If we wished to retain this model of network metal mixing, we should have to explain how it is that *artefacts* retain widely different lead isotope compositions whilst contemporary *ingots*, even on the same ship, are homogenized. Surely we cannot believe that it is only copper metal destined for making oxhide ingots which is thoroughly mixed, whilst that used for artefacts is not? Further points against the recycling hypothesis, which do not seem to have been addressed by Knapp (2000), were summarized by Stos-Gale et al. (1997:108–109). The coup de grace for this hypothesis must surely be that it seems incredible that wholesale recycling and mixing of metal originating all over the postulated *koine* should result in a narrow range of lead isotope compositions which just happens precisely to coincide with the isotopic data for the Apliki region Cypriot ores.

Any postulated need for such a mixing model was partly but strongly based, as we have seen, on the supposed lack of a match in isotopic composition between that for the ingots with any feasible copper ore source. Stos-Gale et al. (1998b, Fig. 4) and Gale (1999:118, Fig. 12) have shown that in fact there is a match for the lead isotopic compositions of the Cape Gelidonya oxhide ingots with the Apliki region copper ores in Cyprus. We have already seen the same match with Apliki copper ores for the oxhide ingots found on Cyprus and Sardinia, and it proves to be true for all post-1250 BC oxhide ingots regardless of their findspot (Gale 1999). Consequently the reason for the postulation of the mixing/recycling model to explain the narrow range of lead isotope compositions of post-1250 BC oxhide ingots, i.e. the presumed lack of match of their isotopic composition with any Mediterranean ore deposit(s), no longer exists. It seems appropriate now to abandon all forms of the mixing model for oxhide ingots. Even its original proponents now seem to be less than enthusiastic about it (Scaife et al. 1999).

CONCLUSIONS

In the context of lead isotope studies conducted to ascertain the source(s) of copper for the copper oxhide ingots, this is a matter to be decided purely from the scientific data; there is no question but that it is entirely unacceptable to massage the data or interpret it so as to fit in with some preconceived archaeological or social theoretic hypothesis. If it proves possible to solve the scientific provenancing question, then it is at this stage that the answer(s) must be woven into an archaeological interpretation in social terms. In this particular case, scientific solutions were obtained after lengthy and detailed work.

The earliest such ingots were found to be made from an as yet unknown copper source (probably non-Mediterranean), the Uluburun ingots were made of copper from a different but as yet unknown copper source (probably Cypriot, but not Apliki), whilst all post-1250 BC ingots, all over the Mediterranean, were made from copper from the Cypriot Apliki ore deposit or its environs. This change of copper source with time for the oxhide ingots, together with the proof from lead isotopes that tools, weapons etc. made in Cyprus utilized copper sources all around the Troodos, are facts available for archaeological interpretation. This seems to be a success story for lead isotope provenancing; there is no need for the ill-defined deconstruction of the interpretation of lead isotope analyses advocated by Budd et al. (1995:169) before sufficient data were available. It was difficult enough to arrive at these conclusions by a long sustained effort, but they should of course not be over-interpreted. Oxhide ingots were but part of the Bronze Age Mediterranean metals trade, and their function and purpose remains a topic of archaeo-metallurgical and archaeological debate (see Melas 1991; Lagarce and Lagarce 1996). For such reasons, our research programme also embraces other types of ingot and artefacts of the nature of tools, weapons. The lead isotope signatures of these other artefacts inform other, equally important narratives about the movement of metal objects around the Mediterranean in the Bronze Age.

ACKNOWLEDGEMENTS

I wish to thank especially my dear colleague Zofia Stos-Gale, who has improved this text, and without whom nothing of value would have been achieved over the last 22 years. I thank also Wolfgang Gentner (posthumously), Colin Renfrew, Gunther Wagner, Otto Müller (posthumously), Valerie Chamberlain, Stavros Papastavrou (posthumously), George Bass, Cemal Pulak, Patricia Sibella, Ann Dayton and many others without whose generosity, collegiality and inspiration I would not have worked in this field. I am grateful to two anonymous referees who commented on this article.

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BIOGRAPHICAL NOTE

Noel Gale is emeritus Director of the Isotrace Laboratory, Dean of Nuffield College and Professor of Archaeological Science, University of Oxford. As a Royal Scholar he read physics and mathematics under Sir George Thomson, Nobel laureate, at the Royal College of Science, Imperial College, London and took his PhD in nuclear physics, later taking a DSc in archaeological science at Oxford. He taught physics and researched in nuclear physics in the Universities of London and Manchester and at Harwell; his research led him to work on the origin of the elements which he later pursued in the field of cosmochemistry in the Department of Earth Sciences, University of Oxford. As joint director of the isotope geology laboratory his work also embraced isotope geochemistry and geochronology, including the absolute calibration of the geological time scale and applications to the genesis of rocks and ore deposits. Collaboration with Wolfgang Gentner at the Max Planck Institute for Nuclear Physics at Heidelberg led him into the field of archaeometallurgy, at first largely into the provenance of silver for the coinage of the Greek city states, involving both laboratory and fieldwork. His work in this field was directed towards Bronze Age Mediterranean archaeology by Colin Renfrew, leading to the founding of the Isotrace Laboratory in 1978 with his wife and colleague, Zofia Stos-Gale. He represents the heads of science departments on the Committee for Archaeology, Oxford and is associate editor of *Archaeometry*, overseas editor of the *Geochemical Journal* and the *Revue d'Archéometrie.*

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ABSTRACTS

Archéologie, archéologie scientifiquement fondée et le commerce des métaux à l'âge de bronze en Méditerranée: Une contribution au débat

Noel Gale

Les grandes lignes du consensus actuel se fondent sur les conclusions d'analyses isotopiques du plomb provenant d'études sur l'origine du métal et sur les indications qu'apporte la structure du commerce du cuivre pendant l'âge de bronze en Méditerranée, en retenant spécialement les lingots de cuivre 'peau de boeuf'. Plusieurs approches erronées, surtout celles publiées par Knapp (1999, 2000), sont revues et corrigées. Il est démontré que le recours à des hypothèses fondées sur le mélange et recyclage du cuivre exercés partout en Méditerranée pour expliquer les caractéristiques de l'isotope de plomb des lingots de cuivre 'peau de boeuf' plus jeunes que 1250 avant J-C est superfétatoire: il y a une corrélation isotopique entre ces lingots et les dépôts de minerais de la région d'Apliki en Chypre. Les points faibles des hypothèses soutenant un regroupement, direct ou indirect, des minerais de Chypre et un recyclage général des métaux dans une *koine* méditerranéenne sont dévoilés, en considérant surtout le défaut de preuve en ce qui concerne l'homogénéité de la composition des isotopes de plomb dans les divers objets archéologiques et l'absence d'étain dans les lingots 'peau de boeuf'.

Archäologie, Wissenschaftsbasierte Archäologie und Mediterraner Bronzezeitlicher Metallhandel: Ein Diskussionsbeitrag

Noel Gale

Der vorliegende Beitrag behandelt unter besonderer Beachtung der sogenannten kupfernen 'Ochsenhautbarren' die Anwendung der Bleiisotopenanalyse für Untersuchungen zur Herkunft von Metall und die Klärung des bronzezeitlichen Metallhandels. Verschiedene Fehlkonzeptionen, besonders die bei Knapp (1999, 2000) genannten, werden berichtigt. Es wird gezeigt, daß es keinen Grund gibt, zur Erklärung der Charakteristika der Bleiisotopen von 'Ochsenhautbarren' nach 1250 BC, erneut auf die Theorie einer mittelmeerweiten Vermischung bzw. eines Recycling zurückzugreifen, da eine gute isotopische Übereinstimmung dieser Barren mit der Erzlagerstätte von Apliki auf Zypern besteht. Schwächen der Hypothesen einer direkten oder indirekten Zusammenfassung zypriotischer Erze und eines postulierten verbreiteten Metall-Recyclings in einer mediterranen *koine* werden in Ermangelung eines Beweises für die Homogenität der Bleiisotopenzusammensetzung von Artefakten sowie des Fehlens von Zinn in den 'Ochsenhautbarren' herausgearbeitet.