PREHISTORY MONOGRAPHS 29

Metallurgy: Understanding How, Learning whY

Studies in Honor of James D. Muhly

edited by

Philip P. Betancourt and Susan C. Ferrence

Published by
INSTAP Academic Press
Philadelphia, Pennsylvania
2011

Design and Production
INSTAP Academic Press

Printing
CRWGraphics, Pennsauken, New Jersey

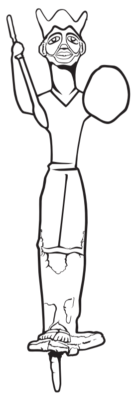
Binding
Hoster Bindery, Inc., Ivyland, Pennsylvania

FPO
FSC

Library of Congress Cataloging-in-Publication Data

Metallurgy, understanding how, learning why : studies in honor of James D. Muhly / edited by Philip P. Betancourt and Susan C. Ferrence.
p. cm. -- (Prehistory monographs ; v. 29)
Includes bibliographical references.
ISBN 978-1-931534-57-4 (hardcover : alk. paper)
1. Metal-work, Prehistoric. 2. Bronze age--Cyprus. 3. Bronze age--Aegean Sea. 4. Bronze implements--Cyprus. 5. Bronze implements--Aegean Sea. 6. Cyrpus--Antiquities. 7. Aegean Sea--Antiquities. 8. Muhly, James David. I. Betancourt, Philip P., 1936- II. Ferrence, Susan C., 1974-
GN799.M4M48 2011
939'.37--dc23

2011017917



List of Abbreviations

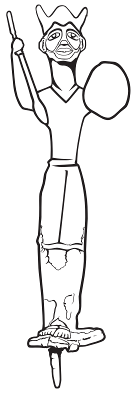
Abbreviations for periodicals in the bibliographies of the individual articles follow the conventions of the *American Journal of Archaeology* 111.1 (2007), pp. 14–34.

AKR	excavation number, Akrotiri, Thera
cm	centimeter
dia.	diameter
EBA	Early Bronze Age
EC	Early Cycladic
EChal	Early Chalcolithic
ED-XRF	emission dispersive X-ray fluorescence
EH	Early Helladic
EM	Early Minoan
gr	gram
h.	height
HM	Herakleion Archaeological Museum
HNM	Hagios Nikolaos Archaeological Museum
L.	length
LBA	Late Bronze Age
LC	Late Cycladic or Late Cypriot
LChal	Late Chalcolithic
LH	Late Helladic
LM	Late Minoan
m	meter
MBA	Middle Bronze Age
MC	Midlle Cycladic
MChal	Middle Chalcolithic
MH	Middle Helladic
MM	Middle Minoan
NCSR	National Center for Scientific Research “Demokritos”
NM	National Archaeological Museum of Greece
NMD	Neolithic Museum, Diros, Mani
pers. comm.	personal communication
pers. obs.	personal observation
pres.	preserved

SEM/EDX	scanning electron microscopy and energy dispersive microanalyses
SM	Siteia Archaeological Museum
th.	thickness
w.	width
wt.	weight
XRD	X-ray diffractometry
th.	thickness
XRF	X-ray fluorescence spectrometry

CHAPTER

22



"Biscuits with Ears:" A Search for the Origin of the Earliest Oxhide Ingots

Zofia Anna Stos-Gale

The Uniqueness of Oxhide Ingots

Copper oxhide ingots are generally flat, rectangular ingots measuring 4–8 cm thick, 30–60 cm long, and 20–45 cm wide. The weight of these ingots varies greatly, from about 10 kg to 37 kg. The most prominent features of the "oxhide" ingots are elongated, pulled-out corners that would facilitate carrying them by two people or tying them together, or to the back of an animal, with a rope. The shape of these "ears" and the ingot sides vary a great deal, from very long hornlike "ears" and a small waist as on the ingot found at Mycenae, to gently concaved sides and small protrusions at the corners as seen on the "pillow" ingots from Kyme, Kato Zakros, Tylissos, and Hagia Triada (Fig. 22.1). The other prominent feature of these ingots is a fleecelike bubbly top surface and smooth pitted sides and underside resulting from pouring freshly smelted copper into the molds made of (most likely) sand or stone. This process left the ingots full of gas holes. Ingots of this shape never have the smooth surface appearance of refined, alloyed, or re-melted metal; the purity of copper in all tested cases is over 99%. Some of them have signs, either stamped or imprinted during casting, or as in many cases, incised after the ingot had cooled. So far there is no firm conclusion as to the meaning of these signs. Similarly, the shapes seem to be without a particular meaning. The best study case for these ingots is the collection of several hundred discovered on the Uluburun shipwreck, which also carried oxhide-shaped tin ingots (Pulak 2000).

To 19th-century archaeologists these ingots resembled an "oxhide," but George Bass and Cemal Pulak often tell the story of discovery of the Uluburun shipwreck, after the sponge divers mentioned to one of their colleagues a site where they have spotted copper "biscuits with ears" at the bottom of the sea. This description seems very evocative. The shape of these ingots made them a symbol

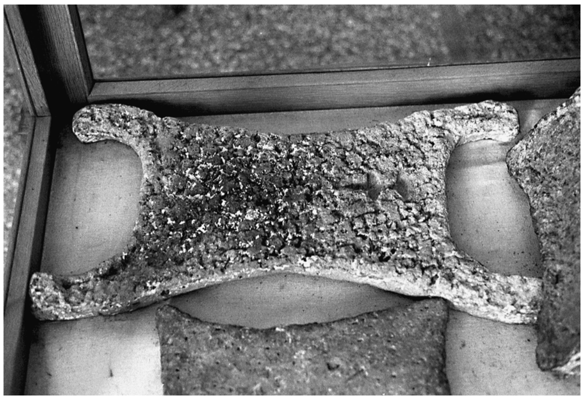


Figure 22.1. Oxhide ingot from Mycenae and ingots from Kyme in the Numismatic Museum, Athens.

of the Late Bronze Age trade in the Mediterranean. Many papers in the last 50 years have been devoted to the discussion of the origin and significance of these ingots. Noël Gale has summarized in detail the early publications concerning these objects, adding the information that was becoming available from the lead isotope (LI) analyses (Gale 1991). Since then, little has been discovered about the ingots from the archaeological point of view, but much more of the analytical data has become available.

The program of LI analyses of metals, ores, and slags related to oxhide ingots was mainly developed in Oxford and Heidelberg-Mainz in the 1980s and 1990s. The Oxford Isotrace Laboratory produced during that time a relatively comprehensive LI database of oxhide ingots that was published simultaneously with a database of ores from Cyprus (Gale et al. 1997; Stos-Gale et al. 1997). More recently, the LI analyses of the ingots from the Uluburun (Gale and Stos-Gale 2005) and Gelidonya (Stos-Gale et al. 1998; Stos 2009) shipwrecks were published. Further survey and collection of ores and slags added more LI and ^{14}C data for Cypriot slag heaps (Stos-Gale, Maliotis, and Gale 1998), while the much more daunting task of surveying the ore deposits in Anatolia was carried out by the Heidelberg-Mainz team (Wagner and Öztunali 2000, with references), with a significant contribution from Yener (Yener et al. 1991).

From the present evident, it seems that the earliest ingots of the oxhide shape are still those found on Crete in the Hagia Triada palace and at Tylissos, Gournia, Zakros, and coastal Mochlos. All these finds are dated to 1500–1450 B.C. (Late Minoan [LM] IB). Most of these ingots and fragments were analyzed for their LI compositions. Perhaps the time is right to look again at the evidence as to the origin of these ingots. The Festschrift to Jim Muhly, who devoted much of his time to these ingots and the Bronze Age metal trade, is an appropriate place for this summary.

The Origin of the Oxhide Ingot Metal

The LI and trace elemental compositions of all analyzed oxhide ingots dated between the 14th and 11th century B.C. are fully consistent with their origin from Cypriot ores. There can be no doubt that Cyprus in this period was a prolific producer of copper ingots of this shape, and a good example of this is the cargo of the Uluburun shipwreck, dated to ca. 1314–1307 B.C. (Gale and Stos-Gale 2005). These ingots of Cypriot copper travelled as far west as Sardinia, north to the coast of the Black Sea, and into central Anatolia (Stos-Gale et al. 1997, 110–111, table 6). The only fragment of an oxhide ingot so far excavated in Egypt, in Qantir, is also fully consistent with the origin from the Cypriot ores (see Table 22.1). It seems that the oxhide ingot shape is what we could call a Cypriot "brand." However, some of the earlier (LM IB) ingots found on Crete are not isotopically consistent with their origin from the Cypriot ores (Table 22.2).

The discussion of the origin of copper of the Hagia Triada ingots was published some 20 years ago (Gale and Stos-Gale 1986). (The ingots discussed here are the "pillow"-shaped whole ingots. Half of an oxhide ingot found in Hagia Triada, discussed by Gale [1991, 202], is of a possibly later date and consistent with Cypriot ores). Because the LI ratios of ores are strongly related to the geological age of the mineral deposits, it was quite clear that these LI ratios do not reflect ore deposits that were created about 100 million years (Ma) ago, as it is known for Cyprus, but from a mineralization of a much older age, around 400–700 Ma (Silurian to Precambrian). On the same

Object Number	Site	Description	Date	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{205}Pb/^{204}Pb$
CA 20/1	Mochlos, Crete	Corner of a "pillow" ingot 790 g	LM IB	2.0697	0.83956	18.525
CA 20/10	Mochlos, Crete	Oxhide fragment	LM IB	2.06735	0.83897	18.543
CA 20/11	Mochlos, Crete	Oxhide fragment	LM IB	2.0672	0.83969	18.571
CA 20/12	Mochlos, Crete	Oxhide fragment	LM IB	2.08168	0.84364	18.573
CA 20/13	Mochlos, Crete	Tip of a horn	LM IB	2.06821	0.83909	18.569
CA 44/9	Mochlos, Crete	Oxhide fragment, side	LM IB	2.07046	0.84114	18.505
CA 45/4	Mochlos, Crete	Corner of a "pillow" ingot	LM IB	2.06547	0.83851	18.548
CA 60/1	Mochlos, Crete	Fused metals: horn of oxhide	LM IB	2.07499	0.84120	18.494
CA 70/1	Mochlos, Crete	1/4 of oxhide HT type	LM IB	2.06541	0.83724	18.647
CA 70/2	Mochlos, Crete	Horn of an oxhide ingot	LM IB	2.07166	0.841	18.520
CA 71/3	Mochlos, Crete	Corner of a pillow	LM IB	2.06652	0.83909	18.566
HM 2602	Kato Zakros, Crete	Oxhide ingot	LM IB	2.07622	0.84595	18.408
HM 2603	Kato Zakros, Crete	Oxhide ingot	LM IB	2.07413	0.84154	18.5394
HM 2604	Kato Zakros, Crete	Oxhide ingot	LM IB	2.06974	0.84056	18.533
HM 2606	Kato Zakros, Crete	Oxhide ingot	LM IB	2.08042	0.84836	18.359
KS	Kato Syme, Crete	Oxhide ingot	LM IB	2.0709	0.83536	18.791
MeP 87/45	Qantir, Egypt	Oxhide ingot fragment	Rameses II	2.07394	0.84124	18.527

Table 22.1. Lead isotope compositions of LM I oxhide ingots not published in Stos-Gale et al. 1997, or in other papers, consistent with their origin from Cypriot ores. Samples courtesy: J. Soles (Mochlos), Herakleion Museum (Kato Syme and Zakros), and T. Rehren (Qantir).

Object Number	Site	Date	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
AT A	Hagia Triada	LM IB	2.11368	0.87139	17.821
AT 721 C	Hagia Triada	LM IB	2.12248	0.87788	17.698
AT 722 I	Hagia Triada	LM IB	2.12962	0.88594	17.488
AT 723 F	Hagia Triada	LM IB	2.11838	0.87479	17.767
AT L	Hagia Triada	LM IB	2.12243	0.87928	17.647
AT M	Hagia Triada	LM IB	2.12411	0.87871	17.685
AT 724 P	Hagia Triada	LM IB	2.12582	0.87842	17.718
AT 726 B	Hagia Triada	LM IB	2.10081	0.85911	18.267
AT 726 B patch	Hagia Triada	LM IB	2.09979	0.86032	18.110
AT 726 E	Hagia Triada	LM IB	2.12782	0.88180	17.641
AT 726 H	Hagia Triada	LM IB	2.13086	0.88109	17.742
AT 726 J	Hagia Triada	LM IB	2.13187	0.88631	17.495
AT 726 O	Hagia Triada	LM IB	2.11965	0.87783	17.674
HM 1763/87	Tylissos	LM IB	2.09794	0.85841	18.138
HM 2601	Kato Zakros	LM IB	2.10254	0.86324	18.093
HM 2605	Kato Zakros	LM IB	2.12275	0.88116	17.593

Table 22.2. Lead isotope compositions of oxhide ingots from three sites in Crete: Hagia Triada, Kato Zakros, and Tylissos. They are not consistent with their origin from Cypriot ores (samples courtesy of the Herakleion Museum).

grounds, the ore deposits from mainland Greece, Crete, and other Aegean islands were rejected as a possible ore source for these ingots.

It has been suggested that the copper ore used for the Hagia Triada ingots might be found in Anatolia. This suggestion seems somewhat strengthened by the fact that out of many hundreds of Bronze Age (BA) copper-based artifacts from the eastern Mediterranean analyzed for their LI compositions, the only other two sites where metals of similar LI compositions have been located were Kastri on Syros (Early Cycladic [EC] III) and Troy (Early Bronze [EB] II). A speculative map of the Anatolian deposits was presented in the paper reporting these results, indicating copper ore deposits of a relevant age (Stos-Gale, Gale, and Gilmore 1984, 27–28). A few years later a speculative possibility of the origin of these ores in the Precambrian copper deposits in Afghanistan, Iran, or southern Russia (Transcaucasus) was suggested by Gale (1991, 226).

Further Search for the Ores Consistent with the Hagia Triada Ingots

Before its closure in 2001, the Isotrace Laboratory in Oxford produced over 2,600 LI analyses of ore and slag samples collected during numerous archaeometallurgical and geological surveys in Greece, Cyprus, Italy, Spain, and Bulgaria. Together with LI data published by other researchers, the Oxford LI database includes over 3,000 LI data for ores relevant to the Mediterranean Bronze Age metals and over 2,600 for the BA metal artifacts (for a summary, see Stos-Gale 2001, 197, table 10.1). The LI database for Cypriot ores and slags includes now over 500 entries. The other very important development is the availability of more analytical data for the ores from Sardinia (over 300) and Wadi Arabah (about 100 from Timna and Feinan), where there are ore deposits of approximately comparable age to that indicated by the LI compositions of the unusual Hagia Triada ingots. Additionally, some 70 ore data from the coast of the Red Sea and about 40 from central Iran have been published. Finally, over 320 LI data for ores from various deposits in Turkey also have been published in the last 15 years. Unfortunately, there are still very important gaps including Egyptian and Middle Eastern ore sources.

The interpretation of the LI data obtained for archaeological artifacts has evolved over the years from simple plotting on LI ratios diagrams. It is currently done by using a three-stage procedure:

1. First, the Euclidean distances in the three-dimensional space with axes defined by the three LI ratios are calculated between each of the artifact's LI ratios and all currently available LI data points for ore and slag samples. Software called TestEuclid sorts the data in the order of increasing Euclidean distances. The LI ratios of the artifact and an ore sample are regarded as identical if all three ratios for both are within the analytical error for each of the three LI ratios. At this stage it is possible to find that several ore samples from two or three geographically different regions have all three LI ratios identical with an artifact.
2. Second, the geochemical, geographical, and historical (archaeological) information is considered.
3. Third and finally, the data points are compared on two-dimensional plots of LI ratios of the artifacts and ores selected in the previous two steps.

Usually, at the end of these procedures, all but one or two ore sources can be eliminated.

These procedures were applied to check if any group of the currently available LI data for ores and slags from the mines in the Mediterranean and the Near and Middle East is consistent with the LI ratios for the oxhide ingots from Hagia Triada. It is not possible to discuss in detail the results of these comparisons in this short paper, but the conclusion is still the same—none of the available groups of LI data for ore deposits match the main group of these ingots. LI ratios in the range for $^{208}Pb/^{206}Pb$ of 2.10–2.13 are quite rare among the published LI data for copper ore deposits surrounding the Mediterranean. The closest LI compositions are for the copper ores from Sardinia and Wadi Arabah.

Current LI evidence for ores from Sardinia (Boni and Koeppel 1985; Stos-Gale et al. 1995; Begemann et al. 2001) definitely excludes the Sardinian ores as sources of the copper for these ingots. The same, so far, is true for the copper ores from Timna and Feinan Bronze Age copper mines in the Arabah Valley (Hauptmann et al. 1992; unpublished data from the Isotrace Laboratory). Among the published LI data for ores from Turkey, there are some minerals that have $^{208}Pb/^{206}Pb$ ratios in this range, but they are from lead-zinc, not copper, deposits. Graphic presentation of this conclusion is presented on Figure 22.2. The LI range of this diagram is nearly the same as in the original publication (Gale and Stos-Gale 1986, figs. 5, 94).

These unusual LM IB ingots fall into two groups: one ingot from Hagia Triada (inv. no. AT 726B) and the ingots from Tylissos (HM 1763) and Kato Zakros HM 2601) have lower LI ratios (from deposits formed around 375 Ma), while the other non-Cypriot ingot from Zakros and the remaining ingots from Hagia Triada form a rather dispersed group related to the earlier ore formation (about 640 Ma). These groups do not necessarily mean that the metal for both of them was derived from geographically different areas. It is not uncommon for certain regions in Europe and the Near East to have mining regions where ore deposits were formed in different geological periods (for example Sardinia).

Who Introduced the Oxhide Ingot Shape?

The ingots from Hagia Triada are not necessarily the ancestors of all other oxhide ingots. As is demonstrated in Table 22.1, a number of LM IB ingots and ingot fragments found on Crete are isotopically fully consistent with their origin from Cypriot ores. The analyzed group of six ingots from Kato Zakros includes four that are fully consistent with Cypriot ores from the Solea region, which includes the big copper mines of Skouriotissa, Apliki, Phoenix, and Mavrovouni.

Oxhide ingots were cast from freshly smelted, unrefined copper, so it is interesting to see in Kato Zakros a group of similarly looking oxhide ingots made from copper mined in geographically different regions. That might suggest that the ore had to be transported to the location where the smelting and then casting of ingots was taking place. This would seem somewhat inefficient, because the ore is much more bulky than metal obtained from it, so it means that the transport of the ore over long distances is not the most economical approach.

However, there are examples of the smelting of copper during the BA in places remote from the mines. An early example of copper extraction far away from the source of the ore is the Early Minoan (EM) site of Chrysokamino on Crete (Stos and Gale 2006). On Cyprus there are copper slag heaps scattered in the mountains in the vicinity of the mines (most of them date to the Roman or Medieval times, see Stos-Gale, Maliotis, and Gale 1998), but there are also quite substantial finds of copper slag in the Bronze Age settlements of Enkomi and Kalavassos–*Ayios Dhimitrios*. LI ratios of slags from both of these sites proved them to be consistent with copper ores from various outcrops in the Troodos Mountains. Some of the slags from Enkomi have LI compositions identical to the ingots carried by the Uluburun ship. An unpublished study of the Uluburun ingot molds carried out by Pulak combined with the LI data for these ingots suggests that some of the ingots were cast in the vicinity of the mines, but some might have been made, for example, in Enkomi or Ayios Dhimitrios (Pulak and Stos-Gale, unpublished data).

The presence of ingots at Hagia Triada in a storeroom of the palace suggests that they were put there as an asset or a status symbol. Perhaps these ingots were a diplomatic gift to the Minoan king? The depictions of oxhide ingots in the procession of gift bearers in the tombs of the Egyptian pharaohs (e.g., Useramon in Thebes; see Wachsmann 1987, pl. 33A) implies that ingots of this shape were well-regarded gifts. It also might suggest that the Egyptians were not casting such ingots themselves, and therefore they were valuable.

From about 1550 B.C. the Anatolian coast facing Cyprus on the northeast was coming under the influence of the emerging Hurrian state of Mitanni, which in the next two centuries became a power equal to Egypt and the Hittite Empire (Kuhrt 2000, 286–287).

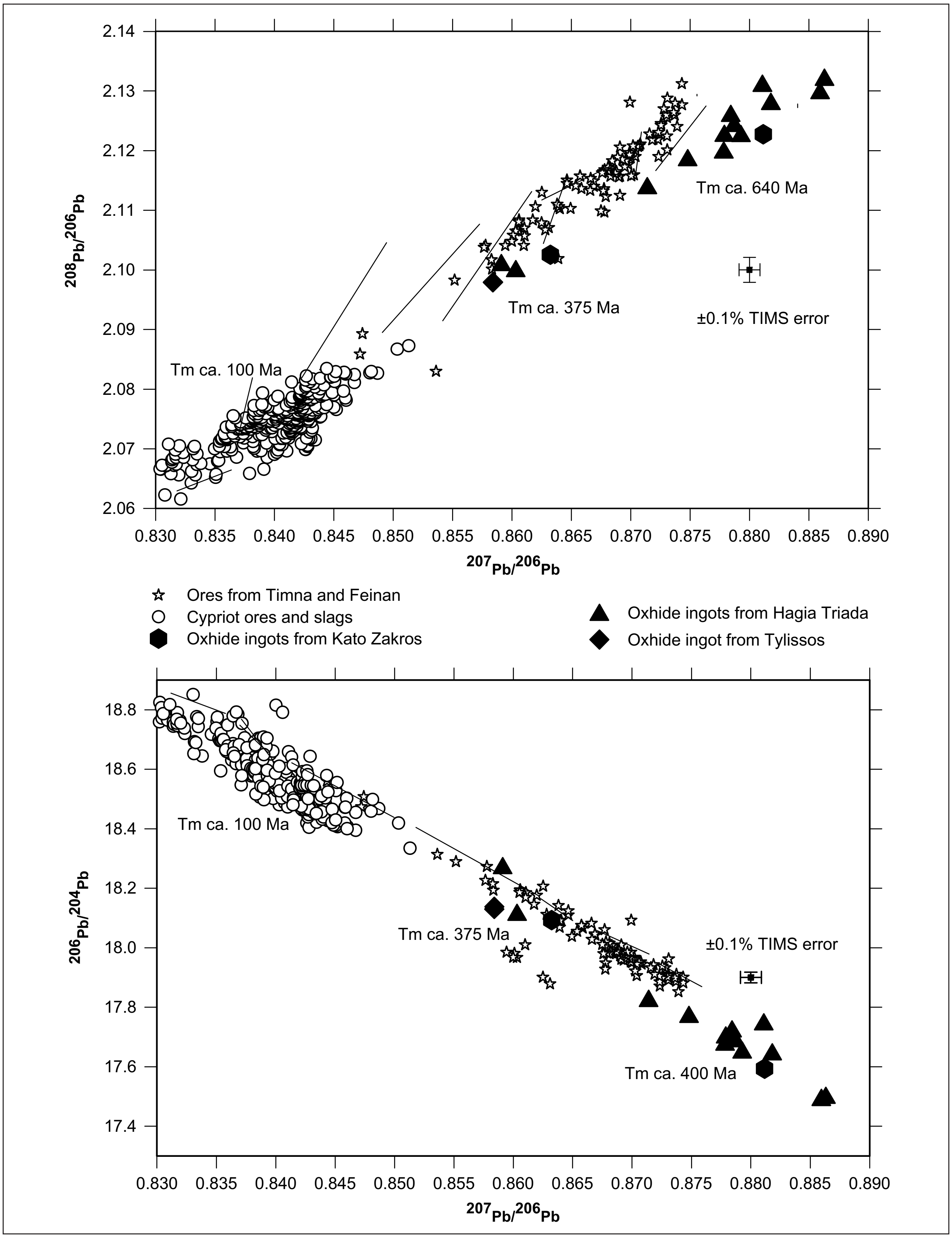


Figure 22.2. LI compositions of the LM I copper oxhide ingots of non-Cypriot origin compared with Cypriot and Near Eastern copper ores. The position of Sardinian ore data is indicated by lines. TIMS = Thermal Ionization Mass Spectometry. Tm = geological age of ore deposits.

At its greatest extent the kingdom of Mitanni controlled an area stretching from Lake Van to the Middle Euphrates and from the Zagros Mountains to the Syrian coast—a region rich in mineral resources and with a long tradition of copper metallurgy. In his paper on the Late Bronze Age technology transfer between Western Asia and Egypt, P.R.S. Moorey (2001, 3–4) summarizes the evidence for the important role that the Hurrians played in this region in propagating innovative technologies. It is very likely that they were also involved in facilitating the tin trade from central Asia to the eastern Mediterranean. Did the Hurrians invent the oxhide ingot shape?

The fact that the ingots from Hagia Triada remained intact supports the conclusion obtained from the LI work on Minoan metals that shows extensive use of copper from Aegean sources (Stos-Gale 2001, 202); there was no need to use these ingots, because the supply of copper was secure. Tin had to be imported, however, and in Crete the tin bronzes were made earlier than in the other parts of the Aegean (Stos-Gale 2001, 204–206). Perhaps these ingots came to Crete together with tin ingots that were immediately used? It seems likely that tin was coming to Crete together with copper from Cyprus (Muhly 1977, 44). About 18% of LM copper-based metals analyzed are consistent with Cypriot ores, and the presence of Cypriot oxhide ingot fragments in the workshop at Mochlos proves that they were used (Soles and Stos-Gale 2004, 45–59).

Thus, we still have no answer based on their LI compositions as to the origin of these unusual LM IB ingots listed in Table 22.2. Their LI ratios do not resemble any of the ores analyzed so far, and they are similar only to a few other Bronze Age metal artifacts from the eastern Mediterranean. However, there is no comparative material from the second millennium B.C. from the areas east of the Syrian coast, from the Kingdom of Mitanni, and from Babylonia. Also, there are no LI analyses of the Transcaucasian copper ores where the metallurgy on the eastern coast of the Black Sea (in present day Georgia and Armenia) was well developed from the Early Bronze Age (Chernykh 1992). Until more LI analytical work is done, we can only speculate about who invented the oxhide ingot shape.

Acknowledgments

The work in the Isotrace Laboratory, Oxford, was made possible thanks to the support of the UK Research Councils, Leverhulme Trust, British Academy, and grants from the Institute for Aegean Prehistory (INSTAP). Generous help came from the geologists of the Greek Institute of Geological and Mineral Exploration (IGME), Hellenic Mining, Ltd. (Cyprus), Agip, Ltd. (Italy), and numerous archaeologists.

References

Begemann, F., S. Schmitt-Strecker, E. Pernicka, and F. Lo Schiavo. 2001. "Chemical Composition and Lead Isotopy of Copper and Bronze from Nuragic Sardinia," *EJA* 4, pp. 43–85.

Boni, M., and V. Koeppel. 1985. "Ore-lead Isotope Pattern from the Iglesiente-Sulcis Area (SW Sardinia) and the Problem of Remobilization of Metals," *Mineralium Deposita* 20, pp. 185–193.

Chernykh, E.N. 1992. *Ancient Metallurgy in the USSR: The Early Metal Age*, Cambridge.

Gale, N.H. 1991. "Copper Oxhide Ingots: Their Origin and Their Place in the Bronze Age Metals Trade in the Mediterranean," in *Bronze Age Trade in the Mediterranean* (*SIMA* 90), N.H. Gale, ed., Jonsered, pp. 197–239.

Gale, N.H., and Z.A. Stos-Gale. 1986. "Oxhide Ingots in Crete and Cyprus and the Bronze Age Metals Trade," *BSA* 81, pp. 81–100.

———. 2005. "Zur Herkunft der Kupferbarren aus dem Schiffswrack von Uluburun und der spätbronzezeitliche Metallhandel im Mittelmeerraum," in *Das Schiff von Uluburun—Welthandel vor 3000 Jahren*, Ü. Yalçın, C. Pulak, and R. Slota, eds., Bochum, pp. 117–132

Gale, N.H, Z.A. Stos-Gale, G. Maliotis, and N. Annetts. 1997. "Lead Isotope Data from the Isotrace Laboratory, Oxford: Archaeometry Data Base 4, Ores from Cyprus," *Archaeometry* 39 (1), pp. 237–246.

Hauptmann, A., F. Begemann, R. Heitkemper, E. Pernicka, and S. Schmitt-Strecker. 1992. "Early Copper Produced in Feinan, Wadi Araba, Jordan: The Composition of Ores and Copper," *Archeomaterials* 6 (1), pp. 1–33.

Kuhrt, A. 2000. *The Ancient Near East—c. 3000–330 B.C.* (*Routledge History of the Ancient World*, 2 vols.*)*, London and New York.

Moorey, P.R.S. 2001. "The Mobility of Artisans and Opportunities for Technology Transfer between Western Asia and Egypt in the Late Bronze Age," in *The Social Context of Technological Change*, A. Shortland, ed., Oxford. pp. 1–14.

Muhly, J.D. 1977. "New Evidence for Sources and Trade in Bronze Age Tin," in *The Search for Ancient Tin*, A.D. Franklin, J.S. Olin, and T.A. Wertime, eds., Washington D.C., pp. 43–48.

Pulak, C. 2000. "The Copper and Tin Ingots from the Late Bronze Age Shipwreck at Uluburun," in *Anatolien Metal* I (*Der Anshnitt Beiheft* 13), Ü. Yalçın, ed., Bochum, pp. 137–157.

Soles, J.S., and Z.A. Stos-Gale. 2004. "The Metal Finds and Their Geological Sources," in *Mochlos* IC: *Period III. Neopalatial Settlement on the Coast: The Artisans' Quarter and the Farmhouse at Chalinomouri. The Small Finds* (*Prehistory Monographs* 9), Philadelphia, pp. 45–59.

Stos, Z.A. 2009. "Across the Wine-Dark Seas . . . Sailor Tinkers and Royal Cargoes in the Late Bronze Age Eastern Mediterranean," in *From Mine to Microscope: Advances in the Study of Ancient Technology*, A.J. Shortland, I.C. Freestone, and T. Rehren, eds., Oxford, pp. 163–180.

Stos, Z., and N.H. Gale. 2006. "Lead Isotope and Chemical Analyses of Slags from Chrysokamino," in *The Chrysokamino Metallurgy Workshop and Its Territory* (*Hesperia Suppl.* 36), by P.P. Betancourt, Princeton, pp. 298–319.

Stos-Gale, Z.A. 2001. "Minoan Foreign Relations and Copper Metallurgy in MM III–LM III Crete," in *The Social Context of Technological Change*, A. Shortland, ed., Oxford. pp. 195–210.

Stos-Gale, Z.A., N.H. Gale, G. Bass, C. Pulak, E. Galili, and J. Sharvit. 1998. "The Copper and Tin Ingots of the Late Bronze Age Mediterranean: New Scientific Evidence," in *Proceedings of the Fourth International Conference on the Beginning of the Use of Metals and Alloys (BUMA-IV): May 25–27, 1998*, H. Kimura, ed., Matsue, Shimane, Japan, pp. 115–126.

Stos-Gale, Z.A., N.H. Gale, and G.R. Gilmore. 1984. "Early Bronze Age Trojan Metal Sources and Anatolians in the Cyclades," *OJA* 3 (3), pp. 23–44.

Stos-Gale, Z.A., N.H. Gale, J. Houghton, and R. Speakman. 1995. "LI Analyses of Ores from the Western Mediterranean," *Archaeometry* 37 (2), pp. 407–415.

Stos-Gale, Z.A., G. Maliotis, and N.H. Gale. 1998. "A Preliminary Survey of the Cypriot Slag Heaps and Their Contribution to the Reconstruction of Copper Production on Cyprus," in *Metallurgica Antiqua, in Honour of Hans-Gert Bachmann and Robert Maddin*, T. Rehren, A. Hauptmann, and J. Muhly, eds., Bochum, pp. 235–262.

Stos-Gale, Z.A., G. Maliotis, N.H. Gale, and N. Annetts. 1997. "LI Characteristics of the Cyprus Copper Ore Deposits Applied to Provenance Studies of Copper Oxhide Ingots," *Archaeometry* 39 (1), pp. 83–124.

Wachsmann, S. 1987. *Aegeans in the Theban Tombs* (*Orientalia Lovaniensa Analecta* 20), Leuven.

Wagner, G.A., and Ö. Öztunali. 2000. "Prehistoric Copper Sources in Turkey," in *Anatolian Metal* I (*Der Anschnitt Beiheft* 13), Ü. Yalçın, ed., Bochum, pp. 31–68.

Yener, K.A, E.V. Sayre, H. Ozbal, E.C. Joel, I.L. Barnes, and R.H. Brill. 1991. "Stable LI Studies of Central Taurus Ore Sources and Related Artefacts from Eastern Mediterranean Chalcolithic and Bronze Age Sites," *JAS* 18 (5), pp. 541–577.