Sources of Tin and the Beginnings of Bronze Metallurgy*

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Abstract

Recent discoveries of Bronze Age tin ingots and tin artifacts, together with new geological evidence on tin deposits in Europe, the Mediterranean and Western Asia, provide the opportunity to survey the evidence for possible sources of tin and the first use of bronze in the eastern Mediterranean and in Western Asia. Afghanistan now emerges as the most promising eastern source of tin, with western sources most likely located in southern England and Brittany. Central European tin sources still provide serious problems within the context of the nature of Bronze Age mining technology and the type of cassiterite being utilized at that time.

During the past ten years there has been an enormous increase in the degree of interest and the quantity of publication on all aspects of ancient metallurgy.[1] The field has acquired a new name, archaeometallurgy, used by at least one Institute for Archaeo-Metallurgical Studies, with several other programs devoted to research in the field.[2] The discipline now has its own journal,[3] a sure sign of status in the research climate of today. It is obvious that our understanding of many basic aspects of the field has been transformed and also—an inevitable corollary—that there are at present no up-to-date surveys or works of synthesis.[4]

Many basic problems remain and, in certain areas, we have yet to see a major breakthrough or significant change in traditional confusion. Foremost in the latter category must be the problem of ancient sources of tin. It is remarkable that, after twenty years of intensive scholarly investigation and fieldwork, we still have no hard evidence regarding the sources of tin being exploited by the numerous and widespread bronze industries of antiquity.[5]

The main sources of tin exploited by the industrialized countries of the world since at least the sixteenth century are located either on the fringes of the ancient world—in southern England (Cornwall and Devon) and in Burma, Thailand and Malaysia—or in places such as Bolivia, Kazakhstan and China that were far beyond the reaches of a world centered on the Mediterranean.[6] What contact there was with countries such as China was only of a most exotic nature and virtually non-existent in any form prior to the time of the Roman Empire (ill. 1).[7]

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[1] The interval is, with no little arrogance and, I hope, some small justification, based upon the publication, in 1973, of my book on *Copper and Tin. The Distribution of Mineral Resources and the Nature of the Metals Trade in the Bronze Age* (Transactions of the Connecticut Academy of Arts and Sciences 43; Hamden, Conn. 1973, issued in 2nd ed., with Supplement, in 1976).

[2] The Institute for Archaeo-Metallurgical Studies (IAMS) is at the University of London. At the University of Pennsylvania we have established the Program for Ancient Metallurgy, while another program on archaeometallurgy is part of MASCA at the University Museum. For the various groups now conducting research in the field, see the special series of articles in T. Berthoud et al., "Production, échange et utilisation des métaux: bilan et perspectives des recherches archéologiques récentes dans le domaine oriental," *Paléorient* 6 (1980) 99–127.

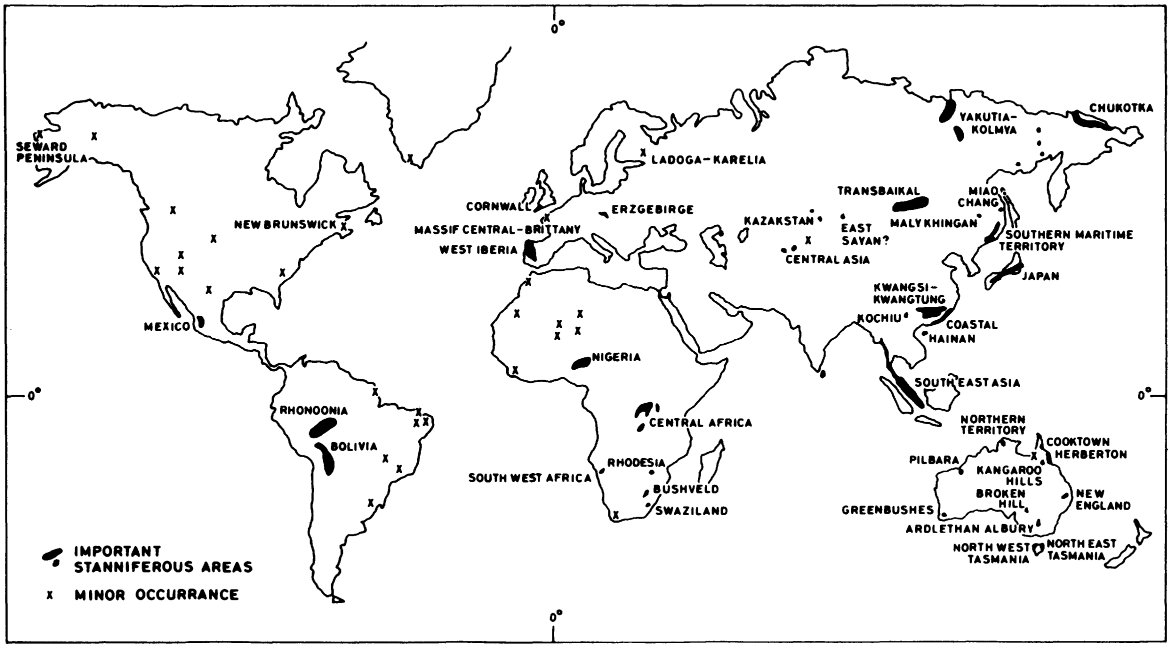
[3] What began in 1963 as the *Bulletin of the Historical Metallurgy Group* became, in 1974, *Historical Metallurgy*, the *Journal of the Historical Metallurgy Society* (abbreviated *JHMS*). The publication history is slightly complicated in that early issues of the *Bulletin* were rather informal, with volume numbers only beginning in 1967 (so that vol. 1 of the *Bulletin* is also no. 9).

[4] R.F. Tylecote published, in 1976, a brief *A History of Metallurgy* (Metals Society, London), covering the use of all metals, precious and base, down to modern times. The volume edited by T.A. Wertime and J.D. Muhly, *The Coming of the Age of Iron* (New Haven 1980), does, as the title indicates, deal mainly with iron but also provides a historical background to the beginnings of the Iron Age.

[5] For background, see J.D. Muhly, "Tin Trade Routes of the Bronze Age," *American Scientist* 61 (1973) 404–13; also "New Evidence for Sources of and Trade in Bronze Age Tin," in A.D. Franklin, J.S. Olin and T.A. Wertime eds., *The Search for Ancient Tin* (Washington, D.C., 1978) 43–48; R. Maddin, T.S. Wheeler and J.D. Muhly, "Tin in the Ancient Near East: Old Questions and New Finds," *Expedition* 19.2 (1977) 35–47.

[6] For world tin resources, see World Mineral Statistics (Institute of Geological Sciences, London 1979). Total world production in 1976 was 197,000 tons. Of this Malaysia, Thailand and Indonesia produced 107,271, China, 20,000 and Bolivia, 30,355. This accounts for 80% of the world total. See also P.J.H. Rich, "Future of Tin as a Tonnage Commodity," *Transactions, Institution of Mining and Metallurgy* 89A (1980) 8–17 (with correction on p. 106 and discussion on pp. 157–64). Rich estimates that, between 1851 and 1976, Malaysia produced 4,817,500 tons of tin.

[7] The discovery of Chinese silk in an early 6th c. B.C. grave near the Heuneburg fort in South Germany is hardly sufficient evidence



Ill. 1. Stanniferous areas of the world. (From R.G. Taylor, *Geology of Tin Deposits* [Amsterdam 1979] 6, fig. 2.1)

The tin resources of the Mediterranean world, as known from modern geological survey, are insignificant in terms of modern economic geology.[8] Whether or not they were of any importance in antiquity is one of the main topics discussed here. It is important to keep in mind that, writing in the mid-fifth century B.C., Herodotus summed up his investigations into this problem by stating that:

> Of the extreme tracts of Europe towards the west I cannot speak with any certainty; for I do not allow that there is any river to which the barbarians give the name of Eridanus, emptying itself into the northern sea, whence (as the tale goes) amber is procured; nor do I know of any islands called the Tin Islands, whence the tin comes which we use. For in the first place the name Eridanus is manifestly not a barbarian word at all, but a Greek name, invented by some poet or other; and secondly, though I have taken great pains, I have never been able to get an eye-witness that there is any sea on the further side of Europe. Nevertheless, tin and amber do certainly come to us from the ends of the earth. (Hdt. 3.115, translation by G. Rawlinson.)

This passage, one of the most famous for the study of ancient geography,[9] clearly shows that Herodotus, who seems to have devoted some effort to working out the problem, was unable to learn anything regarding the sources of tin being consumed in Periclean Athens. The best he could come up with were vague stories regarding the mysterious Tin Islands (Kassiterides), about whose very existence Herodotus obviously had his doubts.[10] The only certainty in the matter was the relationship between tin and amber, both said to come from the "ends of the earth" (ἐξ ἐσχάτης). The significance of this connection is discussed below.

We are dealing here with a period of history—the fifth century B.C.—about which we know a great deal, far more than ever will be known about the Bronze Age world. Periclean Athens was importing large amounts of tin. The inscriptions relating to the casting of the Athena Promachos list single purchases of tin as large as 150 talents or almost 4,000 kg. We also learn from these texts that a talent of tin sold for

for real trade between China and Celtic Europe. Cf. S. Piggott, *Ancient Europe* (Chicago 1965) 195–96. For the later period see J.-M. Poinsotte, "Les Romains et la Chine: réalités et mythes," *MélRome* 91 (1979) 431–79.

[8] The works cited supra n. 6 do not even list Mediterranean sources.

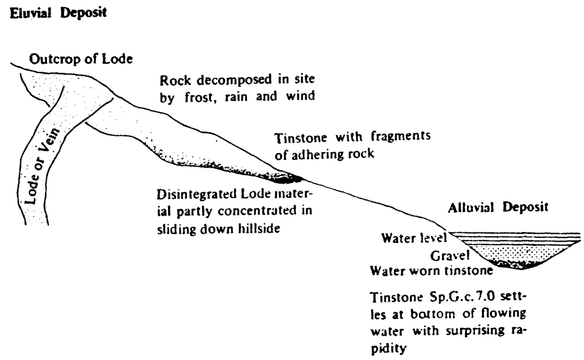
[9] See the discussions in M. Cary and E.H. Warmington, *The Ancient Explorers*[2] (Harmondsworth 1963) 36; R. Carpenter, *Beyond the Pillars of Heracles* (New York 1966).

[10] The Tin Islands (Kassiterides) have long been the subject of much discussion and speculation, with little in the way of convincing conclusions. The identification with the Isles of Scilly, off the coast of Cornwall, goes back at least to the *Britannia* of William Camden, published in 1586. For modern research see R. Dion, "Le problème des Cassiterides," *Latomus* 11 (1952) 306–14; J. Ramin, *Le problème des Cassiterides et les sources de l'étain occidental depuis les temps protohistoriques jusqu'au début de notre ère* (Paris 1965).

233 drachmas while the price of copper was just over 35 drachmas per talent.[11] These values would give a tin:copper ratio of 1:6.6.

We have, then, considerable evidence regarding trade in, price and use of tin in Classical Athens, but little evidence regarding the actual source of that tin. If Herodotus failed to get beyond the tall stories told by sailors, stories told perhaps more to confuse and to obfuscate than to instruct, we have little chance of doing better for the Bronze Age world. It is always hazardous to make predictions regarding what will or will not be uncovered in Bronze Age excavations, but it is nonetheless unlikely that we shall ever have exact knowledge about the sources of the tin being used to supply Minoan Crete or Mycenaean Greece. I believe that we have a better chance of learning more about sources in the ancient Near East thanks to the more abundant textual evidence for daily administrative and economic affairs, as well as to several recent geological discoveries.

It is necessary first to know something regarding the geological formation of tin and the environment in which tin is likely to appear (ill. 2).[12] While technical problems relating to tin mineralization are currently being widely discussed in geological literature, especially the debate on magmatic differentiation versus geochemical heritage,[13] these disputes are of little interest to the archaeologist interested in reconstructing what was going on in the Bronze Age. Of greater relevance is the revival of the concept of metallogenic provinces and the formation of metallic belts—copper belts, lead-zinc belts and tin-tungsten belts—extending over wide areas, as part of on-going research on plate tectonics and theories of continental drift.[14] What this means for the archaeologist is that mineral deposition is unlikely to have taken place in random,



Ill. 2. Diagram showing the formation of alluvial tin deposits. (From J.B. Richardson, *Metal Mining* [London 1974] 60, fig. 7)

isolated deposits and that theories positing the existence of such deposits are to be regarded with great skepticism.[15]

Most important of all is the absolute geological principle that tin is to be found only in association with granite rock. The concentration of tin varies within any single granite formation and among different formations, depending upon local conditions and geological heritage, but without granite there is no possibility of tin ever having been present.[16] Therefore, large areas of the world are automatically ruled out as possible sources of tin. The island of Cyprus is one of these areas; since there is no granite there, it never could have contained deposits of tin.[17]

The Troad presents an entirely different sort of problem, because it has a perfect geological environment for the formation of tin. Everything is there except for the tin. While the area of the Troad is often cited in archaeological literature as being a possible

[11] A.E. Raubitschek, "Greek Inscriptions: Note on the Epistatai of the Athena Promachos Statue," *Hesperia* 12 (1943) 12–17. The latest edition of the text is *SEG* X (1949) no. 243.

[12] For the basic geology of tin, see F. Ahlfeld, *Zinn und Wolfram* (Die metallischen Rohstoffe 11, Stuttgart 1958); R.G. Taylor, *Geology of Tin Deposits* (Amsterdam 1979). The classic article has, for many years, been that by H.G. Ferguson and A.M. Bateman, "Geologic Features of Tin Deposits," *Economic Geology* 7 (1912) 209–62.

[13] B. Lehmann, "Metallogeny of Tin: Magmatic Differentiation versus Geochemical Heritage," *Economic Geology* 77 (1982) 50–59; P.J. Pollard, R.G. Taylor and C. Cuff, "Metallogeny of Tin: Magmatic Differentiation versus Geochemical Heritage—A Discussion," *Economic Geology* 78 (1983) 543–45. There is also much discussion regarding tin in vol. 6 of the series of papers on *Metallization Associated with Acid Magmatism*, A.M. Evans ed. (New York 1982).

[14] The older work on tin belts (cf. R.D. Schuiling, "Tin Belts on the Continents Around the Atlantic Ocean," *Economic Geology* 62 [1967] 540–50) was quite superficial and received considerable criticism. For modern research, see P. Routhier, *Les gisements métallifères. Géologie et principes de recherche* (2 vols., Paris 1963); also, *Où sont les métaux pour l'avenir? Les provinces métalliques. Essai de métallogénie globale* (Bureau de Recherches Géologiques et Minières 105; Paris 1980).

[15] The alleged tin deposit near Kirrha, in Greece, would be a good example of an isolated tin deposit. See S. Benton, "No Tin from Kirrha in Phokis," *Antiquity* 38 (1964) 138.

[16] In addition to the works cited supra n. 12, see W.R. Hesp, "Correlations between the Tin Content of Granite Rocks and their Chemical and Mineralogical Composition," in *Third International Exploration Symposium* (Toronto 1970) 341–53; D.I. Groves and T.S. McCarthy, "Fractional Crystallization and the Origin of Tin Deposits in Granitoids," *Mineralium Deposita* 13 (1978) 11–26.

[17] An examination of the basic geological map of Cyprus, issued by the Geological Survey of Cyprus (last revised in 1980), will demonstrate that Cyprus has no deposits of granite rock.

source of Bronze Age tin, the fact remains that, despite intensive geological survey, not one grain of tin-bearing material has ever been found in the area.[18] Obviously not all granites contain tin and geologists have worked on ways of making a rough, in-the-field distinction between tin-bearing and tin-barren granites in order to facilitate survey work.[19]

Tin is commonly present in association with pegmatites of quartz and feldspar. Like gold, the tin is found within veins of quartz running through the granite rock. The difference is that while gold occurs as a native metal, tin appears in the form of an oxide (SnO_2) known as cassiterite. This cassiterite, again like gold, was frequently exposed and freed from its host through weathering and degradation of the quartz and granite. This degradation was often the result of action by water, the cassiterite (and gold) thus taking the form of small lumps or nuggets present in the stream bed. Although carried along by the force of the current, the cassiterite (and gold), having a high specific gravity because of its density, tends to sink and concentrate in the bed of the stream. In general, concentration increases with proximity to the original deposit of the tin. This process is shown in schematic form in ill. 2.[20]

This stream or alluvial tin was thus to be found in the form of small black nuggets of cassiterite known as tin-stone. Recovery involved the panning of the gravel in the stream bed, separating out the cassiterite from the worthless sand and gravel. The process was similar to that which must have also been used to recover gold, and what was done in antiquity was probably not that different from the techniques—and even the equipment—used by the Forty-Niners in the great Gold Rush in California and Alaska during the mid-nineteenth century.[21]

While gold was recovered as a native metal, the tin was to be found in the form of an oxide that had to be smelted together with charcoal in order to free the oxygen and reduce the oxide to metallic tin. Although metallic tin could only be produced in this way, the on-the-ground evidence for tin smelting in a Bronze Age context is exceedingly rare. I know of only one recorded instance, from the vicinity of the great tin deposits at St. Austell in Cornwall.[22]

The lack of such evidence, combined with the more surprising absence of ingots or artifacts of metallic tin surviving from the Bronze Age, has led some to conclude that, during that period, there was little or no use of metallic tin. This theory would have it that bronze was produced by the direct addition of cassiterite to molten copper, the process being carried out under charcoal in order to maintain the reducing conditions necessary to produce the molten tin which then combined directly with the copper inside the crucible.[23]

While theoretically possible, such a process is difficult to control in actuality. The mixing of the tin with the copper would have been erratic and difficult to regulate so that it would have been almost impossible to maintain a good control over the copper:tin ratio. A product with an uncertain composition could not have been a motivating factor in the shift from arsenic to tin as an alloying element with copper. Although there is still some uncertainty over exact details, it is now generally agreed that arsenical copper was produced by the direct smelting of an arsenical copper ore.[24] The arsenic came down into the molten copper because it was present in the ore body, not because it had been added as a separate alloying element. It was thus impossible to control the amount of arsenic present in the copper. Published analyses of arsenical copper artifacts covering the years 4000–2000 B.C. show that arsenic content varied widely, supporting the theory that arsenical copper is a natural alloy.[25]

[18] Tin deposits in northwestern Anatolia, especially in the vicinity of Eskişehir, still appear in mineral resource maps published by archaeologists (cf. J. Yakar, "Hittite Involvement in Western Anatolia," *AnatSt* 26 [1976] 117–28). There is no geological evidence for such deposits but, despite the lack of evidence, some scholars (e.g., P. de Jesus, "Metal Resources in Ancient Anatolia," *AnatSt* 28 [1978] 101; also, *The Development of Prehistoric Mining and Metallurgy in Anatolia* [BAR International Series 74, Oxford 1980] 55–56) still believe they must once have existed.

[19] R.J. Goodman, "Rapid Analysis of Trace Amounts of Tin in Stream Sediments, Soils and Rocks by X-ray Fluorescence Analysis," *Economic Geology* 68 (1973) 275–78; A.N. Yeates, B.W. Wyatt and D.H. Tucker, "Application of Gamma-ray Spectrometry to Prospecting for Tin and Tungsten Granites, Particularly within the Lachlan Fold Belt, New South Wales," *Economic Geology* 77 (1982) 1725–38.

[20] The diagram given here as ill. 2 is taken from J.B. Richardson, *Metal Mining* (Industrial Archaeology Series, London 1974) 60, fig. 7.

[21] For a pictorial record of Gold Rush California, see R.W. Paul, *California Gold: the Beginning of Mining in the Far West* (Lincoln, Nebraska 1965); M.M. Quaife ed., *Pictures of Gold Rush California* (Chicago 1949).

[22] R.F. Tylecote, "Analysis of Slag Fragments," in H. Miles, "Barrows on the St. Austell Granite, Cornwall," *Cornish Archaeology* 14 (1975) 35–38.

[23] This hypothesis has been discussed on several occasions by J.A. Charles, most recently in "The Coming of Copper and Copper-Base Alloys and Iron: A Metallurgical Sequence," in Wertime and Muhly eds. (supra n. 4) 172–76.

[24] See discussion in J.D. Muhly, "The Bronze Age Setting," in Wertime and Muhly eds. (supra n. 4) 28; also E. Schubert, "Zur Frage der Arsenlegierung in der Kupfer- und Frühbronzezeit Südosteuropas," in *Studien zur Bronzezeit. Festschrift für Wilhelm Albert von Brunn* (Mainz 1981) 447–60.

[25] At Nahal Mishmar, for example, amounts of arsenic ranged

The direct addition of molten tin to molten copper made possible a control over the alloy produced that could never be achieved in working with arsenic. Again, published analyses demonstrate that, once an area had entered the true Bronze Age phase, its metalsmiths were capable of producing a standard 10% tin bronze with astonishing regularity.[26]

The implications are that arsenic was never used as a separate material in the Bronze Age, whereas tin served as one of the basic metals in everyday use, a supposition also borne out by the surviving archaeological evidence. There are no recorded finds of pure arsenic in any archaeological context. Finds of metallic tin, on the other hand, while not numerous, are steadily increasing, with new discoveries being made almost every year as more and more scholars become aware of the possibility of such finds. Artifacts of tin are known from Egypt[27] and from Europe[28] and, now, from the Near East as well.[29] More numerous are the ingots of tin, attested in England and the western Mediterranean.[30] Rings of tin with about 4.0% lead, identified as ingots, are known from Scandinavia.[31]

Metallic tin was also used to cover the outer surface of clay vases, apparently to give the vase a silvery appearance. This practice is known from the Bronze Age Aegean,[32] especially ca. 1400 B.C., from Iron Age Cyprus,[33] Iron Age Italy[34] and even from La Tène Europe.[35] Exactly how the tin was applied is not known,[36] but it is most likely that the clay vessel was dipped in a vat of molten tin. In the Aegean, tin was used as a lining inside the famous Griffin Pyxis from a Mycenaean chamber tomb in the Athenian Agora.[37] There the tin must have been added as a thin sheet or foil designed to protect the ivory from the ointments placed inside the pyxis. This striking difference in the evidence for arsenic and tin reflects the basic difference in the two alloying technologies.

A far more controversial issue regards possible words for arsenic and tin in surviving texts from the Bronze Age. I have long maintained that there is no word for arsenic in any known Bronze Age text and that this is in keeping with the lack of evidence for the use of arsenic as a separate metal.[38] Words for tin, on the other hand, are known in Sumerian, Akkadian, Hittite, Egyptian and Ugaritic, although not in Mycenaean Greek.[39] The long confusion in the world of Assyriology regarding tin or lead as the proper meaning of Sumerian AN·NA, Akkadian *annaku*, was more a comedy of errors than a serious problem in lexicography. The words mean tin and all Assyriologists are in agreement on this point.[40]

It has been proposed that AN·NA, *annaku* desig-

from 1.90% to 11.90%. See C.A. Key in P. Bar-Adon, *The Cave of the Treasure. The Finds from the Caves in Nahal Mishmar* (Judean Desert Studies, Jerusalem 1980) 238–43.

[26] This consistency can best be seen in the Early Bronze Age analyses from Ireland, published in *Studien zu den Anfängen der Metallurgie* 2.4 (Berlin 1974) nos. 16601–17601.

[27] Maddin, Wheeler and Muhly (supra n. 5) 42–44.

[28] Muhly (supra n. 1) 249.

[29] The Belgian excavations at the Mesopotamian site of Tell ed-Dēr have identified several objects of metallic tin. See the report by K. Van Lerberghe, "Contribution à l'étude des métaux de Tell ed-Dēr," forthcoming in a final report on the excavations at this site. (I thank Dr. Lerberghe for sending me an advance copy of his text and for giving me the opportunity to discuss with him these most important finds.)

[30] On tin ingots, see R.F. Tylecote, "Early Tin Ingots and Tinstone from Western Europe and the Mediterranean," in Franklin, Olin and Wertime eds. (supra n. 5) 49–52; Maddin, Wheeler and Muhly (supra n. 5) 44–46.

[31] A. Oldeberg, *Metallteknik under Förhistorisk tid* 1 (Lund 1942–1943) 67–68 and figs. 60–61.

[32] The basic study is by S.A. Immerwahr, "The Use of Tin on Mycenaean Vases," *Hesperia* 35 (1966) 381–96. See also M. Pantelidou, "LH III A1 Vases Covered with Tin Foil," *AAA* 4 (1971) 433–38 (in Greek with English summary).

[33] V. Karageorghis, *Excavations in the Necropolis of Salamis* 3 (Salamis 5, Nicosia 1973–74) 115–16.

[34] A. Andrén, "An Italic Iron Age Hut Urn," *Bulletin of the Museum of Mediterranean and Near Eastern Antiquities* 4 (1964) 30–37; G. Bartoloni and F. Delpino, "Un tipo di orciolo a lamelle metalliche," *StEtr* 43 (1975) 3–45.

[35] L. Süss, "Schwarze Schüsseln mit Zinnapplikationen aus Bad Nauheim," *Marburger Beiträge zur Archäologie der Kelten: Festschrift W. Dehn* (Fundberichte aus Hessen, Beiheft 1, Bonn 1969) 288–327; also "Neue zinnapplizierte Latènekeramik aus Bad Nauheim," in *Festschrift W. Jorns* (Fundberichte aus Hessen 14, 1974) 361–80.

[36] Cf. S. Marinatos, "New Advances in the Field of Ancient Pottery Technique," *AAA* 5 (1972) 296, who discussed what is a most unlikely theory as to how it was done. The theory of an organic binder is advocated by K. Holmberg, "Application of Tin to Ancient Pottery," *Journal of Archaeological Science* 10 (1983) 383–84, and is based upon research conducted by W. Noll, R. Holm and L. Born, "Mineralogie und Technik zinnapplizierter antiker Keramik," *Neues Jahrbuch für Mineralogie*, Abhandlung 139 (1980) 26–42.

[37] S.A. Immerwahr, *The Neolithic and Bronze Ages* (The Athenian Agora 12; Princeton 1971) 158–66.

[38] Muhly (supra n. 1) 105 (of Supplement).

[39] Muhly (supra n. 1). The Ugaritic word for tin is most likely *brr* (C. Zaccagnini "Note sulla terminologia metallurgica di Ugarit," *Oriens Antiquus* 9 [1970] 317–22).

[40] Muhly (supra n. 1) 243–44. Also J.D. Muhly and T.A. Wertime, "Evidence for the Sources and Use of Tin during the Bronze Age of the Near East: a Reply to J.E. Dayton," *World Archaeology* 5 (1973) 111–22, esp. p. 116. The most important study is by B. Landsberger, "Tin and Lead: the Adventures of Two Vocables," *JNES* 24 (1965) 285–96. This is not the place to discuss the interesting text studied by H. Freydank, "Fernhandel und Warenpreise nach einer mittelassyrischen Urkunde des 12. Jahrhunderts v.u.Z.," in *Societies and Languages of the Ancient Near East: Festschrift I.M. Diakonoff* (Warminster 1982) 64–75, which seems to give (in lines 14′–15′) Akkadian *abāru*, "lead," as a gloss for Sumerian AN·NA, with "tin" designated as AN·NA BABBAR. Other interpretations of this enigmatic text are possible.

nated not tin but an arsenic-rich master alloy used in the production of arsenical copper.[41] AN·NA, *annaku* would then more likely be a designation for arsenic than for tin. This hypothesis has attracted much attention and it obviously has profound implications for the study of the Bronze Age textual evidence relating to uses of and trade in tin. Everything based upon such evidence is predicated upon the assumption that AN·NA, *annaku* are to be translated as "tin."

It is not necessary, however, to undertake a complete lexicographical/philological defense of the accepted translation because the challenge to this translation has nothing to do with philological considerations. It is based entirely upon a misconceived correlation between textual and analytical evidence. McKerrell assumed that, since analyses indicated the use of arsenical copper at Old Assyrian Kültepe, whereas the Old Assyrian texts dealt with *annakum* as the only metal being imported into Anatolia, this meant that *annakum* must refer to arsenic, not tin.[42]

But tin bronze was also in use at Old Assyrian Kültepe[43] and tin was what was lacking in Anatolia, not arsenic. Local arsenic-bearing copper ores had been smelted by local Anatolian metal workers to produce arsenical copper since at least the fourth millennium B.C. Arsenical copper was in use as early as the Late Chalcolithic period, as shown by the analyses of pieces from the hoard found in level XXXIV at Beycesultan.[44] It continued to be used in EB I objects from that site.[45] From level VIa at Arslantepe-Malatya, securely dated to the late fourth millennium B.C., comes a hoard of swords and spearheads made of arsenical copper.[46] Clearly the production of an arsenical alloy was a local Anatolian development not involving materials imported from abroad. As the Old Assyrian texts dealt with materials brought by the Assyrian merchants into Anatolia, they mention tin, the crucial material not available in Anatolia itself. It is unfortunate that McKerrell's misunderstanding of the nature of affairs at Kültepe has prompted non-Assyriologists to question once again the translation of AN·NA, *annaku*, as tin.[47]

The very fact that the lack of usage of metallic tin during the Bronze Age could be presented and discussed as a serious possibility indicates just how little we know about Bronze Age metallurgical technology, the role of tin in that technology and the production of bronze. Egyptian New Kingdom tomb paintings, especially one in the Tomb of the Two Sculptors at Thebes,[48] show metal-working scenes depicting ingots above a furnace that must have been used to melt those ingots. One ingot painted in reddish-brown is of the traditional ox-hide shape. The other, a rectangular bar, is bluish gray in color. The distinctions by shape and by color are certainly designed to show that two different metals were involved. One was copper, the other tin.

This evidence is in agreement with that from those Mesopotamian texts which describe the addition of AN·NA/*annaku* to URUDU/*erû* in order to produce ZABAR/*siparru* or, in other words, of tin to copper in order to make bronze.[49] On rare occasions these texts state the amounts of tin and copper used to produce a specified amount of bronze. That bronze can even be designated for the production of a stated number of objects of specified weight.

Such a text is now known from Palace G at Ebla (TM.75.G.1310) where it is stated that 3 minas, 20 shekels of tin were added to 30 minas of copper in order to make 200 "sticks" (giš gu-kak-gíd) of bronze weighing 10 shekels each[50] —a production of 2,000 shekels of bronze with a tin:copper ratio of 1:9 or, in

[41] E.R. Eaton and H. McKerrell, "Near Eastern Alloying and some Textual Evidence for the Early Use of Arsenical Copper," *World Archaeology* 8 (1976) 169–91; H. McKerrell, "Non-dispersive XRF Applied to Ancient Metalworking in Copper and Tin Bronze," *PACT, Journal of the European Study Group on Physical, Chemical and Mathematical Techniques Applied to Archaeology* 1 (1977) 138–73; also, "The Use of Tin-Bronze in Britain and the Relationship with the Near East," in Franklin, Olin and Wertime eds. (supra n. 5) 7–24.

[42] McKerrell, *PACT* (supra n. 41) 169–71.

[43] As indicated by the analyses made in Stuttgart published in U. Esin, *Kuantitatif spektral analiz yardımıyla Anadolu'da başlangıcından Asur kolonileri cağına kadar bakır ve tunç madenciliği* 1 (Istanbul 1969) 138–41, nos. 6788–833, 17637–737.

[44] Publication by D. Stronach, "Metal Objects," in J. Mellaart and S. Lloyd, *Beycesultan* 1 (London 1962) 280–83 (fig. 7.8., and pl. 34). The Stuttgart analyses (hereafter designated JSS analyses) are nos. 11774–81, published by Esin (supra n. 43) 129. According to P.S. de Jesus, "A Survey of Some Ancient Mines and Smelting Sites in Turkey," *Archäologie und Naturwissenschaften* 2 (1981) 103–104, the metalwork of Beycesultan was characteristically arsenical copper in levels XXXIV–VI, with tin-bronze first appearing only in level X (JSS no. 11739).

[45] De Jesus (supra n. 18) 129. For arsenical copper at EB III Ikiztepe, on the southern shore of the Black Sea between Sinope and Samsun, see H. Özbal, "Ikiztepe Kazıları Metal Buldu Analizleri," in *Tübitak Arkeometri Unitesi Bilimsel Toplantı Bildirileri* 2 (Istanbul 1981) 101–12.

[46] A. Palmieri, "Excavations at Arslantepe (Malatya)," *AnatSt* 31 (1981) 104–10. Illustrations of six of these objects appear in Vol. I of the Catalogue of the 18th Council of Europe Exhibition in Istanbul (*Anadolu Medeniyetleri 1. Tarih Öncesi/Hitit/Ilk Demir Çağı* [Istanbul 1983] nos. 167–72).

[47] An example of the confusion already created is to be found in the review by R. McC. Adams (*JNES* 37 [1978] 265–69) of the book by M.T. Larsen, *The Old Assyrian City-State and its Colonies* (Copenhagen 1976).

[48] G.A. Wainwright, "Egyptian Bronze-Making," *Antiquity* 17 (1943) 96–98.

[49] Muhly and Wertime (supra n. 40) passim.

[50] A. Archi, "Notes on Eblaite Geography," *Studi Eblaiti* 4 (1981) 5.

other words, a classic 10% tin bronze. Other texts from Ebla give similar information, although there is often some discrepancy in the figures. According to TM.75.G.1860, 40 shekels of tin were added to 5 minas, 30 shekels of copper in order to make 15 small axes, each 20 shekels in weight.[51] This gives a tin:copper ratio of 1:8.25, but involves the use of 370 shekels of metal to produce axes having a total weight of 300 shekels. Pettinato states that this difference "evidently took into account the loss of metal during the process of smelting [sic, for melting] and subsequent manufacture,"[52] which is unlikely.

The purpose in presenting such evidence is not to discuss the problems connected with the Ebla texts or with Sumerian references to tin and the production of bronze, but rather to show that such references exist already in texts from the E.D. III period in Mesopotamia. Whatever the exact date of the archive L.2769 from Palace G at Ebla,[53] these texts cannot be far removed from the time of the Royal Cemetery at Ur and the first analytical evidence for the use of tin bronze in Mesopotamia.[54] Apart from the, apparently, isolated example of a pin from stratum VIII at Tepe Gawra (ca. 3000 B.C.) having 5.62% tin,[55] the first real use of tin bronze in Mesopotamia comes at the time of the Royal Cemetery of Ur, dated to E.D. IIIa or roughly the twenty-sixth century B.C. To the analytical evidence so far published can now be added the unpublished data recently developed as part of the Mesopotamian Metals Project at the University of Pennsylvania.[56]

Tin appears in the Royal Cemetery, as at Ebla, together with gold and lapis lazuli. All three materials are to be found in Afghanistan[57] and it is quite possible that they did all come to Mesopotamia (and to northern Syria) via an overland route across Iran. The discovery of major tin deposits in Afghanistan is one of the most exciting recent developments regarding sources of Bronze Age tin.[58] There is, as yet, no hard evidence that Sumerian tin came from Afghanistan, but such a source has long been suggested on the basis of textual and archaeological evidence—a suggestion that up to now could only be regarded as but an interesting hypothesis because of the lack of geological evidence for the existence of tin deposits in Afghanistan.

Afghanistan now appears as an area with extremely rich mineral resources having, in addition to tin and gold, major deposits of copper ore and iron ore.[59] It is unlikely, however, that copper would have been brought to Sumer from such a distance, certainly not by an overland route. For the Sumerians, copper came from the land of Magan, a land long thought to have been located in the region of the Arabian Gulf, especially in Oman.[60] Recent discoveries have demonstrated that the rich copper deposits of Oman were being exploited at least by the middle of the third millennium B.C. Current German excavations in Oman, concentrating upon the investigation of ancient mining and smelting sites, have uncovered significant evidence for the smelting of copper ores and the production of copper bun or plano-convex ingots. In association with these remains is a series of radiocarbon dates which, when calibrated, fall in the late third and early second millennia B.C.[61]

From the land of Magan located in Oman, the copper imported by the Sumerians must have gone north from the Gulf area. It is possible that the wealth of Afghanistan came into Mesopotamia by the same route, with some of it continuing on up the Euphrates to Syria and the city of Ebla. This theory would explain why, at Ebla, gold and tin are weighed according to the standard of the Dilmun shekel.[62] As Dil-

[51] G. Pettinato, *The Archives of Ebla* (New York 1981) 178.

[52] Pettinato (supra n. 51) 178.

[53] This is, of course, one of the major controversies regarding the interpretation of the material from Ebla. The archaeological date seems to derive from a destruction of Palace G in the Sargonic period, perhaps at the hand of Naram-Sin. The epigraphical date seems to put the tablets closer to E.D. IIIa and the archive from Tell Abū Ṣalābīkh.

[54] See arguments summarized in J.D. Muhly, "Bronze Figurines and Near Eastern Metalwork," *IEJ* 30 (1980) 151; also, "Kupfer," in D.O. Edzard et al. eds., *Reallexikon der Assyriologie und vorderasiatischen Archäologie* 6.5–6 (Berlin and New York 1983) 353.

[55] E.A. Speiser, *Excavations at Tepe Gawra* 1 (Philadelphia 1935) 101–102. This pin is cited as the earliest tin bronze in Mesopotamia by H. Waetzoldt, "Zur Terminologie der Metall in den Texten aus Ebla," in L. Cagni ed., *La lingua di Ebla* (Naples 1981) 374, and P.R.S. Moorey, "The Archaeological Evidence for Metallurgy and Related Technologies in Mesopotamia, c. 5500–2100 B.C.," *Iraq* 44 (1982) 22.

[56] Work at present has concentrated upon copper and copper-based objects from the Royal Cemetery at Ur and from Tepe Gawra. Analyses are being done by PIXE (proton-induced x-ray emission) and results promise a major re-evaluation of our understanding of the development of Mesopotamian metalworking.

[57] The basic geological study is by S. Abdullah et al., *Mineral Resources of Afghanistan* (United Nations Development Programme, Geological Survey, Programme Support Project AFG/74/12, Kabul 1977). See also F. Berthoud, *Les anciennes mines d'Afghanistan* (*Rapport préliminaire*) (Commissariat à l'Énergie Atomique, Laboratoire de Recherche des Musées de France, Unité de Recherche Archéologique, no. 7, Paris 1977).

[58] The archaeological and historical implications of these discoveries will be discussed in a paper by T. Stech and V. Pigott. For the present, see S. Cleuziou and T. Berthoud, "Early Tin in the Near East," *Expedition* 25.1 (1982) 14–19.

[59] See works cited supra n. 57. Also J.F. Shroder, "Afghanistan's Unsung Riches," *Christian Science Monitor*, 22 February 1982, 26.

[60] Muhly (supra n. 1) 221–31.

[61] G. Weisgerber, "Mehr als Kupfer in Oman—Ergebnisse der Expedition 1981," *Der Anschnitt* 33 (1981) 174–263 (radiocarbon dates, p. 251, Table 2).

[62] For gold according to the Dilmun shekel, see, in particular, the text TM.75.G.1359, in Pettinato (supra n. 51) 123–24. For tin, see the texts published by A. Archi and M.G. Biga, *Testi amministrati-*

mun is almost certainly to be equated with the island of Bahrain, its role in the Gulf trade has long been understood to have been that of an emporium involved in the transshipment of materials.[63] The Sumerian texts from Ur indicate that at certain periods, such as the Third Dynasty of Ur, there was direct trade between Ur and Magan while at other times, notably during the Isin-Larsa period, the copper trade was carried on through Dilmun.[64]

In 1970 G. Dossin published the long awaited edition of a text from Mari relating to the tin trade.[65] According to this tablet, which dates from the first part of the reign of Zimri-Lim and thus to the early years of the eighteenth century B.C., a total of 16 talents and 10 minas of tin were collected together at Mari. Included in this total were one talent sent by Hammurapi of Babylon and 20 minas from Sheplarpak of Susa.[66] The text is set up as a balanced account, listing first receipts and then expenditures, with specified parts of this total being sent to individuals such as Amud-pi-El of Qatna, Ibni-Adad of Hazor and Wari-taldu of Laish/Dan, to a "translator" (*targamannum*, "dragoman") residing at Ugarit and to a Caphtorite (*a-na-Kap-ta-ra-i-im*), presumably to be located on the island of Crete.[67]

The logical implication of this text is that tin was being transported east to west. Tin is brought to Mari from unspecified sources in the east, with Susa and Eshnunna serving as important way stations along the route to Mari. From Mari the tin is then transshipped to various sites in Syria and Palestine and, presumably, even across the sea to Crete. The arrangement of the text implies that contact with Crete was via the great commercial center of Ugarit, a reconstruction to be supported by the archaeological evidence from Ugarit itself.[68]

In the same year Dossin also published an extraordinary archive of texts dated to the reign of Sûmu-Iamam, king of Mari, and thus to be placed in the latter part of the nineteenth century B.C., just prior to the Assyrian conquest by Šamši-Adad I.[69] Several of these texts deal with the addition of tin to copper in order to produce bronze for designated uses. Just as Dossin failed to understand that the "itinerary" text discussed above was in the form of a balanced account, so he also did not understand the key phrase that appeared in these texts.

The clearest use of this phrase comes in text no. 7 where one-third of a mina of tin is added to eight minas of "washed" copper (*i-na* ⅓ MA·NA 4 GÍN <TA·>A·AN *ba-li-il*) in order to make the head of a small battering ram.[70] The phrase given in transcription must mean "mixed at a tin:copper ratio of 1:24" (the figures given amounting to 24 shekels). This text therefore records the production of a 4.0% tin bronze. This must be the proper explanation for these texts, although in other cases the figures do not balance exactly and in one case, on the badly preserved text no. 1, seem to make no sense whatsoever.[71]

In all cases these texts certainly represent the use of metallic tin, a raw material brought up the Euphrates to Mari from undisclosed sources in the east, perhaps from Afghanistan.

The same east-west movement of tin is documented in the numerous Old Assyrian texts from Kültepe, the ancient *kārum* Kaniš.[72] Again from unspecified sources to the east, the tin was brought to Assur and from there shipped overland by donkey caravan to various Assyrian merchant colonies in Anatolia. Of the 3,000 published texts, representing about one-tenth of the total number excavated, only 189 deal directly with the caravan trade. Yet this small number, spread over three generations of merchant activity covering a period of some 100 years, records a total of 90 donkey-loads that brought almost eleven tons of tin into Anatolia.[73]

vi di vario contenuto (*Archivio L. 2769: Tm. 75. G. 3000–4101*) (Archivi reali di Ebla 3, Rome 1982), esp. nos. 94, 524, 526, 630.

[63] There is an enormous bibliography on this subject that need not be cited here. Cf., the excellent survey by D. Potts, "Towards an Integrated History of Culture Change in the Arabian Gulf Area: Notes on Dilmun, Makkan and the Economy of Ancient Sumer," *Journal of Oman Studies* 4 (1978) 29–51. Also E.C.L. During Caspers and A. Govindankutty, "R. Thapar's Dravidian Hypothesis for the Locations of Meluḫḫa, Dilmun and Makan," *Journal of the Economic and Social History of the Orient* 21 (1978) 113–45.

[64] The classic study is by A. Leo Oppenheim, "The Seafaring Merchants of Ur," *JAOS* 74 (1954) 6–17.

[65] G. Dossin, "La route de l'étain en Mésopotamie au temps de Zimri-Lim," *RAssyr* 64 (1970) 97–106.

[66] A. Malamat, "Syro-Palestinian Destinations in a Mari Tin Inventory," *IEJ* 21 (1971) 31–38.

[67] The attempt by J. Strange, *Caphtor/Keftiu. A New Investigation* (Acta Theologica Danica 14, Leiden 1980), to identify Caphtor with the island of Cyprus has not been well received. See reviews by M.C. Astour (*JAOS* 102 [1982] 395–96) and A.B. Knapp (*Orientalia* 52 [1983] 284–89).

[68] For Ugarit, see the summary by J.-C. Courtois, "Ras Shamra, I. Archéologie du site," in H. Cazelles and A. Feuillet eds., *Supplément au Dictionnaire de la Bible* Fascs. 52 and 53 (Paris 1979) 1205–1208.

[69] G. Dossin, "Archives de Sumu-Iamam, roi de Mari," *RAssyr* 64 (1970) 17–44.

[70] Dossin (supra n. 69) 24–25.

[71] Dossin (supra n. 69) 21–22.

[72] For recent research, see M.T. Larsen, *Old Assyrian Caravan Procedures* (Istanbul 1967); K.R. Veenhof, *Aspects of Old Assyrian Trade and its Terminology* (Leiden 1972).

[73] Veenhof (supra n. 72) 69–76; R. McC. Adams, "Anthropological Perspectives on Ancient Trade," *Current Anthropology* 15

Since no significant deposits of tin have ever been attested in Iran, despite hearsay reports by many travellers going back as far as the time of Strabo and his account of tin from Drangiana (Strabo 15.724),[74] it is attractive to see Afghanistan as the main source of tin for the bronze industries of Western Asia. Only in Afghanistan do we have the geological evidence for rich tin deposits within the context of an area known to be in contact with the major urban cultures located to the west and to the south.

The tin deposits of India, although often cited in this context, clearly never were capable of supporting anything more than the local bronze industry.[75] The Eastern Desert of Egypt does have significant deposits of alluvial cassiterite within a geological context that would have made the tin accessible to ancient prospectors.[76] As the Eastern Desert was also a source of gold and of many different varieties of stone, it would be reasonable to suggest that Egypt was a major source of tin for the Bronze Age cultures of the eastern Mediterranean. The problem is that metallurgical developments in Egypt seem to have had little influence from or upon things outside Egypt and that the use of tin bronze in Egypt was extremely sporadic prior to ca. 2000 B.C.[77] It is thus unlikely that the tin for the bronze industries of third millennium Ebla and Ur came from Egypt.

The fact that, for the period documented by the Old Assyrian texts from level II at the *kārum* Kaniš—roughly 1950–1850 B.C.—the Anatolians found it necessary (or desirable) to rely upon foreign merchants to supply them with tin raises interesting questions about the state of affairs prior to the arrival of the Assyrian merchants. What about the bronze industries of EB II and EB III Anatolia? The published analyses show that alongside arsenical copper, tin bronze was in regular use at Early Bronze Age sites such as Alaca Hüyük, Ahlatlıbel, Mahmutlar and Horoztepe.[78] Some of the best evidence for the Early Bronze Age use of tin bronze comes, in fact, from the Early Bronze Age levels at Troy. The analyzed objects from a Troy II/III context demonstrate a predominant use of tin bronze, with little use of arsenical copper.

It is usually stated that tin bronze was already in use at the time of the EB I levels of Troy I, a period that some scholars would place as early as ca. 3600 B.C.[79] This mistaken idea goes back to Dörpfeld, who published a bronze bracelet having 10.18% tin as coming from Troy I.[80] Schliemann had identified the bracelet as coming from the earliest levels at Troy, an association followed by most subsequent scholars who have discussed the object.[81] But Schmidt, in his catalogue of the Schliemann collection in Berlin, regarded

(1974) 247.

[74] O.G.S. Crawford, "Tin Deposits in the Near East," *Antiquity* 12 (1938) 79–81; also "Iranian Tin," *Antiquity* 14 (1940) 195–97; and "The Discovery of Bronze," *Antiquity* 10 (1936) 87–88.

[75] K.T.M. Hegde, "Sources of Ancient Tin in India," in Franklin, Olin and Wertime eds. (supra n. 5) 39–42; D.K. Chakrabarti, "The Problem of Tin in Early India—A Preliminary Survey," *Man and Environment* 3 (1979) 61–74. R.D. Schuiling, "The Position of Indian Tin Occurrences in the Tin-Belts of Gondwana," *Journal, Geological Society of India* 24 (1983) 101–105. Schuiling refers to the recent discovery of significant deposits of alluvial cassiterite in the Bastar District of Madhya Pradesh, one of the most remote parts of India, an isolated area during the entire course of Indian history, which is most likely why these deposits have only recently been discovered. It is unlikely that the Bastar tin deposits could have supplied the tin for the Harappan bronze industry. I am grateful to Prof. G. Possehl for discussing these problems with me.

[76] M.F. El-Ramly et al., "Tin-Tungsten Mineralisation in the Eastern Desert of Egypt," in O. Moharram et al. eds., *Studies on some Mineral Deposits of Egypt* I/A. *Metallic Minerals* (Ministry of Industry, Geological Survey, Cairo 1970) 43–52; A.H. Sabet, V. Chabanenco and V. Tsogoev, "Tin-Tungsten and Rare-Earth Mineralization in the Central Eastern Desert of Egypt," *Annals of the Geological Survey of Egypt* 3 (1973) 75–86.

[77] We are badly in need of a new investigation dealing with the development of copper and copper-based metallurgy in ancient Egypt. For recent studies see T.A. Wertime, "Tin and Egyptian Bronze," in D. Schmandt-Besserat ed., *Immortal Egypt* (Malibu 1978) 37–42; M.M. Farag, "Metallurgy in Ancient Egypt: Some Aspects of Techniques and Materials," *Bulletin of the Metals Museum, Japan Institute of Metals* 6 (1981) 15–30; A. Radwan, *Die Kupfer- und Bronzegefässe Ägyptens* (Prähistorische Bronzefunde 2.2, Munich 1983). The available evidence, limited as it may be, does suggest only sporadic use of tin-bronze prior to the beginning of the Middle Kingdom, ca. 2000 B.C.

[78] The chief body of evidence is represented by the JSS analyses published by Esin (supra n. 43). The results are tabulated in diagramatic form by de Jesus 1980 (supra n. 18) part ii, graphs nos. 2–11, pp. 364–68.

[79] The date of ca. 3600 B.C. for the beginning of Troy I represents the ultra-high chronology advocated by James Mellaart and Donald Easton. Others, such as Doro Levi, prefer a date about 1000 years lower. Such a state of affairs is a fair indication of the confusion that prevails at present. It is most unfortunate that the Proceedings of the Fifth Sheffield Aegean Colloquium, held in 1977 and devoted to Troy and the Trojan War, have never been published. It is not possible to speak of a consensus since, at present, there is no consensus whatever. For current work, see J. Yakar, "Troy and Anatolian Early Bronze Age Chronology," *AnatSt* 29 (1979) 51–67; C. Podzuweit, *Trojanische Gefässformen der Frühbronzezeit in Anatolien, der Ägäis und angrenzenden Gebieten. Ein Beitrag zur vergleichenden Stratigraphie* (Mainz 1979); P.Z. Spanos, "Zur absoluten Chronologie der zweiten Siedlung in Troja," *ZAssyr* 67 (1977) 85–107.

[80] W. Dörpfeld, *Troja und Ilion* (Athens 1902) 324. The bracelet in question is no. 2529 in the Catalogue by K. Branigan, *Aegean Metalwork of the Early and Middle Bronze Age* (Oxford 1974) drawing on pl. 21.

[81] C. Renfrew, *The Emergence of Civilisation* (London 1972) 313; de Jesus 1980 (supra n. 18) 134. The initial publication was by H. Schliemann, *Ilios, the City and Country of the Trojans* (London 1881; reprinted New York 1976) 250–51, no. 116, who describes the bracelet as being made of copper.

the context as suspect, comparing the bracelet (SS 6667) with another (SS 6484) from Troy VII and also of tin bronze (with 9.34% tin).[82]

Schliemann's dating of such contexts is not to be trusted. He also tried to date an iron ingot from Troy to the time of Troy II because it was similar in shape to the six silver ingots from Treasure A. It would be most remarkable indeed to have an iron ingot from Troy II, but Schmidt is surely correct in dating the ingot (SS 6706), as well as an iron chisel (6707), to the time of Troy VII–IX.[83]

Attempts have been made to identify even earlier examples of tin bronze from Anatolia. The strangest candidate is the fragment of copper wire from the lower prehistoric layer at Suberde with 8.4% tin. As the associated radiocarbon dates (uncalibrated, 5730 half-life) are all from the mid-seventh millennium B.C., the excavator, J. Bordaz, was justly skeptical of the context even though there was no evidence for any sort of disturbance.[84]

De Jesus has, on several occasions, argued for the use of tin bronze in Late Chalcolithic levels at Mersin. The objects in question—all of very low tin bronze—are a stamp seal (with 2.6% tin), an awl (with 2.1% tin) and a toggle pin (with 1.3% tin).[85] In the published report on the excavations at Mersin, Garstang mentions only the stamp seal. He makes clear that he had reason to be skeptical of its context and that he did "not find it possible to accept this doubtful provenance as a reliable indication of its date and origin."[86] Indeed, a stamp seal and, in particular, a toggle pin are quite out of place in a Late Chalcolithic context. Analysis showed that all three artifacts also had over 1.0% arsenic and they could equally well be regarded as made of arsenical copper.

Mersin provides no evidence for the early use of tin bronze in Anatolia. Waetzoldt has now also claimed the earliest tin bronze in Anatolia for Mersin.[87] The object cited by Waetzoldt in this context, again on the basis of the analyses published by Ufuk Esin, is actually a curved fragment of a riveted weapon from Room 114 in Level IX at Mersin. The piece does have ca. 10% tin, but it dates to ca. 1600 B.C., some thousand years later than the earliest tin bronze at Troy.[88]

Quite apart from the problematic bracelet mentioned above, there is impressive evidence for the use of tin bronze at Troy from the time of Troy II. To the material published by Schliemann, for which there is reasonable context at least for the pieces from the Great Treasure (or Treasure A), can be added the objects excavated by the Cincinnati expedition that were analyzed by Desch[89] and the collection of objects of almost certain Troy II date published by Bittel.[90] De Jesus concluded that, of 39 analyzed pieces from Troy II, 16, or 41%, were made of tin bronze having at least 5% tin.[91] There are more analyses than those used by de Jesus, but his calculations give a fair indication of the importance of tin bronze at Troy.

If Troy can be considered as a site within a North Aegean cultural province, including Thrace, Macedonia and the islands of the North Aegean, it is significant that the site of Thermi, on the island of Lesbos, has produced what is probably the earliest piece of tin bronze in the eastern Mediterranean. Among the Thermi metal finds analyzed by Desch is a pin from the First City with 83.80% copper, 13.10% tin and 2.56% lead.[92] There was also an unstratified spearhead with 10.10% tin. As Thermi I–V are generally considered to be contemporary with Troy I, both of these bronzes should be earlier than any examples of bronze from Troy.[93] Probably contemporary with the bronzes from Thermi are the unpublished examples of tin bronze from Phase V at the Macedonian site of Sitagroi.[94]

What makes Thermi even more remarkable is that the site has produced what is still the only object of pure tin from the Early Bronze Age Aegean. Al-

[82] H. Schmidt, *Heinrich Schliemann's Sammlung Trojanischer Altertümer* (Berlin 1902) 262 (SS 6667); 257 (SS 6484). For the latter bracelet, see Dörpfeld (supra n. 80) 395, fig. 382.

[83] Schmidt (supra n. 82) 263. The comparison with the silver ingots is also made by A. Götze, in Dörpfeld (supra n. 80) 362.

[84] J. Bordaz, "The Suberde Excavations, Southwest Turkey, an Interim Report," *TürkArkDerg* 17.2 (1968) 50–51 (radiocarbon dates on p. 59).

[85] De Jesus 1980 (supra n. 18) 133. The JSS analyses, published by Esin (supra n. 43) 144–45, are 17871 (stamp seal), 17882 (awl), 17884 (toggle pin).

[86] J. Garstang, *Prehistoric Mersin* (Oxford 1953) 108.

[87] Waetzoldt (supra n. 55) 375 and n. 56.

[88] Garstang (supra n. 86) 216 and fig. 133. The JSS analysis published by Esin (supra n. 43) is no. 17906, with reference on p. 192. From level IX at Mersin also comes a lugged axe, of Hittite type (p. 211 and fig. 129), dated by Garstang to ca. 1600 B.C. (p. 216).

[89] R.F. and E. Tylecote and R.I. Jaffee, "Analyses of Trojan Bronzes," *Bulletin of the Historical Metallurgy Group* no. 7 (1966) 20–29 (this article collects all the Trojan analyses made by C.H. Desch).

[90] K. Bittel, "Beiträge zur Kenntnis anatolischer Metallgefässe der zweiten Hälfte des dritten Jahrtausends v. Chr.," *JdI* 74 (1959) 1–34.

[91] De Jesus 1980 (supra n. 18) 368, graph 10.

[92] W. Lamb, *Excavations at Thermi in Lesbos* (Cambridge 1936) 214–15; Pin no. 31.64.

[93] For the date of the material from Thermi, see C. Blegen et al., *Troy* 1 (Princeton 1950) 40; Renfrew (supra n. 81) 125. To Podzuweit (supra n. 79) 38–40, Thermi I–II are contemporary with Troy Ia, and Thermi III with Troy Ib.

[94] Renfrew (supra n. 81) 313.

though doubts have often been raised regarding the identification of this twisted bracelet as being made of tin, it was examined by Desch who concluded that: "It is, as far as I judge, of pure tin; the metal contains no copper, silver or lead, and the trace of iron which I found is probably contained in the coating derived from the earth."[95] It would be worthwhile re-examining this unique object, if it could be located, but for the time being it must be regarded as further evidence for the decisive use of tin bronze in the Troad and the North Aegean during the Early Bronze Age. It would be most helpful to have analyses of the contemporary metal objects from Poliochni on the island of Lemnos.

This use of tin bronze is not confined to areas in contact with the sea. The same emphasis upon tin as the main alloying element is also found in central Anatolia, especially at Alaca Hüyük and Horoztepe. According to de Jesus' calculations there are 18 objects from EB II Alaca with at least 5.0% tin. Out of 40 analyses this means that 45% were made of tin bronze. At the nearby site of Ahlatlıbel the comparable figures were 8 out of 20 or 40%. At EB III Horoztepe the totals were 32 out of 56 or 57%.[96]

It must be admitted that, on the basis of existing evidence, there is no reasonable candidate(s) for the source(s) of the tin used by the remarkable bronze industries of Anatolia. The metallurgical evidence alone would suggest an inner Anatolian source of tin, but no geological evidence has ever been presented for such tin deposits. It also makes little sense to look southeast across the Taurus, to Syria and an Anatolian extension of the Euphrates trade route discussed above.[97] There are several basic objections to such a hypothesis.

1. There seems to be a greater use of tin in Anatolia than in Syria or Mesopotamia. This would mean that the area at greatest distance from the resource made the greatest use of that resource.
2. It is not possible to document a flow of tin into Anatolia from the southeast. Tarsus, for example, made little use of tin-bronze. According to the figures given by de Jesus it was 4 objects out of 25 (or 16%) for EB II Tarsus and 0 out of 29 for EB III Tarsus.[98]
3. Tin seems to have travelled across Mesopotamia and Syria in association with gold and lapis lazuli. While there is plenty of gold in Early Bronze Age Anatolia, there is no lapis lazuli. The gold probably came from local Anatolian sources, but the absence of lapis lazuli is a real puzzle. Even Schliemann, who managed to discover a collection of jade (nephrite) axes at Troy,[99] does not report finding any lapis lazuli.

The implications of these facts are that we must look to the west, to the Aegean and beyond, for Anatolian sources of tin.

The metallurgy of the Early Bronze Age Cyclades is, typologically, quite similar to that of Anatolia. There is also analytical evidence for a limited use of tin bronze.[100] There are, however, no deposits of tin in the Cyclades or anywhere else in the Aegean. The idea that tin was to be found at Kirrha, near Delphi,[101] was abandoned long ago and no other candidates have been brought forth in recent years. The Aegean may have supplied limited amounts of copper, iron, gold and, of course, lead and silver, but no tin. Simply in terms of geographical proximity, the nearest tin deposit seems to be that at Monte Valerio in Tuscany. Detailed geological studies have been made of this area, with exploited reserves estimated at 4,000 tons of metallic tin.[102] There also are limited deposits of tin in the granites of southern Sardinia.[103]

There is much interest at present regarding Mycenaean contacts with the western Mediterranean and the possibility that Sardinia might have been a major source of metal, both copper and tin, for the bronze industries of the Aegean. Such speculations have been

[95] Desch, in Lamb (supra n. 92) 215. This bracelet is no. 30.24, from Thermi IVa.

[96] De Jesus 1980 (supra n. 18) 364–65, graphs nos. 3 (Alaca), 2 (Ahlatlıbel) and 5 (Horoztepe).

[97] K.A. Yener, "A Review of Interregional Exchange in Southwest Asia: The Neolithic Obsidian Network, the Assyrian Trading Colonies and a Case for Third Millennium B.C. Trade," *Anatolica* 9 (1982) 45–48, believes that, in the Old Assyrian period, the tin brought into Anatolia must have come from northwest Iran. She has nothing to say about possible third millennium sources. M.B. Rowton concludes that "the sources of tin in the Early Bronze Age are still unknown." ("War, Trade and the Emerging Power Center," in H.-J. Nissen and J. Renger eds., *Mesopotamien und seine Nachbarn. Politische und kulturelle Wechselbeziehungen im alten Vorderasien vom 4.–1.Jahrtausend v. Chr.* [Berlin 1982] 193, n. 13.)

[98] De Jesus 1980 (supra n. 18) 367, graphs nos. 8 and 9.

[99] Schliemann (supra n. 81) 240–43, 446–51.

[100] C. Renfrew, "Cycladic Metallurgy and the Aegean Early Bronze Age," *AJA* 71 (1967) 1–20. See also the analyses assembled by Branigan (supra n. 80) 147–52.

[101] Benton (supra n. 15).

[102] A. Stella, "Le miniere di stagno di Monte Valerio e i giacimenti del campigliese nel quadro della catena metallifera toscana," *Bollettino della Società Geologica Italiana* 74 (1955) 109–218; I. Venerandi-Pirri and P. Zuffardi, "The Tin Deposit of Monte Valerio (Tuscany): New Factual Observations for a Genetic Discussion," *Rendiconti Società italiana di Mineralogia e Petrologia* 37 (1981) 529–39. The importance of these deposits is discussed by G. Barker, *Landscape and Society. Prehistoric Central Italy* (London 1981) 86; J.W. Taylor, "A Nigerian Tin Trade in Antiquity?" *Oxford Journal of Archaeology* 1 (1982) 317.

[103] M. Biste, "Geochemistry of South Sardinian Granites Compared with their Tin Potential," in A.M. Evans ed., *Metallization Associated with Acid Magmatism* (New York 1982) 37–50; R.F. Tylecote, M.S. Balmuth and R. Massoli-Novelli, "Copper and Bronze Metallurgy in Sardinia," *JHMS* 17 (1983) 63–77. See also F. Lo Schiavo et al., below pp. 316–18.

reinforced by the discovery of a significant number of copper ox-hide ingots in Sardinia and also by the presence of Mycenaean pottery at several Sardinian sites.[104] If Sardinia is now also to be considered a potential source of tin, then Aegean contacts with the west must be seen in quite a new light. The problem is that, although it is usually difficult to assign exact dates to any of the finds from Sardinia, nothing can be earlier than the Late Bronze Age.[105]

In 1882, the archaeologist F. Nissardi excavated a hoard of bronze tools and weapons at the site of Forraxi Nioi (Nuragus) in Sardinia.[106] Included in this find was a crucible containing what was identified as partially reduced pieces of cassiterite and thought, therefore, to represent evidence for the production of bronze by a cementation process involving the addition of cassiterite to molten copper.[107] More likely, however, the remains in the crucible are to be identified as oxidized bits of metallic tin.[108] The find, which seems to date to the Nuragic period, does demonstrate the use of tin in Sardinia and speaks in favor of the local production of bronze, not the importation of ready-made bronze from outside the island. There is, unfortunately, nothing to be said regarding the provenience of the tin.

The possibility of important sources of tin located in the western Mediterranean has been discussed for a long time.[109] In addition to the minor deposits in Italy and Sardinia discussed above, there are major tin resources in Iberia, especially in northern Portugal.[110] Were lands in the western Mediterranean an important source of tin for the Aegean and the world of the eastern Mediterranean, that tin would almost certainly have come from Iberia. This situation virtually eliminates the possibility of a western Mediterranean tin trade in a Bronze Age context. Contact between the Aegean (and lands to the east) and Iberia goes back no earlier than the ninth century B.C. and the onset of Phoenician expansion/colonization of the western Mediterranean.[111] It has always been assumed that the quest for new sources of metal, especially silver and tin, was a significant motivation underlying Phoenician westward expansion for, as the prophet Ezekiel said of the city of Tyre: "Tarshish traded with you because of your wealth of all kinds of goods; they bartered silver, iron, tin and lead for your wares."[112]

The identification of Tarshish with the Greek land of Tartessos, and the role of Iberia's mineral wealth in Phoenician and Greek activities in the western Mediterranean are problems that fortunately need not be discussed at this time.[113] There are difficulties enough

[104] M.L. Ferrarese Ceruti, "Ceramica micenea in Sardegna; (Notizia preliminare)," *Rivista di Scienze Preistoriche* 34 (1979) 243–53; L. Vagnetti, "Mycenaean Imports in Central Italy" in E. Peruzzi, *Mycenaeans in Early Latium* (Incunabula Graeca 75, Rome 1980) 151–67; F. Lo Schiavo, L. Vagnetti and M.L. Ferrarese Ceruti, "Micenei in Sardegna?" *RendLinc* 35 (1980) 371–93; M.L. Ferrarese Ceruti, "Documenti micenei nella Sardegna meridionale," in *Ichnussa. La Sardegna dalle origini all'età classica* (Milan 1981) 605–12.

[105] The best evidence for dating sites and stratigraphic levels in the western Mediterranean comes from the imported Mycenaean pottery which, with few exceptions, does not appear before the beginning of the Late Bronze Age. Cf. B. Pålsson Hallager, below pp. 293–305. M. Marazzi and S. Tusa, "Die mykenische Penetration im westlichen Mittelmeerraum," *Klio* 61 (1979) 309–51; L. Vagnetti ed., *Magna Grecia e mondo miceneo* (XXII Convegno di Studi sulla Magna Grecia, Taranto 1982). For Sardinia in particular, see F. Lo Schiavo, "Copper Metallurgy in Sardinia During the Late Bronze Age: New Prospects on its Aegean Connections," in J.D. Muhly, R. Maddin and V. Karageorghis eds., *Early Metallurgy in Cyprus, 4000–500 BC* (Nicosia 1982) 271–83; R.F. Tylecote, M.S. Balmuth and R. Massoli-Novelli, "Copper and Bronze Metallurgy in Sardinia," in M.S. Balmuth and R.J. Rowland, Jr., eds., *Studies in Sardinian Archaeology* (Ann Arbor 1984) 115–62.

[106] For discussion, see Tylecote, Balmuth and Massoli-Novelli (supra n. 103) 69, 71, 75.

[107] L. Cambi, "Problemi della metallurgia etrusca," *StEtr* 27 (1959) 415–32, esp. 427; Tylecote (supra n. 4) 14–15. For the technical aspects of the process, see J.A. Charles, "The Coming of Copper and Copper-Base Alloys and Iron: A Metallurgical Sequence," in Wertime and Muhly eds. (supra n. 4) 174–75.

[108] Tylecote, Balmuth and Massoli-Novelli (supra n. 103) 71, 75.

[109] Cf. O. Davies, "The Ancient Tin Sources of Western Europe," *Proceedings, Belfast Natural History and Philosophical Society* 1931–1932, 41–51.

[110] D. Sluijk, *Geology and Tin-Tungsten Deposits of the Regoufe Area, Northern Portugal* (Amsterdam 1963); D.J. Fox, "Tin Mining in Spain and Portugal," in *A Second Technical Conference on Tin, Bangkok 1969* (London 1970) 223–74; D. Thadeu, "Les gisements stanno-wolframitiques du Portugal," *Annales, Société Géologique Belge, Liège* 96 (1973) 5–30; W.C. Kelly and R.O. Rye, "Geologic, Fluid Inclusion and Stable Isotope Studies of the Tin-Tungsten Deposits of Panasqueira, Portugal," *Economic Geology* 74 (1979) 1721–822 (with discussion by C. Marignac in *Economic Geology* 77 [1982] 1263–66); V. Gouanvic and J. Babkine, "Métallogénie du gisement à tungstène-étain de Monteneme (N.O. Galice, Espagne)," *Economic Geology* 80 (1985) 8–15.

[111] Cf. J.D. Muhly, "Homer and the Phoenicians," *Berytus* 19 (1970) 19–64; and more recently "Phoenicia and the Phoenicians," to appear in the Proceedings of the International Congress on Biblical Archaeology (Jerusalem, 1–10 April 1984). See, in particular, the papers published in H.-G. Niemeyer ed., *Phönizier im Westen* (Madrider Beiträge 8, Mainz am Rhein 1982); also W. Kimmig, "Die griechische Kolonisation im westlichen Mittelmeergebiet und ihre Wirkung auf die Landschaften des westlichen Mitteleuropa," *JbRGZM* 30 (1983) 5–78.

[112] Ezekiel 27:12 (translation from H.L. Ginsberg ed., *The Prophets (Nevi'im)*[2] [Philadelphia 1978]).

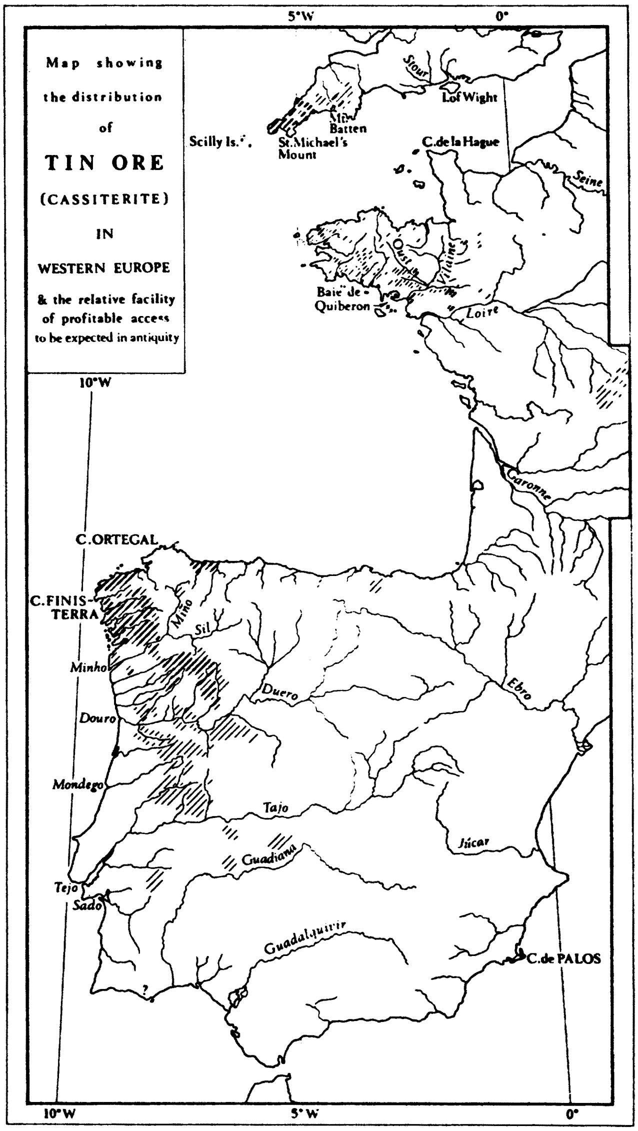
[113] Cf. G. Bunnens, *L'expansion phénicienne en Méditerranée. Essai d'interpretation fondé sur une analyse des traditions littéraires* (Brussels and Rome 1979) 331–48; M. Elat, "Tarshish and the Problem of Phoenician Colonisation in the Western Mediterranean," *Orientalia Lovaniensia Periodica* 13 (1982) 55–69.

in the traditional explanation of what happened during the early Iron Age without projecting our misconceptions into the Late Bronze Age.

I have long argued[114] for the possibility that, from the late Middle Helladic period onward, beginning with the period of the Shaft Graves at Mycenae, the Aegean world was making use of northwest European sources of tin, especially those in southwest England (Cornwall and Devon)[115] and Brittany (the Massif Central) (ill. 3).[116] The geological documentation of the existence of these deposits is extensive. Furthermore there is detailed evidence, especially in the case of Cornwall, for the exploitation of local sources of alluvial cassiterite at least by the beginning of the British Early Bronze Age, ca. 2000 B.C.

From Structure B at the site of Trevisker Round, St. Eval, Cornwall, in a Late Bronze Age context, comes a hoard of alluvial cassiterite pebbles.[117] The published photograph illustrates 28 pieces of cassiterite.[118] It certainly would be stretching credulity to imagine that this find represents anything but the use of local sources of alluvial cassiterite. From an even earlier context, together with an Early Bronze Age dagger from Site I at Caerloggas Down, just east of St. Austell Moor—the source of rich deposits of alluvial cassiterite—comes an actual specimen of tin-smelting slag,[119] apparently the only known example of tin-smelting slag in an archaeological context. There are, in fact, a number of examples of cassiterite pebbles with Bronze Age artifacts in archaeological context from the tin-bearing regions of Cornwall, although the context is often of uncertain date.

There can be no doubt that the tin resources of Cornwall were being exploited more or less continuously from at least 2000 B.C. down into modern times. That such tin found its way into the world of the Aegean Late Bronze Age can, at present, be only a matter of surmise. To argue for the use of Cornish tin at Late Bronze Age Mycenae is not to have the Mycenaeans as builders of Stonehenge. It is most unlikely that anyone from the Aegean ever reached southern



Ill. 3. Map showing location of tin deposits in southern England, Brittany and Iberia. (From C.F.C. Hawkes, *Pytheas: Europe and the Greek Explorers* [The Eighth J.C. Myres Memorial Lecture, Oxford 1977] 24, map 7)

[114] Most recently in "Beyond Typology: Aegean Metallurgy in its Historical Context," in N.C. Wilkie and W.D.E. Coulson eds., *Contributions to Aegean Archaeology: Studies in Honor of William A. McDonald* (Minneapolis 1985) 109–41. See also J.D. Muhly, "Possible Sources of Tin for the Bronze Age Aegean," *BICS* 26 (1979) 122–23.

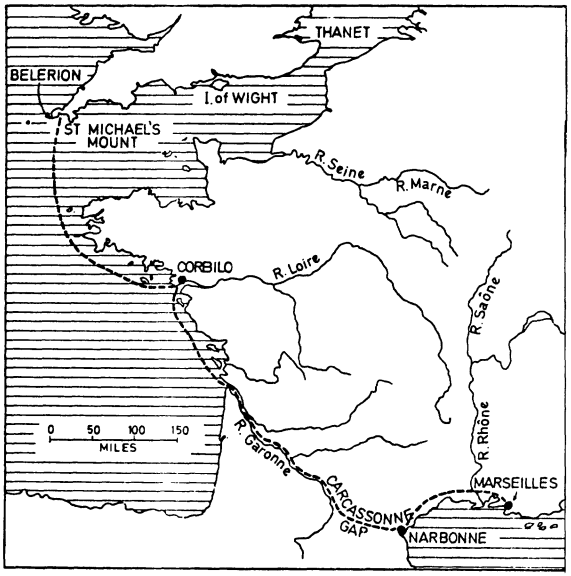
[115] For the archaeologist, the basic work is still W. Pryce's *Mineralogia Cornubiensis* (London 1778). See also F. Haverfield et al., "Romano-British Cornwall," in *The Victoria History of the County of Cornwall* 6.2.5 (London 1924). For basic geology, see E.A. Edmonds et al., *British Regional Geology: South-West England*[4] (London 1975); K.F.G. Hosking, "The Nature of the Primary Tin Ores of the South-West of England," in *Second Technical Conference* (supra n. 110) 1157–244.

[116] C. Derré, "Caractéristiques de la distribution des gisements à étain et tungstène dans l'ouest de l'Europe," *Mineralium Deposita* 17 (1982) 55–77.

[117] C.A. Shell, "The Early Exploitation of Tin Deposits in South-West England," in M. Ryan ed., *The Origins of Metallurgy in Atlantic Europe* (Proceedings of the Fifth Atlantic Colloquium, Dublin 1978) 255.

[118] Shell (supra n. 117) pl. 1.

[119] Shell (supra n. 117) 259 and 263, pl. 3. This is the same slag discussed by Tylecote (supra n. 22).



Ill. 4. One version of the tin route from southern England to the Mediterranean. (After H.O'N. Hencken, *The Archaeology of Cornwall and Scilly* [London 1932])

England during the Late Bronze Age. Tin, like amber, made its way across Europe through a series of middlemen, perhaps as Diodorus Siculus describes, albeit for a much later period (ills. 4–5).[120]

Repeated efforts have been made to identify the presence of Mycenaean or at least of Mycenaean-inspired artifacts, especially swords and gold cups, across Europe and the United Kingdom. Such attempts have, in general, met with little success. Lack of evidence need not, however, rule out the Aegean use of Cornish tin, as such objects are also not known along the amber route and yet there is analytical evidence for the Aegean use of Baltic amber,[121] but it does raise questions regarding the nature of Mycenaean exports.

There is need for a complete re-evaluation of all the evidence for Aegean elements and influences in the European Bronze Age, but such a study must go beyond the search for spiral and curvilinear forms of decoration.[122] Of special interest is the flange-hilted, type D1 sword from a burial mound at Ørskovhedehus in southeastern Jutland, dating to Period II of the Scandinavian Early Bronze Age or ca. 1400 B.C. In his detailed publication of this sword Randsborg gives an excellent evaluation of the evidence for Aegean-European connections.[123] He suggests a trade route through the Rhône Valley and the South of France and thence by sea to Greece, related to the course of the tin route described by Diodorus Siculus.[124]

One of the main reasons for the considerable resistance to the idea of Cornish tin in the Aegean is the belief that there were other, more accessible sources of tin that could have been utilized by Aegean metalworkers. The deposits in Brittany, which seem to have been exploited at least by the time of the West European Middle Bronze Age,[125] have to be considered in conjunction with those in southwest England. What is at issue here is the significance of the famous tin deposits in the Erzgebirge, a region that is today divided between the German Democratic Republic (D.D.R.) and Czechoslovakia.[126]

I have argued that the tin deposits of the Erzgebirge were of a hard-rock type, resulting not in the forma-

[120] Diodorus Siculus, 5.22. See the discussion by J.D. Muhly, *American Scientist* 61 (1973) 409–10. The source used by Diodorus for his account of the western tin trade was most likely the Περὶ τοῦ 'Ωκεανοῦ by Pytheas of Massalia, written and published during the time of Alexander the Great. See C.F.C. Hawkes, *Pytheas: Europe and the Greek Explorers* (The Eighth J.L. Myres Memorial Lecture, Oxford 1975) 29; I.S. Maxwell, "The Location of Ictis," *Journal of the Royal Institution of Cornwall* n.s. 6 (1972) 293–319; C.F.C. Hawkes, "Ictis Disentangled, and the British Tin Trade," *Oxford Journal of Archaeology* 3 (1984) 211–33, esp. 219–20 for the passage in Diodorus which ill. 5 is taken to illustrate.

[121] C.W. Beck, "Analysis and Provenience of Minoan and Mycenaean Amber, I," *GRBS* 7 (1966) 191–211; also Beck et al., "Analysis and Provenience of Minoan and Mycenaean Amber, II: Tiryns," *GRBS* 9 (1968) 5–19; A. Harding and H. Hughes-Brock, "Amber in the Mycenaean World," *BSA* 69 (1974) 145–72.

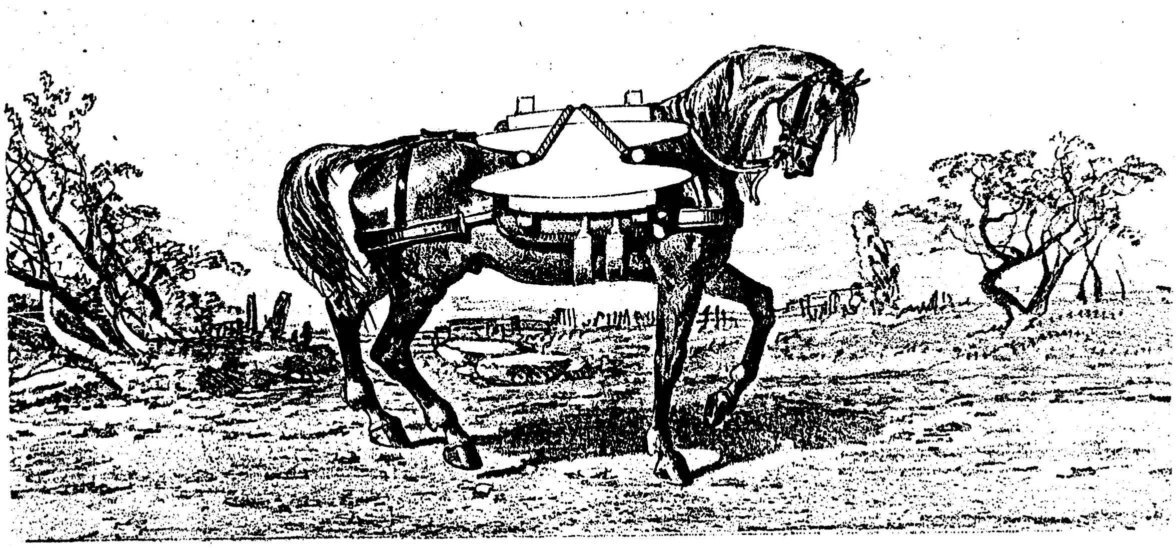
[122] For this approach, cf. J. Vladár, "Osteuropäische und mediterranische Einflüsse im Gebiet der Slowakei während der Bronzezeit," *Slovenská Archeológia* 21 (1973) 253–357; J. Vladár and A. Bartoněk, "Zu den Beziehungen des ägäischen, balkanischen und karpatischen Raumes in der mittleren Bronzezeit und die kulturelle Ausstrahlung der ägäischen Schriften in die Nachbarländer," *Slovenská Archeológia* 25 (1977) 371–431.

[123] K. Randsborg, "'Aegean' Bronzes in a Grave in Jutland," *ActaA* 38 (1967) 1–27. For arguments regarding the metallurgical significance of this find, see N. Sandars, "North and South at the End of the Mycenaean Age: Aspects of an Old Problem," *Oxford Journal of Archaeology* 2 (1983) 51–53.

[124] Randsborg (supra n. 123) 23–24.

[125] J. Briard, "Problèmes métallurgiques du Bronze Armoricain: étain, plomb et argent," in Ryan ed. (supra n. 117) 81–96, esp. p. 85; see also the papers in J. Briard ed., *Paléométallurgie de la France atlantique. Age du Bronze* 1 (Rennes 1984). I thank Professor Briard for sending me a copy of this important publication.

[126] L. Bauman, "Tin Deposits of the Erzgebirge," *Transactions, Institution of Mining and Metallurgy* 79B (1970) 68–75; H. Lange et al., "Fortschritte der Metallogenie im Erzgebirge, B. Zur Petrographie und Geochemie der Granite des Erzgebirges," *Geologie* 21 (1972) 457–89; G. Tischendorf, "The Metallogenetic Basis of Tin Exploration in the Erzgebirge," *Transactions, Institution of Mining and Metallurgy* 82B (1973) 9–24; G. Tischendorf et al., "On the Relation between Granites and Tin Deposits in the Erzgebirge, GDR," *Metallurgical Association on Acid Magmatism, Symposium* 3 (Karlovy-Vary 1978) 123–37.



Ill. 5. Artistic reconstruction of how horse could have carried two tin ingots in the shape of the one found in Falmouth harbor, Cornwall. (From H. James, *Note on the Block of Tin dredged up in Falmouth Harbour* [London 1863])

tion of alluvial or placer cassiterite but in seams of cassiterite buried in granite rock deep beneath the surface of the earth and thus not accessible to a Bronze Age prospector.[127] My main interest in the Erzgebirge has been as a possible source of tin for the Bronze Age Aegean but, as has been widely recognized, questions regarding the accessibility of Bohemian tin from the Erzgebirge have even more profound implications for the European Bronze Age.

Clearly the whole question demands a full-scale reinvestigation, from an archaeological as well as from a geological perspective.[128] The evidence does seem to indicate that there was some alluvial tin in the Erzgebirge, but the extent of these alluvial deposits still remains in doubt.[129] I still find it curious that, while alluvial tin from Cornwall is well attested throughout the entire history of the exploitation of the Cornish mines, alluvial specimens from Saxo-Bohemia are so rare that it becomes necessary to ransack seventeenth century (A.C.) mineralogical collections to come up with a few examples.[130]

I also find it puzzling that, while Cornish tin is prominent in the Graeco-Roman period, with Classical authors describing in some detail the nature of the deposits and of the overland trade route that brought said tin into the Mediterranean world, there is not one reference to tin from Germany. Roman authors have much to say about trade with Free Germany, but what came to Rome were materials such as hides, salt and amber, never tin.[131] If the tin deposits of the Erzgebirge were being exploited in ancient times, then why was such an important source never brought to the attention of Greek and Roman writers? We have literary references to tin from southern England, Brittany and Iberia, but never Germany.

In September 1978, the International Commission on the History of Technology (ICOHTEC) sponsored an international congress on the history of mining and metallurgy held at Freiberg (D.D.R.) under the auspices of the Bergakademie, the oldest academic institution in the world devoted to the history of mining, having been founded in 1765. It was the opinion

[127] Muhly (supra n. 1) 256. In the system of classification used by Taylor (supra n. 12), the Erzgebirge is a Type 1D deposit, known as an "Erzgebirge style" deposit (Taylor 56–62, 503–504). The basic feature of such a deposit is that it is batholithic and subabyssal or, in other words, deposited deep beneath the surface of the earth.

[128] S. Piggott, "A Glance at Cornish Tin," in V. Markotić ed., *Ancient Europe and the Mediterranean: Festschrift Hugh Hencken* (Warminster 1977) 141–45.

[129] A.F. Harding, "The Bronze Age in Central and Eastern Europe: Advances and Prospects," in *Advances in World Archaeology* 2 (New York 1983) 24; J.W. Taylor, "Erzgebirge Tin: A Closer Look," *Oxford Journal of Archaeology* 2 (1983) 295–98; Shell (supra n. 117) 255–56.

[130] Shell (supra n. 117) 256.

[131] O. Brogan, "Trade between the Roman Empire and the Free Germans," *JRS* 36 (1936) 195–222.

of the staff at the Bergakademie, as expressed at this meeting, that the history of Saxo-Bohemian tin was a history of hard-rock mining; they thought it unlikely that these deposits were exploited before Medieval times.[132]

Contrary to the situation in Cornwall, there are no ancient remains or artifacts associated with the mines in the Erzgebirge. The history of hard-rock tin mining in the Erzgebirge seems to go back no earlier than the twelfth century A.C. When hard-rock mining began in Cornwall, during the course of the sixteenth century A.C., the English mine owners brought in German miners, the acknowledged masters of this type of mining. Concessions were granted to these German miners, for they alone had the necessary experience and technology. The last descendant of the German mining engineers, one Eldred Knapp, died on 16 February 1956.[133]

It has often been argued that, in Book VIII of his *De Re Metallica*, published in Basel in 1556, Georgius Agricola described the exploitation of alluvial tin in the streams of the Erzgebirge. Such is not the case. Careful reading makes it clear that Agricola is dealing with the concentration of mined tin ore, following the crushing of that ore by means of an iron-shod stamping mill.[134] The one section of Agricola's work that does deal with alluvial tin streaming is, as he points out, an account describing how things were done in the ancient world and is, in fact, based upon the famous account given by Pliny the Elder of tin streaming in Lusitania and Gallaecia.[135]

This long digression on the history of tin mining in the Erzgebirge is but one example of those necessary in attempting to understand the nature of Bronze Age sources of tin. We can, at present, speak only of possible sources of Bronze Age tin. There is little that could be called hard or solid evidence and, it must be emphasized, there are no scientific or analytical data on the provenience of tin. Important work has been done within the past ten years on Bronze Age sources of lead and—through its lead content—of silver, based upon the comparative distribution of four isotopes of lead.[136] Although many problems remain to be solved, the work to date certainly has demonstrated the enormous potential of lead isotope analysis.[137] In theory it should be possible to set up a similar program for tin, but the separation of the different tin isotopes is a laboratory problem, one not yet dealt with seriously.

For Western Asia Afghanistan has emerged as the most promising source for much of the tin in use during Bronze Age times. Its deposits of gold and lapis lazuli, both materials highly prized by the Sumerians during the third millennium B.C., may have led ancient prospectors to tin, which was also then exported to Sumer.[138] It is even possible that, via Mari and Ugarit, Afghan tin was carried to Middle Minoan Crete, the land of Kaptaru.

Sources of tin in the Bronze Age Aegean remain a far greater enigma. Sardinian tin has emerged as an intriguing possibility, but modern archaeology on Sardinia is still in its infancy, and it will be some years before we can begin to understand the nature of the Sardinian metal industry.[139] The Troad has long been seen as a logical source of tin for the Bronze Age, especially the Early Bronze Age of western Anatolia and the Aegean. The problem remains the lack of any geological evidence for tin in the region. Various attempts have yet to produce so much as a single piece of alluvial cassiterite from all reported tin deposits in the area, including the most recent candidate at Soğukpınar, near Bursa.[140] Northwestern Europe still remains the most plausible source of tin for the Aegean

[132] Information from Professor Robert Maddin, one of the American delegates to the Congress. On the other hand, according to the account provided at the tin mining museum in Krupka (Czechoslovakia), which opened on 30 November 1982, the Erzgebirge was a source of tin already in the Middle Bronze Age.

[133] J.B. Richardson, *Metal Mining* (London 1974) 63–64.

[134] Georgius Agricola, *De Re Metallica* (translated by H.C. and L.H. Hoover, New York 1950) 300–18,

[135] Agricola (supra n. 134) 336–41. Agricola refers to Lusitania, modern Portugal, on p. 325. The Pliny reference is to his *NH* 34.47.

[136] Most prominent in this field of research have been Noël and Sophie Gale of the Department of Geology and Mineralogy at Oxford University. See, in particular, their article on "Cycladic Lead and Silver Metallurgy," *BSA* 76 (1981) 169–224; also "Lead and Silver in the Ancient Aegean," *Scientific American* 244.6 (1981) 176–92. Their most recent contribution on "Lead Isotope and Chemical Analyses of Silver, Lead and Copper Artefacts from Pyla-*Kokkinokremos*" appears as Appendix V in V. Karageorghis and M. Demas, *Pyla-Kokkinokremos. A Late 13th Century B.C. Fortified Settlement in Cyprus* (Nicosia 1984) 96–103.

[137] Cf. J.D. Muhly, "Lead Isotope Analysis and the Kingdom of Alashiya," *RDAC* 1983, 210–18.

[138] For the trade involved see Y. Majidzadeh, "Lapis Lazuli and the Great Khorasan Road," *Paléorient* 8.1 (1982) 59–69. Majidzadeh argues that lapis came into Mesopotamia not via the Great Khorasan Road, the ancient Silk Route, but by a southern route going across Kerman (Aratta), Fars (Anshan) and Khuzistan (Susa). A tin trade by the same route would explain the importance of Susa in the Mari letters dealing with the tin trade.

[139] A joint project on Sardinian metallurgy is now underway, involving the University of Pennsylvania (Muhly and Stech), Harvard University (Maddin), Oxford University (N. and S. Gale) and the Italian government, represented by Dr. Fulvia Lo Schiavo, of the Soprintendenza Archeologica, Sassari, Sardinia: supra n. 103.

[140] Cf. E. Pernicka et al., "Archaeometallurgy of the Troad," *Abstracts, 1984 Archaeometry Meeting* (Washington, D.C. 1984) 107. I thank Dr. Pernicka for discussing with me the research underway at Heidelberg and Mainz, on Bronze Age metallurgy and mineral resources in Greece and in Turkey.

Late Bronze Age, but any convincing solution to the problem of Aegean tin sources is only going to come through new fieldwork and the development of a comprehensive program of analysis in order to create a comparative data base.

If we make any claim to certainty regarding our knowledge of Bronze Age tin sources, we can do so only within the context of historical knowledge as defined by Leo Treitler: "The claim of certainty is no more than a claim that one will have provided the most coherent context of thought that is consistent with all of the evidence."[141]

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[141] L. Treitler, "History, Criticism, and Beethoven's Ninth Symphony," *19th Century Music* 3 (1980) 208–209. See also W.J. Bouwsma, "From History of Idea to History of Meaning," *Journal of Interdisciplinary History* 12 (1981) 279–91. I owe these references to my colleague Professor Gary Tomlinson.