Of brass and bronze in prehistoric Southwest Asia

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ABSTRACT This paper presents a review of the numerous copper-zinc alloys (e.g. brass, gunmetal) that have been found in prehistoric contexts from the Aegean to India in the 3rd to the 1st millennium BC. Through a preliminary analysis of the available data, it is argued that there is a noticeable geographical and chronological correlation between early occurrences of copper-zinc alloys, tin-bronze, and rare examples of tin and tin-based metals. This association may have important implications not only for research into the great 'tin question' of Southwest Asia, but also for research into ancient technologies in general. It is here proposed that brass may have been confused with tin-bronze by local consumers ignorant of or ambivalent about the very different mechanical properties of these two alloys, and that the linguistic separation of these two metals in the 1st millennium BC may reflect larger changes in the sociocultural categorisation of materials.

Keywords: brass, tin-bronze, gunmetal, Near East, colour, symbolism, ethnocategories.

Introduction

The alloys of copper and zinc, including brass (copper-zinc), gunmetal (copper-tin-zinc), and variants thereof, have never played a significant role in our understanding of Old World prehistory (Fig. 1). This is due in large part to their purported absence, or at best sporadic existence, in archaeological assemblages before the Greco-Roman period (Bayley 1998). Indeed, the origins of copper-zinc alloys have long been placed in Anatolia during the early 1st millennium BC (see Craddock 1978a; Forbes 1964: 268–9) – an assumption supported by and somewhat predicated on the discovery of early brass artefacts inside the Great Tumulus at the Phrygian capital of Gordion (Steinberg 1981). The fact that this tomb, labelled 'MM' or 'Midas Mound', was supposed to hold the remains of the mythical king led Dorothy Kent Hill (1969: 61) to famously suggest that perhaps the story of Midas's 'golden touch' in fact referred to the earliest production of brass – i.e. turning copper into 'gold'.

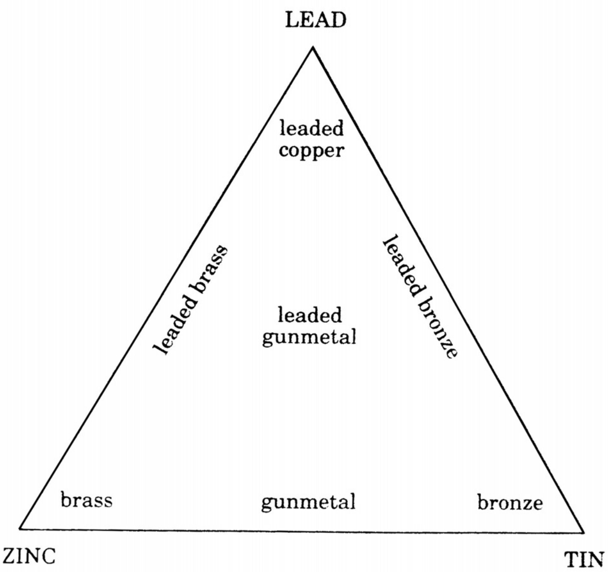

Figure 1 Ternary diagram showing the standard nomenclature for copper-zinc-tin-lead alloys (from Bayley 1998).

This narrative for the development of copper-zinc alloys in Southwest Asia has gradually changed as more examples of these yellow- or 'golden'-coloured metals have been found, both in reviewing the available literature and through further analyses. As recent papers have shown, copper-zinc alloys occur sporadically in this region as early as the 3rd millennium BC, and continue to appear intermittently until the Greco-Roman period (Craddock and Eckstein 2003; Thornton and Ehlers 2003). Having established the existence of copper-zinc alloys in prehistory, we are left with a number of pressing questions including: where are the ancient textual references to the production of brass or gunmetal or to their distribution? Why do we discover only a few copper-zinc alloys in random sites separated by thousands of kilometres despite the innumerable prehistoric artefacts that are analysed every year? Should we care, or can we simply dismiss these sporadic occurrences of copper-zinc alloys as occasional acts of technological serendipity?

In this paper, an up-to-date (i.e. prior to 2006) compilation of prehistoric copper-zinc alloys in Southwest Asia is presented in six general chronologically and spatially defined groupings in an attempt to answer these questions. Although these groupings are based on limited data, they provide us with a new perspective on the where, when and how of early brass and gunmetal exploitation. Using these data, it is argued that there is a notable correlation between the occurrence of these rare metals and the appearance and utilisation of tin-bronze, a metal that (unlike brass) has figured prominently in discussions on the development of urban civilisations in western Asia (e.g. Franklin *et al*. 1978; Muhly 1973; Parzinger and Boroffka 2003; Penhallurick 1986; Pernicka 1998; Stech and Pigott 1986; Weeks 1999). Indeed, it is proposed that by studying ancient copper-zinc alloys, we may gain not only a richer understanding of the production and utilisation of different materials in prehistoric societies, but also discover a new avenue of research into the classic question on the origins of Near Eastern tin and tin-bronze first posed over 75 years ago by V. Gordon Childe (1928). For this reason, it is suggested that copper-zinc alloys are perhaps of greater importance than has long been assumed, and should begin to receive the scholarly attention that they are due.

Of brass

Before delineating the six general groupings mentioned above, it is important to understand the basic processes through which copper-zinc alloys could have been produced in antiquity. As numerous scholars have argued, the production of copper-zinc alloys is more complicated than the creation of other copper-based alloys (Craddock 1998a; Pollard and Heron 1996: 196–204). This is due to the volatility of zinc above 906 °C, which is below the temperature at which zinc will reduce from its ores. Thus any attempt to smelt zinc ores causes zinc to sublimate (vaporise) (Forbes 1964: 263). Under extreme reducing conditions the gaseous zinc will condense along the inner wall of the furnace as zinc metal – a process known as distillation. If air is present – and most ancient furnaces were not designed to be completely airtight – then the zinc vapour condenses along the inner furnace lining in the form of zinc oxide (calamine). Given that distillation apparatuses capable of producing great quantities of metallic zinc were virtually unknown (or at least unused) before historical periods, the zinc had to be added either as a vapour to solid copper through a process known as cementation, or through a specially controlled mixed smelting of zinc and copper oxides. While the actual mechanism through which zinc enters the copper is essentially the same for the two processes, the outlook and the set of choices made by the metalworker is inherently different.

The crucial ingredient in both processes is zinc oxide, which can be found in its natural state as the ore smithsonite ($ZnCO_3$; aka calamine or zinc spar) or sublimated and oxidised by intentionally roasting zinc-sulphide ores such as sphalerite (ZnS; aka zincblende) or zinc-containing fahlerz.[1] Zinc oxide, or even droplets of zinc metal under extreme reducing conditions (cf. 'mock silver' or 'false silver') can also be created accidentally when zinc ores get mixed up with copper or iron ores in a smelt, or with argentiferous lead ores during the production of lead or silver (Craddock and Eckstein 2003: 217–18). In most cases, zinc oxide would be found by the metalworker as a white powder clinging to the inner lining of the furnace walls or in the flue (cf. Wertime 1980: 15). Given the rarity of naturally occurring zinc oxide ores in the Middle East and the ubiquity of mixed zinc-lead sulphide deposits, accidental production in a furnace seems highly probable as the source of ancient zinc oxide.[2] The presence of lead slags bearing significant quantities of zinc at sites such as 3rd-millennium BC Tepe Hissar in northeastern Iran (2.3–14.0 wt% zinc)[3] and 1st-millennium BC Balya in northwestern Anatolia (3.2–30.3 wt% zinc) would seem to confirm this association (Pernicka *et al.* 1984; Pigott *et al.* 1982).

After producing or obtaining zinc oxide, the next step is to create a copper-zinc alloy by separating the zinc from the oxide through sublimation while adding it to copper before it re-oxidises. For the purposes of this paper, an 'alloy' is defined as the *intentional* admixture of two or more elements in order to create a distinct material with certain desired physical properties. Thus, while under extreme reducing conditions the accidental smelting of mixed ores or high-zinc copper ores can produce copper metal with as much as 6–7 wt% zinc (see Pollard and Heron 1996), this is not an intentional alloy per se. Certainly this type of low zinc copper-base metal has some desirable physical differences from pure copper that may or may not have been noticed by the metalworker. Intentionality is not certain, however, especially if we are only confronted with isolated examples – for example the Early Cycladic dagger from Amorgos with 5.1 wt% zinc or the Middle Bronze Age axe from Beth-Shan with 6.5 wt% zinc mentioned by Craddock (1978a: 2). The addition of greater than ~8 wt% zinc produces a metal with at least one unmistakable characteristic – its golden colour – which, even if created fortuitously the first time, probably could have been reproduced if desired. Therefore, copper-zinc alloys will be defined for this paper somewhat arbitrarily as containing greater than ~8 wt% zinc.

Before the intentional production of zinc metal through distillation processes, which according to texts seems to have begun in India in the late 1st millennium BC (Craddock *et al.* 1998), there were two basic ways to create copper-zinc alloys. The first is the cementation method, in which zinc oxide is mixed with pieces of copper metal and charcoal in a tightly closed crucible, heated above 906 °C in order to vaporise the zinc and allow it to diffuse into the solid copper, before then introducing a final stage of raised temperature to melt the metal and thereby homogenise the mixture (Bayley 1998: 9–10). According to recent thinking (see Craddock and Eckstein 2003: 223–6), the temperature range was probably closer to 1000–1100 °C during Roman times, which would have produced in one step a molten copper-zinc alloy of 20–28 wt% zinc. Thilo Rehren (1999: 1085) has argued for a lower temperature range (*c.* 900–1000 °C) based on the material properties of early ceramic crucibles, while Jean-Marie Welter (2003) has suggested an upper limit of zinc uptake closer to 38–40 wt%. The amount of zinc in the resulting metal would also be significantly depleted if insufficient amounts of calamine were added to the mixture or if the base copper contained impurities such as tin or lead. In any case, subsequent melting of the copper-zinc alloy (or re-melting of scrap metal) would invariably cause the loss of about 10% of the zinc present in the alloy[4] (Caley 1964).

The other way to achieve a copper-zinc alloy using zinc oxides, and the one perhaps more likely to have produced the prehistoric examples discussed in this paper, is through a mixed-ore smelting process. This method has been demonstrated by many scholars including Sun and Han (1983–85: 268), who managed to create copper-zinc alloys with up to 34 wt% zinc by mixing chemically pure zinc oxide (ZnO) and cuprous oxide (Cu_2O) (1:1) in a graphite crucible. Of course, this was a modern smelting experiment and one not necessarily representative of ancient processes, but it should be noted that they also produced copper-zinc alloys (up to

18 wt% zinc) by smelting a mixture of naturally occurring malachite ($Cu_2(OH)_2CO_3$) and leaded smithsonite. The efficacy of the mixed-ore smelting method was also supported by the work of Rostoker and Dvorak (1991), who produced a copper-zinc alloy of 10.5 wt% zinc by smelting zinc oxide with malachite in an open crucible, although they note that the zinc uptake would have been higher with a closed crucible. Although we do not as yet have a means of distinguishing these two general methods of copper-zinc alloy production using only the artefacts themselves, the mixed-ore smelting method (which here includes the mixture of copper ores with manmade zinc oxide) seems more likely to have been utilised, given what we know about prehistoric metallurgical processes in Southwest Asia.

Early copper-zinc alloys in Southwest Asia

Having delineated the possible means of copper-zinc alloy production in antiquity, it is time to turn to the evidence itself. As presented in Table 1, there are over 30 examples of prehistoric and protohistoric artefacts from Southwest Asia containing over 8 wt% zinc that have been reported in the literature. Also included are a number of artefacts containing 5–8 wt% zinc that may or may not be intentional alloys, but which are included here for the sake of reference. Notable finds east of the general area of Southwest Asia include the isolated and contested examples of copper-zinc alloys from the Yangshao and Longshan periods in central and eastern China (*c.* 4th–3rd millennia BC) (see An 2000; Han and Ko 2000; Mei and Li 2003: 112; Sun and Han 1983–85). In addition, there are two leaded gunmetal artefacts from Atranjikhera, an early/mid-1st millennium BC site in the Upper Ganga Basin of northern India (Gaur 1983), which precede the leaded brass vessels from Taxila in northern Pakistan (4th century BC) and Begram in the Kabul valley of Afghanistan (2nd century BC) (Craddock *et al.* 1998: 27). While the Chinese examples remain suspect because of their extreme discordance with the development of Chinese metallurgy as we understand it, the finds from Atranjikhera and elsewhere on the Indian subcontinent coincide with (or slightly predate) the earliest textual references to brass and possibly even zinc metal from this region (Craddock *et al.* 1998; see also Rau 1974).

Contemporary with the Indian examples, there are also sporadic examples of copper-zinc alloys from the Hellenistic world as well as textual references to *oreichalkum* ('copper of the mountain'; cf. Latin *aurichalcum* or 'golden copper'),[5] beginning as early as the 7th century BC (see Craddock 1998b; Craddock *et al.* 1980). Also of note from Europe are the 3rd-century BC Etruscan statues analysed by Craddock (1978b) that contain 11.5 and 11.8 wt% zinc (and 0.68–3.0 wt% tin respectively), the 6th-century BC pin with 9.9 wt% zinc from a Phoenician tomb in Cadiz, Spain (Montero-Ruiz and Perea, this volume, p. 136) and the pre-Roman iron sword with the maker's stamps in brass (*c.* 15–20 wt% zinc) from Syon Reach outside London now dated to the 2nd century BC (Craddock *et al.* 2004).[6] These examples join the list of 21 prehistoric copper-zinc alloys compiled by Caley (1964: 3–8) in contesting the widely held belief that copper-zinc alloy production spread throughout Europe with the Roman conquests.

As stated above, the data from Southwest Asia can be grouped loosely into six spatially and chronologically definable clusters that predate the advent of the consistent utilisation of copper-zinc alloys in the late 1st millennium BC (Fig. 2). The first of the six groupings (Group 1) is located in the eastern Aegean region during the first half of the 3rd millennium BC and includes the eight copper-zinc alloys presented by Stos-Gale (1992) and Begemann *et al.* (1992) from the site of Thermi on the island of Lesbos. Here one or two examples of copper-zinc alloys (*c.* 5–17 wt% zinc) were found in almost every stratigraphic phase of the site, which is generally asso-

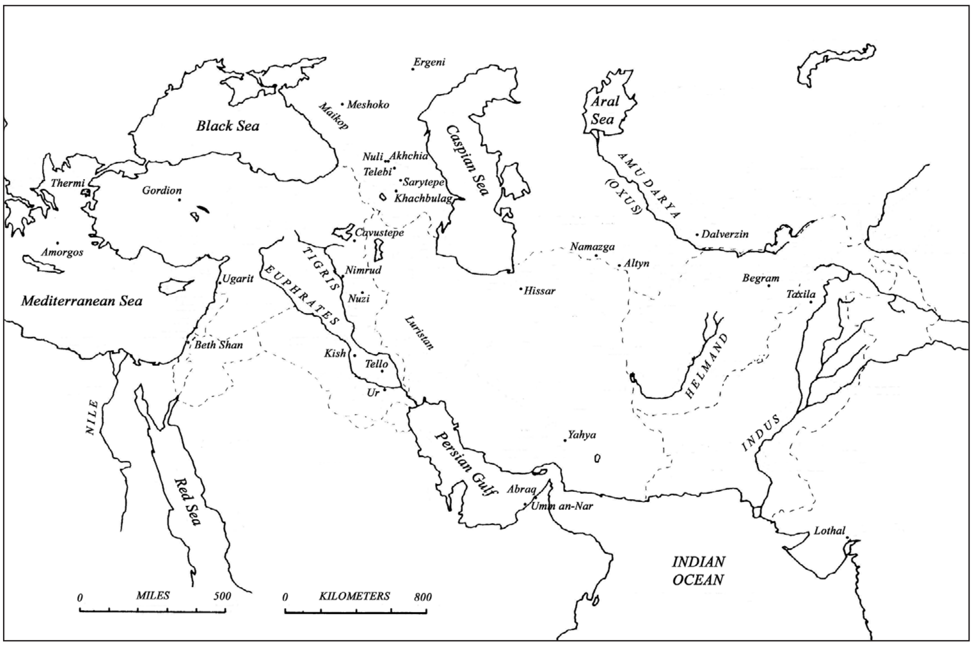

Figure 2 Map showing the major sites discussed in the text.

Table 1 Early copper-zinc alloys from Southwest Asia.

					Composition (wt%)				
Site (level)	Location	Type	Time	Method	Sn	Zn	Pb	Other	Reference
GROUP 1									
Thermi (I-II)	Lesbos	pin	early 3rd mill. BC	XRF		6.8	3.9	Sb: 4.22	Stos-Gale 1992
Thermi (I-II)	Lesbos	pin	early 3rd mill. BC	XRF	0.3	6.2	3.4	Sb: 0.9	Stos-Gale 1992
Thermi (II)	Lesbos	knife	early 3rd mill. BC	XRF/INAA		10.9			Stos-Gale 1992
Thermi (II-III)	Lesbos	pin	early 3rd mill. BC	XRF/INAA		6.6	9.2		Stos-Gale 1992
Thermi (IIIa)	Lesbos	pin	early 3rd mill. BC	XRF/INAA	4.2	5.1		Ag: 1.3	Begemann *et al.* 1992
Thermi (IIIb)	Lesbos	pin	mid-3rd mill. BC	XRF/INAA		8.5		As: 2.8	Begemann *et al.* 1992
Thermi (P.P.)	Lesbos	ornament	mid-3rd mill. BC	XRF/INAA	2.2	10.3	0.7		Begemann *et al.* 1992
Thermi (V)	Lesbos	pierced disk	mid-3rd mill. BC	XRF/INAA	9.2	16.9			Begemann *et al.* 1992
GROUP 2									
Kish (EDIII)	S. Iraq	toilet-knife #577	mid/late 3rd mill. BC	XRF		14.0	0.6	As: 2.3	Hauptmann and Pernicka 2004
Kish (EDIIIb-Akk)	S. Iraq	bowl #461	mid/late 3rd mill. BC	XRF	8.8	14.3		Fe: 3.6	Hauptmann and Pernicka 2004
Kish-Ingarra (?)	S. Iraq	bowl #456	mid/late-3rd mill. BC?	XRF	9.1	7.2		As: 1.3	Hauptmann and Pernicka 2004
Girsu/Tello (EDIII)	S. Iraq	blade rivet #849b	mid/late 3rd mill. BC	XRF	1.0	6.0	10.7	As: 1.7, Fe: 1.2	Hauptmann and Pernicka 2004
Ur (EDIIIb)	S. Iraq	bowl #1048	mid/late 3rd mill. BC	XRF	13.5	6.8		Fe: 1.0	Hauptmann and Pernicka 2004
Ur (EDIIIb-Akk)	S. Iraq	bowl #1057	mid/late 3rd mill. BC	XRF	12.2	5.8			Hauptmann and Pernicka 2004
Ur (EDIII-NeoSum)	S. Iraq	dagger #1474	mid/late 3rd mill. BC	XRF	5.0	7.1	2.0	As: 3.1	Hauptmann and Pernicka 2004
Ur (EDIII?)	S. Iraq	helm #2067	mid/late 3rd mill. BC	XRF		10.7	0.4	Fe: 2.2; As: 0.9	Hauptmann and Pernicka 2004
GROUP 3									
Ergeni	Kalmykia	knife	mid/late 3rd mill. BC	OES		11.0			Egor'kov *et al.* 2004
Ergeni	Kalmykia	hook	mid/late 3rd mill. BC	OES		8.0			Egor'kov *et al.* 2004
Telebi	E. Georgia	blade	late 3rd mill. BC?	OES?		6.6		As: 2.3	Kavtaradze 1999
Nuli	N. Georgia	discoid pin	late 3rd mill. BC?	OES?		5.7	0.4	As: 4.5	Kavtaradze 1999
Akhchia (kurgan 3)	N. Georgia	twisted tube'	late 3rd mill. BC?	OES?	5.8	5.2	1.3		Kavtaradze 1999
Namazga	S Turkmenistan	needle	late 3rd mill. BC	OES		24.7			Egor'kov 2001: 87
Namazga	S Turkmenistan	seal	late 3rd mill. BC	OES		14.8			Egor'kov 2001: 87
Altyn depe (1966)	S Turkmenistan	blade	late 3rd mill. BC	OES	6.6	16.0	12.0	As: 2.2; Fe: 1.6	Egor'kov 2001
Altyn depe (1967)	S Turkmenistan	blade	late 3rd mill. BC	OES	6.5	<6.0	8.5	Fe: 1.0	Egor'kov 2001
Altyn depe	S Turkmenistan	ring	late 3rd mill. BC	OES	1.0	7.0			Egor'kov 2001
Dalverzin	S Uzbekistan	ring	early 2nd mill. BC	OES		25.0		Ni: 10	Bogdanova-Berezovskaja 1962
Dalverzin	S Uzbekistan	pin	early 2nd mill. BC	OES	1-5	15-18		Fe: >5	Bogdanova-Berezovskaja 1962
GROUP 4									
Umm an-Nar	UAE	dagger	late 3rd mill. BC	XRD		10.0			Frifelt 1991
Umm an-Nar	UAE	fragment	late 3rd mill. BC	AAS/XRD		8.6			Frifelt 1991
Tepe Yahya (IVA)	SE Iran	bracelet	early 2nd mill. BC	EMPA/ICP-MS		19.4	0.9		Thornton *et al.* 2002
Tepe Yahya (IVA)	SE Iran	ribbon	early 2nd mill. BC	EMPA/ICP-MS	0.3	17.0			Thornton *et al.* 2002
Tepe Yahya (IVA)	SE Iran	fragment	early 2nd mill. BC	EMPA/ICP-MS	0.8	16.9	1.8		Thornton *et al.* 2002

Site (level)	Location	Type	Time	Method	Composition (wt%) Sn	Zn	Pb	Other	Reference
GROUP 5									
Ugarit	NW Syria	ring	*c.* 1400 BC	OES/XRF/EMPA	~3	~12	~1-2	As: ~1	Schaeffer-Forrer *et al.* 1982
Ugarit	NW Syria	statuette	mid-2nd mill. BC	OES/XRF/EMPA		~12			Schaeffer-Forrer *et al.* 1982
Nuzi (II)	NE Iraq	ring	*c.* 1350 BC	INAA/ICP	0.4	14.4	4.7		Bedore and Dixon 1998
Nuzi (II)	NE Iraq	ring	*c.* 1350 BC	INAA/ICP	6.3	12.2	3.4		Bedore and Dixon 1998
GROUP 6									
Khachbulag	W Azerbaijan	bracelet	early 1st mill. BC	OES	0.6	10.4			Kashkai and Selimkhanov 1973
Sarytepe	NW Azerbaijan	arrowhead	early 1st mill. BC	OES		9.4			Kashkai and Selimkhanov 1973
Sarytepe	NW Azerbaijan	figurine	early 1st mill. BC	OES	10.2	8.0		As: 2.0	Kashkai and Selimkhanov 1973
Luristan Bronze	W Iran	pin head	early 1st mill. BC	EMPA-WDS	10.6	8.4	1.9		Northover 1997
Luristan Bronze	W Iran	brooch	early 1st mill. BC	EMPA-WDS	2.6	8.2	1.1		Northover 1997
Nimrud	N Iraq	bowl	9th century BC	AAS	8.4	6.4			Hughes *et al.* 1988
Nimrud	N Iraq	bowl	9th century BC	AAS	7.8	5.5			Hughes *et al.* 1988
Cavustepe	NE Anatolia	bracelet	8th century BC	SEM-EDAX		11.0		S: 1.8	Geckinli *et al.* 1986
Gordion (MM)	cent Anatolia	fibulae	8th century BC	OES	10.0	>10		Fe: 3.7	Young 1981: 287
Gordion (MM)	cent Anatolia	fibulae	8th century BC	OES	15.6	>10			Young 1981: 287
Gordion (MM)	cent Anatolia	fibulae	8th century BC	OES	6.3	>10		Fe: 3.8	Young 1981: 287
Gordion (MM)	cent Anatolia	fibulae	8th century BC	XRF	3.0	8.5	3.5		Young 1981: 290
Gordion (MM)	cent Anatolia	bowl	8th century BC	XRF	4.0	12.0	2.0		Young 1981: 290
OTHER									
Amorgos	Cyclades	dagger	mid-3rd mill. BC	OES?		5.1	0.5		Renfrew 1967
Sanlihe	E China	awl	mid/late 3rd mill. BC	EMPA	av 1.8	av 23.4	av 2.8		Sun and Han 1983-85
Lothal	W India	fragment	early 2nd mill. BC	unknown		6.0		Fe: 0.9	Rao 1985
Beth Shan	N Israel	axe	early 2nd mill. BC	unknown	8.4	6.5	1.2		Oren 1971
Atranjikhera	N India	unknown	early 1st mill. BC	unknown	11.7	6.3	9.0	Fe: 1.9	Gaur 1983
Atranjikhera	N India	pin	early/mid-1st mill. BC	unknown	20.7	16.2	9.8	Fe: 1.2	Gaur 1983

XRF = X-ray fluorescence; INAA = instrumental neutron activation analysis; OES = optical emission spectroscopy; XRD = X-ray diffraction; AAS = atomic absorption spectroscopy; MS = mass spectroscopy; PA = performance analysis; ICP = inductively coupled plasma analysis; EMPA = electron microprobe analysis; WDS = wavelength dispersive X-ray spectroscopy; SEM = scanning electron microscopy; EDAX = energy-dispersive X-ray analysis ciated with the Troy I–early II periods or *c.* 3000–2500 BC (Pernicka *et al.* 2003). These artefacts, most of which were pins and other ornaments, often included other elements in significant quantities besides zinc, including arsenic (<2.8 wt%), tin (<9.2 wt%), lead (<9.2 wt%), and antimony (<4.2 wt%). These examples are quite isolated in that no other copper-zinc alloys are yet known from related sites in the region nor, indeed, from anywhere else at this date. Troy I–II period sites in the Troad and on the eastern Aegean islands of Lemnos, Lesbos, Chios, etc. however, are notable for the early (and often consistent) use of a wide array of metals including silver, gold, lead and tin, as well as copper alloyed with arsenic, zinc, tin, lead, silver, and antimony (Muhly 2002; Pernicka *et al.* 2003). It is also significant to note that the mines of Argenos on the northern shore of Lesbos contain deposits of copper oxides and sulphides as well as lead and zinc sulphides (Pernicka *et al.* 2003: 153).

The second group of copper-zinc alloys comes from the recent publication of the Frühe Metalle in Mesopotamien project at the University of Heidelberg, which presents the chemical analyses of nearly 3000 artefacts from southern Mesopotamia (Hauptmann and Pernicka 2004). Of these, only eight artefacts, dated to the mid/late 3rd millennium BC, contained greater than 8 wt% zinc, while an additional seven were found to contain between 6 and 8 wt% zinc. If we consider those artefacts analysed only on the surface patina by X-ray fluorescence (XRF) as potentially contaminated and focus specifically on drilled samples, however, then we are left with a helm, a toiletry article and a bowl with 10.7, 14.0 and 14.3 wt% zinc respectively, as well as five other artefacts containing 6–8 wt% zinc. It is worth noting that a number of these examples also contain significant levels of tin, arsenic and/or iron, but show a relative dearth of lead in all but one or two cases. Hopefully, future publications of the Heidelberg analyses of northern Mesopotamian artefacts and the long-awaited Mesopotamian Metals Project of the University of Pennsylvania will provide further prehistoric examples of copper-zinc alloys from this region.

The third grouping of reported copper-zinc alloys comes from the circum-Caspian region, notably from sites in the northern and southern Caucasus and southern Central Asia during the second half of the 3rd millennium BC. Unfortunately, most of the examples from the southern Caucasus and southern Central Asia can only be considered tentatively until further analyses have been conducted. For example, the two copper-zinc alloys from Namazga-depe in southern Turkmenistan, analysed in the 1950s and discussed by Egor'kov (2001: 87), were unstratified finds, as were the blade and the ring from Altyn-depe.[7] In addition, many of the spectrographic analyses performed in the 1960s have been shown to be questionable, such as the Altyn-depe blade that was reported to contain 16 wt% zinc when first analysed in 1966, but which upon re-analysis in 1967 was found to contain less than 6 wt% zinc (Egor'kov 2001). The copper-zinc alloys analysed by Bogdanova-Berezovskaja (1962) from late 3rd/early 2nd millennium BC Dal'verzin in Uzbekistan must also be regarded with a critical eye for these same reasons.

Fortunately, the nine copper-zinc alloys from kurgans at the site of Ergeni ('Yergueni') in northern Kalmykia (*c.* 2500–2200 BC) first reported by Gak (2004) are not as contentious, because the metal artefacts were analysed in the past few years and the burials have been radiocarbon dated (Egor'kov *et al.* 2004). Although the zinc content in these artefacts is relatively low (1.3–5.6 wt% zinc), excluding the dagger (11 wt% zinc) and the hook (8 wt% zinc), it is undoubtedly significant that the other 31 contemporary copper artefacts analysed from this region contain considerable amounts of arsenic (<6.4 wt% arsenic, average: 3.0 wt% arsenic), an element which is missing from the nine artefacts mentioned above (average: 0.2 wt% arsenic) (Egor'kov *et al.* 2005). This may suggest that low zinc brass was being produced at, and imported from, an area not utilising arsenic-bearing copper. Alternatively, zinc was being added intentionally to pure copper (through cementation or mixed-ore smelting, as discussed above) by metalworkers (either locally or elsewhere) who perhaps recognised that zinc uptake is hindered by the presence of other alloying elements in the copper such as arsenic, lead and tin (Craddock *et al.* 1980: 60; Ponting 2002: 559–60). It is worth mentioning that Chernykh (1992: 66) reports a 3rd-millennium BC zinc metal ornament from the Maikop site of Meshoko also in the northern Caucasus, which (if authentic) may force us to reconsider the possible methods for early copper-zinc alloy production.

The fourth grouping of prehistoric copper-zinc alloys appears in the eastern Persian Gulf region in the late 3rd/early 2nd millennium BC in the cemetery of Umm an-Nar, United Arab Emirates (UAE), and at the village site of Tepe Yahya, Iran. At the former site, the copper-zinc alloys include a dagger (10 wt% zinc) and a fragment (8.6 wt% zinc) as well as six other fragments with 2.3–4.7 wt% zinc. All appear to be similar to the Ergeni examples in being relatively low zinc brasses that were made with fairly pure copper as the base metal (Frifelt 1991: 100). Given that 3rd-millennium BC raw copper and copper ingots from eastern Arabia generally have 60–600 ppm zinc (Weeks 2003: 85), the numbers from Umm an-Nar are significant and suggest (as at Ergeni) either importation of zinc-rich copper metal or the intentional production of low zinc brasses, perhaps through open-crucible smelting of zinc and copper oxides. Unfortunately, the few artefacts analysed from the Umm an-Nar cemetery were all fairly corroded and should perhaps be re-analysed, especially in light of the fact that the contemporary artefacts from the associated settlement contained less than 40 ppm of zinc (Hauptmann 1995).

The three copper-zinc ornament fragments from a domestic context at Tepe Yahya IVA (*c.* early 2nd millennium BC) have been reported in detail elsewhere and need not be repeated here (see Thornton and Ehlers 2003; Thornton *et al.* 2002). In general, these artefacts have higher zinc contents than at Umm an-Nar (and are less corroded) and show mixing with small amounts of lead and tin, perhaps suggestive of the recycling of scrap metal. Given the close cultural relations between southeastern Iran and the eastern Arabian Peninsula during the late 3rd millennium BC (see for example Lamberg-Karlovsky and Potts 2001; Méry 2000), the discovery of copper-zinc alloys in both regions is perhaps not surprising. Furthermore, the corroded fragment with ~6 wt% zinc found at the contemporary Late Harappan site of Lothal in Gujarat (Rao 1985: 660), which had significant trade relations with the eastern Persian Gulf region during this period (see Cleuziou and Tosi 2000; Frenez and Tosi 2005), may suggest a wider range for early copper-zinc alloys than previously thought.

The fifth grouping of prehistoric copper-zinc alloys occurs in two mid-2nd millennium BC sites in northern Mesopotamia. Schaeffer-Forrer *et al*. (1982) report two artefacts from Ugarit in western Syria that contain roughly 12 wt% zinc, including a ring with a Hittite-style stamp seal and an Egyptian-style zoomorphic statuette, both of which purportedly date to *c*. 1400 BC. The statuette, however, was not found in good context and can only be dated based on art-historical arguments. Contemporary to these pieces, Christine Ehlers analysed two rings from the destruction layer (*c*. 1350 BC) at Nuzi (Yorgan Tepe) in northeastern Iraq that proved to be leaded copper-tin-zinc alloys with 12.2–14.4 wt% zinc (see Bedore and Dixon 1998; Thornton and Ehlers 2003). The fact that these rings from Ugarit and Nuzi are the earliest substantiated copper-zinc alloys from northern Mesopotamia may suggest that more quotidian artefacts (instead of elite funerary goods) need to be analysed from earlier periods.

The final grouping occurs mainly in the region combining eastern Anatolia, northern Iraq, the southern Caucasus and western Iran in the early 1st millennium BC. There are substantially more examples from this grouping than from the previous five, but some are of questionable authenticity. For example, the horn of the unprovenanced Urartian tin-bronze bull head that was said to be 'a copper-tin-zinc alloy with relatively high concentration of Cr'[8] as reported by Hanfmann (1956: 207) has been found through recent XRF and inductively coupled plasma (ICP) analyses to contain merely traces of zinc.[9] Also unprovenanced (and therefore suspect) are the 'Luristan Bronze' pinhead and brooch analysed by Northover (1997) and found to contain just over 8 wt% zinc. On the other hand, these unprovenanced finds are roughly contemporary with excavated examples of copper-zinc alloys, including a twisted bracelet from the Urartian site of Cavustepe near Van in eastern Turkey containing 11 wt% zinc (Geckinli *et al*. 1986) and three excavated artefacts from Azerbaijan containing 8–10.4 wt% zinc (Kashkai and Selimkhanov 1973; see also Gasanova 2002; Schachner 2005). Also of note are the two 9th-century BC Assyrian bowls from Nimrud containing significant tin and what may be significant levels of zinc (5.5–6.4 wt%) (Hughes *et al*. 1988).

The most famous copper-zinc alloys from the first half of the 1st millennium BC come from just west of this core region at the aforementioned site of Gordion in central Anatolia. Here, three fibulae from the Great Tumulus[10] ('MM') were found to contain >10 wt% zinc as reported by Steinberg (1981: 286–9; see comment in Craddock and Eckstein 2003: 216). In addition, a fourth fibula and a bowl containing 8 and 12 wt% zinc, respectively, were also found in the Great Tumulus and analysed by W.J. Young in 1956 (in Young 1981: 289–90). Although the Greeks attributed the invention of copper-zinc alloys to the Phrygians, it is important to stress that Gordion was simply the last in a series of prehistoric and protohistoric Southwest Asian sites to consume, if not produce, these metals. Phrygia may even have imported these alloys or at least the technology from the core region to the east designated here in the sixth grouping.

Of bronze

The growing list of reported prehistoric copper-zinc alloys presented above does not on its own provide any reasonable answers. While it seems quite likely that many of these copper-zinc alloys were being produced by a mixed-ore smelting method as opposed to cementation, this cannot be substantiated or refuted at present. Furthermore, where and when these rare alloys were being produced and by and for whom are all questions that remain to be answered. When juxtaposed with the relevant dataset for exploring the origins of tin and tin-bronze in the greater Near East, however, an intriguing pattern emerges that may hopefully provide some answers or, at least, some new ways of looking at the question.

As mentioned above, sites in the eastern Aegean witnessed an explosion of new metallic alloys during the Troy I–II periods (3000–2500 BC). All of these new metals, however, including the early copper-zinc alloys from Thermi, have been greatly upstaged in the literature by the early examples of tin-bronze known from the Troy I period at Thermi and recently discovered at the Troad site of Besik-Yassitepe (Begemann *et al*. 2003). Of perhaps even greater significance for the 'tin question' was the discovery of one of the earliest objects made of tin-base metal (also containing 22.7 wt% iron) from Thermi IV in the mid-3rd millennium BC (Begemann *et al*. 1992). It is also interesting to note that three of the four copper-zinc alloys reported from the later periods at Thermi (III–V) are actually made of gunmetal containing 2.2–9.9 wt% tin, which is a metal that remains prevalent throughout the entire sequence of early copper-zinc alloys.

Although uncertain about the origins of these early tin-bronzes and, perhaps by extension, the early copper-zinc alloys, Pernicka *et al*. (2003: 165–7) suggest an importation of tin metal from Central Asia based upon lead isotope data and the excavation of jade and nephrite axes at Troy. It seems equally likely that the Troad tin was coming from southeastern Europe, given the evidence for late 5th/early 4th-millennia BC tin-bronze artefacts and slag from this region (see Glumac and Todd 1991). The evidence for tin-bronze in this region continues into late 4th/early 3rd-millennia BC contexts such as the multiple artefacts from Sitagroi IV–V (Renfrew and Slater 2003) and the dagger from Velika Gruda, Montenegro (Primas 2002). It should be noted, however, that there are no reported copper-zinc alloys from prehistoric contexts in southeastern Europe, although perhaps future analyses will prove otherwise.

The Caucasus region provides another interesting, although less direct, association between brass and bronze. If we follow Kavtaradze (1999) in doubting the reported context of the two tin-bronzes found at Delisi in Georgia (*c*. early 4th millennium BC), then the earliest confirmed copper-tin alloys are the spiral ring with 10.2 wt% tin recently analysed by Laura Tedesco (2006)[11] from a tomb in Armenia dated to the late 4th millennium BC. There are also the tin-bronzes from graves at Velikent, Daghestan, reported by Kohl (2002) dating to the 3rd millennium BC (see also Chernykh 1992: 123–4). These dates coincide with the first reports of zinc appearing as a significant trace element (<2.5 wt%) in tin-bronzes from Kura-Araxes sites as well as the Meshoko zinc ornament discussed above (Chernykh 1992: 66). Tin-bronze becomes more widespread, however, during the second half of the 3rd millennium BC within the Sachkhere and Bedeni cultures of Georgia (Kavtaradze 1999), where purportedly numerous cases of arsenical copper and tin-bronze artefacts are said to contain up to ~5 wt% zinc (Chernykh 1992: 109).[12] It is particularly interesting to note that Chernykh (1992: 121) states that copper-tin-zinc 'alloys' (i.e. tin-bronzes with appreciable amounts of zinc) are specific to the Bedeni culture of eastern Georgia and are not found in the northern Caucasus. Although we must wait until these data are published in order to be entirely certain of the accuracy of these propositions, this statement does correspond well with the lack of tin in contemporary copper-zinc alloys from Ergeni mentioned above.

A third example of this interrelationship between copper-zinc alloys and the 'tin question' is to be found on both sides of the lower Persian Gulf region. As Weeks (1999, 2003) has shown, tin begins to appear as a minor but significant element (0.5–2.0 wt%) in eastern Arabian copper-based artefacts in the mid-3rd millennium BC, before blossoming into true tin-bronzes (>2 wt% tin) in the later 3rd millennium BC. This transition is contemporary with the appearance of the copper-zinc alloys at Umm an-Nar discussed above as well as with the earliest appearance of tin metal in the region in the form of a tin ring from a grave at Tell Abraq (Weeks 2003: 123). Intriguingly, this sequence of copper with minor amounts of tin transitioning to actual tin-bronzes and early brasses is paralleled almost exactly in southeastern Iran at Tepe Yahya.[13] There tin first appears as a minor element in the late 3rd millennium BC (Yahya IVB) before tin-bronzes, the three brasses mentioned above (two of which contain small but significant amounts of tin), and a lead-tin bangle appear in the early 2nd millennium BC (Yahya IVA) (Thornton *et al.* 2005).

Perhaps the most interesting examples that support an association between copper-zinc and copper-tin alloys in prehistory are the consistent copper-zinc-tin alloys that appear in these early periods. From Thermi to Gordion, roughly two-thirds of all the copper-zinc alloys listed in Table 1 and mentioned above contain appreciable amounts of tin, while roughly a half could qualify as 'tin-bronzes' in their own right (i.e. >1–2 wt% tin). This is reminiscent of the controlled mixing of copper, zinc and tin so prevalent during the Roman period (Bayley and Butcher 2004; Craddock 1978a), although markedly different in that prehistoric gunmetal appears to have been produced haphazardly with little regard for (or control of) the alloying process (Fig. 3). Indeed, it is not until the early 1st millennium BC (i.e. 'Group 6'), when almost all of the artefacts contain roughly 8–12 wt% zinc, that the amount of zinc seems to have been somewhat standardised, although the amount of tin in these same artefacts remains haphazard at best.

It may seem reasonable to suggest that prehistoric gunmetal was produced accidentally, perhaps as a result of the recycling of scrap metal for the manufacture of jewellery and other trinkets. If this is true, then why do we find only tin being alloyed with copper and zinc, and not more copper-arsenic-zinc or copper-antimony-zinc alloys? Indeed, the mixing of tin and zinc in copper is not an obvious combination from an archaeometallurgical standpoint, as tin and zinc are rarely found in the same geologic contexts and the presence of tin in copper will reduce the uptake of zinc twice as much as the presence of other alloying elements such as lead[14] (Craddock *et al.* 1980: 60; Ponting 2002: 560). How, then, are we to make sense of prehistoric gunmetal, which on the one hand seems to be haphazardly (perhaps serendipitously) produced, while on the other hand appears to have been intentionally associated with copper-tin alloys and tin metal?

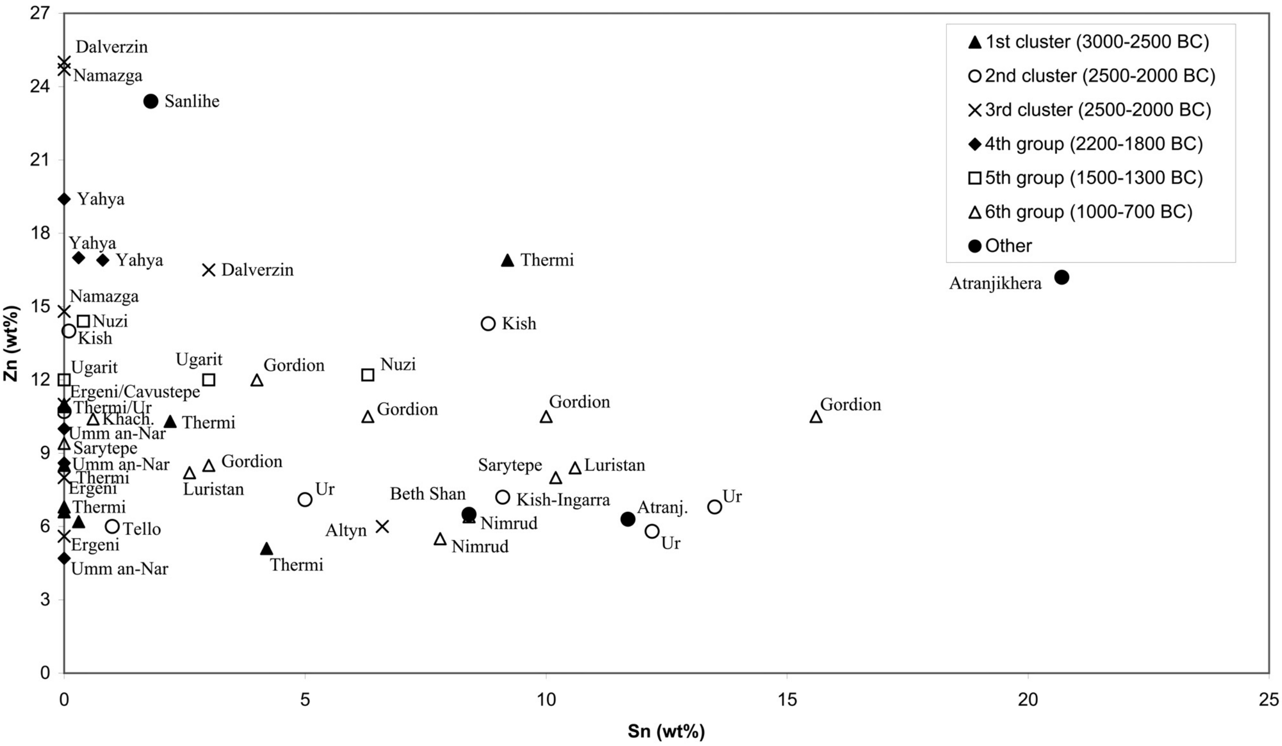

Figure 3 Scatter-plot showing the zinc vs. tin compositions (in wt%) of the various copper-zinc alloys mentioned in the text. The lack of a definable correlation between the tin and zinc contents suggests an uncontrolled or unintentional production of these alloys

Of aurichalcum: a case of technological ethnocategories?

One possible reason for the haphazard production of gunmetal is that brass and tin-bronze were both favoured in the production of items for display (e.g. pins, jewellery, blades) due to their golden colours and may have been confused in the past as they were in the medieval period of Europe and, indeed, even today. This statement is not as straightforward as it may seem. We distinguish copper-zinc and copper-tin alloys based on their chemical and physical properties, although we approach these materials from the privileged position of understanding what they are, how they can be produced, what their similarities and differences are, etc. While skilled prehistoric metalworkers would undoubtedly have realised the physical differences between these materials, we cannot be certain, without textual references such as those provided by the Greeks and Romans, that the ancient local consumers of these metals distinguished them quite so easily.

For example, in a recent paper it was argued, based on metallographic analyses of copper-based artefacts from five millennia of occupation at Tepe Yahya, that at least two of the three brass objects were created by a distinctly local style of metalworking that appears to remain unchanged at the site from the early 4th millennium BC until the 1st millennium BC (Thornton and Lamberg-Karlovsky 2004). This may suggest that these small brass ornaments were worked locally into their final forms, although the metal itself was probably imported given its rarity and the lack of metallurgical remains at the site (cf. similar comment by Begemann *et al.* (1992: 220) in regards to the Thermi examples). Indeed, we often assume only two major stages in the life-cycle of a metal artefact – production and consumption – but this ignores the possibility of intermediary metalworkers or of cottage-industry consumers who melted and crafted metals to fit their specific needs without necessarily understanding the technical properties of the materials with which they worked (cf. Pigott's (1980) discussion of the treatment of iron by Iranian bronzeworkers in the Early Iron Age). This is not to suggest that a master craftsman would not immediately notice the difference between tin-bronze and brass, just as he would undoubtedly notice the difference between a 2 wt% arsenical copper and a 7 wt% arsenical copper. Instead, it is meant to question whether the ancient consumers of the copper-zinc alloys at Yahya or Thermi or Nuzi categorised these metals as different from copper-tin alloys, or whether brass, bronze and gunmetal were treated as variants of the same genre of material that could be combined and exchanged at will.[15]

One thing that we can be fairly certain of is that the people *producing* copper-zinc alloys, who were most likely village-based or itinerant craftspeople located in regions peripheral to mainstream prehistoric societies, were aware that what they were making was not the same as tin-bronze. Disregarding the possibility of zinc metal distillation and ignoring for now the possibility of an early invention of the cementation method, the major distinguishing factor for ancient mixed-ore smelters would have been that zinc and tin ores are visually quite distinct and rarely ever found in the same geologic contexts. Indeed, zinc ores occur most frequently in lead and copper ore deposits, while the latter is often found in granites, in gold-bearing quartz veins and in streams that have eroded away the surrounding rock matrix but, like gold, have left nodules of the water-insoluble tin oxides (Charles 1978). This latter point has been used to explain the association of tin and tin-bronze with gold throughout the prehistoric Near East (Muhly 1973). In contrast it would appear that the only reason for copper-zinc alloys to be found together with tin-bronze is because they both possess a golden colour.

Although it may seem trite to announce that what brass and bronze had in common was their colour, the study of visual characteristics of artefacts can be a powerful means of understanding the past (see Jones and MacGregor 2002). As scholars such as Lechtman (1977, 1999) and Hosler (1994) have demonstrated, by focusing on the more qualitative aspects of metals, archaeometallurgy can go beyond purely technical studies and engage with ancient 'ethnocategories' or the ways in which people gave order and meaning to the world around them. The idea of ethnocategories derives from sociolinguistic and anthropological theories on the relationship between the structuring of language and the structuring of society and the natural world (e.g. the famous Boasian example of Arctic Inuits using multiple words to describe different types of snow). In the case of technology, the creation or adoption of a new material usually leads to a reconfiguration of such ethnocategories (e.g. the discovery of iron in western Asia led eventually to the creation of a 'blacksmith' as a specific social role distinct from other metalworkers), although there is often a lag between the initial introduction of that new material or object and the full understanding of its distinct qualities.[16] In the absence of texts, this type of conceptual delay is also observable archaeologically (e.g. early smelted iron maintaining the high value and prestige of meteoritic iron) and scientifically (e.g. early iron having been worked by bronze workers), and it should be the role of the archaeometallurgist to combine these lines of inquiry in order to study the patterns of social behaviour that led to the formation of new and distinct ethnocategories.

In the case of prehistoric Southwest Asia, it is here proposed that the earliest copper-zinc alloys were not necessarily considered as different from tin-bronze by anyone other than the smelter or by a skilled metalworker able to distinguish the differences in hardness and durability between the two materials. That is, within the greater sociocultural milieux of the 3rd and 2nd millennia BC, these new golden-coloured metals fell into the same ethnocategory as tin-bronze and other golden-coloured, copper-base alloys. In fact it was probably not until the 1st millennium BC that words signifying 'brass' (such as the Greek *oreichalkos*), as opposed to copper and tin-bronze (e.g. *xalkos, kuwkos*), first appeared in texts (Halleux 1973). This linguistic shift may coincide with the florescence of copper-zinc alloys in the sixth grouping discussed above. If that is the case, then the sixth grouping may represent a significant change in the way copper-base metals were categorised by ancient societies – from one based almost entirely on visual characteristics to one involving some level of technical (or 'chemical') knowledge.

Conclusions

Although the number of prehistoric copper-zinc alloys from Southwest Asia has increased significantly since Paul Craddock (1978a, 1980) first began to research their origins, the answers to the questions posited above on the who, when, where and how of early brass production remain elusive. Indeed, it is seemingly impossible to connect such geographically, chronologically and culturally disparate sites as Thermi, Ergeni and Tepe Yahya in the hopes of inducing some larger pattern, although the association with tin and tin-bronze discussed above may provide an important clue for future study. What is needed is to target the copper-zinc artefacts as a distinct corpus for comparative chemical and metallographic analyses, and also to conduct more archaeometallurgical investigations of certain key areas – such as the southern Caucasus – which may contain evidence for early copper-zinc alloy production.

The dataset presented here of early examples of copper-zinc alloys in prehistory can no longer be ignored by all but a handful of scholars. These alloys, although rare, were intimately connected with the development of other important metals such as lead and silver, whence the production of zinc oxide perhaps originated, as well as tin-bronze, with which it may have been confused and inadvertently mixed due to their similar visual characteristics. This hypothesis is not meant to suggest that copper-zinc alloys could not have been intentionally produced by knowledgeable craftspeople in prehistory. Rather, it is meant to emphasise the multiple stages in the life-cycle of metal artefacts – from original production and subsequent trade, to secondary and tertiary manufacturing of consumable goods, to repair, reuse and/or recycling steps, and finally to discard or deposition – and the different episodes of cultural categorisation that these materials and objects must have undergone as they moved from one person or society to another.

Given the fairly extreme differences between the production and functioning of tin-bronze and brass, the strong archaeological association between the two metals (and, indeed, the haphazard mixing of these alloys in prehistory) deserves more research. While technical studies are important for our understanding of the manufacture of metal artefacts, we must temper these studies with a nuanced understanding of more cultural factors such as visual symbolism and how they may have affected and been affected by technological and social practices (cf. Ottaway 2001; Sofaer Derevenski and Sørensen 2002). This can only be achieved by a combination of chemical and metallographic analyses of excavated artefacts from good contexts, scientific experiments into the processes of manufacture and physical properties of copper-zinc alloys, and theoretical discussions on the role of metals and materials in ancient societies.

Acknowledgements

The author wishes to thank the British Museum organisers of the *Metallurgy: A Touchstone for Cross-Cultural Interaction* conference and the Applied Mineralogy Group of the Mineralogical Society who funded his participation. A few colleagues contributed significantly to the numerous drafts of this paper including Justine Bayley, Ben Roberts and Vincent Pigott. In addition, a number of scholars lent their expertise, data and support to this research including: Susanne Ebbinghaus, Katherine Eremin and Henry Lie; Alexander Egor'kov, Evgenii Gak and Natalya Shishlina; Christine Ehlers; Giorgi Kavtaradze; Ignacio Montero-Ruiz; Ernst Pernicka; Thilo Rehren; Josef Riederer; Laura Tedesco; Lloyd Weeks; Michael Witzel and two anonymous reviewers. Finally, the author wishes to acknowledge the constant support and inspiration that he has received from Paul Craddock and his unparalleled contribution to research on early copper-zinc alloys.

Notes

1. Although fahlerz ores such as tetrahedrite ($Cu_{12}Sb_4S_{13}$) and tennantite ($Cu_{12}As_4S_{13}$) often contain appreciable amounts of zinc (see Ixer and Pattrick 2003), very few of the early copper-zinc alloys discussed here contain significant levels of arsenic or antimony. Thus, fahlerz is an unlikely source material for these rare metals.
2. The absence of iron and manganese in the brasses from Tepe Yahya, Iran, may confirm that they were in fact made by manmade zinc oxide and not naturally occurring smithsonite (Thornton *et al*. 2002: 1459).
3. Note that the Hissar data were not corrected for oxides and are only semi-quantitative (Pigott, pers. comm.).
4. In Thornton and Ehlers (2003), this is reported erroneously as the loss of 10 *weight* percent zinc. In actuality, a 28 wt% zinc copper-zinc alloy that is re-melted will become a 25–26 wt% zinc alloy (a 10% loss) and not an 18 wt% zinc alloy.
5. 'Oreichalkum' is considered by Craddock (1998b) and others (e.g. Caley 1964) to refer to 'brass' as it did in the Roman period; contra 'oreichalkum' to mean arsenical copper (Eaton and McKerrell 1976; Forbes 1964; Heskel and Lamberg-Karlovsky 1980). For more on this topic, see Halleux 1973.
6. This artefact can be compared to a La Tene sword with brass inlay from Munich mentioned by Dannheimer (1975). Thanks to Josef Riederer for providing this reference.
7. Egor'kov, pers. comm., May 2005.
8. Henry Lie and Susanne Ebbinghaus (pers. comm., June 2005) of the Fogg Art and Sackler Museums at Harvard report that the horn was found to contain >10 wt% tin and 1–10 wt% zinc when it was analysed in the 1950s.
9. Katherine Eremin, pers. comm., October 2005.
10. The Great Tumulus is now securely dated with dendrochronology to *c*. 743–741 BC and is thus not likely to be the tomb of King Midas (see DeVries *et al*. 2003).
11. Laura Tedesco, pers. comm., April 2005.
12. Giorgi Kavtaradze, pers. comm., 2004.
13. In fact, this sequence is so similar that it may add fodder to the heated debate over the chronology of Yahya IVB–IVA in relation to the Tell Abraq sequence presented by Lamberg-Karlovsky and Potts (2001).
14. It is interesting to note that lead, although the element most commonly found with zinc in geologic contexts of Southwest Asia, is only prevalent in significant quantities (i.e. >1 wt% lead) in roughly one-third of the total corpus in Table 1. Whether the lead came with the zinc or as an independent alloying agent is a question that needs to be addressed in future research.
15. Much in the same way that English speakers today continue to refer to aluminum foil as 'tin foil' despite almost a century since actual tin foil went out of common use.
16. For example, as Renfrew (1978: 102) has noted, the automobile was first referred to as a 'horseless carriage' and only later was considered to be a distinct entity (i.e. the 'car').

References

An Zhimin 2000. On early copper and bronze objects in ancient China. In Linduff *et al.* 2000, 195–9.

Bartelheim, M., Pernicka, E. and Krause, R. (eds) 2002. *Die Anfange der Metallurgie in der Alten Welt*. Rahden/Westf.: Verlag Marie Leidorf GmbH.

Bayley, J. 1998. The production of brass in antiquity with particular reference to Roman Britain. In Craddock 1998a, 7–26.

Bayley, J. and Butcher, S. 2004. *Roman Brooches in Britain: A Technological and Typological Study Based on the Richborough Collection*. London: Society of Antiquaries of London.

Bedore, C. and Dixon, C. 1998. New discoveries in an old collection. *Context* 13: 3–4.

Begemann, F., Schmitt-Strecker, S. and Pernicka, E. 1992. The metal finds from Thermi III–V: a chemical and lead-isotope study. *Studia Troica* 2: 219–40.

Begemann, F., Schmitt-Strecker, S. and Pernicka, E. 2003. On the composition and provenance of metal finds from Besiktepe (Troia). In Wagner *et al.* 2003, 173–201.

Bogdanova-Berezovskaja, I.V. 1962. Khimicheskij sostav metallicheskikh izdelij Fergany epokhi bronzy i zheleza. In *Drevnezemledel'cheskaja Kul'tura Fergany*, Y.A. Zadneprovskij (ed.). Leningrad: MIA, no. 118, 219–30.

Caley, E.R. 1964. *Orichalcum and Related Ancient Alloys*. New York: American Numismatic Society.

Charles, J.A. 1978. The development of the usage of tin and tin-bronze: some problems. In *The Search for Ancient Tin*, T.A. Wertime (ed.). Washington, DC: Smithsonian Institution, 25–32.

Chernykh, E.N. 1992. *Ancient Metallurgy in the USSR*. Cambridge: Cambridge University Press.

Childe, V.G. 1928. *New Light on the Most Ancient Near East*. New York: Frederick Praeger.

Cleuziou, S. and Tosi, M. 2000. Ra's al-Jinz and the prehistoric coastal cultures of the Ja'alan. *Journal of Oman Studies* 11: 19–73.

Craddock, P.T. 1978a. The composition of the copper alloys used by the Greeks, Etruscan and Roman civilizations: the origins and early use of brass. *Journal of Archaeological Science* 5: 1–16.

Craddock, P.T. 1978b. Europe's earliest brasses. *MASCA Journal* 1(1): 4–5.

Craddock, P.T. 1980. The first brass: some early claims reconsidered. *MASCA Journal* 1(5): 131–3.

Craddock, P.T. (ed.) 1998a. *2000 Years of Zinc and Brass*, 2nd edn. British Museum Occasional Paper 50. London.

Craddock, P.T. 1998b. Zinc in classical antiquity. In Craddock 1998a, 1–6.

Craddock, P.T. and Eckstein, K. 2003. Production of brass in antiquity by direct reduction. In Craddock and Lang 2003, 216–30.

Craddock, P.T. and Lang, J. (eds) 2003. *Mining and Metal Production through the Ages*. London: British Museum Press.

Craddock, P.T., Burnett, A. and Preston, K. 1980. Hellenistic copper-based coinage and the origins of brass. In *Scientific Studies in Numismatics*, W.A. Oddy (ed.). British Museum Occasional Paper 18. London, 53–64.

Craddock, P.T., Freestone, I.C., Gurjar, L.K. and Willies, L. 1998. Zinc in India. In Craddock 1998a, 27–72.

Craddock, P.T., Cowell, M. and Stead, I. 2004 Britain's first brass. *Antiquaries Journal* 84: 339–46.

Dannheimer, H. 1975. Zu zwei älteren keltischen Fundstücken aus der Münchner Schotterebene. *Archäologisches Korrespondenzblatt* 5: 59–67.

DeVries, K., Kuniholm, P.I., Sams, G.K. and Voigt, M.M. 2003. New dates for Iron Age Gordion. *Antiquity* 77(296) (http://www.antiquity.ac.uk/projgall/devries/devries.html).

Eaton, E.R. and McKerrell, H. 1976. Near Eastern alloying and some textual evidence for the early use of arsenical copper. *World Archaeology* 8(2): 169–91.

Egor'kov, A.N. 2001. Особенности состава металла Алтын-депе [Features of the metal composition of Altyn-depe]. In *Особенности производства поселения Алтын-депе в эпоху палеометалла* [*Features of Production of the Settlement of Altyn-depe in the Early Metal Age*], V.M. Masson (ed.). St Petersburg: Institut istorii material'no kul'tury PAH, 85–103.

Egor'kov, A.N., Gak, E.I. and Shishlina, N.I. 2004. Могильник Ергени в Калмыкии: латунь в бронзовом веке [Ergeni cemetery in Kalmykia: brass in the Bronze Age]. In *Древний Кавказ: ретроспекция культур* [*Ancient Caucasia: Retrospective on Cultures*], L.T. Yablonskij (ed.). Moscow: Institut Arkheologii RAN, 77–8.

Egor'kov, A.N., Gak, E.I. and Shishlina, N.I. 2005. Chemical composition of metal from Kalmykia in the Bronze Age. *Archaeological News* 12: 71–6.

Forbes, R.J. 1964. *Studies in Ancient Technology*, vol. 8 (2nd edn. 1971). Leiden: E.J. Brill.

Franklin, A.D., Olin, J.S. and Wertime, T.A. (eds) 1978. *The Search for Ancient Tin*. Washington, DC: Smithsonian Institution Press.

Frenez, D. and Tosi, M. 2005. The Lothal sealings: records from an Indus Civilization port town at the eastern end of the maritime trade routes across the Arabian Sea. In *Studi in Onore di Enrica Fiandra*, M. Perna (ed.). Contributi di Archeologia Egea e Vicinorientale 1. Paris: De Boccard.

Frifelt, K. 1991. *The Island of Umm An-Nar. Vol. 1: Third Millennium Graves*. Jutland Archaeological Society Publications XXVI: 1. Aarhus: Aarhus University Press.

Gak, E.I. 2004. Eastern Europe's earliest brasses. Paper presented at the 34th International Symposium on Archaeometry, Zaragoza, Spain, 3–7 May 2004.

Gasanova, A. 2002. *История Познания и Использования Цинка и Латуни (Епохи Бронзы-Средневековье)* [*History of the Knowledge and Utilization of Zinc and Brass (Middle Bronze Age)*]. Baku: Elm Publishers.

Gaur, R.C. 1983. *Excavations at Atranjikhera: Early Civilisations of the Upper Ganga Basin*. New Delhi: Aligarth Muslim University/Motil Banarsidass.

Geckinli, A.E., Bozkurt, N. and Basaran, S. 1986. Cavustepe metal buluntularinin metallografik analizi. *Aksay Unitesi Bilimssel Toplanti Bildirileri I*. Tubitak Pub. No. 648: 229–46.

Glumac, P.D. and Todd, J.A. 1991. Early metallurgy in South-East Europe: the evidence of production. In *Recent Trends in Archaeometallurgical Research*, P.D. Glumac (ed.). Philadelphia: MASCA Research Papers in Science and Archaeology 8, 8–19.

Halleux, R. 1973. L'orichalque et le laiton. *Antique Classique* 42: 64–81.

Han, R. and Ko, Ts. 2000. Tests on brass items found at Jiangzhai, phase I. In Linduff *et al.* 2000, 195–9.

Hanfmann, G.M.A. 1956. Four Urartian bulls' heads. *Anatolian Studies* 6: 203–13.

Hauptmann, A. 1995. Chemische Zusammensetzung von Metallobjekten aus der Siedlung von Umm an-Nar. In *The Island of Umm an-Nar. Vol. 2: The Third Millennium Settlement*, K. Frifelt (ed.). Jutland Archaeological Society Publications XXVI: 2. Aarhus: Aarhus University Press, 246–8.

Hauptmann, H. and Pernicka, E. (eds) 2004. *Die Metallindustrie Mesopotamiens von den Anfängen bis zum 2. Jahrtausend v. Chr.* Orient-Abteilung des Deutschen Archäologieschen Instituts, Orient-Archäologie Bd. 3. Rahden/Westf.: Verlag Marie Leidorf GmbH.

Heskel, D.L. and Lamberg-Karlovsky, C.C. 1980. An alternative sequence for the development of metallurgy: Tepe Yahya, Iran. In Wertime and Muhly 1980, 229–66.

Hill, D.K. 1969. Bronze working: sculpture and other objects. In *The Muses at Work*, C. Roebuck (ed.) Cambridge, MA: MIT Press, 60–95.

Hosler, D. 1994. *The Sounds and Colors of Power: The Sacred Metallurgical Technology of Ancient West Mexico.* Cambridge, MA: MIT Press.

Hughes, M.J., Lang, J.R.S., Leese, M.N. and Curtis, J.E. 1988. The evidence of scientific analysis: a case study of the Nimrud Bowls. In *Bronzeworking Centres of Western Asia*, J.E. Curtis (ed.). London: Kegan Paul, 311–16.

Ixer, R.A. and Pattrick, R.A.D. 2003. Copper-arsenic ores and Bronze Age mining and metallurgy with special reference to the British Isles. In Craddock and Lang 2003, 216–30.

Jones, A. and MacGregor, G. 2002. *Colouring the Past: The Significance of Colour in Archaeological Research*. Oxford: Berg.

Kashkai, M.A. and Selimkhanov, I.R. 1973. *Из Истории Древней Металлургии Кавказа* [*On the History of Early Caucasian Metallurgy*]. Baku: Akademija Nauk Azerbajdzhanskoj CCP.

Kavtaradze, G.L. 1999. The importance of metallurgical data for the formation of a Central Transcaucasian chronology. In *The Beginnings of Metallurgy*, A. Hauptmann, E. Pernicka, Th. Rehren and Ü Yalçin (eds). *Der Anschnitt* Beiheft 4. Bochum: Deutsches Bergbau-Museum, 67–101.

Kohl, P.L. 2002. Bronze production and utilization in Southeastern Daghestan, Russia: c. 3600–1900 BC. In Bartelheim *et al.* 2002, 161–84.

Lamberg-Karlovsky, C.C. and Potts, D.T. (eds) 2001. *Excavations at Tepe Yahya, Iran 1967–1975: The Third Millennium*. American School of Prehistoric Research Bulletin 45. Cambridge: Harvard University Press.

Lechtman, H. 1977. Style in technology: some early thoughts. In *Material Culture: Styles, Organization, and Dynamics of Technology*, H. Lechtman and R.S. Merrill (eds). St. Paul: West Publishing Co., 3–20.

Lechtman, H. 1999. Afterword. In *The Social Dynamics of Technology*, M.-A. Dobres and C.R. Hoffman (eds). Washington, DC: Smithsonian Institution Press, 223–32.

Linduff, K.M., Han, R. and Sun, Sh. (eds) 2000 *The Beginnings of Metallurgy in China*. New York: Edwin Mellen Press.

Mei, J. and Li, Y. 2003. Early copper technology in Xinjiang, China: the evidence so far. In Craddock and Lang 2003, 111–21.

Méry, S. 2000. *Les céramiques d'Oman et l'Asie moyenne: une archéologie des échanges à l'Age du Bronze*. Monographie du CRA, no 23. Paris: CNRS.

Muhly, J.D. 1973. *Copper and Tin: The Distribution of Mineral Resources and the Nature of the Metals Trade in the Bronze Age.* Hamden, CT: Archon Books.

Muhly, J. 2002. Early metallurgy in Greece and Cyprus. In *Anatolian Metal II*, Ü Yalçin (ed.). *Der Anschnitt* Beiheft 15. Bochum: Deutsches Bergbau-Museum, 77–82.

Northover, J.P. 1997. The analysis of early copper and copper alloys. In *The Art of Ancient Iran: Copper and Bronze*, H. Mahboubian (ed.). London: Philip Wilson, 325–42.

Oren, E.D. 1971. A Middle Bronze Age I warrior tomb at Beth-Shan. *Zeitschrift des Deutschen Palästina-Vereins* 87: 109–39.

Ottaway, B.S. 2001. Innovation, production, and specialization in early prehistoric copper metallurgy. *European Journal of Archaeology* 4(1): 87–112.

Parzinger, H. and Boroffka, N. 2003. *Das Zinn der Bronzezeit in Mittelasien I*. Archäologie in Iran und Turan, Bd. 5. Mainz am Rhein: Verlag Philp von Zaubern.

Penhallurick, R.D. 1986. *Tin in Antiquity*. London: Institute of Metals.

Pernicka, E. 1998. Die Ausbreitung der Zinnbronze im 3. Jahrtausend. In *Mensch und Umwelt in der Bronzezeit Europas*, E. Hänsel (ed.). Kiel: Oetker-Voges Verlag, 135–47.

Pernicka, E., Seeliger, T.C., Wagner, G.A. *et al.* 1984. Archaeo-metallurgische Untersuchungen in Nordwestanatolien. *Jahrbuch des Romisch-Germanischen Zentralmuseums Mainz* 31: 533–602.

Pernicka, E., Eibner, C., Oztunali, O. and Wagner, G. A. 2003. Early Bronze Age metallurgy in the north-east Aegean. In Wagner *et al.* 2003, 143–72.

Pigott, V.C. 1980. The Iron Age in Iran. In Wertime and Muhly 1980, 417–61.

Pigott, V.C., Howard, S.M. and Epstein, S.M. 1982. Pyrotechnology and culture change at Bronze Age Tepe Hissar (Iran). In *Early Pyrotechnology: The Evolution of the First Fire-Using Industries*, T.A. Wertime and S.F. Wertime (eds). Washington, DC: Smithsonian Institute Press, 215–36.

Pollard, A.M. and Heron, C. 1996. *Archaeological Chemistry*. Cambridge: Royal Society of Chemistry.

Ponting, M.J. 2002. Roman military copper-alloy artefacts from Israel: questions of organization and ethnicity. *Archaeometry* 44(4): 555–71.

Primas, M. 2002. Early tin-bronze in central and southern Europe. In Bartelheim *et al.* 2002, 303–14.

Rao, S.R. 1985. *Lothal: A Harappan Port Town (1955–1962)*, vol. 2. Memoirs of the Archaeological Survey of India 78. New Delhi: Archaeological Survey of India.

Rau, W. 1974. *Metalle und Metallgeräte im vedischen Indien*. Abhandlungen der Geistes- und Sozialwissenschaftlichen Klasse. Jahrg. 1973, Nr. 8. Wiesbaden: Akademie der Wissenschaft zu Mainz, F. Steiner.

Rehren, Th. 1999. Small size, large scale: Roman brass production in Germania Inferior. *Journal of Archaeological Science* 26: 1083–7.

Renfrew, C. 1967. Cycladic metallurgy in the Aegean Early Bronze Age. *American Journal of Archaeology* 71, 1–120.

Renfrew, C. 1978. The anatomy of innovation. In *Social Organisation and Settlement: Contributions from Anthropology, Archaeology, and Geography*, D. Green, C. Haselgrove and M. Spriggs (eds). BAR International Series (Supplementary) 47. Oxford: Oxford University Press, 89–117.

Renfrew, C. and Slater, E.A. 2003. Metal artifacts and metallurgy. In *Prehistoric Sitagroi: Excavations in Northeast Greece, 1968–1970. Vol. 2: The Final Report*, E.S. Elster and C. Renfrew (eds). Monumenta Archaeologica 20. Los Angeles: Cotsen Institute of Archaeology at UCLA, 301–24.

Rostoker, W. and Dvorak, J. 1991. Some experiments with co-smelting to copper alloys. *Archaeomaterials* 5: 5–20.

Schachner, A. 2005. Von Bronze zu Eisen: Die Metallurgie des 2. und frühen 1. Jahrtausends v. Chr. im östlichen Transkaukasus. In *Anatolian Metal III*, Ü Yalçin (ed.). *Der Anschnitt* Beiheft 18. Bochum: Deutsches Bergbau-Museum, 175–90.

Schaeffer-Forrer, C.F.A., Zwicker, U. and Nigge, K. 1982. Untersuchungen an metallischen Werkstoffen und Schlacken aus dem Bericht von Ugarit (Ras Shamra, Syrien). *Mikrochimica Acta* 1: 35–61.

Sofaer Derevenski, J. and Sørensen, M.-L. S. 2002. Becoming cultural: society and the incorporation of bronze. In *Metals and Society*, B.S. Ottaway (ed.). BAR International Series 1061. Oxford: Archaeopress, 117–22.

Stech, T. and Pigott, V.C. 1986. The metals trade in southwest Asia in the third millennium BC. *Iraq* 48: 39–64.

Steinberg, A. 1981. Analyses of selected Gordion bronzes. In Young 1981, 286–9.

Stos-Gale, Z. 1992. The origin of metal objects from the Early Bronze Age site of Thermi on the island of Lesbos. *Oxford Journal of Archaeology* 11(2): 155–77.

Sun Shuyun and Han Rubin 1983–85. A preliminary study of early Chinese copper and bronze artifacts, J.K. Murray (trans.). *Early China* 9–10: 261–89.

Tedesco, L.A. 2006. *Redefining Technology in Bronze Age Transcaucasia: Copper-alloy Metallurgy in Armenia in the Third to Second Millennium BC.* PhD dissertation, Department of Anthropology, New York University.

Thornton, C.P. and Ehlers, C. 2003. Early brass in the ancient Near East. *IAMS Journal* 23: 3–8.

Thornton, C.P. and Lamberg-Karlovsky, C.C. 2004. A new look at the prehistoric metallurgy of Southeastern Iran. *Iran* XLII: 61–76.

Thornton, C.P., Lamberg-Karlovsky, C.C., Liezers, M., and Young, S.M.M. 2002. On pins and needles: tracing the evolution of copper-base alloying at Tepe Yahya, Iran, via ICP–MS analysis of common-place items. *Journal of Archaeological Science* 29(12): 1451–60.

Thornton, C.P., Lamberg-Karlovsky, C.C., Liezers, M. and Young, S.M.M. 2005. Stech and Pigott revisited: new evidence concerning the origins of tin-bronze in light of chemical and metallographic analyses of the metal artefacts from Tepe Yahya, Iran. In *Proceedings of the Third International Symposium on Archaeometry, 22–26 April 2002, Amsterdam*, H. Kars and E. Burke (eds). Geoarchaeological and Bioarchaeological Studies 3. Amsterdam: Vrije Universiteit, 395–8.

Wagner, G.A., Pernicka, E. and Uerpmann, H.-P. (eds) 2003. *Troia and the Troad: Scientific Approaches*. Berlin/Heidelberg: Springer-Verlag.

Weeks, L. 1999. Lead isotope analyses from Tell Abraq, United Arab Emirates: new data regarding the 'tin problem' in western Asia. *Antiquity* 73: 49–64.

Weeks, L.R. 2003. *Early Metallurgy of the Persian Gulf*. Boston: Brill Academic Publishers, Inc.

Welter, J.-M. 2003. The zinc content of brass: a chronological indicator? *Techne* 18: 27–36.

Wertime, T.A. 1980. The pyrotechnologic background. In Wertime and Muhly 1980, 1–24.

Wertime, T.A. and Muhly, J. (eds) 1980. *The Coming of the Age of Iron*. New Haven, CT: Yale University Press.

Young, R.S. 1981. *Three Great Early Tumuli.* The Gordion Excavations Final Reports 1. Philadelphia: University Museum Monograph 43.

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