On the Composition and Provenance of Metal Finds from Besiktepe (Troia)

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Abstract

Lead isotopy and trace element contents of most of the copper-based artifacts from Besiktepe dating to Troia I suggest that the copper derives from western Anatolian ore deposits. Gümüsköy, Serceörenköy, and Balya, all sites with evidence for prehistoric mining activities going back to the late third millennium B.C., are most conspicuous in this respect. These ore occurrences also qualify as sources for many of the contemporaneous copper objects from Thermi on Lesbos and Poliochni on Lemnos analyzed previously. Exceptions among the Troia I Besiktepe objects are the two pieces of bronze found among the 22 fragments chemically analyzed, and one piece of unalloyed copper. Notably, none of the copper objects can be traced back to Ergani, neither to its copper ores nor to its native copper. Eleven artifacts recovered from graves at the Besik-Necropolis, dating to Troia VI, are all bronze. Their trace element abundance patterns are remarkably uniform; silver contents in the bronzes are much lower than in the unalloyed copper dating to Troia I indicating that these bronzes cannot have been manufactured by alloying tin with the kind of copper that is present in the unalloyed copper. Lead isotope data, not available at present, will have to decide whether the characteristics of these bronze pieces are again foreign to all copper ores from Anatolia and the Aegean just as has been observed to be the case for most bronze objects from Poliochni and Thermi.

1 Introduction

Copper-based metal artifacts from Troia and the Troad previously analyzed for their lead isotopic composition and their trace element contents (Pernicka et al. 1984; Stos-Gale et al. 1984) comprise the Troas hoard find of Bittel (1959), a small collection of daggers and needles from Yortan, and a series of implements, daggers, and vessels from Hissarlik, excavated by Schliemann and published in part by Schmidt (1902). They all have in common that their age setting is rather uncertain. This is true for the objects from Troia-Hissarlik, all of which are of uncertain stratigraphy, and it is even worse for the Troad hoard find and the small collection of weapons and implements from Yortan cemetery which actually derive from the art market. Recently, however, metal objects have become available from well-executed and well-documented excavations performed at Besiktepe from 1982–1986 by M. Korfmann and his team (Korfmann 1984, 1985, 1986, 1988). Therefore, it appeared worthwhile to take up these investigations again. They should be considered complementary to those of the well-stratified and well-dated finds from Poliochni on the island of Lemnos (Pernicka et al. 1990) and Thermi on the island of Lesbos (Begemann et al. 1992, 1995).

Besiktepe is located about 9 km southwest of Troia, on a steep promontory exactly on the present-day Aegean coastline. The settlement layer dating to Troia I has been estimated by Korfmann to cover 150–300 years, at most (Korfmann and Kromer 1993). Thermoluminescence (TL) dating of pottery sherds from the Troia I layer yielded 2820 ± 80 B.C. (Wagner and Lorenz 1992), which accords well with calibrated radiocarbon dates of 2920–2740 B.C. (Korfmann and Kromer 1993). By comparison, a charred fig from the period "azzurro" at Poliochni dates to 2910–2672 B.C. (calibrated) and pieces of charcoal from about the lowest pebble floor level at Thermi to 3022–2700 B.C. cal. (Begemann et al.1992). These sites, then, are closely contemporaneous, dating to the very beginning of the third millennium B.C.

The early objects excavated at Besiktepe are almost all rather indistinct-looking small finds whose typological features do not allow their chronological setting to be determined (see Table 1). Instead, their age had to be deduced from associated pottery sherds retrieved from the same excavation levels. Particular attention was paid to eliminate potential late intrusions. Twenty-three of the copper-based artifacts (one of them a copper crucible slag)[1] and three pieces of lead, all classified as dating to Troia I, were sampled, some of them more than once. Of the 26 samples analyzed for their chemical composition20, including the piece of crucible slag, were selected for the more demanding analysis of the isotopic composition of their lead content.

[1] The excavators identified two of the sampled objects as "slags" (HDM 1021 and 1114). Both objects are rather small (a few hundred milligrams) and broken into a number of pieces. In the case of HDM 1021 the shape of one larger fragment suggests that rather than a slag, the object might be a completely corroded piece of a metal pin. Such a suggestion is corroborated by the low iron content (see below). For the present purpose we have retained the identification of HDM 1114 as "slag", but have classified HDM 1021 as metal. Both classifications are ambiguous, however. Five of the specimens have been assigned probabilities of between 93 and 98% of belonging to Troia I. These are the unalloyed copper pins, or fragments thereof, HDM 1009, 1013, 1108, and 1111 as well as the only arsenical copper in our suite of samples, a needle with double-conical head (HDM 1116; Pfeffer 1990).

Table 1. Metal artifacts from Besiktepe investigated in the present study. When objects were sampled more than once the first column lists the numbers under which the results are reported

HDM No.		Object	Inv. No.	Period
163		Nail fragment, square cross section	LL 83.27	Chalcolithic
164[a]		Angular piece	R 14.492	Uncertain
165		Pin	S 15.166	Troia I, 3
166		Pin with spherical head	S 15.170	Troia I, 3
167	1124	Nail, square cross section	Q 12.94	Uncertain
168	1122	Pin	R 14.430	Troia I, 8–6
171[a]		Sheet fragments (4)	R 12.69	Hellenistic
172[a]		Rod fragment	R 12.150a	Hellenistic
174[a]		Sheet	S 13.260	Hellenistic
176[a]		Token	S 13.289	Hellenistic
180[a]		–	S 13.429	Hellenistic
183[a]		–	S 13.503	Hellenistic
184[a]		–	S 15.56	Hellenistic
185[a]		–	S 15.70	Hellenistic
187[a]		Sheet	T 10.164	Hellenistic
269[a]		Sheet	R 12–61	Hellenistic/ Byzant.
301		Awl fragment	S 15.260	Hellenistic
302		Awl fragment	S 15.269	Hellenistic
303	1250	Pin	ZI 29.7	Uncertain
304	1109	Pin	S 15.272	Hellenistic
305[a]		–	ZI 28.22	Troia VI
306[a]		–	RS 13.162A	Uncertain
307	1120	Pin	S 13.834	Troia I, 3
308		Fragment	ZI 29.28	Troia VI, grave 46
309[a]		–	S 13 Ost.232	Troia I
310[a]		–	XI 29.5	Troia VI
311		Vessel(?) fragment	YI 29.4	Troia VI, grave 15
312		Fragment	ZI 28.23	Troia VI, grave 49
313	1119	Pin fragments (3)	S 13.682	Hellenistic
314[a]		–	ZI 28.19	Troia VI
315[a]		–	S 13.743	Troia I
316		Wire(?) pieces	YI 29.60	Troia VI, grave 25
317[a]		Vessel handle	S 12 Ost.12	Uncertain
318		Arrow head	S 13.683	Hellenistic
319	1244	Knife	YI 28.7	Troia VI
320[a]		–	ZI 28.18	Troia VI
321		Fragment	YI 28.42	Troia VI, grave 4

Table 1 (continued)

HDM No.		Object	Inv. No.	Period
322[a]		–	S 12.388	Uncertain
323	1121	Pin	R 12.411	Troia I, 8
324		Wire(?) piece	YI 29.50	Troia VI, grave 25
325[a]		–	VI 29.4	Troia VI
326		–	YI 29.14	Uncertain
327		–	YI 29.7	Troia VI
328		–	YI 29.10	Troia VI, grave 15
329[a]		–	S 13.694	Troia I
330	1113	Nail, square cross section	S 12 Ost.23	Hellenistic
331		–	S 12 Ost.84 ?	Uncertain
1009	992	Pin	S 12.550	Troia I, 7
1010	993	Nail fragment, square cross section	S 13.625	Troia I, 7
1013	996	Fragment	S 15.405	Troia I, 8
1015		–	S 13.698 ?	Uncertain
1016		Spherule fragment	M 18.61a	Hellenistic
1017	1000, 1219	Awl fragment	Q 12.376	Troia I, 4
1018	1001, 1218	Awl fragment Q 12.364	Troia I, 5/4	
1020	1003, 1220	Awl fragment Q 12.466	Troia I, 1	
1021	1004	Awl(?) fragment	S 12.572	Troia I
1108	994, 1011	Pin	S 15.409	Troia I, 8
1110		Pin(?)	S 15.330	Hellenistic
1111	997, 1014	Awl(?) fragment	S 15.437	Troia I, 8/7
1112	1012	Fragment	S 15.400	Troia I, 8
1114	991, 1008	Slag(?) crumbs	S 12.591	Troia I
1116	989, 1006	Pin with double-conical head	S 12.818	Troia I, 3
1117	990, 1007	Fragment	S 12.853	Troia I, 2
1118		Vessel fragment	S 13.268	Hellenistic
1123	1002, 1019	Chain link(?) fragment	Q 12.391	Troia I, 4
1125		Pin	R 13.260	Uncertain
1126		Awl fragments (2)	R 13.238	Uncertain
1128		Ibex-headed pin	S 15.731	Troia I, 5
1129		Pin with spherical head	S 15.874	Troia I, 4
1130[a]		Sheet fragment	S 15.634	Hellenistic
1131		Sheet fragment	S 14.190	Hellenistic

Table 1 (continued)

HDM No.	Object	Inv. No.	Period
1132	Fragment	S 13.975b	Troia I, 3
1228	Nail(?)	E 22.6	Hellenistic
1229	Nail	S 12.426	Hellenistic
1236	Arm ring(?) fragment	S 15.478	Troia I, 6
1252	Fragment	VI 29.11	Hellenistic
1257	Anklet	ZI 7.12i (4930)	Troia VI, grave 68
1258	Anklet	ZI 7.12i (4931)	Troia VI, grave 68

[a] Lead objects.

From among the later objects analyzed for their chemical composition, 11 are bronze artifacts from graves at the Besik-Bay cemetery; they date back to Troia VI, i.e., to the middle of the second millennium B.C. The remaining samples, copper-based as well as the pieces of lead, are mostly from Hellenistic contexts. A list of all objects analyzed is given in Table 1. It contains the respective inventory numbers, what little typological information is available, and the Mainz/Heidelberg HDM laboratory numbers which are used in the text.

2 Results and Discussion

2.1 Chemical Composition and Trace Elements

Chemical analyses were performed by instrumental neutron activation (INAA). Most objects from the Troia I period were heavily corroded so the metal content of the analyzed samples rarely approaches 100 %; more often it is only around 50 % (Table 2). In order to correct for this, and to make the results comparable with analyses of well-preserved clean metal, the concentrations of minor and trace elements are normalized to the sum of all analyzed elements. Strictly speaking, such a normalization procedure implies that, upon corrosion of the metal, the trace elements behaved just like copper and, moreover, the uptake of trace elements from the environment did not increase their concentration in the artifacts to any significant extent. Note that for bronzes the listed tin contents are as measured; they are not normalized to copper. The same holds also for all trace elements in the slag.

Table 2. Chemical composition of copper-based artifacts from Besiktepe. Copper and tin are listed as measured (in weight percent). All other concentrations are in μg/g, normalized to the sum of the contents of the measured elements. Tin in nonbronzes was less than 0.1 % in all cases

HDM No.	Cu	Sn	As	Sb	Co	Ni	Ag	Au	Fe	Zn	Se
Chalcolithic											
Unalloyed copper											
163	100	–	190	20	33	330	640	15.4	<400	<20	187
Troia I											
Unalloyed copper											
165	27	–	3700	66	<4	370	17,300	1.8	43,000	<260	74
166	47	–	11,200	234	6	570	2360	15.0	4500	<50	94
168[a]	89	–	10,400	370	2	1100	2030	8.5	<800	<50	60
307	99	–	<10	53	1	46	770	18.8	<210	<10	107
323[a]	70	–	6900	950	<1	870	1610	2.4	1680	<50	65
1009	48	–	12,800	750	<1	210	87	1.3	20,600	80	2
1010	39	–	17,500	470	<1	1120	365	1.5	27,000	120	53
1013	28	–	5900	120	37	630	1840	2.3	14,900	290	22
1017[a]	46	–	4900	144	1	770	1200	1.7	7100	70	117
1018[a]	48	–	3900	48	<1	72	880	1.2	2010	160	24
1020[a]	51	–	960	45	67	1200	560	0.5	21,100	140	81
1021	31	-	9800	650	52	2670	80	1.8	13,100	1340	38
1108	87	-	14,400	170	<1	300	520	1.3	<260	<20	92
1111	56	–	10,000	105	18	1060	340	1.1	15,500	30	91
1112	79	–	2520	340	36	230	14	37.0	3000	50	12
1117	52	–	8800	900	6	180	460	1.8	22,500	80	52
1129	100	–	5800	260	<3	350	1290	2.5	11,300	550	103
1132	99	–	9900	400	3	2400	890	<0.5	1320	<40	56
1236	94		10,200	290	14	2790	810	1.1	2220	30	52

Table 2 (continued)

HDM No.	Cu	Sn	As	Sb	Co	Ni	Ag	Au	Fe	Zn	Se
Arsenical copper											
1116	78	–	90,000	490	<1	1030	1780	10.9	<290	<20	70
Bronzes											
1123	49	11.5	3300	1340	38	810	830	82.0	<510	230	123
1128	84	9.2	870	240	28	244	330	37.0	<200	20	124
Crucible slag											
1114[b]	17	–	20,500	310	84	2800	39	0.1	92,000	120	6
Troia VI											
Bronzes											
308	92	6.6	3800	125	190	350	58	7.6	2710	50	43
311[c]	88	10.7	1600	42	100	153	16	3.1	1030	40	67
312	87	9.3	5000	146	91	360	54	10.1	1370	<10	72
316[d]	69	12.8	1830	156	31	84	28	4.7	2200	<30	152
319[a]	94	7.7	1790	75	42	270	30	4.5	680	20	98
321	72	14.1	7300	510	37	116	18	5.9	4600	<40	125
324[d]	69	14.1	2470	220	32	<73	26	6.5	3300	<60	209
327	42	14.6	4100	400	55	220	36	20.0	7600	110	107
328[c]	78	10.5	1930	50	70	90	10	3.6	1800	<30	51
1257[e]	90	10.5	5000	250	590	1410	71	14.3	1340	180	56
1258[e]	85	10.5	5400	290	470	1370	73	13.9	<710	160	66
Hellenistic											
Unalloyed copper											
301	100	–	2400	2400	35	160	1400	15.4	<600	<30	57
302	100	–	1900	370	224	340	296	28.8	<450	<20	38

Table 2 (continued)

HDM No.	Cu	Sn	As	Sb	Co	Ni	Ag	Au	Fe	Zn	Se
304[a]	99	–	3600	4000	<8	235	1440	18.9	<1000	<50	36
330	83	–	810	350	269	<100	102	34.0	<2400	<80	41
1131	65	–	1070	127	310	156	156	23.6	5400	42	16
1228	97	–	1820	113	41	157	223	29.4	2530	20	49
1229	100	–	1490	280	360	275	234	22.6	<900	<50	34
1252	97	–	1200	160	650	320	158	21.9	1240	240	18
Bronzes											
313	68	9.7	540	55	220	190	203	17.6	2360	<15	87
318	79	5.4	1800	363	1800	350	200	30.2	<3000	<110	10
1016	41	1.3	2590	360	30	620	910	3.6	28100	80	<5
1110	100	9.4	670	140	<1	1470	1680	5.7	<1800	1140	23
1118	63	9.9	380	26	9	27	13	2.9	1100	24	6
Uncertain date											
Unalloyed copper											
167	94	–	3600	3100	2	204	2240	12.4	1280	<70	55
303[a]	100	–	1920	230	24	270	152	18.5	2000	<20	20
331	86	–	360	170	1000	180	155	11.6	1620	<50	30
1125	100	–	2240	360	224	310	263	25.5	2000	210	42
1126	60	–	15,500	244	<1	980	24200	330.0	<2750	<150	28
Bronzes											
326	75	8.6	830	32	43	<160	11	2.7	2670	<130	80
1015	50	2.8	1960	160	79	3300	1010	3.5	26500	2100	<4

[a] Because of their poor state of preservation, these objects were sampled and analyzed twice; listed are the averages.
[b] All concentrations as measured.
[c,d,e] Objects are from the same grave, respectively.

Among the artifacts dating to Troia I, a wire loop, which is possibly a chain-link fragment or a piece of a finger ring (HDM 1123), and an ibex-headed pin (HDM 1128) are made of bronze; in addition, a pin with a spherical head (HDM 1116) is made of arsenical copper. All others consist of unalloyed copper. Silver is notable for its constancy; with one exception on the high side[2] and three others on the low side (HDM 1009, 1021, 1112), the total range (330–2360 μg/g) is less than a factor of ten. For all other measured trace elements the concentrations fall into the same ranges as previously observed in roughly contemporaneous objects from the Aegean and western Anatolia (Esin 1969; Pernicka et al. 1984, 1990; Begemann et al. 1992, 1995).

Nevertheless, looking at abundance *ratios* of trace elements reveals significant differences between different sites. At Ilipinar, for example, independent of chronological period, higher arsenic contents and lower concentrations of antimony combine to make As/Sb ratios very much higher than reported here. Ratios usually are around 1000, or higher, at Ilipinar (Begemann et al. 1994), but less than 100, and typically only about 35 here (Fig. 1). Similarly, in the Yortan implements (Pernicka et al. 1984), the As/Sb ratios are again distinctly higher than observed here (Fig. 1). The Ag/Au ratios in the Yortan samples, on the other hand, are about ten times lower than found in the Troia I metal analyzed here (Fig. 2). The same is also the case, even more pronouncedly, for the "Troas" samples analyzed previously (Pernicka et al. 1984). It should be noted, however, that all Troas samples with low silver contents are bronzes, not unalloyed copper. Moreover, since they are of uncertain stratigraphy, but generally dated as late Troia II, a comparison with the older Troia I artifacts made from unalloyed copper is perhaps of only limited relevance.

Although it is true that trace element concentrations, as well as their abundance ratios, are affected by the physical-chemical conditions prevailing during the smelting of ores, or on the conditions during casting and working of metal, such potential changes are not expected to have caused the large differences observed for the metal recovered from the different sites. We maintain the differences rather indicate that different ore sources were exploited at Ilipinar, Yortan, and Besiktepe, respectively. We shall return to this problem when discussing the lead isotope data.

Not surprisingly, all objects dating to Troia VI are bronzes. After all, this period falls right into the Aegean Late Bronze Age. What we do find surprising, however, is that among the metal pieces from Hellenistic times so

[2] Since the high-silver object (HDM 165) is a badly corroded pin fragment, the significance of the high *normalized* silver content is somewhat ambiguous.

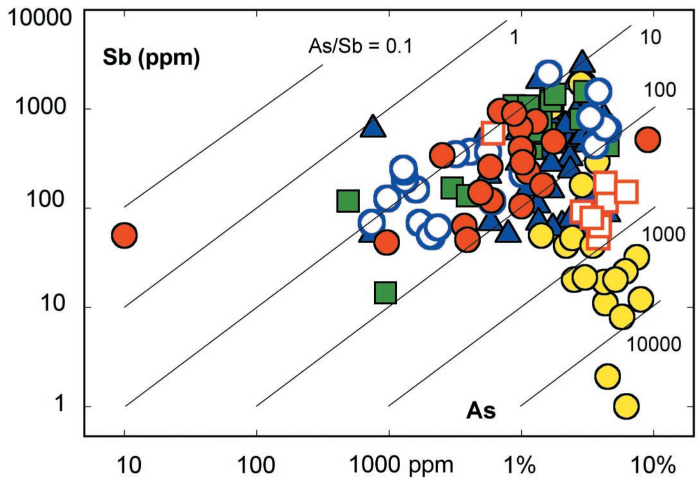

Fig. 1. The concentrations of arsenic (*As*) and antimony (*Sb*) in EBA copper-based metal artifacts (see text) from Besiktepe, dating to Troia I, are similar to the concentrations in contemporaneous objects from Poliochni on Lemnos and Thermi on Lesbos. Metal from Ilipinar and the Yortan cemetery, on the other hand, tends to contain more As and less Sb which, together, results in As/Sb abundance ratios which are 10–100 times higher. *Red dots* this paper; *yellow dots* Ilipinar (Begemann et al. 1994); *blue circles* Troas (Pernicka et al. 1984); *blue triangles* Thermi (Begemann et al. 1992, 1995); *green squares* Poliochni (Pernicka et al. 1990); *red squares* Yortan (Pernicka et al. 1984)

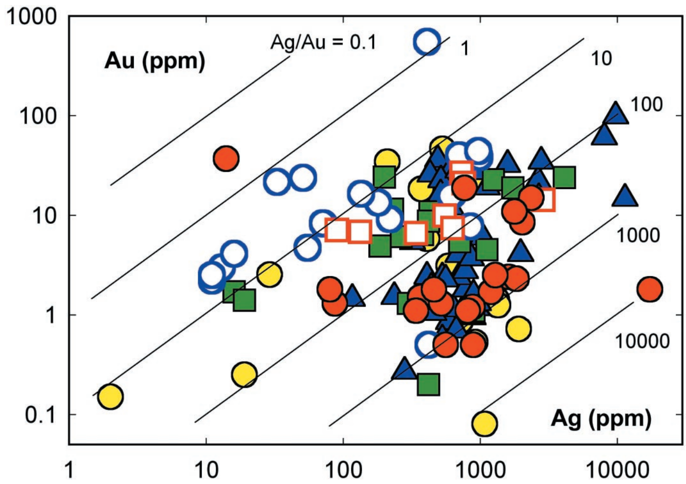

Fig. 2. In a gold vs. silver diagram the Troia I artifacts from Besiktepe fall again together with the EBA objects from Poliochni and Thermi although for Poliochni, and even more so for Ilipinar, the grouping of objects is not very tight. *Symbols* are as in Fig. 1

many (eight out of thirteen) should still be made of unalloyed copper. Apparently, unalloyed copper had its use side-by-side with bronze, a result which would, of course, be more interesting if it were known what type of objects we are dealing with.

The tin content of the bronzes varies considerably, between 1.3 and 14.6 %, similar to what has previously been observed for artifacts from the Aegean and western Anatolia. The low tin concentrations are remarkable in so far as written texts from Ebla und Ur, dating to the second half of the third millennium B.C., prescribe proportions of tin and copper that yield alloys with between 9 and 17 % tin (Limet 1960; Waetzoldt and Bachmann 1984). Since two of the bronzes with a low tin content date to the Hellenistic period when the technical possibilities to rigorously control the tin content did exist, perhaps there was no reason seen why it should be constant in the first place. Of course, remelting "proper" bronzes together with unalloyed copper would also reduce the tin content. For one of the low-tin bronzes (HDM 1015 with 2.8 % Sn) such an explanation is unlikely, however. Of all objects analyzed, this sample is highest by far in nickel content while mixtures, by necessity, must always be intermediate in any of their compositional material features between the putative end members used for mixing.

It is interesting that in the bronzes tin is not correlated with the content of any trace element. Thus, there is no evidence that significant amounts of any of the trace elements in the bronzes have been introduced together with the tin used for alloying; the tin appears to have been rather free from impurities. This accords with analyses of tin ingots from shipwrecks at Uluburun (Kas), Hishuley Carmel and Kefar Shamir in the eastern Mediterranean (Maddin 1989; Begemann et al. 1999), although these ingots date only to the end of the second millennium B.C., i.e., they are much younger than Troia I and also somewhat younger than Troia VI.

Besides the higher fraction of bronzes among the suites of objects later than Troia I, there are, in addition, more subtle chemical differences, in trace element concentrations as well as in concentration ratios, between the objects dating to Troia I and those from later periods. This is true for both the bronzes and the objects made from unalloyed copper. The general tendency is for the younger objects to be higher in cobalt and gold, but to be lower in silver and arsenic. The differences are most obvious from plots of nickel vs. cobalt (Fig. 3), gold vs. silver (Fig. 4), and antimony vs. arsenic (Fig. 5). Note that "uncertain age" as defined here allows for the possibility that an object so classified belongs to Troia I or, for that matter, to Troia VI. Hence, for this reason alone, it is not surprising to find some overlap of the areas populated by the data for artifacts of uncertain age with those of, say, Troia I. We emphasize, however, that such an agreement of trace element

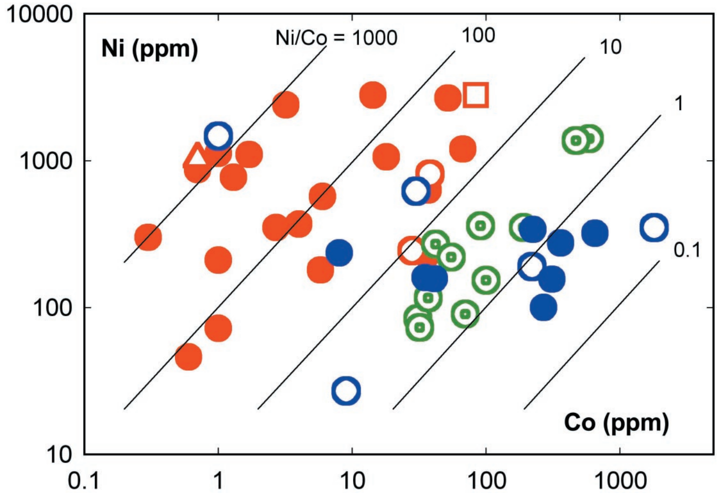

Fig. 3. Nickel and cobalt contents in metal from Besiktepe are very variable. There is a clear tendency for cobalt contents to be higher in younger objects than in those dating to Troia I. Some of the samples of uncertain age (not shown) plotted (see text) together with the objects from Troia I; this must not be construed to mean that these objects are Troia I in age (see text). *Red* Troia I; *green* Troia VI; *blue* Hellenistic. *Full dots* Unalloyed copper; *open circles* bronze; *triangle* arsenical copper; *square* crucible slag(?)

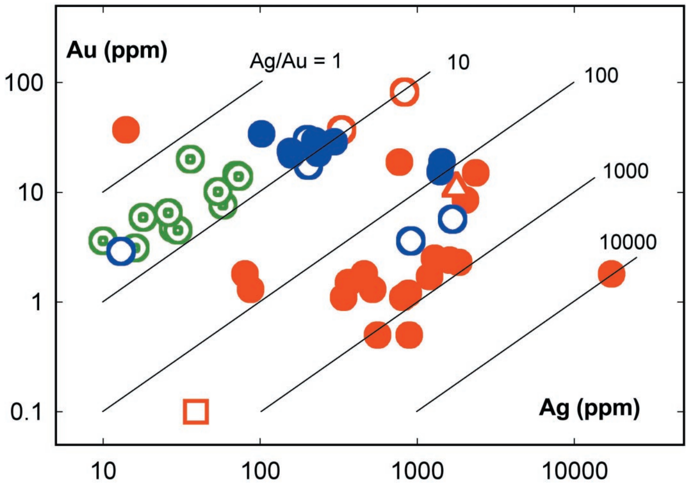

Fig. 4. There is a clear distinction in the trace element abundance pattern between unalloyed copper dating to Troia I and the bronzes from the cemetery dating to Troia VI. The Troia VI grave offerings are remarkable for the constancy of their Ag/Au ratio. Note that the silver content in the Troia VI bronze pieces tends to be very much *lower* than in the unalloyed copper, independent of its age setting. Obviously, this bronze *cannot* have been manufactured by alloying tin with the kind of copper as is present in the unalloyed artifacts. *Symbols* are as in Fig. 3

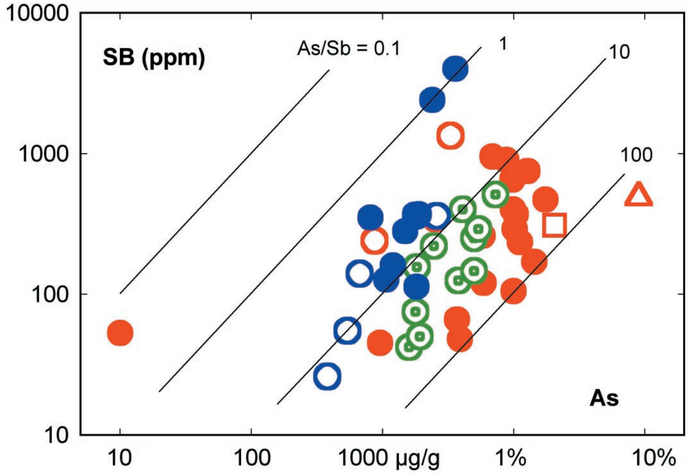

Fig. 5. The tendency for objects from different periods to be distinct in their trace element contents, or trace element abundance ratios, is followed by arsenic and antimony. This is essentially due to arsenic concentrations being lower in later periods. *Symbols* are as in Fig. 3

features must not be construed to indicate these artifacts to be Troia I in age; it is equally plausible that the same ore deposits, or deposits with the same trace element characteristics, were exploited over an extended period of time.

The pieces of bronze from Troia VI are remarkable for the uniformity of their trace element abundance patterns. This is true, in particular, for element abundance ratios (nickel/cobalt $\cong$ 3, silver/gold $\cong$ 5, and arsenic/antimony $\cong$ 23) which are all constant to within a factor of two. In Figs. 3, 4, and 5, respectively, this is obvious from the alignment of the data points along lines of constant abundance ratios[3]. Another important result to be noted from Fig. 4 is that the bronze artifacts dating to Troia VI are set apart from almost all coppers by their low silver contents. Thus, this kind of bronze

[3] An alignment along lines of constant element abundance *ratios* results if different ore charges contained different amounts of an accessory phase which carried the two elements in a constant ratio. The silver-gold diagram suggests, e.g., that the bronze objects dating to Troia VI received their silver and gold from a carrier phase that varied in amount about tenfold, but contained silver and gold in an abundance ratio Ag/Au $\cong$ 5. The unalloyed copper from Troia I, on the other hand, shows about the same tenfold spread in silver and gold contents as the Troia VI bronze objects but in this instance the Ag/Au abundance ratio in the putative carrier phase of the two elements appears to have been several hundred, rather than five as for the Troia VI bronze.

cannot have been manufactured by alloying tin with the kind of copper present in our suite of unalloyed copper objects. In that case, the silver content of the bronzes would be equal to that of the copper, or higher if any silver had been introduced together with the tin. Clearly, this is not the case. As mentioned already, the same has also been observed for the "Troas" artifacts reported by Pernicka et al. (1984). Similar reasoning, although not based on silver contents, but on differences in "cluster assignment" and lead isotopy, led us before to conclude that at Poliochni the bronze artifacts and those made of unalloyed copper are also not genetically related (Pernicka et al. 1990). The bronze from Poliochni also cannot have been manufactured by adding tin to the kind of copper excavated there; a conclusion of particular interest because at Poliochni the copper objects and those made from bronze are strictly contemporaneous.

In the Ag–Au diagram of Fig. 4, there is a kind of grouping of eight coppers and three bronzes, with silver contents around 200 µg/g and Ag/Au ratios close to ten [4]. With one exception (HDM 331 which is too low in arsenic) the members of this group also fall close together in the Sb vs. As plot, with abundance ratios As/Sb $\approx$ 8, and they are fairly constant in Ni content, between 156 and 350 µg/g Ni. All this suggests that these objects might be genetically related as far as the provenance of their metal is concerned. Interestingly, cobalt in these samples is not constant at all, but varies by a factor of 75, between 24 and 1800 µg/g; its abundance is not tied to that of any of the other elements analyzed. What argues rather convincingly against a common origin of the metal in these samples, however, is their lead isotope signature. The differences among the seven samples analyzed for the isotopic composition of their lead are such that a provenance from the same orebody is improbable (see below).

3 Lead Isotopic Composition

Previous analyses for the isotopic composition of lead in copper and copper-based artifacts from western Anatolia and the eastern Aegean had revealed an extremely wide scatter of the lead isotope abundance ratios which to a large extent, but not exclusively, was due to bronze objects (Pernicka et al. 1984, 1990; Stos-Gale et al. 1984; Begemann et al. 1992, 1995; Stos-

[4] Objects in this group are a piece of bronze dating to Troia I (HDM 1128), the Hellenistic coppers HDM 302, 1131, 1228, 1229, 1252 and bronzes HDM 313 and 318, and three objects made of unalloyed copper of uncertain age (HDM 303, 331, 1125). Of these, only HDM 302, 331, 1125, and the three bronzes have been analyzed for the isotopic composition of their lead.

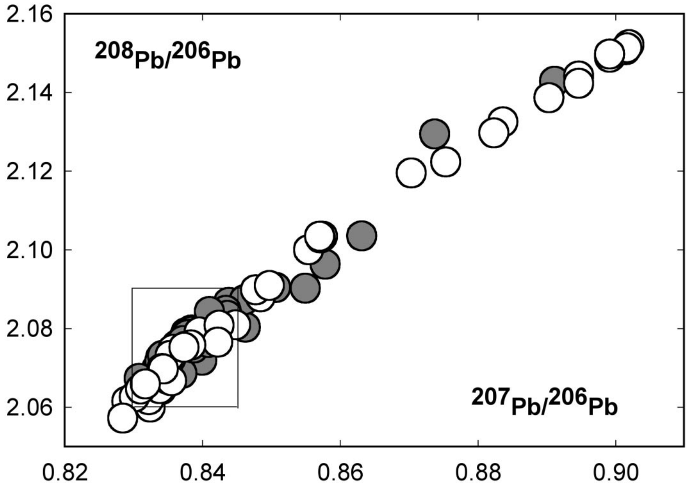

Fig. 6. The isotope abundance ratios of lead traces in copper-based artifacts from the eastern Aegean and western Anatolia cover a wide range which to a large extent, but not exclusively, is due to (tin) bronzes from Poliochni, Thermi and the Troad. In contradistinction the lead in the objects of the present study is much more constant in its isotopic composition; all samples, unalloyed copper as well as bronzes, plot into the *small rectangle* in the lower left corner of the diagram. *Open circles* Bronze; *gray dots* unalloyed copper

Gale 1992). Moreover, at sites where the relative chronology of the artifacts was known, namely at Thermi on the island of Lesbos and at Poliochni on Lemnos, younger artifacts showed a much wider scatter in abundance ratios than the older ones. At Thermi, e.g., objects with widely varying isotope abundance ratios became prominent only during settlement period V, at Poliochni only during period "giallo"[5].

The present metal does not show such a trend. All samples, those dating to Troia I and Troia VI as well as those from Hellenistic times, fall into the small rectangle in the lower left-hand corner of Fig. 6. There are no gross differences in the isotopic composition of their traces of lead between

[5] At Thermi, from the oldest periods I–III, dating to Troia I, there are just 4 objects out of 49 with high ^{206}Pb-normalized abundance ratios, from Thermi IV 1 out of 10, but from settlement period V there are 3 out of 8 with high ratios. Likewise, among the 11 artifacts from the 2 oldest copper-bearing periods at Poliochni, "azzurro" and "verde" (Bernabo-Brea 1964, 1976), there is not a single one with a high ratio; from the next one, period "rosso", it is 1 out of 22, but from period "giallo" it is 11 out of 54. In the present context we define "high" ^{206}Pb-normalized abundance ratio as such with ^{208}Pb/^{206}Pb >2.10. Although somewhat arbitrary, any other reasonable choice for the separation line will change the numbers, but not the conclusion.

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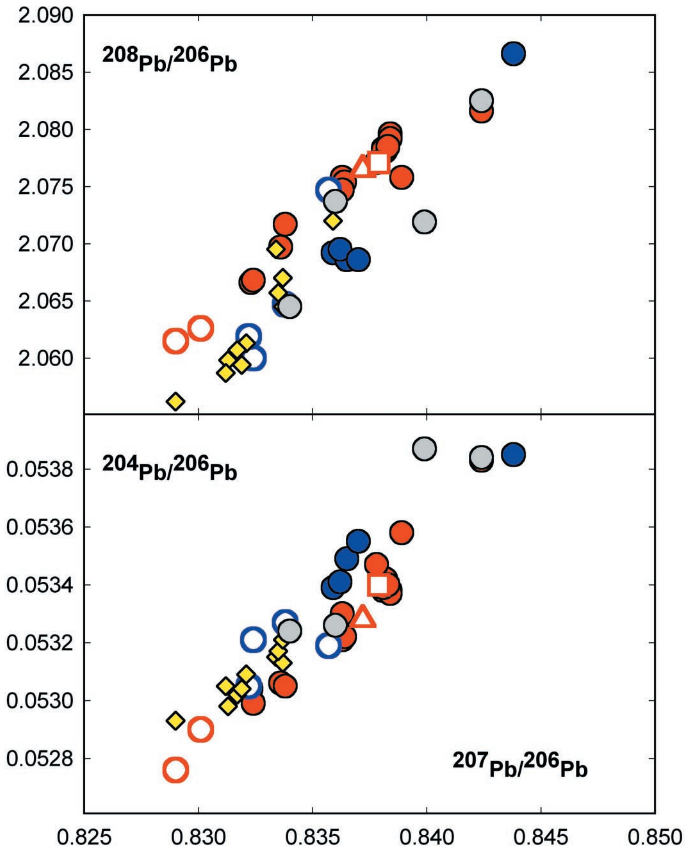

Fig. 7. Lead isotope abundances, normalized to ^{206}Pb, of copper-based artifacts dating to Troia I show some clustering, the most pronounced being at $^{208}Pb/^{206}Pb \cong 2.078$, $^{207}Pb/^{206}Pb \cong 0.838$ and at $^{208}Pb/^{206}Pb \cong 2.075$, $^{207}Pb/^{206}Pb \cong 0.836$, respectively. Objects later than Troia I, copper-based as well as lead objects, tend to fall below the Troia I trend line in the *top panel* and above the trend line in the *lower panel*. They form grouplets of their own. Isotopically matching ores are known to exist in western Anatolia for all samples, but the two Troia I bronzes (*lower left*) and the three objects in the *upper right* of the *top panel*. For the latter matching ores occur at Murgul near the Black Sea coast in northeastern Turkey. *Symbols* are as in Fig. 3 and Fig. 6. Lead objects are marked *yellow*

bronze objects and such made of unalloyed copper (Fig. 7). Nor are objects of uncertain age grossly different in their lead isotopy from the artifacts dating to Troia I. However, more subtle trends do exist. There is a tendency for bronzes to have lower ^{206}Pb-normalized abundance ratios than unalloyed copper which makes the bronze pieces plot into the lower left of both panels of Fig. 7. In addition, all Hellenistic objects and those of uncertain age, bronzes as well as unalloyed copper, in the upper panel of Fig. 7, tend to plot below the trend line defined by the lead in Troia I objects and, in the lower panel of Fig. 7, to plot above the corresponding trend line defined by the Troia I objects.

Most of the artifacts from Troia I – ten made of unalloyed copper, the severely corroded sample tentatively classified as crucible slag (HDM 1114) and the arsenical copper needle (HDM 1116) – have very similar lead isotope abundances. They form two very tight groups(HDM 168, 323, 1009, 1013, 1017, 1111, 1114, 1117, and HDM 166, 1018, 1021, 1116, respectively) which are actually so close to one another that the copper in all these objects might well derive from a single ore deposit (Table 3). One sample of "uncertain" age, the unalloyed copper HDM 1126, and the low-tin bronze HDM 1016 (1.3 % Sn), belong to this (lower) group also. Interestingly, this particular bronze is set apart from the other bronze pieces not only by its low tin content, but together with another bronze fragment (HDM 1110) and one of uncertain age (HDM 1015), by its trace element abundance pattern as well. The silver/gold ratio in these bronzes is around 300, similar to what is characteristic of unalloyed copper dating to Troia I, while in all other bronze objects the ratio is typically below ten (Fig. 4). Similarly, in the Ni vs. Co diagram two of these bronze pieces again plot together with unalloyed Troia I copper, separate from the Troia VI and Hellenistic bronzes (Fig. 3).

Table 3. Isotope abundance ratios of lead in metal objects from Besiktepe. Uncertainties, on the 95 % confidence level, are 0.1% for all isotope abundance ratios. In all cases, the isotope abundance ratios agreed to within the stated uncertainties; listed are the averages

HDM No.	Pb µg/g	$^{208}Pb/^{208}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$
Troia I				
Unalloyed copper				
165	120	2.0697	0.8336	0.05306
166	5400	2.0758	0.8363	0.05321
168 [a]	2080	2.0783	0.8381	0.05338
307 [a]	240	2.0816	0.8424	0.05383
323 [a]	6050	2.0796	0.8384	0.05338
1009	>12,000	2.0792	0.8384	0.05337
1013	>23,000	2.0781	0.8382	0.05342
1017	>14,000	2.0782	0.8381	0.05339
1018	200	2.0754	0.8364	0.05322
1020	40	2.0666	0.8323	0.05304
1021	12,200	2.0747	0.8363	0.05330
1108	>25,000	2.0717	0.8338	0.05305
1111	7700	2.0785	0.8383	0.05340

Table 3 (continued)

HDM No.	Pb µg/g	$\frac{^{208}Pb}{^{208}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{204}Pb}{^{206}Pb}$
1112	120	2.0758	0.8389	0.05358
1117	80	2.0771	0.8378	0.05347
1132	13,700	2.0668	0.8324	0.05299
Arsenical copper				
1116	n.d.	2.0765	0.8372	0.05328
Bronzes				
1123	3900	2.0615	0.8290	0.05276
1128	3250	2.0626	0.8301	0.05290
Crucible slag				
1114	38,700	2.0771	0.8379	0.05340
Hellenistic				
Unalloyed copper				
301	590	2.0866	0.8438	0.05385
302	440	2.0692	0.8359	0.05339
304	75	2.0686	0.8365	0.05349
330[a]	230	2.0695	0.8362	0.05341
1131	110	2.0686	0.8370	0.05355
Bronzes				
313[a]	120	2.0600	0.8324	0.05321
318	50,000	2.0619	0.8322	0.05305
1016	600	2.0747	0.8357	0.05319
1118	60	2.0647	0.8338	0.05327
Lead				
171	n.d.	2.0607	0.8317	0.05302
172	n.d.	2.0695	0.8334	0.05315
174	n.d.	2.0562	0.8290	0.05293
176	n.d.	2.0720	0.8359	0.05327
180	n.d.	2.0598	0.8313	0.05298
183	n.d.	2.0587	0.8312	0.05305
184	n.d.	2.0670	0.8337	0.05313
185	n.d.	2.0657	0.8335	0.05317
187	n.d.	2.0645	0.8337	0.05321
1130	n.d.	2.0594	0.8319	0.05304
Uncertain date				
Unalloyed copper				
167[a]	170	2.0825	0.8424	0.05384
331	90	2.0719	0.8399	0.05387
1125	50	2.0645	0.8340	0.05324
1126	590	2.0737	0.8360	0.05326
Lead				
164	n.d.	2.0613	0.8321	0.05309

[a] Because of their poor state of preservation, these objects were sampled and analyzed twice.

Smaller grouplets of objects where the lead isotope abundance ratios agree within experimental uncertainties are HDM 302, 304, 330, 1131 and several pairs of objects for which the isotopic compositions are virtually identical (HDM 167 and 307, HDM 165 and 1108, HDM 1020 and 1132, HDM 1118 and 1125); all but HDM 1125 are unalloyed copper.

4
Provenance of Copper-Based Artifacts

Although western Anatolia is not, and probably never was, a major source of copper for the Aegean and its surrounding shores, there are nevertheless a number of copper deposits in the vicinity of Troia which, at some time in the past, may have served to fill local demand (Ryan 1960; de Jesus 1980). Many of these occurrences were visited some 15 years ago during field campaigns organized by G. A. Wagner and Ö. Öztunali (Gentner et al. 1978; Pernicka et al. 1984; Wagner et al. 1986). Copper ores were found at about 20 sites. In most instances, however, the occurrences were so small, or copper ores were only so subordinate, that these ore bodies are unlikely ever to have been exploited, even in antiquity when very much smaller occurrences than today would have been of economic interest. Based on criteria such as the presence of ancient slag, of prehistoric stone tools and potsherds, or the winning techniques employed, Wagner and Öztunali (2000), in their recent compilation, list six sites in northwest Anatolia where evidence exists for prehistoric copper mining and/or smelting activities[6]. They also suggest as potential sites for ancient copper production Balya (Balikesir Province) and Gümüsköy (Kütahya Province) although both are major lead-silver deposits. While clear evidence for mining or smelting of *copper* ores was not discovered at either site, the authors argue that the striking visibility of oxidic copper ores close to the surface would hardly have gone unnoticed by chalcolithic metallurgists and, moreover, that at Balya secondary copper minerals in the old mining waste are a common feature.

Lead isotope analyses were performed on copper slags and copper ores or galenas (PbS) from the same sites as the slags. For easy reference the

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[6] The sites in question are Dogancilar (TG 133) and Yuvalar (TG 138) in Canakkale Province, Kozcagiz (TG 142) and Serceörenköy (TG 192) in Balikesir Province, Keles (TG 154) and Tahtaköprü (TG 156) in Bursa Province. Three more sites with copper slags or copper ores, but without evidence for ancient mining activities, are Avcilar (TG 128) and Halilar(TG 144) in Balikesir Province and Camyurt (TG 136, Canakkale Province). Detailed descriptions of the sites as well as lead isotope abundance ratios have been reported in part in Wagner et al. (1986).

data are compiled in Table 4, together with results of some other ore and slag samples relevant for the present discussion[7].

Generally speaking, ores and slags fall together with the artifacts in the same region of the lead isotope diagrams. In detail, the lead from Gümüsköy matches that in the group of 12 objects from period Troia I discussed above. Thus, the lead isotope abundance ratios suggest the copper in these objects to have been derived from Gümüsköy. This result must be qualified, however. First, because the ore sample analyzed was a galena (PbS), not a copper ore. Although more often than not copper ores and lead ores from the same mines agree in their lead isotopy, there are also exceptions (Table 4, see also Fig. 29 in Wagner et al. 1989). Moreover, it must be remembered that an assignment based on material features of an artifact to a specific ore deposit is not unique: there is always the possibility that other deposits might exist which fit the relevant artifact feature equally well. In the present instance these are the deposits at Bakir Dagi (TG 282) in Central Anatolia, Kayseri Province and at Kürtün-Cayircukur (TG 207) in North Anatolia some 50 km southwest of Trabzon (Fig. 8). Both are also listed by Wagner and Öztunali (2000) as sites with archaeometallurgical remains and evidence for early copper production. Still, Gümüsköy is our favorite source site, not only because of its relative proximity to Troia, but also because at Gümüsköy calibrated ^{14}C dates of a piece of mining timber (Demirok 1982) and a piece of charcoal from the backfill in an old mine (Wagner and Öztunali 2000) attest to mining activities in the late third millennium B.C.

Of the smaller lead isotope grouplets of artifacts the one with four members (HDM 302, 304, 330, 1131) has corresponding ores and/or slags at Avcilar, Camyurt, Alihoca, Mentese, and Tekmezar (Table 4). The first two sites geographically are close to Troia, but evidence at these locations for copper production in antiquity is weak or nonexistent (Pernicka et al. 1984; Wagner and Öztunali 2000). Alihoca in the Bolkardag district in the central Taurus in South Anatolia, Mentese in Central Anatolia, and Tekmesar, ca. 10 km inland from the central Black Sea coast are considered more promising in this respect (Wagner and Öztunali 2000). but nothing more definitive can be said at the present time.

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[7] For determining the provenance of copper metal via its lead isotope fingerprint copper slags are to be preferred over copper ores because slags not only contain the lead from the copper ores themselves, which can be very small, but also all extraneous lead as may have been introduced from sources like flux or gangue. Thus, the lead in slags and the lead in the metal are identical in their isotopic composition and this may well be quite distinct from the ore lead. In contradistinction, *trace elements* in slags, concentrations as well as their abundance patterns, are of only limited value for provenance studies.

Table 4. Lead isotope abundance ratios in Anatolian copper and lead ores and slags which have matching compositions among the Besiktepe artifacts. Prehistoric mining and/or smelting activities are reported for all sites except at Avcilar and Camyurt. (Wagner and Öztunali 2000)

	TG No.		$\frac{^{208}Pb}{^{208}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{204}Pb}{^{206}Pb}$	Ref.
Alihoca	287 A	Cu ore	2.0717	0.8375	0.05382	(unpubl.)
Alihoca	287 B	Cu ore	2.0719	0.8354	0.05353	(unpubl.)
Alihoca	287 F	Cu ore	2.0261	0.8139	0.05179	(unpubl.)
Alihoca	287 B-Cu	native Cu	2.0760	0.8405	0.05404	(unpubl.)
Alihoca	287 C.1	Pb slag	2.0542	0.8265	0.05266	(unpubl.)
Alihoca	287 E.1	Pb slag	2.0537	0.8258	0.05262	(unpubl.)
Avcilar	128 B-2	Galena	2.0656	0.8337	0.05323	Wagner et al. (1985)
Avcilar	128 C-8.1	Cu slag	2.0691	0.8352	0.05336	Wagner et al. (1986)
Bakir Dagi	282 B.1	Cu ore	2.0761	0.8379	0.05339	(unpublished)
Bakir Dagi	282 C.1	Cu ore	2.0711	0.8362	0.05328	(unpublished)
Bakir Dagi	282 B.2	Cu slag	2.0764	0.8378	0.05341	(unpublished)
Balya	18 A	Galena	2.0722	0.8348	0.05318	(unpublished)
Balya	18 C	Galena	2.0711	0.8344	0.05314	Wagner et al. (1985)
Balya	18 D-1	Galena	2.0694	0.8340	0.05316	Wagner et al. (1985)
Balya	18 D-2	Galena	2.0695	0.8340	0.05316	Wagner et al. (1985)
Balya	18 D-3	Galena	2.0693	0.8340	0.05317	Wagner et al. (1985)
Balya	18 E	Galena	2.0711	0.8347	0.05319	Wagner et al. (1985)
Balya	18 A-SCH	Pb slag	2.0705	0.8342	0.05315	(unpubl.)
Balya	18 H-SCH	Pb slag	2.0691	0.8335	0.05311	(unpublished)
Balya	18 H-SP	Speiss	2.0704	0.8342	0.05316	(unpubl.)
Camyurt	136	Cu slag	2.0681	0.8355	0.05336	Wagner et al. (1986)
Dogancilar	133 E	Galena	2.0641	0.8333	0.05331	Wagner et al. (1985)
Dogancilar	133 B-2	Cu slag	2.0641	0.8333	0.05319	Wagner et al. (1986)

Table 4 (continued)

	TG No.		$^{208}Pb/^{208}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$	Ref.
Gümüsköy	155 C	Galena	2.0761	0.8373	0.05335	Wagner et al. (1985)
Kozcagiz	142 H-1	Galena	2.0721	0.8350	0.05328	Wagner et al. (1985)
Kozcagiz	142 D-4	Cu slag	2.0668	0.8335	0.05317	Wagner et al. (1986)
Kürtün Cayircukur	207-A	Cu ore	2.0786	0.8398	0.05371	Wagner et al. (1989)
Kürtün Cayircukur	207-G1	Cu ore	2.0744	0.8374	0.05349	Wagner et al. (1989)
Kürtün Cayircukur	207-C	Cu slag	2.0854	0.8442	0.05408	Wagner et al. (1989)
Mamlis	221 A	Cu/Pb ore	2.0611	0.8284	0.05279	Wagner et al. (1989)
Mamlis	221 B	Pb slag	2.0622	0.8287	0.05276	Wagner et al. (1989)
Mentese	281.1	Cu ore	2.0701	0.8371	0.05343	(unpubl.)
Serceören Köy	192–4	Cu ore	2.0723	0.8349	0.05314	(unpubl.)
Serceören Köy	192–5	Cu ore	2.0704	0.8345	0.05314	(unpubl.)
Serceören Köy	192–6	Cu ore	2.0699	0.8342	0.05317	(unpubl.)
Serceören Köy	192–7	Cu ore	2.0700	0.8346	0.05318	(unpubl.)
Serceören Köy	192–8	Cu ore	2.0705	0.8345	0.05317	(unpubl.)
Serceören Köy	192–9	Cu ore	2.0700	0.8346	0.05320	(unpubl.)
Serceören Köy	192–10	Cu ore	2.0715	0.8342	0.05315	(unpubl.)
Serceören Köy	192–11	Cu ore	2.0710	0.8347	0.05318	(unpubl.)
Serceören Köy	192–12	Cu ore	2.0715	0.8347	0.05317	(unpubl.)
Serceören Köy	192 A-1	Cu slag	2.0710	0.8340	0.05318	(unpubl.)
Serceören Köy	192 A-2	Cu slag	2.0707	0.8346	0.05316	(unpubl.)
Serceören Köy	192 B	Cu slag	2.0693	0.8340	0.05312	(unpubl.)
Serceören Köy-Demir	192–2	Cu ore	2.0704	0.8346	0.05319	Wagner et al. (1986)
Serceören Köy-Demir	192–3	Cu ore	2.0695	0.8344	0.05318	Wagner et al. (1986)
Tahtaköprü	156	Cu ore	2.0637	0.8321	0.05314	Wagner et al. (1986)
Tekmezar	202–A	Cu ore	2.0731	0.8378	0.05354	Wagner et al. (1989)
Tekmezar	202–A1	Cu slag	2.0731	0.8374	0.05344	Wagner et al. (1989)

[a] For an explanation of the wide range in isotope abundance ratios see, e.g., Section 2.

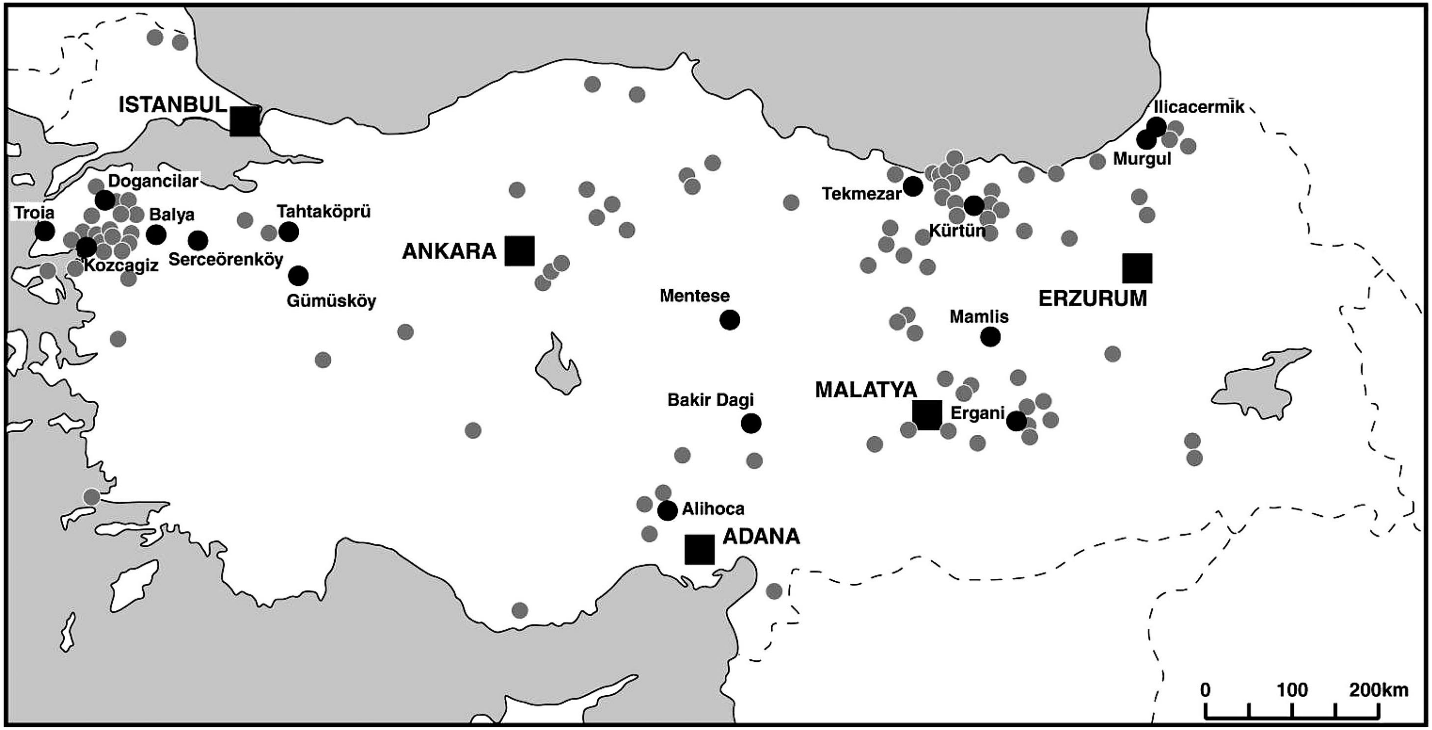

Fig. 8. Prehistoric copper/lead mines in Anatolia with lead isotopic fingerprints as they occur in copper-based artifacts from Besiktepe dating to Troia I. These mines (*black dots*) qualify as sources of the Besiktepe copper during the first half of the third millennium B.C. The total coverage of Anatolia during the various surveys is indicated by *gray dots*

Of the four pairs of objects for which the members of each pair have the same lead isotopy, three have corresponding ores and/or slags in western Anatolia, at sites listed by Wagner and Öztunali (2000) to show evidence for prehistoric exploitation[8]. For the fourth pair (HDM 167, 307) matching copper ores and/or copper slags exist at Ilicacermik, Kayabasi Köyü, and Murgul, all located in northeastern Anatolia near the Black Sea coast (Wagner et al. 1989). Of these, Murgul in particular has been shown to have been operational as early as in the second half of the fourth millennium B.C. (Lutz et al. 1994; Wagner and Öztunali 2000).

The two pieces of bronze from Troia I fall at the extreme lower left end of the distribution (Fig. 7). Isotopically matching ores occur in East Anatolia, at Ergani Maden (Seeliger et al. 1985; Wagner et al. 1986) and at nearby Mamlis (Wagner et al. 1989). Of these, Ergani Maden is a particularly intriguing possibility. Because of its easy accessibility, its location on the upper Tigris at the trade route connecting Central Anatolia with Mesopotamia, and because of the conspicuous occurrence at the surface of colorful oxidic ores and native copper Ergani Maden has frequently been suggested to have been a major supplier of copper in Chalcolithic and Bronze Age Anatolia (Birgi 1950; Wertime 1964). Direct evidence in support of this conjecture is missing, however. There are no traces of old mining reported at Ergani (Seeliger et al. 1985), although this possibly might be due to the destruction and obliteration of such evidence during the extensive modern open-pit exploitation of this important copper producer. However, besides the absence of evidence for old mining, there also is no compelling evidence for the presence in copper-based chalcolithic or Bronze Age artifacts of the combination of trace element and lead isotope signatures as are characteristic of the copper ores, or native copper, from Ergani. Indeed, this is again true for the two pieces of bronze under discussion. While their lead isotopic composition is compatible with a derivation of the copper from Ergani the trace element concentrations are not: cobalt contents are more than 50 times lower in the bronzes than in the ores while silver is 100 times higher in the pieces of bronze than it is in the ores. Judging from the two samples of native copper from Ergani which have been analyzed (Pernicka et al. 1997, Table A3a) the situation is even worse for local native copper. These two specimens of native copper contain arsenic, antimony, cobalt, nickel, silver and gold all in concentrations of 25 µg/g or less which is too low by large factors, of up to several hundred, to fit the two

[8] For HDM 165, 1108 isotopically matching copper ores exist at Serceörenköy and matching lead ores at Balya, for HDM 1020, 1132 at Tahtaköprü, and for HDM 1118, 1125 there are matching copper slags at Dogancilar and at Kozkagiz (Fig. 8).

Troia I bronze objects. Arguing that these trace elements in the bronze were somehow introduced from some extraneous source cannot be refuted, but accepting this explanation goes, of course, to the heart of the whole method of matching material features of artifacts with those of ores; it would make all such provenance studies futile.

Actually, arguments like the present ones, including chemical data of Maddin quoted by Muhly (1989), would appear to have resulted in a change of opinion on the possible role of Ergani as a source of copper in prehistoric Anatolia. Muhly (1989) summarizes the discussion following his presentation at the Heidelberg "Old World Archaeometallurgy" Symposium that "it was the consensus of opinion that Ergani Maden has been greatly overrated as a source of copper, or even the source of copper for the metal industries of prehistoric Anatolia."

5 Lead Artifacts

The trace element contents of the lead objects reveal nothing unusual (Table 5). Antimony, with a mean concentration of 600 μg/g, is about ten times more abundant than is arsenic with a mean content of 72 μg/g. Silver concentrations are remarkably constant (200 ± 90 μg/g). For Troia VI and Hellenistic lead such low values are expected because, by this time, essentially all the lead would have been desilvered by cupellation since, indeed, the production of lead was not aimed at the lead itself, but rather at the silver it contained. Note, however, that the three samples dating to Troia I have low silver contents also.

In the isotope abundance diagram (Fig. 7) lead objects lie in the lower left part, at low ^{206}Pb-normalized abundance ratios, with some overlap of their compositions with those of the lead in copper-based artifacts of Hellenistic age. Five of the samples (HDM 164, 171, 180, 183, 1130) are indistinguishable from one another in their isotopic composition. They agree with lead ores from Laurion (Barnes et al. 1974; Gale et al. 1980; Stos-Gale et al. 1986), the vast lead deposit across the Aegean in southeast Attica which is known to have been exploited more or less continuously from the beginning of the third millennium B.C. to the beginning of last century (Spitaels 1984). Also compatible with a provenance from Laurion are the isotopic fingerprints of two of the bronze objects (HDM 313 and 318). The implications of this result are not quite clear because so far no traces of copper slag have been reported from Laurion. Hence, although copper ores do occur at Laurion their potential role as a source of copper in antiquity remains uncertain.

Table 5. Trace elements in pieces of lead from Besiktepe. Concentrations are listed in µg/g. Copper in all cases was below 0.1% except in HDM 322 where the upper limit is 0.2%

HDM No.	Sn	As	Sb	Ag	Au	Bi
Troia I						
309	<540	4	–	172	<0.02	–
315	<620	63	1160	257	0.31	–
329	<550	34	337	174	0.92	–
Troia VI						
305	<340	21	–	392	0.11	–
310	<3000	<60	–	<150	<0.30	–
314	<340	6	343	388	78.00	–
320	<370	11	371	372	0.09	–
325	<310	433	1240	230	0.69	–
Hellenistic						
171	–	22	573	168	0.20	–
172	–	224	2200	216	0.36	231
174	–	4	42	50	0.96	57
176	–	24	145	174	0.26	11
180	–	128	954	123	<0.02	2
183	–	73	739	178	<0.03	–
184	–	110	417	174	0.23	–
185	–	12	261	162	0.36	–
Uncertain						
164	–	10	115	128	0.06	151
269	–	25	618	172	0.27	34
306	<690	207	–	250	0.33	–
317	<470	5	180	178	0.10	–
322	<1000	36	540	106	0.19	–

Four other specimens (HDM 172, 184, 185, 187) also form a tight isotope cluster. For them, corresponding ores exist at Balya and a few small ore occurrences in northwestern Anatolia (Avcilar and Adasi Maden in Balikesir Province; Dagoba, Dogancilar, and Kustepe in Canakkale Province[Wagner et al. 1985]). Among these, Wagner and Öztunali (2000) report evidence for ancient mining activities aimed at lead only at Balya, however. Other geographically more removed, but nevertheless potentially interesting source regions for this kind of lead, are Thasos and also the Kassandra ore district, west of Stration, in the northwest of the Chalkidike peninsula (Chalkias et al. 1988; Gale et al. 1988). On Chalkidike there is again no evidence for old mining activities, but on Thasos such activities are well documented (Speidel 1929; Gialoglou et al. 1988; Pernicka and Wagner 1988, Fig. 264). Moreover, the concentrations of arsenic, antimony, and gold in lead metal recovered from slags on Thasos agree fairly well with those in the lead from Besiktepe[9].

6 Summary and Conclusions

The lead isotope fingerprints of almost all copper-based Troia I artifacts from Besiktepe are compatible with a derivation of the copper from ore deposits in western Anatolia. The same had been found earlier for many of the contemporaneous objects from settlement phases I–III at Thermi on the island of Lesbos (Stos-Gale 1992; Begemann et al. 1992, 1995) and for objects from periods "azzurro" and "verde" at Poliochni on Lemnos (Pernicka et al. 1990). In detail, the isotopic composition most frequently encountered at Besiktepe is also found in 17 out of a total of 37 objects analyzed from Thermi and in 6 (out of11) objects from Poliochni. Thus, Gümüsköy, the ore deposit we find most plausible to have been the source of this copper may well have been a mayor supplier of copper to Troia and the eastern Aegean during the first half of the third millennium B.C. Serceörenköy-Balya, present with two cases of matching isotopy among Besik-Yassitepe copper pieces, occur with four more samples among the artifacts from Thermi and with one more from Poliochni. Since there are small, but systematic differences between artifacts from the three archaeological sites in their trace element contents it would appear that the metal recovered at the three sites derived from different locations within the large ore deposits of Gümüsköy, Serceörenköy and Balya, possibly because of slight differences in age of the objects from the relevant periods at Besiktepe, Poliochni, and Thermi. Chemical data presently available on ores from the three deposits are not comprehensive enough to indicate the range in trace element concentrations one might reasonably expect. It is, of course, also possible that several different ore deposits were exploited in western Anatolia with very similar lead isotope signatures, but different trace element contents.

Most authors writing on the subject of early Aegean metallurgy stress the difference between the initial phase, equivalent to Troia I, and developed Troia II (Renfrew 1967; Branigan 1974; de Jesus 1980; Yakar 1984). They all note the typological similarities across the Aegean during the later phase which did not exist earlier, suggesting a marked increase of contacts owing to the advances in regular seafaring and the extent of the trade of metals, among other commodities. Renfrew (1972) sees the appearance

[9] Silver in the metal spherules from these lead slags is about ten times higher than in the Besiktepe metal. However, such a difference between original lead and desilvered lead is, of course, to be expected.

during this period of an "international spirit", and dramatic expressions like "Metallschock" (Schachermeyr 1984) and "metallurgy explosion" (Branigan 1974) have been used to describe the sudden increase in the number of metal finds. We note that these conclusions, based on typology, are in accord with the material science data: while during Troia I the lead isotopic composition and the trace element contents of copper-based artifacts at Besiktepe, Poliochni, and Thermi are compatible with a derivation of this copper from western Anatolian sources, during Troia II a different kind of copper reached the Aegean, either as copper ingots or as finished objects (Pernicka et al. 1984, 1990; Begemann et al. 1992) which came to be used side-by-side, but never completely replaced the copper from the old source(s). The provenience of this new metal is still somewhat enigmatic because there is no plausible source among the studied ore deposits in southeastern Europe, the Aegean, and Anatolia. The contemporaneous appearance of such metal also at Kastri on the island of Syros (Stos-Gale et al. 1984) perhaps suggests the influx of foreign metal (and people?) into the Aegean. The most likely direction from where it came seems to be the east.

Lest there be any misinterpretation, we reemphasize that our data, as all such data, do not allow a definitive positive assignment; they only tell us whether or not certain assignments are possible. According to our ore data bank, for many of the artifacts under discussion there are isotopically matching copper ores and copper slags from many more places in the Mediterranean and the Aegean, from Sardinia, Cyprus, Crete, Kea, Siphnos and Thasos, as well as from Afghanistan, Bulgaria, Jordan, and Serbia. Occam's Razor[10], however, makes it prudent first to look for local sources, in particular if evidence exists that these were actually exploited at the times in question.

Problems with definitive conclusions do not exist if the conclusions are in the negative. Therefore, it is worth repeating that none of the copper-based Early Bronze Age artifacts from the eastern Aegean and the vicinity of Troia can be traced to Ergani. Evidence for an important seminal role of Ergani in the development of copper-based metallurgy remains elusive.

Concerning the 11 bronze objects from the Troia VI cemetery we reemphasize that these objects are notable for their uniform trace element abundance patterns (lead isotope data do not exist). The "extensive evidence of the presence of exotic materials among the small finds from the cemetery" (Basedow 2000) is not reflected in a diversity of chemical compositions. Typologically, adornments like the two bronze anklets from grave No. 68 (HDM 1257 and 1258), in particular, are exceedingly rare in the

[10] William of Occam, ca. 1280–1349. "*Entia non sunt multiplicanda praeter necessitatem*". Quoted from Encyclopaedia Brittanica.

Aegean having their closest parallels in samples from the Caucasus and from northern Germany. Still, chemically they are only notable for the perfect agreement in the concentrations of tin and all trace elements, making it virtually certain that they were manufactured together. However, there is nothing that would set this pair of artifacts apart from the other bronzes from the cemetery, except perhaps that nickel and cobalt concentrations are somewhat high. The constancy of the composition of all 11 bronze objects argues for a single, presumably local source of the metal in these artifacts. Since the trace elements in the Besiktepe bronzes are dominated by the contributions originating with the copper, not with the tin used for alloying, the local source of metal pertains only to the copper. Because of the absence of any tin deposits in western Anatolia, tin would have to have been imported and the alloying to have been performed locally, or alloy ingots to have been imported.

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