

## Experimental Co-smelting to Copper-tin Alloys

### Abstract

*Many aspects of prehistoric technologies for copper-tin alloy production are so far unknown to us and require further investigation. In particular, there is a shortage of archaeological slags that strongly contrasts with the frequent discovery of bronze objects. In this article, we will briefly review the most important archaeological evidence concerning tin, as well as describe a successful experiment carried out to obtain bronze through a process of co-smelting copper and tin ores. We will also show the most relevant analytical data obtained during a lab study of the materials coming from this experiment. As we can gather from recent archaeometallurgical research, the technology that has been employed in the experiment is quite close to the one that a prehistoric metallurgist could have used. Thus, co-smelting is a process that we have to consider when talking about early bronze production.*

### Introduction<sup>1</sup>

An oversimplified view of metallurgy can lead us to believe that some aspects of archaeometallurgical research, especially tin-bronze obtaining, do not require more in-depth investigation. However, although, researchers often consider the obtaining of tin-bronze a well-known and easily recognisable practice, most metallurgical processes employed by prehistoric metallurgists to produce bronze are still barely known.

Compared to prehistoric copper and arsenic bronze, tin bronze prompted important technological advances due to its better mechanical properties. Supposedly, it can be obtained through the following processes:

- a) Melting in a crucible metallic copper and tin in convenient proportions;
- b) Cementing in a crucible metallic copper crushed in very fine portions with cassiterite (tin oxide, as it appears in nature);
- c) Co-smelting a mixture of copper-tin ores.

Experimental archaeology and scientific studies of various archaeological evidences prove that some of the processes mentioned above were indeed used during specific historical periods. For example, at the beginning of the 20<sup>th</sup> century W. Gowland obtained bronze by means of a co-smelting process of malachite and cassiterite using an open fireplace and yielded enough metal to account for this practice (Gowland 1912). Thus, his experiment showed how this technique for bronze production (option c) does not require great infrastructural means. More recently, some experiments carried out by Rostoker/Dvorak (1991) and Herdits/Keen/Steinberger (1995) achieved similar results. A few years earlier, after studying the materials coming from the sanctuary of Poseidon at Isthmia (Greece), Rostoker/McNallan/Gebhard (1983) gathered enough evidence to suggest that, between the 7<sup>th</sup> and the middle of the 5<sup>th</sup> century BC, the metallurgical workshops of the sanctuary were producing bronze by the co-smelting of copper and tin ores. Regarding tin obtaining, Timberlake (2007: 31) has carried out successful experiments using a very simple infrastructure.

Despite these experiments, scientific studies of materials related to the technology for obtaining tin and bronze are still very rare and many questions remain unanswered. There are indeed numerous bibliographic references and articles concerning some aspects of tin production – the fundamental metal that when alloyed with copper produces bronze. However, most of that work approaches the topic strictly from an archaeological point of view, focussing on the provenience of bronze in order to study the socio-economic implications of metal production for ancient civilisations.

The most ancient metallic tin findings in the eastern Mediterranean – both ingots and manufactured objects – date back no further than 1600 BC. Worth mentioning here are the ingots from the Uluburum shipwreck, found in the southern part of Anatolia and commonly dated from the Cypriot Late Bronze Age, 1600-1050 BC (Kassianidou 2003: 115). The objects inventoried by Penhallurick, mainly found in Egypt, trace back to even later times (Penhallurick 1986: 9), while some tin beads found in Europe are dated to the beginning of the second millennium BC (Primas 2003: 89). In contrast, it is important to point out that

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the first bronzes from Britain are older, going back to 2300-2200 BC (Needham 1996: fig. 2). The Iberian Peninsula also yielded some evidence of bronze objects, dating from the end of the third millennium BC (Alcalde et al. 1998: 95-97).

These findings beg the question of the origin of the tin employed in the production of the bronze artefacts found in Britain and in Spain. If tin production is based on a process of cassiterite reduction in smelting furnaces, where are the traces of these furnaces and what do we know about their sub-products such as tin-obtaining slags? Unfortunately, so far, the information available on both furnaces and slags is very scarce.

In the metallurgical village of Göltepe in central Anatolia, there is evidence of tin production from the fourth millennium BC (Yener et al. 2003: 183). According to these authors, tin was obtained by the reduction of cassiterite in small vessels or crucibles with a flat base and a bowl-shaped inner part which has a diameter of 12 cm and a depth of 5 cm. After smelting, the slags were crushed to separate the metal.

During surface prospecting in the tin-rich region of southwestern England, Tylecote/Photos/Earl (1989) analysed a group of samples of tin slags and tentatively dated some of them to the Bronze Age. However, since surface prospecting is not a reliable dating method, there is not enough evidence to back up their claim. In contrast, the chronology of some small fragments of tin slags found at the site of St. Renan-Kervéatous (Finistère) in French Brittany is more reliable thanks to radiocarbon dating that places tin exploitation between the end of Middle Bronze Age and the beginning of Late Bronze Age in the late first millennium BC (Giot/Lulzac 1998). There is no doubt that these slags, analysed by Mahé-Le Carlier/Lulzac/Giot (2001), are the result of a reduction process of cassiterite for obtaining tin. In fact, their fine fragmentary state suggests that they were crushed to extract small, trapped tin prills – a practice similar to the one observed at Göltepe. The slags from Caerloggas (Cornwall) dating approximately 1600 BC and studied by Salter (1997) also seem to be the result of this kind of metallurgical technique for tin production. All slags analysed in these studies have shown a great loss of tin.

On the whole, a lack of evidence for obtaining tin compared to a documented increase in the production of bronze objects during prehistoric times, leads us to think that a considerable part of these bronzes may have been produced by co-smelting processes of copper and tin ores – a technique that leaves little metallurgical debris. Moreover, in recent years, some copper-tin slags have been found in the Iberian Peninsula, together with crucible fragments covered by a thick, slagged layer. Copper and tin have been detected in this metallurgical debris, sometimes to-

gether with lead (Rovira 2007) and their analysis has called for new experiments that can verify the viability of the co-smelting process and produce comparative materials.

## The infrastructure of the experiment

A smelting place was prepared with a very simple infrastructure consisting of a small basin excavated in the soil, measuring 30 cm in diameter and 20 cm in depth. Two lateral structures functioning as small walls were also built to hold two cylindrical tuyeres in horizontal position and to protect workers from the heat (fig. 1). Each tuyere was 30 cm long, with an interior perforation of 2.5 cm in diameter and was connected to a manual bag bellows with supporting capacity of 40 litres. The tuyeres, as well as the flat-bottom crucible collecting the crushed ores, were manufactured with ordinary clay from the soil and cooked earlier in a hearth with firewood.

The copper ore used for the experiment was collected in the spoil of an abandoned mine situated in Bustarviejo, a locality close to the mountain range of Madrid (Spain). As the XRF-ED analyses of various samples show in table 1, this polymetallic ore contains relevant quantities of bismuth, arsenic, tin and lead, in addition to copper; it is poor in iron and its gangue is mainly quartz. For the experiment, 1 kg of this ore was finely crushed into millimetre-sized portions. According to the analyses carried out on this ore, the average concentration of copper is estimated at around 25-30 %, implying that the copper recovered through the smelting process would be around 250-300 grams maximum. The cassiterite needed for the experiment was collected from the spoil of a tin mine in Ourense (Galicia, Spain) and was practically pure, with some traces of niobe and quartz gangue al-

Fig. 1: The co-smelting place.



Analysis #	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Bi
PA12799	1.66	nd	16.0	nd	nd	0.121	1.330	0.020	1.33	10.5
PA12800	1.55	nd	23.8	nd	0.42	0.127	1.870	0.001	0.25	3.17
PA12801	0.80	nd	30.7	nd	nd	0.079	2.120	0.027	1.61	2.42
PA12802	0.52	nd	8.54	nd	0.74	0.013	0.893	0.017	0.29	4.85
PA12803	1.53	nd	34.1	nd	0.38	0.180	0.932	0.112	2.34	2.41
PA12804	0.80	nd	15.5	nd	1.01	0.024	0.775	0.002	0.42	6.30
PA12805	0.13	nd	35.1	nd	0.19	0.055	0.042	0.012	0.30	nd
PA12806	1.50	nd	38.4	nd	0.25	0.109	0.459	0.079	2.15	2.45
PA12807	0.21	nd	26.9	nd	0.10	0.022	0.509	0.024	0.52	2.34
PA12808	0.29	nd	31.5	nd	nd	0.067	0.420	0.002	0.46	4.00
PA12809	1.07	nd	44.8	nd	0.26	0.093	1.880	0.031	0.19	0.40
PA12810	0.75	nd	39.5	nd	nd	0.101	0.525	0.021	0.82	2.41

Tab. 1: Selected copper ore samples (XRF-ED analysis, wt %).

most entirely discarded by hand-sorting after crushing the ore. Two hundred grams of cassiterite were used, pointing to a potential yield of 157 g of tin in the oxide. Both ores were finely crushed and homogeneously mixed together in a bowl.

## The co-smelting process

The fireplace was pre-heated with charcoal for 30 minutes. Subsequently, the crucible was placed on the top of the burning charcoal, a little higher than the position of the tuyere nozzles. After testing that the crucible resisted the first thermal shock without cracking, fresh charcoal was added up to cover it and the bellows gently worked. The smelting process started when the crucible began to glow red (fig. 2). Then a handful of ore was spread on the burning charcoal over the crucible and covered with fresh one. This step was repeated every 30 minutes until the charge

was finished (fig. 3). Thirty minutes after the addition of the last handful of ore, the bellows stopped working and the charcoal was left to run out. Afterwards, the crucible was removed from the hearth using two fresh rods. Inside the crucible, a mass of slaggy-like material had formed and, on its surface, some metal prills were visible to naked eye.

The crucible had to be broken to extract the slag that, in turn, was crushed to separate the metal. After crushing the slag, many metal prills, 1 mm to over 20 mm in size, were put aside by hand. The colour of the metal varied from red copper to light-grey tin. The metal obtained weighed 124 g and, assuming that in the ores there were 457 g of copper and tin, the metal recovery was approximately 27 %. This result is close to the one achieved by Zwicker (1980: 15) who melted ores from Norsun-Tepe in a crucible and recovered 25 % of metal, while Rovira (1999: 108) obtained better results with ores from Kargaly (Russia), as the metal recovered was up to 53 %. The crushed slag has been kept for future experiments.

Fig. 2: Pre-heating operation. The arrow points to the crucible rim.



Fig. 3: Charge. The arrow points to a handful of crushed ore on top of the burning charcoal.



## Laboratory analyses of the metallurgical products

Several slag samples and some metal prills were studied using Scanning Electron Microscope and Optical Microscope. The analyses carried out on the different phases of the slag have yielded the results shown in table 2. The sample reveals a material with a heterogeneous structure in which melted phases between undissolved minerals were been detected. The melted regions are predominantly complex glasses where wollastonite and pyroxene have formed frequently. Since no calcium minerals exist in the gangue, a strong reaction occurs between the silicates and the calcium in the charcoal ashes. Euhedral cassiterite is also abundant, usually having a metallic nucleus (fig. 5).



Fig. 4: Metal prills after crushing the slag. Scale in mm.

Tab. 2: Phases in the slags (SEM microanalysis, wt %).

Analysis #	Phase	FeO	MnO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	BaO	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	CuO	SnO <sub>2</sub>
PA12855/3	Glass	4.51	0.80	43.0	4.49	32.3	2.77	nd	6.70	nd	2.02	3.38
PA12855/4	Glass	4.21	0.75	52.1	4.97	18.9	2.15	nd	4.60	nd	5.76	6.58
PA12857/13	Glass	3.89	1.35	57.6	3.79	11.1	1.17	nd	6.24	6.14	6.00	2.80
PA12857/14	Glass	4.82	0.78	61.6	4.22	8.10	nd	nd	3.80	nd	1.11	15.6
PA12857/15	Dark crystals	6.84	0.66	53.6	9.88	5.46	1.02	1.53	1.23	nd	1.26	16.7
PA12857/16	Cassiterite (ore relict)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	98.5
PA12857/17	Cassiterite (crystal)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	100
PA12858/6	Matrix (glass)	5.08	0.57	44.1	7.30	26.2	2.89	nd	4.49	nd	3.84	5.60
PA12858/7	Wollastonite	nd	nd	51.4	nd	48.6	nd	nd	nd	nd	nd	nd
PA12858/8	“Malayaite”	nd	nd	23.1	nd	20.5	nd	nd	nd	nd	nd	56.4
PA12869/07	Wollastonite	nd	1.40	50.0	nd	47.8	0.78	nd	nd	nd	nd	nd
PA12869/08	Iron oxide	89.7	3.22	nd	nd	0.50	nd	nd	nd	nd	3.06	2.16
PA12869/09	Glass	18.3	1.46	32.3	6.38	22.7	5.16	nd	nd	nd	nd	13.7
PA12869/10	Wollastonite	3.62	2.79	50.2	nd	40.0	3.35	nd	nd	nd	nd	nd
PA12869/11	“Malayaite”	2.90	nd	30.6	1.42	18.7	nd	nd	nd	nd	3.91	42.4
PA12869/12	Wollastonite	nd	nd	51.1	nd	48.9	nd	nd	nd	nd	nd	nd
PA12869/13	Matrix (glass)	11.1	1.04	49.5	4.85	9.24	3.76	2.01	11.3	nd	1.50	5.68
PA12869/14	Pyroxene	24.0	1.00	40.6	1.99	8.42	0.70	4.49	15.3	3.51	nd	nd
PA12869/15	Pyroxene	6.68	nd	43.1	1.71	39.4	8.00	nd	1.08	nd	nd	nd
PA12870/01	Cassiterite (ore relict)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	98.8
PA12870/09	Matrix (glass)	7.48	nd	58.6	5.35	6.11	nd	nd	4.89	nd	nd	17.6
PA12870/10	Glass	5.66	2.51	47.1	5.28	5.14	nd	nd	1.74	nd	32.6	nd
PA12870/11	Glass	12.6	5.12	56.9	4.78	8.22	nd	nd	2.52	nd	3.61	5.17
PA12871/03	Matrix (glass)	7.80	4.67	59.5	6.18	8.04	0.89	nd	2.22	nd	0.87	9.78

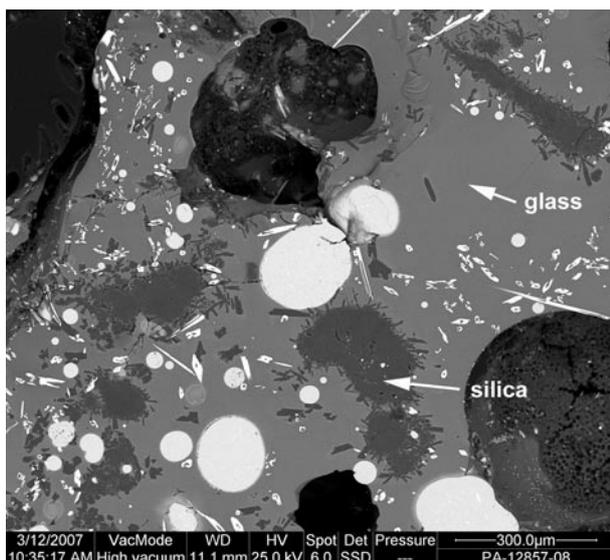


Fig. 5: Slag sample PA12857. SEM image, BS mode. Explanation in the text.

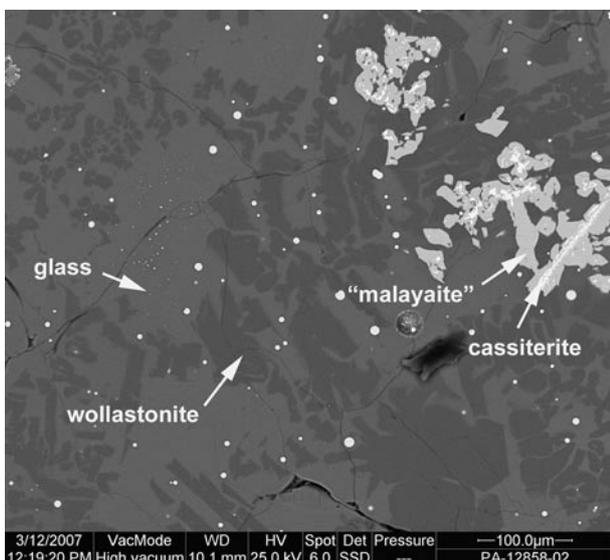


Fig. 6: Slag sample PA12858. SEM image, BS mode. Explanation in the text.

A particular tin-calcium silicate was detected in some samples, which we named “malayaite” due to a certain compositional resemblance with the homonym tin ore (malayaite: Si 22.51 %, Sn 50.48 %, Ca 21.01 %; see values in tab. 2). This compound seems to form as the result of the reaction between cassiterite and wollastonite or, in general, with calcium-rich pyroxenes, and is always detected in the slag regions where these silicates are abundant. Figure 6 shows how some “malayaite” crystals still preserve a white nucleus of cassiterite. This compound is particularly interesting as it has been detected in many Cu-Sn slags coming from Bronze and Iron Age archaeological sites of Spain (Rovira 2007: 27, 30). Its presence could be considered as an indication of the use of the co-smelting technique.

Tab. 3: Metal prills entrapped in the slags (SEM microanalysis, wt %).

Analysis #	Cu	Sn	As	Bi	Fe	S	O	Si
PA12855/1	94.4	0.91	nd	4.71	nd	nd	nd	nd
PA12855/2	96.2	nd	nd	3.78	nd	nd	nd	nd
PA12856/1	98.5	nd	nd	1.46	nd	nd	nd	nd
PA12856/2	99.8	nd	nd	0.20	nd	nd	nd	nd
PA12856/3	99.4	nd	nd	nd	0.54	nd	nd	nd
PA12856/4	99.3	nd	nd	nd	0.64	nd	nd	nd
PA12856/5	99.5	nd	nd	nd	0.50	nd	nd	nd
PA12856/6	99.9	nd	nd	0.10	nd	nd	nd	nd
PA12857/01	74.8	23.5	nd	0.88	nd	nd	nd	nd
PA12857/02	76.2	22.1	nd	1.68	nd	nd	nd	nd
PA12857/03	17.1	81.3	nd	1.59	nd	nd	nd	nd
PA12857/04	67.0	28.3	2.1	2.57	nd	nd	nd	nd
PA12857/05	99.4	nd	nd	0.60	nd	nd	nd	nd
PA12857/06	99.5	nd	nd	0.49	nd	nd	nd	nd
PA12857/07	99.0	nd	nd	0.98	nd	nd	nd	nd
PA12857/08	89.6	7.37	nd	2.99	nd	nd	nd	nd
PA12857/09	79.0	nd	nd	nd	nd	21.0	nd	nd
PA12857/10	82.5	14.0	nd	3.47	nd	nd	nd	nd
PA12857/11	79.8	nd	nd	nd	nd	20.2	nd	nd
PA12858/1	99.8	nd	nd	0.19	nd	nd	nd	nd
PA12858/2	98.0	nd	nd	1.96	nd	nd	nd	nd
PA12858/3	97.5	1.20	nd	1.30	nd	nd	nd	nd
PA12858/4	97.6	nd	nd	1.48	nd	nd	nd	0.94
PA12858/5	99.2	nd	nd	0.76	nd	nd	nd	nd
PA12858/9	99.4	0.16	nd	nd	0.39	nd	nd	nd
PA12869/01	93.0	nd	nd	nd	nd	nd	5.75	1.25
PA12869/02	93.3	nd	nd	nd	nd	nd	5.63	1.04
PA12869/03	91.3	nd	nd	2.23	nd	nd	5.73	0.76
PA12869/04	94.2	nd	nd	0.55	nd	nd	4.47	0.77
PA12869/05	94.8	nd	nd	0.96	nd	nd	4.21	nd
PA12869/06	93.5	nd	nd	2.69	nd	nd	3.81	nd
PA12870/02	92.5	6.41	nd	nd	nd	nd	nd	1.08
PA12870/04	92.0	1.88	nd	6.11	nd	nd	nd	nd
PA12870/05	92.0	4.08	nd	2.38	nd	nd	nd	1.52
PA12870/06	95.2	3.54	nd	nd	nd	nd	nd	1.26
PA12870/07	91.4	1.44	nd	5.86	nd	nd	nd	1.31
PA12870/08	92.0	0.80	nd	5.65	nd	nd	nd	1.57
PA12871/01	90.6	7.99	nd	1.39	nd	nd	nd	nd
PA12871/02	88.9	8.24	nd	2.82	nd	nd	nd	nd
PA12871/04	84.6	9.90	nd	4.28	nd	nd	nd	0.37
PA12871/05	83.7	10.1	nd	5.14	nd	nd	nd	1.12
PA12871/06	83.8	12.7	nd	3.55	nd	nd	nd	nd
PA12871/07	95.4	2.89	nd	1.66	nd	nd	nd	nd
PA12871/08	85.0	11.3	nd	2.54	nd	nd	nd	1.23
PA12871/09	85.1	14.9	nd	0.01	nd	nd	nd	nd
PA12871/10	80.6	14.7	nd	4.74	nd	nd	nd	nd

Tab. 4: Selected slag samples (XRF-ED analysis, wt %).

Analysis #	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Bi
PA12855	1.35	nd	4.45	nd	nd	nd	8.10	0.025	0.45	0.76
PA12856	1.52	nd	6.96	nd	0.30	0.022	5.19	0.033	0.67	1.50
PA12857	1.22	nd	12.8	nd	nd	nd	23.1	nd	0.68	2.44
PA12858	1.14	nd	4.51	nd	nd	nd	8.47	0.019	0.44	1.00
PA12869	1.49	nd	13.6	nd	nd	nd	15.1	0.040	0.77	1.30
PA12870	1.28	nd	9.39	nd	nd	nd	20.7	nd	0.55	1.41
PA12871	1.53	nd	10.4	nd	nd	0.021	19.3	tr	0.64	2.04

Tab. 5: Selected metal prills (XRF-ED analysis, wt %).

Analysis #	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Bi
PA12872	0.53	nd	83.5	nd	0.88	0.341	11.6	nd	0.18	2.93
PA12873	0.30	nd	98.9	nd	0.51	0.009	0.03	0.003	0.21	nd
PA12874B	0.33	nd	68.4	nd	1.25	0.125	28.0	0.042	0.37	1.54
PA12875	1.68	nd	69.4	nd	1.68	0.062	25.4	tr	0.18	1.55
PA12876B	nd	nd	93.9	nd	0.72	0.062	3.24	0.028	nd	2.00
PA12877B	nd	nd	85.1	nd	0.79	0.099	10.8	0.025	0.50	2.63
PA12878B	nd	nd	76.5	nd	0.36	0.102	20.8	nd	0.36	1.91
PA12879	5.37	nd	9.90	nd	nd	nd	80.1	nd	0.75	3.81
PA12880B	0.04	nd	67.6	nd	1.30	0.122	27.6	0.045	1.10	2.23
PA12881B	nd	nd	88.6	nd	0.50	0.095	9.32	0.033	0.48	0.95

Many metallic inclusions in the slag were also analysed, showing extremely variable compositions (tab. 3). The presence of bismuth in almost all the analysed prills is good evidence of the strong polymetallism of the copper ore employed in the experiment (see tab. 1). Although the crushed ores were carefully mixed together, there are some slag samples where metallic inclusions contain hardly any tin. However, in other samples, tin percentages are higher than 80 %. No pure tin inclusions have been found, possibly due to the fact that while the copper is being pro-

duced, it quickly picks up the tin. At the same time, the variable redox conditions in the hearth caused the formation of many alloys with different compositions in different areas of the slags. Hence, the slag retained a significant amount of copper and tin, both as mineral and microscopic metal prills. The bulk analyses of the slag samples gave the results shown in table 4, consistent with the copper loss observed in early Chalcolithic slags obtained through crucible smelting processes or “no-slagging processes” (Bourgarit 2007: 6; Bourgarit et al. 2003: 437; Hauptmann 2003: 461).

The last part of the experiment consisted of the production of a small ingot, obtained by melting 69 g of metal prills in a little flat-bottom crucible (figs. 7 and 8). The ingot weight obtained was 53.88 g, with

Fig. 7: The melting crucible is being removed from the hearth.



Fig. 8: The small ingot.



Tab. 6: Bronze slags from the Late Bronze-Early Iron Age transition site of El Castro (León) (XRF-ED analysis, wt %).

Analysis #	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Bi
PA12000	1.38	nd	14.9	nd	nd	0.009	3.62	0.023	1.28	nd
PA12006	3.04	nd	15.1	nd	nd	0.009	9.95	0.176	1.17	nd

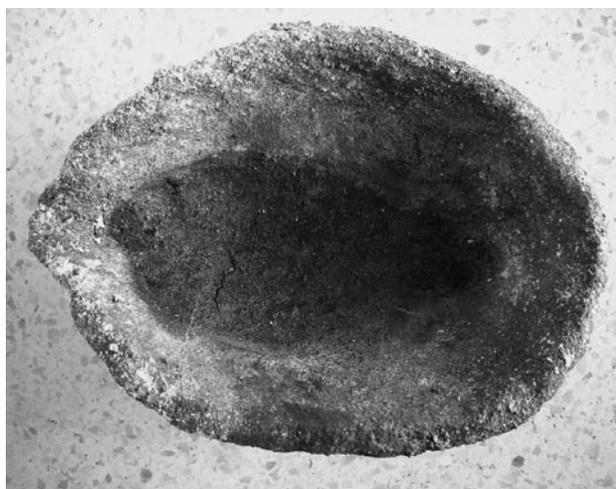


Fig. 9: The crucible after removing the ingot. No slag has formed.

9.08 g of metal lost in the charcoal into the crucible. In total, after the melting operation, we had 62.96 g of metal with a loss of 5.97 g, i.e. 8.65 %. In the crucible, no slag was formed (fig. 9) and we propose that the difference in weight of the metal is due to its evaporation as oxides and to its loss in the fumes. The bulk analysis of the ingot shows a composition of 0.61 % Fe, 79.4 % Cu, 0.70 % As, 0.081 % Ag, 15.74 % Sn, 0.001 % Sb, 0.69 % Pb and 2.81 % Bi, matching quite well the pattern suggested by the analyses in table 5.

### Some preliminary conclusions

This experiment shows that a copper-tin alloy can be easily obtained through the direct co-smelting of the ores of these two metals, using a simple structure as an open fire, a crucible, a couple of bellows connected to tuyeres and employing charcoal as fuel. These enabled us to reach and keep the temperature in the hearth at about 1.200 °C (white-yellow colour in the hearth). During this operation, no noxious fumes were produced, except in the pre-heating phase.

The *chaîne opératoire* involved crushing and mixing the ores, smelting in an open fire, crushing the slag to sort the metal prills, and melting those prills to get an ingot or pouring the liquid metal into a mould. Such a chain is largely accepted as the usual metallurgical procedure in Chalcolithic period (Hauptmann 2003: 465; Shugar 2003: 457; Rovira/Ambert 2002: 114). Therefore, working with copper and tin ores did not imply drastic technological changes in obtaining metal.

The quantity of copper and tin lost in the experimental slag is similar or higher than in other prehistoric copper-tin slags we have analysed – as for example the ones from the Spanish archaeological site of El Castro (Gusendo de los Oteros, León, Spain), dated to the Late Bronze to Early Iron Age transition, roughly 850-750 BC (tab. 6). Many other characteristics of these archaeological slags coincide with the experimental ones (see Rovira 2007: 29-31). Considering all the obtained data, we propose that co-smelting could be a viable hypothesis as the method used in early times to obtain tin-bronzes.

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