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Moving metals II: provenancing Scandinavian Bronze Age artefacts by lead isotope and elemental analyses

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ABSTRACT

The first part of this research published previously proved without doubt that the metals dated to the Nordic Bronze Age found in Sweden were not smelted from the local copper ores. In this second part we present a detailed interpretation of these analytical data with the aim to identify the ore sources from which these metals originated. The interpretation of lead isotope and chemical data of 71 Swedish Bronze Age metals is based on the direct comparisons between the lead isotope data and geochemistry of ore deposits that are known to have produced copper in the Bronze Age. The presented interpretations of chemical and lead isotope analyses of Swedish metals dated to the Nordic Bronze Age are surprising and bring some information not known from previous work. Apart from a steady supply of copper from the Alpine ores in the North Tyrol, the main sources of copper seem to be ores from the Iberian Peninsula and Sardinia. Thus from the results presented here a new complex picture emerges of possible connectivities and flows in the Bronze Age between Scandinavia and Europe.

1. Introduction

The origin of the copper (and tin) in Scandinavian Bronze Age metal artefacts has been discussed widely over the years. The traditional standpoint has been that all copper and tin was imported to Scandinavia in the Bronze Age (Montelius, 1872; Vandkilde, 1996). Another theory has favoured the idea of a local copper extraction (Janzon, 1984; Melheim, 2012). Hence, the initial aim of the current project was to further the discussion if copper was extracted locally or imported to Sweden during the Bronze Age (see also Ling et al., 2013).

It is thus important to stress that this paper should be seen as extension or a second step of the one published in 2013, in terms of questions, aims, and accounts of previous Scandinavian studies with similar methods (c.p Klassen and Stürup, 2001; Kresten, 2005; Schwab et al., 2010).

Preliminary research based on lead isotope and elemental analyses of 39 copper artefacts from the Early Neolithic finds in south Scandinavia was published by Klassen and Stürup (2001) with the conclusion that the ores used for the analysed artefacts were of the Alpine origin.

We have considered the lead isotope data published by Klassen and Stürup (2001) but any direct comparisons are not possible. Apart from the fact that these artefacts are of much earlier date than any of the ones analysed in this project, Klassen's conclusions are based on lead isotope analyses performed by ICPMS instrument which does not allow to make sufficiently accurate lead isotope measurements for comparisons with the TIMS and MC-ICP-MS data (>0.4% for ICPMS, while ≤0.1% for TIMS and MC-ICP-MS) therefore we cannot take this work into account in this paper (Klassen and Stürup, 2001, p. 72).

In the previous paper we have presented the results of MC-ICP-MS lead isotope and chemical analyses (EPMA) of 33 copper-based items, dated between 2000 and 700 cal. BC (Ling et al., 2013). These results demonstrated that the lead isotope compositions of these artefacts are considerably different from the Scandinavian ores, and it was concluded that the copper in these items must have been imported from other regions in Europe. Moreover, the results indicated that the sources of metal varied in relation to chronology.

In this second paper we report lead isotope and elemental data for 38 additional artefacts and metallurgical debris from southern Sweden with the aim to find out which ore bearing regions

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supplied copper to Scandinavia during different periods of the Bronze Age by comparing these data with the large body of archaeological, geological and archaeometallurgical publications pertaining to chronology of copper extraction and circulation in Bronze Age Europe (see for example: Höppner et al., 2005; Niederschlag et al., 2003; Pernicka, 2010; Rohl and Needham, 1998). We will also discuss the possibility of metal recycling (Bray and Pollard, 2012; Liversage and Northover, 1998; Rychner and Stos-Gale, 1998; Stos-Gale, 2009, 2001a).

2. The theoretical background: form versus content

A serious shortcoming of much of the research on the metal sources and trade in the Bronze Age Scandinavia was rooted in the study of the metal sources and movement of metal being based mostly on the forms of the artefacts and their stylistic types. This approach is missing the fact that metal, unlike, for example, pottery or stone, is a material that can change its form several times before attaining its final shape. Even metal ingots are not necessarily the direct products of a specific mining region; their chemical compositions and metallurgy, however, can often help to distinguish between a primary source and a secondary re-melted origin. Another major concern is the idea that manufactured metal from a certain region is often equated with the use of ores from the same region. This is a simplistic perspective which tends to overlook the fact that the Bronze Age was a highly international period characterised by trade and interaction over vast distances in Europe (Chernykh, 1992; O'Brien, 2004; Ottaway, 2001; Sherrat, 1993).

Imported artefacts show important traits that certainly could be connected to trade routes and networks, but they cannot capture the major essence of the metal trade; that is the sources of metal. An important fact to stress is that the metal forms of the Nordic Bronze Age are typical for this region and, moreover, that the imported artefacts in the Nordic region are very few comparing to the indigenous bronzes (Baudou, 1960; Kristiansen, 1998; Thrane, 1975; Vandkilde, 1996). Thus it is not only the forms but also the metal ('content') itself that can give us a more complete picture of the flow of metal to Scandinavia in the Bronze Age.

The metal forms of the Bronze Age objects in Scandinavia mostly belong to the Nordic tradition. If they were not made from local ores it might mean that the major flow of metal to Scandinavia was based on ingots of copper and tin and/or bronze that was cast according to the regional customs. This fact is also supported by the finds of Bronze Age metal workshops in Scandinavia (Hjärthner-Holdar, 1993; Melheim, 2012; Oldeberg, 1942).

In contrast to the stylistic approach to research into the Bronze Age metal sources and trade, in the last 50 years there were many projects based on elemental and lead isotope analyses, mostly concerning the southern and central Europe and the Near and Middle East (for example: Hauptmann et al., 1999, 1992; Höppner et al., 2005; Junghans et al., 1968; Krause, 2003; Pernicka et al., 1993; Stos-Gale and Gale, 2009). This approach seems most promising and has been applied in our project.

3. Material

An important part of our study has been to clarify whether or not copper was extracted locally or imported to Sweden during the Bronze Age. Although a local copper ore extraction was not supported by earlier results (Ling et al., 2013), we have enlarged not only the amount of artefacts from ore bearing districts in Sweden but also included objects from adjacent districts (Figs. 1 and 2, Table 1). Most of the artefacts derive from hoards or wetland locations and workshops, whereas a few are from graves or mortuary milieus and the rest are stray finds (Fig. 3, Table 1).

Special priority has been given to artefacts that belong to the Nordic Bronze Age tradition, 1700–500 cal. BC (Baudou, 1960; Montelius, 1885; Vandkilde, 1996). However, a metal-hilted dagger dated to about 2000–1700 cal. BC and a palstave of British type dated 1500–1400 cal. BC, were also included in this study

Fig. 1. The map shows the location of the sites in Sweden from which the objects have been sampled for analyses in this study (see further Table 1). The polygons mark roughly the ore bearing districts in western and eastern Sweden, including parts of Dalsland and Värmland, Uppland, Södermanland and Småland (c.p Ling et al., 2013: Fig. 2).

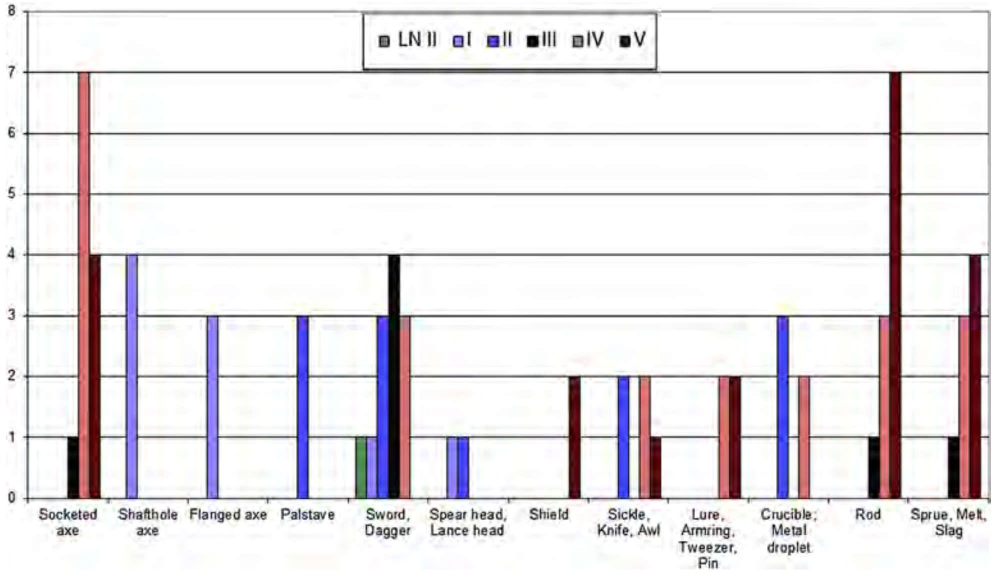


Fig. 2. Histogram showing the categories and the amount of artefacts analysed in this study.

(Table 1). Additionally, exceptional finds, such as the Herzsprung shields (Ling et al., 2013: Fig. 6) and a piece of a lure from period V, have also been sampled (Table 1). One important aim has been to analyse material from bronze production and workshop sites, like droplets of metal left in the crucibles, sprues, melts, rods/ingots and slag in order to capture the materials in the process of casting, rather than just as finished objects. Of special interest is the material from the workshop site at Hallunda, Botkyrka parish which also involves copper slag which is the only of its kind found in Sweden on a Bronze Age site (Table 1).

In the following, all of the materials will be referred to as objects or artefacts, even the casting and/or production debris. Sixty eight objects are made of copper or copper alloys and one is a copper slag. We have also analysed one tin and one lead ingot (Fig. 4).

The account below is an overview of the analysed artefacts from the different chronological periods in the Nordic Bronze Age. More detailed information about chronology, find circumstances and references are given in Table 1 referred to as T1 in the below listing of artefacts, with unique numbers. The Nordic chronology can be translated into broader phases in line with continental chronology; (LNII, period I = EBA, period II = MBA, period III = MBA (LBA), period IV,V = LBA). This approach allows us to discuss the current Swedish results in relation to the interactions and processes that took place in Europe during the Bronze Age.

LN II (2000–1700 cal. BC; EBA): 1 metal-hilted dagger (T1:1)

Period I (1700–1500 cal. BC; EBA): 4 shafthole-axes (Fig. 5, T1:2,3,7,10), 3 flanged axes (Fig. 6, T1:4,5,9) 1 sword (T1:6), 1 spearhead (T1:8).

Period II (1500–1300 cal. BC; MBA) 3 palstaves (Fig. 6, T1:11,17,22), 3 swords/daggers (T1:16,20,21), 1 lancehead (T1:12), 1 curved knife (T1:19), 1 awl (T1:18), 3 droplets from crucibles (Fig. 7, T1:13–15).

Period III (1300–1100 cal. BC; MBA/LBA); 4 swords (Fig. 8, T1:23,24,25, 29), 1 socketed axe (T1:26), 1 sprue and 1 rod/ingot (T1:27,28).

Period IV (1100–900 cal. BC; LBA) 7 socketed axes (Fig. 6, T1:30,31,40,42,44,47,51), 3 swords/daggers (T1:32,41,48), 1 pair of tweezers (T1:43), 7 casting debris (T1:33–39), 1 sickle and 1 arm ring (T1:50,49), 2 droplets from crucibles (T1:45,46).

Period V (900–700 cal. BC; LBA): 4 socketed axes (Fig. 4, T1:52,62,65,68), 2 shields (T1:69,70), 1 lure (T1:66), 1 pin and 1 sickle (T1:61,63), 2 rods (T1:53,64), 1 tin ingot (Fig. 4) and 1 lead ingot (T1:60,67), 6 casting debris (T1:54–58,71), 1 copper slag (T1:59).

4. The European ore deposits that could have supplied copper and tin in the 2nd-1st millennium BC for copper-based artefacts found in Sweden

There are many publications describing the ore deposits in Europe and their lead and their lead isotope and geochemical characteristics, mainly published in geological books and journals. However, for the metal provenance studies the most valuable are the archaeometallurgical surveys that have been conducted by many teams researching ancient mining and metallurgy, many of them are listed in the references to this paper. For identification of the ore sources exploited in the Bronze Age it is necessary to have for comparisons three types of information: the geochemical characteristics of the ore deposit, lead isotope analyses of ore samples and indication of the periods of exploitation. Not all copper and lead deposits in Europe have been fully characterised in this way, but there is a reasonable amount of published data for the major copper mining areas. Another important aspect of lead isotope data is their direct representation of the age of the ore formation.

The main group of lead isotope ratios measured for the Swedish bronzes lies approximately between the values of $^{208}Pb/^{206}Pb$ = 2.065–2.12, $^{207}Pb/^{206}Pb$ = 0.836–0.864 and $^{206}Pb/^{204}Pb$ = 18.12–18.75 (Fig. 10). These lead isotope ratios are directly relevant to the age of the copper ores that were used for smelting copper. There are many younger copper ore deposits in the Old World that have lead isotope ratios of $^{206}Pb/^{204}Pb$ = 18.3–18.9, but there are not many copper ore deposits older than 300 Ma and of $^{206}Pb/^{204}Pb < 18.3$. The main copper ore deposits known to be exploited in the Bronze Age that are older than 300 Ma are on the Iberian Peninsula, on Sardinia, in the Arabah Valley (Jordan and Israel) and in the south Ural mountains. Therefore, even without direct lead isotope measurements of ore samples, some of the deposits can be rejected as sources of nearly half of the analysed Swedish bronzes on the grounds of their geochronology.

The lead isotope data obtained for the Swedish bronzes were compared with all available data for the Old World copper ores including the Near and Middle East, and some Asian deposits (published for example in: Hauptmann et al., 1992, 1999; Pernicka

Table 1
Information about the province, find circumstance, category of item, typology and chronology of all the analysed Bronze Age objects within this study. *= data were reported in Ling et al. (2013). In some cases (= x) it has been possible to assign artefacts to sub-periods (e.g. Ib), whereas others cannot be definitely assigned to a specific period e.g. V-(VI). xx = Denotes the periods we use in this study. Sample identities (= a) are museum identity numbers. AM = Arvika Museum, GAM = Göteborgs stadsmuseum, SHM = Historiska museet (The National Historical Museum), VG = Västergötlands museum, VM = Värmlands museum, UM = Upplandsmuseet, UMF = Uppsala universitet Museum Gustavianum, KM = Kalmar läns museum, ÖM = Östergötlands länsmuseum.

Unr/FID[a]	County	Parish	Object description	Specific Period[x]	Cal. BC	Period xx	Context[y]	References
1: SHM 884943*	Dalsland	Ör	Dagger, Malchiner type IIIa	LN II	1950–1700	LN II	Stray find	Oldeberg 1974:335, no 2619; Schwenzer 2004:34; Ling et al., 2013
2: GAM 5289	Bohuslän	Ödsmål	Shafthole axe, Fårdrup type	Ib	1600–1500	I	Stray find	Oldeberg 1974:333, no 2607; Vandkilde, 1996:227,238; Forssander 1936:277
3: GAM 1255*	Dalsland	Frändefors	Shafthole axe, Fårdrup type	Ib	1600–1500	I	Stray find	Oldeberg 1974:334, no 2614; Vandkilde, 1996:227,238; Ling et al., 2013
4: SHM 971151*	Dalsland	Färgelanda	Flanged axe, Spatulate or Spoon shaped blade	Ib	1600–1500	I	Hoard, including flint spearheads	Oldeberg 1974:334, no 2615; Vandkilde, 1996:94; Ling et al., 2013; Forssander 1936:194
5: SHM 971153*	Småland	Gamleby	Flanged axe, C1:Underåre	Ib	1600–1500	I	Hoard, 2 objects see no 17	Oldeberg 1974:228, no 1759; Vandkilde, 1996:113; Ling et al., 2013
6: UM 40280_3006	Uppland	Viksta	Sword pommel, Valsømagle type	Ib	1600–1500	I	Burial and ritual site	Forsman and Viktor 2007; Vandkilde 1996:224
7: AM 786*	Värmland	Ny	Shafthole axe Fårdrup	Ib	1600–1500	I	Wet find. River of Jössefors.	Oldeberg 1974:336, no 2627; Vandkilde, 1996:227; Ling et al., 2013
8: SHM 884944*	Värmland	Ölme	Spear head, type Bagterp	Ib	1600–1500	I	Stray find	Oldeberg 1974:337, no 2636; Vandkilde, 1996:229; Ling et al., 2013; Jacob-Friesen 1967
9: VM 21916*	Värmland	Östra Fågelvik	Flanged axe C1:Underåre	Ib	1600–1500	I	Wet find. Shallow part of a lake.	Oldeberg 1974:337, no 2636; Ling et al., 2013; c.p Vandkilde, 1996:113
10: KM 33_465_10	Öland	Löt	Shafthole axe Valsømagle	I	1600–1500	I	Wet find. Sacrificial bog also containing animal bones especially horse and a stone paving with post holes.	Therus 2011:15 p; Vandkilde, 1996:238
11: GAM 1993	Bohuslän	Öckerö	Palstave, Type 1a1c, South English-Northwest French shield-ornamented 1500–1400 BC	II	1500–1300	II	Hoard of palstaves, typologically classified to S. English/NW French shield-ornamented	Butler 1963:56,71; Kindgren 1999:55
12: SHM 96775*	Dalsland	Ånimskog	Lance head, type Ullerslev	II	1500–1300	II	Wet find. Lake of Östebo.	Oldeberg 1974:335, no 2617; Jacob-Friesen 1967:146; Ling et al., 2013
13: GAM 5964	Halland	Grimeton	Droplet in crucible	II	1500–1300	II	Mound, workshop 200 mould fragments for spearheads, swords, round belt ornaments etc and 3 whole crucibles, 300 fragments, from period II.	Sarauw and Alin 1923; Svensson 1940
14: GAM 5922-1	Halland	Grimeton	Droplet in crucible	II	1500–1300	II	Mound, workshop 200 mould fragments for spearheads, swords, round belt ornaments etc and 3 whole crucibles, 300 fragments, from period II.	Sarauw and Alin 1923; Svensson 1940
15: GAM 5922-2	Halland	Grimeton	Droplet in crucible	II	1500–1300	II	Mound, workshop 200 mould fragments for spearheads, swords, round belt ornaments etc and 3 whole crucibles, 300 fragments, from period II.	Sarauw and Alin 1923; Svensson 1940
16: LUHM 3527	Skåne		Flange-hilted sword "Das Schwert mit ausgebauchter Zunge"	II (-III)	1500–1300	II	Stray find	Sprockhoff 1931:1 pp; Schauer 1971:119

(*continued on next page*)

Table 1 (*continued*)

Unr/FID[a]	County	Parish	Object description	Specific Period[x]	Cal. BC	Period xx	Context[y]	References
17: SHM 971152*	Småland	Gamleby	Nordic form, Palstave, (Kersten C II, Plastic Y-rib of North German type)	II	1500–1300	II	Hoard, 2 objects se no 5	Oldeberg 1974:228, no 1759; Kersten 1936:78; Engedal 2010:89; Ling et al., 2013
18: GAL F 999	Uppland	Tillinge	Awl	(I-) II	1500–1300	II	Settlement, ritual and burial site, small workshop I-VI.	Karlenby 2011:474 p; Grandin and Willim 2011:477 pp
19: GAL F1607	Uppland	Tillinge	Curved knife	II (-IV)	1500–1300	II	Grave find ^{14}C-dated 1400–1300. Settlement, ritual and burial site, small workshop I-VI.	Montelius 1917; Karlenby 2011:474 p; Grandin and Willim 2011:477 pp
20: VM 1205*	Värmland	Glava	Hilt-plate dagger	II	1500–1300	II	Wet find. Lake Gränsjön.	Oldeberg 1974:335, no 2622; Montelius 1917:60; Ling et al., 2013
21: VM 2931*	Värmland	Övre Ulleryd	Hilt-plate dagger	II	1500–1300	II	Stray find	Oldeberg 1974:337, no 2637; Montelius 1917:60; Engedal 2010:67; Ling et al., 2013
22: AM 1214*	Värmland	Östra Ämtervik	Palstave (Kersten C II, Plastic Y-rib of North German type)	II	1500–1300	II	Stray find	Oldeberg, 1974:337, no 2635; Kersten 1936:78; Forssander 1936:216; Ling et al., 2013
23: LUHM 24283	Skåne	Tullstorp	Hilt-plate sword, type Meinered	III	1300–1100	III	Grave mound. Östra Törnhög	Bruzelius 1860; Schauer 1971:76
24: LUHM 22268	Skåne	Östra Hoby	Flange-hilted sword	III	1300–1100	III	Stray find	Oldeberg 1974:144, no 989; Sprockhoff, 1931:56; Schauer 1971:117
25: LUHM 2846	Skåne		Flange-hilted sword	III	1300–1100	III	Stray find, but probably from a grave	Oldeberg 1974:164, no 1225; Sprockhoff 1931:13,71 pp; Schauer 1971:117
26: SHM 971147	Södermanland	Barva	Socketed axe type A	III	1300–1100	III	Hoard, 3 socketed axes; type A and B	Oldeberg 1974:346, no 2711
27: GAL F 707	Uppland	Tillinge	Sprue	III	1300–1100	III	Settlement, ritual and burial site, cult house. Small workshop I-VI.	Karlenby 2011:474 p; Grandin and Willim 2011477 pp
28: GAL F 810	Uppland	Tillinge	Rod	III	1300–1100	III	Settlement, ritual and burial site, cult house. Small workshop I-VI.	Karlenby 2011:474 p; Grandin and Willim 2011:477 pp
29: AM 1213	Värmland	Sunne	Tanged sword	III	1300–1100	III	Wet find? Marsh ?	Oldeberg 1974:336, no 2630; Montelius 1917:66,7, Ling et al., 2013
30: GAM 3031	Bohuslän	Tjörn	Socketed axe, Scanian type VIIB 2a	IV (-VI)	1100–950/900	IV	Stray find	Baudou 1960:21 p
31: SHM 273741*	Dalsland	Järn	Socketed axe, fragments VII A1a	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929; Baudou 1960:17, 169,325; Ling et al., 2013
32: SHM 411836*	Dalsland	Järn	Tanged sword A2	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929; Baudou 1960:10,325; Ling et al., 2013
33: SHM 411852*	Dalsland	Järn	Sickle XIV B, casting debris	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929; Baudou 1960:325; Ling et al., 2013
34: SHM 971194*	Dalsland	Järn	Sprue	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929; Baudou 1960:325; Ling et al., 2013
35: SHM 362390, sample 1*	Dalsland	Järn	Rod	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929; Baudou 1960:325; Ling et al., 2013
36: SHM 362390, sample 2*	Dalsland	Järn	Rod	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929; Baudou 1960:325; Ling et al., 2013
37: SHM 362388*	Dalsland	Järn	Melt	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929; Baudou 1960:325; Ling et al., 2013
38: SHM 362391*	Dalsland	Järn	Sprue	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929: Baudou 1960:325; Ling et al., 2013
39: SHM 417322*	Dalsland	Järn	Rod	IV	1100–950/900	IV	Scrap hoard, 60 objects	Oldeberg 1929; Baudou 1960:325; Ling et al., 2013
40: SHM 971146	Södermanland	Västerhaninge	Socketed axe, Mälardal type VII B1a	IV (-V)	1100–950/900	IV	Stray find	Baudou 1960:23
41: GAL F 595	Uppland	Rasbo	Dagger	IV	1100–950/900	IV	Grave find, female. The grave ^{14}C-dated to 1040–930 cal. BC	Hjärthner-Holdar et al., 2011
42: UMF 4567	Uppland	Tensta	Socketed axe, Nordic VII C1a	IV (-V)	1100–950/900	IV	Stray find	Baudou 1960:23

43: GAL F 1606	Uppland	Tillinge	A pair of tweezers	IV	1100–950/900	IV	Grave find, the grave ^{14}C-dated to 970–840 cal. BC, settlement, ritual and burial site, small workshop, I-VI	Karlenby 2011:466
44: UMF 5453	Uppland	Tillinge	Socketed axe, Mälardal type VII B1a	IV (-V)	1100–950/900	IV	Stray find	Baudou 1960:19,174
45: SHM 971149_1	Uppland	Vårfrukyrka	Droplet in crucible	IV	1100–950/900	IV	Workshop period IV-V, 400 moulds for both weapons and ornaments, 200 crucibles, only a few square metres excavated	Oldeberg 1960
46: SHM 971149_2	Uppland	Vårfrukyrka	Droplet in crucible	IV	1100–950/900	IV	Workshop period IV-V, 400 moulds for both weapons and ornaments, 200 crucibles, only a few square metres excavated	Oldeberg 1960
47: UMF 6005	Uppland	Vänge	Socketed axe, Mälardal type VII B1a	IV (-V)	1100–950/900	IV	Stray find	Ekolm, 1921:43 pp, XIII no 60; Baudou 1960:19
48: SHM 414109*	Värmland	Grava	Hilt-plate sword, type A1	IV	1100–950/900	IV	Personal hoard, 19 objects	Oldeberg 1928:326; Baudou 1960:9325; SHMM Tillväxten FV 1923:28 p; Ling et al., 2013
49: SHM 414088*	Värmland	Grava	Armring, type XIX D	IV (-V)	1100–950/900	IV	Personal hoard, 19 objects	Oldeberg 1928:326; Baudou 1960:64 p,325; FV 1923: Tillväxten:28 p; Ling et al., 2013
50: SHM 414117*	Värmland	Grava	Sickle XIV B	IV (-V)	1100–950/900	IV	Personal hoard, 19 objects	Oldeberg 1928:332; Ling et al., 2013
51: AM 580*	Värmland	Östervallskog	Socketed axe VII B2c: Mixform, Västergötland	IV (-V)	1100–950/900	IV	Stray find	Baudou 1960:22; Ling et al., 2013
52: GAM 3030	Bohuslän	Tjörn	Socketed axe Westnordische Type VIIC 2b	V (-VI)	950/900–750/700	V	Stray find	Baudou 1960:24,190
53: SHM 884947*	Småland	Gladhammar	Rod/neckring	V	950/900–750/700	V	Personal hoard, 9 bronze objects 1 tin ingot (76% tin, 24% lead)	Baudou 1960:56,325; Oldeberg, 1942:67 p; Ling et al., 2013
54: SHM 122890	Södermanland	Botkyrka	Melt	V	950/900–750/700	V	Workshop period IV-VI, 231 moulds for both weapons and ornaments, 80 crucibles	Jaanusson and Wahlne 1975
55: SHM 971141	Södermanland	Botkyrka	Melt	V	950/900–750/700	V	Workshop period IV-VI, 231 moulds for both weapons and ornaments, 80 crucibles	Jaanusson and Wahlne 1975
56: SHM 971140	Södermanland	Botkyrka	Rod	V	950/900–750/700	V	Workshop period IV-VI, 231 moulds for both weapons and ornaments, 80 crucibles	Jaanusson and Wahlne 1975
57: SHM 971154	Södermanland	Botkyrka	Rod	V	950/900–750/700	V	Workshop period IV-VI, 231 moulds for both weapons and ornaments, 80 crucibles	Jaanusson and Wahlne 1975
58: SHM 971142	Södermanland	Botkyrka	Rod	V	950/900–750/700	V	Workshop period IV-VI, 231 moulds for both weapons and ornaments, 80 crucibles	Jaanusson and Wahlne 1975
59: SHM 971139	Södermanland	Botkyrka	Copper slag	V	950/900–750/700	V	Workshop period IV-VI, 231 moulds for both weapons and ornaments, 80 crucibles	Hjärthner-Holdar 1993:75 p
60: SHM 96898	Södermanland	Vårdinge	Ringshaped rod/ingot? (tin)	V	950/900–750/700	V	Personal hoard, 18 objects	Oldeberg 1928:340, 1933:196 p, 1942:67 p; Baudou 1960:326
61: SHM 414482	Uppland	Härnevi	Pin, disc-headed, Härnevi type, type XXV B2c	V	950/900–750/700	V	Scrap hoard, 47 objects	Ekolm, 1921:56 pp, no 77; Baudou 1960:79,326
62: SHM 414492	Uppland	Härnevi	Socketed axe Nordic type Upplands, VII D2	V (-VI)	950/900–750/700	V	Scrap hoard, 47 objects	Ekolm, 1921:56 pp, no 77; Baudou 1960: 25,326
63: SHM 971150	Uppland	Härnevi	Sickle, type XIV B	(IV-) V	950/900–750/700	V	Scrap hoard, 47 objects	Ekolm, 1921:56 pp, no 77; Baudou 1960:47,326
64: SHM 148960*	Värmland	By	Rod	V	950/900–750/700	V	Personal hoard, 33 objects including 2 swords of Mörigen type	Baudou 1960:325; Ling et al., 2013

(continued on next page)

Table 1 (*continued*)

Unr/FID[a]	County	Parish	Object description	Specific Period[x]	Cal. BC	Period xx	Context[y]	References
65: SHM 414103*	Värmland	Grava	Socketed axe VII C2a, Common Nordic	V (-VI)	950/900–750/700	V	Personal hoard, 19 objects	Oldeberg 1928:326; Baudou 1960:23,325; SHMM Tillväxten FV 1923: 28 p; Ling et al., 2013
66: SHM 884946*	Värmland	Grava	Lure fragment	V	950/900–750/700	V	Personal hoard, 19 objects	Oldeberg 1928:326; Baudou 1960:325; SHMM Tillväxten FV 1923:28 p; Ling et al., 2013
67: SHM 414124*	Värmland	Grava	Rod of lead	V	950/900–750/700	V	Personal hoard, 19 objects	Oldeberg 1928:326; Baudou 1960:325; SHMM Tillväxten FV 1923:28 p; Ling et al., 2013
68: AM 576*	Värmland	Köla	Socketed axe type VII C2a, Common Nordic	V	950/900–750/700	V	Stray find	Baudou 1953:256, 1960:23,185; Ling et al., 2013
69: VG 5*	Västergötland	Sunnersberg	U-notched shield, Herzsprung type	V	950/900–750/700	V	Community hoard, former wet land. 16–18 Herzsprung shields	Hagberg, 1987; Ling et al., 2013; Uckelmann, 2011; Coles, 1962:161; Gräslund, 1967:60
70: VG 11*	Västergötland	Sunnersberg	U-notched shield, Herzsprung type	V	950/900–750/700	V	Community hoard, former wet land. 16–18 Herzsprung shields	Hagberg, 1987; Ling et al., 2013; Uckelmann, 2011; Coles, 1962:161; Gräslund, 1967:60
71: ÖM 4473:322	Östergötland	Styrstad	Melt	V	950/900–750/700	V	Soapstone mould small workshop/settlement site	Nyberg and Nilsson, 2012

et al., 2005; Pryce et al., 2011). The comparisons show that the Swedish bronzes are not consistent with the origin from the deposits located in the Near and Middle East, or Asia. We were also allowed to make comparisons with new unpublished lead isotope data for the Bronze Age copper based artefacts from sites in the Ural Mountains and the local ores (R. Krause – personal communication) – they are isotopically different to the Swedish bronzes.

The main copper deposits that appear relevant to this project, either on the grounds of the archaeologically substantiated trade routes or their lead isotope characteristics, are as follows:

British Isles: Copper ores are found in association with the lead ores in Wales, Cheshire, Ireland, Isle of Man and Cornwall. Copper is present in sulphides, secondary formations as well as minor fahlores, in general with As (e.g. Ixer and Pattrick, 2003). Most of the prehistoric copper mining on the British Isles was confined to the Early Bronze Age (2400–1700 cal. BC) (Timberlake, 2009). However, Middle-Late Bronze Age mining is evident from Great Orme and Late Bronze Age mining at Mount Gabriel, Ireland (O'Brien, 2004; Timberlake, 2009). There are tin ores in Cornwall, but their exploitation in the Bronze Age is not directly proven (for summary see Rohl and Needham, 1998; Timberlake, 2009). Significant database of lead isotope and chemical data for Bronze Age copper based artefacts and over 600 lead isotope data for copper and lead ores from the British Isles and Ireland has been published (OXALID; Rohl and Needham, 1998).

Germany: In western and central Germany there are many lead, zinc, silver and copper deposits that were exploited since prehistoric times. In particular the active mining areas are located in the Black Forest (Schwarzwald) in the south-west, in the Harz Mountains and in the Rhine-Westphalia. Much of the mining was conducted for lead and silver ores, but copper ores were also smelted. The archaeometallurgical research to date is concentrated mostly on the Roman and Medieaval periods and there is a reasonable lead isotope database of about 400 ore samples (Bielicki and Tischendorf, 1991; Bode, 2008; Bode et al., 2009; Durali-Mueller et al., 2007; OXALID).

Erzgebirge, on German and Czech border: This mountain range is generally known for lead, silver and tin ores, but there are also occurrences of copper mineralisation including sulphide mineralisations with several trace elements comprising e.g. As, Ag and Sb (e.g. Niederschlag et al., 2003). Over 170 lead isotope analyses of the ores from Erzgebirge were published (Bielicki and Tischendorf, 1991; Niederschlag et al., 2003), but so far no copper based metals that are consistent with these ores were found amongst the analysed Bronze Age European copper-based artefacts.

Alpine deposits: The Eastern Alps in particular are known for large and rich deposits of copper (also lead and silver). There is a well-documented exploitation throughout the Bronze Age of copper ores, mainly in Tyrol, south of Salzburg. Typical copper minerals in these mines are the fahlores (e.g. Höppner et al., 2005; Krismer et al., 2011), copper smelted from these ores contains significant amounts of As, Sb and Ag, occasionally also Ni. Over 300 lead isotope data that can be used for comparisons have been published for the Alpine copper ores, mainly from Austria (Höppner et al., 2005; Köppel and Schroll, 1983; Schroll, 1997). Unfortunately, there are no lead isotope data published in numerical format for the mines in Mitterberg, the only published information about these ores is plotted as graphs (for example Pernicka, 2010, Fig. 8, p. 729). There is also archaeometallurgical evidence of ancient copper mines in the Italian Alps, but there are no lead isotope data available for these ores (Weisgerber and Goldenberg, 2004).

South-west France, Massif Central: This is a large area with several different centres of mineralisation, comprising fahlores with Sb, As and Ag (Prange and Ambert, 2005). There is a well documented evidence of early copper extraction in the Cabrieres

Fig. 3. Photo of the magnificent scrap hoard from Härnevi, Uppland, Sweden, dated to period V, including 47 artefacts and some sprues. From this hoard we have analysed a disc-headed pin (Table 1:61) a socketed axe of the Nordic type (Table 1:62) and a sickle (Table 1:63). Photo ATA.

mountains, in the south west end of Massif Central that peaked in the 3rd millennium cal. BC and declined about 2000 cal. BC (Ambert, 1995; Carozza and Mille, 2007). There are about 200 lead isotope data available for comparisons (Baron et al., 2006; Brevart et al., 1982; Le Guen et al., 1991). For copper from Cabrieres no data has been published, but there is a range of lead isotope ratios given in Prange and Ambert (2005, p. 79) as ^{208}Pb/^{206}Pb = 2.07–2.09 and ^{207}Pb/^{206}Pb = 0.838–0.845, no ratios to ^{204}Pb are given.

The Carpathians: The ore deposits in the Carpathian Mountains are of great importance for this project, because of the widely accepted belief amongst the archaeologists that copper-based metal supply was coming to Sweden from 'Central Europe' (e.g. Thrane, 1975). The major ore districts in the Carpathians containing multimetallic minerals (Cu, Pb, Zn, Au, and Ag) are in the Central Slovakia and Romanian Baia Mare and South Apuseni Mountains (Neubauer et al., 2005). These are significant deposits of copper, gold and silver, the Apuseni Mountains were an important source of gold for the Roman Empire, but at present there is no archaeometallurgical evidence of Bronze Age exploitation of these ores, There are over 120 published lead isotope analyses of lead and

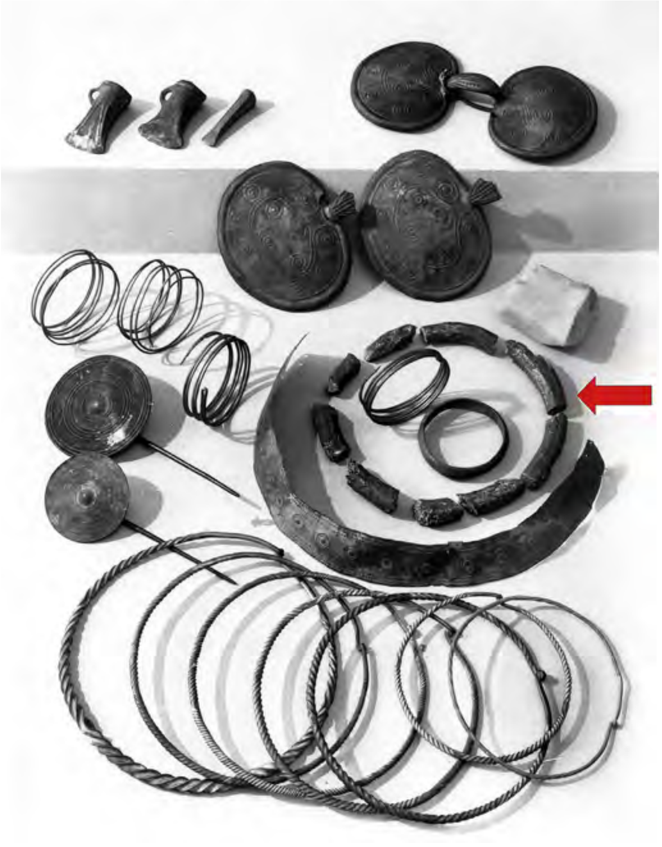


Fig. 4. Photo of the tin ingot (Table 1:60), weighing 510 g, discovered together with 18 bronze objects, in the Långbro hoard, Vårdinge in Södermanland. The hoard is dated to period V. Photo ATA.

copper ores from the Carpathian Mountains (Andras et al., 2010; Chernyshev et al., 2007; Marcoux et al., 2002) and the model ages calculated from these data show that the ore formations in these deposits are quite young, about 10–20 Ma (Neubauer et al., 2005). In terms of lead isotope ratios used in this paper these ages correspond to the range of lead isotope ratios characteristic for these ores to: $^{208}\text{Pb}/^{206}\text{Pb} = 2.06–2.085$, $^{207}\text{Pb}/^{206}\text{Pb} = 0.83–0.845$ and $^{206}\text{Pb}/^{204}\text{Pb} = 18.46–18.9$.

Fig. 5. Photo of two massive shaft-hole axes. In front; shaft-hole axe of Valsømagle type, dated to 1600–1500 cal. BC (Table 1:10). In back; shaft-hole axe of Fårdup type, dated to 1600–1500 cal. BC (Table 1:7). The former axe was discovered in a bog together with horse bones and a stone paving with post holes.

Fig. 6. Photo of various types of bronze axes. To the left; Y-ribbed palstave of North German type (Table 1:9). In the middle; a flanged axe, type C1:Underåre (Table 1:17). To the right; a socketed axe with extended neck, Scanian type VIIB 2a (Table 1:30).

The Balkans: Copper ore deposits are found in Serbia and in Bulgaria. Also there are a number of lead (silver) deposits in the Rhodope Mountains on the border of Bulgaria and Greece. Over 200 lead isotope analyses of copper and lead ores from the larger deposits were published (Gale et al., 2003; OXALID; Pernicka et al., 1993; Stos-Gale et al., 1998).

Greece and Turkey. There are over 600 lead isotope and some chemical analyses available on the OXALID for the Aegean copper, lead and silver deposits. In Turkey many ancient mining regions were surveyed and some 350 lead isotope data published (Hirao et al., 1995; Wagner et al., 2003; Yener et al., 1991). All these data were used for comparisons with the Swedish bronzes.

Cyprus was an important producer of copper for the east Mediterranean world in the Bronze Age (Stos-Gale and Gale, 1994). There is a well-documented exploitation throughout the Bronze Age of copper ores, the most intensive phase being 1400–1100 BC. In fact all oxhide ingots found in the Mediterranean seem to originate from Cypriot copper (Stos-Gale et al., 1997; Stos-Gale and Gale, 2009). Lead isotope data for over 400 ore samples and about 200 Bronze Age metal artefacts, as well as some chemical compositions of the copper ores are available on the OXALID.

Italy: Tuscany and Liguria. There is a possibility of Bronze Age exploitation of the copper ores in Tuscany and Liguria. Fifty eight lead isotope analyses of copper ores from these two regions are available on the OXALID. There are some reports of tin ores in Tuscany, but no indication of prehistoric exploitation.

Italy: Sardinia. The main deposits on Sardinia are of lead-zinc ores, but there are also a number of copper occurrences (Lo Schiavo et al., 2005). Copper and bronze are the main metal finds in the Nuragi, but some lead pottery clamps are made of Sardinian lead (Stos-Gale and Gale, 1992). There are some indications of early extraction of copper in Sardinia: Bell Beakers are present on the island about from 2500 to1700 cal. BC (Lo Schiavo et al., 2005). The

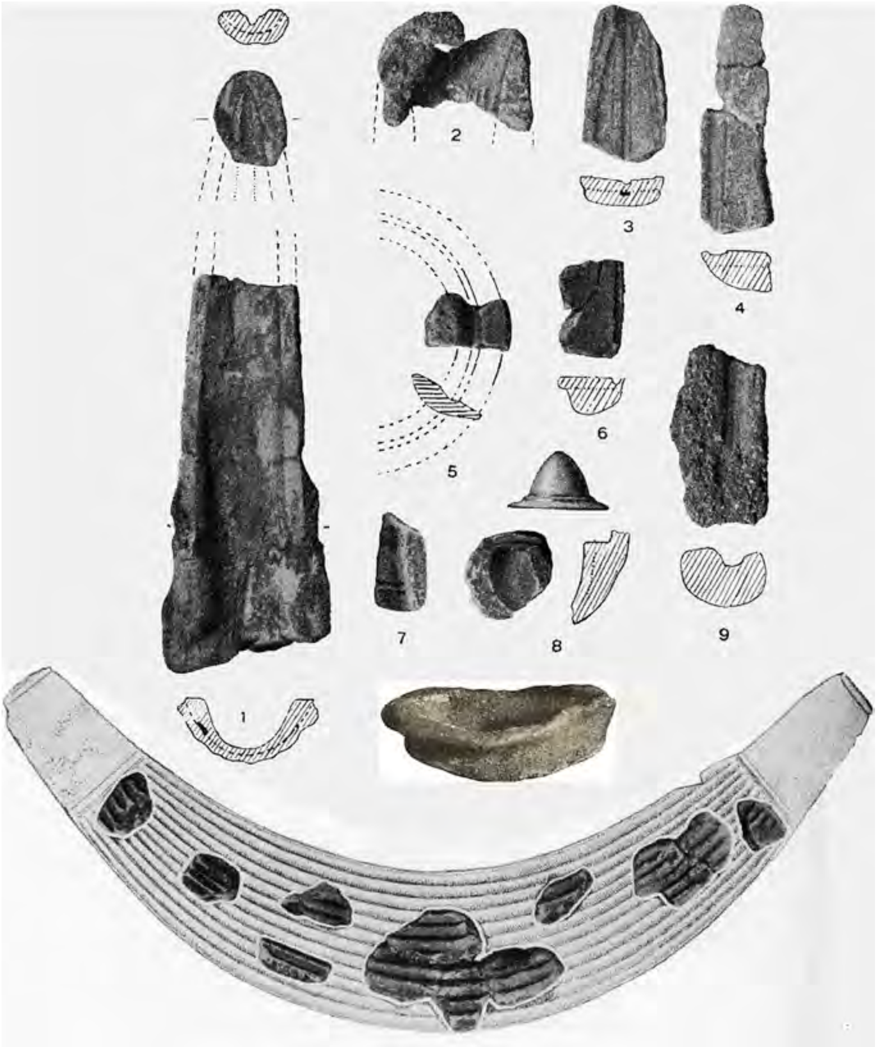


Fig. 7. Mould fragments found at the workshop site in Bro, Grimeton, Sweden. Top, from right to left; mould fragments of a spearhead, a tutulus, a round belt ornament and a sword, all dated to period II. In the middle; one of the crucibles from this site that included a droplet of copper, analysed within this study (Table 1:13). Bottom; mould fragments from a neck ornament dated to period II.

first archaeometallurgical evidence of an early Nuragic copper industry is dated to about 1600–1540 cal. BC. However, the major copper and lead production on Sardinia starts in the late 2nd – early 1st millennium cal. BC (Lo Schiavo et al., 2005). Tin ores are also present on Sardinia but it is not confirmed that they were exploited in the prehistoric times (Lo Schiavo et al., 2005). However, there are finds of tin metal (and perhaps of cassiterite) and copper ingots containing percentages of tin (Lo Schiavo et al., 2005). There is a proven connection with Cyprus and Greece in the late 2nd millennium BC by the finds on Sardinia of Mycenean pottery and Cypriot metalwork, and Cypriot copper oxhide ingots. There are nearly 400 hundreds of lead isotope data published for the copper and lead ores from Sardinia and many chemical and lead isotope analyses of the nuragic artefacts (Begemann et al., 2001; Boni and Köppel, 1985; OXALID). The lead isotope analyses of Nuragic copper-based artefacts in majority confirm their origin from the Sardinian copper ores (Begemann et al., 2001; OXALID).

Iberian Peninsula: There are many copper and lead deposits in the south and east of the Iberian Peninsula. In the south-west there is the massive Iberian Pyrite Belt, which in its south-west part Ossa Morena Zone contains deposits of copper associated with gold and mercury and deposits of tin (Tornos et al., 2004, 2005). The chronology of Spanish copper industry is also well documented from the 3rd -1st millennium cal. BC (Hunt-Ortiz, 2003). There are also several deposits of copper and tin in the western and north-western part of the Iberian Peninsula. Some copper-tin slags were found in the Iberian Peninsula suggesting that bronzes indeed were made by co-smelting copper and tin ores (Gómez Ramos, 1999). Several archaeometallurgical publications and more than a thousand lead isotope and elemental analyses of ores and artefacts have been published (e.g. Arribas and Tosdal, 1994; Huelga-Suarez et al., 2012a,b, 2013; Hunt-Ortiz, 2003; Klein et al., 2009; OXALID; Renzi et al., 2009; Santos Zaldeuegui et al., 2004; Tornos and Chiaradia, 2004). There are some lead isotope analyses of bronzes from Spanish sites (for example: Hunt-Ortiz, 2003; Rovira and Gómez Ramos, 1998; Stos-Gale, 2001b) and they are consistent with their origin from the Iberian ores. Unfortunately, there are hundreds of published elemental analyses of Bronze Age copper-based objects from Spain which are not combined with lead isotope data (Rovira Llorens et al., 1997).

5. Methods

5.1. Analytical methods

The analytical methods used in this project were described in detail in the previous paper (Ling et al., 2013).

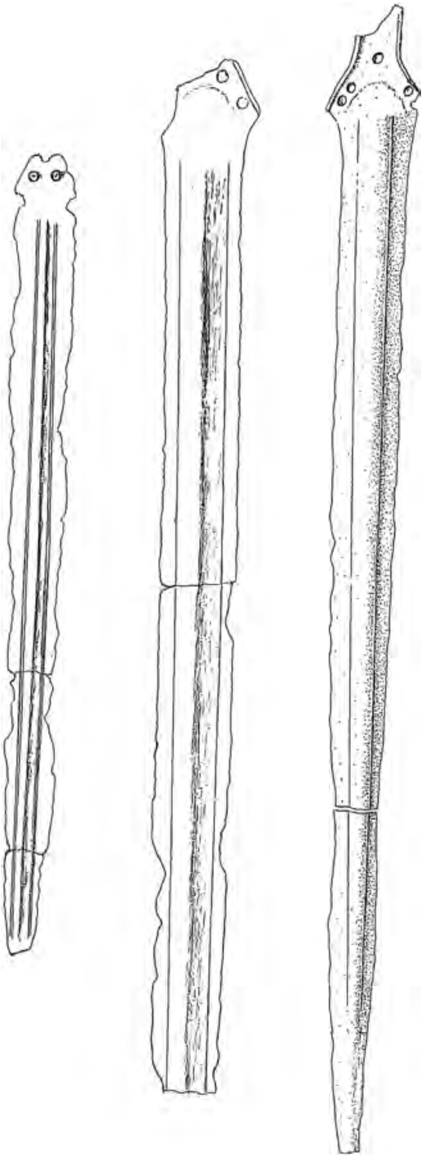


Fig. 8. Drawing of swords from Skåne dated to period III. To the left; a hilt-plate sword, type Meinered (Table 1:23). In the middle; a flange-hilted sword (Table 1:24). To the left; a flange-hilted sword, found in association with a mound (Table 1:25). Re-made after Oldeberg, 1974.

The chemical analyses (electron probe microanalyses-EPMA) of all 71 samples (including the previous 33, of which some were analysed previously on a different instrument) were performed in the Centre for Experimental Mineralogy, Petrology and Geochemistry at Uppsala University using a field emission electron microprobe (JEOL JXA-8530 F). The results from both instruments are within analytical error; however, the new analyses published here have better (lower) detection limits than those published in Ling et al. (2013). The new results for the chemical composition of all samples are listed in Table 2.

Lead isotope analyses were carried out in the Laboratory for Isotope Geology at the Swedish Museum of Natural History in Stockholm using a Micromass Isoprobe multi-collector, inductively coupled plasma mass spectrometer (MC-ICP-MS). The total analytical error for reported Pb isotope ratios is estimated to be ±0.1% for ratios including the ^{204}Pb isotope, and better than 0.03% for the other ratios (i.e. ^{208}Pb/^{206}Pb and ^{207}Pb/^{206}Pb). The lead isotope data for all 71 samples are listed in Table 3 and plotted on Fig. 9.

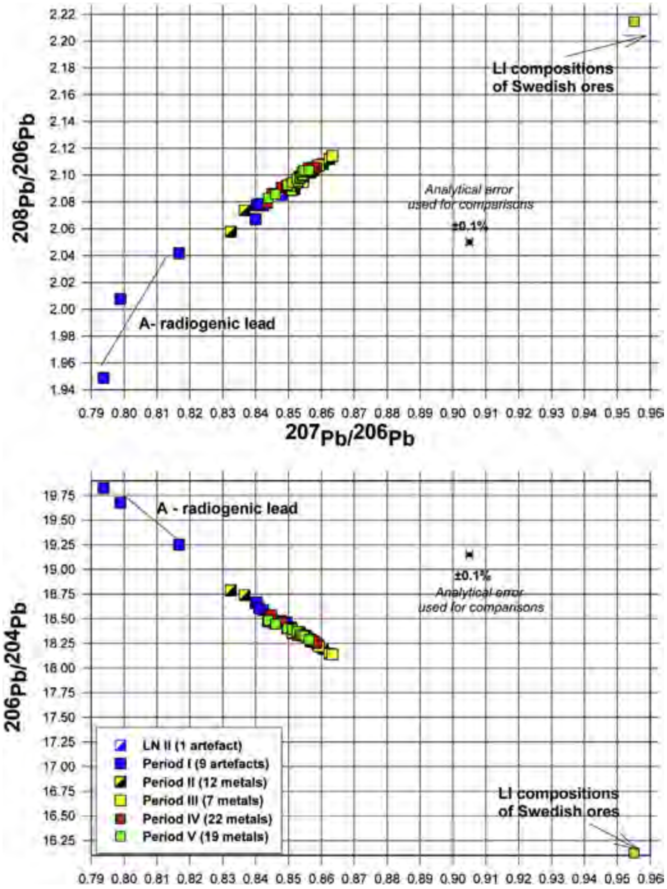


Fig. 9. Mirror image lead isotope plot of all analysed Swedish artefacts. A single data point which plots in the far right corner on both diagrams corresponds to one piece of copper slag from Botkyrka (T1:59; period V). This isotopic signature is consistent with the origin from the Early Proterozoic Bergslagen ores in Sweden (Ling et al., 2013). The data for the three axes dated to Period I in the far left of the plots shows the data for 'radiogenic' lead isotope ratios.

5.2. *Aspects of the interpretation of lead isotope and geochemical data*

The lead isotope methodology relies on the identification of ore deposits that were used for production of metals in antiquity via direct comparisons of available lead isotope data for minerals from different mines and the data obtained from samples of ancient artefacts. The database used for interpretation of lead isotope data includes the data published on the OXALID, and by other researchers (see references in this paper, and also in Cattin et al., 2009; Gale and Stos-Gale, 2000; Stos-Gale and Gale, 2009).

The initial stage of identifying the possible sources of archaeological artefacts is the '*Micro-analysis*' that includes:

i. Finding for each artefact the ore samples that have identical (within ±0.1% of the error) all three lead isotope ratios. This is done using the TestEuclid procedure (Stos, 2009) searching through the database covering all ore data (Table 4).
ii. Plotting the lead isotope ratios of the artefacts on two mirror image lead isotope diagrams, together with the data for all ore deposits that appeared to show matching lead isotope ratios in the TestEuclid procedure. The plots allow consideration of the mutual position of groups of analysed ores from various ore deposits relative to the groups formed by LI ratios representing the Swedish artefacts.

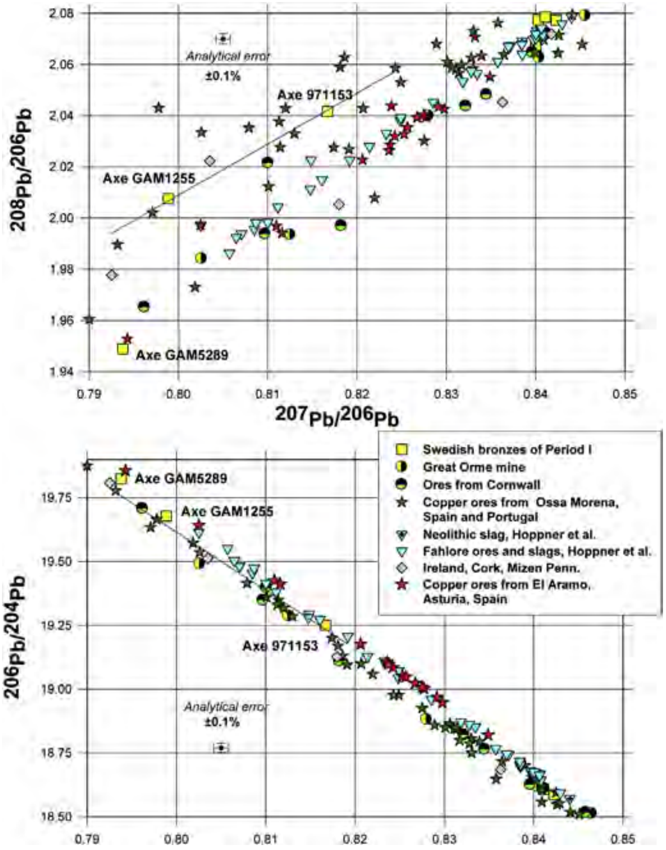


Fig. 10. Comparison of the three axes with the 'radiogenic' lead isotope ratios with the ores from the British Isles, Iberian Peninsula and the Alps. The LI ratios for two axes GAM 1255 and 971153 (Table 1:3,5) are well within the range of ratios for the ores from Ossa Morena. The shaft hole axe GAM 5289 (Table 1:2) plots on the mixing line of lead isotope ratios of copper ores from Cornwall and Great Orme mine in Wales. It is very tempting therefore to deduce that this axe was made of the copper ore from Great Orme mixed with copper ore and tin from Cornwall. However, one of the copper ores from Asturias is fully consistent with the ratios for this axe.

The second stage of the process of interpretation of the analytical data is the '*Macro-analysis*'. This procedure considers a broader picture of the possible origin of metals including:

i. Rejection of the ore deposits that on geochemical or chronological ground could not have supplied copper for these artefacts,
ii. Comparisons with the lead isotope and elemental data for *artefacts* in other regions of Europe.

In addition, the interpretation process involves a comparison between the elemental compositions of the analysed artefacts and the ore regions identified by the isotopic investigation. The elemental compositions of metals can to a considerable degree reflect the type of the ore used, and certain typical impurities are often characteristic of certain deposits. Since some copper ores from Spain have nearly identical lead isotope ratios as certain copper ores from Sardinia and Massif Central, and the Alps, the elemental compositions of the artefacts play very important role in the interpretation of the origin of the metal. Furthermore, the trace element signatures can discriminate metal groups that not only reflect various ore types, but are important for comparison with previously analysed artefacts from various regions and certain chronologies. However, it is important to stress that the identical lead isotope characteristics of a group of metals do not guarantee that their elemental characteristics will also form a group and *vice versa* (Pernicka et al., 1990; Rychner and Stos-Gale, 1998).

Since a deliberate addition of lead would allow only identification of the lead source, not the copper ore, knowledge of the lead content is essential. Deliberate alloying with lead is assumed if the lead content is higher than 2% (Liversage, 2000); below that value lead most likely originates from the copper ores. Only one of the Swedish metals contains lead higher than 2%, all others are well below 1% or around 1% (4 samples), indicating generally that no lead was added.

5.2.1. *Radiogenic lead isotope compositions*

Certain ores show a radiogenic lead isotope compositions characterised by very low $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ (less than about 2.04 and 0.83 respectively). Three artefacts amongst the Swedish Bronzes dated to *period I* have such lead isotope compositions (Figs. 9 and 10). These lead isotope ratios evolve with time in certain copper ores in which lead is present only in trace levels, but that contain significant amounts of uranium and thorium, large enough to produce more radiogenic lead isotopes after the initial ore formation (Pernicka et al., 1993). Radiogenic lead isotope ratios are found in several ore deposits in Europe, for example in the British Isles (Great Orme and Cornwall), Ireland, Tyrol, Asturias in north-west Spain and in the Ossa Morena Zone in the south west of the Iberian Peninsula. Considering the importance of some of these ores to the Bronze Age copper metallurgy it is remarkable how few of so far analysed copper-based Bronze Age artefacts show these radiogenic lead isotope ratios. Relying on the data accumulated on the OXALID it seems that amongst nearly 1500 copper-based artefacts from Greece there is only one such object. Amongst over 400 artefacts from the British Isles only 6 show these low lead isotope ratios. But they are found more frequently amongst the artefacts from Iberia: in Spain 7 out of 130, in Sardinia 7 out of 240.

5.2.2. *The possibility of recycling*

Considering a long distance trade in metals, the identification of the provenance can be strongly affected by the process of recycling of metal (Northover et al., 2001). Since the beginning of the attempts of finding the provenance using composition of metals and ores there were many papers published discussing the effects of multiple re-melting of copper-based alloys on their elemental compositions (Bray and Pollard, 2012; Pernicka, 1999; Tylecote et al., 1977), but not much has been said how the lead isotope compositions will be influenced by recycling of metal. It is quite certain that if one piece of metal is melted and re-made into a different shape then its lead isotope composition will remain unchanged. If two or more pieces of metal are melted together, each representing a specific ore deposit, the resulting lead isotope composition of the final metal will change along straight lines connecting these 'sources', and ultimately being controlled by the proportions of each mixing component, their lead content and absolute isotopic compositions (Bode et al., 2009; Stos, 2009; Stos-Gale, 2001a p.188). With the exception of certain deposits exhibiting 'radiogenic lead', the European ore deposits have mostly lead isotope compositions for $^{208}Pb/^{206}Pb = 2.04–2.12$, $^{207}Pb/^{206}Pb = 0.82–0.87$ and $^{206}Pb/^{204}Pb = 18–19$. Therefore the data for artefacts grouping at the lower and higher ends of these ratios are likely to represent the lead isotope intervals of the deposits that supplied the original ore.

Swedish bronzes from different periods form groups reflecting ranges of specific ore deposits. Additionally, the lead isotope compositions of the later, periods III-IV, bronzes group at the high end of the $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ indicating the origin from these rather rare deposits older than 300 Ma, without the addition of

Table 2
Chemical data, obtained by EPMA analyses (JEOL-JXA 8530F) for the 71 metals from the Swedish Bronze Age context. Data are mean values, calculated from multiple area scans. Gold was also included in the analyses but not recorded above the detection limit. Numbers in italics indicate results at or below detection limits.

Sample	County	Period	Object description	S	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb
1: SHM 884943	Dalsland	LNII	Dagger, Malchiner type IIIa	0.04	0.01	0.01	0.04	91.89	0.03	1.71	1.42	0.04	2.15	*0.05*
2: GAM 5289	Bohuslän	I	Shafthole axe, Fårdrup type	0.74	0.11	0.03	0.47	85.80	0.04	0.39	0.04	9.47	0.10	0.09
3: GAM 1255	Dalsland	I	Shafthole axe, Fårdrup type	0.12	0.03	0.03	0.46	87.96	*0.02*	0.31	0.03	8.14	0.05	0.11
4: SHM 971151	Dalsland	I	Flanged axe, Spatulate or Spoon shaped blade	0.11	0.01	0.03	1.01	83.94	0.04	0.72	0.48	9.10	0.82	*0.07*
5: SHM 971153	Småland	I	Flanged axe, C1:Underåre	0.30	0.03	0.02	0.37	89.58	0.04	0.16	0.04	7.92	0.05	0.10
6: UM 40280_3006	Uppland	I	Sword pommel, Valsømagle type	0.33	0.04	0.03	0.31	85.87	0.04	0.31	0.03	10.23	0.38	0.19
7: AM 786	Värmland	I	Shafthole axe Fårdrup	0.58	0.15	0.03	0.09	92.25	*0.02*	0.33	0.04	4.27	0.05	0.11
8: SHM 884944	Värmland	I	Spear head, type Bagterp	0.19	0.04	0.06	0.50	91.21	*0.01*	0.49	0.38	5.52	1.25	1.30
9: VM 21916	Värmland	I	Flanged axe C1:Underåre	0.08	0.02	0.03	0.11	87.55	*0.03*	0.15	0.04	10.02	0.21	0.15
10: KM 33_465_10	Öland	I	Shafthole axe Valsømagle	0.11	0.02	0.03	0.33	84.58	0.04	0.29	0.04	11.83	0.40	0.11
11: GAM 1993	Bohuslän	II	Palstave, Type 1a1c, South English-Northwest French shield-ornamented 1500–1400 BC	0.27	0.02	0.05	0.03	87.48	*0.02*	0.10	0.02	9.30	0.04	0.09
12: SHM 96775	Dalsland	II	Lance head, type Ullerslev	0.47	0.07	0.04	0.53	87.38	0.04	0.26	0.04	9.50	0.14	0.15
13: GAM 5964	Halland	II	Droplet in crucible	0.08	0.02	0.03	0.27	89.86	0.03	0.11	0.04	8.28	0.13	0.11
14: GAM 5922-1	Halland	II	Droplet in crucible	0.17	0.01	0.05	0.28	90.07	0.04	0.16	0.04	6.92	0.11	0.14
15: GAM 5922-2	Halland	II	Droplet in crucible	*0.01*	0.02	0.03	0.16	97.91	*0.02*	0.04	0.04	0.10	0.04	0.13
16:1LUHM 3527	Skåne	II	Flange-hilted sword "Das Schwert mit ausgebauchter Zunge"	0.97	0.05	0.04	0.15	86.01	0.06	0.08	0.07	10.93	0.05	0.09
17: SHM 971152	Småland	II	Nordic form, Palstave, (Kersten C II, Plastic Y-rib of North German type)	0.42	0.31	0.05	0.51	84.63	*0.03*	0.23	0.03	11.95	0.09	0.09
18: GAL F 999	Uppland	II	Awl	0.13	0.05	0.04	0.54	88.57	0.04	0.41	0.05	7.85	0.11	0.21
19: GAL F1607	Uppland	II	Curved knife	0.24	0.02	0.03	0.45	89.88	*0.03*	0.80	0.50	3.94	2.03	0.13
20: VM 1205	Värmland	II	Hilt-plate dagger	0.24	0.04	0.04	0.25	83.70	0.05	0.29	0.02	11.18	0.24	0.10
21: VM 2931	Värmland	II	Hilt-plate dagger	0.41	0.04	0.03	0.59	82.28	0.03	0.26	0.04	12.63	0.11	0.16
22: AM 1214	Värmland	II	Palstave (Kersten C II, Plastic Y-rib of North German type)	0.46	0.03	0.02	0.22	84.49	0.04	0.13	0.02	10.45	0.05	0.14
23: LUHM 24283	Skåne	III	Hilt-plate sword, type Meinered	0.41	0.03	0.05	0.25	86.05	0.03	0.17	0.05	10.45	0.12	0.19
24: LUHM 22268	Skåne	III	Flange-hilted sword	0.54	0.09	0.05	0.62	85.07	*0.03*	0.15	0.03	11.41	0.10	*0.06*
25: LUHM 2846	Skåne	III	Flange-hilted sword	0.50	0.13	0.05	0.08	86.82	0.06	0.07	0.10	9.65	0.15	0.39
26: SHM 971147	Södermanland	III	Socketed axe type A	0.75	0.06	0.03	0.29	86.62	0.05	0.09	0.03	9.77	0.07	0.15
27: GAL F 707	Uppland	III	Sprue	0.16	0.01	0.07	0.25	88.38	*0.03*	0.08	0.11	8.60	0.15	0.15
28: GAL F 810	Uppland	III	Rod	0.14	0.02	0.06	0.64	92.54	0.04	0.95	0.53	0.69	1.96	0.28
29: AM 1213	Värmland	III	Tanged sword	0.27	0.04	0.04	0.24	86.38	0.06	0.04	0.04	10.14	0.07	0.11
30: GAM 3031	Bohuslän	IV	Socketed axe, Scanian type VIIB 2a	0.13	0.02	0.04	0.09	88.01	0.04	0.13	0.08	8.27	0.11	0.35
31: SHM 273741	Dalsland	IV	Socketed axe, fragments VII A1a	0.12	0.02	0.03	0.54	89.93	0.04	0.90	0.64	3.33	2.58	0.16
32: SHM 411836	Dalsland	IV	Tanged sword A2	0.04	0.02	0.03	0.58	91.84	0.04	0.63	0.50	2.52	1.88	0.26
33: SHM 411852	Dalsland	IV	Sickle XIV B, casting debris	0.19	0.03	0.03	0.39	90.63	0.04	0.77	0.26	4.28	1.54	0.19
34: SHM 971194	Dalsland	IV	Sprue	0.07	0.01	0.03	0.44	90.08	*0.03*	0.74	0.47	3.73	2.30	0.14
35: SHM 362390, s1	Dalsland	IV	Rod	0.15	0.02	0.03	0.38	90.00	*0.03*	0.48	0.25	5.71	1.15	0.12
36: SHM 362390, s 2	Dalsland	IV	Rod	0.13	0.02	0.03	0.40	90.13	*0.03*	0.79	0.44	4.25	1.85	0.11
37: SHM 362388	Dalsland	IV	Melt	0.20	0.01	0.02	0.32	85.63	*0.02*	1.09	0.74	6.75	3.05	0.18
38: SHM 362391	Dalsland	IV	Sprue	0.21	0.05	0.03	0.59	89.10	0.03	1.04	0.62	3.03	3.12	0.11
39: SHM 417322	Dalsland	IV	Rod	0.08	0.02	0.03	0.42	90.43	0.04	0.52	0.31	4.93	1.09	0.10
40: SHM 971146	Södermanland	IV	Socketed axe, Mälardal type VII B1a	0.04	0.03	0.03	0.07	89.44	0.04	0.16	0.04	6.56	0.09	0.14
41: GAL F 595	Uppland	IV	Dagger	0.09	0.03	0.03	0.49	91.58	0.03	0.61	0.51	3.54	1.51	0.15
42: UMF 4567	Uppland	IV	Socketed axe, Nordic VII C1a	0.08	0.05	0.04	0.82	88.80	*0.03*	0.34	0.44	5.86	1.28	0.38
43: GAL F 1606	Uppland	IV	A pair of tweezers	0.31	0.04	0.05	0.45	86.50	*0.03*	0.15	0.08	10.01	0.12	0.09
44: UMF 5453	Uppland	IV	Socketed axe, Mälardal type VII B1a	0.04	0.02	0.03	0.11	89.87	0.04	0.14	0.07	7.21	0.10	0.43
45: SHM 971149_1	Uppland	IV	Droplet in crucible	0.02	0.02	0.02	0.30	95.05	0.04	0.10	0.19	0.26	0.67	0.20
46: SHM 971149_2	Uppland	IV	Droplet in crucible	0.03	0.05	0.05	0.26	95.64	*0.03*	0.09	0.32	1.08	0.31	0.24
47: UMF 6005	Uppland	IV	Socketed axe, Mälardal type VII B1a	0.17	0.02	0.03	0.05	86.67	0.05	0.14	0.04	10.82	0.06	0.09
48: SHM 414109	Värmland	IV	Hilt-plate sword, type A1	0.09	*0.01*	0.08	0.26	88.78	*0.03*	0.28	0.12	7.24	0.34	0.52
49: SHM 414088	Värmland	IV	Armring, type XIX D	0.34	0.02	0.12	0.13	86.22	0.04	0.29	0.08	9.30	0.25	0.52
50: SHM 414117	Värmland	IV	Sickle XIV B	0.07	0.02	0.08	0.44	89.66	0.03	0.46	0.30	5.25	0.98	1.04
51: AM 580	Värmland	IV	Socketed axe VII B2c: Mixform, Västergötland	0.11	0.02	0.03	0.05	84.95	0.04	0.11	0.02	10.65	0.05	0.21
52: GAM 3030	Bohuslän	V	Socketed axe Westnordische Type VIIC 2b	0.03	0.02	0.02	0.46	93.34	0.05	0.26	0.32	1.75	0.82	0.30
53: SHM 884947	Småland	V	Rod/neckring	0.18	0.01	0.05	0.37	89.20	*0.02*	1.19	0.20	4.01	1.19	0.64
54: SHM 122890	Södermanland	V	Melt	1.35	1.97	0.03	0.05	85.87	2.10	1.02	0.15	0.04	2.90	2.66
55: SHM 971141	Södermanland	V	Melt	0.17	0.09	0.02	0.04	83.62	0.03	0.04	0.05	13.91	0.05	0.13
56: SHM 971140	Södermanland	V	Rod	0.01	0.02	0.03	0.67	93.44	*0.03*	0.09	0.30	0.35	1.41	0.23
57: SHM 971154	Södermanland	V	Rod	0.03	0.01	0.08	0.46	86.23	0.03	0.43	0.20	8.43	0.93	1.04
58: SHM 971142	Södermanland	V	Rod	0.37	0.03	0.30	0.88	86.19	0.04	1.29	0.22	5.94	1.38	1.41
59: SHM 971139	Södermanland	V	Copper slag	29.67	35.42	0.28	0.05	25.61	2.48	0.05	0.03	0.04	0.07	0.84
60: SHM 96898	Södermanland	V	Ringshaped rod/ingot? (tin)	0.01	0.03	0.04	0.05	0.13	0.07	0.04	*0.00*	98.64	0.12	0.77
61: SHM 414482	Uppland	V	Pin, disc-headed, Härnevi type, type XXV B2c	0.16	0.05	0.05	0.56	89.25	*0.03*	0.68	0.54	3.19	2.19	0.55

Table 2 (*continued*)

Sample	County	Period	Object description	S	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb
62: SHM 414492	Uppland	V	Socketed axe Nordic type Upplands, VII D2	0.05	0.03	0.05	0.47	89.52	*0.03*	0.60	0.37	3.88	1.48	0.54
63: SHM 971150	Uppland	V	Sickle, type XIV B	0.11	0.02	0.07	0.44	89.09	0.04	0.61	0.41	5.08	1.13	0.67
64: SHM 148960	Värmland	V	Rod	0.91	0.54	0.19	0.19	87.16	*0.03*	0.30	0.05	8.12	0.14	0.22
65: SHM 414103	Värmland	V	Socketed axe VII C2a, Common Nordic	0.05	0.01	0.10	0.53	90.74	0.03	0.44	0.25	4.37	0.99	0.57
66: SHM 884946	Värmland	V	Lure fragment	0.15	0.07	0.06	0.06	81.55	0.04	0.18	0.06	16.10	0.13	0.11
67: SHM 414124	Värmland	V	Rod of lead	*0.00*	*0.00*	*0.01*	*0.00*	0.10	*0.00*	0.10	7.30	*0.00*	1.63	93.19
68: AM 576	Värmland	V	Socketed axe type VII C2a, Common Nordic	0.04	0.02	0.08	0.43	89.85	*0.03*	0.43	0.34	3.98	0.99	0.49
69: VG 5	Västergötland	V	U-notched shield, Herzsprung type	0.34	0.03	0.17	0.15	84.81	0.06	0.37	0.08	11.57	0.14	0.35
70: VG 11	Västergötland	V	U-notched shield, Herzsprung type	0.39	0.03	0.17	0.08	81.21	0.03	0.50	0.06	10.65	0.19	0.67
71: ÖM 4473:322	Östergötland	V	Melt	0.02	0.01	0.04	0.10	98.23	0.03	0.06	0.04	0.05	0.06	0.20

metal extracted from younger ores. The level of typical trace and minor elements found in prehistoric copper (As, Sb, Ag, Ni) in all the bronzes is quite high and very varied, as expected from the varied geochemistry of ores. If the metal was repeatedly mixed from a 'pool' of European bronzes, then the elemental and isotope compositions should be more uniform. The lead content in the Swedish, as well as Danish (Liversage, 2000) and Norwegian (Melheim, 2012) Bronze Age metals, is mostly below 0.5% which is in contrast with artefacts in some other North European regions, e.g. from the British Isles (Liversage and Northover, 1998) which contain lead in considerably higher concentrations. This feature additionally indicates that the Swedish artefacts most likely did not derive from a European 'pool' of re-used bronze, but from primary metals. It seems therefore that (with exception of a very late hoard, as discussed later) the lead isotope and elemental compositions of the analysed Swedish bronzes, indicate that re-melting and mixing together of several pieces of metal made from different ore sources, or already recycled metal, is not a major problem. It seems rather that copper and tin, perhaps as ingots, were imported to Sweden directly from a few copper (and tin) producing areas. The crucibles used in the Bronze Age were not very large and re-making of copper-based objects was most likely conducted by using only one or two pieces of metal that will give the amount required for a new artefact. If the sources of copper were limited to two or three deposits, their lead isotope and elemental compositions will prevail in these artefacts. The fact that pure copper and tin were imported to some of the Swedish sites is also underpinned by the presence of pure copper and tin ingots, as listed in Table 2 and discussed below.

6. Results and discussion

6.1. General results

The conclusions as to the origin of the metal used for the copper-based artefacts from Bronze Age Sweden were obtained by comparing not only lead isotope ratios of the artefacts but also their elemental compositions and the geochemistry of ores from the deposits selected by their lead isotope ratios. Following the outline of the methodology of interpretation of lead isotope data, after comparing each set of lead isotope ratios for one artefact with all available ore data (over 6000 entries) using the TestEuclid, we prepared some 85 lead isotope mirror plots for all three ratios, comparing in detail the data for the bronzes with various ores and artefacts from the Mediterranean, Central and Northern Europe. On these grounds some of the earlier listed ore deposits were rejected as sources of copper for the analysed bronzes:

- The careful comparison with the copper ores from the Massif Central, including the information about the range of lead isotope ratios for Carabrières, led to the conclusion that some of the Swedish bronzes have lead isotope ratios consistent with these ores and in particular with the copper and lead ores from the Montagne Noire. However, so far there is no evidence for a large copper production in this area in the second millennium BC (Ambert, 1995), so at present ores from the Massif Central are not considered a convincing source for these Swedish bronzes.
- Only a few of the Swedish copper-based artefacts analysed fall into the general ranges of lead isotope ratios of the ores from the Carpathian Mountains (Romania and Slovakia), and none of them is fully consistent with the data for these ores.
- None of the analysed Swedish bronzes are consistent with the lead isotope ratios published for the ores and artefacts from Tuscany and Liguria.
- None of the analysed Swedish artefacts have lead isotope compositions consistent with ores from the Erzgebirge or the Balkans (Serbia, Bulgaria).

The majority of the analysed Swedish artefacts are tin-copper alloys, which also contain one or more of the impurities of arsenic, antimony, nickel and silver in the range from 0.2% to several percent. Iron and/or cobalt appear in smaller quantities (Table 2).

The overall picture of the tin content in the alloys shows a shift from somewhat higher tin during periods I-III (medium–high; 7–11%), to lower during periods IV-V (low–medium; 2–8%), except for some outliers. Out of 71 analysed samples, only seven are pure copper or very low in tin. These mainly comprise casting debris or raw material as droplets from crucibles (T1:15,45), two melts (T1:71,54) and two ingots/rods (T1:28,56). Also the earliest analysed artefact, a metal hilted dagger from LN II period (2000–1700 cal. BC) (T1:1) is made of copper with high antimony, arsenic and silver. A copper slag (T1:59) is also free from tin. A ring-shaped rod (T1:60) proved to be made of pure tin and there is also a lead rod (T1:67), both dated to period V.

Some elemental variations are observed for the investigated artefacts within each period, but similarities can also be distinguished that mainly discriminate period I-III artefacts from those from period IV-V (Fig. 11). Artefacts from period I present a variation in trace element pattern, but generally with lower concentrations than during period IV-V. Artefacts from period II and III are characterised by significant content of nickel, in combination with sulphur. Compared to both earlier and later periods the lack of antimony and silver is notable. Finally, in period IV and V, nearly impurity-free items do occur but artefacts with significant contents of arsenic, antimony, nickel and silver are in majority.

The detailed analysis of the lead isotope and chemical data in terms of the geographical regions of origin of the metal are

Table 3
Lead isotope data obtained for all analysed metals from the Swedish Bronze Age context.

Artefact number	County	Parish	Object description	Period	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$	Consistent with the copper ores from
1: SHM 884943	Dalsland	Ör	Dagger, Malchiner type IIIa	LN II	2.08530	0.84809	18.469	Austria, North Tyrol, Brixlegg
2: GAM 5289	Bohuslän	Ödsmål	Shafthole axe, Fårdrup type	I	1.94885	0.79379	19.824	Spain, El Aramo, Asturias (NW Spain)
3: GAM 1255	Dalsland	Frändefors	Shafthole axe, Fårdrup type	I	2.00757	0.79886	19.678	Portugal, Ossa Morena
4: SHM 971151	Dalsland	Färgelanda	Flanged axe, Spatulate or Spoon shaped blade	I	2.06712	0.84002	18.656	Austria, North Tyrol
5: SHM 971153	Småland	Gamleby	Flanged axe, C1:Underåre	I	2.04170	0.81669	19.251	Portugal, Ossa Morena
6: UM 40280_3006	Uppland	Viksta	Sword pommel, Valsømagle type	I	2.09166	0.84946	18.460	Sardinia, Calabona mine
7: AM 786	Värmland	Ny	Shafthole axe Fårdrup	I	2.07851	0.84109	18.608	Cyprus
8: SHM 884944	Värmland	Ölme	Spear head, type Bagterp	I	2.09722	0.85349	18.340	Austria, North Tyrol
9: VM 21916	Värmland	Östra Fågelvik	Flanged axe C1:Underåre	I	2.07731	0.84231	18.587	Cyprus
10: KM 33_465_10	Öland	Löt	Shafthole axe Valsømagle	I	2.07748	0.84028	18.664	Cyprus
11: GAM 1993	Bohuslän	Öckerö	Palstave, Type 1a1c, South English-Northwest French shield-ornamented 1500–1400 BC	II	2.05768	0.83246	18.787	Greece, Lavrion
12: SHM 96775	Dalsland	Ånimskog	Lance head, type Ullerslev	II	2.10676	0.85891	18.237	Spain, South
13: GAM 5964	Halland	Grimeton	Droplet in crucible	II	2.10180	0.85513	18.327	Spain, South
14: GAM 5922-1	Halland	Grimeton	Droplet in crucible	II	2.09860	0.85335	18.364	Sardinia
15: GAM 5922-2	Halland	Grimeton	Droplet in crucible	II	2.09870	0.85378	18.336	Sardinia
16: LUHM 3527	Skåne		Flange-hilted sword “Das Schwert mit ausgebauchter Zunge”	II	2.11188	0.86244	18.145	Sardinia
17: SHM 971152	Småland	Gamleby	Nordic form, Palstave, (Kersten C II, Plastic Y-rib of North German type)	II	2.09360	0.85067	18.413	Sardinia, Ozieri
18: GAL F 999	Uppland	Tillinge	Awl	II	2.08959	0.85183	18.351	Austria, Tyrol
19: GAL F1607	Uppland	Tillinge	Curved knife	II	2.10356	0.85747	18.270	Sardinia
20: VM 1205	Värmland	Glava	Hilt-plate dagger	II	2.07370	0.83665	18.739	Cyprus
21: VM 2931	Värmland	Övre Ulleryd	Hilt-plate dagger	II	2.10176	0.85674	18.268	Sardinia
22: AM 1214	Värmland	Östra Ämtervik	Palstave (Kersten C II, Plastic Y-rib of North German type)	II	2.10828	0.86044	18.193	Spain, South
23: LUHM 24283	Skåne	Tullstorp	Hilt-plate sword, type Meinered	III	2.09471	0.85439	18.330	Sardinia
24: LUHM 22268	Skåne	Östra Hoby	Flange-hilted sword	III	2.10344	0.85579	18.312	Spain, South
25: LUHM 2846	Skåne		Flange-hilted sword	III	2.11433	0.86335	18.137	Sardinia
26: SHM 971147	Södermanland	Barva	Socketed axe type A	III	2.09882	0.85457	18.330	Sardinia
27: GAL F 707	Uppland	Tillinge	Sprue	III	2.09463	0.85296	18.335	Sardinia
28: GAL F 810	Uppland	Tillinge	Rod	III	2.08616	0.84589	18.454	Spain, South
29: AM 1213	Värmland	Sunne	Tanged sword	III	2.10729	0.85917	18.221	Spain, South
30: GAM 3031	Bohuslän	Tjörn	Socketed axe, Scanian type VIIB 2a	IV	2.09076	0.84805	18.469	Sardinia
31: SHM 273741	Dalsland	Järn	Socketed axe, fragments VII A1a	IV	2.10467	0.85786	18.257	Spain, East?
32: SHM 411836	Dalsland	Järn	Tanged sword A2	IV	2.10594	0.85866	18.247	Spain, East?
33: SHM 411852	Dalsland	Järn	Sickle XIV B, casting debris	IV	2.09902	0.85341	18.363	Spain, East?
34: SHM 971194	Dalsland	Järn	Sprue	IV	2.10228	0.85649	18.297	Spain, East?
35: SHM 362390, sample 1	Dalsland	Järn	Rod	IV	2.10603	0.85743	18.263	Spain, East?
36: SHM 362390, sample 2	Dalsland	Järn	Rod	IV	2.10381	0.85673	18.278	Spain, East?
37: SHM 362388	Dalsland	Järn	Melt	IV	2.10349	0.85688	18.292	Spain, East?
38: SHM 362391	Dalsland	Järn	Sprue	IV	2.09934	0.85478	18.331	Spain, East?
39: SHM 417322	Dalsland	Järn	Rod	IV	2.10564	0.85785	18.270	Spain, East?
40: SHM 971146	Södermanland	Västerhaninge	Socketed axe, Mälardal type VII B1a	IV	2.08630	0.84488	18.540	Sardinia, Calabona mine
41: GAL F 595	Uppland	Rasbo	Dagger	IV	2.09430	0.85304	18.353	Austria, Tyrol
42: UMF 4567	Uppland	Tensta	Socketed axe, Nordic VII C1a	IV	2.08879	0.85009	18.404	Austria, Tyrol
43: GAL F 1606	Uppland	Tillinge	A pair of tweezers	IV	2.09435	0.85178	18.358	Sardinia
44: UMF 5453	Uppland	Tillinge	Socketed axe, Mälardal type VII B1a	IV	2.09074	0.84774	18.482	Sardinia
45: SHM 971149_1	Uppland	Vårfrukyrka	Droplet in crucible	IV	2.09205	0.85171	18.366	Austria, Tyrol
46: SHM 971149_2	Uppland	Vårfrukyrka	Droplet in crucible	IV	2.09502	0.85276	18.346	Austria, Tyrol
47: UMF 6005	Uppland	Vänge	Socketed axe, Mälardal type VII B1a	IV	2.07896	0.84359	18.464	Cyprus, Skouriotissa
48: SHM 414109	Värmland	Grava	Hilt-plate sword, type A1	IV	2.10056	0.85412	18.337	Spain, South
49: SHM 414088	Värmland	Grava	Armring, type XIX D	IV	2.10579	0.85591	18.301	Spain, South
50: SHM 414117	Värmland	Grava	Sickle XIV B	IV	2.09740	0.85347	18.337	Austria, Tyrol
51: AM 580	Värmland	Östervallskog	Socketed axe VII B2c: Mixform, Västergötland	IV	2.09009	0.84799	18.459	Sardinia
52: GAM 3030	Bohuslän	Tjörn	Socketed axe Westnordische Type VIIC 2b	V	2.09718	0.85253	18.371	Austria, Tyrol
53: SHM 884947	Småland	Gladhammar	Rod/neckring	V	2.08555	0.84603	18.445	Germany, Siegerland, Rhine-Westphalia
54: SHM 122890	Södermanland	Botkyrka	Melt	V	2.08287	0.84391	18.483	Germany, Schwarzwald
55: SHM 971141	Södermanland	Botkyrka	Melt	V	2.09465	0.85114	18.393	Sardinia
56: SHM 971140	Södermanland	Botkyrka	Rod	V	2.09181	0.85071	18.407	Austria, Tyrol
57: SHM 971154	Södermanland	Botkyrka	Rod	V	2.09789	0.85357	18.336	Austria, Tyrol
58: SHM 971142	Södermanland	Botkyrka	Rod	V	2.09930	0.85415	18.323	Spain, South
59: SHM 971139	Södermanland	Botkyrka	Copper slag	V	2.21440	0.95510	16.124	Sweden

Table 3 (*continued*)

Artefact number	County	Parish	Object description	Period	^{208}Pb/^{206}Pb	^{207}Pb/^{206}Pb	^{206}Pb/^{204}Pb	Consistent with the copper ores from
60: SHM 96898	Södermanland	Vårdinge	Ringshaped rod/ingot? (tin)	V	2.08855	0.85097	18.352	Cornwall
61: SHM 414482	Uppland	Härnevi	Pin, disc-headed, Härnevi type, type XXV B2c	V	2.09262	0.84970	18.402	Austria, Tyrol + other
62: SHM 414492	Uppland	Härnevi	Socketed axe Nordic type Upplands, VII D2	V	2.09183	0.84950	18.397	Austria, Tyrol + other
63: SHM 971150	Uppland	Härnevi	Sickle, type XIV B	V	2.09559	0.85289	18.348	Austria, Tyrol + other
64: SHM 148960	Värmland	By	Rod	V	2.10229	0.85414	18.340	Spain, South
65: SHM 414103	Värmland	Grava	Socketed axe VII C2a, Common Nordic	V	2.09551	0.85287	18.344	Austria, Tyrol
66: SHM 884946	Värmland	Grava	Lure fragment	V	2.10356	0.85625	18.289	Spain, South
67: SHM 414124	Värmland	Grava	Rod of lead	V	2.09399	0.85261	18.332	Austria, Tyrol
68: AM 576	Värmland	Köla	Socketed axe type VII C2a, Common Nordic	V	2.09996	0.85437	18.327	Spain, South
69: VG 5	Västergötland	Sunnersberg	U-notched shield, Herzsprung type	V	2.10340	0.85470	18.327	Spain, South
70: VG 11	Västergötland	Sunnersberg	U-notched shield, Herzsprung type	V	2.10328	0.85527	18.310	Spain, South
71: ÖM 4473:322	Östergötland	Styrstad	Melt	V	2.08830	0.85108	18.346	Cornwall

presented below, and summarised in Fig. 12. Leaving out the copper slag sample and a small group of artefacts made of isotopically ‘radiogenic’ copper, the majority of the analysed objects have lead isotope and elemental compositions consistent mainly with the copper ores from central and southern Europe: North Tyrol in Austria, Sardinia and the Iberian Peninsula.

Six bronzes are isotopically fully consistent with the ores from the Eastern Mediterranean (Fig. 13 for Cyprus, for comparative data for Lavrion see OXALID). It must be emphasised that our interpretation of lead isotope and chemical data for this group of Swedish bronzes is made on the bases of currently available archaeometallurgical and lead isotope information and we are fully open to re-interpretation of these results if new scientific evidence emerges.

6.2. *The specific identification of potential copper sources for Swedish BA artefacts in relation to regions and chronology*

6.2.1. *Austria, North Tyrol*

Seventeen of the analysed artefacts spanning the chronology have lead isotope and chemical compositions that are consistent with the copper fahlores and slags from Brixlegg in North Tyrol. The artefacts include e.g. a metal-hilted dagger (T1:1) dated to *LNII* comprising a copper based alloy of elemental composition that resembles very closely the Ösenring copper with percentage amounts of silver, arsenic and antimony (Höppner et al., 2005). Similar isotopic and elemental consistency is observed for a spear head (T1:8) and a flanged axe (T1:4) from *period I*, both containing arsenic, antimony, nickel and silver. Also consistent with the fahlores from North Tyrol is an awl (T1:18) dated to *period II*, containing mainly arsenic and nickel as impurities, as well as four metal droplets from two crucibles (*period IV;* T1:45,46), with low tin content and some antimony, nickel and silver, Another *period IV object*, a socketed axe (T1:42), and a copper rod (*period V*; T1:56) also have lead isotopic compositions consistent with ores from North Tyrol.

Seven artefacts from *period IV* (sickle T1:50) and *period V* (socketed axes T1:52,62,65, rod T1:57, pin T1:61and sickle T1:63), all with significant contents of arsenic, antimony, nickel and silver have isotopic ratios that are consistent with the origin from the ores in various copper deposits in the Alpine region, although some of them also may derive from Massif Central, if judged on their lead isotope compositions alone. In view of the lack of evidence for Late Bronze Age copper production in the Massif Central, at present we accept the Alpine copper as the source for these bronzes.

The lead rod (T1:67), from *period V*, has lead isotope composition identical not only to the Alpine ores, but also to a number of lead mines in the British Isles, including north England (Cumbria and Lancashire) and Cornwall. However, apart from the uncertainty if these mines were exploited in the early 1st millennium BC, the high antimony and silver (7.3%) is not found in the British galenas, so it seems most likely that this is metal derived from the complex Alpine minerals.

6.2.2. *Iberian Peninsula*

Two shaft-hole axes (T1:2,3) and one flanged axe (T1:5) from *period I* have very unusual lead isotope compositions, distinguished by very low values of ^{207}Pb/^{206}Pb < 0.82 (Fig. 10). These three artefacts are compared with radiogenic copper ores from the British Isles, North Tyrol, Ossa Morena Zone and the copper mines in North

Table 4
Example of the TestEuclid procedure for the socketed axe from Uppland UMF 6005 (T:47). This is just a top part of a table that has over 6000 entries for published lead isotope ratios of lead and copper ores from all of Europe, Near and Middle East and north Africa. The ores listed here are the ones with the closest Euclidean distance from the ratios for the Swedish axe. The ore from Ai Bunar can be disregarded as a source of the Swedish bronze, because there is no evidence for copper smelting of the ores from this mine (Gale et al., 2003).

Normalised Euclidean distance	Artefact LI ratios	2.07896	0.84359	18.464	^{208}Pb/^{206}Pb	^{207}Pb/^{206}Pb	^{206}Pb/^{204}Pb
	Ore sample No.	Country	Mine	Mineral			
0.7414	CY.75.98A	Cyprus	Alestos	Pyrite	2.07930	0.84318	18.454
0.8488	MCY 8	Cyprus	Skouriotissa	Rich sulphidic ore	2.07910	0.84420	18.472
0.8769	AB2/2	Bulgaria	Ai Bunar	Malachite	2.07965	0.84360	18.479
0.9888	Mem6	Cyprus	Memi	Chalcopyri-te	2.08030	0.84341	18.451
0.9988	Memi2	Cyprus	Memi	Chalcopyri-te	2.07970	0.84281	18.467
1.0693	CY578	Cyprus	Skouriotissa	Low grade ore	2.07817	0.84299	18.477
1.1772	USGS (DOE 1)	Cyprus	Skouriotissa	Pyrite	2.07864	0.84277	18.476

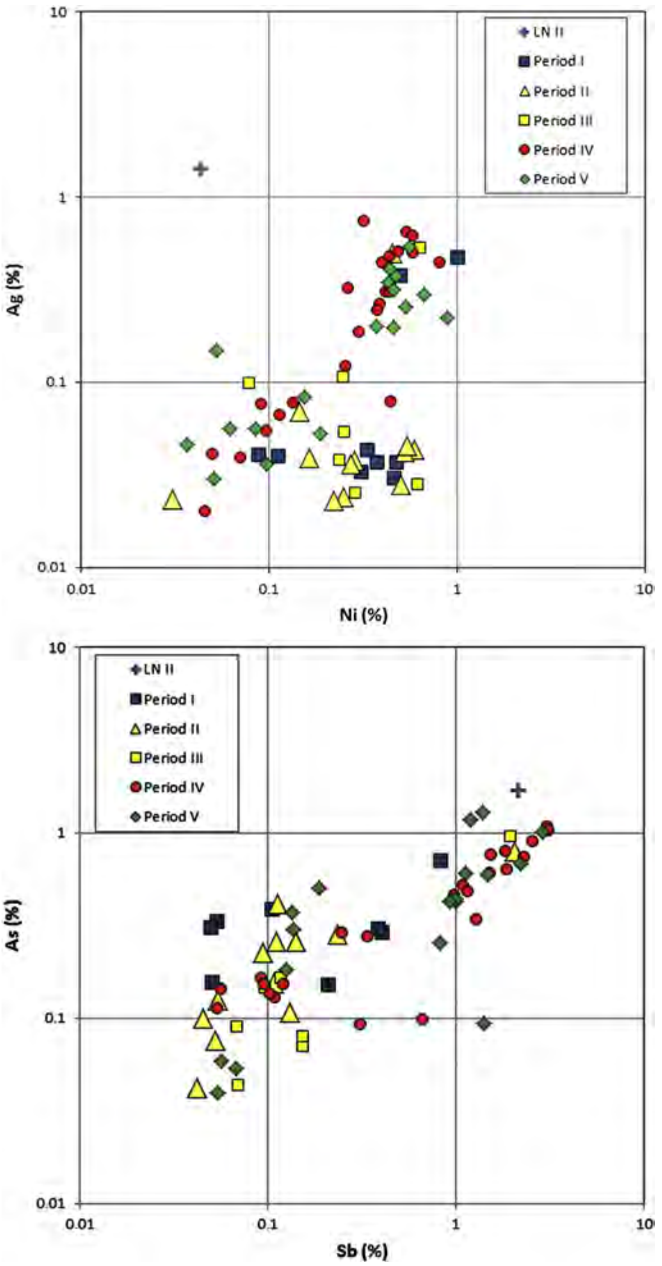


Fig. 11. Graphical presentation of nickel content vs. silver content, and antimony vs. arsenic in all analysed copper and bronze artefacts from the defined chronological periods.

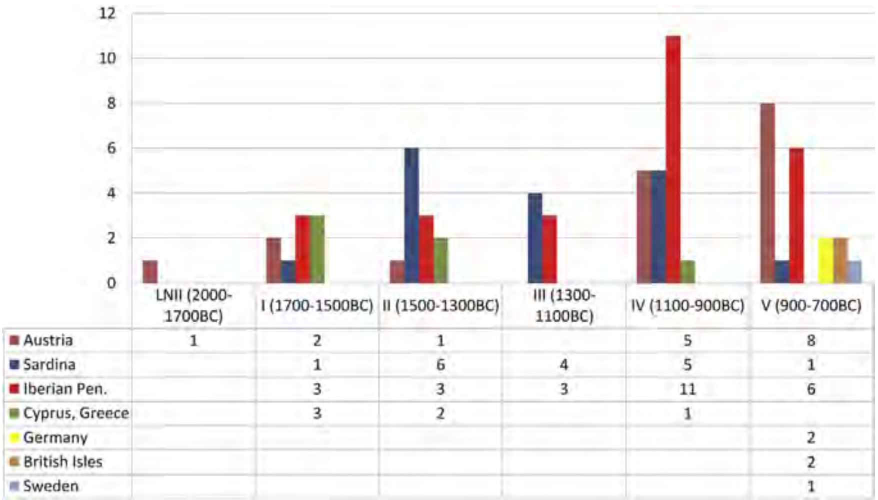
West Spain (El Aramo, La Profunda and El Milagro). Given that one of the copper ores from the El Aramo mine has the same lead isotope composition as the shaft-hole axe T1:2 and in view of the strong evidence of exploitation of this mine in the 2nd millennium BC we accept that the copper for this axe most likely originated from north-west Spain. The other two mentioned axes show similar levels of tin as well as trace element signatures (moderate Ni and As) to the shaft-hole axe T1:2 but their origin is less conclusive. It can be noted that the lead isotope ratios of the flanged axe T1:3 lie on the mixing line of the compositions of two copper ores from the Ballyrisode mine in the Mizen Peninsula (Ireland). However, the presence of nickel is not consistent with the Mizen Peninsula. Neither are the chemical compositions of these axes consistent with Tyrolian fahlores, even if the lead isotope ratios of T1:3 and T1:5 could be placed on the mixing lines of some of them. Another observation is that the lead isotope compositions of these two axes lie on the mixing lines of copper ores from the Portuguese part of the Ossa Morena Zone, and we conclude that radiogenic *period I* axes have a close compositional and isotopical consistency with the copper ores from the western and north-western part of the Iberian Peninsula.

Some artefacts from *period II:* lance head (T1:12), palstave (T1:22) and possibly metal from a crucible (T1:13), isotopically match ores from south–east Spain. Three artefacts from *period III*: flange-hilted sword (T1:24), tanged sword (T1:29) and the copper rod (T1:28) are also consistent with the origin from ores of south–east Spain. These artefacts from *periods II and III* have very similar elemental patterns with nickel as the only significant trace element. Other elements are generally below 0.2%, although the copper rod has higher contents of Ni, As, Sb and Ag. Isotopically, the latter is consistent with the ores from Ossa Morena in the SW and from Los Pedroches in SE Spain, but the geochemistry does not provide means for excluding either of them.

A number of *periods IV* and *V* artefacts from the hoard in Grava are also consistent isotopically with the ores from south and south-east Spain and Bronze Age copper-based artefacts from Spanish sites (Fig. 14). This is exemplified by the hilt-plated sword (T1:48) and the arm ring (T1:49) which have similar lead isotope and trace element compositions with c. 0.2% each of As, Sb and Ni. Another example is the fragment of a bronze lure (T1:66) with low impurity content.

The bronzes from the scrap hoard in Järn, from *period IV*, described in our previous paper (Ling et al., 2013) comprise material from bronze casting processes, as well as weapons, socketed axes, jewellery and tools. All analysed nine metals are bronzes with tin content of 3–7% and lead content below 0.3%. Typically, there are elevated, but variable, contents of Sb, As, Ni and Ag although their concentration ratios are similar. The lead isotope compositions of all samples form a very tight group plotting in the region of the ores from Sardinia and Spain (Fig. 15). Actually, the isotopic and geochemical similarities are so striking that either they all are likely to be made of ores from the same deposit, or they result from casting of a batch of metal of common origin. Alternatively these analysed pieces of bronze are made of already recycled and therefore chemically 'homogenised' bronze. Nevertheless, the resulting lead isotope compositions indicate that the original copper ore was geologically old copper ore (>300Ma), so even if it was a mixture of metals of different origin, they all must have been that old to retain high ^{208}Pb/^{206}Pb and ^{207}Pb/^{206}Pb ratios. Although Sardinian copper deposits match these artefacts from an isotopic point of view, the high antimony content has not been found in Sardinian ores. The ores from the Welsh mines that are consistent with these particular lead isotope ratios are not listed as prehistoric in Rohl and Needham (1998), and are mostly lead mines. However, in north-east Spain, in the region of Catalonia, there are Cu/Sb/Ag/As deposits with many ancient galleries (Martin Colliga et al., 1999) and bronze finds from the caves north-west of Girona containing 0.6–12% of tin and 1–6.8% of antimony are also known (Rovira Llorens et al., 1997). At present there are no lead isotope data published for these copper ores, but the galenas from other ores in Catalonia have lead isotope ratios identical to those from the Järn hoard (Renzi et al., 2009). We can say that these metals were derived from copper mineralisations older than 300 Ma containing high antimony, silver and nickel. At present we indicate the possible origin of these artefacts is east Spain, but more lead isotope and elemental analyses of ores are needed from the deposits located in the Girona province, and in the Pyrenees and western part of Massif Central (Carabrières).

Among the artefacts from the workshop in Botkyrka, dated to *period V*, a bronze rod (T1:58) could be made from copper occurring



	LNII (2000-1700BC)	I (1700-1500BC)	II (1500-1300BC)	III (1300-1100BC)	IV (1100-900BC)	V (900-700BC)
■ Austria	1	2	1		5	8
■ Sardina		1	6	4	5	1
■ Iberian Pen.		3	3	3	11	6
■ Cyprus, Greece		3	2		1	
■ Germany						2
■ British Isles						2
■ Sweden						1

Fig. 12. Summary of the interpretation of the lead isotope and chemical analyses of Swedish Bronze Age metals. The results show that their three main sources were the copper ore deposits of north Tyrol, Sardinia and Spain.

in the south Spain. Artefacts from *period V* also include two U-notched shields (T1:69,70) and a bronze rod (T1:64). These three are similar in their trace element signature, especially by their presence of cobalt (nearly 0.2%), antimony in the same order of magnitude and somewhat higher arsenic. They all have lead isotope compositions consistent with copper ores from southern Spain. The same isotope composition is found in a socketed axe (T1:68), however, with dissimilar trace element pattern, with higher levels of As, Sb, Ni and Ag.

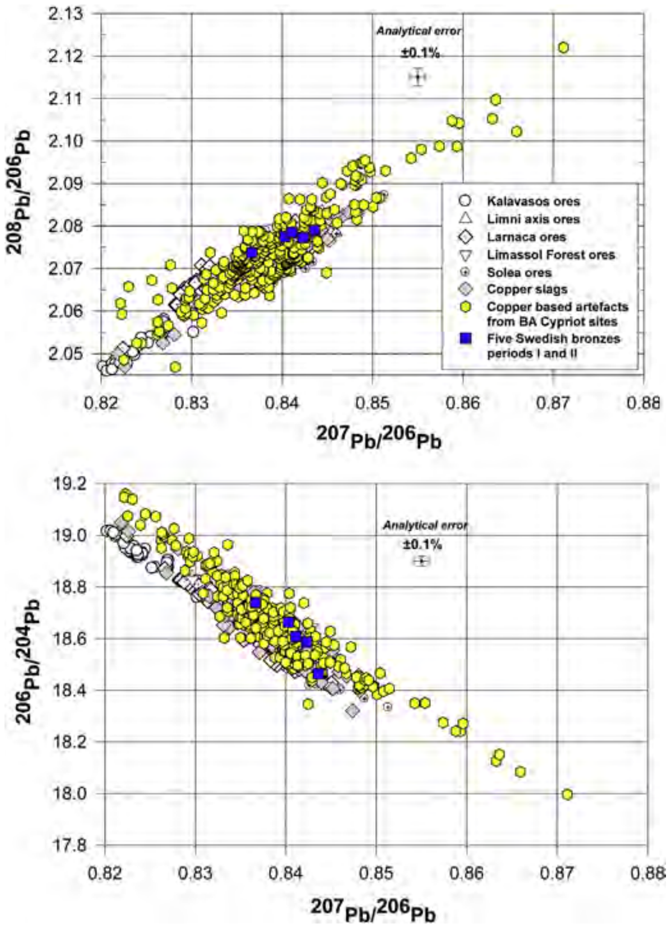


Fig. 13. Lead isotope ratios of five bronzes from Sweden compared with the copper ores from Cyprus and Bronze Age Cypriot copper based artefacts. Not all Bronze Age metals found on Cyprus are made of Cypriot copper: some of them are made of metal from the Taurus Mountains in south Turkey, and some of copper brought from the Western Mediterranean (Stos-Gale and Gale, 2010).

Finally, it is also noteworthy that there is an isotopic correlation between the Swedish bronzes and Spanish a well as Sardinian copper-based artefacts (Fig. 14). The correlation between Swedish bronzes and Sardinia is further discussed below.

6.2.3. Sardinia

The oldest artefact that has lead isotope composition fully consistent with the copper ores from the Sardinian mine of Calabona is a sword pommel (T1:6) from *period I*, with Sb, As, and Ni contents in the range of 0.3–0.4%. A knife (T1:19), from *period II*, is isotopically consistent with Sardinian ores from the Funtana Raminosa copper mine. However, its elevated concentrations of As, Sb, Ni and Ag seem not usual for copper from this mine. A large group of artefacts from *periods II* and *III* are very similar in terms of both isotope ratios and elemental signatures. Among these are eight samples from *period II*; a hilt-plate dagger (T1:21), metal from crucibles (T1:14,15), flange-hilted sword (T1:16) which have lead isotope ratios consistent with Sardinian copper ores, although one palstave (T1:17) also is consistent with ores from the lead mine in Alston, Cumbria (north England), and a few others, namely the lance head (T1:12), the metal from a crucible (T1:13) and a palstave (T1:22) also match isotopically ores from south–east Spain. However, these metals are also quite homogeneous in terms of trace element patterns (0.2–0.5% Ni and a narrow range of As concentrations up to 0.2%) which are matching the elemental compositions of the Sardinian copper ores. Very similar elemental compositions are also found in three artefacts from *period III* (hilt-plate sword T1:23, socketed axe T1:26 and sprue T1:27) which also are consistent with the lead isotope compositions of the Sardinian copper ores. The isotope ratios of the sprue are also consistent with the fahlores from North Tyrol, but the low concentrations of minor elements are not typical for the ores from North Tyrol. Another sword from *period III*, the flange-hilted sword T1:25, which is low in impurities, also has lead isotope ratios that are fully consistent with the ores from Sardinia, but also from south Spain.

Similar low contents of trace elements are found in four socketed axes from *period IV* (T1:44,51,30,40). The first three of these have identical lead isotope ratios that are also consistent with the

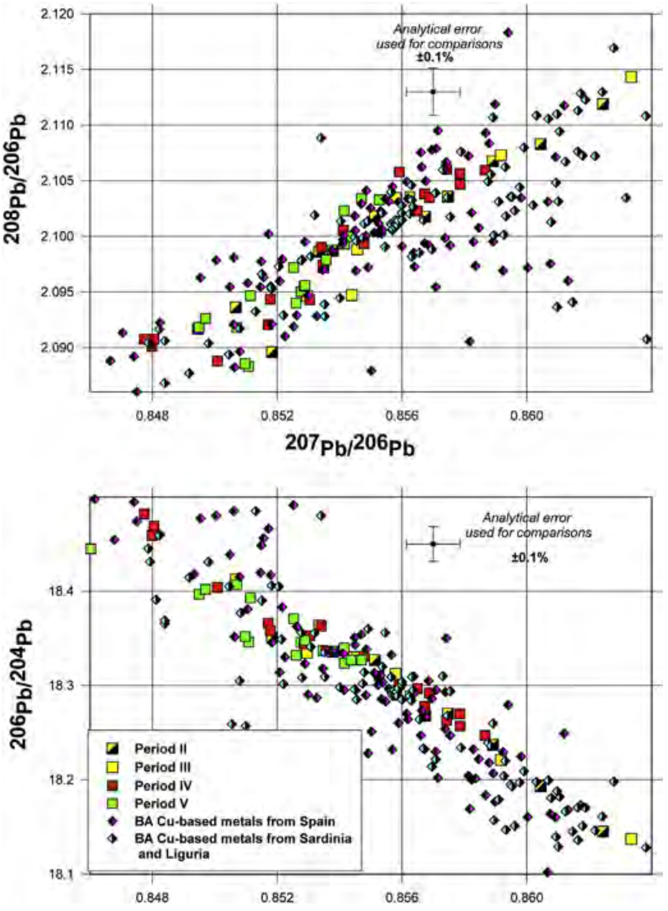


Fig. 14. Comparison of the lead isotope ratios of the main group of the Swedish metals with the Bronze Age artefacts from Sardinia and Spain. While it is not expected that all copper-based metals found on the Sardinian or Spanish sites are made from the local ores, it is remarkable how many of them are identical with the main group of the Swedish metals.

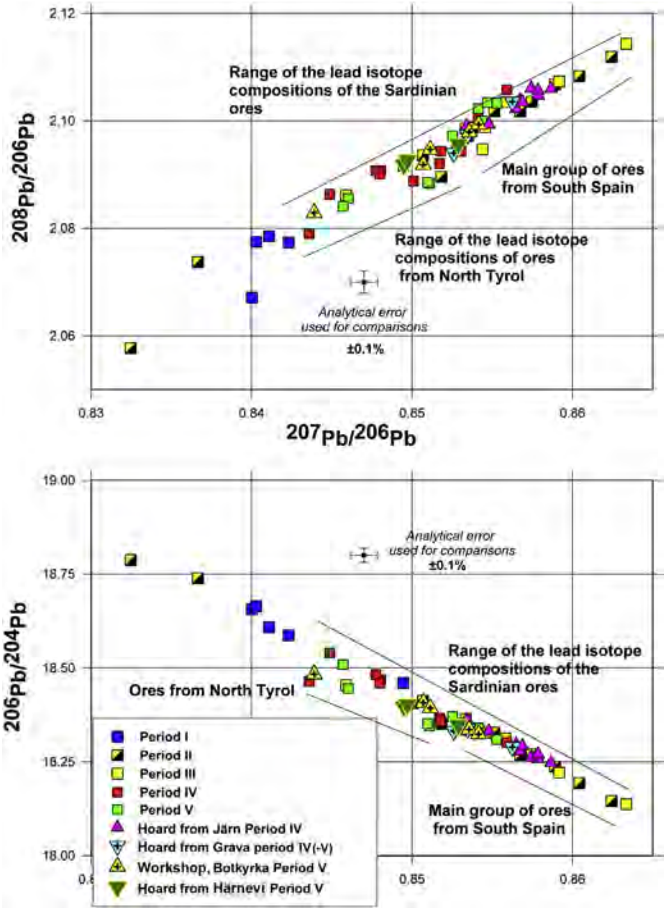


Fig. 15. Lead isotope compositions of artefacts from hoards and a workshop site compared with the other analysed artefacts and approximate range of lead isotope ratios for ore deposits that are consistent with their origin. The lead isotope ratios of the metals from hoards form on the whole compact groups, which might indicate that they are made of recycled, homogenised, metal. However, their lead isotope ratios indicate that in periods IV and V the metal from Spain and Sardinia was predominant.

copper ores from the Montagne Noire in south-west France. If the exploitation of ores from the Massif Central in this period cannot be accepted, then the metal of these three axes could have originated from the Sardinian ores at Calabona. The fourth axe (T1:40) has lead isotope composition identical with copper ores from Sardinia. Tweezers (T1:43) from the same period, enriched in nickel, are isotopically consistent with the ores from Schwaz-Brixlegg, but also within 2 Euclidean distances from Sardinian ores of Monte Sissini. The elemental composition of this metal resembles the Sardinian copper.

Finally, one artefact from *period V*, a melt (T1:55) from the workshop in Botkyrka, free from impurities, is consistent with the ores either from Sardinia or south Spain.

6.2.4. *British Isles, Cornwall*

Detailed comparisons of the lead isotope and elemental characteristics of metals analysed in this project with the data and information about ancient copper mining (Ixer and Budd, 1998; Ixer and Pattrick, 2009; Rohl and Needham, 1998) did not reveal much evidence of the use in Sweden of copper from the British Isles. However, amongst the artefacts from *period V* site of Vårdinge there is a very unusual find of pure tin ring-shaped rod (T1:60) that is fully consistent with the lead isotope compositions of ores from Cornwall, and a copper melt (T1:71), nearly free of impurities, that also could be from Cornwall, if copper was smelted then in Cornwall.

6.2.5. *Cyprus*

Three bronzes from *period I* (in particular 1600–1500 cal. BC): a flanged axe (T1:9) and two shaft-hole axes (T1:7,10) are fully consistent isotopically with the copper ores from Cyprus (Fig. 13). The shaft-hole axe T1:10 has a content of As, Sb and Ni that is a little higher than usually found in Cypriot copper. The other two axes are made of relatively impurity free copper. From *period II*, a hilt-plate dagger (T1:20) has lead isotope composition fully consistent with the ores from Cyprus, and its trace element signature is similar to the shaft-hole axe T1:10. Finally, a socketed axe (T1:47) dated to *period IV*, very low in impurities, is fully consistent with the lead isotope compositions of the ores in the large Cypriot copper mine of Skouriotissa.

6.2.6. *Greece*

The analysed palstave from Öckerö (T:11), dated to *period II*, is a rather spectacular example of a type common in the British Isles (Butler, 1963). However its lead isotope and chemical compositions, free of impurities, are fully consistent with the copper ores from Lavrion in Attica.

6.2.7. *Other districts and connections*

Contrary to objects from the *period IV* scrap hoard at Järn, the samples from the *period V* workshop site in Botkyrka in Södermanland present very wide range of lead isotope and elemental compositions and the origin of copper is less obvious. In this group there is also a piece of slag (T:59; mentioned earlier), rich in iron silicates and with inclusions of complex sulphides, closely resembling matte containing copper, iron and zinc. Its lead isotope composition is consistent with the Swedish Bergslagen ores. From the same workshop site in Botkyrka, a melt (T:54) has over 2% of lead, no tin, but high zinc (2%), nearly 3% of antimony and also percentages of iron, sulphur and arsenic. This is not bronze, but copper smelted from ores with high impurities. Interestingly this lead isotope ratios seem consistent with ores from Germany: the closest match is with galena from Wolfach, Grube Klara in Schwarzwald (OXALID).

Finally, a rod (T:53) has a lead isotope composition quite different to all other objects from *period V*. Its chemical composition indicates that the metal was smelted from copper ores that contained As, Sb, Ni and Ag-bearing minerals. The lead isotope ratios of this rod are fully consistent with the ores from Siegerland in northwest German Rhine-Westphalia region (Bode, 2008; Durali-Mueller et al., 2007). It is believed that in the Siegerland district mining goes back to Celtic times. The chemistry of the copper ores from this region (high Sb and As in the copper) needs to be investigated further before accepting the origin of this artefact from north-western Germany. Alternatively it would be possible to accept that this object was made from melting together metals originating, for example, from the Alpine regions and from Spain or Sardinia.

The metal from the Western Mediterranean might have been used also in other parts of Northern Europe. For example, swords dated to 1500–1100 cal. BC from north Germany (Bunnefeld and Schwenzer, 2011) and the British Isles (Rohl and Needham, 1998) are also consistent with the origin from Spanish and Sardinian ores in terms of lead isotopes (Fig. 16). Furthermore, the elemental signatures (Fig. 17) of the Swedish bonze swords, and a majority of the artefacts from *periods II and III*, are similar to those of the contemporary swords from Germany as wells the British Isles (Bunnefeld and Schwenzer, 2011; Rohl and Needham, 1998).

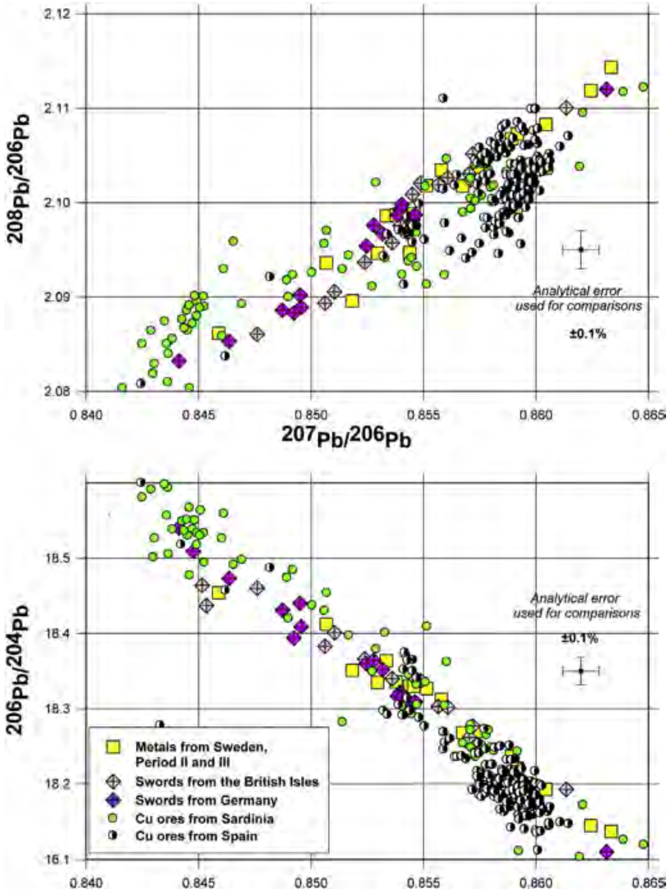


Fig. 16. Lead isotope compositions of Swedish bronze swords from *periods II and III* and contemporary swords from Germany and the British Isles (Rohl and Needham, 1998) and copper ores from Sardinia and Spain.

7. Implications of the inferred sources for metals in Swedish bronze artefacts

Accumulated data from Swedish bronze artefacts reinforce the view that all metals used in casting were imported (Figs. 12–16, Table 3). However, the presence of the copper slag from Botkyrka (T1:59) provides possible evidence of an attempt at smelting of the local ores in LBA, although such an attempt is not reflected in any of the analysed casting debris from the same site, or from any other BA site in Sweden. It is important to stress that the Swedish sulphide ores are highly complex mineralisations containing both copper and iron. These ores are difficult to reduce and at least four consecutive steps of roasting and smelting are required to reduce the sulphides to metal. This technologically complex procedure might have prevented a local extraction of copper during Bronze Age. Thus, the overall evidence of metallurgical activities in Sweden from the Bronze Age supports the assumption that at least some artefacts were produced locally using pure copper and tin respectively, as indicated by the presence of copper droplets in crucibles, some copper rods and the pure tin rod. This feature, in combination with the continuous flow of metal, very low levels of lead in the artefacts and their minor element and lead isotope compositions, seems quite indicative that the Swedish artefacts were not derived from a European 'pool' of re-used bronze, but from primary metals.

The presented interpretations of chemical and lead isotope analyses of Swedish metals dated to the Nordic Bronze Age are surprising and bring some information not known from previous work. Apart from a steady supply of copper from the Alpine ores in the North Tyrol (17), the main sources of copper are ores from the Iberian Peninsula (22) and Sardinia (18) (Figs. 12 and 18). Even more unexpected seems the identification of five objects made of Cypriot copper and one – a typical British palstave – of the copper from Lavrion in Greece. Equally interesting is that the obtained metal signatures clearly disfavour closer ore districts such as Scandinavia, Harz or Erzgebirge in Germany. This regards also regions that provide Scandinavia with artefacts during certain periods in the Bronze Age as for the Carpathian basin and Switzerland (Thrane, 1975; Vandkilde, 1996). On the other hand our material do also match copper and tin signatures with regions, like Austria, British Isles (1) and southern Germany (2), that traditionally have been argued as potential sources for Scandinavian metal (Figs. 12 and 18).

The interpretation of the lead isotope and chemical 'fingerprints' of the analysed artefacts adds essential information to the picture of the ore bearing regions that supplied metal to Scandinavia in the Bronze Age. Generally speaking, artefacts dated to EBA (2000–1500 cal. BC) correlate to copper ores in the North Tyrol (2), Cyprus (3) and the west Mediterranean world (4), while most of the artefacts from the MBA (1500–1100 cal. BC) tie up neatly with copper ores in Sardinia (10) and south-Iberia (6). Most artefacts from the LBA (1100–700 cal. BC) correlate with ores in south Iberia and in North Tyrol. A tin ingot matches with Cornwall and two items with southern Germany (Figs. 12 and 18).

From these results emerges a new complex picture of possible connections between Scandinavia and Europe in the Bronze Age that warrant further attention. The Baltic amber is of special interest here. In fact the Baltic amber constitutes the most concrete evidence of a Scandinavian "commodity" that was traded

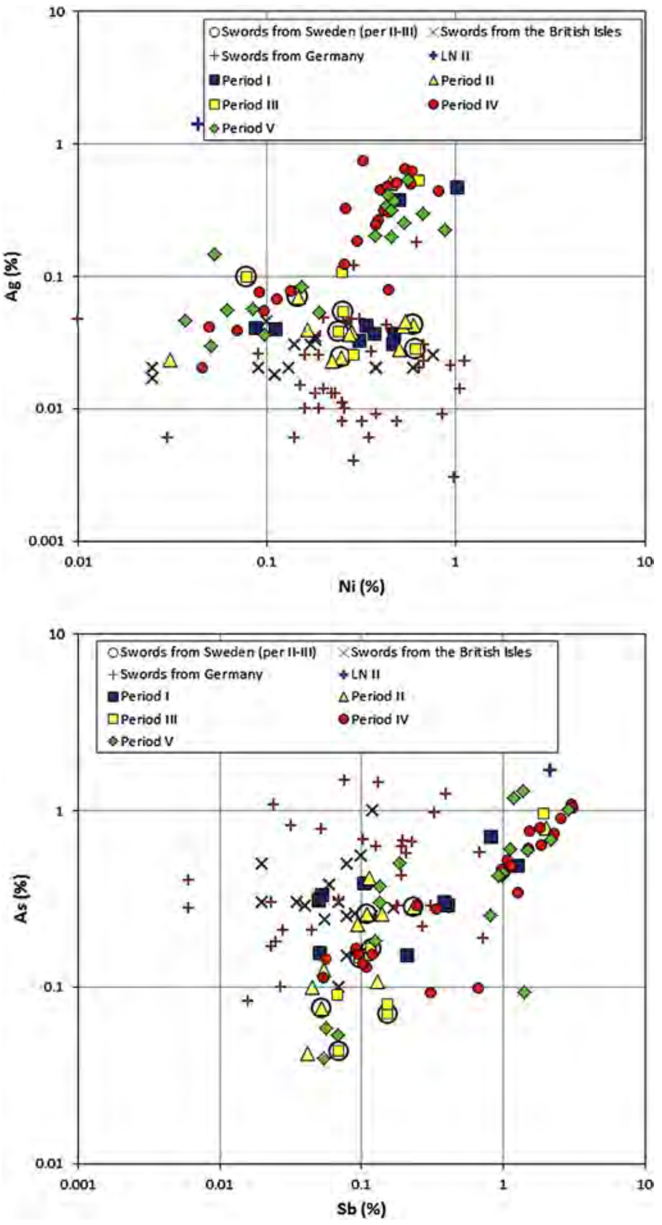


Fig. 17. Comparison of the trace element composition of Swedish bronze swords from periods II and III and contemporary swords from Germany (Bunnefeld and Schwenzer, 2011) and the British Isles (Rohl and Needham, 1998). The majority of the Swedish metals from periods II and III, including the swords, present a variation in trace elements mainly within the compositional variation in the German and British swords. Background data as in Fig. 11.

southwards for copper (Kristiansen, 1998; Montelius, 1888). This is indicated by the findings of Baltic amber (Fig. 19), roughly in the same ore-bearing districts that show consistency with isotopes for Scandinavian artefacts (Beck and Shennan, 1991; Harding, 1984; Murillo-Barosso and Martinón-Torres, 2012).

7.1. *Swords, shields and amber routes*

When discussing the Baltic amber, the Scandinavia-Central Europe connection is of great importance, but also the link between Scandinavia and the late Wessex culture and its ties to the east Mediterranean world, so evident by the amber spacer-plates and other artefacts (c.p Eogan, 1990; Harding, 1984; Kristiansen and Larsson, 2005). It is notable that the main episodes for the traffic of amber to the Aegean world 1600, 1500 and 1200 cal. BC correspond well with the dating of some of the Scandinavian BA artefacts that in turn match the ores in Cyprus (Harding, 1990, 1984).

Regarding the Tyrolean copper in the Swedish artefacts it was probably transmitted to the north via the central European “amber routes” to Scandinavia (Navarro, 1925; Thrane, 1975). Thus, the analyses confirm earlier hypotheses that Austria provided metal to Scandinavia during EBA (3) and LBA (13), however, surprisingly not so much during the MBA (c.p Kristiansen, 1998). During the MBA, the west Mediterranean ores in Sardinia (10) and Spain (6) dominated. Interesting enough, all flange hilted swords and most of the hilt-plate swords and daggers from the MBA correspond to the copper ores from Sardinia or south Spain.

In addition to the importance of Austrian ores during the LBA, also Nuragic copper played a role, for example, most of the socketed axes from period IV can be correlated with the copper ores in this region. However, Spain (15) seems to have been the outermost dominant supplier of copper to Sweden during the LBA and this is in accordance with the evidence of mining in the region (Hunt-Ortiz, 2003). Perhaps the most intriguing correlation is the one between the two Swedish U-notched Herzsprung shields dated to about 1100–800 cal. BC (Uckelmann, 2011) and ores in the Ossa Morena district. In fact, there are about 70 stelae, dated to 1100–800 cal. BC, with depictions of mostly V-notched Herzsprung shields and horned warriors (Fig. 20) (Harrison, 2004), and in addition findings of Baltic amber at LBA sites in the same region (Murillo-Barosso and Martinón-Torres, 2012).

7.2. *Two major systems of metal flow in the Bronze Age*

In the light of the presented observations, and that the inferred source areas for metals are widely apart, we will argue for the possibility of two major systems of metal flow from Europe to Sweden in the Bronze Age (Fig. 21); one Atlantic (maritime) and one via Central and south east Europe (amber routes, overland/riverine). Related to this, is the existence of the continental amber routes which are well documented (Du Gardin, 2003; Kristiansen, 1998).

The western ‘maritime route’ could have been established already in the Neolithic by ‘Beaker’ groups (cf. Cunliffe, 2008; Harrison, 1980; Kristiansen, 1998; Pilar, 2008). Thus, the metal from the west Mediterranean World could either have been channelled via the route “south France–Garrone axis-Brittany-the British Isles and Scandinavia” or via the Atlantic communities northwards. In any case, the British Isles would have had a very strategic position in this north–south network and the strong connections between British Isles and the west Mediterranean World in the Bronze Age is therefore of greatest importance (Bradley, 1997; Eogan, 1995; Harding, 1990; Harrison, 2004). An important observation in the context of the connections between British Isles and Scandinavia is the consistency of the lead isotope composition of the tin ingot from Vårdinge in Sweden (T1:60) with the ores from Cornwall. Actually, the availability of tin might be the reason why several copper producing areas directed their ‘copper routes’ to pass the British Isles during the Bronze Age. Probably, “traders” were in many cases not searching separately for tin and copper, but were receiving the two metals from nearby ports, stressing the possibility that ports in the British Isles acted as transit centres for copper from other parts of Europe as well as providing local tin ore.

This theory is further supported by the evidence from Cliffs End (Bradley, 2013). Additional support to this hypothesis is given by the fact that typical Nordic swords and artefacts from the MBA (1500–1300 cal. BC) share isotopic signatures with British swords

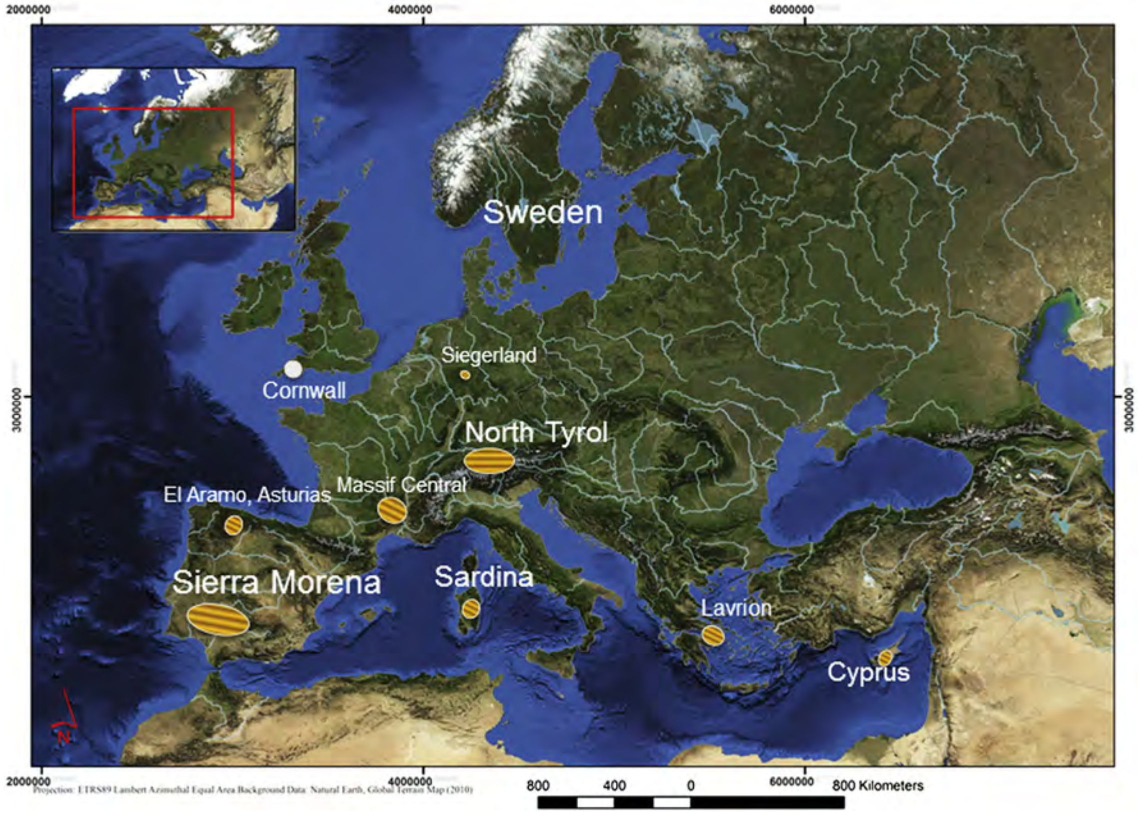


Fig. 18. The map denotes the different ore districts in Europe that the analysed artefacts show consistency with. Most of these districts have evidence of Bronze Age mining.

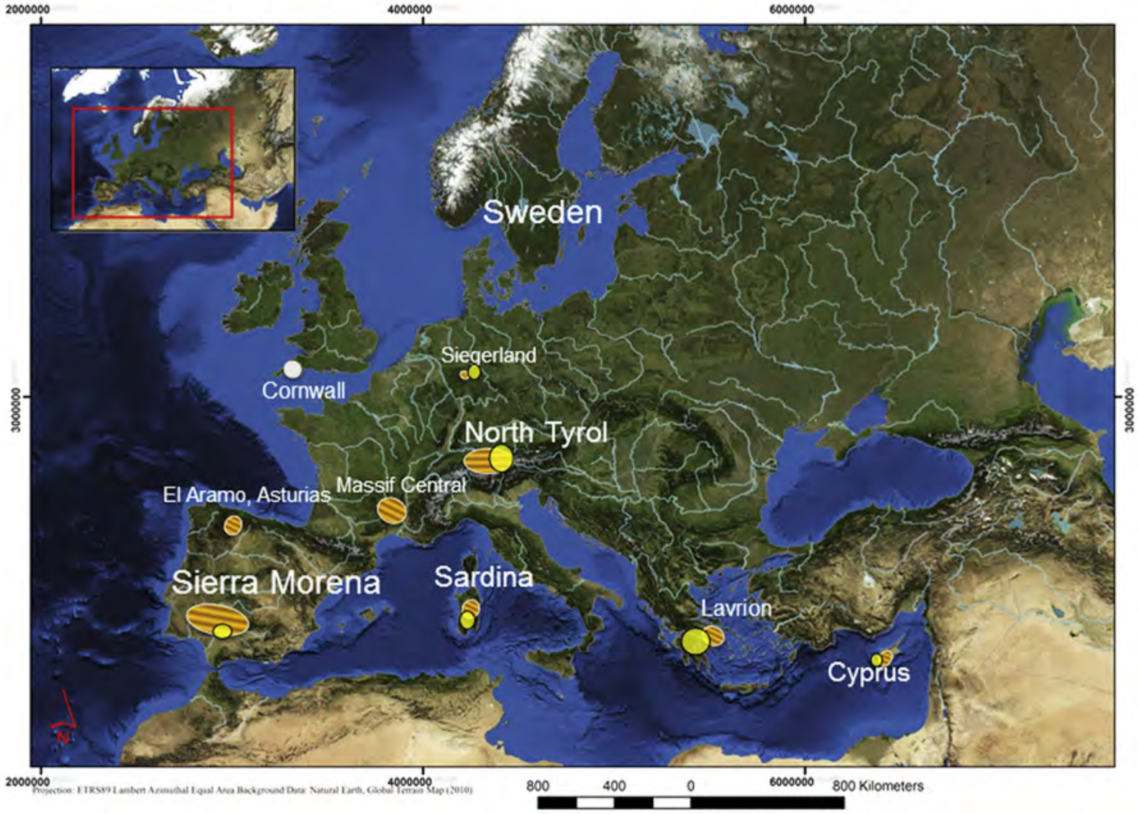


Fig. 19. The findings of Baltic amber, roughly in the same ore-bearing districts that shows consistency with isotopes for Scandinavian artefacts. Circles = amber find made close to the ore-bearing regions with isotopes that correspond with Scandinavian artefacts. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 20. Different features connecting Iberia with Scandinavia during the Bronze Age. Top left; Rock art from southwest Spain and southeast Portugal, dated to 1100–800 cal. BC, marked with c, Top right; Rock art from Bohuslän, Sweden dated to 900–700 cal. BC. Middle, left; the ore bearing district of Ossa Morena, located in southwest Spain and southeast Portugal. Middle, right; a tanged sword and a Herzsprungshield that matches the Cu ores in the Ossa Morena district. Bottom, left; Map of the distribution of rock art in southwest Spain and southeast Portugal (after Harrison, 2004) Bottom, right; Stelae with rock art with Herzsprungshield, warrior and a chariot. In the middle; chariot from Frännarp, Sweden. Bottom right; baltic amber.

from this period that in turn isotopically correspond to the west Mediterranean World (Figs. 16 and 21).

The other major system of metal flow followed, in general, the so called amber routes, channelled through either central or southeast European networks (Figs. 19 and 21). Although Cypriot copper may have arrived to Scandinavia via Sardinia, where Cypriot oxhide ingots are found (Hauptmann, 2009; Lo Schiavo et al., 2005; Stos-Gale et al., 2005), copper from Cyprus could also have been channelled through the east European system via the Carpathian basin and northwards, indicated by the imported artefacts from the Carpathian basin to Scandinavia during EBA and LBA (Kristiansen, 1998; Thrane, 1975; Vandkilde, 1996). Moreover, some of the copper from the North Tyrol may also have passed through this system (Niederschlag et al., 2003). However, most of the copper from the North Tyrol to Scandinavia probably went via the central European "amber routes", established by the North Alpine Danubian/Unitice networks and maintained by the Tumulus and Urnfield systems (Kristiansen and Larsson, 2005; Thrane, 1975; Vandkilde, 2007). It is also logical to assume that part of the copper from the west Mediterranean World during the MBA went through a central European overland/riverine system, in particular ore from Sardinia given its quite distant position from the Atlantic.

7.3. Coda: forms, content and flows; amber and metal

A new complex picture of possible connectivities and flows between Scandinavia and Europe in the Bronze Age emerges from the results presented here (Figs. 12, 18 and 21). This picture has to be considered not the least in terms of ideas of alliances and networks. One of the major reasons for the blooming Bronze Age tradition in Southern Scandinavia, must have been the natural occurrence of amber in this region (Kristiansen, 1998). Besides, this region also had a very favourable maritime position in Northern Europe and could thereby have controlled the distribution of metal into Scandinavia by monitoring the traffic both from the North Sea and from the Baltic Sea. Obviously, the abundant rock art from this period in Sweden illustrates that the Bronze Age communities in Sweden were highly dependent on maritime networks and trade.

It is important to recall that the Central European networks were the ones that delivered most of the finished artefacts to Scandinavia throughout the Bronze Age (Kristiansen, 1998; Thrane, 1975) but, in terms of abundance, Nordic forms dominate from about 1700 BC and onwards. This situation, together with evidence from the existence of local workshops, strongly indicates that most of the metal provided as raw material/ingots was cast into "Nordic"

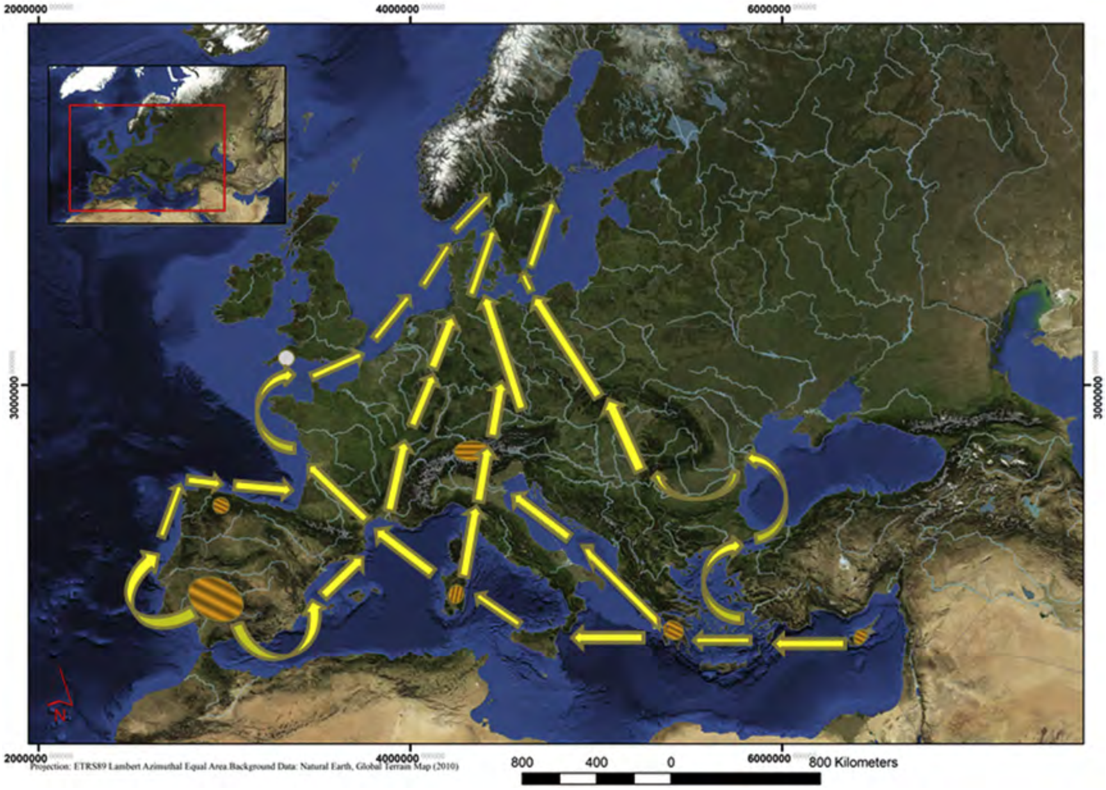


Fig. 21. A hypothetical view of possible flows and routes of metal from the mining district in Europe to Scandinavia in the Bronze Age. It is partly based on existing theories of interaction between the north and south in the Bronze Age (e.g. Cunliffe, 2008; Harrison, 2004; Harding, 1990; Kristiansen and Larsson, 2005).

regional forms. Could this indicate that the Atlantic network foremost provided Scandinavia with ingots of bronze, copper and tin whilst the Central European systems delivered both finished artefacts and ingots of metals?

Apparently, the results presented here raise new questions and this should stimulate further research and discussion. In this respect, we believe that studies combining not just an investigation of the forms but also the content, i.e. the raw material, are useful for deriving a more complete picture of the flow of metal to Scandinavia in the Bronze Age.

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