Analysis of copper-alloy artefacts from the Viking Age

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Viking Age copper-alloy artefacts from Uppland (south central Sweden) were analysed by SEM/EDX to concretise differences in metal composition. Artefacts were selected from two settlements (Birka and Rasbo), and four cemeteries: Birka, Lovö, Norrsunda/Valsta, and Sollentuna/Häggvik, all within a limited area and with social and economic contacts with the world around. The analyses of the Viking Age finds reveal large variations in metal composition, and large differences compared with Bronze Age artefacts. Few objects were made of "conventional" bronze with 5–10% tin. Instead, tin was often replaced by metals such as zinc, lead, and iron. We attribute this significant change to gradual innovations in mining and metallurgy on the continent. Artefacts of almost pure copper were also found. Seventeen gilded oval brooches from Birka graves form a homogenous group with respect to type, dating, and a high copper content. The artefacts' preservation was also examined in order to find possible connections to the composition of alloys. The most corroded finds were those from Birka, with corrosion of metal oxides, carbonates, chlorides and sulphates, an effect of polluted soil. No particular alloy could be singled out as being particularly corrosive.

Keywords: Viking Age, Uppland, Birka, SEM/EDX analyses, bronze, brass

Introduction

The aim of this study was to characterise metal compositions in archaeological Viking Age artefacts, and to search for any differences between the selected sites (Fig. 1). These were all situated in a well-populated area in Uppland, south central Sweden, with similar technological knowledge and with social, political and economic contacts with the world around. It was also important that they might provide useful material for the study. Accordingly, the sites selected were Birka (Adelsö/Björkö), Rasbo (RAÄ 630:1), Lovö (RAÄ 34, 28), Valsta in Norrsunda (RAÄ 59), and Häggvik in Sollentuna (RAÄ 291, 293). Rasbo is situated about 10 km northeast of Uppsala, the other sites lie in south Uppland, in the neighbourhood of Stockholm. Birka and also to some extent Rasbo were trade centres, whereas the cemeteries on Lovö, Valsta and Häggvik belonged to larger farmsteads. Both those living at Birka at that time and people visiting the place were buried outside the Birka trading centre. An underlying assumption in this study is that workshops for making basic tools, weapons and ornaments existed at all the selected sites, thus also at the farmsteads, here represented by their cemeteries. This is in line with results of metal production, from larger Bronze Age settlements and onwards, in Scandinavia.

Native copper, although very scarce, was among the first metals used by man. As early as 5000 BC, copper was extracted from malachite by charcoal reduction at about 500°C (e.g. Rudna Glava in present Serbia, Asia Minor, Egypt). With time, the more intractable copper sulphide ores could be handled and smelted in a two-step procedure. The higher temperature required,

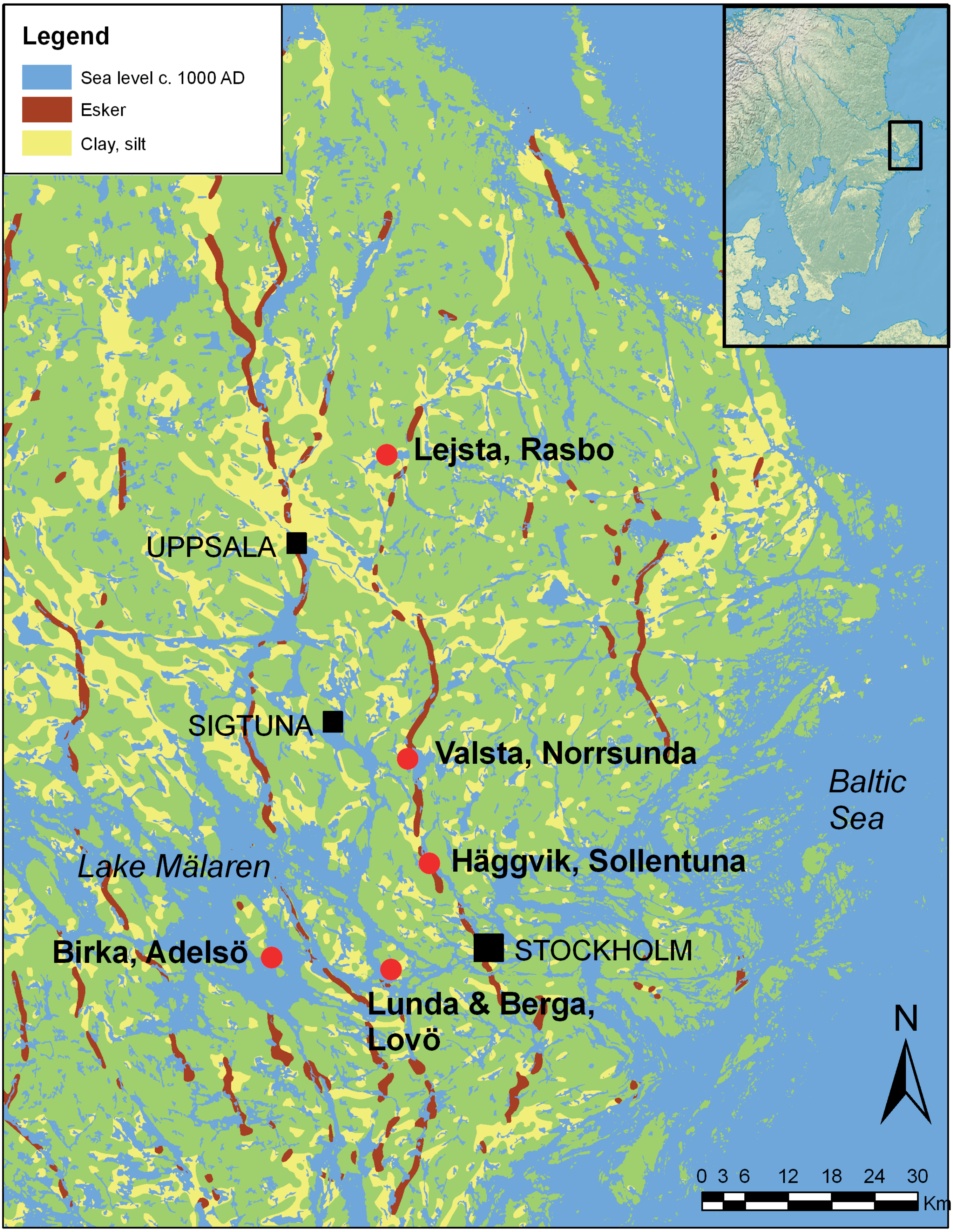

Figure 1. Map of sites mentioned in the text, prepared by Thomas Eriksson. Map based on Geological terrain information from Lantmäteriet (©Lantmäteriet).

Figure 2. A pair of oval brooches from grave 846 at Birka (cf. Table 1). Photo: Inga Ullén.

around 900°C, was achieved by firing with charcoal and use of bellows. Many copper ores contained arsenic or tin, and a simultaneous charcoal reduction produced a useful alloy, bronze (Tylecote 1979; Shepherd 1993; Trotzig 2014). The chemical structure of pure copper, silver or gold may be described as close-packed layers of equal-sized spheres (i.e. atoms), which can slide in various directions and therefore impair the mechanical properties. The introduction of "disturbing" atoms like arsenic or tin, which prevent the sliding, greatly improves the hardness and the mechanical strength, which was soon appreciated by the ancient workshops producing tools or weapons.

Copper ores were ubiquitous in the mountainous districts of Europe (Wittern 2001; Schwab 2005; O'Brien 2015). On the other hand, the only usable tin ore, cassiterite (tin dioxide), was only found in a few regions such as Cornwall, Erzgebirge, Brittany, NW Iberian peninsula, and SE Anatolia (Wilsdorf 1987; Craddock 1995; Shepherd 1993; Trotzig 2014). Probably for this reason, with time other metals came to be substituted for tin. During the Iron Age, the "bronzes" often became manufactured from copper alloyed with lead or zinc, perhaps from the synchronous smelting of ores containing these metals. Galena (lead sulphide) is ubiquitous in Europe, while zinc ores are less common. Moreover, zinc is a volatile metal, so a simultaneous smelting of copper and zinc ores will produce brass with a reduced zinc content. This alloy is clearly connected with the Roman Empire. Ornaments made of bronze, respectively brass, have sometimes been interpreted to originate from different areas of production within the Roman Empire (Istenič & Šmit 2007). Zinc and brass were also imported to Europe from India.

Since all metals, excepting iron, were imported to Scandinavia prior to the Middle Ages, the metallographic changes and conditions on the European continent, the Mediterranean area, and present Great Britain were naturally reflected in northern Europe. Due to the shortage of metallic materials, habitual recycling of the metals had to be undertaken in the local workshops. The metallographic development in Scandinavia is further evolved in the Discussion section below.

Material and methods

Only from the graves of Birka it was possible to obtain a homogeneous group of objects, viz. 17 oval brooches.

From the other sites the authors had to include different kinds of objects and also fragments and scrap bronzes. All sites are situated in Uppland in south central Sweden. Birka, on the small island of Björkö in the Mälaren Sea, was one of the most important trade centres in Scandinavia from the end of the 8th century to the end of the 10th century. The Birka finds selected for this study originate from two areas: the workshop area in the settlement called "The Black Earth" (17 finds), and graves at the surrounding cemeteries (17 finds). Part of the "Black Earth" was excavated early by Hjalmar Stolpe, but for the present study various artefacts have been selected from a later excavation during 1990–1995 led by Björn Ambrosiani (e.g. Ambrosiani 2013; Ambrosiani & Clarke 1992). The material from the cemeteries constitutes a homogeneous group of oval brooches from the 9th and 10th centuries, excavated during the period 1871–1881 by Hjalmar Stolpe (cf. Arbman 1943). An illustration of a pair of brooches from grave No. 846 in Birka is shown in Fig. 2. Rasbo (Rasbo parish, Lejsta) is situated about 10 km NE of Uppsala. Artefacts were excavated from a workshop area in the settlement, contemporary but much smaller than the Black Earth area. Part of the material, such as scrap metals from the production, had already been analysed at RAÄ-GAL in Uppsala (Grandin 2011).

Artefacts from three Viking Age cemeteries representing larger farmsteads were also included in the study: Lovö (Lovö parish, Lunda and Berga cemeteries), Valsta (Norrsunda parish), and Häggvik (Sollentuna parish). The cemeteries on Lovö included both inhumation and cremation graves, and were excavated by the Department of Archaeology and Classical Studies at Stockholm University (Petré 2010). The finds from the cemeteries at Norrsunda and Sollentuna were found in inhumation graves, excavated by the Swedish National Heritage Board (Andersson 1997, 2003).

All samples were analysed with a scanning electron microscope (LEO 1445VP), equipped with a LINK/Oxford unit for X-ray microanalysis, at the Archaeological Research Laboratory (Stockholm University). Each reported value in the tables (cf. below) is an average of three independent measurements. From some regions (e.g. Rasbo) we were allowed to secure small metallic fragments, in which case the analytical uncertainty was better than ±0.2% (per cent by weight). However, as regards most other artefacts, we were compelled to use fragile fragments covered by soil and corrosion products, which could not always be completely removed. Traces of gilding or soldering implied another complication. It was arduous to find spots clean enough for analysis, and with a propitious position for the SEM/EDX instrumentation. For these samples, the analytical uncertainty is estimated to be only around ±1%.

Analytical results

All results are presented in Tables 1–6. All metal contents are given in per cent by weight (wt%). The values for each object are normalised to give a total of 100%. Some abbreviations are suggested for the Tables to characterize the alloys, in order to facilitate comparisons among objects and sites. A red-coloured metal object with low concentrations of alloy metals, or consisting of pure copper, is henceforward denoted "R". (Please note that this classification is *not* identical to the traditional definition of a "red metal".) An alloy in which tin is the dominating metal next to copper, reminiscent of a typical Bronze Age composition, is denoted "B" ("tin bronze"). With "dominating" metal we mean a metal having at least double the concentration of any other alloying metal. Whenever zinc is the dominating metal, this is classified as a brass, and denoted "Bz". In technical Cu-Zn brass, the zinc content may vary within a large range, 5–45% (Hägg 1963). For the present material, the "Bz" artefacts display zinc content in the region of 7–22%. Compositions which don't fit comfortably into any of these three groups are more problematic to categorise. In technology, a bronze may consist of copper alloyed with widely different chemical elements such as tin, lead, nickel, aluminum, beryllium, arsenic, phosphorus, silicon, etc. (Hägg 1963). For simplicity, we use the abbreviation "B2" for copper alloys other than those classified as "R", "B" or "Bz". Some artefacts in this study contained up to four metals other than copper, with none of them present as a dominating metal constituent. Naturally, this unsophisticated classification has its deficiencies, but may nevertheless be useful for the discussions to follow.

A summary of the four composition groups (R, B, Bz, B2) for the Viking Age finds from different sites are shown in Table 7 and Fig. 3. The data indicate a limited number of "conventional" tin bronzes, but a large proportion of brass or similar alloys. It is of importance for this study to compare objects from various sites, although it must be borne in mind that the limited number of objects (87) hinders reliable conclusions. The three cemeteries representing farmsteads (Lovö, Valsta and Häggvik) display similar results, with brass and brass mixtures as the most common metal composition. This is in great contrast to the ornaments selected from the Birka cemeteries. The oval brooches from the Birka graves have a composition which differs from the Black Earth finds and the other grave finds, since they predominantly consist of copper-rich alloys ("R") (cf. also next section). The results also show that the finds from the workshop area at Birka (the Black Earth) display large variations; e.g. compare the Birka object F76551 with

Table 1. Metal composition in per cent by weight of finds from the settlement area "The Black Earth" at Adelsö parish, Björkö, Birka (SHM 35000 and SHM 34000), excavated 1990–1995. Abbreviations: R = copper or red metal, B = tin bronze, Bz = brass, B2 = other bronzes, Dpres = Degree of preservation, where 1 denotes a well preserved artefact with a solid metal core, while 5 indicates a heavily corroded object, see main text.

Find no	Object	Cu (%)	Sn (%)	Zn (%)	Pb (%)	Fe (%)	Type	Dpres
F50268	Key	88.6	11.0	0.0	0.0	0.4	B	2
F50265	Equal armed brooch (Fig. 4)	89.6	3.0	7.0	0.2	0.2	Bz	5
F50267	Equal armed brooch	78.3	0.8	19.2	1.6	0.1	Bz	4
F50266	Equal armed brooch	84.5	0.5	13.3	1.6	0.1	Bz	4
F50263	Needle	72.7	0.0	16.0	10.8	0.5	B2	2
F50269	Needle/brooch	72.0	0.0	18.7	9.2	0.1	B2	2
F59768	Sheet	80.5	4.9	3.6	10.6	0.4	B2	3
F59901	Lump	77.2	0.3	14.8	6.2	1.5	Bz	3
F59902	Rod	77.2	0.9	14.8	5.7	1.4	Bz	3
F59904	Bar	90.3	0.0	4.9	4.2	0.6	B2	4
F76545	Rod	74.7	0.1	21.8	3.2	0.2	Bz	3
F76550	Bar	81.0	0.0	16.2	2.6	0.2	Bz	5
F76551	Sheet	79.9	13.8	1.7	4.0	0.6	B	5
F76553	Brooch	90.4	1.9	0.8	6.4	0.5	B2	4
F76546	Lump	95.1	1.6	2.5	0.0	0.8	R	5
F76549	Bar	92.0	0.5	0.1	7.2	0.2	B2	4
F76554	Needle	73.0	2.7	21.8	1.6	0.9	Bz	3

Table 2. Metal composition in per cent by weight of oval brooches from the cemeteries surrounding the settlement at Birka (SHM 34000), excavated 1871–1881. Abbreviations: R = copper or red metal, B = tin bronze, Bz = brass, B2 = other bronzes.

Grave No	Type	Cu (%)	Sn (%)	Zn (%)	Pb (%)	Fe (%)	Other	Object type
Grave 625	P51	91.1	0.0	7.8	1.0	0.0		Bz
Grave 630	P51	94.8	0.8	0.2	0.3	2.6	>1% As	R
Grave 632	P42	100.0	0.0	0.0	0.0	0.0		R
Grave 711B	P51	87.9	3.8	0.0	6.1	2.2		B2
Grave 739	P52	99.3	0.2	0.0	0.0	0.5		R
Grave 839	P51	100.0	0.0	0.0	0.0	0.0		R
Grave 844	P51	89.2	2.1	0.0	7.1	1.6		B2
Grave 846	P51	99.5	0.3	0.2	0.0	0.0		R
Grave 847	P51	97.6	0.1	0.0	1.3	1.1		R
Grave 901	P55	94.2	0.3	0.3	5.4	0.1		R
Grave 902	P51	83.3	0.2	8.0	0.0	8.7		B2
Grave 960	P55	99.4	0.3	0.3	0.0	0.0		R
Grave 963	P51	99.0	0.0	0.0	0.0	1.0		R
Grave 1085		94.7	0.2	0.0	5.1	0.0		B2
Grave 1102	P52	99.0	0.0	1.0	0.0	0.0		R
Grave 1130	P52A	100.0	0.0	0.0	0.0	0.0		R
Grave 1131	P51,B1	98.1	0.0	0.0	0.9	1.0		R

Table 3. Metal composition in per cent by weight of finds from the settlement Rasbo, Lejsta 7:1, RAÄ 630:1.

Find no	Object	Cu (%)	Sn (%)	Zn (%)	Pb (%)	Fe (%)	Other	Type
F6	Rod	100.0	0.0	0.0	0.0	0.0		R
F64	Rod	100.0	0.0	0.0	0.0	0.0		R
F56	Lump	91.6	5.1	2.4	0.9	0.0		B
F27	Fibula	98.8	1.2	0.0	0.0	0.0		R
F79	Fibula	96.9	2.6	0.0	0.5	0.0		R
F108	Fragment	100.0	0.0	0.0	0.0	0.0		R
F96	Sheet	100.0	0.0	0.0	0.0	0.0		R
F114	Sheet	100.0	0.0	0.0	0.0	0.0		R
F113	Buckle	85.9	0.9	7.1	5.6	0.0	0.5% Ag	B2
F3	Fibula	79.8	0.0	20.2	0.0	0.0		Bz
F119	Fragment	100.0	0.0	0.0	0.0	0.0		R
F46	Button	75.8	1.5	20.6	2.1	0.0		Bz
F154	Sheet	93.4	4.7	0.0	1.9	0.0		B
F4	Fibula	86.9	1.2	6.8	5.1	0.0		B2
F153	Fragment	89.2	9.2	0.0	0.0	1.6		B

Table 4. Metal composition in per cent by weight of artefacts from Lovö, Lunda/Berga cemeteries, RAÄ 34, and Söderby, RAÄ 28.

RAÄ no	Find no	Object	Cu (%)	Sn (%)	Zn (%)	Pb (%)	Fe (%)	Other	Type
Raä 34	F2:1	Button	76.0	12.6	1.6	9.0	0.8		B2
Raä 34	F2:2	Ring buckle	89.1	4.4	2.2	3.8	0.5		B2
Raä 28	F3	Armlet	88.1	4.2	6.5	0.0	1.2		B2
Raä 28	F5	Armlet	85.3	0.2	2.0	6.2	6.3		B2
Raä 28	F6	Armlet	88.2	2.4	7.6	1.0	0.8		Bz
Raä 34	A2, F2	Horse equipment	92.3	0.0	7.7	0.0	0.0		Bz
Raä 28	A62, F4	Tortoise brooch	91.2	2.3	3.0	1.6	0.1	1.9% Ag, traces of As	B2
Raä 28	A62, F2	Armlet	80.9	0.0	17.1	0.0	0.0	2.0% As	Bz
Raä 34	A2, F2	Annular brooch	78.7	2.9	16.8	0.0	0.0	1.6% As	Bz

14% tin, F76554 with 22% zinc, and F50263 with 11% lead. This reflects the fact that Birka, an important cultural and trading centre, with import of metals of different compositions, implied a habitual local recycling of metal objects.

Discussion

Historically, the first metal artefacts imported to Scandinavia were made of almost pure copper, or copper with a low percentage of tin. In a study of the earliest bronze objects found in Denmark, Vandkilde (1996) analysed more than 500 artefacts. About 20% of these were made of almost pure copper, the other of tin bronze (4–10% tin), often with some arsenic. In an earlier study for objects found in Sweden, Oldeberg (1976) analysed more than 100 early Bronze Age artefacts. About 10% of these were made of (more or less) pure copper, while all the others were tin bronzes (2–13% tin) with various trace elements (Oldeberg 1976, cf. also Schwab et al 2010). During the Early Bronze Age, local workshops were established in Sweden, using imported material in the form of artefacts or metal bars (e.g. O'Brien 2015). A recent study was made by Ling et al. (2013, 2014) on artefacts found in Sweden. Based on lead isotope data, they concluded that no Swedish ore was used during the Bronze Age.

A few chemical analyses of Iron Age material have been published in Sweden, mainly from the Vendel and Viking periods. They indicate that copper-rich metals and brass were common (e.g. Kresten et al. 2001; Grandin 2011). As regards Rasbo, Grandin (2011) has suggested that the frequent occurrence of copper-rich red metals is due to reiterated recycling of objects. A study of metallic urns from Birka and Gotland undertaken by Trotzig (1991a,b) showed no relation between shape and decoration *versus* metal composition. He concludes that the material was

Table 5. Metal composition in per cent by weight of artefacts from Norrsunda, Valsta cemetery, RAÄ 59.

Grave	Find no.	Object	Cu (%)	Sn (%)	Zn (%)	Pb (%)	Fe (%)	Type
A49	F788:2	Brooch	88.2	8.2	0.1	2.8	0.7	B
A44	F622:2	Mounting	77.4	0.0	17.3	4.9	0.5	Bz
A59	F740:2	Ring fragment	85.5	0.6	7.9	5.8	0.1	B2
A70	F726	Mounting	86.7	1.7	9.3	2.1	0.1	Bz

Table 6. Metal composition in per cent by weight of artefacts from Sollentuna, Häggvik cemetery, RAÄ 291, 293.

Grave	Find no	Object	Cu (%)	Sn (%)	Zn (%)	Pb (%)	Fe (%)	Type
A1	F 15	Ring	76.8	0.8	15.1	6.5	0.2	Bz
A1	F 16	Ring	73.8	1.0	14.3	10.7	0.2	B2
A1	F 17	Brooch	78.4	0.8	13.5	7.2	0.1	B2
A5	F 5	Mounting	77.8	0.1	9.8	12.0	0.3	B2
A8	F 24	Fragment	76.5	0.0	20.2	3.1	0.2	Bz
A9	F 6	Brooch	83.5	0.2	10.8	5.4	0.1	Bz
A9	F 7	Ring	80.4	0.0	13.3	6.2	0.1	Bz
A9	F 8	Ring	81.6	0.0	11.7	6.5	0.2	B2
A9	F 9	Ring	76.3	0.3	14.6	8.7	0.1	B2
A11	F 7:1	Brooch	79.5	0.0	11.4	9.0	0.1	B2
A11	F 7:2	Rivet	82.0	0.1	14.1	3.5	0.3	Bz
A11	F 7:3	Ring	77.7	0.2	13.8	8.1	0.2	B2
A11	F 7:4	Rivet from belt	73.2	0.1	13.2	13.2	0.3	B2
A11	F 7:5	Rivet from belt	74.9	0.2	12.7	12.0	0.2	B2
A11	F 7:6	Rivet from belt	80.7	0.3	14.0	4.7	0.3	Bz
A11	F 7:7	Rivet from belt	82.7	0.1	14.5	2.5	0.2	Bz
A11	F 7:8	Rivet from belt	71.2	0.0	13.1	15.3	0.4	B2
A11	F 7:9	Rivet from belt	79.8	0.2	15.6	4.2	0.2	Bz
A11	F 7:10	Rivet from belt	77.1	0.1	13.8	8.6	0.4	B2
A11	F 7:11	Rivet from belt	76.5	0.0	14.0	9.3	0.2	B2
A11	F 7:12	Ring	82.7	0.0	15.3	1.8	0.2	Bz
A11	F 7:13	Rivet from belt	80.4	0.1	14.7	4.4	0.4	Bz
A11	F 7:14	Rivet from belt	78.0	0.1	14.5	7.1	0.3	B2
A11	F 7:15	Rivet from belt	73.7	0.3	14.6	11.2	0.2	Bz
A28	F 13	Needle case	75.5	1.8	7.6	14.0	1.1	B2

Table 7. Summary of the 87 artefacts' metal compositions. The number of analysed objects is given. Abbreviations: R = copper or red metal, B = tin bronze, Bz = brass, B2 = other bronzes.

Site	R	B	Bz	B2	Total
Birka/The Black Earth	1	2	8	6	17
Birka (cemeteries)	12	0	1	4	17
Rasbo (settlement)	8	3	2	2	15
Lovö (cemetery)	0	0	4	5	9
Valsta, Norrsunda, (cemetery)	0	1	2	1	4
Häggvik, Sollentuna (cemetery)	0	0	10	15	25

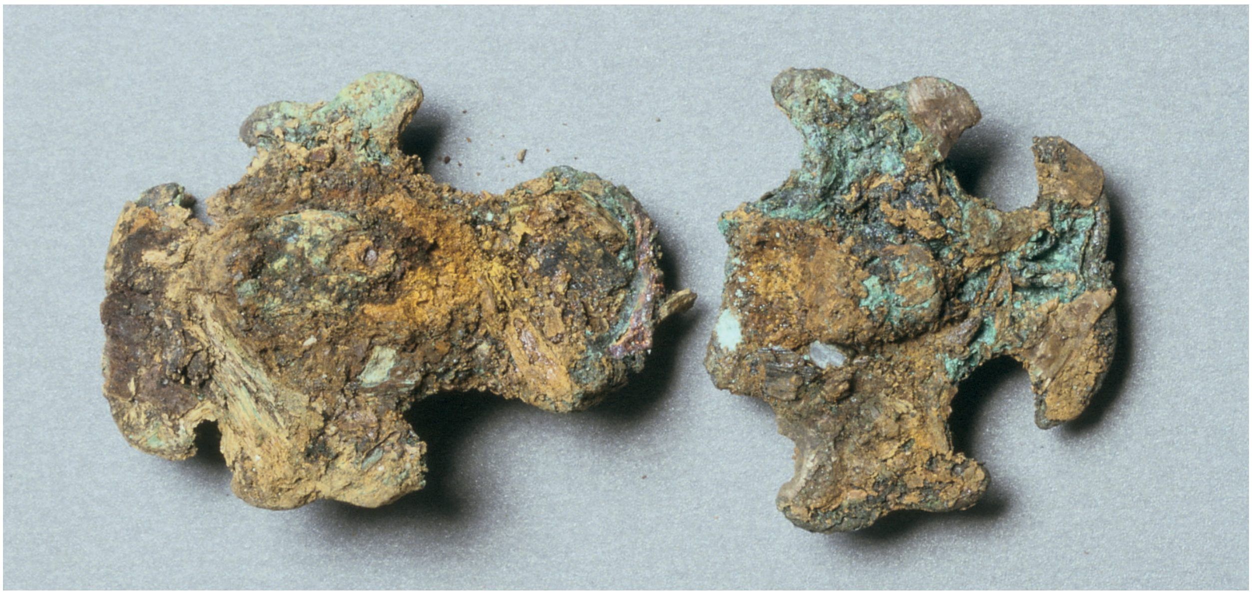

Figure 4. Equal-armed brooch from Birka (F50265), made from brass with a small percentage of tin. Practically no metal core was left. Photo: Swedish National Heritage Board.

basically chosen based only on supply and demand. A comparison can also be made with Iceland, where analyses have been made of finds from a Viking Age farmstead, resulting in copper-tin alloys with traces of lead and silver. This indicates a recycling of bronze objects with silver decorations (Wärmländer et al. 2010).

The shortage of tin might have been a conclusive reason why metals like lead and zinc were substituted for tin, probably during the early part of the Iron Age. Later, the change is clearly indicated in the present study of the 87 Viking Age objects. This observation is also in line with international studies showing that the preference for copper-tin alloys on the continent was early replaced by different compositions like brass and other copper alloys with zinc, lead and to a smaller degree iron, e.g. within with the Roman Empire (Tylecote 1979; Craddock 1995). Thus, the mixed copper-alloys in Scandinavia reflect an international development. In local workshops the imported metals were frequently recycled, giving a still larger variety of compositions.

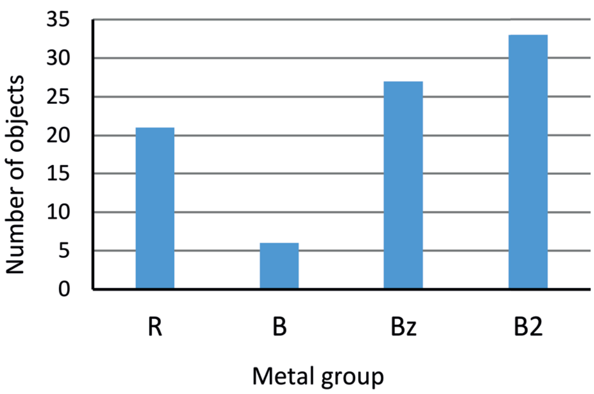

Figure 3. The four metal groups for all objects. Abbreviations: R = copper or red metal, B = tin bronze, Bz = brass, B2 = other bronzes. The vertical axis indicates the number of artefacts within each group.

The 17 oval brooches from the Birka graves form a homogeneous group that differs from the rest of the material analysed, since they predominantly consist of copper-rich alloys ("R"). They were locally produced during the 9th and 10th century and excavated in the 19th century by Hjalmar Stolpe. The oldest brooch in the analysed group, from grave 632 (P42), can be attributed to preserved mould fragments from the workshop in the Black Earth, excavated 1990–1995. The brooch type is dated to 850 AD (Ambrosiani 1997, 2013:240; Petersen 1928; see also Jansson 1985). Experimental studies have shown that gilding of copper instead of bronze is preferential, giving better result (Hubert Hydman, pers. comm.). We suggest that this choice of copper for the gilded brooches was intentional and based on knowledge acquired by the craftsmen. The colour of the product was of minor importance, since the brooches were gilded afterwards. This result also reflects the advantage of uniform objects to indicate techniques in the workshops. In general, material of this kind is rare in Sweden compared to scrap bronzes and fragments from excavations.

Another question within the project was to find out if the metal composition has affected the corrosion. The question is related to a previous extensive research project concerning environmental threats to archaeological finds (cf. Ullén et al. 2004; Nord et al. 2005). The most corroded objects were those excavated 1990–1995 from the Black Earth, which consists of thick archaeological culture layers from the settlement. A striking example is shown in Fig. 4. The severe corrosion can be attributed to the soil which is rich in salt and soot from the inhabitants living there, but also from today's air pollution. Metal corrosion underground is generally favoured by the presence of some oxidant in the soil (usually oxygen from the air) and an electric conductor, such as salt dissolved in water. Also soot enhances metal corrosion – it consists of badly crystallised graphite, which is a good electric conductor (cf. Ullén et al. 2004; Nord et al. 2005). The Black Earth is rich in salt and soot, and with ground loose enough to admit air, which explains why the metal finds here were most corroded. Among the corrosion products, oxides, chlorides and sulphates of copper were common, and sometimes carbonates of zinc or lead. A summary of the preservation status of the Black Earth finds is included in Table 1 as the parameter "Dpres" ("degree of preservation"). One result from this study is that no single alloy metal can be seen as particularly harmful in terms of corrosion. For instance, object F76551 with 14% tin was as bad as F76550 with 16% zinc. The oval brooches from the Birka graves were usually gilded and therefore better preserved. They were found in the surrounding cemeteries with another soil composition, similar to that of the other cemeteries in the study. Also the artefacts from the cemeteries at Lovö, Valsta and Häggvik were generally better preserved, often displaying copper phosphate corrosion due to deteriorated bones in the graves.

Conclusions

The study emphasizes earlier observations that the Viking Age "bronzes" were seldom alloys between copper and tin, but instead a variety of compositions from almost pure copper to brass and copper alloyed with a mixture of tin, zinc, lead and iron. This is in great contrast to bronze artefacts from the Bronze Age. We attribute this striking change in metal composition to innovations in mining and metallurgy that were gradually taking place on the Continent and adopted in Scandinavia during the Iron Age. More common ore mixtures became used and smelted because of the steadily diminishing tin-rich ores. Technological properties like hardness and mechanical strength are similar for a lot of bronze compositions (cf. Brennert 1973), but the chemistry and melting properties fluctuate. It is likely that the Iron Age workshops experimented with different alloys to obtain the best results. For certain specific purposes they may carefully have selected a composition which they considered to be the best. This could be the case for the 17 analysed oval brooches from the Birka graves, as they form a homogenous group with a high percentage of copper.

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Abbreviations

SHM – Swedish History Museum
RAÄ – Swedish National Heritage Board (Sw. *Riksantikvarieämbetet*)

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