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METAL ANALYSIS OF GILDED BROOCHES FROM VIKING AGE BIRKA IN SOUTH-CENTRAL SWEDEN

As part of an earlier extensive research project called »Artefacts and Environment«, a study of 87 Viking Age (800-1050) copper-alloy objects from Uppland (south-central Sweden) has recently been undertaken (Nord/Ullén/Tronner 2020). The artefacts in this later study originate from two settlements and four cemeteries, including the Viking Age town Birka. The analytical results revealed large variations in metal composition. Only a few objects were made from »conventional« bronze with 5-10 % tin. Instead, tin was replaced by metals such as zinc, lead, and (with lower contents) iron. In the present study, some of the gilded artefacts, namely the oval (tortoise) brooches from Birka, have been carefully reexamined utilizing several analytical techniques. In addition, another seven brooches from Birka have now been included, giving a total of 24 objects of the same type. All but one date to the 10th century. Special attention has been given to the composition of the bulk metal and gilding layer, and to some degree also to the provenance of the lead in the material. The brooches were all excavated during the period 1874-1895 (Arbman 1943).

THE GILDED OVAL BROOCHES FROM BIRKA

Birka (c. 750-970; **fig. 1**) on the island of Björkö in Lake Mälaren (Uppland) is the most famous Viking Age settlement in Sweden. The cemeteries »Borg area« and »Hemlanden« surround a central town area, called »the Black Earth« due to soot and ashes from the culture layers in the ground. Other cemeteries are situated at Ormknös, Grindsbacka, Borgs hage and Kvarnbacka. A hillfort and garrison are situated in a strategic position west of the town layers (»the Black Earth«). The site has been described by many archaeologists since its discovery (most recently: Hedenstierna-Jonson 2006; Ambrosiani 2013; Holmquist/Kalmring/Hedenstierna-Jonson 2016; Price et al. 2019).

Between 1874 and 1895, Hjalmar Stolpe excavated no less than c. 1100 graves and most of Birka's c. 300 excavated oval (tortoise) brooches were found in these. All brooches were cast, i.e. the raw material has been melted in a crucible and then poured into a mould. They are generally considered to be part of mass production, at least during the 10th century (Jansson 1985), though some of them are of extremely high artistic quality.

The present authors have now been permitted to analyse the bulk composition and gilded layer (whenever still present) for 24 brooches from the Birka graves. The oval brooches in the study belong to the types P42, P51, P52, or P55, following the typology suggested by Petersen (1928; cf. Jansson 1985). P51 is the most frequently occurring type during the 10th century. Also, P52 or P52/P55 seems to have been a popular brooch type during the same period (**fig. 2**). The discussed types are similar in shape but differ as regards the animal ornaments covering the upper shell and details like knobs and framework bands. One brooch is older, of the type P42, and dates to the 9th century (grave no. 632). Six brooches originate from graves situated east of the settlement area (the »Borg area«) and the others from graves west of the settlement (»Hemlanden«). With two exceptions (graves nos 902 and 1102), they were inhumations in coffins or (wooden) chambers. The human remains were poorly preserved, so the osteologists cannot assess either age or sex. However,

Fig. 1 Map of Birka today (Uppland/S) with traces of the town area »the Black Earth« and surrounding cemeteries. »Hemlanden« is situated to the right and »Borg area« (north and south of the hillfort) to the left, both areas with numerous barrows and burials below the flat ground. Apart from the cemeteries, minor excavations have been carried out in »the Black Earth«, e.g. at the harbour and in a workshop area, as well as of the town defence. However, a major part of »the Black Earth« remains unexcavated. The grave numbers for the investigated brooches are marked in the two areas (cf. **figs 4-8**). – (Map © Charlotte Hedenstierna-Jonsson).

based on jewellery and other accessories, they are interpreted as female. Some of these graves were extraordinarily rich in finds, indicating women of high status at the settlement (**fig. 2**; see also **figs 4-6**).

The brooches form a homogeneous group concerning the type of object, the time of production and the metal composition. The degree of preservation for those selected for the analysis varies considerably. The loose fragments allowed for our study were small and extremely fragile, always covered with soil and corrosion products. Though we presumed that all brooches were gilded, traces of gold were not found on all of them (graves nos 1085-1131). Another brooch was highly fragmented due to cremation (grave no. 902), and for two graves the gilding was infinitesimal (graves nos 901 and 960). Among the remains of clay fragments from casting moulds found in the town layers, those belonging to the type P51 are most common as indicated by the many finished brooches, noted above. However, also mould fragments from the other three types have been observed. Björn Ambrosiani's excavation (2016) of a workshop dated to the 9th century verifies that most oval brooches had probably been produced in the town of Birka (see discussion).

ANALYTICAL RESULTS FOR THE BRONZES

The bulk material of each brooch was analysed with a scanning electron microscope (LEO 1445VP), equipped with a LINK/Oxford unit for X-ray microanalysis, at the Archaeological Research Laboratory (University of Stockholm). Each reported value is the average of five independent measurements. The fragments allowed for analyses were tiny and had fallen off from the brooches after excavation or during storage. They were

Fig. 2 **a** oval gilded (tortoise) brooch from grave no. 739 (type P52, see **tabs 1-3**). – **b** a pair of oval brooches from grave no. 860B (type P51, see **tabs 1. 3**). – **c** a pair of oval brooches from grave no. 963 (type P51, see **tabs 1-3** and **fig. 3, b**). – **d** a pair of oval brooches from grave no. 632 (9th century, type P42, **tab. 1**). – (Photos The Swedish History Museum). – All are approx. 9-10 cm × 5 cm in size.

almost always covered by soil and corrosion products, which could not be completely removed since the fragments were extremely brittle. It was arduous to find spots clean enough for an analysis and to obtain a propitious position for the SEM/EDX instrumentation. Therefore, the analytical uncertainty is estimated to be no better than ± 0.5 wt% for the data listed below (cf. **tab. 1**). The total metal contents of each artefact were normalized to 100 percent by weight (wt%) after the exclusion of irrelevant elements from corrosion and soil such as carbon, oxygen, sulphur, chlorine, phosphorus, silicon, sodium, potassium, aluminium, etc. The corrosion layers contained carbonates, chlorides, sulphates, and phosphates of (mainly) copper. Occasionally, also iron oxides and carbonates of zinc and lead were found, which are common on this kind of artefacts (Ullén et al. 2004; Nord et al. 2005). The results in the two above-cited papers were obtained by SEM/EDX in combination with X-ray powder diffraction data using a Debye-Scherrer camera. The gilding consisted of gold, mercury, and lower concentrations of silver and copper (cf. below).

Some abbreviations are suggested to facilitate comparisons between the artefacts (cf. **tab. 1**, »alloy«). A red-coloured metal object with low concentrations of alloy metals, or consisting of pure copper, is henceforward denoted »R«. An alloy in which tin is the dominating metal next to copper, reminding of a typical »tin bronze« composition, is denoted »B«. (With »dominating« metal we mean a metal having at least the double concentration as compared with any other alloying metals). Whenever zinc is the dominating metal, this is classified as brass and denoted »Bz«. Compositions that badly fit into any of these three groups are given the abbreviation »B2«. The analytical results of the bulk metals are summarized in **table 1**. The large concentration of copper in the bulk material is noteworthy (cf. also Nord/Ullén/Tronner 2020). Since this was found for 17 out of 24 objects, this might have been an intentional choice of the workshop, making them easier to gild than a conventional bronze composition (cf. Anheuser 1997). Of course, the choice of gilding was based on the fact that gold was a prestigious and luxurious metal in Birka.

grave	type	Cu	Sn	Zn	Pb	Fe	alloy	additional analyses	archaeological context
507	P51	100.0	0.0	0.0	0.0	0.0	R	GOLD	north of Borg, chamber grave below flat ground, inhumation. Exc. 1878.
564	P51	100.0	0.0	0.0	0.0	0.0	R	GOLD	north of Borg, coffin below flat ground, inhumation. Exc. 1878.
625	P51	91.1	0.0	7.8	1.0	0.0	Bz		north of Borg, coffin below flat ground, inhumation. Exc. 1878.
630	P51	94.8	0.8	0.2	0.3	2.6	R	PIXE, GOLD, LEAD	north of Borg, coffin below flat ground, inhumation. Exc. 1878.
632	P42	100.0	0.0	0.0	0.0	0.0	R		north of Borg, chamber grave below flat ground, inhumation. Dated to the 9th century. **Fig. 2, d**. Exc. 1877.
660	P51	100.0	0.0	0.0	0.0	0.0	R	GOLD, GLT	north of Borg, chamber grave below flat ground, inhumation. Exc. 1879.
711B	P51	87.9	3.8	0.0	6.1	2.2	B2		Hemlanden, barrow, chamber grave, inhumation. Exc. 1879.
739	P52	97.3	0.2	1.2	0.5	0.7	R	PIXE, GOLD, GLT	Hemlanden, barrow, chamber grave, inhumation. **Fig. 2, a**. Exc. 1879.
791	P51	97.4	0.1	1.3	0.6	0.6	R	PIXE, GOLD, GLT, LEAD	Hemlanden, chamber grave below flat ground, inhumation. **Fig. 3**. Exc. 1879.
791A	P51	97.0	0.0	1.2	0.9	0.8	R	GOLD	Hemlanden, chamber grave below flat ground, inhumation. Exc. 1879. See no. 791.
839	P51	100.0	0.0	0.0	0.0	0.0	R		Hemlanden, coffin in town wall, inhumation. Exc. 1879.
844	P51	89.2	2.1	0.0	7.1	1.6	B2	GOLD	Hemlanden, coffin (?) below flat ground, inhumation.
846	P51	99.5	0.3	0.2	0.0	0.0	R		Hemlanden, coffin below flat ground, inhumation (child).
847	P51	97.6	0.1	0.0	1.3	1.1	R		Hemlanden, coffin in town wall, inhumation.
860B	P51	100.0	0.0	0.0	0.0	0.0	R	GOLD	Hemlanden, chamber grave below flat ground, inhumation (two females). **Fig. 2, b**.
901	P55	94.2	0.3	0.3	5.1	0.1	R		Hemlanden, barrow, chamber grave, inhumation, (poorly preserved brooches).
902	P51	83.5	0.2	8.0	0.0	8.3	Bz		Hemlanden, barrow, cremation (fragmented objects).
960	P55	99.4	0.3	0.3	0.0	0.0	R		Hemlanden, coffin below flat ground, inhumation. Exc. 1881.
963	P51	99.0	0.0	0.0	0.0	1.0	R	PIXE, GOLD, GLT	Hemlanden, chamber grave below flat ground, inhumation. **Fig. 2, c**. Exc. 1881.
964	P51	89.6	2.8	1.9	4.7	1.2	R		Hemlanden, chamber grave below flat ground, inhumation. Exc. 1881.
973	P51	73.0	9.1	9.1	5.0	3.8	B	GOLD, LEAD	Hemlanden, barrow, chamber grave, inhumation. Exc. 1881.
1085	P52/ P55	94.7	0.2	0.0	5.1	0.0	B2		Hemlanden, coffin (?) below flat ground, inhumation (poorly preserved). Exc. 1881.
1102	P52	99.0	0.0	1.0	0.0	0.0	R		Hemlanden, barrow, cremation (child)/ inhumation. Exc. 1881.
1130	P52A	100.0	0.0	0.0	0.0	0.0	R		Hemlanden,coffin (?) in town wall, inhumation. Exc. 1888.
1131	P51, B1	98.1	0.0	0.0	0.9	1.0	R		Hemlanden, coffin made of boat timber below flat ground, inhumation. Exc. 1888.

Tab. 1 Analysed fragments of brooches from Birka (Uppland/S). The values are given in percent by weight (wt%). »Type« refers to Petersen (1928). All artefacts except no. 632 date to the 10th century. Abbreviations for additional analyses (**tabs 2-4**): PIXE = PIXE-data available; GOLD = Gold layer analysed; GLT = Gold layer thickness examined; LEAD = Lead isotope data available. Note: nos 791 and 791A are fragments from the same object.

sample from grave number	chromium	manganese	nickel	arsenic	bismuth
630	526	< 60	< 40	170	97
739 (**fig. 2, a**)	808	< 60	< 40	39	109
791 (**fig. 3, a**)	838	< 60	< 40	49	114
963 (**fig. 2, c**)	1760	< 90	< 50	67	322

Tab. 2 PIXE results of four selected samples. The detected trace elements are given in ppm units (parts per million by weight).

Four samples were also analysed for their trace elements by PIXE (Particle-Induced X-ray Emission spectroscopy) using an accelerator from the National Electrostatic Corporation at the Institute of Nuclear Physics, University of Lund. With this instrument, very low concentrations can be detected. The results of the four selected samples are shown in **table 2** (cf. **fig. 2**). The data obtained for samples from graves nos 739 and 791 are similar and indicate that the metal piece or rod used for the casting is probably the same for the two brooches. This is also supported by the bulk metal composition for the two samples (**tab. 1**). Note that they belong to different ornament types, P51 and P52.

ANALYTICAL RESULTS FOR THE GILDED LAYERS

Eleven gold layers from brooches (**tab. 1**) were separately examined in a field emission microscope, model JEOL JSM-7401F. The high concentration of mercury indicates that the gold layers had been applied using fire gilding. In this process, an amalgam of mercury and gold (proportion around 6:1) is applied to the clean surface. Most of the mercury is then removed by heating the object, leaving a film of gold containing some mercury. When most of the mercury has evaporated, further procedures will follow to give a »golden« surface. This process, when skilfully accomplished, produces gilding of great solidity and beauty, but it is extremely unhealthy owing to the exposure of mercurial fumes to the workers. This was known and commented on in early medieval literature (cf. Trotzig 2014). The present results agree with earlier studies (cf. Oldeberg 1966; Patriksdotter 2019).

Naturally, it was of great interest to estimate the thickness of the gold layers. In earlier studies of gilded metal embroidery threads from textiles, the oldest from the Middle Ages, various methods were used (Nord/Tronner 2000). Analyses by LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) or AES (Auger Electron Spectroscopy) only gave a rough estimate of the gold layer thickness. A third method was instead used, based on the variation in penetration depth of the SEM electron beam for various accelerating voltages, using gilded standards prepared with a Cressington gold sputtering coater (Tronner et al. 2002). The analyses showed that the gold layers of the embroidery threads were < 0.1 µm (1 µm = 0.001 mm). When this technique was tested on the gilded Birka artefacts in the present study, we could only conclude that their gold layers were certainly > 0.5 µm.

A fourth method turned out to be more successful for the Birka brooches. From four artefacts, relatively clean fragments were selected and cast in an epoxy cubicle, perpendicularly to the surface, to give a cross section of the gilded metal fragment. The surface of each cubicle was polished using argon ion sputtering instead of mechanical cleaning with a diamond-based emery cloth, to avoid the contamination of »soft« gold particles on the analysed area. Afterwards, the surface was examined with a field emission microscope. The gold layer was varying in thickness over the cross-section surface, which reflects the difficulty with the fire gilding technique. Data for the gold layers are shown in **table 3**, photos in **figure 3**. The mercury in the

grave number	Au	Ag	Cu	Hg	GLT = approximate range for the gold layer thickness
507	68.9	0.2	15.3	15.6	
564	72.6	2.4	11.8	13.2	
630	84.0	2.8	3.6	9.6	
660	73.4	6.3	7.8	12.5	1.2-1.5 µm
739 (fig. 2, a)	75.1	6.4	8.6	9.9	5-10 µm
791 (fig. 3, a)	77.9	5.3	5.4	11.4	4-7 µm
791A	79.3	5.6	4.7	10.4	
844	70.0	14.8	4.5	10.7	
860B (fig. 2, b)	79.4	1.2	6.5	12.9	
963 (fig. 2, c)	77.7	4.6	6.4	11.3	2-3 µm
973	77.0	2.4	10.0	10.6	

Tab. 3 The composition of the analysed gilded layers, and the range of thickness for the four samples examined with a field emission electron microscope. All objects date to the 10th century and are of the P51 type except for grave no. 739 (P52). The chemical values are given in percent by weight (wt%).

gilt layer is a remainder of the fire gilding process, the silver and copper were impurities in the gold material used when mixing gold and mercury for the gilding.

Finally, three small pieces from three objects (in graves nos 630, 791 and 973) were dissolved in nitric acid and analysed for their lead isotope composition with a MC-ICP-MS (Multicollector Inductively Coupled Plasma) mass spectrometer of the type ThermoScience ELEMENT-XR. Lead exists with four stable isotopes having mass numbers 204, 206, 207 and 208. Except for ^{204}Pb, they have been formed from an extremely slow radiogenic decay of uranium or thorium. Accordingly, the geological age of the original mineral deposit is an important factor for its lead isotope composition. The method has successfully been used earlier, e. g. by Ling et al. (2013; 2014) for bronze artefacts and later by Nord et al. (2015) for lead pigments taken from medieval murals. We are well aware that the metals used to cast a Birka brooch may have been reused several times. Be that as it may, the isotope results for the three lead isotope ratios ^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb, and ^{208}Pb/^{204}Pb are as follows: for sample 630: 18.268, 15.467 and 38.073; sample 791: 17.929, 15.140 and 36.989; sample 973: 18.123, 15.384 and 37.715. By the use of the very extensive data base OXALIDE from Stos-Gale and Gale (2009), we searched for a conceivable origin among the mines. We also utilized data from Tylecote (1979), Lévêque and Haak (1993), Niederschlag et al. (2003) and Monn et al. (2000). Four regions resembled the lead isotope data for sample 630: the Harz and Erzgebirge in Germany, the Pennines in Great Britain, and Sardinia, all these with a similar lead isotope composition. Among them, the two German mining districts seem to be most likely, but also England is possible. Sardinia is the least likely alternative. For samples 971 and 973, a mixture between Harz / Erzgebirge and some other mine(s) is indicated. In future extended work on Viking Age metals, we hope to include comparisons with results from other towns / markets (e. g. Merkel 2018a; 2018b).

DISCUSSION

The results in this paper contribute to the technical knowledge of the local brooch production in Birka during the Viking Age. The excavation of a casting workshop was carried out by Ambrosiani 1990-1995, close to the shore of the town (Ambrosiani 2013; 2016). This important excavation has revealed detailed information about materials and different production processes. Raw materials, manufacturing debris such

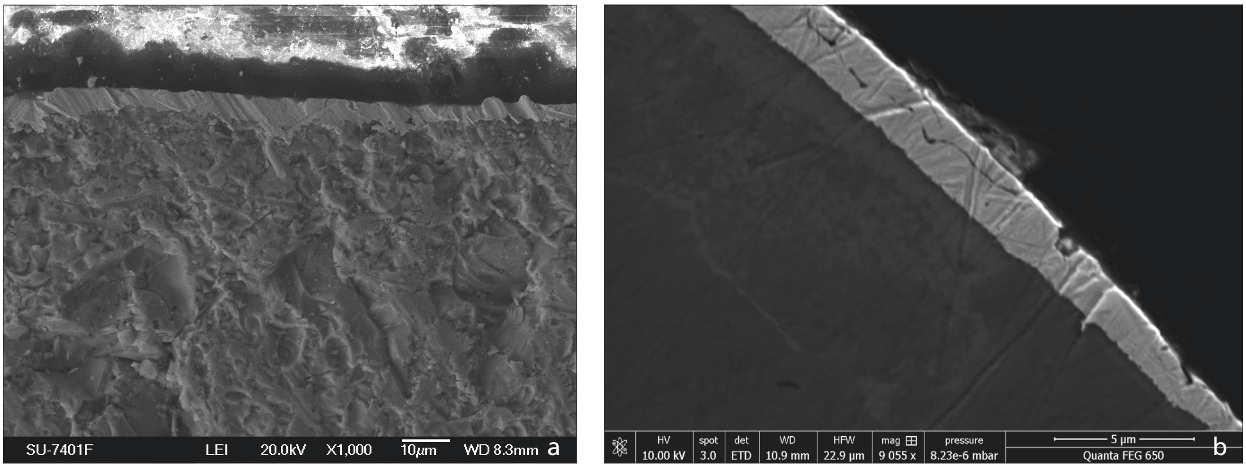

Fig. 3 **a** SEM photo of the sample in grave no. 791. From top to bottom: the epoxy layer (a dark area), the thin gold layer, and below the rough bulk metal. Electron microscope JEOL JSM-7401. – **b** SEM photo of the gold layer of the sample in grave no. 963. Electron microscope FEI FEG-650. – (Photos A. G. Nord).

as scrap bronzes, and equipment like parting vessels, moulds and crucibles were retrieved. The moulds were made of local clay or silt and designed for jewellery, including oval brooches, amulets, and pendants. All moulds are fragmentary because they were broken apart after casting to extract the object. The crucibles consisted of more specialized material, imported kaolin mixed with local feldspar to obtain the best result in melting. Moreover, iron tools, padlocks and mounts for weapons and debris from comb-making were found, thus indicating many other handicrafts. All this testifies to the technical skill of the craftsmen at the wide-ranging workshop area, during the time it was used, c. 790-860. Our observations may be related to the work of Ambrosiani, though the present paper mainly discusses brooches produced somewhat later, from the 10th century.

The base metal used for the bronze brooches turned out to be remarkably rich in copper, according to the study. Among the 24 artefacts, seven were made of pure (or almost pure) copper, and all others had a high concentration of copper, with tin, lead, zinc, and iron as minor components. This metal composition was not found in other contexts or on objects without gilding (Nord / Ullén / Tronner 2020). It is noteworthy that, although classified as different ornament types (P52 respectively P51), two brooches (from graves nos 739 and 791) had an almost identical metal composition. The same piece or bar of metal was used to cast the two artefacts and probably at the same workshop.

The number of objects analysed in this study is small, but even so, a tendency can be observed. The analyses clearly indicate that the (poisonous) technique of fire gilding had been used for the gold layers on the brooches in Birka. The gold layers were rough, with a thickness within the region 1-10 μm. This is more than 100 times that of a modern gilding layer and reflects the trouble and challenge at the workshop to obtain a beautiful gold layer for the brooches. The average of about 5 μm agrees well with similar data published by Figueiredo et al. (2010). The lavish use of gold was necessary for creating objects of great artistic value. The concentration of mercury in the gilt layer, around 10 percent by weight, indicates that a well-established procedure for the gilding seems to have been applied. The frequent use of (almost) pure copper for the bulk may also have been an intentional choice, better suiting the casting and the fire gilding to follow, according to modern experiments (Hubert Hydman, Acta Konserveringscentrum AB, Stockholm; cf. Oddy 2000; Anheuser 1997). Whether the base metal was reused or not is of minor importance for this suggestion. Also, traces of gold have been found in crucibles at the workshop area in Birka, verifying the local use of this precious metal (Ambrosiani 2016). However, traces of mercury are so far missing, but it is probably due to the

relatively high vapour pressure of liquid mercury. In the Viking Age town of Haithabu (Kr. Schleswig-Flensburg/D), mercury has been found, believed to be imported (cf. Steuer/Goldenberg 2002; Trotzig 2014). The corrosion that was noticed on some of the examined brooches may be due to the gilding layer, which in contact with moisture in the ground has created a demolishing situation for Galvanic corrosion (cf. Masi et al. 2016; Scott 1983). This was also obvious for one oval brooch from grave no. 644, not included in the present study (Oldeberg 1966).
So far only a few specific studies on fire gilded Birka objects have been undertaken, but with notable exceptions. Oldeberg (1966) made an early analysis of artefacts from different parts of Sweden including a fire gilded oval brooch from Birka. A recent study of 13 silver and bronze (copper) objects found in Birka (Patriksdotter 2019; cf. Wojnar-Johansson 2004) has revealed that five of them have been fire gilded, though they have not been produced in Birka, but in Byzantium, the Orient or the Carolingian Europe.
Probably fire gilding and metal casting were only two of many techniques used at the multifaceted production at the workshops in Birka, in which other activities such as iron smithing, weapon production, comb- and bead-making were also carried out. So far there is no convincing evidence for a Viking age extraction of copper within Sweden and, consequently, all metals (copper-alloys, mercury) must have been imported. The lead isotope data of three oval brooches indicate metals from at least two different regions. The data for the object from grave no. 630 agrees well with the published data for both the Harz and Erzgebirge regions, and one of these is most likely the true origin. Birka had been part of a trade network between towns and markets along the south Baltic coast, since at least the 8th century (Ambrosiani 2016). As part of this network, the town had access to raw material from further south (e.g. the Harz/Erzgebirge) as well as to other objects from the Continent and the East. This is supported by archaeological finds such as luxury goods, textiles, glass vessels, coins, and pottery. The two other Birka brooches (grave nos 791 and 973) show different lead isotope values and indicate a mixture of metals from at least two mining districts on the European continent. The results support previous observations of continuous recycling of metals (cf. Oldeberg 1966; Patriksdotter 2019). The use of »scrap bronzes« was in fact suggested already in Roman times by Plinius (Trotzig 2014). The most frequent raw material at Birka's workshops was probably broken objects which were used for remelting.
Birka existed from the middle of the 8th century to c. 970-980 and so far, only one of the probably several workshops in the town has been excavated. This workshop was in use for about 100 years meaning that a tradition of technical knowledge was created with craftsmen that achieved an advanced level of craftsmanship during several generations (Ambrosiani 2016). A link back to the nearby impressive Iron Age workshop area at Helgö, another small island near Björkö, might have existed (c. 400-600), underlining the continuity of skilled craftsmen (e.g. Lamm 2012). Obviously, these permanent, high-quality workshops were connected to economic and political centres, Birka being one of them.

SUPPLEMENT: ARCHAEOLOGICAL CONTEXT INFORMATION

The Birka graves included in the present study were barrows and burials without visible signs above ground (today). In some cases, only a shallow depression was noted by the excavators. All, except two, were inhumations in wooden coffins or chambers (**tab. 1**). In a few cases, nails or wooden traces are missing. Three of the graves are depicted in **figures 6-8** and demonstrate the high social rank most female brooch-owners had. From available data, the excavation of the graves took place in 1877-1888. (see **tab. 1**). Note that most human remains are poorly preserved. Based on jewellery and other accessories, all are interpreted as female. Brief locations for the investigated tortoise brooches are presented in **figures 4-5**. Due to a large amount

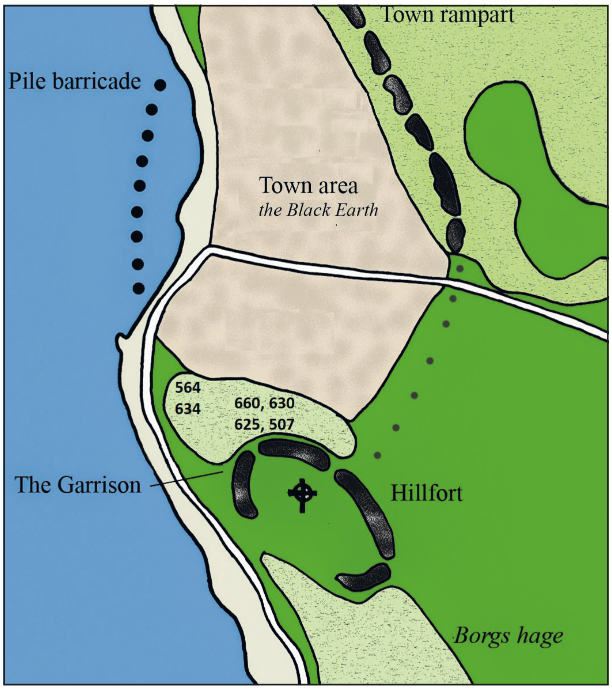

Fig. 4 Birka (Uppland/S). Graves with brooches analysed in the present study, situated north of »Borg area«: nos 564 and 634 were situated in the western part and nos 507, 625, 630, 632 and 660 in the eastern part. – (Map © Charlotte Hedenstierna-Jonsson; after Arbman 1943 and the Swedish History Museum; http://mis.historiska.se/mis/sok/birka.asp?zone=2A [11.2.2021]).

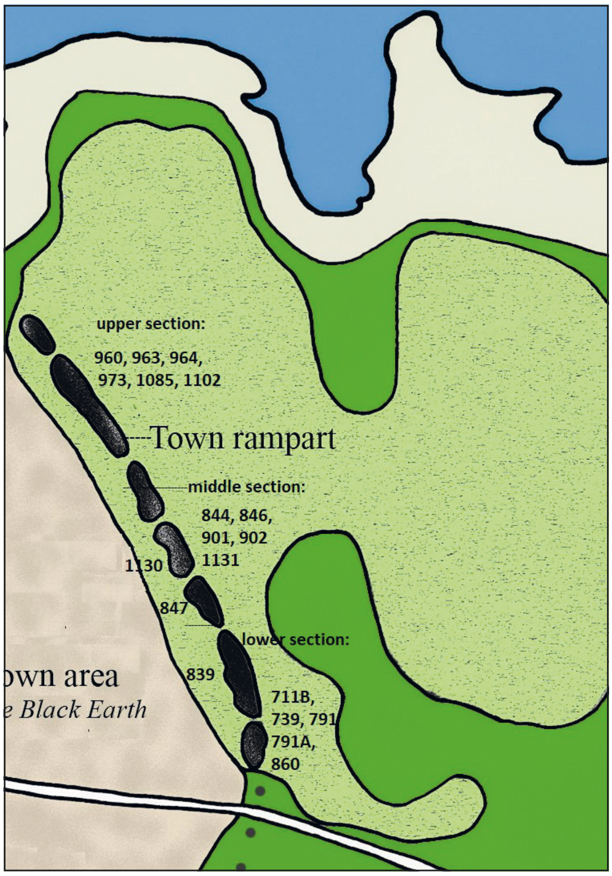

Fig. 5 Birka (Uppland/S). Graves with brooches analysed in the present study, situated at »Hemlanden«: nos 960, 963, 964, 973, 1085 and 1102 in the upper section of the cemetery; 844, 846, 901, 902 and 1131 in the middle section; 711B, 739, 791 (791A) and 860 in the lower section; 1130, 847 and 939 were situated in the town wall (town rampart). – (Map © Charlotte Hedenstierna-Jonsson; after Arbman 1943 and the Swedish History Museum; http://mis.historiska.se/mis/sok/birka.asp?sm=10_7&page=8&zone=&mode= [11.2.2021]).

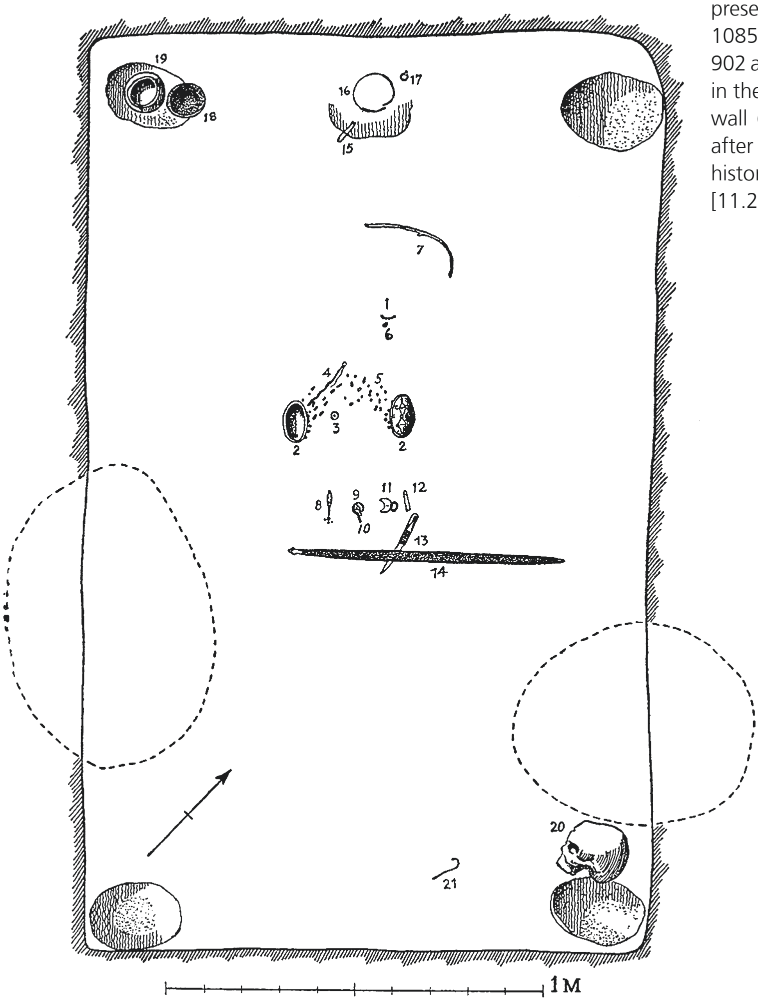

Fig. 6 Birka (Uppland/S). Grave no. 660: (wooden) chamber grave. The two tortoise brooches, analysed in the present study, are in the middle, attached to a silver chain and the oldest native silver crucifix in Sweden (**2. 4**; the crucifix is not visible on the drawing as it laid under one tortoise brooch). Between the brooches, a string originally included beads of glass (some covered in gold foil), silver, and rock crystal (**5**). Below are, among other artefacts, silver filigree pendants, and bronze and iron tools, including an iron staff often interpreted as a tool for female shamans, to prophesying the future (**8-14**). At the top, fragments of a glass beaker were found (**16**) and in the upper left corner several vessels (**18-19**). – (After Arbman 1943, fig. 189).

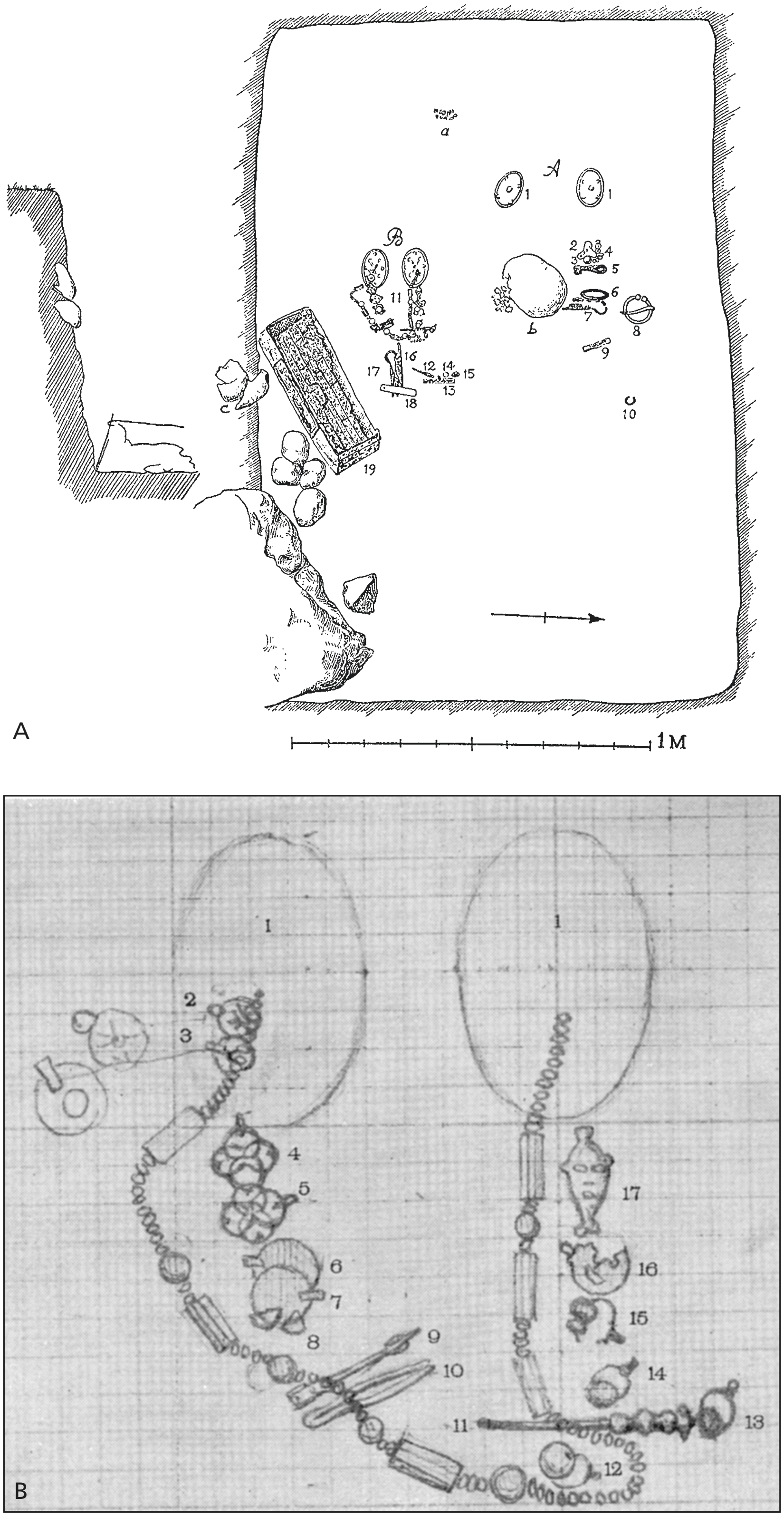

Fig. 7 Birka (Uppland/S). Grave no. 860: (wooden) chamber grave for two women (**A-B**). The tortoise brooches in **B** are analysed in the present study (fig. 7A, 11). Among the personal belongings, a wooden chest was found (to the left, fig. 7A, 19). The bead string in grave no. 860B included Birka coins, and a fragment of an Arabic coin (dirhem, abbasidisch) (fig. 7B, 6-8). Other pearls were made of carneol, rock crystal and glass. At least, one pendant had an anthropomorphic shape (humanlike, fig. 7B, 17). – **B** detail of fig. 7A. Beads attached to the tortoise brooches in grave no. 860B. – (Original drawing made by Hjalmar Stolpe; after Arbman 1943, figs 282-283).

of burials (c. 1100) in Birka, a precise location for each grave has not been made. Instead, they have been marked on the maps according to a section system used by the Swedish History Museum. Detailed descriptions, maps, and drawings of all the excavated graves at Birka can be found in Arbman (1943) and the useful Birka database at www.historiska.se (the Swedish History Museum).

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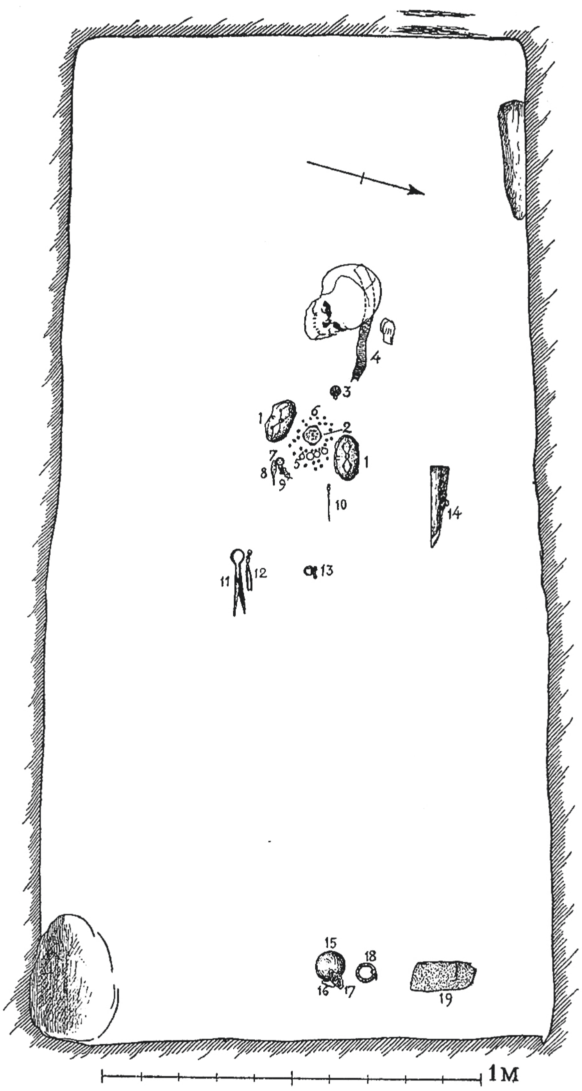

Fig. 8 Birka (Uppland/S). Grave no. 963: (wooden) chamber grave. The tortoise brooches, analysed in the present study, are in the middle and close to them two round, gilded brooches (**1-3**). The human skull was preserved, and partly covered by a woven, textile band (**4**). The bead string (**6**) included a denar pendant and a Nordic coin pendant as well as pieces of amber. Below are a pair of scissors, tweezers, and a bronze/iron weight (**11-13**). At the bottom, a glass smoothing stone was found (**15**), among other finds. – (After Arbman 1943, fig. 339).

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Zusammenfassung / Summary / Résumé

Metallanalyse von vergoldeten Fibeln aus dem wikingerzeitlichen Birka in Südmittelschweden

Die wikingerzeitliche Stadt Birka ist die bekannteste archäologische Ausgrabungsstätte Schwedens und wurde von der UNESCO in die Liste des Weltkulturerbes aufgenommen. In diesem Beitrag werden die Ergebnisse der Metallanalysen von 24 vergoldeten, ovalen Fibeln aus den Bestattungsplätzen der Stadt vorgestellt. Sie wurden zwischen 1874 und 1895 ausgegraben und stammen, mit einer Ausnahme, aus dem 10. Jahrhundert. Die Analyse mit SEM/EDX ergab, dass das Hauptmetall entweder reines Kupfer oder eine Kupferlegierung mit geringen Mengen an Zinn, Zink, Blei und Eisen war. Vier Objekte wurden auf ihre Spurenelemente mit PIXE analysiert. Die Goldschichten von elf Fibeln wurden mit einem Feldemissionsmikroskop untersucht. Die Schichten waren rau, mit einer Dicke im Bereich von 1-10 µm (1 µm = 0,001 mm). Sie enthalten etwa 80 % Gold (Gewichtsprozent), daneben kleinere Mengen Silber und Kupfer sowie 10-16 % Quecksilber aus einer Feuervergoldung. Bleiisotopendaten weisen darauf hin, dass eine Fibel Blei enthielt, das aus dem Harz oder Erzgebirge in Deutschland stammt. Zwei weitere Fibeln enthielten Blei aus verschiedenen Minen in Kontinentaleuropa. Die Ergebnisse tragen zum Wissen über Birka als wichtiges Handelszentrum mit fortschrittlichen Techniken in den Werkstätten bei.

Metal Analysis of Gilded Brooches from Viking Age Birka in South-central Sweden

The Viking Age town of Birka is the best-known archaeological site in Sweden and inscribed in the UNESCO's World Heritage List. This paper presents results from metal analyses of 24 gilded, oval brooches from the cemeteries at the town. They were excavated between 1874 and 1895 and, with one exception, date to the 10th century. The analysis with SEM/EDX revealed that the bulk metal was either pure copper or a copper alloy with low amounts of tin, zinc, lead and iron. Four objects were analysed for their trace elements with PIXE. The gold layers of eleven brooches were examined with a field emission microscope. The layers were rough, with a thickness in the range 1-10 µm (1 µm = 0.001 mm). They contain around 80 % gold (percent by weight), in addition to smaller amounts of silver and copper, and 10-16 % mercury from a fire gilding process. Lead isotope data indicate that one brooch contained lead originating from the Harz or Erzgebirge in Germany. Two other brooches contained lead from different mines in continental Europe. The results contribute to the knowledge of Birka as an important trading centre with advanced techniques in the workshops.

Analyse métallique des fibules dorées du site viking de Birka dans le Sud de la Suède centrale

La ville de Birka est le site archéologique le plus connu de Suède et figure sur la Liste du patrimoine mondial de l'UNESCO. Cet article présente les résultats d'analyses métalliques effectuées sur 24 fibules ovales dorées des nécropoles de la ville. Fouillées entre 1874 et 1895, elles datent toutes, excepté une, du 10e siècle ap. J.-C. Une analyse SEM/EDX a révélé que la majorité du métal utilisé était du cuivre pur ou un alliage de cuivre à faibles teneurs d'étain, zinc, plomb et fer. Les oligo-éléments de quatre objets furent analysés avec PIXE. Les couches d'or d'onze fibules ont été examinées au microscope à émission de champ. Les couches étaient rugueuses, avec une épaisseur allant de 1-10 µm (1 µm = 0,001 mm). Elles contiennent environ 80 % d'or en poids, en plus des faibles quantités d'argent et de cuivre, et 10-16 % de mercure dus au processus de dorure au feu. Les données isotopiques du plomb indiquent qu'une fibule contenait du plomb originaire du Harz ou de l'Erzgebirge en Allemagne. Deux autres fibules contenaient du plomb provenant de différentes mines de l'Europe continentale. Les résultats contribuent à mieux connaître l'important centre commercial de Birka et les techniques avancées de ses ateliers.

Traduction: Y. Gautier

Schlüsselwörter / Keywords / Mots clés

Schweden / Birka / Wikingerzeit / vergoldete Fibeln / Bronzeguss / SEM/EDX-Analysen / PIXE / Bleiisotopen
Sweden / Birka / Viking Age / gilded brooches / bronze casting / SEM/EDX analyses / PIXE / lead isotopes
Suède / Birka / époque viking / fibules dorées / moulage du bronze / analyses SEM/EDX / PIXE / isotopes du plomb

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