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A sword from Vreta Kloster, and black patinated bronze in Early Bronze Age Europe

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An Early Bronze Age sword from southern Sweden with inlaid decoration is investigated with regard to its original appearance, and the initial identification of an encrusted organic material within the ornamental decoration is shown scientifically to be wrong. The inlay technology now revealed is known from several Bronze Age objects from Mycenae and Egypt. A few examples from Central Europe link this sword from Sweden technologically with the eastern Mediterranean.

Keywords: Early Bronze Age, polychrome metal work, bronze corrosion, patination, technology transfer

Introduction

When the exceptional bronze hoard of Nebra was discovered in Saxony-Anhalt in Germany in 1999, it contained among other implements the famous Sky Disc, so far the earliest known representation of the night sky, dating back to the late 17th or early 16th century BC (Meller 2002:9). Because of its uniqueness, the hoard of Nebra, and especially the Sky Disc, raised a number of questions and consequently controversial discussions. Apart from the authenticity of the disc, its date and place of origin and its relation to the other implements in the hoard, a fundamental question concerns the position of the hoard in relation to other Early Bronze Age material. As a part of a group supported by the German Research Foundation, the authors were involved in studying technological aspects of the hoard and its relation to other European Early Bronze Age finds.

The decoration on the Sky Disc consists of gold inlays that were fixed to the bronze plate by inserting the gold foil into grooves in the bronze, the rims of which were then hammered over the gold foil. This is actually not a true inlay technique, which would include the removal of bronze material, and thus the technique should rather be regarded as plating with a peculiar form of fixation (see Pernicka & Wunderlich 2002:28; Wunderlich 2004:43). Several other objects, including two swords, were found together with the Sky Disc, and it was observed during detailed inspection that the decorative lines on the sword blades that had initially been regarded as incrustations consisted of pure copper hammered into channels that had presumably already been produced in the casting process (Fig. 1). Thus the swords are among the very few Early Bronze Age examples of a true inlay technique outside the Mediterranean world (Meller 2002), so that these few finds in central and northern Europe are usually regarded as imports from the Mediterranean region or at least as technologically inspired by work from that region.

There are actually only three finds with bimetallic or polymetallic surface decorations described in the archaeological literature. The golden metal foils of the

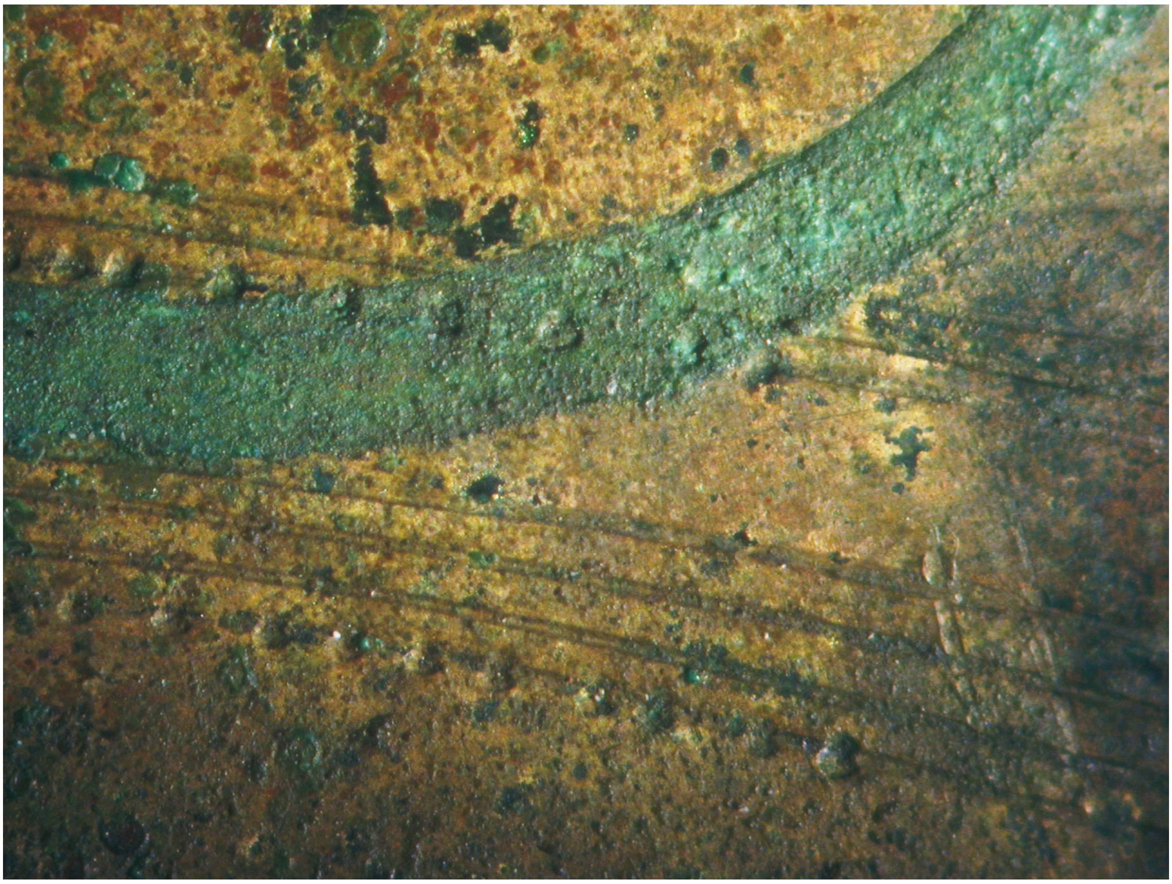

Figure 1. Chased ornaments and green corroded copper inlay work on one of the swords from the Nebra hoard. Photo by Christian-Heinrich Wunderlich.

famous sun cart from Trundholm are considered to be fixed with inlayed copper strips (Brøndsted 1962:86), while it was proposed that the golden inlays on the so-called "axe" from Thun-Renzenbühl in Switzerland had been inserted into a black-coloured copper strip (Strahm 1972:100). Finally, one marvellous piece of work by an Early Bronze Age artisan which probably directly parallels the Mediterranean techniques is the sword from the "Marais de Nantes", which is also described as having black-coloured copper strips inlaid with golden wires (Schauer 1984:175).

An interesting parallel to these has now be found in a sword from the parish of Vreta Kloster in Östergötland, Sweden. Since this find is probably the closest technological equivalent to the swords from the Nebra hoard, we restudied it in detail. Additional investigations are under way on the sword from the "Marais de Nantes", which is now in the "Museum zu Allerheiligen Schaffhausen" in Switzerland.

The sword from the parish of Vreta Kloster

The parish of Vreta Kloster is located in the middle of Östergötland in Sweden (Fig. 2). In view of the number of bronze objects (single finds/bog finds) known in the area, it must have been the richest parish in the county during the Bronze Age (Nordén 1925:178). The find context of the Vreta Kloster sword is not known in detail, but it is thought to have been discovered in a bog on the estate of Kungsbro near Lake Roxen in 1897. It was bought as part of a private collection by the Museum of National Antiquities (Statens Historiska Museum) and given the inventory number SHM 10419. Typologically, the sword can be dated to 1600–1500 BC (Vandkilde 1996:238f; Lomborg 1960:139 f, see below).

The sword measures 461 mm in length and 72 mm in width. Its hilt is missing, however, having originally been made separately and attached to the blade with

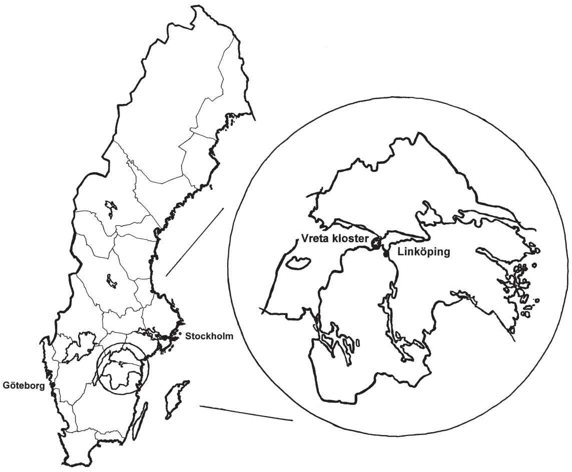

Figure 2. Map of Sweden showing Östergötland and the parish of Vreta. Drawing by Cecilia Bonnevier, SHM.

Figure 3. The sword from the parish of Vreta with its ornamental wavy lines. Photo by Christian-Heinrich Wunderlich.

four rivets. Two of the rivets are still preserved. The elegant shape of the blade and the line decoration on it have parallels in the case of other swords in Sweden, although the lines are of a different type. The Vreta Kloster blade is decorated with sharply chased ornamental lines on both sides (Fig. 3), and two other wavy lines were filled with an almost green, but locally reddish-brown, encrusted inlay (Fig. 4), the bulk of which has been mechanically removed. This inlay has been interpreted in earlier reports as a "residuum of encrusted resin" (e.g. Montelius 1900:325; Oldeberg 1974:296). The closest parallels to the inlay technique used on the Vreta Kloster sword is the surface decoration on the two swords found together with the Sky Disc of Nebra in Saxony-Anhalt, which are incrusted with copper. Against this background, it seemed likely that the green and red-brown colour of the inlay on the sword from Vreta Kloster had originated from the corrosion of a copper strip rather than the pseudomorphic replacement of organic material by bronze corrosion products from the blade.

Analytical methods

The sword was X-rayed with a tube voltage of 120 kV and a cathode current of 5 mA, which rendered the facing strips visible in terms of a reduction in X-ray absorption proportional to the reduced thickness of the metal (Fig. 5). In addition, however, there was an intensity loss in those parts of the facing strip where most of the filling material was detected. The attenuation of X-rays depends on the thickness of the material and its electron density, and thus on its chemical

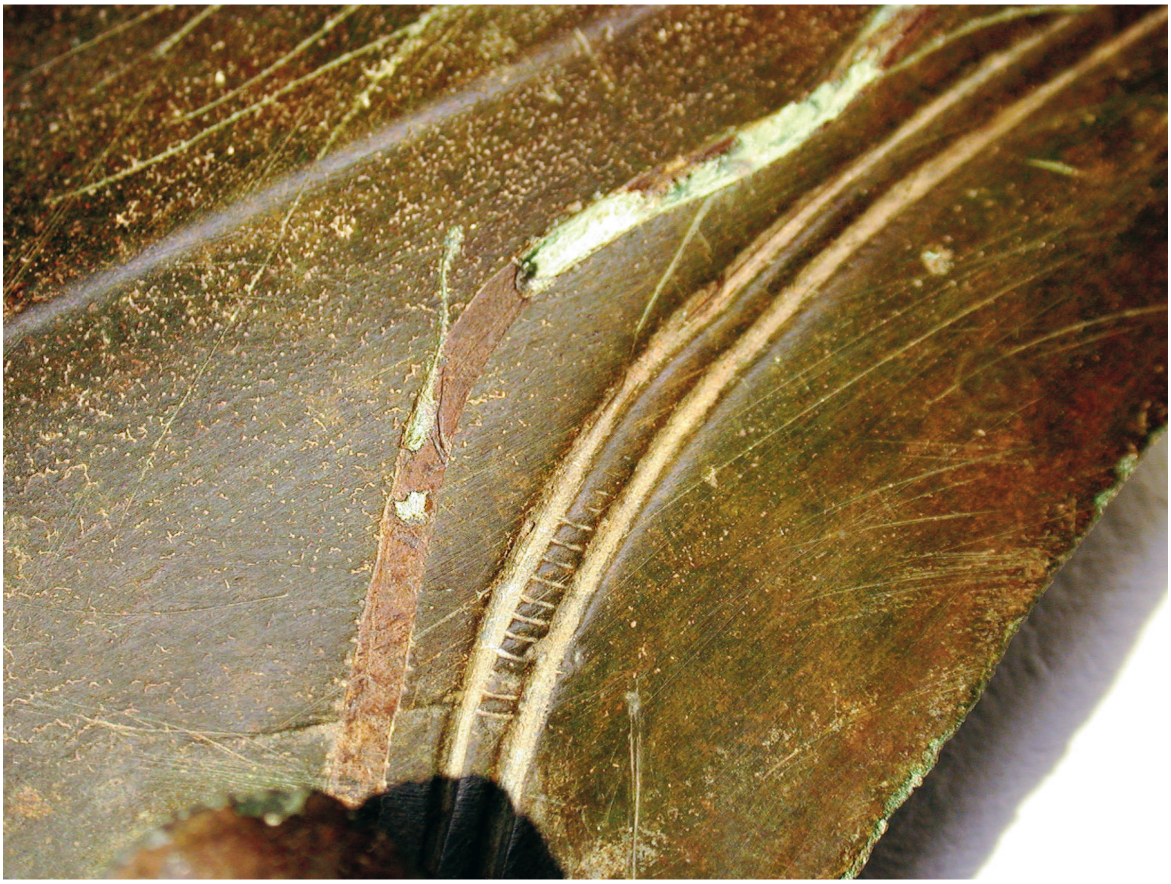

Figure 4. Remains of a red-brown inlay levelled to the surface of the blade from Vreta. Photo by Christian-Heinrich Wunderlich.

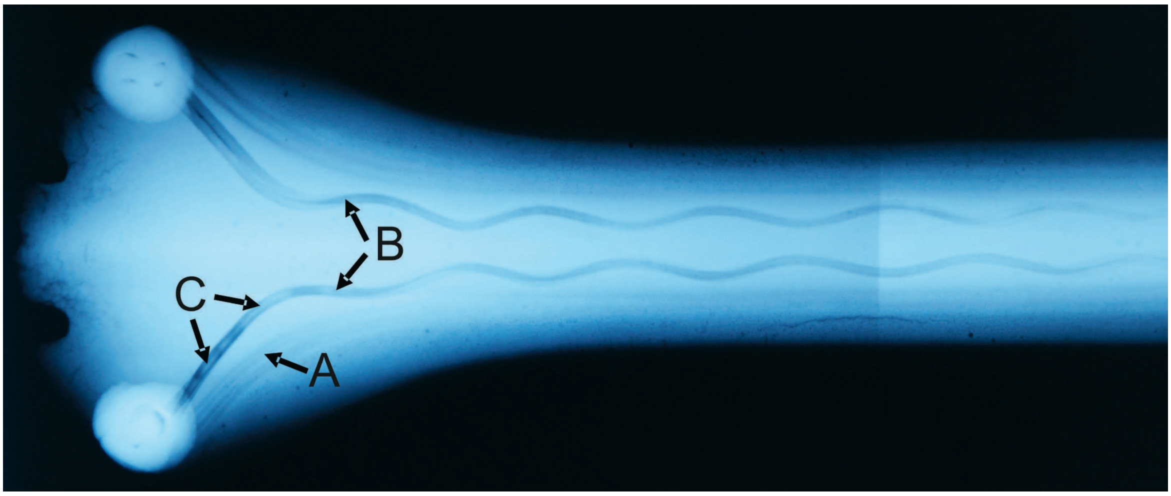

Figure 5. Radiography of the sword blade. The chased ornaments are marked by arrow A, facing strips by arrow B and the residual inlay by arrow C. Photo by Christian-Heinrich Wunderlich.

composition. An organic filling material such as resin would not attenuate the X-rays to the same extent as was seen here by comparison with the copper alloy of the blade. On the other hand, even a corroded metal inlay would cause a similar attenuation, because of the higher atomic numbers of the metal components.

Therefore, small fragments from the inlay were taken and a sample was removed from the sword blade by drilling (FG-050575). A drill sample was also taken from the blade of the "Marais de Nantes" sword (FG-050574), and the museum in Schaffhausen made a tiny sample of the inlay available to us. The bulk compositions of these samples were determined by energy dispersive X-ray fluorescence analysis (EDXRF) using a 0.3 mm-diameter collimator and a dual exposure procedure with tube voltages of 28 kV and 50 kV. Quantification and correction procedures were performed as described by Lutz and Pernicka (1996). The measurements were multi-repeated to achieve reliable compositional data for the blades. The small sample volumes from the Marais de Nantes sword and the corroded inlay of the Vreta Kloster sword are problematic as far as their representativeness is concerned. For more detailed studies, a polished section was prepared from an inlay fragment from the Vreta Kloster sword already used for the determination of its bulk composition, and this was examined with an optical microscope in bright-field and polarised reflected light and with a scanning electron microscope (SEM) equipped with an energy dispersive X-ray analyser (EDX).

There are no lead isotope data available for Swedish Bronze Age artefacts, but isotope ratios for further provenance studies were determined by means of a double-focusing multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) to provide data for possible future investigations.

Results

The chemical compositions of the samples from the Vreta Kloster sword are given in Table 1. The blade consists of a binary tin bronze with the typical 9:1 ratio of fairly pure copper to tin.

The bulk composition of the inlay of the sword from Vreta Kloster would also suggest a copper-tin alloy, but the inlay is in a completely corroded state and analyses of corroded metals or corroded metal surfaces can be fairly inaccurate. In this particular case the low sensitivity of EDXRF to light elements and the calculation procedure using a fundamental parameter model with a sum of 100% is problematic. A typical indicator of pseudomorphic replacement of the original alloy by corrosion products is the presence of a few percent of iron, evidently coming from the soil.

The corrosion of metals is a complex and fascinating field of scientific research, and copper alloys, notably bronzes, have been studied for more than a century. A review is given by Robbiola et al. (1998) and has recently been updated by Piccardo et al. (2007). One of the most intensively studied corrosion phenomena in bronzes is the de-alloying and re-deposition effect of tin (see Meeks 1993; Robbiola et al. 1998; Piccardo et al. 2007). Due to the enthalpies of formation of oxides and hydroxides of copper and tin, preferential corrosion of the tin-rich phases would be expected, but it is not uncommon for a residual and almost unattacked δ-eutectoid to be present in the corrosion layer of bronzes. Stannic oxides and hydrated stannic oxides hardly dissolve at all, so that the selective dissolving of copper from the solid solution can lead to an enrichment of tin compounds in the corrosion layers (Meeks 1993:265; Robbiola et al. 1998:2105). The analysis of corroded surfaces or corrosion products of copper alloys containing tin therefore generally yields tin values that are too high. In our experience, they are normally two to five times higher than in the alloy, depending on the state of corrosion. In the present case polarised light microscopy and EDX analysis revealed that the inlay of the sword mainly consisted of green hydrated copper carbonates (Fig. 6) with chlorine and sulphur contents of <1%. Cuprous oxide was present as a minor phase, mixed with tin-copper oxide and tin

Table 1. Chemical composition of the sword from Vreta Kloster (FG-050575) determined by EDXRF. All concentrations are given in mass percentages. The standard deviation σ relates to the precision of analysis of the blade.

	Fe	Co	Ni	Cu	Zn	As	Se	Ag	Sn	Sb	Te	Au	Pb	Bi
inlay	5.4	<0.01	0.03	88	<0.1	0.63	0.02	0.014	5.5	0.005	<0.008	<0.1	0.07	<0.01
blade	0.15	<0.01	0.11	90	0.1	0.14	0.01	0.015	9.1	<0.005	<0.005	<0.1	0.01	<0.01
σ	0.01		0.01	0.1	0.02	0.01	0.006	0.001	0.2				0.002	

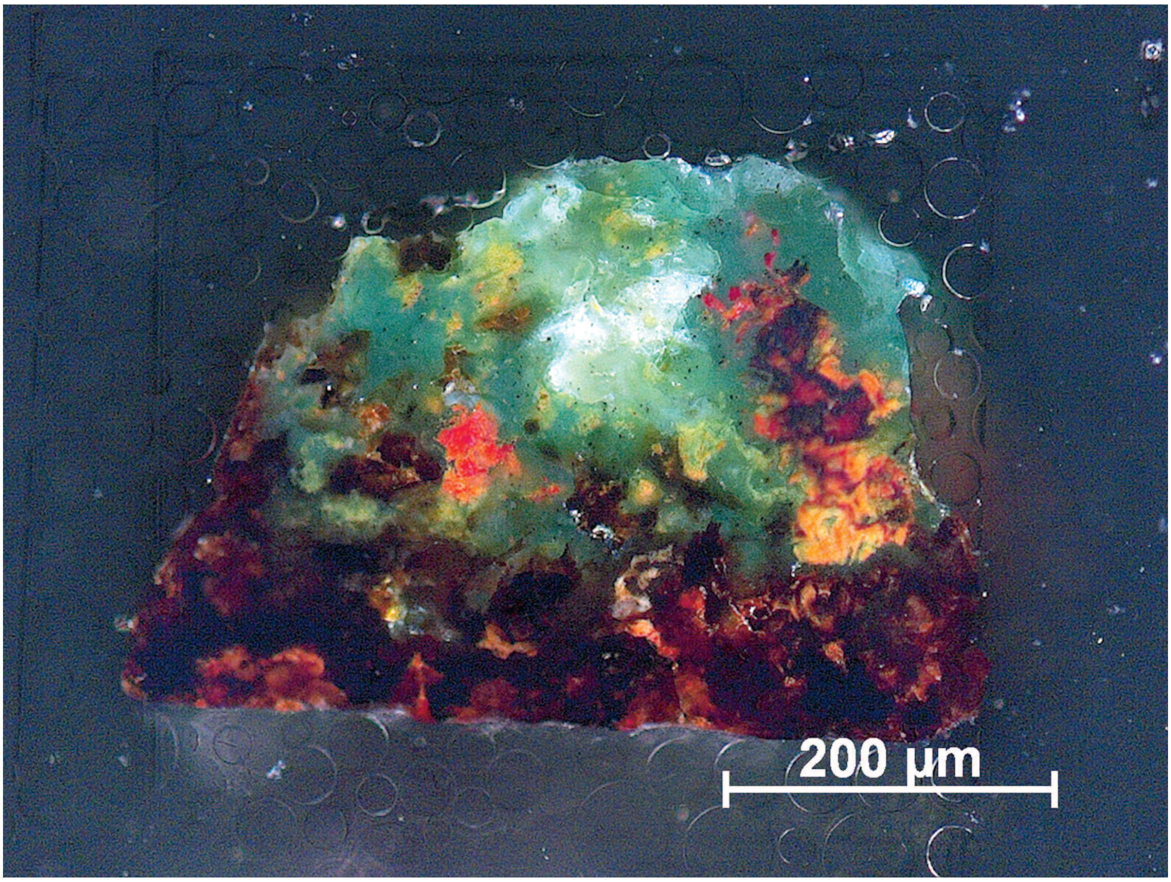

Figure 6. Light micrograph of a section of the copper and tin corrosion products under polarised light. The reddish-orange to brown-black areas (dark grey to black in the printed version) represent the tin-copper oxide and tin oxide compounds. Micrograph by Roland Schwab.

(hydro-)oxide compounds (Fig. 7). Thus the inlays investigated have been completely altered by corrosion and do not represent the original composition. The excessively high tin content is derived from decuprification and the accumulation of immobile tin compounds.

According to Robbiola et al. (1998) there should be a relationship between the patina and metal composition in terms of their Sn/Cu ratios. Using their proposed equation with their dissolution factor for copper of $f_{Cu}=0.94\pm0.04$, an original tin content of between 0.12 to 0.4% can be estimated. The inlay material most probably consisted originally of unalloyed copper with a natural impurities of tin (≤1%) and other trace elements (<1%). This assumption is supported by the results for the two swords from the Nebra hoard and by the analysis of the inlay on the sword from the "Marais de Nantes" (Table 2).

If not patinated, these inlays would originally have had a red copper-coloured appearance, contrasting nicely with the golden bronze-coloured blade. The darkening of the inlays would have been a result of weathering.

Since lead is an accidental contamination coming from the ore, the lead concentrations within the sample solutions were low. The lead isotope ratios of the sword from Vreta Kloster are given in Table 3. The lead concentration of the sample from the Marais de Nantes sword (FG-050574) was much less than 100 µg kg^{-1} (ppb), which too small for any useful determination of lead isotope ratios.

Discussion and conclusions

The swords from Nebra and from Vreta Kloster were originally bicoloured, and they represent very similar production techniques. The surface decorations were achieved by two different means: The ornamental

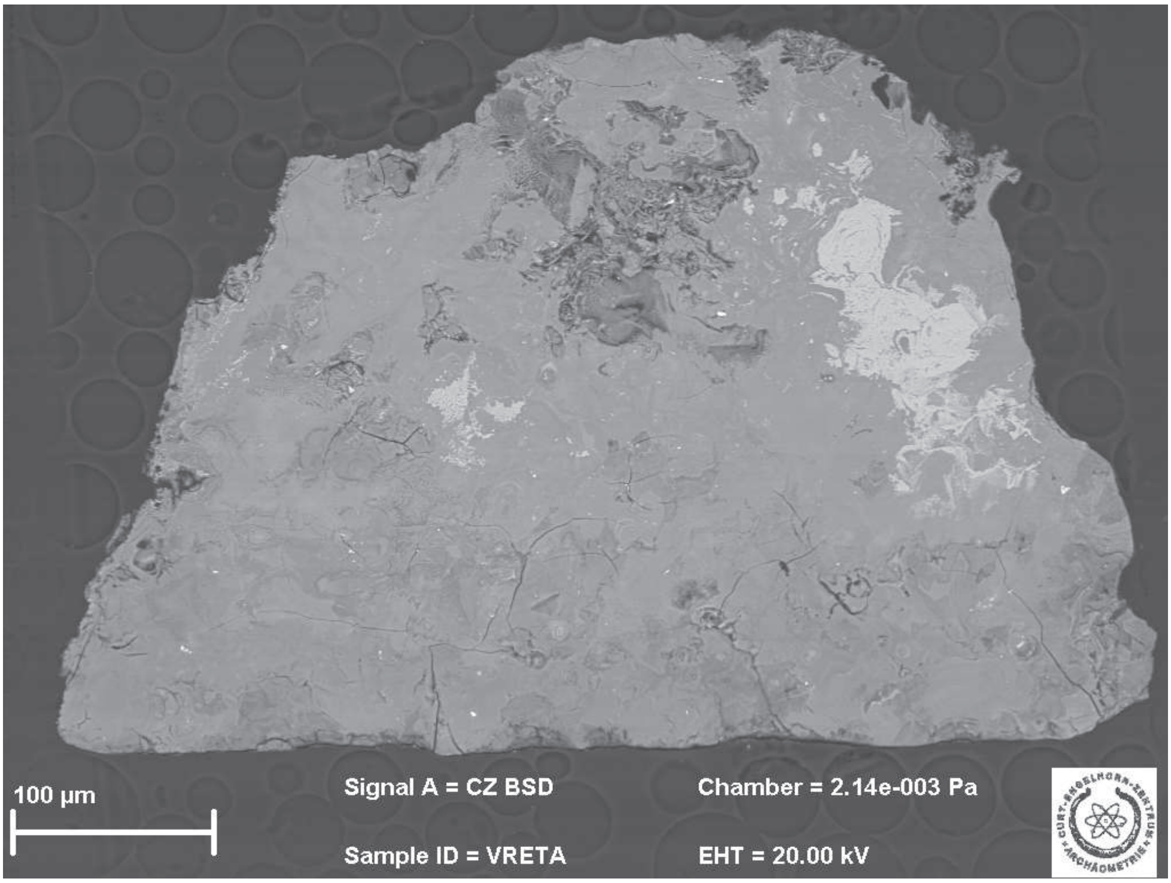

Figure 7. SEM backscattered electron image corresponding to Figure 6 and showing the contrast in atomic numbers between the mainly secondary copper corrosion products (grey) and the copper-tin compounds (white). The backscattering coefficient results from the high copper content of the residual copper oxide (Cu_2O) and the surrounding tin-enriched mixed compounds. Micrograph by Roland Schwab.

lines are chased, while the grooves for the inlays were cast and then incrusted with a second metal. The inlay could also have been deliberately patinated after grinding and polishing the surfaces.

It is likely that the inlays on the swords from Nebra and Vreta Kloster were originally black, as in the case of the two finds from Thun-Renzenbühl and the Marais de Nantes, and similar to the famous black patinated alloys from Egypt and Mycenae (Craddock & Giumlia-Mair 1993; Giumlia-Mair 2001). The inlay

Table 2. Chemical composition of the sword from the Marais de Nantes (FG-050574) as determined by EDXRF. All concentrations are given in mass percentages. The standard deviation σ relates to the precision of analysis of the blade. The amount of inlay sample available was less than 1 mg, which is too small for accurate determination by XRF. The trace elements are obviously overestimated and the analysis should be quoted as semi-quantitative.

	Fe	Co	Ni	Cu	Zn	As	Se	Ag	Sn	Sb	Te	Au	Pb	Bi
inlay	0.4	0.05	0.07	98	<0.1	0.18	0.07	0.01	0.12	0.11	0.47	0.3	0.08	0.02
blade	0.07	<0.01	<0.01	96	0.2	0.14	0.01	<0.005	3.8	<0.005	<0.005	<0.1	<0.01	<0.01
σ	0.03			0.1	0.05	0.003	0.008		0.04					

Table 3. Lead concentration in the sample solution and lead isotope abundance ratios for the sword from Vreta Kloster.

sample	Pb (μg kg $^{-1}$)	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
FG-050575	171	2.0998	0.86014	18.147

materials used on the swords from Nebra and Vreta Kloster, as on the "Marais de Nantes" sword, consisted of unalloyed copper with typical concentrations of natural impurities. Artificial patination with combined heat treatment and aqueous acidic solutions as proposed by Giumlia-Mair (2001:221), for example, would have led to a high-contrast appearance of the copper inlay relative to the blade, because of retardation of the copper oxidation kinetics by the tin used as an alloying element for the blade.

In line with these results, the sword from Vreta can be viewed in a wider perspective. Early researchers interpreted it as an import from central Europe (e.g. Montelius 1917; Gräslund 1967). Typologically, the swords from Nebra and Vreta belong to the Sögel blades, which copy the shape and decoration of Hajdúsámson-Apa swords (e.g. Lomborg 1960). The question of origin and area of production is as yet unresolved, but some light may be thrown onto it by the ongoing research on the Nebra hoard. Meanwhile it can only be stated that the lead isotope ratios of the sword from Vreta (Table 3) do not match those of the Nebra swords.

Concerning the provenance of the swords, the area between the rivers Danube and Tisza in present-day Hungary and Romania has been suggested, as also the production in present Germany (Hänsel 2000; Meller 2002:17). In her study of the transition between the Late Neolithic and the earliest part of the Bronze Age in Denmark, Vandkilde (1996:240) proposed that the swords and daggers of the Sögel and Wohlde type in southern Jutland could have been manufactured locally.

Polychrome surfaces with metallic inlays were almost unknown in central and northern Europe during the Early Bronze Age, however, and the only rare examples are those already mentioned in the introduction.

The technique itself was known since the late 3rd millennium BC, as witnessed by the extraordinary finds at Alaca Höyük in the Near East and in Egypt (Bittel 1976; Giumlia-Mair 1997; Meller 2002). In Europe it was primarily used on high-prestige objects in the eastern Mediterranean world during the earliest phase of the Late Bronze Age (Craddock & Giumlia-Mair 1993; Giumlia-Mair 1997).

The county of Östergötland, where the Vreta sword was found, hosts some exceptional weapons from very early in the Bronze Age, as axes, spears and swords have been found, mostly in bogs or wetlands. Among them are shaft-hole axes of the Fårdrup type,with an elaborated geometric decoration that is stylistically related to the bronzes of the Sögel-Wohlde type (Vandkilde 1996). The weapons are also depicted on numerous rock-carvings in the county, although the carving tradition in general is considered to have begun somewhat later. Also, another unique sword has been found in addition to the one from Vreta Kloster: a curved sword from the parish of Heda which is one of only five similar swords found in Denmark and Sweden. This has been interpreted as a copy of an ordinary sword stuck in a scabbard (Gräslund 1967). Because of the contexts of their discovery and their exceptional character, the Early Bronze Age weapons of Östergötland can be interpreted both as prestige objects and as ritual symbols. Although local bronze work started early in the area, several of the weapons are considered to have been imported (see Nordén 1925).

The history of the region during the Early Bronze Age corresponds to that of Scandinavia in general. Societies with strong ritual and political leaders may already have formed in Scandinavia around 2000 BC. In terms of cultures, the earliest Nordic Bronze Age is related to the contemporary Sögel-Wohlde culture of north-western Germany and the Tumulus culture of central Europe. Together they formed a cultural uniformity that extended over vast areas. To maintain their power, the Scandinavian leaders intensified systems of trade and exchange with central Europe in order to secure the flow of exotic prestige goods (see Kristiansen & Larsson 2005). As evidence of this communication and exchange, the sword from Vreta in Östergötland plays an important role as a technological and consequently cultural link with the Nebra find, with continental Europe and possibly with the eastern Mediterranean area.

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