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UV GAL RAPPORT 2014:22

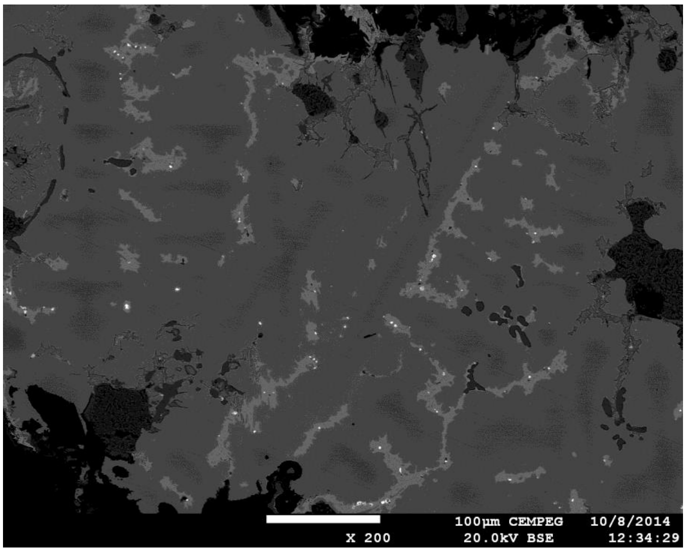
GEOARKEOLOGISK UNDERSÖKNING

Elemental analyses of bronze artefacts

Socketed axes, spears, swords and crucibles

Samples from Scandinavian Early and Late Bronze Age in Sweden and from abroad

Lena Grandin and Eva Hjärthner-Holdar



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On the cover:
A spear, period IV, from Bohuslän (Kville) (UM1102:1). Photo: J.Ling.
The same spear in an analysed detail of the section of the sample. Photo from the electron microprobe illustrating the bronze phases in various grey colours. The brightest spots are droplets of lead.

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Contents

Abstract

Bulk elemental analyses have been made by WDS-technique on 11 bronze artefacts by Geoarchaeological Laboratory (GAL) on commission by Johan Ling at the Department of Historical Studies:Archaeology, University of Gothenburg. The current analytical project is a continuation on a previous project "Extraction of copper in Sweden during the Bronze Age? Possibility, myth or reality?" (Ling *et al.* 2013, 2014) that by analysing 70 bronze artefacts from Swedish Bronze Age sites stated that casting was made using imported metals (copper and tin) from several sources in Central Europe and the Mediterranean area.

Twelve artefacts from Early (EBA) and Late Bronze Age (LBA) mainly from Bohuslän but also from Halland were sampled at Göteborgs stadsmuseum and at Bohusläns museum. The artefacts comprise mainly socketed axes, swords and sickles. In addition droplets from crucibles were collected, representing casting debris from one site in Bohuslän (Lyse) and one in Halland (Grimeton). Two artefacts in the collection of Göteborgs stadsmuseum from Romania and one from Hungary were also integrated in the study. Some of the samples were severely corroded and bulk data could not be achieved for three of them.

In general the currently analysed artefacts from several periods of the Scandinavian Bronze Age that were analysed match the chronological-compositional pattern that has previously been demonstrated (Ling *et al.* 2014. This means that, in general, the artefacts from EBA contain the trace elements nickel and arsenic and also sulphides. Artefacts dating to LBA, although only a few Scandinavian are included in this study, also present the general feature earlier shown. That is, either rather free from impurities, like the socketed axe from Naverstad (period V). The other compositional group from LBA presents signatures characteristic of copper ores of the Fahlore type, here containing all four of arsenic, antimony, silver and nickel. This is seen for example in a droplet from crucibles from the metal working site from period V at Lyse, Bohuslän.

Two Romanian artefacts from the collection in Göteborgs Stadsmuseum, an axe and a sickle, deviate from most of the Scandinavian samples. They are more similar to other Romanian samples.

Yet another outcome of the analyses is how to apply compositional data for chronology. The spear GAM 2032 has been discussed, on typological basis whether it should be from EBA or LBA. However, the chemical composition is typical of earlier periods and therefore we suggest that it derives from period II.

Introduction and background

Geoarchaeological Laboratory (GAL) has made metallographic and elemental analyses on bronze artefacts mainly from Bohuslän, Sweden on commission by Johan Ling at the Department of Historical Studies:Archaeology, University of Gothenburg. Additional artefacts that were analysed are from Halland in Sweden and also some axes and sickles from Austria-Hungary and Romania. The foreign artefacts have been in the museum collections since the 19th century. The analytical work is financed by research grant from Lennart J Hägglunds Stiftelse to Johan Ling.

The artefacts were sampled at Göteborgs Stads museum and Bohusläns museum in Uddevalla by GAL in cooperation with Johan Ling and the museum staff. Special thanks to Else-Britt Filipsson and Anna Adrian at Göteborgs Stadsmuseum and Ingela Lundin at Bohusläns museum.

The samples were generally cut by a pair of tongs. For thicker artefacts a saw, with a single-use blade, was used. In addition metallic droplets were carefully removed from crucibles. The samples are generally small metallic fragments, one or a few millimetres in size. A few were, however, even smaller.

The first priority for sampling was to achieve material for elemental and lead isotope analyses. Sampling positions were selected in order to minimize destruction of the artefacts. This means that samples were taken close to previous damages, and in most cases this means at the socket side rather than at the edge. In most samples the outer surface of the artefact is included and the orientation from surface and inwards can be followed. These however, comprise very short distances and are not selected for studying variation in working techniques within or between artefacts. Still, in the metallographic examination this will briefly be described when relevant.

The currently sampled artefacts mainly comprise swords and axes of various types. In addition also droplets from crucibles have been given priority to be able to define the casting alloys. The artefacts are chronologically distributed from Early to Late (Scandinavian) Bronze Age

Methods

The cut samples were split into one part used for elemental analyses and another for lead isotope analyses. Samples for elemental analyses were mounted in resin, ground and finally polished. Subsequently, an optical microscope with polarised reflected light was used in order to define the structure and texture and prepare for succeeding wavelength dispersive (WDS) electron microprobe analyses (EMPA).

We carried out the elemental analyses at the Centre for Experimental Mineralogy, Petrology and Geochemistry at Uppsala University using a field emission electron microprobe (JEOL JXA-8530 F), with an acceleration voltage of 20.0 kV and an electron beam current of 20.0 nA Point analyses as well as area scans were made. The point analytical function was applied for each separate phase in the copper alloy, especially for cast textures, and also for the distinct lead droplets or sulphides distributed in homogenous or multi-phase alloys. The area scans (50 by 50 microns) were distributed along traverses to attain the bulk chemical composition of the alloy. Due to the common heterogeneity of copper alloys, multiple area scans were made and mean values calculated. The obtained analytical data were related to standards (oxides, sulphides, metals) and ZAF corrected. Detection limits are presented for each element in table 2, together with the detailed results. The bulk elemental data is compiled in table 2.

Lead isotope analyses were carried out at the Laboratory for isotope geology at the Swedish Museum of Natural History (Stockholm), using subsamples of most of the artefacts. In a few cases (droplets from crucibles) the same sample that was used for elemental analyses was re-used for lead isotope analyses. The results from the lead isotope analyses are not included in this analytical report, but will be presented elsewhere.

Results

The general background information for each artefact is short, presenting the site and county and parish were it was found as well as chronological designation based on typology. The samples from Bohusläns museum is presented by a by a photograph marking the sampling site. For photographs of artefacts from Göteborgs Stads museum, we refer to their database “Carlotta”. The samples from the artefacts are described briefly in terms of structure and texture as they appear in the polarising microscope. In many a dendritic structure characteristic of casting is obvious; in others a grain structure indicating cold working is observed. Designated colours of various phases are given as they are observed in the optical microscope. Generally they refer to copper-rich phases of bright red and/or yellow tints. Phases that are richer in tin (referred to as high-alloy in the text and tables) are generally bright grey. Darker grey colours are normally observed for sulphides, generally containing copper, and occasionally also iron.

In addition to this, the general features observed in the electron microprobe, generally by the back scattered electron image (BSE), will be described. Normally droplets of lead are difficult to discern in the optical microscope. These are however easily recognised in the electron microprobe in which heavier elements, as lead, appear brighter than lighter elements, as copper. Elemental composition is given in short for each sample but all results of the elemental analyses are collectively assessed.

Sample description

GAM 20288, socketed axe, period IV, from Austria-Hungary

The nearly rectangular sample (from the socket), ca 5×1.5 mm in size, presents a metallic surface that is corroded along the outermost rim and in patches in more central areas in the cross-section. In optical microscope a multi-phase alloys is observed. The alloy is dominated by two bright phases (slightly red and yellow). In the BSE-image in the microprobe these are also clearly separated resulting in different Cu:Sn-ratios (1.6 and 12 % Sn).

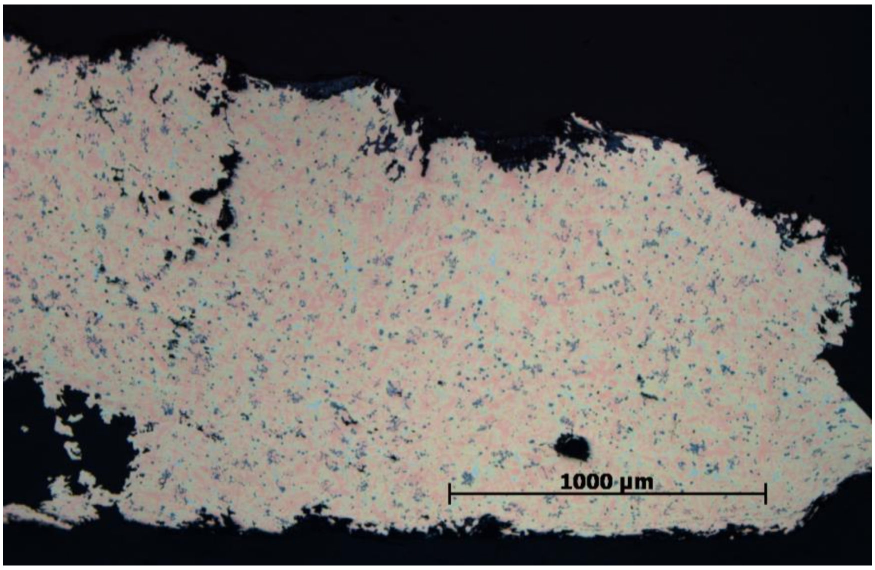
A subordinate, lighter grey high-alloy phase is rather frequent and homogeneously distributed. In this the Sn-content exceeds 29 %. All three phases are generally free from impurities.

Common is also a dark-grey, dendrititic phase that also is homogeneously distributed all over the surface. This is a copper sulphide with traces of iron.

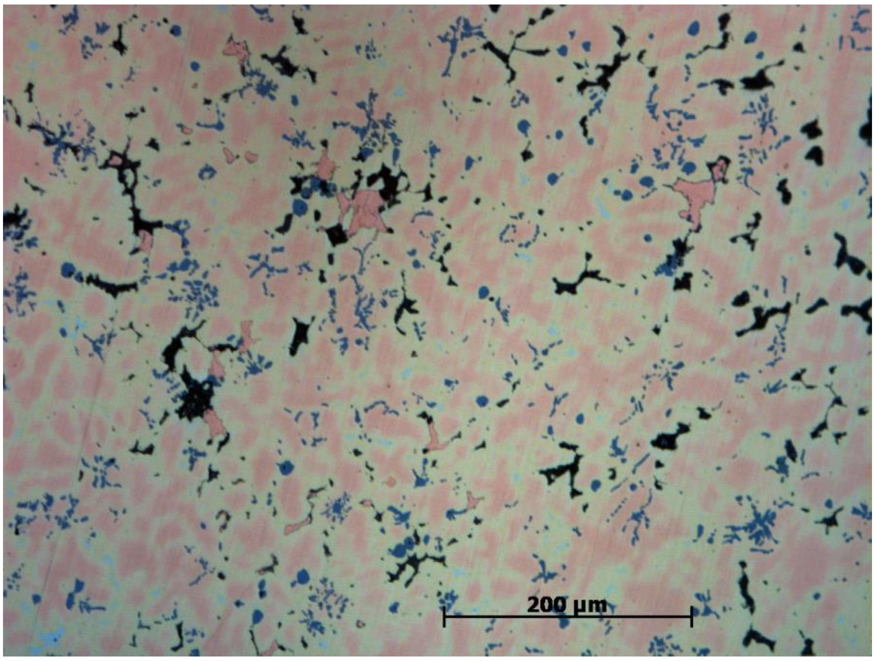
A few observations of metallic copper are generally in close contact with corroded areas and are probably secondary formations, inheriting the primary texture of the high-alloy phase. These are not analysed by WDS but a test with EDS shows it is pure copper.

In the BSE-image only very few droplets of lead can be distinguished. EDS-analysis confirms it to be lead with traces of bismuth.

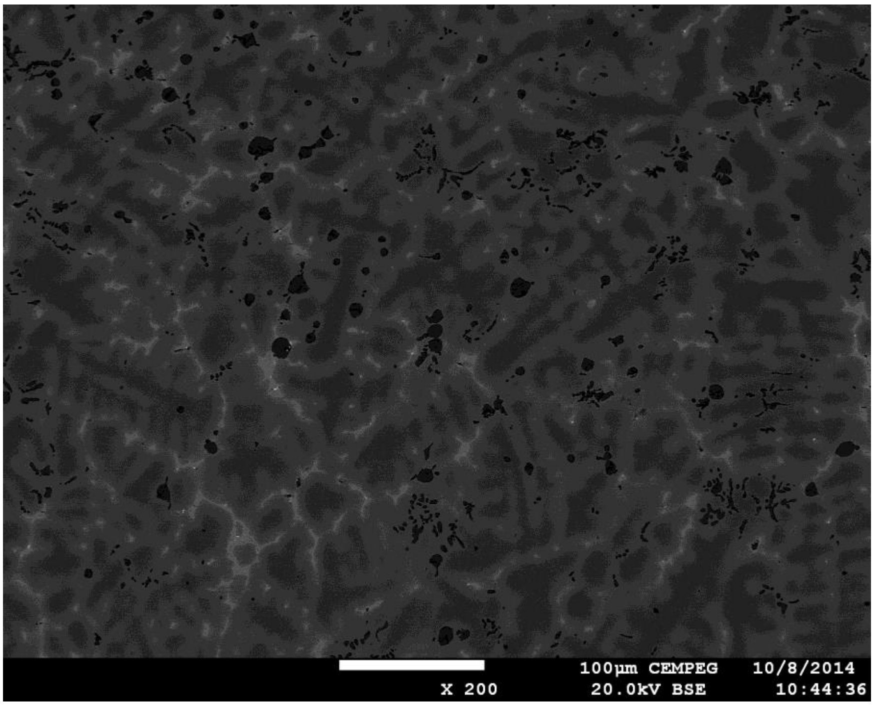
The bulk composition shows a bronze with c. 7 % Sn. The sulphides contribute to a total content of c. 0.8 %. The over-all lead content is very low.



GAM 20288, an overview of the analysed cross section clearly demonstrating the multi-phase alloy (photo with enlarged contrast to easier discriminate the phases). Photo GAL.



GAM 20288, detail of previous photo in which several phases can be distinguished in the alloy, including sulphides (dark grey) and (probably secondary) metallic copper in red. Photo GAL.



GAM 20288. Photo from the electron microprobe (BSE-image) in which several phases can be distinguished in various grey colours. Dark are light phases (sulphides). The two most frequent are the copper-rich bronze and the brighter the tin-rich phase in the bronze. Only a few small bright droplets of lead can be seen. Photo GAL.

GAM 2032, spear, period II, from Bohuslän (Orust)

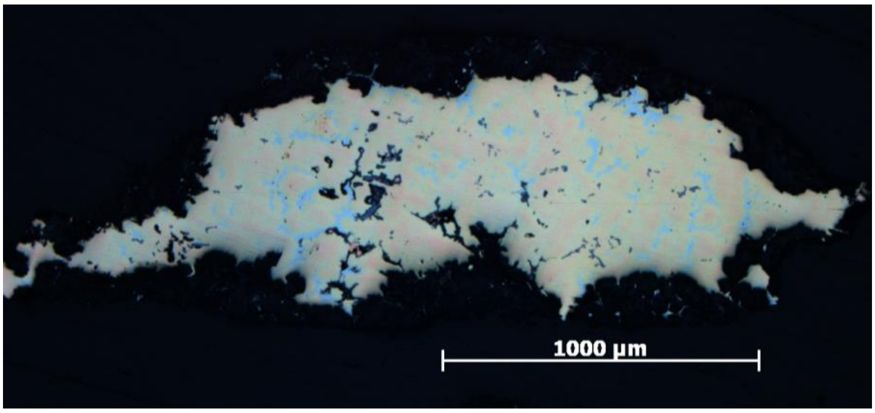
The irregular sample (from the socket), c. 3×1 mm in size, is corroded in its outer parts with preserved metal in the core. In optical microscope a multi-phase alloy is observed. The alloy is dominated by two bright phases (slightly red and yellow). In the BSE-image in the microprobe these are also clearly separated resulting in different Cu:Sn-ratios (5 and 12 % Sn).

A light-grey, high-alloy phase is concentrated along what appears to be grain boundaries. In this the Sn-content is c. 28 %. In all three phases, Ni is present in concentrations varying from 0.3 to 0.6 %.

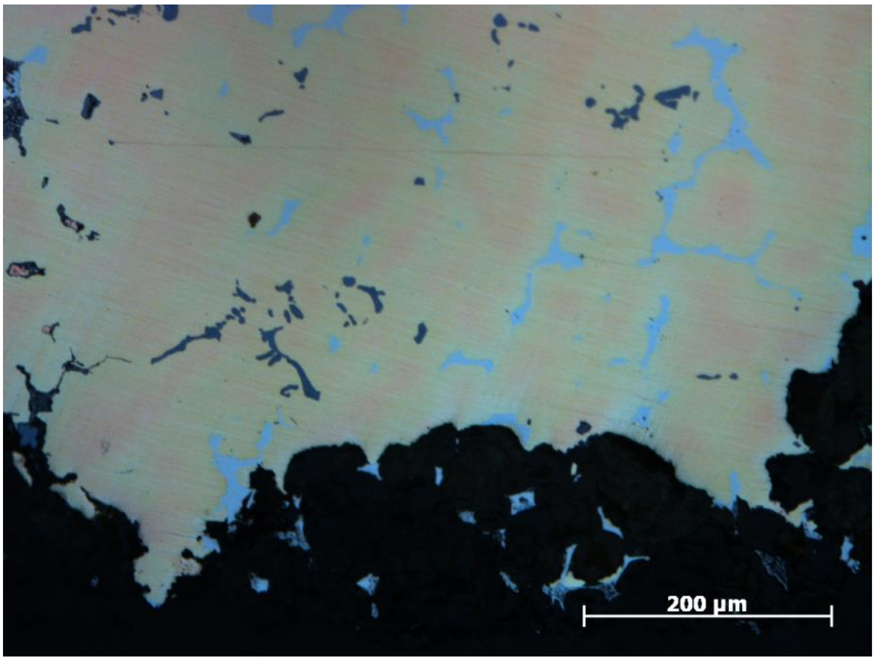
In addition, a darker grey dendritic phase is distributed in the metal. This is a copper sulphide with traces of iron.

A few occurrences of metallic copper are observed, probably secondary formations. Along the rim the corrosion is selective discerning only the high-alloy phase.

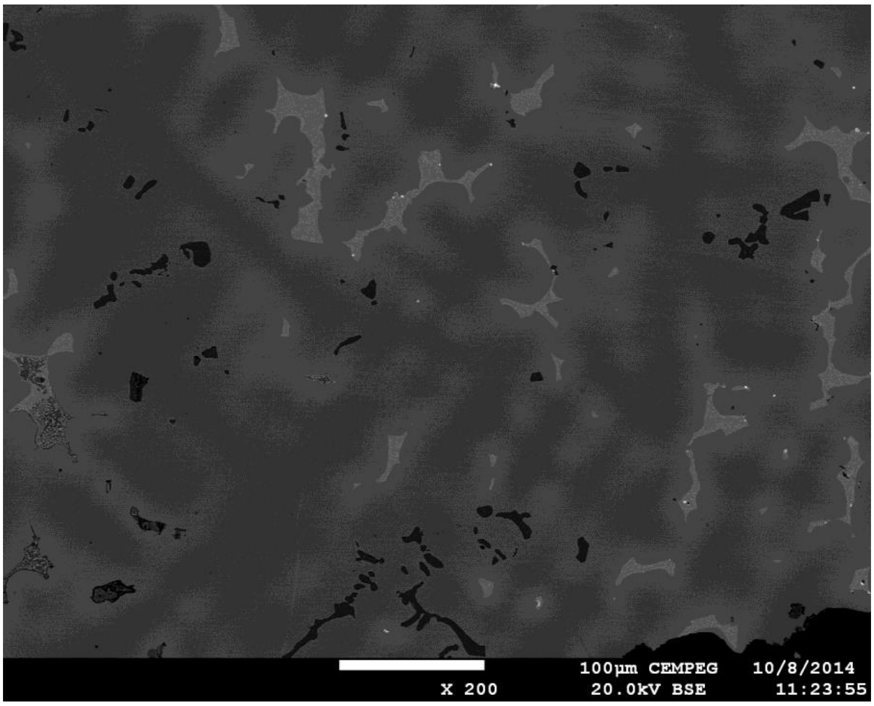
In the BSE-image a few small droplets of lead are visible. EDS-analysis of these confirms they are lead. However, the total content is too low to be reflected in the bulk composition (c. 0.01 %). The overall Sn-content is c. 10.5 % and Ni 0.3 %.



GAM 2032, an overview of the analysed cross section. Photo GAL.



GAM 2032, detail demonstrating the multi-phase alloy in red, yellow and bright grey, and the sulphides (dark grey). In the lower part the partly corroded rim is observed in dark grey with only the bright grey phase unaffected. Photo GAL.



GAM 2032. Photo from the electron microprobe (BSE-image) in which the three alloy phases can be distinguished in various grey colours. Dark patches are sulphides. In addition, a few small bright droplets of lead can be seen. Photo GAL.

GAM 5900, droplets from crucible, period II, from Halland (Grimeton)

Two small droplets, slightly less than 1 mm in diameter, were removed from the crucible's interior. In optical microscope one is observed to be metallic in its core (1) while the other one (2) is totally oxidised.

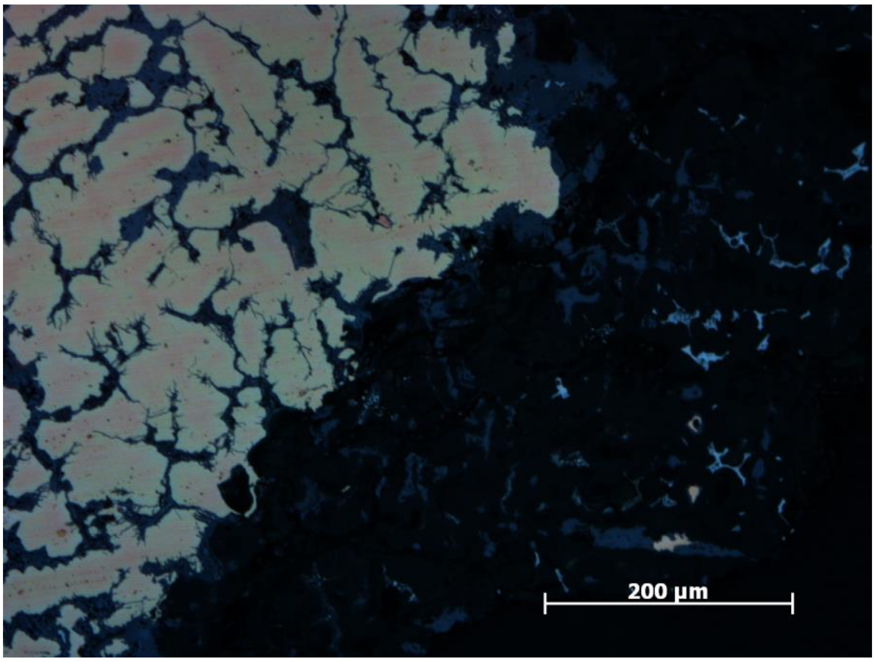
The one with a metallic core (1) is made of a multi-phase alloy dominated by a red and a yellow phase. In the BSE-image in the microprobe these are also clearly separated resulting in different Cu:Sn-ratios (5 and 11 % Sn). Both contain Ni (c. 0.4 %).

Subordinate is a bright grey phase (high-alloy) with a content of nearly 33 % Sn and 0.8 % Ni. This phase is also present in the outer part where the two copper-rich phases are oxidised.

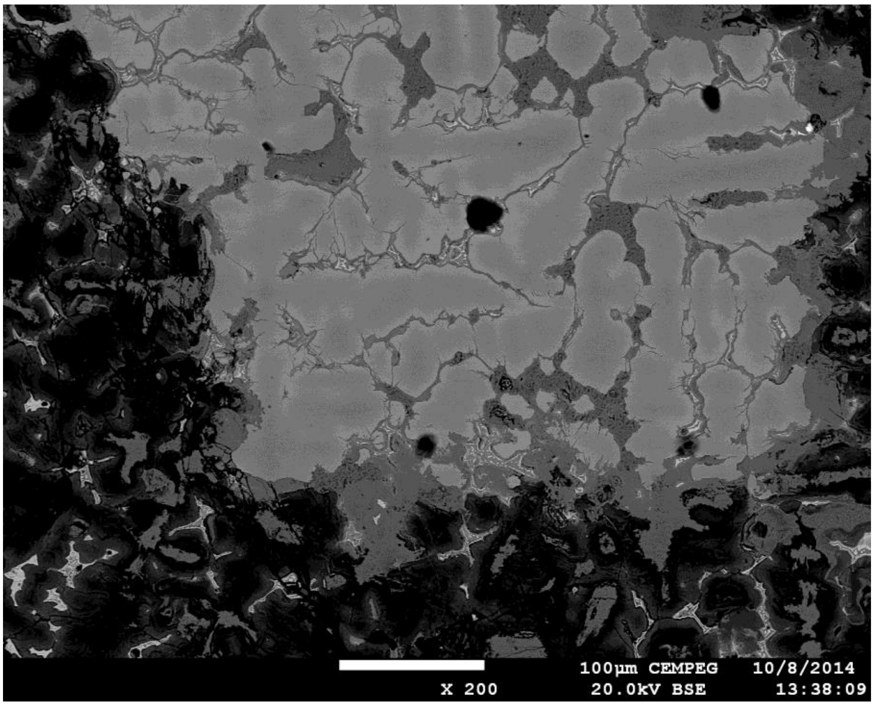
Small patches of metallic copper (secondary) are also present in the core. However, neither sulphides nor droplets of lead are observed.

The bulk composition presents a total Sn-content of c. 7% and c. 0.4 % Ni.

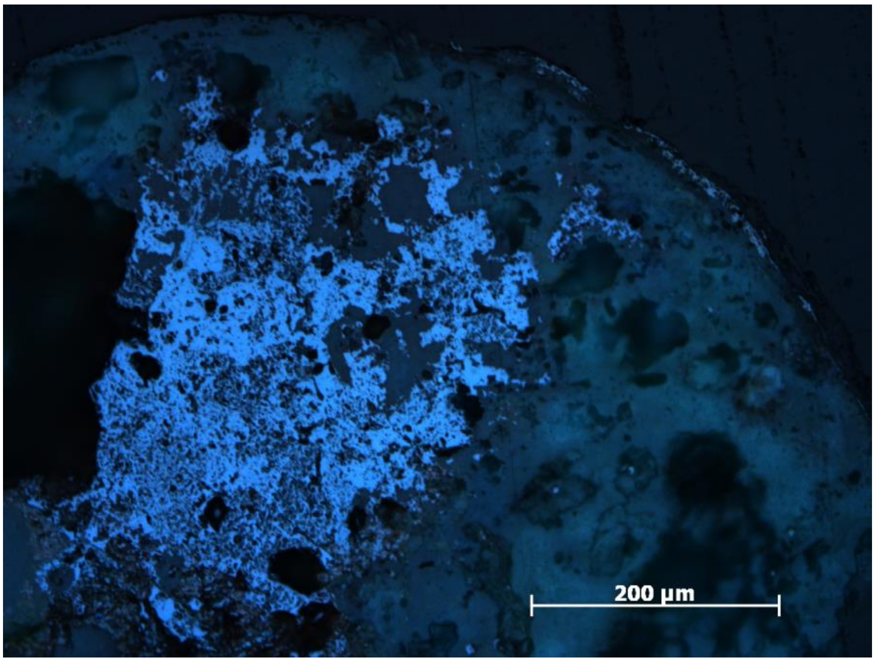
In the oxidised droplet (2) no metallic remains can be detected.



GAM 5900 (1). Detail from the analysed cross section. To the left the metallic alloy with two easily distinguished phases in red and yellow. To the right the corroded rim in grey with remains of a high-alloy bright grey phase. Photo GAL.



GAM 5900 (1). Photo from the electron microprobe (BSE-image) showing the two major phases in the bronze and the partly corroded areas (darker). In the lower part the corroded rim (dark) with remains of a high-alloy bright grey phase as in previous image. Photo GAL.



GAM 5900 (2). Detail from the analysed cross section of the corroded droplet in various grey colours. No preserved metal is observed. Photo GAL

GAM 5911, droplet from crucible, period II, from Halland (Grimeton)

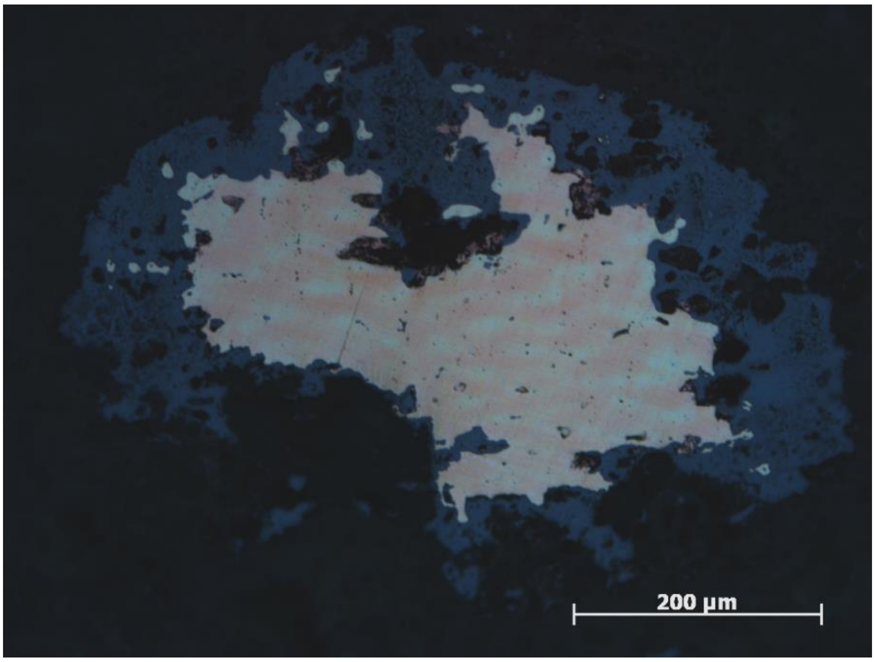
One droplet, ca 1 mm in diameter, is removed from the glassy inner surface of the crucible.

In optical microscope an extensively corroded alloy is detected. Only the inner core is metallic, surrounded by secondary products in the rim. The corrosion is extensive, and no textures that might be inherited from the metal can be detected. The metallic core is rather homogeneous but two copper-rich phases can be distinguished; one red and one yellow. In the BSE-image in the microprobe these are also separated resulting in different Cu:Sn-ratios (2 and 7 % Sn). Both phases contain Ni (c. 0.3 %). Antimony is also detected in one analysis, but not in any of the bulk data and therefore its presence is uncertain.

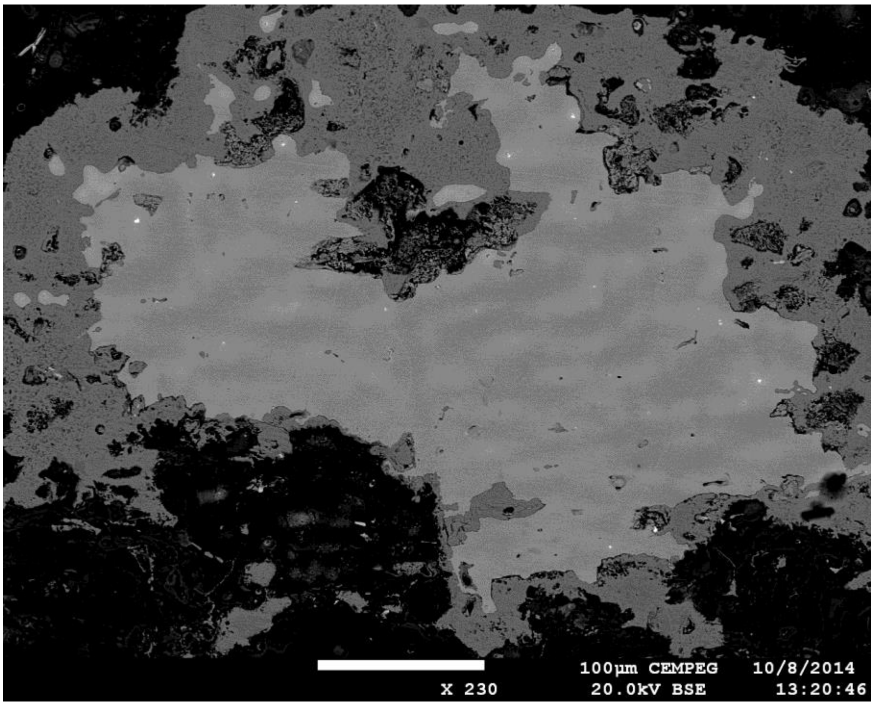
Neither a high-alloy phase, nor sulphides can be observed. However, in small patches metallic copper (secondary) is present.

In the BSE-image in the electron microprobe few small droplets of lead are observed but these are too few to be reflected in the bulk content.

The composition of the bulk alloy presents a Sn-content of c. 3.5 % and 0.3 % Ni.



GAM 5911. Detail from the analysed cross section of the corroded droplet. In the core the metallic alloy with two easily distinguished phases in red and yellow. Photo GAL.



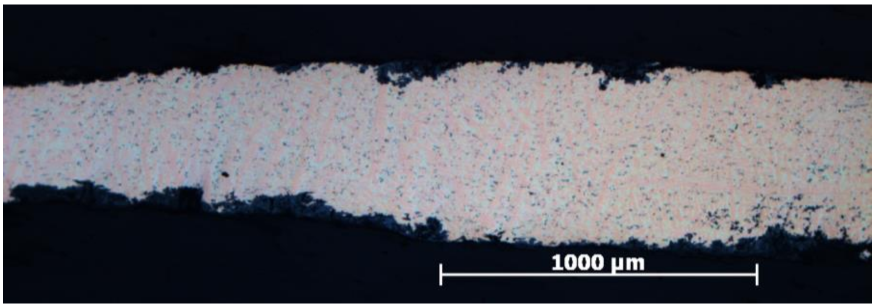
GAM 5911. Photo from the electron microprobe (BSE-image) on similar area as in previous image. The metallic alloy with two phases in the core surrounded by a corroded rim. In addition also a few droplets (bright) of lead are seen. Photo GAL.

GAM 7963, sickle, period IV, from Romania (Maros Ujvár)

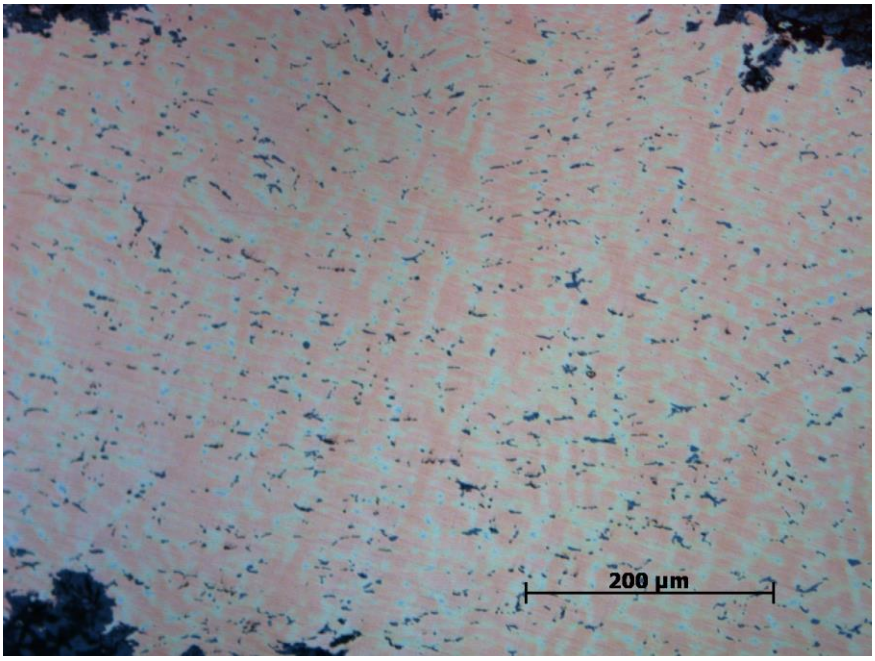
The triangular sample (from the edge), ca 4×1 mm in size, is mainly preserved metal. In optical microscope a multi-phase alloy is observed. A red dendritic, copper-rich phase is dominating. Subordinate is a yellow phase, somewhat poorer in copper. In the BSE-image in the microprobe these are also clearly separated resulting in different Cu:Sn-ratios (0.6 and 9.4 % Sn). Both also contain Ni (0.6–0.7 %). In the Sn-rich phase also Sb (1.2 %) and As (0.9 %) is noticeable.

Two grey phases are concentrated to the yellow phase. One is the high-alloy light grey phase with very limited frequency but high concentration not only of Sn (19 %) but also Sb (8 %), Ni (1.5 %), As (1.4 %). Also Ag and Bi is detected in the high-alloy phase. The other more common grey phase is (copper) sulphide.

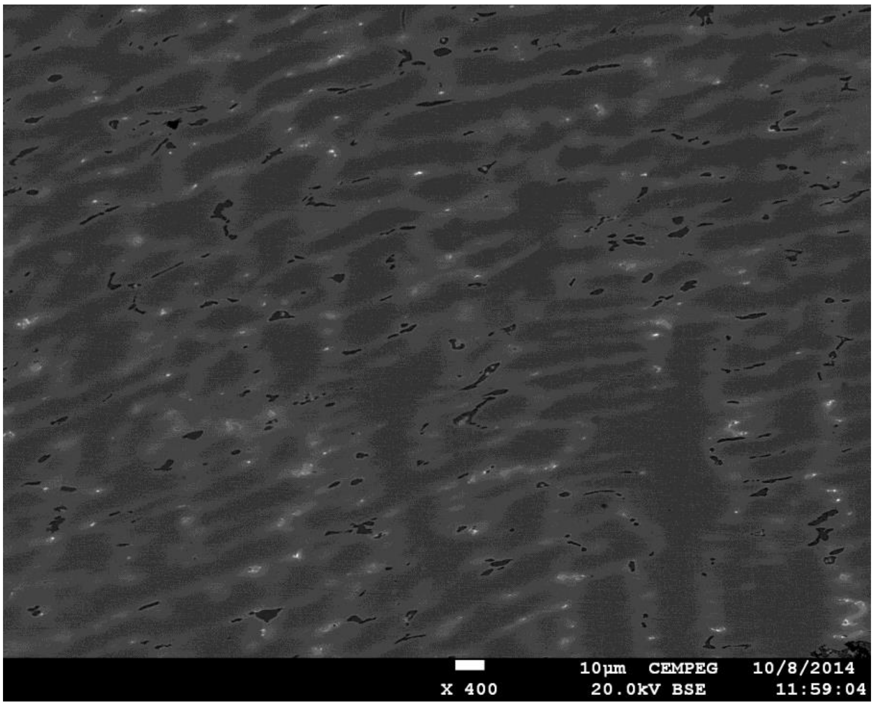
This artefact is much more fine-grained than e.g. GAM 7964 and GAM 20888. I addition the red, copper-rich, phase is prevailing which is reflected in the bulk content with comparatively low Sn of 3.4 %. Several trace elements are present: 0.5 % Ni, 0.4% As, 0.4 % Sb, and 0.4 % S.



GAM 7963. An overview of the analysed cross section clearly demonstrating the multi-phase alloy (photo with enlarged contrast to easier discriminate the phases). Photo GAL.



GAM 7963. Detail in which the multi-phase alloy is illustrated with the two dominating copper-rich phases in red and yellow and the subordinate high-alloy phase in bright grey. Also the more frequent darker grey sulphides are distinguished. Photo GAL.



GAM 7963. Detail from the electron microprobe (BSE-image) with two dominating copper-rich phases in grey and light grey, and the even brighter subordinate high-alloy phase. A few white spots are lead droplets. Also the more frequent darker grey sulphides are distinguished. Photo GAL.

GAM 7964, socketed axe, period IV, from Romania (Maros Ujvár)

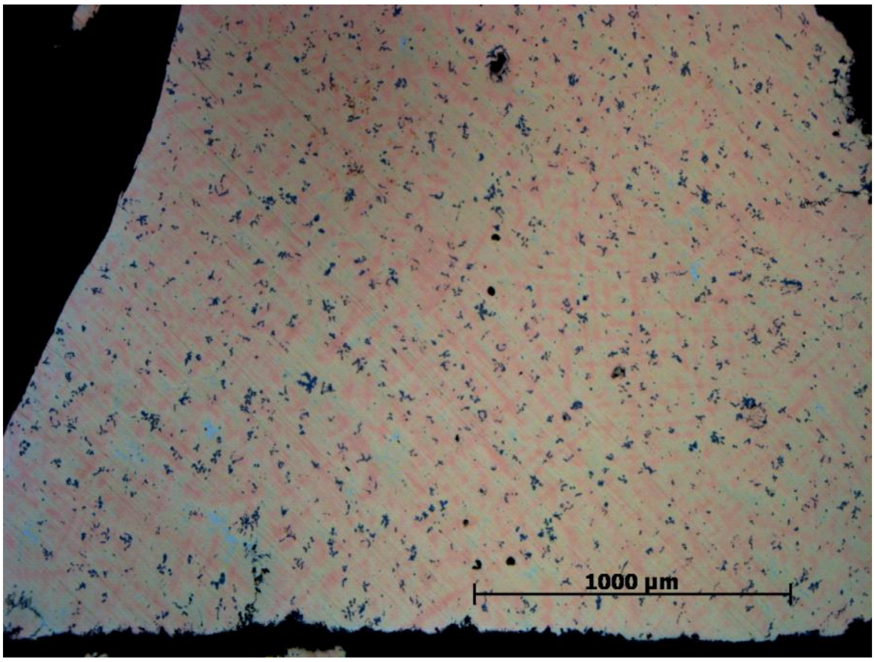
The irregular sample (from the socket), ca 3×2 mm in size, presents a fairly well-preserved metallic surface. Only the outermost rim is corroded. In optical microscope a multi-phase alloy is observed. The alloy is dominated by two bright phases (slightly red and yellow). In the BSE-image in the microprobe these are also separated resulting in different Cu:Sn-ratios (2 and 9 % Sn). Several other elements are present in concentrations at or below 1 % each (As, Sb, Ni and Fe) in general with slightly higher content in the Sn-rich phase.

A subordinate, lighter grey, high-alloy phase is present in a few concentrations. This is enriched in most elements found in the other two phases; 26 % Sn, 5 % Sb and 4 % Ni. However, As and Fe are lower. IN addition also low concentration of Ag is noted. In the BSE-image heavy droplets, confirmed by EDS to be lead with some Bi, are observed in close contact to this high-alloy phase.

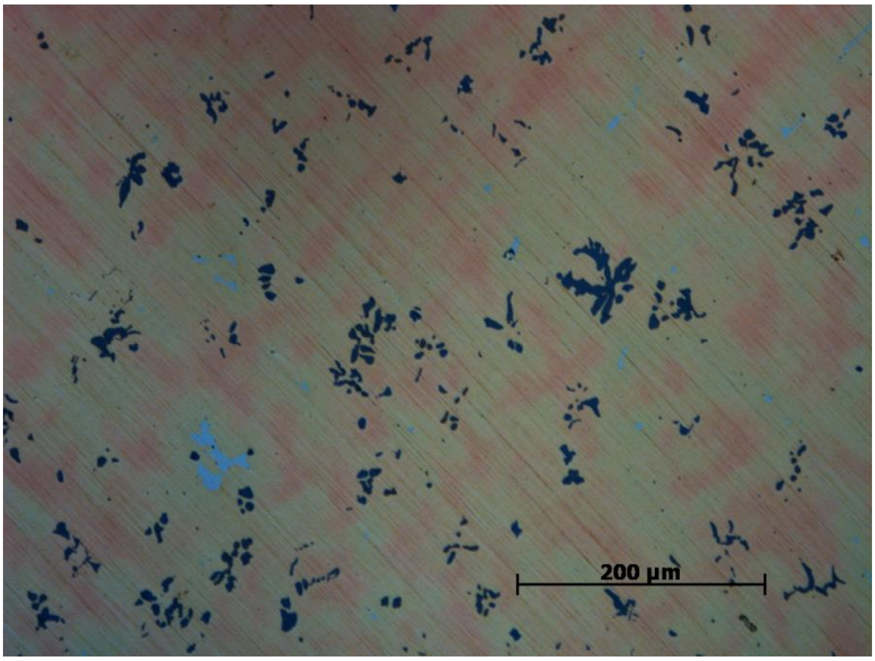
Common is also a dark-grey, dendritic phase homogeneously distributed all over the surface. This is a copper sulphide with iron content (2 % Fe).

Generally no other texture can be revealed, but in a few areas close to the rim, a selective corrosion gives an indication of a plain grain structure.

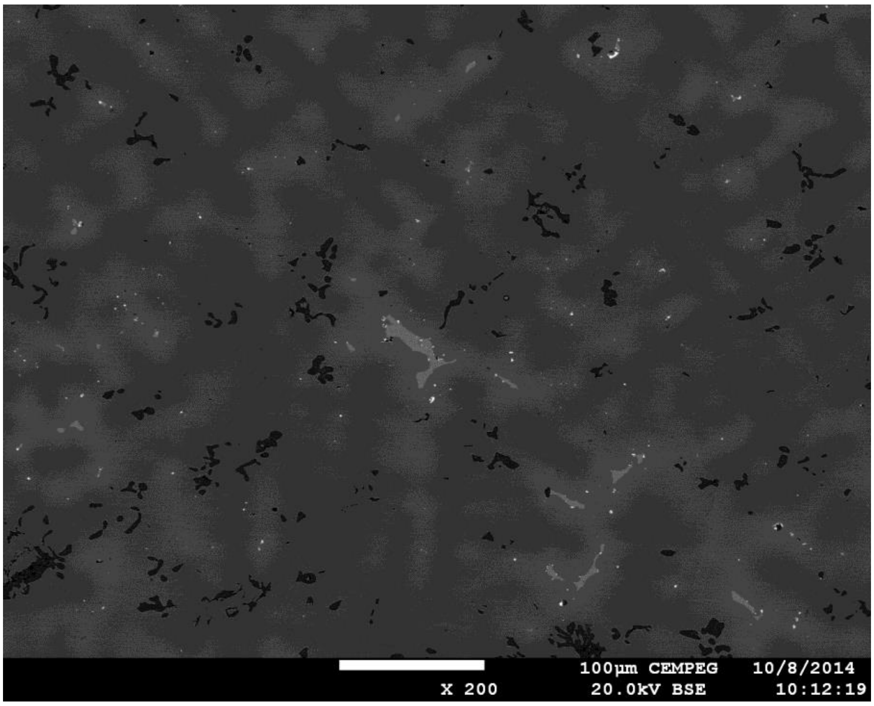
The bulk composition of the alloy is 6.4 % Sn, 0.6 % each of Sb, Ni and As, and 0.5 % S and 0.3 % Fe.



GAM 7964. An overview of the analysed cross section clearly demonstrating the multi-phase alloy (photo with enlarged contrast to easier discriminate the phases). Photo GAL



GAM 7964, detail demonstrating several phases in the alloy, including the bright high-alloy phase and the darker grey sulphides. Photo GAL.



GAM 7964, detail from the electron microprobe showing the same phases as in the previous image. In addition also the bright lead droplets are discerned. Photo GAL.

UM1102:1, spear, period IV, from Bohuslän (Kville)

The rectangular sample, 3×1 mm in size, is a cross section from the central part of the blade, near the ridge (not the edge).

In optical microscope it is observed that the outer part of the sample is nearly totally corroded and the core partly corroded. However, a multi-phase alloy can clearly be defined. The alloy is dominated by two copper-rich phases. Of this the yellow is more common than the red-coloured one. In the BSE-image in the microprobe these are also clearly separated resulting in different Cu:Sn-ratios (6 and 9 % Sn). They both also contain Sb (0.5 and 0.9 %), As (0.3 and 0.5 %) and Ni (both 0.3 %).

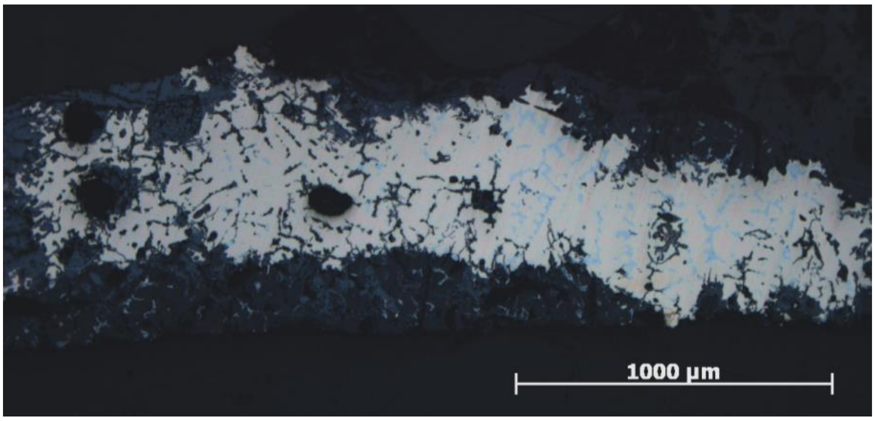
Subordinate, but frequent compared to most other samples, a light grey high-alloy phase is found in most of the sample. The Sn-content is 22 % and this phase is also enriched in the elements detected in the copper-rich phases; Sb (5 %), As (1 %), Ag (0.9 %) and Ni (0.5 %).

In addition, small, darker grey droplets (sulphide) are concentrated to a few areas in the central part, generally related to the high-alloy phase.

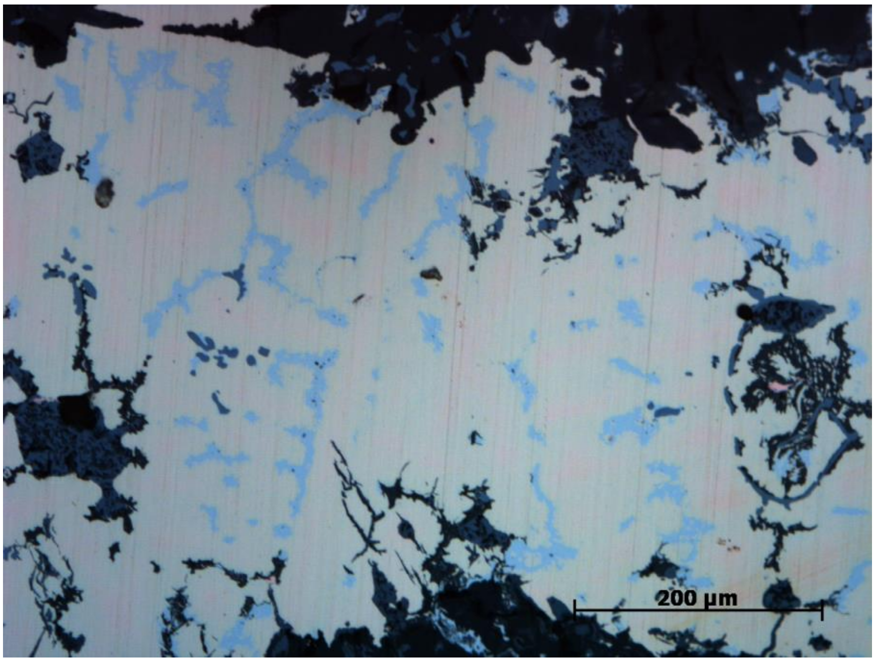
In the BSE-image a few lead droplets can also be observed, confirmed by EDS to also contain some Bi.

The bulk composition of the alloy is 9.8 % Sn, 2.1 Sb, 1.2 % S, 0.6 % As and 0.3 % each of Ag and Ni.

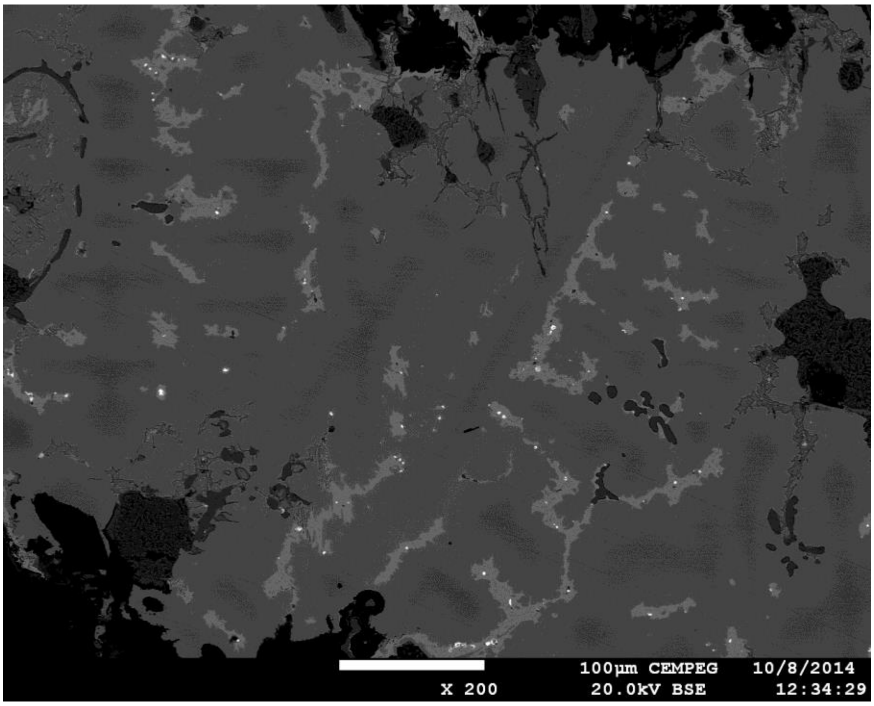
UM1102:1, spear. Sample from the central part of the blade. Photo J.Ling.



UM1102:1, an overview of the analysed cross section with selective corrosion in the central parts and more extensive along the surface (dark grey). Photo GAL.



UM1102:1, detail demonstrating the multi-phase alloy in red, yellow and bright grey and the dark grey sulphides. Secondary formed copper is seen to the right in contact with grey corroded patches. Photo GAL.



UM1102:1, detail from the electron microprobe from same area as above showing the same phases and in addition the bright lead droplets. Photo GAL.

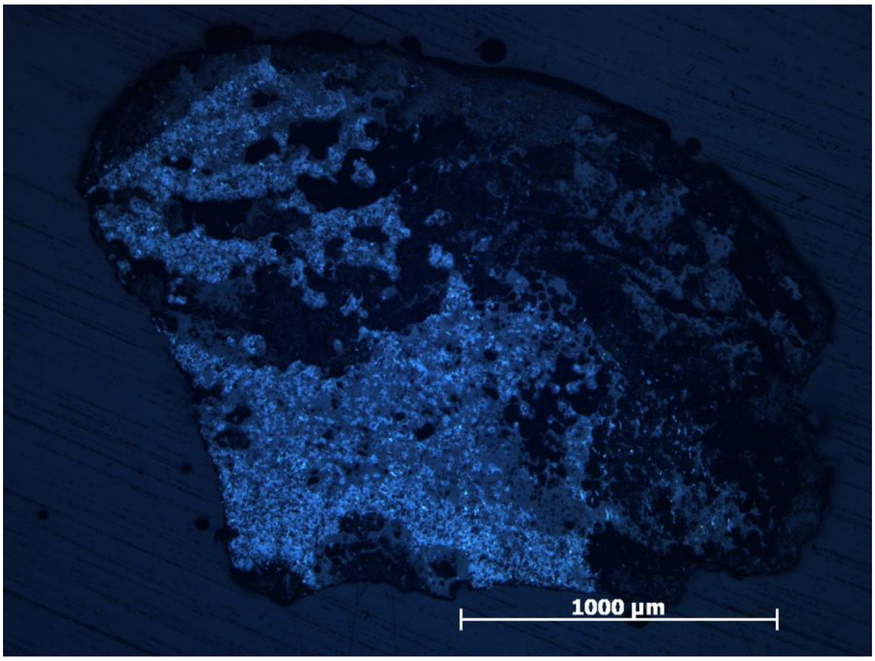
UM19634:1060, rod, period V, from Bohuslän (Lyse)

The cross section from the rod, measuring 3×2 mm, is almost totally corroded. Several, grey (copper) oxides can be discriminated. No metal is preserved from the expected high-copper phase(s) in the alloy. However, small globular or dendritic grey droplets are distributed all over the sample surface. Analyses with the EDS in the electron microprobe demonstrate that these are copper sulphides.

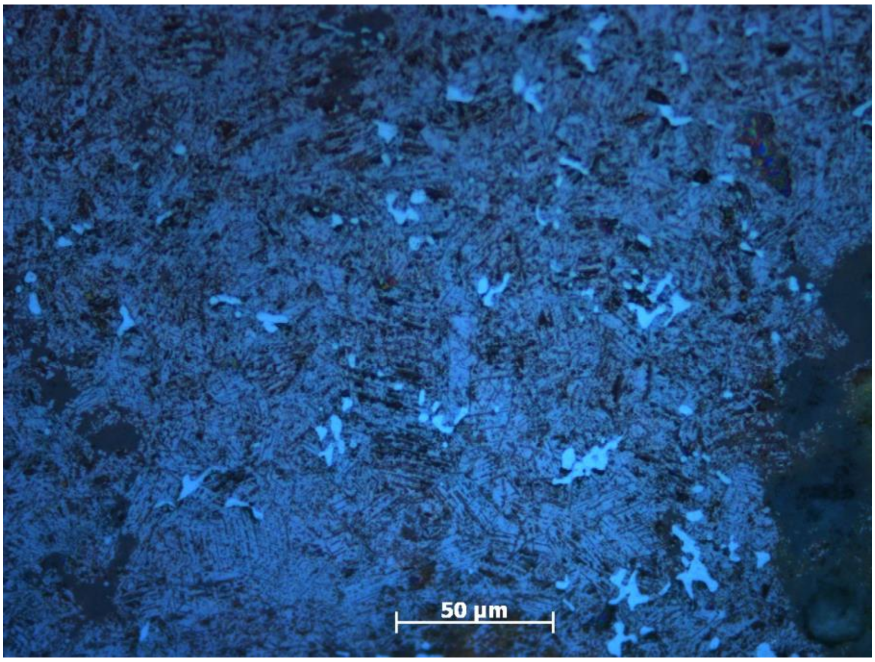
In the corroded areas in the core of the sample, the corrosion is selective revealing a (faint) grain structure from cold working, and twinning indicative of annealing.

No bulk composition was determined in this corroded sample. However, a search for trace elements showed that As is present.

UM19634:1060, rod. Sample from broken end. Photo J.Ling.



UM19634:1060. Overview of the analysed cross section of the corroded sample in various grey colours. Photo GAL.



UM19634:1060. Detail from the corroded sample in various grey colours. However, the bright grey irregular lumps are copper sulphide as in many other samples. In addition a grain structure with twinning is discerned (thin black lines in grey matrix). Photo GAL.

UM19634:2540, droplet from crucible, period V, from Bohuslän (Lyse)

A droplet, 2–3 mm in diameter, is removed from the inner part of the crucible fragment. Most of the sample is metallic. Only a very thin rim is corroded. Part of the rim is covered with a glassy, or microcrystalline, thin film, probably rich in silicates from the molten crucible. In this film, also small droplets of copper (confirmed by EDS) is observed. Along another part of the rim a complex concentration of silicates (?) contain light grey crystals of tin oxide (EDS).

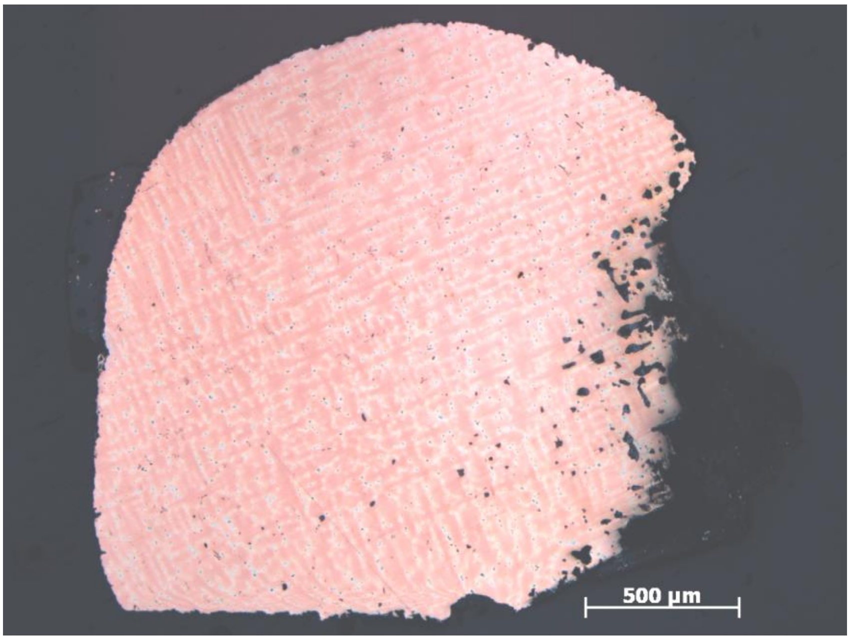
In the large droplet, a multi-phase alloy can be distinguished in the optical microscope. The alloy is dominated by two copper-rich phases; one red and one yellow. In the BSE-image in the microprobe these are also clearly separated resulting in different Cu:Sn-ratios (0.3 and 2.8 % Sn). Both also contain Sb (0.3 and 4.5 %) Ag (0.4 and 0.7 %) and Ni (0.7 and 0.5 %). Arsenic is detected only in the high-Sn phase (1 %).

Subordinate is a light-grey high-alloy phase with 2.8 % Sn. It is however dominated by Sb (28 %). Notable is also As (2.7 %), Ag (2.3 %) and Ni (1.1 %).

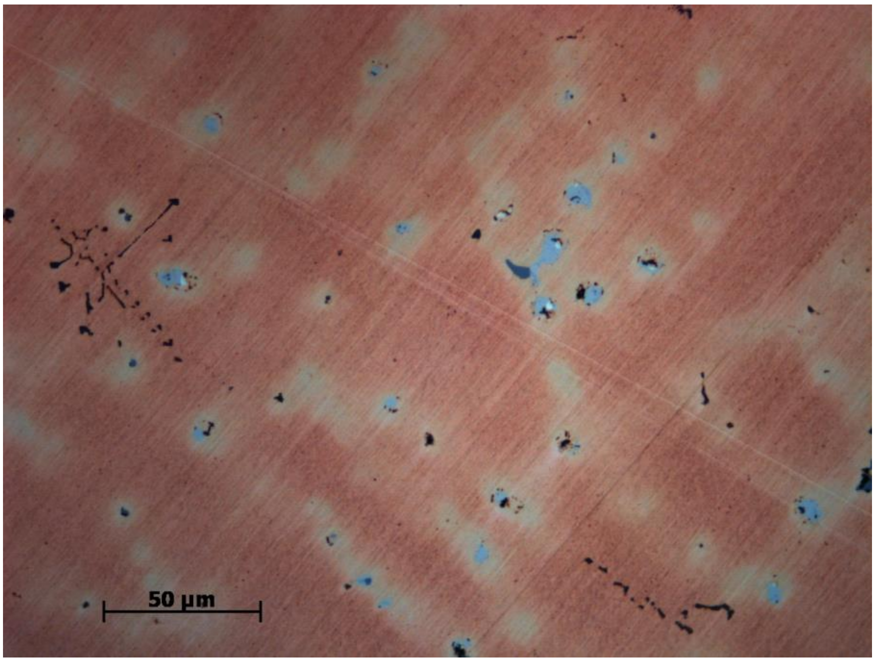
Also subordinate are darker grey sulphides. An additional phase comprises angular formations of tin oxide, included in the alloy. In the BSE-image also bright spots are observed, with a feature characteristic of lead. However, EDS-analysis reveals that these are Ag-dominated.

The bulk composition of the alloy is 0.9 % Sn, 1.4 % Sb, 0.5 % Ag, 0.5 % Ni and 0.4 % As.

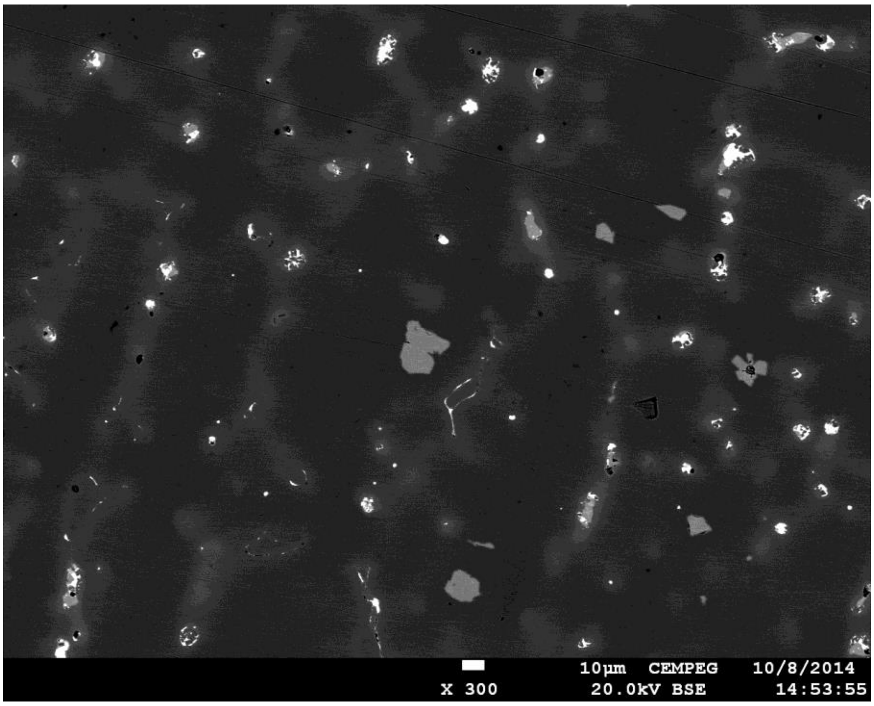
The alloy hence has a higher content of antimony than of tin. Whether the tin oxide crystals are primary or secondary formations are discussed elsewhere.



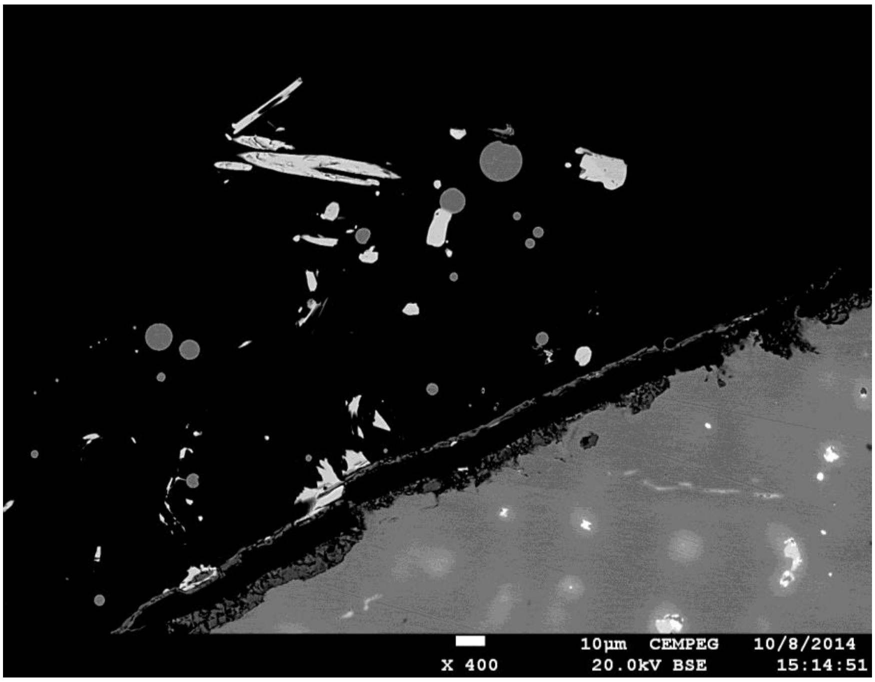
UM19634:2540. An overview of the analysed droplet clearly demonstrating the multi-phase alloy. To the upper left and lower right the rim is covered with other material (see following photos). Photo GAL.



UM19634:2540. Detail of the alloy. The dominating red and yellow phases and the subordinate high-alloy bright grey phase from the previous photo are clearly visible. In this higher magnification additional phases can be distinguished. Photo GAL.



UM19634:2540. Detail of the alloy, in the BSE-image from the electron microprobe. In addition to the two most frequent alloy phases, the bright high-alloy phases is seen and in in contact with that, the even brighter droplets that are rich in silver. In the centre: one of the angular formations that are tin oxide. Photo GAL.

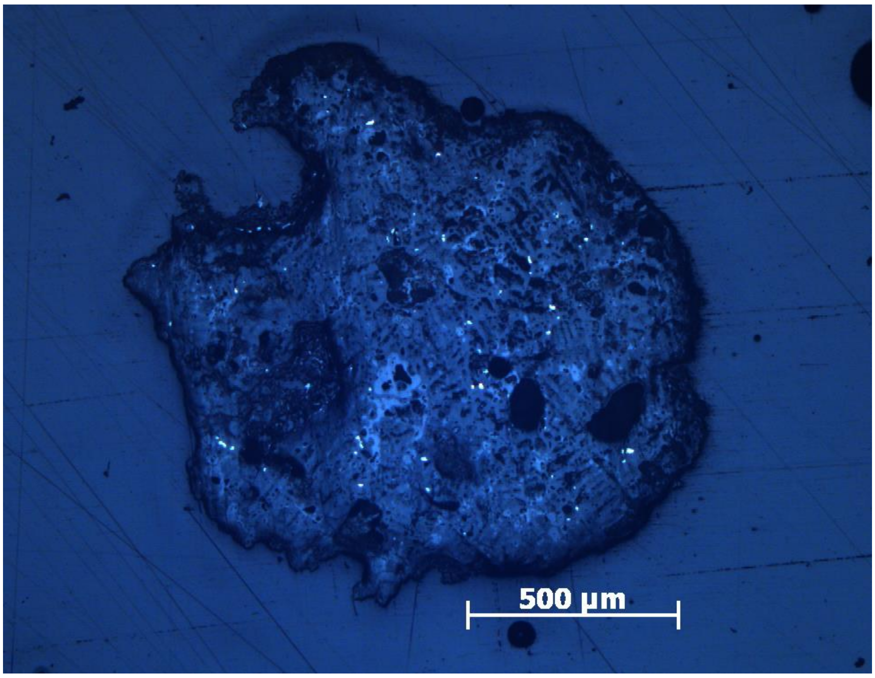


UM19634:2540. Detail (BSE-image) from the rim in the upper left in the first micrograph (slightly rotated). The major droplet at the bottom is in contact with a glassy and microcrystalline matrix carrying small droplets of copper and crystals of tin oxide. Photo GAL

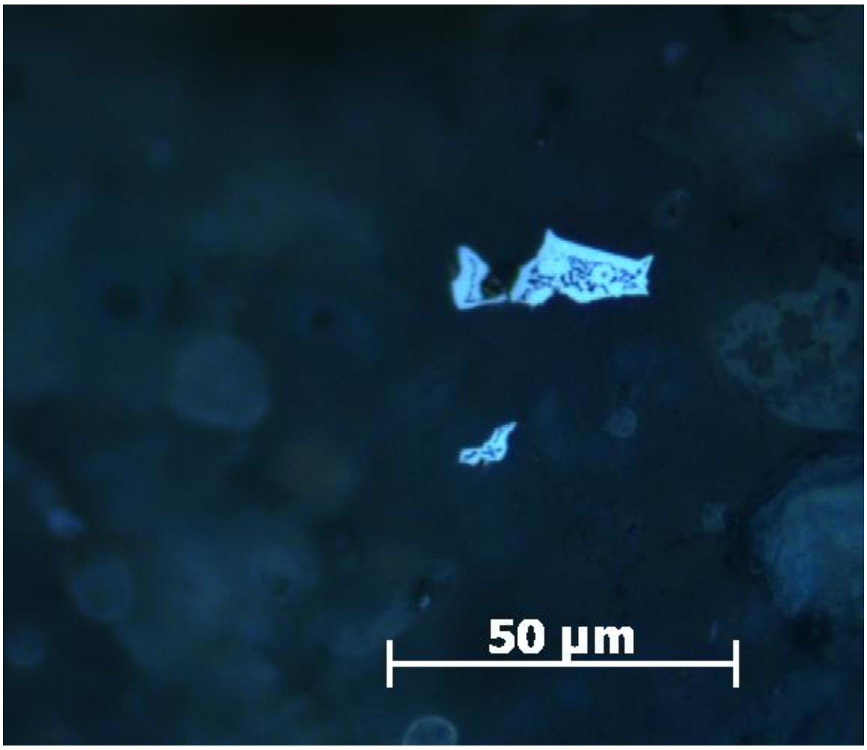
UM19634:2541, droplet from crucible, period V, from Bohuslän (Lyse)

The droplet, ca 1 mm in diameter, is removed from the inner part of the crucible fragment. In optical microscope no preserved metallic areas can be detected. However, a faint dendritic texture is indicated. Within this texture a light-grey phase with features that are significant of the subordinate high-alloy phase is present. Probably only this phase has survived the extensive corrosion.

This high-alloy phase contains nearly 30 % Sn. In addition also antimony (1.1 %) and nickel (0.3 %) is present.



UM19634:2541. Overview of corroded droplet in various grey colours. A faint dendritic structure is indicated. The bright spots are magnified in the following photo. Photo GAL.



UM19634:2541. Detail of two of the bright spots in the previous photo. These are characteristic of the high-alloy phase in copper alloys, and are the only metallic part left in the corroded droplet. Photo GAL.

UM28291:1A, socketed axe, period V, from Bohuslän (Naverstad)

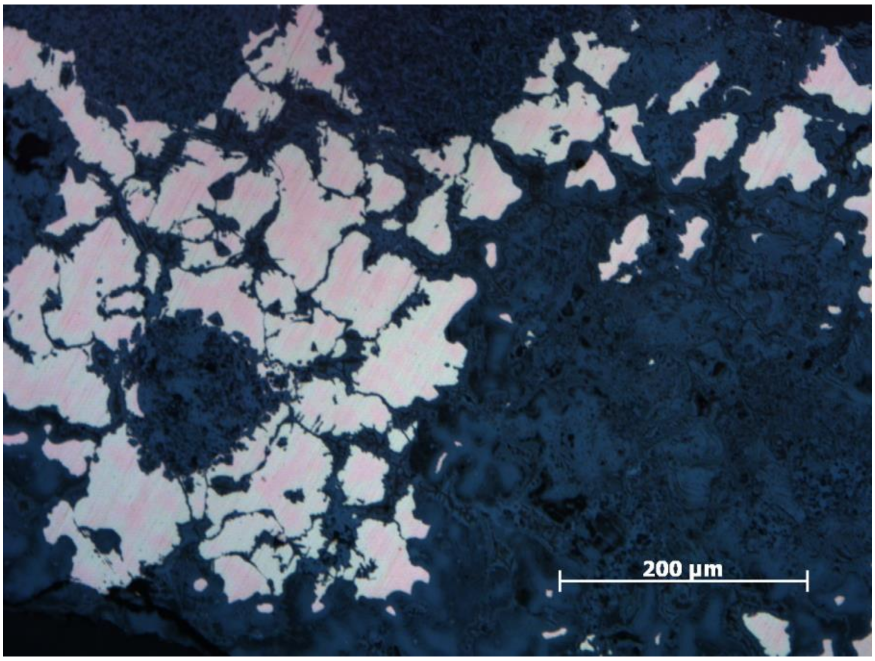
The rectangular sample, 3×1 mm in size, is from the outermost part of the socket of the socketed axe. Most of the sample appears to be corroded. In optical microscope however, patches of remaining metal reveals a multi-phase alloy dominated by a red and a yellow copper-rich phase. In the BSE-image in the microprobe these are also clearly separated resulting in different Cu:Sn-ratios (1.6 and 8 % Sn). No other elements are present in levels much higher than the detection limit.

No evident grey high-alloy phase can be observed. Since the high-alloy phase normally sustains the corrosion better than the copper-rich phases, it might not have been present.

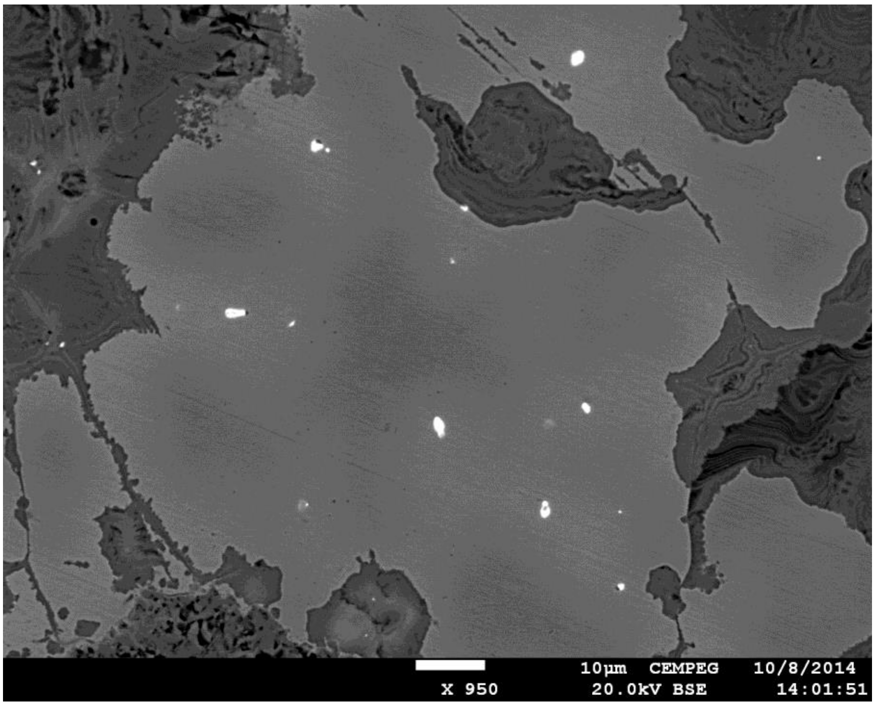
No sulphides have been observed, but in the BSE-image in the electron microprobe a few droplets of lead have been spotted.

Since the corrosion extends into the interior of the sample the bulk data is a bit uncertain. However, it is generally free from trace elements (possibly very low content of Ni, As and Ag). The resulting Sn-content of 4.6 % might however be shifted either towards somewhat higher or lower values.

UM28291:1A, socketed axe. Sample from socket. Photo J. Ling.



UM28291:1A. Detail from the analysed cross section. To the left the metallic alloy with two easily distinguished phases in red and yellow. To the right extensively corroded areas. Also in the left part corrosion is present e.g. as larger patches. Photo GAL.



UM28291:1A. Detail from the electron microprobe (BSE-image) in which the small bright lead droplets can be seen in the alloy. Photo GAL.

UM29218:458A, sword, period Ib, from Bohuslän (Tanum)

The sample, 2×1 mm, is a non-orientated section from the edge of the blade, close to the tang.

In optical microscope it is observed that metal is preserved only in the core of the sample. The rim is totally corroded and the core partly corroded revealing a grain structure, probably from cold working. Furthermore a twinning is detected, indicating annealing as well.

The alloy seems to be dominated by one yellow, copper-rich, phase (in contrary to most analysed samples with two phases). This is confirmed also in the BSE-image in the microprobe. The phase contains 12 % Sn, 1.1 % Ni and 0.2 % As.

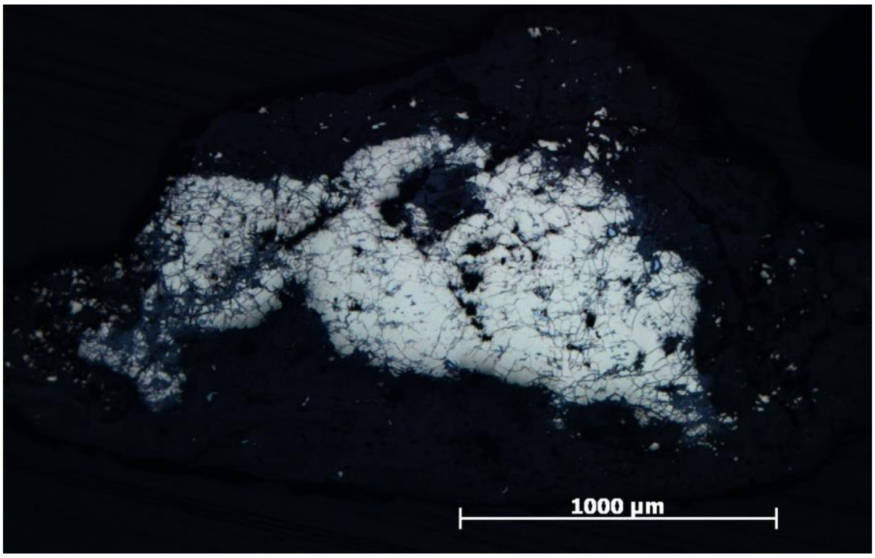
A light-grey high-alloy phase is also common but subordinate. In this the Sn-content is 34 %. It is also enriched in Ni (7 %) but As is present in similar amount (0.2 %) as in the major phase.

An additional phase of smaller darker droplets (copper sulphides also containing iron) is also distributed in the alloy. Along grain boundaries, secondary copper has developed.

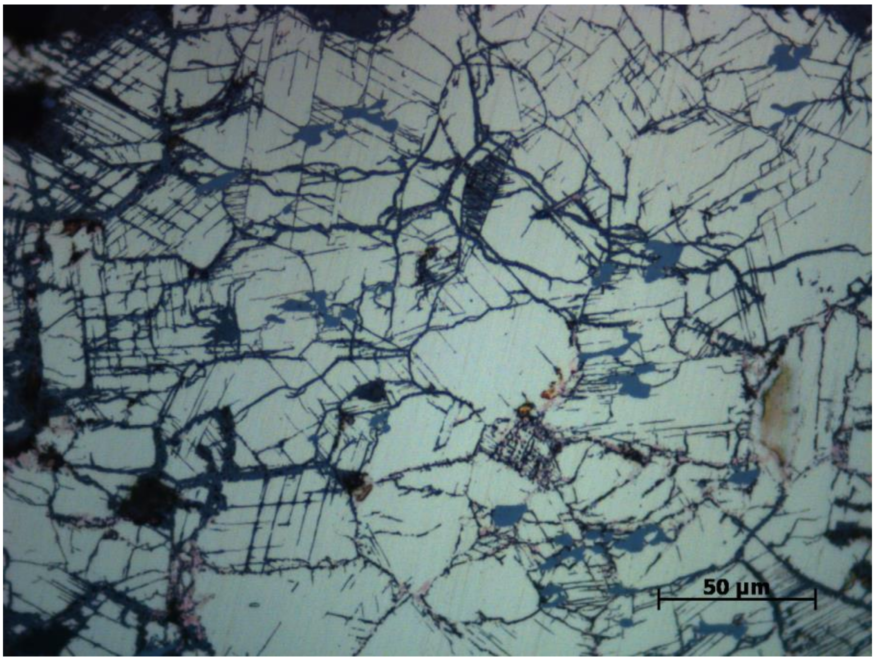
No droplets of lead have been observed.

The resulting bulk composition of the alloy is 14 % Sn, 1.0 % Ni and 0.3 % As.

UM29218:458A, sword. Sample from blade. Photo J. Ling.



UM29218:458A, an overview of the analysed cross section with selective corrosion in the central parts and more extensive along the surface (dark grey). The metallic surface appears homogeneous in composition. Photo GAL.



UM29218:458A, detail demonstrating the selective corrosion in the homogenous alloy along grain boundaries and within them as parallel lines in two directions. In addition a subordinate irregular grey phase (high-alloy) is revealed. Photo GAL.

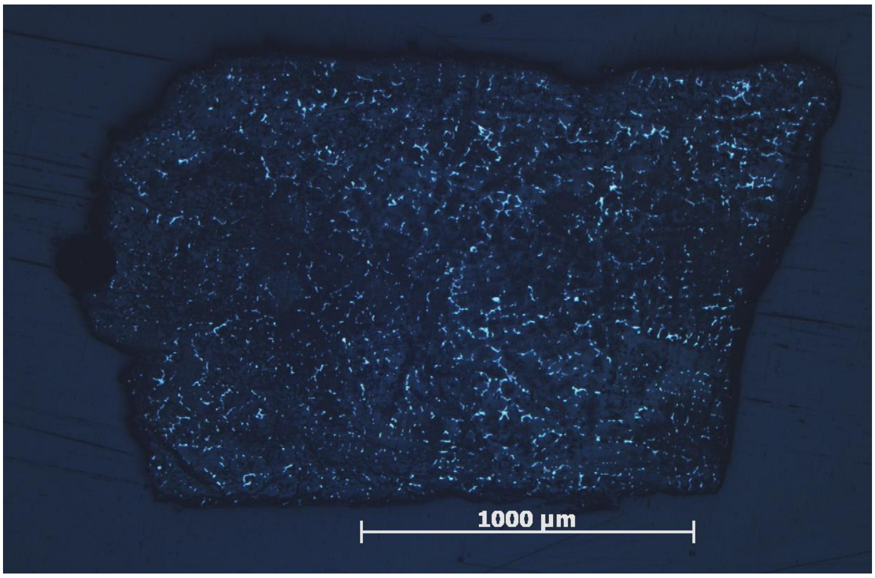
UM29282:188A, dagger, period II, from Bohuslän (Tanum)

The sample, 2×1.5 mm in size, from the blade is almost totally corroded. In optical microscope a texture that is characteristic of the light grey subordinate high-alloy phase can be identified in a dendritic network (indicating a casting, non-worked, structure). However, selective corrosion of the major phase reveals a faint grain structure that probably is from cold working.

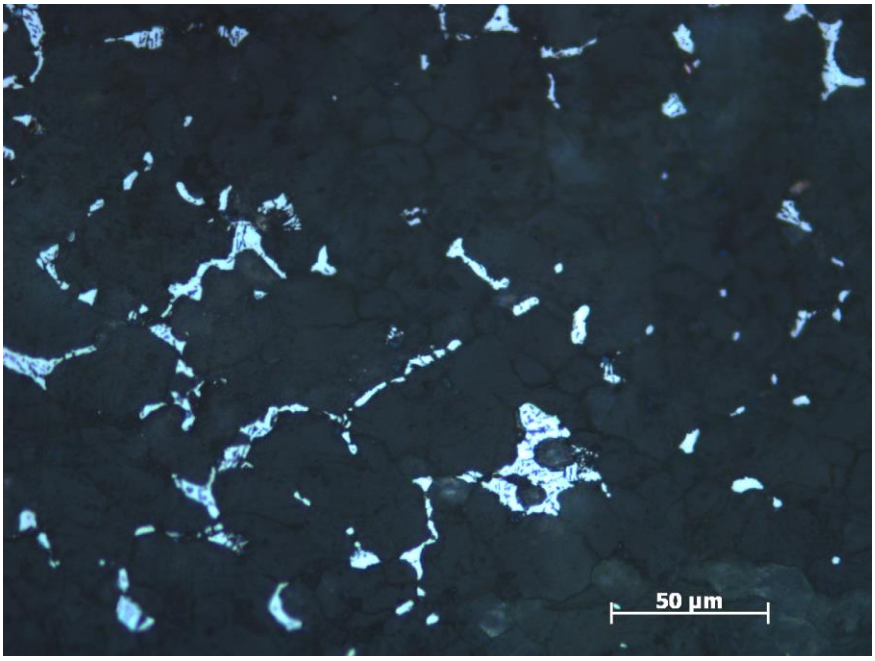
Analyses of the high-alloy phase results in a high Sn-content of 41 %. In addition it contains Ni (4.3 %), Sb (0.2 %) and Co (0.1 %).

No bulk composition was analysed in this corroded sample.

UM29282:188A, dagger. Sample from blade. Photo J.Ling.



UM29282:188A. Overview of corroded sample in various grey colours. A faint dendritic structure is indicated. The bright spots are magnified in the following photo. Photo GAL.



UM29282:188A. Detail of the bright spots in the previous photo. These are characteristic of the high-alloy phase in copper alloys, and are the only metallic part left in the corroded sample. Photo GAL.

Tossene 316:Nr6, tutulus, period II, from Bohuslän (Tossene)

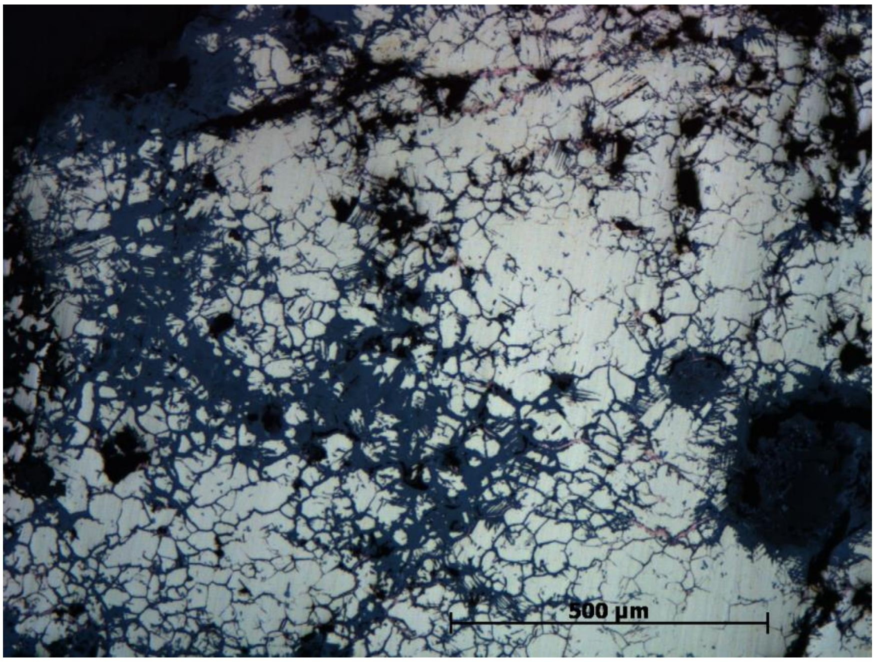
The irregular sample, 3×2 mm in size, is partly corroded. The corrosion is more extensive in some parts than in others but characteristic is that it is selective, revealing a grain structure, from cold working, and twinning indicating annealing.

The preserved metal is an alloy dominated by a copper-rich yellow phase. Contrary to many other samples, an additional red phase cannot be detected. This is confirmed also in the BSE-image in the microprobe. The phase contains 11 % Sn, 0.8 % Ni, 0.2 % Sb and 0.2 % As.

As in sample UM29218:458A a light-grey high-alloy phase is also present, but it is very rare and heterogeneously distributed.

Subordinate is a grey phase (copper sulphide; without iron as analysed by EDS), somewhat heterogeneously distributed in the sample. The distribution may however be erroneously interpreted due to the corrosion.

The resulting bulk analysis demonstrates a Sn-content of 11 %, Ni 0.7 %, Sb 0.2 % and As 0.2 %.



Tossene 316:Nr6, an overview of the analysed cross section with partly extensive, corrosion (dark grey) of a metallic surface that appears homogeneous in composition. The corrosion is selective along grain boundaries and within them as parallel lines in two directions. In addition secondary formed copper (red patches) are present along the corrosion.

Assessment of analytical data

In all fourteen artefacts were sampled for analyses. Eleven of these had enough metal for bulk elemental data. Two others (UM 29282:188A and UM 1963:2541) were partially oxidised and only the high-alloy phase was intact. Yet another sample was even more oxidised and only qualitative analyses were done (UM 19634:1060). Among the eleven samples that were quantitatively analysed for their elemental composition are six from Bohuslän and two from Halland. In addition three samples from abroad, but within the museum collections were included in the analyses. The detailed analytical results, including each separate phase, are presented for each separate sample above. All bulk data is presented in Table 1. All analytical data is compiled in Table 2, also including selectively oxidised samples.

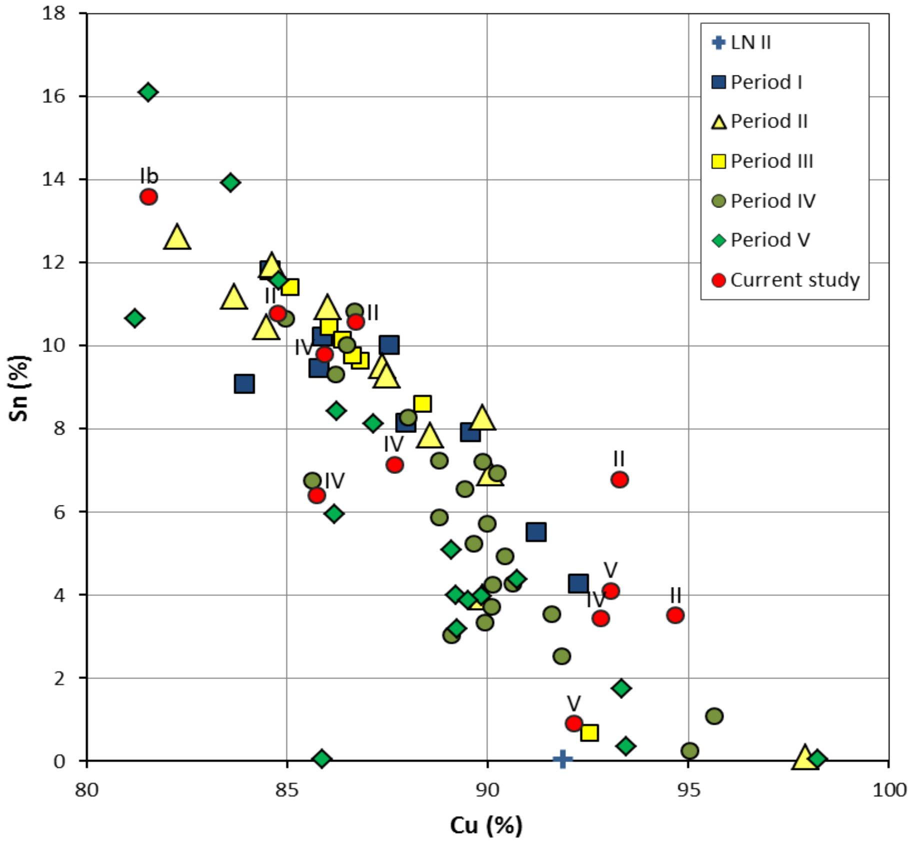
The analytical data is assessed and briefly interpreted, comparing the currently analysed samples. In order to gain some essential understanding of how representative or disparate to other artefacts the currently analysed artefacts are, these are also briefly discussed with reference to previously analysed Swedish Bronze Age artefacts (Ling *et al.* 2014).

This study however, does not aim at drawing any major conclusions regarding origin of metals, relations to ore regions or comparing with other groups of artefacts. Such topics will be further evaluated by Ling and co-workers and further discussed elsewhere in combination with result from lead isotope analyses on the same samples.

Firstly, some general comments can be made for the analysed artefacts. They are all bronzes, but with varying tin content from nearly 1 % to 14 %. A mutual feature is the low concentration of lead. In many of the artefacts a few tiny droplets of lead have been observed, in others such droplets are lacking, or at least not observed. The presence of lead is so low that it is merely detected in the bulk analyses, with a maximum lead content of 0.02 %.

Table 1. Bulk analytical data of bronze samples (see Table 2 for details).

Sample	Object	County	Parish	Period	S	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Au	Pb	Bi	Hg	Total
UM29218:458A	Sword	Bohuslän	Tanum	Ib	0,50	0,11	0,04	1,04	81,56	0,04	0,27	0,03	13,59	0	0,01	0,02	0,00	0,02	97,23
GAM5900	Droplet from crucible	Halland	Grimeton	II	0,09	0,00	0,04	0,40	93,28	0,04	0,04	n a	6,79	0	0,01	0,01	0,01	0,01	100,71
GAM5911	Droplet from crucible	Halland	Grimeton	II	0,09	0,00	0,01	0,33	94,68	0,05	0,11	n a	3,51	0,05	0,00	0,01	0,01	0,01	98,85
GAM2032	Spear	Bohuslän	Orust	II	0,07	0,04	0,05	0,30	86,70	0,05	0,04	0,05	10,57	0	0,01	0,01	0,01	0,01	97,91
RK316:6	Tutulus	Bohuslän	Tossene	II	0,33	0,07	0,02	0,70	84,77	0,04	0,21	0,02	10,77	0,19	0,02	0,01	0,01	0,01	97,17
UM1102:1	Spear	Bohuslän	Kville	IV	0,15	0,00	0,02	0,27	85,92	0,04	0,55	0,33	9,79	1,28	0,01	0,01	0,02	0,01	98,41
GAM7963	Sickle	Romania	Maros Ujvár	IV	0,44	0,02	0,01	0,51	92,82	0,05	0,42	0,07	3,44	0,39	0,01	0,01	0,02	0,01	98,22
GAM7964	Socketed axe	Romania	Maros Ujvár	IV	0,47	0,31	0,05	0,60	85,75	0,05	0,65	0,08	6,41	0,62	0,00	0,01	0,06	0,01	95,07
GAM20288	Socketed axe	Austria-Hungary		IV	0,77	0,08	0,01	0,02	87,67	0,05	0,01	0,06	7,14	0	0,01	0,01	0,02	0,02	95,86
UM19634:2540	Droplet from crucible	Bohuslän	Lyse	V	0,02	0,00	0,00	0,54	92,16	0,04	0,44	0,51	0,90	1,35	0,02	0,01	0,01	0,01	96,02
UM28291:1A	Socketed axe	Bohuslän	Naverstad	V	0,09	0,01	0,01	0,06	93,07	0,05	0,06	0,06	4,11	0,00	0,01	0,02	0,02	0,01	97,59



Graph illustrating the content of copper (Cu) and tin (Sn) in the bronze artefacts analysed in the current study compared to previously analysed bronzes from Sweden (Ling et al. 2014). The tin content in the current study varies between similar values as in the previous study.

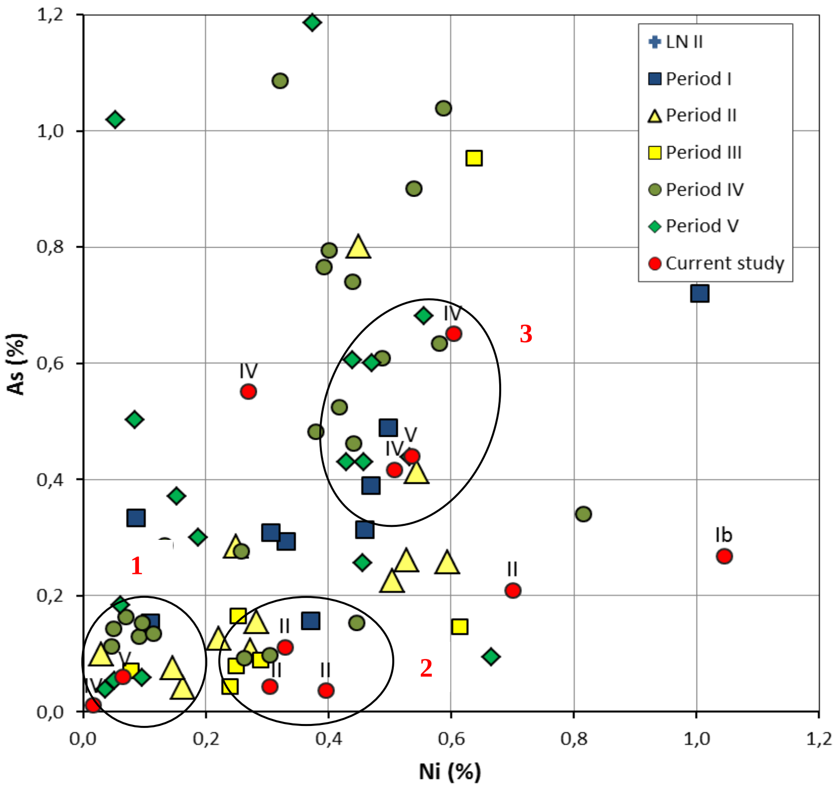
In many of the artefacts sulphides have been observed and these also contribute to a bulk content of sulphur (0.8 % as a maximum obtained result). Among the samples that lack sulphides are the droplets from crucibles from Grimeton in Halland (per II) and the socketed axe UM28291:1A from Bohuslän (per V). Among the artefacts that contain sulphides, those are generally copper sulphides. However, a few of them contain copper sulphides with a small amount of iron (GAM 20288 (per IV), GAM 2032 (per II), GAM 7964 (per IV) and UM29218:458A (per Ib)).

Some general comments can also be made regarding the presence of trace elements. Single artefacts have very low content of impurities and the samples that do contain trace elements have a combination of mainly two, occasionally three or four elements (Ni, As and occasionally Sb and Ag). A few samples (4) present cobalt. Also sulphur and iron are detected (Table 1). And, additionally, bismuth is detected in relation to lead droplets but rarely contributes to the overall bulk composition. All these elements will be discussed in more detail in the following.

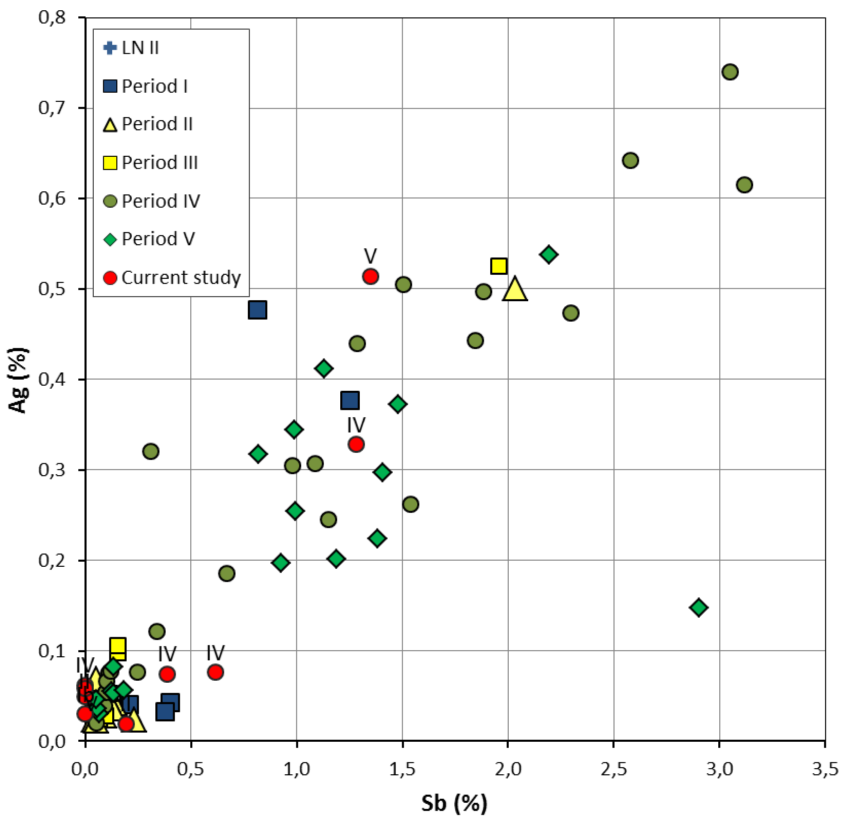
The total number of analysed artefacts from each site or from each chronological period, or of defined typology, is too limited for making any general conclusion regarding this batch of samples. However, some observations regarding groups of artefacts are evaluated. In order to assess the data further, a preliminary evaluation is made in relation to previously analysed artefacts (Ling *et al.* 2013, 2014), generally from a chronological view since some broad chronological metal groups have been defined in many earlier studies.

Chronological comparison

As mentioned above the analysed samples are distributed in time, typology and geography and therefore not relevant to compare in detail. However, a brief comparison with previously analysed Bronze Age artefacts from Sweden (Ling *et al.* 2014), demonstrate that the current samples largely correlate with the major compositional groups that can be described on general terms in relation to chronology. This is illustrated in a graph comparing nickel and arsenic, two elements that are common in many of the samples.



Linear graph illustrating the content of arsenic (As) and nickel (Ni) in the bronze artefacts analysed in the current study compared to previously analysed bronzes from Sweden (Ling et al. 2014). The numbered compositional areas (1–3) are further discussed in the text and following graphs. A few artefacts in the reference material with higher values are excluded in this graph.



Linear graph illustrating the content of silver (Ag) and antimony (Sb) in the bronze artefacts analysed in the current study compared to previously analysed bronzes from Sweden (Ling et al. 2014). A few artefacts in the reference material with higher values are excluded in this graph. Most of the currently analysed artefacts are low in both Ag and Sb, however two samples (from periods IV and V) are on the same level as previously analysed contemporary artefacts.

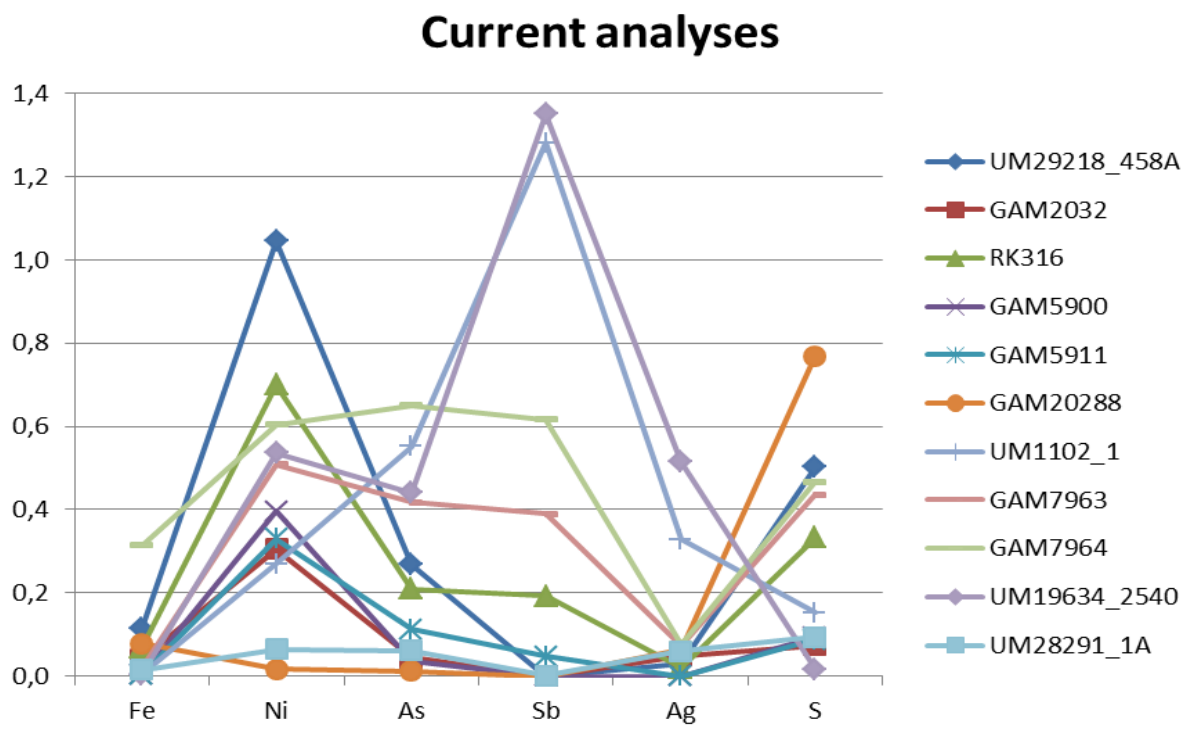
Some of these groups will be highlighted. One group (no. 1 in the graph Ni-As) comprises two socketed axes from periods IV and V (GAM28291:1A and GAM20288) that are low in both As and Ni, correlating to several contemporaneous socketed axes.

Another group of samples (no. 2) with similar arsenic content but slightly higher nickel content are the droplets from crucibles (Grimeton in Halland) from period II and a spear (GAM2032) from Orust (in Bohuslän) also currently dated to period II. These show compositional resemblance with many other samples from period II that will be mentioned in short. Since typological dating of the spear GAM2032 can be discussed (earlier as well as later dating has also been suggested), the compositional similarity with artefacts dated to period II may support such an archaeological interpretation (see below).

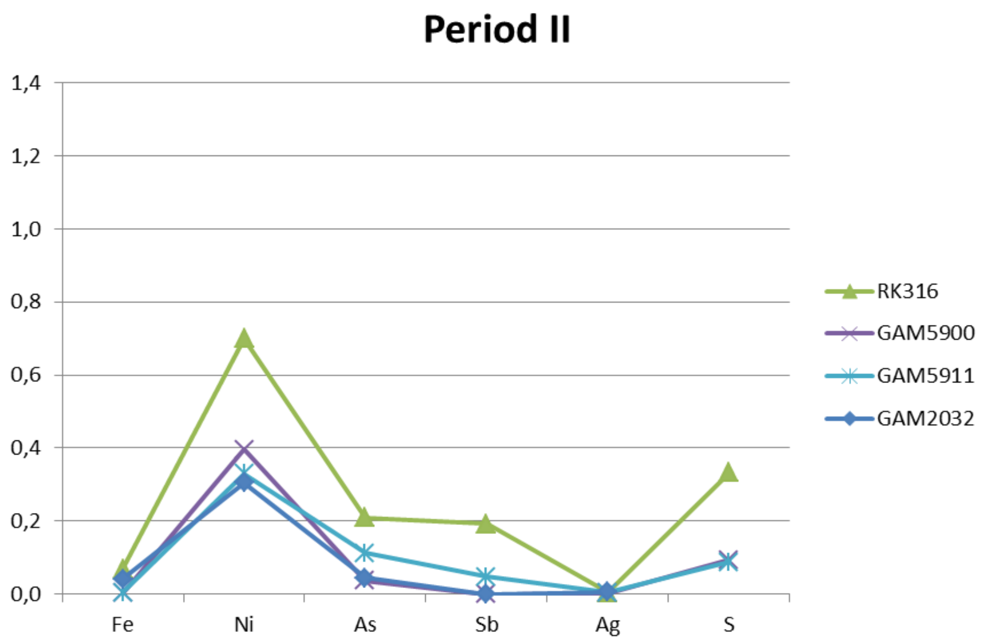
Slightly higher concentration of nickel, in combination with somewhat higher arsenic (no. 3) is present in several samples from period IV, from Romania as well as from Bohuslän (e.g. Lyse), and are similar to several previously analysed artefacts from periods IV and V. In this case, presence of other elements demonstrates some differences, exemplified later by the Romanian artefacts.

A few compositional outliers are also observed. Among these is the sword UM29218:458A dated to period Ib from Tanum in Bohuslän. In this sword the comparatively high content of nickel is rare, especially in combination with low arsenic. Other Swedish, or Scandinavian, artefacts with similar nickel content normally also are enriched in arsenic.

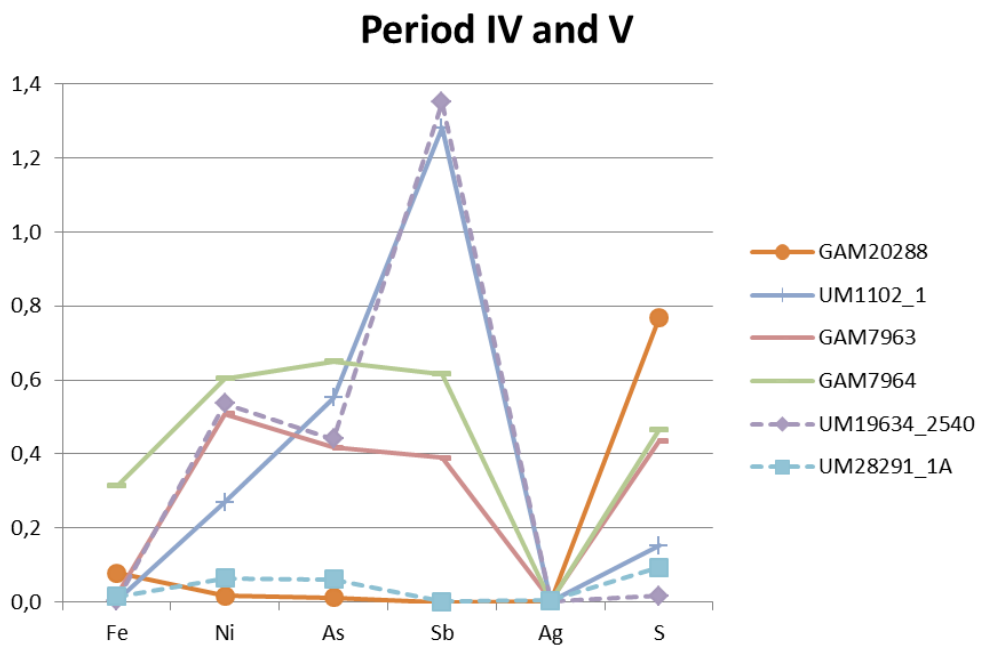
Most of the currently analysed artefacts are low in both Ag and Sb, however two samples (from periods IV and V) are on the same level as previously analysed contemporary artefacts.



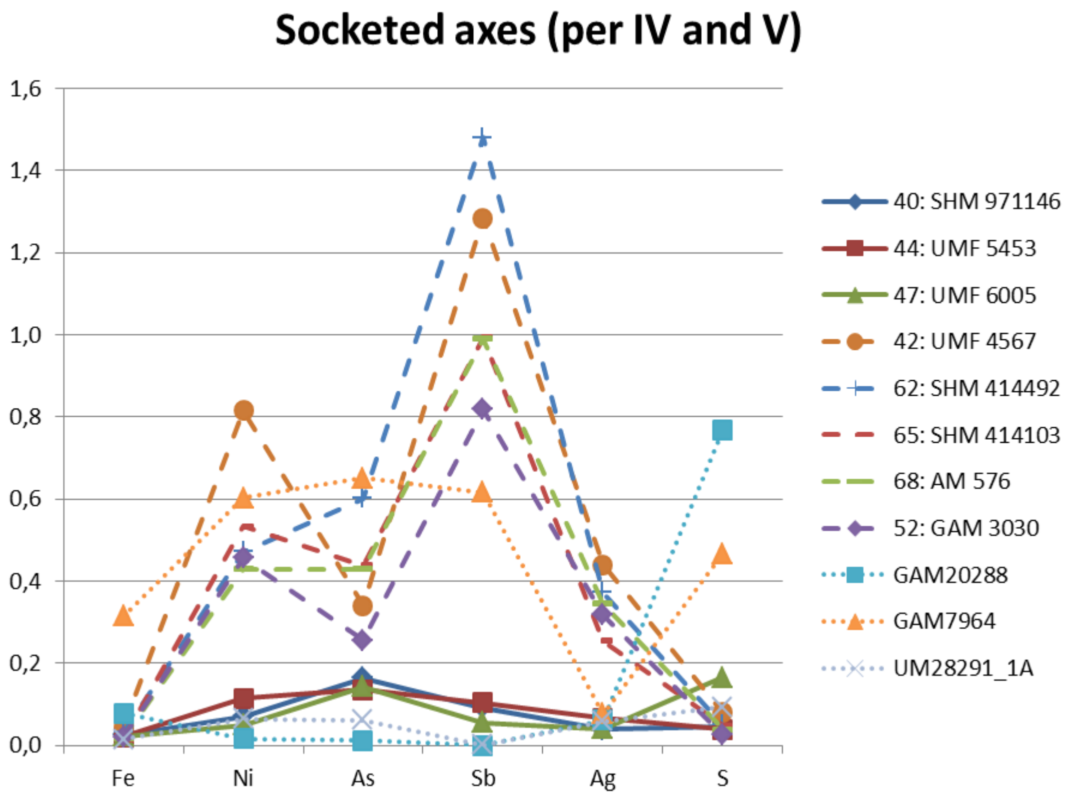
The compositional variation in the currently analysed samples is illustrated by the set-up of several trace elements in each sample. The various patterns reflect the various compositions. These are described in more detail in the following graphs.



Detail from the previous graph, with focus on samples dated to period II. GAM5900 and GAM5911 are droplets from crucibles from Grimeton in Halland with similar pattern. Similar pattern is also observed for the spear GAM2032. The tutulus RK316 has a different elemental pattern.



Detailed graph with focus on samples dated to periods IV and V (dashed lines). Also within each period various elemental patterns can be distinguished. However, similarities can also be seen between the chronological periods.



Comparison of the elemental patterns in previously analysed socketed axes (Ling et al. 2014) of the Mälardal type and Nordic type (dashed lines) and three socketed axes from the current study (dotted lines). The socketed axe from Naverstad in Bohuslän (UM28291) resembles the previously analysed axes of the Mälardal type in its elemental pattern. The axe from Romania (GAM7964) is different from all other axes.

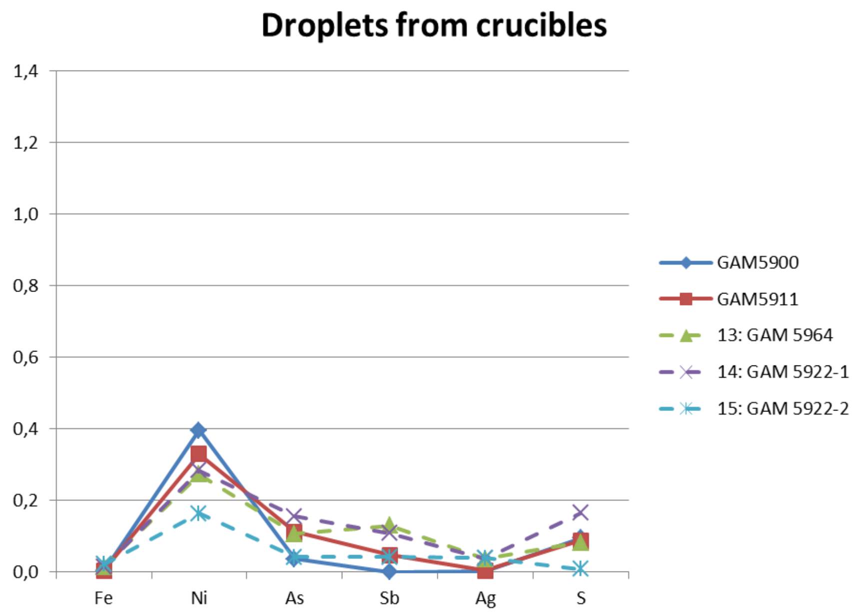
Socketed axes from periods IV and V

Among the analysed samples are three socketed axes, one from Romania, one from Austria-Hungary and finally one from Bohuslän (Naverstad). Socketed axes of various types from several sites in Sweden have also previously been analysed (Ling *et al.* 2014). When comparing the currently analysed socketed axes with the contemporaneous previously analysed socketed axes it is demonstrated that the socketed axe from Naverstad in Bohuslän (period V) is chemically similar to previously analysed axes of the Mälardal type and clearly separated from the Nordic type. The Mälardal type does contain trace elements but in low concentrations in contrast to the elevated content of several trace elements observed in the socketed axes of the Nordic type. The two axes from Austria-Hungary and Romania are chemically dissimilar from both these two types of axes, and furthermore they are mutually different with generally low content of trace elements in the one from Austria-Hungary and higher in the Romanian artefact.

Crucibles from Grimeton, Halland

The droplets from crucibles GAM5900 and 5911 from Grimeton in Halland (period II) are similar but not identical in composition. The concentration of Ni (0.3–0.4 %) is similar, but the generally somewhat lower concentration of As (0.1 and 0.04 %) is different. Both lack sulphides and the overall S-content is hence low. Previously, three droplets from three other crucibles from the same site (GAM5922-1. GAM5922-2 and GAM5964) have been analysed (Ling *et al.* 2014), presenting similar levels of Ni, and a maximum level of As of 0.1 %. A difference from the now analysed droplets is the detected, but low, content of Sb (0.1 %). In general, and compared to other samples, all five droplets have similar trace element signatures. However, the overall Sn-content varies from 0 to 8%. Although the trace element signatures of the previously analysed droplets are similar, lead isotope analyses suggested two separate origins for the copper ore (Ling *et al.* 2014).

An interesting observation within the group of samples analysed in the current study is the resemblance in trace element signature that the crucibles from Grimeton shows with the spear GAM2032 from Orust in Bohuslän. The dating of this spear has been discussed and also period V has been suggested. However, in period V other trace element signatures are prevailing; either that with multi-element signature (As, Sb, Ag and Ni) as in the Nordic celts or rather pure, as in the Mälardalen celts (see above). On the basis on this well-defined compositional group that mainly is present in artefacts from period II (or period III) we therefore suggest that the spear from Orust (GAM2032) may be considered to be from period II.

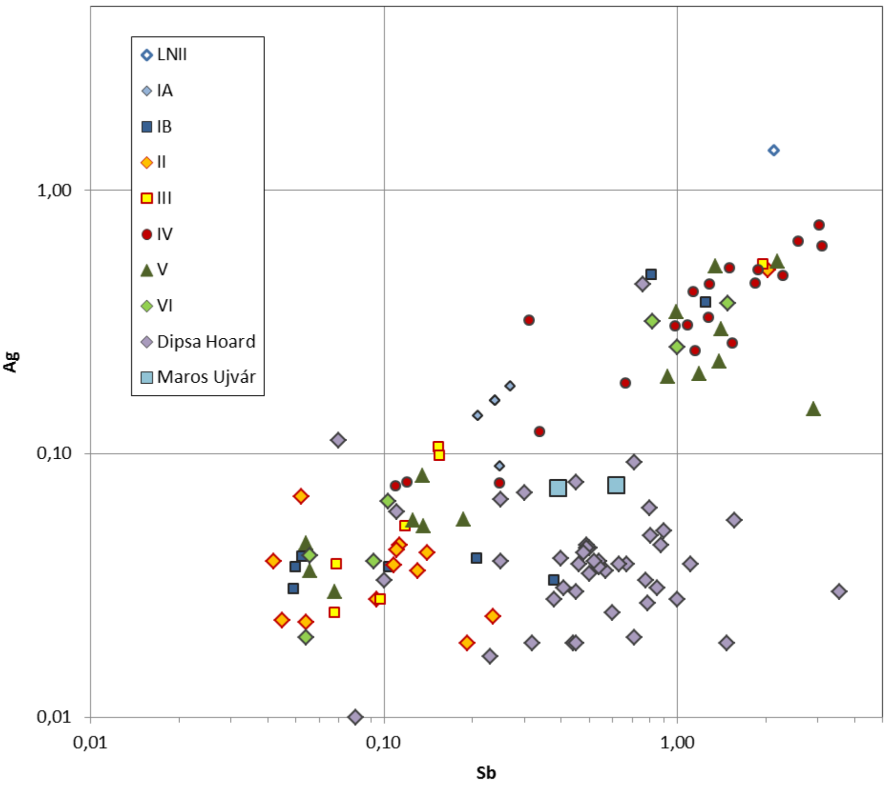


Comparison of the currently analysed droplets from crucibles from Grimeton in Halland (dated to period II), and previously analysed droplets (dashed lines) from the same site (Ling et al. 2014). The plotted scale is similar to the previous graphs in order to easily compare all of the samples. Although some minor differences can be noted, the general elemental pattern is of the same order of magnitude in all droplets.

The samples from Romania (Maros Ujvár)

A socketed axe (GAM7964) and a sickle (GAM7963), from period IV, from Maros Ujvár in Romania, both in the museum collection of *Göteborgs Stads museum* have been analysed. They differ somewhat in Sn-content but have similar set-up of trace elements – Ni, As and Sb all within 0.4–0.6 %. In addition they have a bulk content of sulphur of 0.4–0.5 % representing the presence of copper sulphides in the alloy. However, one difference that is noted is the sulphide composition with "pure" copper sulphides in the sickle and complex copper sulphides with iron content in the socketed axe.

Among the other analysed samples, none has similar trace element signatures. A short general comparison can also be made with those previously analysed Scandinavian artefacts from periods IV-VI that are enriched in the same elements as the Romanian artefacts; Ni, As and Sb. The Scandinavian artefacts with presence of these elements are normally also enriched in silver (Ag), which is not the case for these Romanian artefacts. These are rather more similar to other Romanian artefacts, e.g. from the Dipşa Hoard (Ciugudean et al. 2006) with lower Ag in combination with relatively high concentration of the other three elements.



Logarithmic graph illustrating the content of silver (Ag) and antimony (Sb) in Swedish bronze artefacts analysed in the current study and previously (Ling et al. 2014). The two Romanian samples (From Maros Ujvár) deviate from the majority of the Swedish samples (same feature is seen in Scandinavia in general. For comparison also samples from the Dipşa Hoard (Ciugudean et al. 2006) is plotted with even lower content of Ag for relatively high Sb.

The samples from the site Lyse

Two droplets from crucibles and one rod were selected for analyses from the metal working site from period V at Lyse, Bohuslän. Two of the three samples are however extensively corroded. Only one of the droplets has well-preserved metallic material. In the other droplet the high-alloy phase is occasionally still present. A comparison with the corresponding high-alloy phase in the other droplet demonstrates large differences between them. The better preserved droplet (2540) has an unusually high content of antimony (28 %) in combination with silver, arsenic and nickel. The other droplet (2541) has much lower antimony (1 %) and less Ni (and nearly no As and probably no Ag). If present in an alloy, these elements are generally enriched in the high-alloy phase. These differences hence suggest that two different metals/alloys were melted in the respective crucibles. Furthermore, the rod (1060), even more corroded, indicates a third metal/alloy. In the rod the only preserved phase are the sulphides; and interestingly enough, no sulphides are observed in neither of the droplets.

Although rather poor preserved alloys in the samples, the results are able to demonstrate that several alloys were available at this metal working site from period V. Whether these are of various ore sources is however not possible to establish merely from the compositional data.

In summary

In general the currently analysed artefacts from several periods of the Scandinavian Bronze Age that were analysed match the chronological-compositional pattern that has previously been demonstrated (Ling *et al.* 2014). Although this minor study cannot on its own evaluate chronological relations to elemental signatures, the comparison with previous analyses has proven useful.

In general, artefacts from Scandinavian Early Bronze Age contain the trace elements nickel and arsenic and also sulphides. This is in accordance with previous results from the same periods (e.g. Ling *et al.* 2014). Artefacts dating to the Scandinavian Late Bronze Age, although only a few Scandinavian are included in this study, also present the general feature earlier shown. That is either rather free from impurities, like the socketed axe from Naverstad (period V), similar in composition to contemporaneous socketed axes of the Mälardal type. The other compositional group from Late Bronze Age presents signatures characteristic of copper ores of the Fahlore type, here containing all four of arsenic, antimony, silver and nickel. This is seen for example in a droplet from crucibles from the metal working site from period V at Lyse, Bohuslän. Similar trace element signatures have for example been shown (Ling *et al.* 2014) to be common, also in higher concentration, in casting debris and rods from the scrap hoard in Järn, Dalsland (period IV).

Furthermore; among the analysed samples are two from Romanian artefacts, from the collection in Göteborgs Stadsmuseum. These, an axe and a sickle, deviate from most of the Scandinavian samples analysed so far. They are more similar to other Romanian samples, here exemplified by the Dipşa Hoard (Ciugudean et al. 2006).

Yet another outcome of the analyses is how to apply compositional data for chronology. The spear GAM2032 has been discussed, on typological basis whether it should be from EBA or LBA. However, the chemical composition is typical of earlier periods and therefore we suggest that it derives from period II.

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Table 2. Electron microprobe analyses of the bronze artefacts. Analyses made on JEOL JXA-8530 F with WDS-method.

Sample	Object	County	Parish	Period	Description	S	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Au	Pb	Bi	Hg	Total
UM29218:458A	Sword	Bohuslän	Tanum	Ib	Bulk (10)	0,50	0,11	0,04	1,04	81,56	0,04	0,27	0,03	13,59	0	0,01	0,02	0,00	0,02	97,23
UM29218:458A					Cu rich_1	0,03	0,09	0,05	1,14	85,86	0,05	0,25	0,01	11,60	0	0,00	0	0,04	0	99,13
UM29218:458A					high alloy	0,01	0,07	0,10	7,06	59,85	0,05	0,17	n a	34,56	0	0	0,07	0	0	101,94
UM29218:458A					sulphide	21,80	3,19	0,03	0,07	72,32	0,08	0	n a	0,13	0	0	0,02	0,07	0	97,70
GAM5900	Droplet from crucible	Halland	Grimeton	II	Bulk (10)	0,09	0,00	0,04	0,40	93,28	0,04	0,04	n a	6,79	0	0,01	0,01	0,01	0,01	100,71
GAM5900					Cu rich_1	0,09	0	0,04	0,37	93,23	0,04	0	n a	5,32	0	0	0,03	0	0,02	99,14
GAM5900					Cu rich_2	0,09	0	0,02	0,40	88,19	0,02	0	n a	10,87	0	0	0	0,00	0,01	99,61
GAM5900					high alloy	0,01	0,01	0,05	0,78	61,03	0,07	0	n a	32,84	0	0	0	0,02	0,01	94,81
GAM5911	Droplet from crucible	Halland	Grimeton	II	Bulk (10)	0,09	0,00	0,01	0,33	94,68	0,05	0,11	n a	3,51	0,05	0,00	0,01	0,01	0,01	98,85
GAM5911					Cu rich_1	0,04	0	0,01	0,32	96,73	0,04	0,07	n a	2,11	0,01	0,01	0	0	0,04	99,37
GAM5911					Cu rich_2	0,07	0	0,02	0,35	90,85	0,05	0,36	n a	6,71	0,21	0	0,01	0,03	0	98,65
GAM2032	Spear	Bohuslän	Orust	II	Bulk (18)	0,07	0,04	0,05	0,30	86,70	0,05	0,04	0,05	10,57	0	0,01	0,01	0,01	0,01	97,91
GAM2032					Cu rich_1	0,01	0,06	0,04	0,30	94,63	0,04	0	0,04	5,44	0	0	0	0	0	100,55
GAM2032					Cu rich_2	0,01	0,03	0,03	0,31	87,18	0,10	0,05	0,04	11,76	0	0,02	0	0,05	0	99,58
GAM2032					high alloy	0	0,01	0,04	0,56	71,17	0,06	0,07	0,10	28,21	0,03	0,02	0,01	0	0	100,28
GAM2032					sulphide	20,11	0,39	0,01	0,01	78,73	0,04	0,00	n a	0,10	0,01	0,00	0,03	0,089	0,00	99,51
UM29282:188A	Dagger	Bohuslän	Tanum	II	high alloy	0,04	0,03	0,11	4,28	50,02	0,06	0,00	0,01	41,10	0,18	0,01	0,05	0	0,04	95,94
RK316:6	Tutulus	Bohuslän	Tossene	II	Bulk (10)	0,33	0,07	0,02	0,70	84,77	0,04	0,21	0,02	10,77	0,19	0,02	0,01	0,01	0,01	97,17
RK316:6					Cu rich_1	0,01	0,03	0,03	0,82	84,14	0,05	0,23	0,03	11,26	0,23	0,03	0	0,02	0,02	96,88
UM1102:1	Spear	Bohuslän	Kville	IV	Bulk (17)	0,15	0,00	0,02	0,27	85,92	0,04	0,55	0,33	9,79	1,28	0,01	0,01	0,02	0,01	98,41
UM1102:1					Cu rich_1	0,04	0,02	0,03	0,27	93,69	0,05	0,29	0,12	5,78	0,50	0	0,06	0,01	0,01	100,86
UM1102:1					Cu rich_2	0,05	0,00	0,03	0,27	89,57	0,02	0,49	0,31	8,66	0,91	0	0,03	0,02	0	100,36
UM1102:1					high alloy	0,03	0,00	0,03	0,47	69,95	0,06	1,00	0,905	22,31	4,86	0,04	0,01	0,05	0	99,71
UM1102:1					sulphide	20,07	0	0	0,03	78,01	0,04	0	n a	0,12	0,02	0,05	0	0,10	0,02	98,47
GAM7963	Sickle	Romania	Maros Ujvár	IV	Bulk (14)	0,44	0,02	0,01	0,51	92,82	0,05	0,42	0,07	3,44	0,39	0,01	0,01	0,02	0,01	98,22
GAM7963					Cu rich_1	0,01	0,00	0,02	0,67	99,89	0,08	0,04	0,051	0,63	0,02	0	0,03	0	0,02	101,46
GAM7963					Cu rich_2	0,01	0,00	0,01	0,57	88,25	0,07	0,88	0,31	9,41	1,21	0,02	0	0,02	0	100,75
GAM7963					high alloy	0	0	0,02	1,53	65,79	0,04	1,41	0,701	19,49	7,66	0,07	0,04	0,77	0,05	97,57
GAM7963					sulphide	19,51	0,00	0,01	0,08	78,32	0,04	0	n a	0,46	0,08	0,02	0	0,08	0	98,59
GAM7964	Socketed axe	Romania	Maros Ujvár	IV	Bulk (18)	0,47	0,31	0,05	0,60	85,75	0,05	0,65	0,08	6,41	0,62	0,00	0,01	0,06	0,01	95,07
GAM7964					Cu rich_1	0,02	0,38	0,07	0,67	93,97	0,06	0,22	0,064	2,33	0,16	0	0	0	0	97,94
GAM7964					Cu rich_2	0,01	0,22	0,04	0,62	86,07	0,07	1,06	0,113	8,90	1,13	0,02	0	0,02	0,03	98,29
GAM7964					high alloy	0,00	0,04	0,11	3,67	63,85	0,06	0,50	0,228	25,99	4,83	0,00	0,03	0	0	99,30
GAM7964					sulphide	21,21	2,20	0,04	0,05	73,50	0,07	0	n a	0,06	0,00	0,06	0,04	0,12	0,03	97,38
GAM20288	Socketed axe	Austria-Hungary		IV	Bulk (20)	0,77	0,08	0,01	0,02	87,67	0,05	0,01	0,06	7,14	0	0,01	0,01	0,02	0,02	95,86
GAM20288					Cu rich_1	0,01	0,08	0	0,01	97,01	0,05	0,05	0,027	1,55	0	0	0,02	0,02	0	98,82
GAM20288					Cu rich_2	0,01	0,03	0,01	0,02	86,91	0,04	0,07	0,08	12,18	0	0,02	0	0	0,01	99,38
GAM20288					high alloy	0,01	0,01	0,01	0,02	70,63	0,03	0	0,27	29,09	0	0,07	0	0	0,05	100,19
GAM20288					sulphide	19,81	0,14	0,01	0	77,83	0,06	0	n a	0,13	0	0	0	0,19	0	98,16
UM19634:2540	Droplet from crucible	Bohuslän	Lyse	V	Bulk (20)	0,02	0,00	0,00	0,54	92,16	0,04	0,44	0,51	0,90	1,35	0,02	0,01	0,01	0,01	96,02
UM19634:2540					Cu rich_1	0,03	0	0	0,75	93,62	0,06	0,09	0,351	0,31	0,28	0,00	0	0,02	0,01	95,51
UM19634:2540					Cu rich_2	0,02	0	0,01	0,54	86,34	0,03	1,00	0,681	2,84	4,53	0,08	0	0	0	96,06
UM19634:2540					high alloy	0,02	0	0	1,14	63,16	0,03	2,66	2,38	2,88	27,70	0,14	0	0	0	100,12
UM19634:2541	Droplet from crucible	Bohuslän	Lyse	V	high alloy	0	0	0,01	0,31	55,56	0,05	0,04	n a	29,99	1,08	0,01	0,04	0	0,04	87,11
UM28291:1A	Socketed axe	Bohuslän	Naverstad	V	Bulk (9)	0,09	0,01	0,01	0,06	93,07	0,05	0,06	0,06	4,11	0,00	0,01	0,02	0,02	0,01	97,59
UM28291:1A					Cu rich_1	0,03	0	0,01	0,06	93,08	0,06	0	0,05	1,63	0	0,02	0,02	0	0	94,97
UM28291:1A					Cu rich_2	0,01	0,01	0	0,07	87,83	0,04	0,06	0,07	7,65	0	0	0	0,03	0,04	95,81

Detection limits are generally in the order of c. 0.01; for As c. 0.02, for Bi, Cu, Zn in the order of 0.03–0.04, for gold 0.05 and for lead 0.07.

Analyses are referred to as “Bulk” (mean value of multiple area scans), “Cu-rich 1/2” (the dominant Cu-rich phases in the alloy), “High-alloy” (the phases low in Cu but high in Sn and generally also impurities if present; the phase is generally subordinate), “Sulphide” (patches of sulphides, generally Cu-sulphides, occasionally also including Fe). Droplets of lead are not analysed quantitatively; these are generally less than 1 micrometre in size.

Ag is in some cases referred to as “n a”; not analysed. The reason for this is that there was some instrumental error in the silver measurement during the analyses, resulting in too low Ag-concentrations. Therefore, Ag was re-analysed at a later occasion. However, not all phases were re-analysed and therefore Ag is noted as not analysed instead of a wrong value. In addition, some had already been re-used for lead isotope analyses and were no longer available for new analyses.