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Joachim Lutz, Sebastian Krutter, Ernst Pernicka

Composition and spatial distribution of Bronze Age planoconvex copper ingots from Salzburg, Austria

First results from the "Salzburger Gusskuchenprojekt"

ABSTRACT: *Planoconvex copper ingots (also named "casting cakes" and "bun ingots") were found in huge amounts in the Salzach and Saalach Valleys, but also at the Mitterberg and in the Saalfelden district. 103 of these ingots (partly fragments) were analysed chemically and about 50 complete or nearly complete ingots were classified by means of their shapes and sizes into six different morphological types. A coarse chronology of these morphological types was developed. The chemical data was statistically analysed (cluster analysis) and four main metal groups were defined. As might be expected, the largest group corresponds to chalcopyrite copper and ores from the Mitterberg district. Ingots made of fahlore copper or "diluted fahlore copper" are rare and occur only in the later periods. Previous analytical investigations of bronze finds and archaeological excavations of prehistoric mines have shown a reappearance of fahlore copper in the Late Bronze Age. Thus, the coarse chronology of copper varieties analysed in the ingots matches the overall picture. The analytical results also provide the opportunity to characterize the chalcopyrite copper from the Mitterberg district much better than it was hitherto possible.*

KEYWORDS: BRONZE AGE, SALZBURG, PLANOCONVEX INGOTS, COPPER, GEOCHEMISTRY, LEAD ISOTOPES

Introduction

The rich copper ore deposits in the Eastern Alps, especially in Tyrol and Salzburg, are considered as important sources for copper in prehistoric Europe (Pernicka et al., 2016; Lutz, 2016; Stöllner, 2009). In the past decades several archaeometallurgical and analytical projects in this region attempted to link prehistoric metal artefacts with copper ores based on the geochemical characteristics of the ore deposits that have been exploited in ancient times. Most notable for the analytical attempts are the SSN project ("Bronze Age copper supply in Southern Bavaria, Salzburg and North Tyrol"; Möslein & Pernicka, 2018, this volume) and the HiMAT project ("History of Mining Activities in Tyrol and Adjacent Areas"; Lutz, 2016; Lutz & Pernicka, 2013). In the SSN project mainly metal finds were analysed, whereas later in the HiMAT project the focus was more on excavations and ore analyses, especially in the well-known prehistoric mining areas at the Mitterberg district (Zschocke & Preuschen, 1932; Eibner, 1994; Stöllner et al., 2012; Stöllner et al., 2016), the Viehhofen area northwest of Zell am See, the Kitzbühel district (Pittioni 1976; Goldenberg, 2004) and the fahlore deposits in the Inn Valley near Schwaz and Brixlegg (Martinek & Sydow, 2004; Rieser and Schrattenthaler, 1998/1999; Goldenberg et al., 2012). During the Bronze Age, especially in the Middle and Late Bronze Age, these ore deposits were mined on a large scale. But it is still not clear which role each deposit played, as it is often difficult or nearly impossible to collect enough ore samples to fully characterize a large deposit. Most old mines are nowadays inaccessible and old mining dumps are often reworked by mineral collectors.

Analyses of raw copper ingots (or "casting cakes") found or excavated in the vicinity of the deposits are an important supplement to ore analyses as they often provide much more reliable data for provenance studies of prehistoric metal artefacts than analyses of the ores. They represent the original raw metal that has been smelted and afterwards was traded and distributed to areas outside the Alpine regions. Furthermore, geochemical and isotopic patterns measured in ores may be altered to some degree during processing and smelting. Therefore, the raw copper ingots often provide a better geochemical "fingerprint" than ores. After analysis of about 100 ingots it is now possible to calculate reliable values for element concentrations in chalcopyrite copper, especially from the Mitterberg district. (JL, EP)

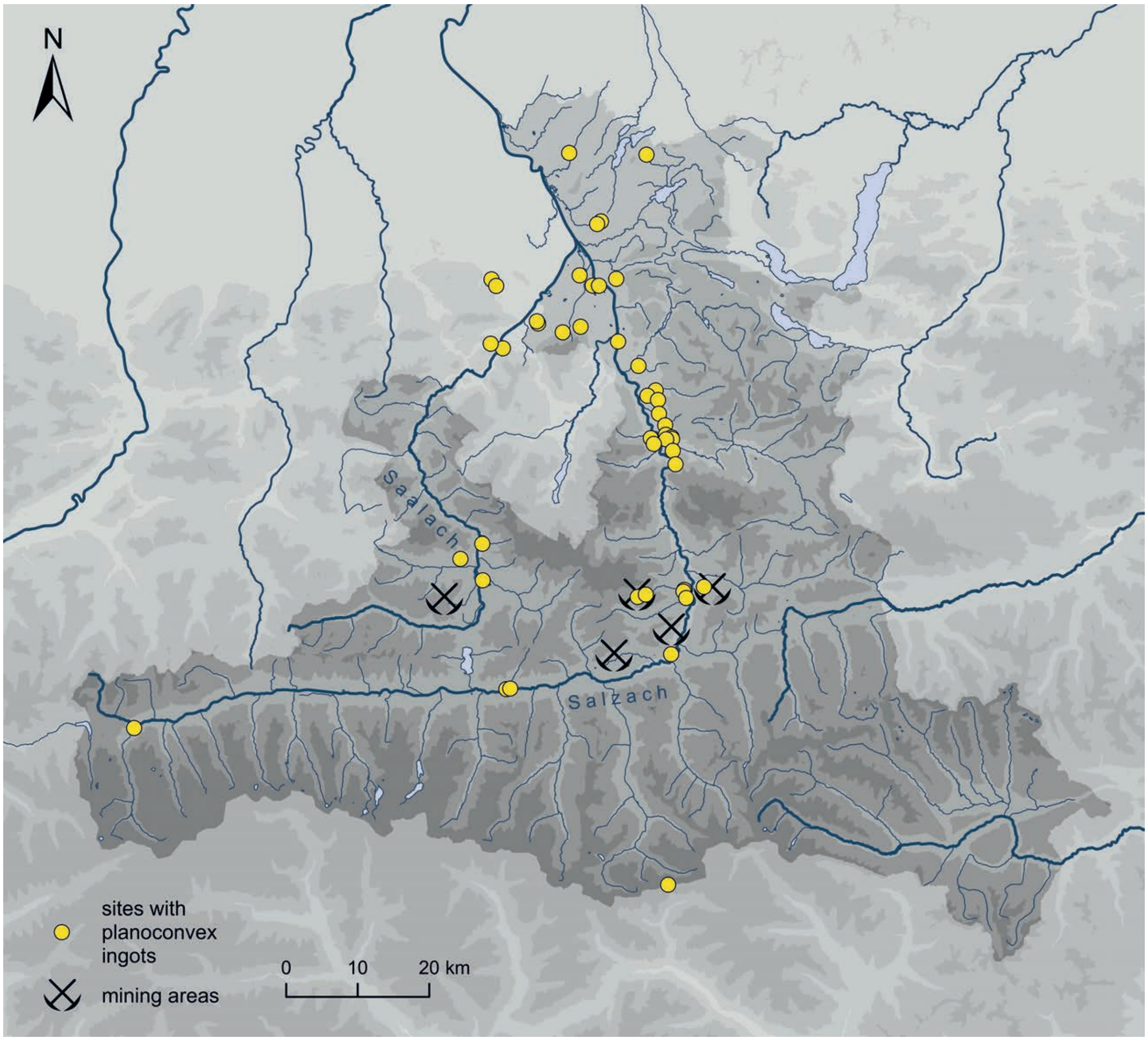

Fig. 1: Distribution of planoconvex ingots in the Salzach and Saalach Valleys (© SAGIS, OSM, Sebastian Krutter).

Planoconvex ingots in the Salzach and Saalach Valleys

In the Salzach and Saalach Valleys there are overall 46 archaeological sites known where about 1,000 complete planoconvex copper ingots and their fragments with a total weight of about 300 kg were found. Besides two isolated accumulations in the Mitterberg region as well as in the Saalfelden basin, the sites with planoconvex ingots cluster mainly in the northern Salzach Valley, in the Salzburg Basin and the Alpine Foreland along the main distribution route of the Alpine copper (Fig. 1). The majority of the planoconvex ingots was found in hoards consisting only of ingots and their fragments, which are located in special environmental situations such as elevated terrain terraces and passes, but rarely within mining areas. The planoconvex ingots were usually deposited in simple earth pits containing up to 17 complete planoconvex ingots, such as known from the hoard Saalfelden-Wiesersberg (Krauß, 1998/1999). Occasionally the pits are covered with stone slabs and the ingots are arranged in a special way and sometimes even organic wrappings and ceramic vessels are preserved. Hoards of planoconvex ingots are also known from fluviatile, lacustrine and palustrine environments and in addition, a few small fragments of planoconvex ingots were found inside some Bronze Age settlements. (SK)

Classification and dating

Due to a combination of unfavourable preservation conditions in form of mostly small fragments and archaeological contexts without any associated dateable finds,

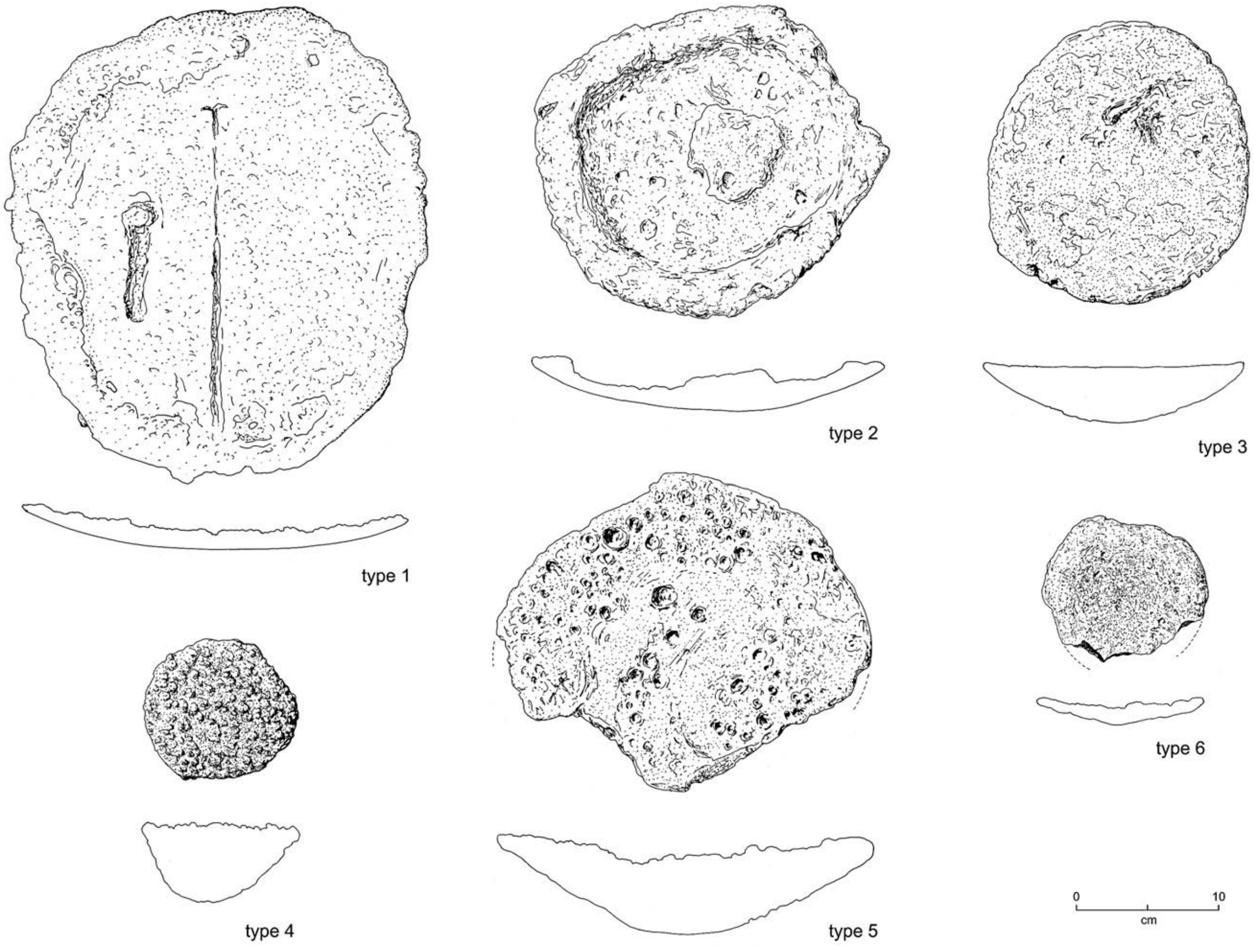

Fig. 2: Types of planoconvex copper ingots from the Salzach and Saalach Valleys (© Salzburg Museum, Franz Krois).

planoconvex ingots and their fragments are usually very difficult to classify and date. This is why they have been generally assigned to the Late Bronze Age in most cases. According to this framework, various basic investigations with different methodological approaches in several regions of central Europe have been published (e.g. Bachmann & Jockenhövel, 2004; Czajlik, 1996; Kyrle, 1918; Modl, 2019; Nessel, 2014; Primas & Pernicka, 1998; Reinecke, 1938; Le Carlier de Veslud et al., 2014).

Considering their comparatively good preservation and the spatial proximity to the Bronze Age copper mining regions, the planoconvex ingots of the Salzach and Saalach Valleys offer a unique basis for a typological study. Hence, the ingots could be separated into six different types (Fig. 2-3) based on a combination of morphometric attributes such as diameter, thickness, basic form, form of the cross-section and form of the casting edges. Due to a lack of typological relevance, the weight as well as the chemical composition could not be used as diagnostic attributes within this classification. Based on radiocarbon dates of charcoal remains from the surface of some ingots and some dateable associated metal finds from hoards and typological parallels in the Alpine piedmont the different types range from the Early Bronze Age up to the Late Bronze Age. Characteristic for the Early and the beginning Middle Bronze Age (BzA2-BzB) are planoconvex ingots of type 1 showing an oval basic form, a bowl-formed cross section and a very distinctive bulging casting edge. Besides a smaller diameter and an almost round basic form, planoconvex ingots of type 2 reveal a close relationship to type 1 and can be considered contemporary. The "classic" planoconvex ingots are represented by type 3 of this classification showing a planoconvex cross-section and a round or oval basic form. Ingots of this type appear over the whole Bronze Age and can be further divided into two variants with different thicknesses and basic forms: Variant 3a is clearly thinner than variant 3b and frequently shows an oval basic form, while variant 3b occurs only with a round basic form and chronologically appears mainly in the Late Bronze Age (BzD-HaB). Planoconvex ingots of type 4 also belong to the Late Bronze Age (BzD-HaB) and are characterised by a planoconvex cross-section and an almost round basic form, but differ from the previous type by a clearly smaller diameter and a larger thickness. In contrast, the largest as well as the heaviest planoconvex ingots within the Salzach and Saalach Valleys are represented by type 5, which shows a round basic form, a planoconvex

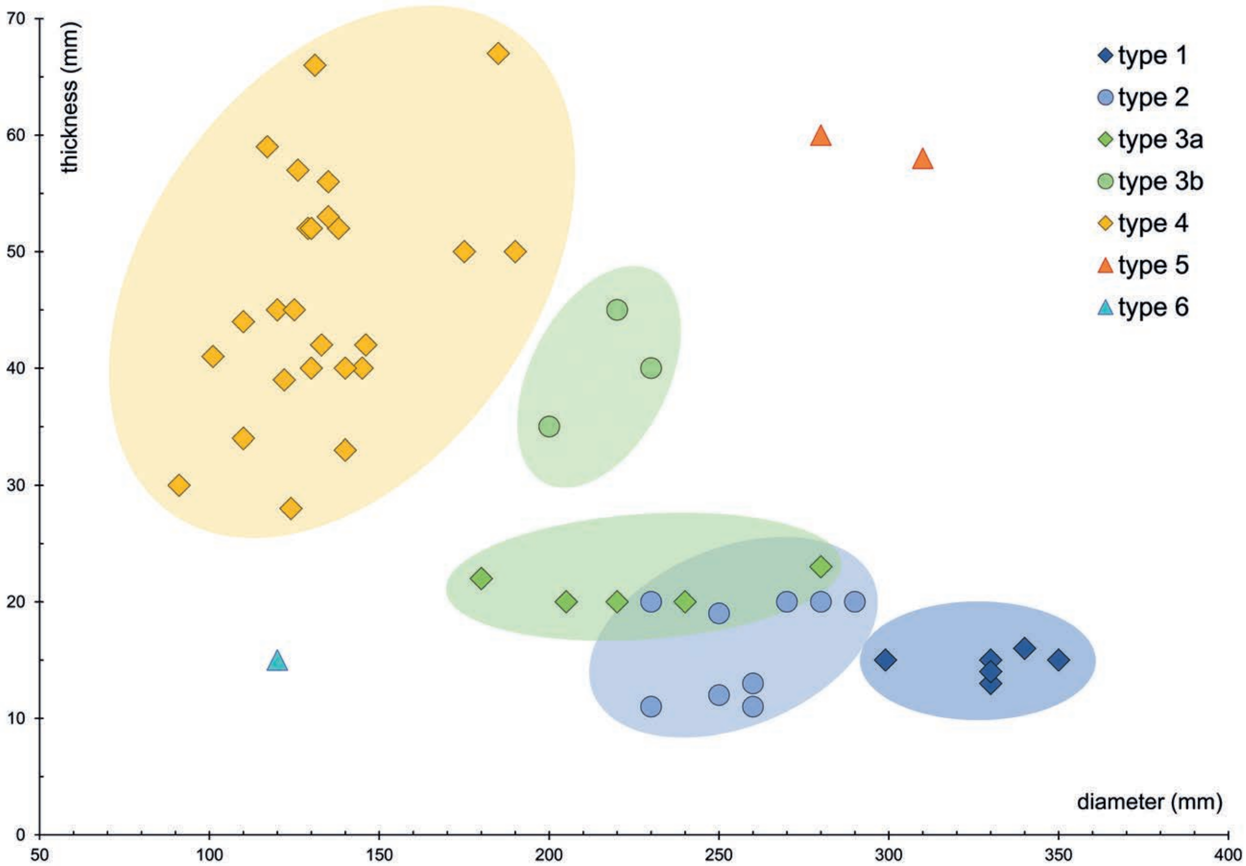

Fig. 3: Metric attributes of planoconvex copper ingots from the Salzach and Saalach Valleys. The diagram includes only planoconvex ingots and fragments whose preservation conditions allow a secure recording of the diameter and the thickness. (© Sebastian Krutter).

cross-section and are dateable also to Late Bronze Age (BzD-HaB). Contemporaneous to the previous type, type 6 is characterised by a round basic form, an almost bowl-formed cross-section and very small dimensions.

Based on the defined types, for the planoconvex ingots of the Salzach and Saalach Valleys a morphometric evolution from the Early to the Late Bronze Age can be stated, within which the diameter becomes smaller and the thickness larger. Furthermore, a change from oval to almost round basic forms is recognisable. Contrary to the previous traditional dating of planoconvex ingots into the Late Bronze Age and especially the Urnfield period, it can now clearly be shown that planoconvex ingots already occurred in the Early Bronze Age and have played much earlier an important role as trading form of raw copper than supposed so far. (SK)

Data and analysis techniques

The chemical analyses of ingots evaluated in this paper were performed during the last 15 years in the frame of different archaeometallurgical projects. Therefore, also different analytical methods and instruments were used. Several hoards with ingots was discovered in Kuchl-Benzbichl and metal samples were analysed at the TU Bergakademie Freiberg in Saxony in 2003. Some ingots were analysed as part of the SSN project (Möslein & Pernicka, 2019, this volume), also at the TU Freiberg. Later, a few ingots from Salzburg were investigated during the HiMAT project (Oeggl et al., 2012) together with a number of artefacts from the Salzach Valley (Stöllner et al. 2016). The dataset was then completed in the last years with a series of analyses for the "Salzburger Gusskuchenprojekt" funded by the Landesarchäologie Salzburg. These analyses were also carried out at the Curt-Engelhorn-Zentrum Archäometrie in Mannheim.

All ingots were sampled with a small steel drill. Afterwards the alloy composition was determined by energy-dispersive X-ray fluorescence analysis (XRF) using different XRF spectrometers, but always following the quantification and correction procedures of Lutz & Pernicka (1996). Therefore, the data is well comparable. In some ingot samples lead isotope ratios were determined using multi-collector ICP-MS following the procedure described by Niederschlag et al. (2003).

The ore samples from the Mitterberg district (Pernicka et al., 2016), the Kelchalm near Kitzbühl, Viehofen and Schwaz/Brixlegg (Höppner et al., 2005) used for com-

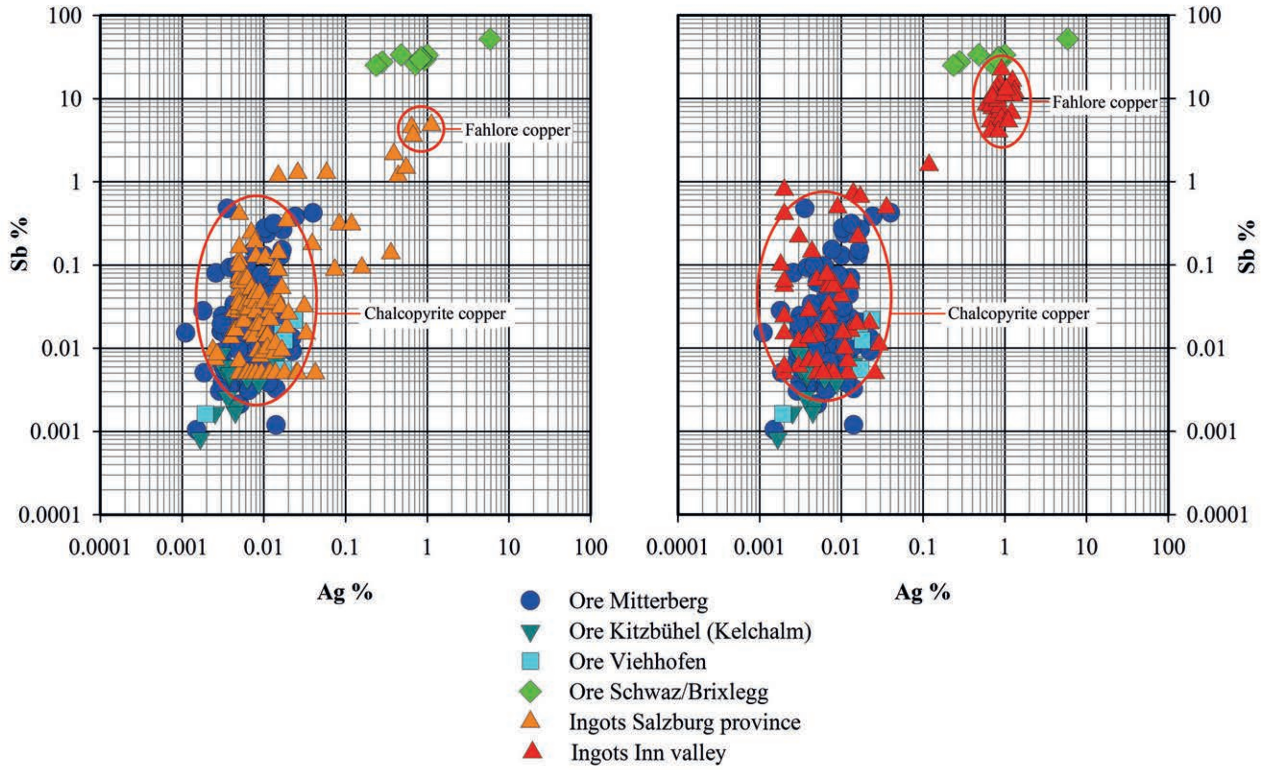

Fig. 4: Concentrations of silver and antimony in fahlores from the Inn Valley (Schwaz/Brixlegg) and in chalcopyrite ores from Mitterberg, Kitzbühel and Viehhofen compared with copper ingots from Salzburg (left) and from the Inn Valley (right). The concentration of antimony in fahlore copper ingots is lower than in the fahlores because it was the aim of the fahlore smelting process to reduce the high antimony contents. While most of the ingots from Salzburg consist of chalcopyrite copper, the proportion of fahlore copper is much higher in ingots from the Inn Valley. This reflects the geographic location of the main fahlore deposits in the west and the most important chalcopyrite deposits more in the east. (© CEZA, Joachim Lutz).

parison were analysed chemically by neutron activation analysis (NAA, for Fe, Co, Ni, Cu, As, Sb, Ag, Au, Se, Te, Zn, Sn) and inductively-coupled plasma mass spectrometry with a quadrupole ion filter (QICP-MS, for Pb, Bi). Furthermore, the lead isotope ratios were determined in some of the ore samples and in addition also in some slag samples from the Mitterberg district. These ore and slag analyses were carried out during the HiMAT project. (JL, EP)

Regional trends in composition

Most of the raw copper ingots discovered in the last hundred years were found in the eastern Alpine foreland and the Inn and Salzach Valleys, especially where the valleys open to the foreland. From the Inn Valley a series of ingots was analysed during the SSN project and this offers the opportunity to compare the composition of ingots from the Inn Valley with those from Salzburg (Fig. 4). In both series ingots of the main copper varieties (chalcopyrite copper, fahlore copper and copper with mixed patterns) occur, but the proportion of the copper varieties differs. In the west (Inn Valley) much more fahlore copper ingots occur whereas in the east (Salzburg) only three fahlore copper ingots were discovered. In Salzburg, most ingots consist of chalcopyrite copper. This reflects the geographic location of the main fahlore deposits (Schwaz and Brixlegg) in the Inn Valley. In Salzburg, chalcopyrite is the predominant copper mineral and fahlore mineralisations are of minor importance. (JL, EP)

Cluster analysis

The chemical data of the Salzburg copper ingots performed with XRF were statistically analysed with cluster analysis (statgraphics software). The elements Co, Ni, As, Ag, Sb and Bi (logarithmic values) were selected for clustering as they were detected in most samples (except Bi which was only detected in fahlore copper ingots and some ingots with mixed patterns). Detection limits were transformed into estimated values (half of the detection limit) to prevent the loss of objects for classification due to missing values. 103 analyses were clustered with the group average clustering method using Euclidean distance metric. The best results were observed on a clustering level with four groups (Fig. 5):

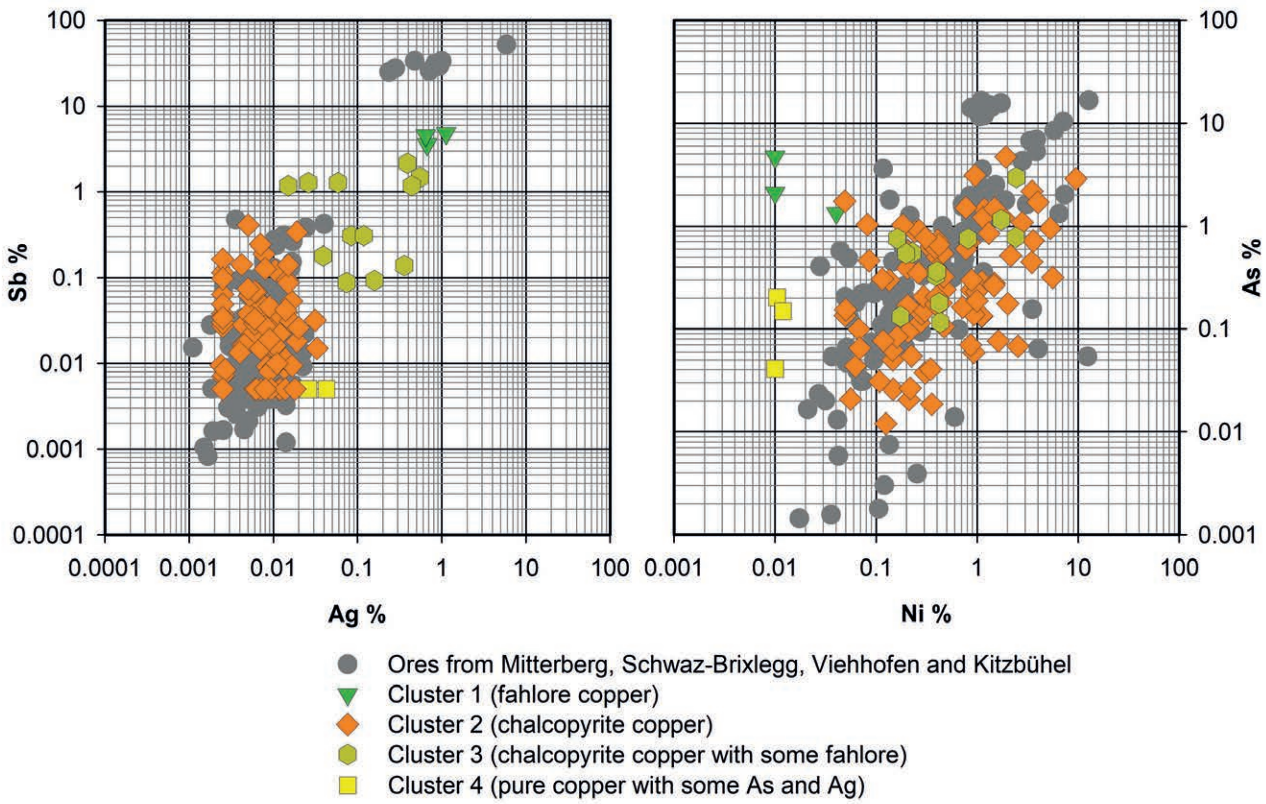

Fig. 5: Concentrations of silver and antimony in ingots from Salzburg (left) and of nickel and arsenic (right) for the four different cluster groups. (© CEZA, Joachim Lutz).

Cluster 1 includes only three ingots of fahlore copper with typically high values of arsenic, antimony and silver and also some bismuth. The concentrations of cobalt and nickel are very low and mostly below detection limits.

Cluster 2 is the largest group with 85 chalcopyrite copper ingots. They match perfectly with the data of the chalcopyrite ores from the Mitterberg (Fig. 5). This result was expected as the Mitterberg is the predominant copper deposit in the region with extensive prehistoric mining remains.

Cluster 3 includes 12 ingots with trace element patterns plotting between the fahlore cluster 1 and the chalcopyrite cluster 2. This variety of copper might be a mixture of fahlore copper and chalcopyrite copper in some cases, but then it should contain also some bismuth from the fahlore copper. But only in two ingots of this “mixed” copper variety bismuth was detected. More likely, fahlore minerals were part of the primary ore paragenesis. Six of these ingots derive from a hoard discovered near Saalfelden. Possibly those ingots derive from the nearby located deposit Leogang, where both chalcopyrite and fahlore occur.

Cluster 4 (3 ingots) is possibly just a variety of chalcopyrite copper with relatively high silver and arsenic contents but low nickel concentrations. Astonishingly they derive all from Anger in Southern Bavaria near the Austrian border, but were found at two different sites. (JL, EP)

Lead isotope analysis

In a small series of copper ingots also lead isotope ratios were determined and compared with copper ores from the Mitterberg (Fig. 6, left diagram). Lead isotope ratios of ores from the Mitterberg show a large variation (especially the Mitterberg Main Lode) due to low lead contents combined with occasionally high uranium concentrations. The variation of lead isotopes in the ingots is smaller because a greater amount of ore was homogenized during processing and smelting. In contrast, the variation of the ingots is nearly congruent with the variation of the Mitterberg slags (Fig. 6, right diagram), as they are also smelted from of a greater amount of ore like the ingots. (JL, EP)

Results

With the data of the chalcopyrite copper ingots it is now possible to define exact concentration ranges for trace elements in copper from the Mitterberg district (Tab. 1) as it was produced and distributed in prehistory. Typical copper from the Mitterberg contains about a percent of arsenic and nickel (these elements are correlated) but only traces of silver and antimony.

	Co %	Ni %	As %	Ag %	Sb %	Bi %	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
Min	<0.01	0.05	0.012	0.002	<0.005	<0.01	1.9611	0.76957	18.632
Max	0.46	9.5	3.1	0.020	0.41	<0.01	2.0918	0.82093	20.498
Median	0.04	0.40	0.32	0.007	0.028	<0.01	2.0509	0.84088	19.104

Tab. 1: Chemical and lead isotopic characteristics of chalcopyrite copper from the Mitterberg district. The ingots from Saalfelden were omitted for the calculation of the values, as they possibly may not derive from the Mitterberg mining district. (© CEZA, Joachim Lutz).

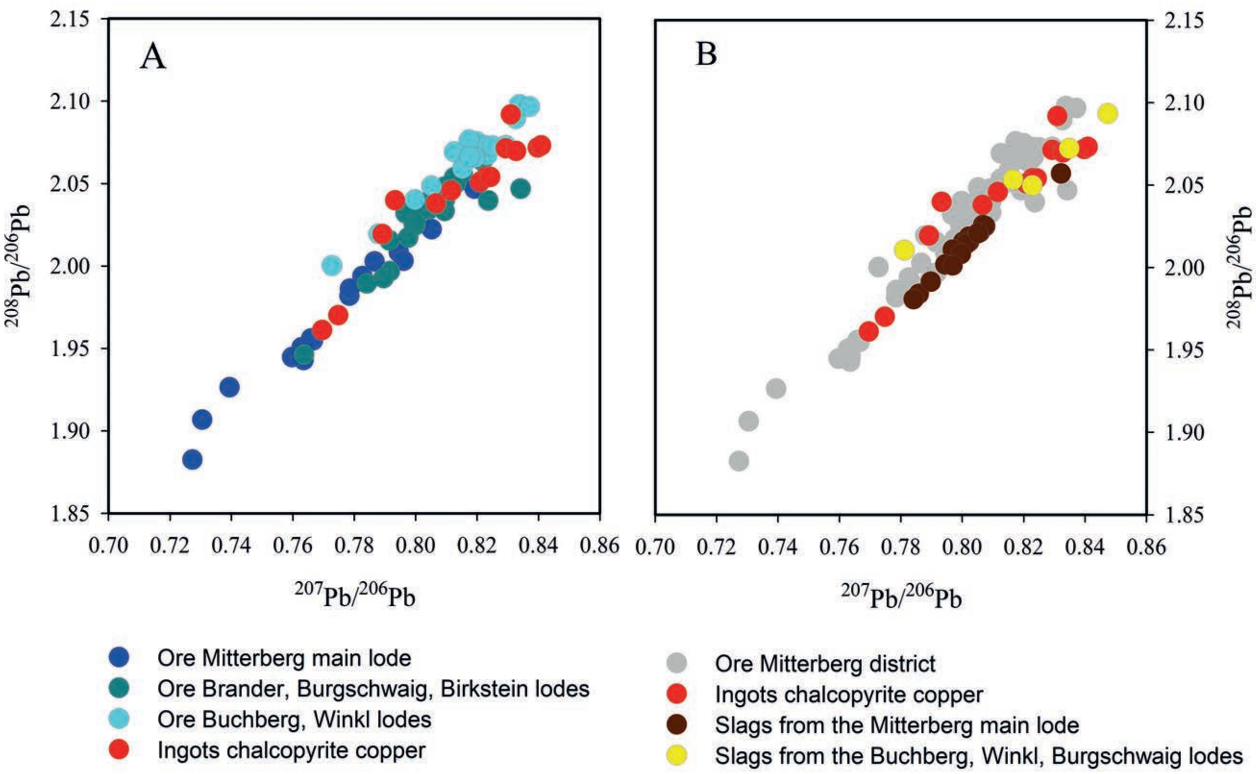

Fig. 6: Lead isotope ratios in ores from the Mitterberg district compared with some chalcopyrite copper ingots from Salzburg (left). The variation of lead isotope ratios is greater in the ores. In contrast, the scattering range of the copper ingots and slags from the Mitterberg region is almost identical. During processing and smelting of ores a greater amount of ore is homogenized. Therefore, the scattering range is smaller in slags and ingots compared with relatively small ore samples that were used for characterizing ore deposits. (© CEZA, Joachim Lutz).

Despite the fact that most ingots consist of chalcopyrite copper, it is interesting to see how the other copper varieties are distributed among the different morphological types in Salzburg (Fig. 7). The chalcopyrite copper (cluster 2) is present in all types, whereas the fahlore copper (cluster 1) and the copper with "mixed" patterns (cluster 3) tend to occur only in the later types. Cluster 4 occurs only with type 2. Analytical investigations of bronze finds and archaeological excavations of prehistoric mines have proven a re-appearance of fahlore copper in the Late Bronze Age. Thus, the chronology of copper varieties in the ingots matches the overall picture. (JL, EP)

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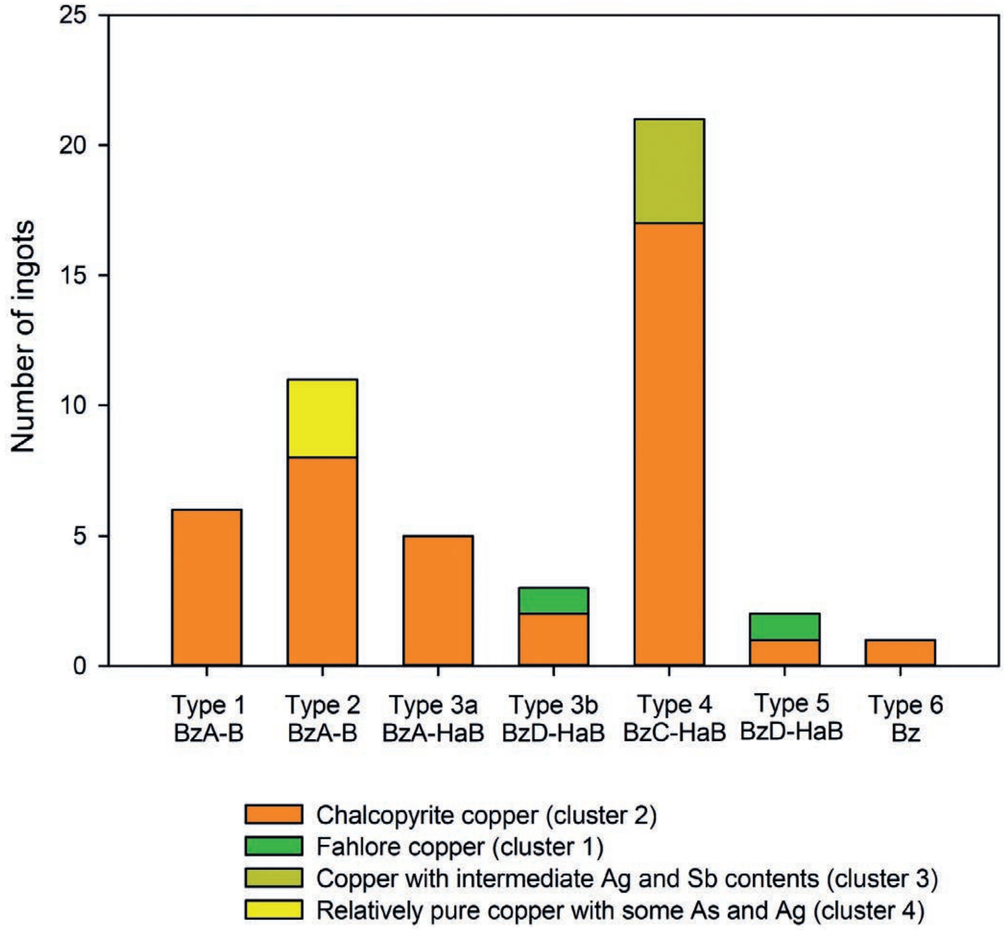

Fig. 7: Number of ingots of the different types analysed. The total number of analyses is larger, but many fragments could not be assigned to a certain type. Most ingots consist of chalcopyrite copper. Ingots made of fahlore copper or "diluted fahlore copper" are rare and occur only in the later periods. (© CEZA, Joachim Lutz).

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Authors

Joachim Lutz – Curt Engelhorn Centre of Archaeometry gGmbH, Mannheim
Sebastian Krutter – Landesarchäologie Salzburg, c/o Salzburg Museum
Ernst Pernicka – Curt Engelhorn Centre of Archaeometry gGmbH, Mannheim

Correspondence and material requests should be addressed to: joachim.lutz@ceza.de