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Copper and bronze axes from Western Austria reflecting the use of different copper types from the Early Bronze Age to the Early Iron Age

ABSTRACT: *First evaluations of analytical data from East Alpine prehistoric metal artefacts have shown that a use of different types of copper can be expected varying in time and space (Sperber, 2004, Möslein, 2008). These studies mainly emphasise a change from the use of fahlore based copper in the Early Bronze Age to the major use of chalcopyrite based copper in the Middle Bronze Age, with a shift in the Hallstatt A2 period, when both materials were used to produce bronze (Lutz & Pernicka, 2013, Pernicka & Lutz, 2015, Lutz, 2016).*

In the following these general observations are specified for a defined area and a certain object group. Copper and bronze axes from Western Austria (Vorarlberg, Tyrol, Salzburg, Upper Austria) have been chosen as these objects are available in all periods and regions and contain a representative amount of copper. The above mentioned succession of fahlore copper use, chalcopyrite copper use and the use of both materials is also observed within the examined axes. A more detailed picture evolves regarding the Late Bronze Age and the Early Iron Age, when the use of fahlore copper is mainly observed in bronzes based on diluted fahlore copper and not on pure fahlore copper. This is particularly notable as a big Late Bronze Age/Early Iron Age fahlore production center – Schwaz/Brixlegg – lies in the heart of the examined area.

Regarding alloying practice, two observations are remarkable: In the Late Bronze Age (Ha A1-B3) the average tin content drops significantly, correlated to the reuse of fahlore copper. In the Early Iron Age (Ha C1-D2), the alloying practice changes again and the tin content in the axes rises to a level like in the Middle Bronze Age, but also the lead contents rise.

KEYWORDS: EASTERN ALPS, WESTERN AUSTRIA, COPPER AND BRONZE AXES, EARLY BRONZE AGE TO EARLY IRON AGE, ARCHAEOMETALLURGICAL ANALYSES, COPPER TYPES, ALLOYING, EXCHANGE NETWORKS

Premises

The DACH-project[1] (2015-2018) “Prehistoric copper production in the Eastern and Central Alps – technical, social and economic dynamics in space and time” financed by the Austrian Science Fund (FWF), the German Research Foundation (DFG) and the Swiss National Science Foundation (SNF) gives the frame for the below presented work. It is a joint project of the Universities of Innsbruck (Research Centre HiMAT[2]), Bochum and Zürich, the Deutsches Bergbau-Museum Bochum (DBM), the Curt-Engelhorn Zentrum Archäometrie gGmbH (CEZA) Mannheim and the Archäologischer Dienst Graubünden.

Spadework and hypothesis

First evaluations of analytical data from East Alpine prehistoric artefacts have shown that a use of different types of copper (fahlore based, chalcopyrite based) can be expected varying in time and space and produced in different copper districts (Sperber, 2004, Möslein, 2008). These studies mainly emphasise a change from fahlore copper use in the Early Bronze Age to the major use of chalcopyrite copper in the Middle Bronze Age, with a shift in Hallstatt A2 period, when both materials were used (Lutz & Pernicka, 2013, Lutz, 2016). For these developments not only the technical progress but also demand-orientated decisions and other influences must be taken into consideration.

In the following these general observations are specified for a certain object group in a defined area (axes of western Austria[3] and adjacent areas). Furthermore examinations regarding standardized tin alloying and a relation between low tin-contents and high trace element contents are conducted. The use of lead within the bronze alloys is also examined.

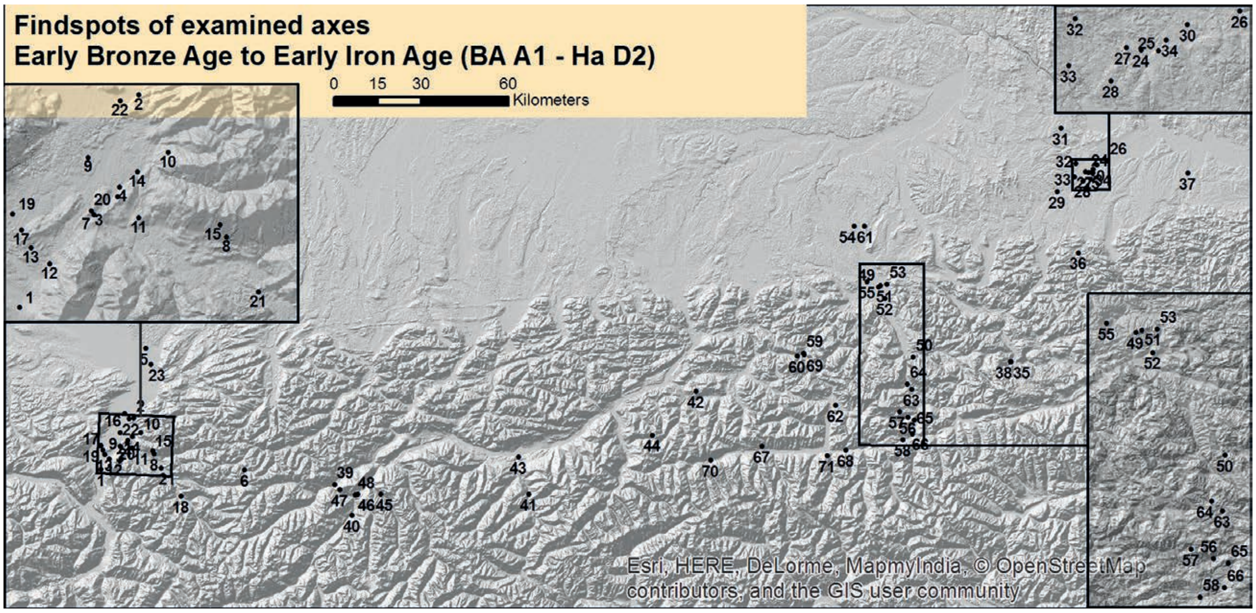

Fig. 1: Distribution map of the 175 examined axes. For corresponding site names see Tab. 1.

Goals

Since the 1950's hundreds of chemical and isotope analyses of ores and artefacts have been produced (Otto & Witter,1952, Junghans et al,1960 and 1968, Ottaway, 1982, Rychner & Kläntschi,1995, Krause, 2003, Kienlin, 2008, Pernicka et al, 2016, Möslein & Pernicka in this volume), complemented by data created within the HiMAT project within the last decade.

The aim of the work at hand is a consolidating research for Western Austria, bringing together the archaeological data with the geochemical data. There is revealing work for either special periods or parts of Western Austria (e .g. Ottaway, 1982, Sperber, 2004, Kienlin, 2008, Möslein, 2008, Lutz & Schwab, 2014) or on the scale of an overview (Pernicka & Lutz, 2013, Lutz, 2016), but no detailed research on the developments within one object group from the Early Bronze Age to the Early Iron Age. The Axes of Western Austria were chosen for this approach as they were in use during all periods of interest in all regions and they embody a representative mass of copper.

On the basis of 175 axes and by combining the archaeological with the geochemical data the work investigates:

1. the chronological development of the use of different copper types in the Eastern Alps from the Early Bronze Age to the Early Iron Age and
2. the chronological development of alloying practices in the Eastern Alps from the Early Bronze Age to the Early Iron Age.

Material

The 175 axes discussed, derive from the vorarlberg museum[4] (28 axes), Northern Tyrol (94 axes), Salzburg (32 axes)[5] and Upper Austria (21 axes) (Tab. 1, Fig. 1). The earliest pieces date to Bronze Age A1, the latest to Hallstatt D2 (Fig. 2). Therefore the material covers about 1700 years of regional copper and bronze production.

All analyses are either measured or remeasured by the CEZA or the TU Bergakademie Freiberg[6] using XRF and are therefore comparable, except 10 older analyses[7] (Otto/Witter, 1952). The latter are not used for the element plots, as the data is not well comparable. They are only included in the interpreting histogram (Fig. 8), as the assignment to a copper type was possible. This means that for Northern Tyrol and Salzburg analyses from Otto and Witter (10 objects), the SSN-project[8] (16 objects) and the HiMAT-project[9] (100 objects) are used. 18 objects from the vorarlberg museum as well as the axes from Upper Austria (21) have been sampled and analysed within the DACH-project[10] (for these analyses see Tab. 3). 10 samples from the vorarlberg museum derive from the SAM-project[11] and have been remeasured at the CEZA for the study at hand.

As within the HiMAT-project two big hoard finds were analysed, there is an accumulation of data for the Middle Bronze Age and the beginning Late Bronze Age (BA B1-D1) for Northern Tyrol (46 axes from the hoard find Moosbruckschrofen/Piller (Tomedi, 2001 and 2007)) and for the Early Iron Age (Ha C1-D2) in Northern Tyrol (38 axes from the so called Kathreinfund/Fließ (Sydow, 1995)). In Upper Austria 4 of the analysed pieces derive

Fig. 2: Selection of characteristic axe types sampled to illustrate the typo-chronological development of axes in the Eastern Alps from BA A1 to Ha C1-D2 (types from upper left to bottom right: Salez A, Langquaid II/Koblach, Absatzbeil mit gedrungen herzförmiger Rast, Freudenberg/Elixhausen, Freudenberg/Retz, Lappenbeil mit herabgezogenen Lappen, Breites mittelständiges Lappenbeil, Winkel- und bogenverziertes Tüllenbeil, Hallstatt). For corresponding data see Tab. 1, for corresponding find spots see Fig. 1. Red crosses mark the sampling positions if the objects have been sampled within the DACH-project.

from the Oberösterreichische Landesmuseum and 17 from the Stadtmuseum Wels – this explains the accumulation of sampled objects in the vicinity of Wels. In Vorarlberg there are find concentrations around the rivers Ill and Rhine. This may actually reflect the prehistoric picture, although an academic void for nowadays sparsely populated areas due to missing investigations and chance finds has to be taken into account.

Methods

As already mentioned the main target of this work is to merge the archaeological data with the geochemical data. The archaeological part comprises the material selection, typological determination, artefact dating, photo and drawing documentation, weighing of artefacts and object sampling. The geochemical part includes sample preparation, analysing and determination of copper types. Conclusions are drawn in close cooperation between archaeologists and geologists/geochemists.

Artefact selection not only depends on the availability of prehistoric axes in the questioned area but also on the accessibility and the possibility of sampling. For Vorarlberg and Upper Austria cooperation with the vorarlberg museum (G. Grabher), the Oberösterreichisches Landesmuseum (J. Leskovar) and the Stadtmuseum Wels (R. Miglbauer) was agreed, otherwise it would have been very difficult to obtain material and analyses. For the Tyrol and Salzburg the predominant aim was to process the already existing data[12]. For South Tyrol work is in progress[13] but cannot be presented yet. Objects from Southern Bavaria[14] which also should be considered when speaking about the Eastern Alps have been sampled and are dealt with in the SSN-project (Möslein/Pernicka in this volume).

Sampling of the objects is done with the Proxxon TBM 220 with a 1.5 mm drill. After carefully removing the patina, about 40 mg of fresh metal drillings are gained. Afterwards the drill holes are sealed with a colour-coordinated restoration wax[15].

As this paper exclusively deals with the differentiation of chalcopyrite copper from fahlore copper and with tin contents in relation to trace and minor element contents deriving from the ore, X-ray Fluorescence Analyses (XRF) are sufficient. All ore analyses plotted in the diagrams are Neutron Activation Analyses (NAA).

The alloy composition of the metal samples was determined by energy-dispersive XRF analysis following the quantification and correction procedures of Lutz & Pernicka (1996). Ore samples were irradiated together with appropriate neutron flux monitors and standard materials in the TRIGA reactor of the Institute for Nuclear Chemistry of the University of Mainz. The measurement of the activated ore samples (gamma-radiation) was carried out at the CEZA in Mannheim using Ge-detectors. The NAA-method used is published in Kuleff & Pernicka (1995).

The two main East Alpine copper sources are fahlore and chalcopyrite deposits with their secondary minerals. The discrimination of copper produced from fahlores and copper produced from chalcopyrite is based on trace element contents, especially silver and antimony. Plotting the silver and antimony contents of East Alpine fahlores and chalcopyrite, results in two well distinguishable groups – silver and antimony rich fahlores, but silver and antimony poor chalcopyrite. This picture is reproduced when plotting the silver and antimony contents of prehistoric raw copper (plano-convex copper ingots), which has some clear advantages to distinguish different copper types (Fig. 3). As prehistoric mining areas are often inaccessible, altered or largely exploited, sometimes only small remains of ores on mining heaps can be sampled. Furthermore each ore sample represents only one possible composition, deriving from an usually very heterogeneous ore body. To understand the whole system, it is of course essential to characterize the ores of a mining district. But raw copper in contrast to an ore sample depicts a deposit already homogenized through beneficiation and smelting. Furthermore it also reflects the smelting process.

There are 192 analysed plano-convex copper ingots (raw copper) not only from the Inn Valley, but also from the Alpine foothills, North Tyrol and Salzburg[16] (Figs. 4 and 5), which illustrate the composition of the prehistorically produced copper of this region very well (Lutz 2016). This set of data is the basis for the following calculations.

The analyses have shown that the average silver content in fahlore copper (FC) is a hundred times higher than the one in chalcopyrite copper (CC). As only one plano-convex copper ingot has a silver content of 0.2 to 0.3 mass% silver, the statistic distribution divides silver rich from silver poor copper at 0.22 mass% silver, with two peaks at around 0.01 and 1.0 mass% (Fig. 4). The median silver contents for the two groups received, are 0.008 mass% silver in chalcopyrite copper and 0.82 mass% silver in fahlore copper. Consequently the silver content is an appropriate tool to distinguish objects made of alpine fahlore copper from those made of alpine chalcopyrite copper. Even more since silver is not lost during further processing (melting/remelting) and can be measured precisely with XRF-analyses (detection limit of 20 ppm). Although antimony gets lost during smelting, there is still a substantial content-difference observed in the casting cakes. Therefore raw copper obtained from fahlores comprises about 300 times higher antimony contents on average than raw copper obtained from chalcopyrite[17]. Consequently also increased antimony contents are expected in objects made of fahlore copper, though it is more difficult to estimate at what height, as it was one aim of further processing to get rid of the antimony. While arsenic is also a significant component of fahlores, it is not that useful for differentiation. Especially the chalcopyrite from Mitterberg occurs together with gersdorffite (NiAsS). Thus a lot of arsenic (and also nickel) can arise in chalcopyrite copper objects produced from Mitterberg ores.

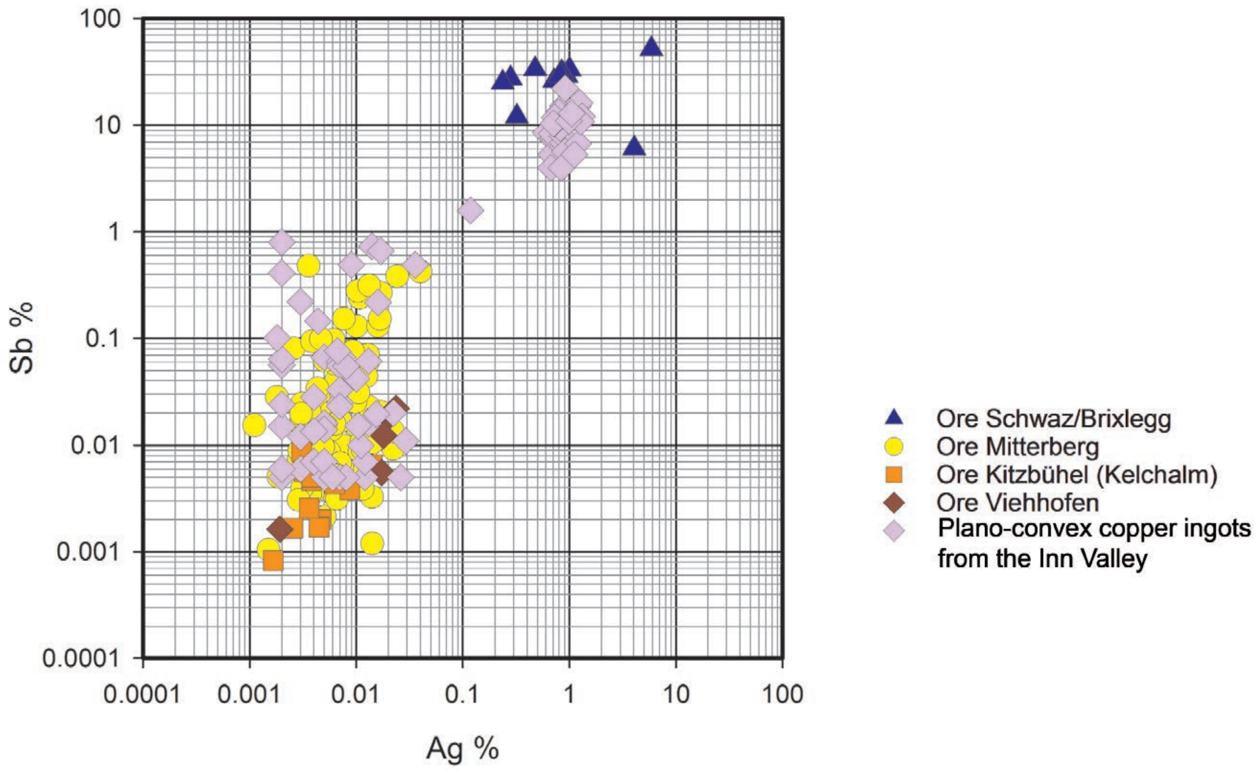

Fig. 3: Plotting silver versus antimony emerges two very well distinguishable groups of silver and antimony rich and poor ores and raw copper (plano-convex copper ingots). For the silver and antimony rich fahlore-group it is also evident, that antimony gets lost during processing, while silver gets homogenized.

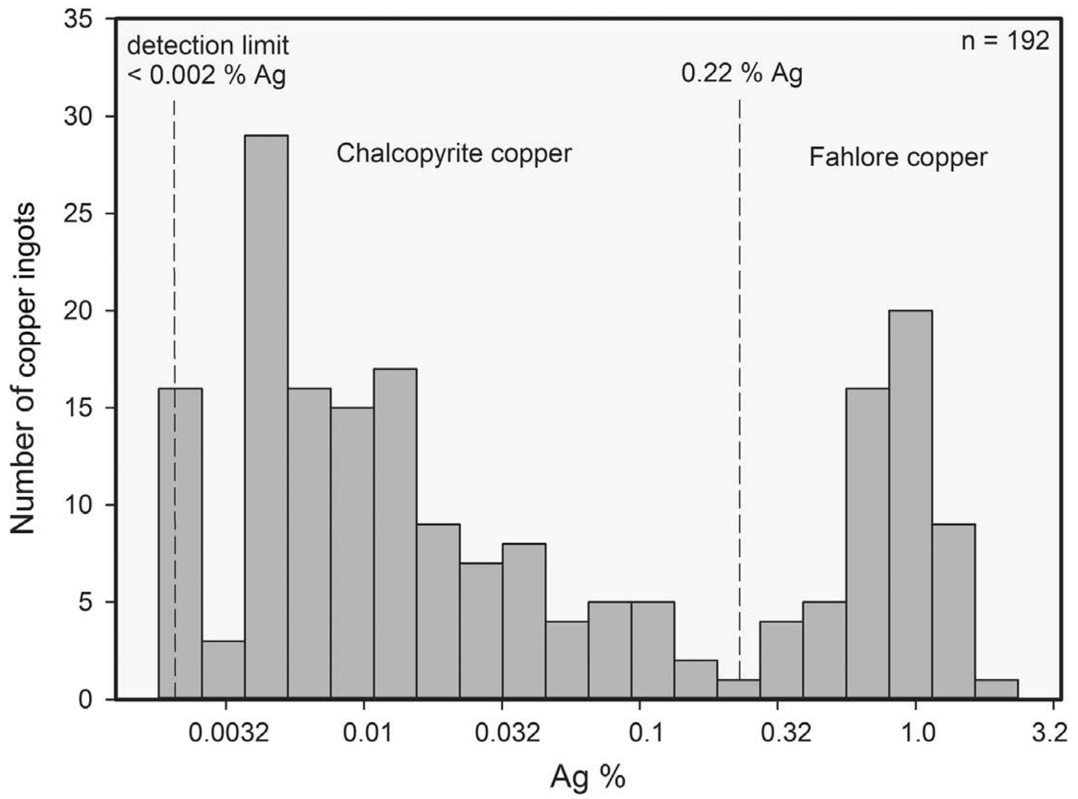

Fig. 4: Silver content (logarithmic) in 192 East Alpine casting cakes. The two peaks represent two types of copper. Nonetheless all gradations are present, though only within a few pieces.

First results

Merging the data basically means bringing together the archaeological information (typology, chronology and chorology of the artefacts) with the geochemical information (ore resources, copper types). Hence an evaluation of the chronological and spatial development of fahlore copper / chalcopyrite copper use is possible.

Development of fahlore and chalcopyrite copper use in the Eastern Alps from the Early Bronze Age to the Early Iron Age

Chronology

Axes are an object group for which fine dating is not always possible as most of them derive from single or hoard finds, especially after the Early Bronze Age. For hoard finds it becomes increasingly obvious, that one single deposit can cover a long time span, sometimes 200 or 300 years. Circular reasoning led to misinterpretation and objects, among them also axe types, are misdated, referring to the youngest piece in a hoard. (On these issues e.g. Tomedi, 2007, Hansen, 2016). In this paper lifespans of types (Tab. 1) are used, which are merged to succeeding dating groups (Tab. 2). Axes for example which can clearly be assigned to BA A1 will of course be found in the first group "Beginning Early Bronze Age". If an axe type can derive from either BA A1 or A2, it will be found in the next group "Early Bronze Age" – as we cannot decide to put it either into A1 or A2 – thus considering the lifespan of an axe-type but also a tendency of an object to be of later origin. Because of this, some developments in the succession of copper types might be expressed slightly weakened. On the other hand presumed fine dating can be avoided and at least the succession of copper types is depicted correctly.

As quite a few axes of the type Freudenberg are included, a short comment shall be attached. According to Mayer the majority of Freudenberg axes is – consistent with the youngest objects in some hoard finds[18] – dated to the early Urnfield period, with a possible maximum life span of this type from BA C to Ha A1 (Mayer, 1977, 141). "*In contrast*" the grave finds containing Freudenberg axes date to the Middle Bronze Age (Mayer 1977, pp. 142-144, Pászthory & Mayer,1998, 97 f.). In addition there is a terminus ante quem for a Freudenberg axe from the ritual site for burnt offerings (*Brandopferplatz*) Piller Höhe/Tyrol (HiB161). The layer covering the axe is radiocarbon-dated to the Middle Bronze Age as follows: 1504-1311 cal. BC (2σ) (IntCal 13, 3158 +/- 34 BP) or 1504-1383 cal. BC (89,3%) (IntCal 13, 3158 +/- 34 BP)[19] (Tschurtschenthaler &Wein,1998). In the work at hand the Freudenberg axes which cannot be fine dated based on their variation or other information are therefore placed into the group „End of Middle Bronze Age / beginning Late Bronze Age".

Chronological development of fahlore copper and chalcopyrite copper use

Plotting the silver and antimony contents of the chronologically grouped axes displays the following developments through time (Fig. 5).

The earliest axes (dating group 1) show high silver and antimony contents. These objects are all made of fahlore copper, which does not surprise due to the known technical standard in this period.

But the next two phases plotted in the same diagram (dating groups 2, 3), show a development towards silver and antimony poor copper, with still some silver rich objects. This trend reaches its climax in the Middle Bronze Age and the earlier phase of the Late Bronze Age (dating groups 4, 5, 6). Not a single axe has more than 0.1 mass% silver. The antimony content is slightly varying, but besides one piece it is significantly below 1 mass%.

Plotting the data of the latest examined axes, dating to the later phase of the Late Bronze Age and the Early Iron Age (dating groups 7, 8), reveals at first sight a confusing result. Nearly all pieces neither fit the silver and antimony rich nor the silver and antimony poor raw material group, but lie somehow in between. Compared to the ores of the East Alpine copper districts, it clearly shows that the bulk of these axes cannot be made of chalcopyrite copper as the silver and/or antimony contents are too high. In contrast these contents are too low to derive from fahlores (Fig. 6, left side). This is also visible compared to the plano-convex copper ingots (Fig. 6, right side). Only a few casting cakes which lie in between the two bulks seem to fit. Having a closer look to the composition of these objects in between, they show a somehow diluted fahlore copper signature. They have clearly too much silver and antimony to derive from chalcopyrite[20], but also clearly less than expected for copper produced from fahlores, as the silver content cannot drop. Hence the copper type "diluted fahlore copper" (DFC) or "mixed copper" shall be introduced.

As fahlore copper and chalcopyrite copper are primarily defined by the silver content, this is also the determining parameter for the "diluted fahlore copper" or "mixed copper". Looking at the ores from the chalcopyrite deposits Mitterberg, Kitzbühel and Viehhofen and especially the silver poor casting cakes, the silver content varies from 0.002 mass%[21] to 0.05 mass%. The fahlores from Schwaz/Brixlegg show a very high variation due to the inhomogeneity of ore deposits. Therefore the calculations are based on the silver and antimony rich plano-convex copper ingots, which are considered to be more representative for the entire fahlore deposit than individual ore samples. These pieces have a silver content from 0.5 mass% to 1.3 mass% (with one statistical outlier containing 2.3 mass%). Therefore the limits for "diluted fahlore copper" where defined as follows: The silver content must not be less than 0.1 mass% and not higher than 0.5 mass%. For the lower limit the maximum of 0.05 mass% silver was multiplied by a safety factor of 2, not to include too many chalcopyrite copper objects as

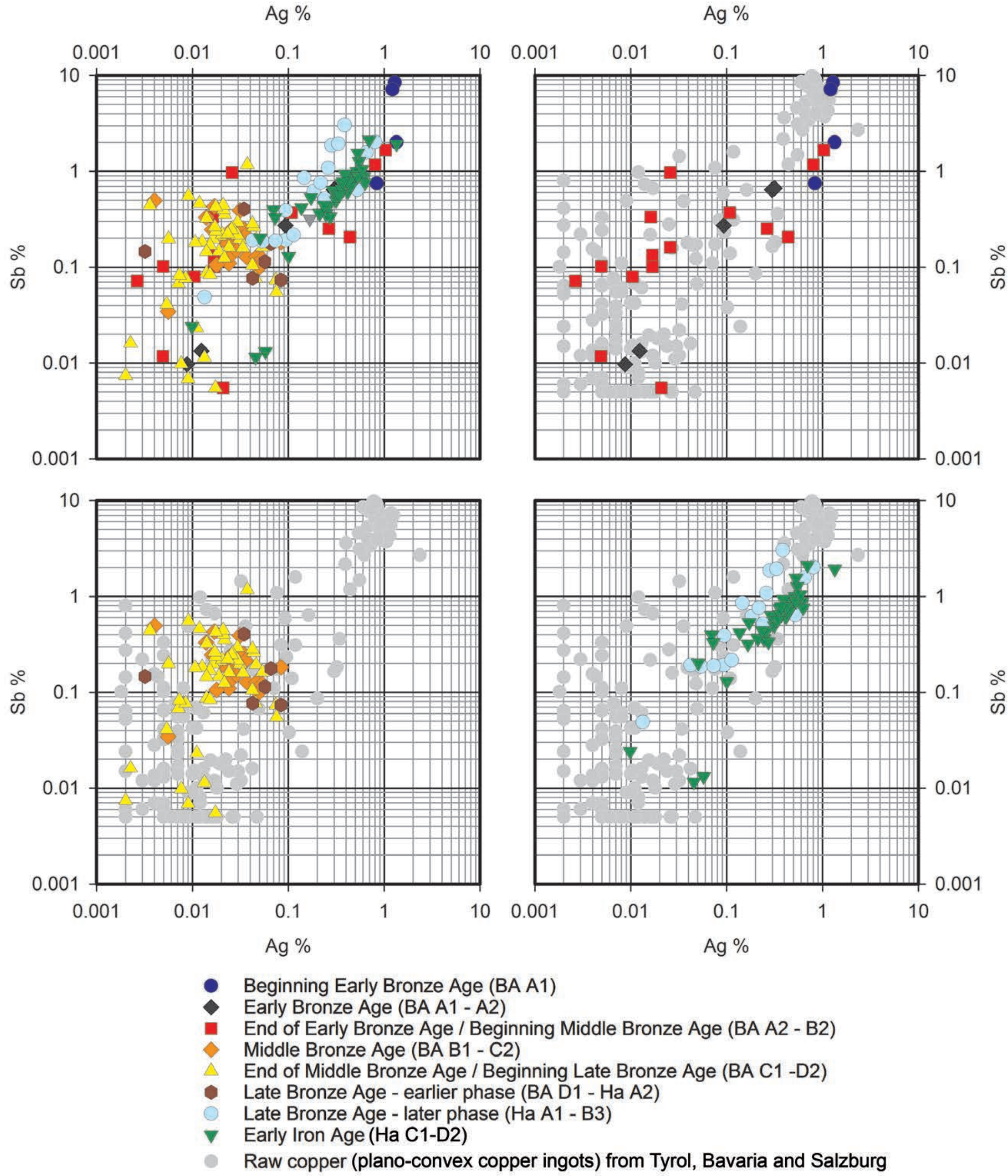

Fig. 5: Silver versus antimony for 165 East Alpine axes through time (as mentioned without Otto/Witter samples) and 192 East Alpine casting cakes. For the latter the two groups of silver/antimony-rich and -poor material are evident.

the maximum and minimum silver contents can vary by a factor of 4 downward and a factor of 6 upward (based on the median for chalcopyrite copper of 0.008 mass%). Variation for the fahlore copper casting cakes is much lower with the factors of 1.6 down- and upward (based on the median of 0.82 mass% silver). Therefore no safety factor was taken into account.

For now these calculations of course only lead to a valuation of the quantity of “diluted fahlore copper” or “mixed copper” objects – but whether the limits have to be corrected slightly, it is obvious that there is a group of objects which lies in between what the known chalcopyrite or fahlore deposits are expected to produce. In the following we will operate with these limits.

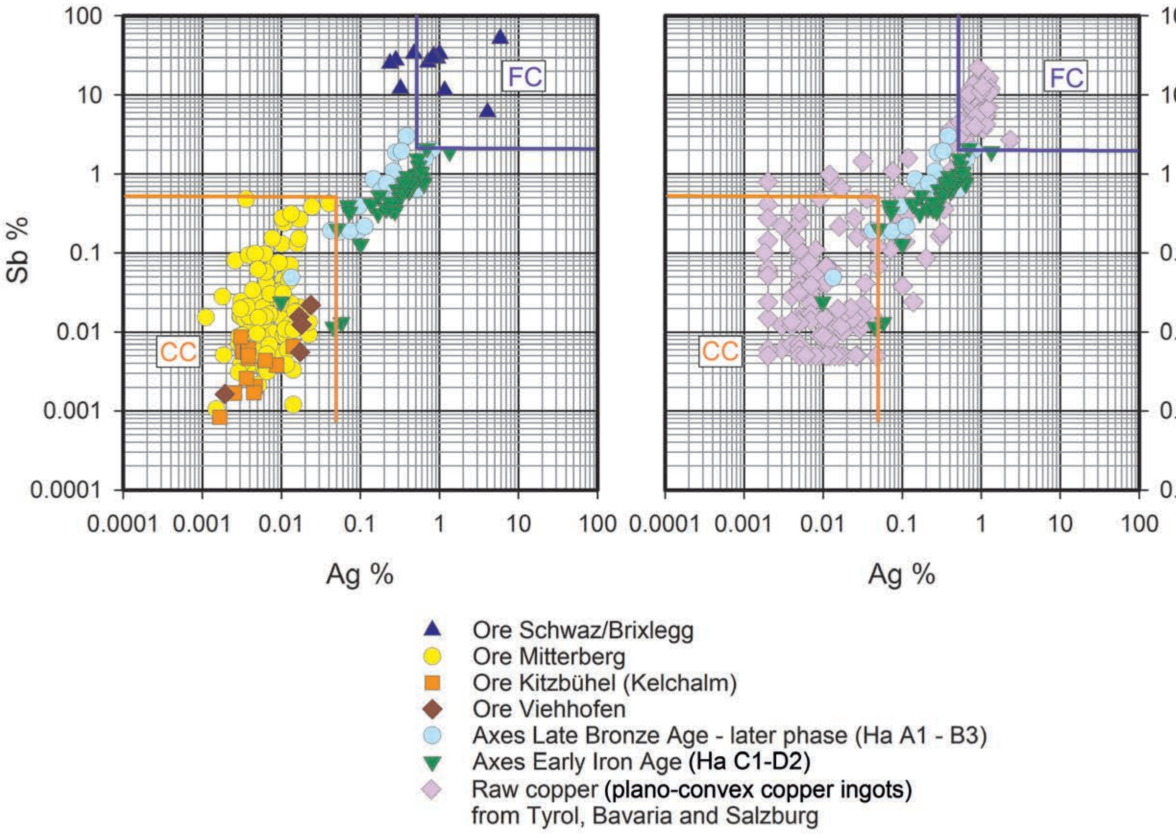

Fig. 6: Most of the axes from the later phase of the Late Bronze and Early Iron Age neither fit the silver / antimony contents expected for chalcopyrite copper nor for fahlore copper.

At the moment it cannot be decided whether this "diluted fahlore copper" originates from mixing chalcopyrite copper with fahlore copper[22] or if it represents polymetallic deposits where chalcopyrite and fahlore occur together, sometimes interwoven. Such deposits are known for example from Leogang, Kitzbühel or Navis (for the last cf. Grutsch et al. in this volume). The use of such ores would also explain the few copper ingots with the chemical signature of "diluted fahlore copper" (see also Figs. 4, 5, 6). Anyhow intentional mixing of fahlore copper with chalcopyrite copper seems more likely for the majority of objects, not least because the mainly exhausted deposits and the archaeological record from smelting sites show a specialisation on either fahlore or chalcopyrite processing. In return the possibility of recycling does not seem very likely, as the chemical signatures of these objects are quite uniform and alloying with tin, especially for Early Iron Age axes, is quite standardized, which would not have been easy to manage, when mixing together objects with unknown composition. Furthermore if recycling would have played a major role, the changes throughout time would not be that visible. Anyway specific recycling of fahlore copper in these periods would not have been easy as for 300 years none has been produced.

Charting the obtained data in a histogram, the succession of copper types through time is even more evident, especially the chalcopyrite copper domination in the Middle Bronze Age and the beginning Late Bronze Age and the reuse of fahlore copper from Ha A1 on (Figs. 7 and 8).

Fig. 7 depicts the amounts of fahlore copper and chalcopyrite copper per period in *purely arithmetical terms*, based on the median silver contents. The percentage of fahlore copper in use during BA A1 (dating group 1) shrinks from 100% to about only 10% already during the following period (dating group 2). Throughout the succeeding epochs (dating groups 3, 4, 5) there is some kind of "fahlore copper background noise", becoming a clear signal again only in Ha A1 (dating group 7, already slightly visible in dating group 6). But even in the later phase of the Late Bronze Age and the beginning Iron Age (dating groups 7, 8) chalcopyrite copper remains the dominant copper type.

If the classification is not solely conducted on the statistically obtained silver medians, but *each piece assigned to a defined copper type*[23] including "diluted fahlore copper", a somewhat different picture evolves (Fig. 8).

As this diagram also contains the Otto/Witter samples mentioned above, there are some very early axes made of arsenical copper (AC) in retrospective of the Chalcolithic, together with pure fahlore copper objects in BA A1. But already in BA A2 chalcopyrite copper comes in use, though there is still fahlore copper available. A few pieces made of mixed copper are also observed until

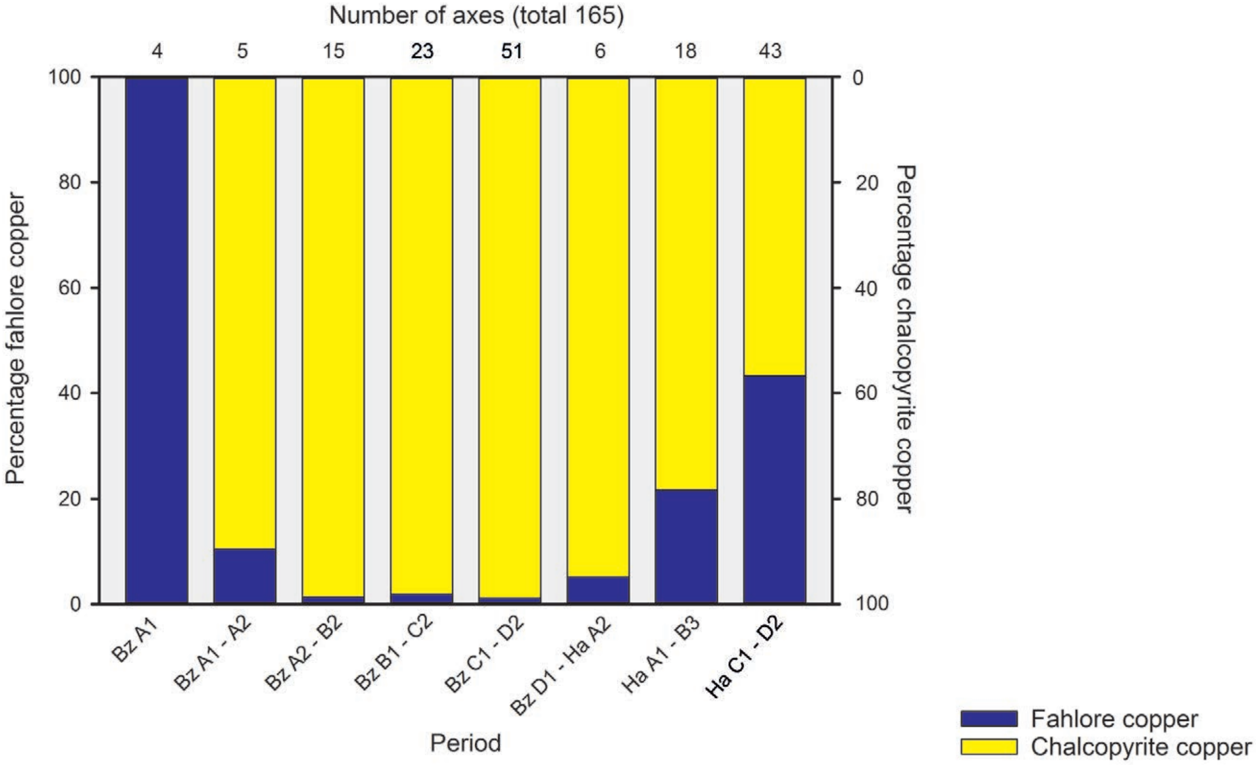

Fig. 7: Fahlore copper and chalcopyrite copper amounts within the axes, calculated on the statistically obtained silver medians of the two copper types. Though the use of fahlore copper rises again in the later periods, chalcopyrite remains the most relevant copper ore (for explanation of overlapping periods see Tab. 2).

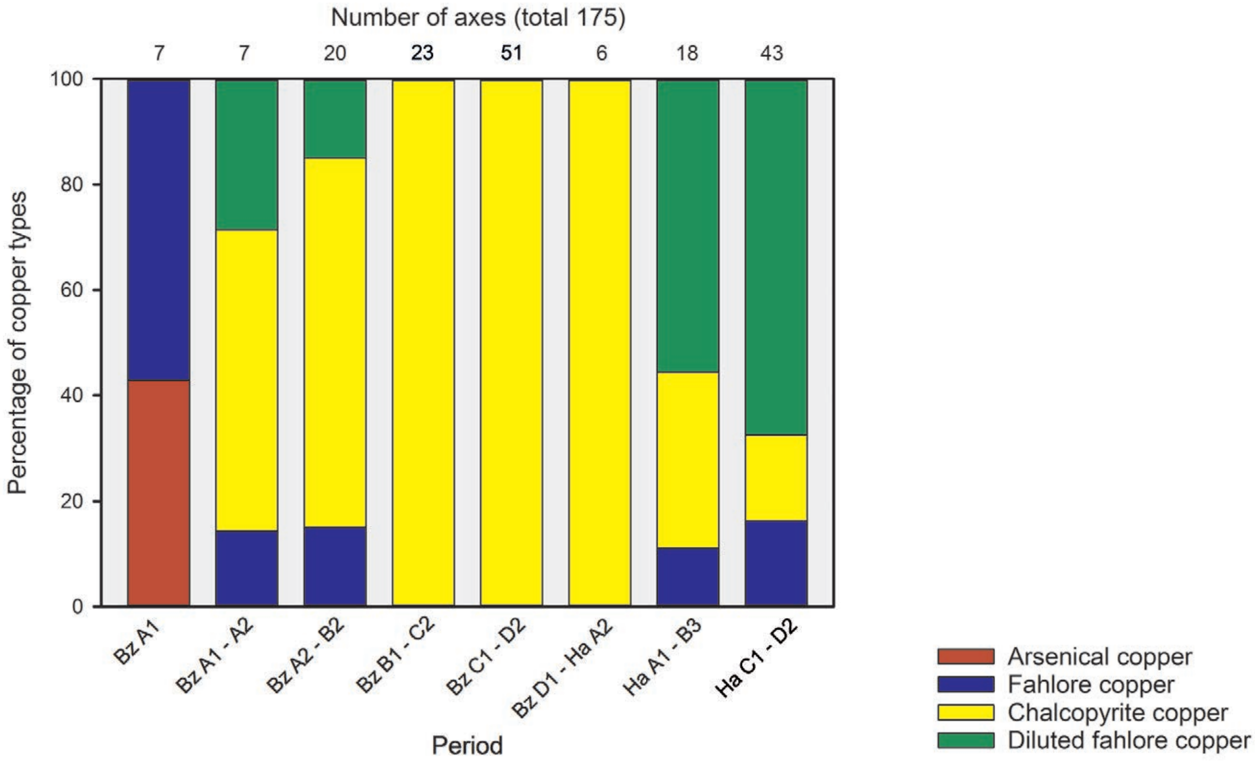

Fig. 8: Differentiated use of fahlore and chalcopyrite copper from the Early Bronze Age to the Early Iron Age (for explanation of overlapping periods see Tab. 2). 10 Otto/Witter samples have been included here as the determination of the copper type was possible.

BA B2. Thereby copper types must not be related to axe types, not even if they are found in one hoard. From six pieces of the type Langquaid for example one is based on fahlore copper, three on chalcopyrite copper and two on diluted fahlore copper. Three pieces of this type where found in the hoard Koblach-Kadel – two of them are based on diluted fahlore copper, one on chalcopyrite copper. If the diluted fahlore copper in this period actually depicts mixed East Alpine copper sources or probable import, has to be discussed elsewhere, as for the Early Bronze Age a big variety of copper suppliers has to be taken into account.

After the early Middle Bronze Age chalcopyrite copper is the utterly dominant copper type in use for about 300 years. For 23 Middle Bronze Age axes and 51 axes from the end of the Middle Bronze Age / beginning Late Bronze Age the maximum, median and minimum nickel, arsenic, silver and antimony contents are compared (Fig. 9). The minimum values drop significantly at the end of the Middle Bronze Age / beginning Late Bronze Age. It becomes apparent that new chalcopyrite copper producers, characterized by lower trace element contents in the ore, appear. This can be explained on the basis of the mining archaeological record (Stöllner et al., 2016). Slightly higher[24] nickel and arsenic but also antimony values are known from the Mitterberg, while particularly pure chalcopyrite copper can derive from the Kitzbühel and Viehhofen districts (Lutz et al, 2009, Lutz, 2013 and 2016). Therefore these results probably display copper from Kitzbühel and Viehhofen from the end of the Middle Bronze Age on, which fits the time of production at least for the Kitzbühel district very well (Koch Waldner & Klaunzer, 2015). The quite constant median values would depict the still ongoing production at the Mitterberg.

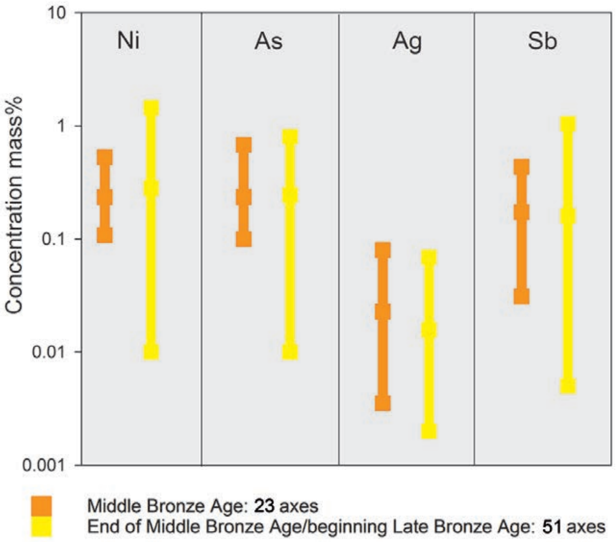

Fig. 9: Maximum, median and minimum nickel, arsenic, silver and antimony contents of the axes show that at the end of the Middle Bronze Age / beginning Late Bronze Age (dating group 5) a type of chalcopyrite copper with fewer trace elements appears.

As far as the examined axes provide information, fahlore copper has its revival not earlier than in Ha A1. Notably it is mainly recognized in diluted fahlore copper objects not in pure ones, which is also true for the next period, the Early Iron Age (dating group 8). This is especially striking, as for these periods there is plenty of evidence for fahlore mining and processing from the Schwaz/Brixlegg district (Staudt et al., in this volume). It seems that fahlore copper on its own was not competitive, but in demand when mixed with chalcopyrite copper, which was already suggested by Sperber (2004).

But why is there a comeback of fahlore copper at all after several hundred years of chalcopyrite copper use? The Mitterberg and Kitzbühel districts both show a decline in production during Ha A1 whereby production in Kitzbühel seems to end in this period as far as we know at the moment (Koch Waldner & Klaunzer, 2015), whereas the Mitterberg keeps producing on a smaller scale also during Ha B and the Early Iron Age (Breitenlechner et al., 2014, Stöllner, 2009). On the other hand there is still plenty of chalcopyrite copper available in both periods, possibly also coming from the Southern Alps, where production starts in Laugen-Melaun A (Cierny, 2008). The axes of the Ha C-D hoard find from Fließ/Tyrol[25] for example have a total weight of 20.36 kg, thereof 0.85 kg bronze based on chalcopyrite copper, 2.1 kg based on fahlore copper and 17.41 kg based on diluted fahlore copper. Less the median tin content of 10.6 mass% this leaves 1.88 kg of fahlore based copper, 0.77 kg of chalcopyrite based copper and 15.56 kg of diluted fahlore copper, the latter with a median silver content of 0.36 mass%. Based on the silver medians for fahlore copper (0.82 mass%) and chalcopyrite copper (0.008 mass%) this means that for these axes in total still 9.58 kg of chalcopyrite copper is needed, opposing 8.63 kg of fahlore copper. This picture gets even clearer looking not only at the axes but at the hoard find in total: 61% of the copper is chalcopyrite copper accompanied by only 39% of fahlore copper[26]. Therefore a decline of chalcopyrite copper production cannot be the only reason for the comeback of fahlore copper. Maybe chalcopyrite copper just could not supply the increased demand and fahlore copper is produced additionally. Another explanation could be an insufficient tin supply, which revaluates fahlore copper with its trace elements probably used as tin substitutes. (Lutz & Schwab, 2014, Lutz, 2016).

Spatial development of fahlore copper and chalcopyrite copper use

From Upper Austria no BA A1 axes were available for the investigations. The three BA A1 axes from Salzburg are made of arsenical copper. Four from the vorarlberg museum are made of fahlore copper.

But then it gets interesting. There seems to be a slight east-west divide in the early use of chalcopyrite copper. While the investigated objects dating to BA A2-B1 from the Tyrol are still dominated by fahlore copper (4 pieces), in Salzburg and Upper Austria there is only chalcopyrite copper in use (4 pieces), with the earliest piece dating to BA A1-A2 from Aigen/Salzburg. Notably the BA A2 axes from Vorarlberg already represent chalcopyrite copper (3 pieces) and two are based on diluted fahlore copper. From the vorarlberg museum there are no axes based on pure fahlore copper in this period. While the picture for the Tyrol and Salzburg/Upper Austria seems consistent with their relative vicinity to specialized fahlore copper or chalcopyrite copper production centres respectively, the situation in Vorarlberg seems remarkable. After BA A2 all regions get dominated by chalcopyrite copper. Only 2 pieces from Vorarlberg and 1 piece from Upper Austria still contain fahlore copper within objects based on mixed copper. (Fig. 10 a) These conclusions are so far drawn only on a small number of objects, which has to be broadened.

In the Middle Bronze Age and the earlier phase of the Late Bronze Age all regions are dominated by chalcopyrite copper (Fig. 10 b).

Diluted fahlore copper is the dominant copper type in the later phase of the Late Bronze Age and the beginning Iron Age (dating groups 7, 8), even in the Tyrol, though intense fahlore copper production at that time is proved in Schwaz/Brixlegg (Staudt et al. in this volume). At least the few pure fahlore copper axes are from the Tyrol (7 pieces) but also from Salzburg (2 pieces), dating to Ha B2, Ha B3 and Ha C1-D2. Pure chalcopyrite copper is present in all regions and phases of this time segment (Fig. 10 c).

Chronological development of alloying techniques in the Eastern Alps from the Early Bronze Age to the Early Iron Age

The earliest alloyed pieces (5 objects dating to BA A2) have a median tin content of 6.7 mass%. This value rises to 10 mass% within BA A2-B2. Notably three unalloyed flanged axes from the Tyrol[27] dating to this time segment are all made of fahlore copper, which indicates, that these artefacts rather date to BA A2 within their possible lifespan (BA A2-B1). Furthermore there are seven axes with pretty high tin contents of more than 10 mass% - one even with 14 mass% tin (Fig. 11).

While in the Middle Bronze Age and the earlier phase of the Late Bronze Age some statistical outliers still display similar minimum and maximum tin contents like in the periods before, the majority of objects (61 of 80 pieces) is alloyed with 8 to about 12 mass% tin, with a median in these periods of 9.7 mass%. Chalcopyrite copper and tin supply seem very stable and alloying quite standardized in this era. This can be considered as one reason which made the success of chalcopyrite copper possible (cf. Kienlin, 2008) (Fig. 11).

In the later phase of the Late Bronze Age changes can be observed: 55% of the objects now have a tin content less than 8 mass% and the median drops to 7.2 mass%. Maybe tin supply is not able to keep up with the risen bronze demand already mentioned as one possible reason for revived fahlore copper production (Fig. 11).

In the Early Iron Age tin supply seems more stable again. 41 of 43 axes dating to this period are alloyed with more than 8 mass% tin, leading to a median of 10 mass%. As during all periods, there are statistical outliers, one with 6.2 mass% and one with only 3.2 mass%. Remarkable are the high lead contents in the Early Iron Age. While in all other periods nearly all objects (except 10) have a lead content lower than 0.5 mass%, most of the Ha C1-D2 axes lie above 0.5 mass% lead, with an accumulation of axes around 1 mass%. Tin concentrations in the Middle Bronze Age and earlier phase of the Late Bronze Age are very similar to the ones in Ha C1-D2, but lead contents differ significantly. Consequently the lead does not come into the objects as a natural component of tin, at least not in the amount claimed. Examinations on the so called Kathreinfund, the Ha C-D hoard from Fliess – from which most of the examined axes derive (38 of 43) – showed that there is a positive correlation between the lead content and fahlore copper, meaning the lead comes into these objects together with the fahlore copper component – whereby the lead isotopes fit the Brixlegg district very well (Lutz et al., 2011, Lutz & Schwab, 2014). On the other hand, when comparing the axes based on fahlore and diluted fahlore copper from the later phase of the Late Bronze Age to the ones from the Early Iron Age, a significantly different median lead content is observed (0.28 mass% for the former versus 0.77 mass% for the latter) (Fig. 11). It would be worthwhile to examine if this could correlate with different working zones within the Schwaz and Brixlegg mining districts.

Another explanation for the risen lead contents in the Early Iron Age would be that tin diluted with lead is exchanged, as reaction to risen demand. Tin alloyed with 10% of lead would yield to 1% lead in a bronze object with 9 % tin, which would not change bronze-quality significantly from a technical point of view (Dies, 1967). The latter would be an argument against intentional admitting of such a small amount of lead for any other reason than for saving tin.

While tin and lead do not seem to correlate, there is a negative correlation of tin and the fahlore copper determining elements silver and antimony within the examined axes in the later phase of the Late Bronze Age (Fig. 12). This was already shown for objects from Northern Tyrol, Southern Bavaria and Salzburg (Stöllner et al., 2016, esp. Figs. 16a and b). The more silver and antimony, the less tin – indicating selective alloying in the sense of saving tin when using fahlore copper, which is naturally alloyed with arsenic and antimony. These elements can substitute tin to some extent. Therefore the axes based on diluted fahlore copper or pure fahlore copper respectively have a median tin content of only 6.0 mass%. On the opposite axes based on chalcopyrite copper are alloyed with a median tin content of 9.6 mass%. This is also visible during the Early Iron Age – though minimized – when tin supply seems to be sufficient again.

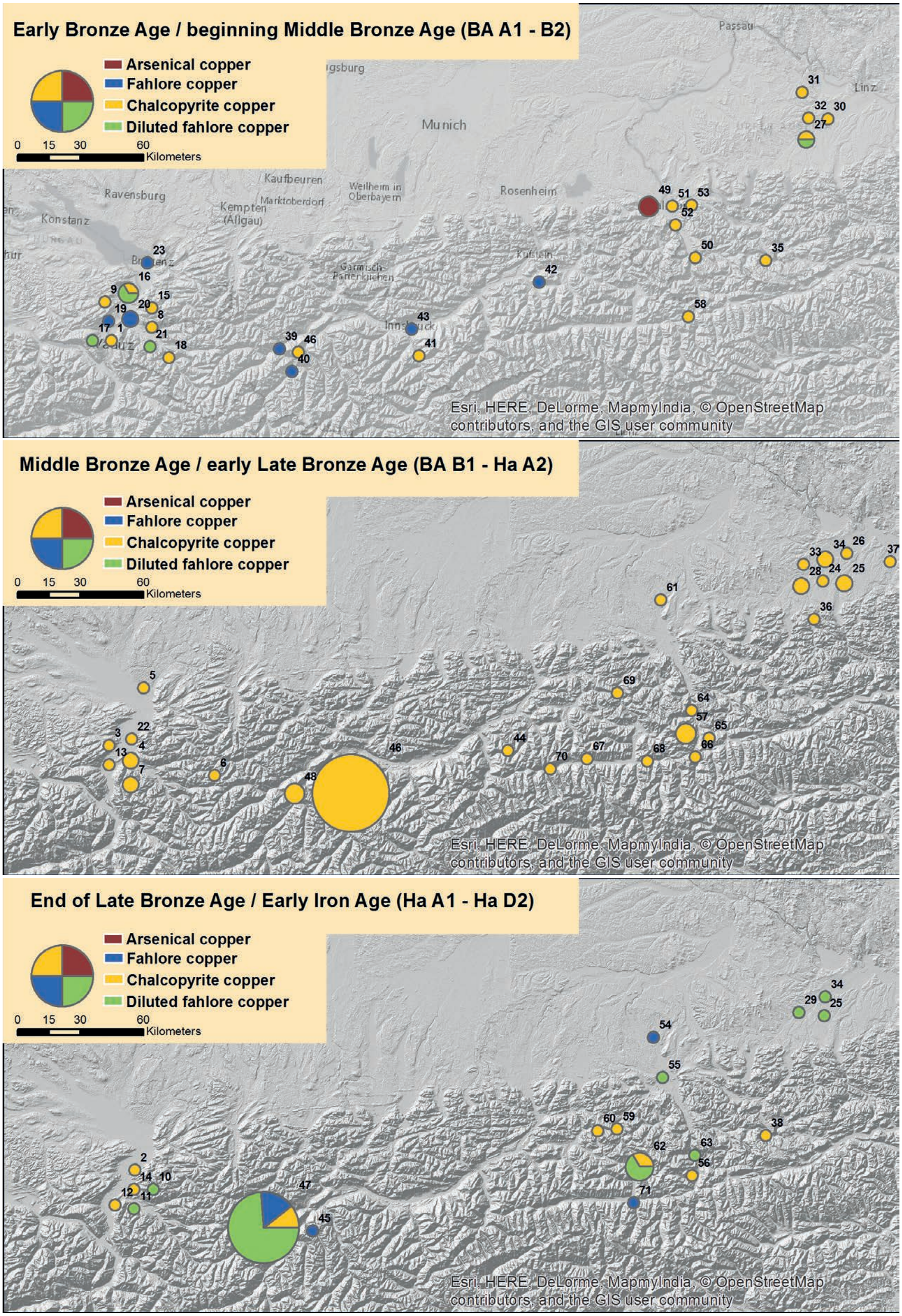

Fig. 10 a / b / c: Chronological and spatial development of the use of different copper types in the Eastern Alps.

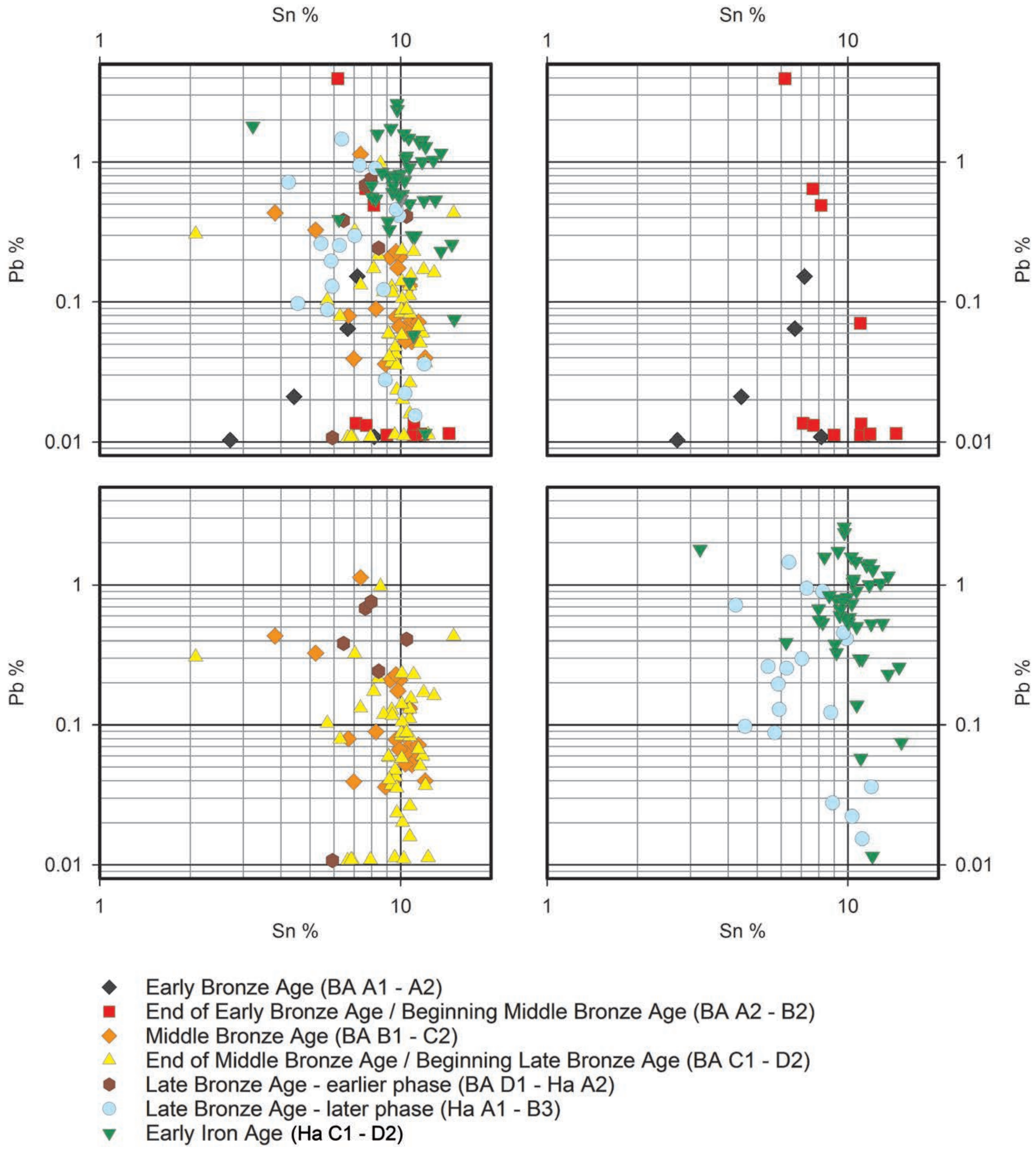

Fig. 11: Tin compared to lead contents through time show no correlation between the two elements. A rise of lead contents in the Early Iron Age is apparent, which could depict a lead rich copper source or tin diluted with lead.

It should also be mentioned that mixing tin-bronze scrap metal based on chalcopyrite copper with fresh fahlore copper could yield a similar composition. Anyhow this practice might not have played a major role as recycling is not observed on large scale anyways, as already discussed above.

Finally nearly no correlation of tin with silver and none with antimony is observed in the chalcopyrite copper dominated periods.

Summary

The analyses of 175 Early Bronze Age to Early Iron Age axes show a differentiated and sequential use of copper ores and tin in correlation to each other in Western Austria. According to the technical development of metallurgy the earliest phase of the Bronze Age (BA A1) is characterized by the use of fahlore copper complemented by arsenical copper. In BA A2 chalcopyrite copper appears though

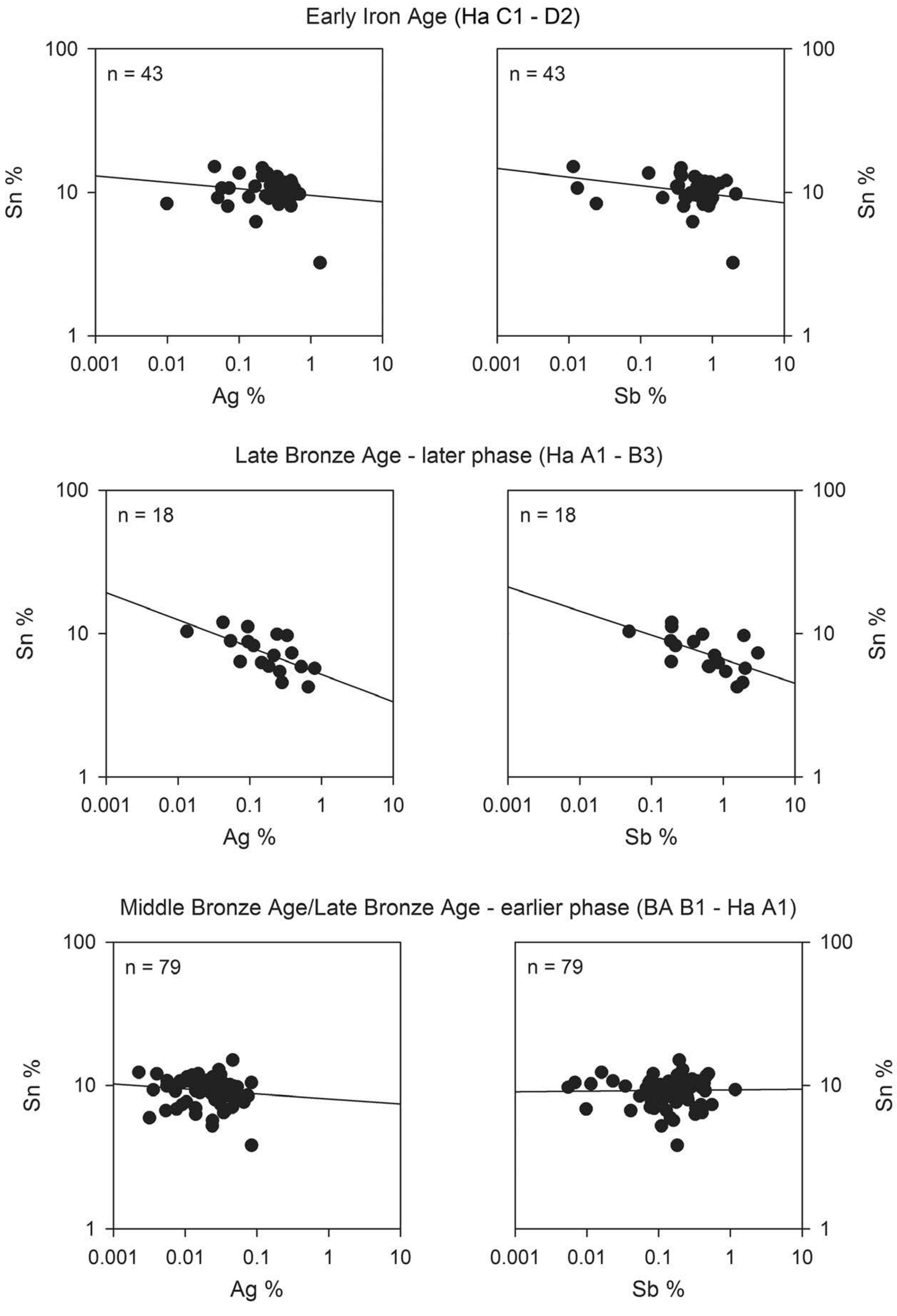

Fig. 12: Correlation of tin and the typical fahlore copper elements silver and antimony. Especially during the later phase of the Late Bronze Age negative correlation shows very well, that tin was intentionally saved when using fahlore copper.

until BA B1 fahlore copper is still in use. From BA B2 on chalcopyrite copper clearly dominates the metal supply for more than 300 years. Until Ha A1 there is not a single axe made of fahlore copper, even not in the variant of diluted fahlore copper. It seems that due to the chalcopyrite copper supply[28] together with a regular tin supply fahlore copper is no longer of interest. The previously popular fahlore copper as a natural alloy falls behind, as objects with the same or better properties can be produced more easily with the purer chalcopyrite copper and tin (see also Kienlin, 2008). After its comeback in Ha A1 it is first recognized within diluted fahlore copper, from Ha B2 on also as pure fahlore copper. Anyway the axes do not show a replacement of chalcopyrite copper by fahlore copper, although with the Schwaz/Brixlegg district there is a potent fahlore copper producer for that period and region. The amount of the available chalcopyrite copper is still remarkable. As the Kitzbühel district does not seem to produce anymore at that time and production at the Mitterberg takes only place on a smaller scale other chalcopyrite dominated mining districts, like in the Trentino, must be taken into account as important copper suppliers.

Regarding alloying, two observations can be pointed out. From Ha A1 on the by than quite standardized tin contents decrease contemporaneous with the reuse of fahlore copper. It cannot be decided yet, whether fahlore is reused to compensate a declining tin supply, or due to an increasing bronze demand, which only secondarily allows to economize tin when using fahlore copper. As mentioned also recycling would be a possibility, though unlikely. In the Early Iron Age not only tin contents rise again, but also lead contents increase to a median value of 0.68 mass%[29] in contrast to a median of 0.08 mass% for all periods before. Whether this is also a hint on a problematic tin supply, which maybe was petered with lead, or if the lead comes in together with a new type of copper, needs to be investigated. Intentionally alloying with lead seems rather unlikely as mentioned above.

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Claudia Ginthart, University of Innsbruck
Manuel Scherer-Windisch, University of Innsbruck

Notes

1 D - Germany, A – Austria, CH – Switzerland.
2 History of Mining Activities in the Tyrol and Adjacent Areas - Impact on Environment & Human Societies.
3 Including Vorarlberg, North Tyrol, Salzburg and Upper Austria and therefore covering large parts of the Eastern Alps.
4 23 of them deriving from Vorarlberg itself, 4 from Liechtenstein, 1 from Switzerland and 1 from the Bodensee/Germany.
5 Kindly provided by courtesy of Thomas Stöllner, Ruhr-University and DBM Bochum (cf. also Stöllner et al., 2016).
6 At the time of the measurements each under the direction of Ernst Pernicka.
7 Cf. Tab. 1.
8 Research of *the Bayerisches Landesamt für Denkmalpflege* on the Middle and Late Bronze Age copper supply in Southern Bavaria, Salzburg and North Tyrol; measured at the TU Bergakademie Freiberg, Ernst Pernicka.
9 Measured at the Curt-Engelhorn-Centre Archaeometry Mannheim.
10 At the Curt-Engelhorn-Centre Archaeometry Mannheim.
11 Studien zu den Anfängen der Metallurgie (Junghans et al., 1960).
12 Sampling of additional objects from the Tiroler Landesmuseum Ferdinandeum was not possible.
13 Thanks to the cooperations with the Amt für Bodendenkmäler, Autonome Provinz Bozen – Südtirol, Catrin Marzoli, Umberto Tecchiati, the Palais Mamming Museum, Elmar Gobbi, the Soprintendenza per i beni culturali, Franco Marzatico and the Museo Castello del Buonconsiglio Laura Dal Prà, Silvano Zamboni.
14 As well as further objects from Salzburg and Northern Tyrol.
15 Kindly provided by Ulrike Töchterle, Restauration, Institute for Archaeologies, University of Innsbruck.
16 HiMAT and SSN data.
17 The median antimony content for the fahlore copper ingots is 6.7 mass%, for the chalcopyrite copper ingots 0.02 mass%.
18 E.g. Riedhöfl, though this deposit also contains clearly Middle Bronze Age objects.
19 *„Probe 342/94: konv. 14C Alter BP: 3158 +/-34, kal. Alter 1 Sigma: BC 1435 – 1400"* (Tschurtschenthaler/Wein 1998, footnote 21, no laboratory code given).
20 As silver is a precious metal contents rise very slightly from ore to object, but not to this extent. Antimony contents would drop anyways.
21 Which is the detection limit for silver with XRF-analyses.
22 Already discussed for the Kathreinfund/Fließ (Lutz et al., 2011).
23 See definitions mentioned above based on the silver contents: less than 0.1 mass% for chalcopyrite copper, equal or more than 0.1 mass% to equal or less than 0.5 mass% for diluted fahlore copper or mixed copper respectively, more than 0.5 mass% for fahlore copper.
24 In terms of chalcopyrite copper, not in comparison with fahlore copper.
25 The so called Kathreinfund, which also includes some italic types (Sydow, 1995).
26 Interestingly the median silver content of all objects within the hoard find is only 0.27 mass%, which means that in comparison to other objects a slightly higher fahlore copper portion was used for the axes.
27 No. HiB063, HiB066 and HiB067.
28 The Mitterberg district starts its production in the 17th century (Stöllner et al., 2016).
29 For all axes, including the ones based on chalcopyrite copper.

DACH-No.	Axe type/variation		Dating	Dat-ing Group	Cop-per type	Findspot, province or country	No. map	Ana-lysed by	Literature	Inventory-No.
HiB008	RLB	Norddeutscher Typ	BA B1-B2	3	CC	Schaan, FL	1	CEZA	Abels (1972, No. 433)	PR 632
HiB009	LPB	Haidach/Trössing	Ha A1-B3	7	CC	Götzis/Ruine Neumontfort, Vbg.	2	CEZA	Mayer (1977, No. 700); Heeb (2012)	PR 561
HiB010	LPB	Grigny	Ha A1	6	CC	Feldkirch/Tosters, Vbg.	3	CEZA	Mayer (1977, No. 621); Heeb (2012)	PR 596
HiB011	LPB	breites mittelständiges	Ha A1	6	CC	Feldkirch/Bickel'sche Ziegelei, Vbg.	4	CEZA	Mayer (1977, No. 622); Heeb (2012)	PR 587
HiB012	LPB	Freudenberg/Retz	BA C2-D1	5	CC	Lindau/Bodensee, GER	5	CEZA	Pászthory & Mayer (1998, No. 518)	PR 573
HiB013	LPB	herabgezogene Lappen	BA C2-D1	5	CC	Stutz, Vbg.	6	CEZA	Mayer (1977, No. 631)	PR 617
HiB014	LPB	herabgezogene Lappen	BA C2-D1	5	CC	Feldkirch, Vbg.	7	CEZA	Mayer (1977, No. 626)	PR 563
HiB015	LPB	breites mittelständiges	Ha A1	6	CC	Feldkirch/Bickel'sche Ziegelei, Vbg.	4	CEZA	Mayer (1977, No. 620), Heeb (2012)	PR 588
HiB016	LPB	herabgezogene Lappen	BA C2-D1	5	CC	Feldkirch, Vbg.	7	CEZA	Mayer (1977, No. 625)	PR 1939.1
HiB017	RLB	Langquaid I/Linz-St. Peter	BA A2	2	CC	Schnifis/Bassigg, Vbg.	8	CEZA	Mayer (1977, No. 270); Heeb (2012)	without No.
HiB018	RLB	Möhlin/A	BA B1	3	CC	Feldkirch/Paspels, Vbg.	9	CEZA	Heeb (2012, No. 303)	PR 1988.1
HiB019	OS LPB	mit Öse	Ha B2-B3	7	DFC	Zwischenwasser, Vbg.	10	CEZA	Mayer (1977, No. 791); Heeb (2012)	PR 604
HiB021	OS LPB	mit Schulterbildung	Ha C1-C2	8	DFC	Göfis, Vbg.	11	CEZA	Mayer (1977, No. 898); Heeb (2012)	PR 556
HiB022	LPB	Hallstatt	Ha C1-D2	8	CC	Nendeln, FL	12	CEZA	Gridling (2016)	PR 564
HiB023	LPB	abgesetzter hoher Oberteil	BA D1-D2	6	CC	Eschen-Nendeln, FL	13	CEZA	Frei (1954/55, Taf. XXVII, 5)	PR (19)19.1*
HiB024	LPB	Hallein	Ha C1	8	CC	Rankweil, Vbg.	14	CEZA	Mayer (1977, No. 884); Heeb 2012)	PR 626
HiB025	RLB	Neerach/A	BA B2	3	CC	Dünserberg, Vbg.	15	CEZA	Heeb (2012, No. 293)	PR 1993.3
HiB026	RLB	Langquaid II/Koblach	BA A2	2	DFC	Koblach-Kadel, Vbg.	16	TUF	Mayer (1977, No. 277); Heeb (2012)	PR (19)58.1
HiB027	RLB	Langquaid II/Koblach	BA A2	2	DFC	Koblach-Kadel, Vbg.	16	TUF	Mayer (1977, No. 275); Heeb (2012)	PR (19)58.2
HiB028	RLB	Langquaid II/Koblach	BA A2	2	CC	Koblach-Kadel, Vbg.	16	TUF	Mayer (1977, No. 276); Heeb (2012)	PR (19)58.3
HiB029	RLB	Nehren/A	BA B1	3	DFC	Gamprin/Bendern, FL	17	TUF	Abels (1972, No. 435); Heeb (2012)	PR 580
HiB030	RLB	Langquaid II	BA A2	2	CC	Gantschier/Hosensee, Vbg.	18	TUF	Mayer (1977, No. 287)	PR 1956.1688**
HiB031	RLB	Salez/A	BA A1	1	FC	St. Gallen/Salez, CH	19	CEZA	Abels (1972, No. 29); Heeb (2012)	PR 569
HiB032	RLB	Salez/D	BA A1	1	FC	Feldkirch/Levis, Vbg.	20	TUF	Mayer (1977, No. 231); Heeb (2012)	PR 621
HiB033	RLB	Regensburg/Nüziders	BA B1	3	DFC	Nüziders, Vbg.	21	TUF	Mayer (1977, No. 298); Heeb (2012)	PR 567
HiB034	RLB	Salez/A	BA B2-C1	4	CC	Koblach/Ruine Neuburg, Vbg.	22	TUF	Mayer (1977, No. 315); Heeb (2012)	PR (19)13.1
HiB035	RLB	Neyruz	BA A1	1	FC	Bregenz/Rieden-Vorkloster, Vbg.	23	TUF	Mayer (1977, No. 221); Heeb (2012)	PR (19)58.5
HiB037	RLB	Salez/D	BA A1	1	FC	Feldkirch/Levis, Vbg.	20	TUF	Mayer (1977, No. 232); Heeb (2012)	PR 620

DACH-No.	Axe type/variation		Dating	Dating Group	Copper type	Findspot, province or country	No. map	Analysed by	Literature	Inventory-No.
HiB038	LPB	Freudenberg/Retz	BA C2-D1	5	CC	Wels/Rosenau, OÖ	24	CEZA	Mayer (1977, No. 552)	10619
HiB039	LPB	Freudenberg/Retz	BA C2-D1	5	CC	Thalheim bei Wels/Aschet, OÖ	25	CEZA	Mayer (1977, No. 572)	14004
HiB040	LPB	Freudenberg	BA C1-D2	5	CC	Thalheim bei Wels/Aschet, OÖ	25	CEZA	Mayer (1977, No. 499)	48
HiB041	LPB	Freudenberg	BA C1-D2	5	CC	Wels/Schafwiesen, OÖ	26	CEZA	Mayer (1977, No. 498)	13473
HiB043	RLB	Norddeutscher Typ	BA B1-B2	3	DFC	Wels/Brandln, OÖ	27	CEZA	Mayer (1977, No. 317)	13525
HiB044	RLB	Norddeutscher Typ	BA B1-B2	3	CC	Wels/Brandln, OÖ	27	CEZA	Mayer (1977, No. 318)	13538
HiB047	LPB	Greiner Strudel/ Niederalm	BA C2-D1	5	CC	Steinhaus/Traunleiten, OÖ	28	CEZA	Mayer (1977, No. 615)	14901
HiB049	TB	mit Öse	Ha A2-B2	7	DFC	Stadl Paura/Lambach, OÖ	29	CEZA	Mayer (1977, No. 1024)	13763
HiB050	RLB	Mägerkingen/Wels	BA B1-B2	3	CC	Wels/Pernau, OÖ	30	CEZA	Mayer (1977, No. 324)	1253
HiB051	ABB	offener Absatz	BA A2-B1	3	CC	St. Thomas, OÖ	31	CEZA	Mittermaier (2017)	217904
HiB052	ABB	gedrungen herzförmige Rast	BA A2-B1	3	CC	Gunskirchen/Fernreith, OÖ	32	CEZA	Mayer (1977, No. 388)	13762
HiB053	LPB	Freudenberg/Amlach	BA C2-D2	5	CC	Gunskirchen, OÖ	33	CEZA	Mayer (1977, No. 601)	14764
HiB054	TB	winkel- und bogenverziert	Ha A2-B3	7	DFC	Wels, OÖ	34	CEZA	Mayer (1977, No. 1064)	13353
HiB055	TB	ohne Öse	BA D1-Ha A1	6	CC	Steinhaus/Traunleiten, OÖ	28	CEZA	Mayer (1977, No. 1032)	12043
HiB056	ABB	langgestreckt herzförmige Rast	BA C1-D1	5	CC	Wels, OÖ	34	CEZA	Mayer (1977, No. 418)	12063
HiB057	LPB	Freudenberg/ Elixhausen	BA B1-C2	4	CC	Wels, OÖ	34	CEZA	Mayer (1977, No. 514)	10618
HiB058	TB	winkel- und bogenverziert	Ha A2-B3	7	DFC	Thalheim bei Wels/Aschet, OÖ	25	CEZA	Mayer (1977, No. 1073)	10617
HiB059	ABB	gedrungen herzförmige Rast	BA A2-B1	3	CC	Hallstatt/Rudolfsturm, OÖ	35	CEZA	Mayer (1977, No. 377)	A669
HiB060	ABB	spitze Rast	BZ B1-C1	4	CC	Viechtwang/Mühldorf, OÖ	36	CEZA	Mayer (1977, No. 429)	A642
HiB061	NSA	B3/Tîrguşor	BA D1-Ha A2	6	CC	Linz/Kronstorf, OÖ	37	CEZA	Mayer (1977, No. 86)	A3143
HiB062	TB	meißelartig	Ha C1-C2	8	CC	Hallstatt/Gräberfeld, OÖ	38	CEZA	Mayer (1977, No. 1160)	A2672
HiB063	RLB	Emmerberg	BA A2-B1	3	FC	Perjen, Tir.	39	O/W	Mayer (1977, No. 307)	TLM 62
HiB064	RLB	Langquaid II	BA A2	2	FC	Ried im Oberinntal, Tir.	40	O/W	Mayer (1977, No. 290)	TLM 1131
HiB065	RLB	Mägerkingen/A	BA B1-B2	3	CC	Matrei am Brenner/ Mühlbachl, Tir.	41	O/W	Mayer (1977, No. 321)	TLM 8933
HiB066	RLB	Randleistenbeil	BA A2-B1	3	FC	Hopfgarten/Hohe Salve, Tir.	42	TUF	Huijsmans (1994); Wada (1975)	TLM 29
HiB067	RLB	Emmerberg/Wilten	BA A2-B1	3	FC	Innsbruck/Berg Isel, Tir.	43	TUF	Mayer (1977, No. 308)	TLM 30
HiB068	LPB	breites mittelständiges	BA C1-D2	5	CC	Alpbach/Steinberg Alpe, Tir.	44	TUF	Mayer (1977, No. 624)	TLM 34
HiB069	OS LPB	ohne Öse	Ha B2-B3	7	FC	Ritzenried im Pitztal, Tir.	45	TUF	Mayer (1977, No. 921)	TLM 18.407

DACH-No.	Axe type/variation		Dating	Dating Group	Copper type	Findspot, province or country	No. map	Analysed by	Literature	Inventory-No.
HiB070	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Tomedi (2001, 79)	PM 017
HiB071	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Tomedi (2002a, 78)	PM 029
HiB072	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 052-071
HiB073	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Nicolussi Castellan (2002, 48)	PM 057
HiB074	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 060
HiB076	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 082
HiB077	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Tomedi (2001, 77)	PM 083-145
HiB078	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 099
HiB079	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 103
HiB080	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Nicolussi Castellan (2002, 49)	PM 122
HiB081	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 123-288
HiB083	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 126
HiB084	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 127
HiB085	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 134-336
HiB087	RLB	m. z. Schneide herabg. Lappen	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 213
HiB088	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 224
HiB090	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Tomedi (2002a, 77)	PM 242
HiB091	RLB	Grenchen	BA B2-C1	4	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 324
HiB092	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 004
HiB093	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 033
HiB094	LPB	m. z. Schneide herabg. Lappen	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 034
HiB095	LPB	Kösching	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 090
HiB096	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Tomedi (2002b, 44)	PM 093
HiB097	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 095
HiB098	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 112
HiB099	LPB	Guntramsdorf	BA C2-D2	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 113
HiB100	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 135
HiB101	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 136

DACH-No.	Axe type/variation		Dating	Dating Group	Copper type	Findspot, province or country	No. map	Analysed by	Literature	Inventory-No.
HiB102	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 148
HiB103	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 157
HiB105	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 169
HiB106	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Nicolussi Castellan (2002, 49)	PM 170
HiB107	LPB	Kösching	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 172
HiB108	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 175
HiB109	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 185
HiB110	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 192
HiB111	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 208
HiB112	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 214
HiB113	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 215
HiB114	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 219
HiB116	LPB	Freudenberg	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Nicolussi Castellan (2002, 48)	PM 325
HiB117	ABB	langgestreckt herzförmige Rast	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 014
HiB118	ABB	langgestreckt herzförmige Rast	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	unpublished	PM 059
HiB119	ABB	langgestreckt herzförmige Rast	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Tomedi (2002b, 44)	PM 084
HiB120	ABB	langgestreckt herzförmige Rast	BA C1-D1	5	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Tomedi (2001, 77)	PM 257
HiB122	RLB	Cressier	BA B1-B2	3	CC	Piller/Moosbruckschrofen, Tir.	46	CEZA	Tomedi (2002b, 44)	PM 188
HiB123	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	1
HiB124	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	2
HiB125	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	3
HiB126	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	4
HiB127	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	5
HiB128	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	6
HiB129	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	7
HiB130	LPB	Hallstatt	Ha C1-D2	8	FC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	8
HiB131	LPB	Hallstatt	Ha C1-D2	8	CC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	9
HiB132	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	10

DACH-No.	Axe type/variation		Dating	Dat-ing Group	Cop-per type	Findspot, province or country	No. map	Ana-lysed by	Literature	Inventory-No.
HiB133	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	11
HiB134	LPB	Hallstatt	Ha C1-D2	8	FC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	12
HiB135	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	13
HiB136	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	14
HiB137	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	15
HiB138	LPB	Hallstatt	Ha C1-D2	8	FC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	16
HiB139	LPB	Hallstatt	Ha C1-D2	8	FC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	17
HiB140	LPB	Hallstatt	Ha C1-D2	8	CC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	18
HiB141	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	19
HiB142	LPB	Hallstatt	Ha C1-D2	8	CC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	20
HiB143	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	21
HiB144	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	22
HiB145	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	23
HiB146	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	24
HiB147	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	25
HiB148	LPB	Hallstatt	Ha C1-D2	8	FC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	26
HiB149	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	27
HiB150	LPB	Hallstatt	Ha C1-D2	8	FC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	28
HiB151	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	29
HiB152	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	30
HiB153	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	31
HiB154	LPB	Hallstatt	Ha C1-D2	8	CC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	32
HiB155	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	33
HiB156	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	34
HiB157	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	35
HiB158	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	36
HiB159	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	37
HiB160	LPB	Hallstatt	Ha C1-D2	8	DFC	Fließ/Kathrein Hof, Tir.	47	CEZA	Sydow (1995)	38

DACH-No.	Axe type/variation		Dating	Dat-ing Group	Cop-per type	Findspot, province or country	No. map	Ana-lysed by	Literature	Inventory-No.
HiB161	LPB	Freudenberg/ Niedergößnitz	BA C1	4	CC	Piller/Pillerhöhe, Tir.	48	CEZA	Tschurtschenthaler & Wein (1998)	-
HiB162	LPB	mittelständig	BA C1-D1	5	CC	Piller/Pillerhöhe, Tir.	48	CEZA	Fundberichte Österreich 33 (1994)	-
HiB163	LPB	mittelständig	BA C1-D1	5	CC	Piller/Pillerhöhe, Tir.	48	CEZA	Fundberichte Österreich 33 (1994)	-
HiB164	FB	Salzburg/Rainberg	BA A1	1	AC	Salzburg/Mönchsberg, Sbg.	49	O/W	Mayer (1977, No. 186)	2658
HiB165	FB	Salzburg/Rainberg	BA A1	1	AC	Salzburg/Mönchsberg, Sbg.	49	O/W	Mayer (1977, No. 187)	2659
HiB166	FB	Salzburg/Rainberg	BA A1	1	AC	Salzburg/Mönchsberg, Sbg.	49	O/W	Mayer (1977, No. 188)	2660
HiB167	RLB	Mägerkingen/A	BA B1-B2	3	CC	Golling/Pass Lueg, Sbg.	50	O/W	Mayer (1977, No. 322)	282
HiB168	RLB	Salzburg	BA B1	3	CC	Salzburg, Sbg.	51	O/W	Mayer (1977, No. 299)	334/24
HiB169	RLB	Salzburg/Hellbrunn	BA B1	3	CC	Salzburg/Hellbrunner Berg, Sbg.	52	O/W	Mayer (1977, No. 301)	2515
HiB170	RLB	Emmersdorf/ Bürglstein	BA A1-A2	2	CC	Aigen/Parsch, Sbg.	53	O/W	Mayer (1977, No. 293)	20
HiB171	OS LPB	mit Öse	Ha B3	7	FC	Lamprechtshausen/ Bürmoos, Sbg.	54	TUF	Mayer (1977, No. 789)	16
HiB172	OS LPB	mit Öse	Ha B3	7	DFC	Wals-Siezenheim/ Siezenheim, Sbg.	55	TUF	Mayer (1977, No. 792)	125/69
HiB173	LPB	Bad Goisern	Ha B1-B2	7	CC	Bischofshofen/Salzach, Sbg.	56	CEZA	Mayer (1977, No. 735)	1726
HiB174	LPB	Freudenberg/Retz	BA C2-D1	5	CC	Mühlbach a. Hochkönig/ Mitterberg, Sbg.	57	TUF	Mayer (1977, No. 558)	1723
HiB175	LPB	Freudenberg/Retz	BA C2-D1	5	CC	Mühlbach a. Hochkönig/ Mitterberg, Sbg.	57	TUF	Mayer (1977, No. 566)	1725
HiB176	LPB	Freudenberg/ Obertraun	BA C1-D2	5	CC	Mühlbach a. Hochkönig/ Mitterberg, Sbg.	57	TUF	Mayer (1977, No. 580)	1724
HiB177	RLB	Randleistenbeil	BA B1-B2	3	CC	Schwarzach, Sbg.	58	CEZA	Stöllner et al. (2016, Fig. 10, 2)	8/89
HiB178	LPB	Bad Goisern/Bad Aussee	Ha B1	7	CC	Lofer, Sbg.	59	CEZA	Mayer (1977, No. 763)	5223
HiB179	LPB	Bad Goisern/Bad Aussee	Ha B1	7	CC	Lofer/Pass Strub, Sbg.	60	CEZA	Mayer (1977, No. 762)	679
HiB180	LPB	Greiner Strudel/ Niederalm	BA C2	4	CC	Lamprechtshausen/Nopping, Sbg.	61	TUF	Mayer (1977, No. 616)	123/69
HiB181	OS LPB	ausschwingende Schneide	Ha B1	7	CC	Saalfelden/Magnesitfeld, Sbg.	62	TUF	Moosleitner (1991, Taf. 18, 8)	-
HiB182	OS LPB	ausschwingende Schneide	Ha B1	7	CC	Saalfelden/Magnesitfeld, Sbg.	62	TUF	Moosleitner (1991, Taf. 18, 6)	-
HiB183	OS LPB	ausschwingende Schneide	Ha B1	7	DFC	Saalfelden/Magnesitfeld, Sbg.	62	TUF	Moosleitner (1991, Taf. 18, 7)	-
HiB184	OS LPB	ausschwingende Schneide	Ha B1	7	DFC	Saalfelden/Magnesitfeld, Sbg.	62	TUF	Moosleitner (1991, Taf. 18, 5)	-
HiB185	OS LPB	ausschwingende Schneide	Ha B1	7	DFC	Saalfelden/Magnesitfeld, Sbg.	62	TUF	Moosleitner (1991, Taf. 18, 2)	-
HiB186	LPB	mittelständig	Ha B1	7	DFC	Saalfelden/Magnesitfeld, Sbg.	62	TUF	Moosleitner (1991, Taf. 18, 4)	-
HiB187	LPB	Hallstatt/Wörschach	Ha B1-B3	7	DFC	Werfen, Sbg.	63	CEZA	Mayer (1977, No. 850)	15
HiB188	LPB	Freudenberg/ Niedergößnitz	BA C1-D1	5	CC	Werfen/Tenneck, Sbg.	64	CEZA	Mayer (1977, No. 541)	121/69

DACH-No.	Axe type/variation		Dating	Dat-ing Group	Cop-per type	Findspot, province or country	No. map	Ana-lysed by	Literature	Inventory-No.
HiB189	-	Fragment	BA C1-D2	5	CC	Mühlbach a. Hochkönig/ Einödberg, Sbg.	65	CEZA	Stöllner et al. (2016, 104)	531/81
HiB190	LPB	Freudenberg/ Niedergößnitz	BA C1-D1	5	CC	St. Johann im Pongau/ Halldorf, Sbg.	66	CEZA	Mayer (1977, No. 547)	1/69
HiB192	LPB	Freudenberg/Rosenau	BA C1-D2	5	CC	Stuhlfelden/Dürnberg, Sbg.	67	CEZA	Mayer (1977, No. 521)	1261
HiB193	ABB	gedrungen herzförmige Rast	BA B1-C2	4	CC	Gries im Pinzgau, Sbg.	68	CEZA	Mayer (1977, No. 392)	285
HiB194	LPB	breites mittelständiges	BA C1-D2	5	CC	Gumping bei Lofer, Sbg.	69	CEZA	Mayer (1977, No. 623)	281
HiB195	LPB	Gmunden	BA C1-D2	5	CC	Neukirchen im Pinzgau, Sbg.	70	CEZA	Mayer (1977, No. 472)	6082
HiB196	LPB	Lappenbeil	Ha C1-C2	8	FC	Salzburg/Brucker Berg, Sbg.	71	CEZA	Stöllner et al. (2016, Fig. 11, 21)	81/86

*also: 1901.1 (519)
**also: 1957.1688

HiB008 to HiB037: vorarlberg museum
HiB038 to HiB058: Stadtmuseum Wels
HiB059 to HiB062: Oberösterreichisches Landesmuseum
HiB063 to HiB069: Tiroler Landesmuseum Ferdinandeum
HiB070 to HiB163: Archäologisches Museum Fließ
HiB164 to HiB180, HiB187 to HiB196: Salzburg Museum
HiB181 to HiB186: Museum Schloss Ritzen Saalfelden

Abbreviations:
FB = Flachbeil (flat axe)
RLB = Randleistenbeil (flanged axe)
ABB = Absatzbeil (palstave)
LPB = Lappenbeil (winged axe)
OS LPB = oberständiges Lappenbeil (end-winged axe)
TB = Tüllenbeil (socketed axe)
NSA = Nackenscheibenaxt
m. z. Schneide herabg. Lappen =
mit zur Schneide herabgezogenen Lappen

FL = Fürstentum Liechtenstein
GER = Deutschland
CH = Schweiz
Vbg. = Vorarlberg
OÖ = Oberösterreich
Tir. = Tirol
Sbg. = Salzburg

Tab. 1: Short-catalogue of the analysed axes. For corresponding Dating Groups see Tab. 2.

No.	Group	Included lifespans	Definition
1	Beginning Early Bronze Age	BA A1	solely dating to BA A1
2	Early Bronze Age	BA A1-A2	mainly BA A2 lifespans not reaching BA B1
3	End of Early Bronze Age / Beginning Middle Bronze Age	BA A2-B1 BA B1-B2	mainly BA B1 - B2 lifespans neither reaching BA A1 nor C1
4	Middle Bronze Age	BA B1-C1 BA B1-C2 BA B2-C1	mainly BA C1 lifespans neither reaching A2 nor D1
5	End of Middle Bronze Age / Beginning Late Bronze Age	BA C1-D1, BA C1-D2 BA C2-D1, BA C2-D2	mainly BA C2 - D1 lifespans neither reaching BA B2 nor Ha A1, nor solely dating to BA C
6	Late Bronze Age (earlier phase)	BA D1-D2 BA D1-Ha A1 BA D1-Ha A2	mainly BA D2 - Ha A1 lifespans neither reaching BA C2 nor Ha B1, nor solely dating to Ha A
7	Late Bronze Age (later phase)	Ha A1-B3, Ha A1-B1 Ha A2-B2, Ha B1-B2 Ha B1-B3, Ha B2-B3	mainly Ha A2 - B3 lifespans neither reaching BA D2 nor Ha C1
8	Early Iron Age	Ha C1-D2	dating to Ha C1-D2

Tab. 2: Chronology-groups used in this paper and their definition. For dating of every single axe see Tab. 1.

DACH-No.	SAM No.	Lab.-No.	Cu %	Mn %	Fe %	Co %	Ni %	Zn %	As %
HiB008	-	MA-155015	91	< 0,01	< 0,05	0,02	0,21	< 0,1	0,88
HiB009	-	MA-155016	91	< 0,01	< 0,05	0,05	0,35	< 0,1	0,12
HiB010	-	MA-155017	90	< 0,01	0,07	0,05	0,12	< 0,1	0,20
HiB011	-	MA-155018	92	< 0,01	0,28	0,05	0,02	< 0,1	0,06
HiB012	-	MA-155019	96	< 0,01	< 0,05	0,05	0,70	< 0,1	0,63
HiB013	-	MA-155020	90	< 0,01	0,47	0,05	< 0,01	0,1	0,05
HiB014	-	MA-155021	92	< 0,01	0,09	0,05	0,29	< 0,1	0,20
HiB015	-	MA-155022	92	< 0,01	< 0,05	0,04	0,06	< 0,1	0,09
HiB016	-	MA-155023	92	< 0,01	0,10	0,04	0,06	< 0,1	0,15
HiB017	-	MA-155024	92	< 0,01	0,08	0,02	0,19	< 0,1	0,20
HiB018	-	MA-155025	89	< 0,01	0,21	0,03	0,28	< 0,1	0,22
HiB019	-	MA-155026	89	< 0,01	< 0,05	0,06	0,32	< 0,1	0,31
HiB021	-	MA-155028	92	< 0,01	0,11	0,14	0,50	< 0,1	0,30
HiB022	-	MA-155029	91	< 0,01	< 0,05	0,09	0,20	< 0,1	0,29
HiB023	-	MA-155030	92	< 0,01	< 0,05	0,05	0,06	< 0,1	0,16
HiB024	-	MA-155031	91	< 0,01	< 0,05	0,04	< 0,01	0,1	0,19
HiB025	-	MA-155032	93	< 0,01	< 0,05	0,02	0,24	0,1	0,30
HiB026	SAM 2763	FG-810002	95	n.a.	< 0,05	0,01	0,41	< 0,1	0,73
HiB027	SAM 2764	FG-810003	93	n.a.	< 0,05	< 0,01	0,45	< 0,1	0,80
HiB028	SAM 2765	FG-810004	92	n.a.	< 0,05	< 0,01	0,45	< 0,1	0,62
HiB029	SAM 2766	FG-829994	89	n.a.	< 0,05	< 0,01	0,61	< 0,1	0,51
HiB030	SAM 2767	FG-829992	97	n.a.	0,26	0,05	0,04	< 0,1	0,17
HiB031	SAM 2768	MA-160001	84	n.a.	< 0,05	0,60	4,4	< 0,1	2,57
HiB032	SAM 2769	FG-829996	96	n.a.	< 0,05	0,02	0,34	< 0,1	0,69
HiB033	SAM 2770	FG-810007	89	n.a.	< 0,05	< 0,01	0,31	< 0,1	0,16
HiB034	SAM 2771	FG-810005	92	n.a.	0,05	0,02	0,53	< 0,1	0,51
HiB035	SAM 2772	FG-829995	94	n.a.	< 0,05	0,07	1,69	< 0,1	0,35
HiB037	SAM 2774	FG-829997	88	n.a.	< 0,05	< 0,01	< 0,01	< 0,1	3,90
HiB038	-	MA-162786	88	< 0,01	0,06	0,03	0,32	< 0,3	0,18
HiB039	-	MA-162787	90	< 0,01	0,10	0,03	0,31	< 0,3	0,15
HiB040	-	MA-162788	89	< 0,01	< 0,05	0,04	0,40	< 0,3	0,29
HiB041	-	MA-162789	88	< 0,01	0,25	0,07	0,73	< 0,3	0,35
HiB043	-	MA-162791	90	< 0,01	0,05	0,05	0,65	< 0,3	0,73
HiB044	-	MA-162792	88	< 0,01	0,06	0,04	0,59	< 0,3	0,48
HiB047	-	MA-162795	92	< 0,01	0,11	0,03	0,31	< 0,3	0,38
HiB049	-	MA-162797	93	< 0,01	< 0,05	< 0,01	0,05	< 0,3	0,35
HiB050	-	MA-162798	88	< 0,01	0,21	0,02	0,37	< 0,3	0,54
HiB051	-	MA-162799	87	< 0,01	< 0,05	0,01	0,24	< 0,3	0,23
HiB052	-	MA-162800	88	< 0,01	0,23	0,04	0,31	< 0,3	0,54
HiB053	-	MA-162801	94	< 0,01	0,05	0,04	0,34	< 0,3	0,22
HiB054	-	MA-162802	88	< 0,01	0,12	0,16	0,50	< 0,3	0,97
HiB055	-	MA-162803	92	< 0,01	0,09	0,05	0,27	< 0,3	0,56
HiB056	-	MA-162804	90	< 0,01	0,20	0,07	0,49	< 0,3	0,76
HiB057	-	MA-162805	93	< 0,01	0,09	0,03	0,25	< 0,3	0,14
HiB058	-	MA-162806	88	< 0,01	< 0,05	0,07	0,39	< 0,3	0,43
HiB059	-	MA-162807	89	< 0,01	< 0,05	0,02	0,52	< 0,3	0,39
HiB060	-	MA-162808	88	< 0,01	0,08	0,08	0,27	< 0,3	0,53
HiB061	-	MA-162809	93	< 0,01	< 0,05	0,03	0,47	< 0,3	0,24

Tab. 3: Samples and analyses conducted within the DACH-project and relevant for this paper (Sampling: Caroline Grutsch, Analyses: Joachim Lutz).

Se %	Ag %	Cd %	Sn %	Sb %	Te %	Pb %	Bi %	Inventory No.
< 0,01	0,019	< 0,005	7,4	< 0,005	< 0,005	0,45	< 0,01	PR 632
< 0,01	0,049	0,012	8,1	0,169	< 0,005	0,03	< 0,01	PR 561
< 0,01	0,075	< 0,005	9,4	0,066	< 0,005	0,37	0,03	PR 596
< 0,01	0,039	< 0,005	7,7	0,070	< 0,005	0,22	0,02	PR 587
< 0,01	0,042	< 0,005	2,0	0,252	< 0,005	0,29	0,01	PR 573
< 0,01	0,067	< 0,005	7,8	0,066	< 0,005	0,88	0,02	PR 617
< 0,01	0,042	< 0,005	6,5	0,071	< 0,005	0,30	0,02	PR 563
< 0,01	0,060	0,005	7,0	0,162	< 0,005	0,63	0,03	PR 588
< 0,01	0,069	< 0,005	7,7	0,050	0,006	0,20	0,04	PR 1939.1
< 0,01	0,008	0,007	7,5	0,009	< 0,005	< 0,01	< 0,01	without No.
< 0,01	0,004	< 0,005	9,8	0,011	< 0,005	< 0,01	< 0,01	PR 1988.1
< 0,01	0,214	< 0,005	8,8	0,46	< 0,005	0,37	0,01	PR 604
< 0,01	0,159	< 0,005	5,7	0,49	< 0,005	0,36	0,02	PR 556
< 0,01	0,064	< 0,005	7,3	0,36	< 0,005	0,62	0,02	PR 564
< 0,01	0,052	< 0,005	7,3	0,105	0,006	0,70	0,02	PR (19)19.1*
< 0,01	0,009	0,013	7,6	0,022	< 0,005	1,43	< 0,01	PR 626
< 0,01	0,016	< 0,005	6,6	0,094	< 0,005	0,01	< 0,01	PR 1993.3
< 0,01	0,283	n.a.	4,2	0,61	< 0,005	0,02	0,01	PR (19)58.1
< 0,01	0,294	n.a.	6,2	0,62	< 0,005	0,06	0,01	PR (19)58.2
< 0,01	0,086	n.a.	6,6	0,250	< 0,005	0,14	0,01	PR (19)58.3
< 0,01	0,235	n.a.	8,0	0,225	< 0,005	< 0,01	< 0,01	PR 580
< 0,01	0,012	n.a.	2,60	0,013	< 0,005	0,01	< 0,01	PR 1956.1688**
< 0,01	1,08	n.a.	< 0,005	7,1	< 0,005	0,20	0,01	PR 569
< 0,01	0,80	n.a.	0,92	0,72	< 0,005	0,01	< 0,01	PR 621
< 0,01	0,39	n.a.	5,5	0,185	< 0,005	3,5	< 0,01	PR 567
< 0,01	0,022	n.a.	4,8	0,101	< 0,005	0,30	< 0,01	PR (19)13.1
< 0,01	1,26	n.a.	0,013	1,89	< 0,005	0,02	< 0,01	PR (19)58.5
< 0,01	1,07	n.a.	< 0,005	6,3	< 0,005	0,02	0,17	PR 620
< 0,01	0,028	n.a.	10,6	0,174	< 0,005	0,15	< 0,01	10619
< 0,01	0,038	n.a.	9,1	0,094	< 0,005	0,21	< 0,01	14004
< 0,01	0,026	n.a.	9,8	0,261	< 0,005	0,20	0,01	48
< 0,01	0,017	n.a.	9,6	0,187	< 0,005	0,14	< 0,01	13473
< 0,01	0,097	n.a.	6,9	0,34	< 0,005	0,58	< 0,01	13525
< 0,01	0,014	n.a.	9,8	0,296	< 0,005	0,01	< 0,01	13538
< 0,01	0,008	n.a.	6,7	0,51	< 0,005	0,12	< 0,01	14901
< 0,01	0,262	n.a.	4,2	1,74	0,007	0,09	0,03	13763
< 0,01	0,023	n.a.	10,4	0,85	0,008	< 0,01	< 0,01	1253
< 0,01	0,002	n.a.	12,6	0,062	< 0,005	< 0,01	< 0,01	217904
< 0,01	0,004	n.a.	10,4	0,089	< 0,005	< 0,01	< 0,01	13762
< 0,01	0,023	n.a.	5,3	0,151	< 0,005	0,10	< 0,01	14764
< 0,01	0,34	n.a.	6,4	2,66	0,022	0,83	0,01	13353
< 0,01	0,032	n.a.	5,9	0,37	0,006	0,35	0,03	12043
< 0,01	0,003	n.a.	8,3	0,39	0,010	0,03	< 0,01	12063
< 0,01	0,034	n.a.	6,2	0,119	< 0,005	0,07	< 0,01	10618
< 0,01	0,291	n.a.	8,5	1,71	0,020	0,40	< 0,01	10617
< 0,01	0,015	n.a.	10,0	0,119	< 0,005	< 0,01	< 0,01	A669
< 0,01	0,004	n.a.	10,6	0,43	0,006	0,04	< 0,01	A642
< 0,01	0,003	n.a.	5,5	0,136	< 0,005	< 0,01	< 0,01	A3143

„<" = detection limit
n.a. = not analyzed

*also: 1901.1 (519)
**also: 1957.1688

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