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Encapsulated industrial processes: slag-tempered ceramics and its implications for prehistoric metallurgy in the Lower Inn Valley (North Tyrol, Austria)

ABSTRACT: *The use of slag-tempered ceramics is a characteristic feature of prehistoric inner-Alpine settlements associated with Cu-ore deposits. Slag-tempered ceramic fragments from three sites in the Lower Inn Valley were investigated with mineralogical, petrographical and geochemical methods: (1) the hilltop settlement Kiechlberg near Thaur, (2) the gravel quarry Kundl-Wimpissinger and (3) the cemetery St. Leonhard site, latter both in the vicinity of Kundl. The Kiechlberg (1) site is a small hill on the south face of the Karwendel mountain range, a few kilometers northeast of Innsbruck. Superficial finds of artefacts and metallurgical slags led to first archaeological excavations in the frame of the Special Research Program HiMAT (supported by the Austrian Science Fund FWF). On the Kiechlberg, a huge amount of ceramic and flint artefacts as well as metal objects made of copper and bronze were collected during the investigation of a prehistoric layer of debris, indicating an occupation of the site from Late Neolithic up to Early and Middle Bronze Age. One specific feature was the occurrence of slag-tempered ceramic fragments. The slag fragments are <5 mm in size and often occur greenish due to alteration of Cu-minerals. The slag mineral assemblage is olivine + clinopyroxene + spinel + Cu-droplets. Chemical compositions of the Cu metal droplets are identical to compositions from slag samples from the site itself. At the gravel quarry Wimpissinger (2) near Kundl a Late Bronze Age settlement was discovered with a metal workshop containing slag residues and ceramic fragments. In these ceramic fragments slag temper was also found. The mineralogy of the analyzed slag fragments as well as the slag temper indicates that the ore used to produce Cu-metal came from the nearby fahlore-group mineral deposits of Brixlegg (embedded in Devonian dolomites, "Schwazer Dolomit"). Significant amounts of Ni and Co also indicate that ores of Triassic age ("Schwazer Trias") were also used. On the south side of the Inn Valley near the village of St. Leonhard (3) near Kundl (Tyrol, Austria) a few pieces of bronze and pottery have been discovered on a field. Here, a Late Bronze Age (Urnfield period) burial site is suggested. Because of the greenish spots observed on one of the pottery fragments it was assumed that some of the jars could have been tempered with slag sand. Slag sand/grit is a by-product of copper ore smelting processes and can be found in the copper smelting sites Mauk A in the nearby Mauken Valley, only two kilometres southwest, as well as at the smelting site in Rotholz (Buch i. T.). Mineralogical investigations of ceramic fragments confirm the first assumption that in the three above mentioned sites primarily slag fragments were used as temper. The slag temper has a characteristic chemical/mineralogical composition. The metal/copper inclusions in the slag have typical "fahlore-signature" containing Sb and As. The chemical composition and textures of the silicate phases are comparable to the Late Bronze Age copper slags from the adjacent site "Mauk A". Chemical analysis of the slag-tempered fragments from all three sites indicate so far that local fahlore-group minerals from the Lower Inn Valley have been used.*

KEYWORDS: CERAMICS, SLAG TEMPER, ARCHAEOMETALLURGY, KIECHLBERG, KUNDL-WIMPISSINGER, HIMAT

Introduction

Investigations of ceramic fragments in the Alps have a long tradition (e.g. Maggetti, 2005). Ceramic provenance analysis begins with the petrographic study of the ceramics itself (e.g. Quinn, 2009). Sometimes petrographic analysis of the temper alone, due to the presence of some mineral inclusion distinctive enough, is sufficient to determine regions of source procurement and hence manufacture (Peacock, 1969; Shepard, 1956). For instance, the Kiechlberg revealed a large number of ceramic fragments and stylistically the different ceramic fragments can be attributed to the following groups (Töchterle, 2015): 1.) The Polling group (4,100-3,900 BC), which has already been found at Brixlegg-Mariahilfbergl, Innsbruck-Norer Sandgrube and Thaur-Kiechlberg. 2.) The „Vasi a Bocca Quadrata" (Isera II, 4,200-3,800 BC) south of the Alps. 3.) The Pfyn and Altheim style (3,800-3,300 BC) and 4.) local manufacture from Early Bronze Age (2,200-1,600 BC). Since petrographic investigations of prehistoric

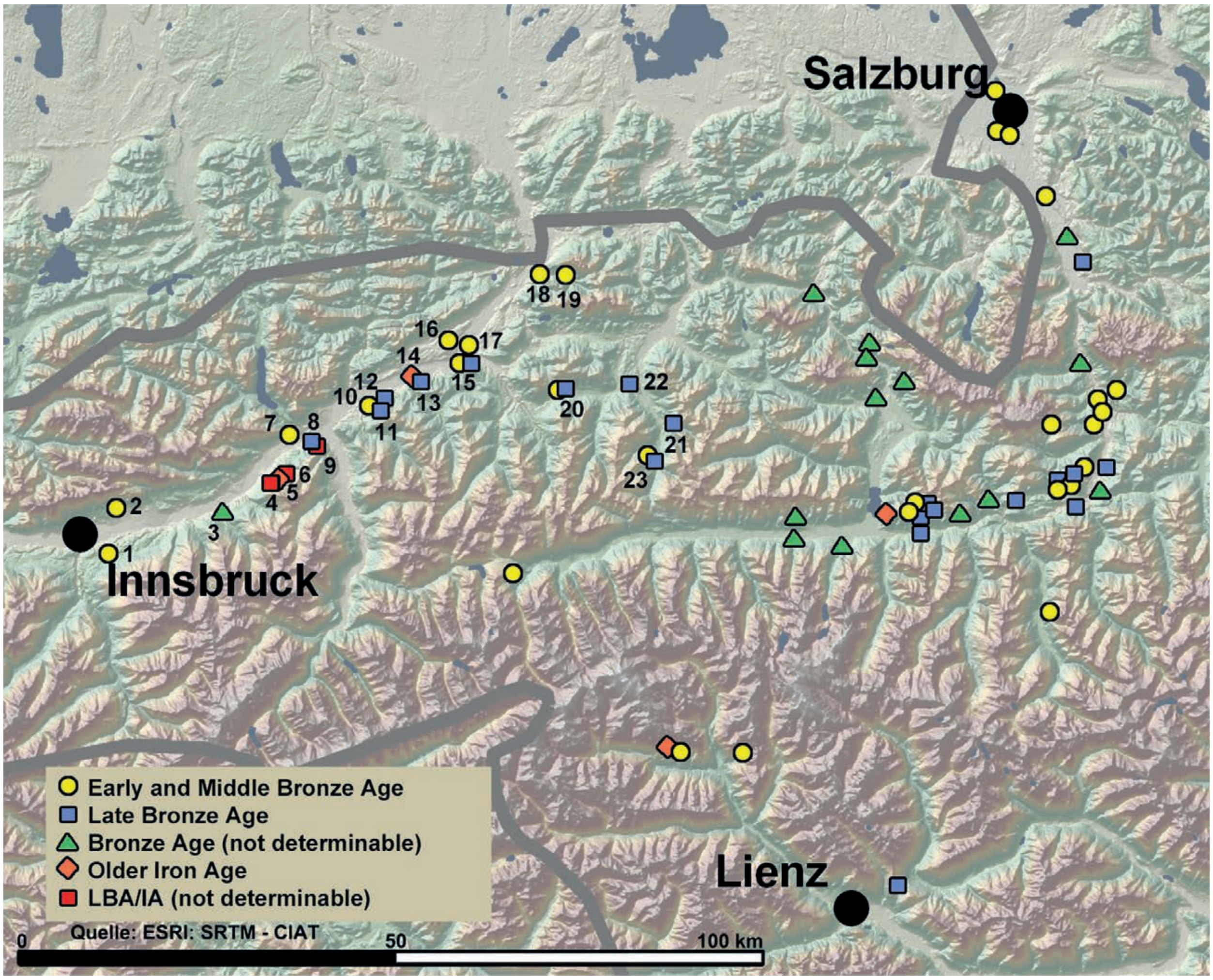

Fig. 1: Map showing the distribution of Bronze Age/Iron Age slag-tempered ceramics in North Tyrol: *1: Goldbichl, Igls; 2: Kiechlberg, Thaur; 3: Stadlerhof, Weer; 4 + 5: Blutskopf/Gallzeiner Joch, Gallzein; 6: Obertroi, Buch in Tirol; 7: Buchberg, Wiesing; 8: Smelting site Rotholz, Buch in Tirol; 9: Weißer Schrofen, Strass im Zillertal; 10: Hochkapelle-Mariahilfbergl, Brixlegg; 11: Smelting site Mauk A und Pingenfeld Mauk D, Radfeld; 12: St. Leonhard, Kundl; 13: Wimpissinger-quarry (settlement), Kundl; 14: Wimpissinger-cemetery, Kundl; 15: Inntalmilch, Wörgl; 16: Siedlung, Angath; 17: Grattenbergl, Kirchbichl; 18: Festungsberg, Kufstein; 19: Tischofer Höhle, Ebbs; 20: Götschen, Brixen im Thale; 21 Kelchalm, Aurach; 22 Tiefenbrunner Feld, Kitzbühel; 23 Smelting site SP9 (Wurzhöhe), Jochberg. Sources: 5, 7, 10, 16, 19 Sölder 1987/88, 2015; 1-3, 15, 17, 20 Töchterle et al. 2013; 4, 6, 8, 9, 18, 21 Staudt pers. comm.; 12 Krismer et al. 2012; 13 Prader 2013; 14 Lang 1998; 11 Goldenberg 2014; 22 Huijsmans 1994; 23 Preuschen & Pittioni 1955.*

ceramic fragments in the Tyrol have only been done at the Mariahilfbergl, Brixlegg (Huijsmans, 2001), Buchberg, Wiesing (Martinek, 1996), Mauken Valley, Radfeld (Mauk A, Reider, 2003), Mairhof, Kaunerberg (Staudt, 2016) and Pirchboden, Fritzens (Ciresa, 2006), there is an absolute need to increase the database. One peculiar feature observed during the investigations of the research centre HiMAT (The History of Mining Activities in the Tyrol and adjacent areas: Impact on Environment and Human Societies) is the use of metallurgical products as ceramic temper. So far it seems that slag sand tempered ceramic is an alpine phenomenon and can be found in technical ceramics (tuyères and crucibles), domestic pottery from settlements as well as in grave goods (ceramics) since the Early Bronze Age up to the Early Iron Age (Sölder, 1987/1988, Töchterle et al., 2013; also Stöllner et al. 2016, pp.83-87). In the Inn Valley such findings can be located near the fahlore-group mineral mining district Schwaz-Brixlegg (Preuschen & Pittioni, 1955; Gstrein, 1981, 1988; Sölder, 1987/1988; Huijsmans, 1994; Rieser & Schrattenthaler, 1998/1999, 2004; Goldenberg & Rieser, 2004; Goldenberg et al., 2012; Goldenberg, 2013, 2014, 2015; Töchterle, 2015). Within the framework of the research centre HiMAT (since 2007) and the international DACH-project “Prehistoric copper production in the eastern and central Alps – technical, social and economic dynamics in space and time” (supported by the Austrian Science Fund FWF, the German Research Foundation DFG and the Swiss National Science Foundation SNF, 2015-2018) comprehensive investigations on prehistoric copper production were done on the mining area Schwaz-Brixlegg over the past years. This lead to the identification of so far 23 sites where metallurgical remains were used as ceramic temper in Tyrol. Most of these sites, 19 of them, are found in the Lower Inn Valley as shown in Fig. 1. The westernmost occurrence of slag-tempered ceramics in the Lower Inn Valley is at the Early Bronze Age hilltop-settlement at the Kiechlberg (Thaur) about 30 km west of the important fahlore-group mineral deposits in the Tyrolean Lower Inn Valley (Krismer et al., 2010, 2012a; Töchterle, 2015). Most of the sites containing slag-tempered ceramic centre around the mining district Schwaz-Brixlegg and in the course of recent investigations new locations dating into the Late Bronze Age/Early Iron Age could be identified inside the mining district, the most prominent being the sites near Kundl and St. Leonhard. The dimensions of the slag fragments found inside the ceramic strongly vary from small grain sizes of <2 mm up to a size of 1 cm.

Prominent examples of archaeological sites with slag-tempered ceramics

Archaeological background

(1) Kiechlberg: The Kiechlberg (1028 meters a.s.l.) is a small hill at the foot of the Karwendel mountain range, 400 metres above the Inn Valley a few kilometres northeast of Innsbruck. Superficial finds of prehistoric artefacts and metallurgical slag led to first archaeological excavations, which started in 2007 within the frame of the Special Research Programme HiMAT. A huge amount of ceramic and flint artefacts as well as copper and bronze objects were collected during the investigation of a prehistoric layer of debris, indicating a multiphase-occupation of the site from the Late Neolithic up to the Middle Bronze Age. On the steep northern slope of the Kiechlberg a massive deposit of cultural layers contains metallurgical finds. The radiocarbon samples of the oldest layers deposited on the bedrock and postglacial sediments and particularly poor metallurgical finds provide the earliest data of 4050-3810 cal. BC (2σ) and 4230-3970 cal. BC (2σ) (VERA-4457: 5170 ± 35 BP; VERA-4911: 5255 ± 40 BP; Töchterle, 2015). According to the assemblage with numerous fine-decorated potteries of the Polling group in today's South Bavaria, they confirm the first settlement activities on the Kiechlberg between the 5th and 4th mill. BC. More recent data (3020–2870 cal. BC (2σ), VERA-4455: 4300 ± 35 BP; 2470–2200 cal. BC (2σ), VERA-4454: 3875 ± 40 BP; 2200–1950 cal. BC (2σ), VERA-4458: 3680 ± 35 BP) originate from the upper layers, which represent the Copper Age and Early Bronze Age occupation but without chronological order. Especially in these upper layers slag and copper-rich semi-products are abundant. Metallurgical remains on the top of the hill only occur in Early Bronze Age context (1880-1620 cal. BC (2σ), VERA-4906: 3425 ± 40 BP). One bronze pin and a radiocarbon date (1630-1430 cal. BC (2σ), VERA-4907: 3260 ± 40 BP) of a posthole indicate the Middle Bronze Age as the final phase of the prehistoric presence. Metallurgical artefacts, such as copper ore fragments, copper slag, raw copper as well as finished copper- and bronze artefacts are concentrated mainly in Late Copper Age to Early and Middle Bronze Age layers (Töchterle, 2015; Krismer et al., 2010, 2012a). Within these artefacts slag-tempered ceramic fragments from the Early Bronze Age occur (Fig. 2). Often these fragments can be spotted due to their alteration to a green copper carbonate-hydroxide mineral, malachite. The small amount of slag and the presence of slagged and thermally altered ceramic fragments might indicate a small-scale workshop for copper production. Most probable sulfide-rich ores were smelted in crucibles in a hearth fire with blowpipes.

(2) St. Leonhard: On the south side of the Inn Valley near the hamlet of St. Leonhard a few bronze artefacts and pottery have been discovered on a field. Due to the high quantity of findings and to the fact that some of the artefacts show partial signs of the effects of fire, a Late Bronze Age burial site is suggested. Most of the bronze objects were identified as dress accessories, like belt hooks, arm-rings and some globe-headed pins. The finding of a tang knife represents typical Urnfield period burial equipment. Analysis of the pottery fragments suggests large wide-mouthed and round-bodied vessels (urns). All of the artefacts date to the Urnfield period around the 13th -12th century BC (Staudt et al., 2013). The cemetery is situated on the eastern part of the Schwaz-Brixlegg fahlore-group mineral mining district just 2 km (linear distance) north of the smelting site Mauk A (Krismer et al., 2012b, 2012d; Krismer et al., 2015). Because of small greenish spots observed on the surface of one of the pottery fragments it was assumed that some of the vessels could have been tempered with slag sand. Some pieces of slag are even visible with the naked eye due to their brown colour and/or alteration to malachite (Fig. 3). This is the first cemetery where slag sand-tempered ceramics has been observed in Tyrol so far. Late Bronze Age layers, which have been discovered nearby the church of St. Leonhard in the 1950´s could represent the corresponding settlement (Bachmann, 1956).

(3) Kundl-Wimpissinger: Just 4 km east of St. Leonhard in the gravel quarry Wimpissinger in Kundl, three thick cultural layers could be documented at the east slope. Below two layers of an Iron Age settlement, remains of a Late Bronze Age settlement and metallurgical activities were found during archaeological investigations in 1977 (Lang, 1998). Abundant metallurgical artefacts such as different pieces of slag (also plate slag), secondary copper minerals, crucible fragments, pieces of tuyères (from blowpipes and big tuyères) and slagged furnace clays were found in the Late Bronze Age layer (Staudt

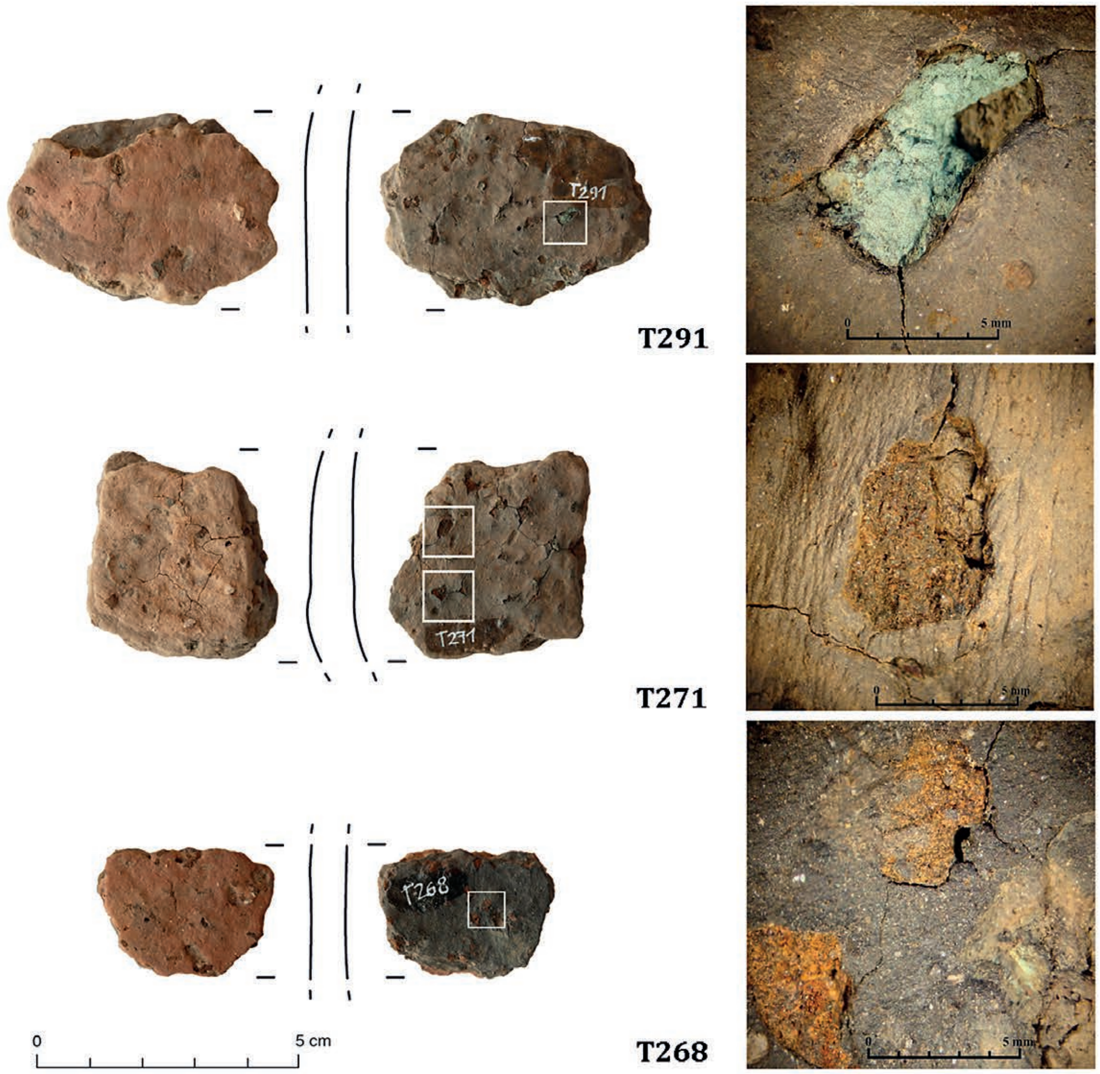

Fig. 2: Photographs of ceramic fragments from the Kiechlberg and the positions of slag temper fragments (left). Close-up of the slag fragments (right). In sample T291 the alteration of the slag fragment to the copper carbonate-hydroxide mineral malachite can be seen.

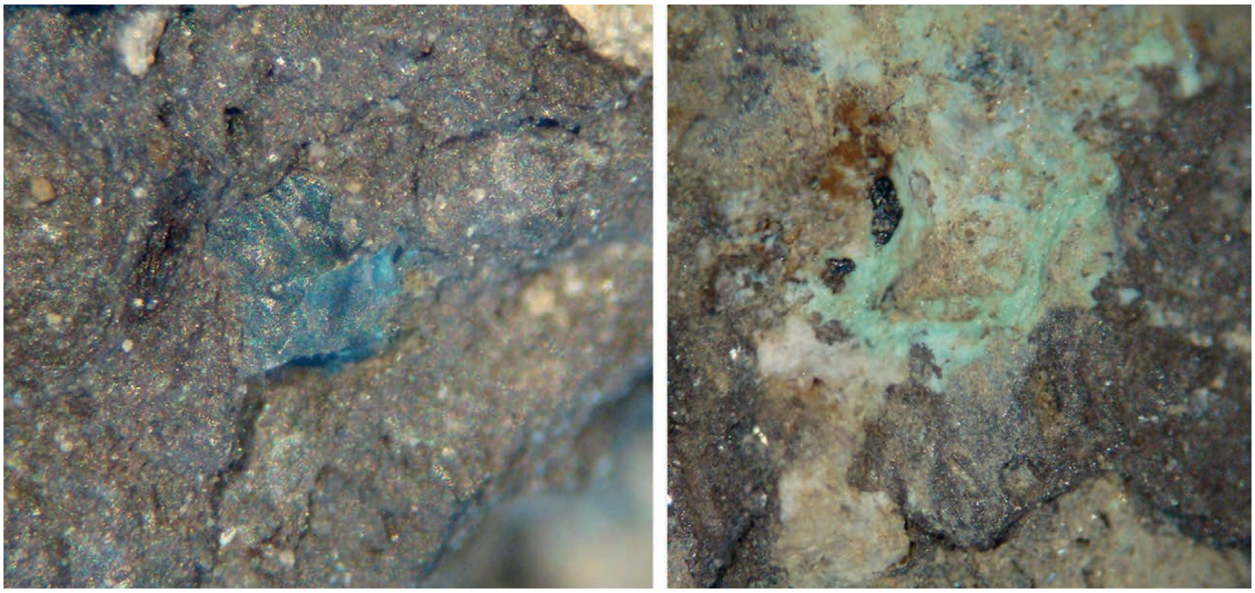

Fig. 3: Close-up photograph of slag-temper fragments visible on the surface of ceramic fragments (blue, left image and brown, right image, partly altered to green malachite) from the cemetery of St. Leonhard. The width of both images corresponds to approximately 1 cm.

Fig. 4: Photograph of a ceramic fragment with visible slag-temper fragments on the surface (dark aggregates indicated with black arrows) from Kundl-Wimpissinger (sample W1).

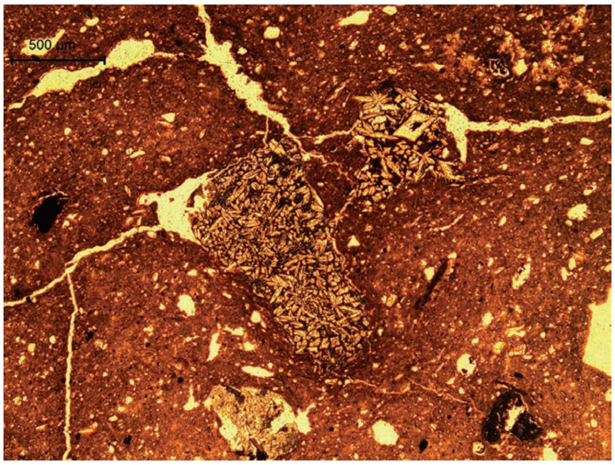

Fig. 5: Microphotograph of slag fragments showing aggregates of clinopyroxene crystals in sample T005-013 from the Kiechlberg.

& Tomedi, 2015). Further some constructions made of stone and reddened clay in combination with surrounding pieces of smelting slags were also documented and could represent remnants of smelting furnaces (Lang, 1998). The same Late Bronze Age settlement layer also was identified at the west slope profile of the gravel quarry (Weber, 2003; Patzelt & Weber, 2015; Tomedi, et al. 2013). The Bronze Age horizon is as far as 7 m below today's surface and approximately 5 m underneath the Iron Age layers. This demonstrates huge masse movements (land slides) already in prehistoric times and later on. During these investigations it was possible to recover two big storage vessels, which were filled with pieces of pottery, which contains tiny, dark slag fragments (Fig. 4), slagged furnace clay, secondary copper minerals and animal bones from the deepest layer in the steep slope of the quarry. Patzelt's five radiocarbon analyses of charcoal, taken from the Late Bronze Age layer and the storage vessels yield a time period from the 11th to the 9th century BC (Patzelt & Weber, 2015; Staudt & Tomedi, 2015). The collected samples present different pieces of slags and in some of the fragments pieces of dolomite were still visible. This could be a sign for a first smelting process, where remains of the ore-bearing host rock (dolomite) did not completely melt. These slags together with other findings of metallurgical activities (clay tuyères from small blow pipes as well as big bellows and small pieces of fahlore-group mineral ores) definitely document smelting activities in the settlement (Staudt & Tomedi, 2015). This is the first Late Bronze Age settlement where this kind of metallurgical activities (primary smelting) could be proven in North Tyrol. During the investigations at Kundl-Wimpissinger many slag-tempered ceramic fragments were documented in the Bronze Age layers. On one ceramic fragment (Nr. 3) from the underlying Iron Age cemetery in Kundl (Fig. 1) slag temper is visible (area 626, Nr. 1867, Lang, 1998). The piece of pottery was found together with a serpentine fibula with loop, which dates in the Hallstatt period (Ha D2, 6th century BC) and is so far the youngest known slag tempered pottery fragment in the Inn Valley. By looking at pictures from the excavation it is obvious that some of the graves were covered with smelting/ore preparation tools like grinding and anvil stones. It could be possible that some of the buried Early Iron Age people were miners too. Latest investigations by dendrochronology on some mines in the district Schwaz-Brixlegg prove the youngest exploitation activities till the end of the 8th century BC (youngest dated tree ring: 707 BC; Nicolussi & Pichler, 2013; Nicolussi et al., 2015).

Petrography of slag tempered ceramic fragments

(1) Kiechlberg: Petrographical and mineral-chemical investigations were made of the slag fragments contained in the ceramic material (Trauner, 2010; Doberer, 2014). The slag fragments show randomly oriented crystals and occur in a fine-grained reddish matrix (Fig. 5). As temper, rock fragments and crystal fragments dominate. The rock fragments show sizes of up to 500 µm and most of them are orthogneiss and quartzite fragments. In addition abundant recycled ceramic fragments also occur. The crystal fragments are mostly quartz, feldspar and mica and their size is below 50 µm. The slag assemblage is olivine + clinopyroxene (Fig. 6a) + spinel (magnetite) ± melilite (akermanite $Ca_2MgSi_2O_7$-gehlenite $Ca_2AlSiAlO_7$ solid solutions) + Cu-droplets + glass. The Cu-droplets often occur as tiny inclusions in clinopyroxene (Fig. 6b) are ca. 10-30 µm in size and show a chalcosine or digenite rim. Rarely Sb_2O_3 and Ag_2S occur.

(2) St. Leonhard: Mineralogical investigations of ceramic fragments confirm the first assumption that primarily slag fragments were used as temper (Krismer et al. 2012c;

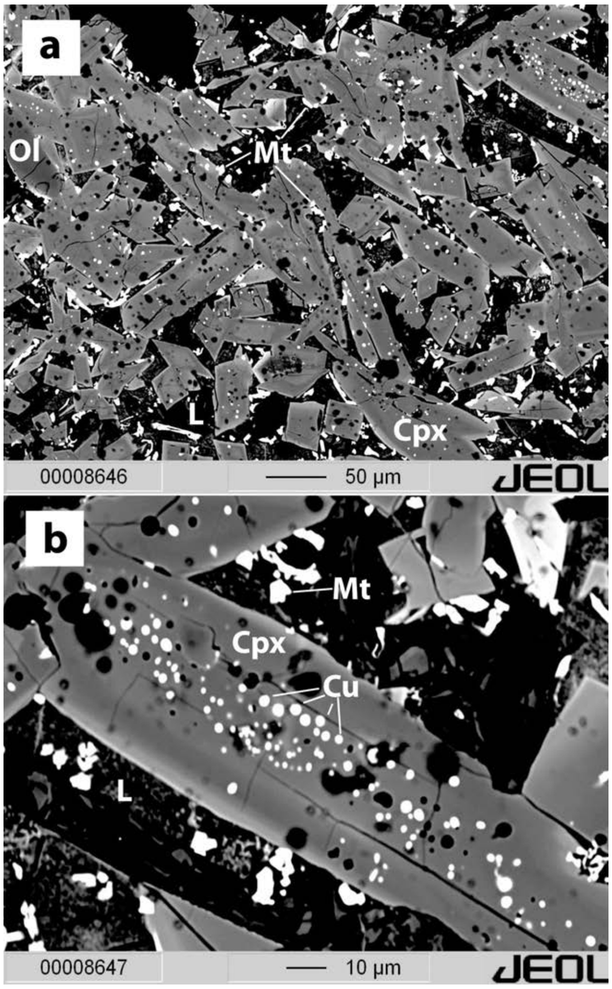

Fig. 6: Backscatter electron (BSE) images of a slag fragment from the Kiechlberg (sample T005-013). (a): overview of the mineral assemblage clinopyroxene (Cpx) + olivine (Ol) + magnetite (Mt) + glass (L). (b): close-up of a clinopyroxene (Cpx) crystal with abundant tiny Cu-inclusions.

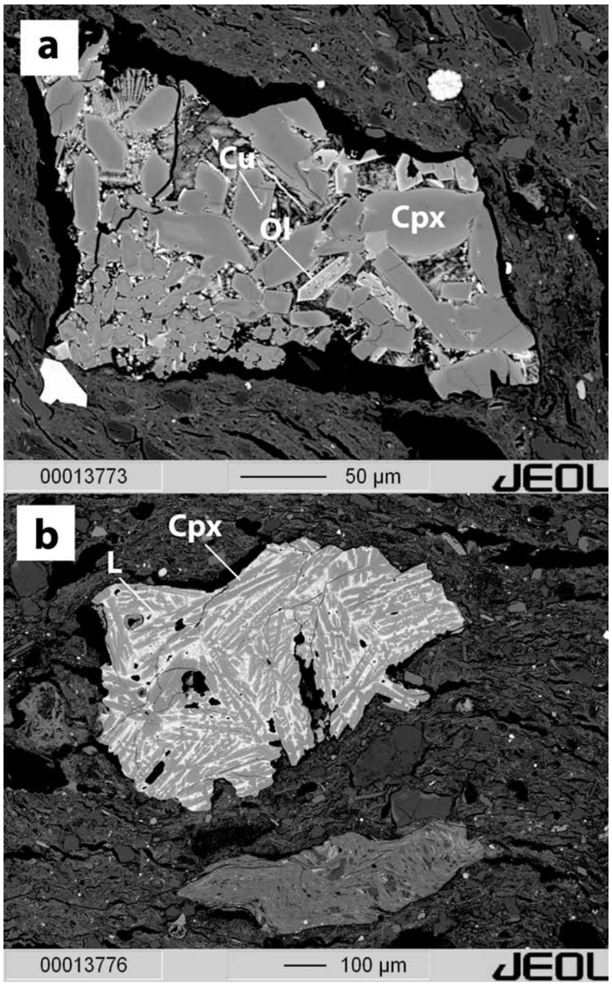

Fig. 7: Backscatter electron (BSE) images of slag fragments from the cemetery St. Leonhard (a: sample SL3; b: sample SL4). (a): slag fragment with the mineral assemblage clinopyroxene (Cpx) + olivine (Ol). Rarely clinopyroxene contains very tiny Cu-droplets (sample SL3). (b): slag-fragment with the mineral assemblage clinopyroxene (Cpx) + glass (L). Directly below a quartzphyllite temper fragment can be seen (sample SL4).

Krismer & Staudt, 2012). The coarser temper components consist mostly of two types of polycrystalline aggregates: slag fragments and rock fragments The size of these coarse temper fragments ranges from a few hundred up to thousands µm. Finer temper fragments with a size below 100 µm consist mostly of monomineralic quartz and feldspar fragments. The rock fragments consist of quartzphyllites with the mineral assemblage muscovite + chlorite + K-feldspar + albite + quartz + rutile + zircon (Fig. 7b). The slag temper has a characteristic chemical/mineralogical composition. Most slag fragments consist of minor skeletal crystals of olivine, and clinopyroxene (Fig. 7a), or only of clinopyroxene + glass (Fig. 7b). In addition to the silicate minerals, spinel (magnetite) also occurs. Rounded Cu-rich droplets occur in the slags. Close examination of the Cu-rich droplets yields a Cu-core and a rim of chalcosine (Cu_2S).

(3) Kundl-Wimpissinger: The slag fragments are clearly visible without a microscope and the size of the slag grains is sometimes up to 1 cm (Fig. 4). Nearly all of the recovered ceramic artefacts from the quarry Wimpissinger show slag (plate slag) as the main tempering material (Prader, 2013). For instance, in the pottery sample W1 sharp-edged homogeneous slag fragments of plate slag with iron silicate (fayalite) crystals and iron oxides in a glassy matrix are clearly visible. Subordinately rock fragments and crystal fragments occur as temper. The rock fragments are also quartzphyllites have a size of up to 500 µm and consist of the mineral assemblage muscovite + chlorite + K-feldspar + plagioclase + quartz + rutile + epidote + allanite. The crystal fragments (quartz, feldspar, mica) are much smaller and show a size of 10-50 µm. No specific orientation of the fragments was observed. The slag fragments show a size of 300 to 400 µm and

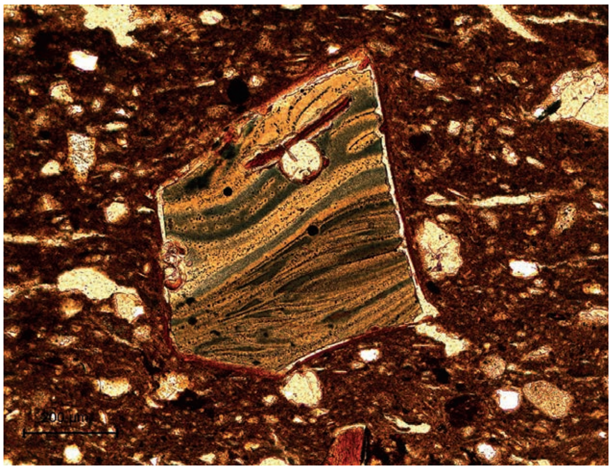

Fig. 8: Microphotograph of a slag fragment showing layers of glass with color ranging from dark grey to light brown in sample W-4 from Kundl-Wimpissinger.

consist mostly of glass, which shows a characteristic schlieren-texture with colours ranging from dark grey to light brown (Fig. 8). Only very few clinopyroxene crystals occur in the glass matrix (Fig. 9a). Within the glass small composite Cu-droplets with sizes between 5 and 30 µm occur. By using a larger magnification, copper droplets in the matte could be identified (Fig. 9b). The Cu-droplets are composite aggregates and contain Cu- and Sb-As-rich Cu intergrowth in the core and chalcosine (Cu_2S) at the rim.

Mineral chemistry of slag tempered ceramic fragments

For standard elemental analyses of sulfide, oxide and silicate the electron microprobe JEOL JXA 8100 SUPERPROBE with five WDS detectors and a Thermo Noran EDS system was used at the Institute of Mineralogy and Petrography of the University of Innsbruck. To cover the whole range of possible elements in the sulfides and sulfosalts, an analysis set-up with 21 elements (S, Cu, Fe, Zn, Hg, Mn, Mo, Cd, Ni, Pb, Co, Au, Ag, Ge, In, As, Sb, Bi, Se, Sn, Te) was developed. Oxide and silicate phases were measured by a routine including the elements O, Si, Mg, Fe, Mn, Cr, Ca, K, Na, Ba, Sr, Al, Ti, P, Zn, Cl, F, Sb, As, Cu, Ba and Zn. The analytic conditions were 15 kV acceleration voltage and 10 nA beam current.

(1) Kiechlberg: Extensive electron microprobe analysis was done on the olivines and they show a highly variable Fe content ranging between 5 and 48 wt.% FeO, which corresponds to 5-66% fayalite (Fe_2SiO_4) component (Trauner, 2010; Doberer, 2014). CaO contents range from 2 to 4 wt.% and ZnO contents are slightly higher with 2-8 wt.%. Olivines often occur chemically zoned with Zn-rich cores as shown in Fig. 10. For example olivin

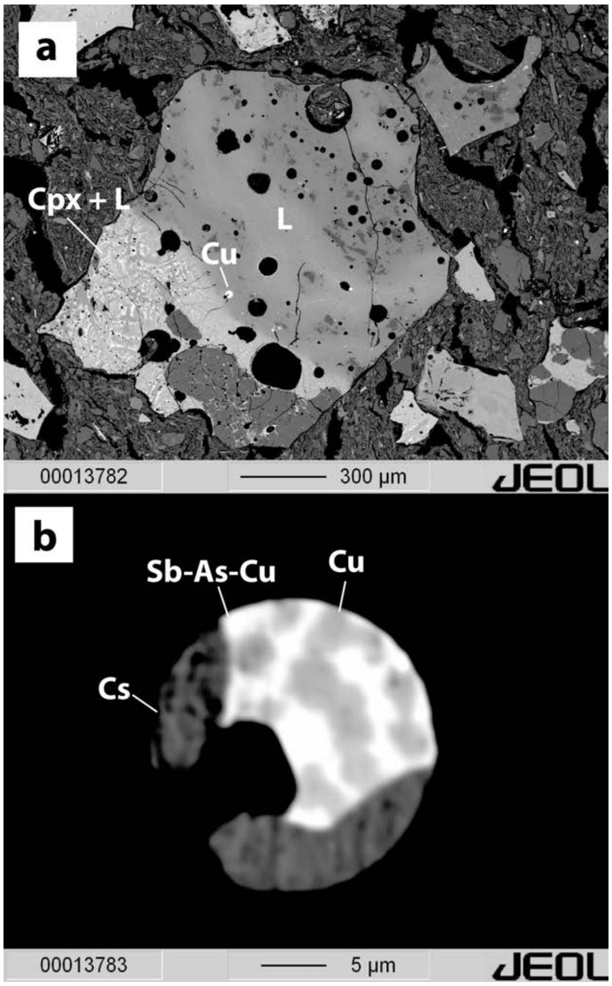

Fig. 9: Backscatter electron (BSE) images of a slag fragment from Kundl-Wimpissinger (sample W5). (a): slag fragment with the mineral assemblage clinopyroxene (Cpx) + glass (L). A small Cu-droplet is visible in the glass matrix. (b): close-up of the composite Cu-droplet showing a small-scale intergrowth between Cu and Sb-As-bearing Cu. The rim of the droplet is chalcosine (Cs).

composition from sample T268 changes from 6.31 wt.% FeO, 46.63 wt.% MgO, 3.97 wt.% CaO and 5.75 wt.% ZnO in the core to 18.67 wt.% FeO, 37.66 wt.% MgO, 4.11 wt.% CaO and 3.10 wt.% ZnO in the rim. This indicates a strong increase in the Fe component accompanied by a decrease in the Mg component and Zn component from core to rim.

Figure 10 clearly shows discontinuous chemical zoning with respect to ZnO, FeO and MgO (Doberer, 2014). This is indicative of a sequence of mineral reactions taking place during firing whereby a Zn-rich phase (e.g. fahlore-group minerals) breaks down in a first step and releases ZnO. It is also interesting that ZnO occurs in melilites with up to 13 wt.%. Most Cu-droplets show significant amounts of Sb and As and FeAsSb compounds sometimes occur. Most Cu-droplets contain 60 wt.% Cu, 30 wt.% Sb and ca. 10 wt.% As but in one sample a droplet with Cu and Sb contents of 48 wt.% and 4 wt.% As occurs. Although

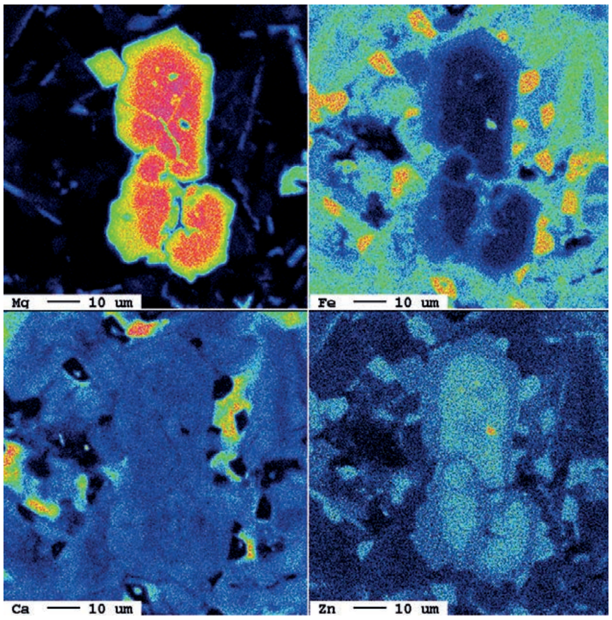

Fig. 10: Elemental distribution maps of MgO (upper left), FeO (upper right), CaO (lower left) and ZnO (lower right) of an olivine crystal from a slag fragment from sample T268 from the Kiechlberg. Note that almost no chemical zoning occurs in CaO.

the As contents are mostly below 10 wt.% one droplet contains up to 30 wt.% As!

(2) St. Leonhard: The chemical composition of the silicates is in the chemical system Ca-Fe-Mg-Si-O and the glass matrix contains in addition to these elements Zn, Al, Na and Ba contents (Krismer et al., 2012c). Zn also occurs up to a few wt.% ZnO in the silicate phases. The Cu-droplets show chemical compositions in the system Cu-Sb-As-S. Microprobe analysis yielded ca. 70-90 wt.% Cu and 10-30 wt.% Sb + As. Thus the metal/copper inclusions in the slag have a typical "fahlore-signature" containing antimony (Sb) and arsenic (As). The chemical composition and textures of the silicate phases are comparable to the Late Bronze Age copper slag's from the close Mauk A site.

(3) Kundl-Wimpissinger: Chemically the slag shows variations in the SiO_2 content from 44 to 58 wt.% and elevated Mg- and Ca-contents of 6-10 wt.% MgO and 9-19 wt.% CaO (Prader, 2013). In addition, the glass contains little Al with contents of 3-4 wt.% Al_2O_3 and relatively low Fe contents of 9-17 wt.% FeO. A noticeable exception is the relatively high MnO content of 4-6 wt.%. The glass also contains up to 7 wt.% ZnO. The clinopyroxenes are diopside ($CaMgSi_2O_6$)-hedenbergite ($CaFeSi_2O_6$) solid solutions and contain no Al. The composition of the Cu-droplets is 70-98 wt.% Cu and <30 wt.% Sb, As and very little Ag. The Ag contents range up to 0.5 wt.% Ag. The As-content varies between 0.4 und 16 wt. % and the Sb-content varies between 0.1 und 19 wt.%. Low Fe-contents of 0.2 and 1.6 wt.% and Mn of 0.1 and 0,8 wt.% were also analysed. Trace contents of Pb, Bi and Co were also detected.

Discussion

Pernicka and Lutz (2015) show that at the beginning of the Early Bronze Age the fahlore copper of the Lower Inn Valley played a dominating role not only in this region but also in the northern foothills of the Eastern Alps and even further to the North. From the late Early Bronze Age on and during the Middle Bronze Age fahlore copper is replaced by the east Alpine copper of the Mitterberg type, produced mainly from chalcopyrite ores. Fahlore copper reappears in the Late Bronze Age and is then used parallel to east Alpine copper. In this period mixing of chalcopyrite copper and fahlore copper is also common (Pernicka & Lutz, 2015). Fahlore-group mineral deposits of the Lower Inn Valley in the Schwaz-Brixlegg area were primarily mined during the Early and Late Bronze Age, while during the late Early Bronze Age and the Middle Bronze Age chalcopyrite was preferred from Mitterberg district (Salzburg) (Höppner et al., 2005; Sperber, 2004; Stöllner et al., 2012; Hanning et al., 2015) or similar ore deposits (e. g. Kelchalm near Kitzbühel). In the Late Neolithic and Early Bronze Age copper ore smelting is evident only in settlements on a small scale. Although, extensive trade of copper from the Lower Inn Valley emerged in the Early Bronze Age (Ösenring copper), thus leading to an intensive exchange between the cultures and causing significant effects on the economic and social structures of the society.

The chemical composition of slag and raw metals found at the Kiechlberg site confirm Fe-Zn tetrahedrite-tennantite (fahlore-group mineral) smelting in the Early Bronze Age (Krismer et al., 2012e). The mineralogy and chemical composition of the slag-temper fragments also fit this observation very well. The slag temper also contains fine metallic inclusions with sizes of 10-30 µm, which are sulfidic Cu-Fe droplets with significant amounts of Sb and As as well as low amounts of Ag. Krismer et al. (2012e) concluded that smelting fahlore-group minerals results in impure Cu with a composition of 75-80% Cu + Ag and 25-20% Sb + As, which was observed in a sample. This chemical signature and the presence of ore fragments from the mining area of Brixlegg at the Kiechlberg site can be regarded as evidence for the smelting of fahlore-group minerals from the 30 km distant copper ore deposits of Schwaz/Brixlegg. Slag textures and mineralogy also indicate that the process was relatively reducing below the $2Sb + 1.5O_2 \rightarrow Sb_2O_3$ reaction producing Sb-rich (>10 wt.% Sb in metal) raw copper. The occurrence of Ca-rich slag phases such as minerals of the melilite group and significant Ca- and Mg-contents of the olivines indicate that dolomitic gangue was present during smelting, which fits the Brixlegg ore deposit (Arlt & Diamond, 1998; Krismer et al., 2011). In addition, inhomogeneous slag remains containing high amounts of sulfide- and metal inclusions suggest a poor separation of metal, matte (copper sulfide, chalcosine) and silicate/oxide melt during the smelting process. This indicates that for instance the reaction $Cu_2S + O_2 \rightarrow 2\ Cu + SO_2$ did not run to completion due to the presence of still abundant S_2. Similar conclusions can be drawn for the slag temper fragments from the Late Bronze Age sites St. Leonhard and Kundl-Wimpissinger. Textures, mineralogical and chemical composition of the slag-temper fragments from St. Leonhard fit the observations in the slags from the smelting site Mauk A very well. Except for the slag temper fragments from Kundl-Wimpissinger, the slag fragments most likely represent slag sand fragments.

These observations from the Late Bronze Age period support demographic studies of population development by Sperber (1992, 2004) based on investigations on the Late Bronze Age cemetery of Volders. He proposed that the increase and decrease of the population in the Late Bronze Age correlates with the fahlore-group mineral mining activities in the district Schwaz-Brixlegg. Based on different grave constructions as well as grave goods (black copper, slags and metalworking tools) from another Late Bronze Age cemetery in Fiecht-Au it is assumed that immigrants from the northern foothills of the Alps came to Tyrol for the reason of copper mining and metalworking (Sölder, 2015). The reason why the prehistoric people used slag tempered ceramic lies in the physical properties of these slag fragments. For ceramic objects associated with firing processes like tuyères and crucibles as well as cooking pottery it is best to use these already heat proof temper components. Since slag represents already a high temperature product it will not suffer again from shrinking during ceramic firing and thus its shape will not deform easily due to low expansion properties. This temper property will significantly reduce the danger of cracking during ceramic burning. In addition the sharp-edged shape of the crashed and grinded slag fragments has perfect binding properties with the fine-grained clay matrix. On the other hand the easy availability of these temper fragments from dumps of the smelting sites and their already homogenous size after grinding makes it also an attractive material as temper.

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