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The Late Bronze Age smelting site Rotholz in the Lower Inn Valley (North Tyrol, Austria)

ABSTRACT: *Since the 1990s, archaeological investigations of prehistoric copper mines have been conducted in the famous mining district of Schwaz/Brixlegg in the Lower Inn Valley, North Tyrol (Austria). A large number of sites (mainly from the Late Bronze Age and up to the Early Iron Age) have been investigated so far with the aim to record and to analyse this extraordinary prehistoric mining landscape. A focal point of research is the reconstruction of the process chain connected to the prehistoric copper production comprising ore mining, beneficiation, and smelting processes. This paper discusses the final step of metal production, the smelting of copper ores. Whereas dozens of prehistoric mines and several sites with traces of mechanical ore treatment have been examined in the last years, only two smelting sites from the period under consideration are known so far. One of these sites, the smelting site Rotholz (municipality of Buch in Tyrol), could be prospected by geophysical methods (geomagnetic) and partly excavated during several campaigns in 2010 and 2015-2017. A detailed documentation of the archaeological remains could be performed in the frame of the 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 Research Foundation SNF, 2015-2018). The Rotholz smelting site dates into the 12th/11th cent. BC (Late Bronze Age, Urnfield culture, dated by ^{14}C-analysis). The basic raw material used for the local copper production were fahlores which occur in considerable quantities in the Devonian dolomitic hostrock (Schwazer Dolomit). As a result of the excavations a multiphase roasting bed, a battery of four furnaces, a slag heap (crushed slag, slag sand) and many other informative structures could be uncovered and documented. The findings (ceramic, slags, ores, stone tools, animal bones,…) have been furnished to archaeological and archaeometrical analysis.*

KEYWORDS: LATE BRONZE AGE, COPPER PRODUCTION, SMELTING SITE, FURNACES, ROASTING HEARTHS, SLAG BENEFICIATION, SLAG SAND

Introduction

In the framework of the international DACH-project (see above, the Austrian part being supported by the Austrian Science Fund FWF, project-number: I-1670-G19), the Late Bronze Age smelting site Rotholz (municipality of Buch in Tyrol, Lower Inn Valley) was chosen for detailed archaeological investigations.

Although the archaeological remains of prehistoric copper ore mining in the fahlore mining district of Schwaz/Brixlegg are impressive, numerous and manifold, like fire setted mines, mining pits and dumps (see article Staudt et al., in this volume; Staudt et al, 2017a, 2018b), only two prehistoric smelting sites (Radfeld-Mauk A and Rotholz) are known so far. It is assumed that there must exist much more sites of extractive copper metallurgy in the field, but they are not visible anymore because of natural erosion processes, overprinting by younger mining activities (from late Medieval and more recent times), and particularly by extensive mass movements. The latter are frequent in the zone of the steep hillslopes, which are covered with mighty and instable talus and deposits of mining debris. Wet landslides (Muren) are especially common near springs and along the brooks and streams, places which have been explored also by the prehistoric metallurgists. So it is not astonishing, that the two known smelting sites have been discovered only by coincidence in the succession of forest road constructions.

The evidence of the earliest fahlore smelting in North Tyrol could be observed in Neolithic and Early Bronze Age settlements like the Mariahilfbergl (Brixlegg; Huijsmans & Krauß, 1998, 2015), Kiechlberg (Thaur; Töchterle, 2015), Buchberg (Wiesing; Martinek & Sydow, 2004; Schubert, 2005) and inside the Tischofer Höhle (Kufstein; Mostler, 1969; Neuninger et al., 1970; Harb, 2002; Harb & Spötl, 2015). For this earliest metal production a mix of sulfidic fahlore and secondary (oxidic) copper minerals was probably smelted in small crucibles in open fire pits using blowpipes and clay tuyères (Bartelheim et al., 2002; Martinek & Sydow, 2004; Höppner et al., 2005; Krismer et al., 2015; Hanning et al., 2015; Lutz, 2016). Finds of small tuyères are characteristic features of Copper Age and Early Bronze Age metallurgy (Töchterle et al., 2013). So far only one radiocarbon date from the mining pit field Mauk D (Radfeld) in the Mauken Valley gives direct evidence for early fahlore mining in the district Schwaz/Brixlegg (VERA-1605, Mauk D 239, 3795 ± 35 BP, cal. BC 2400-2050, 2 σ).

During the second fahlore mining boom which started in the 12th century BC (Late Bronze Age) and lasted until the end of the 8th cent. BC (Early Iron Age, see article Staudt et al., in this volume) the extractive metallurgy took place on a more "industrial" scale in the mining districts. Now larger amounts of ore could be processed on smelting sites which show quite similar structures when compared with other excavated sites of this period in the Eastern and Southern Alps (Weisgerber & Goldenberg, 2004). Important requirements for the installation of smelting sites are the availability of fire wood respectively charcoal, clay for the metallurgical constructions, and water for wet-mechanical ore and slag processing.

The two known smelting sites in the fahlore district could only be identified because of forest road constructions cutting through the prehistoric slag heaps. In a drainage trench (Mauk A, Radfeld) and in the batter of a forest road (Rotholz) conspicuous dark sandy layers including reddish burnt stones (fragments of furnace wall), greenish animal bones, slags and slag sand were visible.

The Late Bronze Age smelting site in the Mauken valley (Mauk A, Radfeld) was object of several excavation campaigns between 1994 and 2009 (supported by the Austrian Science Fund FWF), which were accompanied by archaeometrical investigations: geomagnetic prospection, radiocarbon-dating, dendrochronological, archaeozoological and mineralogical/geochemical analysis (Goldenberg & Rieser, 2004; Goldenberg et al., 2012; Goldenberg 2013, 2014, 2015; Schibler et al., 2011). This site yielded archaeological features like a multiphase roasting bed, two furnaces, a water basin/sluice with wooden construction elements for the wet mechanical processing of slag sand, a few postholes, and a big slag heap comprising mainly of slag sand/grit. Beside different types of slag (heterogeneous slag cake fragments respectively tiny bulky pieces of heterogeneous slag, homogeneous platy slag, slag sand and slagged furnace-lining), domestic and technical pottery (from pot bellows) and stone tools (hammer stones, anvil stones, grinding stones), a casting mould made of sandstone, animal bones, a sewing needle made of bronze, some textile fragments and a glass bead could be recovered from the excavations (Goldenberg, 2013; Grömer et al., 2017).

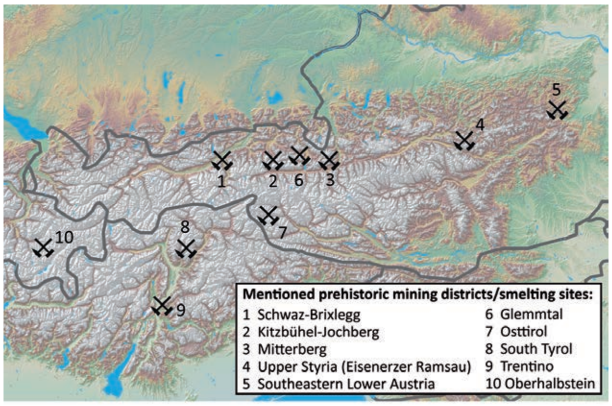

Fig. 1: Mentioned prehistoric smelting districts (graphic: M. Staudt).

Extractive copper metallurgy (primary smelting) could also be observed at the Late Bronze Age settlement site in the gravel quarry Kundl-Wimpissinger (Lang, 1998; Tomedi et al., 2013; Prader, 2013; Patzelt & Weber, 2015). This is the only Late Bronze Age site in North-Tyrol so far where smelting activities could be proved within a settlement. Here also the coeval finds of small blowpipe tuyères and bigger bellow tuyères are extraordinary for Late Bronze Age smelting sites (Staudt & Tomedi, 2015). These finds are indicating a smelting and casting workshop at the same spot. One other smelting site was mentioned and published from the mining district Weißer Schrofen (Rieser & Schrattenthaler, 2007). Recent investigations in the frame of the DACH-project could demonstrate that the slags from this site are the remains from a blacksmith workshop dating into the 15th/16th century AD (see article Staudt et al., in this volume). Indirect evidence of copper ore smelting activities can also be observed in ceramic finds. Especially in the Lower Inn Valley and in the surroundings of the Mitterberg mining district (Salzburg-Bischofshofen) ceramic products are often tempered with slag sand/grit from prehistoric copper smelting sites (Sölder, 1987/88; Reider, 2003; Krismer et al., 2012; Kluwe, 2013; Tomedi et al., 2013; Töchterle et al., 2013; Staudt & Tomedi, 2015; Stöllner et al., 2016; Tropper et al., slag-tempered ceramics and its implications for prehistoric metallurgy in the Lower Inn Valley in this volume).

Considering the large number of smelting sites known from the Mitterberg (Much, 1879; Zschocke & Preuschen, 1932; Eibner, 1972, 1974; Stöllner et al., 2004; Stöllner, 2015), Glemmtal/Viehhofen (Scherer-Windisch et al., 2019; Kyrle, 1918; Preuschen & Pittioni, 1956), Kitzbühel/Jochberg (Pittioni, 1968; Koch Waldner & Klaunzer, 2015; Koch Waldner, 2017), Upper Styria (Preuschen, 1968; Eibner, 1982; Preßlinger & Eibner, 1993; Modl, 2012; Klemm, 2015), Lower Austria (Trebsche, 2015a, 2015b), Virgental/East Tyrol (Preuschen & Pittioni, 1953), South Tyrol (Dal Ri, 1972; Niederwanger, 1984; Niederwanger & Tecchiati, 2000; Nothdurfter, 1993; Lunz, 2005; Nothdurfter & Hauser, 1986), the Trentino (Perini, 1992; Cierny, 2008; Silvestri et al., 2015) and the Oberhalbstein (Schaer, 2001,

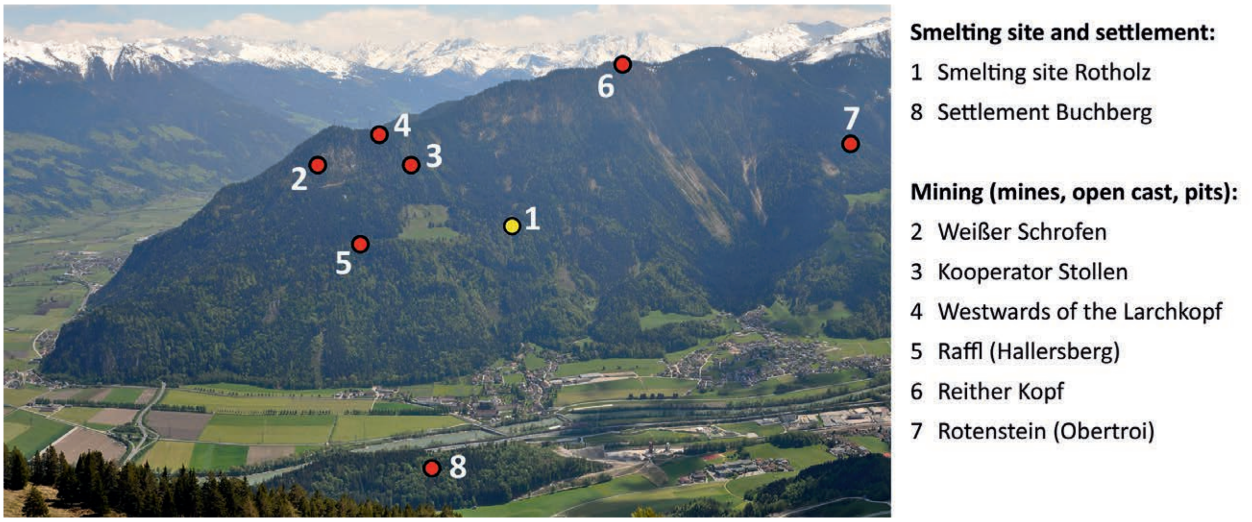

Fig. 2: Potential prehistoric copper mining spots (2-7) in the surroundings of the smelting site Rotholz (1); Early Bronze Age settlement (8) Buchberg Wiesing (graphic/photo: M. Staudt).

2003; Fasnacht, 2004; Wyss, 2004; Turck et al., 2014; Naef, 2015; Reitmaier-Naef et al., 2015; Della Casa et al., 2016) it becomes evident that in the mining district of Schwaz/Brixlegg a lot of smelting sites are still to be discovered (Fig. 1). This is especially the case for the Early Iron Age copper production (8th cent. BC), from which a remarkable number of mines are known, but no contemporaneous smelting sites.

The technical considerations, ethnological aspects and experimental approaches dealing with the different steps of copper production are mainly based on the smelting of chalcopyrite. The investigations are going on since more than a hundred years (Much, 1893; Kyrle, 1918; Klose, 1918; Zschocke & Preuschen, 1932: Czedik-Eysenberg, 1958; Preuschen & Pittioni, 1955; Hampl & Mayerhofer, 1963; Böhne, 1968; Sperl, 1969; Preßlinger et al., 1980; Eibner, 1982; Moesta, 1983; Piel et al., 1992; Herdits, 1997; Metten, 2003; Anfinset, 2011; Modl, 2004, 2011; Goldenberg et al., 2011). According to old chronicles from observations in Asia, three steps (1: first smelting = matting stage, 2: roasting stage and 3: second smelting = reduction stage) are mentioned for the production of copper extracted of chalcopyrite as well as fahlore (Prinsep, 1831; Percy, 1861; Zschocke & Preuschen, 1932; Craddock, 1995; Anfinset, 2011).

Fig. 3: The compressed slag sand inside the former washing basins and the appertaining slag dump (in the profile right) at the smelting site Rotholz (photo: M. Staudt).

Archaeological investigations 2010

The smelting site Rotholz (Fig. 2) is situated at about 950 m a.s.l. in the mining district of Schwaz, west of the Ziller Valley and south of the village Rotholz (municipality Buch in Tyrol). In the vicinity of the nearby Rottenburg castle ruins some Iron Age dress accessories made of bronze have been recorded and prehistoric features therefore are presumed (Zanesco, 2009). The smelting site was first located by Brigitte Rieser and Hanspeter Schrattenthaler in 2007 while a forest road was constructed (Rieser, 2007). In the course of earth-moving work slag sand/grit layers up to 1 m thick came to light. These layers included fragments of furnace wall, charcoal, tuyère fragments, stone tools, pottery and greenish bones. Also a piston-headed pin which dates from the Ha A1 period (= SB IIa, ca. 1200-1150 BC) was picked up by the discoverer.

In the frame of the special research program SFB HiMAT (the History of Mining Activities in the Tyrol and adjacent areas, impact on environment and human societies, supported by the Austrian Science Fund FWF 2007-2012, project-no. F3106-G02) a first small excavation could be realised in the slope of the forest road in 2010 (Klaunzer et al., 2010a, 2010b; Tomedi et al., 2013; Staudt & Tomedi, 2015). A profile through the slag deposit was documented and at its basis the remains of two washing basins/sluices were uncovered (Fig. 3). These constructions were bordered with wooden planks (in a bad state of preservation) which showed repairs. The inner width

Fig. 4: The wooden constructions (washing basins) filled with fine slag sediments from wet slag sand processing at the smelting site Mauk A (left) and Rotholz (right, photos: G. Goldenberg, M. Staudt).

between the planks is around 50 cm. The excavated part of the basin/sluice is around 2 m long and the structures continue into the documented profile towards the hill side. On the downhill side the former construction was totally destroyed during the forest road construction. A small channel without a wooden structure (refilled with fine and compressed slag sediment) is situated close to the basins/sluices and is covered by the slag dump. It looks like, that the leftover of the slag sand processing in the washing basins/sluices was deposited here.

The two wooden basins are filled up with fine and hardly compressed dark-grey slag sand. Macroscopically this material looks like a kind of sandstone. Tiny charcoal fragments in between the grains are indicating an anthropogenic origin of this material as residues of a technical process. The tiny slag grains can be easily recognised and identified in thin sections under the microscope (Fig. 14, RH25-1_10). The slag sand is a left over from a wet mechanical beneficiation process similar to gold washing. Slag from the ore smelting process was systematically crushed and grinded with stone tools into the grain size of sand. Copper rich inclusions (copper and matte droplets) could then be enriched in the washing basins/sluices by gravity separation. This concentrate could be added again to a furnace charge in order to optimise the overall output of the smelting process.

An extended dump of slag sand up to 0.5 m thick covers the area above and around the washing constructions. It is clear that all types of slag (slag cakes as well as platy slags) were treated for this reason, because – like at the smelting site Mauk A – only a handful of bigger slag fragments could be found in all of the excavation sections

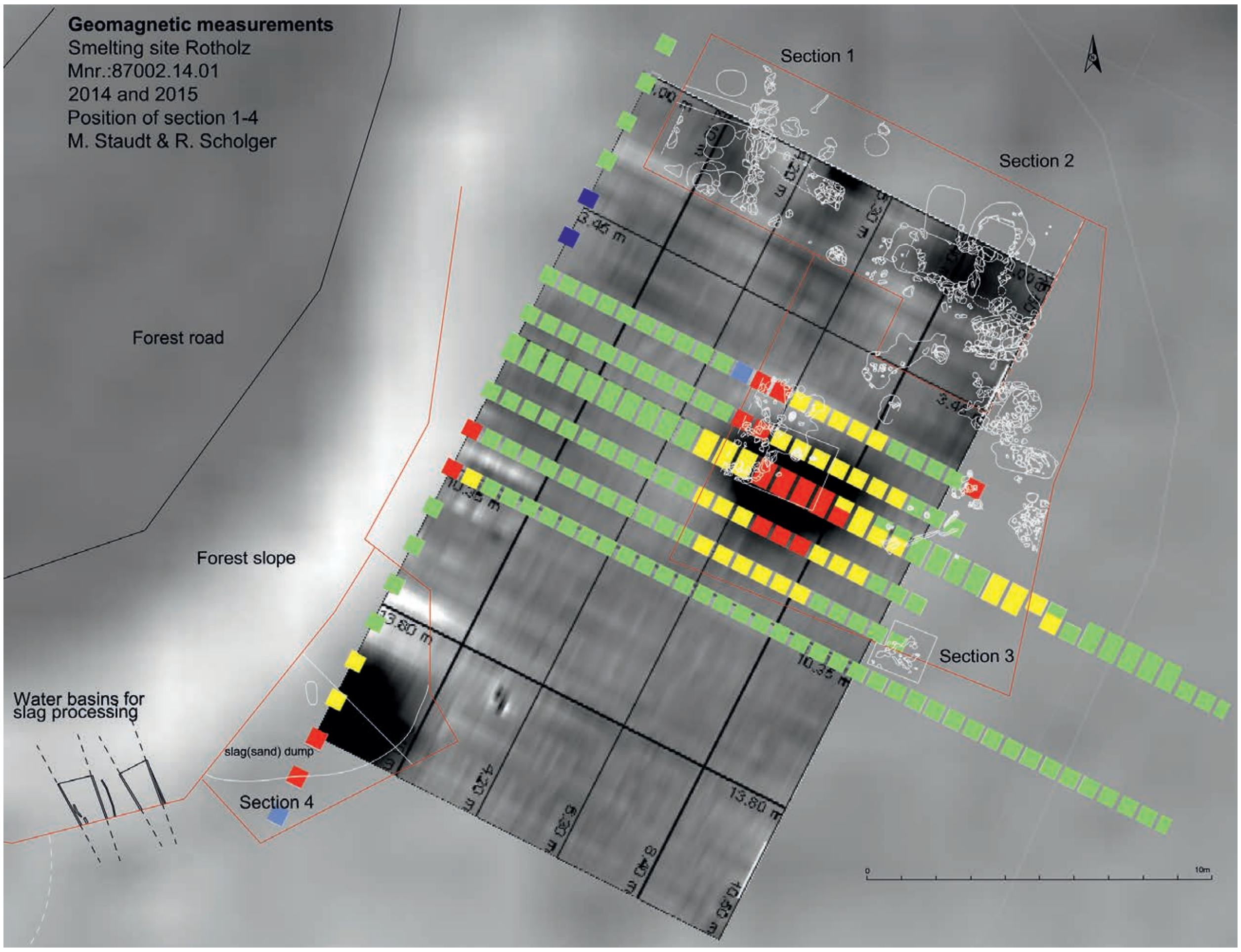

Fig. 5: The results of the geomagnetic measurements (grey area: Innsbruck team, coloured area: Leoben team) with the excavated features in section 1-4 and the documented profile in the slope of the forest road (graphic: M. Staudt, R. Scholger).

from 2010, 2015 and 2016. The slag heap must have been thicker in the western part of its extension where the downhill parts of the washing installations and the slag dump were destroyed by the forest road construction. From this fine grained slag sand heap, greenish animal bones, different stone tools (hammer, picking and grinding stones), technical and domestic pottery (some tempered with slag sand/grit) and just a few bigger slag fragments were picked up.

At the second known smelting site in the Mauken Valley (Mauk A) which is situated 13 km east of the smelting site Rotholz and southeast of Radfeld, a similar wooden basin/sluice for wet mechanical slag processing was excavated by Goldenberg et al. in 1995 and 1997 (Goldenberg & Rieser 2004). Like in Rotholz, it was built into the natural soil (Fig. 4). On the Mauk A site a few pieces of textile were used sealing up the wooden construction (Goldenberg, 2013; Grömer et al., 2017). Also a small slat, which regulated the outflowing water, was preserved. A dendrochronological analysis of one of the planks which bordered the basin/sluice yielded a cutting age of the tree used of around 1010 BC (Nicolussi et al,. 2015). This is one of the youngest dates of this site so far where first smelting activities are assumed to have started already in the 12th century BC. Whether the slag sand beneficiation was a part of the metallurgical process from the beginning or if this technique has been introduced later is still unclear. It could be possible also that the smelters tried to recycle the whole mass of cupriferous slag before they left this site.

On the other hand, just 2 km northeast of the Mauk A smelting site near St. Leonhard, slag sand tempered pottery could be found along with some bronze artefacts which date from around 1200 BC (SB Ib-SB IIa; Staudt et al., 2013). It is supposed that these finds belong to a Late Bronze Age cemetery. The analysed slag temper shows the same intermetallic composition of copper/arsenic/antimony inclusions like at the smelting site Mauk A (Krismer et al., 2012; Tropper et al., in this volume). Because of the adjacency of the two sites and the mineralogical/geochemical analyses of the slags, there is a certain plausibility that the buried people stood in close contact to the nearby miners and smelters community. This in turn would give a clear hint that the technology of slag sand processing at the Mauk A site already started in the 12th century BC within the smelting activities.

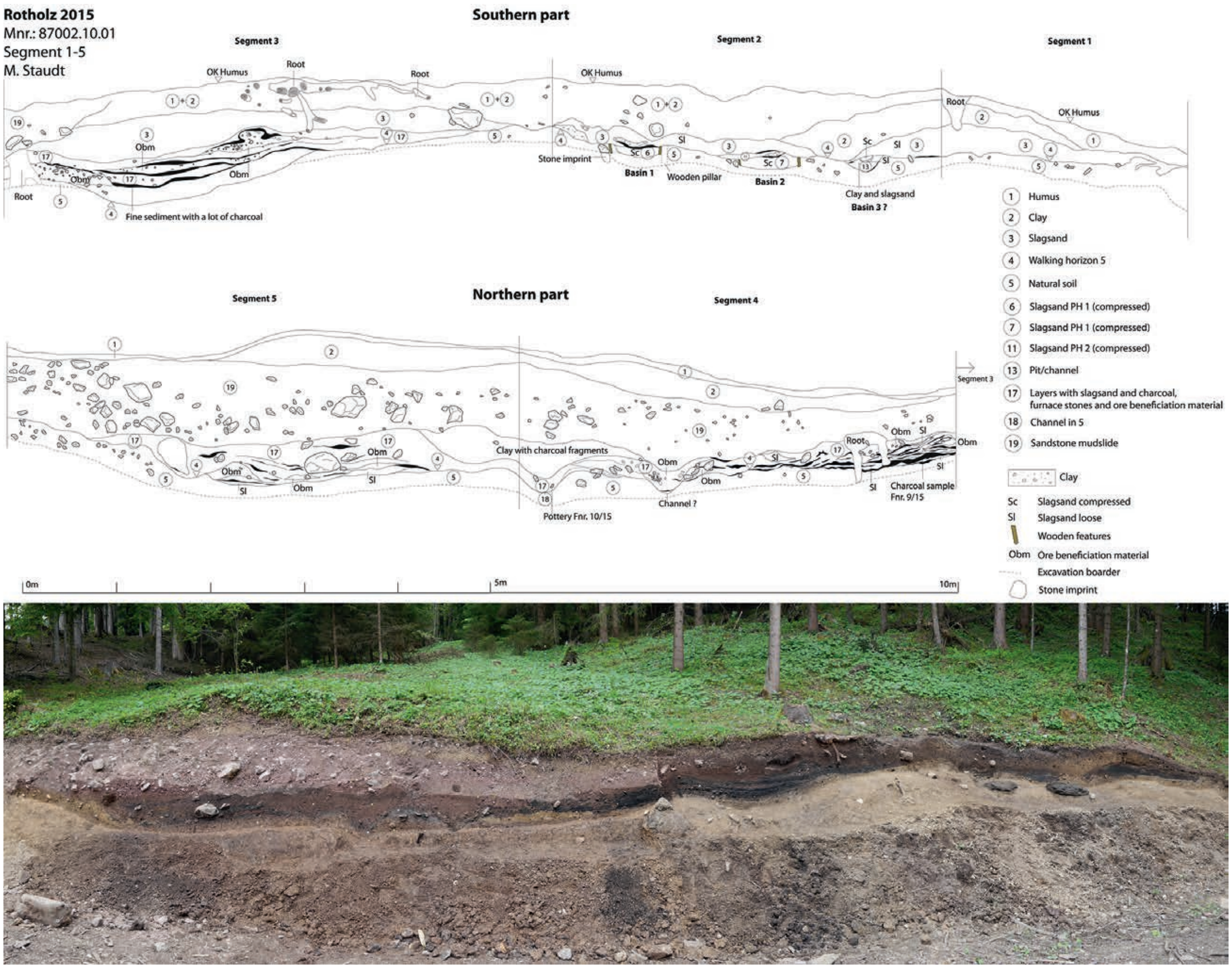

Fig. 6: Profile of segment 1-5 at the forest road; on the right side (southern part), the slag beneficiation features are visible (graphic/ photo: M. Staudt).

The archaeological investigations 2015 and 2016 at the smelting site Rotholz

In the framework of a course with students from the Department of Archaeologies, University of Innsbruck, geomagnetic measurements with a 5 channel magnetometer (Sensys) could be undertaken at the smelting site Rotholz on the flat area eastwards above the forest road (Staudt et al., 2016). Robert Scholger (Montanuniversität Leoben) with students from the Department of Geology, University of Innsbruck, did some additional geoelectric and geomagnetic investigations. As a result of the geomagnetic surveys different anomalies could be measured which have been interpreted to indicate the position of slag deposits and structures of the metallurgical installations in the underground (Fig. 5). In addition core drillings up to a depth of 4 m were undertaken by Christoph Spötl and Valerie Göttgens (Department of Geology, University of Innsbruck) in order to obtain information about the stratigraphy of the natural ground as well as the position and depth of prehistoric features and cultural layers (Göttgens, 2015). As a result of the drillings an extended sandstone mudslide could be detected in the underground overlaying the archaeological features with a thickness of more than 1 meter. Furthermore, a red, burned clay layer was recorded in the northern part of the investigated area in a depth of about 1.2 meters which later on turned out to be part of a well preserved roasting bed.

The lateral extension of the prehistoric layers could be excavated and documented at the eastern profile of the side-cut of the forest road. Here the north-south dimension of the smelting site reaches around 20 meters in width (Fig. 6). The profile also shows clearly that the layers on the south side of the profile consist mainly of slag sand/grit deposits. On the north side of the profile slagged furnace stones and burned clay could be documented. Because of these observations, together with the results of the geomagnetic survey and the core drilling, it was concluded that the smelting structures (furnaces and roasting beds) must be situated in the northern part of the investigated area, a few meters eastwards uphill of the forest road. One animal bone taken from the profile

Fig. 7: The three-phase roasting bed and the partly visible furnaces 1 and 2 at the eastern profile of section 2 (photo: M. Staudt).

could be dated by ^{14}C-analysis to 2895 +/- 24 BP (MAMS 25910, cal. BC 1192-1004, 2σ).

According to the promising results of the first investigations two trenches (section 1 and 2) were traced out in the area of the assumed metallurgical structures in 2015 (Fig. 5 and 12). In around 1 meter depth a three-phase roasting bed (23, 28, 30) could be excavated underneath the reddish sandstone mudslide in section 2 (Staudt et al., 2017b). The oldest roasting hearth shows a north-south orientation and was built in the natural soil (5). Therefore, parts of the soil were dug out in the area of the out running slope to get a nearly flat working area for the installation of the metallurgical constructions.

The oldest roasting hearth 1 (30) is 2 meters long and 1 meter wide (reaction space: 0.80 x 1.80 m) and bordered with larger stones (Kellerjoch-Augengneis and red sandstone). The younger roasting hearths 2 (28) and 3 (23) are placed at right angles to and directly above the older structure 1. At the eastern boundary of the roasting hearth 2 (width of reaction space: 0.90 m) the stone construction of the roasting hearth 1 was reused. The back border of the youngest roasting hearth 3 (reaction space: 0.90 x 1.90 m) was slightly displaced 0.50 m westwards from the back border of roasting hearth 2. The youngest phase was destroyed in it's west part by a rootstock and shows nearly the same dimensions (width) like structure 1. Between the boarder stones of phases 2 and 3 clay was placed and flattened. The clay is quite red indicating its exposure to high temperatures and open fires during many runs of the roasting hearths.

The stones of the two younger constructions consist mainly of Kellerjoch-Augengneis. Five of these stone blocks show distinct use marks and represent the broken fragments of a large grinding stone. ^{14}C-analysis of charcoal samples from the roasting hearths 1 and 2 date these structures roughly into the 14th to 12th century BC (roasting hearth 1: 3044 ± 26 BP, MAMS 25908, cal. BC 1399-1218, 2σ; roasting hearth 2: 2995 ± 26 BP, MAMS 25909, cal. BC 1369-1129, 2σ). Considering the state of the art of regional copper production including other mining and smelting sites, dendrochronological investigations, geochemical analysis on bronze artifacts, as well as the development of North Tyrol's urnfield cemeteries it can be supposed that the large-scale smelting activities of the Late Bronze Age did not started before the 12th century BC. The older dates (^{14}C) can probably be argued with the old wood effect (samples taken from heartwood, time-lag between felling and final deposition).

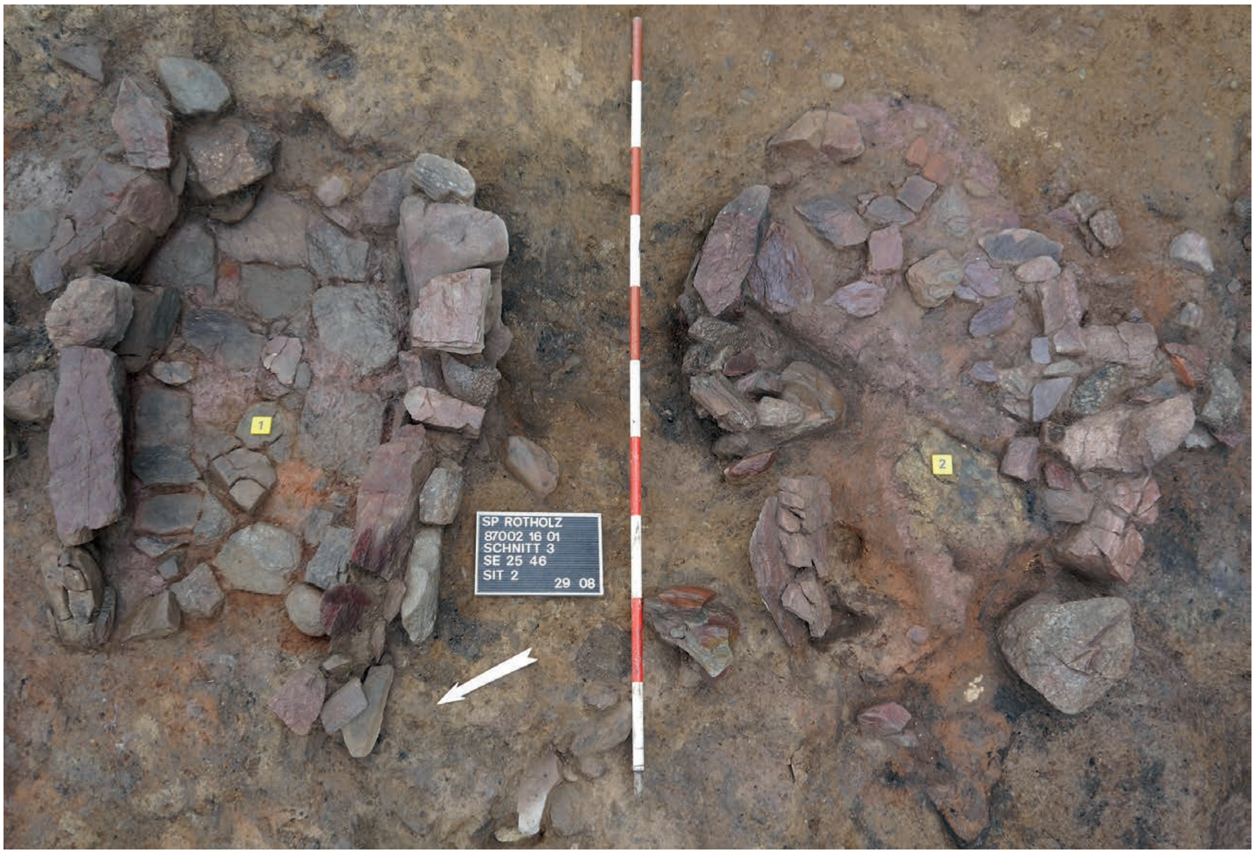

Fig. 8: The excavated furnaces 1 and 2 in section 2-3 (photo: M. Staudt).

In the immediate vicinity south of the roasting hearths in section 2, two smelting furnaces (1 and 2) were partly excavated in 2015 (Fig. 7). Based on these features and on the geomagnetic investigations, section 3 was opened in summer 2016 east- and southwards of the already uncovered smelting structures (Staudt et. al., 2017b, 2018). During this campaign a battery of four smelting furnaces could be uncovered and documented. Furnace 1 is especially well preserved and shows multi-layered stone walls on three sides (Fig. 8). From furnaces 3 (47) and 4 (48) only the bottom parts are left under the overlaying sandstone mudslide which at this place is 1.6 m thick. The furnaces are built mainly with angular sand stones. The reddish stones show high temperature exposure due to the impact of fire and are placed upright in the natural soil. From furnace 1 three layers of stones with a total height of maximal 0.5 m are still preserved. Because of the amount of collapsed furnace stones found inside furnace 1, a minimum height of 1 meter is supposed for the original furnace structure. The bottom of all the furnaces is stone paved with mainly smaller plates of sand stone, phyllite, schist and Kellerjoch-Augengneis. The shape of the constructions is oval and slightly wider at the back part (reaction chamber). The structures of furnace 1 and 2 are east-west orientated and show a length of 1.50 m and a width of 1.00 m (reaction space: 1.30 x 0.70 m; Fig. 8 and 12). Inside the furnaces no slagged clay or stones are left in situ. Such expected slagged stones and clay fragments from the furnace chambers could be found in the near surroundings of the furnaces. In furnace 2 some greenish coloured clay-layer (Cu-oxide minerals, malachite) is a leftover of the copper smelting activities. It is not clear if all four furnaces were used at the same time or alternating. All 4 furnaces were built into the natural soil and belong to the same stratigraphic working layer. Furnaces 3 and 4 show a slightly different orientation with an angular misalignment of about 15 degrees compared to furnaces 1 and 2. This fact and the bad preservation could be an indication that furnaces 3 and 4 were used in an earlier phase. Stratigraphically all of the furnaces belong to the nearby three phase roasting bed. It is noticeable that the furnaces as well as the roasting hearths from Rotholz are built with a different construction technique than those already known from the Mauken Valley smelting site Mauk A. There the roasting beds are paved with flagstones and the 2 uncovered furnaces show a smooth flat bottom made of clay (Goldenberg et al., 2011, 2015). Radiocarbon analyses on charcoal fragments from all four furnaces could be obtained:

- Furnace 1: 2916 ± 24 BP, MAMS 29931, cal. BC 1207-1024, 2σ
- Furnace 2: 2936 ± 22 BP, MAMS 29932, cal. BC 1213-1054, 2σ

Fig. 9: Unexplained structure at the southern profile (left) and probably another younger roasting bed at the western profile (right) of section 3 (photos: M. Staudt).

- Furnace 3: 2939 ± 22 BP, MAMS 29933, cal. BC 1215-1055, 2σ
- Furnace 4: 2994 ± 22 BP, MAMS 29934, cal. BC 1367-1127, 2σ

At the southern profile of section 3 other remains from metallurgical processes came to light. The structure (51) shows a mixture of reddish layers of clay, charcoal and some smaller stones, which were destroyed and relocated by tree roots. The clay fragments are up to 10 cm thick and show strong impact of heat/fire and are definitely not leftovers of a simple fireplace (Fig. 9 and 12). The original structure of this feature is unreproducible and could represent a destroyed smelting furnace or a roasting hearth. 5 m north-west, at the western profile of section 3, another construction with bordering stones and thick layers of burned clay could be excavated. This feature (50) is situated 4.5 m westwards of the furnaces and is also partially destroyed by tree roots in the northern part. The rectangular frame made of stones shows two different reddish layers (Fig. 9 and 12). It looks similar to the other multi-phase roasting hearth in section 3, and the stratigraphic arrangement of the reddish layers is indicating at least two phases. This structure is built on the same working layer which belongs to the furnaces 1 to 4 including the roasting hearth (phases 1 to 3) described above and is therefore stratigraphically younger. The radiocarbon age of a charcoal sample from this structure (2869 ± 22 BP, MAMS 29935, cal. BC 1116-946, 2σ) indicates a younger date than those of the other roasting hearths. Another younger furnace or furnace battery in the nearby area may be expected but no traces have been detected till now. Within the geomagnetic measurements the whole area could not be explored due to the presence of trees and the rising terrain.

Connected to the features from metallurgical activities, a post-hole with wedge stones (53) and an acute pit (49) could be documented. This post-hole could be interpreted as a part of a simple roofing of the furnace battery like it is known from traditional copper ore smelters in Nepal (Anfinset, 2011). The pit does not show any signs of heat impact. It could maybe represent the negative imprint from a clay extracting point as clay was a necessary base material for the construction of the metallurgical installations. In section 3 the remains of a burned wooden plank (55) were found on the surface of the natural soil at the basis of the cultural horizon, representing stratigraphically one of the oldest features of the whole site. A radiocarbon analysis dates this find into the 13th/12th century BC (2983 ± 21 BP, MAMS 29936, cal. BC 1269-1126, 2σ).

In section 2 and west of the multiphase roasting hearth more pits were excavated. One of these depressions (38) is similar to the already described acute pit and was maybe produced for the same reason. Next to it lays a shallow pit (33, max. 20 cm deep) with a flat bottom which is filled up with a layer of charcoal and covered with a layer of stones. Also this feature does not show any impact of heat/fire and therefore has nothing to do with the roasting and smelting process itself. After more recent publications it is supposed that the last step of smelting of sulfidic copper ores is probably done in small pit-hearths (Hanning et al., 2015), but a feature like this has not been identified at the smelting site Rotholz so far.

Fig. 10: The stone wall and the shallow pits for slag beneficiation in the western part of section 1 (photos: M. Staudt).

At the western part of section 1 close to the side-cut of the forest road a north-south orientated dry stone wall (40) made of mainly sand stones was uncovered. The construction shows up to three stone layers and continues into both profiles of section 1. The remaining height of the wall is up to 0.5 m and the mass of collapsed stones is indicating an original height of about 1 m. The function of this structure is not clear. It could either be interpreted as the foundation wall of a former building or as a construction for the stabilization of the slight hillside with the roasting beds above. The wall can be seen in direct connection with several shallow pits (41, 43, 44) which could be uncovered in a regular distance westwards in front of the wall (Fig. 10 and 12). These roundish depressions are aligned next to the wall and orientated north-south. Three of these pits are filled up with hard compact sediment at the bottom, which macroscopically looks similar to the sediments from the slag sand beneficiation basins/sluices. Both materials from the pits and the basins/sluices were examined and compared under the microscope and consist for the major part of small slag fragments mixed with tiny pieces of charcoal

Fig. 11: The slag(sand) dump in section 4 at the forest road with the leftover compressed slag sediment of the washing basins (left) in the background (photos: M. Staudt).

and natural soil (Fig. 14). It is supposed that in these pits a further preparation process with slag sand took place representing a still unknown beneficiation technique. So far comparable features from other contemporaneous smelting sites are unknown. The clay of the older phase of the third pit is slightly reddened by heat. In summary, the ensemble of the wall and the pits can be considered as the leftovers of a former hut / roofed workshop where some special slag treatments took place.

Section 4 was excavated north-east of the wood bordered washing basins/sluices which appeared in the profile of the forest road cut. Here the slag sand dump achieved its biggest thickness confirmed by the geomagnetic measurements. Unfortunately the major part of the slag sand dump was already destroyed by the road building (Rieser, 2007). In consequence of the undocumented destruction only the small leftovers in the south-eastern part of the former slag sand dump (3.5 x 5.0 m) could be investigated (Fig. 5 and 11). In the excavated area the thickness of the cultural layers attains up to 0.6 m maximum. The lower layers consist mainly of slag sand, charcoal, relocated clay and stones. In the upper layer finely grinded slag sand dominates the material. The sandy sediment shows a dark grey rusty colour and is more oxidised at its top part. Inside the dump a few stone tools could be picked up. A big and heavy stone tool (cobble stone, garnet amphibolite, ca. 120 kg) with clear traces of use on two sides can be highlighted amongst these findings. On one side several shallow depressions deriving from crushing slags with hammer stones are apparent (function: anvil stone). On the opposite side a typical slightly concave surface from grinding processes is developed deriving from reducing the slags to the grain size of fine sand (function: mortar stone). Only in the bottom layer small amounts of material from mechanical ore beneficiation processes could be identified. In general all the stone tools described could have been used for the purpose of ore processing as well as slag processing. Especially from the layers in section 4 a lot of greenish animal bones could be collected. These food remains were thrown to the slag dump after the meals. Because of the cuprous salts included in the slag sediments with their antibacterial properties, bones and other organic materials are very well preserved. Geochemical analysis on some of the bones show a distinct enrichment of copper, arsenic and antimony and therefore point out the fact that fahlores have been processed on the site (Rieder, 2014).

Finds from the smelting site

A variety of informative artefacts which are typical for smelting sites of the period under consideration could be found (Fig. 13). Beside the described piston-headed pin (Rieser, 2007) the following materials came to light: food waste (greenish animal bones), fragments of technical and domestic pottery (tuyères, cooking- and dinnerware), stone tools (hammer stones, anvil stones, grinding stones, mortar stones), pieces of fahlore in dolomite, slag fragments, vitrified furnace clay as well as furnace stones and intermediate products from different steps of the pyrometallurgical process like copper matte and/or speiss with copper-arsenic- and copper-antimony-sulphides. The pottery consists mainly of ordinary coarse-ceramic but there are quite a lot of fine-ceramic

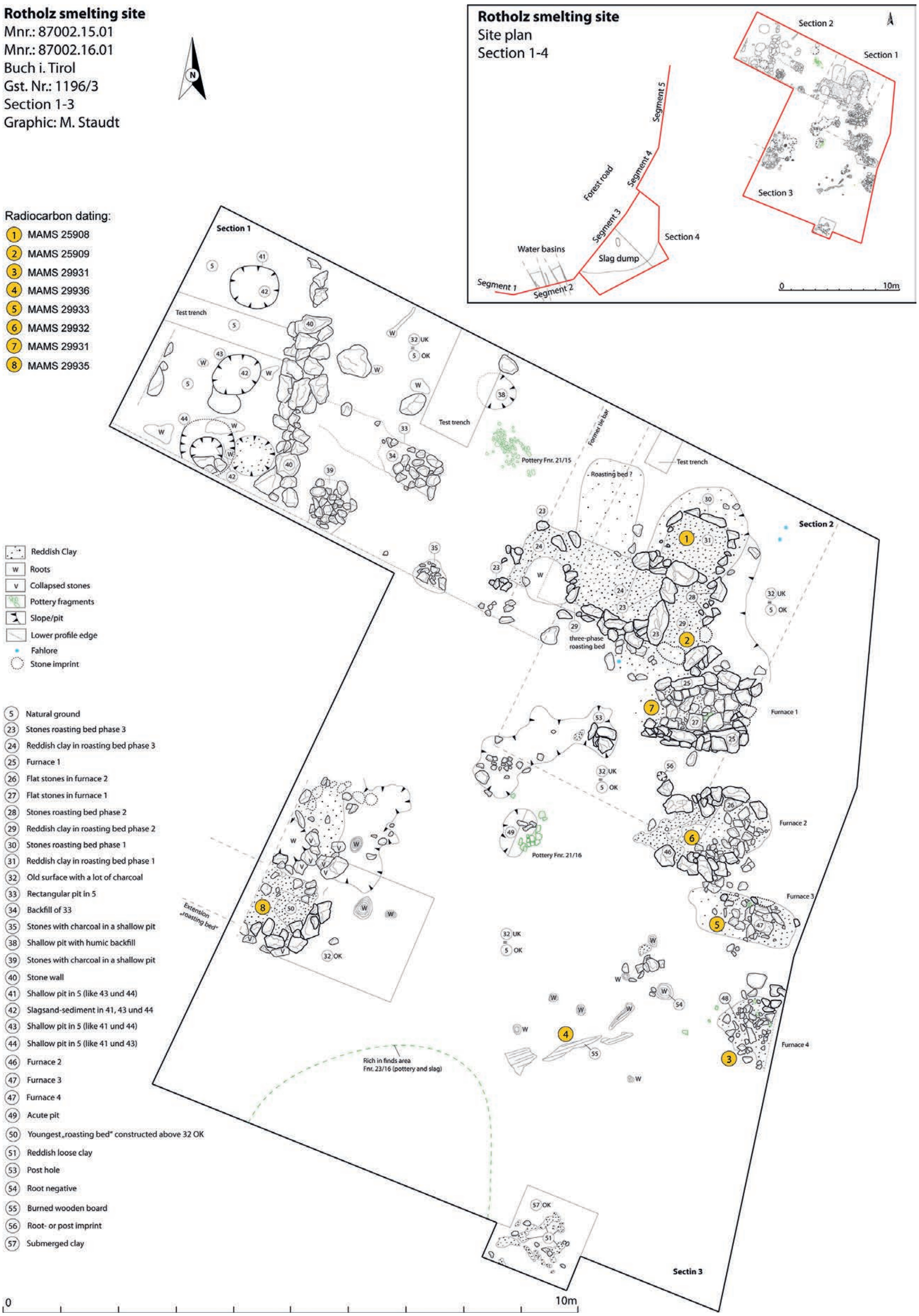

Fig. 12: Plan of the smelting and beneficiation features in section 1-3 (graphics: M. Staudt).

Fig. 13: Finds from the smelting site Rotholz: plate slag (RH8_10, RH20-2_16), heterogeneous slag (RH7-2_15), fahlore (RH13-2_15), fine ceramics (RH4-3_16, RH14-3_15, RH17-16_16, RH17-18_16, RH28_16, RH30_17, RH35-2_17, RH43-2_17), encrusted domestic pottery (RH25_16), fragments of tuyères (RH10_17, RH10-6_17, RH17-20_16) and stone tools (RH3_10, RH31_16; graphics: M. Staudt).

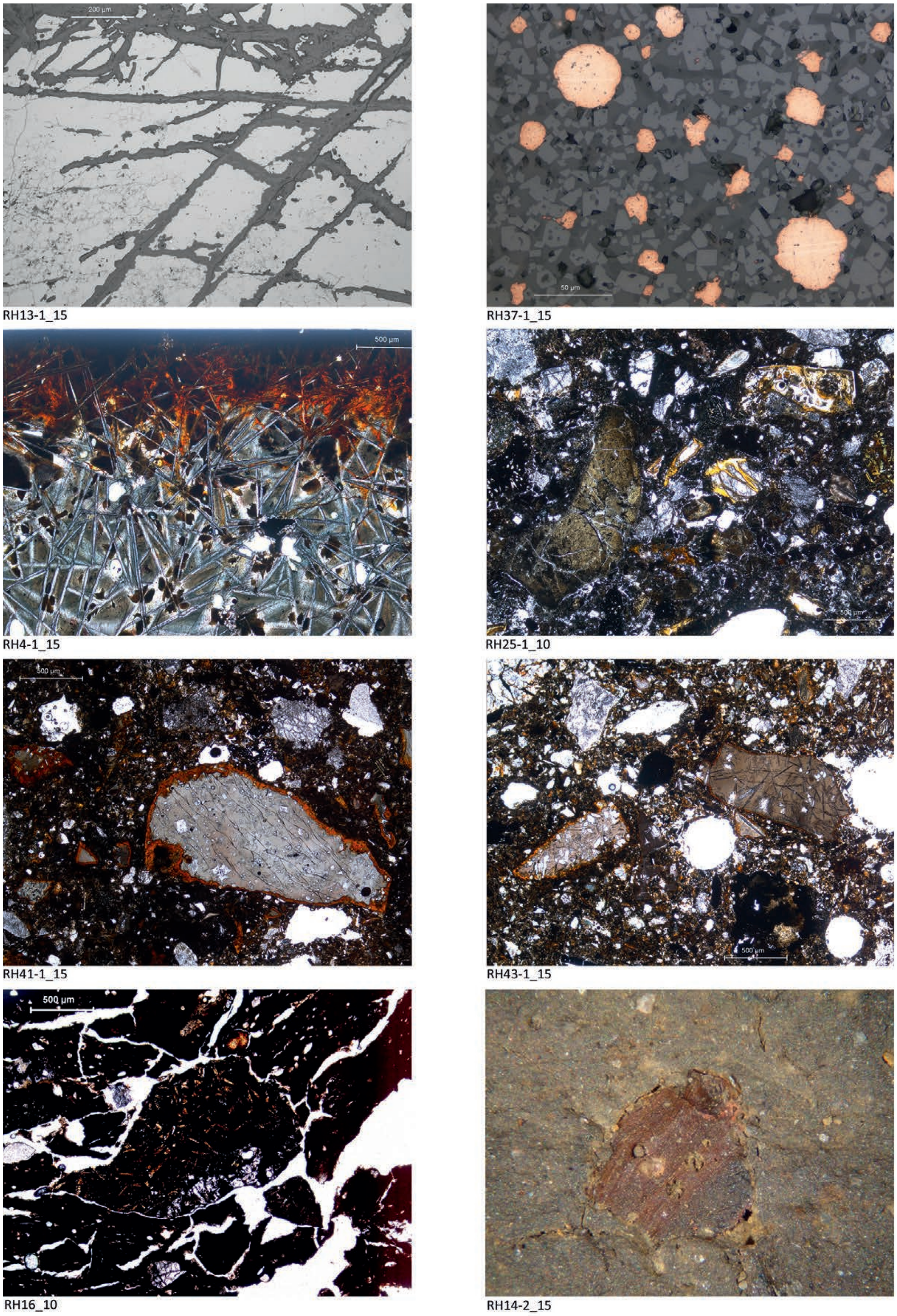

Fig. 14: Microscope pictures of thin sections from Rotholz: Fahlore (RH13-1_15), copper droplets and iron oxides in slag matrix (RH37-1_15), plate slag (RH4-1_15), compressed sediment with slag fragments from washing basin 1 (RH25-1_10), compressed sediment with slag fragments from pit 41 (RH41-1_15), compressed sediment with slag fragments from pit 43 (RH43-1_15), slag temper inside the pottery matrix (RH16_10). Surface microscope picture of slag tempered pottery (RH14-2_15; graphics: M. Staudt, G. Goldenberg, P. Tropper).

fragments in the inventory as well (Fig. 13). In some cases the fine-ceramic is decorated with grooves (RH28_16) and two pieces show an incrustation with a white material (RH25_16, RH35-2_17). Geochemical analyses of such an incrustation from comparable pottery of a Late Bronze Age settlement in the Kauner Valley, North Tyrol, approve the use of a mixture of bone ash, quartz and feldspar partly transformed to the mineral phase apatite (Staudt, 2016). The lower ends of the collected tuyère pieces are never slagged. In total four tuyère fragments show a tiny hole (Fig. 13: RH10-6_17). This fact has also been observed at other prehistoric smelting sites (Töchterle et al., 2013) and could be part of fixing the bellow or a valve system. The domestic pottery from the smelting site Rotholz is many times slag tempered. The temper can be recognised mainly in the coarse-ceramic fragments and the components are sometimes even visible with the naked eye. The metallurgical slags consist mainly of three distinguishable types: heterogeneous slag cakes (fragments, fig 13: RH7-2_15) respectively tiny bulky pieces of heterogeneous slag, homogeneous platy slag (fig13: RH8_10, RH20-2_16) and slag sand. Also some slagged furnace clay has been excavated. In polished sections under the microscope the slag samples show matte and copper inclusions (Fig. 14). Due to the fact that only a very small amount of bigger slag fragments could be observed on the site, it is supposed that all slag types were systematically crushed and grinded to slag sand. The latter then was washed in special washing basins/ sluices and pits, in order to obtain concentrates of metal rich inclusions (matte and copper metal). This material could be smelted again together with a new charge of ore to optimise the overall output of copper metal. By examining thin sections of slag tempered pottery under the microscope, it becomes clear that no selection was done for the comminution of slag.

The use of slag temper in the Late Bronze Age

It seems obvious why the prehistoric potters used slag fragments or slag sand as a temper component:

- large quantities of such materials were available from smelting sites and already in a useable size
- it is a heat proof temper component with a stable shape because it was already heated up to very high temperatures
- it has good thermal conductivity and is therefore well-suited for the production of cooking pottery
- the sharp-edged shape of the crushed and ground slag fragments has perfect binding properties
- maybe it had to do with religious beliefs; similar believes could be observed in Nepal where the traditional copper smelters treat the produced metal as a holy object and broken tuyères are kept for good luck (Anfinset, 2011)

The use of slag temper in the Lower Inn Valley is noticeable in the Early and mainly the Late Bronze Age. Perhaps such a temper addition was used in the Middle Bronze Age as well (Sölder, 1987/88; Töchterle et al., 2013). It can mainly be found in domestic and rarely in grave pottery from the vicinity of the fahlore-mining district. Ceramic finds from this district (mining pits Mauk D, Weißer Schrofen, Rotenstein and Burgstall; smelting sites Mauk A and Rotholz; settlement Kundl-Wimpissinger and cemetery St. Leonhard) prove the intense use of slag temper in the Late Bronze Age. So far only one of the pottery fragments from the Iron Age fire setted mines in the Lower Inn Valley shows this kind of temper (Mauk E, 707 BC) and only one Iron Age slag tempered pottery fragment is known from the cemetery in Kundl. The grave (626) is dated in the Early Iron Age by a serpentine fibula (Lang, 1998). It seems that slag tempered ceramic is typical for the Late Bronze Age and ends around the Early Iron Age. At this stage (end of the 8th century) the latest mining activities could so far be proved through dendrochronological analyses (Goldenberg et al., 2012; see article Staudt et al., in this volume).

It looks like that there is a chronological change in size of the slag temper. Especially in the 12th/11th century BC, the slag temper contains grains with the size of sand. At the final stage of the Late Bronze Age bigger slag temper fragments (up to 1 cm) can be observed at the settlement Kundl Wimpissinger and the mining pits at the Burgstall. Perhaps the early Late Bronze Age pottery is tempered with grinded slag from smelting sites, where slag beneficiation was an important part of the copper production. It is possible that in the final stage of the Late Bronze Age the slag processing stopped for whatever reasons and the slag was just added traditional and because of the positive properties as a surcharge. Maybe at this time the ore was smelted only in settlements (like Kundl-Wimpissinger) and slag beneficiation was not important anymore.

The nearby prehistoric mining districts

Prehistoric copper mining has been proved at the nearby district Weißer Schrofen (Pirkl, 1961; Gstrein, 1978), which is situated just 1.2 km east of the smelting site Rotholz. This is probably the place where some of the smelted fahlore came from (Fig. 2). During the excavations in 2016 at the pit field Weißer Schrofen, a piece of plate slag could be picked up which definitely comes from a prehistoric smelting site. Also the ^{14}C-data from the mining pits at the Weißer Schrofen (12th to 10th century BC) correspond well within the ones from the nearby smelting site Rotholz (see article Staudt et al., in this volume). Just 300 m westwards of this sub-district a few traces of fire setting activities are clearly visible (like the “Kooperatorstollen”; Perger, 1995; Rieser & Schrattenthaler, 2002). Even though this spot is not

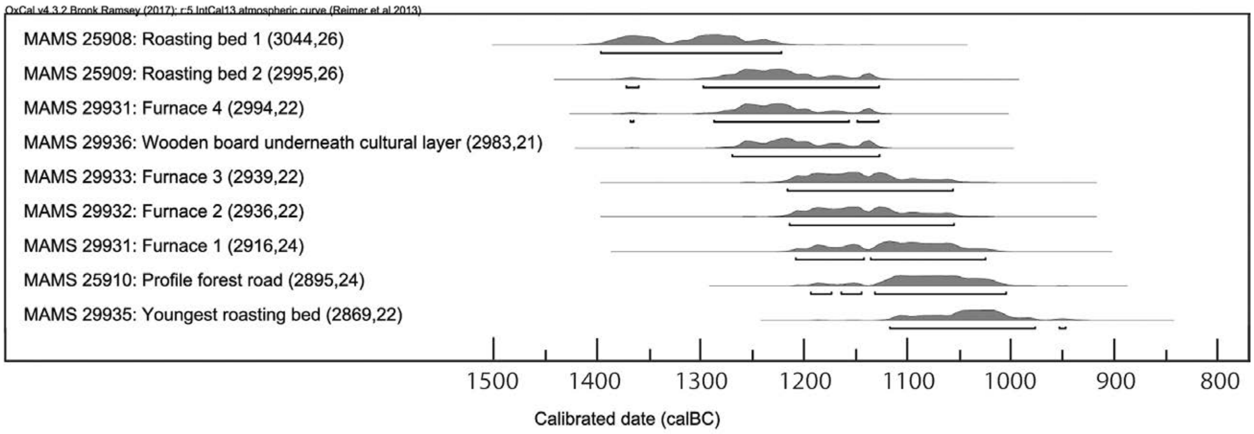

Fig. 15: Calibrated ^{14}C-data from samples of the smelting site Rotholz (graphic: OxCal v4.3.2.).

dated yet, it is supposed that these traces come from prehistoric mining. 200 m westwards of the Larchkopf (1 km east of the smelting site Rotholz) some collapsed furrow pits and former open cast mines could indicate prehistoric work as well. So far nothing is known about modern mining activities in this man made rugged area. Maybe some of the smelted ore also came from the area of todays Raffl farm (Hallersberg) where small fire settings are visible in the Schwazer Dolomit as well. It is conceivable that some fahlore from the Reither Kopf was brought to the smelting site too. This prehistoric mining spot with the remains of big pits is situated 1.2 km southwards (Rieser & Schrattenthaler, 1998/99 & 2002). Prehistoric mining could be detected also along some mining pits in the district Rotenstein (Obertroi) which is situated only 1.2 km southwest of the excavated smelting features (see article Staudt et al., in this volume; Rieser & Schrattenthaler, 1998/99, 2002).

Conclusions

The ^{14}C-data from the smelting site Rotholz are documenting metallurgical activities in the period from the 13^{th} to the 11^{th} century BC (Fig. 15). Considering the possible “old wood effect“, it is supposed that the earliest smelting activities started around the beginning of the 12^{th} century BC, like it could be demonstrated for the second known smelting site Mauk A. The complex smelting site Rotholz, with many different structures of technical processes (smelting, roasting, ore/slag beneficiation), represents an industrial-like copper production. The slag beneficiation played a very important role. This can be concluded by examining the features like the shallow pits, the wooden basins and the slag sand heap. For all the different kind of work a well organised subsistence strategy concerning ore, wood, and food supply is essential. It is supposed, that the smelters were specialists in their field. These activities are based on the transfer of knowledge, which probably came from other mining districts like Mitterberg and/or Kitzbühel-Jochberg, where the copper production based on chalcopyrite deposits was already well established before. A traditional association and a specific technical transfer of those smelters from the different districts can be seen by the phenomenon of slag tempered pottery which spreads between the Lower Inn Valley and the Mitterberg mining district (Sölder, 1987/88; Töchterle et al., 2013; Stöllner et al., 2016; see Tropper et al., in this volume). The smelting activities at the two known smelting sites in the Lower Inn Valley lasted for more than one century. Fahlore from the surrounding ore deposits was smelted in these strategically well placed spots where wood, clay and water as well as food supply was available. It is also evident that there must exist more still unknown smelting sites, which are considered to be buried underneath massive mudslides. Such observations can be made at different archaeological sites along the Lower Inn Valley (for example: mining pit field Mauk D, Goldenberg, 2014; mine Mauk B, Goldenberg & Rieser, 2004, Staudt et al., 2017a; settlement Kundl-Wimpissinger, Patzelt & Weber, 2015). These earth movements caused by erosion can partly be explained as a result of large scale deforestation accompanying the extensive prehistoric, late medieval and modern mining activities.

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