Der Anschnitt, Beih. 42, S. 229–244, 2019

Leandra Reitmaier-Naef

Copper smelting slag from the Oberhalbstein (Canton of Grisons, Switzerland)

Methodological considerations on typology and morphology

ABSTRACT: *Mining archaeologists and archaeometallurgists have attempted to decipher the prehistoric multistage process of copper smelting from chalcopyrite for a number of decades. For this purpose, various examinations of archaeological remains, historical and ethnographical comparisons and archaeological experiments have been carried out. Apart from archaeological structures such as furnaces, very little if any of the original raw materials (copper ore) or final products (matte/raw copper) remain from which the process could be reconstructed. Only smelting slag is usually available in vast quantities. By conducting geochemical and mineralogical analyses of this by-product, information can be gained concerning the raw material, charge composition, process temperature, furnace atmosphere and even the resulting (intermediate) product. Despite these efforts, a number of questions remain unsolved, e.g. the much-debated association of different slag types with different process steps or reactors. From an archaeological point of view, this is due in part to the fact that slag samples are usually described and discussed in insufficient detail, if at all. They are often generally classified as one of only two tentatively defined types: "slag cakes" and "plate slags". This paper aims to demonstrate the additional value of a detailed archaeological evaluation of macroscopic characteristics of smelting slag using finds from the Oberhalbstein region (Canton of Grisons, Switzerland) as an example. The typology and morphology of smelting slag must be taken into account in addition to, and not instead of, further investigations, particularly of geochemical and mineralogical analyses.*[1]

KEYWORDS: COPPER SMELTING, PROCESS RECONSTRUCTION, SLAG TYPOLOGY, BRONZE AGE, IRON AGE, CENTRAL ALPS

Introduction

The Oberhalbstein region is located in the central Alpine Canton of Grisons (Switzerland) and has a north-south extension of 35 km. Connecting the Rhine and Albula Valleys with the Engadin Valley to the north across the Julier Pass and with the Bregaglia Valley to the south across the Septimer Pass, the Oberhalbstein Valley has been an important transalpine traffic route since prehistoric times. The first perennial settlements throughout the valley date back to the beginning of the 2nd millennium BC. Besides trade and Alpine farming, the exploitation of local copper ore deposits also formed part of the economy from no later than the Late Bronze Age onwards.

Although site distribution maps have therefore included the Oberhalbstein region in south-eastern Switzerland as a prehistoric copper production region for a number of years[2], no systematic archaeological investigation had until recently been carried out. For this reason, little was known about this prehistoric mining district, which stands in sharp contrast to the long tradition of research in the eastern and western Alps.[3]

The Department of Prehistoric Archaeology at the University of Zurich and the Archaeological Service of the Canton of Grisons have been carrying out extensive fieldwork in the Oberhalbstein in recent years as part of an international research project entitled "Prehistoric copper production in the eastern and central Alps - technical, social and economic dynamics in space and time".[4]

The current results clearly show the peripheral location of the copper production area under investigation – both from a geographical and a chronological point of view. While most of the (south)eastern and western Alpine mining districts flourished during different periods of the Bronze Age, the Oberhalbstein Valley did not reach its production peak until the Early Iron Age.[5]

This raises questions regarding the economic, technological and social significance of the Oberhalbstein

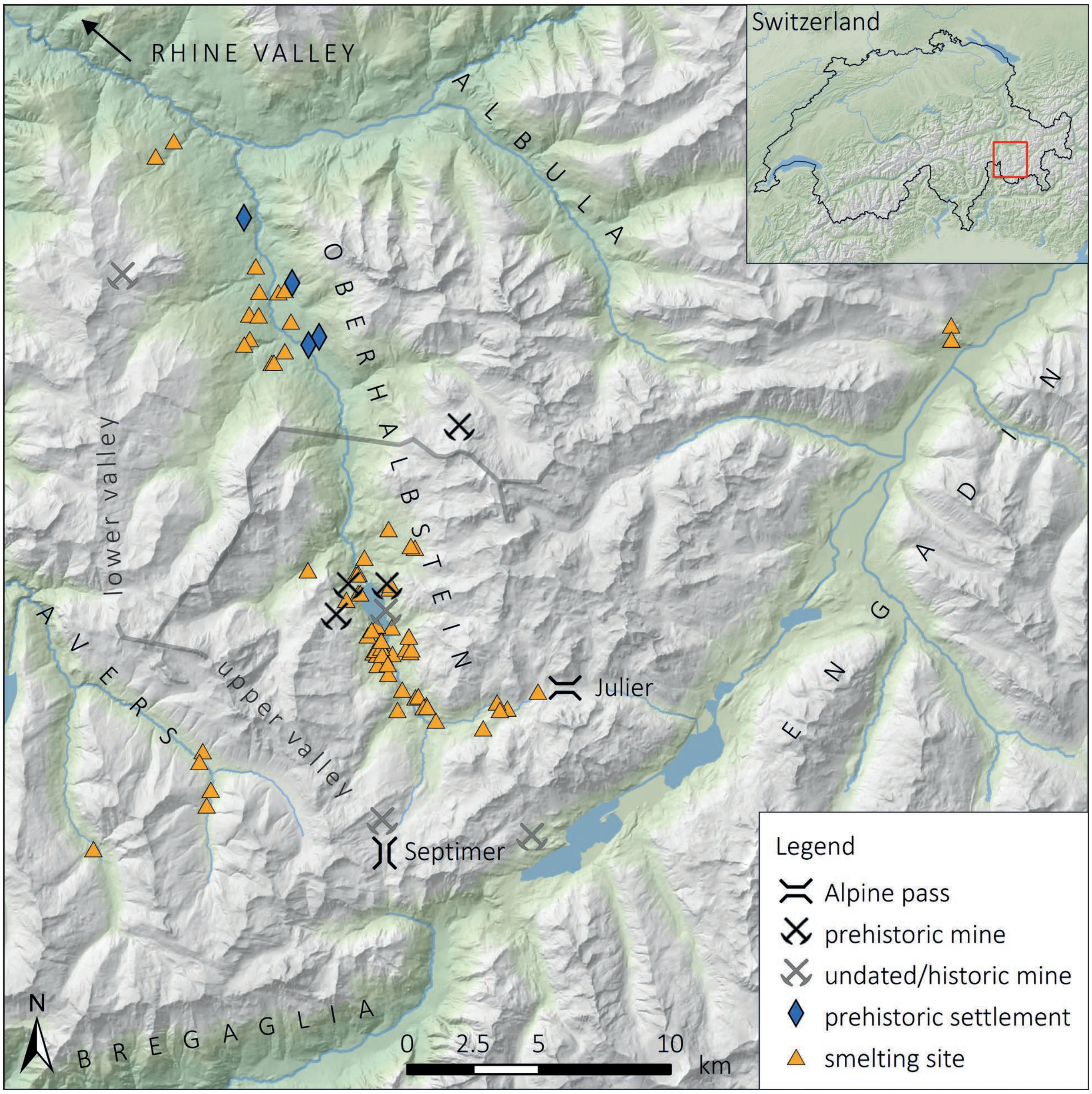

Fig. 1: Site distribution map of the study area (map: L. Reitmaier-Naef, University of Zurich; geodata: Federal Office of Topography and Canton of Grisons).

Valley in the context of prehistoric copper production and the associated processes in the Alpine region. Thanks, among other things, to the availability of an extensive material basis in the study area and a considerable body of (published) data from other regions, this paper focuses on the technological aspects of the smelting process.

The study area contains a significant number of mainly small dispersed sulphidic ore deposits with a rather low copper content. The majority are found in the ophiolithic serpentinite of the Platta nappe. Like the smelting and mining sites, mineralisation is divided along the same lines as the geography of the Oberhalbstein Valley. While the ores in the lower part of the valley show simple compositions of pyrite, chalcopyrite and magnetite, the mineralisation in the upper part of the valley is much more complex in that it includes varying percentages of pyrrhotite, chalcopyrite, magnetite, ilvaite, sphalerite, bornite and bravoite. [6]

In order to investigate and attempt to understand the production process ("chaîne opératoire") from start to finish or at least to an advanced stage, the mineralogical and geochemical evaluation of the ore mineralisation was studied as part of a subproject, which included surveying, sampling and analysing the majority of the known outcrops.[7]

As part of the ore prospection a series of old workings were documented, most of which were already known. Besides a number of medieval/modern sites, at least three prehistoric mining sites were identified and investigated.[8] A more detailed investigation of another set of promising mines of unknown date is still ongoing.

While our knowledge of prehistoric mining in the Oberhalbstein Valley has clearly been extended in recent years, the next step in the process, i.e. ore beneficiation, has not yet been sufficiently studied since no beneficiation site has been uncovered so far. It remains unclear whether this type of site never actually existed in the study region or whether the lack of evidence simply reflects the current state of research. Moreover, the complete absence of slag sand at smelting sites means that there is no evidence of the use of (wet)mechanical enrichment methods. It is therefore conceivable that a simple beneficiation process was carried out in the immediate vicinity of the individual mines and that this did not take place at specific sites. This assumption is reinforced by the most recent discovery of several stone tools in the vicinity of a prehistoric mine in Cotschens.[9]

The vast majority of mining-archaeological evidence points to smelting sites. Around 80 smelting sites and slag deposits dating from the Late Bronze and Early Iron Ages are known throughout the Oberhalbstein and the adjacent Avers and Engadin Valleys at altitudes of between 1100 and 2050 m a.s.l. Almost all of these sites were re-recorded or even newly discovered in the course of an extensive survey in 2014-2018.[10] Furthermore, excavations at selected sites around Lake Marmorera in the upper part of the valley extended our scarce knowledge of smelting structures in general.[11]

A number of prehistoric settlements near these mining archaeological sites regularly yield slag finds, thus creating a link to copper production activities. It is not yet clear which steps in the copper mining process, if any, took place at these sites, though a substantial number were subject to archaeological excavations in the 20th century.[12] Future investigations of the slag material and metal artefacts will hopefully shed further light on this matter.

Smelting slag – a key to deciphering the smelting process

All mining and smelting sites are characterised by a scarceness of or an imbalance in the archaeological finds. Apart from a very small number of potsherds and potential stone tools, the finds consist merely of fragments of tuyères, and large amounts of smelting slag and charcoal.

As a consequence, only two main groups of material besides the archaeological finds and structures are available for analysis, from which the reconstruction of the local smelting process can be attempted: copper ore[13] and smelting slag. Intermediate and finished products such as matte and copper have not yet been discovered at any of the smelting sites in the Oberhalbstein Valley. This paper will therefore focus mainly on the slag.

There are different ways of approaching this type of archaeological material. The most common approach involves mineralogical and geochemical analysis in order to decipher step by step the chemical reactions that take place in the process of turning ore into metal. While appropriate analyses have been carried out at the German Mining Museum in Bochum in collaboration with Prof. A. Hauptmann, they are not the subject of this paper.[14]

Since the results of such analyses are not always self-explanatory, complementary investigations such as historical or ethnological comparisons and archaeological experiments must be carried out in order to provide a more plausible interpretation of the data. In recent years, various studies have demonstrated the importance and considerable potential of such approaches.[15]

However, since no archaeological evidence in the form of smelting furnaces or roasting beds were known in the research area until recently, the data available was too limited to allow for scientific archaeological experiments.

With a view to overarching questions, economic and econometrical aspects are also of interest with regard to wide-ranging dynamics and processes.[16] However, this complex topic is still subject to theoretical and methodological debate. A significantly large database and extensive knowledge of the study region are required in order to deal with the numerous variables and to produce realistic results.

Therefore, a different approach has been taken for the present study, which focuses on the typology and morphology of slag, a popular archaeological method, which is often neglected or at least not sufficiently considered in this specific field of research.[17] This is all the more surprising given that typological methods represent a cornerstone of archaeological science.

In recent decades the precise mode of operation of Middle and Late Bronze Age smelting sites in the Alps has been subject to ongoing scientific debate. One of the key issues is the question as to whether different slag types (slag cakes and plate slags in particular) were the result of the same smelting processes. Slag tapping is yet another controversial issue.[18] However, the typology of slag almost always forms an inherent part of the line of argument without it actually being a subject of the discussion. An exception is a study by A. Schaer from the early 2000s, which was one of the main inspirations for the study presented here. Unless it was further processed into slag sand, slag is usually available in large quantities and therefore well suited for statistical evaluation at least from the Middle Bronze Age onwards. In contrast to most other archaeological finds, slag does not seem to have served any specific purpose upon completion of the smelting process. Above all, slag was a waste product, a side effect of the technological process. It can therefore be assumed that its outer form was a product of its function, not of an intentional shaping process. Therefore, it is not necessary to take socio-cultural factors into consideration when typologically evaluating this material. Typological changes over time and space thus most probably represent a modification of the framework conditions such as the nature and availability of the raw material. It must be borne in mind, however, that socio-cultural reasons may have had a bearing on certain technological choices. However, even if the classification of smelting slag can be understood as an attempt to build a functional typology, the resulting types should not automatically be seen as historical entities.[19]

Moreover, due to its material properties such as the fact that it was at least partially liquid, slag is a material that carries a lot of information concerning, for example, the process reactor, the solidification process and/or the deposition milieu. A detailed investigation of such morphological characteristics may help us answer any open questions concerning the smelting process, or at least give an indication as to how the data should be interpreted.

In the Oberhalbstein Valley specifically, slag is often the only source of information available with regard to a particular smelting site. Because comprehensive sampling and investigation of the material by mineralogical and geochemical means is not feasible, typological and morphological investigations seem to be an appropriate approach, so as not to neglect many of the smelting sites within the prehistoric mining area. Whilst the evaluation of all the slag material from our own fieldwork and from earlier surveys, test trenches and excavations would be useful, it would also be very time-consuming. The work therefore requires a clear sampling strategy. A two-stage evaluation process was therefore applied consisting of an initial rough typological quantification followed by a detailed morphological analysis and documentation of selected pieces of slag.

Typology – a different approach to the study of smelting slag

The question that inevitably comes to mind revolves around the definition and terminology of different slag types. What types exist and how can they be distinguished? The discussion is further complicated by the slightly inconsistent use and definition of slag types in the archaeological literature. In terms of Middle and Late Bronze Age chalcopyrite smelting, the discussion is mainly dominated by the trilogy of the porous, coarse so-called “slag cake” (Schlackenkuchen), the homogenous, thin and platy, so-called “plate slag” (Plattenschlacke) and the deformed “slag sand” (Schlackensand) consisting of crushed slag. Other terms such as “Blasenschlacke” or “Laufschlacke” are also sometimes used[20], which does not help matters, especially since there is often no explicit definition of the different types for the specific region concerned. An independent typology was developed for the Oberhalbstein slags by A. Schaer, who divided the material into seven types. These types can be at least partially correlated to the types mentioned above (Tab. 1).

The scarcity of typological descriptions for the slag often stands in contrast to a very detailed mineralogical or geochemical characterisation, which cannot be easily equated with macroscopic characteristics. Archaeometallurgical analyses can assist in answering questions concerning the raw material, the chemical reactions that took place during individual steps in the process, the (intermediate) product created, the process atmosphere and temperature, the cooling rate of the slag etc. However, they should not form the basis for an archaeological classification of the material since the sample usually represents only a small fraction of the total number – quite irrespective of the high variability between and within different fragments of slag. In order to avoid overvaluing random samples, the typology and sampling should, rather, be based on independent archaeological classification, which can and should subsequently be tested using the results of the scientific analyses.

It appears unreasonable to establish a fixed universal typology with a long list of criteria for each type, since certain distinctions must be made between the mining regions based on the differences between the raw materials on one hand and for chronological reasons on the other. However, based on the assumption that a high degree of standardisation existed in smelting technology from the Middle Bronze Age onwards[21], one would generally also expect to see a certain standardisation among waste products over the course of time and throughout different areas. A more detailed macroscopic description of the slag, particularly in connection with archaeometallurgical analyses, would undoubtedly increase the comparability of the sampling and research results. In addition, the publication of more and better-quality illustrations would be helpful.

Against this background, it appeared more reasonable to refer to the most widely used typology and terminology when examining the slag from the Oberhalbstein Valley rather than using the classification developed by Schaer[22]. Two notable exceptions applied:

Firstly, since there was no evidence of slag processing, the category of slag sand was not taken into consideration. The same applied to special types of slag such as drops, taps and slagged stones or furnace walls, since the sample number was too small to achieve a statistically significant result.

Secondly, because quite a considerable quantity of slag could not be assigned to either of the two commonly used types (slag cake or plate slag), the spectrum had to be extended by an additional type. In line with two recent works from the Trentino region[23] this intermediate type was called “massive slag[24]”. Although this type of slag is seemingly found in the southern and central Alps only, the possibility of its existence in other areas cannot be excluded.[25]

The polythetic classification used here therefore consisted of the following three types[26], which were defined on the basis of their fundamental shape, homogeneity, porosity, liquidity and thickness:

mining district	period	coarse, porous, heterogenous slag	platy, thick, slightly heterogenous slag	platy, thin, homogenous slag	crushed slag	reference
Mitterberg (A)	MBA	A (Schlackenkuchen)	-	C (Plattenschlacke)	-	Herdits 1997
	MBA	Schlackenkuchen	-	Plattenschlacke	Schlackensand*	Stöllner et al. 2011
Kitzbühel (A)	MBA	Schlackenkuchen	-	Plattenschlacke	Schlackensand	Krismer et al. 2012
	MBA	Schlackenkuchen	-	Plattenschlacke	Schlackensand	Koch Waldner/ Klaunzer 2015; Koch Waldner 2017
Eisenerzer Ramsau (A)	MBA	B (Blasenschlacke); A (Laufschlacke)**	A (Laufschlacke)**	C (Plattenschlacke) 3-10 mm thickness	Schlackensand*	Doonan 1996
	MBA	B (Blasenschlacke); A+B (Typen-kombination)**; A (Laufschlacke)**	A (Laufschlacke)**; A+B (Typen-kombination)**	C (Plattenschlacke) ≤ 5 mm thickness	Schlackensand*	Kraus 2014
Raxgebiet (A)	LBA	lumpy slag (cake or amorphous)**	rich slag (7-36 mm thickness)**	fine slag (3-7 mm)**	-	Larreina-Garcia et al. 2015
Trentino (I)	LBA	Schlackenkuchen, slag cake	massive Schlacke	Plattenschlacke, plate slag (3-8 mm)	Schlackensand, crushed slag	Silvestri et al. 2014; Silvestri et al. 2015a
	LBA	coarse slag (slag cake)	massive slag	flat slag (Plattenschlacke)	slag sand	Addis et al. 2017
	LBA	Schlackenkuchen	heterogene Plattenschlacke	homogene Plattenschlacke	Schlackensand	Metten 2003
Unterinntal (A)	LBA	Schlackenkuchen, (heterogene Schlacken)	-	Plattenschlacke	Schlackensand	Goldenberg 2013; Goldenberg 2014
	LBA/EIA	slag cake (typ II and III)	-	plate slag (typ I)	slag sand	Staudt (in press)
Oberhalb-stein (CH)	LBA/EIA	K	B1 (1.05-1.4 cm), B2 (1.4 cm <)	A1 (0.2-0.55 cm) A2 (0.6-1.0 cm)	-	Schaer 2003
	LBA/EIA	Schlackenkuchen, slag cake	massive Schlacke, massive slag (≥ 1.5 cm)	Plattenschlacke, plate slag (<1.5 cm)	Schlackensand*, slag sand*	Reitmaier-Naef 2018
various districts	MBA/LBA	Schlackenkuchen	-	Plattenschlacke	Schlackensand	Hanning et al. 2015
various districts	EBA-EIA	Schlackenklötze; stückige Laufschlacke**	stückige Laufschlacke**; plattige Laufschlacke**	plattige Laufschlacke?**	Sandschlacke	Eibner 1992

* missing in the archaeological record but mentioned in the cited publication
** classification uncertain

Tab. 1: Overview on the terminology used in recent papers/works for prehistoric copper smelting slags in the Alps.

Slag cake (SC): basic amorphous shape exhibiting bulges on top and flattened bottom surface; layered internal structure; high heterogeneity (numerous small to large inclusions of unmolten material fused together by a liquefied slag matrix); high porosity (interspersed with numerous small to large bubbles); high viscosity (only partially liquefied); low density; thickness irrelevant

Massive slag (MS): platy, disc-shaped basic form with a flat, usually partially blistered top surface and a flat to highly textured bottom surface (drops, bulges); internal structure not layered; medium heterogeneity (small to average number of small to medium inclusions of unmolten material in a mass of liquefied slag matrix); medium porosity (interspersed with a small to average number of small to large bubbles); low viscosity (predominantly liquefied); middle to high density; thickness ≥ 1.5 cm

Plate slag (PS): basic platy shape with flat to smooth top and bottom surfaces; internal structure not layered; low heterogeneity (few or no small inclusions of unmolten material in a liquefied slag matrix); low porosity

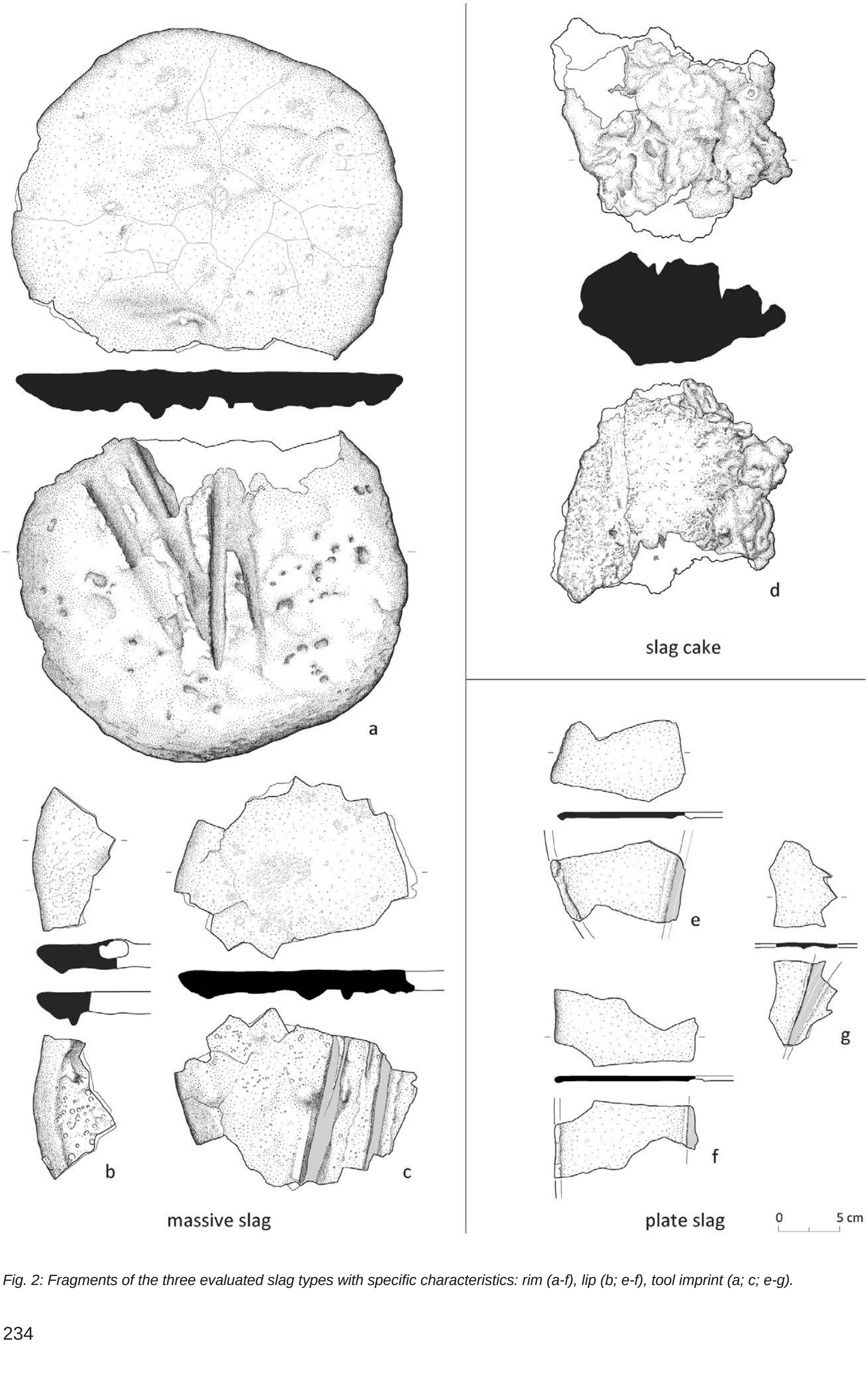

Fig. 2: Fragments of the three evaluated slag types with specific characteristics: rim (a-f), lip (b; e-f), tool imprint (a; c; e-g).

Fig. 3: The surface colour changes are due to strong corrosion (a-c) and surface reactions during the drying process on a metal lattice (f). (Ill./photo: Archaeological Service of the Canton of Grisons).

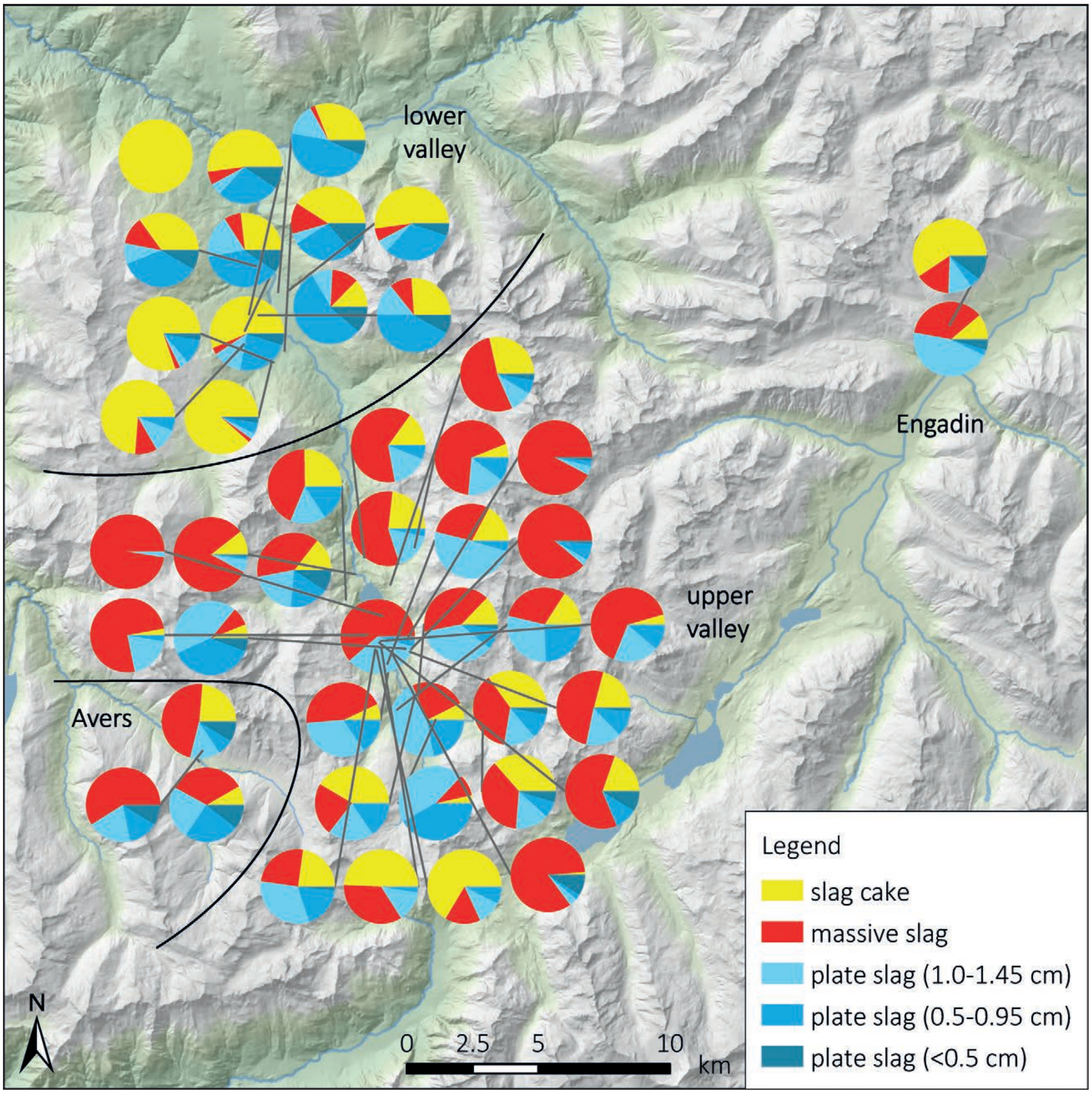

Fig. 4: Mapping of different proportions of slag types grouped by smelting site (map: Leandra Reitmaier-Naef, University of Zurich; geodata: Federal Office of Topography and Canton of Grisons).

(interspersed with few or no small bubbles); very low viscosity (completely liquefied); high density; thickness < 1.5 cm (subdivided into three subgroups 1.0-1.45 cm / 0.5-0.95 cm / 0.2-0.45 cm).

While in most cases the distinction between slag cakes and massive or plate slag posed no difficulty, the distinction between massive and plate slag was less evident. Clarification was required regarding the question as to whether there existed a clear boundary between two platy slag types or whether they merged seamlessly into one another. To simplify the data collection, particularly in the case of small slag fragments on one hand and to detect a potential threshold value on the other, these two types were distinguished by thickness: the maximum thickness of a plate slag was set at 1.45 cm with a subdivision into 0.5 cm steps (1.0-1.45 cm / 0.5-0.95 cm / 0-0.45 cm) in order to determine whether and in what way the differences related to the thickness of a plate slag. The information found in the literature suggests that there was no general rule (see Tab. 1).

In addition, further characteristics such as magnetism[27], fragmentation and secondary minerals were documented but not taken into account for the classification, as they are influenced by other factors such as the state of preservation and the supply of raw material at the site concerned.

So far, the dataset contains almost all earlier finds retrieved prior to 2012 and a large proportion of the slag collected during surveys since 2013. In addition, a large part of the sample derives from the partially excavated sites of Gruba I, Val Faller and Scalotta I.[28] Just under 12,000 slag fragments weighing a total of 421 kg were examined overall.

More than half (57.3%) of the investigated slag fragments were classified as plate slag, 27% as massive slag and only 15.6% as slag cake. This reflects a type-specific degree of fragmentation rather than the actual ratio between the different types. The picture changes towards a predominant proportion of massive slag (38.6%) followed by 35.9% slag cake and only 25.5% plate slag once the representation is based on weight.

Spatial distribution of slag types

At first glance the map with the results plotted by weight percentages and grouped by smelting site shows that the sites in the lower (northern) part of the valley tend to yield significantly more slag cakes than the sites in the upper (southern) part of the valley (Fig. 4). All sites show a small amount of massive slag: the largest share is represented either by slag cakes (8 sites)[29] or by plate slags (5 sites)[30].

Interestingly, the proportion of massive slag is smaller than the other two categories at each site. In fact, the actual presence of massive slag might be questioned in more than one case, since the evidence often consists of only a few individual fragments measuring 1.5 cm in thickness or slightly more. Therefore, they may just belong to the grey zone at the upper end of the plate slag scale.

The upper, southern part of the valley shows a completely different picture, with smelting sites containing significantly more massive slag and rather small proportions of slag cakes, rarely more than 25%. At 24 out of 34 sites, the massive slag, at up to 95.7%, represented the largest category by far.[31] In line with the northern part of the study region it is also clear that, with very few exceptions, all sites yielded a considerable quantity of plate slag, regardless of the ratio between slag cakes and massive slags. In seven cases, plate slag was even the largest category.[32] Only in three cases, all located south of Lake Marmorera, slag cakes were the largest category.[33]

A similar picture, dominated by massive slags and plate slags of 0.5-1.45 cm thickness, can be seen in the neighbouring Avers Valley. The samples from the two sites in the Engadin, on the other hand, clearly show different compositions – a result that can probably also be partially explained by the small sample quantity.[34]

Not included on the map are 19 sites, which yielded less than 20 slag fragments – including the prehistoric settlements of Motta Vallac and Davos Tigignas Sot I – and four samples with uncertain site allocations.

This brings us to an important aspect of discussion: the critical assessment of sources. The results presented may have been distorted by various factors including selective sampling. The majority of slags were collected throughout the 20th century under different circumstances and with varying intentions. The situation was certainly better in relation to the newly discovered sites where slag finds were sampled systematically. Nevertheless, the chronological and spatial distribution remains an unknown and potentially complicating factor. Even systematic sampling of a slag heap does not necessarily lead to a representative result because smelting sites are only rarely fully examined.[35]

Despite these objections, the results of the typological examination of the smelting slag from the Oberhalbstein Valley appear to be consistent and correspond with the study undertaken by Schaer[36]. It does seem likely that the reason for the apparent differences in the slag type combinations between the two areas of the Oberhalbstein Valley lies either with the raw material source[37] (same process, different raw material) or the smelting process (e.g. different production phases). The former seemed a plausible explanation a few years ago, since the Late Bronze Age smelting sites appeared to concentrate mainly in the lower part of the valley, while the Early Iron Age sites clustered primarily around Lake Marmorera in the upper part. New dendrochronological and radiocarbon analyses[38] have now shown, however, that copper was most probably produced both in the lower and in the upper part of the valley in both periods. It seems unlikely that different processing techniques were used simultaneously throughout the valley in both production phases. It is therefore highly likely that the differences in type composition were down to the raw materials, which, due to their differences in composition behave differently and therefore produce different slags or slag type proportions. This interpretation is confirmed by the results obtained from ore and slag analyses carried out in respect of both valley sections.[39]

Morphology – from big to small

In order to obtain more specific information on the smelting process(es), we must turn our attention to a more detailed study of the slags. The main goal of such a detailed examination of individual slag fragments is to identify and more precisely define the different slag types and to determine any relevant information with regard to the smelting process that has potentially been imprinted in a slag fragment's morphology. Furthermore, it is hoped that the information collected will make it easier in the future to macroscopically evaluate copper smelting slag in a more timely fashion.

So far, out of the sample presented, more than 2000 particularly significant specimens have been selected for further investigation. They have undergone the initial step of being recorded in a catalogue of characteristics and measurements as described above. All fragments that

site			fragments						weight (in g)						proportion by weight (in %)				
area	village	name	total	SC	MS	PS-A	PS-B	PS-C	total	SC	MS	PS-A	PS-B	PS-C	SC	MS	PS-A	PS-B	PS-C
OBERHALBSTEIN (LOWER VALLEY)	Cunter	Dafora	1035	120	18	169	603	125	15754	4886	337	2206	7291	1034	31,0	2,1	14,0	**46,3**	6,6
	Riom-Parsonz	Davos Tigignas	139	77	10	33	17	2	7438	5483	704	810	430	11	**73,7**	9,5	10,9	5,8	0,1
	Cunter	Glignia II	109	51	9	12	28	9	2631	1372	147	146	830	136	**52,1**	5,6	5,5	31,5	5,2
	Salouf	Gneida	236	84	15	18	86	33	2382	833	286	218	845	200	35,0	12,0	9,2	**35,5**	8,4
	Riom-Parsonz	Motta Mola	764	65	37	106	426	130	10402	2714	996	1467	4418	807	26,1	9,6	14,1	**42,5**	7,8
	Salouf	Motta Vallac	6	2	0	0	3	1	122	40	0	0	74	8	32,8	0,0	0,0	**60,7**	6,6
	Riom-Parsonz	N Riom	19	0	0	1	14	4	245	0	0	102	126	17	0,0	0,0	41,6	**51,4**	6,9
	Savognin	Oberhalb Savognin	31	1	2	4	18	6	285	36	33	26	158	32	12,6	11,6	9,1	**55,4**	11,2
	Savognin	Parseiras I	92	16	3	12	46	15	9289	7454	189	374	1027	245	**80,2**	2,0	4,0	11,1	2,6
	Savognin	Parseiras II	175	32	2	18	81	42	14505	12823	231	380	712	359	**88,4**	1,6	2,6	4,9	2,5
	Savognin	Son Martegn	516	94	25	30	219	148	9219	3768	1251	428	2507	1265	**40,9**	13,6	4,6	27,2	13,7
	Riom-Parsonz	Tigignas Sot I	4	2	0	0	1	1	28	5	0	0	6	17	17,9	0,0	0,0	21,4	**60,7**
	Riom-Parsonz	Tigignas Sot II	103	13	1	9	55	25	3570	958	260	677	1334	341	26,8	7,3	19,0	**37,4**	9,6
	Riom-Parsonz	Tigignas Sot III	140	15	6	29	78	12	5315	2996	160	680	1220	259	**56,4**	3,0	12,8	23,0	4,9
	Stierva	Tiragn	33	25	0	2	5	1	60370	60098	0	127	112	33	**99,5**	0,0	0,2	0,2	0,1
	Riom-Parsonz	Ual da Val	404	24	4	30	259	87	5914	3086	337	308	1630	553	**52,2**	5,7	5,2	27,6	9,4
OBERHALBSTEIN (UPPER VALLEY)	Sur	Alp Flix I	76	6	39	19	12	0	1964	121	1324	319	200	0	6,2	**67,4**	16,2	10,2	0,0
	Sur	Alp Flix II	128	33	41	37	17	0	2681	624	1519	448	90	0	23,3	**56,7**	16,7	3,4	0,0
	Sur	Alp Flix III	16	2	6	8	0	0	487	23	389	75	0	0	4,7	**79,9**	15,4	0,0	0,0
	Marmorera	Alp la Motta	182	14	98	56	13	1	3348	96	2516	642	86	8	2,9	**75,1**	19,2	2,6	0,2
	Marmorera	Alp Natons	81	4	33	18	14	12	6317	61	5777	245	155	79	1,0	**91,5**	3,9	2,5	1,3
	Marmorera	Bajols	12	0	5	3	2	2	224	0	134	49	19	22	0,0	**59,8**	21,9	8,5	9,8
	Bivio	Barscheinz II	14	0	0	6	8	0	110	0	0	57	53	0	0,0	0,0	**51,8**	48,2	0,0
	Bivio	Barscheinz III	23	3	3	10	7	0	297	22	71	139	65	0	7,4	23,9	**46,8**	21,9	0,0
	Bivio	Bötg da las Serps	30	1	2	13	14	0	362	13	34	164	151	0	3,6	9,4	**45,3**	41,7	0,0
	Bivio	Brüscheda I	228	68	59	40	33	28	4330	1513	1623	596	482	116	34,9	**37,5**	13,8	11,1	2,7
	Bivio	Brüscheda II	2	0	0	0	0	2	14	0	0	0	0	14	0,0	0,0	0,0	0,0	**100,0**
	Marmorera	Burgfelsen	111	5	74	13	16	3	6355	192	5353	421	341	48	3,0	**84,2**	6,6	5,4	0,8
	Bivio	Caschegna	84	14	31	12	22	5	2875	117	2281	163	295	19	4,1	**79,3**	5,7	10,3	0,7
	Bivio	Clavazöl	14	3	6	3	2	0	265	68	128	42	27	0	25,7	**48,3**	15,8	10,2	0,0
	Bivio	Clavè d'Mez I	5	2	1	2	0	0	1353	1269	41	43	0	0	**93,8**	3,0	3,2	0,0	0,0
	Marmorera	Clavè d'Mez II	197	44	35	72	41	5	3052	697	761	990	558	46	22,8	24,9	**32,4**	18,3	1,5
	Bivio	Clavè d'Mez III	29	4	1	9	15	0	205	48	9	65	83	0	23,4	4,4	31,7	**40,5**	0,0
	Marmorera	Clavè d'Mez IV	165	32	74	40	19	0	9857	4865	3417	1323	252	0	**49,4**	34,7	13,4	2,6	0,0
	Bivio	Cresta	4	1	0	1	2	0	89	19	0	36	34	0	21,3	0,0	**40,4**	38,2	0,0
	Bivio	Fuortga	214	5	110	20	11	68	5550	69	4660	199	124	498	1,2	**84,0**	3,6	2,2	9,0
	Sur	Furnatsch	459	67	180	149	58	5	17112	2575	10690	2738	1031	78	15,0	**62,5**	16,0	6,0	0,5
	Marmorera	Gruba I	1022	207	401	213	114	87	45243	12880	24035	4423	2756	1149	28,5	**53,1**	9,8	6,1	2,5
	Marmorera	Mot la Bova	31	3	1	14	10	3	265	16	21	114	99	15	6,0	7,9	**43,0**	37,4	5,7
	Marmorera	Pardeala	32	0	19	4	5	4	14930	0	14293	367	142	128	0,0	**95,7**	2,5	1,0	0,9
	Marmorera	Pareis I	811	69	332	233	161	16	26379	1180	16802	5202	2937	258	4,5	**63,7**	19,7	11,1	1,0
	Marmorera	Pareis II	28	7	13	0	5	3	442	87	273	0	44	38	19,7	**61,8**	0,0	10,0	8,6
	Marmorera	Pareis III	20	5	3	9	3	0	113	21	29	39	24	0	18,6	25,7	**34,5**	21,2	0,0
	Marmorera	Pareis IV	21	0	9	7	4	1	444	0	270	151	19	4	0,0	**60,8**	34,0	4,3	0,9
	Marmorera	Pareis V	10	3	3	0	4	0	497	330	50	0	117	0	**66,4**	10,1	0,0	23,5	0,0

site			fragments						weight (in g)						proportion by weight (in %)				
area	village	name	total	SC	MS	PS-A	PS-B	PS-C	total	SC	MS	PS-A	PS-B	PS-C	SC	MS	PS-A	PS-B	PS-C
OBERHALBSTEIN (UPPER VALLEY)	Bivio	Plaz I	137	31	22	51	32	1	1936	802	444	389	298	3	**41,4**	22,9	20,1	15,4	0,2
	Bivio	Plaz II	65	8	17	26	11	3	667	86	268	241	61	11	12,9	**40,2**	36,1	9,1	1,6
	Marmorera	Pra Miez	32	7	9	8	6	2	1143	286	494	177	178	8	25,0	**43,2**	15,5	15,6	0,7
	Bivio	Preda	26	4	8	12	2	0	410	71	118	203	18	0	17,3	28,8	**49,5**	4,4	0,0
	Bivio	Radons	22	4	5	8	5	0	214	34	65	63	52	0	15,9	**30,4**	29,4	24,3	0,0
	Marmorera	Scalotta I	2077	338	890	592	249	8	29925	2947	19819	5694	1387	78	9,8	**66,2**	19,0	4,6	0,3
	Marmorera	Scalotta II	227	26	160	21	10	10	11789	1235	9641	648	139	126	10,5	**81,8**	5,5	1,2	1,1
	Bivio	Sot al Crap	53	4	16	22	10	1	1052	73	467	347	162	3	6,9	**44,4**	33,0	15,4	0,3
	Sur	Spliatsch I	3	0	0	1	1	1	34	0	0	18	9	7	0,0	0,0	**52,9**	26,5	20,6
	Marmorera	Sül Cunfin I	29	4	8	9	7	1	894	187	455	139	101	12	20,9	**50,9**	15,5	11,3	1,3
	Marmorera	Sül Cunfin II	36	0	20	4	7	5	2975	0	2645	81	212	37	0,0	**88,9**	2,7	7,1	1,2
	Bivio	Sur Eva I	41	8	8	15	6	4	1240	452	464	180	88	56	36,5	**37,4**	14,5	7,1	4,5
	Bivio	Sur Eva II	1	0	0	0	0	1	12	0	0	0	0	12	0,0	0,0	0,0	0,0	**100,0**
	Bivio	Sur Gonda	6	1	2	2	1	0	310	95	61	128	26	0	30,6	19,7	**41,3**	8,4	0,0
	Bivio	Tges Alva I	8	0	7	1	0	0	292	0	258	34	0	0	0,0	*88,4*	11,6	0,0	0,0
	Bivio	Tges Alva II	19	2	7	10	0	0	591	65	380	146	0	0	11,0	*64,3*	24,7	0,0	0,0
	Mulegns	Val Faller Plaz	591	103	197	89	107	95	37277	5377	14401	7660	6392	3447	14,4	*38,6*	20,5	17,1	9,2
ENG.	Madulain	Alp Es-cha Dadour	20	2	1	2	3	12	2154	1280	324	225	97	228	**59,4**	15,0	10,4	4,5	10,6
	Madulain	Plaun Grand	119	16	11	27	22	43	8117	906	2925	3715	205	366	11,2	**36,0**	45,8	2,5	4,5
AVERS	Juppa	Skilift	192	14	42	25	34	77	9281	2191	4415	1215	649	811	**23,6**	47,6	13,1	7,0	8,7
	Juppa	Ober-Juppa I	115	3	27	26	31	28	2532	14	1484	486	326	222	0,6	**58,6**	19,2	12,9	8,8
	Juppa	Vorderbergalga I	19	2	10	2	3	2	920	79	695	82	57	7	8,6	**75,5**	8,9	6,2	0,8
	Juppa	Vorderbergalga II	28	1	3	5	12	7	314	26	106	74	75	33	8,3	**33,8**	23,6	23,9	10,5

Tab. 2: Number and type distribution of the investigated slags per smelting site, including sites with less than 20 slag fragments (not considered in the text). The most frequent type (by weight) per site is written in bold.

are either part of a rim, bear an imprint of a structure or object or contain other informative traces, deformations or inclusions, have been more closely examined. Of particular interest are pieces of a certain size that exhibit a combination of several characteristics, since they help identify relationships between specific traces.[40]

One good example of this is the question concerning the top and bottom of a slag. Plate slags, in particular, often exhibit two completely smooth and level surfaces, distinguished only by a characteristic lip whose origin remains unclear. Illustrations of plate slag (where illustrations are provided at all) clearly show a lack of agreement with regard to the correct orientation of such fragments, which originates from a lack of reflection rather than representing any particular opinion regarding functionality.[41] However, one possible answer lies in the morphology: many of the massive and plate slag fragments – but hardly any slag cakes – show imprints of elongated tools on one surface only (Figs. 2 and 3: slags a, c, e, f, g). We can safely assume that these traces mark the underside of the slag, since they were generated by lifting the slag off the molten metal, as a comparison with the ethnoarchaeologically documented and experimentally examined "Nepal Process" plausibly shows.[42] This assumption can be confirmed by comparing the bubble formation on both surfaces (Fig. 5). The bubbles on the side that bears the imprint are in negative, while those on the other side are in positive, which means that they denote the original orientation of the slag within the reactor. Interestingly, a few pieces of plate slag have both a lip and an imprint on the same side (Fig. 2 and 3: slag e, f, g). This clearly proves that the lip marks the underside of the plate slag. A similar observation can be made on several massive slag fragments, which occasionally also exhibit a more or less distinct step on the underside (Figs. 2 and 3: slag b). The obvious explanation for this morphological feature is that it marks the negative of an underlying metallic melt of a slightly smaller size. Similar, easily recognisable traces were identified, for example, on the bottom surfaces of early copper smelting slags from Shahr-I Sokhta or Nevali Çori.[43]

Apart from the discussion revolving around the top or bottom, the tool imprints themselves are also of

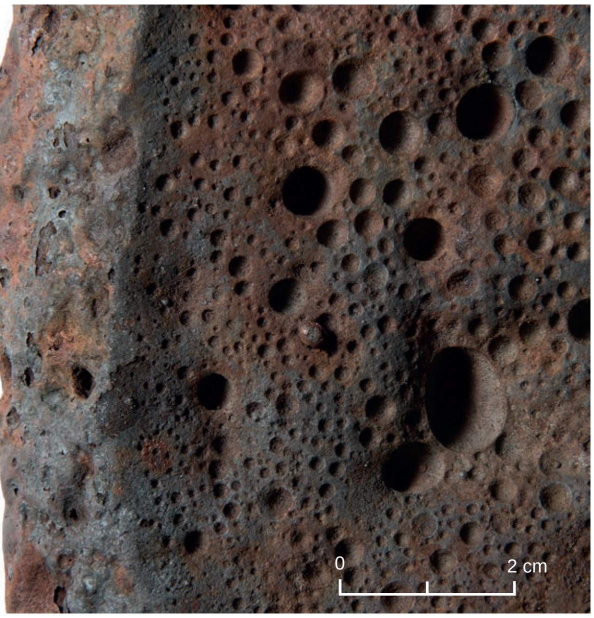

Fig. 5: Bottom surface of a massive slag fragment (rim) with negative (ascending) bubbles and a step (photo: Archaeological Service of the Canton of Grisons; L. Reitmaier-Naef).

Fig. 6: Bottom surface of a plate slag fragment with half of a tool imprint (r.) and an undulated surface showing the direction of the insertion (photo: Archaeological Service of the Canton of Grisons; L. Reitmaier-Naef).

interest: they vary in shape (straight to pointy), profile (flat to round) and width (0.5-2.5 cm). Most fragments show only a single imprint, others, however, bear two or more (Figs. 2 and 3: slags a, c) – usually in multiple directions. A handful of the larger massive slag fragments exhibit two or more imprints positioned like a branch fork, but due to the sharp intermediate angle and a lack of direct evidence for a connecting piece, they are probably just the result of two crossed tools or two stabs made by the same tool. Judging by a number of imprints with a distinguishable texture, it is, nevertheless, conceivable that the tool imprints originated from simple wooden sticks (Fig. 3: slag g). Drops and bulges alongside the imprints attest to the fact that the slag was only superficially solidified when it was lifted off the molten metal (Figs. 2 and 3: slags c, g). This argument is reinforced by the phenomenon of undulated surfaces sometimes accompanying imprints on plate slag fragments. The so-called "Milchhautrunzeln" are often labelled as flow structures and thus as evidence of tapping. On closer inspection, it becomes obvious that they are much more likely to have originated from lifting the slag when it was only superficially solidified. In contrast to the tapping scenario, this is also a more plausible explanation for the occasional occurrence of double-sided undulated surfaces (Fig. 6).

Furthermore, the fact that imprints almost exclusively occur on massive and plate slag provides an important clue in terms of reconstructing the smelting process. In contrast to the perforation seen on the slag cakes from the Mitterberg region[44], the few imprints documented are also located on the bottom surface of the slag but are only barely visible. Therefore, they most likely originated from some time after the smelting process, when the slag had already almost completely cooled down (in the furnace/reactor).

Apart from the impressions, the rim shapes also provide some information about the conditions that prevailed at the time of the slag formation (Fig. 7). While slag cakes always show a layered rim with (1b: 8%) or without (1a: 92%) a boundary, massive slag almost exclusively exhibits bevelled rims with (2b: 42.7%) or without (2a: 48.5%) a step on the underside. The angles of type 2 rims vary between 30° and 50° and their outer surfaces are frequently characterised by a rough, blistered texture which most probably represents the nature and shape of the reactor.[45] The transition between the bevelled rims of the massive slags and the lip-shaped rims of the second and third plate slag subgroup is taken up by the plate slag fragments of the first subgroup (1-1.45 cm) showing a wide range of rim shapes (2a: 17.8%; 2b: 42.2%; 3a: 24.4%; 3b: 11.1%; 3c: 4.4%). The other two subgroups only exhibit rims of the types 3b (32%) and 3c (68%).

This result provides additional classification criteria and further evidence to suggest that there is no sharp border between the two platy slag types, since the thickest plate slags share characteristics with both the thin plate slag and the massive slag categories. It remains unclear whether the two types defined represent different technological entities or only two subgroups of one and the same type. It seems possible, that the differentiation between the two is based mainly, if not solely, on differences in the material properties (esp. viscosity) and interrelated characteristics (e.g. the shape of the rims). The results of the type distribution clearly show that it is, nevertheless, legitimate or even central for a detailed understanding of

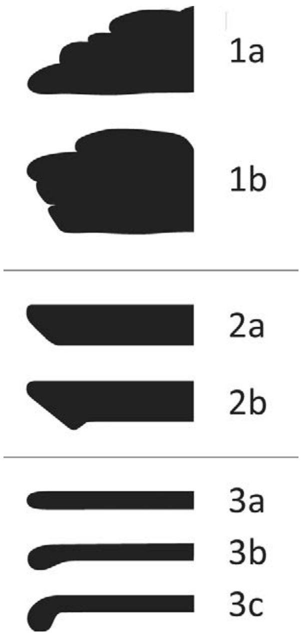

Fig. 7: Overview of the different rim shapes: 1a: layered rim; 1b: layered rim with boundary (angular); 2a: bevelled rim; 2b: bevelled rim with step on the underside; 3a: rim without specific characteristics; 3b: slightly thickened rim; 3c: rim with distinct lip (ill.: L. Reitmaier-Naef, University of Zurich).

the process applied to divide the plate-shaped slags into (at least) two types.

From the outside, this probably looks like a small increase in knowledge. Overall, however, findings as those described above lay an important foundation for future morphological evaluations and may eventually help answer further research questions. In order to paint a complete picture, a number of other attributes such as the diameter and colour of the slag should also be taken into account.

Conclusion

The typological and morphological evaluation of the smelting slag from the Oberhalbstein Valley has provided important indications for the reconstruction of the local Late Bronze and Early Iron Age smelting process. A significant difference in the slag spectrum between the lower and upper parts of the valley points to technological differences, more likely based on the raw material used rather than the period of production or the process, as shown by newly obtained absolute dates as well as geochemical and mineralogical analyses.

The morphological criteria of the different slag types have allowed us to make a series of interesting observations. Closer examination has yielded further confirmation of a profound difference between the coarse, viscous slag cakes and the platy, less viscous, less heterogenous massive and plate slags. The amorphous cakes most probably formed and cooled within the smelting furnace. They were not removed after the smelting process had been completed until a certain period of time had elapsed and therefore each presumably represents a single smelting process. This type of slag is thus quite probably associated with a first smelting step within the typical shaft furnace, which is known from almost all Bronze to Iron Age copper districts in the central, eastern and southern Alps.

The opposite is true for the other two types: the fact that they were lifted whilst only partially solidified, clearly evokes the image of an accessible reactor where slag plates were repeatedly removed during a dynamic smelting process. Since none of the investigated slag fragments showed any convincing evidence of tapping, this option has been excluded. The alternative scenarios of a second smelting step in an open, pit-shaped reactor proposed by Hanning et al.[46] seem to offer the best fit. For the Oberhalbstein, this interpretation can now also be linked to a concrete archaeological finding thanks to the most recent excavations: Previously unknown, hearth-shaped furnaces that strongly resemble structures in Nepal have been documented at two smelting sites – Gruba I and Val Faller.[47]

However, a conclusive overall picture of the prehistoric smelting process used in the Oberhalbstein region can only be obtained by bringing together the results of the macroscopic investigation, the existing archaeological findings and the archaeometallurgical analysis.[48] Furthermore, the individual steps of the overall development of the copper smelting process from the time and area of origin (MBA Mitterberg area) to the target region (EIA Oberhalbstein Valley) should be subjected to a more detailed examination in order to reach a better understanding of the intention and impact of technological adaption processes.[49]

Notes

1 In accordance with the principle that *"A typological study of finds would not be sufficient, and a scientific analysis of the material is necessary."* Hauptmann, 2010, p.8.
2 E.g. Stöllner, 2009.
3 Summary of the state of research at the end of the HiMAT-project: Goldenberg et al., 2012.
4 Project funded by FWF, DFG and SNF; project partners: University of Innsbruck, Deutsches Bergbau-Museum Bochum and the Curt-Engelhorn-Zentrum für Archäometrie in Mannheim.
5 See Oberhänsli et al. in this volume.
6 Dietrich, 1972; Reitmaier-Naef, 2018.
7 Geochemistry: German Mining Museum Bochum, material science laboratory; mineralogy: cooperation with Klaus-Peter Martinek, Munich.
8 Marmorera, Vals; Marmorera, Cotschens; Tinizong-Rona, Avagna-Ochsenalp; see Reitmaier-Naef et al., 2015; Reitmaier-Naef et al., in prep.
9 Reitmaier-Naef et al., in prep.

10 Della Casa et al., 2015; Reitmaier-Naef, 2018.
11 See Turck in this volume.
12 Nauli, 1977; Wyss, 1981; Wyss, 1982; Rageth, 1986.
13 Not documented at smelting sites so far.
14 See Reitmaier-Naef, 2018.
15 Anfinset, 2011; Hanning & Pils, 2011; Goldenberg et al., 2011; Hanning, 2012; Hanning in this volume.
16 Stöllner et al., 2011; Pernicka et al. 2016; Rose et al. 2019.
17 In contrast to the study of primary copper metallurgy, the classification of iron smelting and smithing slags by morphological and typological means has become more widely used at least since the 1980s (Sperl 1980) and is now a commonly accepted component of archaeometallurgical studies.
18 Most recently summarised by Hanning et al., 2015.
19 Vossen, 1970, pp.30-31.
20 The use of a different terminology in Styrian research may be related to the history of research, see Sperl, 1980.
21 Hanning et al., 2015; Stöllner et al., 2016.
22 Schaer, 2003, p.29; see also table 1.
23 Addis et al., 2017; Silvestri et al., 2015.
24 Partly correlates with the “coarse, bulky slag” in Schaer, 2003.
25 Judging by the pictures, the “Laufschlacke” type in Kraus 2014 bears a close resemblance to the “massive slag” type.
26 The type definitions and limit values are based on a systematic evaluation of an exemplary sample set. Therefore, they are not exactly identical to those in Schaer 2003, but nevertheless correlate well with the first five of her seven types.
27 On the relevance of magnetism for process reconstruction, see Reitmaier-Naef, 2018, pp.127-128.
28 See Turck in this volume.
29 Davos Tigignas I; Glignia II; Parseiras I; Parseiras II; Son Martegn; Tigignas Sot III; Tiragn; Ual da Val.
30 Dafora; Gneida; Motta Mola; oberhalb Savognin; Son Martegn; Tigignas Sot II.
31 Alp Flix I; Alp Flix II; Alp la Motta; Alp Natons; Brüscheda I; Burgfelsen; Caschegna; Fuortga; Furnatsch; Gruba I; Pardeala; Pareis I; Pareis II; Pareis IV; Plaz II; Pra Miez; Radons; Scalotta I and II; Sot al Crap; Sül Cunfin I and II; Sur Eva I; Val Faller Plaz.
32 Barscheinz III; Bötg da las Serps; Clavè d’Mez II and III; Mot la Bova; Pareis III; Preda.
33 Clavè d’Mez I and IV; Plaz I.
34 Only some 20 slag fragments from the early 1980s are available from the smelting site at Alp Es-cha Dadour.
35 E.g. smelting site S1 Eisenerzer Ramsau: Klemm, 2004; Staudt et al. in this volume; Turck in this volume.
36 Schaer, 2003.
37 Fasnacht, 1991.
38 See Oberhänsli et al. in this volume; Reitmaier-Naef, 2018.
39 Reitmaier-Naef, 2018.
40 The data used in the morphological evaluation were too extensive to be printed here. For the complete dataset see Reitmaier-Naef, 2018.
41 E.g. Herdits, 1997, Pl. pp.13 (lip at the bottom); Staudt, 2017 (lip at the top).
42 Anfinset, 2011; Goldenberg et al., 2011.
43 Hauptmann et al., 1993, 547.
44 Klose 1918, p.31, Fig. 41; Zschocke & Preuschen, 1932, p.79, p.89, Pl. 33a, p.8.
45 Herdits 1997, pp.45-46.
46 Hanning et al., 2015.
47 Anfinset, 2011; Goldenberg et al., 2011; Turck in this volume.
48 For a summarised reconstruction of the “Oberhalbstein process” see Reitmaier-Naef, 2018.
49 We should expect to find complex mechanisms (Stöllner et al., 2016) rather than a linear modification of the smelting process, structures and products as proposed by Eibner, 1992.

Bibliography

Addis, A., Angelini, I. & Artioli, G., 2017. Late Bronze Age copper smelting in the southeastern Alps: how standardized was the smelting process? Evidence from Transacqua and Segonzano, Trentino, Italy. *Archaeol Anthropol Sci* 2017, online (doi:10.1007/s12520-016-0462-5).

Anfinset, N., 2011. *Social and Technological Aspects of Mining, Smelting and Casting Copper. An Ethnoarchaeological Study From Nepal*. Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum 181, Bochum.

Della Casa, Ph., Naef L. & Turck, R., 2015. Prehistoric copper pyrotechnology in the Swiss Alps: Approaches to site detection and chaîne opératoire. *Quaternary International* 402, 26-34.

Dietrich, V., 1972. *Die Sulfidischen Vererzungen in den Oberhalbsteiner Serpentiniten. Ein Beitrag zur Kenntnis der alpinen Metamorphosen und des Gebirgsbaues im südlichen Graubünden*. Beiträge zur Geologie der Schweiz, Geotechnische Serie, Lieferung 49. Kümmerly & Frey, Bern.

Doonan, R. C. P., 1996. *Old Flames, Slags and Society. Copper smelting technology in the Ramsau Valley, Austria during the Bronze Age.* Doctoral thesis, University of Sheffield.

Eibner, C., 1992. Der Kupferbergbau in den österreichischen Alpen in der Urzeit. *Archäologie Österreichs* 3/1, pp.12-16.

Fasnacht, W., 1991. Analyses de scories de l’âge du bronze en Suisse. In: *Archéologie expérimentale, tome 1 – le feu: le métal, la céramique.* Actes du Colloque International «Expérimentation en achéologie: Bilan et Perspectives ». Editions Errace, Paris, pp.156-159.

Hanning, E., 2012. Reconstructing Bronze Age Copper Smelting in the Alps: an ongoing process. *Experimentelle Archäologie in Europa*, Bilanz 2012, 75-86.

Hanning, E. & Pils, R., 2011. Experimentelle Untersuchungen zur bronzezeitlichen Kupferverhüttung im ostalpinen Gebiet – Erste Ergebnisse. In: K. Oeggl; G. Goldenberg; Th. Stöllner & M. Prast (eds.): *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten.* Proceedings zum 5. Milestone-Meeting des SFB-HiMAT vom 7.-10.10.2010 in Mühlbach. Innsbruck: University Press, pp.129-134.

Hanning, E.; Herdits, H. & Silvestri, E., 2015. Alpines Kupferschmelzen – technologische Aspekte. In: Stöllner, Th. & Oeggl K., eds. 2015. *Bergauf Bergab. 10000 Jahre Bergbau in den Ostalpen. Wissenschaftlicher Beiband zur Ausstellung Bochum und Bregenz.* Veröffentlichungen DBM 207, Bochum-Rahden: Deutsches Bergbau-Museum Bochum in Kommission bei Marie Leidorf, pp.225-231.

Hauptmann, A., 2010. *The Archaeometallurgy of Copper. Evidence from* Faynan, Jordan. Publications oft the Deutsches Bergbau-Museum Bochum no. 155. Springer, Berlin Heidelberg.

Hauptmann, A., Pernicka, E., Lutz, J. & Yalcin, Ü., 1993. Zur Technologie der frühesten Verhüttung von Kupfererzen im östlichen Mittelmeerraum. In: M. Frangipane; H. Hauptmann; M. Liverani; P. Matthiae; M. Mellink (eds.): *Between the Rivers and Over the Mountains: Archaeologica Anatolica et Mesopotamica Alba Palmieri Dedicata*. Universita di Roma „La Sapienza“, 1993, pp.541-572.

Herdits, H., 1997. *Ein bronzezeitlicher Kupfererzverhüttungsplatz in Mühlbach/Hochkönig (Salzburg)*. Diplomarbeit, Universität Wien.

Goldenberg, G., 2013. Prähistorischer Fahlerzbergbau im Unterinntal – Montanarchäologische Befunde. In: Montanwerke Brixlegg AG; Oeggl, K.; Schaffer, V. (eds.): *Cuprum Tyrolense. 5550 Jahre Bergbau und Kupferverhüttung in Tirol*. Edition Tirol, Brixlegg, pp.89-122.

Goldenberg, G., 2014. *Montanarchäologische Fallstudien zur prähistorischen Kupfergewinnung in den Ostalpen und auf der Iberischen Halbinsel.* Habilitation, Universität Innsbruck.

Goldenberg, G., Anfinset, N., Silvestri, E., Belgrado, E., Hanning, E., Klaunzer, M., Schneider, P., Staudt, M. & Töchterle, U., 2011. Das Nepal-Experiment – experimentelle Archäometallurgie mit ethnoarchäologischem Ansatz. In: K. Oeggl; G. Goldenberg & Th. Stöllner; M. Prast (eds.): *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten*. Proceedings zum 5. Milestone-Meeting des SFB-HiMAT vom 7.-10.10.2010 in Mühlbach. Innsbruck: University Press, pp.83-90.

Goldenberg, G., Töchterle, U.; Oeggl, K. & Krenn-Leeb, A. (eds.), 2012. *Forschungsprogramm HiMAT – Neues zur Bergbaugeschichte der Ostalpen.* Archäologie Österreichs Spezial 4. Österreichische Gesellschaft für Ur- und Frühgeschichte, Wien.

Klemm, S., 2004. Der prähistorische Kupferschmelzplatz S1 in der Eisenerzer Ramsau (Steiermark). In: G. Weisgerber & G. Goldenberg eds., *Alpenkupfer – Rame delle Alpi.* Der Anschnitt, Beiheft 17. Bochum: Deutsches Bergbau-Museum Bochum, pp. 189-198.

Klose, O., 1918. Die prähistorischen Funde vom Mitterberge bei Bischofshofen im städtischen Museum Carolino-Augusteum zu Salzburg und zwei prähistorische Schmelzöfen auf dem Mitterberge. In: *Urgeschichte des Kronlandes Salzburg*. Österreichische Kunsttopographie 17. Wien 1918, Beitrag II.

Koch Waldner, Th., 2017. *Räumliche und zeitliche Struktur des prähistorischen Bergbaus in der Region Kitzbühel. Charakterisierung einer alpinen bronzezeitlichen Bergbaulandschaft anhand von archäologischen Befunden, Geländeanalysen und* überregionalen *Vergleichen*. Dissertation Universität Innsbruck.

Koch Waldner, Th. & Klaunzer, M., 2015. Das prähistorische Bergbaugebiet in der Region Kitzbühel. In: Stöllner, Th. & Oeggl K., eds. 2015. *Bergauf Bergab. 10000 Jahre Bergbau in den Ostalpen. Wissenschaftlicher Beiband zur Ausstellung Bochum und Bregenz.* Veröffentlichungen DBM 207, Bochum-Rahden: Deutsches Bergbau-Museum Bochum in Kommission bei Marie Leidorf, pp.165-173.

Kraus, S., 2014. *Archäometallurgische Studien zur bronzezeitlichen Kupferverhüttungstechnologie am Kupferschmelzplatz S1 in der Eisenerzer Ramsau (Steiermark, Österreich).* Dissertation, Universität Tübingen.

Kraus, S., Schröder, Ch., Klemm, S. & Pernicka, E., 2015. Archaeometallurgical studies on the slags of the Middle Bronze Age copper smelting site S1, Styria, Austria. In: A. Hauptmann; Modarressi-Tehrani, D. (eds.): *Archaeometallurgy in Europe III. Proceedings of the 3rd International Conference Deutsches Bergbau-Museum Bochum.* Der Anschnitt, Beiheft 26 = Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum 122, pp.301-308.

Krismer, M., Chiaramonte, J., Koch Waldner, Th., Goldenberg, G. & Tropper, P., 2012. Mineralogische und chemische Untersuchungen an metallurgischen Verhüttungsprodukten von der Wagstättalm bei Jochberg (Kitzbüheler Alpen, Tirol). *Geo.Alp* 9, pp.100-109.

Larreina-Garcia, D., Cech, B. & Rehren, T., 2015. Copper Smelting in the Raxgebiet (Austria): A Late Bronze Age Alpine Industrial Landscape. In: P. Suchowska-Ducke, S. Scott Reiter, H. Vandkilde eds., *Forging Identities. The Mobility of Culture in Bronze Age Europe*. Report from a Marie Curie Project 2009-2012 with Concluding Conference at Aarhus University, Moesgaard 2012, Volume 1. British Archaeological Reports Ltd, Oxford, pp.213-219.

Metten, B., 2003. Beitrag zur spätbronzezeitlichen Kupfermetallurgie im Trentino (Südalpen) im Vergleich mit anderen prähistorischen Kupferschlacken aus dem Alpenraum. *Metalla* 10.1/2, pp.1-122.

Nauli, S., 1977. Eine bronzezeitliche Anlage in Cunter/Caschligns. *Helvetia Archaeologica* 8, 29/30, pp.25-34.

Pernicka, E., Lutz, J. & Stöllner, Th. 2016. Bronze Age Copper. Produced at Mitterberg, Austria, and its Distribution. *Archaeologia Austriaca* 100, pp.19-55.

Rageth, J., 1986. Die wichtigsten Resultate der Ausgrabungen in der bronzezeitlichen Siedlung auf dem Padnal bei Savognin (Oberhalbstein GR). *Jahrbuch der Schweizerischen Gesellschaft für Ur- und Frühgeschichte* 69, pp.63-103.

Reitmaier-Naef, L., 2018. *Vom Erz zum Metall. Die chaîne opératoire der prähistorischen Kupfergewinnung im Oberhalbstein GR*. Dissertation Universität Zürich.

Reitmaier-Naef, L., Turck, R. & Della Casa, Ph., 2015. Prähistorische Kupfergewinnung im Oberhalbstein. *Minaria Helvetica* 36, pp.35-54.

Reitmaier-Naef, L., Thomas, P., Bucher, J., Oberhänsli, M., Grutsch, C., Martinek, K.-P., Seifert, M. Rentzel, P., Turck, R., Reitmaier, Th. & Della Casa, Ph., in prep. High-altitude prehistoric copper mining in the Oberhalbstein Valley (Grisons, Switzerland).

Rose, Th., Hanning, E. & Klein, S., 2019. Verhüttungsexperimente mit Chalkopyrit-Erz nach Vorbildern aus dem bronzezeitlichen Ostalpenraum und Nepal. *Experimentelle Archäologie in Europa*, 18, pp. 47-60.

Silvestri, E., Bellintani, P., Mottes, E. & Nicolis, F., 2014. Evidence of mining without mines: smelting activety [sic!] during the Bronze Age in Trentino. In: J. Silvertant (ed.): *Research and preservation of ancient mining areas*. Yearbook of the Institute Europa Subterranea 2014, pp.88-103.

Silvestri, E., Hauptmann, A., Bellintani, P., Mottes, E. & Nicolis, F., 2015. Bronzezeitliche Kupferverhüttung in Trentino. In: Th. Stöllner & K. Oeggl (eds.): *Bergauf Bergab. 10000 Jahre Bergbau in den Ostalpen. Wissenschaftlicher Beiband zur Ausstellung Bochum und Bregenz. Veröffentlichungen DBM 207, Bochum- Rahden: Deutsches Bergbau-Museum Bochum in Kommission bei Marie Leidorf,* pp.201-208.

Schaer, A., 2003. Untersuchungen zum prähistorischen Bergbau im Oberhalbstein (Kanton Graubünden). *JbSGUF* 86, 7-54.

Sperl, G., 1980. Über *die Typologie urzeitlicher, frühzeitlicher und mittelalterlicher Eisenhüttenschlacken*. Studien zur Industrie-Archäologie VII. Österreichische Akademie der Wissenschaften, Wien.

Staudt, M., 2017. Recycling of „slag sand“ in technical ceramics and domestic pottery during the Bronze and Early Iron Age in North Tyrol. In: *La metallurgia primaria della tarda etá del Bronzo in Trentino. Nuovi scavi, confronti e stato dell´arte.* Internationaler workshop, Trento 09.-11.05.2013. In press.

Stöllner, Th., 2009. Die zeitliche Einordnung der prähistorischen Montanreviere in den Ost- und Südalpen – Anmerkungen zu einem Forschungsstand. K. Oeggl & M. Prast (eds.): *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten.* Proceedings zum 3. Milestone-Meeting des SFB HiMAT vom 23.-26.10.2008 in Silbertal. Conference Series, Innsbruck 2009, pp.37-60.

Stöllner, Th., Hanning, E. & Hornschuch, A., 2011. Ökonometrie des Kupferproduktionsprozesses am Mitterberger Hauptgang. In: K. Oeggl, G. Goldenberg, Th. Stöllner & M. Prast, eds. *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten.* Proceedings zum 5. Milestone-Meeting des SFB-HiMAT vom 7.-10.10.2010 in Mühlbach. Innsbruck: University Press, pp.115-128.

Stöllner, Th., von Rüden, C., Hanning, E., Lutz, J. & Kluwe, S., 2016. The Enmeshment of Eastern Alpine Mining Communities in the Bronze Age. From Economic Networks to Communities of Practice. In: G. Körlin; M. Prange; Th. Stöllner & Ü. Yalcin (eds.), *From Bright Ores to Shiny Metals. Festschrift for Andreas Hauptmann on the Occasion of 40 Years Research in Archaeometallurgy and Archaeometry.* Der Anschnitt, Beiheft 29 = Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum 210. Bochum 2016, pp.75-107.

Vossen, R., 1970. Klassifikationsprobleme und Klassifikationssysteme in der Amerikanischen Archäologie *Acta Praehistorica et Archaeologica* 1, pp.29-79.

Wyss, R., 1981. Wyss, R. (1981): Der Rudnal. Ein rätselhaftes Bauwerk im bündnerischen Oberhalbstein. *Jahresbericht Schweizerisches Landesmuseum* Zürich 1981, pp.51-52.

Wyss, R., 1982. Die Höhensiedlung Motta Vallac im Oberhalbstein (Salouf GR). *Archäologie Schweiz* 1982/5, pp.76-81.

Zschocke, K. & Preuschen, E., 1932. *Das urzeitliche Bergbaugebiet von Mühlbach-Bischofshofen.* Wien 1932.

Author

Dr. des. Leandra Reitmaier-Naef – Dep. of Prehistoric Archaeology, Institute of Archaeology, University of Zurich

Correspondence and material requests should be addressed to: leandra.reitmaier@gmx.ch