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# Bronze Age copper ore mining and smelting in Trentino (Italy)

***ABSTRACT:*** *Knowledge about Trentino as a mining district has grown within the last years, based on new excavations at smelting sites, radiocarbon datings and archaeometallurgical analyses of slags. Following a general description of indications for copper mining and smelting in the area during the last phases of the Bronze Age, two new excavations, Valcava and Sant'Orsola both in the Mocheni Valley are briefly presented. The results of eleven new radiocarbon datings from LBA smelting sites are improving the discussion about chronology of the smelting activity in the region. Preliminary results of the analytical part of the research, focused mostly on plate slags, are presented, including bulk composition of plate slag samples and chemical composition (method: SEM-EDX) of Cu-Fe-sulphide inclusions in plate slags from different smelting sites.*

**KEYWORDS:** COPPER PRODUCTION, SMELTING SITES, FURNACES, CHRONOLOGY, SLAG ANALYSES

## Introduction

In 1987, before most of the publications about copper smelting in the area had been published, Reinhard Exel defined the prehistoric exploitation of the copper ore in the eastern part of Trentino as probably even more important than the silver exploitation of Monte Calisio during medieval times (Exel, 1987). The importance of the local copper ores emerged even more thanks to the project of systematic investigation of prehistoric smelting sites in the area carried out by the Deutsches Bergbau-Museum (DBM) Bochum (Germany) and the Ufficio beni archeologici of Trento (UBA) during the 1980s and the 1990s (Cierny, 2008; Metten, 2003). The research, through survey and excavations, showed how large metallurgical activity was during Prehistory, with over 200 smelting sites found and mapped (Fig. 1). Thanks to this research the heritage protection could reach more remote areas of the territory, where most of the smelting sites are located and frequently in danger to be destroyed, mostly by ski tracks and roads construction.

A very important part of the collaboration between Bochum and Trento was the archaeological excavation carried out at Acqua Fredda (near the Redebus Pass in the Mocheni Valley, Trento), at an altitude of about 1,500 m a.s.l. between 1979 and 1995 (Cierny, 2008 and references therein). Here, a large and well-preserved smelting complex with nine smelting furnaces built into stone walls on an artificial terrace has been excavated. It is one of the most important metallurgical sites in the Alpine area. The site is dated, thanks to archaeological findings and 13 radiocarbon datings, to the Late and Final Bronze Age. The analysis of stratigraphy identified two main phases of construction of the furnaces[1]. An area with a large deposit of slags, slag sand (finely crushed slag) and tools (grinding stones, hammer stones) was identified close to the site, with a quantity estimated to be around 800-1000 tons of slags.

During the last years, new excavations have been carried on by the Ufficio beni archeologici (Archaeological Heritage Office) during its activity of heritage protection. The archaeometallurgical research project started again in 2011 with a PhD study at the Ruhr Universität Bochum in collaboration with the DBM and the Ufficio beni archeologici of Trento. It includes field work (excavation, survey) and analytical investigations, mainly focused on plate slags.

## The copper ore and the mining activity

A general overview of the evidence by Renato Perini shows that during Prehistory two main metallurgical phases can be distinguished (Perini, 1992; Cierny et al.,

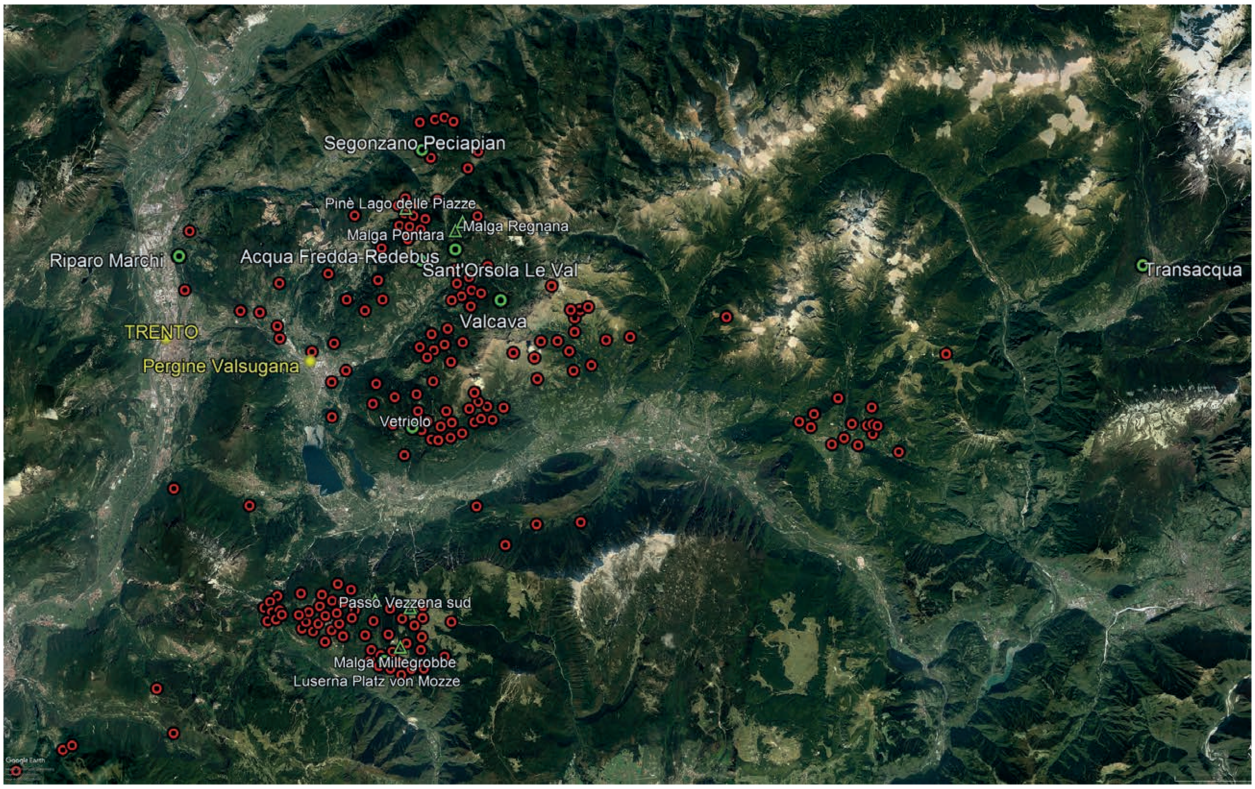


*Fig. 1: Map of eastern Trentino with the sites mentioned in the text. The red spots are the so far mapped smelting sites, the green spots are the smelting sites excavated in the last years. The green triangles are the smelting sites where slags have been surface sampled for archaeometrical analyses.*

1995; Angelini et al., 2013). The earliest copper smelting sites in Trentino date back to the Copper Age-Early Bronze Age (second half of the third millennium BC). They lie under or near rock shelters on the floor of the Adige Valley or in open areas. Smelting took place in oval-shaped pits coated with clay or square smelting furnaces with open fronts. The second period of copper metallurgy after Perini took place during the Late-Final Bronze Age according to the Italian chronology (second half of the $14^{th}$ century-$12^{th}$ century BC)[2]. The smelting activity seems to have dramatically improved and moved to mountain areas over 1,000 m a.s.l. This is proven by slag heaps and the remains of smelting furnaces built on slopes near water and timber resources, especially in eastern Trentino (Mocheni Valley, Tesino, Altopiano di Lavarone e Luserna, Vezzena; Fig. 1).

The number of sites belonging to the first phase is quite small (eleven sites found till now) while the activity during the Late Bronze Age includes a large number of smelting sites, with a concentration up to 1 site/$km^2$ in specific areas. It needs to be specified that only a minor part of these sites is securely dated to Late-Final Bronze Age, on the basis of pottery typology or of $^{14}C$ datings (Acqua Fredda, Malga Pontara, Cambroncoi, Brombisc, Malga Stramaiolo, Bedelar, Prati di Montagna, Malga Trenca, Val Morta, Luserna Platz or Pletz von Mozze, Segonzano Peciapian, Transacqua, Valcava, Sant'Orsola, Terrebis). The other sites are dated to the same phase due to the morphology of the slags, especially the flat and very homogeneously composed plate slags (in German language called *Plattenschlacken*), typical of this period.

The main area with copper ores leads to the east of Trento along a system of faults ENE-WSW called "Linea della Valsugana" (Valsugana tectonic line), in the central part of the province, to the east of the Monte Calisio, up Mocheni Valley to the North and North-East and north of the Valsugana. It is coinciding with zones for which historic mining is documented (Preuschen, 1973; Šebesta, 1992; Forenza, 2005; Pearce, 2007; Cierny, 2008). There are copper deposits in the western part of the Province also, e.g. Val di Non and Giudicarie, but so far no smelting sites are known, and the research focused so far on the deposits to the east of the Adige Valley.

The copper ore deposits in this area have been discussed by Ernst Preuschen (Preuschen, 1968; 1973 translation in Italian) and Beate Metten (Metten, 2003). Preuschen (1973, pp.122-129) describes the deposits in detail, connecting the medieval mines and mining dumps with the presence of smelting sites, dated to Prehistory on the grounds of slags and stone tools. Many deposits described by Preuschen contain abundant chalcopyrite (Nogarè, Erdemolo, S. Francesco, Cinque Valli, etc.). The smelting sites mapped by him have been afterwards included in Cierny's database (Cierny, 2008).

The ore outcrops show three different types of deposits, with a mixture in different proportions of sulphidic, carbonatic and oxidic ores. Metamorphic rocks like quartz phyllites contain sulphides with pyrite as main mineral. Minor minerals are galena, chalcopyrite and arsenopyrite. In the hydrothermal veins of quartz phyllite and vulcanites the main minerals are arsenopyrite, galena, chalcopyrite, pyrite and sphalerite with malachite, azurite and calcite. Both types of deposits feature quartz. In the deposits related to the Bellerophon formation, small quantities of chalcopyrite, covellite, malachite and azurite can be found also, playing only a minor role during Bronze Age exploitation, together with silver and lead minerals.

Up to now, no data about copper mining during Prehistory is available. A reason for that could be the intensive exploitation of the area during medieval times that could have partly destroyed the traces of former mining activities.

In most cases the smelting sites are in proximity of the mineral outcrops, and they represent so far the only evidence of their exploitation during Bronze Age. There is nevertheless an important exception in this scenario: the Lavarone-Luserna-Vezzena plateau (Altipiani Cimbri). Here there is a high concentration of smelting sites, but there do not seem to be any significant copper deposits in the area (the reasons for the smelting activity in the area are discussed in detail in Pearce, 2007, pp.77-81).

In Vetriolo (Levico, Trento), at an altitude of 1,700 m a.s.l., the only site appearing to have been an area dedicated to the crushing and washing of ore had been discovered by E. Preuschen (Preuschen, 1962; 1973 pp.121, 126, fig. 4 & 7, tav. 1 & 2). The peculiar tools, including large grinding stones with and without vertical incisions, mostly made of porphyry, allowed him to date the site to the Bronze Age (Figure 2). No pottery has been found during the excavation, only two atypical fragments. The dating of the site is based on the morphology of the stone tools only. In the area of the mining dump, heavy, only partially liquified slag cakes can still be found, the so called *Schlackenkuchen* (Fig. 11). Outcrops of chalcopyrite and pyrite are present in the vicinity, smelting sites (at least six known in an area of ca. 10 km$^2$) and an impressive medieval and modern mining activity, although more focused on the extraction of pyrite, galena and barite (Detomaso, 2005, pp.99-100, 109-110; Gramola, 2000, pp.229-238).

In the adjacent area, Alto Adige/Südtirol, copper smelting is also attested from the third millennium BC (Millan, Gudon, Bressanone/Brixen, Velturno; Angelini, et al., 2013; Tecchiati, 2015 and references therein). Only one major deposit occurs, in Monte Fondoli/Pfundererberg near Chiusa/Klausen, and it seems to have been the source of chalcopyritic charge for all the sites along the Isarco Valley (Artioli et al., 2015, p.81). The more recent metallurgical phase is also attested by smelting sites with plate slags, "slag sand" and stone tools in Luco/Laugen culture contexts (Nothdurfter, 1993, pp.72-75; Anguilano et al., 2002a).

In spite of the difficult context, some hypotheses about the origins of copper ores have been advanced on the basis of chemical and mineralogical analyses of the slags. The

*Fig. 2: Grinding stone found in Vetriolo, dimensions 57x35 cm, height 18 cm (after Preuschen, 1962, fig. 4).*

analyzed smelting slags reveal a provenance of the raw material from the phyllitic basement of Valsugana (slags from Gaban, Acquaviva, Romagnano, Luserna sites), or from the deposits related to post-variscan volcanism (Val Fersina; Cattoi et al., 2001; D'Amico et al., 1998). Moreover, isotope analyses performed by Artioli and his team led to identify the Valsugana fault (Calceranica, Vetriolo) as the ore provenience area for the slags from Romagnano, La Vela, Gaban and Acquaviva, and the Mocheni Valley as the origin of the mineral processed at Montesei di Serso (Angelini et al., 2013; Artioli et al., 2014; 2015; 2016; Nimis et al., 2012).

The destination of the final product, the metal, is one of the most interesting topic of debate between scholars. The last researches based on isotopic data are shedding new light on the importance of the southern Alpine area as possible source of copper on a much larger scale than expected (Artioli et al., 2016; Jung et al., 2011; Jung & Mehofer, 2013; Stos-Gale, 2017).

An interesting case study is the mining district around Pergine Valsugana and Mocheni Valley, for the outcrops but also for the long history of mining activity (Fig. 3). The exploitation started during Prehistory, although we have no direct evidence of it, and had an important phase during medieval times, with residual activity up to the last century (Detomaso, 2005). In the area of Pergine the medieval exploitation was started in the 14$^{th}$ century AD by companies coming from Bohemia. One of the largest medieval mining district in the area is Serso-Viarago (Pergine Valsugana) with a polymetallic ore composed of chalcopyrite, pyrite, galena and sphalerite in quartz gangue, in veins up to 1 m thick. In the 14$^{th}$ century over 10 mines were active. They had been exploited till 1940. One of the mines, still existing, includes seven levels (by that the name "Sette sospiri", "Seven sighs"), the main mineral being chalcopyrite.

During the 14$^{th}$ century AD copper ore was exploited in the area around Pinè, in the Mocheni Valley, Viarago,

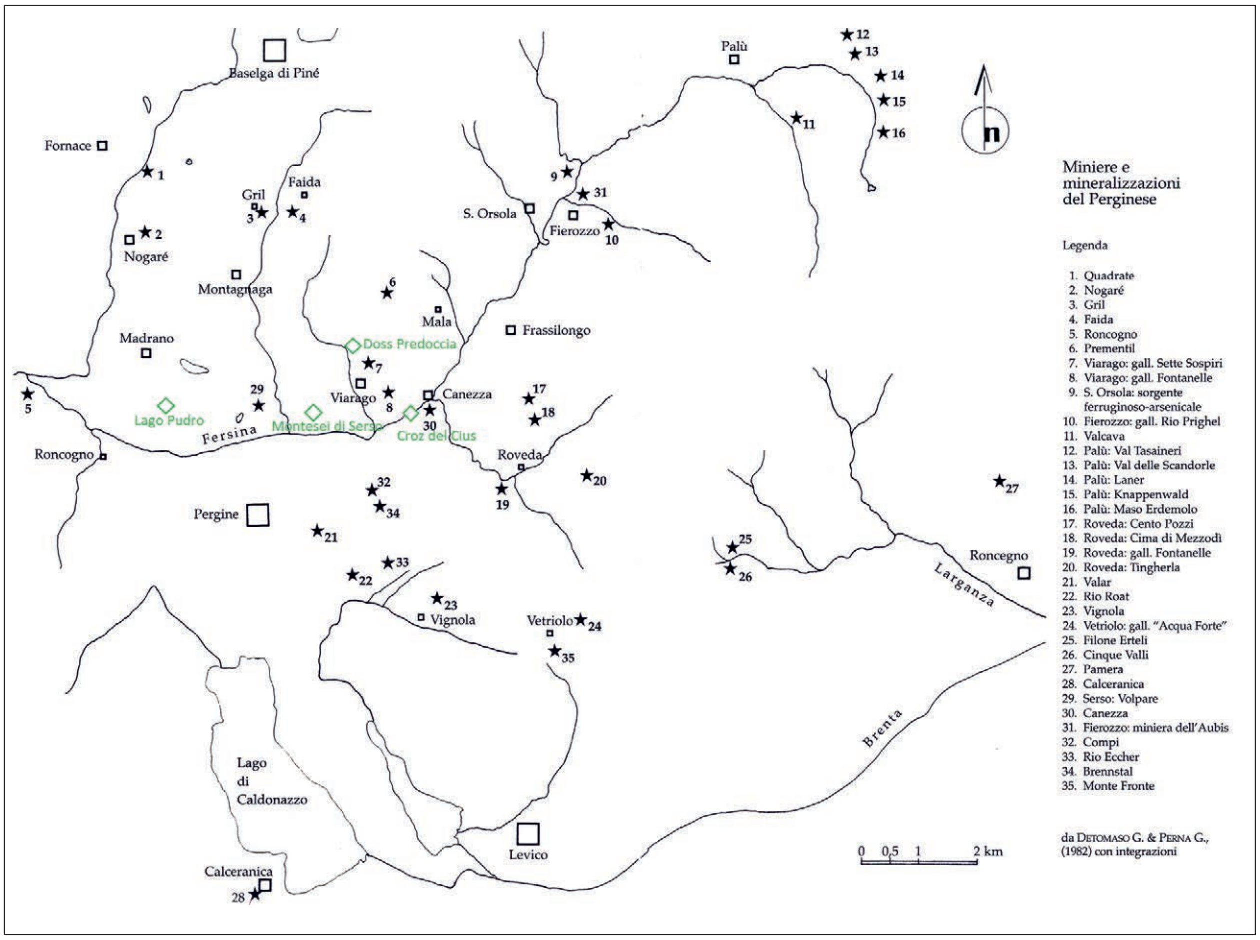


*Fig. 3: Map of the area around Pergine Valsugana and the Mocheni Valley (after Forenza et al., 2005). The star symbols indicate the mines and the outcrops exploited during medieval and modern times (not only copper ores); the green symbols are the prehistoric sites cited in the text. For the smelting sites see Figure 1.*

Roveda, Falesina, Vignola, Frassilongo (Zammatteo & Zampedri, 2004, p.414). A report written in 1522 states that in the mines in Viarago and Vignola 350 miners were working; Forenza reports 700 persons around 1400 in the area around Pergine (Forenza, 2005). In 1816 G.N. Hoffer writes about copper being still extracted in Valar, Vignola, Palù and Nogarè. According to G. Gasser (1913) there were more than 40 old mines and tests, with extraction of pyrite, sphalerite, galena and chalcopyrite.

Perna (1964, p.176) writes that at Viarago, in the Galleria delle Fontanelle, in 1916 the content of copper was 10,6 % and of silver 0,064 %. He reports that in 1964 the vein was max. 1 m thick and contained up to 6 % of copper. One should consider that at that time the deposits had been mined for centuries, and the veins were considered not exploitable anymore, according to industrial standards.

The same author reports that the mining area in Fierozzo was still working around half of the 19th century with an attempted copper ore extraction; in 1890 researches in Mocheni Valley and at Cinque Valli by an Austrian mining company showed important quantities of copper, lead and zinc minerals potentially to be exploited.

Juxtaposing the data about mining during medieval and modern times with the geological information about copper ores in the area gives a general overview of what could have been the exploitation during Prehistory, even with due caution when comparing exploitation during different ages.

The proxy evidence of mining activity in the area of Pergine and Mocheni Valley is the large number of smelting sites, of which two (Montesei di Serso and Croz del Cius) even belong to the first phase of metallurgy, between Copper Age and Bronze Age.

The human landscape is then completed by the presence of settlements belonging to the Late-Final Bronze Age (Montesei di Serso and Doss Predoccia), and, if we want to consider the enlarged chronology, a hoard from Lago Pudro including a wonderful sword (Bianco Peroni, 1970, tab. 42 no. 284) dated back to 10th century BC (that could be imported from Central Europe, Marzatico, 2001, p.402) and isolated finds like bronze objects and hoards in different localities of the Valsugana.

*Fig. 4: General view of the site of Valcava, with the two slag concentrations visible above the Balkof stream (photo: Ufficio beni archeologici PAT, N. Pagan).*

## Excavations

As mentioned above, the Ufficio beni archeologici has been carrying out excavations at different smelting sites in the last years. A new smelting site, Riparo Marchi, dating back to the so called "first metallurgical phase", during the second half of the third millennium BC, has been found and partly excavated.

The majority of the new excavations are smelting sites dating to Late-Final Bronze Age (Luserna Platz von Mozze, Valcava, Transacqua, and Segonzano Peciapian, Fig. 1).

About Luserna Platz von Mozze, Segonzano and Transacqua short notes have been published already (Bellintani et al., 2010; Silvestri et al., 2014; 2015a; 2015b). Here we are going to present the two sites that have been less described or more recently investigated: Valcava and Sant'Orsola Le Val.

### Valcava

In the area of the Mocheni Valley between Palù and Erdemolo, there are many small outcrops of pyrite with chalcopyrite, sphalerite and galena in a quartz-carbonatic gangue, with iron, copper and lead oxides (Lenzi, Tasaineri, Val delle Scandorle, Laner, Knappenwald, Maso Erdemolo, Ai Meus at Valcava, Figs. 1 and 3). The site of Valcava lies in the focal point of this area, less than 1 km from the "Ai Meus" mine.

The site consists of two different concentrations of slags: the southern area is around 110 m in length and between 10 and 30 m in width, with a max thickness of 40 cm, while the area to the north, around 30 m from the first one, is 70 m long and 10-12 m in width (Fig. 4). The area had been compromised by a ski track passing over it, hence the slags are quite spread and fragmented. The slag heaps are mostly consisting of broken plate slags/*Plattenschlacken,* with dimensions between 2-3 and 10 cm. Less slag cakes/*Schlackenkuchen*, sometimes even complete specimens (up to 40 cm in diameter), can be found.

In summer 2012 it was possible to establish that the area with evidence of smelting activity is around 900 m$^2$. The excavation was focused on the area with the structures, around 200 m$^2$, but the furnaces have been brought to light, documented and not excavated yet, because the financial support was missing.

Three furnaces have been found, two close to each other and a third one around 15 m far from them (Figs. 5 and 6). At least the two closer to each other were belonging to a complex, or they seem to have been operative at the same time. An evidence of that could be the similar orientation (NW-SE with open front to NE, facing the valley)


*Fig. 5: Valcava (Mocheni Valley). Photomosaic of the excavation area, with the three smelting structures shown in red. The burnt clay areas north of the two structures and in between furnace 2 and 3 could be remains of roasting beds. (graphic: N. Pagan Ar.Tech. srl.).*

and the belonging of furnace 1 and 2 to the same phase. It cannot be confirmed for sure that furnace 3 belongs to the same phase. Possible remains of at least two roasting beds have been found also. It is clearly evident that the smelting activity continued after the dismissing of furnaces 1 and 2 (and most probably of furnace 3 also), because the structures were completely covered by a thick layer of "slag sand". The structures belonging to this last phase have not been found yet.

*Fig. 6: Valcava (Mocheni Valley). Detail of furnace 1. (photo: Ufficio beni archeologici PAT, N. Pagan).*

## Sant'Orsola Terme

In the Mocheni Valley, on the mountain above Sant'Orsola Terme, works for a new forest road unearthed a slag heap. This was the starting point for a rescue excavation which took place during summer 2014. Two smelting furnaces have been excavated, singularly standing on an artificial terrace delimited uphill by a stone retaining wall (Fig. 7). In both furnaces the upper part was missing. The lower part was partly dug into the ground and built with a large flat stone to the bottom and stone walls on three sides. The stone structure was then coated with clay.

Both structures show layers of renovation, usually a layer of stones below, and above a layer of burnt clay covered by charcoal. Furnace 1 shows two phases of renovation (Fig. 8) and furnace 2 three phases. In the area around, some stone tools have been found, and some slags. No pottery has been found, besides a decorated body of a vessel that could be most likely dating to the beginning of the Iron Age. The slag heap was close by, downhill, but it hasn't been investigated. A very interesting structure is a pit, oval shaped, 90x54 cm and 50 cm deep, excavated in the terrace around 1 m from the closest furnace. The pit is filled with layers of slags, quite horizontal, stones and charcoal, but it does not show traces of burnt clay inside (Fig. 9). This

*Fig. 7: Sant'Orsola Le Val (Mocheni Valley). View of the area from East, with furnace 2 to the front and furnace 1 in the background. (photo: Ufficio beni archeologici PAT, N. Degasperi).*


*Fig. 8: Sant'Orsola Le Val (Mocheni Valley). Detail of furnace 1 during the excavation. The different phases of renovation are clearly visible. (photo: Ufficio beni archeologici PAT, N. Degasperi).*


*Fig. 9: Sant'Orsola Le Val (Mocheni Valley). The pit filled with stones and slags. (photo: Ufficio beni archeologici PAT, N. Degasperi).*

is not the first example of pits in a smelting site, and the discussion about the usage of these structures is still open (Hanning et al., 2015).

The position of the structures is the most important information. The use of the geomagnetic prospection was difficult because in all cases, with the exception of Sant'Orsola Le Val, the structures were covered by heaps of slags or "slag sand". The destruction of the furnaces seems to have happened during the frequentation of the sites for metallurgical activity. This is interesting because it clearly shows a sequence of events, with multiple phases of frequentation, even if chronologically limited in time, as the datings show (see below). The state of conservation of the smelting structures in Acqua Fredda seems to be an exception in the panorama of the area: in the other sites furnaces are always at least partly destroyed.

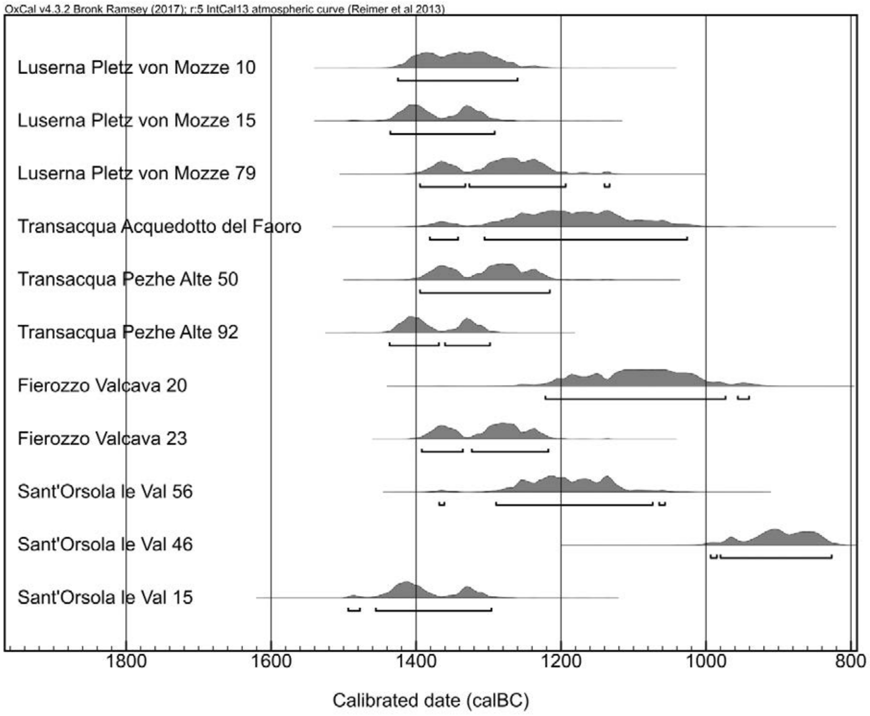


*Fig. 10: Diagram of radiocarbon datings of smelting sites from Late Bronze Age. Analyses performed at CIRCE (Center for Isotopic Research on the Cultural and Environmental heritage), Caserta (Italy).*

These furnaces are similar to those found at smelting sites in the Alpine area, belonging to partly different periods: at Kurtatsch (Bolzano, Alto-Adige) (Nothdurfter & Hauser, 1986; Hauser, 1986; Nothdurfter, 1993; Anguilano et al., 2009; Schifferle et al., 2014), at Mitterberg, Austria (Stöllner, 2015 and references therein), in the Jochberg area (Nordtirol; Koch Waldner & Klaunzer, 2015 and references therein) and in the Mauken area (Tyrol, Austria: Goldenberg, 2015 and references therein).

## The chronology

Eleven new radiocarbon datings (plus those from Riparo Marchi, first metallurgical phase, not presented here), still unpublished, are increasing our knowledge about the metallurgy in Trentino. The results are shown in Fig. 10 and tab. 1, calibrated at 95,4 % with the more recent radiocarbon curve (IntCal13, Reimer, et al., 2013, OxCal 4.3, Bronk Ramsey, 2009).

Other 28 datings are already existing (of which 13 from Acqua Fredda, 13 from other smelting sites in eastern Trentino and two from Lodner Moor/Bozen: Cierny, 2008, pp.68-70, tab. 3; Marzatico et al., 2010, tab. 2, 3, 7; Pearce et al., in press). They confirm the general attribution of the smelting activity to the final phases of Bronze Age, but on the basis of the radiocarbon datings it is possible to hypothesize that the smelting activity actually started during the Middle Bronze Age, in the 16th century BC, and continued till the 11th century BC. In some cases, like Sant'Orsola (see Fig. 10 and tab. 1), Acqua

| Site | Sample | Lab.Code | Material | Radiocarbon Age | Unmodelled (BC/AD) | |
|---|---|---|---|---|---|---|
| | | | | | From | to |
| Luserna Platz von Mozze | 10 | DSH8294_C | charcoal | 3080 (33) | -1426 | -1261 |
| Luserna Platz von Mozze | 15 | DSH8293_C | charcoal | 3111 (28) | -1436 | -1292 |
| Luserna Platz von Mozze | 79 | DSH8308_C | charcoal | 3028 (30) | -1395 | -1134 |
| Transacqua Acquedotto del Faoro | 15 | DSH8317_C | charcoal | 2972 (50) | -1382 | -1027 |
| Transacqua Pezhe Alte | 50 | DSH8310_C | charcoal | 3039 (27) | -1395 | -1216 |
| Transacqua Pezhe Alte | 92 | DSH8296_C | charcoal | 3114 (25) | -1437 | -1299 |
| Fierozzo Valcava | 20 | DSH8304_C | charcoal | 2903 (45) | -1222 | -941 |
| Fierozzo Valcava | 23 | DSH8299_C | charcoal | 3038 (25) | -1393 | -1218 |
| Sant'Orsola le Val | 56 | DSH8315_C | charcoal | 2975 (32) | -1369 | -1057 |
| Sant'Orsola le Val | 46 | DSH8307_C | charcoal | 2757 (32) | -994 | -827 |
| Sant'Orsola le Val | 15 | DSH8303_C | charcoal | 3127 (31) | -1494 | -1297 |

*Tab. 1: Results of the most recent radiocarbon datings.*

Fredda, Luserna, Casara Conti Mirafiori (Cierny, 2008; Marzatico et al., 2010), also more recent frequentations have been found.

Sample no. 10 of Luserna Pletz von Mozze is from layer 86, which consists of a lens of charcoal intergrown with lenses of burnt soil and clay, many pieces of plate slags and less numerous small pieces of slag cakes. The layer belongs to the most recent phase of activity. The sample no. 15 was associated with rare plate slags and Luco/Laugen pottery.

The datings from Transacqua Pezhe Alte are confirming the chronological attribution to the Late-Final Bronze Age made during the excavation, based on the pottery (Luco/Laugen A troncoconic vases). Sample no. 50 comes from layer 303, which is part of a large slag heap with stone tools, pottery, pieces of burnt clay and both plate slags and slag cakes. Sample no. 92 comes from layer 515, an ash layer which has been interpreted during the excavation as the bottom of a completely destroyed possible fire structure. The sample from Transacqua Acquedotto del Faoro, a site where a probable roasting bed has been found, comes from layer 1005, a layer of sandy clay completely burnt, above a layer of slags and stones, interpreted as the surface of the roasting bed. This site seems to be more recent than Transacqua Pezhe Alte, but so far it's still too early to get to conclusions, because the hypothesis is based on one dating only, and because the roasting bed, on the same mountain but lower in altitude compared to Pezhe Alte, clearly shows two if not three phases of use and renovation.

The samples from Fierozzo Valcava are, respectively, remains of the pole in a post hole connected to the smelting activity, and charcoal coming from a layer of abandonment of a structure completely destroyed.

The sample no. 15 from Sant'Orsola le Val comes from the layer filling the pit we mentioned above, with slags (*Schlackenkuchen*) and porphyry clasts. Samples no. 46 and 56 are coming from the charcoal lenses inside furnace 2 and 1 respectively, which belong to the most recent phase of both furnaces.

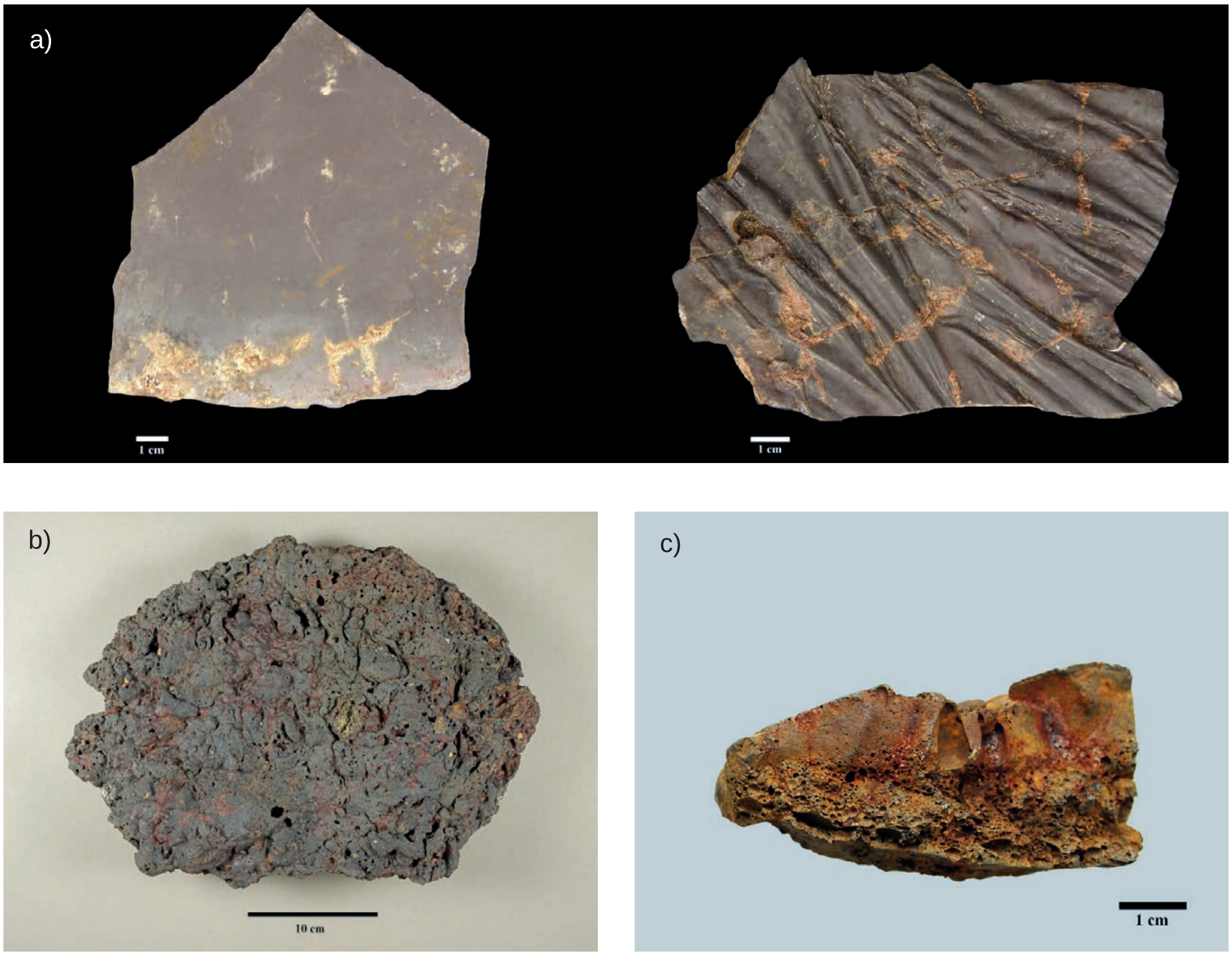


*Fig. 11: Different types of slags from the smelting sites in Trentino. A. Plate slags or Plattenschlacken with smooth and wrinkled surface; B. Only partially liquefied slag cake or Schlackenkuchen. On top, the cake shows inclusions of unmelted plate slags that were added as a "flux" for (s)melting. In addition, partly decomposed pieces of sulphidic CuFe-ores embedded in a siliceous gangue were identified. Note, that the slag only in spots shows flow structures. C. massive slag; (photo: DBM Bochum, E. Silvestri).*

## The slag database[3]

Since the early beginning of the work about copper metallurgy, description and definition of copper slags had been a problem. With the aim to collect as much information as possible about slag formation in the different sites, between 2006 and 2009 a systematic sampling took place at the major sites (Luserna, Segonzano, Transacqua) and data about slags have been inserted in a database. Short notes have been published so far (Bellintani et al., 2010).

The slag database records the visual and macroscopic characteristics of the fragments, in order to recognize typological classes and differences between sites. At the moment the database has 2000 slags recorded, coming from Luserna and Segonzano. They are part of 43 samples inserted, 22 from Luserna, 21 from Segonzano.

The database fields are: slag type, sides (for plate slags), thickness, weight, presence and type of rim, presence/absence of quartz inclusions, max diameter of quartz pieces, charcoal alveola, unreacted ore and slag fragments inclusions. Because it is difficult to recognize the type of the slag if the sample is too small, only pieces of plate slag larger than 4 cm have been recorded in the database. Morphometrical data is also being recorded, as the hypothetical diameter of the slag.

The definition of the slags and the terminology used to address the different kinds of slag is still not defined and homogeneous in the archaeometallurgical literature. So after the work of classification of the slag, a protocol of definition has been established. Most of the slags fit into three main groups, although there is a large variability. The thin plate slags, with a thickness between 0,2 and 0,8 cm, homogeneous with smooth, wrinkled or granular surfaces (Fig. 11a) correspond perfectly to plate slags. There is a variant of the plate slag*,* with a thickness of ca. 1-1,2 cm. The second type corresponds to the large, inhomogeneously composed slag cakes (Fig. 11b). A third type of slag has been called by us “massive“ slag: it is more than 1,8 cm thick, it has a higher density in the centre and a lower density close to the surfaces but the composition is quite homogeneous (Fig. 11 c).

The quantitative analyses are particularly exaustive in Luserna, where a slag heap, composed by layers 110 and 111, has been sampled by 30 to 30 cm excavation trenches. The result are 36 samples, with a total slag weight of 673 kg.

Out of these samples, particularly representative is sample 61 from layer 111, 75 cm thick, described as an example of composition of slag heap. The total weight of the sample is 38,68 kg. The observation of the sample gives a clear idea about the composition of a slag heap: around 80 % are thin plate slags, about 13% are thick (≥ 1 cm) plate slags, and the rest are coarse or undetermined. We described in detail around 100 fragments of plate slags, 65% of which present both smooth surfaces, in 19 % of the cases one surface is smooth and one wrinkled; 6 % show one smooth surface and one with drops on the lower side (dropping down to the molten material below); 5 % one smooth and one granular surface; 5 % one smooth and one irregular. In every site the composition of the slag heaps can vary a lot.

The samples from Segonzano have not been considered here because we excavated part of the “slag sand” heap but not yet the area with slag fragments, dispersed over a much larger area.

## The investigation of slags

Only a correlation between archaeology and archaeometry can help answering to the big problem of the formation of the slags (Hauptmann, 2007; 2014). The archaeological data from Jan Cierny´s survey (Cierny, 2008) and from the new excavations carried out by the UBA in the last decade need to be integrated with the archaeometallurgical analyses on the slags.

Other research teams have been investigating the composition of late Bronze Age slags from Trentino and Alto Adige/Südtirol (Metten, 2003; Cattoi et al., 2000; Anguilano et al., 2002a; 2002b; Addis et al., 2016; 2017), giving partly different interpretations of the operative chain.

The project is going to be an in depth examination of the chemical and mineralogical composition of about one hundred slag samples, collected from ten different smelting sites, part of them from excavations and part from the surface collections. The sites are: Segonzano Peciapian, Transacqua, Valcava, Luserna Pletz von Mozze, Malga Millegrobbe, Pinè lago delle Piazze, Malga Pontara, Malga Regnana, Malga Laghetto and Passo Vezzena sud (Fig. 1).

The questions and problems the research is trying to solve are:

- From which metallurgical operations are plate slags (*Plattenschlacken)* resulting? Did they form inside a furnace or have they been tapped?
- What is the difference to a slag cake? Is the difference between the two kinds of slag only due to the cooling or is there a difference in the texture and/or chemical composition?
- What was the reason for processing slags to produce “slag sand“ frequently found in the smelting sites in the Alpine area? Is it a product of crushing slag cakes or plate slags? What was extracted, what was the aim of this activity?

Other questions can be correlated:

- Are there differences between slags from the different smelting sites mentioned above?
- Why have plate slags been found only in Recent-Final Bronze Age and not in the more ancient sites? Is it a technological development?
- Why are plate slags and the slag cakes, most of the times, found in different layers in the stratigraphy?

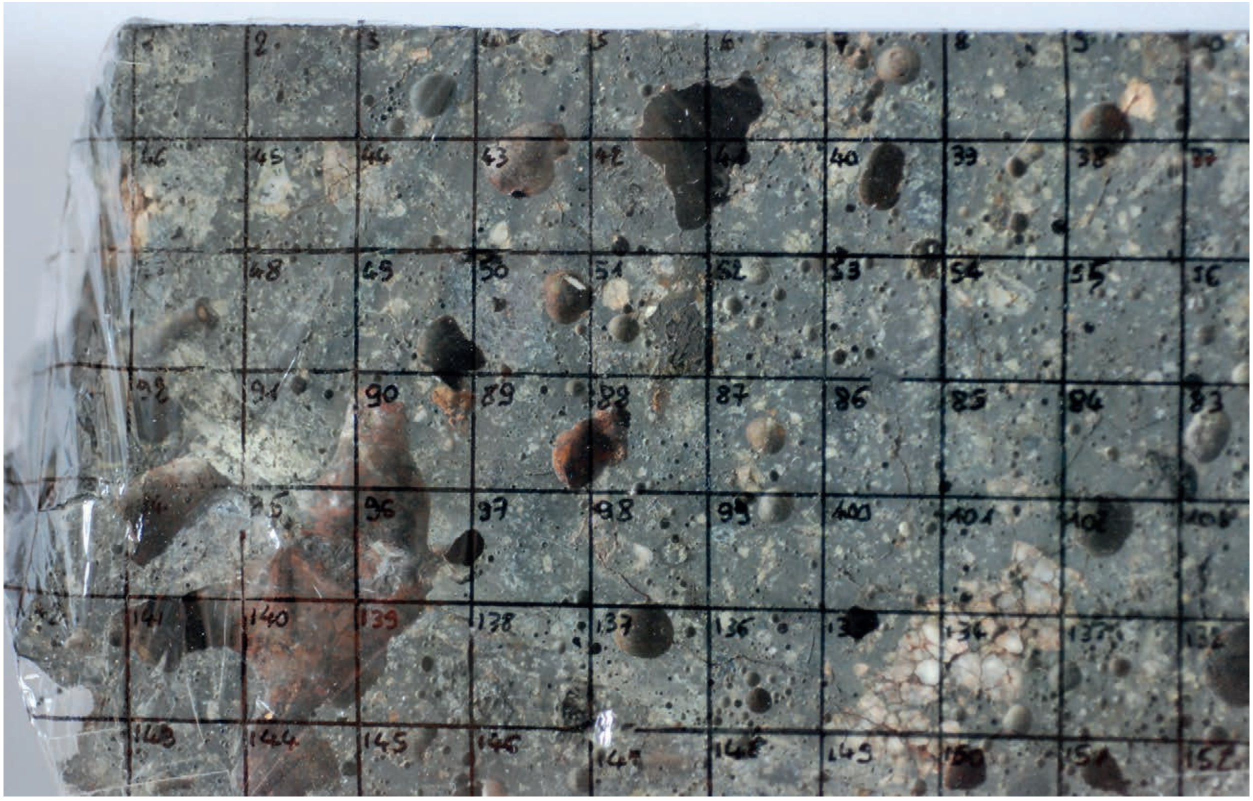

*Fig. 12: Luserna, slag cake. The slag cake has been cut in two parts, to demonstrate the heterogeneous texture of this type of slag. Squares of 1 cm have been drawn on the surface, with the help of a transparent plastic foil. The image shows that relics of highly refractive, light minerals (mm- to cm-sized) are distributed throughout the cake. See Figure 17 for the chemical composition of the slag in the different squares (photo: DBM Bochum, E. Silvestri).*

Plate slags tend to be in connection with LBA smelting processes, but their formation is still unclear. Surface polished thin sections of 20 samples have been examined by optical and scanning electron microscopy (SEM) to establish the texture of silicate and oxide phases of the slag, and the presence, shape and size of the sulfide inclusions. SEM with an attached EDX-system was used to analyze the bulk composition of the slag by scanning various subareas in the slags, the composition of the sulphidic inclusions (by plane squared scans) and the presence of oxidized silicate phases at the surfaces of the slags to determine the location of their cooling.

In addition, a completely preserved slag cake with a diameter of 20 cm has been cut and investigated in detail, analyzing by portable XRF more than one hundred points on the surface of the inhomogeneously composed slag (Fig. 12). We analysed the most homogeneous areas only, trying to avoid quartz relics, in order to compare the matrix with the one of the plate slags.

## Preliminary results

First in a macroscopic observation it can be clearly seen that the plate slags have been cooled on top of a liquid mass, because they have mostly smooth or wrinkled surfaces both above and below. In other cases one of the surfaces (never both of them) shows clearly that the slag cooled down on an irregular, granular surface, probably the ground. The fragments of the plate slags show that the original shape was circular and they frequently have rounded edges with inwardly-twisting rims. The appearance fits perfectly with the description of plate slags/ *Plattenschlacken* in the German literature.

The slags have been described on the basis of macroscopical observation, optical microscopy and SEM-EDX analyses combined together. In general, it can be observed that:

- Plate slags are composed mainly of the iron silicate fayalite ($Fe_2SiO_4$). The texture of the fayalite crystals is varying in size and shape, but frequently it forms needles vertically to the surfaces. In addition, magnetite ($Fe_3O_4$) and Cu-Fe-sulphide inclusions composed like chalcopyrite ($CuFeS_2$), bornite ($Cu_5FeS_4$) and digentite ($Cu_2S$) are distributed throughout the slag. The slags are only 0.5 cm thick in average and rarely contain any macroscopically visible inclusions. They appear to consist of an ideal eutectic composition. The bulk composition values of the analysed samples have been inserted in a FeO (+ CaO + MgO) – $Al_2O_3$-

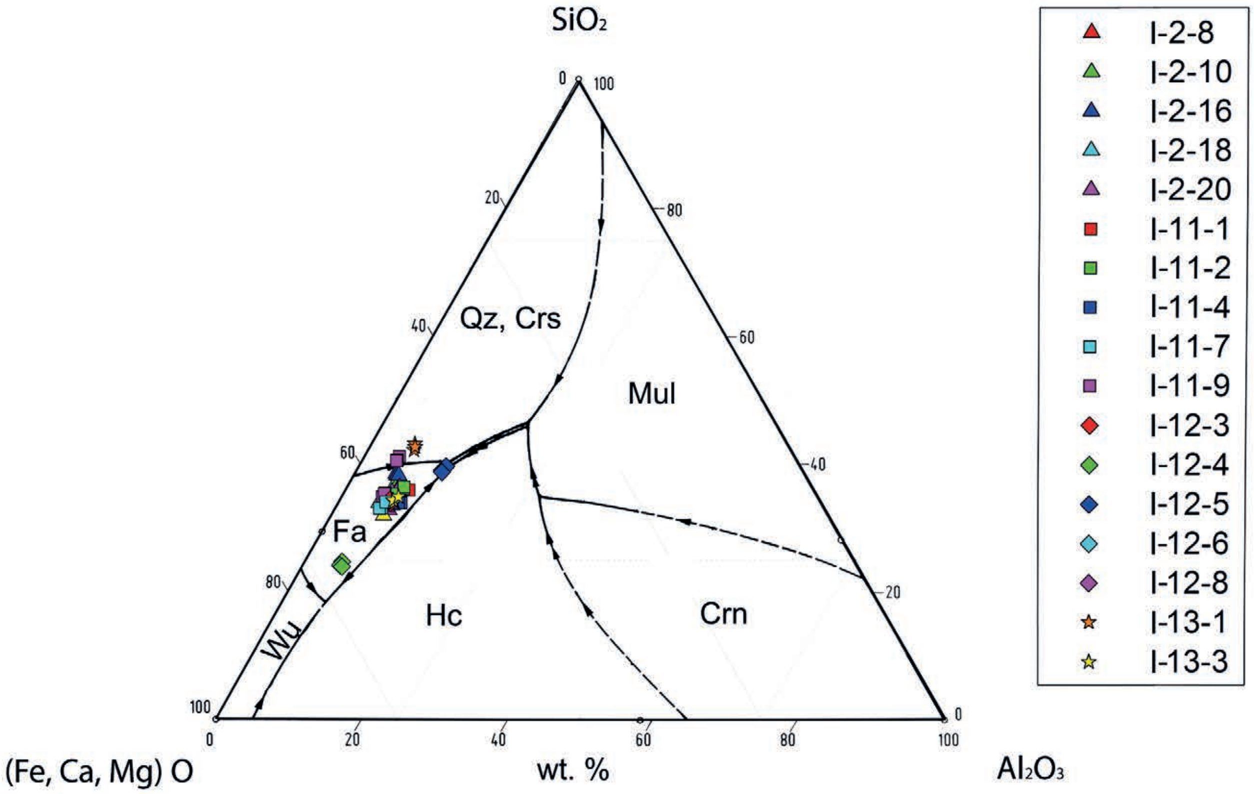


*Fig. 13: Phase diagram FeO - $Al_2O_3$ - $SiO_2$ (after Osborn & Muan, 1964) showing the bulk composition of plate slag samples from various slag heaps in the Trentino (I Italy, 2 Luserna, 11 Transacqua, 12 Segonzano, 13 Malga Pontara), and sample number. Note that lower MgO and CaO contents were added to FeO.*



*Fig. 14: Pictures of thin sections of plate slags (samples I-2-16 and I-2-18 from Luserna, Platz von Mozze) taken with an Olympus optoscope in the panorama mode (light from below). Up to 40 pictures of every slag have been taken and composed together in a photo mosaic; (photo: DBM Bochum, E. Silvestri).*

$SiO_2$ diagram (Fig. 13). They fit perfectly in the low melting liquidus field of fayalite with an eutectic point around 1150 - 1200 °C.

- The amount of magnetite and Cu-(Fe-)sulphide inclusions can vary, plate slags are not as homogeneous as they seem; different subtypes can be recognized (examples in Fig. 14). Some are really homogeneous and composed mostly by fayalite, with very few inclusions of magnetite and Cu-Fe-sulphides; others contain much more magnetite and Cu-Fe-sulphides, scattered or in agglomerations. The difference is not only in the quantity of Cu-Fe-sulphides included, but also in their size: the inclusions are normally bigger in the latter type.
- The SEM analysis of the mineral phases along the rim of the slag shows the oxidation of the two surfaces,

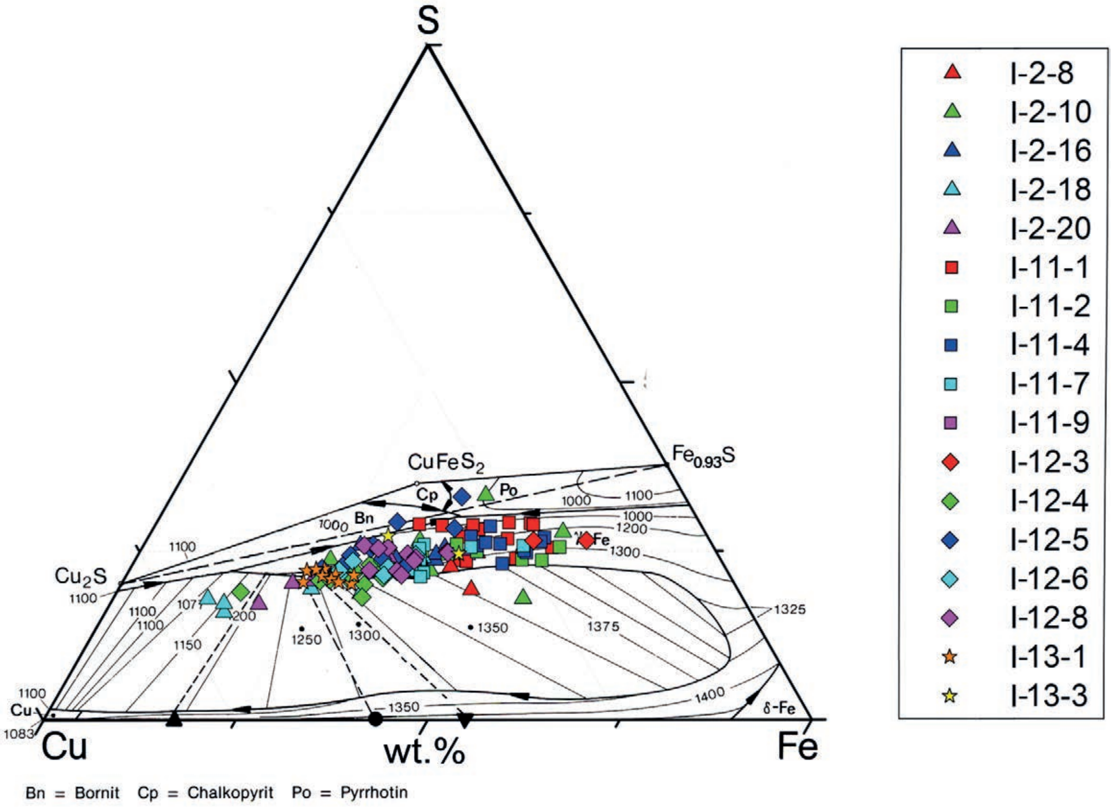


*Fig. 15: Chemical composition (method SEM-EDX) of Cu-Fe-sulphide inclusions in plate slags from various localities in the Trentino (for captions see Figure 13), plotted in the lower sulphide area of the Cu-Fe-S diagram (after Schlegel & Schüller, 1952). Note the miscibility gap between the S-rich side (represented almost by the line $Cu_2S$ - $CuFeS_2$ - $Fe_{0.93}S$) and the metal-rich side between Cu and Fe. The majority of the sulphide inclusions have high iron contents. The connection lines (conodes) clearly show that these compositions would exclude a precipitation of copper, i.e., these slags are not suitable to produce copper. Exceptions are a few sulphide inclusions in slags from I-12/6 which are in equilibrium with copper and copper low in iron.*

and helps to recognize which one is the upper part of the slag. In several cases both surfaces show traces of oxidation. This makes it difficult to distinguish the upper surface of the slag, in contact with the oxygen, from the bottom. The oxidation seems to be correlated with the different types of surface: the smooth surface shows (almost always) oxidation traces. If the slag has two smooth surfaces it often happens that both of them have oxidation traces. The wrinkled surface may also show traces of oxidation. The irregular and the granular surfaces very rarely present oxidation.

- Cu-Fe-sulphide inclusions are scattered throughout the matrix, with no difference between upper and lower part or particular concentrations, except for magnetite agglomerations. It is important to note that we did not find evidence for any enrichment of matte or metal rims above or below the plate slag.
- The Cu-Fe-sulphide inclusions can be round-shaped prills or, more frequently, irregular shaped with a size of some micrometers only. They consist mostly of chalcopyrite, sometimes with lamellae of bornite, and surrounded by covellite (Fig. 15). These phases were formed by corrosion. Most of the sulphide inclusions, however, were more or less totally corroded and leave a hole in the matrix.

Fig. 16 shows that the Cu-Fe sulphide inclusions are quite homogeneous, usually their size is less than 200 µm.

The most interesting point is that in the slag cakes from Trentino there's no clear separation between liquefied matrix and inclusions, which are scattered throughout the slag without being concentrated, on one or the other side.

- Plate slags normally do not contain inclusions of quartz, with the exception of two analysed samples. Some samples from Acqua Fredda, already analysed by Beate Metten in the 1990s, have been reconsidered under the optical microscope. They seem to contain more quartz. The reason is probably because they have been classified as plate slags but most of them are "massive slag", following our definition.

Quartz grain fractures and inclusions normally contain a lot of Cu-Fe sulphide inclusions. This is coherent with the kind of ore available in the area, containing quartz in the gangue.

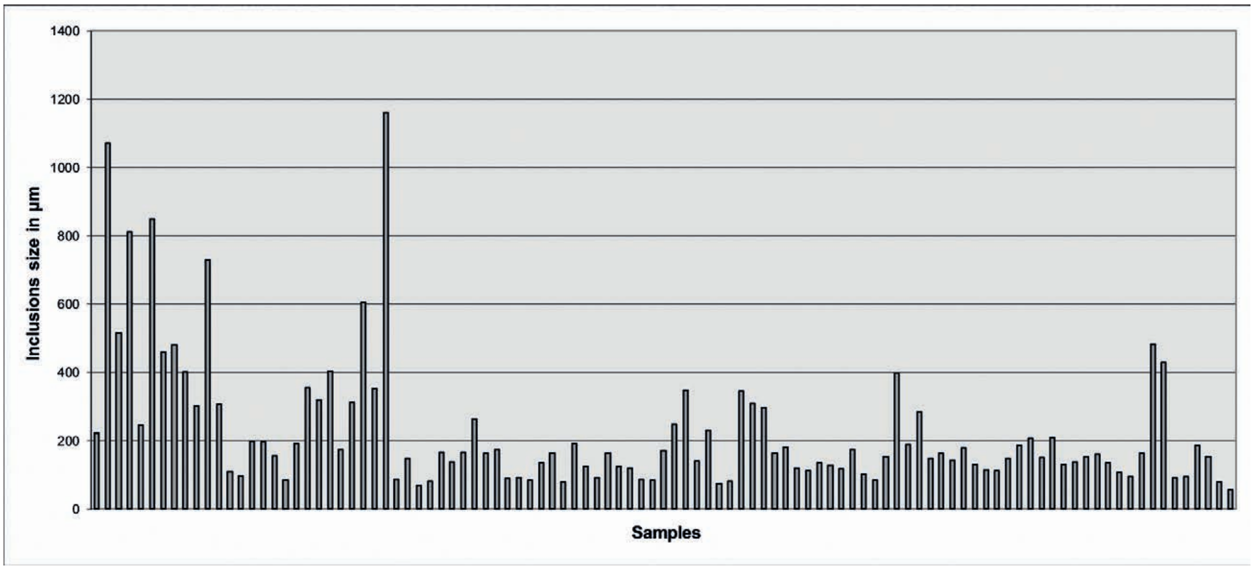


*Fig. 16: Diagram showing the size of Cu-Fe sulphide inclusions in plate slags.*

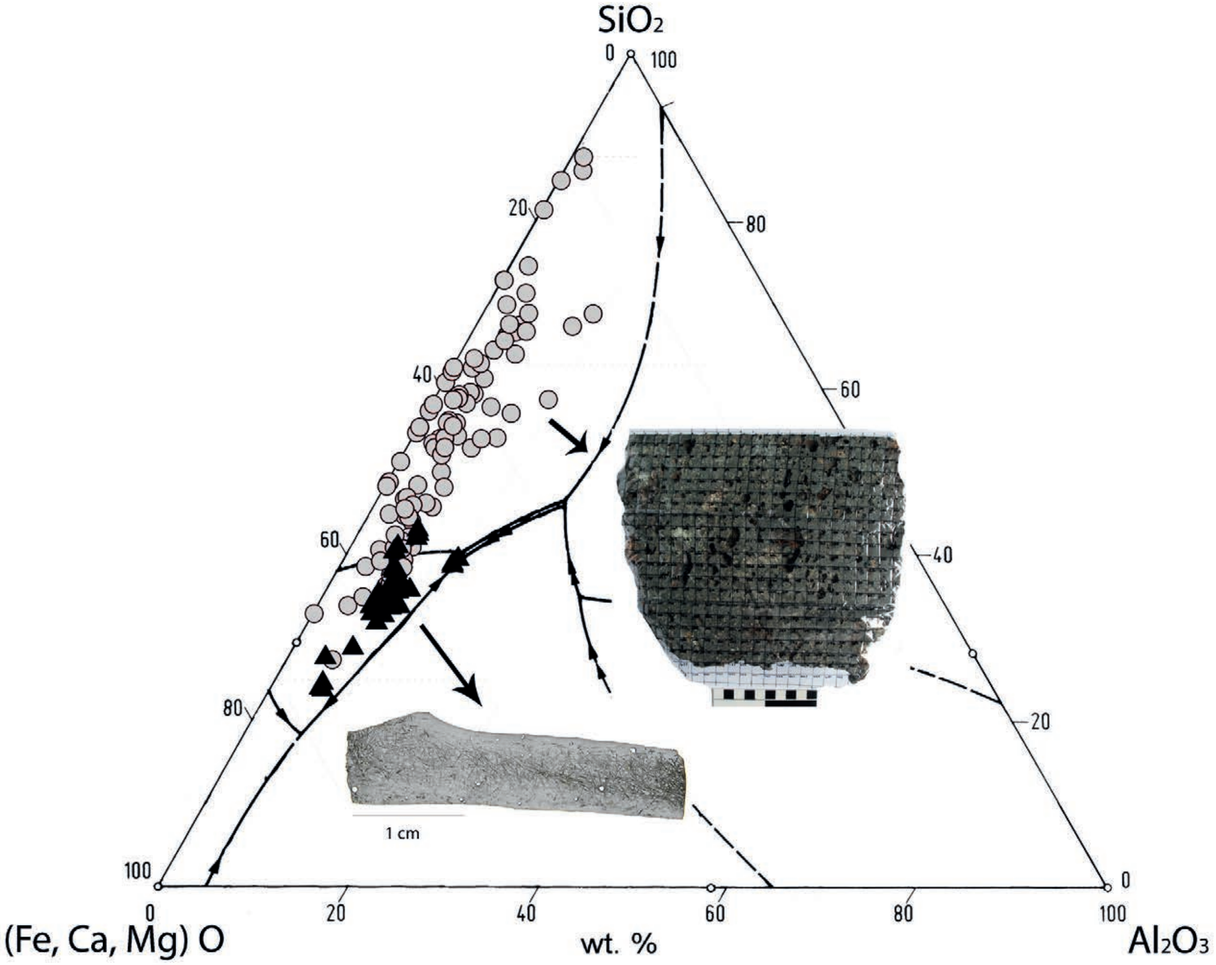


*Fig. 17: Plots of the main oxide constituents in the phase diagram $SiO_2$ – FeO (+CaO+MgO) – $Al_2O_3$ of plane scans performed on a slag cake (see Figure 12) and various plate slags. Ca. 100 spots were analysed on the slag cake, and 55 in thin sections of plate slags. Methods: pXRF (Niton XL3t), SEM (Zeiss Supra 40 VP). Note development from $SiO_2$-rich (unmelted) compositions to low melting subareas in the slag cake.*

## Comparison with the other kinds of slag

The coarse slags (or slag cakes or *Schlackenkuchen*) are much more heterogeneous than the plate slags and contain quartz inclusions, charcoal and non-reacted ore. They can be interpreted as partially liquefied charged material ("immature slag") composed of unmelted "resisters" and fully liquefied subareas with eutectic composition. The liquefied areas of them are composed mainly of fayalite with Cu-Fe sulphide inclusions, apparently not so different from the plate slags/*Plattenschlacken* matrix (Fig. 17).

The so called "slag sand", or better "crushed slag", two samples of which have been analysed, is composed of small pieces of slag (granulometry 1 - 3 mm). Some of these pieces contain fayalite but most of them are composed of quartz. "Slag sand" is found at LBA smelting sites only. It results from slag, probably crushed in order to separate and collect the remaining copper, matte or unprocessed mineral particles.

## Conclusions

The research carried out in the last ten years has increased consistently the knowledge about the Bronze Age smelting processes in the southern Alpine area. The new excavations have brought to light the evidence of technological steps unknown before, like the existence of roasting beds as it is common in the northern part of the Alps. The research at the smelting sites showed important differences between sites, which need to be further investigated. The radiocarbon datings confirm the general attribution of the smelting activity to the final phases of Bronze Age, but show in some cases also surprisingly recent frequentation of the sites.

The other field of the research, the investigation of the slag by optical microscopy and SEM-EDX analyses, shows that plate slags predominately consist of fayalite. Hence, they were almost totally liquified around 1150 - 1200 °C and cooled down very quickly. The slag formation was concentrated in the low melting range of the main components of the material system $FeO$-$SiO_2$-$Al_2O_3$. This means that the composition of materials for the formation of plate slags was deliberately and most carefully controlled. Alternatively, plate slag have been automatically formed as a partial liquid in a larger silicate system – perhaps from the slag cakes.

The slag cakes are much more heterogeneous. They are never completely liquified and contain inclusions of (sulphide bearing) quartz and of plate slags (as a flux?). The liquefied areas are free of inclusions and consist mainly of fayalite with Cu-Fe sulphide inclusions, apparently not so different from the plate slags matrix.

The analyses are still in progress, and the focal point of the next steps of the research will be the formation of the different kinds of slags found in the archaeological context. In order to better understand the technological processes applied in the Late Bronze Age Trentino it would be helpful to include any methods of small scaled metallurgy or any ethnographic evidence.

## Notes

1 A third phase has been evidenced by radiocarbon datings but no clear evidence of structures has been recorded (Cierny, 2008; Marzatico et al., 2010).

2 The chronology is now under discussion, see paragraph "The chronology" below.

3 In collaboration with Livia Stefan.

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