2016 | Nr. 22.1

METALLA

DBM

METALLA (Bochum)
Biannual journal (June, December)

Subscription Price: 30€ per year. Price includes postage and packing. For subscription contact the Deutsches Bergbau-Museum Bochum
Am Bergbaumuseum 28,
D-44791 Bochum, Germany

Impressum

Publisher

Deutsches Bergbau-Museum Bochum
Museum Director: Prof. Dr. Stefan Brüggerhoff

Layout Design: Dipl. Ing. Angelika Wiebe-Friederich

Printing: Grafisches Centrum Cuno GmbH & Co. KG

ISSN 0947-6229

Geoarchaeological Investigations in the Bronze Age Ore Beneficiation Landscape of Troiboden (Province of Salzburg, Austria)

Elnaz Rashidian

Keywords

copper mining, geoarchaeology, Kubiëna, Middle Bronze Age, ore beneficiation, pXRF, XRD

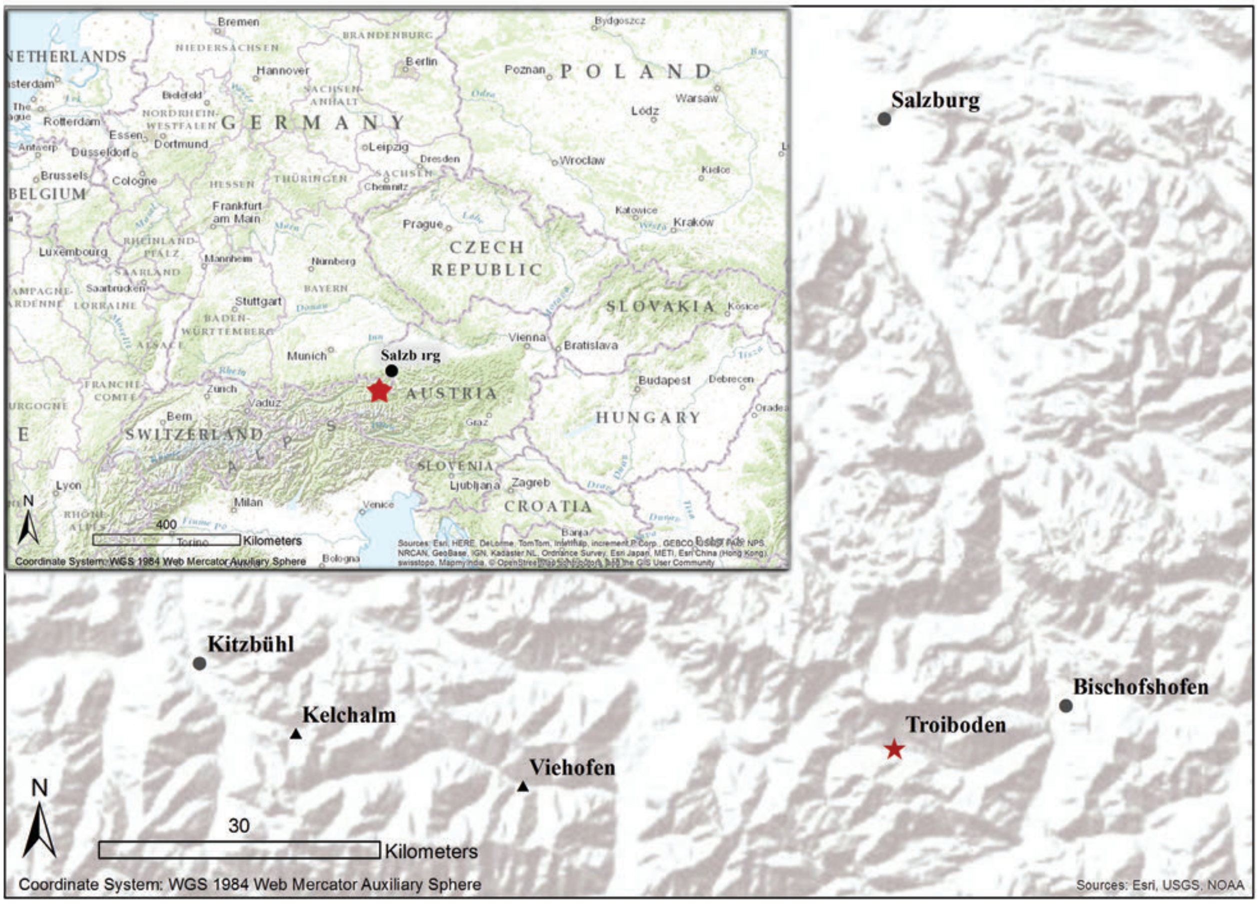
Abstract

Mitterberg is the largest known Middle Bronze Age copper mining area in the Austrian Alps. During the course of the 2011 excavation campaign, a geoarchaeological investigation was conducted at the Troiboden peat bog, immediately southwest of the Mitterberg mine's main entrance, which shows evidence of a more sophisticated ore beneficiation process with less copper loss than previously anticipated and has yet to be demonstrated at Bronze Age sites elsewhere. A portion of results of this investigation is summarized here. A sediment typology based on geoarchaological analysis is presented, and interpretations are made regarding the situation of the ore beneficiation landscape of Troiboden and its relationships both with the Mitterberg mines and its natural setting.

Introduction

Mitterberg – surpassing the mines of Kelchalm and Viehhofen (Preuschen and Pittioni, 1954) – is one of the most important mining areas of the Middle Bronze Age

Figure 1. Outline map of Troiboden in Austria.



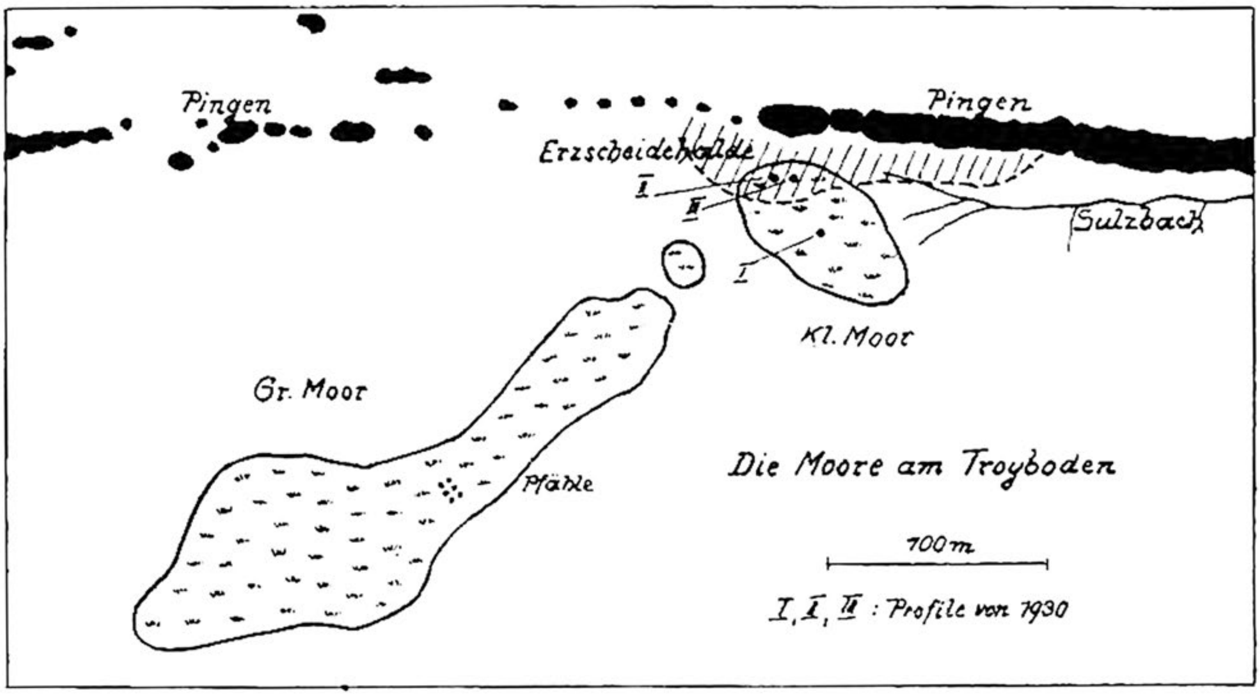


Figure 2. Troiboden peat bogs and documented traces of Middle Bronze Age mining and ore beneficiation (after Firbas, 1932, p.174). The *pingen* are collapsed mine remains and the *Erzscheidehalde* are heaps of mining waste rock. Three sections were made (I-III) to try to understand stratigraphic layers and to reconstruct the climate and vegetation.

in Europe. Although all of these districts are situated in the so-called geological “greywacke” zone in the Alps (Oxburgh, 1968, pp.22ff), each has their unique geological characteristics (Lutz, et al., 2010). The Mitterberg chalcopyrite ore deposit is located about 45 km south of Salzburg, at the northeastern edge of the Austrian Alps. At the current state of research, the name “Mitterberg” includes not only deposits of the so-called main course near the Mitterberg Alm (the original region), but also the veins to the south and to the east (Stöllner, 2011, p.94). Archaeological evidence suggests an extensive use of *“Mitterberg type”* copper during the Bronze Age, being identified in most of the prehistoric copper-containing objects throughout central and western Europe (Stöllner, 2011, p.95).

Directly southwest of the main entrance to the Mitterberg mines lays the modern-day peat bog of Troiboden (Figure 1), which covers a buried landscape of Bronze Age ore beneficiation of approximately 2.5 hectares, containing massive heaps of sediment waste material (Eibner, 1972 p.3; Stöllner, 2009 p.54). These waste dumps at Troiboden were rediscovered accidentally early in the 20th century, as a test trench was dug along the existing water drainage in order to examine a possible peat extraction for economic purposes (Kyrle, 1912, p.198).

Extensive traces of ore beneficiation from the Bronze Age came to light in the 1930s (Figure 2), but C. Eibner was the first to excavate the area systematically in the 1969-72 campaigns (Eibner-Persy and Eibner, 1970, p.16; Eibner, 1972, pp.4ff). In addition, he found a surprisingly well-preserved wooden wash box, which was interpreted as part of a wet beneficiation process (Eibner, 1972, p.5). Later, another box was excavated near the first one during the 2008 campaign (Stöllner, et al., 2010), which was then dendrochronologically examined, suggesting a precise absolute dating of 1377-76 BC (Stöllner, 2011, p.101). During the course of the 2011 excavation campaign[1] in this area, a geoarchaeological investigation was conducted in order to get a better understanding of the ore treatment methods in Bronze Age Europe.[2] A summary of the results shall be presented now.

Ore Beneficiation – A Geoarchaeological Approach

There are different aspects to be considered when studying ore beneficiation processes, such as the theoretical (Stöllner, 2003, p.418) or technical aspects. Geoarchaeological methods can bring to light details of the technical aspects via studying micro-geo-factors of this area and its containing sediments, which are mostly remains of the ore beneficiation process. In addition, post-burial disturbances of the archaeological site context – in this case, the remains of copper ore treatment – are to be considered thoroughly, being an important factor to influence anthrosols[3] as those found at Troiboden.

The process of ore beneficiation has certainly evolved and grew in sophistication over the millennia; however, the procedure cannot be other than the separation of ore and waste rock, which can be done generally by crushing the ore-containing rock and washing the material repeatedly. The conscious processing of copper ores was probably carried out with the help of numerous wooden and stone tools in a specific order, in which the sulfide ores were crushed repeatedly, to ultimately extract up to 95% of the copper out of the remaining material. The rest ended up as "waste rock" on the numerous waste heaps at Troiboden.

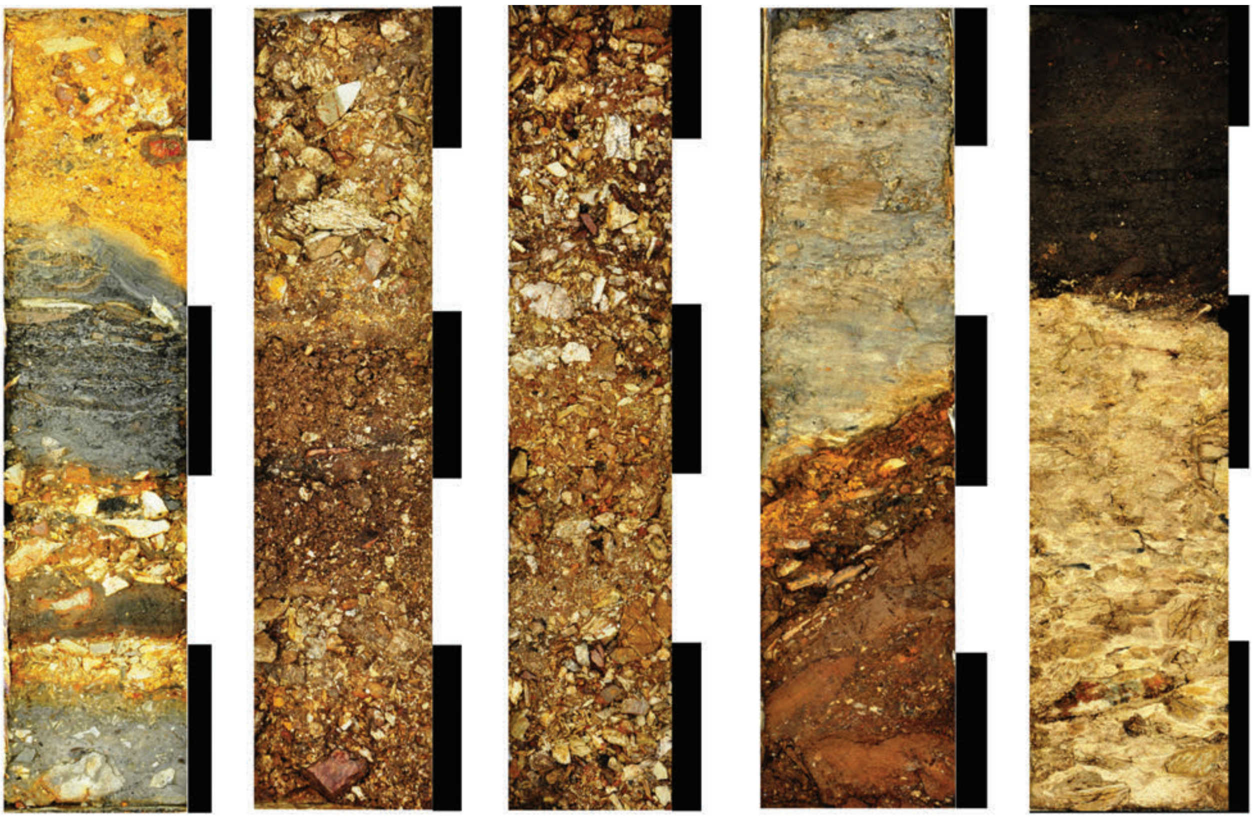
Processes such as hammering, pounding, washing and grinding leave different traces on the soil morphology and affect both the shape and size of each grain of each layer. These characteristic traces allow a geoarchaeological approach to reveal specific details about ore beneficiation processes at Troiboden.

Sampling and Methods

For the current study, during the excavation season in August 2011 a total of five sediment sections were sampled *en bloc* after the "Kubiëna" protocol.[4] Their locations were continuously recorded and designated, using the Troiboden archaeological database system, as 7289, 7290, 7293, 7294 and 7295. These samples were selected from different sections of the moor in a manner so that they could represent the diversity and complexity of existing sediments at Troiboden, being spatially distributed along the natural depression (Figure 3). The first four samples are selected from the northern profile (south-facing) of the excavated trench; only the last one belongs to the southern profile.

Methods used to analyze the sediments are the following. Color determination was based on the Munsell Color Chart (1998). The particle and grain sizes were determined by the Köhn method: dry and wet sieving and pipettes.[5] A K-factor was determined for the particle sizes of each sediment layer and it is based on a 1 to 5 scale – fine, middle fine, middle coarse, coarse and very coarse.[6] The sorting degree (0 to 100 – unsorted to well sorted),[7] gravel portion (0 to 70% sand to pebble-sized grains), roundness (0 to 1 – sharp to round), sphericity (0 to 1 – irregular to spherical) and elongation (0 to 3 – equidistant to elongated) were determined by polarized light microscopy. Loss on ignition (0 to 1), water content (0 to 200%), electrical conductivity and pH-values are routine soil laboratory analyses. The copper (0 to 2 %) and iron (0 to 25 %) contents were measured semi-quantitatively with a portable X-ray fluorescence

Figure 3. Sections in Kubiëna (from left to right, 7289, 7290, 7293, 7294, 7295) showing the range of variation of the stratigraphic layers and the color and morphology of the sediments. The scale is 50 cm.



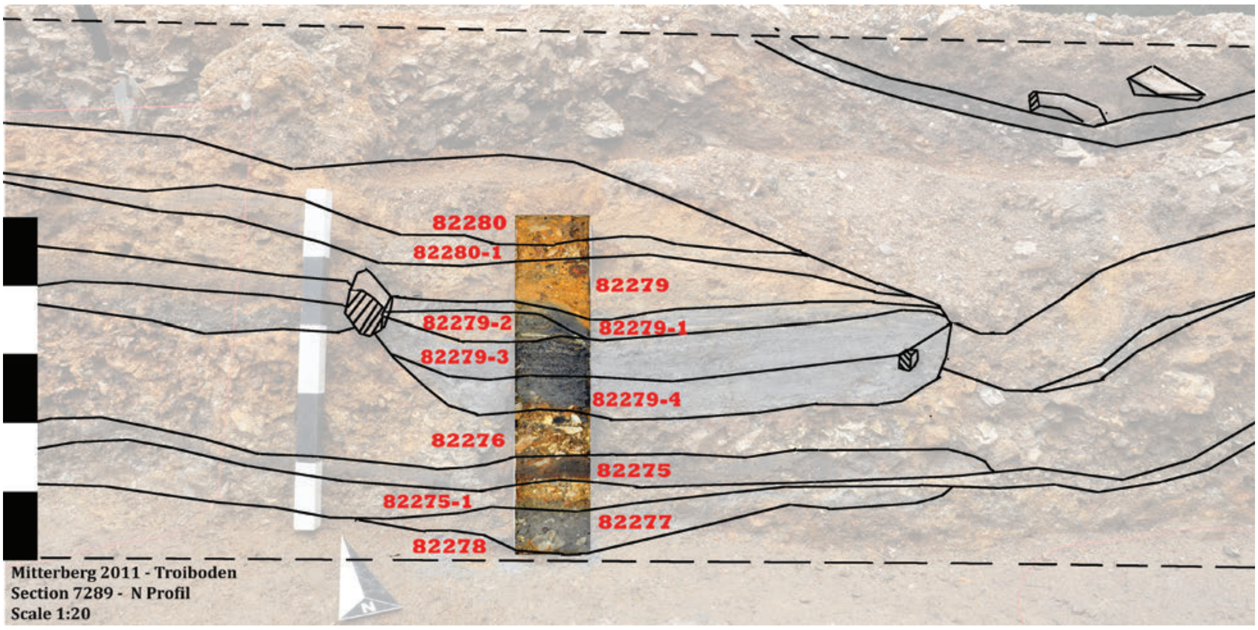


Figure 4. Section 7289 *in situ* and its recognized sediments.

device (pXRF, Thermo Scientific NITON XL3t). For the identification of minerals present in the sediment samples, X-ray diffraction (XRD) was used. The instrument is a PAN alytical X'Pert (PRO MPD) with a X'Celerator detector and uses High Score Plus-software.

Results

A short explanation of each section based on visual observation as well as laboratory results follows:

Section 7289: At the first glance (Figure 4), this section may represent the remaining fine sediments of possible wet treatment and appear similar to those of the wet treatment box excavated by Stöllner, et al. (2010, particularly p.24). Boxes are known to have been found at the Troiboden; an additional box feature interpreted as a wet treatment box was excavated previously by Eibner-Persy and Eibner (1970). The presence of a fine ashy "blue sediment" as the most crucial evidence of wet beneficiation process in this section points to this interpretation. However, the existence of several tiny fragments of wooden splinters, or *Leuchtspäne*, in the sediment texture may indicate a fire assemblage. There is no doubt that the upper ash-blue materials in this section are layered via water over the course of a span of time.

Eibner was confronted with the same layer in his excavation area where he came upon a stone hearth in the trench B3 / B4. He suggested that the hearth could have had a certain multifunctionality due to its complex structure and the frequency of such findings in other known beneficiation landscapes, i.e. the hearth could have been used for cooking, as well as to facilitate the work in cold and / or humid seasons.

Other functions could be drying of wet sediments, heating water for wet processing, as well as practical everyday uses (Eibner, 1972, pp.13ff). The two existing blue layers from the present section were each compared to the one layer (Stöllner, et al., 2010, p.24) from the 2008 excavated wash box. This has been done in order to find out whether their origin might be the same, i.e. wet-beneficiation through a wash box. Interestingly, only one of the two presented blue layers of this section was identical in its elemental and mineralogical composition to the 2008 wash box layers. The peaty characteristic of the second one and the overall greater complexity of this section in comparison to the known wash box sections suggest a wet beneficiation process, yet there seem to be slight differences in technique and may exhibit a stronger influence by nature than the others.

This particular combination of the layers, the sorting of the sediments and the above mentioned composition suggest a further meaning, beside its original interpretation or other than it being merely a wash box. The existence of a tiny pond[8] seems plausible in this regard. Whether this area was deliberately filled with water for practical uses, or if it was just a natural sedimentation of materials carried by surface water over a period of time, is unclear at the moment.

Certainly, the complexity of this section suggests several methods of wet beneficiation, maybe even different washing methods after each step of dry-treatment. This is suggested based on two or more types of sediments

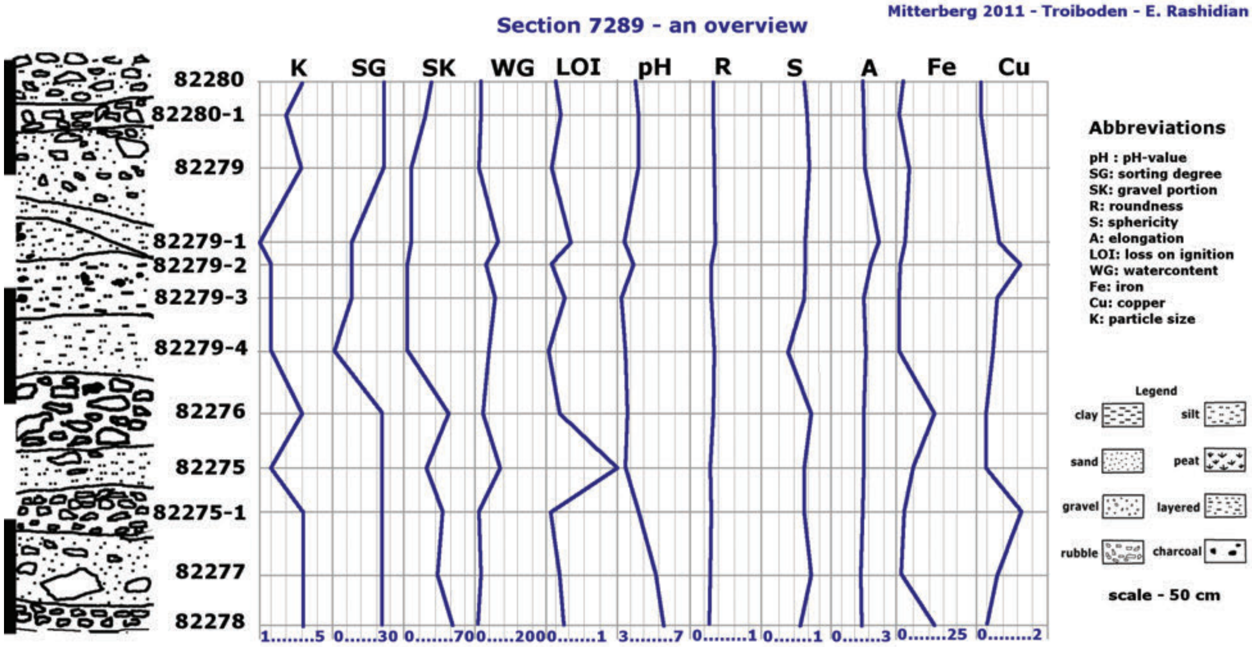


Figure 5. An overview of section 7289 based on selected laboratory results (see Methods).

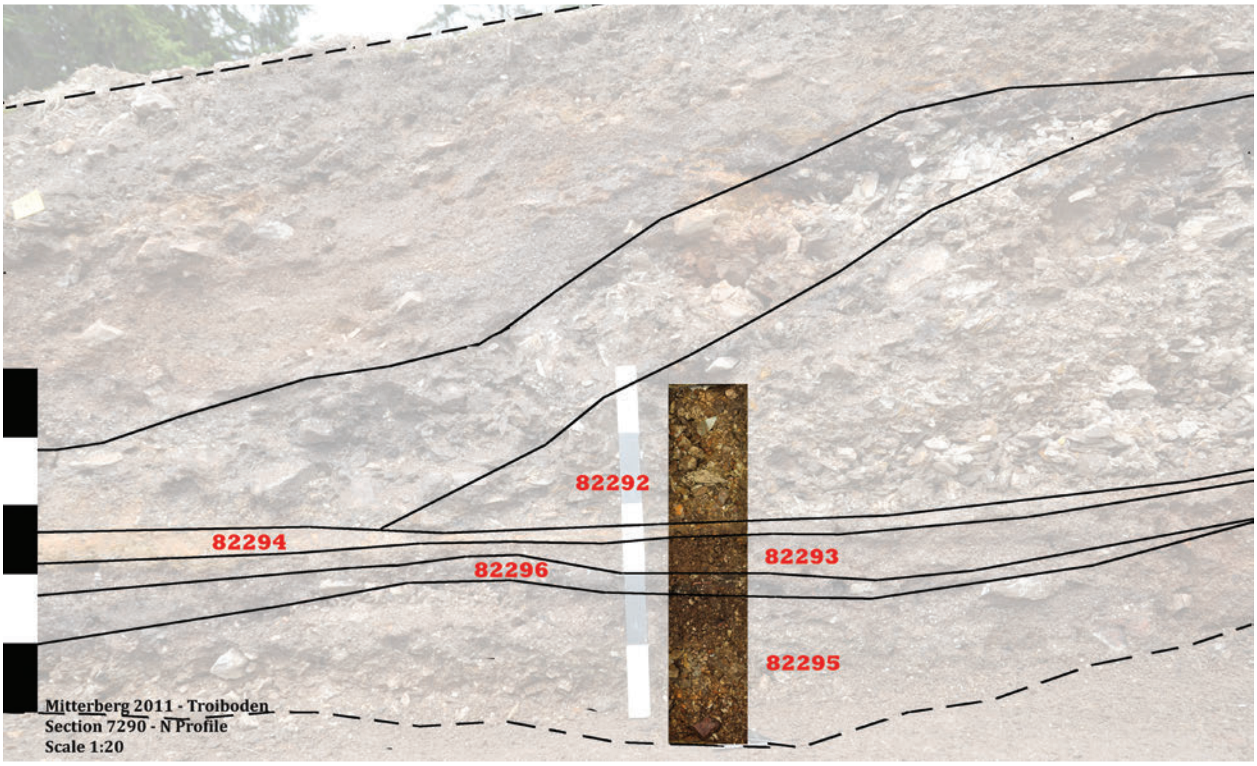


Figure 6. Section 7290 *in situ* and its recognized sediments.

associated with the wet treatment. They must have been caused by slightly different methods of treatment for them to be slightly different in composition. A summary of the laboratory results of section 7289 can be seen below (Figure 5).

Section 7290: This section contains of a horizontally elongated and relatively thick, ca. 5 to 7 cm, orange layer, which basically splits the whole section in two areas; the lower sediments of coarse waste debris and the upper material of finer remains. Whether this separation is related to the deliberately separated work processes, seems indeed plausible, but it is not necessarily certain (Figure 6). In fact, such a distribution is not naturally formed, but clearly influenced anthropogenically.

Another interesting characteristic of this section is the existence of a charcoal-dark thin layer at the lower part, which seems to be in direct connection with the

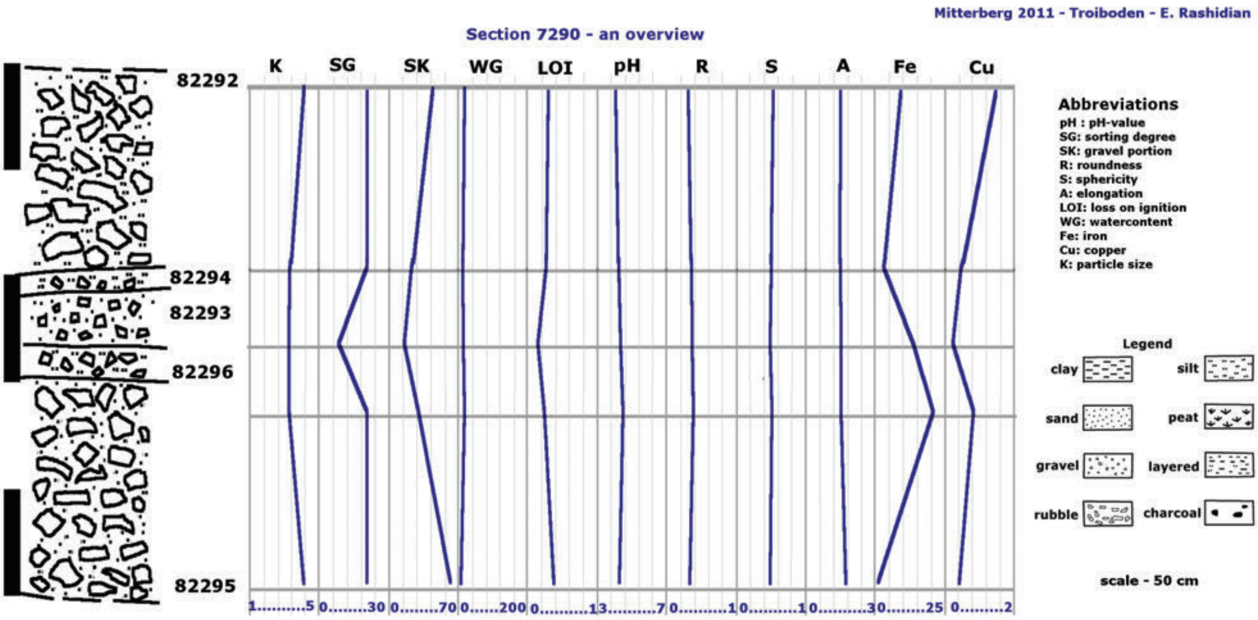


Figure 7. An overview of section 7290 based on selected laboratory results.

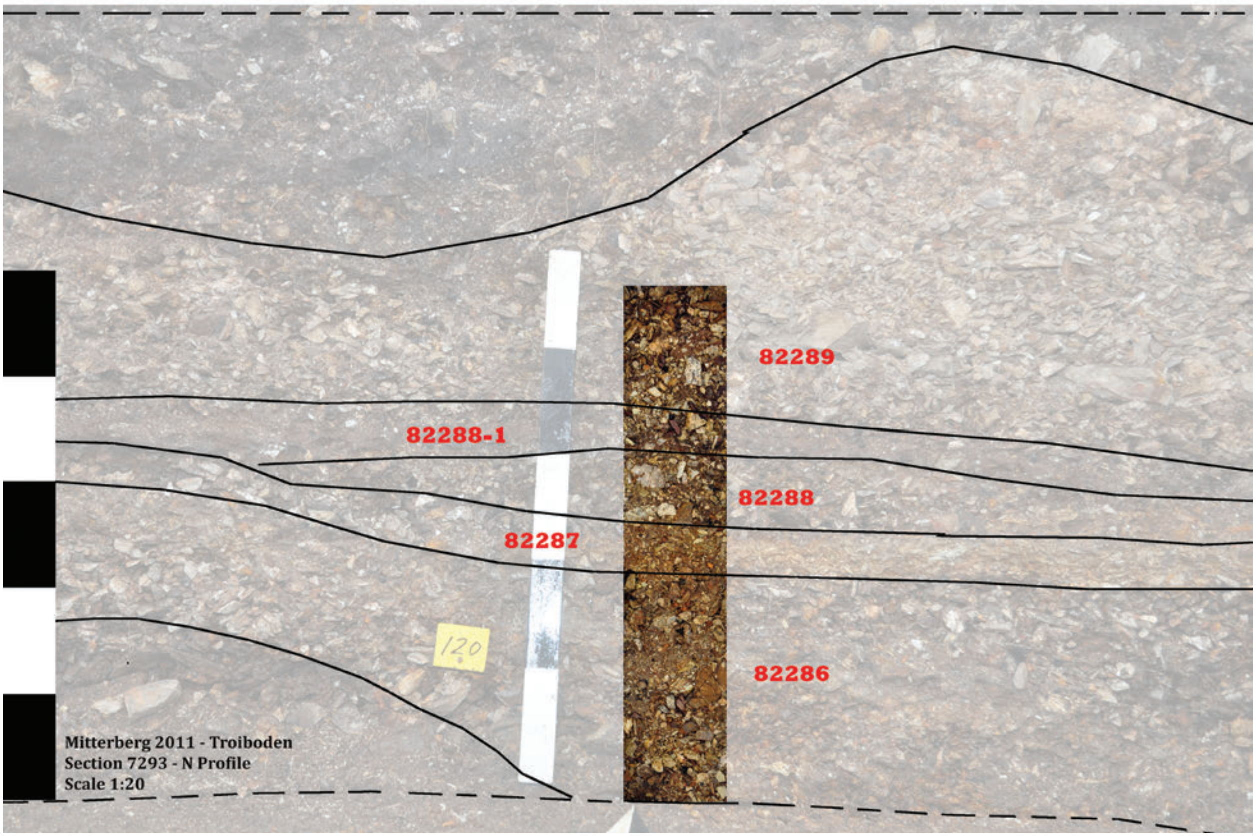


Figure 8. Section 7293 *in situ* and its recognized sediments.

beneficiation process, since it follows exactly the upper edge of the coarse waste heap, parallel to the natural slope with the exact same slope gradient. The dark layer separates yet another layer of coarse debris from the finer lower ones. However, this dark layer should not be interpreted as a totally separate sediment, since its chemical composition identified via x-ray florescence is identical to both the lower and the upper materials, with exception of the higher amount of charcoal in the dark layer. The higher iron and copper content of this section compared to other sampled sections suggests either a less careful or less efficient ore procesing than the others; this sediment is not the products of a first processing step because the very coarse material indicative of early stage beneficiation is absent. The laboratory result are summarized below (Figure 7).

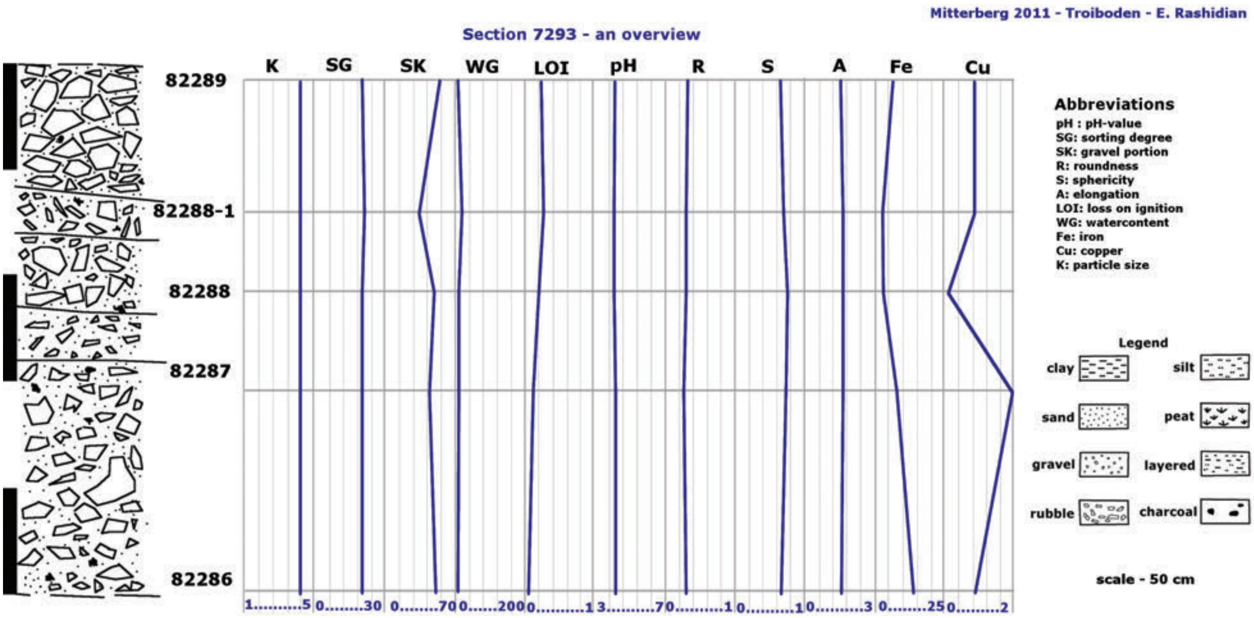


Figure 9. An overview of section 7293 based on selected laboratory results.

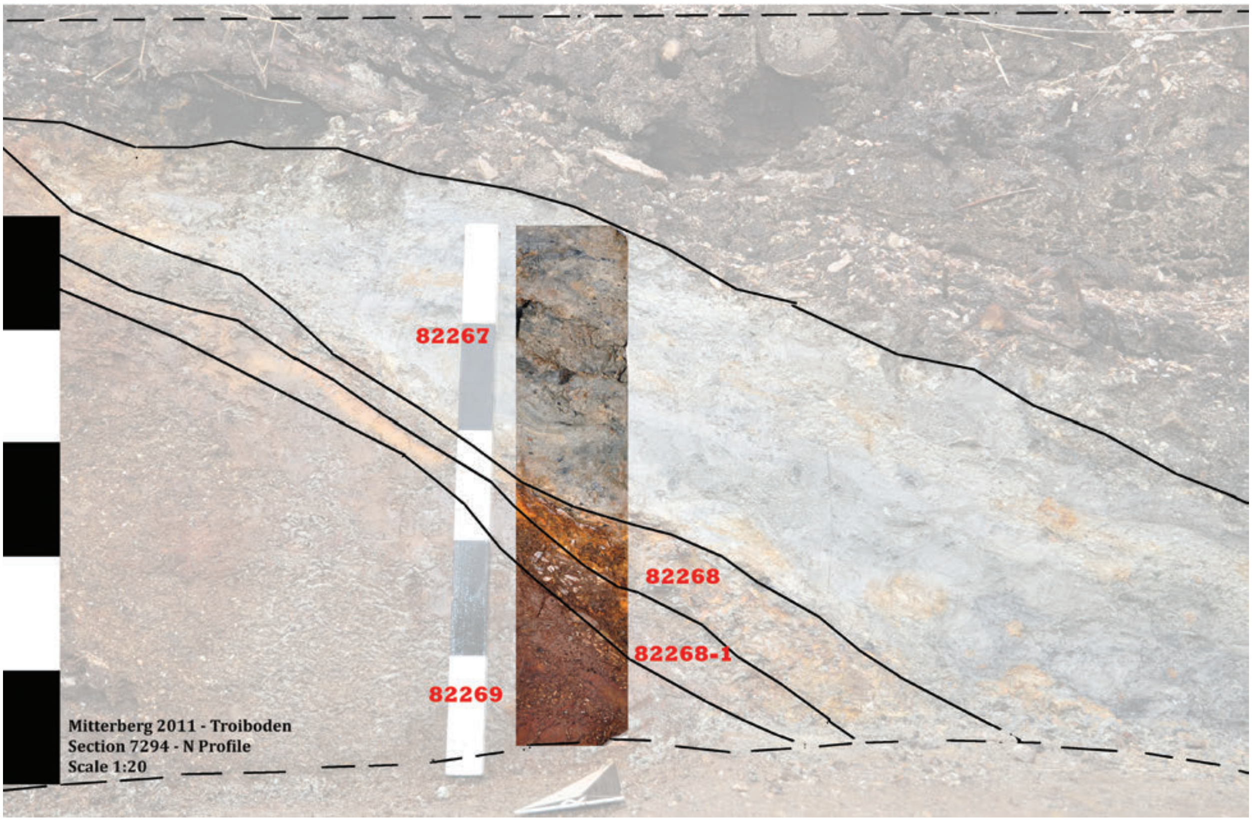


Figure 10. Section 7294 *in situ* and its recognized sediments.

Section 7293: This section is visually identified as a series of several coarse waste heaps with slight differences in particle size and color. The coarser materials of this section seem to be similar on first sight, even identical to the coarser material of the previously discussed section (7290); yet, this similarity is only visual; the chemical composition of these sediments indicates fundamental differences (Figure 8).

The mentioned layers of this section contain a high amount of hematite, while the coarse wastes of the former section consist of large amounts of magnetite as the dominant iron oxide, based on the five XRD spectra. As the initial amount of iron in both sections is more or less identical, and they were both embedded at the same time in the same landscape, the only reason for existence of hematite in one section and its absence in the

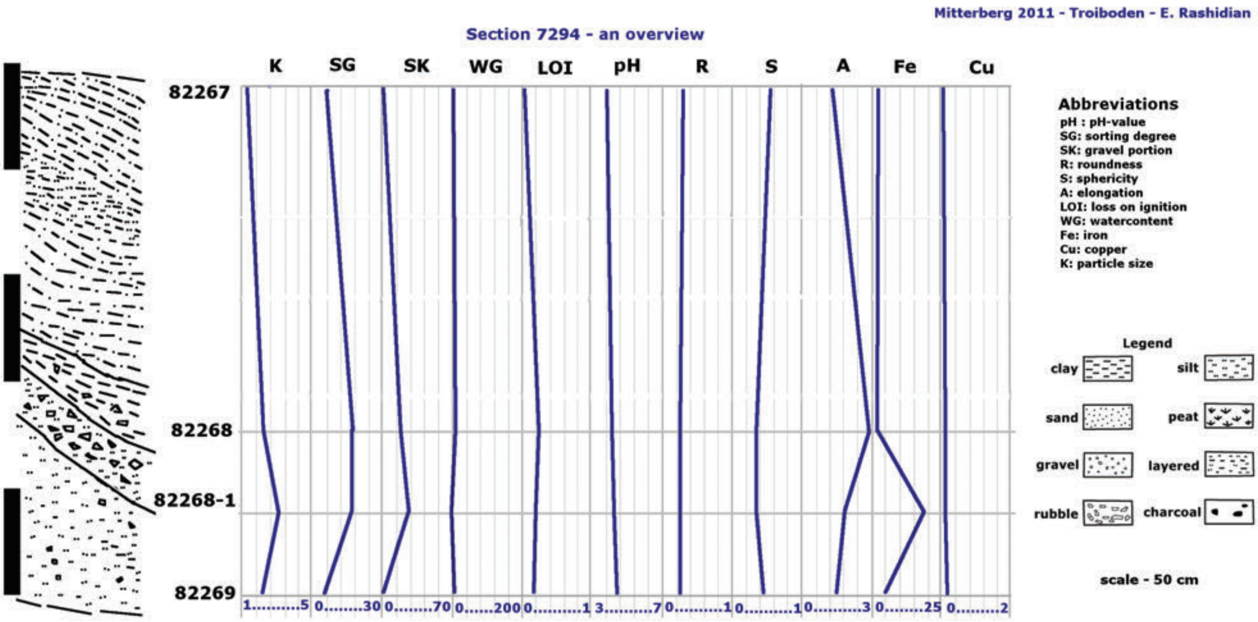


Figure 11. An overview of section 7294 based on selected laboratory results.

other one, could be the existence of still water, which is a typical geographical factor in building hematite out of other iron-rich minerals. This section must therefore been exposed to still water over a rather long, but indeterminable, time span.

Whether this suggested scenario has happened as a part of a certain beneficiation method, or was a natural post-burial occurrence, is yet unknown. Nevertheless, it can be attested with certainty that there are several categories of coarse material as waste heaps, which are different not only in size but also in composition. This means different methods of beneficiation even during the initial steps of working the coarse ore material. The relevant laboratory results of section 7293 are summarized below (Figure 9).

Section 7294: This section has an unusual blue upper part, which can be interpreted as a reduction horizon, since these layers are situated between a loamy lower layer and an upper thick peat layer. This horizon is a great example of water's influence on buried anthropogenic material during millennia. The lower layers are orange-brown in color and contain far more minerals containing iron oxides and copper than the average, while the mentioned upper layers of light gray-blue color are very poor in comparison to the average (Figure 10).

Though, it shall be noted that this fact has nothing to do with the ore beneficiation, but rather with the post-burial natural factors. Another interesting fact in this section is the difference of slope gradient of the lower layers. In other words, the lower brown layer with oxidized lenses is sloping exactly in the same direction of the slope of initial natural landscape of Troiboden, while the upper one has less of a slope and lacks this slope gradient. Such a slope is only seen in the present section. This change of slope may indicate a deliberate attempt to prepare a rectilinear surface as a working area, which is highly plausible, due to several surface finds such as stone tools concentrated above this section. A summary of the laboratory results is given below (Figure 11).

Section 7295: This section as the only one from the southern profile, initially looks like a simple natural two-layered sediment relating to a natural channel. The upper layer is a thick organic wet soil of several-layered recent brown peats. The lower part is light gray colored and exactly horizontal without any slope. There is no lens or layer dividing the two sediments (Figure 12).

One may assume that this section could be a natural soil profile of A-C and therefore the initial landscape of Troiboden without anthropogenic influence. But several indications suggest otherwise: firstly, the lower layer contains charcoal and lenses of oxidation and reduction which are a result of deliberate sedimentation; secondly, the sorting of this material does not indicate a natural sedimentation, as it is extremely poorly sorted, just like the other fine sediments of Troiboden; thirdly, the coring material of the nearby slopes of the landscape outside of the assumed ore beneficiation area, shows a totally different natural soil horizon, namely a blue-brown moraine soil, which is non-existent in current samples of Troiboden; fourthly, the chemical composition of this layer is nearly identical to the similar layer of section 7294, which suggests a similar genesis, i.e. remains of a certain

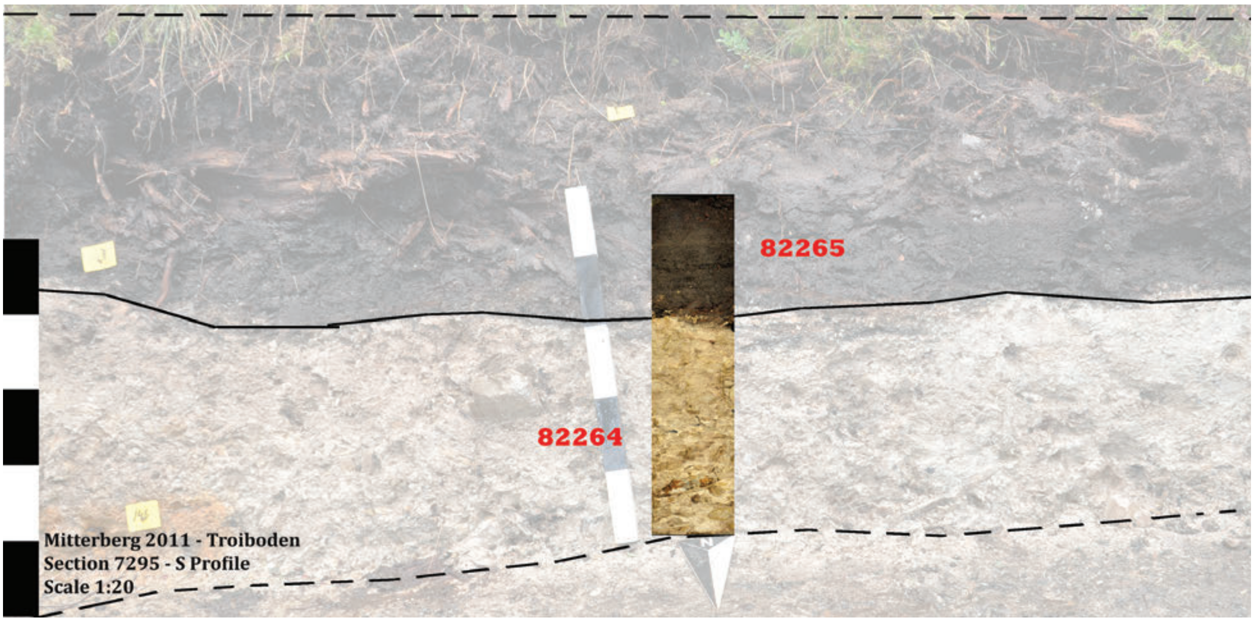


Figure 12. Section 7295 *in situ* and its recognized sediments.

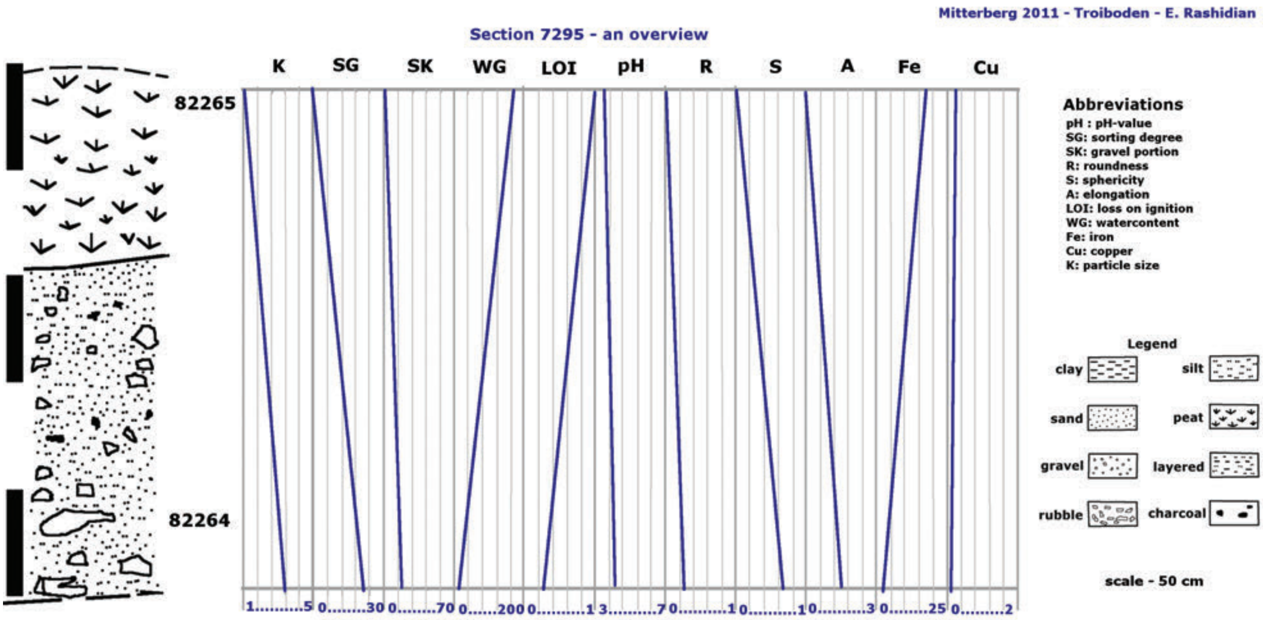
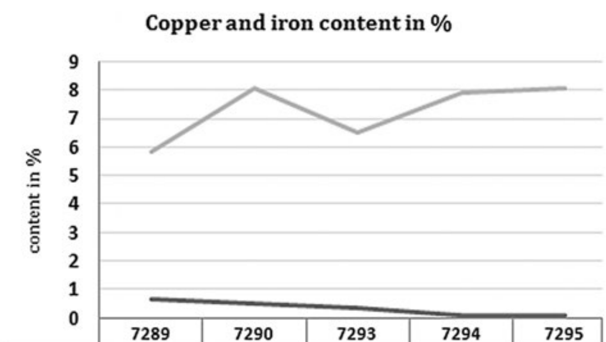


Figure 13. An overview of section 7295 based on selected laboratory results.

ore beneficiation process.[9] Assuming these layers are also products of an unknown ore beneficiation method, their rather different visual characteristic are to be considered as results of post-burial processes. Its lack of complexity, compared to the other four ones, must be regarded as a key factor to the understanding of this section's genesis. The relevant laboratory results of section 7295 are summarized below (Figure 13).

Copper and Iron Measurements: The effectiveness of the ore treatment processes in the Bronze Age in Troiboden can be identified by measuring the levels of copper in each sample and producing an average value for



	7289	7290	7293	7294	7295
Copper	0.68	0.49	0.34	0.10	0.11
Iron	5.85	8.08	6.53	7.89	8.06

Figure 14. Average copper and iron content of the presented sections as determined by pXRF.

comparison. According to the pXRF results, an amount of 0.1 to 0.5% copper is to be found in the ore beneficiation waste heaps at Troiboden, which is an indicator for a very thorough and successful separation of copper ore from the less valuable gangue rock. The fact that the content of copper varies in samples with different particle size distribution might be related to the different ore preparation procedures. In addition, as the existence of the iron in the very rich ores of Mitterberg was still unattractive at that time, iron at the Troiboden is to be detected in the form of oxides, in amounts of 6% up to 9% in most of Troiboden sediments (Figure 14).

One is able to gain a better image of the characteristics of a soil sample via the XRD method. The result of this analysis is a spectrum, which presents the structural characteristics of mineral constituents graphically. As every measurement of such complex sediments leads to a distinctive spectrum, it is possible first to investigate each soil sample as a single item; furthermore one can compare the produced spectra with each other in order to identify similarities or potential matches (clusters) and differences (variations); thus, one is able to interpret the analytical results to form archaeological conclusions.

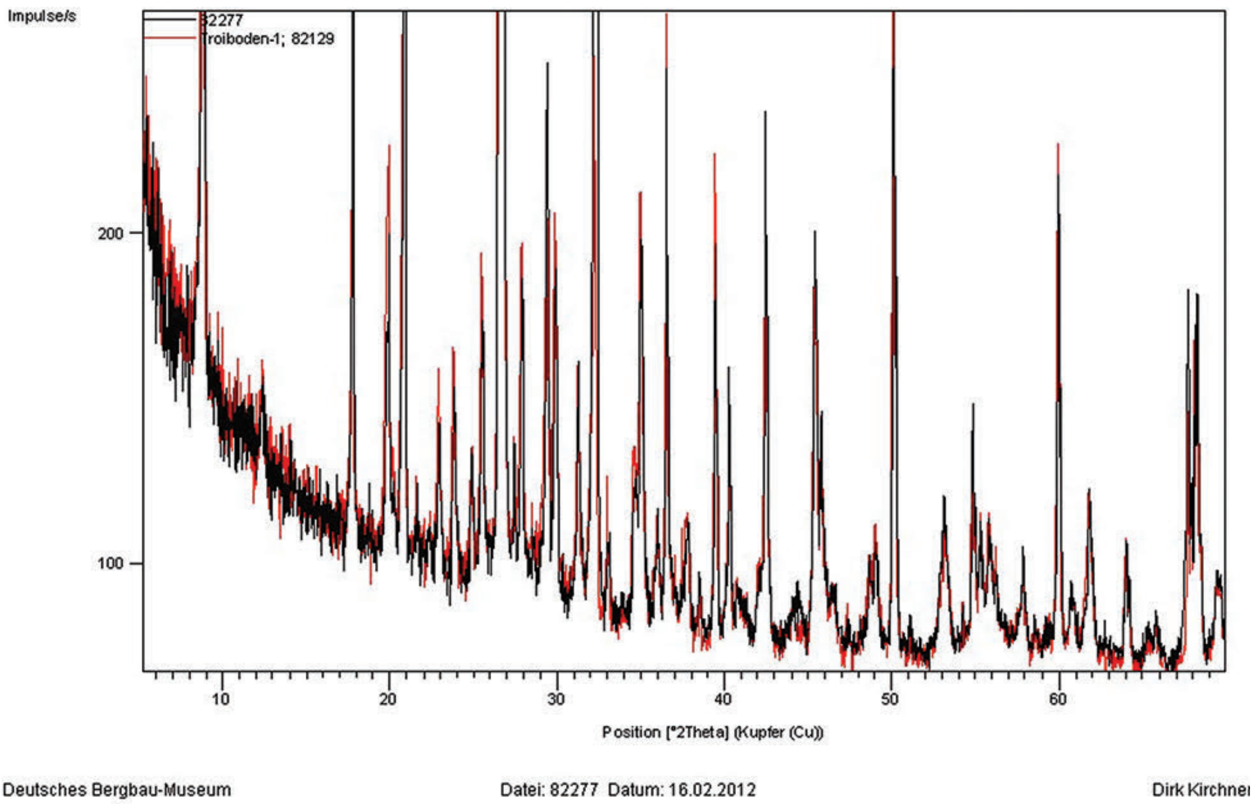
In this case, samples were divided into five different groups based of their relative amount of minerals, such as quartz, muscovite, microcline, hematite, lepidocrocite, calcite, etc. Amongst these categories, there were twelve comparisons drawn, in order to classify the layers into finer categories based on their elemental / mineralogical compositions. The samples were also compared with the existing results of the 2008 excavated wooden box, while the astonishing similarities between two samples of these different sediments can be interpreted in favor of a similar genesis, namely being the waste of a wet ore beneficiation process (Figure 15).

The mineral form(s) of the copper present in the sediments could not be determined by the XRD due their small quantity (< 1 %). Grains of chalcopyrite could be seen in the sediments, but the presence of secondary copper minerals could not be determined. Optical and scanning electron microscopy are recommended for future studies.

Interpretation

The interpretation of the results of the analyses performed is considered the most important part in understanding the archaeological process that occurred and must be undertaken with utmost caution. It must be emphasized that every given interpretation is based

Figure 15. XRD curves of the fine blue sediments of 2008 and 2011 of wet treatment remains, shows an identical composition. The peaks reflect primarily the minerals quartz, calcite, clinochlore, muscovite and hematite.



on the current state of research and is to be reevaluated constantly as new data are collected. The following conclusions can be made:

Conclusion 1: The anthropogenic genesis of the examined sediments at Troiboden can be demonstrated due to the results of the performed analysis. For this, the gravel portion analysis was useful. The gravel component of any given natural sediment is influenced by the following two factors: element / mineral components and soil classes. The cluster analysis of the gravel portion was compared with the classification of the elemental / mineralogical analysis. However, the results of these two factors were not matching. Therefore, it can be assumed that the gravel portion of the samples is not related to their mineralogical or elemental composition.

Furthermore, the identified soil classes were compared with the structure of the gravel component for each sample (e.g. sediment). Here the two factors pointed to no conformity. It can therefore be said that there is no relationship between the gravel portion of each sample and their respective soil class.

Since the above mentioned factors were examined and have proven to be unlikely, it can be stated that the gravel content of these samples is with certainty the result of various ore beneficiation processes, not of natural causes.

Conclusion 2: Mining has always been a time and energy consuming activity. For this reason, the primary objective of ore beneficiation processes was to optimize the particle size of the ore fragments in order to maximize the quantity of the extracted metal. Logically, applying increasingly effective beneficiation methods reduces the amount of copper left behind to be lost in the debris (copper loss). In other words, calculating the average quantity of copper loss of an ore beneficiation landscape, such as Troiboden, can indicate the effectiveness of the employed beneficiation technique(s).

Additionally, it can be regarded as a measure for a quantitative comparison of several beneficiation landscapes / methods. The results of the present study yield an estimation of copper loss much less than anticipated before. The potential copper loss during the ore treatment process left on the dumps of Troiboden has been estimated during prior excavations to be not more than 10% and not less than 1.15% (Stöllner, Hanning and Hornschuch, 2011, pp.122ff; Zschocke and Preuschen, 1932, p.133). However, this estimation can be updated, now, to an average of 0.5% due to results of the analyses undertaken. In other words, the copper content of the all the waste heaps in the landscape at Troiboden contains less than half a percent of the total mass of the heaps based on the pXRF results. of this study.

According to earlier estimates, copper loss (1.15%) of the total content of the waste heaps was estimated about 200 to 300 tons (Stöllner, Hanning and Hornschuch, 2011, p.122); While the area covered by the waste heaps at Troiboden has been determined to be about 1.02 hectares, a volume of about 25,500 m^3 corresponds to a heap thickness of about 2.5 m. Thus according to the present analysis, the total copper loss at Troiboden should not be more than 50 tons. The figures that are available seem to indicate that the ore beneficiation methods used at the Troiboden were far more effective than previously thought (see Conclusion 5). The results are promising for further research, and an increase in sample size and the use of quantitative techniques to determine copper contents would help to confirm if this is truly representative for the entire site.[10]

An issue that has not been properly discussed is the potential water-induced migration of copper, as copper is known to be water soluble and can be leached out and redeposited as secondary copper minerals. Therefore, the identification of the copper minerals present in the sediments may provide an indication on whether the copper content of the sediment represents relics of the sulfide ore, i.e. chalcopyrite, or if the copper is present as secondary minerals which could have be redeposited by water. Future studies should examine and evaluate the interaction between the water level and the distribution / mineralogy of the copper minerals present in the sediments.

Conclusion 3: Considering the very close similarity of the results of laboratory analyses regarding the amount of copper and overall predominance of the rounded grains in almost all layers, and since there are hardly any cobble-sized particles between 64 and 256 mm in diameter found at Troiboden, which would represent the first beneficiation steps, the material may be due to a complete reworking of the coarse heap material into finer grain sizes.[11]

In the case of Troiboden, the tools are perhaps our only evidence for the presence of very coarse, cobble-sized, ore beneficiation treatment. In summary, it is noted that at the present state of research, the investigated sediments are likely remains of the last four steps of the ore processing.[12]

On another note, the amount of the remaining copper of the heaps does vary spatially. However, this difference in copper content cannot demonstrate any spatial aspect of the ore treatment steps. It is more likely related to the different preparation processes rather than the consecutive sequence of the steps. Therefore the waste amount of copper cannot be used to reconstruct the working areas and the sequence of treatment steps, spatially.

However, this cannot be regarded as counter-evidence either. It only confirms that the issue of working areas should be clarified with the help of an excavation to search for other direct evidence of a spatial distribution of various treatment steps. The best evidence of such systematic allocation of treatment steps at Troiboden is to be found in some perpendicular wood remains at both sides of the excavated depression west of the so-called "Eibner"-trench that can be interpreted as part of a water supply system. Their function in the context of Troiboden can only be explainable as a deliberate water distribution and drainage system. Furthermore, the spatial location of the wooden wash boxes corresponds to the estimated direction of the water drainage and fits within the typology and ore beneficiation model presented here.

Conclusion 4: Although not a primary aim of this study, it is important to mention the question of the ore preparer's identity at Troiboden. At the present it is still unanswered. Some archaeologists claim that every step of the copper extraction must have been undertaken by specialized individuals; i.e. the preparation was carried out by persons who did not participate in the mining process and so on (Ottaway, 2001, p.92). It is suggested that children may have participated in the treatment process (Ottaway, 2001, p.93).

In the case of Troiboden, the close proximity of the beneficiation area to the main entrance of the Mitterberg mines on the hill, could be an indication that the two steps, e.g. ore extraction and beneficiation were carried out by the same group of individuals. Another reason for this assumption is the absence of settlement traces immediately near the Troiboden,[13] traces which are common in some other processing areas, such as Kelchalm. Thus, it must be admitted that a generalization of the treatment situation for the Bronze Age Europe is not possible.

Whether the miners, smelters, or even an exclusive group of individuals carried out the beneficiation process, certainly this is connected to the social arrangements or organization, and each case must be observed individually in every single mining area. Regarding the current study, except for the absence of the everyday life of a settlement, there is no direct or specific evidence found to make a firm conclusion possible. From the author's own observations during the 2011 excavation and subsequent analysis, the examined layers at Troiboden are generally poor in most forms of material culture; there were no ceramic, bones or traces of buildings found. The absence of a recognizable cultural horizon or a distinguishable work surface at Troiboden until now is equally remarkable.

Conclusion 5: The anthropogenic ore beneficiation landscape of Troiboden shows both similarities and differences in comparison to other such sites like the Kelchalm in Jochberg in North Tyrol, Austria (Preuschen and Pittioni, 1954, pp.18ff). The similarities demonstrate an overall framework of general beneficiation steps, function and procedure of the Middle Bronze Age working areas including most of the tool types; while the differences exclude an identical processing technology all over the mentioned mining area. For example, the waste heaps of Troiboden are finer grained and contain less copper in comparison to Kelchalm. Therefore, based upon the current state of knowledge concerning the Troiboden landscape, it can be concluded that the Troiboden processing technology is the more effective among the two areas.

In another note, there are some fine whitish chemically leached sediments[14] present at Troiboden, which are absent in Kelchalm. These sediments, often considered natural until now, are certain to be of anthropogenic genesis, yet mostly influenced post-burial via natural factors such as water and frost.[15] These could be remains of a particular and special form of wet-beneficiation at Troiboden. Whether the high treatment effectiveness and quality is the result of customized and creative work of individual workers at Troiboden or a deliberate improvement of the overall technique, is not to be clarified here.

Conclusions: Patterns of Unsortedness, a Reconstruction

C. Eibner developed the most cited model for ore beneficiation in the 1970s, which may explain the origin of most of the known types of ore treatment remains (Eibner, 1982, p.403). This model was based on both excavated material of Troiboden and post-medieval metallurgical manuscripts such as Agricola's *De Re Metallica* (1556).

There is always a great risk of oversimplification when it comes to reconstructing such complex processes via a model, as the results must be generalized to some extent in order to fit in a limited number of defined categories. Nevertheless, every model should be revised and polished constantly to meet the complexity of the context, which due to new findings proves – at least for Troiboden – to be far more complex than anticipated (Stöllner, et al., 2011), though every reconstruction is based on a system of categories i.e. typology.

An aim is to present a revised geo-data-based typology of 28 total sediment layers from the 5 Kubiëna boxes (50 cm x 10 cm x 10 cm) of Troiboden in order to provide a classification to categorize the current findings as well as creating a guide for future investigations at similar landscapes. It is worthy to note that the present typology is not the first such attempt, but the first one to create a model based on clearly documented geoarchaeological results. The difference with previous classifications is that the typology presented here has been developed based on quantifiable laboratory analysis, while the previous ones were mainly developed based on visual criteria of the layers.

The outline of ore beneficiation processes at Troiboden and similar landscapes is relatively well-known due to previous investigations in this field. Each of the four steps (hammering, dry grinding, milling and wet treatment) is responsible for a category of sediments in Troiboden. Some of the resulted sediments can be therefore identified by their physical characteristics. Yet, there are two issues to be addressed: firstly, to identify sediments of other origin than the ore treatment processes (for example natural sediments or sediments of other anthropogenic origin), which can be found in such landscapes. Secondly, to identify the interaction and relationship between the natural impact of these sediments on the landscape and the landscape's impact of the buried sediments to date.

Since each anthropogenic sediment in Troiboden is the waste product of a particular beneficiation process and thereafter altered by post-burial processes, both must be considered in an attempt to draw an outline on their genesis. To develop such a model, corresponding characteristics of the layers must be selected and compared.

There are some features that may prove very helpful, while other physical characteristics are less suitable for this purpose. Accordingly, the selected characteristics may be divided into two groups: the formal, which includes the grain shape, and the mineral composition of the layers. As examples of the less suitable characteristics, the color and sorting of the layers may be mentioned, which are significantly and constantly influenced by post burial processes and therefore are rather useless for a origin-based categorizing of the sediments. It shall be noted that these categories are only suited to describe anthropogenic layers; purely natural horizons, such as the peat or gley (groundwater-influenced sediments), are listed in a separate category named "Other".

All results considered, four steps of the beneficiation process were confirmed to have been employed in Troiboden and can be further elaborated upon. The steps identified are: sorting by hand, hammering by a mallet or / and stone pound, grinding by a quern, washing / sieving and sorting by a wooden knife. Each of these methods causes a special and unique waste dump, which is recognizable in the existing sediments, and can be categorized into one of the five types (Type I to Type V).

Consequently, each analysis leads to estimating a decisive factor which is employed to recognize each sampled sediment of Troiboden as one of the mentioned types, except for the natural sediments, which are not a product of ore beneficiation. As the anthropogenic sediments of Troiboden are directly related to the copper ore beneficiation process, the sediments can be classified as followed:

Type I: very coarse debris
Type II: coarse debris
Type III: fine debris
Type IV: very fine debris
Type V: fine sediment as a result of wet ore treatment
Other: natural sediments

The following ore beneficiation model is developed based on the above typology of sediments, to explain the various steps of ore treatment process at Troiboden (Figure 16).

The geoarchaeological investigations at Troiboden have, for the first time, prepared a basis of quantitative results regarding ore beneficiation in the eastern Alps in the Middle Bronze Age, and this achievement can be of great advantage for future archaeological campaigns.

Furthermore, the quantitative characteristic of these results allows others to draw interregional comparisons amongst several ore beneficiation landscapes in order to find out about the social and technical similarities and differences on a regional scale. The resulting data can be used for further investigations (Table 1).

As for the future work in this area, many important questions are yet to be answered. Most importantly is the question of the water supply and the spatial working allocation of various beneficiation steps as a system. In this sense, the exact relationship of the so-called wash boxes with the water management needs to be clarified. A topographic examination and an overall reconstruction of the entire water supply system at Troiboden can contribute greatly to this issue. Other questions include the position of the respective working areas or facilities and the related steps of dry and wet processing with the spatial position of both fine and coarse heaps.

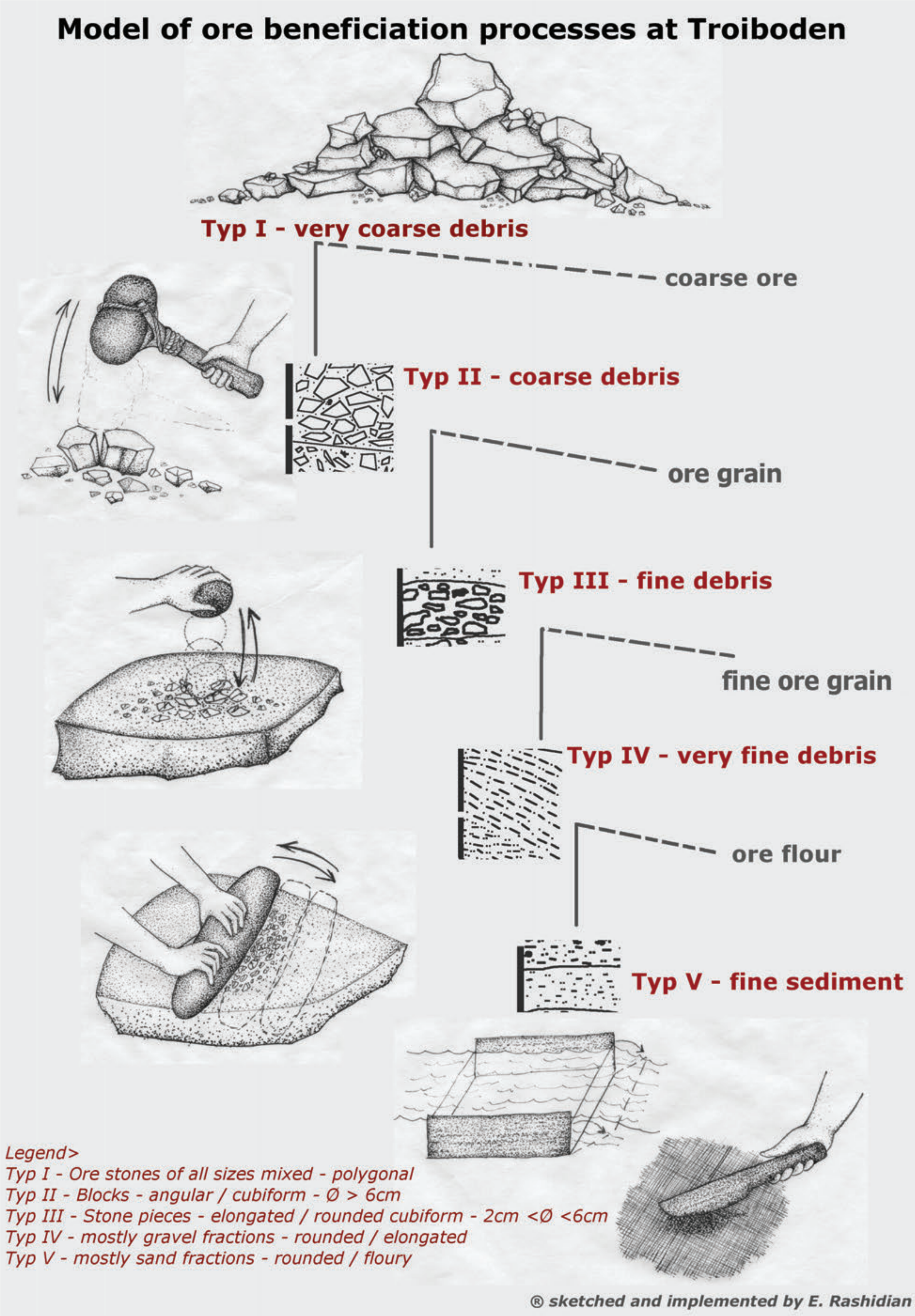


Figure 16. Model of ore beneficiation at Troiboden based on the new sediment typology.

Table 1. A summary of the characteristics of the sample layers.

Sect.	Layer	Color	Munsell	pH	EC (mS/m)	Thick-ness (cm)	Particle Size (K-factor)	Soil	Character	Type
7289	82275	Dark grayish brown	2.5Y 4/2	3.8	1.34	4	OL		Mostly bog	Other
	82276	Grayish brown	10YR 5/2	3.9	1.05	8	Coarse	SM3	Charcoal	III
	82277	Gray	10YR6/1	5.0	0.67	7	Coarse	SM4	Washed horizon	V
	82278	Brownish yellow	10YR6/6	5.2	0.59	1	Coarse	SCC	Oxidized	III
	82279	Brownish yellow	10YR6/8	4.3	0.79	5	Coarse	SM3	Highly oxidized	III
	82280	Yellowish brown	10YR 6/6	4.4	0.39	7	Coarse	SM3	Highly oxidized	III
	82275-1	Very pale brown	10YR 7/3	4.5	0.50	3	Coarse	SM4		III
	82279-1	Gray	10YR 5/1	3.7	3.12	2	Fine	SP	Ash+charcoal	V
	82279-2	Light brownish gray	2.5Y 6/2	4.1	1.18	1	Middle fine	OH	Wood reamains	Other
	82279-3	Gray	10YR5/1	3.2	2.60	6	Middle fine	SM4	Ash+charcoal	Other
	82279-4	Gray	10YR 5/1	3.8	2.26	4	Middle fine	SM4	Ash+charcoal	Other
	82280-1	Light yellowish brown	2.5Y 6/3	4.5	0.53	3	Middle coarse	SM4		III
7290	82292	Brown	10YR 5/3	4.4	0.12	20	Very coarse	SM3	Limonitized	II
	82293	Reddish brown	5YR 4/3	4.8	0.09	7	Coarse	SM2	IV	
	82294	Dark reddish gray	5YR 4/2	4.4	0.12	2	Coarse	SM3	Oxidized	IV
	82295	Reddish gray	5YR 5/2	4.7	0.16	21	Very coarse	SM2	Burnt, charcoal	III
	82296	Dark reddish brown	5YR 3/2	4.8	0.11	1	Coarse	SM3	Charcoal	IV
7293	82286	Yellowish brown	10YR 5/4	4.5	0.14	21	Very coarse	SM2	II	
	82287	Light yellowish brown	10YR 6/4	4.7	0.18	4	Very coarse	SM2	Leached	II
	82288	Brown	10YR 5/3	4.5	0.16	8	Very coarse	SM2		II
	82289	Brown	7.5YR 4/2	4.6	0.18	6	Very coarse	SM2		II
	82288-1	Brown	10YR 4/3	4.5	0.21	1	Very coarse	SM2		II
7294	82267	Light gray	10YR 7/1	4.3	0.77	31	Middle fine	SCC	Reduced horizon	IV
	82268	Strong brown	7.5YR 5/8	4.6	0.19	4	Middle coarse	SC4	Highly oxidized	III
	82269	Brown	7.5YR 4/4	4.9	0.09	16	Middle coarse	SM3	Heavily burnt	IV
	82268-1	Brown	7.5YR 4/4	4.8	0.11	4	Coarse	SM3		III
7294	82264	Pinkish white	7.5YR 8/2	4.6	0.08	40	Coarse	SM2	Highly reduced	IV
	82265	Very dark grayish brown	2.5Y 3/2	3.9	0.55	15		Pt	Peat	Other

Key: Gray blank areas mean that no data exists. Soil types: OL – organic silt or clay with low plasticity. SCC means clay rich sand. SM# means silty sand with the number indicating the proportion of sand – the higher the number the sandier the soil. SP means poorly graded sand. Pt is peat.

Acknowledgments

I would like to thank Prof. Dr. T. Stöllner for welcoming me warmly as a member of his excavation team in 2011 and allowing me to work on the collected samples in order to complete my Master's thesis of Geoarchaeology at the University of Marburg. R. Pils helped me with the documentation and sampling on a late rainy evening in August 2011, for which I am most grateful. I am obliged to thank all the members of laboratories of the Deutsches Bergbau-Museum Bochum (DBM), specially M. Prange and D. Kirchner, as well as the University of Marburg

(Geo-Labor) for correcting me steadily during the analysis. My sincere thanks go also to Dr. M. Zeiler for kindly finding the time to read an earlier draft of my Master's thesis, commenting and correcting it thoroughly, as well as P. Thomas for his good ideas based on his knowledge of the Mitterberg project. I would like to thank Prof. Dr. A. Müller-Karpe for his encouragement and support as well as his useful comments regarding the interpretation of the results and the model. I am truly thankful for the given opportunity to be a part of this project, supported by the DBM and the Ruhr University Bochum. My sincere gratitude goes to Dr. S. W. Merkel for editing and also for his support during the review process. At the end, I would like to thank Prof. Dr. Andreas Hauptmann and one anonymous reviewer for their insights and constructive feedback.

References

Agricola, G., 1556. *De Re Metallica*. H. C. Hoover and L. H. Hoover, trans. 1950. New York: Dover Publications.

Eibner, C., 1972. Mitterberg – Grabung 1971. *Der Anschnitt*, 24(2), pp.3-15.

Eibner, C., 1982. Kupfererzbergbau in Österreichs Alpen. In: B. Hänsel, ed. 1982. *Südosteuropa zwischen 1600 und 1000 v.Chr. Prähistorische Archäologie in Südosteuropa*, 1. Berlin: Volker Spiess. pp.399-408.

Eibner-Persy, A., and Eibner, C., 1970. Erste Großgrabung auf dem bronzezeitlichen Bergbaugelände von Mitterberg. *Der Anschnitt*, 22(5), pp.12-19.

Firbas, P., 1932. Die Beziehungen des Kupferbergbaus im Gebiete von Mühlbach – Bischofshofen zur nacheiszeitlichen Wald und Klimageschichte. In: K. Zschocke and E. Preuschen, eds. 1932. *Das Urzeitliche Bergbaugebiet von Mühlbach-Bischofshofen. Materialien zur Urgeschichte Österreichs,* 6. Vienna: Anthropologischen Gesellschaft. pp.173-179.

Goldberg, P., and Macphail, R. I., 2006. *Practical and theoretical geoarchaeology*. Oxford: Blackwell.

Kyrle, G., 1912. Die zeitliche Stellung der prähistorischen Kupfergrube am Mitterberg bei Bischofshofen. *Mitteilung der anthropologischen Gesellschaft in Wien*, 42, pp.196-208.

Lutz, J., Pernicka, E., Pils, R., Tomedi, G., and Vavtar, F., 2010. Geochemical characteristics of copper ores from the Greywacke Zone in the Austrian Alps and their relevance as a source of copper in prehistoric times. In: P. Anreiter, et al., eds. 2010. *Mining in European History and its Impact on Environment and Human Societies – Proceedings of the 1st Mining in European History Conference of the SFB-HIMAT, 12–15 November 2009*. Innsbruck: Innsbruck University Press. pp.145–150.

Munsell Color Chart. 1998. New Windsor, New York: Gretag Macbeth.

Ottaway, B. S., 2001. Innovation, production and specialization in early prehistoric copper metallurgy. *European Journal of Archaeology*, 4(1), pp.87-112.

Oxburgh, E. R., 1968. An outline of the geology of the central eastern Alps. *Proceedings of the Geologists‘ Association*, 79(1), pp.2-48.

Preuschen, E., and Pittioni, R., 1954. *Untersuchungen im Bergbaugebiet Kelchalm bei Kitzbühl, Tirol (Dritter Bericht über die Arbeiten 1946-53 zur Urgeschichte des Kupferbergwesens in Tirol). Archaeologia Austriaca* 15. *Archiv für Ur- und Frühgeschichtliche Bergbauforschung*, 7. Vienna: Deuticke.

Stöllner, T., 2003. Mining and Economy – a Discussion of Spatial Organisations and Structures of Early Raw Material Exploitation. In: T. Stöllner, et al., eds. 2003. *Man and Mining. Der Anschnitt, Beiheft*, 16. Bochum: Deutsches Bergbau-Museum Bochum. pp.417-446.

Stöllner, T., 2009. Prähistorische Montanreviere in den Ost- und Südalpen. Anmerkungen zu einem Forschungsstand. In: K. Oeggl and M. Prast, eds. 2009. *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*. Innsbruck: Innsbruck University Press. pp.37-60.

Stöllner, T., Breitenlechner, E., Fritzsch, D., Gontscharov, A., Hanke, K., Kirchner, D., Kovács, K., Moser, M., Nicolussi, K., Oeggl, K., Pichler, T., Pils, R., Prange, M., Thiemeyer, H., and Thomas, P., 2010. Ein Nassaufbereitungskasten vom Troiboden; Interdisziplinäre Erforschung des bronzezeitlichen Montanwesens am Mitterberg (Land Salzburg, Österreich). *Jahrbuch des Romisch-Germanischen Zentralmuseums*, 57, pp.1-32.

Stöllner, T., 2011. Der Mitterberg als Großproduzent für Kupfer in der Bronzezeit: Fragestellung und bisherige Ergebnisse. In: K. Oeggl, G. Goldenberg, T. Stöllner and M. Prast, eds. 2011. *Die Geschichte des Bergbaus in Tirol und seinen angegrenzten Gebieten. Proceedings zum 5. Milestone-Meeting des SFB – HiMAT vom 7.-10.10.2010 in Mühlbach*. Innsbruck, Innsbruck University Press. pp.93-106.

Stöllner, T., Hanning, E., and Hornschuch, A., 2011. Ökonometrie des Kupferproduktionsprozesses am Mitterberger Hauptgang. In: K. Oeggl, G. Goldenberg, T. Stöllner and M. Prast, eds. 2011. *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: Innsbruck University Press. pp.115-128.

Stöllner, T., Fritzsch, D., Gontscharov, A., Kirchner, D., Nicolussi, K., Pichler, T., Pils, R., Prange, M., Thiemeyer, H., and Thomas., P., 2011. Überlegungen zur Funktionsweise des mittelbronzezeitlichen Nassaufbereitungskastens vom Troiboden". In: K. Oeggl, G. Goldenberg, T. Stöllner and M. Prast, eds. 2011. *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: Innsbruck University Press. pp.141-155.

Stoops, G., 2009. Evaluation of Kubiëna's contribution to Micropedology at the occasion of the seventieth anniversary of his book "Micropedology". *Eurasian Soil Science*, 42(6), pp.693–698.

Zschocke, K., and Preuschen, E., eds. 1932. *Das Urzeitliche Bergbaugebiet von Mühlbach-Bischofshofen. Materialien zur Urgeschichte Österreichs*, 6. Vienna: Anthropologischen Gesellschaft.

Notes

1 Supported by the Deutsches Bergbau-Museum Bochum (DBM) and the Ruhr University Bochum, as a project within the research framework "HiMAT" (History of Mining Activities in Tyrol and Adjacent Areas - Impact on Environment & Human Societies).

2 The primarily results of this geoarchaeoplogical investigation have been partly presented by the author in order to achieve a Master's degree of geoarchaeology at the university of Marburg in 2012.

3 Soils made or heavily influenced by long term human activities.

4 Kubiëna is the most common sampling protocol used in the geoarchaeology, which was introduced for the first time about 80 years ago by an Austrian soil scientist and since then continues to evolve. For a detailed explanation of Kubiëna´s protocol see Stoops (2009, pp.693ff). For other protocols in geoarchaeological sampling see Goldberg and Macphail (2006, pp.353ff).

5 The particle size classification is based on the DIN 4220 of the German Insistute for Norms and Standards and the Unified Soil Classification Norm was used. The grain size is based on DIN 4220: Block >200 mm, cobble between 63 and 200 mm, Pebble/gravel between 2 and 63 mm, Sand between 0.063 and 2 mm, Silt between 0.002 and 0.063 mm, Clay < 0.002 mm.

6 It is based on a factor, measuring the relation of particle size via polarized light microscopy: fine means more than 80% fine particles (which are defined as the sum of silt and clay materials). Middle fine means between 50 and 80% fine particles. middle coarse means 50 to 70% coarse particles (which are defined as sum of sand and pebbles). Coarse means 70 to 80% coarse particles. Very coarse means more than 80% coarse particles in each measured sediment sample.

7 This factor is based on a formula which calculates the relation of particle sorting in the sediment on a scale of 0 to 100 from unsorted to well sorted. In the Troiboden the soils are poorly sorted and range from 0 to 30.

8 The existence of a series of ponds as a part of water management system is already suggested by Eibner, yet never geographically examined until now; see Eibner (1982, p.403).

9 The sorting shows no sign of redeposition and strongly indicate that the sediment is not of a natural genesis. It is identical in composition to other anthropogenic sediments and is quite different to the natural sediments of the Troiboden, which are glacial moraine in character documented by the coring around the Troiboden in 2011.

10 The aim of the sampling strategy was to capture representative picture of the Troiboden landscape. In this geoarchaeological stratified sampling survey all of the different optically distinguishable "Halden" or "deposition" types available in the 70 meter long excavated trench are represented. It is not the number of samples that determines whether they are representative but rather a distribution that captures the total variability. Despite this, further sampling of site would be productive to create a larger basis for interpretation.

11 Thanks to Dr. M. Zeiler for pointing out this fact.

12 This is based on Eibner (1982, Figure 2). The four steps are: hammering, dry grinding, milling and wet treatment.

13 The next known settlement to Troiboden is the Götschenberg ca. 4 km to the east (see Eibner, 1972, p.4). The recent findings come from a settlement horizon at Griesfeld near the entrance to the Maria-Hilf-Stollen, which is ca. 4 km to the west of Troiboden (see Stöllner, 2011, p.101). The absence of a settlement immediately in the environs of Troiboden is also shown by the recently analyzed LiDAR scans from Stöllner, et al. (2011). There were no anomalies in that scan, which could be interpreted as buildings or settlement traces. The only anomalies found on this scan are the Pingenzüge, which are the rows of collapsed mineshafts at the northern most part of the Troiboden.

14 For example 82264 of section 7295 and 82269 of section 7294.

15 See section 7295

Autor

Elnaz Rashidian
Goethe-Universität Frankfurt,
Institut für Archäologische Wissenschaften,
Campus Westend, Hausfach 7,
Norbert-Wollheim-Platz 1,
D-60629 Frankfurt a.M., Germany,
elnaz.rashidian@gmail.com

Cover Images

1. Excavations at Troiboden the Middle Bronze Age copper ore beneficiation site in the Austrian Alps. The anthropogenic sediments resulting from ore beneficiation and subsequent weathering processes were studied with a geoarchaeological approach and give an indication that the benefication process were more effective than previously thought. See contribution Rashidian. Photo: Fabian Schapals (DBM Archiv Montanarchäologie)

2. Polished section of a crucible fragment from Dortmund Thier-Brauerei excavation with inclusions of leaded brass. The copper-based metallurgical remains from Carolingian/Ottonian levels of Dortmund and Soest were analyzed by microscopy, high-resolution ICP-MS and lead isotope analysis to reveal information about some of the earliest archaeological evidence for medieval brass production in western Europe. See contribution Merkel.

3. Royal Tombs of Ur, Mesopotamia, 3rd millennium BC. Most of the cosmetic pigments found in the tombs were stored in shell containers. They are composed of a complex mixture of bluish-greenish minerals, bone white and fats or oils. The chromophores are thought to be produced from acid or wine in copper vessels making verdigris. See contribution Hauptmann et al. on cosmetic pigments.

4. Royal Tombs of Ur, Mesopotamia, 3rd millennium BC. Wreath with golden leaves, lapis lazuli and carnelian. The golden leaves are possibly made according to the leaves of the sisso tree which is distributed in the Indo-Iranian borderlands (Iranian Plateau, northwestern India, Pakistan). Lapis lazuli comes from Sar es-Sang (northeast Afghanistan), and the carnelian beads are characteristically Harappan. See contribution Armbruster on the jewelry of Ur.

metallum, i, n:
Mine (often pl.)
Metal, also stone, mineral

μεταλλον, το:
Mine, shaft, gallery;
esp. a) Mine (usually pl.)
b) Quarry

Contents

Reviewed Original Articles:

Supplement:

DBM
Deutsches Bergbau-Museum
Bochum

ISSN 0947-6229