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Reconstructing the History of Copper and Silver Mining in Schwaz, Tirol

Introduction

The Eastern Alps have been an important source of raw materials such as metal and salt for the past 5,000 years. In particular, the landscape of the Tirolean Inn valley was shaped by the impact of ore mining and agricultural activities like livestock farming and tillage. Archaeological evidence for the beginnings of ore mining in central Europe has been found as far back as the fourth millennium BCE in northern Italy (Monte Loreto1) and the second and third millennium BCE in the Western Alps (St. Véran2), suggesting that the availability and the usage of copper may have been a development stimulus for European societies.

At present scientists still lack evidence about the beginnings of copper mining and metallurgy in the Eastern Alps, but there are indirect indications of early metallurgical activities. The confirmation of small-scale metallurgy in settlements like the Mariahilfbergl (Brixlegg, Tirol) from the fifth millennium BCE onwards,3 and the geochemical signature of archaeological finds like Ösenringe and metallurgical slags from various early Bronze Age sites in central Europe offer hints about where and when Tirolean copper production may have begun. These artifacts consist of fahlore-derived copper, characterized by high amounts of antimony as well as minor concentrations of arsenic, silver, and zinc.4 Copper ore with this geochemical signature is found in the deposits of the lower Inn valley in Tirol.

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4 Höppner et al., “Prehistoric Copper Production.”
However, archaeological finds are not the only evidence available. Methodological advances in pollen analysis over the last decade have enabled detailed reconstructions of past vegetation and its use in agriculture. These same methodological approaches may be applied to reconstructing the history of mining, as well. Mining activities impact the regional vegetation in various ways: there is high demand for wood for different purposes (construction, fuel), and local and regional agriculture is intensified in response to subsistence needs of the miners. Additionally ore-processing procedures release metals (e.g., lead, copper, arsenic, antimony) into the environment, as is seen in the local deposits.

Human-environment interactions in a mining territory may be reconstructed based on the information stored in wetlands regarding vegetation history, anthropogenic activities, and atmospheric metal deposition. At the same time, the challenge is to separate the signals from mining activities and those from agricultural activities, which are quite similar. The palaeoecology of mining has not yet been investigated in depth. Several multi-proxy studies of combining palynological (pollen and microcharcoal) and geochemical data from wetlands in mining districts display promising results and show coeval changes in vegetation and heavy metal deposition. However, the correlation of the vegetation changes in the pollen diagram with mining activities is a crucial step.

This study corrects this research gap by using current knowledge about the palaeoecology of mining as a calibration set to evaluate mining activities in Tirol displayed in pollen diagrams. The data from the palaeoecological record is supplemented by historical data for the area studied concerning settlement, agricultural development, and ore mining and smelting operations. Archaeological evidence of past metallurgical activities and their dendrochronological age determination completes the picture. We thus present an interdisciplinary survey by palynologists, geochemists, historians, and linguists that reconstructs the early history of mining in the Tirolean district Schwaz by showing the connections between mining activities and changes in the vegetation.

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Context and Sampling Site

Because the Eastern Alps contain large amounts of profitable ore deposits, they have been an important mining region over the last millennia. One of the most prominent Tirolean mining areas (after the Kelchalpe near Kitzbühel) is located in the lower Inn valley between Schwaz and Brixlegg. The use of artifacts made from copper from local deposits is documented to no later than the beginning of the fourth millennium BCE. According to research by Goldenberg and his colleagues, humans have been extracting copper ores from the bedrock in the lower Inn valley since at least the Early to Middle Bronze Age. Several archaeological findings as well as historical references confirm metallurgic activities involving copper and silver processing in the mining district of Falkenstein near Schwaz in prehistoric and post-Roman times. The reconstruction of successive periods of mining activity in past mining sites in particular may be improved by the combination of pollen and geochemical analysis of mires.

The investigated area is located near Schwaz in the lower Inn valley (Tirol, Austria). The sampling site is situated in the Falkenstein district (the main mining district of the prominent mining area of Schwaz) in the Inn valley on the northwestern slope of the Mehrerkopf. The northern Austroalpine Greywacke Zone around the former mining center of Schwaz consists of dolomites, schists, and porphyric gneisses. The ore exploited at the Falkenstein mining district is found in the Devonian Schwaz Dolomite and contains mainly fahlore of the tennantite-tetrahedrite series ($\text{Cu}_{12}\text{As}_4\text{S}_{13}$ - $\text{Cu}_{12}\text{Sb}_4\text{S}_{13}$). As indicated by the formula, the main components of the fahlore are copper, antimony, arsenic, and sulfur.

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11 Monna et al., “Environmental Impact of Early Basque Mining.”
Additionally, the copper in the fahlore crystals is supplemented by minor components like silver, mercury, iron, zinc, and bismuth. Scarce chalcopyrite and galena deposits are also present in the ore. During the Bronze Age, copper was the main target of the miners in the region around Schwaz. Due to the low lead concentrations of the fahlore, prehistoric ore smelting and copper production caused only negligible lead pollution in the Inn valley. Later improvements in the smelting process made it possible to extract the fractional amounts of silver in the ore, which lead to a blossoming of mining in medieval and (early) modern times. Because the methods used—the Saigerhütten process and cupellation—required large quantities of lead to extract silver from the silver-bearing copper, the lead pollution in the Inn valley was much higher at that time. These industrial procedures could be seen as the main cause of lead pollution in medieval and (early) modern times.

In this study, the peat of the fen of Kogelmoos was used to reconstruct the history of vegetation and pollution of the formerly prominent Tirolean mining district of Falkenstein. The mire in the copper- and silver-ore-bearing region near Schwaz was selected after detailed surveys of the north-facing slope of the Mehrerkopf. At 1,120 m above sea level, near the farmsteads of Kogelmoos, the 0.2 ha fen is located between coniferous forest and intensively used meadows. A spruce forest with larch (Larix) and fir (Abies) is situated to the southwest of the mire. This area is characterized by various mining waste heaps from early modern times, which are still in part bare of vegetation cover even today. In the higher altitudes the spruce forest (Picea) is mixed with pine (Pinus) and larch (Larix) and in the lower areas with fir (Abies) and beech (Fagus).

Archaeological and Historical Background

The current state of research holds that mining activities in the region around Schwaz in the Tirolian Inn valley were initiated during the first half of the Middle Bronze Age. Archaeological findings and radiocarbon analyses in the Falkenstein area suggest that some galleries date back to prehistoric times. Several remains of prehistoric mining activities in that area can be dated to sometime between the Late Bronze Age (Urnfield culture) and the first half of the Iron Age (Hallstatt culture).

13 Goldenberg, “L’exploitation du cuivre.”
16 Rieser and Schrattenthaler, “Urgeschichtlicher Kupferbergbau.”
Written evidence for mining activities around Schwaz first occurs much later, at the end of the fourteenth century CE. In a rent-roll of the monastery of St. Georgenberg-Fiecht, which dates back to the years between 1361 and 1370, the first written mention of a farm settlement at the “Hohenchogel” (today the hamlet of Kogelmoos) is found. In 1409, according to legend, a bull revealed a vein of ore by pawing the ground with its hooves in the hamlet of Kogelmoos. The existence of mining activities in the mountains of Schwaz as early as 1400 has been demonstrated through an onomastic analysis of mining-related family and occupational names taken from early tax lists and subject registers. The Schwazer Bergbuch (“Schwaz Mining Book”) states that the first ores were extracted some 110 years before 1556. Mining activities in and around Schwaz are also documented in clerical, sovereign, and municipal sources from the 1440s onward. The first “Bergordnung” (mining ordinance) concerning the mining district of Schwaz dates back to the year 1449.

By the beginning of the sixteenth century, the rise of Schwaz from a small marketplace on the shores of the river Inn to the center of European copper and silver mining had begun. From that time on, Schwaz left other European silver-producing centers such as the districts in Mansfeld (today: Thuringia in Germany), Oberungarn (today: Slovakia), as well as the towns in the Saxon and Bohemian Erzgebirge (Ore Mountains) far behind. Between 1470 and 1525 more than half of the silver produced in the above-mentioned European districts was mined in the various subdistricts of Schwaz. As Westermann has demonstrated, lists of the production of refined silver in the subdistrict of Falkenstein show that the quantity of ore mined in the Schwaz mining district peaked in the 1520s. In the second half of the sixteenth century, mining activities in Schwaz began to decline again. In 1657 the mine holdings were sold to the sovereign by the Fugger family, who owned the last private “Gewerken” (mining operation); the state-operated silver and copper production was ultimately abandoned in 1827.

19 Bartels and Bingener, Der Bergbau bei Schwaz.
20 Wolfgang Tschan and Gerd Hofmann, Das Schwazer Bergrecht der frühen Neuzeit: Eine Quellenedition (Reutte: Ehrenberg-Verlag, 2008).
22 Thomas Sokoll, Bergbau im Übergang der Neuzeit (Idstein: Schulz-Kirchner, 1994).
Material and Methods

Lake and bog sediments are great archives of the vegetation history of former landscapes. The plant remains in the wetlands provide information about the spectra of plant species and their changing proportions in the past.\textsuperscript{25} The information stored in the plant remains is preserved in the sediment and is influenced by how and where they were deposited.\textsuperscript{26} Additional palaeoecological data can be obtained by geochemical analyses of the deposits.

Pollen grains of flowering plants as well as spores of ferns and mosses are archived in peat bogs for millennia. These 10–100 µm particles can only be recognized with a microscope, but it is nevertheless possible to identify families, genera, and sometimes even species due to the variety of their morphology.\textsuperscript{27} Pollen and spores of vascular plants, which are often produced in large quantities, spread through the atmosphere and settle in the vicinity of their source. Because of their high sporopollenin content, pollen and spores are resistant to decomposition if they are hermetically sealed in wetlands and may be preserved for thousands of years.\textsuperscript{28} By counting pollen grains in the samples, researchers can draw conclusions about the occurrence and frequency of various species. The palynological data gained in this manner enables a reconstruction of the vegetation history of the area surrounding the wetland.

As mentioned above, humans have changed the landscape mainly through settlement activities and agriculture, but mining and metallurgic workings have also had enormous consequences for the environment. The heavy metal emissions, which originate from ore extraction and particularly from smelting activities, were deposited in sediment basins in much the same manner as pollen and spores. Some of these heavy metals are bound to the sediment and remain in the layer where they were deposited. The combination of palynological and geochemical data with methods of age determination like radiocarbon dating enables the identification of mining phases in the areas surrounding the sediment basin. By this multi-proxy approach, wetlands could be used as archives of the mining history of the last millennia.\textsuperscript{29}

\textsuperscript{25} Gerhard Lang, \textit{Quartäre Vegetationsgeschichte Europas} (Jena: Gustav Fischer Verlag, 1994), 33–51.
\textsuperscript{27} Lang, \textit{Quartäre Vegetationsgeschichte Europas}.
\textsuperscript{28} Moore, Webb, and Collison, \textit{Pollen Analysis}.
\textsuperscript{29} Shotyk et al., “History of Atmospheric Lead Deposition”; Monna et al., “Environmental Impact of Early Basque Mining.”
Field Sampling
The Kogelmoos fen was surveyed using an avalanche probe, after which a core sample of the peat was taken with a Geonor piston corer from the deepest part in the middle of the bog (fig. 1). The resulting core is 2 m long and has a diameter of 52 mm. Additionally, the uppermost layers were excavated and a peat column of 1 m was collected in metal boxes pressed into the wall of the core site. This method was used in place of boring in order to minimize the compression of the more recent deposits.

Pollen Analysis
The sample material was wrapped with cling film before being stored in a cooling chamber until sample preparation. For pollen preparation, subsamples were taken of a constant volume of 1 cm³ in standardized intervals. The chemical treatment of the peat samples followed the standard procedure used at the Botanical Institute of Innbruck University according to Erdtman and Seiwald (including treatment by hydrochloric acid, chlorination, acetolysis, and, if necessary, hydrofluoric acid). Afterwards the samples were colored with fuchsin and mounted in glycerin jelly. Pollen grains were counted at 400x magnification (for critical determinations at 1,000x magnification).

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and were identified by using the standard identification keys of the central European pollen flora as well as the reference collection of the Botanical Institute of Innsbruck University. At least 1,000 tree pollen were counted for each pollen spectrum. Furthermore, non-pollen palynomorphs (NPPs), such as fungal hyphae, spores of coprophile fungi, zoological residues, and microcharcoal, were specified and quantified.

The pollen sum consists of the arboreal and non-arboreal pollen counted, but marshland taxa such as alder (*Alnus*), sedges (Cyperaceae), and water plants, as well as spores and NPPs, were excluded from the pollen sum because they would interfere with the data for the area being studied. The calculation of the pollen diagrams was carried out by the program FAGUS, which was developed at the Botanical Institute of Innsbruck University. The graphical representation was performed by the program C2.

**Geochemical Analysis**

The peat subsamples were homogenized and digested. The received solutions underwent trace element and lead isotope analyses at the Curt Engelhorn Center for Archaeometry in Mannheim. Total concentrations of lead (Pb) and scandium (Sc) were determined using a quadrupole inductively coupled plasma mass spectrometer (Thermo Scientific XS 2). While lead is an indicator of mining activities, scandium concentrations remain largely unaffected. By comparing the ratio of lead to scandium in the samples, it was possible to determine whether increases in lead were due to anthropogenic sources. Lead isotope ratios ($^{208}$Pb/$^{206}$Pb, $^{207}$Pb/$^{206}$Pb, $^{206}$Pb/$^{204}$Pb) of the peat samples were measured with a double-focusing magnetic-sector-based multi-collector inductively coupled plasma mass spectrometer (AXIOM, VG Elemental).

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Radiocarbon Dating

The AMS radiocarbon-dating measurements were conducted at the Vienna Environmental Research Accelerator of the Faculty of Physics Isotope Research Group, University of Vienna. The achieved radiocarbon dates were calibrated using the OxCal Version 3.10. Using the calibrated radiocarbon dates (fig. 2) an age-depth model of the samples was calculated. The timescale in the diagram is shown in calendar years in BCE/CE.

<table>
<thead>
<tr>
<th>Laboratory no.</th>
<th>Depth (cm)</th>
<th>Material</th>
<th>Uncalibrated date BP</th>
<th>Calibrated age range (2 sigma)</th>
<th>Calibrated calendar year BCE/CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERA-4290HS</td>
<td>30</td>
<td>Sedge peat</td>
<td>230±30</td>
<td>Cal CE 1640–1946</td>
<td>1659 CE</td>
</tr>
<tr>
<td>VERA-4291HS</td>
<td>50</td>
<td>Sedge peat</td>
<td>465±35</td>
<td>Cal CE 1409–1477</td>
<td>1438 CE</td>
</tr>
<tr>
<td>VERA-4461</td>
<td>65</td>
<td>Sedge peat</td>
<td>1655±35</td>
<td>Cal CE 261–527</td>
<td>410 CE</td>
</tr>
</tbody>
</table>

Results and Interpretation

In about 600 CE, the area surrounding the Kogelmoos fen was dominated by forests with fir (Abies) and spruce (Picea). While there are isolated indicators (such as artifacts) of human presence in the area, there is not enough evidence to suggest there were permanent settlements at this time. The low values of microcharcoal indicate moderate local fire activity in the Falkenstein area. The continuous presence of low amounts of cultural indicators over the next several centuries suggests there was human activity in the greater vicinity of Kogelmoos, although the spruce-fir forest of the area remained mainly undisturbed.

Around 1350 CE a major alteration of the vegetation in the Falkenstein district took place. The fir (Abies) values decrease dramatically whilst grasses (Poaceae), pasture, and cultural indicators, as well as the values of local microcharcoal, begin to rise (fig. 3). This pattern in the pollen diagram shows a more open landscape and reflects large-scale forest clearance. The first written mention of a farm at “Hohenchogel”

(homonymous to the present-day hamlet of Kogelmoos) was found in the oldest rent-roll of the monastery of St. Georgenberg-Fiecht and dates back to the years between 1361 and 1370. The connection between the significant change in the vegetation and the appearance of the farmstead in the second half of the fourteenth century is obvious. The landscape was opened by (fire) clearance to establish space for agriculture and livestock farming, which is shown in the continuous curves of cultural and pasture indicators. The establishment of the farmstead at Kogelmoos reflected the expansion of settlement activities in the mining area of Schwaz at the end of the Middle Ages. At that time the small marketplace expanded and left multiple historical traces in clerical, sovereign, and municipal archives.

A further intensification of settlement activities in the surroundings of the Kogelmoos farmstead is documented in the pollen diagram a century later. The data show an increase in pine (Pinus), larch (Larix), and grasses (Poaceae). Additionally, charcoal values increase synchronously with the values of the heavy metal lead. There is no doubt that there was a major change in vegetation occurring, but was this vegetation

38 Bachmann, Die Mittelalterlichen Stiftsurbar.  
39 Tschan, “Das Schwazer Berglehenbuch.”

Figure 3: Middle Ages and modern times in the relative pollen diagram (selected species) of the Kogelmoos with geochemistry and historical data (Nöh 1948, 128). Black-colored areas = fraction of different species in %; grey areas = fraction of different species multiplied by 10; main diagram: x = values of fir (Abies) in %, Δ = values of spruce (Picea), solid line = border of fraction of tree and non-tree-species, black area = values of grasses (Poaceae).
change caused mainly by farming or mining activities? The intense admixed usage of the former woodland area of the Falkenstein district for agriculture and mining is shown in a historical drawing from the sixteenth century (fig. 4).

The implication of mining activities as the dominant shaping force of the vegetation could also be seen in increasing lead values at the beginning of the modern era. As there is always a natural input of lead to the wetland, indicated by the variation of mineral matter in the peat, this fraction has to be deducted from the measured lead values. The Pb/Sc ratio displays the measured lead values in the deposits normalized to the lithogenic fraction. At the transition from the Middle Ages to the modern era, the silver and thus also copper production in the Falkenstein mine eventually reached its peak. At the same time, the Saiger technique was implemented in the Tirolean


mining sites at around 1492.\textsuperscript{42} This special smelting technique enabled the extraction of silver from the fahlore by using high amounts of lead. The use of this heavy metal in the metallurgical process caused an elevated emission of lead from the smelting works and an increased concentration of lead in the vicinity, including the surrounding wetlands. Because of the lack of profitable lead ore deposits in the lower Inn valley, the lead was imported from neighboring regions, like mining districts near Villach in Carinthia, Gossensass in South Tirol, and others.\textsuperscript{43} Another sign of the usage of external lead in the smelting process is the alteration of the isotope ratio in the fen. The reduction of the $^{206}\text{Pb} / ^{207}\text{Pb}$ ratio at the beginning of the modern era might be a result of added lead with a different isotope ratio.

As mentioned, the crucial problem in the palaeoecology of mining is to distinguish between mining activities and agriculture in the pollen data. The vegetation change caused by mining activities is partly the result of large-scale stockpile areas. These mostly steep areas of loose coarse rock offer very difficult conditions for recolonization

\textsuperscript{42} Wolfgang Ingenhaeff and Johann Bair, eds., 

\textsuperscript{43} Bartels and Bingener, \textit{Der Bergbau bei Schwaz}. 

\textbf{Figure 5: Recolonization of a mining dump in the Falkenstein district by pine (Pinus mugo, P. sylvestris) and larch (Larix decidua) trees}
by plants. The low nutrient availability and the poor water balance allow only very specialized plants to colonize the mining dumps. The vegetation development on these rock piles is similar to that on natural rockslides. The succession of the tree vegetation is indicated by pine (*Pinus mugo, P. sylvestris*) and larch (*Larix decidua*) (fig. 5). With increasing soil development and water-holding capacity, spruce (*Picea abies*) is able to immigrate and finally a larch-spruce forest develops. However, the conditions on mining dumps correspond to the situation of an artificial rock fall caused by ore extraction, in which waste rock material is deposited continuously in the course of intensive ore extraction in the galleries. The permanent supply of scree material causes constant mechanical stress and inhibits the recovery of the vegetation on the loose rock material. On the other hand, the decrease of the mining activity, which is indicated by lower copper and silver production rates in the Falkenstein area, implicates less mining waste or even abandoned galleries. Consequently, the reduction of the mechanical stress on the mining dumps speeds up the secondary succession of vegetation on the former spoil piles in the mining area. The data of the Falkenstein district show a decline in the copper and silver production in the area from 1520 onward. Contemporaneous with the cutback of mining activities in the vicinity of the fen, pine (*Pinus*) and larch (*Larix*) values in the pollen diagram rise, reflecting the spread of these heliophile pioneer tree species on abandoned mining dumps.

The relationship between the decline of the ore production and the expansion of the pioneer species mentioned above is shown by the correlations between pine (*Pinus*), larch (*Larix*), cultural indicators, and the calculated copper and silver ore production volume. The Pearson product-moment correlation coefficients of both pine (*Pinus*) and larch (*Larix*) with the ore production in the Falkenstein area indicate a significant and highly significant negative relationship (fig. 6). The correlation between cultural indicators and ore production is not significant, however, and seems to be independent of the copper and silver production volume. There is no doubt that the ore production is connected with ore extraction in the mines. The decrease of the copper and silver production reflects lower activities in the mines of the Falkenstein district. With the decrease in mining activities, the amount of waste material deposited on the dumps also decreases. This in turn initiates or intensifies the recolonization of the spoil piles by pine (*Pinus*) and larch (*Larix*), as mentioned above.

44 Nöh, “525 Jahre Schwazer Bergbau.”
45 Ibid.
Conclusion

In this study, the data show that increased mining activity in the Falkenstein area is indicated by elevated Pb/Sc ratios and decreasing lead isotope ratios in the fen deposits. The decreasing copper and silver production from the sixteenth century onwards initiates the intensified recolonization of the mining dumps. This change in the vegetation is shown by increasing pine (Pinus) and larch (Larix) values in the pollen diagram. The assemblage of palynological, geochemical, and historical data provides a detailed picture of past mining phases and helps explain the human-environment interactions in a mining landscape.