Rachel Carson Center

Perspectives

How to cite:

Breitenlechner, Elisabeth, Marina Hilber, Joachim Lutz, Yvonne Kathrein, Alois Unterkircher, and Klaus Oeggl. “Reconstructing the History of Copper and Silver Mining in Schwaz, Tirol,” In: “Mining in Central Europe: Perspectives from Environmental History,” edited by Frank Uekoetter, *RCC Perspectives* 2012, no. 10, 7–20.

All issues of *RCC Perspectives* are available online. To view past issues, and to learn more about the Rachel Carson Center for Environment and Society, please visit www.rachelcarsoncenter.de.

Rachel Carson Center for Environment and Society
Leopoldstrasse 11a, 80802 Munich, GERMANY

ISSN 2190-8087

SPONSORED BY THE

Federal Ministry of Education and Research

Deutsches Museum

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Elisabeth Breitenlechner, Marina Hilber, Joachim Lutz, Yvonne Kathrein, Alois Unterkircher, and Klaus Oeggl

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 Loreto[1]) and the second and third millennium BCE in the Western Alps (St. Véran[2]), 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 metallurgic 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.

Acknowledgement: This study was conducted in the framework of the special research program HiMAT (The History of Mining Activities in the Tyrol and Adjacent Areas—Impact on Environment & Human Societies) and financially supported by the Austrian Science Fund (FWF) (grant no.: F3111-G02) as well as the municipality of Schwaz.

1 Roberto Maggi and Mark Pearce, "Mid Fourth-Millennium Copper Mining in Liguria, North-West Italy: The Earliest Known Copper Mines in Western Europe," *Antiquity* 79 (2005): 66–77.
2 Hélène Barge, *Saint-Véran, la montagne, le cuivre, et l'homme,* vol. 1, *Mine et métallurgie préhistoriques dans les Hautes-Alpes* (Theix: Actilia Multimédia, 2003).
3 Martin Bartelheim et al., "Kupferzeitliche Metallgewinnung in Brixlegg, Österreich," in *Die Anfänge der Metallurgie in der Alten Welt*, ed. Martin Bartelheim, Ernst Pernicka, and Rüdiger Krause. (Rahden, Westfalia: Verlag Marie Leidorf, 2002), 33–82; Bernd Höppner et al., "Prehistoric Copper Production in the Inn Valley (Austria), and the Earliest Copper in Central Europe," *Archaeometry* 47, no. 2 (2005): 293–315.
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.[5] 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.[6] 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.

5 Tim Mighall et al., "Geochemical Evidence for Atmospheric Pollution Derived from Prehistoric Copper Mining at Copa Hill, Cwmystwyth, Mid-Wales, U.K.," *Science of the Total Environment* 292 (2002): 69–80.

6 William Shotyk et al., "History of Atmospheric Lead Deposition Since 12,370 14C yr BP from Peat Bog, Jura Mountains, Switzerland," *Science* 281 (1998): 1635–40; Mighall et al., "Geochemical Evidence for Atmospheric Pollution"; Fabrice Monna et al., "Environmental Impact of Early Basque Mining and Smelting Recorded in a High Ash Minerogenic Peat Deposit," *Science of the Total Environment* 327 (2004): 197–214; Sandrine Baron et al., "Records of Metal Workshops in Peat Deposits: History and Environmental Impact on the Mount Lozère Massif, France," *Environmental Science and Technology* 39 (2005): 5131–40; Isabelle Jouffroy-Bapicot et al., "Environmental Impact of Early Palaeometallurgy: Pollen and Geochemical Analyses," *Vegetation History and Archaeobotany* 16 (2007): 251–58.

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.[7] 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.[8] 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.[9] 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.[10] 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.[11]

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 ($Cu_{12}As_4S_{13}$ - $Cu_{12}Sb_4S_{13}$).[12] As indicated by the formula, the main components of the fahlore are copper, antimony, arsenic, and sulfur.

7 Clemens Eibner, "Der Kupferbergbau in den Österreichischen Alpen in der Urzeit," *Archäologie Österreichs* 3 (1992): 12–16; Höppner et al., "Prehistoric Copper Production."

8 Irenäus Matuschik, "Der neue Werkstoff—Metall," In "Goldene Jahrhunderte: Die Bronzezeit in Südwestdeutschland," ed. Dieter Planck, *ALManach* 2 (1997): 16–25; Melitta Huijsmans et al.,"Prähistorischer Fahlerzbergbau in der Grauwackenzone—Neolithische und bronzezeitliche Besiedlungsgeschichte und Kupfermetallurgie im Raum Brixlegg (Nordtirol)," in "Alpenkupfer = Rame delle Alpi," ed. Gerd Weisgerber and Gert Goldenberg, *Der Anschnitt* Supplement 17 (2004): 53–62.

9 Gert Goldenberg, "L'exploitation du cuivre dans les Alpes Autrichiennes à l'âge du Bronze," in *L'Atelier du bronzier en Europe du XXe au VIIIe siècle avant notre ère: Actes du colloque international Bronze '96,* vol. 2, ed. Claude Mordant, Michel Pernot, and Valentin Rychner (Paris: CTHS, 1998), 9–24; Gert Goldenberg and Brigitte Rieser, "Die Fahlerzlagerstätten von Schwaz/Brixlegg (Nordtirol): Ein weiteres Zentrum urgeschichtlicher Kupferproduktion in den österreichischen Alpen," in Weisgerber and Goldenberg, "Alpenkupfer = Rame delle Alpi," 37–52.

10 Christoph Bartels and Andreas Bingener, *Der Bergbau bei Schwaz in Tirol im mittleren 16. Jahrhundert, Das Schwazer Bergbuch*, vol. 3 (Bochum: Deutsches Bergbau-Museum, 2006).

11 Monna et al., "Environmental Impact of Early Basque Mining."

12 Peter Gstrein, "Geologie, Mineralogie und Bergbau des Gebietes um Brixlegg," in *Brixlegg: Eine Tiroler Gemeinde im Wandel der Zeiten*, ed. Sepp Landmann (Brixlegg, 1988), 11–31.

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.[13] Archaeological findings[14] and radiocarbon analyses[15] 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).[16]

13 Goldenberg, "L'exploitation du cuivre."
14 See Brigitte Rieser and Hanspeter Schrattenthaler, "Urgeschichtlicher Kupferbergbau im Raum Schwaz-Brixlegg," *Archaeologica Austriaca* 82/83 (1998–99): 135–79.
15 Goldenberg and Rieser, "Die Fahlerzlagerstätten von Schwaz/Brixlegg."
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,[17] 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.[18] The *Schwazer Bergbuch* ("Schwaz Mining Book") states that the first ores were extracted some 110 years before 1556.[19] Mining activities in and around Schwaz are also documented in clerical, sovereign, and municipal sources from the 1440s onward.[20] The first "Bergordnung" (mining ordinance) concerning the mining district of Schwaz dates back to the year 1449.[21]

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 abovementioned European districts was mined in the various subdistricts of Schwaz.[22] 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.[23] 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.[24]

17 Hanns Bachmann, *Die Mittelalterlichen Stiftsurbare des Bistums Brixen 4: Das Älteste Urbar der Benediktinerabtei St. Georgenberg zu Fiecht von 1361/70 und das Weinzinsregister von 1420 und 1422* (Innsbruck: Universitätsverlag Wagner, 1981).

18 Yvonne Kathrein, "Bei- und Familiennamengeographie im 14. und 15. Jahrhundert in Tirol: Ein onomastischer Beitrag zur Beginnphase des Schwazer Bergbaus," *Innsbrucker Beiträge zur Onomastik* 7 (2009): 53–76.

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).

21 Wolfgang Tschan, "Das Schwazer Berglehenbuch und die Anfänge des Schwazer Bergbaues," *Der Anschnitt* 5/6 (2008): 202–13.

22 Thomas Sokoll, *Bergbau im Übergang der Neuzeit* (Idstein: Schulz-Kirchner, 1994).

23 Ekkehard Westermann, *Die Listen der Brandsilberproduktion des Falkenstein bei Schwaz von 1470 bis 1623* (Vienna: Verband der wissenschaftlichen Gesellschaften Österreichs, 1988).

24 Georg Mutschlechner, "Vom alten Bergbau am Falkenstein (Schwaz): Nach gedruckten und ungedruckten Quellen," in *Schwazer Buch: Beiträge zur Heimatkunde von Schwaz und Umgebung*, ed. Raimund von Klebelsberg (Innsbruck: Wagner, 1951), 113–25.

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.[25] The information stored in the plant remains is preserved in the sediment and is influenced by how and where they were deposited.[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.[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.[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.[29]

25 Gerhard Lang, *Quartäre Vegetationsgeschichte Europas* (Jena: Gustav Fischer Verlag, 1994), 33–51.
26 Peter D. Moore, J. A. Webb, and Margaret E. Collison, *Pollen Analysis,* 2nd ed. (Oxford: Blackwell, 1991), 216.
27 Lang, *Quartäre Vegetationsgeschichte Europas*.
28 Moore, Webb, and Collison, *Pollen Analysis*.
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.

Figure 1: Coring (Geonor piston corer) at the Kogelmoos fen (Courtesy of the author)

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 cm^3 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[30] and Seiwald[31] (including treatment by hydrochloric acid, chlorination, acetolysis, and, if necessary, hydrofluoric acid). Afterwards the samples were colored with fuchsine and mounted in glycerin jelly. Pollen grains were counted at 400x magnification (for critical determinations at 1,000x magnification)

30 G. Erdtman, "The Acetolysis Method: A Revised Description," *Svensk Botanistik Tidskrift* 54 (1960): 561–69.
31 Alois Seiwald, "Beiträge zur Vegetationsgeschichte Tirols IV: Natzer Plateau—Villanderer Alm," *Berichte des Naturwissenschaftlich-Medizinischen Vereins Innsbruck* 67 (1980): 31–72.

and were identified by using the standard identification keys of the central European pollen flora[32] 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.[33] The calculation of the pollen diagrams was carried out by the program FAGUS,[34] which was developed at the Botanical Institute of Innsbruck University. The graphical representation was performed by the program C2.[35]

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).[36]

32 Hans-Jürgen Beug, *Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete* (Stuttgart: G. Fischer, 1961); William Punt, ed., *The Northwest European Pollen Flora,* vol 1, vols. 2–4 ed. with G. C. S. Clarke, vol. 5 ed. with Stephen Blackmore and G. C. S. Clarke (Amsterdam: Elsevier, 1976–88); Moore, Webb, and Collison, *Pollen Analysis*; Maurice Reille, *Pollen et spores d'Europe et d'Afrique du nord* (Marseille: Laboratoire de Botanique historique et Palynologie, 1992, supplement 1 published 1995); Knut Faegri and Johannes Iversen, *Bestimmungsschlüssel für die nordwesteuropäische Pollenflora* (Jena: Gustav Fischer Verlag, 1993).

33 P. E. J. Wiltshire and K. J. Edwards, "Mesolithic, Early Neolithic and Later Prehistoric Impacts on Vegetation at a Riverine Site in Derbyshire," in *Climate Change and Human Impact on the Landscape: Studies in Palaeoecology and Environmental Archaeology*, ed. F. M. Chambers (London: Chapman & Hall, 1994), 157–68.

34 Gernot Gelmini, "Programm zur grafischen Darstellung von Pollenzähldaten," Diplomarbeit, Universität Innsbruck, 1997.

35 Stephen Juggins, "C2 Version 1.5 User Guide: Software for Ecological and Palaeoecological Data Analysis and Visualisation," (Newcastle upon Tyne: University of Newcastle, 2007).

36 For a more detailed description of the method used see Elisabeth Breitenlechner et al., "The Impact of Mining Activities on the Environment Reflected by Pollen, Charcoal and Geochemical Analyses," *Journal of Archaeological Science* 37 (2010): 1458–67.

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.[37] 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.

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

Figure 2: Radiocarbon dates from Kogelmoos

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"

37 Christopher Brock Ramsey, "OxCal Program v3.10," last modified 9 February 2005, http://c14.arch.ox.ac.uk/oxcal3/oxcal.htm; Atmospheric data from Paula J. Reimer et al., "IntCal09 and Marine09 Calibration Curves, 0–50,000 Years Cal BP," *Radiocarbon* 51, no. 4 (2009): 1111–50.

(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.[38] 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

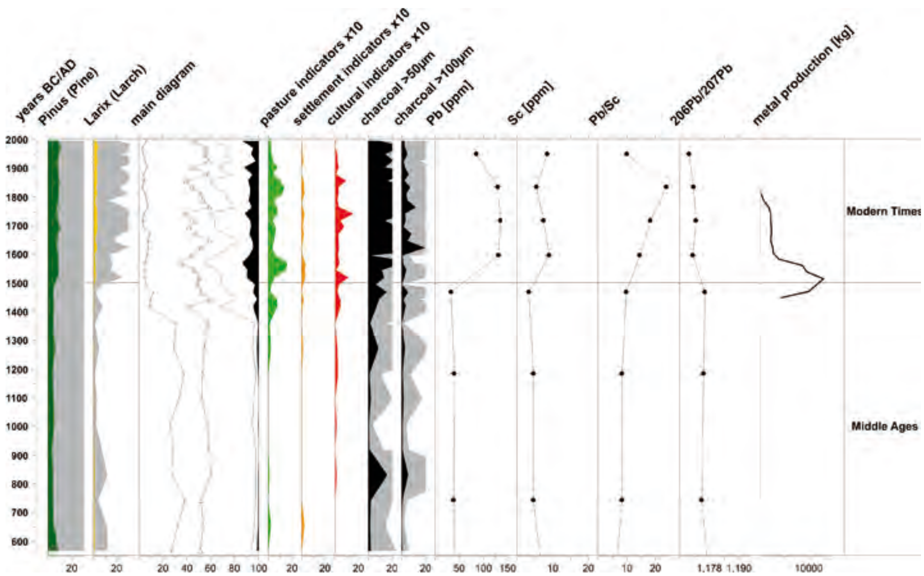


Figure 3: Middle Ages and modern times in the relative pollen diagram (selected species) of the Kogelmoos with geochemistry and historical data (Nöh 1948, 128). Black/colored areas = fraction of different species in %; grey areas = fraction of different species multiplied by 10; main diagram: x = values 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).

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.[39]

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 Stiftsurbare.*
39 Tschan, "Das Schwazer Berglehenbuch."

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).

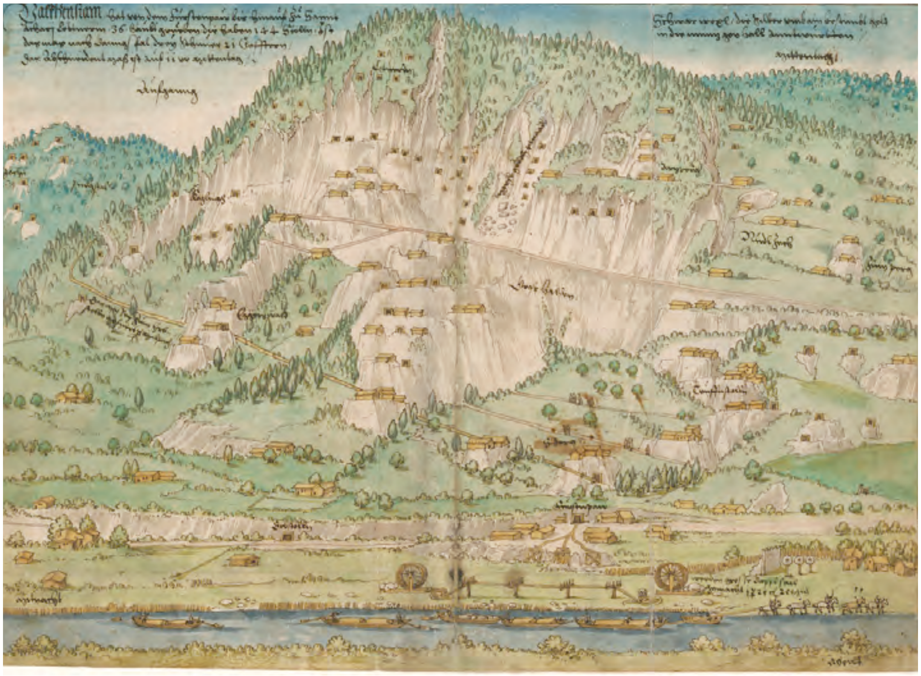


Figure 4: The formerly dense fir-spruce forest in the Falkenstein district was thinned out by mining and farming activities. (Source: Illustration from the *Schwazer Bergbuch,* Tiroler Landesmuseum Ferdinandeum, Innsbruck)

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.[40] 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.[41] At the same time, the Saiger technique was implemented in the Tirolean

40 William Shotyk et al., "Geochemistry of the Peat Bog at Étang de la Gruère, Jura Mountains, Switzerland, and Its Record of Atmospheric Pb and Lithogenic Trace Metals (Sc, Ti, Y, Zr, and REE) Since 12,370 14C yr BP," *Geochem Cosmochim Acta* 65 (2001): 2337–60.

41 Albert Nöh, "525 Jahre Schwazer Bergbau: Eine geschichtliche Zusammenfassung der Verhältnisse des Schwazer Bergbaues vom Beginn 1420–1945," unpublished manuscript 1948.

Figure 5: Recolonization of a mining dump in the Falkenstein district by pine (*Pinus mugo, P. sylvestris*) and larch (*Larix decidua*) trees

mining sites at around 1492.[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.[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 $^{206}Pb/^{207}Pb$ 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

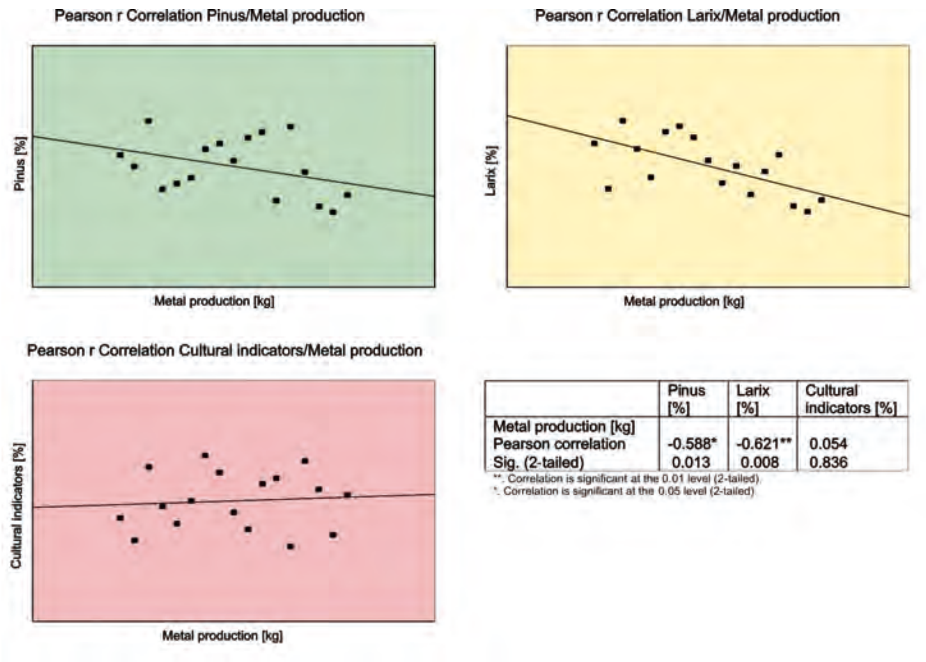
42 Wolfgang Ingenhaeff and Johann Bair, eds., *Schwazer Silber—vergeudeter Reichtum? Verschwenderische Habsburger in Abhängigkeit vom oberdeutschen Kapital an der Zeitenwende vom Mittelalter zur Neuzeit,* Tagungsband, 1. Internationales Bergbausymposium (Innsbruck: Berenkamp, 2003).

43 Bartels and Bingener, *Der Bergbau bei Schwaz.*

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[44] 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.[45] 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.



	Pinus [%]	Larix [%]	Cultural indicators [%]
Metal production [kg]			
Pearson correlation	-0.588*	-0.621**	0.054
Sig. (2-tailed)	0.013	0.008	0.836

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Figure 6: Correlation diagrams and the Pearson correlation coefficient of *Pinus, Larix* and cultural indicators [%] with the metal production (copper/silver) [kg] in the Falkenstein district.

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.