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WATER POWER IN 16TH CENTURY PRECIOUS METAL PRODUCTION IN THE GASTEIN DISTRICT OF THE AUSTRIAN ALPS

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Abstract: Interdisciplinary research methods were used to study gold and silver mining and smelting in the mining district of Gastein/Rauris near Salzburg, Austria, in the mid 16th century. A brief general history is given, archaeology of the settlement and water power usage is described.

Introduction
The area selected for interdisciplinary research into precious metal production in the Austrian Alps was the mining district of Gastein/Rauris in the federal country of Salzburg. Mining and ore dressing were studied in the Bockharttal valley and smelting in the Angertal valley. Both valleys belong to the mining district of Gastein (Fig. 1). The aim of this study was to cover all important aspects of precious metal production at the time of Georgius Agricola. Apart from archaeology, the following sciences were included: mineralogy and geology of mineral deposits, geophysics and petrophysics, geochemistry, geodetic surveying, process engineering, metallurgical engineering, as well as contributions from dendrochronology, analysis of glass, palaeozoology and history.[1]

Water power was used to drive the ore mills in the Bockharttal valley and the bellows of the smelting plants in the Angertal valley.

History of Precious Metal Production in the Hohe Tauern
Analysis performed on gold objects found at the Dürrnberg near Hallein shows that the gold deposits of the Hohe Tauern were first exploited during the Iron Age (6th century BC). Prehistoric gold production reached its peak around 130 BC. Polybios tells of rich gold deposits found in the region of the "Noric Tauriskoi". The gold used in this era was probably placer ore found in the rivers. The withdrawal of the Romans at the end of the 5th century AD brought the first gold production in the Hohe Tauern to an end.

Intensive mining of the ore deposits around Gastein and Rauris started in the 14th century. In 1342, the archbishop of Salzburg issued the first "Constituciones". This corpus of mining laws regulated taxation as well as work procedures. During the following centuries, mining activities became more and more important. The peak of ore production was reached in the middle of the 16th century. For example in 1557, 830 kilograms of gold and 2713 kilograms of silver were produced. The 17th century brought a decline that led to the nationalisation of the mines. During the 18th and 19th centuries modern mining and production technology was introduced in a final, but unfortunately unsuccessful, attempt to improve profitability. At the end of the 19th century however, the mines finally shut down. The last mining in the area took place during the second world war by the Preussische Bergwerks- und Hütten AG.

During the Middle Ages and Early Modern Times, smelting of the ore was done close to the mining areas. Smelting activities began in the Angertal valley, one of the most important smelting centres in the Gastein mining district, during the 14th century. During the course of the 16th century however, the centre of smelting activities moved ever nearer the main valley of Gastein. At the end of the 16th century the supply of timber was exhausted and smelting was at last permanently transferred to Lend in the Salzachtal valley, where rafting was possible (Moosleitner 1994; Günther 1994; Ludwig and Gruber 1987).

Topography and geology of the Bockharttal and the Angertal
The Bockharttal valley is a roughly east-west trending valley situated at the southern end of the Gasteiner Tal valley. It is surrounded by the Unterer Bockhartsee lake (1850 metres) to the east, the notch of the Bockhartscharte (2226 metres), which is an old pass into the valley of Rauris to the west, the mountain range of the Silberpfennig (2600 metres) to the north and the ranges of the Seekopf (2413metres) and the Kolmkarspitze (2529 metres) to the south. The ore veins that were mined encompass an area of up to one kilometre in width. They run at a length of 5 km from the Siglitztal valley to the south across the Seekopf, the Bockharttal valley and the Silberpfennig to the Erzwies mining field to the north. The main minerals that contain the gold and silver are quartz, pyrite and arsenopyrite. To the north of the ore deposit, lead, copper, zinc and iron are also found.

The Angertal valley lies to the west of the Gasteiner Tal at an altitude of between 950 metres and 1300 metres. From its upper end, an old pathway leads to the Erzwies mining field from whence the ore was transported down to the smelting plants (Gstrein 1993).

Archaeological Sites in the Bockharttal
The main archaeological sites (Fig. 2) are a central group of houses to the south-east of the Oberer Bockhartsee lake and an ore dressing plant about 250 metres to the north-east of these houses. Numerous sites of ancient mining activity are found along the ore veins. Outside most of the entrance tunnels of the mines, terraces with ruins of miners' living quarters are to be found. Only one of these mines, that on the flanks of the Seekopf mountain, was studied in more detail (Cech 1998; Cech 2000; Cech and Paar 1997; Cech and Walach 2001).

The Central Group of Houses - Results of the Excavations
The central group of houses lies at an altitude of 2100 metres above sea level and consists mainly of three buildings whose dry stone walls are still visible above ground, the remains of two mines and a house that was discovered during the

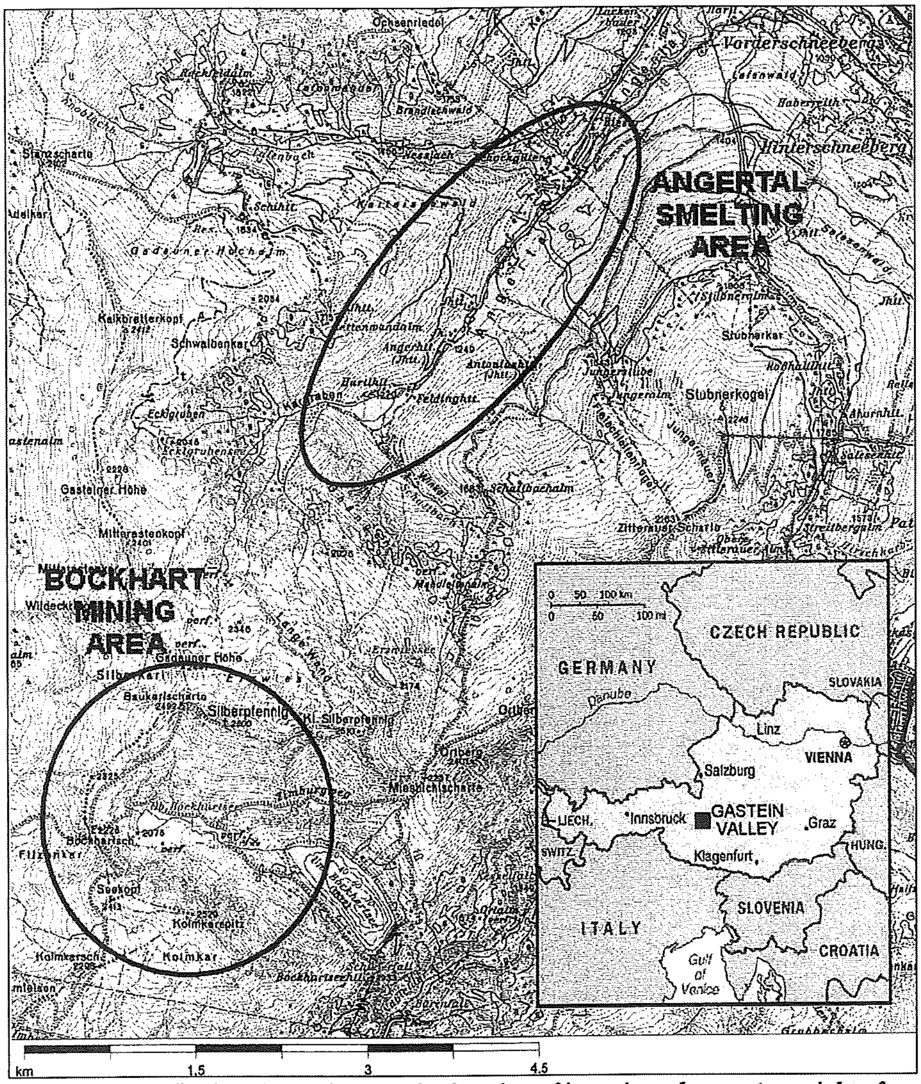
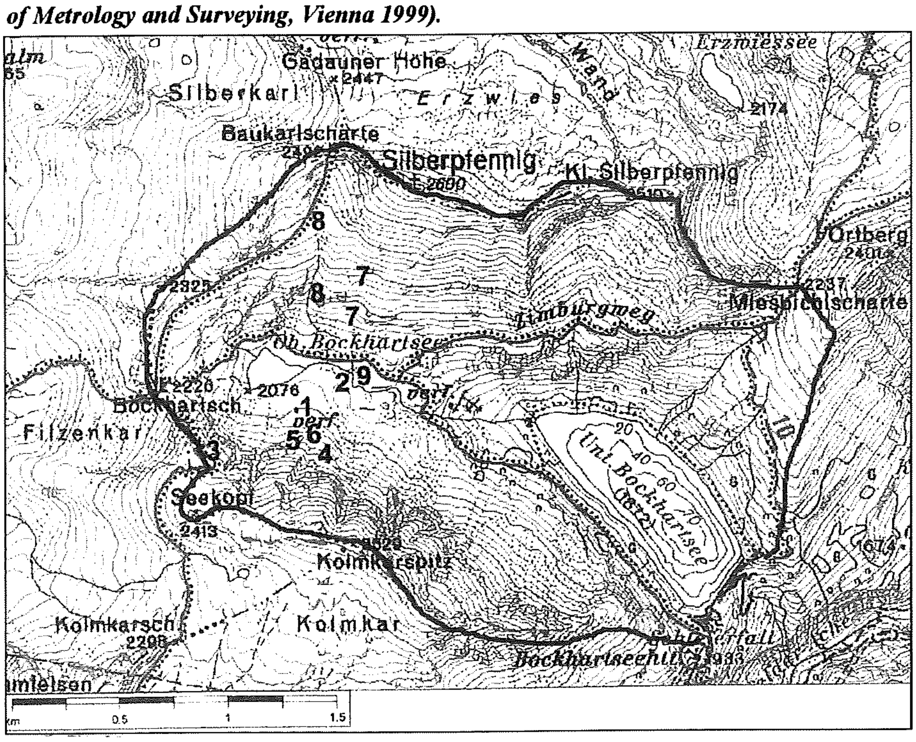


Fig. 1. Mining district of Gastein, Austria; location of investigated areas (copyright of base map: Austrian Federal Office of Metrology and Surveying, Vienna 1999).

Fig. 2. Find locations in the Bockharttal valley: 1-Central group of houses, 2-Ore dressing plant, 3, 4, 5, 6, 7, 8, 9 - Mines (copyright of base map: Austrian Federal Office of Metrology and Surveying, Vienna 1999).



excavation. The buildings are representative of three chronological phases. The eldest phase is characterised by a small building and the remains of a mine. According to the stratigraphy of the site, this earliest activity took place before the 15th century. In the course of the 15th century after the first mine was deserted, a house used as miners' living quarters made of wood and partial stone foundations, was built. This house was heated by a tiled stove. It had at least two rooms, the easternmost room being the miners' sleeping quarters. At the end of the 15th century this building was destroyed by fire. The area where the house stood was then levelled and remained free of buildings until the 16th century when a new house for the miners and a large smithy were erected. This house was built from a combination of wooden and dry stone walls. It had glass windows and also a tiled stove for heating and cooking. The sleeping quarters were in the north-east corner. A Schneekragen, which is a covered walkway, led from the house to the mine. As the mines were worked the whole year round this was necessary to ensure safe passage between the house and the mine during winter. At the same time a smithy built with dry stone walls was erected. Some time during the 16th century the old mine collapsed in front of one of the entrances to the smithy. This cave-in also destroyed parts of the remains of the house and most probably the 16th century smithy. The collapsed shaft was then reinforced with dry stone walls and filled up with stones, smithy slag and general rubbish. In the last third of the 16th century the mines in the Bockharttal were shut down.

The large 16th century smithy covers an area of 9 by 11 metres and is built from dry stone walls, which are in part still standing up to a height of two metres. It has two rooms. The workshop of the smith was in the small room at the south-east corner of the house. The bigger, L-shaped room, was used for storage (Cech and Walach 2000).

Covered by tons of stones, the interior of the smithy was very well preserved. In the south-east corner was the forge with the stone that held the anvil and the remains of the water barrel in front of it. The area in front of the forge was the only one covered with a wooden floor. On the eastern wall next to the forge was a small round assay furnace for testing the quality of the ore. Small fragments of slag from this process were also found. The rest of the room was covered by a layer of charcoal and iron implements, with an accumulation along the western wall. All the finds showed signs of use and were probably kept by the smith on shelves along the walls. There is evidence of secondary use of these objects. The fact that there are no smith's tools suggests that the smithy was abandoned in an orderly fashion. The smith took all his tools such as the anvil, the hammers and the pliers with him when the mines were shut down at the beginning of the 17th century.

The Ore Dressing Plant - Plates 1 and 2

The site of the ore dressing plant, about 250 metres to the north-east of the central group of houses, was marked by mill stones and the channel for the water wheel. The excavation was planned according to the results of geophysical prospecting. The plant stood on an artificially levelled area that was secured by dry stone walls to the south and to the west. The construction of the ore dressing plant falls into two chronological phases. According to the results of the dendrochronology, the first plant was erected in the late nineties of the 15th century and operated for about 20 years. The construction of the new plant was probably related to technological innovations. The earlier phase is represented by four big wooden posts. They are linked with each other two by two. In the course of building the later plant they were cut down. The traces of the axe are clearly visible. The later phase consisted of an ore mill and a small stamp mill. The ore mill rested on two big wooden posts that were connected with each other. In order to give them the necessary stability they stood on a stone pavement and two layers of wooden boards. A large amount of pounded ore was found in the vicinity of this construction (Steiner 2000). To the east of the actual ore mill was a small stamp mill consisting of an iron block fitted into a piece of wood. The water wheel itself has not been preserved. It was probably taken apart when the mines were shut down.

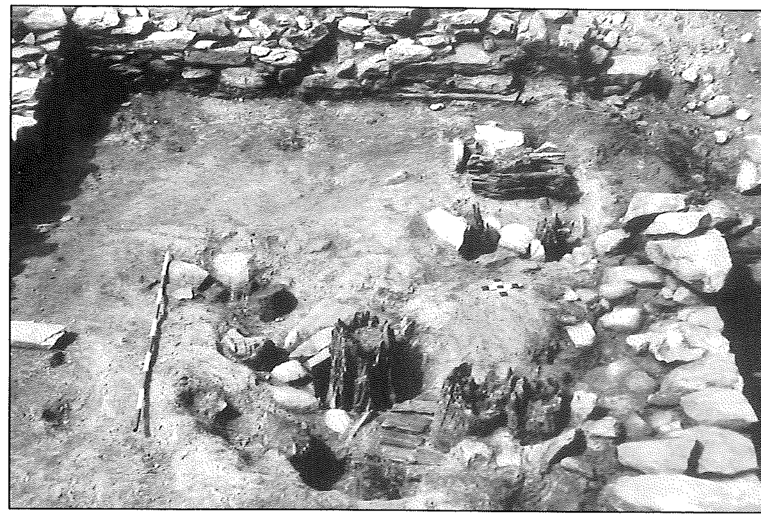
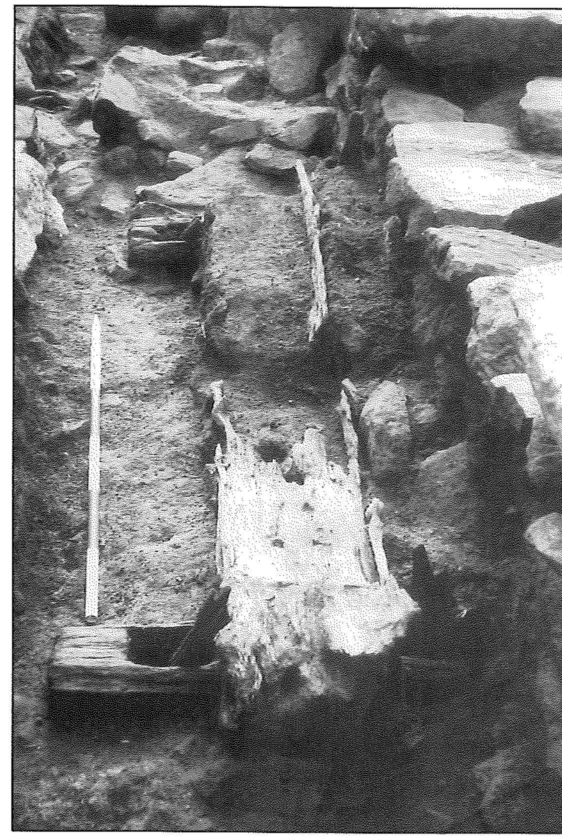


Plate 1 (above). The ore dressing plant. *(photos: B.Cech).*
Plate 2. End part of the chute with its supports lying in the wheel pit.

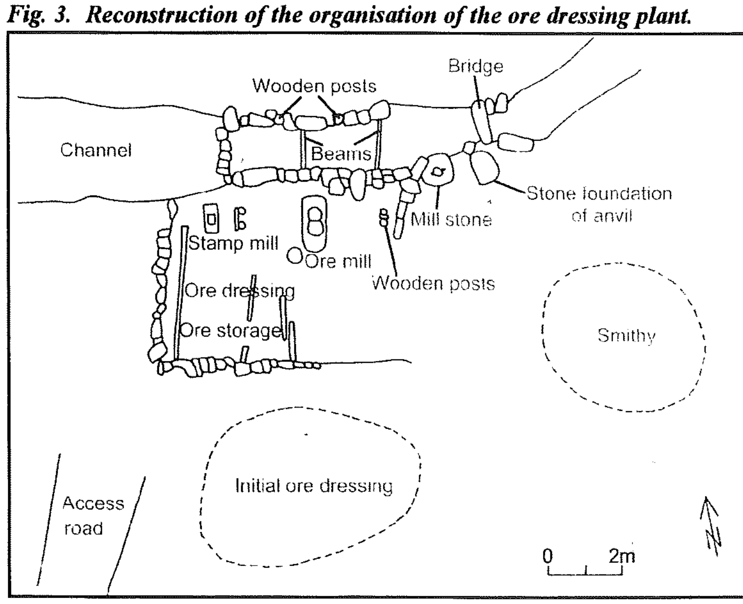


Only a few artefacts were found on this site, the most important being the iron head of a stamp-stem. A small quantity of smithy slag from a small ground based forge was also found.

The Reconstruction of the Ore Dressing Plant - its Layout and Mechanics

The topography and the geometry of the archaeological features uncovered during the excavation, as well as the evidence of contemporary sources, make it possible to reconstruct the layout and mechanics of the ore dressing plant (Figs 3-6).

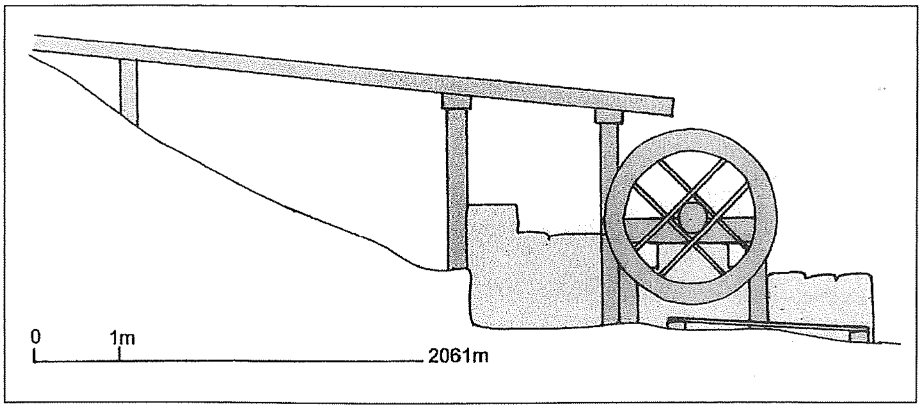
Fig. 3. Reconstruction of the organisation of the ore dressing plant.



The Layout of the Ore Dressing Plant

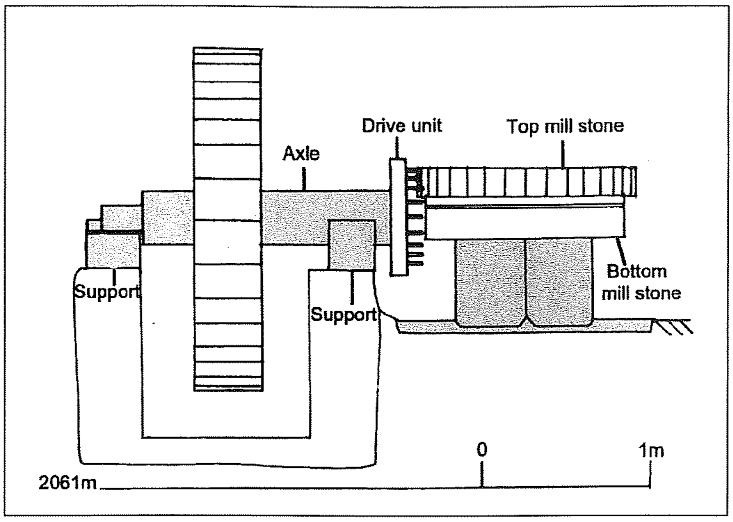
The results of geophysical prospecting and the petrophysical analysis of the ores found at the site show that the ore was transported from the mines to the dressing plant along the clearly visible access road. These ores were deposited outside the actual plant. This was also the site of the initial ore dressing which was by hand-picking. Wooden beams and planks just inside the walled off area of the plant belonged to sheds where this ore was stored. Before it was fed into the stampmill it was again sorted by hand. The stamp mill was used for breaking up the ore into small pieces that could then be fed into the mill.

The reconstruction of the different stages of the ore



ore (arsenopyrite, 5.5, host rock 2.65) the dressing process led to an increase of ore content from 20% to 40% by volume (Cech and Walach 2001).

Smithy slag found during the excavation came from an earthbound forge, whose location to the east of the ore dressing plant could be determined by geophysical prospecting. The foundation stone of the anvil was found lying at the southern edge of the water channel.



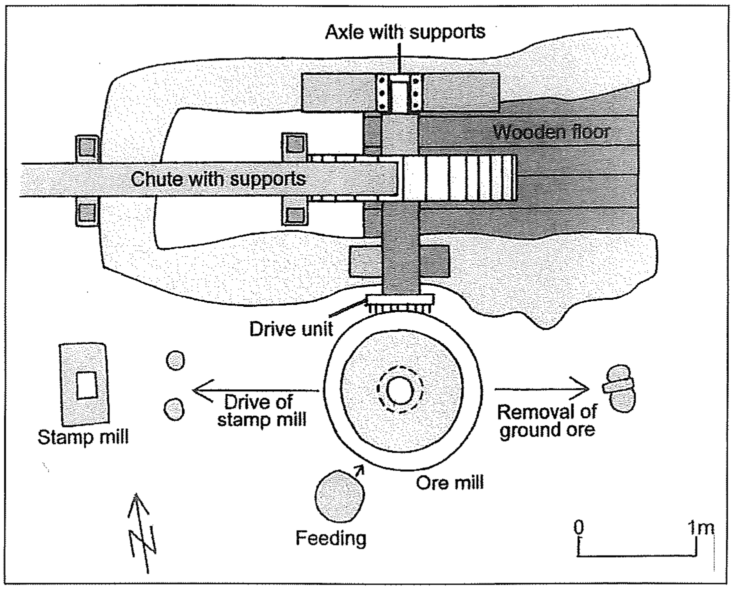


Fig. 4 (top). Reconstruction of the wheel pit, the chute and the water wheel.
Fig. 5 (middle). Reconstruction of the drive unit of the mill.
Fig. 6 (above). Reconstruction of the main part of the ore dressing plant.

dressing process was made possible by statistical analysis performed on 2100 pieces of ore collected during the excavation. The parameters used for the statistics were the main dimensions and the weight of each piece of ore. The density distribution across the excavated area yield characteristic groupings. To the south of the actual plant relative densities (specific gravity) of 3.3 were found. Ore found in the area of the sheds shows relative densities of 3.5 and the ore that was fed into the actual mill had an average relative density of 3.8. At the same time the average volume decreased from 15 cm^3 to 5cm^3. Considering the density of the

The Mechanics of the Ore Dressing Plant

The drive

At an altitude of 2070m above sea level the water coming from the Obere Bockhartsee lake is led into an artificial channel that runs over a distance of 100 metres to a terrace to the west of the ore dressing plant. From this point onwards, covering a distance of 28 metres to the water wheel, the gradient of the channel inclines markedly. The height of the drop is 7 metres. Twenty metres to the west of the water wheel the channel is divided into two parts. The northern branch served as a drain when the plant was not in use. The southern channel led the water along a wooden chute to the wheel. The wooden posts supporting this chute can still be seen. The end part of the chute consisted of a 2.2 metres long hollowed out fir tree with a cross section of 350 cm^2. This end section, together with its supporting construction, was found lying at the bottom of the wheel pit. (Plate 2)

The wheel pit is fortified by dry stone walls. It is 1 metre wide, 3.5 metres long and about 1 metre deep. Its bottom was covered with a wooden floor to prevent the water from undermining the walls of the wheel pit. The position of the wheel's axle was marked by its supporting posts that were built into the northern wall of the wheel pit. The southern supports however are not preserved. According to the geometry of the archaeological features (depth of the wheel pit, height of the posts supporting the mill) it can be assumed that the water wheel had a diameter of about 2 metres. Its chambers were 30-40 cm wide. The number of chambers and their volume cannot be determined (Fig. 4).

The gross capacity of the wheel can be computed using the height of the fall and the amount of water coming through the chute. The height of the fall is 7 metres and the amount of water coming through the chute is 0.075 to 0.15m^3/sec. The resulting gross capacity is 5 to 10 KW; that amounts to a net capacity of 3 to 6 KW (Giesecke 1985).

The power transmission and the mill-construction

The power transmission consists of the water wheel, its axle, its northern and southern supports and the drive unit of the mill. The posts supporting the millstones are set in line with the axle that was 1.7 to 1.8 metres long and had a diameter of approximately 20 to 30cm. A gear wheel of 30cm diameter fixed to its southern end drove the top millstone, whose diameter was 1.2 metres. This results in a transmission ratio of 1:2. (Plate 2)

A post to the south-west of the mill supported a platform used for feeding the ore into the mill. Posts to the east of the mill are probably connected with the removal of the ground ore (Fig.6).

The Stamp Mill

A small stamp mill is situated 2.8 metres to the west of the ore mill, at a right angle to the axle. This stamp mill is a simple construction working like a drop hammer. It was used to break the ore into the right size for feeding it into the mill. It was not driven directly by the axle of the wheel but probably by a connecting rod fixed to the top millstone.

The well preserved archaeological features, together with the results of the geophysical prospecting, and the petrophysics of the ores found at the site, make it possible to reconstruct the layout of the later phase of the ore dressing plant and its mechanics. The main phase of its working fell in the second half of the 16th century. At that time arsenopyrite was needed in great quantities as a flux for smelting ore. The stamp mill is of particular interest. It is the first archaeological evidence of the beginnings of change to mechanised crushing. The stamp mill was not yet used independently but in connection with the earlier ore dressing methods.

Smelting Plants in the Angertal Valley

So far eight smelting plants have been located in the Angertal valley. They are situated on the floor of the valley. The best preserved site (H1) was excavated. The core of the smelting plant is made up of three furnaces arranged in a row or bank. Furnace 1 and 2 form a unit separated by a joint. Furnace 1 features a hearth cover of fired clay and a forehearth, whereas Furnace 2 is a shaft furnace. About 0.5 metres east of this furnace complex lies furnace 3. This probably also is a shaft furnace of which, however, only the lowermost layer of stones remains. On the bottom of the furnace or hearth remains of smelting (rocks, slags, charcoal, ore?) were found as well as a tapping channel pointing north.

From the bank of furnaces, the smelting plant extends about 6 metres to the south. Here at the time of the construction of the plant, an outcrop was levelled to create a flat working surface. From this direction the ventilation of the furnaces was supplied by bellows powered by water wheels. A

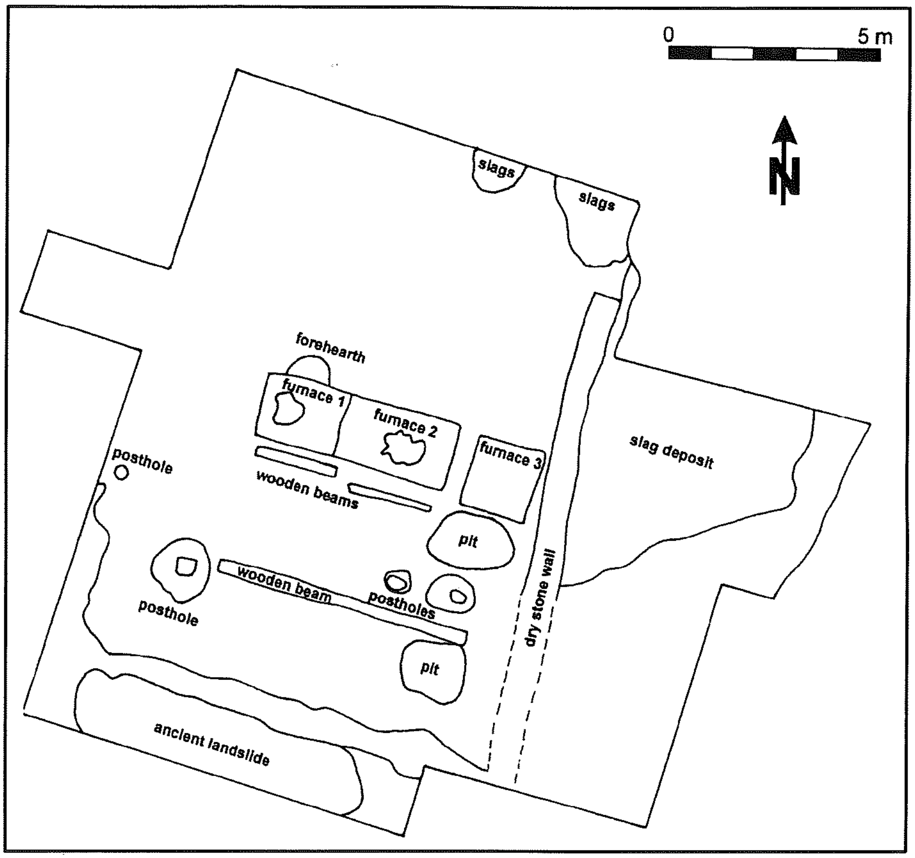
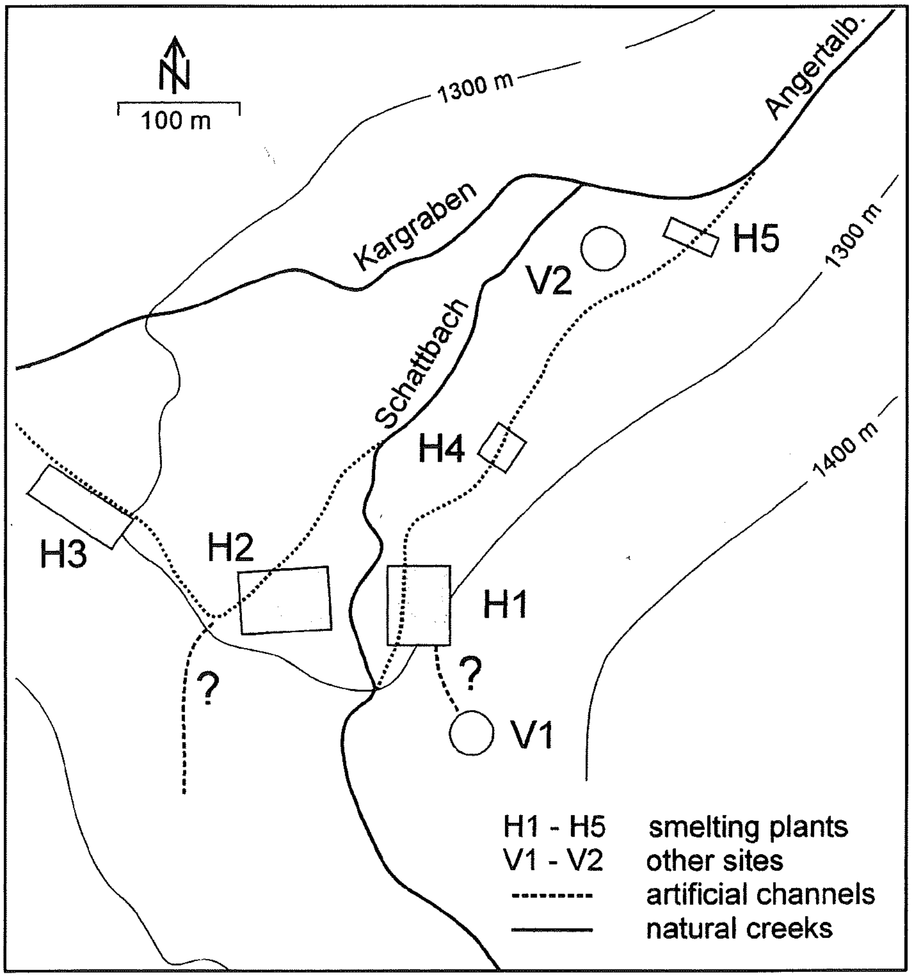


Fig. 7 (above). Angertal smelting center, site H1; result of the archaeological excavation

Fig. 8 (below). Angertal smelting centre, relationship between natural creeks, artificial channels and smelting plants



part of the ventilation system was a massive wooden beam running parallel to the furnaces for a distance of about 3 metres. This beam leads to a hole 40 by 40 centimetres wide with a depth of 70 centimetres which is walled throughout the whole of its depth with dry masonry. Probably, two beams running immediately south of Furnaces 1 and 2 also form part of the venting system. The function of two pits to the south of Furnace 3 however is still unclear (Fig. 7).

The excavation area extends to the north of the bank of furnaces for about 6.5 metres. In this area, besides the aforementioned forehearth belonging to Furnace 1, isolated slag deposits but no construction of any importance were found. In the east, the smelting plant is delimited by a dry-stone wall of about 10 metres length separating the smelting area from the slag heap. An additional function of this wall was to provide protection for the furnaces from rock avalanches and land slides, as is documented in several instances in the excavation findings. For the operation of the water wheel, a part of the Schattbach creek running west of the plant was diverted into a channel. In parts, this channel can still be clearly seen in the field. The wheel pit, as well as any supports of the water wheel, have been destroyed by the creek.

Archaeological mapping and geophysical prospecting in the Angertal valley show that the smelting plants are situated next to a well planned system of artificial channels for the supply of water for the wheels (Fig. 8). This system makes optimum use of the topographic situation. On the one hand, this guarantees optimum safety of operation of the plants in extreme Alpine landscape and altitude. On the other hand a nearly un-interrupted production of the smelting plants could be assured in spite of a seasonal variation, by a factor of ten, of the runoff of precipitation.

Notes

(1) The results of this project have been the topic of the habilitation thesis: Cech, Brigitte (2002) Spõtmittelalterliche bis frühneuzeitliche Edelmetallgewinnung in den Hohen Tauern. Montanarchõologische Forschungen im Bockhartrevier, Gasteiner Tal (Bundesland Salzburg), unpublished habilitation thesis (Wien).
See also - Cech and Walach 2001.

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