Mine Water Hydrology of the Schneeberg Mine (Saxony) Fifty Years after Flooding

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Abstract
The Schneeberg mine in the south-western part of Saxony (Germany) is flooded up to the overflow level. The mine water discharges via a historical adit to the Zwickauer Mulde river. Although the Schneeberg mine has been flooded for a 50 years period, and it is relatively small, the mine discharges a significant arsenic load at a nearly constant level, which seems to be typical for base metal/ uranium mines of the Erzgebirge province. Recently, the Schneeberg mine is the most significant arsenic emitter within the Zwickauer Mulde watershed. The paper gives an overview of the hydrology of the Schneeberg mine and its relevance to the prediction of the long-term impact of flooded underground mines in the Erzgebirge Mineral province.

Key words: Mine flooding, long term effects, arsenic emission, Erzgebirge, Schneeberg, Germany

Introduction
The Schneeberg mine is located in the south-western part of Saxony in the foothills of the Western Erzgebirge. It lies in the immediate vicinity of the Schlema-Alberoda uranium mine (Fig. 1). This latter mine has been closed and then step by step flooded on the basis of the Federal Mining Law by Wismut GmbH as part of a complex remediation program to revitalise the Schlema-Alberoda mining area since 1991. The Wismut programme is financed by the government of the Federal Republic of Germany.
By contrast, the Schneeberg mine is one of the so-called old or abandoned mine sites which has no legal successor. Recent mine closure remediation work is being carried out to eliminate immediate risks on the basis of the Saxon Cavity Regulation (police regulation).
The mine water from Schneeberg is drained via the Markus Semmler adit, which by-passes the Schlema-Alberoda mine, into the Zwickauer Mulde, since the Schneeberg mine was flooded in 1958. In the past no systematic studies of the hydrological and hydrochemical development of the Schneeberg mine water had been conducted. This information, however, is important for predictions in the course of flooding the Schlema-Alberoda mine, and also for the assessment of the long term development of the water quality of the Zwickauer Mulde river. Therefore, current remediation activities at the Schneeberg mine give the opportunity for carrying out additional studies in terms of mine water hydrology. The paper illustrates preliminary results.

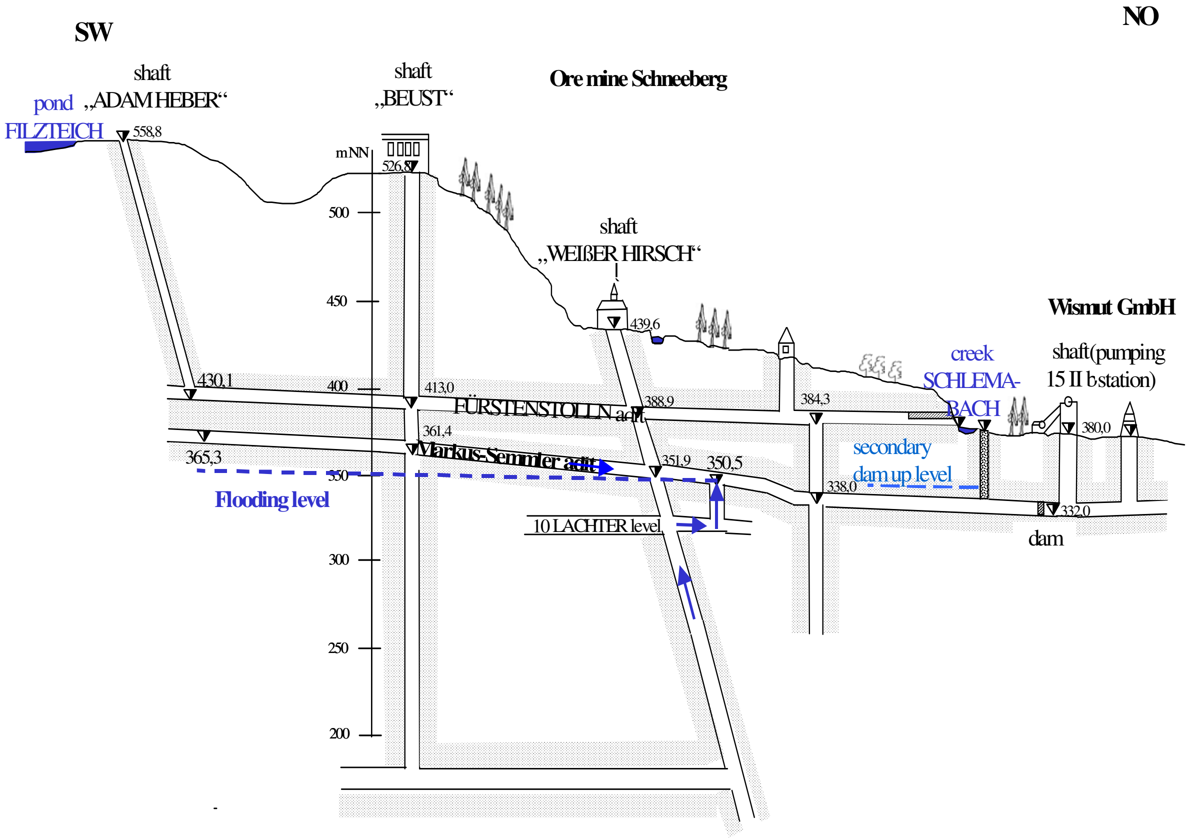
Site characteristic of the Schneeberg area
The Schneeberg mine is predominantly located in the immediate vicinity of the town of Schneeberg. The mine area covers an area of around 10 km^2 at an altitude of approximately 400 m to 550 m above sea level. Apart from the town, the area is primarily put to agricultural use whilst there are wooded areas on its edges.
The long term annual average precipitation for the area is 900 mm (corrected) whilst the annual mean temperature is 7°C. The area is drained primarily by tributaries of the Zwickauer Mulde, which is the main river of the Western Erzgebirge (average volumetric flow rate 12 m^3/s). The average runoff rate drained from the Schneeberg area amounts to about 50% of the rainfall. As a result of the mining activities, half of this volume is drained through underground galleries of the Schneeberg mine.
The Schneeberg and Schlema-Alberoda mines are located in the ore field of the Lößnitz-Zwönitz-syncline on the outer contact zone of the Aue granite. The metamorphic slates in this area contain hydrothermal vein deposits with a polymetallic mineralisation. The depth of this mineralisation increases from west (Schneeberg: 400 m) to east (Schlema-Alberoda: 1800 m). The ore metals are chiefly oxides

and arsenides or are present in elementary form. Sulphides are relatively rare. The gangue is primarily oxide/carbonate.

Hydrology

Since the Middle Ages, the Schneeberg mining area has been a major place for mining copper, silver, bismuth, cobalt, but also nickel and uranium. Mining was stopped in the early fifties of the 20th century and the mine was abandoned thereafter. The mining area comprises a large number of former individual mines which were originally independent but were united over the course of time. Initially the mining activities were concentrated near the surface but they reached maximum depths of up to 400 m in the 19th century. The volume of the mining voids of the Schneeberg mine is not known precisely, but has been estimated between 1 and 1.5 million cubic metres.

***Figure 1** Simplified cross section of the Schneeberg mine*



After the mining activities were stopped, the mine has been flooded since 1958. The mining area is primarily drained through the 25 km long Markus Semmler adit into the Zwickauer Mulde. During the period when uranium mining was taking place in the neighbouring Schlema-Alberoda mine, a pressure dam was built in the Markus Semmler adit to keep the Schlema-Alberoda mine free of Schneeberg mine water. The mine water which accumulated behind the dam was pumped up to the surface and was discharged to the Schlemabach creek for decades. As part of the closure process for the Schlema-Alberoda mine, efforts were made to re-establish the previous drainage situation through the Markus Semmler adit to save costs for water management.

Over the past ten years the average annual drainage volume from the Schneeberg mine amounted to around 5 million cubic metres with a quite high variation, since the monthly records range from 0.2 to 0.8 million cubic metres which provides evidence of a strong influence of the weather conditions at the surface on the mine water flow rate.

For decades after its closure it was not possible to enter the Schneeberg mine directly. The recent remediation activities, however, make it possible to examine the mine step by step from east to west.

The investigations showed that the hydraulic overflow point of the flooded deeper part of the mine into the Markus Semmler adit is located at an old shaft called "Alter Weißer Hirsch" at 350 m above sea level. This shaft is interconnected with one of the main shafts in the mining area, the "Weißer Hirsch" shaft. From there a whole series of deeper galleries below the Markus Semmler are connecting the overflow point to the central and western mining field (Fig.1). Volumetric measurements conducted since 2005 indicate a proportion of the drainage from the overflow point (deep mine water, DMW) of at least 50% of the total mine drainage (mixed water, MW).

As a consequence of these observations it can be concluded that the Schneeberg mining area is currently flooded to an altitude of 350 m above sea level, which corresponds to a flooded mine volume of about 0.6 million cubic metres.

The extension of the hydrological analyses into the central and western sections of the Schneeberg mine have not been possible to date due to a lack of access, since the Markus Semmler adit is collapsed at various locations in this area. This is also hindering the free drainage of the mine water at the adit level, assisting the diversion of mine water from the adit system into deeper parts of the mine which therefore acts as a bypass.

Hydrochemistry

The mine water flowing towards the pressure dam erected by Wismut GmbH is a mixture of deep mine water (DMW), uprising from the flooded mine sections, and infiltration water (IW) collected and drained by the Markus Semmler adit.

According to the results of chemical analyses provided in Table 1 there are no major differences in the water quality between the two streams. Both have a very low mineralisation but contain significant quantities of arsenic. In comparison, the mine water of the neighbouring Schlema-Alberoda uranium mine has much higher concentrations of salts, heavy metals, arsenic and uranium (by a factor of 10…100), however, these mine waters are being treated in the Schlema-Alberoda water treatment plant before discharge into the Zwickauer Mulde.

The DMW tends to be warmer and to have a lower oxygen concentration than the IW. This indicates that it passes through the lower, permanently flooded mine cavities. Another striking finding is the comparatively higher arsenic concentration in the DMW. Moreover, the IW shows relatively large fluctuations in its arsenic concentrations, whilst the corresponding fluctuations in the FW are low (Fig. 2).

The arsenic concentration in the outflowing mixed water has been nearly constant for the period of 2003 to 2007 with concentrations around 0.3 mg/L, which results in an annual arsenic load to the Zwickauer Mulde of approx. 1.5 tonnes.

Table 1 *Water quality of Schneeberg mine water. Median values of selected substance (2005-2007, quarterly sampling)*

	pH	T	O_2	Elektr. conductivity	TDS	Suspended solids	Ca
	[-]	[°C]	[mg/L]	[mS/cm]	[mg/L]	[mg/L]	[mg/L]
DMW	6.8	11.2	5.4	0.44	305	< 5	43
IW	6.9	10.5	8.2	0.45	300	< 5	41

	Mg	SO_4	HCO_3	Fe	As	U	Ni
	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]
DMW	20	82	84	< 0.02	0.35	0.03	0.04
IW	20	84	78	0.12	0.23	0.01	0.04

Conclusions

The Schneeberg mine is the largest mining emitter of arsenic within the Zwickauer Mulde watershed. The main quantity of arsenic originates from the deep flooded area of the Schneeberg mine. The arsenic mobilisation in this area is very constant decades after mine flooding has been finished, which is evidence for a very substantial arsenic source existing in the flooded part of the mine.

Generally similar situations have been observed in the flooded areas of the Schlema-Alberoda and Pöhla uranium mines which are being operated by Wismut GmbH, and also at other legacy sites of mining, milling and metallurgy in the Western Erzgebirge. Mineralogical studies conducted for the Schlema-Alberoda mine have highlighted the hydrochemical significance of elementary arsenic in particular, as well as of certain species of Co-Ni arsenides whilst Fe arsenides seem to be of lower relevance as an arsenic source. A quantification of these different arsenic minerals as sources for the arsenic contamination within the flooded mines is hard to achieve due to the lack of data from previous geological studies.-It is therefore very likely that the emission of arsenic observed today will principally continue in the long term. However, there is a hypothetical chance for the Schneeberg mine to reduce the arsenic emission by means of changing the drainage regime by stimulating the volume of the IW stream whilst throttling the DMW stream, which is expected to result from the planned reconstruction of the Markus Semmler adit.

Figure 2 *Arsenic concentrations in the Schneeberg mine water*