The flooded Freiberg/Sachsen Mining District – Hydrogeochemistry, Hydrodynamics and Environmental Impacts

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ABSTRACT
Mining in the Freiberg mining district began as early as 1168 AD and since then several hundreds of kilometres of galleries, shafts and mine workings where constructed to extract silver and lead ores. The Freiberg Mining district has been flooded about 30 years ago. Due to a 50 km long dewatering adit, the Rothschönberger Stollen, the mines are divided in a phreatic and a vadose zone. Furthermore, the flooded part of the mine shows a hydrodynamic stratification and the total mass load of the different water constituents impacts parts of the downstream river courses at the dewatering adit's fall out location.
The publication will describe the historical development of the Freiberg mining area, the current state of the flooding process and some of the hydrogeological, hydrodynamic and geochemical investigations that where and will be conducted to understand the flooding regime.
Remark: this paper just gives a short overview about the Freiberg mine water situation. A longer work about the Freiberg mining district by the authors is currently in preparation and will be published in 2006.

INTRODUCTION

The Freiberg/Saxony mining district once belonged to the richest silver deposits in Europe (Jobst et al. 1994). In 1168 AD mining started at a small place called Christiansdorf, which later became a part of Freiberg. Due to economical reasons the last mine producing in Freiberg was closed in 1969 and thereafter the uncontrolled flooding of the mine workings started. Because the deepest dewatering adit is the 128 years old *Rothschönberger Stollen*, all the mine water drains through that adit into a northerly direction and discharges 18 km north of Freiberg into the rivers Triebisch and Elbe. According to different sources, the total flooded mine volume is about 2—5 · 10^6 m³ (Kolitsch et al. 2001) and the discharge volume 0.4—1.1 m² s^{-1} (Weyer 2003). Since the adit has been finished in 1877 the mine water is discharging into the Triebisch without further treatment and even after the collapse in 2002 nothing changed.

Below the flooding level, which is the *Rothschönberger Stollen*, are 494 m of flooded mine workings which were driven into the polymetallic ore veins of the Erzgebirge (Oelsner 1958). Therefore, the water penetrates through the flooded shafts, galleries, backfilled veins and open veins and gets enriched in nearly all metals of the periodic table, as can be seen from the chemical analyses (e.g. Baacke 1999). Despite the fact that the *Rothschönberger Stollen* is the main drainage gallery, severl other drainage galleries for isoloated parts of the mine exist, thereunder the *Königliche Verträgliche Gesellschaft Stollen* and the *Fürstenstollen*, which dewater into the *Freiberger Mulde* river (Becke et al. 1986).

Though numerous studies have been conducted about the Freiberg mine waters, no comprehensive hydrogeological investigation has been done so far. This is mainly due to the fact that only a small part of the mine is accessible from the surface and underground but also to the complicated responsibilities concerning the mine and the flooded part of the mine.

HYDROGEOCHEMISTRY

Many parts in the Freiberg mining district, especially above the flooding water level, have extremely acid mine water of up to pH 2 (Baacke 2000) but reach 6—8 at the *Rothschönberger Stollen* portal (Yefimochkina 2004) with a conductivity of 0.7—0.9 mS cm^{-1}. This shows that enough buffer capacity exists, which mainly comes from the carbonates in the *Braunspatformation* (siderite formation) und die *BiCoNiAg-Formation* (bismuth, cobalt, nickel, silver formation). Geochemically, the discharge water can be classified as a Ca-SO_4-type, and in some parts of the drainage water system as a Ca-Mg-SO_4-type, thus showing that calcite and dolomite are relevant buffering minerals.

Table 1 gives an overview about some important parameters of the *Rothschönberger Stollen* drainage waters between 1996 and 2004. Baacke (1999) calculated the average mass loads for some selected parameters for the tree relevant discharge adits (Baacke 1999) and if they are used as a conservative data for estimating the mass loads having left the mine since its closure in 1969 some extreme values can be calculated: 560 t of As, 4,300 t of Zn, 1,400 t of Mn, and 108 t of Fe.

Table 1: Selection of mine water parameters from the Rothschönberger Stollen (from Baacke et al. 1996, Beuge et al. 2001, Yefimochkina 2004). Conductivity in µS cm^{-1}, temperature in °C, concentrations in mg L^{-1}. Values are rounded in accordance with the original data.

Parameter	pH	Cond	Temp	Ca	Mg	Cl	SO_4	Zn	As	Cd	Pb	Mn
Min	6.8	620	12	100	24	35	155	2	0.001	0.01	0.002	0.8
Max	7.5	980	14	112	40	54	300	5	0.003	0.03	0.4	2

Figure 1: Portal of the *Rothschönberger Stollen* near Rothschönberg (from Yefimochkina 2004).

HYDRODYNAMICS

Some of the already existing publications gave a conceptual model of the hydrogeological situation in the flooded and the non-flooded part of the Freiberg mining district (e.g. Baacke and Degner 2000). Based on that conceptual model the authors conducted a tracer test in the *Reiche Zeche Schacht* in 2002 but were not able to detect any tracer, though the existing models predicted that a tracer should be found at the shafts outfall. Currently, we can only conclude that the published conceptual hydrogeological and hydrodynamic models of the Freiberg mine are not complete and that an extended conceptual model is necessary. Yet, as described above, the mine is not accessible in all parts and an artificial tracer test is therefore not possible at the current situation.

From a hydrodynamic point of view the existing conceptual model is impossible in that way that water cannot flow down a shaft against the hydrostatic pressure. Water always flows in the direction of the lowest hydrodynamic pressure. Furthermore, water can flow in fluid loops if the hydrodynamic situation allows fluid loops or it can flow through flooded levels in the direction of the lowest hydrodynamic pressure. Moreover, the water flow can split in one of two directions relative to the different hydrostatic pressures at each of the end-points of the possible flows. Tracer tests conducted by the Hydrogeology Department of Freiberg University in other mines (e.g. Wolkersdorfer and Hasche 2001) clearly showed that the conceptual model of the Freiberg mine needs relevant amendments.

ENVIRONMENTAL IMPACTS

To our knowledge, the environmental impacts or environmental damages of the mine water leaving the Freiberg mining district have not been studied in detail – if at all. Nearly all the available publications touch the environmental aspects of the mine water, but they don't investigate the impacts on the aquatic environment. If this is true for the "standard" water parameters, the situation is different for the uranium mining regions of the Erzgebirge (e.g. Meinrath et al. 2003) – yet, Uranium never was mined in Freiberg and therefore such investigations do not touch the Freiberg mining district.

From our observations, it seems as if the bio-environment already adopted to the pollution from the mine water – which does not mean that the mine water is not any longer polluted. Because the acidity and the pH of the mine waters are not extreme, no extraordinary macroscopic impacts can be observed downstream the drainage galleries. Yet, a proper micro- and macrobiological investigation will be necessary to clarify the real impact and to compare the affected surface streams with non-impacted streams. If we conclude that the ground water – to a certain extend – mirrors the situation of the surface streams and if we take into account that the ground water bodies under the river *Freiberger Mulde* are classified as "will reach the goals of the water framework directive" (Dehnert et al. 2005) we can further conclude that the macroscopic observations are to a certain degree correct.

FURTHER INVESTIGATIONS

Our further investigations will convey a sampling of all relevant drainage water galleries on the course of the river *Freiberger Mulde* and compare the results with historical data. Furthermore a tracer test in the Freiberg mining district will try to clarify the hydrodynamic situation underground.

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