Hydrochemical Development in Flooded Uranium Mines – A comparison between the Mines at Olší (Czech Republic) and Pöhla (Germany)

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Abstract Flooding of uranium mines in Central Europe leads usually to a substantial and long-lasting discharge of mine waters enriched in radionuclides and heavy metals. The understanding of the governing geochemical processes is crucial to predict further water quality trends, as a precondition for decision making in the context of either metal recovery or mine water treatment. The paper outlines first findings of a comparison of monitoring results of the two flooded uranium mines at Olší (Czech Republic) and Pöhla (Germany) which are comparable in size, geological setting and mine flooding history but show different water quality features.

Key Words Mine water quality, mine flooding, long term effects, Olší, Pöhla

Introduction
In the recent past, the majority of underground uranium mines in the Czech Republic and Germany have been decommissioned. Due to the prevailing humid climate in Central Europe the mine workings are largely flooded by groundwater rise due to natural groundwater inflow. After reaching an overflow level, mine water discharges into surrounding receiving streams or, avoiding that, has to be pumped. Consequently, mine flooding leads to an essential long-lasting discharge of mine waters into the environment. The mine waters are mostly critically contaminated with radionuclides and heavy metals, so that water treatment is necessary to reach relevant water quality standards. Simultaneously, in some cases uranium recovery may be a profitable option. The understanding of the governing geochemical processes in the flood water body is crucial to predict further trends in the contaminant concentrations over time, which is a necessary precondition for decision making in the context of water management and treatment.

Being part of the remediation activities at several former uranium mining districts the state-owned companies DIAMO (Czech Republic) and WISMUT (Germany) are running huge monitoring programmes for flooded underground mines. Besides environmental monitoring the gathered data is also used to investigate essential processes and finally to estimate the long-term contaminant release.

To identify general rules of the hydro geochemical behaviour of flooded mines it is necessary to analyse and compare key data from various mines with regard to the monitoring results. A comparison of four WISMUT mines has been recently published (Jenk et al. 2009). Within the frame of on-going Czech-German cooperation the two mines at Olší (Czech Republic) and Pöhla (Germany), which show some similar features in terms of size, geological setting and mining history, have been assessed and compared in this context. The paper outlines basic features of both mines and discusses first findings of the assessment of the mine water quality, with a certain focus on uranium.

Mine characteristics
The Uranium deposit of Olší was mined between 1959 and 1989 (no old mining activities before). Ore bodies of the Olší deposit were characterised by their irregular shape, variable thickness and uranium content. The deposit is of hydrothermal origin (low-heat). The content of sulphide minerals is low (up to 1%, mainly pyrite, arsenopyrite and copper sulphides). Mineral composition of uranium mineralisation includes coffinite and uraninite with an average grade of 0.1 %. The total amount of uranium extracted was app. 2,900 t. The deposit is situated in crystalline complex rocks, with the uranium deposit in the metamorphic sedimentary-effusive rocks of the Precambrian. The proper rocks of the deposit are composed of biotitic to amphibolic gneisses of various degrees of migmatisation and amphibolites, ranging from low permeability to impermeability. The Olší deposit largely drains by a small receiving stream (Hadůvka stream). For the controlled use of mine waters (pumped from the flooded mine) a drainage adit and a water treatment plant

were constructed and set into operation in January 1996. Uranium is recovered from the mine water for commercial use.

The Pöhla uranium deposit was mined between 1967 and 1990 (also no old mining activities before). The uranium ore (average uranium grade 0.2 %, mainly pitchblende) was found in hydrothermal carbonate veins, imbedded in metamorphic rock. Accompanying minerals are arsenides (Bi-Co-Ni-formation) and massive arsenic, but also Sn-skarns. The content of sulphide minerals is low. Uranium production totalled at ca. 1,200 tons. The mine is situated relatively deep under surface and covered by a hundreds of meters thick massive, undisturbed rock formation. The proper rocks of the deposit composed of mica schists, gneisses and amphibolites. Mine dewatering is hydraulically determined by a dewatering adit, groundwater flow via tectonic structures is marginal. The receiving stream is a small creek (Luchsbach). Due to the thick rock cover above the mine the infiltrating water has a very low mineralisation, and oxygen input is limited. Water treatment started in 1995. Additional characteristics are given in Table 1.

Mine water quality

Since 1997, the mine water level of the Olší mine has been maintained by pumping at levels of 1.5–7.0 m below the overflow level. The quantity of mine waters treated annually varies from 200.000 to 280.000 m^3. Since flooding of the Olší mine was complete, the flood water volume was renewed about 1.5 times. The mine water is of Ca(Mg)-SO_4-HCO_3 type (pH app. 7.3, oxidizing) with a current a stable sulphate concentration of 865 mg/L. The average content of uranium in the mine water pumped from the upper part of the water body has gradually decreased from ca.12 mg/L in 1996 to ca. 4 mg/L at present (Figure 1). However, this effect does only occur in the upper part of the flooded mine and not in its deeper parts (Michálek et al, 2007, 2008). A distinct vertical stratification of mine waters has developed which is especially governed by the minimisation of mine water flow after the cessation of the hydraulic gradient induced earlier by actively draining the mine.

Since flooding of the Pöhla mine was complete, the flood water volume was also renewed about 1.5 times. The water is characterized as a Ca(Mg)-Na-HCO_3 type with a pH of app. 7.2. After only about three years after flooding had reached steady-state conditions, the uranium and sulphate levels in the discharging mine water were found to have significantly decreased. Eh dropped down to –100...0 mV. The uranium concentrations developed from about 4 mg/L in 1993 down

Table 1 *Key characteristics of the uranium ore mines of Olší (DIAMO, Czech Republic) and Pöhla (Wismut GmbH, Germany)*

Mine Site	Pöhla	Olší
Operating Life	1967-1990	1959- 1989
Type of Deposit	Vein deposit, crystalline rock	Vein deposit, crystalline rock
Mining Method	Cut and fill, room and pillar mining, ca. 0.1 Mill. m³ self-fill	Cut and fill, secondary excavation of backfill, 0.5 Mill. m³ of backfill remained
Mine Geometry	Main adit, 2 blind shafts, mine shielded from ground surface by undeveloped stable overlying rock	2 main shafts, 2 blind shafts, subsurface mining, some mine workings with surface outlet general, surface disruption
Maximum depth	approx. 800 m, thereof approx. 500 m below dewatering level	approx. 870 m, thereof approx. 820 m below the mine water level
Mining Voids	ca. 1.5 Mill. m³	ca. 2.6 Mill. m³
Mining Voids, flooded	ca. 1 Mill. m³	ca. 2.1 Mill. m³
Mining Voids, non-floodable	ca. 0.5 Mill. m³, in unproductive host rock	ca. 0.5 Mill. m³
Remedial Action	no backfilling	Backfilling of shafts and near-surface stopes (unconsolidated backfill)
Flooding	1992-1995, uncontrolled	1989-1996, uncontrolled
Post flooding dewatering	Drainage tunnel	Drainage adit
WTP	Passive biological with redundant conventional WTP	Conventional (ion exchange resin used), about 30 yrs

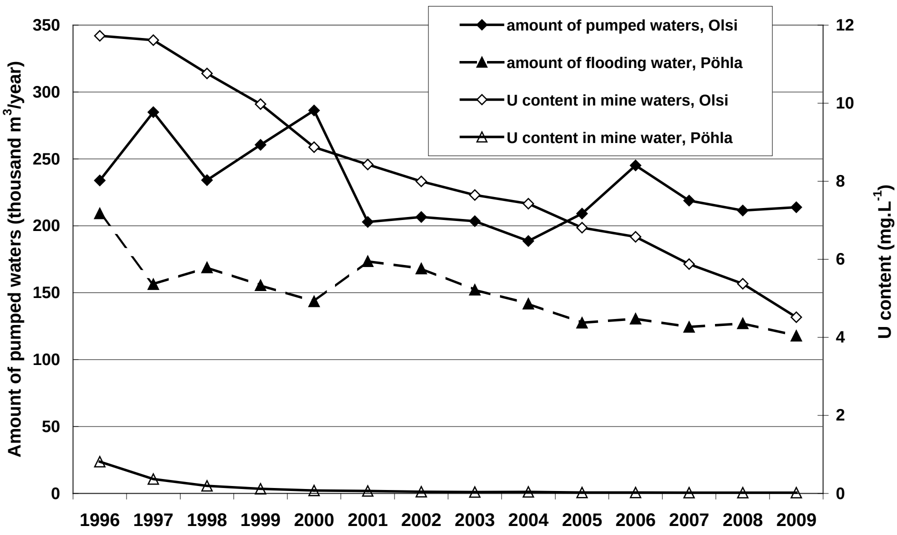

Figure 1 *Amount of annual water discharge and uranium concentrations of the Olší and Pöhla mines*

below the discharge limit of 0.2 mg/L in 1998; recently they are as low as 0.02 mg/L (Figure 1). Sulphate went down from 300 mg/L in 1993 to concentrations below the detection limit of < 10 mg/L since 1997. This rapid concentration drop at Pöhla cannot be explained by dilution alone. In addition to dilution, chemical reduction processes catalysed by micro organisms must have taken place, while a continuous uranium mobilisation from the non-flooded overlying rock does not occur.

Conclusions

Key factors influencing the characteristics of contaminant release from abandoned mines include, besides original source strength and hydraulic residence time, many more like mine geometry, degree of internal convection, ore composition, general hydro-geochemical milieu, and the availability of key reactants like oxygen. Comparing the two mines by means of those factors, many of the criteria e.g. mining history, geological setting, flooding history, mine size, water discharge and hydraulic residence time, are similar or at least comparable. Uranium concentrations in the discharging mine waters, however, differ substantially after flooding was completed.

Uranium concentrations at Olší are on a significantly higher level and have decreased only slightly over the last two decades. Besides dilution by groundwater inflow uranium mobilisation from remaining uranium sources is important, both from stagnant water bodies in the depth and from infiltrating seepage water from the disturbed, unsaturated deposit above the water level (Figure 2). The geometry and the high degree of mine backfill at shafts and stopes lead to only poor convection inside the flooded mine and development of isolated water bodies.

At Pöhla the mine water body is very homogeneous in quality due to thermal convection in open shafts and workings. Strong reductive conditions have soon developed as a result of the deep and isolated water body (Figure 2), the very low influx of oxygen rich ground waters and the microbiological activity, which led to a demobilisation of redox-sensitive compounds including uranium. Although significant uranium resources have been left in the mine, leaching from uranium sources does not occur.

Based on the facts presented above the main reasons for the different behaviour of uranium at both mines seems to be (i) the mine geometry, giving rise to a strong reductive environment at Pöhla, and (ii) the existence of active uranium mobilisation from unsaturated and saturated sources at Olší.

Investigation and assessment of the water quality trends and the governing geochemical processes will be continued at both mine sites. Concerning the Pöhla mine in particular, sulphur

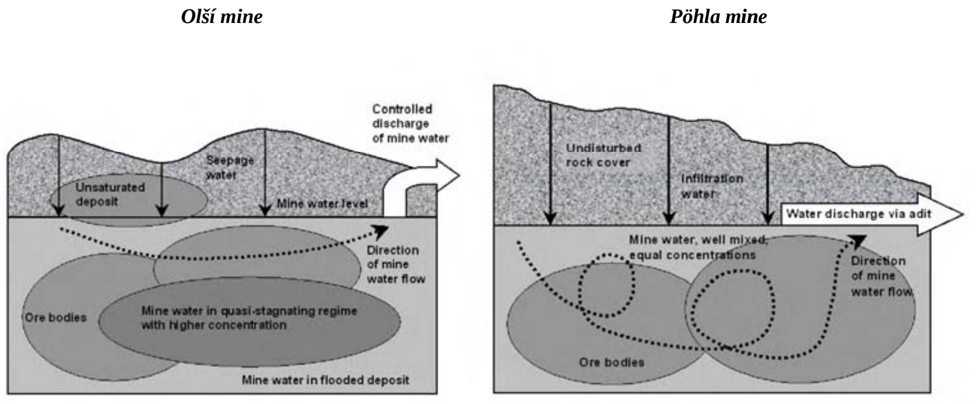

__Figure 2__ Schematic of water flow in the flooded mines of Olší and Pöhla

isotope techniques and microbiological investigations are planned to further clarify the process characteristics leading to the self-purification observed with regard to uranium.

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