Mine Water Stratification at Abandoned Mines and its Geochemical Model

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Abstract
Important factor which play main role at high concentrated mine water formation is stratification of mine water. The stratification of mine water body was observed on all studied ore and coal deposits (five) by in-depth resistivity and temperature logging, and mine water sampling. On Oslavany coal mine Jindřich II there can be identified three layers of stratified mine water. Sharp transition between layers and very distinctive concentrations of dissolved solids are characteristic. Stratification is stable despite of mine water discharge about 50 L/s. Detailed geochemical model of stratified layers formation and their time evolution is be presented.

Key words: mine water, stratification, geochemical model, redox potential, mine flooded

Introduction

Closing of many ore and coal mines in Czech Republic at the beginning of ninetieths invoked need to solve many problems at abandoned mine sites. One of the most serious problems was formation of high concentrated mine water after mine were completely flooded. As turned out the important factor which play key role at origin of highly concentrated mine water is its stratification. The stratification of mine water body was observed on all studied ore and coal deposits (five) by in-depth resistivity and temperature logging, and mine water sampling. The depth of measured and sampled shafts varied from 450 to 1 500 m below surface. Mine water stay stratified for long time despite of temperature gradient which should have cause mixing and homogenization of mine water as was originally supposed. Stable stratification of mine water was observed even in mines which were abandoned for several tens of years. This stratification is not disturbed by temperature gradient or by mine water discharging. Stability of stratification is caused by increased water density because of high concentrations of dissolved species and increasing hydrostatic pressure in depth (and thus increased density of water). The circulation and homogenization of mine water is quite good within individual layers, communication between layers is very limited if any. In the last ten years the similar evolution of mine water chemistry or some of these phenomena were observed on some ore and coal deposits worldwide, see for example Geller et al. (1998), Ladwig et al. (1984), Marsden et al. (1997), Nuttal and Younger (2004), Younger (1998, 2000a,b, 2001), and Younger et al. (2002). Various individual features of this behavior were described and partial influences linked to local conditions were identified.

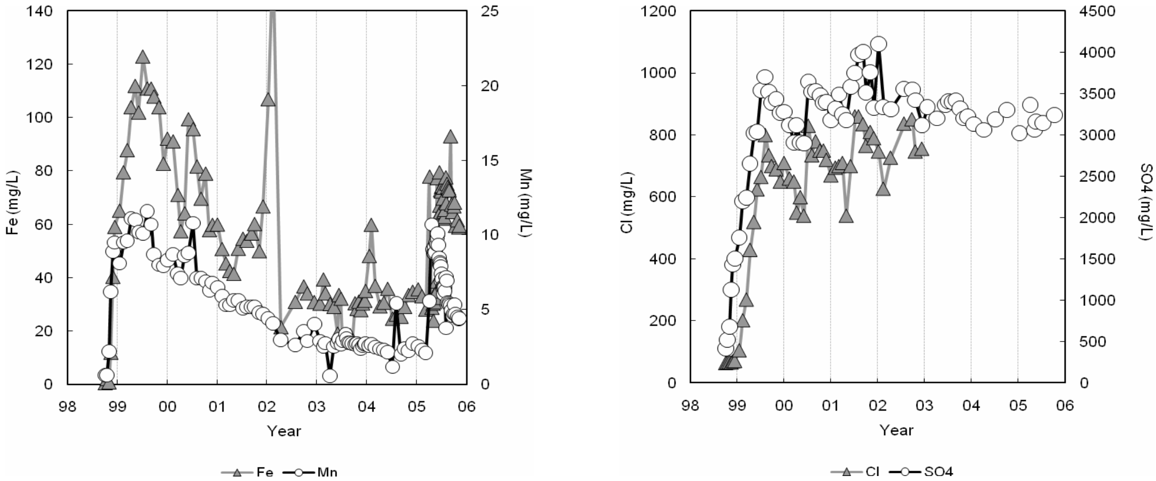
Methods

Standard procedures were used for sampling and analyses. The pH, Eh, temperature, conductivity, and dissolved oxygen concentration were measured directly on sampling site using WTW Multi 340i multimeter with electrodes SenTix® 41, SenTix® ORP, TetraCon® 325 and CellOx 325. The samples were sampled and analyzed in certified laboratories of AQUATEST a.s. company according to EN ISO norms. Samples for heavy metals analyses were stabilized right after sampling by addition 1 mL of concentrated nitric acid, sampling vessels were filled up to the cap, transported in cooling box at 4 °C and analyzed within 24 hours. In depth sampling and logging was performed by AQUATEST a.s.

Results and discussion

As a vivid example of mine water stratification the results of in-depth sampling and logging on shaft Jindřich II belonging to the Rosice–Oslavany coal field is presented. The Rosice–Oslavany coal field is situated about 25 km in southwest direction from Brno and it spreads over about 25 km2. It was exploited by several deep shafts for more than 240 years. Some shafts reached depth more than 1 500 m below surface. After the last shafts were closed in 1992 the natural flooding started, and was ended in 1998 by overspill of mine water to the surface by drainage adit. After several months lag phase there was observed steep increase of dissolved species concentrations. In this case there were identified two different long term trends (Fig. 1). For dissolved iron, manganese, nickel etc. the increasing trend was reversed approximately after one year with clear time separation among individual species. At second group of dissolved species like sulfates, chlorides, sodium etc. the fast one year concentration increase was followed by moderate but still clearly evident growth. This trend was reversed after three years to decreasing and is still notable but very different of that which is characteristic for previous group (the first one has exponential shape). These trends are strongly modified by seasonal changes with local minimum in the middle of summer immediately followed by sharp jump to the maximum concentrations.

Figure 1 *Long-term and seasonal trend of iron, manganese, sulfate and chloride concentrations in mine water on flooded Rosice-Oslavany coal field.*



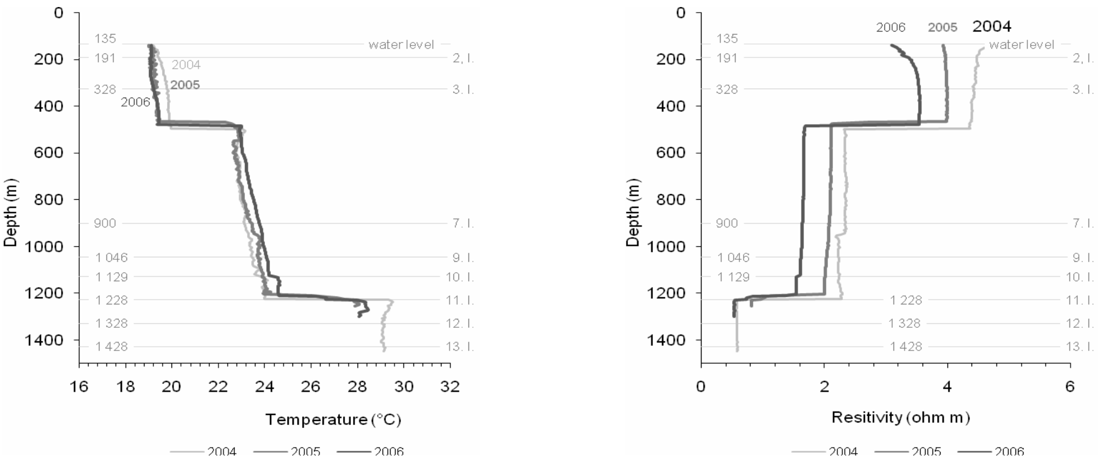
The discussion of precipitation and hydrological regime influences on long and seasonal trends in mine water on Rosice–Oslavany coal field goes beyond the scope of this paper. Here can be stated that there is no direct or apparent relationship between seasonal and long term trends and hydro-meteorological regime on locality. To identify possible causes of this behavior particularly presence of lag phase and observed long-term and seasonal trends authors take advantage of still accessible coal mine shaft Jindřich II and performed in depth logging and mine water sampling. There can be identified three layers of stratified mine water in the shaft Jindřich II (Fig. 2). Sharp transitions between layers with very distinctive difference in concentrations of dissolved solids as well as in physical properties (temperature, conductivity) are characteristic. This stratification is stable over the years despite of mine water discharge about 50 L/s and was confirmed by logging and sampling in four successive years in 2004–2007.

Based on extensive field measuring, mine water sampling and analyses, succeeded by careful data processing and geochemical modeling the following processes can be marked as responsible for observed behavior mine water during mining, flooding and discharging mine water to the surface. The main factor is significant change of oxidation-reduction (redox) conditions within exploited ore body. Before mining activity starts the boundary between oxidation and reduction zone lies in principle around ground water level usually not far below the surface. These conditions ensure stability of ore and rock forming minerals in natural environment over the period of millions of years. When the mine is opened the ground water level is significantly lowered. The ore minerals and rocks are exposed to the strong oxidative action of atmospheric oxygen. As the main oxidant serve oxygen (in air or dissolved in infiltrating water), but the effect of dissolved ferric iron can be very important, too.

As a consequence the ore minerals are dissolved; their constituents are released into mine water and concentration of dissolved species increase. Some of these products are further oxidized and immobilized by oxohydroxides precipitation (e.g. amorphous ferric iron hydroxide, goethite, ferrihydrite etc.).

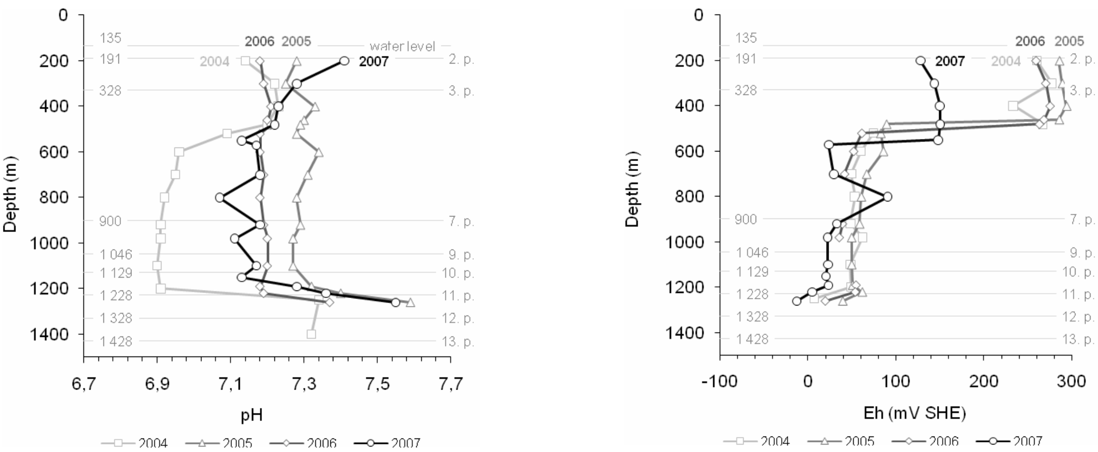
These reactions are promoted by intensive shaft ventilation and by mechanical breaking of wall rock during mining which enables the easy infiltration of rain and surface water with high concentration of dissolved oxygen to the depth.

Figure 2 *Stratification of mine water on shaft Jindřich II in Rosice-Oslavany coal field six and more years after flooding. Vertical profile of* temperature *and resistivity is given. On the left side there is marked depth below surface, on the right side adit level).*



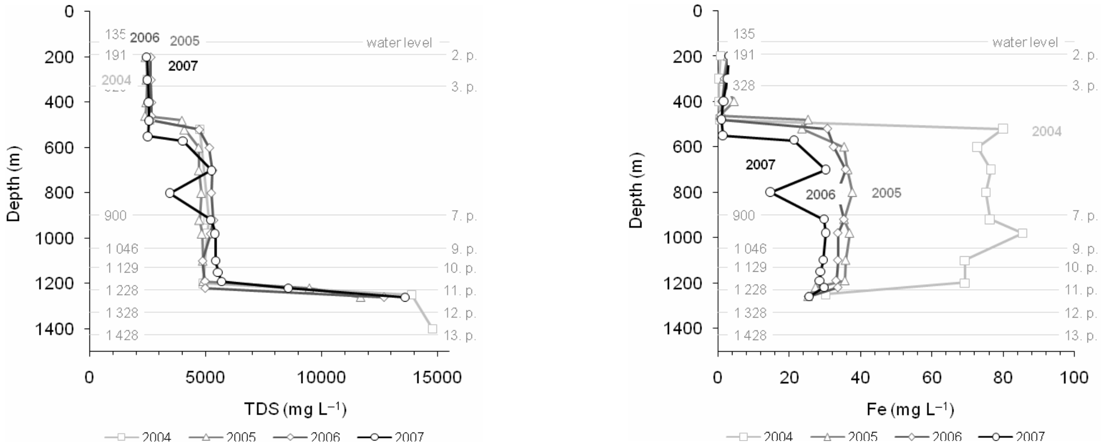
After shaft is closed and flooded, the water level gradually comes back to its original level and reducing conditions are subsequently restored. For the long time aerated and therefore for secondary minerals enriched part of ore deposit is again plunged below water level into reducing conditions. The oxidation zone enriched for secondary minerals, especially oxohydroxides of iron and manganese, underlie to the reductive dissolution formerly formed minerals.

Figure 3 *Stratification of mine water on shaft Jindřich II in Rosice-Oslavany coal field six and more years after flooding. Vertical profile of pH and Eh values is given.*



The low redox potential in deeper zones (Fig. 3) causes dissolution of originally formed supergene minerals resulting in high concentration of dissolved iron and manganese. As a result ferrous iron, manganese and all adsorbed and co-precipitated species are again released into mine water producing highly mineralized mine water (Fig. 4). Some component can be slowly reduced and again immobilized. In the long term perspective the original stable environment is restored. Mine water stay stratified for long time despite of usual temperature gradient which should have cause mixing and homogenization of mine water.

Figure 4 *Stratification of mine water on shaft Jindřich II in Rosice-Oslavany coal field six and more years after flooding. Vertical profile of total dissolved species and concentration of dissolved iron is given.*



We observed stable stratification of mine water in mines which were abandoned for more than ten years. This is caused by raised water density because of higher concentrations of dissolved species. The circulation and homogenization is quite good within individual layers, communication between layers is very limited if any. This stratification is not disturbed by temperature gradient and is stable for long time. The mechanism of stratified layers formation is not clear and still under study.

Conclusions

Mining activity has deep impact on the surface environment. Among the most significant effect belongs the deterioration of ground water quality. As the key factor which determine quality and long term geochemical evolution of mine water was identified change in oxidation-reduction conditions during mining and flooding ore deposit.

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