Evaluation of the Environmental Impact of Coal Waste Pile at Smolnica, Upper Silesia, Poland

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Abstract

Mine drainage impact of the coal waste pile at Smolnica site was monitored. Ground water in the aquifer downgradient from the pile has neutral pH, but high concentrations of sulfate, chloride, and sodium. The behavior of sulfate seems to be conservative. Mine drainage enters the Bierawka River and causes increasing sulfate concentrations. Concentrations of sodium and chloride in the river decrease because water in the river is already contaminated by discharge of mine waters. Calculated P_{CO2} values for the river water are high, suggesting lack of equilibrium with atmospheric P_{CO2}.

Key words: coal waste, environment, acid main drainage, groundwater, water Bierawka river (Poland)

Introduction

Acid mine drainage (AMD) from waste rock piles is a serious environmental problem. Oxidation of sulphides such as pyrite generates low pH water with high concentrations of sulfate, iron, and other metals (Blowes et al. 2003). In some cases neutralization capacity of waste rock material is high and only mine drainage (MD) with about neutral pH is produced.

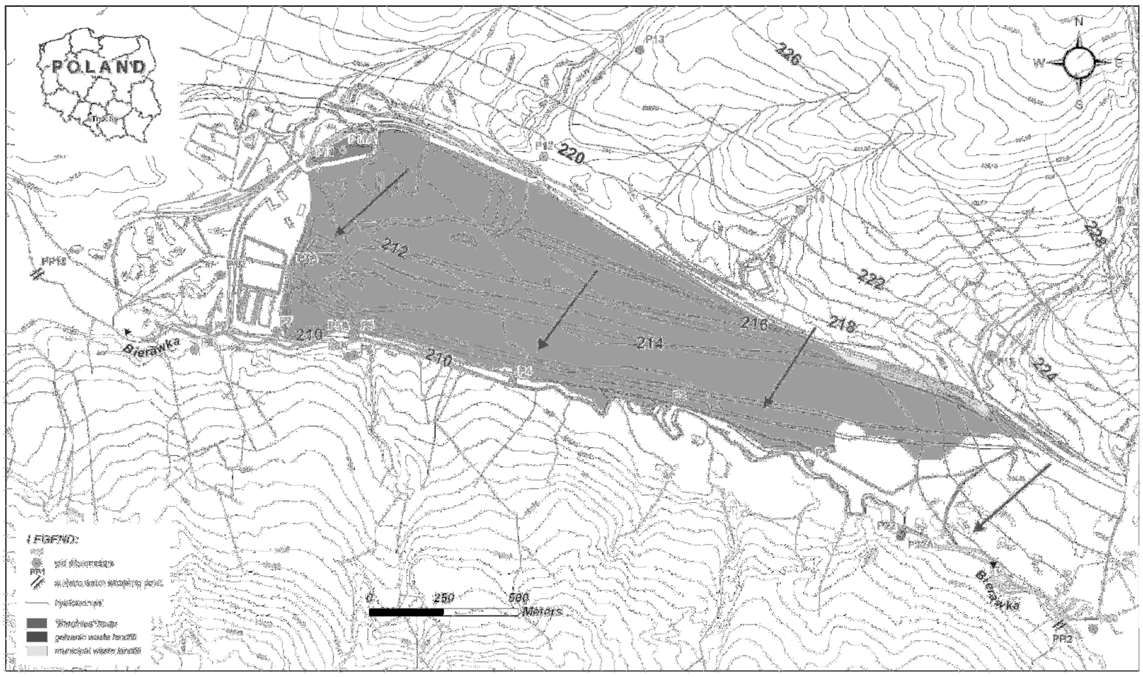
The Upper Silesian Coal Basin (USCB) is located in the south of Poland. There is a large number of coal waste piles in the region and drainage from the piles is generally neutral (Szczepanska and Twardowska 1999). The coal waste pile at Smolnica in Gliwice region (Fig. 1) is about 20 m high and covers an area of about 130 ha with a volume of waste rock about 13,845 x 10^3 m^3. The pile comprises waste from coal mine KWK Szczyglowice. Drainage from the pile is neutral or slightly acidic, i.e., there is no acid mine drainage (AMD), but only mine drainage (MD). This is a consequence of high neutralization capacity of the waste rock material. Mine drainage mixes with background groundwater in the unconfined Quaternary aquifer around and below the pile and then flows towards the Bierawka River located close to the southern slope of the pile (Fig. 1). The river functions as a discharge boundary and after entering it MD is diluted. Due to the presence of coarse sands, hydraulic conductivity of the aquifer is relatively high, from 2.20 x 10^{-6} m/s to 3.71 x 10^{-4} m/s. Hydraulic gradient is 0.009 at the west and 0.0012 at the east of the site. Calculated average linear velocities are 0.2 – 0.3 m/day, but they can be much higher locally (> 2.0 m/day at well PM-10 west of the pile, based on borehole dilution test). South of the Bierawka River the ground water flow is towards northwest, i.e., the river is gaining stream from both sides.

The principal objectives of the project were: (1) determination of geochemical processes in the aquifer surrounding the Smolnica pile and in the Bierawka River, and (2) evaluation of the impact of mine drainage from the pile on the aquifer and the Bierawka River.

Materials and methods

Groundwater from the piezometers was sampled after pumping out at least two volumes of stagnant water, no sooner than the values of parameters (pH, conductivity) measured online in field had stabilized. Samples for cations and metals were acidified and stored at low temperature before being analyzed in the central laboratory of Institute for Ecology of Industrial Areas in Katowice, Poland. Cations and metals were determined by AAS, anions were determined by ion chromatography. Discharge in the river was measured by the velocity-area method.

Figure 1 *Smolnica pile with location of sampling points and flow pattern*



Results and Discussion

Geochemistry of shallow aquifer

Selected species for a cross-section in a roughly W-E direction (along the Bierawka River) are shown in Fig. 2a. All wells except the easternmost P20 are contaminated with sulfate, reaching a maximum of 3,827 mg/l in P4. However, the maximum Cl concentration is in P3 located about 1040 m east of P4. This may be a consequence of more limited leaching of very mobile Cl at the zone of the pile or higher initial Cl concentration in waste material. Ca concentrations are around 400 mg/l with a maximum of 470 mg/l in P2. The Fe concentration in the most contaminated well P4 is at the detection limit, but its concentrations in wells P5A, P2, and P3 are significant, reaching 78 mg/l, 148.4 mg/l, and 26.4 mg/l, respectively. Since pH is close to neutral, the differences probably reflect more reducing conditions in these wells. The highest concentration of Na coincides with the maximum for sulfate in P4. Concentrations of Na are generally higher than those of Cl, but they converge in well P3.

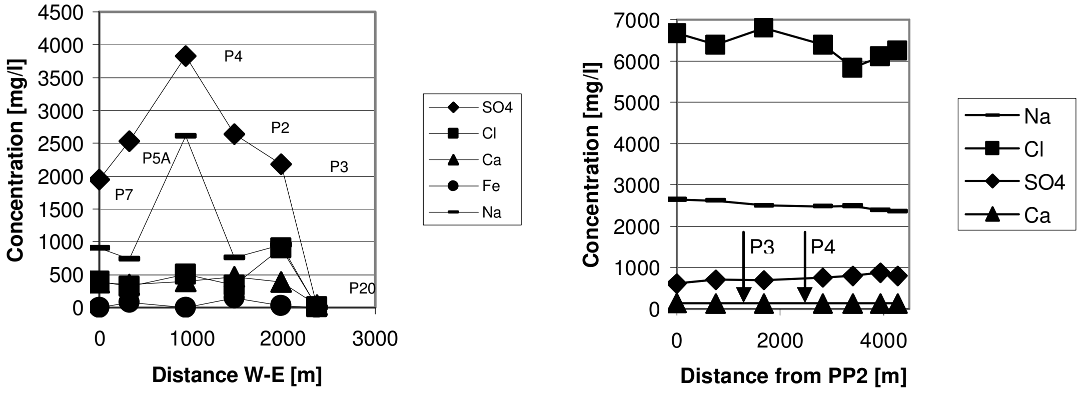
Background concentrations in the aquifer north of the pile are much lower: 44 mg/l of sulfate, 11 mg/l of chloride, and 5 mg/l of sodium in well P13.

All samples except one are undersaturated with respect to gypsum (Sracek 2007) suggesting conservative behavior of sulfate in shallow aquifer. Almost all samples are supersaturated with respect to barite. This is consistent with lower than background concentrations of barium in contaminated samples, where precipitation of barite controls Ba concentration. Many samples also are supersaturated with respect to amorphous $Fe(OH)_3(a)$, which seems to control dissolved iron concentration. Finally, saturation with respect to Sr minerals strontianite and celestite is not reached and Sr seems to behave conservatively with a possibility of co-precipitation with barite in some samples.

Geochemistry of the Bierawka River

River water is already strongly contaminated at profile PP2 upgradient of the pile (Fig. 2b). Concentrations of sodium, chloride, and sulfate are very high. Also notable is concentration of ammonium ions. At profile PP12 concentrations of sodium and chloride slightly decrease and concentration of sulfate increases by about 30 %. Concentrations of Fe and Mn increase only slightly and concentrations of strontium and ammonium ions decrease (Sracek 2007).

Figure 2 *(a) Concentrations of selected species in groundwater, (b) in river water, Fe is close to zero*



It is evident that the concentration of chloride increases close to the well P3, where its concentration in ground water is highest (903 mg/l). Chloride concentration in the river then decreases beyond the well P4, where it is only 507 mg/l. There seems to be a slight decrease in sodium concentration and increase in sulfate concentration, which increases downgradient from well P4 with a maximum of 3,827 mg/l. On the other hand, concentration of calcium is almost constant.

Selected results of geochemical speciation modeling for river water samples, performed with code PHREEQC (Parkhurst and Appelo 1999), are shown in Table 1. The modeling was performed with equilibration of samples with atmospheric log P_{O2} = -0.68 because no Eh values or analytical speciation of redox sensitive species were available. Samples at background profile PP2 are supersaturated with respect to calcite and dolomite, but most samples located downgradient and affected by mining drainage are undersaturated with respect to these minerals. However, sample PP8 is close to saturation with calcite and is supersaturated with respect to dolomite. This means that carbonate minerals may precipitate from some samples. All samples are undersaturated with respect to gypsum and sulfate seems to behave conservatively in the river. Value of pH downgradient of the pile decreases, suggesting that river water is not equilibrated with atmospheric P_{CO2}.

Table 1 *Results of speciation calculations for river water*

Profile/ param.	$SI_{calcite}$	$SI_{dolomite}$	SI_{gypsum}	$SI_{Fe(OH)3(a)}$	$SI_{goethite}$	$SI_{manganite}$	SI_{barite}	$SI_{strontianite}$	$SI_{celestite}$	log P_{CO2}
PP2	**0.12**	**0.49**	-1.23	**3.11**	**8.69**	**4.98**	**0.60**	-0.99	-1.13	-2.11
PP3	-0.26	-0.28	-1.17	**2.97**	**8.55**	**4.21**	**0.64**	-1.37	-1.08	-1.17
PP5	-0.40	-0.57	-1.17	**3.02**	**8.60**	**4.02**	**0.63**	-1.53	-1.10	-1.17
PP6	-0.35	-0.48	-1.13	**3.22**	**8.82**	**4.28**	**0.70**	-1.51	-1.09	-1.13
PP8	-0.36	-0.48	-1.10	**3.27**	**8.85**	**4.27**	**0.70**	-1.50	-1.03	-1.10
PP10	-0.07	**0.09**	-1.08	**3.39**	**8.97**	**4.84**	**0.73**	-1.23	-1.03	-1.08
PP12	-0.41	-0.60	-1.12	**3.12**	**8.7**	**4.18**	**0.68**	-0.57	-1.06	-1.59

Bold *– supersaturation*

Discussion

Background groundwater in the shallow aquifer, represented by wells P13 and P16 (Fig. 1), is of Ca-SO_4-HCO_3 type and is undersaturated with respect to calcite, dolomite, and gypsum. Values of pH are slightly acidic (around 6.0) and redox potential Eh (330 – 370 mV) indicates moderately reducing conditions. Concentrations of Ba are from 0.38 to 0.66 mg/l and are controlled by equilibrium with barite. Concentrations of Fe and Mn are low, close to detection limit. In the pile, pyrite oxidation by oxygen in the presence of water is coupled to the dissolution of calcite and precipitation of ferric hydroxide. The global equation is

$$FeS_2(s) + 3.75O_2 + 3.5H_2O + 2CaCO_3(s) = Fe(OH)_3(s) + 2SO_4^{2-} + 2Ca^{2+} + 2H_2CO_3$$

Ground water in the shallow aquifer resulting from reactions above and sampled in wells downgradient from the pile has close to neutral pH (values 6.2 – 6.7), reducing Eh (180 – 230 mV), and relatively low concentration of iron and high concentration of sulfate, calcium and magnesium. Concentrations of sodium and chloride are also high because there is flushing of residual brine. Most iron is immobilized in Fe(III)-minerals precipitating on the surface of pyrite already in the pile. The coating of reactive pyrite surfaces may result in decreasing pyrite oxidation rate (POR) due to increasing resistance to the diffusion of oxygen, (Hossner and Doolittle, 2003). Species like Na, Cl, and NH_4 originate in brine, which was initially present in waste material and is gradually flushed out. Based on the speciation modeling, behavior of sulfate, sodium, and chloride in the aquifer between the pile and the Bierawka River is conservative and there is advective loading of contaminants into the river.

Water in the Bierawka River is already strongly contaminated by sodium, chloride, and sulfate upgradient from the Smolnica pile. The input of ground water contaminated from the pile results in about 30 % of sulfate concentration increase in the river, but in some dilution and attenuation of sodium and chloride. Field observations and geochemical modeling suggest that there is not fast equilibration with atmospheric CO_2 and O_2. Sodium, chloride, and sulfate behave conservatively in river water.

Conclusions

There is mine drainage from the waste rock pile at the Smolnica site. Acidity and iron are already attenuated in the pile and sulfate is transported through the shallow unconfined aquifer to the Bierawka River south of the pile. Other contaminants are sodium, chloride, and ammonia produced by the flushing of residual brine in waste rock. In the river, sulfate concentration increases downgradient, but concentrations of sodium and chloride decrease due to dilution. High calculated partial pressures of CO_2 suggest only slow equilibration of river water with atmosphere. Behavior of contaminants in the shallow aquifer and the river are conservative and they contribute to the contamination of the Odra River further downgradient from Smolnica site.

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