

Geochemical Evaluation of Mine Water Quality in an Open-pit Site Remediated by Backfilling and Sealing

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Abstract A geochemical evaluation of the mine water quality at a remediated open-pit mine site, Kimheden, was performed in 2009. Kimheden is a small copper mine situated in Västerbotten, northern Sweden, which was operated in the 1970s by Boliden AB. It was subsequently backfilled with waste rock and sealed with clayey till in 1996. Surface water and groundwater samples were taken on site in summer 2009 and on a regular basis in the main watercourse of the mine by the mining company since 1983. The results show that the metal concentrations decreased and pH increased after remediation, indicating a favourable evolution of the water quality.

Key Words Water quality, geochemistry, open pit, remediation, backfilling, sealing

Introduction

Rehabilitation in open-cut mining represents a challenge due to the increasing number of open pits (McCullough 2007) and because the selection of the best remediation option is complicated by the local hydrology. The choice between backfilling and evolution into a pit lake is a non trivial question (McCullough and Lund 2006).

Severe Acid Mine Drainage (AMD) at the Kimheden copper mine (Kristineberg mining area, Fig. 1) required a complex remedial action that was performed in several stages ending with the complete backfilling of waste rock into the two open pits of the site and subsequent sealing of the pits.

Fourteen years after the completion of the remedial activities, water quality in the main watercourse flowing through the mine is still considered insufficient; therefore an evaluation of the water quality was judged necessary. The assessment was carried out on the basis of a water sampling campaign on site in summer 2009, supplemented by the mining company's own measurements. The objective is to bring information on the success of the remediation performed at Kimheden which could be of value for other open-pit sites with similar characteristics.

Description of the study site

The area is set in a Palaeoproterozoic ore-bearing volcano-sedimentary domain and is dominated by felsic volcanic rocks that are altered to pyrite-bearing, quartz–muscovite–chlorite rocks (Årebäck et al. 2005). The mine operated underground and in two open pits that were mined for copper in the 1970s, and exhibited an early onset of metal-rich leaching from the open pits and the waste rock dumped on the surface. The Cu and Zn-rich AMD required an extensive remediation of the site that started in 1982 with the excavation of a watercourse to collect the contaminated water to a tailings pond downstream of the mine. It was followed by several attempts to refill the open pits with waste rock and cover them with till, and ended in 1996 with the complete clearing-up of the waste rock from the surface and treatment of the pits. As Kimheden is set on a steep hill slope where the upper edges of the pits are 10–15 m higher than the lower edges, the establishment of pit lakes turned out to be impossible. Instead, the mining excavations were backfilled with waste rock and sealed by a 1.8 m composite till layer (0.3 m/1.5 m sealing/protective layer). The mine water brook still nowadays discharges into one of Kristineberg's tailings ponds which is limed, raising up the pH and promoting the precipitation of metals. In the future, however, the mining company plans to divert the water into a river showing natural geochemical conditions (Vormbäcken).

The results of Cu and Zn concentrations as well as pH measured by the mining company in 1991 (before the last stage of the remediation) at S1, S3, and SD – outlet of the eastern open pit, outlet of the western open pit, and downstream of the mine, Fig. 2 – are given in Table 1. They show highly elevated concentrations of Cu and Zn, and a very low pH.

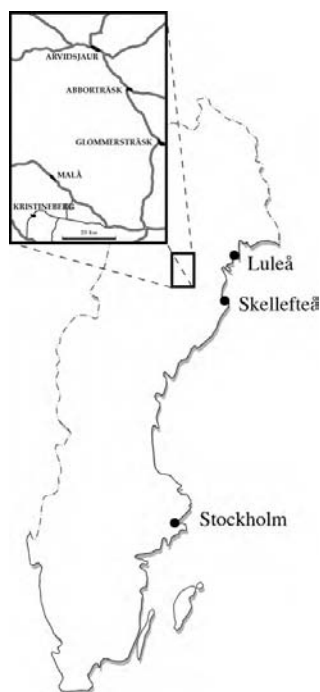


Figure 1 Location of the Kristineberg mining area, Västerbotten, northern Sweden.

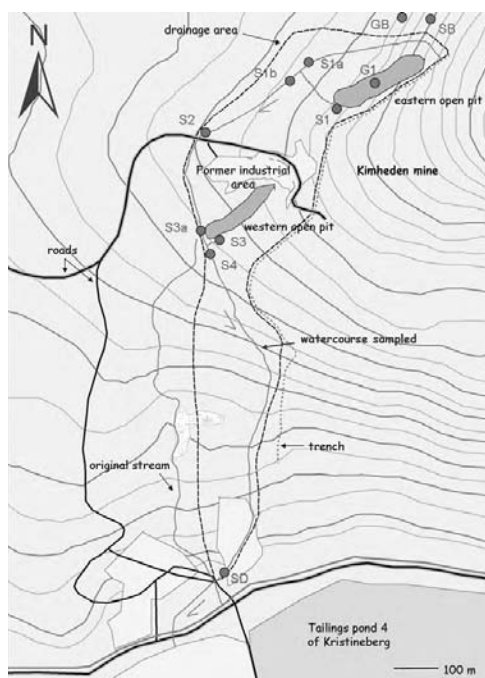


Figure 2 Water sampling area with sampling locations ('S'- surface water, 'G'- groundwater)

Table 1 pH, copper and zinc concentrations at S1, S3 and SD in 1991, before the last stage of the remediation (average of the measurements from the mining company over the year 1991)

1991	pH	Cu (mg/L)	Zn (mg/L)
S1	2.6	15.2	0.51
S3	2.4	16.1	1.95
SD	2.8	7.04	0.59

Methods

The mine water monitoring programme at Kimheden was performed from May to October 2009. On 7 occasions spaced out by 2–3 weeks, surface water and groundwater samples were collected at 2 to 8 locations in the artificial mine watercourse (Fig. 2) and in a groundwater well placed on the eastern open pit (G1). Surface water and groundwater reference points upstream of the mine were also sampled (SB and GB). pH was measured on site with a Metrohm 704 portable pH metre. Water was filtered through 0.22- μm nitrocellulose membranes washed in 5% acetic acid into plastic bottles washed in 50% hydrochloric acid followed by 1% nitric acid. They were sent to the ALS Scandinavia accredited commercial laboratory for metal analysis with ICP-AES and ICP-SFMS after acidification with 1 mL ultra high-purity nitric acid per 100 mL of sample. To describe the results, the Swedish Environmental Protection Agency (EPA) classification of water quality was used (Swedish EPA 2000).

Results

Geochemistry in the mine water in 2009

Table 2 gives an overview of the current geochemistry at SD, SB, G1 and GB as an average of the values obtained in the 2009 campaign. The concentrations of the metals are classified according to the Swedish EPA criteria.

Table 2 Metal concentrations and pH at SD, SB, G1 and GB in 2009, and classification of the concentrations (Swedish EPA 2000)

µg/L	Cu	Zn	Cd	Pb	Cr	Ni	As	pH
SD	400 Very high conc.	120 High conc.	0.30 High conc.	0.96 Low conc.	0.72 Low conc.	3.9 Low conc.	0.058 Very low conc.	3.7
SB	2.3 Low conc.	7.2 Low conc.	0.013 Low conc.	0.14 Very low conc.	0.26 Very low conc.	0.38 Very low conc.	0.13 Very low conc.	4.6
G1	790 Very high conc.	410 Very high conc.	0.58 High conc.	0.73 Low conc.	1.0 Low conc.	9.5 Low conc.	0.074 Very low conc.	3.7
GB	9.1 High conc.	5.7 Low conc.	0.017 Low conc.	0.018 Very low conc.	0.092 Very low conc.	0.56 Very low conc.	<0.05 Very low conc.	4.6

Comparison between pre-remediation and post-remediation geochemical conditions

Mine water geochemical data before the first stage of the remedial activities (1982) are lacking. Nevertheless, the mining company started sampling in the watercourse in 1983 and has performed regular Cu, Zn and pH measurements since then. The purpose is to assess the evolution of the main parameters in the water quality as a result of the remediation attempts, and to discriminate which factors are the most influential for a successful rehabilitation. The most regular measurements were taken at SD downstream of the mine site and are shown in Fig. 3.

Both Cu and Zn exhibit a substantial decrease since 1983. The decrease occurred progressively over the rehabilitation process, but only after the last remediation stage the concentrations got stable. The evolution of pH does not reveal a distinct trend, but the values after rehabilitation are also stabilised and they are slightly higher than before the last remediation stage.

Discussion

The comparison of the water quality downstream of the mine (SD) with the reference surface water (SB), and of the groundwater quality in the eastern pit (G1) with the reference groundwater (GB) indicates that pH, Cu and to a lesser extent Zn and Cd still exhibit poor values in the mine

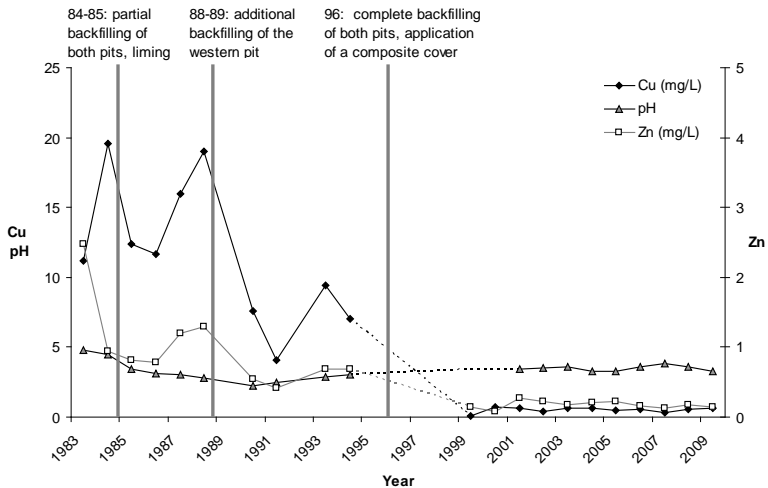


Figure 3 Copper and zinc concentrations and pH at sampling location SD between 1983 and 2009 (data from the mining company)

water in 2009. pH is already highly acidic in the reference surface water and groundwater according to the Swedish EPA, but pH at SD and G1 is 1 unit lower and it is 1.5 unit lower in the surface water close to the open pits.

It is unsure whether the relatively higher concentrations of copper and zinc and lower pH of the mine water compared to the reference water are caused by an on-going oxidation of the mineralised rocks in spite of the application of covers on the waste rock, or if they result from the progressive discharge of old oxidation products which have been retained to a certain extent by the sealing of the pits. A future step in the project will be to investigate if the oxidation of the waste rock is still going on. In particular, the presence of unsaturated fractures in the bedrock in the vicinity of the pits will be studied by means of a geophysical campaign in summer 2010, and the redox conditions in the eastern pit will be further evaluated.

Even though the mine water quality is not considered satisfactory, the follow-up programme indicates an encouraging evolution of the water geochemical conditions following the remedial activities. The objective set to the mining company in 1994 to reduce (Cu+Zn) concentrations by 87% from 1991 values at S1, S3 and SD is today achieved.

The geochemical conditions in the watercourse have been well monitored since the beginning of the remediation; nevertheless it is very probable that this watercourse is not the major pathway for mine water on the site. Considering the site topography, it is possible that most of the water exiting from the pits is flowing underground on the western slope of the hill. Consequently, to obtain a more comprehensive representation of the water quality in the mine, efforts have to be made in order to study the groundwater. Water samples collected in the groundwater well on the eastern pit during the 2009 investigation give only local results. Therefore, they are to be complemented by the geophysical campaign which is expected to give indirect information on the groundwater pathways and quality.

Conclusions

Current geochemical conditions in the watercourse downstream of the Kimheden mine are still not satisfactory in terms of pH (3.7) and Cu concentrations, and to a lesser extent Zn and Cd concentrations. The quality requirements for the mine water have not been achieved to allow the diversion of the water to the Vormbäcken River. Nevertheless, the quality of the water flowing through the Kimheden mine watercourse has largely improved since the initiation of the remedial activities. More information on the pathways and quality of the groundwater is expected from the application of geophysical methods on the site in the near-future.

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