Effect of a Till Cover in Harmful Element Reduction in Waste Rock Drainage

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Abstract

This study investigates the effectiveness of a thin (0.3 m) till cover layer in reducing harmful element mobilization in waste rock drainage at the closed Särkiniemi Ni-Cu mine site in Finland. In the study, lysimeters (diameter 1.0 m, height 0.3 m) were filled with crushed waste rock, buried in the upper parts of the waste rock pile, and drainages were monitored through 2020-2021. Results demonstrate that the till cover reduced the mobility of elements like Cu, Co, Ni, SO4, and Zn, primarily by decreasing the amount of infiltrating water. However, more efficient cover layers may be necessary depending on closure objectives.

Keywords: Acid mine drainage, mine closure, cover structure, lysimeter, Särkiniemi

Introduction

The environmental impacts of mining activities, particularly related to acid mine drainage (AMD) originating from mine waste facilities, are one of the main concerns of the mining industry. AMD, generated by the exposure of sulfide minerals to atmospheric water and oxygen, poses significant risks to ecosystems, water resources, and human health (Lottermoser 2010). Effective strategies for mitigating AMD and managing mine waste facilities are crucial to minimize these risks.

Various cover systems are commonly used in mine waste management (INAP 2017). Till covers, which act as a physical barrier to reduce water and oxygen infiltration, are a widely adopted closure technique for mine waste facilities in Nordic countries (Kauppila 2023). Typical layer thicknesses of the single-layer till/soil covers range from 0.3 to 1.5 m (Garbarino *et al.* 2018). However, comprehensive studies assessing the effectiveness of the covers with lower-end thicknesses in reducing harmful element mobilization in waste rock drainage remain limited, and the optimal thickness and long-term performance of till covers warrant further research.

This study investigates the impact of a relatively thin, 0.3 m, cover layer made of local till on waste rock drainage at the closed Särkiniemi Ni-Cu mine in Finland. Through the analysis of lysimeter monitoring data, we will assess the extent to which the till cover reduces the mobility of harmful elements, such as Cu, Co, Ni, SO_4, and Zn from weathered waste rock material. The insights gained from this study can be utilized in modelling and designing mine waste cover structures and helping to minimize the environmental impacts of mining.

Materials and methods

The study was conducted at the closed Särkiniemi Ni-Cu mine site, located in Northern Savo, Finland (Fig. 1). The mine was active in 2007-2008, during which approximately 165000 tons of waste rock was excavated. The waste rock material consists mainly of mica gneiss, gabbro, and amphibole rock (Karlsson *et al.* 2018).

Due to inadequate closure, piles of uncovered waste rock material can still be found at the site, including material crushed for aggregates. The actual waste rock pile was unevenly covered with till and some waste rock boulders can still be seen. Currently, the surrounding environment is affected by waste rocks-originated AMD, characterized by a low pH (around 3-4) and elevated amounts of Ni, Co, Cu, Zn and SO4 (Karlsson *et al*. 2021).

A lysimeter study was carried out to evaluate the effect of a 0.3 m cover layer made of local till on waste rock drainage water quality. In 2019, three lysimeters (diameter 1.0 m, height 0.3 m) were buried in the upper parts of the waste rock pile and filled with weathered waste rock material obtained from the aggregate piles. One of the lysimeters was left uncovered as a control lysimeter (LY1) and two were covered with 0.3 m of till (LY2 and LY3).

The mineralogy of the crushed waste rock material was characterised at GTK Research laboratory with a FE-SEM-EDS. The geochemical properties, including aqua regia extractable element concentrations and total S were investigated in an accredited commercial laboratory, as well as the geotechnical properties of the till material, including water conductivity and grain size distribution.

The lysimeter drainages were monitored throughout the study period of May 2020 – December 2021. Water samples were collected at approximately monthly intervals of around once per month and analysed for harmful elements, including Cu, Co, Ni, SO4, and Zn. Precipitation data was also recorded by installing a weather station (Campbell Scientific WXPro) at the site, and the amount of water infiltrating the lysimeters was compared between the covered and uncovered setups.

Oxygen (O_2) concentrations below the till cover were measured using O-sensors (Campbell Scientific SO-110), providing data on the availability of oxygen within the covered lysimeter setups. These measurements were compared to the atmospheric O_2 concentrations, which were determined by an O-sensor installed above the cover layers (open air, atmospheric conditions), to determine the influence of till cover on oxygen availability. The mV data was transformed to O_2 % by first calculating a conversion factor, which was obtained by dividing the median mV value of the O-sensor installed in open air by the standard atmospheric O_2 % of 20.9. Then, the mV values were multiplied by this factor to yield the corresponding O_2 % measurements.

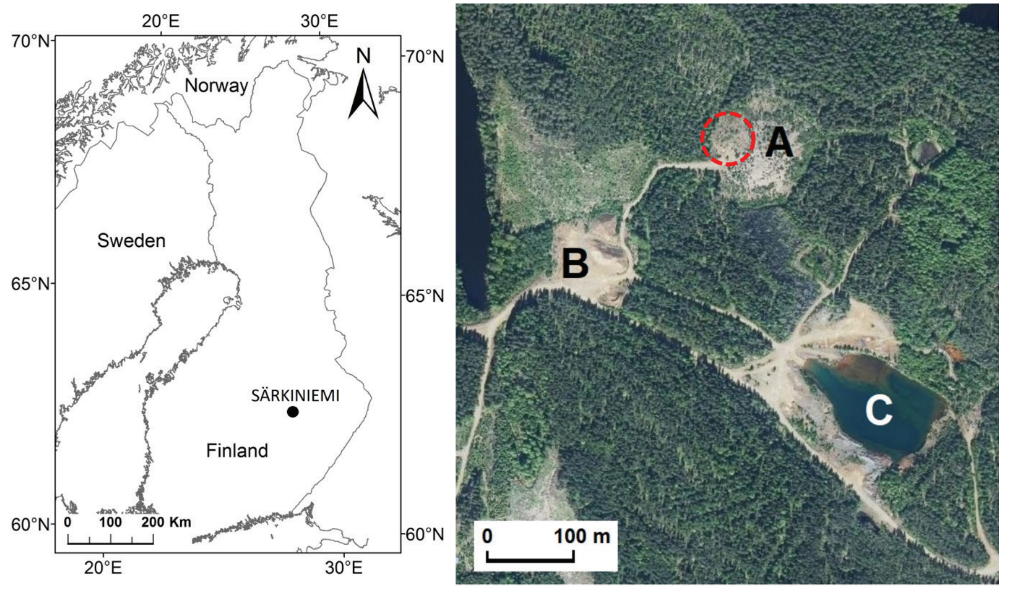

Figure 1 The location of the Särkiniemi mine in Finland and an aerial image of the mine site. A = waste rock area, B = piles of crushed waste rock, C = open pit filled with water. The area where the lysimeter test was conducted is presented by red circle. Basemap and aerial image © National Land Survey of Finland and HALTIK 2013.

The monitoring data collected from the lysimeter study was analysed to quantify the reduction in harmful element mobility due to the 0.3 m till cover. Reduction percentages were calculated for each element by comparing the concentrations in the covered lysimeters to those in the uncovered control lysimeter.

Results and discussion

The crushed waste rock material used in the lysimeter tests contained elevated aqua regia extractable amounts of Co (67 mg/kg), Cu (522 mg/kg), Ni (560 mg/kg) and Zn (92 mg/kg). The total S concentration was 1.6 %. Based on the FE-SEM-EDS results, the main minerals (wt% > 5) included quartz (20.3 wt%), biotite (18.1 wt%), non-albitic plagioclase (15.3 wt%), a mixture of chlorite (smectite), jarosite and sulfides (14.9 wt%), and hornblende (6.6 wt%). The detected sulfide minerals included pyrrhotite (0.8 wt%), pyrite (0.2 wt%), chalcopyrite (traces) and pentlandite (traces), while no carbonates were detected. As the orange colour of the crushed waste rock aggregate piles already indicated, the material was weathered and contained detectable amounts of secondary mineral jarosite.

The till material used to construct the cover can be classified as sandy till, comprising approximately 50 % cobble and gravel (>2 mm), 40 % sand (0.06 – 2 mm) and 10 % fine-grained material (<0.06 mm). The hydraulic conductivity of the till was measured to be $4.5*10^{-7}$ m/s, indicating its classification as permeable material (Garbarino *et al.* 2018).

The till cover demonstrated a notable impact on the amount of water infiltrating the waste rock material. During the summer seasons 2020-2021, approximately half of the precipitated water was recorded as drainage from the uncovered lysimeter, while the corresponding amount for the till-covered lysimeters was around one-tenth. Previous studies conducted by Wilson *et al.* (1995) have demonstrated that increasing the thickness of the till cover, such as the 0.8 m thickness they investigated, can further enhance the reduction of rainwater infiltration to as low as 1-5 % of the total precipitation.

According to the lysimeter monitoring results, the amounts of mobilized harmful elements were substantially reduced by the till cover (Table 1). On average during the monitoring period, the Cu mobility was reduced the most, around 86-93 %. Reduction for Co was 60-71 %, for Ni 48-61 %, for SO4 52-64 % and for Zn 17-40 % (Fig. 2). In general, the element concentrations were lower in the LY1 drainage compared with the LY2 and LY3, but the amount of drainage water was significantly higher. The till cover had only a minor effect on the drainage pH; the average pH of the uncovered LY1 was 3.6, while the average pH's of the LY2 and LY3 drainages were only slightly higher, 3.8 and 3.7, respectively (Table 1).

According to the O-sensor data, the O_2 concentrations below the till cover were not substantially lower than the atmospheric O_2 concentration of 20.9 % (Fig. 3). On top of LY1, in atmospheric conditions, the median O-sensor value was 51.8 mV (assuming 20.9 O_2 %, which implies a conversion factor of 2.48 mV per O_2 %), while under the till cover, the median values were 44.0 mV (17.7 O_2 %) in LY2 and 46.6 mV (18.8 O_2 %) in LY3. This suggests that oxygen is diffusing through the till cover. While the exact impact of these oxygen levels on sulfide oxidation is difficult to determine without further investigation, it is likely that the main factor affecting the reduced harmful element mobility in the

***Table 1** The masses (grams) of Co, Cu, Ni, Zn and SO4 leached out from the lysimeters LY1-3 and the average drainage pH during the monitoring period 2020-2021. The masses have been calculated based on drainage concentrations and amounts of drainage water.*

Lysimeter	Average pH	Co	Cu	Ni	Zn	SO_4
		g	g	g	g	g
LY1	3.6	2.55	2.61	10.45	0.84	453.76
LY2	3.8	0.73	0.19	4.04	0.51	164.48
LY3	3.7	1.02	0.38	5.44	0.70	217.08

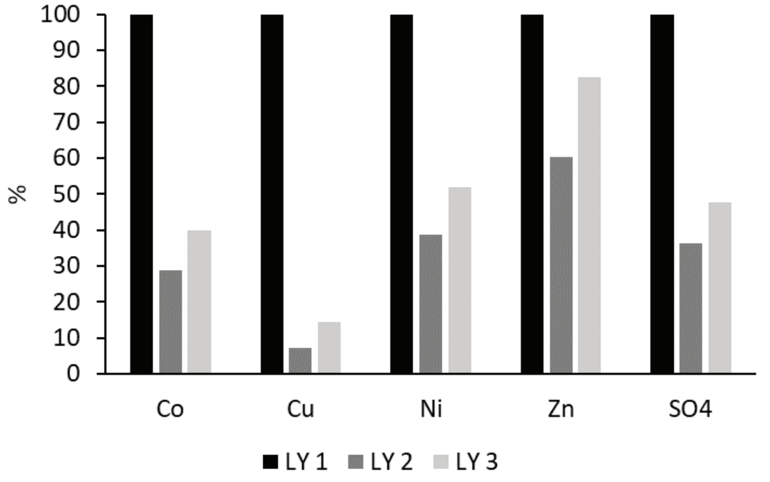

Figure 2 *The mobilities of the harmful elements Co, Cu, Ni, Zn and SO4 from the till covered lysimeters LY2 and LY3 compared with the uncovered LY1.*

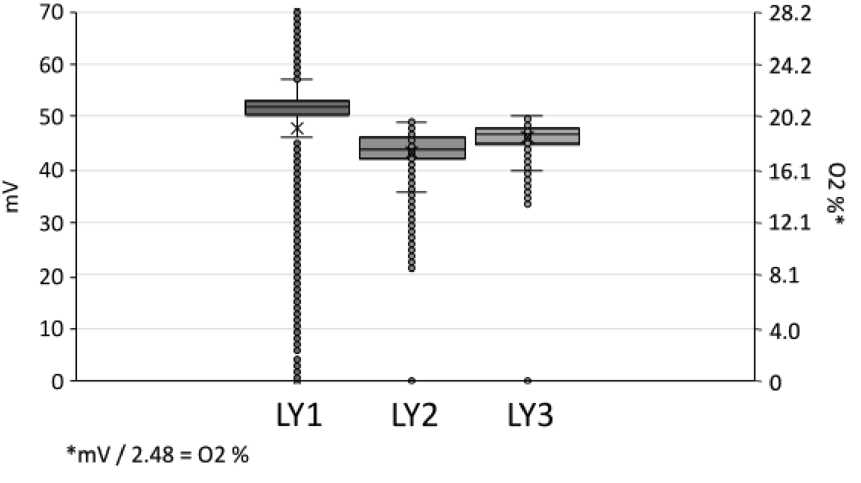

Figure 3 *O-sensor data from LY1-LY3. In LY1, the sensor was positioned above the lysimeter in atmospheric conditions, while in LY2 and LY3, the sensors were placed below the till cover. The O_2 %Is calculated assuming that the median LY1 sensor value of 51.8 mV represents the average atmospheric O_2 concentration of 20.9 %, which implies 2.48 mV per O_2 %.*

covered lysimeters is the lower amount of infiltrated water, rather than the decreased oxygen availability. Furthermore, in the case of the weathered waste rock material of the Särkiniemi mine, the previously accumulated secondary minerals and adsorbed metal(loid) concentrations most likely participate in sustaining acidic pH and elevated harmful element concentrations in the drainage (Kaasalainen *et al*. 2019), which decreases the significance of O2 reduction by the cover.

This study demonstrates that even a relatively thin (0.3 m) till layer can substantially reduce the mobility of harmful elements, primarily by decreasing the amount of infiltrating water. However, the efficiency of the till cover in reducing harmful element mobility varied depending on the specific element. Depending on closure objectives and impacts on the surrounding environment, the achieved reduction may not be sufficient, and more efficient cover layers or additional mitigation measures might be needed. Indeed, such thin single-layer cover systems are not recommended for acid generating mine waste material (Garbarino *et al*. 2018, INAP 2017).

The findings of this study provide valuable insights into the effectiveness of till covers as a mitigation strategy for AMD, contributing to a broader understanding of sustainable mining practices and the development of more effective mine closure techniques. Since large quantities of natural till may be difficult to obtain for larger mine waste areas, future research should explore the potential of utilizing secondary materials and examine their long-term performance as alternative cover materials.

Conclusions

The results of this study indicate that even a relatively thin till layer (0.3 m) can substantially reduce the mobility of harmful elements. During the monitoring period from 2020 to 2021, the average reduction in element mobility was as follows: Cu mobility decreased by 86–93%, Co mobility by 60–71%, Ni mobility by 48–61%, SO4 mobility by 52–64%, and Zn mobility by 17–40%. The oxygen concentrations below the till cover were not substantially lower than atmospheric levels, suggesting that the primary factor in reducing harmful element mobility was the decreased water infiltration rather than the reduced oxygen availability.

While the results of this study contribute to our understanding of till covers as a mitigation strategy for AMD, it is essential to recognize that the achieved reduction in harmful element mobilities may not be sufficient for all closure objectives and environmental contexts. More efficient cover layers or additional mitigation measures may be required in some cases. Moreover, as obtaining large quantities of natural till for mine waste cover applications may be challenging, future research should explore the use of secondary materials and assess their long-term performance as alternative cover materials. Overall, this study offers valuable insights for the development of sustainable mining practices and the improvement of mine closure techniques.

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