

# Assessment of the effects of mine closure activities to waste rock drainage quality at the Hitura Ni-Cu mine, Finland

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**Abstract** Choosing right management methods is essential for efficient closure and design of mining waste facilities. To assess potential effects of mine closure activities to waste rock drainage quality at the Hitura Ni-Cu mine in Finland, a surface water investigation and filled-in lysimeter tests were performed. According to the results, current environmental effect on the surface water quality caused by the waste rock piles is relatively small, but disruption of the mica schist pile *e.g.* by shaping might cause additional mobilisation of harmful elements, especially Ni. Instead, the mica schist pile could be shaped and covered with the serpentinite waste rock material which has significantly lower element mobility and alkaline drainage.

**Key words** lysimeter, static tests, waste rock utilisation, element mobility

## Introduction

After mining operations, mineral waste material dumps are left behind that may cause detrimental effects on the environment if closure is not done appropriately (Kauppila et al. 2013). Thorough planning, field investigations and characterisation of materials are crucial for the selection of suitable closure methods. Desired closure objectives may not be achieved due to inappropriate closure activities, or the environmental impacts may even get worse as a result of undesired mobilization of potentially harmful elements.

The effects of closure activities on waste rock facilities and possibilities for waste rock utilization were assessed at the Hitura Ni-Cu mine, which is currently facing closure. Two different waste rock piles are situated at the Hitura mine site: a serpentinite pile and a mica schist pile. The planned closure activities would include shaping and landscaping of both piles. In this study, the current environmental effects on surface waters around the mine site caused by the rock piles were investigated through field measurements and water quality analyses. The waste rocks were characterised chemically and mineralogically, and field scale lysimeters were constructed to assess leaching of potentially harmful elements from disturbed weathered rock material, and to study the potential use of serpentinite as a cover material on the mica schist pile.

## Study area

Hitura mine is located in Nivala, Finland (fig. 1). The mine operated in several periods during 1970–2013. The main products were Ni and Cu, which were extracted from an ultramafic sulphide deposit. The operations started as open pit mining shifting to underground min-

ing in 1991 (Heikkinen et al. 2002). The last mining company was declared bankruptcy at the end of 2015 and final closure of the site was initiated including plans to shape the waste rock piles.

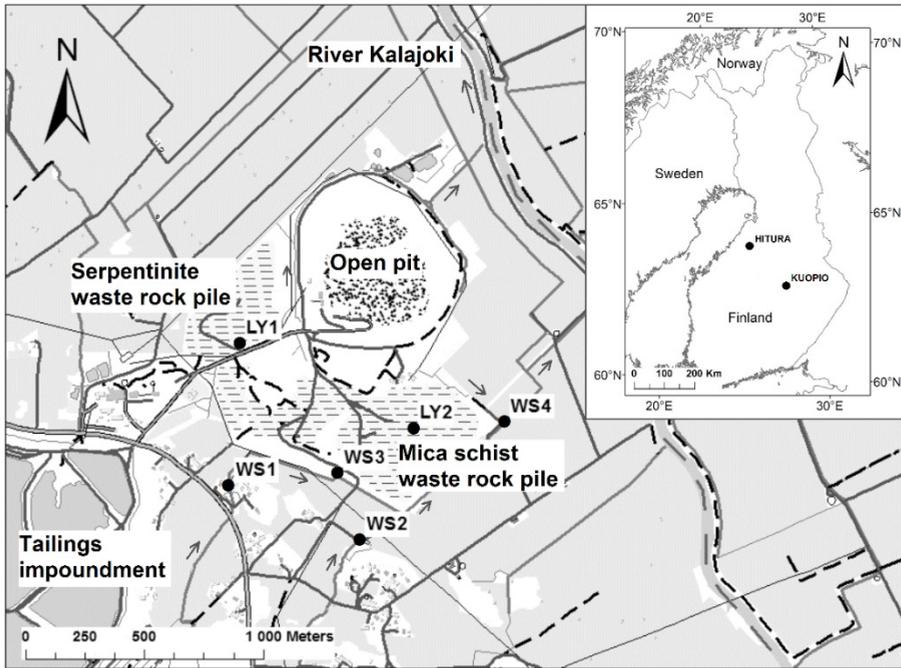
The Hitura deposit consists mainly of serpentinite and, in lesser amounts, amphiboles and mica schists (Papunen 1970). Waste rocks have been deposited in two separate piles during 1970–1993: the serpentinite pile (2.2 Mm<sup>3</sup>) and the mica schist pile (3.5 Mm<sup>3</sup>) with additional 3 Mm<sup>3</sup> of overburden of Quaternary sediments (Ahma ympäristö 2013). Mine waters from the Hitura mine site flow through a ditch system to the nearby Kalajoki River (fig. 1), which discharges to the Bothnian Bay of the Baltic Sea around 70 km northwest.

### Materials and methods

The current environmental effects on the water quality of the ditches surrounding the waste rock piles were investigated through field measurements and water quality analyses in June 2016. Field measurements were repeated in April 2017. The water samples were taken from the ditches Hituranoja (WS1) and Töllinoja (WS2), upstream of the mica schist waste rock area representing background water quality, from seepage water discharging from the mica schist pile (WS3), and from the ditch of the joined Hituranoja and Töllinoja ditches downstream of the mica schist waste rock pile (WS4) (fig. 1). Representative surface water sampling points could not be found around the serpentinite pile, therefore only field measurements were performed. The field analyses were performed with a portable YSI multiparameter sonde, and included pH and electrical conductivity (EC). Laboratory analyses included total concentrations of dissolved elements with ICP-OES/MS from filtered (0.45 µm), preserved (1 M HNO<sub>3</sub>) samples, and anion concentration analyses with ion chromatography from untreated samples.

Field scale lysimeters were applied to investigate longer term leaching of the waste rock materials in natural conditions to simulate the impact of disturbance of the mica schist waste rock pile by earthworks and the usability of serpentinite in covering the mica schist pile. The samples for the lysimeters (1 m<sup>3</sup> of serpentinite, LY1, and 2 m<sup>3</sup> of mica schist, LY2) were collected from the weathered surface parts of the waste rock piles with an excavator (fig. 1). The grain size distribution of the samples was heterogeneous with the largest rocks up to 10 to 20 cm. Rocks larger than that were removed manually.

The lysimeter test setup consisted of four 1 m<sup>3</sup> lysimeters, which were constructed on December 2015 at the premises of the Geological Survey of Finland (GTK) in Kuopio, eastern Finland. One lysimeter was left empty for background water analysis and to monitor potential contamination of the lysimeter containers, one was filled with serpentinite (LY1.1), and two with mica schist (LY2.1 and LY2.2). The filled-in lysimeters contained around 800 L of waste rocks, weighing approximately 1600 kg. The mica schist lysimeter LY2.2 was covered with a 15 cm layer of serpentinite in April 2016 to further evaluate suitability of serpentine as a cover material for mica schist. The cover was placed five months after the construction to ensure equal starting levels for both mica schist lysimeters and applicability of lysimeter LY2.1 as a control lysimeter for the cover material test.



**Figure 1** The location and setting of the Hitura mine site and sampling points. WS = water sampling point, LY = sampling point for lysimeter tests. (Basemaps © National Land Survey of Finland.)

During the filling of the lysimeters, 10 L samples were taken from the serpentinite and mica schist for the chemical and mineralogical characterisation. The chemical characterisation included analyses of total element concentrations of pulverised samples with XRF and assessment of acid production potential with modified ABA-test (standard CEN EN 15875:2008). Total sulphur was determined using high temperature combustion method and IR detection (ISO15178, Leco-furnace method). Chemical analyses were performed in the accredited laboratory of Labtium Oy. Mineralogical composition was measured from the ground samples with field-emission scanning electron microscope (FE-SEM, JEOL JSM 7100F Schottky) at the GTK Geolaboratory.

The amount and quality of lysimeter seepage waters were measured periodically. Seepage waters were collected in plastic canisters and analysed for pH, EC, anions and dissolved elements. The pH and EC were measured in the field with a portable YSI-meter, and anions (from untreated samples) and dissolved elements (from filtered (0.45 µm), preserved (1 M HNO<sub>3</sub>) samples) were determined in an accredited laboratory by Labtium Oy using ion chromatography and ICP-OES/MS, respectively. Field duplicates, field blanks and laboratory duplicates were used to ensure quality in the sampling and the analysis.

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## Results and discussion

### Surface waters

Surface waters in the ditches around the Hitura mica schist waste rock pile were mainly neutral (fig. 2). In June 2016, the pH value in the water discharging from the waste rock pile area was practically the same (6.8) as in the background measurement points in the Töllinoja and Hituranoja ditches (6.9) suggesting negligible input of acidity from the waste rock pile. This was despite the seepage waters of the pile were acidic with pH around 4. However, the EC of the seepages was around 300–500 mS/m, and an increase in the EC of the Töllinoja ditch (from around 12 mS/m upstream of the pile to around 35 mS/m downstream of the pile) indicated minor input of ARD affected waters into the ditch. Water in the ditch flowing around the serpentinite waste rock pile altered from circumneutral (pH 6.5) to alkaline (pH 7.6–8). The field measurements in April 2017 showed similar pH tendencies in the surface waters as observed in June 2016, but the pH values were overall slightly lower. For instance, the Töllinoja background pH value dropped from 6.8 in June 2016 to 6.1 in April 2017. This might be due to the seasonal water quality changes as the April samples were taken after the snow melt period.

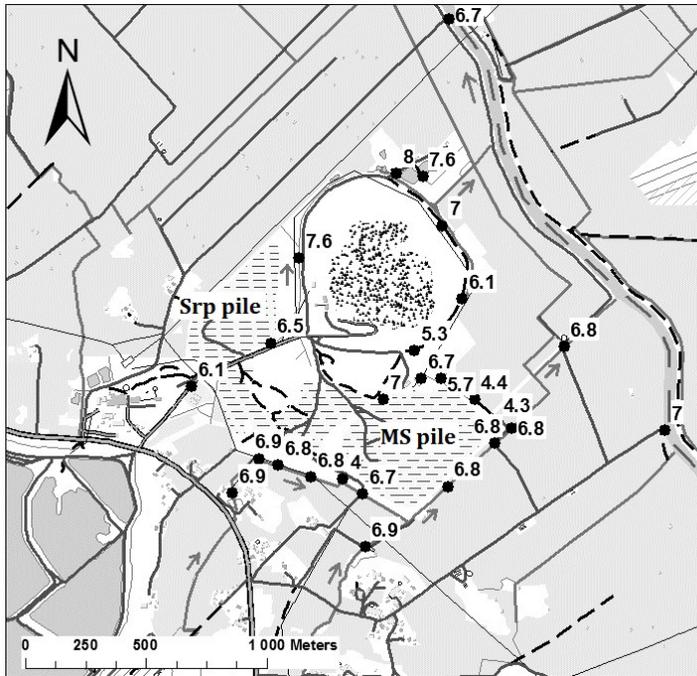
As suggested by the EC, some metal loading occurred from the mica schist pile into the ditches with Ni and Cu as primary metals. The dissolved metal concentrations in the mica schist pile seepage water (WS3) were high, the water containing 4520 µg/L of Ni and 245 µg/L of Cu (fig. 3). However, the Ni concentrations in the Töllinoja ditch increased from 3.3–6.3 µg/L of the background (WS1 and WS2) only to 94 µg/L in the downstream sampling point of the waste rock area (WS4). In addition, increase in the Cu concentration in the Töllinoja ditch was negligible, from 2.1–2.8 to 3.7 µg/L (fig. 3). Obviously, small flow rates of the seepages compared to those of the Töllinoja ditch result in dilution of the metal concentrations.

Despite the dilution, the nickel concentration in the discharge point of the mica schist waste rock area in the Töllinoja ditch (94 µg/L) exceeded the average annual Ni limit value of 20 µg/L set by the European environmental quality standard (EQS) applicable to surface waters (EC 2008). Nevertheless, the effect caused by the ditch water is considered overall insignificant, as the average flow of the Kalajoki River, the receiving water body of the Hitura waste rock discharge, is relatively high, 164 m<sup>3</sup>/s (Savolainen & Leiviskä 2008), compared to the flow in the Töllinoja ditch, 0.2 m<sup>3</sup>/s (Heikkinen et al. 2004). In fact, no marked change was observed in the EC of the Kalajoki River water between the sampling points located upstream (EC 4.4 mS/m) and downstream (EC 4.8 mS/m) of the discharge from the waste rock area. In addition, pH remained circumneutral in the Kalajoki river below the discharge point even though a minor change in pH was recorded between the two sampling points (from 7.0 to 6.7).

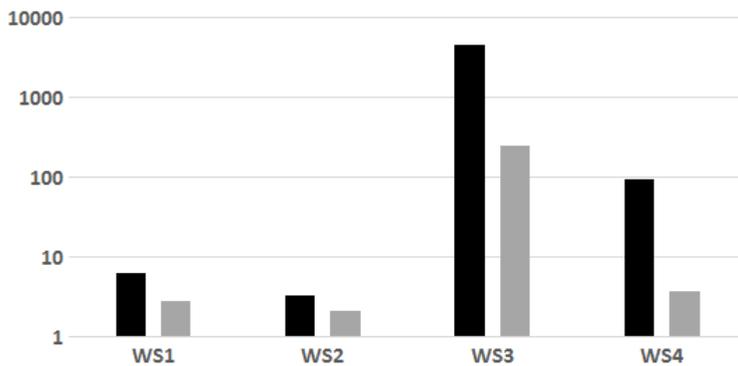
### Lysimeter tests

Mineralogical and chemical characterization of the mica schist and serpentinite used in the lysimeter tests were carried out to assess their environmental properties and ARD potential. Based on the results, the mica schist (LY2) is composed of quartz (24.3%), plagioclase

(21.1%), biotite (14.5%) and muscovite (5.1%) with accessory sulphides and very low carbonate content (calcite 0.01%). The primary sulphides include pyrrhotite (1.41%), pyrite (0.89%), pentlandite (0.18%) and chalcopyrite (0.15%). The main contaminants in the mica schist are Ni and Cu, which showed high concentrations: 2290 and 771 mg/kg, respectively (tab. 1). Based on the ABA test and the mineralogy, the mica schist (LY2) is potentially acid producing (NPR = 0.2 and neutralizing minerals << acid producing minerals) (tab. 1).



**Figure 2** pH values measured in the surface waters around the Hitura mine site in June 2016. SRP pile = serpentinite pile, MS pile = mica schist pile (Basemap © National Land Survey of Finland.)



**Figure 3** Dissolved Ni and Cu concentrations in the Hituranoja and Töllinoja ditches in the background sampling points (WS1 and WS2), seepage point (WS3) and in the ditch downstream of the mica schist waste rock area (WS4).

The serpentinite (LY1) is mostly composed of serpentine (70.0%) and talc (13.7%) and contains only small amount of sulphides (pyrrhotite 0.02% and pentlandite 0.01%) but notable carbonates (calcite content 0.96%). Similar to the mica schist, the primary contaminants in the serpentine are Ni (1009 mg/kg) and Cu (169 mg/kg) (tab. 1). The ABA test and the mineralogy indicated that the serpentinite is not potentially acid producing (NRP = 28.5 and neutralizing minerals >> acid producing minerals) (tab. 1).

Following the characterization, a total mass of the main contaminants in the lysimeters was estimated based on the total Ni and Cu concentrations and the estimated mass of rock material in the lysimeters (1600 kg). The calculations showed that the serpentinite lysimeter (LY1.1) contains less than half the amount of Ni (1.6 kg) and Cu (0.3 kg) than the mica schist lysimeters (LY2.1 and LY2.2; Ni 3.6 kg and Cu 1.2 kg).

**Table 1** Ni and Cu concentrations, and parameters for acid production potential calculations of the lysimeter rock materials.

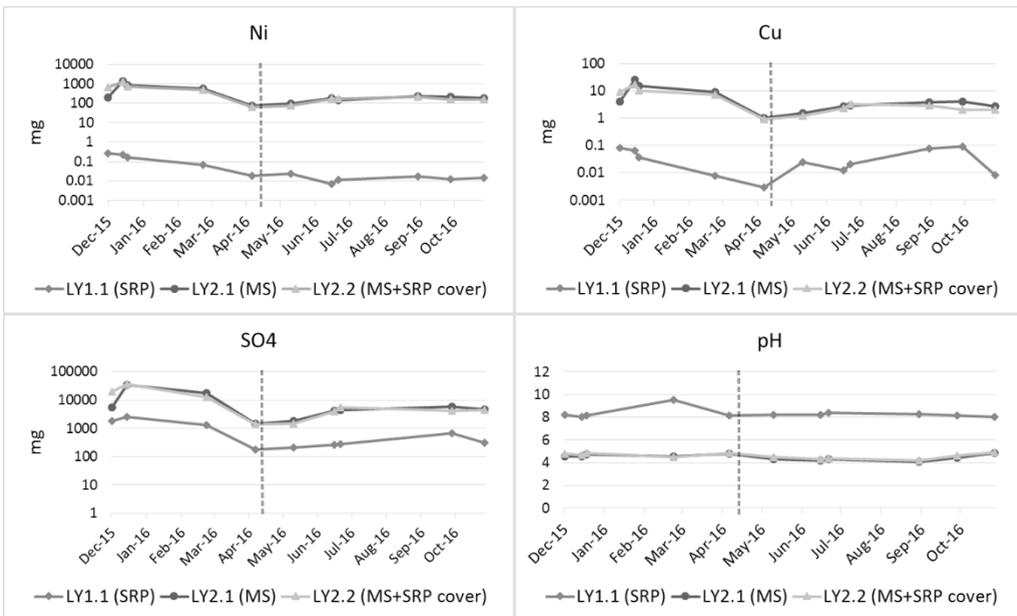
|                    | Ni    | Cu    | S    | AP                      | NP                      | NPR  |
|--------------------|-------|-------|------|-------------------------|-------------------------|------|
|                    | XRF   | XRF   | Leco |                         |                         |      |
|                    | mg/kg | mg/kg | %    | kg CaCO <sub>3</sub> /t | kg CaCO <sub>3</sub> /t |      |
| LY1 / serpentinite | 1009  | 169   | 0.14 | 4.4                     | 124                     | 28.5 |
| LY2 / mica schist  | 2290  | 771   | 2.28 | 71.1                    | 15.7                    | 0.2  |

AP = acid production potential, NP = neutralization potential, NPR = neutralization potential ratio

Altogether 9 water samples were collected from the lysimeters during a one-year monitoring period (fig. 4). In accordance with the characterization results, the seepage water from the serpentinite lysimeter (LY1.1) was alkaline (pH around 8.3 on average) with low metal contents (Ni 4–15 µg/L, Cu 0.8–30 µg/L) and EC (53 mS/m), whereas the seepages from the mica schist lysimeters (LY2.1 and LY2.2) were acidic (average pH≈4.5) and contained high amounts of dissolved metals (average EC≈250–240 mS/m), especially Ni (24300–120000 µg/L) and Cu (400–2000 µg/L). In addition, the SO<sub>4</sub> concentrations of the mica schist lysimeter seepages (620–3100 mg/L) were tenfold compared with those of the serpentinite (95–220 mg/L) indicating considerable sulphide oxidation in the mica schist and only minor oxidation in the serpentinite. The leached metal concentrations from the mica gneiss lysimeters were notably higher than observed in the actual seepage water of the waste rock pile. This underlines that disturbance of the pile may result in excess release of ARD from the pile.

The released loads of metals and SO<sub>4</sub> were calculated for the whole observation period based on the amounts and metal concentrations of the seepage waters (fig. 4). The results show that the release of Ni and Cu from the serpentinite with good buffering capacity (lysimeter LY1.1; 0.8 mg of Ni i.e. 0.00005% of the total Ni mass in the lysimeter) is negligible compared to those of the oxidized mica gneiss with low acid buffering capacity (lysimeter LY2.1:

4030 mg of Ni and 74 mg of Cu i.e. 0.1% Ni and 0.006% Cu of the total masses; lysimeter LY2.2 4046 mg of Ni and 60 mg of Cu i.e. 0.1% Ni and 0.005% Cu of the total masses), even though the amounts of Ni and Cu were also high in the serpentinite material. Overall, the loads of the metals and  $\text{SO}_4$  from the lysimeters were the highest in the beginning of the lysimeter tests (fig. 4). This is likely due to the mobilization of metals from secondary minerals and weathered mineral surfaces as especially the collected mica schist samples were strongly weathered.



**Figure 4** Amounts (mg) of Ni, Cu and  $\text{SO}_4$ , and pH leached out of the lysimeters during the observations period. LY1.1 = serpentinite, LY2.1 = mica schist, LY2.2 = mica schist with 15 cm of serpentinite on top. The dashed line represents the date when LY2.2 was covered with a 15 cm layer of serpentinite.

The addition of 15 cm of serpentinite on top of the mica schist lysimeter (LY2.2) five months after the initial set up of the lysimeter tests did not have any significant effect on the seepage water pH or the metal and  $\text{SO}_4$  loads during the observation period, despite the alkalinity of the serpentinite (fig. 4). This is most likely because the sulphide oxidation is difficult to cease once started. In addition, the observation period after the placement of the cover was quite short.

## Conclusions

Both waste rock piles at the Hitura mine site, the serpentinite and mica schist piles, contain high concentrations of potentially harmful elements, especially Ni and Cu. In addition, the mica schist is potentially acid producing. According to the field investigations, the current environmental effect on the surface water quality caused by the waste rock piles is nevertheless relatively small. Even though the seepages of the mica schist pile are acidic and contain

high Ni, Cu and SO<sub>4</sub>, the outflow water from the waste rock area is neutral with low metal contents as a result of e.g. dilution with background stream waters, and the existing impact on the receiving water body, the River Kalajoki, seems to be insignificant.

According to the lysimeter test results, disturbance of the weathered mica schist waste rock pile surface, e.g. by shaping the slopes, is likely to result in excess production of ARD and in degradation of the surface water quality discharging from the mine site. On the other hand, the lysimeters showed that the serpentinite is producing alkaline waters with low input of metals, and could therefore provide a potential cover material for the mica schist to decrease ARD. Monitoring of lysimeters will be continued to evaluate the use of serpentinite as a cover in longer term.

### Acknowledgements

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