Field Experimental Cells to Evaluate the Generation of Contaminated Neutral Drainage by Waste Rock at the Tio Mine, Quebec, Canada

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Abstract
Contaminated neutral drainage (CND) with nickel release is observed at the Tio mine, Canada. To better understand CND generation at this site, 7 intermediate-scale field experimental cells were built. This paper presents a brief description of the site, a detailed characterization of the different materials tested and the design and instrumentation of the cells. Results of the first two years of water quality monitoring showed that cells with previously weathered materials leach more nickel than cells with freshly blasted waste rock. Observations also show that the weathered materials are more prone to leach nickel when they contain more ore.

Introduction
The oxidation of sulphides contained in waste rock can sometimes lead to a significant acidification of the drainage water, a phenomenon known as acid mine drainage (AMD). Another type of contaminated leachate, called contaminated neutral drainage (CND) is defined as a neutral leachate (or effluent) whose chemical quality is detrimentally affected by its flow through mine wastes, such as waste rock (Nicholson, 2004). Even if CND usually has a lower environmental impact than acid mine drainage (AMD), it can nevertheless contain soluble element concentrations that exceed the environmental regulation criteria. CND can also have negative impacts on the environment, particularly in the long term perspective when no corrective measures are taken at the source.
Predicting the water quality from a future waste rock pile is a critical aspect at the preliminary phase of a mine project. However, results obtained with laboratory kinetic tests (often used to characterize the geochemical behaviour of waste rock) are not always concordant with the behaviour observed in the field (Malmstrom et al., 2000; Miller et al., 2003; Frostad et al., 2005), especially when the waste rock has a low acid generating potential or generates CND. Such discrepancies between laboratory predictions and *in situ* measurements have been observed at the Tio mine, located near Havre-St-Pierre (Quebec, Canada), following preliminary studies performed to establish the CND generation potential of the waste rocks (Bussière et al., 2005). Hence, the mine has decided to investigate further the geochemical behaviour of their different waste rock. Selected early results are presented in this paper.
Below, early results obtained from a field study are presented . The study was undertaken to better understand the geochemical behaviors of various waste rock samples in order to explain the occasional generation of CND when infiltrating water percolates through the Tio mine waste rocks. After a brief presentation of the studied site, the main characteristics of the six different waste rock types tested are described. The different waste rock types represent the diversity of the waste rocks excavated at the Tio mine. The design and instrumentation of the 7 cells follows, with some water quality data obtained from the experimental cells.

Study site and waste rock description
The orebody exploited at the Tio mine is the largest massive ilmenite deposit in the world. This mine has been in operation since the 1950's, and has generated over 72 Mt of waste rock. The waste rock piles occupy an area of approximately 100 ha.. The orebody still offers a large mining potential which will generate a large quantity of waste rock in the future. The experimental cells used for this study were implemented directly on one of the waste rock pile at the Tio mine.
The waste rocks are composed of igneous intrusive rocks. There are 2 main types of rocks constituting the majority of the waste rock piles: the gangue and the low grade ore. The gangue has an anorthositic composition and contains plagioclase (90-95%), hemo-ilmenite (2-3%), and sulphides (1-2%, with

pyrite at 1-1,7% and chalcopyrite < 0,4%). The other minerals occurring at very small amounts are biotite, Ni-chlorite, normal chlorite (low in Ni), and epidote. The ore is a massive oxide composed mainly of hemo-ilmenite (80-98%), plagioclase (0,5-15%), and sulphides (<0,5 to 2,5%; with pyrite at 0,3-2%, chalcopyrite <0,1%-0,6% and Cu-Fe-Ni-sulphides up to 0,2%). The other minerals are spinel (<0,5-2%), magnetite (trace to 0,1%) and rutile (<0,1%).

Various waste rocks were targeted for the present *in situ* study in order to have a representative sampling of the materials contained in the existing waste rock piles. The impact of three parameters is investigated through in the experimental cells: concentration of hemo-ilmenite, degree of alteration, and origin (location) in the mine. The cut-off grade for the mill is established at ~82% ore concentration, which means that the waste rocks generated at the Tio mine can have a concentration in hemo-ilmenite up to 82%. In the test cells, 3 different ilmenite percentages are studied: ≈ 20%, 40-45%, 60%. Since the Tio mine has been active for about 50 years, some of the waste rock found in the piles has naturally been altered and oxidized at different degrees. To investigate the impact of this factor, fresh waste rock (less than 1 month old) and aged waste rock (approximately 25 years old) were placed in different cells. Furthermore, the company presently operates two pits: the Tio pit and the North-West pit. These two pits have different geochemical signatures and different concentrations; such variation is also addressed here.

The main goal of the present study is to investigate with experimental cells the geochemical behaviour of different waste rocks that represent realistic conditions. Table 1.1 summarizes the main characteristics of the waste rocks placed in the cell. Detailed results on the characterization of the waste rocks can be found in Pepin (2008).

Table 1.1 *Main characteristics of the different waste rocks studied*

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
Concentration in ilmenite	Low ≈ 20%	medium ≈ 45%	high ≈ 60%	low ≈ 20%	medium ≈ 40%	high ≈ 60%	Idem cell 3
Age	Recent 1 month	Recent 1 month	Recent 1 month	Old ≈ 25 years	Old ≈ 25 years	Old ≈ 25 years	Idem cell 3
Pit	Tio	Nord-West	Nord-West	Tio	Tio	Tio	Idem cell 3

Design and instrumentation of the experimental cells

Seven experimental cells were built to study the CND generation potential of the different waste rocks of the Tio mine. Six cells were built to expose the waste rocks to the natural climatic conditions. The objective here is to simulate at an intermediate scale the conditions of the majority of the waste rock.

Each of these cells contains approximately 30 m³ of waste rock sieved to obtain a grain size smaller than 50 cm. The waste rock was dumped on a watertight geomembrane which collects the precipitations that percolate through. The geomembrane is protected by 30 cm thick layers of compacted sand on each side. A perforated drain was placed inside the cell to collect the percolating water. The drain is connected to a pipe that evacuates the water outside the cell into a reservoir to measure flow rate and for sampling.

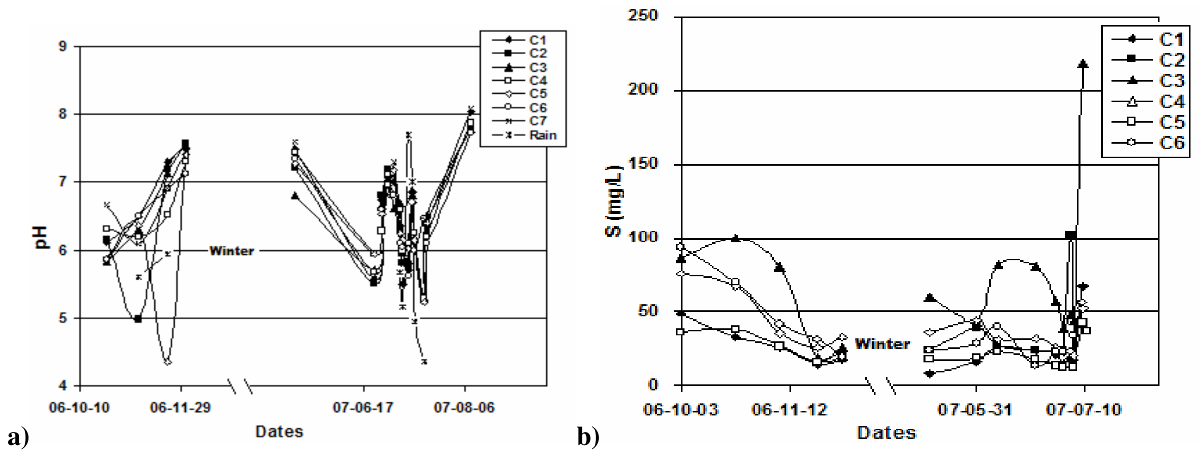
The seventh cell was designed to totally or partially submerge the waste rocks. This design allows to evaluate the geochemical impacts of flooding the waste rock. If the CND phenomenon can be controlled under these conditions, the option of depositing the waste rocks into water bassins could then represent an option for the mine for waste management. Due to its particular function, this cell was digged into the existing waste rock pile (1,8 m) and designed to control the water level with an overflow. The walls include a geomembrane, protected by two layers of sand. The water evacuated during precipitations can flow in a reservoir designed to measure the flow rate and for sampling. A drain was also installed 1 meter deep in the submerged waste rock for sampling pore water. This cell contains approximately 30 m³ of sieved waste rock, similarly to the other cells.

The reservoirs include V-notch outlets to evaluate the flow rate of water percolating through the cells. These are equipped with HOBO U20 pressure gages to measure the water level. The flow rate within the V-notch outlets was estimated with a calibration curve. Furthermore, a weather station was installed on the site to correlate measured flow rates with the meteorological conditions (not presented here; see details in Pepin, 2008). Water quality of the effluents is evaluated periodically. Monthly sampling is typically performed, but more intense sampling was conducted during the summer 2007, due to nordic climate. The physico-chemical parameters measured in the water samples are: major soluble elements inclusing metals and sulfur, pH, ORP and conductivity. More information on experimental cells design and instrumentation can be found in Pepin (2008).

Early results

Monitoring of the cells began in October 2006 and was interrupted during the winter period (December 2006 to May 2007) due to lack of drained water. Figure 1.3 shows that the pH varied between 4 and 8 during the monitoring period; the pH variations seem to follow the pH of the precipitations. Sulfur concentrations in the leachates stayed nearly constant during the testing period. All cells have leached a relatively low concentration of sulfur, with values usually lower than 100 mg/L.

Figure 1.2 *a)Variation of pH for the 7cells b)Variation of sulfur concentration for the 6 cells*

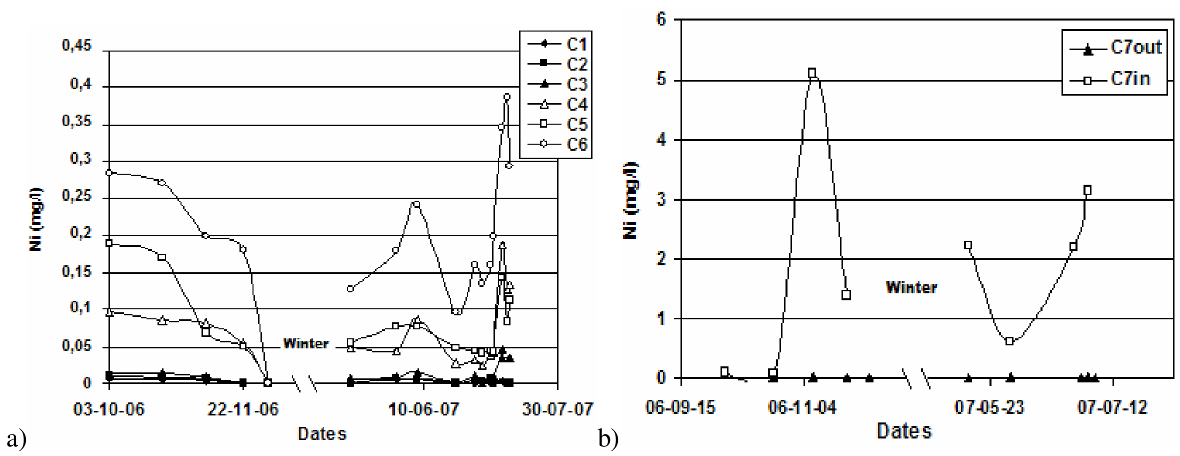


A trend in the Ni concentration results can be observed in Fig. 1.3 for the 6 cells exposed to natural conditions (Ni being the main problematic element at the Tio mine). The cells with the altered materials (C4-C5-C6) leached more nickel (concentrations between 0,1 and 0,4 mg/L) than the cells with freshly blasted waste rock (C1-C2-C3; concentrations < 0.05 mg/L). Furthermore, altered material containing more ore (C6~60%; C5~40%; C4~20%), tend to leach more nickel. The seventh (submerged) cell has a particular behaviour (see figure 1.3b). The water samples from the piezometer (1 meter deep) contain a much higher nickel concentration (between 0.1 and 5 mg/L) than the samples taken in the top reservoir (< 0.05 mg/L). This aspect will be investigated further in the future.

Conclusion

Seven experimental cells were designed and constructed at the Tio mine site to investigate the geochemical behaviour (in terms of the CND generating potential) of different waste rocks encountered at the mine. Each cell contains approximately 30 m³ of different waste rocks (6 types) having typical characteristics. The main control parameters investigated are: concentration in ilmenite, degree of natural alteration, origin within the mine, and disposal conditions (exposed to natural or submerged conditions). Water quality results in 2006 and 2007 showed that the pH of the leachate is strongly dependent on the rain water quality. The concentrations in S are low, which confirms that little oxidation occurs in the experimental cells. In terms of Ni concentrations in the leachates, the cells with the altered materials (C4-C5-C6) leach more nickel than the cells with freshly blasted material. This could be due at least in part to the retention of metals by adsorption in the fresh waste rock. More work is presently underway to better understand the geochemical behaviour of the Tio mine waste rock. Monitoring of the experimental cells will continue for the next two years in parallel with laboratory testing and numerical modelling. The combination and integration of all these results should lead to a better understanding and higher quality prediction of the CND phenomenon.

Figure 1.3 *a) Variation of nickel concentration for the 6 cells in natural surface condition b)Comparaison of nickel concentration for the submerged cell, sampled in the top reservoir (C7out) and at 1 metre depth (C7in)*



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