Evaluation of the Ni-contaminated neutral drainage generation potential in the Tio mine waste rocks

Benoît PLANTE[1], Mostafa BENZAAZOUA[2], Geneviève PEPIN[3], Bruno BUSSIÈRE[4]

[1]Université du Québec en Abitibi-Témiscamingue, 445 boul. de l'Université, Rouyn-Noranda, Québec, J9X 5E4, Canada, benoit.plante@uqat.ca
[2]Université du Québec en Abitibi-Témiscamingue, 445 boul. de l'Université, Rouyn-Noranda, Québec, J9X 5E4, Canada, mostafa.benzaazoua@uqat.ca
[3]Groupe Stavibel Inc., 25 Gamble Ouest, Rouyn-Noranda, Québec, J9X 3B6, Canada, gpepin@stavibel.qc.ca
[4]Université du Québec en Abitibi-Témiscamingue, 445 boul. de l'Université, Rouyn-Noranda, Québec, J9X 5E4, Canada, bruno.bussiere@uqat.ca

Abstract An extensive research program was undertaken in 2005 by the authors to better understand the geochemical behavior of Tio waste rock, focusing on the source and behaviour of Ni, with an emphasis on the effect of rock weathering on Ni leaching behaviour. Results showed that Ni is generated by the oxidation of sulfide minerals. Gangue minerals provide sufficient neutralization to keep the effluent pH near neutral. In the short term, sorption phenomena control Ni release in the effluent. However, the limited sorption capacity of the waste rock suggests that Ni levels will rise in the future without a proper waste rock and water management system. The results also illustrate that humidity cells fail to accurately predict effluent chemistry of CND generating Tio mine waste rocks, while field test pads render more accurate results.

Key Words contaminated neutral drainage, Tio mine waste rock, nickel, prediction

Introduction

Many toxic metals such as Ni, Zn, Co, As, and Sb are soluble at near-neutral pH, and can potentially contaminate mine effluents even without acidic conditions; this phenomenon is called Contaminated Neutral Drainage (hereinafter called CND) or simply Neutral drainage (Pettit et al., 1999; Nicholson, 2004; Bussière, 2007; Heikkinen et al., 2009). For tailings ponds or waste rock piles exposed to atmospheric conditions, these metals are often produced by oxidation of sulfide minerals (mainly pyrite and pyrrhotite) which also generates acid in the process. However, when sufficient neutralization is available in the mine wastes and/or when the sulfide oxidation rate is sufficiently slow, CND conditions are maintained (Heikkinen et al., 2009).

The Tio mine (near Havre-Saint-Pierre, Quebec, Canada) operates as a hemo-ilmenite open pit mine since 1950, and has sufficient reserves for at least 40 years. The material in the waste rock piles is mainly composed of a calcic plagioclase gangue (close to labradorite, $Na_{0.4}Ca_{0.6}Al_{1.6}Si_{2.4}O_8$) and of residual hemo-ilmenite ore (Fe_2O_3-$FeTiO_3$), with traces of sulfide minerals (Ni-bearing pyrite, FeS_2, and millerite, NiS) responsible for Ni generation in drainage waters. Some of the waste rocks contain up to 70—80 % residual hemo-ilmenite (near the cut-off value). Parts of the waste rock piles currently generate drainage with Ni concentrations sometimes over regulatory levels. Prediction techniques readily available (MEND, 1991; Lawrence & Wang, 1997; Paktunc, 1999; White et al., 1999) were developed for AMD generation prediction and might not be suitable for CND generating sites (Nicholson, 2004). This work focuses on the water quality prediction of Ni-CND generating mine waste rocks from the Tio mine by means of laboratory kinetic tests and sorption studies, in comparison to field test pads.

Materials and methods

Six different waste rock samples were selected to represent the heterogeneity in the piles in terms of both mineralogical composition (20—60 % hemo-ilmenite) and degree of alteration (fresh vs 25 years of exposition to natural conditions). In order to evaluate the geochemical behaviour of the waste rock, each of the waste rock samples was submitted to lab-scale humidity cell tests (fig.1a) (Plante et al., 2008; Plante et al., 2010a) and field test pads containing 30 m^3 of waste rocks (fig. 1b) at the mine site (Pepin et al., 2008).

Humidity cell tests were performed for over 500 days (75 weekly cycles) while field test pads are monitored since October 2005. Sorption phenomena were studied with batch sorption tests

Figure 1 View of a humidity cell (a) and a field test pad (b) installed at the Tio mine site

and sorption cells (kinetic procedure similar to humidity cells which measures the sorption capacity), and also by using sequential chemical extractions, and XPS analyses (Plante et al., 2008, Plante, 2010). For practical purposes, only the results from one of the fresh and weathered waste rocks are presented here; these sample results illustrate the general tendencies observed for the other samples (see Plante, 2010 for details). The chemical characterizations of the samples (tab. 1) show that the studied waste rocks contain Fe and Ti (hemo-ilmenite), Al and Ca (gangue), $S_{sulfide}$ (sulfide minerals), and Ni.

Results and discussion

The pH of the leachates from both the humidity cells and field test pads (Plante, 2010) remained near-neutral (pH 6.5—8.5) throughout the tests. The S concentrations (as sulfates resulting from sulfide oxidation) in the leachates from the humidity cells on fresh and weathered waste rock are similar (fig. 2a, ≈1 mg/L), while in field test pads the S concentrations (fig. 2b) in leachates from the fresh waste rock are slightly higher (25—100 mg/L) than for weathered ones (10—60 mg/L).

These results illustrate that sulfide oxidation appears to occur at slightly higher rates in fresh waste rocks than in weathered ones, even though the fresh waste rocks contain almost 3 times more sulfides than the weathered ones (tab. 1).

Table 1 *Chemical characterization of the samples studied*

	Al (%)	Ca (%)	Fe (%)	Ni (ppm)	$S_{sulfide}$ (%)	Ti (%)
Fresh waste rock	3.54	1.45	33.7	430	0.466	17.6
Weathered waste rock	4.47	1.70	30.9	370	0.167	14.9

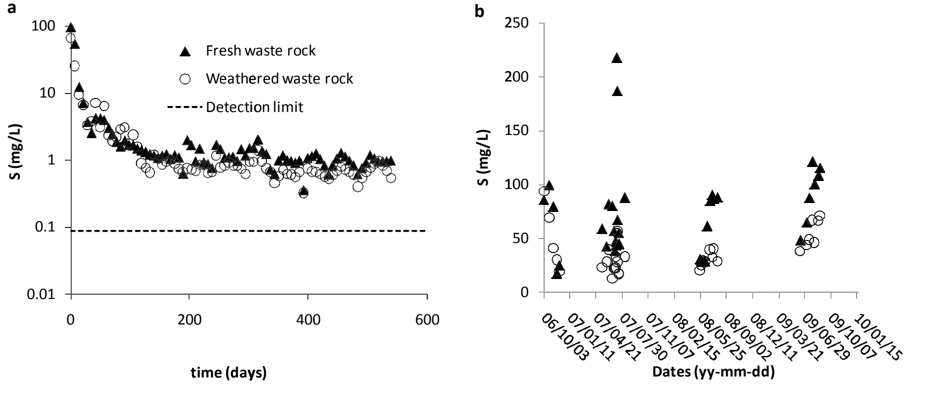

Figure 2 Typical S concentrations obtained in leachates from humidity cell tests (a) and field test pads (b)

Typical Ni concentrations obtained in leachates from humidity cells and field test pads are presented in fig. 3 for the fresh and weathered waste rocks. The Ni concentrations in the leachates from humidity cell tests remain relatively low (fig. 3a, under 0.01 mg/L) in comparison to the leachates from the field tests pads (fig. 3b, up to 0.05 mg/L for the fresh sample and up to 3.0 mg/L for the weathered one). For the humidity cells, the weathered waste rock produces detectable Ni concentrations in the leachates more often than for the fresh waste rock, while the leachates from field test pads contain significantly higher Ni concentrations for the weathered waste rock than for the fresh one.

Since sulfide oxidation, responsible for Ni production, occurs at similar rates in fresh and weathered waste rocks, the differences in Ni releases must be explained by other mechanisms, such as secondary mineral precipitation or sorption phenomena. Chemical equilibrium calculations do not suggest that Ni-bearing secondary mineral precipitation is occurring in laboratory kinetic (Plante, 2010) tests or in field test pads (Pepin, 2009). In order to evaluate the Ni sorption properties of the Tio waste rock, batch sorption studies were performed with varying Ni concentrations (1, 10, 25 mg/L) at different pH levels (5, 6, and 7). Typical results from batch sorption tests are shown on fig.4.

The batch sorption tests illustrate that the fresh waste rock removes more Ni from solution and does so faster than the weathered waste rock, probably because readily available sorption

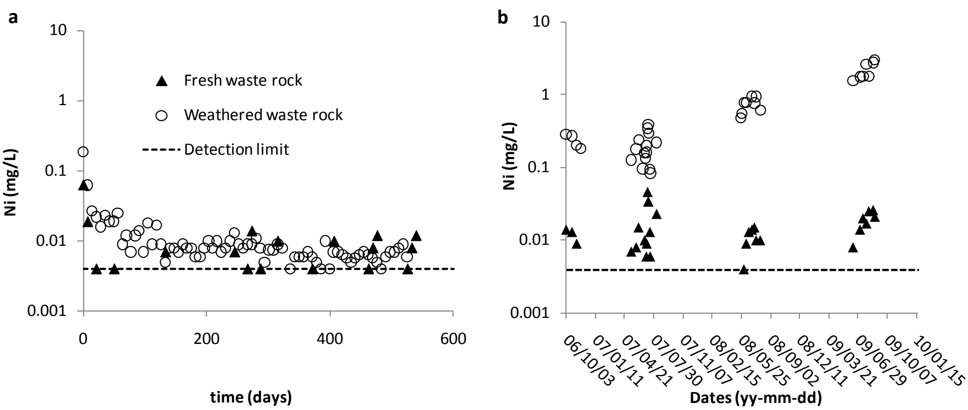

Figure 3 *Typical Ni concentrations obtained in leachates from humidity cell tests (a) and field test pads (b)*

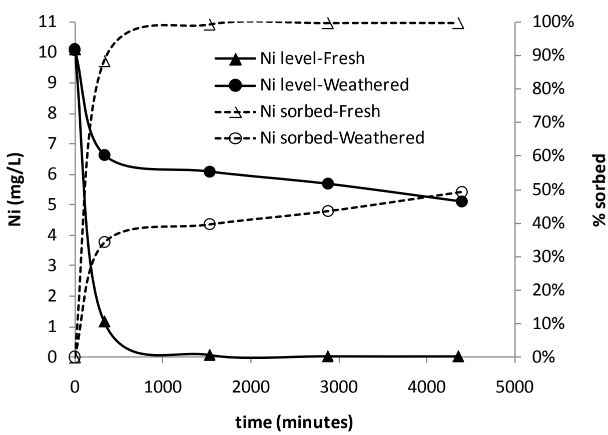

Figure 4 *Typical batch sorption test results (10 mg/L Ni, and pH 6, 0.053) from fresh and weathered waste rock*

sites within the weathered waste rock were partially saturated in-situ prior to sampling. These different sorption capacities explain, at least in part, the different geochemical behaviours in terms of Ni leaching from the fresh and weathered waste rock observed in fig. 3. XPS studies (Plante, 2010) demonstrated that Ni is sorbed as the hydroxide $Ni(OH)_2$, and sequential extractions suggest that the sorption sites are mostly associated with oxides and hydroxides (Plante, 2010). Thus, the sorbed Ni is unstable in reductive conditions, and the waste rock management program will have to avoid reductive conditions in order to avoid the release of sorbed Ni into the drainage waters.

Conclusions

This research highlights that sorption phenomena control Ni mobility in the Tio mine waste rock. However, further work is required in order to extrapolate the sorption results from the laboratory to field scale. The results also illustrate that humidity cells fail to accurately predict effluent chemistry of CND generating Tio mine waste rocks, while field test pads render more accurate results. More research is currently under way in order to better understand the scale effect on the CND prediction studies by means of kinetic tests, and to define a laboratory protocol that would enable a more precise CND prediction.

Acknowledgements

The authors would like to acknowledge the NSERC Collaborative Research and Development (CRD) program for supporting this research program. The authors would also like to thank the NSERC Polytechnique-UQAT Chair in Environment and Mine Wastes Management for financial support, are grateful to Rio Tinto-Fer et Titane Inc. (especially Donald Laflamme) for the financial and technical support throughout the project, and are also thankful to the URSTM personnel for their technical support.

References

Bussière, B, 2007. Colloquium 2004: Hydrogeotechnical properties of hard rock tailings from metal mines and emerging geoenvironmental disposal approaches. Can Geotech J 44: 1019—1052.

Heikkinen P, Räisänen M, Johnson R (2009) Geochemical Characterization of Seepage and Drainage Water Quality from Two Sulphide Mine Tailings Impoundments: Acid Mine Drainage versus Neutral Mine Drainage. Mine Water Environ 28: 30—49.

Lawrence RW, Wang Y (1997) Determination of neutralization potential in the prediction of acid rock drainage. In Proc 4th International Conference on Acid Rock Drainage (ICARD). Vancouver, Canada, pp. 451—464.

MEND (1991) Acid Rock Drainage Prediction Manual. MEND Project 1.16.1b, report by Coastech Research. MEND, Natural Resources Canada.

Nicholson RV (2004) Overview of near neutral pH drainage and its mitigation: results of a MEND study. MEND Ontario workshop, Sudbury, Canada, may 2004

Paktunc AD (1999) Mineralogical constraints on the determination of neutralization potential and prediction of acid mine drainage. Environ Geol 39: 103—112.

Pepin G, Bussière B, Aubertin M, Benzaazoua M, Plante B, Laflamme D, Zagury GJ (2008) Field experimental cells to evaluate the generation of contaminated neutral drainage by waste rocks at the Tio mine, Quebec, Canada. Proc 10th International Mine Water Association (IMWA) Congress on Mine Water and the Environment, Czech Republic, pp. 309—312

Pettit CM, Scharer JM, Chambers DB, Halbert BE, Kirkaldy JL, Bolduc L (1999) Neutral mine drainage. Proc Sudbury 1999 Mining and the Environment International Conference, vol. 2, pp. 829–838

Plante B, Benzaazoua M, Bussière B, Pepin G, Laflamme D (2008) Geochemical behaviour of nickel contained in Tio mine waste rocks. In: Rapantova, N., Hrkal, Z. (Eds) Proc 10th International Mine Water Association (IMWA) Congress on Mine Water and the Environment, Czech Republic, pp. 317—320

Plante B (2010) Prédiction du drainage neutre contaminé en Ni: cas de la mine Tio. Ph.D. thesis, Université du Québec en Abitibi-Témiscamingue (UQAT), Québec, Canada.

White III WW, Lapakko KA, Cox RL (1999) Static-test methods most commonly used to predict acid-mine drainage: practical guidelines for use and interpretation. Plumlee GS, Logsdon MJ (Eds) The Environmental Geochemistry of Mineral Deposits: Part A. Processes, Techniques, and Health Issues, Rev Econ Geol 6A, pp.325–338.