Waste Rock Characterisation versus the Actual Seepage Water Quality

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Abstract

Proper characterisation is needed to predict the long term behaviour of mine waste material and to successfully close a waste facility. The objective of this study was to compare the performance of commonly used prediction methods with the actual seepage water quality from closed or active mine sites. This was carried out by characterising waste rock material and seepage waters from seven mine sites. The prediction methods included static tests, NAG leachate, shake flask test and hot *Aqua Regia*.

Differences were observed between the methods predicting acid production potential (APP) and the actual acidity of the seepage waters. The study indicated that the laboratory tests were often too pessimistic in comparison with the pH values measured from the seepages. Therefore, the use of several different methods, as well as mineralogical data, is recommended for the APP prediction.

According to the results of the different examined leachability tests, the hot *Aqua Regia* extraction had the best correspondence with the actual seepage water quality in predicting which elements will be present in the effluents. In general, performance of the NAG test leachate was reasonable, but it underestimated the metal concentrations when NAG leachate pH was higher than around 4. The shake flask test was observed to be the most unsuitable for the effluent quality prediction.

The results obtained from the *Aqua Regia* extraction and NAG leachate can be used to predict the elements that will appear as elevated concentrations in the effluents, considering that the concentrations are only approximate, not exact. Elevated concentrations in any of the evaluated leaching tests indicate a possibility of increased element loads in the seepages.

Key words: Mine waste characterisation, mine water, drainage quality, prediction

Introduction

Mining wastes and waste facilities are usually the most fore standing sources of harmful drainage at a mine site. Proper characterisation is needed already before actual mining operations, to predict the long term behaviour of disposed waste material, for example, for the environmental impact assessment, and for the planning of waste and seepage water management methods and their closure. Therefore, selection of suitable characterisation methods is crucial. Seepage water quality can be predicted, for example, by using geochemical characterisation, geochemical modelling, or analogies between similar deposit types (REFs?).

To determine acid production potential (APP), the acid base accounting (ABA) tests are the most commonly used static test methods. These tests characterise if sample material is either non-acid producing, i.e. neutralisation potential (NP) exceeds acid production potential (AP), or potentially acid generating, i.e. AP exceeds NP (Sobek et al. 1978, White et al. 1999). Also the net acid generation (NAG) test can be used to assess the risk for acid generation, either as a standalone tool (Miller et al. 1997), or as a supplement to other static tests, e.g. the ABA test (Jambor 2003).

Leachability of potentially harmful elements can be evaluated with several methods. According to the European legislation concerning mine waste characterisation, the leachability of metals, oxyanions and salts over time should be evaluated by pH dependence leaching test, and/or percolation test and/or time-dependent release and/or other suitable testing, and for sulphide-containing waste, static or kinetic tests should be carried out in order to determine acid rock drainage and metal leaching over time (European Commission 2009). In Finland, to fulfil the requirements of the European Commission and to predict metal leaching, one of the most common selective extractions used for mine waste characterisation is the hot *Aqua Regia* leach (Doležal et al. 1968, Niskavaara 1995). Also the NAG test leachate can be analysed to assess the harmful element mobility during long-term acid generation reactions (Räisänen et al. 2010). Furthermore, the leachability of elements can be assessed using the two-stage batch leaching test/shake-flask test SFS-EN 12457-3, which complies with the waste disposal related Decrees 202/2006 and 403/2009 of the Finnish Government.

The objective of this study was to compare performance of various prediction methods with the actual seepage water quality from closed and active mine sites. This was carried out by characterising waste rock material and seepage waters from seven mine sites. For the prediction of APP, suitability of modified ABA and NAG test was evaluated. Dissolution of metals and metalloids during hot *Aqua Regia* extraction, NAG test and two-stage shake-flask test was investigated and performance of these methods to assess the mobility of contaminants during the long term waste rock storage was evaluated.

Methods

Seepage water and waste rock samples were collected from seven operating or closed mine sites, in total from nine waste rock areas originating from varying commodities and with different disposal periods (Table 1). From the mine sites 3 and 6 samples were collected from waste rocks piles of different disposal periods, i.e. from a waste rock pile, in which waste rock disposal had ceased already some 15-20 years ago, and from a waste rock pile, in which disposal was still active.

***Table 1** Commodities of the studied mine sites and disposal periods of the waste rock piles*

Target Site	Commodity	Time of waste rock disposal
Mine 1	Au	2011 -
Mine 2	Cu, Co, Zn, Ni	1972 - 1985
Mine 3 (old)	Talc, Ni	1982 - 2000?
Mine 3 (fresh)	Talc, Ni	2004 -
Mine 4	Cu, Co, Zn, Ni, Au	2011 -
Mine 5	Ni, Co	1970 - 1993
Mine 6 (old)	Apatite	1975 - 2000?
Mine 6 (fresh)	Apatite	2000? -
Mine 7	Cu, Zn	1973 - 1986

Seepage waters were collected from the edges of the waste rock piles from points where the water surfaces from the pile. The pH was measured in the field using a portable multi-parameter YSI meter. Filtered (0.45 µm), HNO_3-acidified samples were collected for dissolved cations and trace element analyses, and measurements were made by ICP-OES/MS.

Waste rock samples were collected as 10-15 kg composite samples of fist sized subsamples taken from the waste rock pile surface above the seepage points. The amounts of carbonate carbon and total sulphur were measured using pyrolytic methods. The APP of the waste rock material was studied with ABA (CEN-EN 15875) and NAG (AMIRA 2002) tests. *Aqua Regia* was used to dissolve the samples according to the modified ISO-11466 standard. Leachability of elements was further studied by analyzing trace metal concentrations from the leachates of the NAG test, and using the shake-flask test/batch leaching test (SFS-EN 12457-3). The trace element were measured from the leachates with ICP-OES/MS.

Results and discussion

Table 2 shows the results of the acid production potential of the rock samples measured with the modified ABA and NAG test, the contents of carbonate carbon and total sulphur, and the *in-situ* measured pH values of the seepage waters. Based on the results, the ABA and NAG tests revealed differences in assessing the acid production potential of the rock samples. According to the ABA test, six samples were likely to produce acid rock drainage (NP/AP < 1) and three samples were non-acid generating, whereas based on the NAG test, only four samples were potentially acid forming (PAF) and five non-acid forming (NAF) (tab 2).

The samples that showed differences in assessing the APP were sample Mine 3 (old) and Mine 4. The NAG test assessed both samples as non-acid forming, while the ABA tests indicated both samples to be likely acid generating. For the classification of acid generation, the AMIRA guidebook (2002) further recommends the use of the net acid production potential (NAPP) together with the NAG results. When applying the NAPP to the NAG results, the APP of sample Mine 4 classified as uncertain, and the sample 3 (old) as NAF but close to the uncertain field. Based on the results, the contradictory results between the two tests can be expected with samples falling under the uncertain category of APP.

Table 2 *Carbonate carbon and total sulphur concentrations, APP test results and the actual seepage water pH at the mine sites. NAF = non-acid forming, PAF = potentially acid forming.*

Sample	C carb (%)	S (tot) %	NAG	ABA	Seepage pH
Mine 1	0.8	0.1	NAF	None	6.7
Mine 2	0.2	1.7	PAF	Likely	6.3
Mine 3 (old)	1.3	1.4	NAF	Likely	7.3
Mine 3 (fresh)	1.4	2.3	PAF	Likely	7.7
Mine 4	0.7	4.3	NAF	Likely	7.1
Mine 5	0.1	3.4	PAF	Likely	6.7
Mine 6 (old)	2.8	0.1	NAF	None	6.5
Mine 6 (fresh)	0.8	0.2	NAF	None	7.0
Mine 7	< 0.1	1.6	PAF	Likely	3.9

Furthermore, clear differences between the test results and the actual measured seepage water pH values were observed. The laboratory tests, especially the modified ABA test, gave principally too pessimistic estimates on the APP compared with the realized seepage water pH at the mine sites.

The sums of dissolved heavy metals in the extracts produced in the NAG test and the *Aqua Regia* leach, and in the waste rock seepage waters are presented in Figure 1. The batch leaching / shake-flask test results are not shown in the Figure, because element concentrations were mainly low or below the detection limit of the analytical method. The concentrations presented in Figure 1 should not be considered as exact estimations of seepage water quality, but merely as approximates of potentially elevated metal concentrations.

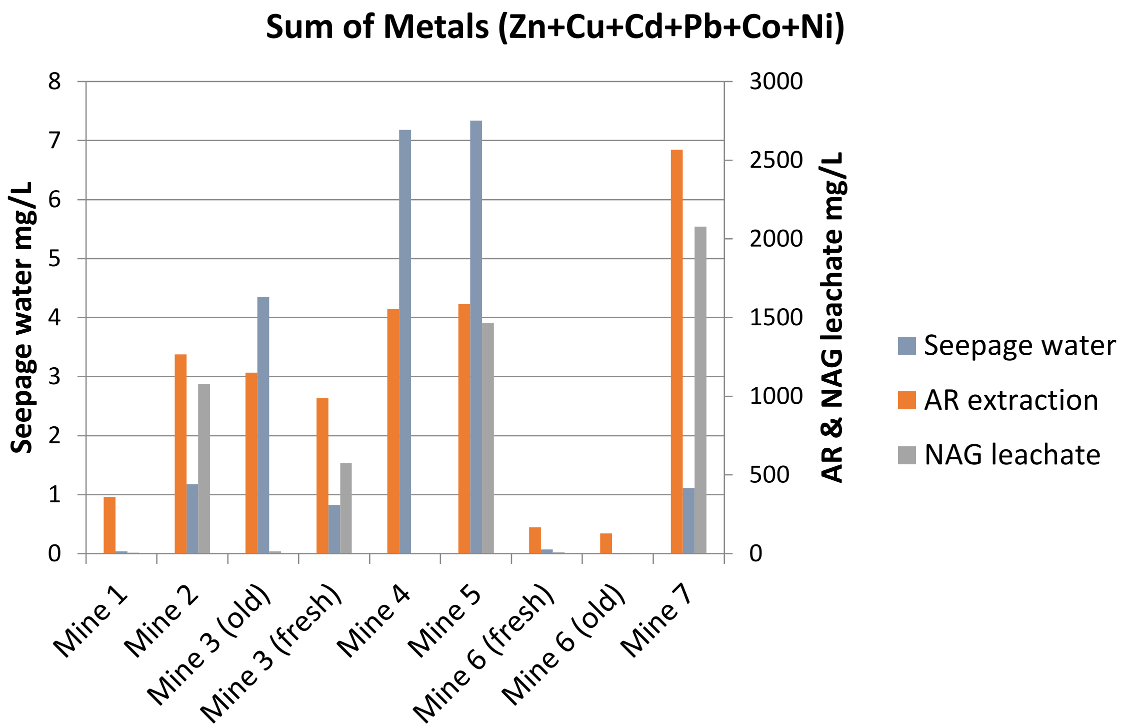

Figure 1 *The sums of dissolved heavy metals in the extracts from the NAG test and the Aqua Regia leach, and in the waste rock seepage waters.*

The *Aqua Regia* extraction seems to have the best correspondence with the elevated metal concentrations in the actual seepage waters. The NAG test leachate underestimated the metal load in the cases of sample Mine 3 (old) and Mine 4. In general, performance of the NAG leachate test was reasonable, but it underestimated the metal concentrations when the NAG leachate pH was higher than around 4, which is due to the precipitation processes (Räisänen et al. 2010, Charles et al. 2015).

The batch leaching test seems to be the most unsuitable for the seepage water quality prediction, as the results were mainly under the detection limit of the analytical method even though seepage waters showed elevated concentrations of trace metals. The solvent used in the batch leaching test (distilled water) is probably too weak and the reaction time too short for crystalline waste rock materials. Based on the results, elevated concentrations in any of the tests used in this study indicate a possibility for dissolution of trace metals from the rocks.

Interpretation of the results is complicated by the representativeness and weathering grade of the samples. Seepage water qualities should be monitored for a longer time period to detect the seasonal and annual variation in the quality.

Conclusions

Based on the results, the performance of the studied characterisation methods to predict acid rock drainage and metal leaching over time could be compared and evaluated. Differences were observed between the modified ABA and NAG tests predicting APP and the actual acidity of the seepage waters. The results indicated that the laboratory tests, especially the ABA test, were often too pessimistic in comparison with the real measured pH values at the mine sites. Therefore, the use of several different methods, together with mineralogical data, is recommended for comprehensive APP prediction.

According to the results of the different evaluated leachability tests, the hot *Aqua Regia* extraction had the best correspondence with the actual seepage water quality in predicting which elements will be present in the effluent waters. In general, performance of the NAG test leachate based test was reasonable, but it underestimated the metal concentrations when the NAG leachate pH was higher than around 4. The shake flask test was observed to be the most unsuitable for the effluent quality prediction, probably due to a weak solvent used in the test (water) and the too short reaction time for the crystalline waste rock material.

According to this study, the results obtained from the *Aqua Regia* extraction and NAG leachate based test can be used to predict the elements that will appear as elevated concentrations in the effluents, considering that the concentrations are only approximate, not exact, and that the pH of the NAG test leachate is sufficiently low. Elevated concentrations in any of the evaluated leaching tests indicate a possibility of increased element concentrations in the seepage waters.

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