Use of Exploration, Laboratory and Site-Specific Data for the Purpose of Mine Rock Classification, NICO Gold-Cobalt-Bismuth-Copper Project, Northwest Territories, Canada

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ABSTRACT

Mine rock classification criteria for rock with a high potential for acid generation and / or metal leaching are a key component of environmentally protective management practises. A rigorous mine rock management plan will account for the geochemical characteristics of mine rock in the context of existing site conditions, the proposed mine plan, and engineering concepts for mine rock and tailings deposition. The mine rock management plan is a living document, which should incorporate data from all stages of a project cycle to ensure that the plan's classification criteria are commensurate to site conditions during construction, operations and closure.

The proposed NICO Gold-Cobalt-Bismuth-Copper Project, owned by Fortune Minerals Limited, is located in the Northwest Territories, Canada. Site-specific mine rock classification criteria have been developed based on an evaluation of the results of the extensive dataset of exploration assay data, and the results of laboratory-based geochemical characterization of mine rock. Large-scale field tests were constructed at the Project site in 2008 to generate data to support the proposed operational classification criteria.

The objective of this paper was to determine simple, straightforward criteria that could be used to classify mine rock with a potential for acid rock drainage (ARD) and metal leaching (ML). After a thorough evaluation of the available laboratory and field testing data, mine rock classification criteria were established based on sulphide-sulphur content for acid rock drainage potential, and solid phase arsenic and bismuth concentrations for arsenic and selenium leaching potential, respectively. The mine rock classification criteria are an integral component of protective engineering designs and environmental management strategies for the NICO Project.

Key Words: Mine rock classification, environmental management, static testing, kinetic testing, field scale testing

INTRODUCTION

The Fortune Minerals Ltd.NICO Project (Project) contains approximately 31 million tonnes (Mt) of ore, 6.5 Mt of sub-economic mine rock and 90 Mt of mine rock, which will be developed over a proposed duration of 18 years. Mine rock will be used for the construction of site facilities at the Project. Rock with potential for acid rock drainage (ARD) and / or metal leaching (ML) will be stored in the mine rock and tailings co-disposal facility (CDF).The geochemical stability of mine waste is a key consideration in the development of operational and post-closure management strategies for the Project.

Mine rock classification criteria are required to properly design and construct a site, and reduce the effect of the Project at closure. Development of mine rock classification criteria is a typical requirement of the environmental permitting process for new mines, including for the NICO Project. Inputs to the site water quality predictions are also typically developed in consideration of how the mine rock classification criteria and placement will influence contact water quality or treatment requirements. An iterative approach is typically followed which allows for refinement and improvement of operational and post-closure management plans over time.

An extensive geochemical dataset, supplemented by the exploration assay data for the Project, formed the basis from which the mine rock classification criteria were developed. Laboratory-based static and kinetic tests formed the preliminary determination of the ARD/ML potential of each mine rock lithology. Field tests, which are ongoing, were then constructed to evaluate the site-specific ARD/ML potential of mine rock in site conditions.

SITE OVERVIEW

The Project site is located in the Northwest Territories, Canada. The Project site has rugged topography, with the ore zone located in a ridge of exposed bedrock, which slopes into a depression referred to as the "Bowl Zone". Very little overburden suitable for construction will be available during the early stages of construction and operation at the Project, therefore mine rock will be the main material used to construct Project infrastructure.

Underground mining methods will be used during the first 8 to 10 months of operations; however, the majority of the ore will be extracted using open pit mining methods. It is currently anticipated that a total of 97 Mt of mine rock will be produced. Only 1% of the mine rock produced during the Project life is required for construction purposes. The remainder of the mine rock will be co-disposed with flotation tailings in the CDF.

Mineral processing on site will produce a small amount of metallurgical concentrate that will be shipped off-site and flotation tailings that will be co-disposed with mine rock in the CDF. The perimeter embankments of the CDF will be constructed with mine rock that meets an appropriate mine rock classification criterion. In addition to the CDF, Project infrastructure requiring mine rock for construction includes roads, building foundations and water management structures. The mine plan was evaluated in the context of the mine rock classification criteria in order to determine the availability of materials for construction purposes.

At closure, the roads and project infrastructure will be gradually removed from the Project site. A closure cover will be constructed on the CDF to limit the infiltration of water through the co-disposed mine rock and tailings. The closure cover will either be constructed with overburden excavated during the Project life, or mine rock that has been prepared to the appropriate size specifications for the cover design.

GEOLOGY AND MINERALIZATION

An in depth understanding of the geology and mineralization of mine rock at the Project was a key component in the development of the mine rock classification criteria. Gold, cobalt, bismuth and copper mineralization occur in an iron oxide copper gold (IOCG) type, or "Olympic Dam" type deposit (Goad et al 2000). The deposit formed in response to metasomatism of sedimentary rocks. The metasedimentary rocks, including siltstone, wacke and ironstone (referred to as "black rock schist" (BRS)), are overlain by volcanic rocks (rhyolite). Quartz feldspar porphyry dykes cross-cut the metasediments and volcanic rocks. The main mine rock lithology at the Project is the BRS. The BRS mine rock is composed of biotite [$K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$], amphibole [$Ca_2(Mg,Fe,Al)_5Si_8O_{22}(OH)_2$], magnetite [$Fe_3O_4$], hematite [$Fe_2O_3$], feldspar [$KAlSi_3O_8$], chlorite and calcite [CaCO3]. Mineralized zones contain native bismuth, bismuth telluride, native gold and sulphide minerals such as pyrrhotite [FeS], pyrite [FeS_2], chalcopyrite [$CuFeS_2$], bismuthinite [Bi_2S_3], cobaltite [CoAsS], arsenopyrite [FeAsS]. The dominant sulphide minerals are pyrite, pyrrhotite, and arsenopyrite.

Ore is hosted in a 200 meter thick package of three subparallel zones of mineralization within the BRS. Gold mineralization is restricted to the Middle and Lower ore zones, and cobalt mineralization occurs throughout the Lower, Middle and Upper ore zones. Small lenses of mineralization also occur in the rhyolitic rock and altered quartz-feldspar porphyry dykes (Goad et al, 2000).

Metamorphic alteration and the resulting sequence of mineral formation in the NICO ore deposit controls the distribution, texture, and abundance of sulphide minerals. BRS is the product of the first stage of metamorphism, during which pyrite, pyrrhotite and magnetite were formed. The iron oxides formed during this stage comprise up to 20% of mineralized zones (Goad et al, 2000).Copper and gold mineralization was emplaced during the second stage of alteration. Copper was restricted to chalcopyrite and copper sulphosalts, and gold accumulated as native gold, and in association with bismuth telluride, bismuthinite and feldspar. Cobalt mineralization occurred during the third and fourth stages of alteration. Cobalt originally accumulated in cobaltite, which then reacted with metasomatic alteration fluids rich in arsenic. The result was the widespread precipitation of cobalt-rich arsenopyrite and bismuthinite. In the fifth, and final, stage of alteration, arsenopyrite became the primary sulphide precipitating from the metasomatic fluids. Bismuth mineralization, in particular, began in the second stage of alteration, with the formation of native bismuth and bismuth tellurides [Bi_2Te_3]. Bismuthinite crystallization occurred throughout the second, third, and fourth stage of alteration.

GEOCHEMICAL CHARACTERIZATION OF MINE ROCK

Over 300 samples of exploration drill core, surface outcrops and stockpiles of rock generated during the development of an underground exploration ramp were submitted for geochemical testing. The geochemical characterization program was developed iteratively, in response to the evolution of the Project. Geochemical characterization of mine rock is ongoing.

The ARD/ML potential from the various rock types has been evaluated using standard static and kinetic geochemical tests (MEND, 2009; INAP, 2009), including:

- Acid base accounting (ABA) (314 samples), by the Sobek method. Acid potential (AP) was calculated by multiplying the sulphide-sulphur content by the standard conversion factor of 31.25 (MEND, 2009).
- Trace metal analysis (314 samples), according to standard methods (ie, strong acid digest followed by inductively coupled plasma) (ASTM, 2001).
- Single addition net acid generation (NAG) testing (42 samples), according to the method proposed by AMIRA (2002).
- Short-term leach (STL) testing, by a variety of methods including comprehensive analysis of NAG leachates (22 samples), shake flask extraction (70 samples) (ASTM, 2006) and the synthetic precipitation leaching procedure (82 samples) (USEPA, 2002).
- Humidity cell tests (HCT) (12 samples), as per ASTM method D5744-07 (ASTM, 2007).
- Field cells (5 samples), constructed at the Project site using large volumes of stockpiled mine rock.

The results of static tests, including ABA, trace metal analysis, NAG testing and STL testing, were used to evaluate general ARD/ML characteristics of mine rock and ore. The results of HCTs were used to confirm the ARD/ML predicted by static testing, and to provide insight into the rates of mine rock reaction. Field cell tests were constructed to confirm the geochemical characteristics of rock in the climatic conditions at the Project site.

In addition to the geochemical dataset, over 17,000 samples were submitted for solid phase analysis during the various stages of the exploration stage of the Project. A total of 17,123 samples underwent total sulphur and comprehensive trace metal analysis, and 72 samples were submitted for ABA of which, 62 were analyzed for sulphide sulphur.

ACID GENERATION POTENTIAL

The acid generation potential of mine rock samples was assessed using the results of ABA, which were then confirmed using the results of HCT and NAG tests. A comparison of the total sulphur and sulphide sulphur content was performed, and it was found that sulphide sulphur was the main sulphur species in the samples collected for geochemical characterization. Sulphide minerals represent the main source of acid potential (AP) in mine rock at the Project. The range of sulphide sulphur concentrations in mine rock was less than 0.01 to 1.6%. At a screening level, most mine rock samples in the combined geochemistry and exploration datasets contained insufficient sulphide minerals to produce appreciable acidity (Figure 1). An evaluation of the available data identified a distinction between samples based on a sulphide sulphur content of 0.3%. Only 19% of the Mine Rock samples in the combined dataset contained greater than 0.3% sulphide sulphur. As to be expected, rock from the mineralized zones (including sub-economic mineralized mine rock and ore) had greater sulphide sulphur abundances, and a greater potential for acid generation (Figure 1).

Most mine rock contains little carbonate mineralization, which is the main source of neutralization potential. However, the sulphide concentrations of most mine rock samples were so low (ie, much less than 0.3% sulphide sulphur) that the potential for generating acidity was negligible. The NP of Mine Rock samples varied from less than 0 to 190 t $CaCO_3$ / 1000 t. The range of NP in mineralized mine rock and ore varied from 3 to 20 t $CaCO_3$ / 1000 t. The similarity of the median NP of mine rock, mineralized mine rock and ore was similar presumably controlled by the metamorphic overprint that also resulted in the mineralization in these rocks.

Samples that contained less than twice as much NP than AP (ie, an NP/AP ratio of less than 2) were considered to represent material with a potential for acid generation. An NP/AP ratio of less than2 is commonly used to distinguish potentially acid generating (PAG) from non-acid generating (non-AG) rock (MEND, 2009). A well defined trend was noted with respect to NP/AP and sulphide sulphur: samples with NP/AP ratios less than 2 typically contained greater than 0.3% sulphide sulphur (Figure 1). As illustrated in Figure 1, samples from BRS and ore have the greatest potential for acid generation. Relatively few volcanic, siltstone and dyke samples were PAG according to NP/AP ratio when considering sulphide sulphur content. The volcanics lithotype, which forms a volumetrically low proportion of the total amount of mine rock at the project, had a greater proportion of samples with an uncertain potential for acid generation according to the results of ABA. This is presumably a function of the carbonate poor groundmass of this rock type.

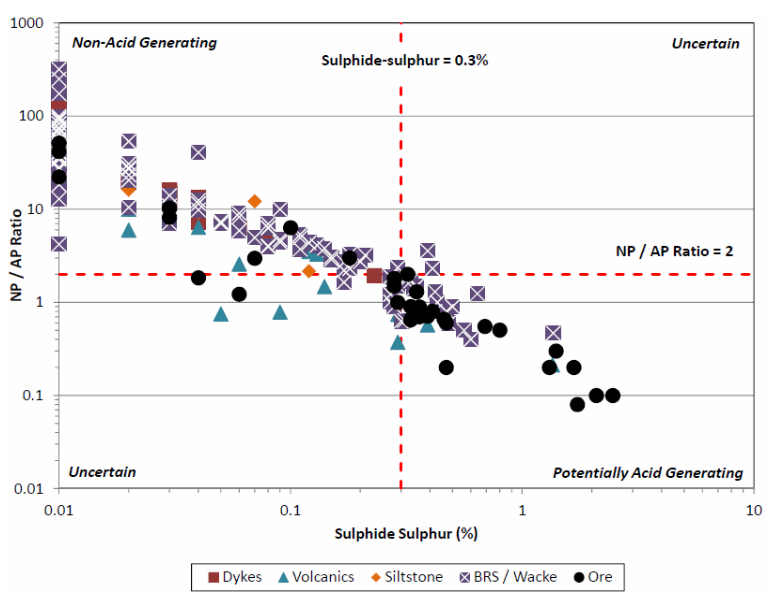

Figure 1. Comparison of NP/AP and sulphide sulphur concentrations.

The NAG test was used to confirm the acid generation potential inferred by the results of ABA. NAG testing was performed on a sub-set of samples in the geochemical dataset. The NAG test is a rapid, static test commonly used to rapidly oxidize all reactive sulphide minerals in a sample (AMIRA, 2002). The results of NAG testing were interpreted according to the criteria proposed in AMIRA (2002): samples with a NAG-pH less than 4.5 were classified as PAG, as a result of the lack buffering capacity relative to the acid generation potential of a sample.

Figure 2 compares the results of NAG testing to the NP/AP ratio and sulphide sulphur content of samples in the geochemistry dataset. Figure 2 illustrates that the NP/AP ratio, sulphide sulphur content, and NAG pH produce consistent results with respect to defining potentially acid generation potential for most samples.

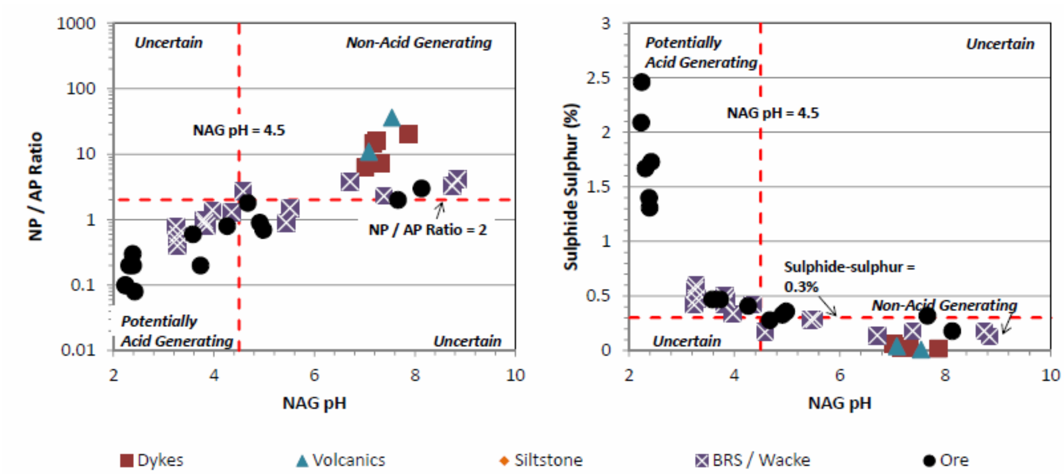

Figure 2. Comparison of NP / AP ratio and sulphide sulphur concentrations to NAG pH.

With the exception of the volcanics lithotype, the results of ABA and NAG testing clearly distinguished PAG from non-AG material. Based on the similarity of conclusions based on these results, it is considered reasonable to use either NP/AP or sulphide concentrations to distinguish PAG from non-AG material at the NICO Project. Some volcanics samples are classified as “uncertain” according to the results of ABA. This uncertainty was addressed through kinetic testing, and this lithological unit will be considered further as geochemical testing advances.

Laboratory and field scale kinetic tests were undertaken to establish rates of acid generation, acid neutralization and metal release from samples of mine rock and ore. Humidity cell tests are a widely used standard technique for simulating accelerated weathering in a laboratory setting. A total of 12 samples of mine rock were submitted for kinetic testing. The duration of the kinetic tests ranged from 40 to 169 weeks. Two of the samples had NP/AP ratios less than 2, and sulphide sulphur concentrations greater than 0.3% (Table 1). One sample was composed of rhyolite, and the other of BRS. Both samples generated acidic leachate pH values in the duration of the tests. Rates of sulphide depletion and NP depletion were calculated to determine the lag time to the onset of acidic conditions in the laboratory tests. The calculations show that for the samples with NP/AP ratios of greater than 2, sulphide minerals will be depleted prior to depletion of neutralization potential. It is therefore unlikely that acidic conditions would develop in the other 10 HCTs. With respect to rhyolite, three samples were tested. One sample, classified as non-AG according to ABA, generated acidity during kinetic testing. The other two samples, classified as non-AG according to ABA, did not generate acidity during the kinetic test.

Table 1. Summary of Acid Base Accounting Characteristics of Humidity Cell Tests and Field Tests

Test ID	Lithology	Humidity Cell Test (HCT) or Field Cell (FC)	Test Duration (Number of Weeks)	Sulphide-sulphur (%)	Neutralization Potential (t $CaCO_3$/1000 t)	Carbonate NP (t $CaCO_3$/1000 t)	NP/AP	Acid Generation Potential at Conclusion of Test
100859	Dykes	HCT	40	0.02	12	11	20	Non-acid generating
100913	Dykes	HCT	40	0.04	16	10	13	Non-acid generating
100863	Volcanics	HCT	169	<0.01	11	8	36	Non-acid generating
100932	Volcanics	HCT	169	0.5	0	1	0	Acid generation realized
100872	Volcanics	HCT	40	0.01	12	8	40	Non-acid generating
100925	Breccia	HCT	169	0.01	8.7	3	28	Non-acid generating
100890	BRS / Wacke	HCT	40	0.03	10.2	2	11	Non-acid generating
100977	BRS / Wacke	HCT	40	0.04	14	2	12	Non-acid generating
100802	BRS / Wacke	HCT	40	<0.01	28	4	90	Non-acid generating
100907	BRS / Wacke	HCT	169	0.3	10	2	1.2	Acid generation realized
100881	BRS / Wacke	HCT	40	0.02	17	8	27	Non-acid generating
100914	BRS / Wacke	HCT	169	<0.01	9.5	1	31	Non-acid generating
FC-1	Dykes	FC	Ongoing, initiated August 2008	0.02	12.7	8.3	20.5	Test ongoing
FC-2	BRS / Wacke	FC	Ongoing, initiated August 2008	0.2	12.8	8.9	2.3	Test ongoing
FC-3	BRS / Wacke	FC	Ongoing, initiated August 2008	0.3	13.9	5.5	1.5	Test ongoing
FC-4	BRS / Wacke	FC	Ongoing, initiated August 2008	0.3	14.5	2.9	1.4	Test ongoing
FC-5	BRS / Ore	FC	Ongoing, initiated August 2008	1.4	11.6	4.3	0.3	Test ongoing

The potential for acid generation of mine rock and ore is currently being evaluated using on-site field tests. The sulphide sulphur content of samples submitted for field testing ranged from 0.02 to 1.4%. Field tests were initiated in 2008; although many of the samples are considered PAG based on NP/AP ratio and sulphide sulphur content, acidic pH values have not yet been measured in the field cell leachates.

METAL LEACHING POTENTIAL

Based on the results of laboratory and field scale leach tests, metals are capable of leaching from Mine Rock (aluminum, arsenic, iron and copper) and sub-economic mineralized Mine Rock (aluminum, arsenic, cadmium, cobalt, copper, iron, molybdenum, antimony, selenium, uranium, and zinc) under both neutral and acidic pH conditions and required further consideration within the overall context of the Project. A detailed assessment of the solid phase association of these metals was required to better understand the factors that control metal leachability before criteria for mine rock management could be established.

A simple statistical analysis was performed to determine elemental associations in mine rock and ore for the purpose of identifying metals that could be used as indicators of metal leachability. The results of the statistical analysis show strong agreement between the trace metal abundances and the geologic description of the deposit. Based on this analysis, two key groupings of elements were identified: metals that are associated with sulphide mineralization, and elements that are associated with bismuth mineralization.

Cobalt, arsenic, nickel and copper occur in association with base metals sulphides. Metal sulphides are ubiquitous in mineralized rock at the NICO Project. Arsenic is associated with both arsenopyrite and cobaltite. The occurrence of arsenopyrite is widespread throughout the ore deposit. Cobaltite, however, is found in zones of high grade gold mineralization. Arsenic is released by the oxidation of arsenic-bearing sulphide minerals.

Selenium and antimony are associated with bismuth mineralization. Although selenium minerals were not identified by the mineralogical analysis conducted during the exploration stage, the solid phase correlation between selenium and bismuth suggests an association with bismuth mineralization. Bismuth selenide is commonly associated with bismuth ore deposits. The incorporation of tellurium in bismuth selenide can result in the formation of bismuth telluride, one of the main bismuth minerals present at the Project (Marcoux et al, 1996). Selenium-bearing mineralization is concentrated in mineralized zones within the BRS. Selenium is released by the dissolution of selenium bearing bismuth minerals.

After elemental associations of key metals of concern were established, a detailed evaluation of metal leaching characteristics relative to a samples lithology and mineral association was undertaken. The results of laboratory-scale and field scale geochemical leach tests were compared to solid phase metal concentrations to identify parameters that could be used to characterize a sample's potential for metal leaching.

The correlation of leachate concentrations of cobalt, copper, nickel and zinc with solid phase metal concentrations was not well defined. The rate of release of these metals is not linear with respect to solid phase concentrations, suggesting that metal solubility could be affected by secondary processes influenced by the conditions in which the geochemical tests were conducted. Specific criteria were not established for these metals, owing to the poor correlation between solid phase and leachate correlations. This evaluation concluded that, in general, high leachate concentrations of cobalt, copper, nickel and zinc occurred in samples with elevated sulphide content.

Leachate concentrations of arsenic correlated well with solid phase arsenic concentrations. Figure 3 compares solid phase concentrations of arsenic to leachate concentrations measured in a range of geochemical test results. The results of geochemical testing were used to represent conditions that could be realized at the NICO Project, including rapid flushing of solid phase samples during precipitation events (ie, shake flask extraction and synthetic precipitation leaching procedure leachates), metal release in oxidizing conditions (analysis of NAG leachates), and longer-term metal leaching trends under laboratory (kinetic tests) and site conditions (field cells). Leachate concentrations are compared with background concentrations in receiving water (ie, the Grid Ponds, NICO Lake and Peanut Lake), represented by the horizontal coloured lines in Figure 3. The Grid Ponds, which receive drainage from the ore zone, contain naturally elevated concentrations of arsenic. Flow from the Grid Ponds enters Nico Lake, which also has elevated concentrations of arsenic relative to the site specific water quality objectives. The site specific water quality objective identified in Figure 3 was designed to be protective of aquatic life.

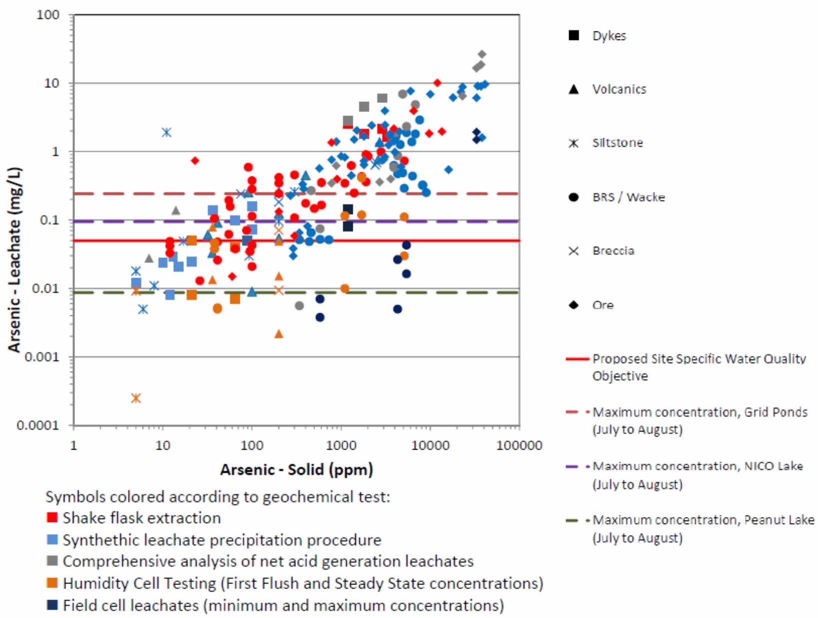

Figure 3. Comparison of leachate and solid phase arsenic concentrations.

Selenium concentrations in geochemical test leachates had a reasonable correlation with solid phase concentrations of selenium. However, selenium concentrations also correlate well with the extensive bismuth dataset for the Project (Figure 4). Selenium concentrations were less than the analytical detection limit in many samples collected outside the mineralized zones. Samples collected within the mineralized zones had higher solid phase concentrations of selenium and bismuth, and a higher potential for selenium leaching.

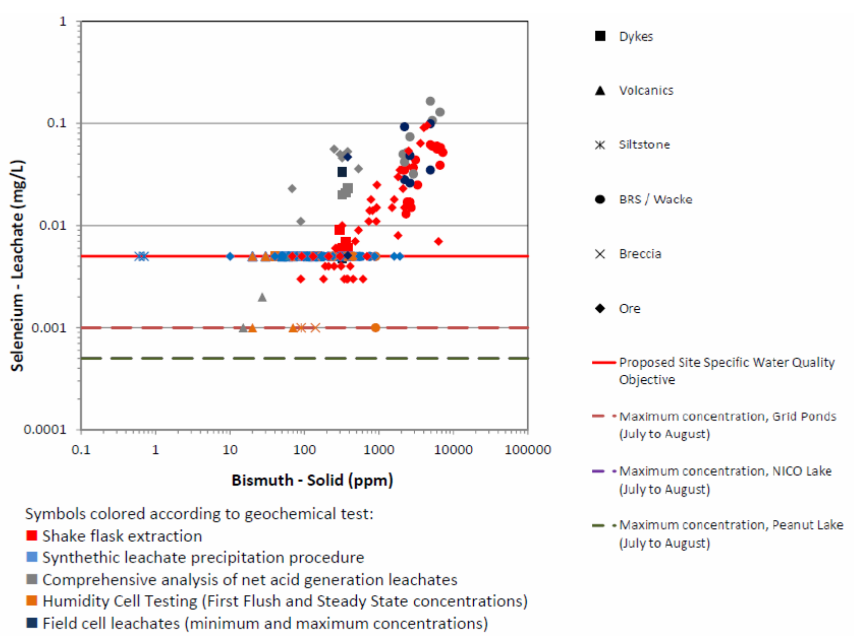

Figure 4. Comparison of leachate selenium concentrations and solid phase bismuth concentrations.

GEOCHEMICAL CRITERIA FOR MINE ROCK MANAGEMENT

After careful consideration of the results of geochemical characterization, mine rock classification criteria were established based on the following considerations:

- Rock containing sulphide mineralization greater than 0.3 percent by weight has a high potential for acid generation, and should not be exposed to water or oxygen for extended periods of time; and,
- The site specific key metals (ie, selenium and arsenic) are capable of mobilizing in neutral and acidic mine water; and,
- Owing to the nature of the ore deposit, rock with a high metal leaching potential may not have a high potential for acid generation. However, as discussed below, most samples with a high potential for acid generation have a high potential for metal leaching.

Several parameters were considered for use as criteria for acid generation potential, including NP/AP ratio, sulphide-sulphur content and NAG pH:

- Determination of the NP/AP ratio involves the separate measurement of AP and NP. AP is typically calculated based on the sulphide sulphur content, and NP is measured by titration. An NP/AP ratio of 2 is then used to classify PAG rock. However, the measurement of NP/AP ratio can take more time and resources than other methods of determining the potential for acid generation.
- Sulphide sulphur content is the primary source mineral contributing to acid generation, metals and sulphate in mine rock. Sulphide sulphur concentrations can be measured quickly and reliably on-site using a Leco furnace. On-site measurement of sulphide sulphur is one of the most common methods used for operational classification of mine rock (MEND, 2009).
- Lastly, the NAG test is a rapid method of measuring acid generation potential by completely oxidizing all sulphide minerals in a sample using hydrogen peroxide. This method relies on an estimation of whether the reaction is complete. Incomplete reaction or overly aggressive reaction of the sample can result in erroneous estimations of NAG pH, particularly in carbonate deficient, trace sulphide materials.

Based on a review of these methods and the measured results, sulphide sulphur content was selected as the primary criterion to determine acid generation potential. The acid generation potential predicted by NP/AP ratio, sulphide sulphur content and NAG testing agrees reasonably well. A sulphide sulphur cut-off of 0.3% was selected for the purpose of identifying PAG rock. Rock containing greater than 0.3% sulphide sulphur has a confirmed potential for acid generation based on the results of NAG tests and long-term HCTs. Measurement of sulphide sulphur concentrations is the most rapid method of the three parameters considered for classifying PAG rock. This criterion will allow for the classification of PAG rock at a schedule amenable to the rate of mining at the Project, which is a key consideration with respect to construction and short-term mine planning. Sulphide sulphur concentrations were available for 293 samples in the combined dataset. A total of 81% of the available dataset contains less than 0.3% sulphide sulphur

Classification of metal leaching potential was not straightforward. For example, arsenopyrite (ie, the main source of arsenic) is disseminated throughout the deposit. Cobalt and selenium-bearing minerals tend to be concentrated in mineralized zones. As demonstrated in Figure 5, PAG rock (represented by samples that contain greater than 0.3% sulphide sulphur) does not necessarily have a high potential for leaching arsenic and selenium, two of the main metals of concern. The criterion for acid generation potential is not sufficient for predicting metal leachability. However, the correlations presented in Figures 3 and 4show that solid phase metal concentrations are reliable indicators of arsenic and bismuth leachability.

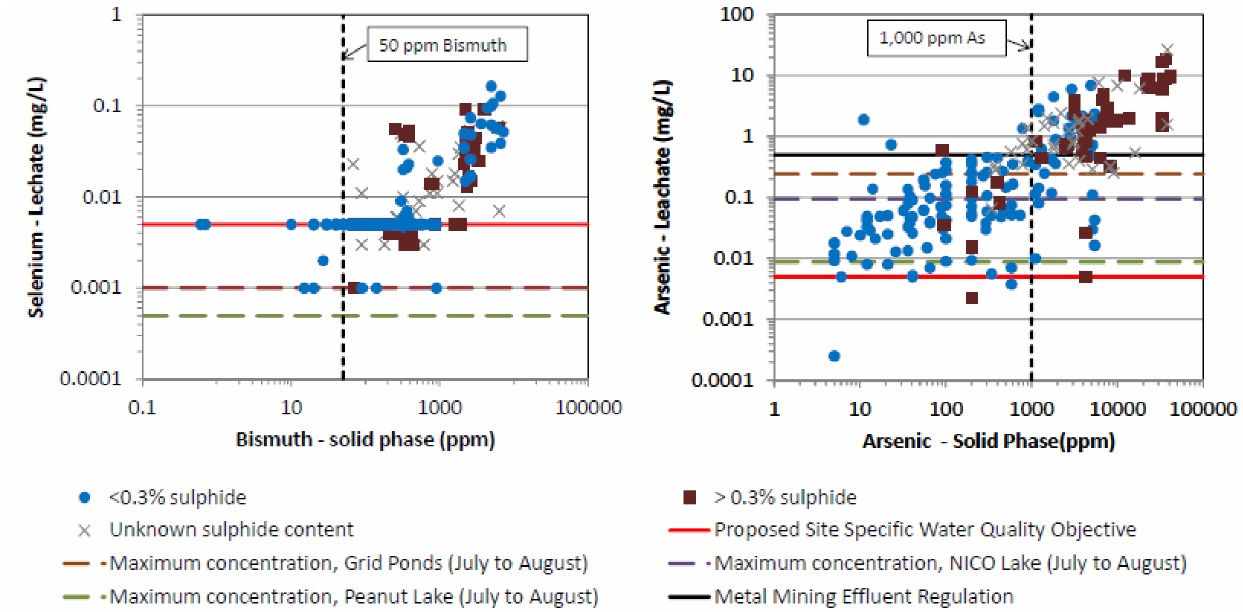

Figure 5 Acid generation and metal leaching criteria for the NICO Project

The criteria for metal leaching were selected by comparing solid phase concentrations to the range of concentrations measured in variety of geochemical test leachates. The criteria developed using this approach account for the range of conditions represented by the geochemical leaching tests. Site specific field tests are underway to evaluate the effects of climate on the rate of reaction of mine rock.

As presented in Figure 5, a solid phase concentration of 1,000 ppm arsenic can be used to identify rock expected to leach arsenic at concentrations lower than the Metal Mining Effluent Regulations (MMER) average monthly criterion for arsenic (0.5mg/L) and background concentrations in the Grid Ponds. The intention of this criterion is to mimic the concentrations of arsenic in runoff in existing site conditions. Runoff that enters the Grid Ponds is subsequently naturally diluted prior to reaching downstream receiving water bodies. Solid phase arsenic concentrations were available for 6,921 samples in the combined dataset; 48% of the available samples contained less than 1,000 ppm arsenic.

Solid phase and leachate selenium concentrations correlate well with bismuth. The solid phase selenium dataset is limited in size in comparison to the bismuth dataset. Therefore, it was proposed that bismuth concentrations be used to distinguish rock with a selenium leaching potential. A criterion of 50 ppm bismuth is considered reasonable for use in distinguishing rock with a low selenium leaching potential (Figure 5). All samples with measurable selenium concentrations in geochemical test leachates contain greater than 50 ppm bismuth.

APPLICATION OF MINE ROCK CLASSIFICATION CRITERIA

The mine rock classification criteria will form the basis for use of construction materials at the Project. Less than 1% of the mine rock produced during mining will be used for construction. The remainder of the mine rock will be placed within the CDF. The mine rock classification criteria were used to develop a decision matrix for mine rock management (Table 2).

Table 2. Decision Criteria for Mine Rock Management

Classification	Criteria	Description
Cover Construction Material	Glacial till / sand	Cover construction material with a low potential for acid generation and metal leaching, and the required grain size characteristics to meet the objectives of the closure cover.
Type 1	< 0.3 % sulphide sulphur < 50 ppm bismuth < 1,000 ppm arsenic	Rock with a low potential for acid generation and metal leaching to be used for construction of surge pond dams, seepage collection pond dams, roads, rock pads and lay down areas.
Type 2	< 0.3% sulphide sulphur < 1,000 ppm arsenic	Rock with a low potential for acid generation, to be used for construction of perimeter dykes within the CDF.
Type 3	> 0.3% sulphide sulphur > 50 ppm bismuth > 1,000 ppm arsenic	Potentially acid generating and metal leaching rock, to be contained within the CDF.

It is expected that proper use of the proposed Mine Rock management criteria, in combination with a rigorous operational management plan during construction and operations, will help limit the potential for acid generation and metal leaching from major site infrastructure. Based on the available information, it is considered that the Mine Rock classification criteria are suitable for the classification of acid generation potential and metal leaching potential in most samples in the range of conditions that could be encountered during construction, operations and closure.

CONCLUSIONS

Geochemical classification criteria were developed using an extensive dataset of exploration assay data, ABA, solid phase metal analysis, short-term leach tests and kinetic tests. The geochemical classification criteria forms the basis of the mine rock classification decision matrix, which is expected to be used to control the use of ARD/ML mine rock during the Project life cycle.

The development of the mine rock classification criteria demonstrate that it is necessary to evaluate all of the available data, including exploration data, to determine appropriate management thresholds. Detailed analysis may yield representative criteria that allow for measurement of surrogate parameters that can be more effectively screened on a operational level; for example, the use of sulphide sulphur rather than NP/AP ratios to represent AG potential, or the use of bismuth concentrations as an indicator of selenium leaching potential. Management criteria should account for the acid generation potential of mine rock, as well as the metal leaching potential of mine rock in neutral conditions.

Geochemical characterization of mine rock is an iterative process, which will continue throughout the Project. The proposed mine rock classification criteria will be verified, and if necessary, revised based on actual conditions encountered at the Project. Furthermore, the proposed criteria will continue to be tested using large scale geochemical leach tests that have been constructed at the Project site for the purpose of confirming the rate of reaction of each rock type in site conditions. This approach allows for ongoing refinement of management and closure plans for the Project in a practical and environmentally protective manner.

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ACRONYMS

ARD	Acid rock drainage
BRS	Black rock schist or ironstone (metasedimentary rock)
CDF	Co-disposal facility
IOCG	Iron oxide copper gold type deposit
HCT	Humidity cell test
ML	Metal leaching
NAG	Net acid generation testing
Non-AG	Non-acid generating
PAG	Potentially acid generating
STL	Short term leach