

PREDICTION AND REALITY: STATIC ANALYSES VERSUS ACTUAL ROCK WEATHERING IN WASTE DUMPS AT ISLAND COPPER MINE, PORT HARDY, B.C.

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ABSTRACT

Island Copper Mine (ICM), owned by BMP Minerals Canada Ltd. is one of Canada's largest open pit low-grade copper mines and is located at the north end of Vancouver Island, British Columbia.

Acid rock drainage (ARD) was first detected in the open pit area in 1982, and from the on-land waste rock dumps in 1985. All drainage from the mine area is directed to a water management pond for recycling in the concentrator and discharge when all provincial effluent standards are met.

Island Copper is a calc-alkaline copper-molybdenum-gold porphyry deposit. Rock units have been both metasomatically (contact metamorphism) and hydrothermally altered. Minerals relevant to ARD-generating potential include pyrite, feldspar minerals, calcite, sericite and pyrophyllite.

Data analysis of 214 acid-base accounting (ABA) results indicate that most ICM waste rock has a net neutralization potential (NNP) of less than +20 kg H₂SO₄/tonne, and an acid consuming to acid producing (ACPAP) ratio of less than 3:1.

Detailed study of eight weathered samples from ICM waste rock dumps indicate that type and intensity of alteration coupled with total sulphur content may be the primary ARD controls at the site. Two of the six samples (both weakly altered volcanic) predicted by ABA analysis to generate net acidity have yet to do so despite up to 12 years of weathering on the waste rock dumps.

INTRODUCTION

In recent years in British Columbia, acid-base accounting (ABA) analyses have become an unproclaimed industry standard for inexpensively determining acid rock drainage (ARD) potential of rock. Although not intended to be used as a stand-alone tool for ARD prediction, many waste rock management decisions are based on the result of this test alone. In this discussion, actual weathering behavior of Island Copper Mine waste rock is compared with corresponding ABA results. Major ARD controlling factors other than those evaluated by ABA testing are also proposed.

Island Copper Mine

Island Copper Mine, owned by BMP Minerals Canada Ltd. (formally BHP-Utah Mines Ltd.), is one of Canada's largest open pit, low-grade copper mines. The mine is located at the north end of Vancouver Island about 16 kilometres south of the town of Port Hardy, on the north shore of Rupert Inlet. Mining commenced in 1971, and with current reserves is expected to continue until 1996.

In 1982, water permeating through parts of the west pit wall showed pH values as low as 3.5. In 1985, seepages from one of the on-land waste rock dumps were found to contain elevated zinc levels which prompted the establishment of an extended monitoring network and the finding of a few areas of the dump where sulphide minerals in the waste rock were oxidizing and producing acidic, metal-contaminated, drainage (ARD). Currently, seepage emanating from the on-land waste dumps and pit area is collected by a system of drainage ditches and culverts which direct the water to a water management pond where it is treated and then recycled through the concentrator as process make-up water. Excess water in this pond is released into Rupert Inlet when all effluent standards prescribed in the permit are met.

Island Copper Mine has conducted and funded considerable research in prediction and monitoring of ARD from waste rock. This includes over 500 acid-base accounting analyses, intensive water quality and hydrological monitoring, and most recently, kinetic test work on selected waste rock material from the North dump, the largest on-land dump at the mine.

Island Copper Geology

Island Copper is classified as a calc-alkaline copper-molybdenum-gold porphyry deposit (Ney and Hollister, 1976). Ore minerals (chalcopyrite and molybdenite) occur with pyrite in breccia and fracture stockworks immediately adjacent to an approximately 350 m wide steeply dipping quartz feldspar porphyry dyke which intrudes Jurassic andesitic to basaltic pyroclastic Bonanza Volcanics.

As is typical for a porphyry-type deposit, rock units have been altered in various degrees by thermal (contact) metamorphism from the original intrusion, and by later hydrothermal action associated with emplacement of ore minerals.

Contact metamorphism affects only the host volcanic and forms three distinct zones; the inner, characterized by biotite and magnetite, the middle transitional zone by chlorite, and the outer by epidote (Cargill, 1975).

Hydrothermal alteration affects host volcanics, porphyry, and breccias, and is characterized by replacement of original minerals by sericite, pyrophyllite, kaolinite, and quartz. The most intense alteration generally occurs in marginal breccias at porphyry-volcanic contacts and in envelopes surrounding quartz veins and open fractures.

Island Copper Mineralogy

Minerals relevant to waste rock ARD potential at Island Copper include pyrite, feldspar minerals, calcite, sericite and pyrophyllite.

Pyrite is the most abundant sulphide mineral and occurs both within and outside of the ore zone in 0.5 to 2 mm euhedral cubes, and generally ranges from 2 to 5 but occasionally up to 15 areal percent. Within the ore zone, pyrite occurs with chalcopyrite and molybdenite on fracture surfaces and within chloritized mafic minerals. In the porphyry dyke, pyrite occurs as a finely disseminated accessory mineral, and in the Bonanza Volcanic units occurs along fractures and disseminated in the rock groundmass (Cargill 1975).

Feldspar in the form of sodic (=An₂₅) plagioclase phenocrysts and ground mass accounts for about 70 percent of the non- or weakly altered Bonanza Volcanic pyroclastic rock, and at least 20 percent of the quartz-feldspar porphyry. Approximately 20 percent potassium feldspar is also present in the matrix of the quartz-feldspar porphyry. In weak to strong alteration zones, plagioclase is replaced by sericite and kaolinite.

Calcite generally occurs as an accessory mineral at Island Copper and does not comprise a significant portion of the rock mass. It is most frequently found on fractures with quartz veins, and occasionally within rock groundmass as an alteration product of mafic minerals (Cargill, 1975). Other minor carbonate minerals at Island Copper include ferroan dolomite and ankerite.

As discussed above, sericite occurs as an alteration product of plagioclase. The most intense sericite replacement occurs proximal to the ore body (both in volcanic and porphyry units). Unless highly silicified, sericitized rocks are generally much less competent than their unaltered counterparts, and commonly contain elevated amounts of pyrite.

Pyrophyllite-altered breccia caps the porphyry dyke at the northwest end of the deposit, and is seen in significant quantities in the waste dump. The rock tends to be soft, weathers to a clayey talc, and is usually associated with only trace amounts of pyrite.

ACID-BASE ACCOUNTING

Acid-base accounting (ABA) analysis is the most common "static" method of determining the balance between potentially acid-generating and acid-neutralizing minerals. If potential acidity exceeds neutralization potential, net acidity (ie. ARD) can theoretically be generated at some point in time (Steffen, Robertson, and Kirsten (SRK), 1989). Static tests cannot predict future quality of drainage. In addition, tests are conducted on small amounts of pulverized rock, eliminating critical ARD-influencing factors such as mode of occurrence of various acid-generating and neutralizing minerals.

Kinetic testing involves weathering rock under experimental conditions and monitoring changing leachate and rock quality over time for evidence of acid generation. These tests are expensive and time consuming (months to years), and are usually performed on select samples "shortlisted" from static-tested waste rock.

ABA: General Procedure

The method of ABA analysis was first documented by Sobek et al. (1978) and was initially conducted on sulphidic coal refuses in the Appalachians. The analysis is done on a small amount of pulverized rock sample and consists of two components: acid consuming potential (ACP) and acid producing potential (APP). ACP determination involves adding a known amount of hydrochloric acid to 2 grams of sample, and allowing the neutralizing reactions to go to completion. In Sobek's original procedure (the "hot" acid procedure), the sample and acid mixture are heated to nearly boiling, while in a more recently amended "cold" acid procedure, the sample and acid mixture is kept at room temperature. Once the reaction is complete, the solution is titrated with base to pH 7.0 to determine the amount of acid consumed by the pulverized rock. This is usually expressed as kg CaCO₃ per tonne of rock (kg CaCO₃/t) or kg H₂SO₄/t. APP is determined through total sulphur analysis of the sample using a Leco furnace, then

converting to kg CaCO₃/t by multiplying weight percent sulphur by 31.25 (or 30.63 for kg H₂SO₄/t). These factors have been stoichiometrically determined from oxidation and neutralization reactions of the most common sulphide mineral, pyrite (FeS₂).

Once ACP and APP are determined, the sample's net neutralization potential (NNP) is calculated by taking the difference between ACP and APP. A positive NNP indicates that there is an excess of neutralizing potential in the sample, while a negative NNP signifies that there is insufficient neutralizing capacity in the sample for the amount of sulphide present.

Paste pH is also commonly determined when an ABA analysis is performed. This simple procedure involves making a 2 to 1 sample to water mixture and recording its pH. A low paste pH (below 4.0) indicates that significant acid products have already accumulated in the sample.

Problems With Acid-Base Accounting Analysis

The ABA procedure has been criticized in several respects. Use of the "hot" ACP procedure can overestimate ACP by likely allowing participation of acid-consuming minerals that would not normally be activated at ambient temperatures. Morin (1990) noted that the 31.25 multiplication factor commonly adapted for calculating APP would be grossly inappropriate if for example manganese replaced oxygen as the pyrite oxidant (125.00 factor), or chalcopyrite rather than pyrite was the major sulphide mineral (15.63 factor). Cravotta et al (1990) recommended that the total weight percent sulphur be multiplied by 62.50 rather than 31.25 to derive the APP in kg CaCO₃/t, because the most probable end product of carbonate neutralization to neutral pH is HCO₃⁻ rather than gaseous CO₂.

Another problem with ACP determination has been proper selection of acid strength for each test. Too strong an acid will cause acid consumption by otherwise non-neutralizing minerals, resulting gross overestimation of ACP. Conversely, insufficient acid will not drive a reaction to completion. To select proper acid strength, the "fizz test" must be performed on each sample. This is a highly subjective test involving dropping 10% HCl onto a small amount of sample and rating the reaction intensity. A high ranking "fizz" requires high strength acid for ACP determination, while little or no fizz is assigned a weaker strength. Selection of proper acid strength is critical to accurate ACP determination, and has in some cases resulted in significant error.

The ABA analysis method has generally been recognized to fall short in prediction of samples with NNP values close to zero. Samples with NNP values of between +20 and -20 are usually classified as "maybe" in terms of ARD generating potential, and usually then subject to kinetic tests. Considered equally important as NNP is the ACP to APP (ACP:APP) ratio; a ratio of greater than or equal to 3 to 1 is considered to have no potential for ARD, while a sample with less than a 3 to 1 ratio may or may not be a future acid generator, again requiring kinetic testwork.

ACID-BASE ACCOUNTING AT ISLAND COPPER

Approximately 560 acid-base accounting analyses have been performed on Island Copper waste rock since 1982.

Upon discovery of acidic seepage in the pit area, 11 samples of various waste rock types were submitted for ABA analysis. As part of the South Wall Pushback project study in 1988, a large-scale sampling program (approx. 350 samples) was conducted on core from drillholes penetrating the south pit wall (BHP-Utah, 1988). Li (1990 and 1991) reported results of 170 ABA analyses from the North and Northwest on-land dumps, as well as the Beach Dump.

In order to demonstrate general ABA characteristics for Island Copper waste rock, ABA results of 214 samples from the South Wall Pushback study were correlated with their rock types and alterations.

Analyses include ACP and APR; no paste pH measurements were done. Samples were assigned a rock type, and alteration type(s) and intensity. In addition, carbonate and pyrite contents were also assigned.

Acid-base accounting characteristics of the 214 sample data set are given in tables 1 and 2.

Table 1. NNP Characteristics of South Wall Pushback Waste Rock

| NNP (kg H ₂ SO ₄ /t) | Number of Samples | Percentage of Total Samples |
|--|-------------------|-----------------------------|
| > 20 | 48 | 22.4 |
| ≤ 20 and ≥ 0 | 78 | 36.4 |
| < 0 and ≥ -20 | 39 | 18.2 |
| < -20 | 49 | 22.8 |
| | 214 | 100.0 |

Table 2. ACP:APP Characteristics of South Wall Pushback Waste Rock

| ACP : APP | Number of Samples | Percentage of Total Samples |
|-----------------|-------------------|-----------------------------|
| ≥ 3:1 | 77 | 40.0 |
| < 3:1 and ≥ 1:1 | 49 | 22.9 |
| < 1:1 | 88 | 41.1 |
| | 214 | 100.0 |

The data set was then subdivided into three major rock type categories:

- 1) breccias, faults, and units altered beyond rock type recognition (46 samples)
- 2) Bonanza Volcanic tuffs, porphyries, and undifferentiated units (151 samples)
- 3) intrusive quartz-feldspar porphyry (17 samples)

Since ABA analyses show a log-normal distribution, ACP, APR and ACP:APP values were log-transformed and geometric means and standard deviations calculated. Results are shown in Table 3.

Table 3. ABA Characteristics of South Wall Pushback by Rock Category

| Parameter | ACP (kg H ₂ SO ₄ /t) | | | APP (kg H ₂ SO ₄ /t) | | | ACP : APP | | |
|---------------------|--|------|------|--|------|------|-----------|-------|-------|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Geometric Mean | 24.2 | 24.0 | 14.2 | 12.5 | 14.3 | 11.2 | 1.93 | 1.68 | 1.27 |
| Geometric Std. Dev. | 1.6 | 1.8 | 2.5 | 1.6 | 3.8 | 3.7 | 4.04 | 3.89 | 4.06 |
| Minimum Value | 7.8 | 5.2 | 2.9 | 2.0 | 2.0 | 2.0 | 0.18 | 0.06 | 0.05 |
| Maximum Value | 89.0 | 90.6 | 81.7 | 83.2 | 99.4 | 82.0 | 15.15 | 32.00 | 18.80 |

It is observed from Tables 1 and 2 that over 75 percent (77.6) of the South Wall Pushback samples have an NNP of less than +20 kg H₂SO₄/t, and 64 (22.9 plus 44.1) percent have an ACP:APP ratio of less than 3:1. Therefore, a significant amount of Island Copper waste rock is categorized as "maybe" or "yes" in terms of ABA methods of acid rock drainage prediction.

Rock units demonstrate a wide range of ABA results, as illustrated by the geometric standard deviations in Table 3. Quartz-feldspar porphyry units tend to have the lowest NNP values (approx. +3 kg H₂SO₄/t) and the lowest ACP:APP ratio (1.27). Few conclusions can be drawn from analysis of alteration, carbonate content and pyrite content data, due to insufficient number of data points for various alteration intensities.

WASTE ROCK WEATHERING AT ISLAND COPPER

General Observations of Weathering

At Island Copper waste rocks with apparently similar sulphide contents and neutralizing capacity can have markedly different weathering behavior. In the North dump (last active dumping 1985) the only rock type currently producing acid is the strongly sericitized, pervasively pyritic, and weakly to moderately silicified volcanic and porphyry units. The matrix of this material appears to break down much more rapidly under atmospheric conditions than less altered rock. Conversely, waste rock that is only weakly altered (eg. epidote-chlorite) with significant sulphide content generally shows negligible ARD generation and little apparent physical breakdown in its 8+ years in the dump. Thus based on field observations alone, it appears that degree of alteration is a major controlling factor in ARD generation at Island Copper (Lister, 1992).

Weathering Study Procedure

Eight samples from waste rock dumps at Island Copper were selected to i) assess prediction "accuracy" of ABA analysis, and ii) more systematically study the relationship between degree of alteration and acid generation potential. Samples each consisting of 2 to 5 rocks of the same rock type were collected during visits to the mine site in May and September 1992. Selection was based in part on obtaining representation of each major rock and alteration type, as well as representation of both acid-generating samples and non-acid generating samples with significant sulphide mineral content.

Samples were first identified and photographed. One rock from each sample was cut with a rock saw so that rock type and alteration could be confirmed by Island Copper staff and HCl reactivity could be tested.

Carbonate content in fractures, rock matrix and fragments (if breccia or pyroclastic rock) of each sample was qualitatively evaluated by determining reactivity to a 10% HCl solution.

Surface pH was measured to ascertain if the sample was generating acidic leachate. This was done by brushing at least 1 gram of weathered product from the sample surface. The amount of accumulated weathering product was qualified based on the ease of obtaining sufficient sample for the test. The material removed was then passed through an 80 mesh sieve, and the -80 mesh portion weighed and transferred to a small vial. An amount of distilled water equal to one half of the product's mass was then added and the sample allowed to equilibrate for one half hour. PH of the 2:1 (sample:water) mixture was then measured in duplicate. If pH was 4.0 or less, the sample was deemed to be currently generating net acidity (SRK, 1989).

The rock samples were then washed with tap water to remove the majority of weathered product, and placed in a drying oven. Once dry, samples were crushed and pulverized. Paste pH, using a 10.00 gram sample : 5.00 gram distilled water mixture was then measured to approximate unweathered rock pH.

Acid-base accounting analysis of each sample was performed at the Island Copper Mine assay lab using the "hot" HCl ACP procedure. Total sulphur was determined through Leco and soluble sulphate analysis.

Results of the various tests performed are given in Table 4.

Discussion of Results

Figures 1 and 2 illustrate that two of the six samples predicted by ABA analysis to generate net acidity (samples 0016 and 0017) have yet to do so, despite up to 12 years of weathering on the waste dumps. Samples currently generating net acidity are moderately to strongly sericitized and contain at least 1.6 wt% total sulphur. Sample 0017, which is not currently generating net acidity, has 14.4 wt% total sulphur, but is not strongly sericitized. Conversely, sample 0020 has an NNP of close to zero ($-3 \text{ kg H}_2\text{SO}_4/\text{t}$), but is currently generating acid.

Some experimental errors are inherent with this type of retrospective study of weathering behavior, the most significant being the effect of weathered product accumulation on the rock mass. Although all visible surface weathering was washed and brushed from the samples before pulverizing, it is likely that all pulverized samples were contaminated to some degree with weathering product. Evidence of contamination is apparent in sample 0015, where the rock's "unweathered" pH was measured to be 4.0. To avoid contamination in future studies, it may be necessary to cut or grind off an outside "rind" of at least 1 cm from each sample before pulverizing.

CONCLUSIONS

Based on the results of this study and numerous field observations on the Island Copper waste rock dumps, type and intensity of alteration are dominant factors in ultimate weathering behavior. The "best" candidate rock type for generating net acidity appears to be one that is moderately to strongly sericitically altered and contains at least 1.5 wt% total sulphur.

These conclusions are supported by pit wall studies documented by Morin (1992). Of five wall stations of various alteration types and intensities, maximum sulphate loadings were generated in an area of sericite-chlorite \pm magnetite altered tuff. Hillis (1982) also proposed that plagioclase minerals significantly contribute to acid consumption at Island Copper, and that sericite-altered rock has low ACP due to the fact that sericite is a replacement mineral of plagioclase.

Further studies of ARD controls at Island Copper are continuing, which include further sampling, analyses and detailed mineralogical investigations.

It is hoped that this paper illustrates the need for consideration of more than just acid-base accounting when attempting to predict ARD. In developing mines with surface outcrops, a study of this type can easily be conducted and will generate important information for site-specific ARD controls. In addition, a tremendous amount of information could be gained by compiling similar rock weathering data from all mine sites (both with and without ARD) in British Columbia.

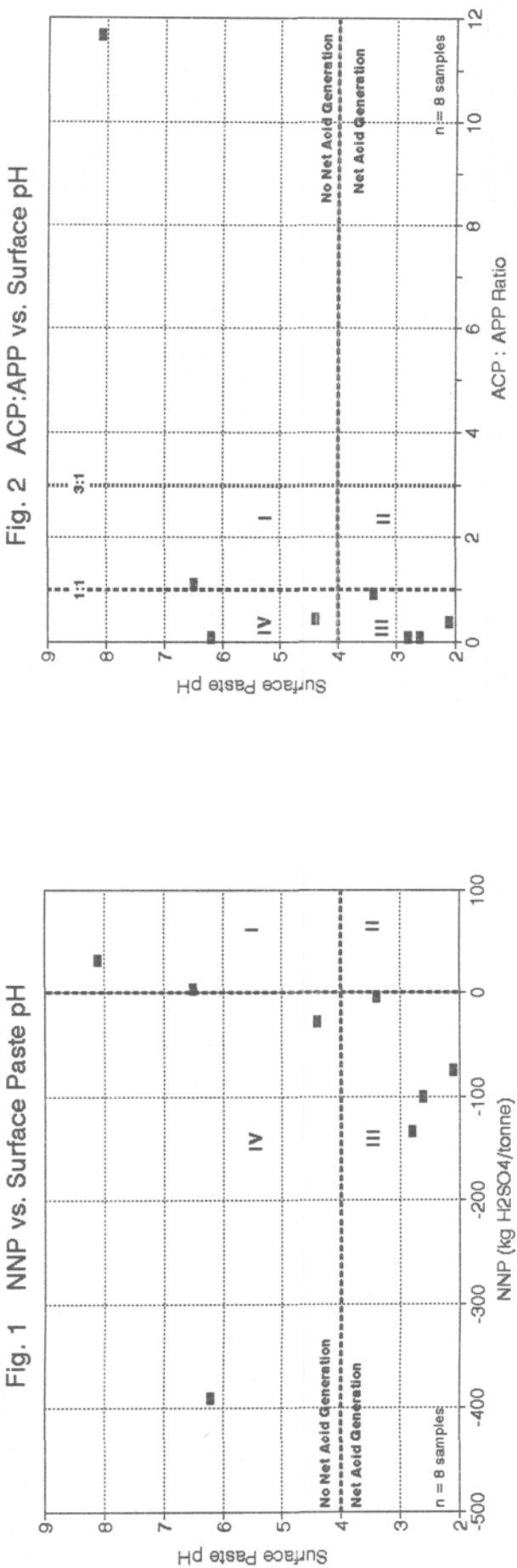
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Table 4. Results of Island Copper Waste Rock Weathering Study

| Samp # | Rock Type | Alteration | Yr. Mined | Paste pH | | Acid Gen.? | Amt. Weath. | HCl Reactivity | | | %S _{tot} | | ABA (kg H ₂ SO ₄ /t) | | | ACP: APP |
|--------|-----------|-------------------|-----------|----------|------|------------|-------------|----------------|----|-----|-------------------|--|--|-----|------|----------|
| | | | | Surf. | Rock | | | Mx | Fr | Frc | | | APP | ACP | NNP | |
| 0013 | BVAT | Str. Ep-Chl | 1984-85 | 8.1 | 9.4 | N | L | M | NA | H | <0.1 | | 3 | 35 | 32 | 11.67 |
| 0014 | PPQF | Mod. Ser | 1981 | 2.8 | 5.8 | Y | M | N | NA | W | 4.9 | | 147 | 14 | -133 | 0.10 |
| 0015 | BVBX | Str. Ser, Wk. Qz | 1984-85 | 2.6 | 4.0 | Y | M | N | N | N | 3.7 | | 111 | 11 | -100 | 0.10 |
| 0016 | BVAT | Str. Ep-Chl | 1981 | 4.4 | 8.6 | N | H | N | W | N | 1.6 | | 48 | 21 | -27 | 0.44 |
| 0017 | BVBX | Str. Chl | 1984-85 | 6.2 | 7.1 | N | L | N | NA | N | 14.4 | | 432 | 42 | -390 | 0.10 |
| 0018 | BVAT | Str. Chl-Mt | 1981 | 6.5 | 9.7 | N | L | W | W | S | 1.2 | | 36 | 40 | 4 | 1.11 |
| 0020 | BVAN | Str. Ser | 1989 | 3.4 | 6.5 | Y | L | N | NA | N | 1.6 | | 48 | 45 | -3 | 0.94 |
| 0021 | BVAN | Mod. Ser, Mod. Mt | 1972-75 | 2.1 | 5.8 | Y | H | N | NA | N | 4.0 | | 120 | 46 | -74 | 0.38 |

| Rock Type: | Weathering: | | | HCl Reactivity: | | |
|-------------|------------------------------------|---|---|-----------------|---|--|
| BVAN | Bonanza Volcanic, Undifferentiated | H | large amounts with brush | Mx | rock matrix | |
| BVAT | Bonanza Volcanic Tuff | M | sufficient product for analysis could be removed with brush | Frg | fragments | |
| BVBX | Bonanza Volcanic Breccia | | | Frc | fractures | |
| PPQF | Quartz-Feldspar Porphyry Dyke | L | difficult to obtain sufficient product for analysis | H | effervescence easily observed with naked eye | |
| Alteration: | | | | M | effervescence just visible with naked eye | |
| Str. | Strong | | | L | effervescence visible only under binocular microscope | |
| Mod. | Moderate | | | NA | not applicable (eg. rocks with no included fragments in matrix) | |
| Chl | Chlorite | | | | | |
| Ep | Epidote | | | | | |
| Mt | Magnetite | | | | | |
| Qz | Quartz | | | | | |
| Ser | Sericite | | | | | |



Figures 1 and 2.

ABA analysis results versus actual weathering behavior for eight selected samples from Island Copper waste rock dumps. Samples with a surface paste pH of less than or equal to 4.0 are designated as "net acid generating". Points falling in quadrants I and III indicate agreement between ABA prediction and ARD and actual weathering study, while points falling in quadrants II and IV indicate failure of ABA in predicting field ARD conditions to date.

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