PREDICTION OF ACID ROCK DRAINAGE

RED MOUNTAIN PROJECT, NORTHWESTERN BRITISH COLUMBIA

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ABSTRACT

A kinetic ARD prediction program was conducted for the Red Mountain project, located in northwest British Columbia, to provide the operators with more precise prediction data and thereby allow for a more cost effective and confident development of the waste management plan. Kinetic tests such as humidity cells are widely used in an attempt to predict the rates of acid generation and neutralization, water quality and time to onset of acidity. Laboratory kinetic tests at the University of British Columbia evaluated the effects of testing under various conditions. The laboratory test results were compared to 20-tonne (field) test results to evaluate scaling up of laboratory data.

Test results indicate that non-aerated cells provide rates of weathering that are similar to the standard humidity cell and that the results are more repeatable than humidity cell results. The laboratory rates of weathering could not be scaled up to predict field results with confidence. The inability to scale up the results is believed to be caused by inadequate hydrogeological assumptions and deficiencies in the experimental protocols.

INTRODUCTION

The Red Mountain gold-silver deposit is located in northwestern British Columbia. The existing reserve is 2.77 million tonnes assaying 8.15 grams of gold per tonne and containing 800,000 ounces of gold. The property is currently for sale since the owner, Royal Oak Mines Inc., was placed in receivership April 1999. Royal Oak purchased the property from Barrick Gold Corp. who had acquired the property through a takeover of all Lac Minerals Ltd. assets in 1994.

An extensive acid rock drainage (ARD) kinetic prediction program was conducted using samples from the Red Mountain deposit to evaluate the effects of testing under a variety of controlled conditions and to make predictions of waste rock weathering rates. Humidity cell tests are widely used to predict the rate of acid generation, rate of neutralization potential (NP) depletion, water quality, and the time until ARD is generated. A standard humidity cell is operated on a weekly cycle that is comprised of three days of dry air, three days of moist air, and a leach with distilled water on the seventh. Current leaching protocols include trickle-leaching, flooding then draining and, simulating precipitation by varying the frequency of leaching and the volume of rinse water applied. Other conditions of the kinetic test that may vary include operating temperature, rate of supplied airflow, amount of material used, and particle size distribution.

SITE DESCRIPTION

The Red Mountain property is located in steep, rugged terrain near the Alaska-B.C. border, approximately 18 km east of Stewart, B.C. The project area lies between the Cambria Ice Field to the east and the Bromley Glacier to the south. The ore deposit is located near the top of Red Mountain at an elevation of 1,700 to 2,000 metres. Access to the site is by helicopter from Stewart.

The high altitude and close proximity to the Pacific Ocean directly influences the Red Mountain climate. The recorded a mean annual precipitation at the Stewart Airport was 1880 mm for the years 1974 to 1992, which was found to be similar to that received at the project site (Rescan 1994). The air temperature at the Red Mountain camp from July 1993 to June 1994 averaged 0°C.

The deposit is situated within a volcano-plutonic belt composed of Upper Triassic Stuhini Group and Upper Triassic to Lower-Middle Jurassic Hazelton Group. The Marc and AV Zones occur within altered bedded andesitic volcanoclastic rocks and altered massive feldspar-hornblende porphyry and crystal tuffs (Rhys et al., 1995).

KINETIC TEST PROGRAM

The five samples selected for this study represents the two main waste types for the proposed mine: feldspar porphyritic intrusive rock and bedded sedimentary rock. Sample HC-I, feldspar porphyry, and sample HC-2, sedimentary, were obtained from underground slashes while the other three samples were collected during the development of the exploration drift.

Thirty-four kinetic tests were performed, with two of these being conducted in large-scale field cells. The laboratory tests included twenty-five cylindrical bench-top humidity cells, five leach columns and two 50 kg cells. The kinetic tests that were conducted are listed in Table 1.

Tests were conducted on 1 to 3 kg samples using different protocols to evaluate the effects on the results and their subsequent interpretation. Testing was also conducted on 50 kg samples in the laboratory and 20 tonne samples at the mine site to provide results that could be compared and help provide more confidence in the scaling up of laboratory data to predict field rates of weathering. To assist in scaling up laboratory rates to actual field conditions, the influence of simulated precipitation events of various frequencies, duration and intensity were examined, and grain size analyses were conducted. Tests to determine the effective neutralization potential were also carried out with the purpose of refining predictions of when a waste pile will become acidic.

Table 1. Summary of kinetic test program

Kinetic test Type	Charge mass	Particle size	No. of tests	Protocol
Standard	1 kg	- 6.4 mm	8	Dry/wet cycles, trickle leach
Tall	3 kg	- 6.4 mm	5	Dry/wet cycles, trickle leach
Shaken	1 kg	- 6.4 mm	5	Dry/wet cycles, flood leach, gentle agitation
Non-aerated	1 kg	- 6.4 mm	1	Weekly trickle leach, open system, free draining
Simulated precipitation	1 kg	- 6.4 mm	6	Standard protocol for initial 215 days; then non-aerated with leach volumes, frequency and duration varied
NP column	5 kg	- 6.4 mm	5	Trickle leach with pH 3 (H_2SO_4) rinse water
50-kg	50 kg	- 38.1 mm	2	Trickle leach; initially with dry/wet cycles, then non-aerated
20-tonne	20 tonnes	- 400 mm	2	Field conditions

<u>20-tonne (Field) Cells</u>

Two wooden cribs, measuring 2.5 by 2.5 metres at the base and 1.5 metres in height, were constructed near the Red Mountain exploration portal during October 1994. The crib design was based on designs developed by Rescan Environmental Services Ltd. (1990) for the Kutcho Creek Property near Dease Lake, British Columbia. Each crib held approximately 20 tonnes of waste rock. The walls of these cribs were slatted and lined with geotextile to permit limited oxygen entry and thereby simulate an actual waste rock pile. Rock was blasted and removed from within the exploration adit to obtain fresh samples of the feldspar porphyry (HC-I) and sediment (HC-2) material used to fill these field cells.

The floor of each crib was lined with 40-mil high-density polyethylene and was sloped inwards and towards the front. Infiltrating water was collected from each crib by two PVC pipes that lay along the floor centre and two short PVC pipes at the front of the crib. A manifold made from PVC piping, joined the four pipes and directed water into a 7.5 litre vessel. . The tight fitting vessel lid had hoses for water entry and overflow, and probes to measure conductivity, pH and water temperature. A temperature / humidity probe and a precipitation tipping bucket gauge were installed on top of the cribs and temperature probes were buried within each crib. Readings from all these instruments were recorded by a

Campbell Scientific CR10 data logger which was powered by a solar panel.

The cribs were filled with HC-1 and HC-2 slash material during November 1994 at which time the measuring of internal and external temperatures commenced. Water data collected during the summer of 1995 was not complete due to access difficulties. However, the 1996 data was recorded from spring thaw (June 10th) to freeze-up (September 20th). Only one water sample was collected in 1995 and six were taken during 1996. These samples were analyzed for pH, conductivity, alkalinity, acidity, sulfate, and dissolved metals.

Grain size analyses were conducted on 5-7 tonne portions of HC-I and HC-2 samples by hand sieving slash material previously placed onto a bermed palate lined with polyethylene plastic. The mass of the fragments coarser than 3-inches was calculated from the fragment specific gravity (S.G.) and measured dimensions. The remaining material was sieved and the mass of each size fraction determined with a hanging weight scale. The specific surface area was then derived using the grain size distribution and geometric estimates.

Measurements of void ratio were conducted for the two slash samples to facilitate mass estimates and to calculate degree of saturation. To determine the void ratio, the rate of water flow from an underground pipe was measured and the flow rate was calculated from the time needed to fill a 200-litre barrel. The volume of a scoop bucket, which had welded steel plates over the drainage holes, was calculated from the time needed to fill the bucket with water. The bucket was then filled with slash material 5 times and the void volume calculated using the average time needed to top up the bucket with water. The 200-litre barrel was filled repeatedly throughout the testing to determine fluctuations in the water flow rate. The sample mass within each crib was calculated from the sample bulk S.G., void ratio, and the cell dimension.

Field rates of sulfate production were estimated from the water sample data, daily conductivity averages, and volumes of water released. The sulfate production was correlated to conductivity with a best-fit line using linear regression. The resulting equation was then used to calculate daily sulfate concentrations from the average conductivity and these concentrations were applied to the day's outflow volume to provide a daily sulfate release. The amount of dissolved sulfate within each cell was estimated by assigning the sulfate concentration of the final water sample to the volume of water stored (pore water).

The amount of sulfate stored as precipitate within the field cells was assumed to be minor based on equilibrium modeling of the field water chemistry. The average sulfate production rate was calculated by dividing the total sulfate (flushed and dissolved) by the weeks of operation.

PRIMARY RESULTS OF TEST PROGRAM

Sulfate production profiles from the standard, non-aerated, and 50-mL simulated precipitation cell that contained sample HC-1 are shown in Figure 1. The horizontal lines represent the average sulfate production rate from the last five cycles of the HC-I standard cell (58 mg/kg/wk). The results indicate that maintaining a relatively constant moisture, adding a consistent volume of leach water, and leaching with a regular frequency (at least once a week) will establish a steady state equilibrium within the cell and produce sulfate release rates that are similar to those obtained from the standard cell protocol.
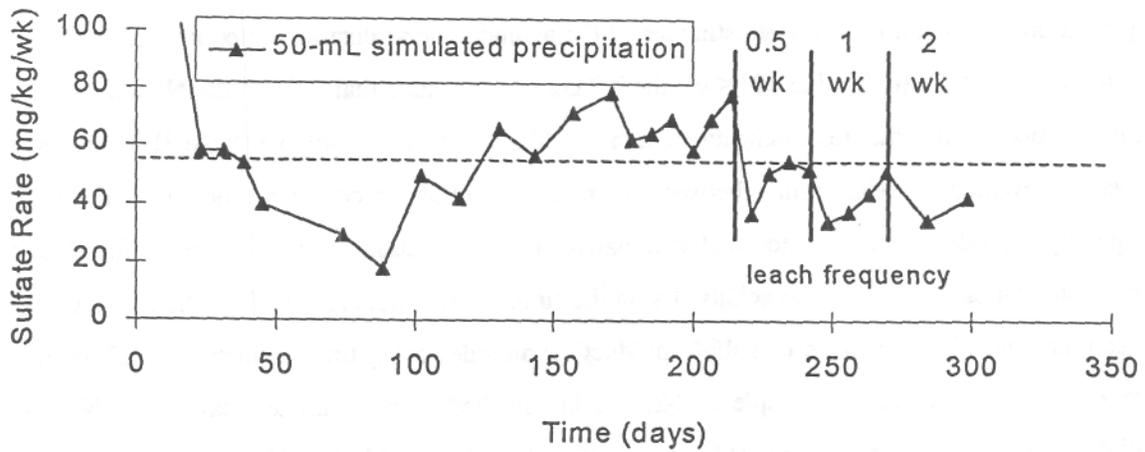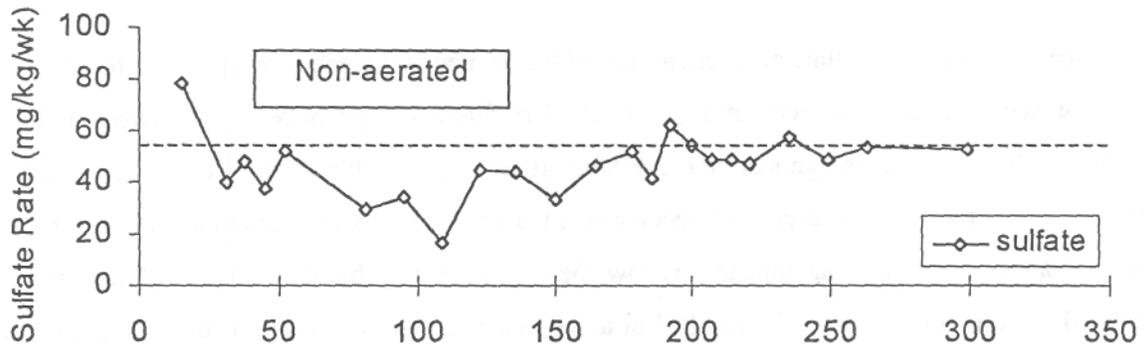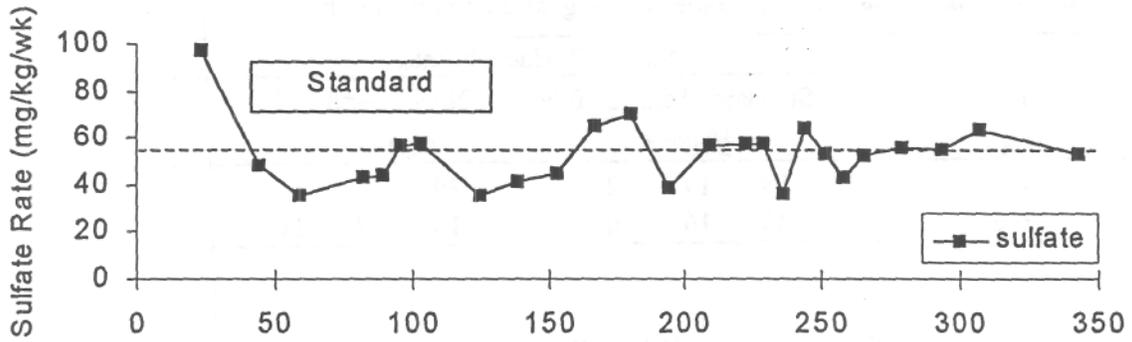
Figure 1. Sulfate release over time from standard, non-aerated, and 50-mL simulated precipitation cells containing sample HC-1.

Table 2. Sulfate production rates of standard, 50-kg, and 20-tonne kinetic tests

Sample Number	Rock type	Sulfate Production Rates					
		Standard, Aerated 50-kg, and Non-aerated 50-kg					
		mg/kg/wk			mg/m²/wk		
HC-1	fp	58	19	12	20	38	24
HC-2	sed	48	16	10	18	37	23

Sulfate production rates in the standard and 50-kg cells are more comparable on a surface area basis than a mass basis (table 2). Therefore, it is considered that measurements of specific surface area are required to properly scale up kinetic test results.

On a surface area basis, the sulfate production rates of the aerated 50-kg cells are approximately twice as high as the standard humidity cell rates (table 2). The 50-kg charge material is coarser and less homogeneous than the 1 -kg charge material and therefore more favourable to the development of micro-environments. Elevated acidity levels will occur where the concentration of sulfide minerals is high and the concentration of neutralizing minerals is low thereby promoting biotic oxidation of the sulfides. Turning off the air to the 50-kg cells resulted in a decreased rate of sulfate production suggesting that sulfide oxidation became limited by oxygen supply.

NP column tests showed that a high addition of acidic water increases the rate of NP depletion relative to acid generation which can lead to overestimates of the available neutralization potential. At the point of acidity for sample HC-2 (defined as pH < 6), the NP column indicated that 67% of the NP was available for neutralization, while other tests indicated that only 4.5% to 33% was available (table 3). However, the test results revealed a relationship between cumulative sulfate production and time to acidity. Consequently, sulfide oxidation rates and cumulative acid production may be more useful than NP depletion rates for estimating time to acidity. Using the cumulative sulfate results from the HC-I and HC-2 NP columns and the field rates of sulfate production provides a lag time prediction of 23 years for sample HC-I and 6 years for sample HC-2. Using methods that estimate unavailable NP (50% unavailable, 8 kg $CaCO_3$/tonne unavailable), the predicted lag time is 550 to 960 years for sample HC-I and 60 to 120 years for sample HC-2.

Table 3. Time to acidity, NP depletion, and sulfur depletion for sample HC-2

| Kinetic Test Type | Time to pH < 6.0 (days) | Neutralization | | Sulfur | |
		Cumulative NP Depletion (mg/m^2)	NP Depleted (%)	Cumulative Sulfate Produced (mg/m^2)	Sulfur Depleted (%)
Standard	209	1180	26	900	2.0
Tall	209	1390	30	950	2.1
Shaken	328	1530	33	1220	2.7
50-kg, aerated	221	200	4	1200	0.4
NP Column	244	3050	67	1080	2.4

Table 4. Laboratory sulfate production rates corrected for field temperatures

| Sample Number | Rock type | Sulfate Production Rates | | | | | | 20-tonne mg/m^2/wk |
| | | Standard, Aerated 50-kg, and Non-aerated 50-kg Corrected for Field Temperatures | | | | | | |
		pH 7 *Ea* mg/m^2/wk			pH 4 *Ea* mg/m^2/wk			
HC-1	fp	0.27	0.52	0.33	1.7	3.2	2.0	2.2
HC-2	sed	0.24	0.49	0.30	1.5	3.0	1.9	3.7

The laboratory rates of weathering, corrected for temperature and surface area, could not be scaled up to predict field results with confidence. The rates were corrected for temperature using the Arrhenius equation that requires a sulfide oxidation energy *(Ea),* which is sensitive to pH. Using an activation energy based on the field drainage pH of 7.0 returned oxidation rates an order of magnitude lower than the field weathering rates (Table 4). Calculations using activation energies at pH 4 predicted sulfate production rates that are much closer to meaisured field rates, possibly due to the presence of lower pH micro-environments within the field rock mass.

PRIMARY PROBLEMS ENCOUNTERED DURING TEST PROGRAM

Difficulties were encountered in maintaining equal and uniform airflow through the standard, tall and shaken cells. The unequal airflow caused dissimilar pore moisture loss and gain for the respective cells during the dry/wet air cycles. Similar operating conditions were deemed necessary to ensure repeatability of results and to permit meaningful comparisons of test protocols.

The aeration conditions of the field cells continually changed throughout the test period due to changing environmental conditions (rain, temperature). The variable operating condition of the field cells made the data difficult to interpret.

RECOMMENDATIONS

The non-aerated, trickle leach cell protocol should be evaluated further to determine its ability to provide weathering rates that are similar to those obtained from standard humidity cells. This test protocol has the following advantages over the standard humidity cell test:

- improved repeatability of results,

- less expensive apparatus,

- easier to operate, and

- may require less time to obtain rates of weathering.

Site specific conditions should be incorporated into a kinetic test program. The inability to scale-up is believed to be caused by the influence of particle size distribution, improper estimation of the influence of temperature, and changing aeration conditions of the field cells. Operating laboratory kinetic tests with coarse material and under field temperatures may provide data that is more confidently scaled up. Field tests are recommended when time permits and the costs associated with supply of material, access for monitoring, and operation are not prohibitively high. Field tests will provide the most reliable results since the errors from estimating the influences of particle size, aeration, and temperature are removed.

Manually adding water to a field test could help create less complex operating conditions and allow easier interpretation of results. Manual water addition would overcome any short-term influence that a slow increase to maximum moisture retention has on aeration and weathering rates. Periodically adding enough water to the test pile to simulate a 100-year storm event would define worst-case drainage metal concentrations. Adding enough water on a weekly basis to flush weathering products would provide more useful weathering rates than a laboratory test. The method addition of water must be in a manner that simulates precipitation.

The cost of building a kinetic field test can be relatively inexpensive. A proven field design consists of a bermed wooden platform that is lined with polyethylene and sloped towards one corner where a pipe

drains water into a sealed vessel. Other designs that have been used include drilling mud tanks and lined, V-shaped trenches. Since a small field test is subject to higher evaporation rates, greater fluctuations in internal temperatures, and better aeration than an actual waste pile, larger field tests are preferable.

Further research is necessary before empirical/engineering models will enable confident predictions of acid generating rates and water quality to be made from laboratory tests.

ACKNOWLEDGMENTS

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