

Geochemistry of Tailings from the Mount Polley Mine, British Columbia

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To support remedial decisions for the Tailings Storage Facility breach at the Mount Polley Mine (MPM), a geochemical characterization program assessing the metal leaching and acid rock drainage potential of the tailings and other materials released into Polley Lake, Hazeltine Creek, and Quesnel Lake was performed. Because the tailings and other materials settled under subaerial conditions along the banks of Hazeltine Creek and in subaqueous conditions in Polley and Quesnel Lakes, the geochemical characterization assessed reactivity in both terrestrial and aquatic environments. Tailings and other materials deposited in these areas were found to be consistently non-acid generating indicating that weathering conditions are expected to be pH-basic under all depositional conditions. Leaching potential of tailings in subaerial environments was low and the potential for oxidative and reductive dissolution under deep water conditions was found to be negligible. Sub-aerial copper leaching is likely controlled by mineral solubility, which will limit loadings to the environment and can be used to inform remedial decisions.

1 INTRODUCTION

A failure of a glacial lacustrine layer beneath the Perimeter Embankment of the Tailings Storage Facility at the Mount Polley Mine (MPM), British Columbia caused a breach of the embankment tailings dam on August 4, 2014 (IEEIRP, 2015). The dam breach resulted in a release of tailings and other materials into Polley Lake, Hazeltine Creek, and Quesnel Lake. As part of remediation planning, a geochemical characterization program assessed the metal leaching and acid rock drainage (ML/ARD) potential of the spilled tailings and other materials and this paper presents the key findings from the investigation.

2 BACKGROUND

2.1 *Geological Setting*

The Mount Polley deposit is classified as an alkalic porphyry copper gold deposit (BC MIN-FILE No. 093A 008). The host rocks for porphyry mineralization are intrusions into the Nicola Volcanics varying in composition from diorite to syenite. Alteration is potassic (secondary biotite and pink orthoclase) and propylitic (calcite-epidote-chlorite-pyrite). Sulphide mineralization consists mainly of chalcopyrite (CuFeS_2) and pyrite (FeS_2), with lesser bornite (Cu_5FeS_4), covellite (CuS), and digenite (Cu_9S_5). Carbonate mineralization is principally calcite, with occurrences of malachite ($\text{Cu}_2\text{CO}_3(\text{OH})_2$); iron carbonates have not been reported.

A significant portion of the copper at the MPM is not associated with sulphides (upwards of 50% in the upper portions of each pit) and has been historically been termed copper-oxide, although this includes both silicate hosted copper (e.g., chlorite) and copper carbonates like malachite (Taplin 2002).

2.2 Ore Processing and Tailings Deposition

Processing of ore mined from the Mount Polley yields a copper sulphide concentrate. In general terms, the concentrate is produced by blasting the ore and then hauling it to the processing plant, where it undergoes three stages of crushing, and three stages of grinding, followed by rougher and cleaner flotation to produce a copper concentrate. The flotation circuit concentrates sulphide minerals as they are hydrophobic. Following the removal of the copper sulphide minerals by flotation, the remainder of the slurry is disposed of as tailings. The tailings are lower in sulphide mineral content compared to the ore as majority of the copper sulphides have been removed.

Mill process reagents, with the exception of lime, are not expected to be present with the tailings and other materials deposited as they would either have remained with the concentrate (chemically bound to mineral surfaces) or degraded quickly in the environment. Life-of-mine processing changes were minimal and not expected to affect the geochemical reactivity of the tailings. As a result, the tailings geochemistry can be considered in aggregate.

Tailings slurry produced in the mill is gravity-fed to the TSF with deposition by single-point discharge. The single point discharge was often directed to cells, where bulldozers and weirs were used to separate the coarser fraction of the tailing from the finer fractions and build up sand adjacent to the embankments. The discharge point was sequentially rotated along the entire length of the three embankments (i.e. the Perimeter, Main, and South Embankments). The tailings produced during operations would have been well mixed and there appears to have been limited potential to create anomalous geochemistry zones that could have spilled after the dam breach.

3 CONCEPTUAL MODEL AND STUDY DESIGN

An initial geochemical conceptual model (IGCM) was formulated to guide the design of the characterization approach for the tailings and other materials deposited, which effectively represents hypotheses about tailings characteristics and reactivity that are subsequently evaluated through observations, sampling, testwork, and interpretation.

Complete details of the IGCM are provided in SRK (2015) and indicated that two main configurations of the tailings and other materials deposited needed to be evaluated. First, subaerial tailings along the banks of Hazeltine Creek would be susceptible to oxidation of sulphides due to exposure to atmospheric oxygen. Second, subaqueous tailings on the bottom of Polley Lake and Quesnel Lake would be much less reactive in terms of sulphide oxidation due low or oxygen free water but could facilitate dissolution of secondary minerals (i.e. iron hydroxides).

4 CHARACTERIZATION METHODS

4.1 Overview

Geochemical characterization of the tailings and other materials deposited consisted of field sampling along Hazeltine Creek and a series of geochemical tests to understand the composition, mineralogy and leaching characteristics under various storage configurations. SRK focused on the tailings and other materials deposited along Hazeltine Creek because weathering under sub-aerial conditions should represent the most likely scenario for leaching based on the IGCM. In addition, sampling by another consulting group (Minnow Environmental) included tailings and other materials deposited that settled in Polley and Quesnel Lakes. Between the historical data for the site, and two independent sampling campaigns, the assumption was that geo-

chemical variability would be characterized. Complete details of field sampling and analytical methods are provided in SRK (2015) and the following section provides key aspects of the methods used as part of the ML/ARD characterization program.

4.2 Hazeltine Creek Sampling

Samples of exposed tailings and other materials deposited in Hazeltine Creek were collected along 18 parallel transects, oriented roughly perpendicular to the course of Hazeltine Creek. The transects were spaced approximately 500 m apart beginning with transect ST17/18 in the area of the dam breach and ending with transect ST01 near the mouth of Hazeltine Creek at Quesnel Lake (Figure 4-1).

At each transect, major physical/depositional features were sampled, with up to five samples per transect. Physical/depositional features were determined in the field based on particle size (fine grained versus coarse), colour, or depositional area (e.g. high on a bank or shoulder versus adjacent to the creek). In total, 68 samples containing tailings and other materials deposited were collected. Approximately 10% of samples were collected as field duplicates and silica sand samples were included as field blanks.

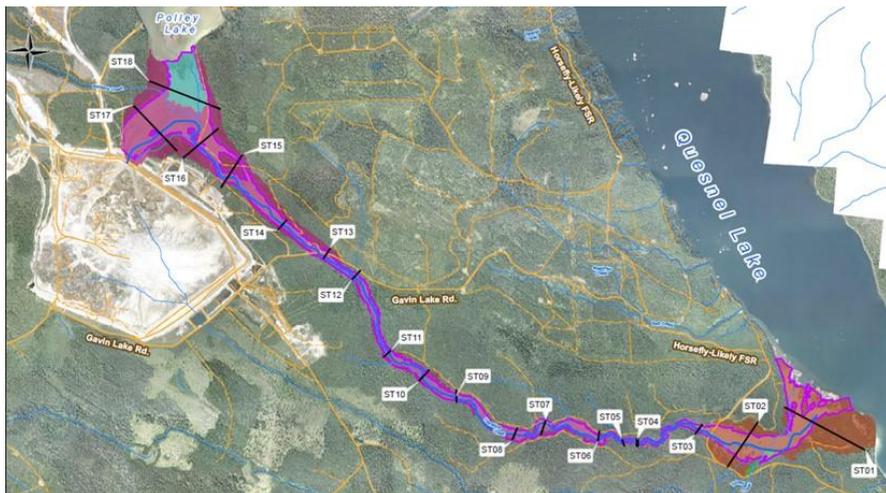


Figure 4-1: Location of Hazeltine Creek Sampling Locations (SNC-Lavalin, 2015).

A total of 78 additional samples were collected from the study area for sequential extraction analyses by Minnow Environmental between August 13 and October 24, 2014. Specific details of the sample collection procedures and locations are provided in Minnow (2015). Of the samples collected, 18 were from the profundal zone in Quesnel Lake (6 lake sediment samples and 12 tailings and other materials deposited), 18 were from the littoral zone in Quesnel Lake (2 lake sediment samples and 16 tailings and other materials deposited), and 15 were tailings and other materials deposited from along Hazeltine Creek. Fifteen samples from the bottom of Polley Lake were also collected.

4.3 Laboratory Analyses

4.3.1 Acid-Base Accounting and Trace Element Composition

A two-phase testing approach was used for geochemical characterization in order to constrain composition variability and understand specific acid-base accounting (ABA) and mineralogical characteristics of the Hazeltine Creek samples.

Phase one testing included moisture content, multi-element analysis, including sulphur content by aqua regia digestion with an inductively coupled plasma mass spectrometry (ICP-MS) finish, total inorganic carbon (TIC), and particle size distribution by sieving.

Phase two testing was conducted on 25% of the samples, which were selected to capture the range of sulphur, TIC, copper, and selenium content in the Hazeltine Creek samples based on the results of the phase 1 analyses. Testing included paste pH and conductivity, modified Sobek Neutralization Potential determination (MEND 1991), total sulphur (by LECO furnace) and sulphate sulphur (by hydrochloric acid (HCl) leach). A non-sulphide copper analysis was also conducted by leaching sampled using 2.5% sulphuric acid with the filtered leachate submitted for ICP-MS multi-element scans.

4.3.2 Mineralogical Characterization

Mineralogical characterization using Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) was conducted on splits from all of the kinetic test program samples (see Section 4.3.4). Rietveld X-ray diffraction (XRD) and electron microprobe were selectively used to refine and confirm modal abundances, mineral form (e.g. the different iron oxides present) and element department for low concentrations that could not be resolved by QEMSCAN.

4.3.3 Sequential Extractions

Sequential extractions involve a progressive series of chemical extractions applied to the same sample in order to partition the total element content into geochemical ‘fractions’. The sequential extractions conducted for the tailings were designed and directed by Minnow Environmental (Minnow 2015) and based on Tessier et al.’s (1979) procedure with modifications. However, the procedure is designed for soils, and as a result, some of the reagents used would likely target different mineral fractions in tailings than they would in soils. The most significant deviation included the ‘organically bound’ elements as there are expected to be limited amounts of organic materials in the tailings and the reagents (nitric acid, hydrogen peroxide) and temperatures (85°C) used likely oxidized some of the sulphide and may also leach more resistant oxide minerals. Tessier et al. (1979) also noted some alteration of the minerals smectite, chlorite and mica in this digestion step and these minerals are present in the MPM tailings.

4.3.4 Kinetic Testing

The kinetic testing program consists of six standard laboratory humidity cells (MEND, 1991) (labelled HCs 1 - 6), three column leach tests (COLS 1 – 3), two blanks (a HC and a column), and one HC duplicate. The intent of the kinetic testing program was to establish weathering rates under oxygen unlimited conditions using humidity cell testing and then use column tests to evaluate the effect of longer flow paths and lower water to solids ratios that were more similar to the field than dilute HC tests.

A range of tailings samples containing mean and upper 95th percentile materials for copper, selenium and sulphur were selected. Columns tests consisted of between 1.5 and 4.5 kg of material that were splits from the humidity cells (i.e. HC-1 = COL-1) and were leached with between 150 and 500 mL of water in a week, respectively. All kinetic tests were flushed weekly with leachate analysed for anions, major cations and trace elements needed for the province of British Columbia water quality assessments.

5 RESULTS

5.1 Hazeltine Creek Field Sampling

Two types of tailings-bearing samples were observed along Hazeltine Creek. They were classified in the field as ‘grey tailings’ and ‘magnetite sands’ based on physical and mineralogical characteristics. The grey tailings were silty-sand sized particles, and reacted strongly to HCl fizz test in the field. The magnetite sands samples were pinkish-orange, had a moderate to weak fizz reaction and were strongly magnetic.

The grey tailings tended to be most abundant along the embankments and upper benches of the creek, whereas the magnetite sands were commonly present in low-lying areas near the creek. With the exception of the area near the tailings dam breach and Polley Lake, the tailings were deposited in relatively thin 'skiffs' (e.g. 10 to 20 cm deep). The thickest observed subaerial tailings deposits (e.g. 1 to 1.5 m deep) were in the immediate vicinity of the tailings dam breach and Polley Lake (SNC-Lavalin 2015).

5.2 Laboratory Analyses

5.2.1 Acid Base Accounting

The form of sulphur was found to be sulphide, with sulphate typically below detection. Sulphide sulphur from ICP-MS was used for calculating acid-potential (AP). Neutralization potential (NP) by titration was found to be overestimated and carbonate by TIC was used to estimate NP for acid-base account calculations (SRK 2015). Iron carbonates, which can also overestimate carbonate NP, have not been identified at MPM.

Consistent with expectations from operational sampling (data provided by MPMC to BC Ministry of Environment (MoE) http://www.env.gov.bc.ca/eemp/incidents/_2014/mount-polley.htm), the tailings and other materials deposited were found to all be non-ARD generating (Figure 5-1).

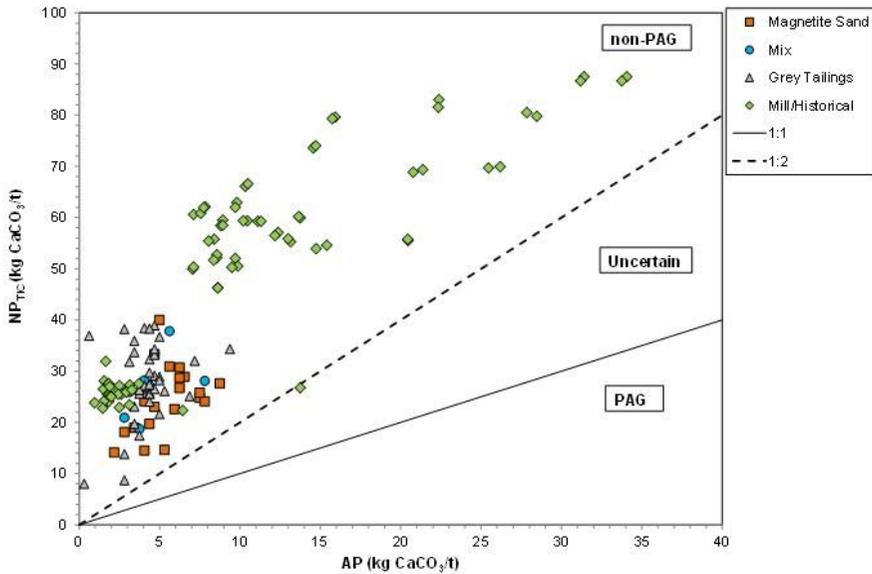


Figure 5-1: Comparison of tailings and other materials deposited and MPM mill/historical tailings.

5.2.2 Trace Element Occurrence

Complete analytical composition results for all samples from a 35 element scan are provided in SRK (2015). A statistical summary and shortened list of element concentrations that have guidelines for the protection of freshwater aquatic life in British Columbia is provided in (Table 5-1).

Table 5-1: Statistical summary of selected trace elements in MP tailings and other materials deposited.

| Statistic | As mg/kg | Cu mg/kg | Pb mg/kg | Hg mg/kg | Mo mg/kg | Se mg/kg | V mg/kg | Zn mg/kg |
|-----------|-------------|-------------|-------------|-------------|-------------|-------------|------------|-------------|
| Min | 7.2 | 29 | 4.0 | 0.03 | 0.57 | 0.3 | 86 | 40 |
| P5 | 8.7 | 360 | 4.4 | 0.06 | 1.9 | 0.74 | 120 | 45 |
| P25 | 10 | 800 | 4.9 | 0.08 | 3.9 | 1.2 | 160 | 52 |
| Mean | 11 | 880 | 5.7 | 0.091 | 4.3 | 1.4 | 180 | 57 |
| Median | 11 | 910 | 5.4 | 0.08 | 4.6 | 1.5 | 180 | 56 |
| P75 | 12 | 990 | 6.0 | 0.10 | 5.0 | 1.6 | 200 | 61 |
| P95 | 13 | 1300 | 8.5 | 0.13 | 5.5 | 1.8 | 250 | 74 |
| Max | 13 | 1500 | 12 | 0.28 | 6.5 | 1.9 | 300 | 82 |

To provide an indication of trace element enrichment in the tailings and other materials deposited samples, concentrations were compared to typical global average concentrations for basalt (Price 1997). This comparison approach is a standard element leaching screening practice as outlined by MEND (2009). Concentrations present at more than an order-of-magnitude above global average values were considered enriched for the purpose of screening and enrichment ratios are shown in **Figure 5-2**. The ratios were calculated by dividing the concentration of copper (for example) in the sample by the typical concentration of copper in basalt. Ratios greater than 10 are considered enriched. Ratios less than one indicate lower concentrations in the Hazeltine Creek samples than in average basalt. ‘Box and whisker’ plots were used to illustrate the results, with the boxes representing the 25th to 75th percentile ranges. The solid horizontal line represents equivalence with typical basalt, whereas the dashed line represents ten times the concentration of basalt.

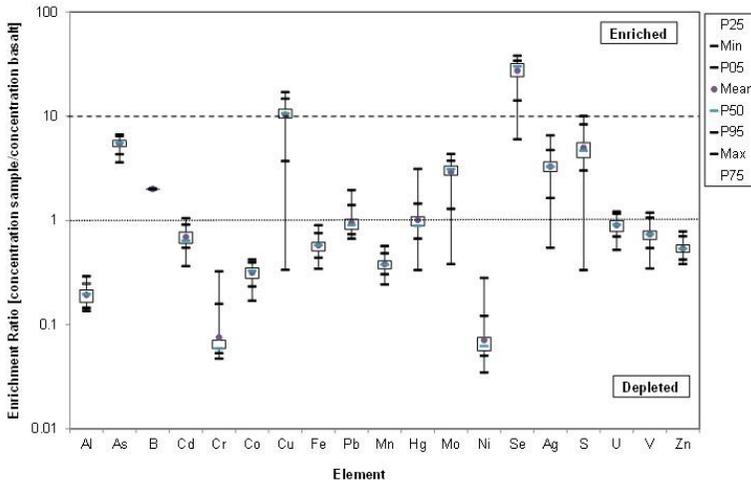


Figure 5-2: Element enrichment assessment for Hazeltine Creek tailings samples.

Based on the enrichment screening method of MEND (2009), copper and selenium are considered to be enriched in the tailings. However, the average concentration of selenium in operational tailings from within the TSF is lower (1.1 mg/kg) than the spilled materials and similar to the average of 137 regional stream sediment samples from the region surrounding Mount Polley (average 1.0 ppm, range 0.1 to 9.1 ppm)(GSC 1981; Jackman 2008)(**Figure 5-3**).

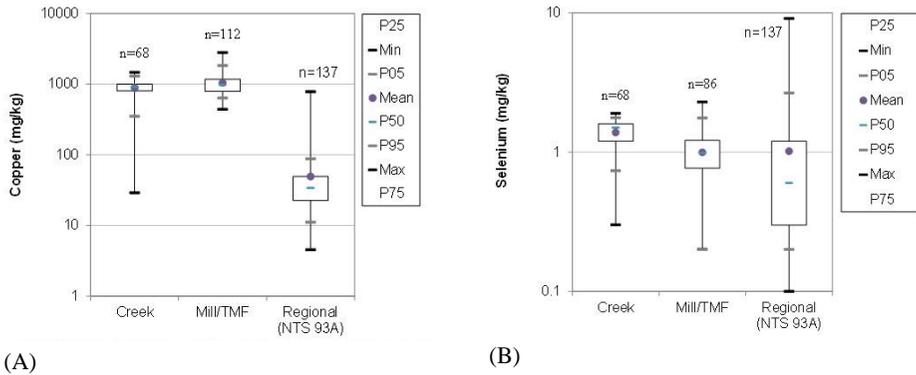


Figure 5-3: Comparison of copper (A) and selenium (B) concentrations in Hazeltine Creek tailings and other materials deposited, operational mill tailings and regional sediments.

5.2.3 Mineralogy

The samples are dominated by silicates, including feldspars, chlorite and quartz. Iron oxides (mainly magnetite) were frequently the next most abundant minerals after the silicates, followed by carbonates and the minor amounts of sulphides. The presence of quartz at concentrations greater than 1% is a good indication that the tailings are intermixed with native sediments as the deposit is syenitic to monzonitic and the tailings should contain very little to no quartz (BC MINFILE No. 093A 008).

Sulphide mineralogy is consistent with the ore mineralogy previously described for the project, including pyrite and chalcopyrite as the two main sulphide minerals in approximately equal proportions (approximately 0.2% for each mineral), followed by bornite (less than 0.1%) and other copper sulphides (likely covellite).

The main carbonate present was calcite, ranging from 0.7% to 4.5%. Dolomite was also present, although typically less than 0.1% with the exception of one sample (HC-4) at 0.4%. Malachite was also present, although at near detection levels.

Copper and selenium deportment was investigated, however, the concentration of selenium was too low to be detected by QEMSCAN or electron microprobe and only copper results are available. Chalcopyrite contained approximately half of the copper when total copper concentrations were above 0.05%. Chlorite was the next most abundant mineral to host copper, followed by bornite and covellite/chalcocite.

The deportment in chlorite was unexpected as previous investigations have indicated that chrysocolla was the non-sulphide mineral phase hosting copper. However, other studies have also noted the same finding (Chanquia et al, 2010) and the overall implication is likely insignificant in terms of reactivity as previous work by MPMC has shown copper in the non-sulphide phase extremely resistant to leaching by acidic solutions (Taplin 2002; Henry 2009). Results from the non-sulphide copper leach also support these findings with an average of 50% of the copper in a non-sulphide phase. Given the recalcitrant nature of this copper mineral phase, it is also considered a much less reactive phase compared to copper sulphides.

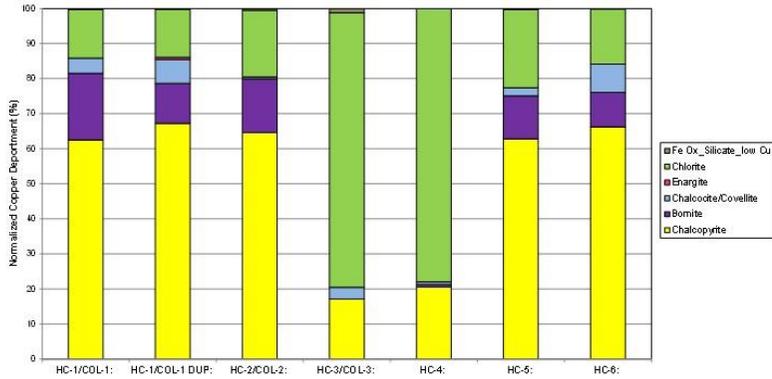


Figure 5-4: Mineral department of copper in Hazeltine Creek tailings and other materials deposited samples.

5.2.4 Sequential Extraction Results

Results from the extractions were grouped together to represent tailings and other materials deposited from Hazeltine Creek, from the bottom of Quesnel and Polley Lake, and also lake sediments that were not impacted by the tailings discharge (i.e. a background lake reference). Iron and copper are shown in

Figure 5-5. Iron is not considered enriched the tailings, but is often associated with minerals that are susceptible to dissolution under sub-oxic conditions.

Iron was predominantly associated with the 'residual metals' fraction (e.g. 85% of total iron extracted in lake tailings) in all samples tested, which is likely comprised of mainly sulphides due to the use of an aqua regia digest as the final step. Magnetite was not likely dissolved in any of the sequential extraction steps. Only a small portion of the iron was present in the reducible fraction (~ 12%) and at lower concentrations than the background lake reference samples.

Copper was mainly associated with the 'organic bound' fraction, although as previously discussed in Section 4.3.3, this is likely partially associated with sulphide minerals and also chlorite due to the reagents and temperatures used in the extraction step (Tessier 1979). Mineralogy results also support this with the department of copper partially in chlorite. The 'residual' fraction contained the next highest amount, but also notable for copper was the presence of 4% in the 'carbonate metal', likely reflecting the presence of malachite.

Selenium results (not shown) were predominantly below detection (0.2 mg/kg based on aqueous concentrations in the extractions), with only the 'organic bound' and residual fraction slightly above detection limits.

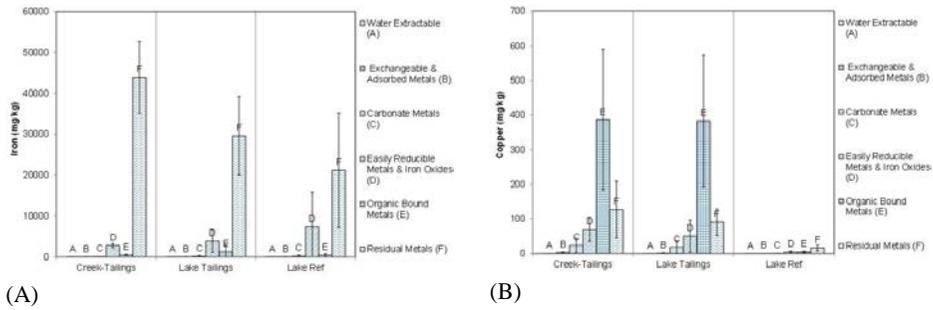


Figure 5-5: Sequential extraction results for iron (A) and copper (B).

5.2.5 Kinetic Testing

Complete results for all elements regulated by the province of British Columbia are provided in SRK (2015) for both humidity cells and columns. Approximately one year of testing has been completed for this investigation, with testing on-going.

Copper is the focus of results presented below as copper is one of the two elements identified as enriched in the tailings. Sampling by the British Columbia Ministry of Environment (BC MOE) at the Mount Polley Mine has also identified copper as the main element of concern. Copper leaching is strongly pH dependent and therefore pH is also included for discussing long term copper behavior.

Humidity cell results (data not shown) have shown steadily declining rates of copper leaching under pH neutral conditions (pH of 8). Copper is leaching at a rate of 0.002 mg/kg/week, with concentrations around 0.005 mg/L. The columns (which are splits from HC composites) are also pH slightly basic (pH of 8) with a copper leaching rate slightly lower than the humidity cells at 0.001 mg/kg/week with concentrations now around 0.01 mg/L (

Figure 5-6). The higher concentrations and lower leaching rate in the columns are interpreted here to reflect a solubility limit being reached, which is discussed in Section 6.1.1.

The lower pH and higher copper concentrations during the start of the kinetic tests are likely a result of the samples being stored in the laboratory for several months before testing began. During this time, the sulphide minerals would still have been oxidizing but the acidity formed could not be neutralized by the available carbonate minerals as there was no flow of water through the sample. As the column test started and water was passed through the tailings, pH increased and copper concentrations decreased.

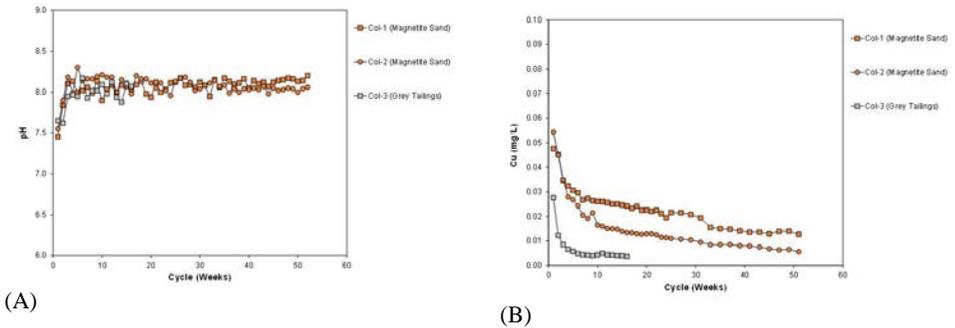


Figure 5-6: Column testing results of pH (A) and copper (B).

6 DISCUSSION

6.1 *Leaching Mechanisms*

6.1.1 *Subaerial Weathering of Tailings*

Tailings and other materials deposited are expected to weather under neutral pH conditions. ARD has not been identified as a concern for Mount Polley tailings historically and the results of this program confirm the previous findings that weathering and trace element release will be under neutral pH.

The tailings and other materials deposited and mixed-in sediment materials deposited along the banks of Hazeltine Creek and any other subaerial setting will weather in the presence of oxygen. However, leaching is expected to be slow because sulphides leach at relatively slow rates under neutral to basic pH conditions when compared to acidic conditions, which is typically orders-of-magnitude faster. On-going geochemical testing is supporting this assessment and showing slowly declining copper release rates. Silicates will also weather, but at even slower rates that are dependent on mildly acidic rainwater (the dissolved carbon dioxide equilibrium pH of rainwater is ~5.5). Given the carbonates present in the MPM tailings, mildly acidic rainwater will be neutralized upon contact and leaching of silicates would be slower than could occur by rainwater.

Thermodynamic first principles and the equilibrium modelling software package PHREEQC (version 2.17.4137) (Parkhurst and Appelo, 1999) predicts low solubility of copper at neutral pH as compared to concentrations that are associated with copper porphyry deposits under acidic pH (Day and Rees, 2006). This is because secondary copper oxide minerals (i.e. malachite, tenorite) that would form after oxidative dissolution from a copper sulphide are only sparingly soluble. The prediction of contact water (i.e. tailings seepage) by PHREEQC under aerobic conditions and pH 8 carbonate buffered rainwater is an upper limit of 0.02 mg/L due to copper oxide solubility limits. This is consistent with other copper concentrations measured under neutral pH at the MPM and other copper porphyry sites (Day and Rees, 2006).

Copper concentrations were used to evaluate copper solubility control in water samples from the laboratory and field. The sites included a sampling site in upper Hazeltine Creek downstream of a one kilometre stretch of deposited sub-aerial tailings (referred to as HAC-13), from the column test containing tailings with 95th percentile copper content, and from a ditch collecting seepage from subaerial tailings and other materials deposited after two years since the tailings spill (provided by the BC MOE and MPM). The ditch water is from an area referred to as the Polley Flats, which is just below Polley Lake and one kilometer downstream of where the width of the area of tailings and other materials deposited is narrow (Figure 4-1). Results were plotted against solubility curves generated using PHREEQC for malachite ($\text{Cu}_2\text{CO}_3(\text{OH})_2$), tenorite (CuO), and copper hydroxides ($\text{Cu}(\text{OH})_2$). A saturation index of zero was used for all three secondary copper minerals, but a saturation index of 0.5 was also used for malachite as activation energy barriers often need to be overcome before a mineral can precipitate and this requires a higher degree of saturation. Malachite (as opposed to tenorite or copper hydroxides) was chosen to evaluate the saturation index range as it is the most likely secondary mineral control based on it being commonly identified on site and in the tailings.

The outcome of the comparison is shown in **Figure 6-1**. There is a good fit of the dissolved copper concentration results to the predicted concentrations based on pH and mineral solubility, especially to malachite with an SI of 0.5. Lower pH values were associated with spring freshet were similar to the initial flush of material in the laboratory kinetic testing program. During the winter (or prolonged dry periods), the majority of tailings are no longer receiving infiltration due to snow and ice cover allowing oxidation products and acidity to accumulate around the sulphide grains in tailings that do not freeze in the winter. Once freshet begins, these oxidation products and acidity will be neutralized and get flushed from the tailings, with pH increasing while copper concentrations decrease.

Selenium was shown to be correlated with copper (SRK 2015) and likely is present as an accessory element in the copper sulphides as this element often replaces sulphur owing to similar

geochemical properties (Ralston et al, 2008; MEND 2015). However, the methods used in this study could not detect selenium co-precipitated with silicate minerals and so selenium release should be conservatively assumed to be associated only with oxidative dissolution of sulphides.

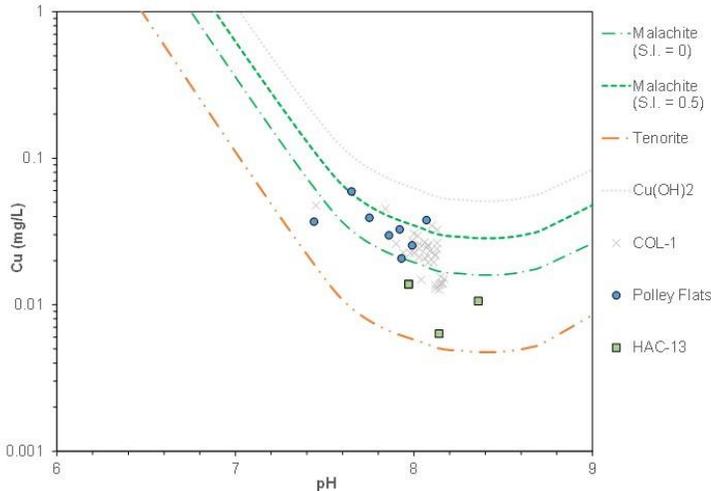


Figure 6-1: Secondary copper mineral solubility curves and monitoring results.

6.1.2 Subaqueous Dissolution of Tailings

For any of the tailings and other materials deposited that ended up in Quesnel or Polley Lake, water saturation is the best way to inhibit oxidation of sulphides (INAP 2010). Therefore, leaching of any elements hosted in sulphides (i.e. copper and selenium) that would be released by oxidation is effectively inhibited for tailings present in Quesnel and Polley Lakes.

Based on the results of the mineralogical characterization work and sequential extractions, the risk for mobilization of elements under reducing conditions was found to be low. Easily reducible iron oxides were minor components of the tailings samples tested and neither copper nor selenium were associated with a mineral phase that would be susceptible to reductive dissolution.

It should also be noted that selenium behaves quite differently under reducing conditions and will either sorb to mineral surfaces if it is present as selenite, or precipitate as elemental selenium (Ralston et al, 2008; MEND 2015). In either event, even if selenium was released from reductive dissolution processes, its geochemical behaviour under reducing conditions would result in it being removed from the water column and it is not considered a water quality risk under subaqueous reducing conditions.

6.2 Reclamation Considerations

The presence of a secondary mineral control on copper concentrations is an important finding for reclamation planning. This is because any efforts to encourage precipitation run-off and discourage infiltration into the tailings, through either grading or evapotranspiration through soil covers and vegetation growth, will likely result in a decreased loading of copper to the receiving environment. Mineral solubility control will maintain concentrations at a fixed level, so despite unchanging copper concentrations, with less water moving through the tailings, less copper can be transported. The establishment of vegetation on the top of the tailings may also help slow

down oxygen diffusion into the tailings and probably result in lower rates of sulphide oxidation and therefore primary copper leaching rates.

6.3 References

- Chanqua, C.M. et al. 2010. Speciation of Copper in Spherical Mesoporous Silicates: From the Microscale to Angstrom. *Journal of Physical Chemistry* (114):12221–12229.
- Day, S. and Rees, B. 2006. Geochemical controls on waste-rock dump seepage chemistry at several porphyry mines in the Canadian cordilleran. International Conference on Acid Rock Drainage (ICARD 2006).
- GSC 1981. Regional geochemical surveys, British Columbia. Geological Survey of Canada, Open File 776/British Columbia Regional Geochemical Survey RGS 50.
- Henry, C. 2009. Semi-Industrial Scale Testing of Biologically-Induced Copper Heap Leaching at Imperial Metals Corporation – Mount Polley Mine. MSc Thesis in Natural Resources and Environmental Studies (Environmental Science), University of Northern British Columbia, December 2009.
- IEEIRP, 2015. Independent Expert Engineering Investigation and Review Panel Report on Mount Polley Tailings Storage Facility Breach. Government of British Columbia. January 2015.
- INAP 2010. The Guide for Acid Rock Drainage (GARD) produced by the International Network for Acid Prevention (<http://www.inap.com.au>).
- Jackaman, W. 2008. QUEST Project sample reanalysis; Geoscience BC, Report 2008-3, 4 p.
- MEND 1991. Acid Rock Drainage Prediction Manual. Mine Environment Neutral Drainage Program. Report 1.16.1b
- MEND 2009. Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials. Mine Environment Neutral Drainage Program. Report 1.20.1.
- MEND 2015. Role of Nitrate in the Remobilization and Attenuation of Selenium in Coal Mine Waste. MEND Report 10.3.
- Parkhurst, D.L., and Appelo, C.A.J (1999). User's Guide To Phreeqc (Version 2) - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations, Water-Resources Investigations Report 99-4259.
- Price, W. 1997. Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia. Reclamation Section, British Columbia Ministry of Energy and Mines. April 1997.
- Ralston VC, Unrine J, Wallschlager D. 2008. Biochemistry and analysis of selenium and its species. Prepared for: North American Metals Council. Washington, DC.
- SNC-Lavalin 2015. Soil Quality Impact Assessment. Report prepared for Mount Polley Mining Corporation by SNC-Lavalin. April 2015.
- SRK 2015. Mount Polley Mine Tailings Dam Failure: Geochemical Characterization of Spilled Tailings. Provided in Mount Polley Mining Corporation Post Event Environmental Impact Assessment Report. Prepared by Golder Associates for Mount Polley Mining Corporation. July 2015.
- Taplin, L.B. 2002. Recovery Improvement Process Development for Copper from Oxide Materials. Internal Imperial Metals report prepared with the National Research Council of Canada. Project No. 456076, April 2002.
- Tessier, A., Campbell, P. G. C. & Bisson, M. 1979. Sequential extraction procedure for the speciation of particulate trace metals. *Analytical Chemistry* (51):844-851.