



## REPORT

# GEOCHEMICAL CHARACTERIZATION OF RESOLUTION TAILINGS UPDATE: 2014 - 2016

RESOLUTION COPPER MINING, PINAL COUNTY, ARIZONA

JUNE 8, 2016



## **REPORT**

# **GEOCHEMICAL CHARACTERIZATION OF RESOLUTION TAILINGS UPDATE: 2014 - 2016**

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JUNE 8, 2016

## **TECHNICAL REVIEW NOTICE**

Technical review of this document was provided by Mr. Mark Logsdon of Geochimica, Inc., Aptos, California at the request of Resolution Copper Mining LLC and Duke HydroChem LLC.

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**Appendix B:** Humidity cell test results for scavenger tailings from 2014 master ore composites

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## List of Acronyms and Abbreviations

ABA	acid-base accounting
ADEQ	Arizona Department of Environmental Quality
AGP	acid generating potential
ANP	acid neutralizing potential
APP	Aquifer Protection Permit
ARD	acid-rock drainage
BADCT	best available demonstrated control technology
BLM	Bureau of Land Management
EPA	Environmental Protection Agency
HCT	humidity cell test
IC	individual (ore) composite
ICP-MS	inductively coupled plasma – mass spectrometry
ICP-OES	inductively coupled plasma – optical emissions spectrometry
MC	master (ore) composite
NAG	net acid generation
NNP	net neutralization potential
NPAG	not potentially acid generating
NPR	neutralization potential ratio
PAG	potentially acid generating
QEMSCAN	Quantitative Evaluation of Minerals by Scanning Electron Microscopy
RCM	Resolution Copper Mining, LLC
SFE	shake flask extraction
SPLP	Synthetic Precipitation Leaching Procedure
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TSF	tailings storage facility
XRD	x-ray diffraction

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## 1.0 Executive Summary

The Resolution tailings geochemical characterization program commenced in 2002. In 2014, a baseline tailings geochemistry report was published (DHC, 2014) and included in the Resolution General Plan of Operations as Appendix H (RCM, 2014). The DHC (2014) report provides a summary of the tailings characterization program over the period 2002 through 2013. Data needs identified at the time of writing the initial report informed planning of further geochemical characterization efforts that are reported in the current document. Results presented in this report are consistent with the findings of the earlier work and further enhance the Project's understanding of the likely geochemical reactivity of the Resolution tailings if allowed to weather under oxidizing conditions. These studies were conducted to support Resolution's ongoing National Environmental Policy Act (NEPA) process as well as the Project's application for an Aquifer Protection Permit (APP) from the Arizona Department of Environmental Quality (ADEQ).

### 1.1 Geochemical Tailings Characterization Program (2014 – 2016)

Based on data needs identified at the end of 2013, further geochemical characterization of Resolution tailings was undertaken over the period January 2014 through May 2016. Resolution's tailings management strategy includes separation of tailings into two mineralogically and geochemically discrete streams known as "pyrite" and "scavenger" tailings (the pyrite tailings are also referred to as "cleaner" tailings in many Project documents). The primary objective of the testing presented in this report was to further enhance and expand the Project's understanding of the potential geochemical reactivity of the scavenger tailings, although some process waters and pyrite tailings from the 2014 pilot plant were also tested.

Geochemical characterization was conducted on tailings generated from metallurgical testing of three different size ore composites produced by RCM Metallurgy. Composites are chosen to represent the lithologies, alteration types, and predominant mineralogies of the ore that will be produced over the life of the mine. Smaller ore composites are called "individual composites" and are aggregated to form "master composites" that represent longer borehole intervals. The largest composite, used by RCM Metallurgy as feed for the 2014 pilot plant testing, was composed of approximately four tonnes of rock from 11 boreholes composited to represent roughly the first ten years of mine life.

The following static and kinetic testing was conducted as part of the 2014 – 2016 geochemical characterization program:

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- Static testing of 55 scavenger tailings samples produced from metallurgical processing (batch flotation) of 2014 Resolution individual ore composites including material representative of both anticipated operational conditions and a potential worst-case scenario that might result in high-pyrite ore being sent to the mill
  - Static testing of 34 scavenger tailings samples produced from metallurgical (locked cycle) testing of 2014 Resolution master ore composites
  - Static testing of five scavenger tailings and five pyrite tailings samples generated from pilot plant testing of about four tonnes of ore representative of ore that will be produced over approximately the first ten years of mining
  - Water quality analysis of 18 process water samples collected over eight days of pilot plant testing
  - Humidity cell testing of 12 scavenger tailings samples produced from metallurgical processing (locked cycle testing) of 2014 Resolution master ore composites (four tests are currently ongoing)
  - Humidity cell testing of six replicate samples of scavenger tailings produced from the 2014 pilot plant testing
  - Oxygen-consumption testing of two scavenger tailings samples and two high-pyrite tailings samples at three different moisture contents to provide pyrite oxidation rates as a function of pyrite concentration and moisture content

## **1.2 Potential Geochemical Reactivity of Resolution Tailings**

Based on earlier work presented in DHC (2014), and additional refinement from the recent testing outlined above, the composition and potential geochemical reactivity of the Resolution tailings are summarized in the following sections.

### **1.2.1 Pyrite Tailings**

- The majority of the non-economic sulfides (largely pyrite) and residual metals are segregated and concentrated into the pyrite tailings during metallurgical processing; this tailings stream will account for approximately 15 percent of the total tailings volume.
- Geochemical characterization studies consistently demonstrate that pyrite tailings are potentially acid generating, meaning that, if allowed to weather in an oxidizing environment, they may be expected to generate acidic conditions and produce drainage with elevated metal/metalloid and sulfate/total dissolved solids (TDS) concentrations.
- The acid generating potential of the pyrite tailings has long been recognized by the Resolution Project, and their tailings management strategy includes emplacement of the pyrite tailings under saturated conditions. Over the life of the mine, pyrite tailings will

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be encapsulated by scavenger tailings and, ultimately, covered with an engineered cover to prevent exposure to oxidizing conditions while maintaining a high moisture content.

### 1.2.2 Scavenger Tailings

- Scavenger tailings are primarily composed of silicate minerals with very small amounts of pyrite and carbonate minerals; this tailings stream will account for approximately 85 percent of the total tailings volume.
- Data from 41 scavenger tailings samples that represent anticipated operational conditions over the life of the mine show a range of sulfide sulfur contents between 0.01 and 1.09 weight percent; the sulfide sulfur contents of the 41 samples are log-normally distributed with a geometric mean of 0.07 weight percent. Over 80 percent of the tailings samples contain less than 0.2 weight percent sulfide sulfur.
- Based on interpretation of static test data using criteria provided in ADEQ's Best Available Demonstrated Control Technology document for APP (ADEQ, 2004) approximately 41 percent of the scavenger tailings samples are designated not potentially acid generating (NPAG), 15 percent are designated potentially acid generating (PAG), and 44 percent are Uncertain.
- Comparison of static test designations and humidity cell test (HCT) leachate chemistry indicates that the static test results are a reliable indicator of long-term geochemical reactivity as represented by the HCTs.
- Humidity cell tests indicate that, when weathered under oxidizing conditions:
  - Scavenger tailings designated NPAG produce circumneutral leachates (pH between 6 and 8 standard units (s.u.)) with titratable alkalinity and low sulfate and metal/metalloid concentrations
  - Scavenger tailings with Uncertain designation produce leachates with somewhat depressed pH values (between 4 and 5 s.u.) but with low titratable acidity (generally less than 20 mg/L as CaCO<sub>3</sub>). Sulfate, and metal/metalloid concentrations are low, similar to those observed in the circumneutral leachates
  - Scavenger tailings designated PAG produce leachates with pH less than 4 s.u., titratable acidity on the order of 50 to 150 mg/L as CaCO<sub>3</sub>, and sulfate concentrations ranging between approximately 25 and 100 mg/L. Consistent with low pH conditions, more metals are released at slightly higher concentrations than in the neutral and intermediate pH leachates.

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- Release of acidity, sulfate and metals/metalloids from the scavenger tailings is limited by the very low sulfide and residual metals content of these materials.

### **1.3 Application of Geochemical Testing Results**

It should be noted that the results of Resolution's geochemical tailings characterization program simply pertain to the likely geochemical reactivity of the tailings materials should they be exposed to consistently oxidizing conditions. Such bounding assumptions are industry standard practice (INAP, 2009) and are anticipated as a starting point in regulatory environments (ADEQ, 2004). These tests do not predict the composition of discharge from the tailings storage facility (TSF) or the quality of groundwater adjacent to the impoundment. Analytical data generated from geochemical testing of tailings will be used, along with metallurgical, engineering, and operating information, in solute/water-balance and fate-and-transport modeling that is planned pending completion of the hydrogeologic characterization of the proposed TSF site. The goal of the solute/water-balance and fate-and-transport modeling will be to provide a quantitative assessment of the potential chemical composition of discharge from the TSF as well as the groundwater quality adjacent to the proposed TSF during mining operations and post-closure.

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## 2.0 Introduction

Resolution Copper Mining LLC (RCM or Resolution) is proposing to develop an underground copper mine using the block cave mining method approximately two miles east of the town of Superior in the Pioneer Mining District, Pinal County, Arizona. It is anticipated that this project would generate approximately 1.5 billion tons (1.4 billion tonnes) of tailings material over a projected mine life of 40 years. RCM has conducted a series of characterization studies beginning in 2002 in order to determine the geochemical properties of the tailings and assess the potential for them to generate acidic drainage and leach metals or sulfate if allowed to weather under oxidizing conditions. This work has been conducted to support development of RCM's General Plan of Operations and subsequent NEPA assessment as well as the Project's application for an Aquifer Protection Permit (APP) from the Arizona Department of Environmental Quality (ADEQ).

The purpose of the current report is to present the results of geochemical characterization of Resolution tailings since the initial baseline report was published in August 2014 (DHC, 2014). The ultimate goal of the geochemical testing of tailings presented in this report is to understand the potential geochemical reactivity of the tailings were they allowed to weather under oxidizing conditions. Geochemical characterization of tailings materials has been carried out in accordance with industry best-practice guidelines including guidance from ADEQ regarding selection of best available demonstrated control technology (BADCT) for a tailings storage facility (TSF). The ADEQ divides characterization procedures into Tier 1 (static) and Tier 2 (kinetic) categories (ADEQ, 2004). Tests from both of these categories have been undertaken as part of RCM's geochemical characterization program.

It is important to note that geochemical characterization tests do not, and are not intended to, predict the quality of groundwater or surface water in the environment. Geochemical testing of the sort reported in this document allows identification of those materials that are likely to generate acidic conditions in an oxidizing environment and those that are likely to remain circumneutral. In addition, analysis of leachates generated from both static and kinetic testing provides information regarding constituents that might potentially be released under acidic conditions. For the purposes of this report, constituents are identified as having the potential to be released under acidic conditions if they are elevated with respect to metals concentrations in natural waters in non-mineralized systems as presented by Hem (1985). The leach tests reported in this document are not, themselves, representative of effluents that may be generated in the full-scale tailings storage facility; they are the results of standardized experiments, and so reflect the controls (such as water:rock ratio) characteristic of those experiments. The use of the Hem data is qualitative and intended only to provide an initial indication of elements that may require further attention as fate-and-transport models are



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developed and as Resolution continues to refine its engineering plans for tailings management during operations and final closure.

**Section 3** provides background information including:

- The process by which RCM generates metallurgical ore composites
- The process by which tailings are generated from metallurgical testing of RCM ore composites
- Information regarding the static and kinetic geochemical testing methods used to characterize the potential geochemical reactivity of RCM tailings
- A summary of Resolution's geochemical characterization program over the period 2002 through 2013 along with principal observations presented in the initial baseline report (DHC, 2014)
- A summary of the geochemical characterization tailings program undertaken in the period January 2014 through May 2016

**Section 4** provides a discussion of each of the principal program components including:

- Objectives of the study
- Sample selection and tailings generation
- Summary of the geochemical testing and characterization methods employed
- Results of testing

**Section 5** provides details regarding quality control/quality assurance (QA/QC) protocols.

Principal findings regarding the geochemical reactivity of the two tailings streams are presented in **Section 6**.

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## 3.0 Background

This section provides an overview of:

- Sample selection and tailings generation approach
- Geochemical testing methods utilized in RCM's tailings geochemical characterization program
- Resolution's geochemical characterization program over the period 2002 through 2013 presented in the initial baseline report (DHC, 2014)
- Geochemical testing conducted over the period January 2014 through May 2016

### 3.1 Sample Selection and Tailings Generation

#### 3.1.1 Ore Composites

Care was taken to select tailings generated from ore composites that are representative of the anticipated mill feed over the life of the mine. This is important because the composition of the mill feed is the primary determinant of the composition (and therefore potential geochemical reactivity) of the tailings. In order to ensure that the sample suite included tailings generated from ore representing all the principal lithologies and alteration types, and the operational range in pyrite grade, the ore composites were compared against the distribution of these characteristics in the entire ore body as represented by the Resolution geology block model. Results of this analysis are presented in **Section 4.1.2**.

The mill feed will be a highly blended mixture of the range of lithologies, alteration types, and predominant mineralogies present in the ore body. The high degree of blending is a function of the block cave mining method which provides mill feed that is a mixture of ore being produced from a series of drawpoints distributed areally (i.e. laterally) across the active block. Each drawpoint produces ore from a different elevation depending on its relative time in service and the rock quality and fragmentation times encountered. Therefore, the composition of the mill feed is a function of: the geometry of the Resolution ore body; the distribution of lithology, alteration type, and mineralogy; and, the ore production schedule. Life-of-mine models produced from the Resolution geology block model indicate that the maximum pyrite grade in the mill feed is estimated to be 15 weight percent, and for much of the life of the mine it will be substantially lower.

Geochemical characterization was conducted on tailings generated from metallurgical testing of three different-size ore composites produced by RCM Metallurgy. The smaller ore composites

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are built from rock from a single borehole collected from the interval between approximately 330 feet (100 meters) above the top of the ore body (defined by the 1 percent copper grade shell) and the total depth of the borehole. The smallest composites, called “individual composites”, are collected over intervals of approximately 100 to 230 feet (30 to 70 meters). These composites are then aggregated to form “master composites” that represent borehole intervals on the order of 500 to 820 feet (150 to 250 meters) in length. Composite boundaries are selected on the following criteria (in order of descending importance):

1. Major lithological boundaries
2. Predominant alteration boundaries
3. Significant changes in copper grade and/or changes in predominant copper mineralogy
4. Pyrite content
5. Length

The largest composites tested by RCM Metallurgy are the pilot plant ore feed samples. Geochemical characterization data for tailings generated during the 2014 pilot plant testing are presented in this report. The ore composite tested in the 2014 pilot plant was approximately four tonnes of quarter core from 11 boreholes composited to represent roughly the first ten years of mining.

### **3.1.2 Tailings Generation (Metallurgical Testing)**

Metallurgical testing has been conducted at both laboratory and pilot-plant scales as described below. The overall approach to extractive metallurgical testwork for the Resolution Copper Deposit is considered to be representative of the unit processes and their products for a full-scale mine.

#### ***3.1.2.1 Batch Flotation Testing***

Batch flotation testing is laboratory-scale testing that is conducted in two stages. The first stage (called the “rougher/scavenger” stage in metallurgical engineering) separates the copper and molybdenum-bearing minerals and the sulfide gangue minerals (mainly pyrite) from the non-sulfide gangue (mostly quartz and aluminosilicate minerals), producing a low grade concentrate. The second stage (called the “cleaner” stage) utilizes additional flotation to increase the copper content of the rougher concentrate and generate a copper concentrate. During the cleaner stage, additional non-sulfide and sulfide gangue minerals are rejected as cleaner tailings (referred to as “pyrite tailings” in this document).

Two flotation approaches (“bulk” and “selective”) were assessed during the 2014 metallurgical testing that provided tailings for environmental characterization. Both approaches are fundamentally the same from the perspective of the scavenger tailings. Where they differ is in

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the way the pyrite tailings are produced. The bulk approach moves more of the pyrite into the cleaner circuit (where it is eventually discharged as “cleaner tailings”), whereas the selective approach results in some of the pyrite being discarded without passing through the cleaner circuit (as “pyrite scavenger concentrate”). In the selective approach, the pyrite scavenger concentrate is eventually combined with the cleaner tailings to make a high-sulfide tailings product known as pyrite tailings. In this document, all low-sulfide tailings are referred to as “scavenger tailings” and all high-sulfide tailings, whether they are generated using the bulk or the selective approach, are referred to as “pyrite tailings”.

### ***3.1.2.2 Locked Cycle Testing***

A locked cycle test in extractive metallurgy is composed of a series of batch flotation tests (typically seven cycles) in which copper and molybdenum minerals are progressively recovered. Each stage of the test results in a concentrate that is enriched in the ore minerals of interest and tailings that are depleted in economic minerals. The locked cycle testing conducted on Resolution ore has varied from study to study in terms of the reagents used, number of stages, number of cycles, and other operational details. However, all the locked cycle tests produced only two tailings streams, the scavenger and pyrite tailings. Tailings samples used in RCM’s tailings characterization program were a composite of material from the final three cycles of testing. This approach is consistent with industry standard practice and generates samples that represent the steady-state conditions attained toward the end of each test.

### ***3.1.2.3 Pilot Plant***

Design of the 2014 pilot plant was based on the results of laboratory-scale metallurgical testing (batch and locked cycle) and included a grinding circuit followed by rougher/scavenger flotation, regrinding, and three stages of cleaner flotation. Approximately four tonnes of ore, deemed by RCM Geology and Metallurgy to be representative of ore that will be produced over approximately the first ten years of mine life, were processed through the pilot plant, and both pyrite and scavenger tailings streams were produced. Roughly sixty percent of the sample was dedicated to the bulk flotation approach and forty percent was tested in accordance with the selective approach.

## **3.2 Geochemical Characterization of Tailings: Static and Kinetic Methods**

Geochemical characterization of tailings has been carried out in accordance with industry best-practice guidelines (INAP, 2009) and guidance from ADEQ regarding best available demonstrated control technology (BADCT) for a tailings storage facility (TSF). The ADEQ divides characterization procedures into static (Tier 1) and kinetic (Tier 2) categories (ADEQ, 2004).

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Data generated from both static and kinetic testing methods are presented in this report and a brief description of each testing method is provided below.

### **3.2.1 Static (Tier 1) Geochemical Testing**

Static geochemical testing consists of a set of analyses that, taken together, describe the potential for a material to generate acidic conditions and/or leach metals or other constituents of concern when weathered under oxidizing conditions. These scoping tests do not provide information regarding whether such acidic conditions would actually occur, nor do they provide information regarding the potential timing of the onset of such conditions. Data from kinetic tests, described in **Section 3.2.2**, are used to investigate leachate composition and the timeframe within which geochemical changes occur. The following sections provide a brief description of each of the static tests conducted as part of the RCM baseline tailings characterization program.

#### ***3.2.1.1 Acid-Base Accounting***

Acid-base accounting (ABA) is used as an initial screening tool to evaluate the potential of a material to generate acidic conditions due to weathering in an oxidizing environment. ABA analyses measure the relative amounts of potentially acid generating minerals and potentially acid neutralizing minerals in a given sample. Results are expressed in this report using the terms listed below. It should be noted that many variations on this nomenclature are used in the literature, and in other Project documents, but all terms are generally intended to express the potential of a material to produce or neutralize acidity under oxidizing conditions and, as such, are largely equivalent.

- Paste pH indicates the present drainage pH of the sample and may be used to identify samples that have undergone some degree of oxidation between being generated and tested.
- Acid generating potential (AGP) is calculated from the sulfide sulfur content of the sample. The AGP of materials determined using ABA methods is a conservative measure in that the calculations assume that all sulfide sulfur is present as pyrite and that all the pyrite is available for oxidation (see **Section 3.2.1.5** for a brief discussion of the relationship between pyrite and sulfide sulfur content). The AGP value generated by ABA calculations is a maximum value that does not account for the presence of sulfides that produce less acidity than pyrite during oxidation, or those sulfide grains that are not accessible due to encapsulation by silicates or other less reactive minerals.

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- Acid neutralizing potential (ANP) is a measure of the amount of acid that a given material is capable of neutralizing. There are two forms of ANP which are calculated from the amount and type of potentially neutralizing minerals in a sample. The carbonate ANP is based on the carbonate mineral content of the sample which is calculated from the measured total inorganic carbon. In contrast, bulk ANP (often called Sobek NP, after the lead author of the original EPA study (Sobek et al., 1978)) is measured using a titration test that determines the amount of strong acid the rock can neutralize. This ANP test does not distinguish neutralization provided by silicate minerals (e.g. phlogopite, chlorites, and amphiboles) from that provided by carbonates.
  - Net neutralization potential (NNP) is calculated as the difference between ANP and AGP ( $NNP = ANP - AGP$ ).
  - AGP, ANP, and NNP are all expressed in units of tons of equivalent calcium carbonate ( $CaCO_3$ ) per kiloton of rock ( $T CaCO_3/kT$  rock).
  - Neutralization potential ratio (NPR) is the ratio ANP to AGP ( $NPR = ANP/AGP$ ) and is unitless.

Theoretically, materials with an NNP of less than  $0.0 T CaCO_3/kT$  rock and an NPR of less than 1 are classified as potentially acid generating (PAG), whereas materials with an NNP of greater than  $0.0 T CaCO_3/kT$  rock and an NPR of greater than 1 are not potentially acid generating (NPAG). It should be noted that, in classifying the NNP of RCM scavenger tailings, it is necessary to calculate the difference between two very small values that are close to the analytical limit of detection. The AGP of the scavenger tailings is small due to very low sulfide sulfur contents, and the ANP is often small due to the low carbonate content of the Resolution tailings. In order to avoid potential error and ambiguity associated with NNP calculated from small AGP and ANP values, greater weight is given to NPR values in this report. This approach is consistent with guidance provided in MEND (2009).

Although, theoretically, materials with NPR greater than 1 are NPAG it is recognized that determination of the NPR is subject to analytical uncertainty as well as variability introduced through sample selection, handling, and storage (INAP, 2009; MEND, 2009). In order to account for limitations imposed by these factors a safety margin is often applied to the upper threshold criterion used to classify materials as NPAG. Many entities involved in geochemical characterization of mine wastes suggest that an NPR value of 2 provides a reasonable margin of safety (AMIRA (2002), INAP (2009), MEND (2009)) and this was the threshold used to categorize potential geochemical reactivity based on ABA data in the initial baseline tailings geochemistry report (DHC, 2014). However, the criterion currently recommended for designation of a material as NPAG in the Arizona Department of Environmental Quality's (ADEQ's) Best Available Demonstrated Control Technology (BADCT) guidance document is an NPR value of 3 (ADEQ, 2004). Given that the work presented in this current document has been conducted to support

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Resolution's application for an Aquifer Protection Permit from the ADEQ (as well as for use during ongoing NEPA investigations) categorization of tailings as NPAG based on ABA data presented in this report use a threshold criterion of NPR equal to 3 (i.e. tailings samples with NPR greater than 3 are classified NPAG and with NPR between 1 and 3 are classified as Uncertain). It should be noted that the change in threshold criterion affects the distribution of samples between the NPAG and Uncertain categories, but does not change the proportion of tailings designated PAG as that criterion remains at NPR less than 1.

An additional consequence of the low acid-generating and acid-neutralizing capacities of the scavenger tailings is that material heterogeneity, the ability of a given sample to represent that heterogeneity, and analytical uncertainty all impact the values to a greater degree than when large quantities of acid-generating or acid-neutralizing materials are present and the NPR is clearly dominated by one or the other. Although comparisons to industry guidelines are provided in this report, it should be noted that ABA results must be interpreted within the larger context of mineralogy and the results of kinetic testing in order to form an accurate understanding of the potential reactivity of these materials under oxidizing conditions.

### ***3.2.1.2 Net Acid Generation Testing***

Net acid generation (NAG) testing is used to assess whether a sample is capable of neutralizing the acid produced by the complete oxidation of all sulfide minerals present in the sample. The oxidation is achieved using hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), a much stronger oxidizer than is oxygen in air. NAG testing may also provide an estimate of the leachate chemistry should complete oxidation of sulfide minerals occur. After complete oxidation of the sulfide minerals within the sample, the NAG solution is analyzed for pH and a full suite of chemical parameters; however, it should be understood that the observed concentrations are specific to the test protocol, including use of H<sub>2</sub>O<sub>2</sub> and a high solution: solid leaching ratio. The NAG tests are most useful when evaluated in conjunction with the standard ABA methodologies, as independent methods of assessing acid generation potential at the screening level.

NAG results are interpreted as follows (MEND, 2009; Stewart et al., 2006):

- Final pH > 4.5 s.u.: not potentially acid generating (NPAG)
- Final pH < 4.5 s.u.: potentially acid generating (PAG)

The division at pH = 4.5 s.u. is a consequence of the titration end-point for carbonate alkalinity.

### ***3.2.1.3 Synthetic Precipitation Leaching Procedure***

The Synthetic Precipitation Leaching Procedure (SPLP) is used to determine what chemical constituents are likely to initially leach from a geologic material during natural weathering (e.g.,

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exposure to precipitation or surface water runoff). The initial leach solution is distilled water that has been slightly acidified to match precipitation chemistry (pH 4.2 s.u.) according to U.S. EPA Method 1312. The leach solution and geologic material are combined with a water:rock ratio of 20:1 and rotated end-over-end for 24 hours and the resulting leachate is analyzed for common ions, metals, metalloids, and water quality parameters. SPLP results need to be considered in terms of the history of the sample under leach (i.e., whether it is fresh rock or an aged, weathered sample that has already been exposed to oxidation) and the water: rock ratio of the test in light of site-specific hydrology (i.e., the 20:1 water: rock ratio used in the SPLP in comparison to a water: rock ratio of approximately 1:6 for a saturated sample of porous-medium, aluminosilicate rock at 30 percent porosity). If the final SPLP pH is above the initial leachate pH of 4.2 s.u., then the solid consumed acidity and released alkalinity during leaching and is therefore not considered to be acid generating. Conversely, if the final pH is below the initial leachate pH, there was addition of mineral acidity during leaching and the sample is classified as acid generating.

#### ***3.2.1.4 Whole Rock Chemical Analysis***

Whole rock chemical analyses were conducted using two techniques: 1) strong acid digestion followed by analysis by inductively coupled plasma-mass spectrometry (ICP-MS) for a full suite of major ions and metals; and, 2) a lithium borate fusion followed by x-ray fluorescence (XRF) spectroscopy for major and minor oxide determinations. Whole rock chemistry data are compared with crustal element abundances to identify constituents present at elevated concentrations in a given sample. This analysis does not provide information regarding the leachability or mobility of any chemical component but does allow identification of potential constituents of concern for further investigation. This study uses crustal abundances from Price (1997); where Price (1997) does not provide data, values from Mason and Moore (1982) were used.

#### ***3.2.1.5 Mineralogical Analyses***

Mineralogical analyses conducted as part of the geochemical characterization of tailings include:

- X-ray diffraction (XRD) with semi-quantitative analysis to identify the relative abundance of mineral phases present in a sample. XRD does not detect amorphous or non-crystalline compounds. Detection limits are generally on the order of about 0.5 to 2 weight percent.
- Quantitative Evaluation of Minerals by Scanning Electron Microscope (QEMSCAN) also provides data on bulk mineralogy and relative abundance with lower detection limits than XRD.



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Mineralogical analyses often report pyrite, which is a mineral containing both iron and sulfur. The ideal composition of pyrite (i.e., pyrite where all the iron is in the Fe(II) oxidation state and where no other trace metals are substituted for iron in the mineral lattice) is represented by the chemical formula FeS<sub>2</sub>. According to the stoichiometry of the pyrite molecule, sulfur accounts for approximately 53 percent of the mass of ideal pyrite. Therefore, if pyrite is the only sulfide mineral present, a sample containing 10 weight percent pyrite would be expected to have a sulfide sulfur content of 5.3 weight percent. This is important because sulfide sulfur is a principal component in determination of the acid generating potential of a given material, and, in Resolution ore, the primary source of sulfide sulfur is pyrite. Any large discrepancy between sulfide calculated from pyrite content and sulfide sulfur content measured as part of ABA analyses, likely indicates either the presence of additional, non-pyrite, sulfide minerals or analytical error in either the mineralogical analysis or the sulfide sulfur determination.

### ***3.2.1.6 Particle Size Distribution***

The particle (or grain) sizes of the solid tailings materials were determined using sieve and hydrometer methods. Understanding the distribution of grain sizes in a sample, and how the grain sizes correlate with mineralogy, provides valuable insight into the relative reactivity of a material. In general, materials that contain reactive minerals (e.g., sulfides or carbonates) in the smaller size fractions will weather more quickly than materials that contain reactive minerals in the larger size fractions. Particle size distribution (PSD) is commonly used to scale experimental results up or down between materials used in the laboratory and those expected to be encountered under operational conditions. However, for the testing summarized in this report, the test tailings are understood to be equivalent in PSD to the anticipated operational tailings, and little or no scaling of results should be required.

### ***3.2.1.7 Chemical Analysis of Process Water***

During mining operations the chemistry of discharge from the TSF will be dominated by the chemistry of pore-water released from the tailings due to compaction and drain-down. Process water samples generated during pilot plant testing have been analyzed in order to determine the likely chemical composition of pore-waters in the tailings at the time of deposition in the tailings storage facility. Samples were analyzed for water quality parameters, common ions, and trace metals and metalloids using standard analytical methods.

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## 3.2.2 Kinetic (Tier 2) Geochemical Testing

Kinetic (Tier 2) tests provide information on the rates at which weathering and leaching reactions occur in a sample. In this study humidity cell testing (HCT) and oxygen-consumption testing were conducted. Brief descriptions of both methods are provided below.

### 3.2.2.1 Humidity Cell Testing

Humidity cell tests (HCTs) were conducted to determine: 1) the rate at which acid generation and neutralization reactions occur when a sample is exposed to water and air; 2) the chemical composition of, and mass loading to, the leachate; 3) changes in the solid phase geochemistry such as the depletion of acid generating or neutralizing minerals; and, 4) in the case of samples that do generate acidic conditions, the lag time to onset of acid generation. In addition, HCTs are used to determine the likelihood that a rock type with Uncertain ABA classification will produce acidic leachates.

Humidity cell testing was carried out in accordance with the American Society of Testing and Materials (ASTM) D5744-96 procedure (ASTM, 1996). The tailings material is placed in a cylindrical column, saturated with deionized water and allowed to drain. Then dry air is circulated through the sample for three days followed by three more days of humid air. At the end of each one-week cycle, deionized water is added to the samples at a fixed mass: mass ratio of 1:1, allowed to sit for one hour, and then drained. The leachate is preserved and analyzed for water quality parameters and common and trace chemical constituents. Results are assessed in order to identify changes in pH, acidity, alkalinity, sulfate, and metals with time.

There are generally two primary domains in the time-series data yielded by HCTs. Over the first few weeks of testing, higher concentrations of acidity, sulfate, and metals/metalloids may be observed in the leachates. This “first-flush” period may be due to dissolution of soluble mineral phases (such as sulfates) and/or rinsing out of secondary oxidation products produced by alteration of the tested material during sample production, collection or storage. After the first flush, leachate chemistry generally stabilizes to a composition controlled by the primary mineral alteration processes occurring in the tested material (primarily oxidation of sulfides and dissolution of carbonate phases with perhaps some impact from dissolution or leaching of the more reactive silicate phases). The leachate composition in this second time domain is taken to be indicative of the potential long-term geochemical reactivity of the tested materials.

For the purposes of this report HCT leachates are organized into three categories based on pH:

- Circumneutral: pH between 6 and 8 s.u. and containing titratable alkalinity
- Intermediate: pH between 4 and 6 s.u. with titratable acidity less than 20 mg/L as CaCO<sub>3</sub>

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- Low: pH between 3 and 4 s.u. with titratable acidity ranging between 20 and 150 mg/L CaCO<sub>3</sub>

Note that acidity values reported in this document are total acidities determined by titration to a pH endpoint of 8.3 s.u. Alkalinity values are determined by titration to pH 4.5 s.u. for samples containing alkalinity greater than 20 mg/L as CaCO<sub>3</sub>. For samples with alkalinity less than 20 mg/L as CaCO<sub>3</sub> this is followed with an additional titration to pH 4.2 s.u.

### ***3.2.2.2 Oxygen Consumption Testing***

Geochemical modeling of the processes involved in weathering of tailings under oxidizing conditions requires quantification of the kinetic rate at which pyrite is oxidized. Oxygen consumption testing is a method designed to determine pyrite oxidation rates by measuring the amount of oxygen consumed by the reaction over a given period of time. The material to be characterized is placed in a closed reaction vessel and the oxygen and carbon dioxide content of the head-space gas is monitored. By combining the oxygen consumption data with the stoichiometry of the pyrite oxidation reaction, the initial pyrite oxidation rate is calculated.

## **3.3 Summary of Geochemical Characterization of Tailings 2002 through 2013**

This section provides a summary of the principal findings of the testing program over the period 2002 through 2013. The results of this work informed the design of the subsequent testing program, implemented since 2014. Further information regarding the testing program between 2002 and 2013 and detailed results are provided in the initial tailings geochemistry baseline report (DHC, 2014)

### **3.3.1 Background**

- Geochemical characterization of Resolution tailings began in 2002. Over the following decade, a series of studies utilizing both static and kinetic (Tier 1 and 2) tests was conducted culminating in three multi-year kinetic studies at both laboratory and field-cell scales.
- Resolution's tailings management strategy calls for separation of tailings into two mineralogically and geochemically discrete streams known as "pyrite" and "scavenger" tailings. Historically, Project documents have referred to pyrite tailings as "cleaner" tailings; however, in order to be consistent with metallurgical nomenclature, the Project now uses "pyrite" tailings as a more descriptive and less process-specific term.

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- Pyrite tailings contain the majority of the pyrite and residual metals segregated from the ore; this tailings stream will account for approximately 15 percent of the total tailings volume.
  - Scavenger tailings contain very low concentrations of sulfide sulfur and residual metals due to segregation of the majority of the pyrite to the pyrite tailings and segregation and recovery of the remaining sulfide and metals to the concentrate; the scavenger tailings will account for approximately 85 percent of the total tailings volume.
  - Other tailings products considered during process development and optimization, including whole tailings and cycloned scavenger tailings, were also subjected to geochemical testing; however, these products are not produced per the mine plan of operations and tailings management plan.
  - It should be noted that the results of geochemical testing included in both the initial tailings geochemistry baseline report (DHC, 2014) and the current report simply pertain to the likely geochemical reactivity of the tailings materials should they be exposed to oxidizing conditions. These tests do not predict the composition of discharge from the tailings storage facility (TSF) or the quality of groundwater adjacent to the impoundment.
  - Analytical data generated from geochemical testing of tailings will be used, along with metallurgical, engineering and operating information, in solute/water-balance and fate-and-transport modeling that is planned pending completion of the hydrogeologic characterization of the proposed site of the TSF. The goal of the solute/water-balance and fate-and-transport modeling is to provide a quantitative assessment of the potential chemical composition of discharge from the TSF under the range of operating conditions of gas and water flux through the design-basis tailings as they will be deposited and managed. These evaluations also will provide the ranges of groundwater quality adjacent to the proposed TSF during mining operations and post-closure.

### **3.3.2 Pyrite Tailings**

- The majority of the non-economic sulfides (largely pyrite) and residual metals are segregated and concentrated into the pyrite tailings during metallurgical processing (flotation).
- Geochemical characterization studies consistently demonstrate that pyrite tailings exposed to atmospheric levels of oxygen are potentially acid generating, meaning that, if allowed to weather in an oxidizing environment, they may be expected to generate acidic conditions and produce drainage with elevated metals and sulfate.

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- The acid generating potential of the pyrite tailings has long been recognized by the Resolution Project, and the current tailings management strategy includes emplacement of pyrite tailings under saturated conditions. Over the life of the mine, pyrite tailings will be encapsulated by scavenger tailings and, ultimately, enclosed with an engineered cover to prevent exposure to oxidizing conditions while maintaining a high moisture content.

### **3.3.3 Scavenger Tailings**

- Scavenger tailings contain very little pyrite due to the segregation of pyrite to the pyrite tailings.
- RCM's metallurgical program has demonstrated that production of scavenger tailings with very low sulfide sulfur content is an achievable goal.
- Geochemical characterization indicates that scavenger tailings with very low sulfide sulfur contents are unlikely to leach metals or sulfate at concentrations of environmental concern.
- Geochemical characterization of scavenger tailings was ongoing at the time the initial tailings geochemistry report was submitted. The primary focus of the 2014 – 2016 tailings characterization program has been to supplement and expand the Project's understanding of the likely geochemical reactivity of the scavenger tailings.

## **3.4 Summary of Geochemical Characterization of Tailings 2014 to Present**

This section provides a brief summary of the principal components of the tailings characterization program conducted between January 2014 and May 2016. Details regarding each component of the program and selected data are presented in **Section 4**.

### **3.4.1 Static Testing**

Scavenger tailings produced from metallurgical testing in 2014 were subjected to static geochemical testing. These tailings are the product of metallurgical testing on three scales and levels of complexity: batch flotation testing of individual composite ore samples, locked cycle testing of master composite ore samples, and pilot plant testing of a large (roughly 4 tonne) ore composite designed to represent approximately the first ten years of mining. A brief summary of each set of static tests (or Tier I tests as defined by ADEQ) is provided in the following sections.

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#### ***3.4.1.1. Static Testing of Scavenger Tailings from 2014 Individual Ore Composites***

Fifty-five scavenger tailings samples generated from individual ore composites were subjected to ABA, NAG pH, and NAG leachate testing (see **Section 3.1.1** for explanation of ore composites). The goal of this work was to develop a database of ABA and NAG data for scavenger tailings deemed representative of scavenger tailings that will be produced under operational conditions. Forty-one of the 55 scavenger tailings samples were produced from ore samples representative of the full range of lithology, alteration type, and pyrite content that will be produced over the life of the mine. In addition, a smaller set of tailings samples (14 samples) generated from high-pyrite ore composites were submitted for testing to provide data representative of a potential worst-case scenario that might result in a period of high-pyrite mill feed. Static test results are presented in **Section 4.1**.

#### ***3.4.1.2 Static Testing of Scavenger Tailings from 2014 Master Ore Composites***

Thirty-four scavenger tailings samples generated from master ore composites were subjected to ABA, NAG pH, and NAG leachate testing (see **Section 3.1** for explanation of composites). The goal of this work was to provide an initial, scoping-level characterization of the master composite scavenger tailings to enable a representative subset of the samples to be chosen for kinetic testing. Master composites were compiled from the 2014 individual ore composites discussed in **Section 4.1**. Scavenger tailings were produced from flotation of master ore composites following two approaches (bulk and selective). Static test results are presented in **Section 4.2**.

#### ***3.4.1.3 Static Testing of Tailings from 2014 Pilot Plant Testing***

Scavenger and pyrite tailings streams from the 2014 pilot plant were subjected to a suite of static tests including: ABA, NAG pH, NAG leachate, SPLP, and TCLP. In addition, process water samples were collected over the period of the test and submitted for water quality analyses. The goal of this work was to characterize the geochemical composition and acid generation potential of both the scavenger and pyrite tailings and to determine the chemical composition of process water representative of the water that will be delivered to the TSF in the tailings slurry. The pilot plant feed was a composite ore sample deemed representative of approximately the first ten years of mine life. Static test results are presented in **Section 4.3**. Laboratory reports for the process water analyses are provided in **Appendix A**.

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### 3.4.2 Kinetic Testing

Tailings produced from 2014 metallurgical test work were subjected to kinetic geochemical testing utilizing two test methods: humidity cell testing (HCT) and oxygen-consumption testing (Ox-Con). Two sets of samples were subjected to humidity cell testing (some of which are currently ongoing). The first is a set of 12 scavenger tailings samples generated from locked cycle testing of 2014 master ore composites, and the second is a set of six replicate samples of scavenger tailings generated from 2014 pilot plant testing. Oxygen-consumption testing was conducted on both scavenger and pyrite tailings from the 2014 pilot plant. A brief summary of each of these studies is presented below.

#### ***3.4.2.1 Humidity Cell Testing of Scavenger Tailings from 2014 Master Ore Composites***

Humidity cell testing of twelve scavenger tailings samples generated from master ore composites was initiated April 28, 2015. Care was taken to select tailings samples produced from ore that is representative of the distribution of principal lithologies and alteration types in the Resolution deposit. Nine of the 12 samples were generated from ore composites representative of the range of pyrite grade anticipated in the mill feed under operational conditions. Three samples were included to assess the geochemical reactivity of scavenger tailings that might be produced if “worst-case” conditions were to result in a period of high-pyrite mill feed.

The goal of this work is to assess the potential long-term geochemical reactivity of scavenger tailings representative of those anticipated to be produced under both operational and worst-case conditions. Prior to commencement of humidity cell testing, all HCT samples were submitted for a second round of static tests to identify any changes that had occurred in storage and to provide more detailed characterization of this subset of the scavenger tailings samples. Eight HCTs have been decommissioned as leachate chemistry had stabilized and depletion rates of sulfide sulfur and neutralization potential were well-defined. Four HCTs are ongoing; data for these tests are provided through week 51. Selected results and discussion are presented in **Section 4.4.9**; complete data are provided in **Appendix B**.

#### ***3.4.2.2 Humidity Cell Testing of Scavenger Tailings from 2014 Pilot Plant Testing***

Six replicate samples of scavenger tailings from Day 3 of the 2014 pilot plant testing were subjected to humidity cell testing for a leaching period of 50 weeks. The goal of this work is to assess the repeatability of the HCT method and associated sub-sampling techniques. Selected results and discussion are presented in **Section 4.5**; complete HCT data are provided in **Appendix C**.

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### ***3.4.2.3 Oxygen-Consumption Testing of Scavenger and Pyrite Tailings from 2014 Pilot Plant Testing***

Four pilot plant tailings samples, two scavenger and two pyrite, were subjected to oxygen consumption testing in 2015. Each of the samples was tested at three different moisture contents. The goal of this work was to determine initial pyrite oxidation rate in tailings as a function of pyrite concentration and moisture content. Results and discussion are presented in **Section 4.6.**



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## 4.0 Geochemical Characterization Studies

This section presents summaries of the principal tailings geochemical characterization tasks undertaken over the period January 2014 through May 2016. Each subsection provides information regarding the objective of the study, the materials that were tested, the test methods implemented, principal results and observations, and references to the laboratory reports.

It is important to note that the geochemical characterization tests presented in the following sections do not, and are not intended to, predict the quality of groundwater or surface water in the environment. Geochemical testing of the sort reported in this document allows identification of those materials that are likely to generate acidic conditions in an oxidizing environment and those that are likely to remain circumneutral. In addition, analysis of leachates generated from both static and kinetic testing provides information regarding constituents that might potentially be released under acidic conditions. These tests do not predict the composition of discharge from the tailings storage facility or the quality of groundwater adjacent to the impoundment.

### 4.1 Static Testing of Scavenger Tailings from 2014 Individual Ore Composites

Static testing of scavenger tailings from 2014 individual ore composites was conducted at SGS Environmental Services (SGS) in Lakefield, Canada. Analyses include ABA, NAG pH, and NAG leachate composition. Results are provided in SGS (2015a) and summarized below.

#### 4.1.1 Objectives

The goal of this work was to develop a large set of ABA and NAG data for scavenger tailings deemed representative of scavenger tailings that will be produced during mining.

#### 4.1.2 Sample Selection and Preparation

Individual ore composites (ICs) were selected from four boreholes RES-027C, RES-029A, RES-029B, and RES-031 by RCM Geology and Metallurgy personnel. Sample identifiers, borehole intervals, and the lithology, alteration type, and pyrite grade of the ICs are summarized in **Table 4.1-1**. Individual composites from RES-027C, RES-029A, and RES-029B were subjected to batch flotation testing at FLS (Dawson) in Salt Lake City, Utah. Approximately 400 milliliters (mL) of the final scavenger tailings slurry was collected from each test, filtered, bagged, and submitted to SGS Lakefield for environmental testing. Batch flotation testing of ICs from RES-031 was

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conducted at SGS Lakefield and scavenger tailings samples were collected for environmental testing in a manner consistent with sampling procedures used at FLS (Dawson).

An important question regarding the individual ore composites used to generate the scavenger tailings characterized in this task is: “To what degree are the ore composites representative of ore that will be produced over the life of the mine?” In order to address this question several properties of the ore composites were compared against the distribution of the same characteristics in the entire ore body as represented by the Resolution geology block model. The benchmark parameters used in this assessment included: lithology, alteration type, and pyrite grade. As illustrated by the comparisons presented below, the individual ore composites are representative of the distribution of lithology and alteration within the modeled ore body and, where there are small departures, they are conservative (i.e. material properties that contribute to acid generation are more highly represented in the individual composites than in the modeled ore body).

Although the individual ore composites are representative of the range of ore lithology and alteration type that will be produced over the life of the mine, they also represent substantially higher pyrite grades than will be sent to the mill. This is because the individual ore composites include samples that contain as much as 40 weight percent pyrite which is considerably higher than the anticipated maximum mill feed pyrite grade of 15 weight percent (see **Section 3.1.1** for further discussion of anticipated mill feed composition). Scavenger tailings from these very high-pyrite ore composites were included in the sample set to provide data should a worst-case scenario result in a period of higher than anticipated pyrite grade in the mill feed. In addition, flotation of these ore composites provides confidence that the flotation approach can successfully partition the majority of the pyrite to the pyrite tailings and produce low-sulfide scavenger tailings from high-pyrite ore. This means that, even under a very conservative worst-case scenario in which high-pyrite ore is sent to the mill, there would not be an associated period during which high-pyrite scavenger tailings were deposited in the TSF.

Note that as part of the detailed assessment of the IC suite presented below we refer to the results of acid base accounting and net acid generation testing although these data have not yet been presented. Please see **Sections 4.1.3 through 4.1.5** for ABA and NAG results and discussion.

#### ***4.1.2.1 Distribution of Lithologies in Individual Ore Composites***

The following lithologies are represented in the suite of individual ore composites (geologic abbreviations are provided in parentheses). Also provided is the number of composites composed of each lithology.

- Breccia: 14

- Cretaceous quartzose sandstone (Kqs): 1
- Cretaceous volcanoclastics rocks (Kvs): 11
- Precambrian basalt (pCbas): 1
- Precambrian diabase (pCdiab): 14
- Precambrian Mescal Limestone (pCmls): 1
- Paleozoic carbonates (Pz): 1
- Quartz Eye Porphyry (QEP; also known as Cretaceous-Tertiary rhyodacite porphyry (KTrdp)): 4
- Quartzite: 8

The lithologies represented in the IC sample suite are summarized in the table below along with the proportions of the principal lithologies in the RCM ore body block model (a principal lithology is defined for the purposes of this report as any lithology present at greater than 5 volume percent). Inspection of this table shows that all principal lithologies present in the RCM block model are represented in the IC sample suite. The IC sample suite is reasonably representative of the distribution of modeled lithologies in the ore body (and therefore over the life of the mine) with diabase slightly under-represented and Kvs somewhat over-represented.

Lithology	Fraction of Ore Body (by volume)	Fraction of ICs (by number of samples)
Breccia	0.17	0.25
pCdiab	0.36	0.25
Kqs	0.05	0.02
Kvs	0.09	0.20
QEP (KTrdp)	0.15	0.07
Quartzite	0.12	0.15

**Figure 4.1-1** provides a plot of NPR vs. NAG pH as a function of the principal lithologies. Inspection of **Figure 4.1-1** yields the following observations:

- Scavenger tailings from breccia ICs are generally NPAG
- Scavenger tailings from Kvs ICs are generally PAG
- Scavenger tailings from pCdiab ICs span the whole spectrum but yield more NPAG samples than PAG
- Scavenger tailings from QEP ICs are all NPAG
- Scavenger tailings from quartzite ICs are distributed evenly across the AGP spectrum

The relationship between AGP and lithology shown in **Figure 4.1-1** indicates that the over-representation of Kvs (which tends to be more PAG) and under-representation of pCdiab (which

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tends to be more NPAG) in the IC suite may skew the distribution of AGP in the scavenger tailings toward a slightly higher proportion of PAG samples than will be produced over the life of the mine. Data generated from these tailings may therefore be expected to provide a conservative estimate of the potential for the scavenger tailings to produce acidic conditions.

#### ***4.1.2.2 Distribution of Alteration Types in Individual Ore Composites***

The following alteration types are represented in the IC suite (the number of samples of each alteration type is also provided):

- Advanced Argillic: 8
- Phyllic: 28
- Potassic: 17
- Skarn: 2

The alteration types represented in the IC sample suite are summarized in the table below along with the proportions of the principal alteration types in the RCM ore body block model. Inspection of this table shows that all principal alteration types present in the RCM block model are represented in the IC sample suite. The IC sample suite is reasonably representative of the distribution of modeled alteration types in the ore body with phyllic slightly over-represented and potassic slightly under-represented.

<b>Alteration Type</b>	<b>Fraction of Ore Body (by volume)</b>	<b>Fraction of ICs (by number of samples)</b>
Advanced Argillic	0.18	0.15
Phyllic	0.37	0.51
Potassic	0.44	0.31

**Figure 4.1-2** provides a plot of NPR vs. NAG pH as a function of the principal alteration types. Inspection of **Figure 4.1-2** yields the following observations:

- Scavenger tailings from advanced argillic ICs are all PAG
- Scavenger tailings from phyllic ICs span the whole spectrum but yield more NPAG samples than PAG
- Scavenger tailings from potassic ICs also span the whole spectrum but are strongly skewed toward NPAG

The relationship between AGP and lithology shown in **Figure 4.1-2** indicates that the IC suite is reasonably representative of the AGP with respect to alteration type although the slight over-representation of the phyllic alteration type may skew the AGP of the IC suite somewhat toward the PAG end of the spectrum. This results in a data set that is expected to provide a conservative estimate of the potential for the scavenger tailings to produce acidic conditions.

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#### **4.1.2.3 Distribution of Pyrite Grade in Individual Ore Composites**

Life-of-mine models produced from the Resolution geology block model indicate that the maximum pyrite grade in the mill feed is estimated to be 15 weight percent, and for much of the life of the mine it will likely be substantially lower (see discussion in **Section 3.1.1**). Samples with pyrite head grades less than 15 weight percent account for 75 percent of the IC suite (41 of 55 samples). Therefore, higher pyrite grades are over-represented in the IC suite compared with the anticipated distribution in ore produced over the life of the mine. **Figure 4.1-3** provides a plot of NPR vs. NAG pH as a function of IC pyrite grade. Inspection of **Figure 4.1-3** shows that the majority of PAG scavenger tailings were generated from ore samples with pyrite grades greater than 15 weight percent.

Of the 55 scavenger tailings samples generated from individual ore composites, 41 samples were generated from individual ore composites with pyrite grade less than 15 weight percent that are considered representative of operational conditions. An additional 14 samples were generated from higher pyrite ore. These samples provide data representative of scavenger tailings that might be produced under a maximum worst case production scenario with higher than anticipated pyrite mill feed.

#### **4.1.3 Acid-Base Accounting**

ABA results are provided in **Tables 4.1-2 through 4.1-5** (adapted from Tables 3 through 6 in SGS (2015)) and summarized below:

- Scavenger tailings from 55 individual composites were subjected to ABA testing
- 41 of the 55 ICs had pyrite grade less than 15 percent and produced scavenger tailings that are considered representative of operational tailings
- Paste pH of the scavenger tailings ranged between 6.55 and 9.33 s.u. which indicates that no net acidity was produced by the samples prior to testing
- Sulfide sulfur content of the 55 scavenger tailings samples ranges from 0.01 to 1.28 weight percent; the smaller, more representative subset of 41 samples contains a range of sulfide sulfur between 0.01 and 1.09 weight percent
- Sulfide sulfur contents of the 55 scavenger tailings samples are log normally distributed with a geometric mean of 0.1 weight percent; the smaller subset (41 samples) is also log normally distributed with a geometric mean of 0.07 weight percent
- Total inorganic carbon ranges from 0.014 to 0.614 weight percent with 49 of the 55 samples (89 percent) containing less than 0.04 weight percent
- Bulk NPR of the 55 scavenger tailings samples ranges from 0.05 to 24.8; within the smaller (41 sample) subset the NPR ranges between 0.15 and 24.8. NPR for the

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representative scavenger tailings (41 sample set) is log-normally distributed with a geometric mean of 2.8.

#### 4.1.4 Net Acid Generation Testing (pH and Leachate Composition)

NAG pH results are provided in **Table 4.1-6** (adapted from Tables 3 through 6 in SGS (2015)) and summarized as follows:

- Final NAG pH results indicate that 60 percent of all scavenger tailings samples from individual composites are designated NPAG (pH > 4.5 s.u.) and 40 percent are designated PAG (pH < 4.5 s.u.).
- Residual (i.e. un-neutralized) acidity in the scavenger tailings is generally low with acidity up to pH 4.5 s.u. ranging from 0 to 12 kg H<sub>2</sub>SO<sub>4</sub>/T and acidity up to pH 7.0 s.u. ranging from 0 to 21 kg H<sub>2</sub>SO<sub>4</sub>/T. Low titratable acidities are consistent with the low sulfide and metals contents of the scavenger tailings.

The chemical compositions of the NAG leachates are provided in **Tables 4.1-7 through 4.1-10** (adapted from Tables 3 through 6 and Appendix C in SGS (2015)) and summarized as follows

- Concentrations of sulfate, metals, and metalloids are low in NAG leachates (including those samples with acidic pH values) consistent with the low sulfide and residual metal/metalloid contents of the scavenger tailings.
- Approximately 60 percent of the NAG leachates have fluoride concentrations that are slightly higher than are generally observed in natural waters in non-mineralized systems (i.e. somewhat greater than 1 mg/L; Hem, 1985).

#### 4.1.5 Potential for Acid Generation and Metals Leaching: Summary

**Figure 4.1-4** presents a plot of NPR vs. NAG pH for the scavenger tailings generated from individual composites. As discussed in **Section 4.1.2**, mill feed under operational conditions is anticipated to contain less than 15 weight percent pyrite. Of the 55 scavenger tailings samples subjected to static testing, 41 were from individual ore composites with pyrite grades less than 15 percent. Integration of ABA and NAG testing data from these samples indicates that:

- 17 of 41 scavenger tailings samples (41 percent) are designated NPAG (NPR > 3 and NAG pH > 4.5 s.u.)
- 6 of 41 (15 percent) are PAG (NPR < 1 and NAG pH < 4.5 s.u.)
- 18 of 41 (44 percent) are Uncertain (NPR between 1 and 3 and/or the NPR and NAG pH designations are inconsistent).

Integration of the results of ABA and NAG testing for the full dataset (including samples that are representative only of scavenger tailings that might be produced under a worst-case scenario high-pyrite mill feed) indicates that:

- 17 of 55 of the scavenger tailings samples (31 percent) are designated NPAG (NPR > 3 and NAG pH > 4.5 s.u.)
- 20 of 55 (36 percent) are PAG (NPR < 1 and NAG pH < 4.5 s.u.)
- 18 of 55 (33 percent) are Uncertain (NPR between 1 and 3 and/or the NPR and NAG pH designations are inconsistent).

Note that, as discussed in **Section 3.2.1.1**, the threshold criterion used in this report to determine between a designation of NPAG or Uncertain, is NPR = 3 based on ADEQ (2004) BADCT guidance. For comparison, the distributions of ABA designations based on NPR = 2 (e.g., AMIRA (2002), INAP (2009), MEND (2009)) for the operational and high-pyrite data sets are presented in the table below.

Threshold Criterion	AGP DESIGNATION		
	NPAG	Uncertain	PAG
SAMPLES REPRESENTATIVE OF OPERATIONAL CONDITIONS (n = 41)			
NPR = 2	27	8	6
NPR = 3	17	18	6
DATA INCLUDING HIGH-PYRITE ORE COMPOSITES (n = 55)			
NPR = 2	27	8	20
NPR = 3	17	18	20

**Figure 4.1-5** shows the bulk acid neutralization potential (ANP) plotted against acid generation potential for the IC scavenger tailings. Shown on this plot are lines indicating the values of NPR = 1, 2, and 3. NPR > 1 is the level at which a sample is technically considered NPAG (that is, the ANP is greater than the AGP). The other two lines, NPR = 2 and NPR = 3 represent two widely accepted safety margins. As shown in this plot, and in the table above, the impact of applying one safety factor or the other to this data set is to move 10 samples between the NPAG and the Uncertain classifications. Choice of safety factor does not affect the proportion of tailings classified as PAG as that threshold remains at NPR < 1).

**Figure 4.1-6** shows NPR vs. sulfide sulfur content of IC scavenger tailings. Note that 16 of 20 PAG samples (samples with NPR < 1) contain more than 0.2 weight percent sulfide sulfur.

**Figure 4.1-7** presents sulfide sulfur in the scavenger tailings samples vs. pyrite grade of the ore samples from which the tailings were generated. This plot shows that the residual sulfide sulfur in the scavenger tailings generally increases with higher ore pyrite grade. This is the primary reason for the correlation between acid generation potential and pyrite grade shown in **Figure**

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**4.1-3.** Another factor that contributes to the larger AGP of the scavenger tailings from higher pyrite ore is the association of higher pyrite ore with phyllic alteration that results in a very low ANP mineral assemblage that contains little, if any, carbonate or faster-acting silicate minerals (Hehnke et al., 2012).

NAG testing and leachate analysis indicate that acidity, sulfate and metal/metalloid release is small even when low pH conditions are generated during NAG testing. This result is consistent with the low sulfide and residual metals/metalloids contents of all the scavenger tailings samples. Note that the potential geochemical reactivity of the scavenger tailings indicated by static testing presented here is consistent with results of prior testing detailed in the 2014 tailings geochemistry report (DHC, 2014) presented as Appendix H of the General Plan of Operations (RCM, 2014)

## **4.2 Static Testing of Scavenger Tailings from 2014 Master Ore Composites**

Scavenger tailings generated from metallurgical testing of master ore composites were submitted to SGS Environmental Services in Lakefield for environmental tests including: ABA, NAG pH, and NAG leachate composition. Results are provided in SGS (2015b) and summarized below.

### **4.2.1 Objectives**

The goal of this work was to provide an initial, scoping-level characterization of the master composite scavenger tailings to enable a representative subset of the samples to be chosen for further characterization and kinetic testing.

### **4.2.2 Sample Selection and Preparation**

Eighteen master ore composites generated from the individual composites discussed in **Section 4.1** were subjected to locked cycle metallurgical testing in 2014 at FLS (Dawson) in Salt Lake City, Utah and at SGS Mineral Services in Lakefield, Ontario. A summary of the individual composites used in each of the master composites is provided in **Table 4.2-1**. Locked cycle testing was conducted following two metallurgical approaches (bulk and selective; see **Section 3.1.2** for a brief explanation of metallurgical testing methods).

### **4.2.3 Acid-Base Accounting**

ABA results are provided in **Tables 4.2-2 through 4.2-5** (adapted from Tables 2 through 5 in SGS (2015b)) and summarized below:



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- Thirty-four samples of scavenger tailings generated from 18 master composites were subjected to ABA testing
  - Paste pH of scavenger tailings ranged between 6.59 and 8.80 s.u. which indicates that no net acidity was produced by the samples prior to testing
  - Sulfide sulfur contents of scavenger tailings samples range from 0.01 weight percent to 1.15 weight percent
  - Sulfide sulfur contents of the 34 scavenger tailings samples are log-normally distributed with a geometric mean of 0.08 weight percent
  - Total inorganic carbon ranges from 0.011 to 0.484 weight percent with 28 of 34 samples (82 percent) containing less than 0.4 weight percent
  - Bulk NPR ranges from 0.11 to 30.1. NPR is log-normally distributed with a geometric mean of 2.7.
  - Based on bulk NPR, 17 of 34 samples (50 percent) are designated NPAG, 10 of 34 (29 percent) are designated PAG, and 7 of 34 (21 percent) are Uncertain with NPR values between 1 and 3.

**Figure 4.2-1** shows a comparison of the NPR of master composite scavenger tailings between the bulk and selective flotation approaches. Scavenger tailings generated from the same master composite using the two flotation approaches are very similar with no systematic variation observed (i.e., there is not one approach that consistently produces scavenger tailings with either higher or lower NPR than the other).

#### **4.2.4 Net Acid Generation Testing (pH and Leachate Composition)**

NAG pH data are provided in **Table 4.2-6** (adapted from Tables 2 through 5 in SGS (2015b)) and leachate compositions are provided in **Tables 4.2-7 through 4.2-10** (adapted from Tables 2 through 5 and Appendix B in SGS (2015b)). Principal observations are as follows:

- Final NAG pH results indicate that 71 percent of the scavenger tailings samples from master ore composites are designated NPAG (pH > 4.5 s.u.) and 29 percent are designated PAG (pH < 4.5 s.u.).
- Residual (i.e. un-neutralized) acidity in the scavenger tailings is generally low with acidity up to pH 4.5 ranging from 0 to 7.9 kg H<sub>2</sub>SO<sub>4</sub>/T and acidity up to pH 7.0 ranging from 0 to 17 kg H<sub>2</sub>SO<sub>4</sub>/T. Low titratable acidities are consistent with the low sulfide and metals contents of the scavenger tailings.
- Concentrations of sulfate, metals, and metalloids are generally low in NAG leachates (even for those samples with acidic pH values) consistent with the low sulfide and residual metal/metalloid contents of the scavenger tailings.

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## 4.2.5 Potential for Acid Generation and Metals Leaching: Summary

Integrating the results of ABA and NAG testing indicates that 50 percent of the scavenger tailings samples generated from 2014 master ore composites are designated NPAG (NPR > 3 and NAG pH > 4.5 s.u.), 29 percent are PAG (NPR < 1 and NAG pH < 4.5 s.u.), and 21 percent are Uncertain (NPR between 1 and 3). See **Figure 4.2-2** for a plot of NPR vs. NAG pH.

**Figure 4.2-3** shows NPR vs. sulfide sulfur content of MC scavenger tailings. Note that 8 of 10 PAG samples (samples with NPR < 1) contain more than 0.2 weight percent sulfide sulfur.

NAG testing and leachate analysis indicates that acidity, sulfate and metal/metalloid release is small even when low pH conditions are generated during NAG testing. This result is consistent with the low sulfide and residual metals/metalloids contents of the scavenger tailings.

## 4.3 Static Testing of Scavenger and Pyrite Tailings from 2014 Pilot Plant Testing

The 2014 pilot plant test was conducted at ALS Metallurgy in Kamloops, British Columbia, Canada between October 27 and November 5, 2014. Environmental testing was conducted at SGS Environmental Services, Lakefield, Canada. Static geochemical testing included: ABA, NAG pH, NAG leachate composition, SPLP, TCLP, and water quality analysis of process water samples. Results are provided in SGS (2016a) and summarized in the following sections.

### 4.3.1 Objectives

The objectives of this work were to:

- Characterize the geochemical composition and acid generation potential of both the scavenger and pyrite tailings produced in the pilot plant testing
- Assess any differences in the tailings products produced by two different flotation methodologies (bulk and selective)
- Characterize the chemical composition of process water which is representative of the water that will be delivered to the TSF in the tailings slurry

### 4.3.2 Sample Selection and Preparation

The ore feed to the pilot plant consisted of approximately four tonnes of ore from boreholes: RES-005L, RES-009G, RES-013F, RES-017M, RES-025B, RES-025E, RES-027D, RES-028B, RES-028D, RES-031, and RES-031B. This ore composite is deemed by RCM Geology and Metallurgy to be representative of ore that will be produced over approximately the first ten years of mine

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life. The pilot plant operated for eight days, five using the bulk approach and three using the selective approach. Samples of the scavenger and pyrite tailings were collected for environmental characterization on the test days on which flotation conditions were deemed representative of likely operational conditions. This approach generated bulk samples on Days 3 and 4 and selective samples on Days 6 through 8. It should be noted that although Day 7 data are included in this report there was substantial dilution of the pyrite tailings with non-sulfide gangue and this sample is likely not representative of operational conditions. Environmental samples consisted of approximately 2 kg dry weight equivalent of wet filter cake; samples were shipped to SGS, Lakefield for splitting and geochemical testing.

### **4.3.3 Acid-Base Accounting**

ABA results are provided in **Tables 4.3-1 and 4.3-2** (adapted from Tables 7 and 8 in SGS (2016a)) and summarized below. Note that, due to the smaller sample size, descriptive statistics (e.g. distribution and central tendency) are not provided for this data set as they were for the larger data sets in **Sections 4.1 and 4.2**.

#### ***4.3.3.1 Scavenger Tailings***

- Paste pH of scavenger tailings ranged between 7.15 and 7.99 s.u. which indicates that no net acidity was produced by the samples prior to testing
- Sulfide sulfur contents of scavenger tailings samples range from 0.08 weight percent to 0.16 weight percent
- NPR ranges from 1.36 to 2.92.
- Based on NPR, all 7 scavenger tailings samples are Uncertain with NPR values between 1 and 3 (**Figure 4.3-1**).
- There is no systematic difference in ABA characteristics of scavenger tailings generated from the two flotation approaches.

#### ***4.3.3.2 Pyrite Tailings***

- Paste pH of pyrite tailings ranged between 6.72 and 7.28 s.u. except for the sample collected on Day 4 which has a paste pH of approximately 5.0 s.u. This indicates that, in general, no net acidity was produced by the samples prior to testing except for the Day 4 sample that appears to have undergone some initial oxidation during sampling and storage.
- Sulfide sulfur contents of pyrite tailings samples from the bulk circuit are approximately 21 to 23 weight percent

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- Sulfide sulfur contents of pyrite tailings samples from the selective circuit range between approximately 12 and 17 weight percent; however, the low-end sample (Day 7) is likely not representative of operational conditions as there was substantial dilution by non-sulfide gangue. The more representative pyrite tailings (from Days 6 and 8) contain approximately 16 to 17 weight percent sulfide sulfur.
  - NPR of all pyrite tailings is approximately 0.01 to 0.02.
  - All pyrite tailings are designated as PAG based on NPR < 1 (**Figure 4.3-1**).

#### **4.3.4 Net Acid Generation Testing (pH and Leachate Composition)**

NAG pH and leachate composition data are summarized in **Tables 4.3-3 and 4.3-4**, respectively (adapted from Tables 7 and 8 in SGS (2016a)) and summarized below.

##### ***4.3.4.1 Scavenger Tailings***

- Final NAG pH values for the scavenger tailings samples from the 2014 pilot plant testing ranged from pH 4.90 to 5.76 s.u.
- All scavenger tailings samples from the 2014 pilot plant testing gave final NAG pH values greater than pH 4.5 s.u. and are therefore designated NPAG based on the NAG testing results.
- Residual (i.e. un-neutralized) acidity in the scavenger tailings is low with acidity up to pH 7.0 s.u. ranging from 0.4 to 2.0 kg H<sub>2</sub>SO<sub>4</sub>/T. Low titratable acidities are consistent with the low sulfide and metals contents of the scavenger tailings.
- Concentrations of sulfate, metals, and metalloids are low in the NAG leachates consistent with the low sulfide and residual metal/metalloid contents of the scavenger tailings.
- NAG leachates from the pilot plant scavenger tailings have fluoride concentrations that range from 2.54 to 3.10 mg/L which is slightly higher than the maximum of 1 mg/L generally observed in natural waters in non-mineralized systems (Hem, 1965).

##### ***4.3.4.2 Pyrite Tailings***

- Final NAG pH values for the pyrite tailings samples from the 2014 pilot plant testing ranged from pH 2.21 to 2.48 s.u.
- All pyrite tailings samples gave final NAG pH values lower than pH 4.5 s.u. and are therefore designated PAG based on NAG testing results.

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- Residual (i.e., un-neutralized) acidity is higher in the high sulfide tailings than in the scavenger tailings. Acidity up to pH 4.5 s.u. ranges from 24 to 54 kg H<sub>2</sub>SO<sub>4</sub>/T and acidity up to pH 7.0 s.u. ranges from 60 to 91 kg H<sub>2</sub>SO<sub>4</sub>/T.
  - Analysis of NAG leachates indicates that, were the pyrite tailings to become oxidized, they may potentially release: aluminum, copper, fluorine, iron, nickel, and sulfate.

#### 4.3.5 Simulated Precipitation Leaching Procedure

SPLP results are provided in **Table 4.3-5** (adapted from Tables 5 and 6 in SGS (2016a)) and summarized as follows:

- pH of all samples, both scavenger and high-pyrite tailings, was neutral to alkaline with an observed range of pH values between 7.36 and 9.26 s.u.; pH values above the initial leachate pH of 4.2 s.u. indicate that acidity was consumed and alkalinity was released from the sample during leaching.
- Concentrations of measured anions, metals, and metalloids were low in leachates from both the scavenger and the high-pyrite tailings consistent with circumneutral conditions. However, in leachates from scavenger tailings, concentrations of fluoride, cobalt, manganese, and nickel were somewhat elevated in some samples with respect to values observed in natural waters in non-mineralized systems (Hem, 1985). In some leachates from pyrite tailings the following constituents were slightly elevated: cobalt, manganese, molybdenum, and selenium.

#### 4.3.6 Toxicity Characteristic Leaching Procedure

The Toxicity Characteristic Leaching Procedure (TCLP) is described by the U.S. EPA as follows (U.S. EPA, 2016a):

The test [TCLP] was designed to model a theoretical scenario in which a waste is mismanaged by placing it in an unlined landfill containing municipal solid waste. The acetic acid solution in Method 1311 is designed to simulate the result of rainwater infiltrating the landfill, reacting with the municipal solid waste, and then leaching through the waste being tested. The numerical limits for the RCRA toxicity characteristic (40 CFR 261.24) were derived using the same scenario and were set at levels that would prevent the groundwater under the landfill from posing a threat to human health and the environment.

The TCLP leaching procedure is not used to regulate mining wastes (ADEQ, 2004). Mine wastes would certainly not be exposed to an organic acid, such as acetic acid. However, TCLP testing was conducted on 2014 pilot plant tailings to assess the potential for the tailings to be a

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hazardous waste. Results are provided in **Table 4.3-6** (adapted from Tables 3 and 4 in SGS (2016)). The maximum concentration limits for the TCLP as presented in the Code of Federal Regulations 40 CFR 261.24 (U.S. EPA, 2016b) are included in the table for reference. Results in **Table 4.3-6** show that both the scavenger and the pyrite tailings generated TCLP leachate with concentrations well below the maximum concentration limits for TCLP presented in the Code of Federal Regulations.

#### **4.3.7 Chemical Characterization of 2014 Pilot Plant Process Water**

A series of samples taken throughout the 2014 pilot plant test were submitted for analyses including: water quality parameters (pH, TDS, hardness), anions, and total and dissolved metals. Samples were collected at the beginning and end of each day of the pilot plant. Laboratory certificates of analysis are provided in **Appendix A**.

The goals of process water characterization included:

- To assess the chemistry of process water representative of entrained water that will be deposited along with tailings in the tailings storage facility during operation
- To assess the degree of variability of the recycled water over the period of the pilot plant test. Samples were collected to allow identification of any systematic changes in chemistry over the period of the test as well as to provide a check on any potential changes that might occur between testing days when the pilot plant was shut down.

The chemical compositions of pilot plant process water samples and the laboratory tap water used as both the initial fluid and as makeup water on Day 6 are provided in **Table 4.3-7**.

Principal observations are presented below:

- All process water samples were circumneutral with pH ranging between approximately 7.2 and 7.9 s.u.; there was no systematic trend in pH over the period of the test
- Sulfate increased from 7.78 mg/L in the morning of Day 1 to 253 mg/L in the morning of Day 6. During Day 6, makeup water was added to the circuit which decreased the sulfate concentration of the process water to 170 mg/L in the Day 6 afternoon sample. Sulfate concentrations continued to increase throughout the final days of the test with a final (Day 8 afternoon) concentration of 315 mg/L.
- Alkalinity generally decreased over the period of the test from approximately 45 mg/L as CaCO<sub>3</sub> to approximately 25 mg/L as CaCO<sub>3</sub>
- Concentrations of metals and metalloids were low consistent with circumneutral conditions. However, concentrations of fluoride, manganese, molybdenum, selenium,

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and zinc were elevated in some samples with respect to values observed in natural waters in non-mineralized systems (Hem, 1985).

- Concentrations of metals and metalloids were generally stable with the exception of the following analytes that did show a small systematic increase in concentration over the period of the test: aluminum, copper, molybdenum, selenium, and silver.
- Fluoride concentrations increased over the period of the test with a final (Day 8 afternoon) concentration of 2.43 mg/L

#### **4.4 Humidity Cell Testing of Scavenger Tailings from 2014 Master Ore Composites**

This section presents the results of humidity cell testing of selected scavenger tailings samples generated from locked cycle testing of 2014 master ore composites. Humidity cell testing commenced on April 28, 2015 and is ongoing. Also included below are results of static geochemical testing and mineralogical analysis of the scavenger tailings samples subjected to humidity cell testing.

##### **4.4.1 Objectives**

The goal of this work is to assess the potential geochemical reactivity of scavenger tailings representative of those that will be produced under operational conditions over the life of the mine. Humidity cell tests provide long-term data regarding the potential of these materials to produce acidic conditions and leach metals if allowed to weather under oxidizing conditions. In addition, characterization of the leachate chemistry provides an initial assessment of constituents that may be present at elevated concentrations. Data generated from humidity cell testing of the 2014 Resolution master ore composites will be used in sulfide-oxidation and fate-and-transport modeling intended to predict the likely composition of groundwater beneath, and adjacent to, the TSF.

##### **4.4.2 Sample Preparation/Selection**

**Table 4.4-1** provides information regarding scavenger tailings generated from locked cycle testing of 2014 master ore composites and subjected to humidity cell testing. Care was taken to select scavenger tailings samples that were generated from ore composites representative of the distribution of lithology and alteration type in the Resolution ore body. In addition, nine of the 12 HCT samples were generated from master composites that represent the anticipated range in the pyrite grade of mill feed over the life of the mine (i.e., pyrite content less than 15 weight percent). An additional three scavenger tailings samples generated from ore composites containing more than 15 weight percent pyrite were included in the HCT sample

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suite in order to provide data relevant to scavenger tailings that might be produced should upset conditions lead to high pyrite mill feed.

#### **4.4.3 Static Testing of Samples Subjected to Humidity Cell Testing**

Master composite scavenger tailings samples were subjected to limited static testing (ABA, NAG pH, and NAG leachate) at the time that the tailings were generated. For initial static test results see **Section 4.2** of this report. Scavenger tailings were generated over approximately a year of metallurgical testing so some of the samples were stored for up to one year prior to commencement of humidity cell testing. In order to assess any potential changes to the scavenger tailings during this storage period, ABA and NAG testing was repeated for samples subjected to humidity cell testing. In addition, a more comprehensive suite of environmental and mineralogical tests were conducted for further characterization of the HCT samples. Environmental tests included: ABA, NAG pH, SPLP, particle size distribution, and whole rock analysis using XRF and strong acid digestion with ICP-MS. Mineralogical characterization includes: QEMSCAN, semi-quantitative XRD, and optical petrography. Results of static geochemical and mineralogical testing of the HCT samples are presented in SGS (2016b) and summarized in the following sections.

##### ***4.4.3.1 Acid-Base Accounting***

ABA results are provided in **Table 4.4-2** (adapted from Tables 25 and 26 in SGS (2016b)) and summarized below:

- Scavenger tailings from 12 master composites were subjected to ABA testing prior to commencement of HCTs
- Paste pH decreased in all the samples over the storage period (compare initial paste pH results in **Table 4.2-2**). For 7 of the 12 samples paste pH remained above pH 7 s.u. For the remaining 5 samples paste pH dropped to below pH 6 s.u. This indicates that some sulfide oxidation occurred while the samples were stored and that the acidity produced by that oxidation was not neutralized by the sample.
- Sulfide sulfur content generally did not change substantially over the storage period. The one sample that did show a substantial change in sulfide sulfur content is sample MC-1 LCT 35 (Hole 29A); initial sulfide sulfur measurement was 1.15 weight percent and the pre-HCT measurement was 0.71 weight percent. Given the relatively small change in paste pH over the same period (6.59 to 5.14 s.u.) it is likely that the difference in sulfide sulfur values is due to sample heterogeneity and not to oxidation of a large portion of the sulfide over the storage period.
- Bulk NPR for the HCT samples ranges from 0.08 to 16.2



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- Based on bulk NPR, 7 of the 12 HCT samples are designated NPAG, 3 are designated PAG, and 2 are designated Uncertain (with NPR between 1 and 3)
  - The majority of designations (11 of 12) did not change over the storage period. The exception is MC-1 LCT 23 which was initially designated PAG but was classified as Uncertain after storage (NPR changed from 0.53 to 1.54)

#### ***4.4.3.2 Net Acid Generation Testing***

NAG testing results are provided in **Table 4.4-3** (adapted from Tables 25 and 26 in SGS (2016b)) and summarized below:

- Scavenger tailings from 12 master composites were subjected to NAG testing prior to commencement of HCTs
- NAG pH values generally remained consistent over the storage period. Values range between 3.26 and 8.82 s.u. (compared with 3.02 to 9.79 s.u. in the initial testing)
- Based on NAG pH, 9 of the 12 HCT samples are designated NPAG (pH > 4.5 s.u.) and 3 are designated PAG (pH < 4.5 s.u.).
- The AGP designation of one sample changed over the storage period. Sample MC-1 LCT 23 was initially designated PAG with a NAG pH of 3.73 s.u. but changed to a designation of NPAG with a post-storage NAG pH of 4.87 s.u. Note that this is consistent with ABA results that indicate a classification change for this sample over the storage period from PAG to Uncertain.

#### ***4.4.3.3 Potential for Acid Generation and Metals Leaching: Summary***

Integrating the results of ABA and NAG testing indicates that 7 of the 12 scavenger tailings samples subjected to humidity cell testing are designated NPAG (NPR > 3 and NAG pH > 4.5 s.u.), 3 of 12 are PAG (NPR < 1 and NAG pH < 4.5 s.u.), and 2 are Uncertain by NPR (NPR between 1 and 3) but NPAG by NAG (NAG pH > 4.5 s.u.). See **Figure 4.4-1** for a plot of NPR vs. NAG pH.

**Figure 4.4-2** shows NPR vs. sulfide sulfur content of the MC scavenger tailings samples subjected to humidity cell testing. Note that all three PAG samples (samples with NPR < 1) contain more than 0.2 weight percent sulfide sulfur. In addition, all three PAG samples were generated from ore containing more than 15 weight percent pyrite (**Table 4.4-1**) and are included in order to provide data regarding a worst-case high-pyrite mill feed that is not anticipated to occur under operational conditions.

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#### 4.4.4 Mineralogy

Mineralogical analysis was conducted using semi-quantitative x-ray diffraction (XRD), Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN), and optical microscopy. Principal findings are summarized below:

##### ***4.4.4.1 Semi-Quantitative X-Ray Diffraction (XRD)***

Semi-quantitative x-ray diffraction (XRD) was conducted on the 12 scavenger tailings samples subjected to humidity cell testing. Data are provided in **Table 4.4-4** (adapted from Tables 3 and 4 in SGS (2016b)) and summarized as follows:

- Scavenger tailings are predominantly composed of silicate minerals including: quartz, muscovite, phlogopite, orthoclase, illite, and kaolinite
- Pyrite was detected in only three of the 12 scavenger tailings samples at concentrations less than 1 weight percent. All other samples were reported as having pyrite concentrations less than the detection limit of between 0.5 and 2 weight percent.
- No calcite or dolomite were detected in any of the scavenger tailings samples
- No sulfate minerals were detected in any of the scavenger tailings samples

##### ***4.4.4.2 Quantitative Evaluation of Minerals by Scanning Electron Microscopy***

All 12 scavenger tailings samples subjected to humidity cell testing were submitted for mineralogical analysis using QEMSCAN. Polished sections were subjected to particle minerals analysis (PMA) which provided quantitative abundance and liberation and association data. Modal analysis results (i.e. quantitative abundance of mineral phases in each sample) are presented in **Table 4.4-5** (adapted from Tables 6 and 7 in SGS (2016b)). Detailed results, including mineral liberation and association data, are reported in SGS (2016b). Principal observations are as follows:

###### **4.4.4.2.1 Modal Analysis**

- QEMSCAN modal analysis shows that the scavenger tailings samples subjected to humidity cell testing are composed predominantly of silicate minerals (consistent with XRD results).
- Principal silicate phases identified with QEMSCAN include: quartz, feldspars, muscovite, biotite/phlogopite, chlorites, illite, kaolinite, and topaz.
- Pyrite ( $\text{FeS}_2$ ) was detected in trace or minor amounts in all the samples with a range between 0.01 and 0.64 weight percent.
- Total sulfide minerals including pyrite, chalcopyrite ( $\text{CuFeS}_2$ ), other copper sulfides and other non-copper sulfides ranged between 0.02 and 0.69 weight percent. Pyrite accounts for between 14 and 100 percent of the total sulfide mineral content. It should

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be noted that when acid generation potential (AGP) is calculated from sulfide sulfur content as part of ABA analyses it is assumed that pyrite accounts for 100 percent of the sulfide sulfur. When pyrite is less than 100 percent of the total sulfide mineral content the ABA calculations of AGP are overly conservative.

- Calcite and dolomite measurements ranged between 0.00 and 0.29 weight percent and 0.00 and 1.96 weight percent, respectively. These low Ca/Mg-carbonate values are consistent with very low neutralization potentials reported in ABA analyses.
- Trace amounts of the other carbonate minerals ankerite ( $\text{Ca(Fe,Mg,Mn)(CO}_3)_2$ ) and siderite ( $\text{FeCO}_3$ ) were reported.

#### 4.4.4.2 Liberation and Association

The degree to which potentially acid generating minerals (generally pyrite in RCM tailings) and potentially neutralizing minerals (generally Ca-Mg carbonates) are liberated from the surrounding silicate matrix controls the degree to which they are available to react. Liberation data are provided in Tables 9 and 10 in SGS (2016b). Data show that both the Ca-Mg carbonates and the pyrite particles are reasonably well exposed (likely as a result of grinding of the ore during processing). The degree to which the pyrite and carbonate minerals are exposed varies from sample to sample but, in general, more than 90 percent of both types of mineral particles are exposed to some degree. Note that results of ABA analysis assume 100 percent of sulfide mineral particles are exposed.

#### **4.4.4.3 Optical Microscopy**

Polished thin sections were examined optically in order to determine whether any oxidation of sulfide minerals had occurred. A summary of optical microscopy observations is provided in Table 14 of SGS (2016b) and photomicrographs are presented in the mineralogy report in Appendix A of SGS (2016b). Evidence of incipient oxidation in some samples includes: corroded edges on pyrite particles; oxidation within microfractures in pyrite, chalcopyrite, and bornite particles; and formation of alteration rims on bornite and chalcopyrite particles. Oxidation of the sulfide phases is very minor and in several samples was not detected at all. There is no systematic correlation between decreased paste pH over the storage period and observed sulfide alteration.

#### **4.4.5 Whole Rock Analysis with X-ray Fluorescence (XRF)**

Whole rock analysis was conducted using x-ray fluorescence (XRF) on the 12 scavenger tailings samples subjected to humidity cell testing. Data are provided in **Table 4.4-6** (adapted from Tables 16 and 17 in SGS (2016b)) and summarized as follows:

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- The principal component of all the scavenger tailing samples is silica (SiO<sub>2</sub>); concentrations range from 56.0 to 84.7 weight percent. This is consistent with data from XRD and QEMSCAN analyses presented in **Sections 4.4.4.1 and 4.4.4.2** that indicate that the primary mineral phases are silicates.
  - Four samples (MC-3 LCT 27 (Hole 27C), MC-3 LCT 38 (Hole 29A), MC-5 LCT 42 (Hole 29A) and LCT-6 Comb Py Sc Tls (Hole 31; MC-1)) contain higher concentrations of iron (approximately 6 to 8 weight percent compared with a range of <1 to 2 weight percent in the remaining samples).

#### 4.4.6 Strong Acid Digest and Elemental Analyses

Elemental analysis was conducted on the 12 scavenger tailings samples subjected to humidity cell testing. Samples were digested using a mixture of nitric, hydrofluoric, perchloric, and hydrochloric acids and elemental analysis was conducted using inductively coupled plasma-optical emission spectrometry (ICP-OES) or inductively coupled plasma-mass spectrometry (ICP-MS). Data are provided in **Table 4.4-7** (adapted from Tables 19 and 20 in SGS (2016b)).

Elemental analyses were compared with crustal abundances provided in Price (1997). Where Price (1997) does not provide a value (for boron, lithium, selenium, silicon, tin, and yttrium) values from Mason and Moore (1982) were used. The following elements were identified as being present in the scavenger tailings samples subjected to humidity cell testing at concentrations greater than five times crustal abundance: bismuth, copper, lead, molybdenum, selenium, silver, tin, and tungsten.

#### 4.4.7 Particle Size Distribution

Particle size distribution of scavenger tailings from 2014 master composites subjected to humidity cell testing was determined using sieving and hydrometry (SGS, 2016b). Results are summarized in **Tables 4.4-8 and 4.4-9** (adapted from Tables 29 through 32 in SGS (2016b)). Particle size distributions are plotted on **Figure 4.4-3**; principal results are provided below:

- Particle size classifications for scavenger tailings are as follows:
  - Sand (percent)
    - Average: 52.3
    - Range: 42.8 to 64.9
  - Silt (percent)
    - Average: 43.2
    - Range: 30.1 to 52.2

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- Clay (percent)
    - Average: 4
    - Range 1 to 7
  - Average specific gravity of the scavenger tailings is 2.77 with a range between 2.72 and 2.85.

#### 4.4.8 Synthetic Precipitation Leach Procedure

SPLP results are provided in **Table 4.4-10** (adapted from Tables 22 and 23 in SGS (2016b)) and summarized as follows:

- pH of all samples was circumneutral to alkaline with an observed range of pH values between 6.10 and 9.82 s.u.; pH values above the initial leachate pH of 4.2 s.u. indicate that alkalinity was released and acidity consumed during leaching.
- Concentrations of measured anions, metals, and metalloids were generally low in leachates from scavenger tailings consistent with circumneutral conditions. However, concentrations of aluminum, beryllium, copper, fluoride, manganese, nickel, selenium, and zinc were elevated in some samples with respect to values observed in natural waters in non-mineralized systems (Hem, 1985).

#### 4.4.9 Humidity Cell Testing

Twelve scavenger tailings generated from locked cycle testing of 2014 master ore composites were submitted for humidity cell testing. Humidity cell tests (HCTs) were initiated on April 28, 2015; sample identifiers and supporting information are provided in **Table 4.4-1**. Currently, four of the original twelve samples are ongoing; data for these HCTs are presented through Week 51. Three samples (MC-1 LCT 23 (Hole 27C), MC-3 LCT 38 (Hole 29A), and MC-3 LCT 28 (Hole 29B)) were decommissioned after 38 weeks of leaching. An additional five samples were decommissioned after 54 weeks (MC-3 LCT 27 (Hole 27C), MC-2 LCT 37 (Hole 29A), MC-1 LCT 24 (Hole 29B), MC-4 LCT 30 (Hole 29B), and LCT-4 Comb Py Sc Tls (Hole 31)). HCTs are decommissioned when leachate chemistry has stabilized and depletion rates of sulfide sulfur and neutralization potential are well-defined.

Post-test characterization of the HCT residues is in process and results will be presented in a future report once post-test characterization of all HCT samples is complete. Details regarding HCT methodology and data are provided in SGS (2016b). HCT data are also provided in **Appendix B** of this report.

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**Figure 4.4-4** provides time-series plots of pH for the 12 master composite HCTs. The pH of the HCT leachates fall into three general categories, those that have remained circumneutral (pH between approximately 6 and 8 s.u. with titratable alkalinity), those that have generated leachates with intermediate pH values (pH between approximately 4 and 6 s.u.) and those samples, selected to represent a potential worst-case scenario that might lead to high-pyrite mill feed, that have generated leachates with pH between 3 and 4 s.u. The following sections provide a summary of the results of HCTs to date organized by pH category.

#### ***4.4.9.1 Circumneutral pH HCT Samples***

Six of the twelve HCTs remained circumneutral either throughout the 38-week period of the test (for those two that have been decommissioned) or through week 51 for the four ongoing tests. Circumneutral HCTs include the following samples: MC-3 LCT 27 (Hole 27C), MC-3 LCT 38 (Hole 29A), MC-7 LCT 46 (Hole 29A), MC-3 LCT 28 (Hole 29B), MC-4 LCT 30 (Hole 29B), and LCT-6 Comb Py Sc TIs (Hole 31) (**Figure 4.4-4**). Discussion of principal parameters in the circumneutral leachates is provided below.

##### **4.4.9.1.1 Alkalinity**

To date, alkalinity concentrations in the circumneutral leachates have generally been less than 10 mg/L as CaCO<sub>3</sub> (**Figure 4.4-5**) with the following exceptions:

- MC-4 LCT 30 (Hole 29B) initially generated alkalinity on the order of 30 mg/L as CaCO<sub>3</sub> which decreased to below 10 mg/L as CaCO<sub>3</sub> in approximately 25 weeks.
- MC-3 LCT 27 (Hole 27C) generated leachates containing less than 10 mg/L as CaCO<sub>3</sub> for the majority of the test but has sporadically generated alkalinity values as high as 30 mg/L as CaCO<sub>3</sub>

##### **4.4.9.1.2 Acidity**

Consistent with the inverse relationship that exists between alkalinity and acidity, the circumneutral HCTs producing detectable alkalinity do not produce detectable acidity. One circumneutral HCT (sample MC-3 LCT 28 (Hole 29B)) sporadically produced very low concentrations of acidity on the order of 2 to 4 mg/L as CaCO<sub>3</sub> (**Figure 4.4-6**). Note that acidity values reported in this document are total acidities determined by titration to a pH endpoint of 8.3 s.u.

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#### 4.4.9.1.3 Depletion Rates

Depletion rates of carbonate neutralization potential, bulk neutralization potential, and sulfide sulfur for samples with circumneutral HCT leachates are plotted on **Figure 4.4-7**. Inspection of depletion rates for circumneutral HCTs yields the following observations:

- In all six circumneutral HCTs, sulfide sulfur either has been, or will be, depleted before bulk neutralization potential is depleted.
- In three of the six circumneutral HCTs, sulfide sulfur either has been, or will be, depleted before carbonate neutralization potential is depleted.
- These relative depletion rates indicate that none of the circumneutral samples has the potential to produce acidic conditions in the future.

#### 4.4.9.1.4 Comparison with ABA and NAG pH Results

All samples that have yielded circumneutral HCT leachates, and that are expected to remain neutral based on relative depletion rates for sulfide sulfur and neutralization potential, were classified as NPAG based on bulk NPR and NAG pH results (**Section 4.4.3.1**).

#### 4.4.9.1.5 Sulfate

Time-series plots of sulfate concentration are shown on **Figure 4.4-8**.

- Sulfate concentrations in the circumneutral HCT leachates show an initial flush of between approximately 80 and 650 mg/L
- By week 10 sulfate concentrations in all the circumneutral HCTs had dropped to below 40 mg/L. For the remainder of the testing period sulfate concentrations declined slowly to between approximately 1 and 12 mg/L by week 45.
- Two small peaks in sulfate concentrations are observed in leachate from sample MC-3 LCT 27 (Hole 27C). The larger peak occurred over weeks 21 to 25 and generated a maximum sulfate concentration of 120 mg/L. A second, smaller peak occurred over weeks 36 to 38 and generated a maximum sulfate peak of 57 mg/L.

#### 4.4.9.1.6 Metals/Metalloids

Consistent with circumneutral pH conditions, metal and metalloid concentrations are very low in the circumneutral HCT leachates (**Appendix B**). Most analytes measured were lower than average concentrations in natural waters in non-mineralized systems (Hem, 1985). However, the following metals/metalloids were present at concentrations higher the averages provided in Hem (1985): barium, cobalt, manganese, molybdenum, and selenium.

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#### ***4.4.9.2 Intermediate pH HCT Samples***

To date, three HCTs have maintained intermediate pH leachates with pH values between approximately 4 and 6 s.u. Samples with intermediate pH leachates are MC-1 LCT 23 (Hole 27C), MC-5 LCT 42 (Hole 29A) and LCT-4 Comb Py Sc TIs (Hole 31) (**Figure 4.4-4**). Discussion of principal parameters for the intermediate pH leachates is provided below.

##### **4.4.9.2.1 Alkalinity**

To date, alkalinity concentrations in the intermediate leachates have generally been below the detection limit of 2 mg/L as CaCO<sub>3</sub>.

##### **4.4.9.2.2 Acidity**

Acidity concentrations observed in the intermediate pH leachates are plotted on **Figure 4.4-6** and summarized as follows:

- MC-1 LCT 23 (Hole 27C): Acidity generally less than 20 mg/L as CaCO<sub>3</sub> after week 12. Initial flush yielded acidity concentrations between 28 and 142 mg/L as CaCO<sub>3</sub>.
- MC-5 LCT 42 (Hole 29A): Acidity generally between 2 and 4 mg/L as CaCO<sub>3</sub> with the exception of two slightly higher values of 14 and 6 mg/L as CaCO<sub>3</sub> detected in the initial flush (weeks 2 and 3, respectively).
- LCT-4 Comb Py Sc TIs (Hole 31): Acidity generally less than 20 mg/L as CaCO<sub>3</sub> except during the initial flush (weeks 0 through 5) where acidity concentrations between 24 and 34 mg/L as CaCO<sub>3</sub> were measured.

Note that acidity values reported in this document are total acidities determined by titration to a pH endpoint of 8.3 s.u.

##### **4.4.9.2.3 Depletion Rates**

Depletion rates of bulk neutralization potential and sulfide sulfur for samples with intermediate pH HCT leachates are plotted on **Figure 4.4-9**. Inspection of depletion rates for intermediate HCTs yields the following observations:

- In all intermediate HCTs, sulfide sulfur either has been, or will be, depleted before bulk neutralization potential is depleted, although in LCT-4 Comb Py Sc TIs the depletion rates are very similar
- These relative depletion rates indicate that the intermediate samples do not have the potential to produce increased acidity in the future. This is consistent with the low and stable concentrations of acidity measured over the last 30 to 35 weeks of leaching



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(**Figure 4.4-6**) and the stable pH trends for all three intermediate pH samples (**Figure 4.4-4**).

#### 4.4.9.2.4 Comparison with ABA and NAG pH Results

Static test results for HCT samples are presented in **Section 4.4.3.1** and compared with observed geochemical behavior as follows:

- MC-1 LCT 23 (Hole 27) produced the most acidic of the intermediate HCT leachates (later time pH approximately 4.2 s.u. and acidity concentrations less than 20 mg/L as CaCO<sub>3</sub>). Static testing classified this sample as Uncertain based on a bulk NPR of 1.54 and NPAG based on NAG pH of 4.87 s.u.
- LCT-4 Comb Py Sc TIs (Hole 31) produced HCT leachate with a stable pH of approximately 5 s.u. and later-time (post-first-flush) acidity concentrations generally less than 20 mg/L as CaCO<sub>3</sub>. Static testing classified this sample as Uncertain based on a bulk NPR of 1.02 and NPAG based on NAG pH of 5.51 s.u.
- MC-5 LCT 42 (Hole 29A) produced HCT leachate with a stable (though somewhat noisy) pH between approximately 5.5 and 6 s.u.; acidity concentrations are very low, on the order of 2 to 4 mg/L as CaCO<sub>3</sub>. Static testing classified this sample as NPAG based on both bulk NPR (5.23) and NAG pH (6.18 s.u.).

#### 4.4.9.2.5 Sulfate

Time-series plots of sulfate concentration are shown on **Figure 4.4-8**.

- Sulfate concentrations in the intermediate HCT leachates show an initial flush of between approximately 94 and 370 mg/L
- By week 12 sulfate concentrations in the intermediate HCTs had dropped to below 30 mg/L. For the remainder of the testing period sulfate concentrations declined slowly to approximately 10 mg/L by week 45.

#### 4.4.9.2.6 Metals and Metalloids

Metal and metalloid concentrations are low in the intermediate HCT leachates. Most analytes measured were lower than average concentrations in natural waters in non-mineralized systems (Hem, 1985). However, in leachate from sample MC-5 LCT 42 (Hole 29A), manganese, selenium, and zinc were elevated compared to natural waters. In addition, in leachates from MC-1 LCT 23 (Hole 27C) and LCT-4 Comb Py Sc TIs, the following metals/metalloids are present at concentrations higher than the averages provided in Hem (1985): aluminum, beryllium, cobalt, copper, manganese, nickel, selenium, and zinc. The release of more metals in the latter two

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leachates is consistent with lower pH conditions (between approximately 4 and 5 s.u. compared with MC-5 LCT 42 leachate with pH between approximately 5.5 and 6 s.u.).

#### ***4.4.9.3 Low pH HCT Samples (Worst-Case Conditions)***

To date, three HCTs have generated mildly acidic leachates with pH values between approximately 3 and 4 s.u. (MC-1 LCT 35 (Hole 29A), MC-2 LCT 37 (Hole 29A), and MC-1 LCT 24 (Hole 29B)) (**Figure 4.4-4**). Note that these samples were chosen to provide data under a potential worst-case scenario that gives rise to high-pyrite mill feed and are not representative of the anticipated composition of operational scavenger tailings. A summary of principal parameters is provided below.

##### 4.4.9.3.1 Alkalinity

To date, alkalinity concentrations in the low pH leachates are below the detection limit of 2 mg/L as CaCO<sub>3</sub>, as expected given the presence of titratable acidity in these samples.

##### 4.4.9.3.2 Acidity

Acidity concentrations observed in the low pH leachates are plotted on **Figure 4.4-6** and summarized as follows:

- MC-1 LCT 35 (Hole 29A): Acidity increasing slightly from approximately 55 mg/L as CaCO<sub>3</sub> at week 10 to on the order of 100 to 150 mg/L as CaCO<sub>3</sub> after week 30. The initial flush yielded a peak acidity of 323 mg/L as CaCO<sub>3</sub>.
- MC-2 LCT 37 (Hole 29A): Acidity generally between 20 and 80 mg/L as CaCO<sub>3</sub> after week 3. The initial flush yielded a peak acidity of 217 mg/L as CaCO<sub>3</sub>.
- MC-1 LCT 24 (Hole 29B): Acidity generally less than 50 mg/L as CaCO<sub>3</sub> over the period of the test.

Note that acidity values reported in this document are total acidities determined by titration to a pH endpoint of 8.3 s.u.

##### 4.4.9.3.3 Depletion Rates

Depletion rates of bulk neutralization potential and sulfide sulfur for samples with lower pH HCT leachates are plotted on **Figure 4.4-9**. Inspection of depletion rates for lower pH HCTs yields the following observations:

- In all lower pH HCTs, neutralization potential has been depleted with sulfide sulfur remaining

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- These depletion rates indicate that all three samples are likely to continue producing acidity until the sulfide sulfur is depleted.

#### 4.4.9.3.4 Comparison with ABA and NAG pH Results

All samples that have yielded HCT leachates with pH between 3 and 4 s.u. were classified as PAG based on bulk NPR and NAG pH results (**Section 4.4.3.1**).

#### 4.4.9.3.5 Sulfate

Time-series plots of sulfate concentration are shown on **Figure 4.4-8**.

- Sulfate concentrations in the lower pH HCT leachates show an initial flush with maximum concentrations on the order of 600 to 650 mg/L
- By week 10 sulfate concentrations in the lower pH HCT leachates had dropped to below 125 mg/L. For the remainder of the testing period sulfate concentrations remained fairly stable though somewhat noisy between approximately 25 and 100 mg/L with occasional values up to 160 mg/L observed in sample MC-1 LCT 35 (Hole 29A).

#### 4.4.9.3.6 Metals/Metalloids

Metal and metalloid concentrations are higher in the acidic leachates compared with the compositions of circumneutral and intermediate HCT leachates. Most analytes measured were lower than average concentrations in natural waters in non-mineralized systems (Hem, 1985). However, the following metals/metalloids are identified as elevated compared to natural waters: aluminum, beryllium, cadmium, chromium, cobalt, copper, iron, manganese, nickel, selenium, thorium, uranium, and zinc. Release of more metal/metalloid constituents at higher concentrations than are observed in the neutral and intermediate pH leachates is consistent with lower pH conditions.

## **4.5 Humidity Cell Testing of 2014 Pilot Plant Scavenger Tailings Replicates**

This section presents the results of humidity cell testing of six replicate sub-samples of scavenger tailings generated on Day 3 of the 2014 pilot plant testing. Humidity cell tests commenced on March 31, 2015 and ran for 50 weeks. Also included below are results of static geochemical testing and mineralogical analysis of the scavenger tailings replicates. Details regarding static and kinetic testing methods and results are presented in SGS (2016b). HCT data are also provided in **Appendix C** of this report.

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### 4.5.1 Objectives

The goal of this task is to assess the repeatability of the HCT method and associated sub-sampling techniques.

### 4.5.2 Sample Preparation/Selection

Samples used in the repeatability study presented here are replicates subsampled from the scavenger tailings produced on Day 3 of the 2014 pilot plant testing. The parent sample identifier is P3 Bulk Ro TIs and the aliquots are named P3-1 through P3-6.

### 4.5.3 Static Testing of Pilot Plant Scavenger Tailings Replicates

The Day 3 pilot plant scavenger tailings sample (P3 Bulk Ro TIs) was subjected to limited static testing (ABA, NAG pH, SPLP, and TCLP) along with all the other pilot plant products at the time that the tailings were generated. For initial static test results see **Section 4.3** of this report. In order to assess consistency between the replicate samples, a comprehensive suite of environmental and mineralogical tests were conducted for further characterization of the HCT samples. Environmental tests included: ABA, NAG pH, SPLP, particle size distribution, whole rock analysis using XRF and strong acid digestion with elemental analysis using ICP-MS. Mineralogical characterization included QEMSCAN and semi-quantitative XRD. Results of static geochemical and mineralogical testing of the P3 replicates are presented in SGS (2016b) and summarized in the following sections.

#### 4.5.3.1 Acid-Base Accounting and Net Acid Generation Testing

ABA and NAG pH results are provided in **Table 4.5-1** (adapted from Table 24 in SGS (2016b)) and summarized below:

- Six replicate samples of scavenger tailings from Day 3 of the 2014 pilot plant test were subjected to ABA and NAG testing prior to commencement of HCTs
- Paste pH ranged between 7.39 and 7.67 s.u. which indicates that no net acidity was produced by the samples prior to testing
- Sulfide sulfur content was similar in all samples (five samples contained 0.12 weight percent and one sample contained 0.11 weight percent sulfide sulfur)
- Total inorganic carbon content was also very similar in all samples ranging from 0.046 to 0.053 weight percent
- Bulk NPR for the pilot plant HCT samples ranged from 1.65 to 2.24; based on bulk NPR, all six pilot plant HCT samples are designated Uncertain (with NPR between 1 and 3)

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- NAG pH for the pilot plant HCT samples ranged from 4.92 to 5.88 s.u.; all samples are designated NPAG based on NAG testing results

### **4.5.3.2 Mineralogy**

Mineralogical analysis was conducted using semi-quantitative x-ray diffraction (XRD), Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN), and optical microscopy. Principal findings are summarized below.

#### **4.5.3.2.1 Semi-quantitative X-Ray Diffraction (XRD)**

Semi-quantitative x-ray diffraction (XRD) was conducted on the six pilot plant scavenger tailings replicates. Data are provided in **Table 4.5-2** (adapted from Table 2 in SGS (2016b)). Below is a summary of the principal minerals identified in the 2014 pilot plant scavenger replicates using semi-quantitative XRD. Inspection of these results indicates that the principal mineralogical makeup of all six pilot plant scavenger replicates is very similar.

- Quartz
  - Mean: 56.5 weight percent
  - Range: 54.9 to 59.2 weight percent
- Muscovite
  - Mean: 23.3
  - Range: 21.8 to 24.5
- Phlogopite
  - Mean: 10.3
  - Range: 8.9 to 11.1

Minor and trace minerals identified with semi-quantitative XRD include: orthoclase, illite, kaolinite, rutile, clinocllore, tremolite, fluorapatite, and magnetite. These minerals are present in small amounts from < 1 to a few weight percent.

Note that the detection limit for XRD is dependent on the crystallinity of the minerals (amorphous minerals will not be detected) and is generally on the order of 0.5 to 2 weight percent so identification of the minor and trace minerals is tentative.

#### **4.5.3.2.2 Quantitative Evaluation of Minerals by Scanning Electron Microscopy**

All six pilot plant scavenger tailings replicates were submitted for mineralogical analysis using QEMSCAN. Polished sections were subjected to particle minerals analysis (PMA) which provided quantitative abundance, liberation and association data. Modal analysis results (i.e. quantitative abundance of mineral phases in each sample) are presented in **Table 4.5-3**

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(adapted from Table 5 in SGS (2016b)). Detailed results, including mineral liberation and association data, are reported in SGS (2016b). Principal observations are as follows:

### *Modal Analysis*

This section provides a summary of the results of modal analysis using QEMSCAN. Details are provided in SGS (2016). Inspection of these results indicates that the QEMSCAN and XRD data are generally in agreement and that little variability is observed in the principal mineralogical makeup of the six pilot plant scavenger replicates. The three major mineral components of the scavenger tailings include quartz, muscovite and biotite/phlogopite in the following amounts:

- Quartz
  - Mean: 55.0 weight percent
  - Range: 53.3 to 57.8 weight percent
- Muscovite
  - Mean: 24.6 weight percent
  - Range: 22.9 to 25.9 weight percent
- Biotite/Phlogopite
  - Mean: 10.3 weight percent
  - Range: 9.0 to 11.1 weight percent

Minor and trace minerals identified by QEMSCAN are largely consistent with those identified with semi-quantitative XRD although, due to lower detection limits, a larger suite of trace minerals is provided. This includes information on carbonate and sulfide distribution that cannot be obtained from the XRD data due to the very small amounts of both phases present in the scavenger tailings. QEMSCAN provides the following information regarding the sulfide and carbonate phases in the 2014 pilot plant scavenger replicates:

### *Sulfides*

Sulfide distribution data indicate that the average total sulfide content of the 2014 pilot plant scavenger replicates is 0.19 weight percent. Approximately 50 percent of the average total sulfide mineral content is pyrite and about 30 percent is chalcopyrite. Undifferentiated copper sulfide minerals and other sulfide minerals account, on average, for about 20 percent of the sulfide mineralogy.

- Sulfide mineral categories provided in QEMSCAN data include: pyrite, chalcopyrite, other Cu-sulfides, and other sulfides.
- Total sulfide minerals
  - Mean: 0.19 weight percent
  - Range: 0.14 to 0.21 weight percent
- Pyrite as a fraction of total sulfide minerals
  - Mean: 0.54

- 
- Range: 0.47 to 0.60
  - Chalcopyrite as a fraction of total sulfide minerals
    - Mean: 0.30
    - Range: 0.16 to 0.38

### *Carbonates*

Carbonate distribution data indicate that the average total carbonate content of the 2014 pilot plant scavenger replicates is 0.17 weight percent. Approximately 70 percent of the average total carbonate mineral content is made up of calcite and dolomite (Ca-Mg carbonates) and about 20 percent is siderite (Fe-carbonate).

- Carbonate minerals detected in the scavenger samples include: calcite, dolomite, ankerite, and siderite.
- Total carbonate minerals
  - Mean: 0.17 weight percent
  - Range: 0.09 to 0.30 weight percent
- Distribution of average mineral content (as a fraction of total carbonates):
  - Calcite: 0.17
  - Dolomite: 0.54
  - Ankerite: 0.08
  - Siderite: 0.21

### *Carbonate/Sulfide Mineral Liberation*

QEMSCAN data provide information regarding the degree to which specific minerals are liberated. For the scavenger pilot plant replicates principal minerals of interest are the potentially acid producing and neutralizing minerals Fe-sulfide and Ca-Mg carbonate, respectively. The degree to which a mineral is liberated, or exposed, as opposed to encapsulated in a potentially less reactive mineral phase such as a silicate, is an important determination of the degree to which it is available to react should the tailings be exposed to oxidizing conditions. QEMSCAN analysis shows that Fe-sulfide and Ca-Mg-carbonate minerals are largely available to react with 96 and 97 percent liberated, respectively (SGS, 2016b).

#### ***4.5.3.3 Whole Rock Analysis with X-Ray Fluorescence***

Whole rock analysis was conducted using x-ray fluorescence (XRF) on the six replicate scavenger tailings samples subjected to humidity cell testing. Data are provided in **Table 4.5-4** (adapted from Table 15 in SGS (2016b)) and summarized as follows:

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- The principal component of all the scavenger tailing samples is silica (SiO<sub>2</sub>); concentrations are consistent across the six replicates at approximately 72 to 73 weight percent. This result is consistent with data from XRD and QEMSCAN analyses presented in **Section 4.5.3.2** that indicate that the primary mineral phases are silicates.
  - XRF data are very consistent across the six replicates for all components measured.

#### ***4.5.3.4 Acid Digest and Elemental Analysis***

Elemental analysis was conducted on the six scavenger tailings replicates subjected to humidity cell testing. Samples were digested using a mixture of nitric, hydrofluoric, perchloric, and hydrochloric acids and elemental analysis was conducted using inductively coupled plasma-optical emission spectrometry (ICP-OES) or inductively coupled plasma-mass spectrometry (ICP-MS). Data are provided in **Table 4.5-5** (adapted from Table 18 in SGS (2016b)). Elemental compositions of the scavenger tailings replicates are very consistent for all elements measured.

#### ***4.5.3.5 Particle Size Distribution***

Particle size distribution of scavenger tailings from the 2014 pilot plant subjected to humidity cell testing was determined using sieving and hydrometry (SGS, 2016b). Particle size distribution and classification results are summarized in **Tables 4.5-6 and 4.5-7** (adapted from Tables 28 and 27 in SGS (2016b)), respectively. Particle size distribution is plotted on **Figure 4.5-1**. Principal observations are provided below:

- Particle size distribution and classification for the six scavenger tailings samples are very consistent across the replicates
- P<sub>80</sub> of the scavenger tailings is approximately 140 microns (0.14 millimeters)
- Particle size classifications for scavenger tailings are as follows:
  - Sand (percent)
    - Average: 40.1
    - Range: 39.7 to 40.6
  - Silt (percent)
    - Average: 54.9
    - Range: 54.4 to 55.3
  - Clay (percent)
    - All replicates contain 5 percent clay-sized particles
- Specific gravity of the scavenger tailings is 2.78 with a range between 2.77 and 2.79.



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#### **4.5.3.6 Simulated Precipitation Leaching Procedure**

SPLP results are provided in **Table 4.5-8** (adapted from Table 21 in SGS (2016b)) and summarized as follows:

- pH of all samples was circumneutral with a reported range of pH values between 7.75 and 8.60 s.u.; pH values above the initial leachate pH of 4.2 s.u. indicate that alkalinity was released from the sample during leaching.
- Concentrations of measured anions, metals, and metalloids were generally low in leachates from scavenger tailings consistent with circumneutral conditions. However, concentrations of fluoride and manganese were slightly elevated with respect to values observed in natural waters in non-mineralized systems (Hem, 1985).
- Identification of potentially elevated constituents is consistent across the replicates with the exception of fluoride which was not elevated in one replicate (P3-6 Bulk Ro TIs) with a concentration of 0.93 mg/L compared with concentrations between 1.14 and 2.32 mg/L for the other five replicates.

#### **4.5.4 Humidity Cell Testing**

Six replicate samples of scavenger tailings generated from the 2014 pilot plant test were subjected to humidity cell testing. The goal of this task is to assess the repeatability of humidity cell tests and the associated sample collection. Static geochemical and mineralogical data presented in **Section 4.5.3** show that all six replicate samples have very similar physical and geochemical characteristics and we conclude that standard homogenization and sub-sampling techniques successfully provide a representative sub-sample. The objective of the humidity cell testing presented in this section is to assess the repeatability of the HCT testing given six similar samples. Clearly there are sources of variability in the samples that may be expected to result in a distribution of solute concentrations and water quality parameters in leachates across the six HCTs. However, the variability is small and data presented in the following sections indicate that, had we chosen any one of these sub-samples to represent the scavenger tailings, we would have drawn the same conclusions regarding the likely geochemical reactivity of the material in question.

It is important to note that this set of HCT replicates was conducted with the focused objective presented above, and that the results are not intended for use in predictive studies. Results of humidity cell testing of scavenger tailings generated from 2014 master composites, presented in **Section 4.4.9**, are the appropriate data for use in sulfide oxidation and fate-and-transport studies.

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Humidity cell tests (HCTs) were initiated on March 31, 2015 and ran for 50 weeks. Details regarding HCT methodology and results are presented in SGS (2016b). HCT data are provided in **Appendix C** and summarized below.

#### ***4.5.4.1 pH***

HCT leachates from the replicate scavenger tailings samples had an initial pH of approximately 6.5 s.u. The pH values of all six samples declined slowly over the period of the test and stabilized between approximately 5.5 and 6 s.u by the end of testing. **Figure 4.5.2** shows that the pH trend was similar across the six replicates.

#### ***4.5.4.2 Alkalinity***

Over the 50 week testing period, alkalinity concentrations in the HCT replicates were generally at or below the detection limit of 2 mg/L as CaCO<sub>3</sub>.

#### ***4.5.4.3 Acidity***

Titratable acidity in the replicate HCT leachates was low (**Figure 4.5-3**). After an initial flush that yielded acidity concentrations between 20 and 30 mg/L as CaCO<sub>3</sub>, acidities were consistently on the order of 2 to 5 mg/L as CaCO<sub>3</sub>. Starting in approximately Week 35 there was a little more spread in the acidity concentrations but all samples were still generating acidity at concentrations less than about 7 mg/L as CaCO<sub>3</sub> by the end of the testing period.

#### ***4.5.4.4 Depletion Rates***

Depletion rates of carbonate neutralization potential, bulk neutralization potential and sulfide sulfur for the replicate pilot plant scavenger tailings are plotted on **Figure 4.5-4**. Inspection of relative depletion rates yields the following observations:

- In all six HCTs carbonate neutralization potential was depleted in approximately 20 weeks.
- In all six HCTs, sulfide sulfur was depleted at a higher rate than bulk neutralization potential was depleted.
  - By the end of the testing period approximately 50 to 60 percent of the sulfide sulfur had been depleted in all six samples.
  - By the end of the testing period approximately 30 to 40 percent of the bulk neutralization potential had been depleted in all six samples.

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#### **4.5.4.5 Sulfate**

Time-series plots of sulfate concentration are shown on **Figure 4.5-5**.

- Sulfate concentrations in the replicate HCT leachates show an initial flush of between approximately 95 and 200 mg/L
- By week 20 sulfate concentrations in all the replicate HCTs had dropped to below 40 mg/L. For the remainder of the testing period sulfate concentrations declined slowly to between approximately 10 and 20 mg/L by week 51.
- Sulfate concentration trends were very similar for all six replicate samples.

#### **4.5.4.6 Metals and Metalloids**

Metal and metalloid concentrations are low in the pilot plant scavenger tailings HCT leachates and are generally similar across the replicates. Cobalt, manganese, selenium, and zinc are slightly elevated in all samples with respect to average concentrations in natural waters from non-mineralized systems (Hem, 1985). In several samples there are occurrences of slightly elevated nickel although these generally do not persist beyond the first flush (weeks 0 to 5).

### **4.6 Oxygen-Consumption Testing of 2014 Pilot Plant Tailings**

Geochemical modeling of the processes involved in weathering of tailings under oxidizing conditions requires quantification of the kinetic rate at which pyrite is oxidized. Oxygen consumption testing is a method designed to determine initial pyrite oxidation rates by measuring the amount of oxygen consumed by the reaction over a given period of time. This provides an additional approach to assessment of sulfide oxidation to be considered in conjunction with the results of humidity cell testing. The material to be characterized is placed in a closed reaction vessel and the oxygen and carbon dioxide content of the head space gas is monitored. By combining the oxygen consumption data with the stoichiometry of the pyrite oxidation reaction the pyrite oxidation rate is calculated. Pyrite oxidation rates were calculated based on the initial oxygen depletion rate that was measured over the first 7 to 31 days of testing. It should be noted that pyrite oxidation rates from Ox-Con testing are not directly comparable to those calculated from HCT leachate data as the tests are conducted over different time frames (HCTs much longer than Ox-Con) and under different environmental conditions (Ox-Con tests are conducted in a closed system and HCTs are exposed to constant air-flow of varying humidity and rinsed once a week).

Oxygen consumption testing was conducted on materials of differing pyrite content (i.e., scavenger and pyrite tailings) at three different moisture contents in order to determine pyrite oxidation rates over a range of potential conditions. The oxygen consumption testing (Ox-Con)

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was conducted by E.S. Analytical in Melbourne, Australia. Detailed methods and results are provided in E.S. Analytical (2015) and summarized below.

#### **4.6.1 Objectives**

The goal of this work was to determine the initial pyrite oxidation rate for pyrite in each of the two tailings types (scavenger and pyrite) as function of moisture content.

#### **4.6.2 Sample Preparation/Selection**

Four 2014 pilot plant tailings samples, two scavenger and two pyrite, were subjected to oxygen consumption testing in 2015. Each of the samples was tested at three different volumetric moisture contents (VMC). Samples and moisture contents are as follows:

##### Day 4 Pilot Plant (P4)

- Scavenger tailings run at volumetric moisture contents of 5 percent, 20 percent, and 24 percent
- Pyrite tailings run at volumetric moisture contents of 5 percent, 20 percent, and 40 percent

##### Day 8 Pilot Plant (P8)

- Scavenger tailings run at volumetric moisture contents of 5 percent, 20 percent, and 26 percent
- Pyrite tailings run at volumetric moisture contents of 5 percent, 20 percent, and 37 percent

The volumetric moisture contents for each sample were chosen by the RCM geochemistry team to include a low value close to residual moisture content (10 percent saturation), a high value based, as close as possible, on 80 percent saturation, and an intermediate value at approximately 40 to 45 percent saturation.

#### **4.6.3 Results of Oxygen-Consumption Testing**

Pyrite oxidation rates for the four tailings samples at three volumetric moisture contents are provided in **Table 4.6.1** and summarized below.

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#### **4.6.3.1 Scavenger Tailings**

- Initial pyrite oxidation rate for the P4 scavenger tailings ranged from  $5.9 \times 10^{-8}$  to  $2.1 \times 10^{-7}$  kg O<sub>2</sub>/t/s (kilograms of oxygen consumed per tonne of tailings per second)
- Initial pyrite oxidation rate for the P8 scavenger tailings ranged from 2.8 to  $7.2 \times 10^{-8}$  kg O<sub>2</sub>/t/s
- Initial pyrite oxidation rate is positively correlated with volumetric moisture content in the scavenger tailings samples

#### **4.6.3.2 Pyrite Tailings**

- Initial pyrite oxidation rate for the P4 pyrite tailings ranged from  $4.2 \times 10^{-8}$  to  $2.7 \times 10^{-6}$  kg O<sub>2</sub>/t/s
- Initial pyrite oxidation rate for the P8 pyrite tailings ranged from  $2.5 \times 10^{-8}$  to  $1.4 \times 10^{-6}$  kg O<sub>2</sub>/t/s
- In the P4 pyrite tailings samples, initial pyrite oxidation rate is strongly negatively correlated with moisture content; at the highest volumetric moisture content (40 percent VMC; approximately 80 percent saturation) the POR is very low consistent with hydraulic saturation control on oxygen availability
- In the P8 high sulfide tailings the sample tested at approximately 80 percent saturation (37 percent VMC) also exhibits a very low initial pyrite oxidation rate. However, the relationship is slightly more complex than in the P4 pyrite tailings with the highest POR occurring in the intermediate VMC sample.

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## 5.0 Quality Assurance/Quality Control

### 5.1 Analytical Laboratory QA/QC

Analytical data for element concentrations in solids and solutions presented in this report were produced by SGS Environmental Services (SGS), an environmental testing laboratory located in Lakefield, Ontario, Canada. All quality assurance/quality control (QA/QC) is performed by SGS, and data are used by Duke HydroChem as provided.

SGS maintains full ISO (International Organization for Standardization) and CALA (Canadian Association for Laboratory Accreditation) certification in accordance with ISO/IEC 17025:2005. The quality assurance system at SGS provides all required documentation including a quality manual, methods and written instructions, standard operating procedures, and data approval criteria.

Samples received into the laboratory for analysis are assigned a unique identifier and custody of samples is traceable through the laboratory information management system (LIMS). Samples are inspected at the time that they are received in order to ensure sample integrity. Depending on sample type and method requirements this initial inspection may include checking for damage or leakage, compliance with container-type and preservation requirements, and proper sample temperature.

Quality control procedures are method specific and may include duplicate samples, spiked blanks, spiked replicates, reagent/instrument blanks, preparation control samples, certified reference material analysis, and instrument control samples. Summaries of analytical methods are available from SGS upon request.

Certificates of Analysis and Chain of Custody documentation are provided in each of the SGS reports referenced in this document.

### 5.2 Comparison of Duplicate Samples

In addition to the laboratory QA/QC provided by SGS, duplicate samples of tailings generated from the metallurgical testing of 2014 individual and master composites, and the 2014 pilot plant testing were submitted for static testing. These duplicate samples are splits of the tailings material and are therefore subject not only to analytical uncertainty but also variability due to the heterogeneous nature of the tailings materials. The degree to which the data vary between duplicates is an indication of the repeatability of the sampling method (i.e. how reliably a given material can be subsampled) and the precision of the analytical method. Duplicates were submitted from approximately 15 percent of each of the static datasets as described below:

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- Scavenger tailings from 2014 individual ore composites: eight of the 55 scavenger tailings samples subjected to static testing (ABA, NAG pH, and NAG leachate). Data are provided in **Tables 4.1-5, 4.1-6, and 4.1-10**.
  - Scavenger tailings from 2014 master ore composites: three of the 34 scavenger tailings samples subjected to static testing (ABA, NAG pH, and NAG leachate). Data are provided in **Tables 4.2-5, 4.2-6, and 4.2-10**.
  - Scavenger and high sulfide tailings from 2014 pilot plant testing: three of the ten pilot plant tailings samples subjected to static testing (ABA, NAG pH, NAG leachate, SPLP, and TCLP). Data are provided in **Tables 4.3-1 through 4.3-6**.

Duplicates were compared to assess the degree of reliability of both the sub-sampling and the analytical methods. The duplicates are generally in good agreement and we conclude that the data are suitable for the intended use.

### **5.3 Repeatability of Humidity Cell Test Method**

In order to assess the repeatability of the humidity cell test (HCT) method and the associated sub-sampling procedures, six HCTs were run on replicate scavenger tailings samples generated from the 2014 pilot plant testing. Static geochemical and mineralogical data presented in **Section 4.5.3** show that all six replicate samples have very similar physical and geochemical characteristics. In addition, the composition of HCT leachates generated from the six replicates including: pH, alkalinity, acidity, sulfate concentration, and metal/metalloid concentrations were very similar and the depletion rates for sulfide sulfur, carbonate neutralization potential, and bulk neutralization potential were in good agreement. Data and further discussion of the HCT results are provided in **Section 4.5.4** of this report.

In summary, the results of this investigation provide evidence that the standard homogenization and sub-sampling techniques used to produce replicates successfully provide a representative sub-sample and that, given similar replicate samples, the HCT method produces repeatable results.

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## 6.0 Discussion

Resolution's tailings management strategy calls for separation of tailings into two mineralogically and geochemically discrete streams known as pyrite tailings and scavenger tailings (note that in earlier Project documents the pyrite tailings were referred to as cleaner tailings). These separate tailings streams will be produced simultaneously at all stages of mineral processing. The pyrite tailings contain the majority of the pyrite segregated from the ore during mineral processing and show elevated sulfide and residual metals contents; this tailings stream is anticipated to account for approximately 15 percent of the total tailings volume. Scavenger tailings contain very low concentrations of sulfide and residual metals due to segregation of the majority of the pyrite to the pyrite tailings; this tailings stream is anticipated to account for approximately 85 percent of the total tailings volume. A summary and discussion of the composition and potential reactivity of both tailings streams is provided in the following sections. Note that the focus of recent work has been characterization of the scavenger tailings, and that focus is reflected in this discussion. For further details regarding the pyrite tailings please see the initial baseline tailings geochemistry report (DHC, 2014).

### 6.1 Geochemical Reactivity of Pyrite Tailings

The potential geochemical reactivity of the pyrite tailings has been clearly defined by the RCM geochemical characterization program. As reported in the initial baseline tailings geochemistry report (DHC, 2014), the pyrite tailings are classified as potentially acid generating. If these materials were allowed to weather in an oxidizing environment, they would be expected to generate acidic conditions and leach elevated concentrations of fluoride, sulfate, and metals/metalloids. This classification of the pyrite materials is supported by the results of static geochemical testing of pyrite tailings produced during the 2014 pilot plant testing and presented in the current report. The potential for pyrite tailings to generate acidic drainage with elevated concentrations of metals and sulfate has long been recognized by the Project. The current tailings management strategy includes emplacement and storage of pyrite tailings under high-saturation conditions; pyrite tailings will be encapsulated by scavenger tailings and, ultimately, covered with an engineered cover to prevent exposure to oxidizing conditions and maintain a high moisture content.

### 6.2 Geochemical Reactivity of Scavenger Tailings

The primary goal of the work presented in this report has been to expand the Project's understanding of the potential geochemical reactivity of the scavenger tailings. Initial characterization of scavenger tailings conducted over the period 2002 through 2013 informed planning of geochemical characterization efforts starting in 2014 and continuing through the



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present. Results of recent work support the principal findings of the earlier program as well as providing a larger and more robust data set from which it is possible to assess the likely variability of scavenger tailings characteristics over the life of the mine.

### **6.2.1 Mineralogy of Scavenger Tailings**

Mineralogy of the scavenger tailings is dominated by silicate minerals including: quartz, muscovite, phlogopite, orthoclase, illite, and kaolinite. Scavenger tailings contain very little pyrite as the majority of the pyrite is segregated into the pyrite tailings stream during flotation. Scavenger tailings also contain very small amounts of calcite and dolomite (the primary source of acid neutralization potential). This is because carbonate mineral content of the ore is naturally low and is not the result of ore processing.

### **6.2.2 Distribution of Geochemical Characteristics in Scavenger Tailings**

A large set of scavenger tailings was generated from metallurgical testing of individual ore composites deemed representative of the lithology and alteration assemblages present in the Resolution orebody. In total, 55 samples were subjected to static geochemical testing. Of these 55 scavenger tailings samples, 41 were generated from ore composites representative of anticipated mill feed under operational conditions (i.e. with pyrite grade less than 15 weight percent). The remaining 14 samples were generated from ore composites with higher pyrite grades and were included to provide data regarding a potential worst case scenario of scavenger tailings production should the mill feed contain more pyrite than anticipated.

Static testing of scavenger tailings representative of operational conditions indicates that sulfide sulfur contents will range between approximately 0.01 and 1 weight percent. Sulfide sulfur content is log-normally distributed with a geometric mean of 0.07 weight percent. Approximately 83 percent of these samples contain less than 0.2 weight percent sulfide sulfur.

Sulfide sulfur in scavenger tailings samples representative of a potential worst case production scenario (i.e. those generated from ore composites containing greater than 15 weight percent pyrite) ranges between approximately 0.1 and 1.3 weight percent. These values are log-normally distributed with a geometric mean of 0.4 weight percent.

Sulfide sulfur, and therefore acid generation potential, is very low in all the scavenger tailings samples; however, neutralization potentials are also low due to the small carbonate mineral content of the Resolution ore. Results of static testing (acid base accounting and net acid generation testing) indicate that, of the 41 scavenger tailings samples deemed representative of operational conditions, 41 percent are classified as not potentially acid generating (NPAG), 15 percent are potentially acid generating (PAG), and 44 percent are Uncertain.

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### 6.2.3 Long-Term Geochemical Reactivity of Scavenger Tailings

Comparison of humidity cell leachates with static geochemical testing results indicates that the static designations are reasonably reliable indicators of the long-term geochemical reactivity of the scavenger tailings. Tailings samples designated NPAG generally produce circumneutral leachates (pH greater than 6.5 s.u.) with very low sulfate and metal/metalloid concentrations. Samples classified as Uncertain produce leachates with slightly depressed pH values (between 4 and 5 s.u.), low titratable acidity (less than 20 mg/L as CaCO<sub>3</sub>) and low metal/metalloid concentrations. Sulfate concentrations in these leachates are low, similar to those observed in circumneutral leachates. In the humidity cell tests run using PAG scavenger tailings (derived from higher pyrite ore samples), the pH is lower (less than 4 s.u.) although titratable acidity is still small compared, for example, with acidities observed when testing pyrite tailings (50 to 150 mg/L as CaCO<sub>3</sub> compared with up to 1,000 mg/L as CaCO<sub>3</sub> in pyrite tailings HCT leachates (DHC, 2014)). Sulfate concentrations are higher in these leachates (long-term concentrations generally range between 25 and 100 mg/L). In addition, consistent with lower pH conditions, more metals are released at slightly higher concentrations. It should be noted that, even under acidic conditions, release of sulfate and metals/metalloids from the scavenger tailings is limited by the very low sulfide and residual metals content of these materials.

### 6.3 Pyrite Oxidation Rate in Scavenger and Pyrite Tailings

Geochemical modeling of the processes involved in weathering of tailings under oxidizing conditions requires quantification of the kinetic rate at which pyrite is oxidized. Four tailings samples, two scavenger and two pyrite, were subjected to oxygen consumption testing at three different volumetric moisture contents. The volumetric moisture contents for each sample were chosen by the RCM geochemistry team to include a low value close to residual moisture content (10 percent saturation), a high value based, as close as possible, on 80 percent saturation, and an intermediate value at approximately 40 to 45 percent saturation.

An important outcome of this testing was the clear relationship observed between high moisture content (close to 80 percent saturation) and substantially decreased pyrite oxidation rates in the pyrite tailings. Pyrite oxidation rate in the pyrite tailings decreased approximately two orders of magnitude from the fastest rates (observed at lower moisture contents) to the slowest rates (measured in the high moisture content tests). The strongly non-linear reduction in oxygen diffusion as a function of increasing relative hydraulic saturation is well established in theory and often measured empirically in the literature (INAP, 2009; MEND, 2009) as well as in the tests presented here. These widely accepted scientific findings are central to the RCM

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approach for pyrite tailings disposal (i.e., emplacement and storage under high moisture conditions).

#### **6.4 Repeatability of Humidity Cell Tests**

In order to assess the repeatability of the humidity cell test (HCT) method and the associated sub-sampling procedures, six HCTs were run on replicate scavenger tailings samples. Static geochemical and mineralogical characterization indicates that all six replicate samples have very similar physical and geochemical characteristics and we conclude that standard homogenization and sub-sampling techniques successfully provide a representative sub-sample. The chemical compositions of HCT leachates generated from the six replicates were very similar and the depletion rates for sulfide sulfur and neutralization potential were in good agreement. This study shows that, given similar replicate samples, the HCT method produces repeatable results.

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