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То:	Jim Scott	Date:	January 21, 2015 ¹			
Company:	PolyMet Mining	From:	Stephen Day			
Copy to:		Project #:	1UP005.001			
Subject: Update on Kinetic Test Data, NorthMet Project – DRAFT						

1 Introduction

Kinetic tests (mainly humidity cells) were initiated for the NorthMet Project in 2004 on samples of rock, simulated tailings and hydrometallurgical process residues according to overall program designs prepared following discussion between PolyMet Mining Inc. (PolyMet), Minnesota Department of Natural Resources (MDNR) and SRK Consulting (Canada) Inc. (SRK). Results from these tests have been used at various junctures of the project to develop waste management plans and evaluate project environmental effects. In 2009, the program was modified in consultation with MDNR to stop some tests and modify the frequency of analysis of leachates based on trend interpretation (SRK 2009).

The purpose of this memorandum is to provide an update on the progress of the testwork and transmit release rates as it relates to water quality source term predictions in the Environmental Impact Statement (EIS).

2 Data Presentation

Electronic updates to the data graphing and calculations are available on Barr Engineering's NorthMet Project website. The data period covered by the testwork now includes up to 6.5 years because some waste rock humidity cells were initiated in August 2005. The cutoff for interpreting data for this update was the end of January to early February 2012. Due to reduced analytical frequency for most tests (SRK 2009), complete QA review and update of the database occurs quarterly. Data collected subsequent to February 2012 completed QA after this update was prepared and are not included in this review.

3 Waste Rock, Lean Ore and Ore Kinetic Tests

3.1 Status of Program

The original waste rock humidity cell program consisted of 92 tests distributed according to the four initially defined classifications shown in Table 1. Waste rock was subsequently classified into three categories. The current program consists of 43 tests with most ongoing tasks in the mid-sulfur range for waste rock and lean ore (19 tests). Table 2 shows all samples and the testwork duration used to calculate rates for use in water quality predictions.

The primary uses of the data in the waste characterization program are to:

- Understand long term performance of wastes and inform definition of waste management categories based on sulfur content; and
- Provide leaching rates for use in source term geochemical predictions.

¹ This version replaces a memo of the same title dated October 19, 2012 to correct graphs shown in Figure 1.

Initial Classification	Waste Category	Totals	Stopped	Continuing	
S≤0.05%	1	27	20	7	
S>0.05%	1	10	6	4	
	2/3	14	3	11	
	4	13	8	5	
Lean Ore	1	4 3		1	
	2/3	13	5	8	
	4	8	4	4	
Ore	Not applicable	3	0	3	
Totals	All	92	49	43	
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Table 1. Sample Categories

Mining/1UP005.01_Northmet_project_2004\Testwork\WR_KT\Characteristics\Humidity_Cell_Table\[1UP005.001_WR_Outcomes_ver01.xlsx]Testwork Tallies

Results are described below in the context of these two objectives. Each heading describes results according to the waste categories (1, 2/3 and 4). Charts for indicator parameters are shown to indicate major features (Figures 1 to 4). Overall tendency toward acidic conditions is shown by pH. Sulfate indicates sulfide mineral oxidation rates. Nickel is shown because as observed in this test program and testwork performed previously by DNR it (along with cobalt) tends to respond first to declining pH. Copper is shown because it leaches more rapidly as pH declines further. Arsenic provides an indication of how a heavy oxyanion is affected by changes in pH.

In order to obtain average leaching rates, typical trends have been recognized and average rates calculated for common qualitative leaching features or "conditions" as summarized in Table 3. In these definitions, "stable" means typically neither clearly increasing or decreasing. Due to variability in the testwork results, the definitions are not strict and require some flexibility in interpretation. For example, the transition from Condition 1 to 2 may not occur exactly at pH 7.

Condition 2 is typically accompanied by increasing release of cobalt and nickel which may continue into Condition 3. Lower pH (less than 6) typically occurs during Condition 3 and 4. In some cases, pH recovery is observed during Condition 4 as oxidation rates decrease.

HCT ID	Comment	Original Waste Type	Geological Unit	Rock Type	Category	Sample ID	S %	Initial Date	Data Record Length weeks	Duration Used in Current Modeling ² weeks
1	9 Dup	RWR	1	Anorthositic	1	99-320C(830-850)	0.09	8/8/2005	337	284
3		RWR	1	Anorthositic	1	00-361C(345-350)	0.05	8/8/2005	337	284
26		NRWR	2	Anorthositic	1	00-366C(185-205)	0.02	8/9/2005	198	198
27		NRWR	2	Anorthositic	1	00-366C(230-240)	0.02	8/9/2005	198	198
28		NRWR	2	Anorthositic	1	99-320C(165-175)	0.03	8/9/2005	198	198
40		NRWR	3	Anorthositic	1	00-334C(30-50)	0.02	8/9/2005	337	284
41	37 Dup	NRWR	3	Anorthositic	1	00-368C(125-145)	0.04	8/10/2005	337	284
42		NRWR	3	Anorthositic	1	00-368C(20-40)	0.04	8/10/2005	198	198
13		NRWR	1	Troctolitic	1	00-340C(595-615)	0.04	8/10/2005	198	198
14		NRWR	1	Troctolitic	1	00-334C(580-600)	0.06	8/15/2005	336	284
15		RWR	1	Troctolitic	1	00-334C(640-660)	0.07	8/8/2005	337	284
16		RWR	1	Troctolitic	1	00-347C(795-815)	0.07	8/8/2005	198	198
29		NRWR	2	Troctolitic	1	99-318C(250-270)	0.04	8/9/2005	198	198
30		NRWR	2	Troctolitic	1	00-373C(95-115)	0.04	8/9/2005	198	198
31		NRWR	2	Troctolitic	1	00-373C(75-95)	0.06	8/9/2005	198	198
32		RWR	2	Troctolitic	1	00-357C(110-130)	0.08	8/9/2005	198	198
33		RWR	2		1	99-320C(315-330)	0.07	8/9/2005	337	284
43		NRWR	3		1	00-366C(35-55)	0.02	8/10/2005	198	198
44		NRWR	3		1	00-334C(110-130)	0.04	8/10/2005	198	198
45		NRWR	3		1	00-347C(155-175)	0.06	8/10/2005	198	198
46		RWR	3		1	00-347C(280-300)	0.06	8/10/2005	198	198
49		NRWR	4		1	00-367C(50-65)	0.03	8/10/2005	198	198
50	67 D	NRWR	4		1	00-367C(260-280)	0.04	8/10/2005	198	198
51	57 Dup	NRWR	4		1	00-367C(290-310)	0.04	8/10/2005	337	284
52		RWR	4	I roctolitic	1	00-370C(20-30)	0.08	8/10/2005	198	198
56			5	Troctolitic	1	26064(44-54)	0.02	8/10/2005	337	284
59			5	Troctolitic	1	26064(264+146-269+156)	0.06	8/10/2005	337	284
74			0	Troctolitic	1	20030(110-123)	0.04	0/0/2005	190	190
74			6	Troctolitic	1	26029(613-623)	0.02	9/6/2005	221	279
00			1	Troctolitic	1	20030(133-133)	0.05	9/22/2005	187	186
21		RWR	1	Illtramafic	1	00-357C(335-340)	0.00	8/9/2005	198	198
35		NRWR	2		1	00-368C(460-465)	0.00	8/9/2005	198	198
36		NRWR	2		1	26055(940-945)	0.00	8/9/2005	198	198
39		NRWR	2	Ultramafic	1	26098+00-337C	0.00	8/9/2005	198	198
72	61 Dup	LeanOre	2	Ultramafic	1	00-361C(240-245)	0.06	8/11/2005	337	284
101	1	LeanOre	2	Ultramafic	1	26039(310-315)	0.06	10/28/2005	187	186
2		RWR	1	Anorthositic	2/3	00-361C(310-320)	0.18	8/8/2005	337	284
103		LeanOre	1	Anorthositic	2/3	99-320C(400-405)	0.18	10/28/2005	326	273
5		RWR	1	Sed Honfels	2/3	26030(1047-1052)	0.24	8/8/2005	337	284
6		RWR	1	Sed Honfels	2/3	26061(1218-1233)	0.44	8/8/2005	337	284
7		RWR	1	Sed Honfels	2/3	00-340C(990-995)	0.55	8/8/2005	337	284
17		RWR	1	Troctolitic	2/3	00-350C(580-600)	0.19	8/8/2005	337	284
18		RWR	1	Troctolitic	2/3	00-327C(225-245)	0.44	8/8/2005	198	198
34		RWR	2	Troctolitic	2/3	00-369C(335-345)	0.18	8/9/2005	337	284
47		RWR	3	Troctolitic	2/3	00-326C(60-70)	0.14	8/10/2005	337	284
48	38 Dup	RWR	3	Troctolitic	2/3	00-369C(305-325)	0.25	8/10/2005	198	198
53		RWR	4	Troctolitic	2/3	00-369C(20-30)	0.21	8/10/2005	337	284
54		RWR	4	Troctolitic	2/3	00-367C(170-175)	0.51	8/10/2005	337	284
71		LeanOre	2	Troctolitic	2/3	00-340C(380-390)	0.15	8/11/2005	198	198
75		LeanOre	3	Troctolitic	2/3	26049+26030	0.59	8/11/2005	198	198
77		LeanOre	5	Troctolitic	2/3	26056(302-312)	0.23	8/11/2005	337	284
80		LeanOre	6	Troctolitic	2/3	26142(360+345-365+350)	0.18	8/11/2005	337	284
96		LeanOre	2	Troctolitic	2/3	99-318C(325-330)	0.17	10/28/2005	326	273
98		LeanOre	5	Troctolitic	2/3	26056(282-292)	0.32	10/28/2005	187	186
100		LeanOre	1	Troctolitic	2/3	00-340C(910-925)	0.36	10/28/2005	326	273
102		LeanOre	1	Troctolitic	2/3	00-331C(190-210)	0.42	10/28/2005	326	273
105		LeanOre	3	Troctolitic	2/3	00-367C(495-500)	0.28	10/28/2005	326	273
22		RWR	1	Ultramafic	2/3	00-326C(680-685)	0.30	8/9/2005	198	198
23		RWR	1	Ultramafic	2/3	00-357C(535-540)	0.2	8/9/2005	337	284
94		LeanOre	1	Ultramafic	2/3	00-344C(630-635)	0.34	10/28/2005	187	186
95		LeanOre	1	Ultramafic	2/3	00-326C(495-505)	0.16	10/28/2005	187	186

 2 Waste Characterization Data Package Version 9 (July 3 2012).

HCT ID	Comment	Original Waste Type	Geological Unit	Rock Type	Category	Sample ID	S %	Initial Date	Data Record Length weeks	Duration Used in Current Modeling ² weeks
104		LeanOre	2	Ultramafic	2/3	00-326C(225-235)	0.12	10/28/2005	326	273
4		RWR	1	Anorthositic	4	00-343C(240-250)	0.68	8/8/2005	198	198
65		LeanOre	1	Anorthositic	4	26027(616-626)	1.83	8/11/2005	337	284
93		LeanOre	1	Anorthositic	4	00-331C(255-260)	0.86	10/28/2005	326	273
8		RWR	1	Sed Honfels	4	00-340C(965-974.5)	1.74	8/8/2005	198	198
11		RWR	1	Sed Honfels	4	26043+26027	2.47	8/8/2005	337	284
68		LeanOre	1	Sed Honfels	4	26062+26026	4.46	8/11/2005	337	284
106		LeanOre	1	Sed Honfels	4	26058(704-715)	1.46	10/28/2005	326	273
19		RWR	1	Troctolitic	4	00-371C(435-440)	0.88	8/8/2005	337	284
20	10 Dup	RWR	1	Troctolitic	4	00-340C(765-780)	1.68	8/8/2005	337	284
55		RWR	4	Troctolitic	4	00-367C(395-400)	0.77	8/10/2005	198	198
69		LeanOre	1	Troctolitic	4	00-340C(725-745)	0.91	8/11/2005	198	198
76		LeanOre	4	Troctolitic	4	00-367(400-405)	1.37	8/11/2005	198	198
24		RWR	1	Ultramafic	4	99-318C(725-735)	0.72	8/9/2005	198	198
25		RWR	1	Ultramafic	4	99-317C(460-470)	1.24	8/9/2005	198	198
70		LeanOre	1	Ultramafic	4	00-344C(515-520)	1.2	8/11/2005	198	198
97		LeanOre	1	Ultramafic	4	00-330C(275-280)	0.75	10/28/2005	187	186
62		RWR	20	Virginia	4	00-361C(737-749)	2	8/11/2005	337	284
63	58 Dup	RWR	20	Virginia	4	00-364C(210-229)	3.79	8/11/2005	198	198
64		RWR	20	Virginia	4	00-337C(510-520)	5.68	8/11/2005	198	198
66		Ore			-	P10	0.86	9/8/2005	333	268
67		Ore			-	P20	0.9	9/8/2005	333	268
73		Ore			-	P30	0.86	9/8/2005	333	268

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Table 3. Qualitative Definition of Leaching Conditions

Condition	Trend Features
1	pH>7, stable SO ₄
2	pH<7, typically stable SO ₄
3	SO ₄ sharply increasing and unstable
4	SO₄ peaked and decreasing

3.2 Description of Results by Waste-Rock Category

3.2.1 Category 1

Results for pH, sulfate, nickel, copper and arsenic are shown in Figure 1.

All Category 1 humidity cells have yielded pH above 6 throughout the program. Generally, pHs declined as the tests proceeded. Initial pHs in most cases were above 8 but declined rapidly and have typically fluctuated between 6.5 and 7.5. There is no indication for the 12 continuing tests that pHs are on a declining trend. In a few cases, pHs have recovered slightly. At the same time, the alkalinity trend is stable.

Sulfate leaching rates have been low throughout the program with most continuing tests showing rates below 1 mg/kg/week. At these low rates, variability in trends is apparent but no clear upward trends have been apparent.

Nickel showed slight increases in leaching rates relative to other tests in the few cells in which pH decreases and peak nickel leaching rates were observed in cell 99-320C(830-850). This sample also showed the highest sulfate and cobalt leaching rates. Copper generally showed stable leaching rates.

Arsenic showed no increase in leaching rates due to pH changes. Arsenic leaching has either stabilized or decreased steadily.





_____ 00-367C(495-500)/S=0.28%







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1.4

1.2

0.8

0.6

0.4

0.2

Cu [mg/kg/wk]







Testing on Category 1 samples has confirmed to date that alkalinity generated by weathering of silicate minerals is able to result in pH above the pH of de-ionized water. This indicates that the alkalinity is consuming acidity introduced by both the dissolved CO_2 , introduced by the deionized water (pH 5 to 6), and acidity produced by oxidation of sulfide minerals (locally pH<4). The steady maintenance of pHs above 6 shows that this is a steady long term mechanism for preventing pH depression below 6 in humidity cells.

3.2.2 Category 2/3

Results for pH, sulfate, nickel, copper and arsenic are shown in Figure 2.

Five samples (including three of the continuing 19 samples) showed pH depression below 6 while all other samples have shown stable pHs above 6 with similar trends to the Category 1 samples. Only one of the six samples has shown pH below 5. The sulfur content of the five samples varied from 0.2% to 0.42%. The sample with 0.2% sulfur showed the highest pH in this set at near 5.5. The sulfur contents of the other four samples were 0.3% and higher.

Sulfate release for Category 2/3 samples varied between 1 and 10 mg/kg/week with the highest rates being observed for samples containing higher sulfur contents. While sulfate release has varied, there was a lack of consistent upward trends.

A number of samples showed upwards trends in nickel and cobalt were related to pH decrease below 7. For the five samples showing distinctive pH depression, nickel release increased steeply during the first year of testing and subsequently showed gentle decline. Other samples showed slower nickel increase later in the program due to slower decline in pH. The same five samples also showed increase in copper leaching though the increase was less rapid than nickel and decline occurred later or not at all. One other sample (99-318C-325-330) showed accelerated copper leaching. Leachate pH was at the low end of those samples not showing substantial pH depression. It is a lean ore sample containing 0.1% copper.

Arsenic leaching trends were similar to Category 1. Rates have trended downwards. Higher rates are associated with samples yielding higher leachate pHs.

3.2.3 Category 4

Results for pH, sulfate, nickel, copper and arsenic are shown in Figure 3. Eight tests are continuing, two of which are Duluth Complex troctolite samples (00-371C(435-440) and 00-340C(765-780)), two are Duluth Complex Anorthositic Troctolites (00-331C (255-260) and 26027(616-626)), three are sedimentary hornfels samples (26058 (704-715), 26043&26027(740&1501-745&1506)) and DDH-26062&26026(993&565-998&568)-68) and one is Virginia Formation (00-361C(737-749)).

All tests have shown pH depression to some degree with pHs below 4. Of the continuing tests, one sedimentary hornfels sample (26058-704-715) showed the least depression with stable pHs near 5.3. The other samples showed leachate pHs near or below 4 and have recently shown pH recovery from minimum values. The two troctolite samples have shown pHs above 4.5 following a steep decline to pH near 4 earlier in the program. The other two Duluth Complex samples, Virginia Formation sample and other sedimentary hornfels samples have shown weaker pH recovery. Stabilization at pHs between 4 and 5 are indicative of buffering by reaction of acidity with alumino-silicate minerals resulting in formation of secondary aluminum minerals.

Some increases in sulfate release have been observed as pH decreased. Peak sulfate release rates have typically been less than a factor of five times lowest levels earlier in the test and peaks are not sharp but erratic. Decline in sulfate release has been observed following the peak. These declines are rapid at first then lessen as shown by straight lines on the log axis plot.

Due to the consistent pH depression below 7, all samples showed accelerated nickel leaching followed by declining leaching after reaching a subdued peak. All continuing tests have shown this decline parallels the sulfate release trend implying that nickel release is derived from sulfide minerals. Cobalt showed similar trends.

Upward trends in copper release were also apparent for all tests but as observed for acidifying Category 2/3 samples, the increase in copper release occurred later than nickel. Also, peaks followed by downward trends in copper release were less apparent for nickel and most ongoing tests have shown increase in copper release rather than a decrease paralleling nickel and sulfate release.

As with all other tests, arsenic release followed a declining trend.

3.2.4 Ore Composites

Results for pH, sulfate, nickel, copper and arsenic are shown in Figure 4.

Leachate pH trends for the three samples are nearly identical and show pH has been stable near 5 for over 2 years. Likewise, sulfate release has been similar for all three tests and has not shown consistent upward or downward trends. As pH decreased, nickel release accelerated, reaching peak rates after about three years then declining. Composite P30 showed a marked separate pH after 4 years that was not apparent in the other tests. A sulfate release peak was observed about the same time though was less pronounced compared to the other two tests.

Copper release also increased as the tests progressed but the upward trend was delayed compared to nickel and reached peak values after more than 4 years of testing. Copper release has subsequently declined.

3.3 Comparison Tests

Five samples tested as four size fractions continue to be tested in parallel with the humidity cell program. These tests are comparing differences in the weathering characteristics of the samples as well as differences in testing configuration (ASTM Humidity Cell and DNR Reactor) Samples are classified as Category 1 (two samples), Category 2/3 (two samples) and Category 4 (1 samples).

Both Category 1 samples have yielded leachate pHs near 7 in all size fractions and flat sulfate release trends. Sulfate release continues to be a function of particle size with lowest release (when detected) coming from the coarser size fractions. Similar findings apply to metal release. Nickel release is greater for the finer size fractions.

Consistent with the conventional humidity cells for Category 2/3 samples, lower pHs were observed but due to the sulfur content near 0.2% for both samples, pHs have remained above 6 and the samples continue to generate alkalinity particularly from the finer size fractions. Sulfate release was variable for both samples and no trends were apparent. Difference between sulfate releases in size fractions was most apparent for one sample (00-361C-310-320) with the fine fractions releasing higher sulfate than the coarse fraction. Both samples showed accelerated nickel leaching from all fractions as pH decreased below 7. Differences between size fractions were strongest for 00-361C-310-320. Temporal trends in copper release were not apparent but copper release rates were greater for the finer size fractions.

Virginia Formation rock classified as Category 4 showed sharp decline in pH to near and below 3.5 in all size fractions. Peak sulfate release was observed around 4 years for the two fine fractions. Peak sulfate release rates for the coarsest fractions have not observed because rates began increasing after six years. These differences in timing were not linked to greater pH depression for the fine fractions, in fact, the finer fractions yielded higher pHs.

These tests have shown that:

- Testing of different size fractions to date has shown that samples generating acidic leachate did so regardless of size fraction tested and protocol used.
- Rates of sulfate and metal release are generally higher for the finer size fractions presumably reflecting differences in surface area.
- For one sample that became strongly acidic, the finer fractions showed more rapid sulfate release earlier than the coarse fractions presumably reflecting faster oxidation and greater liberation of sulfide minerals.

3.4 Duplicate Testwork

Following observation of good reproducibility of trends previously (SRK 2009), all seven standard humidity cell tests being run as duplicates were stopped as part of reduction of the program in consultation with the DNR. Duplicate DNR reactor tests on two samples, and duplicate humidity cells containing size fractions for two samples have continued for a total of four duplicates (eight tests).

The two humidity cell-style duplicates are continuing to show strong reproducibility for the major ions and trace elements of interest (arsenic cobalt, copper, nickel). Weak reproducibility was apparent for barium (one sample).

The DNR-style reactors showed good reproducibility for one sample and poor reproducibility of pH for the other sample. The difference in pH (near 6 compared to 6.5) appeared to be due to differences in oxidation rate (faster for lower pH) which also resulted in greater leaching rates for cobalt and nickel.

3.5 Interpretation

3.5.1 Effect on Sulfur Management Criteria

Figure 5 shows minimum leachate pH as a function of total sulfur content for all humidity cell tests. Lowest pHs are observed for samples containing highest sulfur concentrations (Virginia Formation and Sedimentary Hornfels). The lowest sulfur concentration showing pH depression below 5 (i.e. below the range of pH of deionized water used in the test) was 0.36%. Samples with sulfur content below the Category 1 threshold of 0.12% have shown leachate pH above 6 indicating the threshold is appropriate based on current data.



Figure 5. Minimum Leachate pH as a Function of Total Sulfur Content

3.5.2 Effect on Dissolution Rates Used to Estimate Water Quality

The condition definitions shown in Table 3 were used to assess trends for each test.

An example for one test showing all four conditions is provided in Figure 6. Condition 1 lasted for 39 weeks and was marked higher pHs and relatively stable SO_4 following an initial flush in the first few weeks. As pHs declined below 7, sulfate in this case become more variable and leaching of nickel accelerated. Condition 3 began at week 164 and was marked by steep decline in pH to 3.5 and rapidly increasing sulfate release paralleled by nickel. Condition 4 began at week 194 when sulfate release peaked and then began to declining.



Figure 6. Example of Condition Assignment for a Waste Rock Humidity Cell Test

Resulting rates for each condition have been provided to Barr Engineering and include data collected to late January and early February 2012. These may be used as the basis for various inputs to source term predictions for the water quality model. However, the updated rate table primarily adds a few rates for samples that transitioned to acidic conditions. The majority of samples leaching under non-acidic conditions continue to show stable rates that have not changed significantly. As a result of this finding, there is likely little incremental value in modifying the rates used as inputs to the water quality modeling.

4 Tailings Kinetic Tests

4.1 Status of Program

A review of the tailings program was provided recently (SRK 2011). All tests have continued since findings were reported resulting in about six months of additional data. As this represents less than 15% additional time for most tests (with the exception of tests started in 2009), this memorandum provides a limited review to indicate whether any significant changes have occurred since the previous review.

4.2 Description of Results

4.2.1 NorthMet Project Tailings

Table 3 lists all tailings humidity cells. The test program consists of conventional humidity cells with parallel tests using the MDNR reactor configuration on bulk tailings and tailings size fractions.

Tests started in 2005 and 2006 (Pilot Plant 1) have continued to the same trends reported by SRK (2011) including stable or increasing pH, decreasing sulfate and stable or decreasing metal concentrations.

Tests started in 2008 (Pilot Plants 2 and 3) have reached stable pH with no indication of trends below pH 7 as shown in some samples produced by Pilot Plant 1. Sulfate release has stabilized for all tests. Nickel and cobalt release have not shown the same trends as Pilot Plant 1 samples but have shown stable concentrations in leachates below 0.002 mg/L and 0.0001 mg/L, respectively. PP2 +100 mesh showed an arsenic spike to 0.08 mg/L at week 168 following repair of the cell to address rapid drainage of water during the leach cycle.

Tests started in 2009 (scavenger tailings samples) have shown downwards trends in pH with lowest pHs typically above 7. At the same time, sulfate release has also trended downward and for some tests has stabilized. Nickel and cobalt release trended downward initially for all tests. Upwards trends for both elements were most apparent for samples Oct 1/09 09:00 (-100+200 mesh) which also showed some pHs below 7.

An arsenic spike resembling those for the 2008 samples discussed above was also apparent for two cells. These spikes were correlated with a large number of spikes in other parameters including aluminum, iron and silicon. It appears the cell malfunctioned perhaps allowing solids to be present in the leachates and thereby causing an increase in the dissolved fraction due to the presence of colloidal matter.

Table 4: Tailings Humidity Cells Used as Basis for Update Report

НСТ	Fraction	HCT Full ID	Total Sulfur	Start Date	Total	Duration Used for
ID			(%)		Duration weeks	Current Modeling ³ weeks
T1	Whole	P1 (CuSO4)	0.1	9/8/2005	333	
T2	Whole	P1 (no CuSO4)	0.23	9/8/2005	333	
Т3	Whole	P2 (no CuSO4)	0.2	9/8/2005	333	
T4	Whole	P3 (CuSO4)	0.15	9/8/2005	333	
T5	100	Parcel 2 P2S +100 mesh	0.15	2/10/2006	311	
T6	100	Parcel 2 P2S -100 +200 mesh	0.17	2/10/2006	311	
T7	-200	Parcel 2 P2S -200 mesh	0.24	2/10/2006	311	
T8	100	Parcel 1-2 PISCS +100 mesh	0.11	2/10/2006	311	271
Т9	100	Parcel 1-2 PISCS -100 +200 mesh	0.1	2/10/2006	311	271
T10	-200	Parcel 1-2 PISCS -200 mesh	0.09	2/10/2006	311	271
T11	100	Parcel 3 P3S +100 mesh	0.11	2/10/2006	311	271
T12	100	Parcel 3 P3S -100 +200 mesh	0.14	2/10/2006	311	271
T13	-200	Parcel 3 P3S -200 mesh	0.14	2/10/2006	311	271
T52	Whole	Pilot Plant 2 (0.30 Cu feed) Composite Bulk Tailings (as rec'd)	0.07	7/8/2008	185	
T53	100	Pilot Plant 2 (0.30 Cu feed) Composite (+100 mesh)	0.08	7/8/2008	185	146
T54	100	Pilot Plant 2 (0.30 Cu feed) Composite (-100 + 200 mesh)	0.06	7/8/2008	185	146
T55	-200	Pilot Plant 2 (0.30 Cu feed) Composite (-200 mesh)	0.09	7/8/2008	185	146
T56	Whole	Pilot Plant 3 (0.25 Cu feed) Composite Bulk Tailings (as rec'd)	0.08	7/8/2008	185	
T57	100	Pilot Plant 3 (0.25 Cu feed) Composite (+100 mesh)	0.1	7/8/2008	185	146
T58	100	Pilot Plant 3 (0.25 Cu feed) Composite (-100 + 200 mesh)	0.08	7/8/2008	185	146
T59	-200	Pilot Plant 3 (0.25 Cu feed) Composite (-200 mesh)	0.08	7/8/2008	185	146
T60	Whole	SCAV TAILS 9/30/09 1600	0.09	11/24/2009	113	
T61	100	SCAV TAILS 9/30/09 1600 +100	0.1	11/24/2009	113	74
T62	100	SCAV TAILS 9/30/09 1600 -100+200	0.09	11/24/2009	113	74
T63	-200	SCAV TAILS 9/30/09 1600 -200	0.11	11/24/2009	113	74
T64	Whole	SCAV TAILS 10/1/09 09.00	0.13	11/24/2009	113	
T65	100	SCAV TAILS 10/1/09 09.00 +100	0.11	11/24/2009	113	74
T66	100	SCAV TAILS 10/1/09 09.00 -100+200	0.14	11/24/2009	113	74
T67	-200	SCAV TAILS 10/1/09 09.00 -200	0.14	11/24/2009	113	74
T68	Whole	SCAV TAILS 10/1/09 17.00	0.12	11/24/2009	113	
T69	100	SCAV TAILS 10/1/09 17.00 +100	0.1	11/24/2009	113	74
T70	100	SCAV TAILS 10/1/09 17.00 -100+200	0.1	11/24/2009	113	74
T71	-200	SCAV TAILS 10/1/09 17.00 -200	0.13	11/24/2009	113	74

³ Waste Characterization Data Package Version 9 (July 3 2012)

4.2.2 LTVSMC Tailings

Four samples of LTVSMC tailings are being tested in humidity cells. No significant changes in leachate chemistry have been observed since the previous update (SRK 2011). Leachate pHs have continued to vary in a narrow band between 7.4 and 8 with variable but non-trending alkalinity and sulfate.

Other parameters have continued to show no upward trend or downward trends. Isolated data spikes (for example, arsenic) are observed but do not represent significant trends.

4.3 Interpretation

Ongoing tailings testwork has shown no indication of development of pHs below that of the deionized water used to leach the samples (Figure 7) indicating that weathering of silicates minerals in the samples is continuing to generate alkalinity to offset acidity from sulfide oxidation and the deionized water even in the tests that have been operating for 7 years. The longer term tests yielded pH minima in their trends which are responsible for the lower pHs shown in Figure 7. Upward trends in pH are observed in most cases so that recent pHs are higher than the lowest values.



Figure 7. 5th Percentile pH as a Function of Total Sulfur Content for Tailings Humidity Cells

Correlations between initial total sulfur content and average release rates are apparent as have been observed previously (Figure 8). However, this figure suggests different relationships for the 2006 and 2007 datasets compared to the 2008 and 2009 datasets apparently implying that the earlier samples are less reactive. However, the differences are probably caused by significant depletion of sulfide as the tests have progressed with a correlated decrease in release rates, reducing the calculated average release rates. For example, between 30% and 78% of the initial sulfur has been depleted from the earlier tests compared to less than 30% for the more recent tests. For the oldest tests, remaining sulfur content varies from 0.04% to 0.12%. The general downward trend in sulfate release has resulted in progressively lower average sulfate release. The downward trend in sulfate release (and therefore acid generation rate) also provides a reasonable explanation for upward trends in pH.

The implication of results from the older tests is that the potential for long term pH depression below 5 is shown to be very low because silicate weathering was able to offset acid generation when sulfur content was higher than the current depleted levels.



Figure 8. Average Sulfate Release as a Function of Initial Total Sulfur Content

The long term downward trend in sulfate release rates (Figure 9) indicates that average sulfate release rates for individual tests as used as input into the tailings water quality models are a function of time and will decrease as the test duration increases. To address this finding and provide sulfate release rates that are consistent with the assumed zero order reaction rate law for sulfide oxidation in the water quality model, relationships between sulfate release and sulfur depletion were examined to estimate sulfide oxidation rates at the initial sulfur content. The concept is to obtain the initial rates at t=0 by regressing depleted sulfur content against sulfate release rates to obtain equations of the form:

$$\frac{dM_{SO_4}}{dt} = a_1 M_S + a_0$$

Graphs of sulfate release rate as a function of sulfur remaining showed three different relationships. The most common relationship (15 tests) was for the slope of the equation to be steeper at the start than in the longer term. Other trends were (1) initially lower rates followed by a peak then long term decay (about 6 tests); and (2) consistent slope for the duration of the test (12 tests).

The first type of relationship is commonly observed in humidity cell results and is interpreted as initial flushing of stored sulfate oxidation products followed by sulfide oxidation. The initial part of the trend therefore does not represent sulfide oxidation and should not be included in the regression equations to obtain the oxidation rate at t=0. The preferred approach is to use the data for each test on its own merit to evaluate the break point when leaching of stored oxidation products is complete and the long term decay trend is well-established. LAM MDNR disagreed with this approach and required that the regression equations be developed excluding the first 5 weeks of data based on the following commentary in the ASTM humidity cell method D5744-96, (Section 11.2):

"In the testing of mining wastes, cation and anion loadings are commonly high in the Week 0 leachate due to the dissolution of pre-existing soluble oxidation salts present in the sample prior to sample collection. The average number of weekly accelerated weathering cycles required to flush these pre-existing salts ranges from 3 to 5 weeks. Oxidation products observed during these 3 to 5 weeks are principally from pre-existing salts, while those

products observed after this period are considered to be solely a function of the accelerated weathering procedure."

SRK does not agree with the use of a fixed initial flushing period because it is unlikely that this flushing process can be generalized. In reality, the period required to fully flush stored oxidation products depends on the types, solubility and quantity of the oxidation products, and the physical and mineralogical characteristics of the samples. Tailings samples also contain entrained process water which is expected to be soaked into the finer particles leading to a protracted initial flushing trend. Nonetheless, to advance the process of acceptance, the LAM MDNR requested method was adopted to calculate oxidation rates at t=0.

Graphs for all tests showing regression relationships using the MDNR method are provided in Attachment A

Figure 9 shows initial sulfate release (determined from the regression equation using the initial sulfide content of the sample) as a function of initial total S content of the samples for comparison with Figure 8. Initial sulfate release calculated using the MDNR and SRK methods is shown. The difference in rates between tailings samples generated by different pilot plants implied by Figure 8 is reduced by both methods but the DNR method appears to result in lower rates for the 2005 samples and a weaker correlation with sulfur content than the SRK method which eliminates differences between the different datasets. The similarity of rates implies that the tailings generated at different times have similar reactivity. Correlation between initial sulfur content and initial sulfate release is apparent when considering the entire data range though weaker at lower initial sulfur contents.

For the purpose of water quality modeling, the distribution of sulfate release rates will be based on the initial sulfate rates (Figure 9) calculated using the MDNR method as agreed This method will result in the use of sulfide oxidation rates in the model that are nearly always higher than would actually be expected. Application of a single initial rate will result in predicted sulfate and trace element concentrations that are likely to be much higher than would really occur as sulfide content depletes over time. The approach is therefore conservative for predicting water quality.

For the purpose of modeling other parameters the following recommendations are made for rates:

- For parameters based on a solid ratio to sulfur content, rates should be calculated based on the ratios previously specified.
- For parameters based on average rate to average sulfate rate ratios (Ca, K, Mg, Na, Se), rates should be calculated based on the average rate ratio as previously specified. For the major ions, downward trends are apparent that parallel decrease in sulfate indicating that ratios of average rates are appropriate.



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Figure 9. Calculated Initial Sulfate Release as a Function of Initial Total Sulfur Content Using MDNR (top) and SRK (bottom) methods.

5 Hydrometallurgical Residue Kinetic Tests

As agreed with MNDR, hydrometallurgical kinetic tests were stopped shortly after reported by SRK (2009).

6 Conclusions

Review of data generated by up to nearly eight years of testing indicates that:

- Waste rock classification into three categories using sulfur content to address potential for pH acidification appears to be robust. In particular, samples classified as Category 1 have not shown pH depression below that of the deionized water used to leach the samples.
- Sulfide oxidation and metal leaching trends for waste rock samples show well defined phases as pH depression occurs. These trends have been used to calculate release rates for use in development of source terms. Ongoing testwork has resulted in some additional rate information for later phases.
- Tailings humidity cells have not shown pH depression below that of the deionized water indicating that weathering of silicates provides alkalinity to offset acidity from sulfide oxidation.
- Long term trends in tailings humidity cells show declining oxidation rates which are presumably linked to depletion of the sulfide minerals and indicates that sulfide oxidation is following a non-zero order reaction rate law. However, to be consistent with the simplified modeling approach used in GoldSim®, which assumes a zero order reaction rate law, trends in sulfide oxidation rates have been used to back-calculate reaction rates at the initial sulfur content for use in modeling.
- Other than addressing this recommendation, updating the rates used as inputs to tailings water quality modeling is not recommended.

7 References

SRK Consulting. 2009. RS82 - Update on Use of Kinetic Test Data for Water Quality Predictions – DRAFT 02. Memorandum to Kim Lapakko, MDNR. February 7, 2009.

SRK Consulting. 2011. Update on Tailings Humidity Cell Test Data – NorthMet Project – Draft. Memorandum to Peter Hinck, Barr Engineering. December 23, 2011.

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Attachment A: Graphs





G:\PolyMet Mining\1UP005.01_Northmet_project_2004\Water_Quality_Predictions\Closure_Tailings\2012-07_Initial_Tailings_Rate\[Tailings_t0_rate_1UP005001_SJD_rev01.xlsx]



P3



PA2P2S_100



PA2P2S_200



PA2P2S_200



PA1_2PISCS_100



PA1_2PISCS__100_200



PA1_2PISCS__200





G:\PolyMet Mining\1UP005.01_Northmet_project_2004\Water_Quality_Predictions\Closure_Tailings\2012-07_Initial_Tailings_Rate\[Tailings_t0_rate_1UP005001_SJD_rev01.xlsx]

SO4 Rate (mg/kg/week)

PA3P3S_100_200



PA3P3S_200















PP3_100_200





ST_Sept30_bulk



ST_Sept30_100



ST_Sept30_100_200



ST_Sept30_200





ST_Oct1_9am_100





* _{*} * * × * • • * • ********************** S Remaining (mg/kg)

SO4 Rate (mg/kg/week)



ST_Oct1_5pm_100







SO4 Rate (mg/kg/week)