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# Memo

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Copy to:	Jim Scott, PolyMet	Project #:	1UP005.001		
Subject:	Update on Tailings Humidity Cell Test Data, NorthMet Project – DRAFT				

### 1 Introduction

Kinetic geochemical testing of samples of tailings produced by pilot plant processing of NorthMet Project ores began in 2005 when the first process testing occurred. Subsequently, PolyMet has repeated similar pilot plant testing three times to optimize the flotation process and evaluate recovery of concentrate for different ore composites. Each time a pilot plant was operated, the resulting tailings samples have been submitted for the same geochemical test procedures including solids analysis for sulfur and trace element content and kinetic testing on whole samples and size fractions.

Fundamentally, the flowsheet of the flotation process has not changed except for copper sulfate not being used in the very first runs of Pilot Plant 1. Due to the improvement in recovery of sulfide minerals (and consequent reduction in sulfide content of tailings), copper sulfate has been used in all subsequent pilot plants. As a result, it is appropriate to consider all tailings results as a single dataset rather than individual datasets for each pilot plant run.

Separate tailings testwork has been initiated on four samples of LTVSMC tailings which will be used for construction of tailings embankments. As these tests are being performed on completely different materials, they are described separately at the end of this memorandum.

The purpose of the memorandum is to provide an update on tailings humidity cell data and their influence on inputs to water quality prediction models. A previous update (RS82 - Update on Use of Kinetic Test Data for Water Quality Predictions, February 2, 2009) was prepared with approximately 3 years data from NorthMet Project pilot plant samples generated in 2005 and 2006. Since that time, an additional three years of data have been collected for these tests and two additional data sets have been generated from tailings produced by the two additional pilot plants run in 2008 and 2009.

Due to the change in conceptualization of the overall modeling approach from the use of metal to sulfate ratios of release rates to the use mainly of sulfate release rates and metal to sulfur ratios in solids to predict pore water chemistry, this update report focuses mainly on a comparison of trends in pH and sulfate between the tests.

# 2 NorthMet Project Tailings Kinetic Tests

### 2.1 Status of Program

Table 1 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. All cells are currently running smoothly however, some repairs have occurred in addition to those stated in the RS82 report.

The filter fabrics in T55 and T62 humidity cells were found to be torn and allowing the breakthrough of solids into the leachate collection chamber. The cells were dismantled and repaired in September 2009. All solids were recovered and returned to the respective cells. Following these repairs, leachate chemistry re-stabilized within 2 weeks, returning to pre-repair levels. Arsenic levels were slower to decline, taking 7 weeks to return to pre-repair levels. This type of occurrence has been previously observed in the RS82 report.

All tests originally started are continuing and none of the tests have been terminated. Laboratory and analytical methods are unchanged from that developed in consultation with the MDNR and are consistent between all tests included in this update report.

# Table 1: Tailings Humidity Cells Used as Basis for Update Report

HCT ID	Fraction	HCT Full ID	Total Sulfur %	Initial Start Date	Total Weeks
T1	Whole	P1 (CuSO4)	0.1	9/8/2005	304
T2	Whole	P1 (no CuSO4)	0.23	9/8/2005	304
Т3	Whole	P2 (no CuSO4)	0.2	9/8/2005	304
T4	Whole	P3 (CuSO4)	0.15	9/8/2005	304
T5	+100	Parcel 2 P2S +100 mesh	0.15	2/10/2006	282
Т6	-100+200	Parcel 2 P2S -100 +200 mesh	0.17	2/10/2006	282
T7	-200	Parcel 2 P2S -200 mesh	0.24	2/10/2006	282
Т8	+100	Parcel 1-2 PISCS +100 mesh	0.11	2/10/2006	282
Т9	-100+200	Parcel 1-2 PISCS -100 +200 mesh	0.1	2/10/2006	282
T10	-200	Parcel 1-2 PISCS -200 mesh	0.09	2/10/2006	282
T11	+100	Parcel 3 P3S +100 mesh	0.11	2/10/2006	282
T12	-100+200	Parcel 3 P3S -100 +200 mesh	0.14	2/10/2006	282
T13	-200	Parcel 3 P3S -200 mesh	0.14	2/10/2006	282
T52	Whole	Pilot Plant 2 (0.30 Cu feed) Composite Bulk Tailings (as received)	0.07	7/8/2008	156
T53	+100	Pilot Plant 2 (0.30 Cu feed) Composite (+100 mesh)	0.08	7/8/2008	156
T54	-100+200	Pilot Plant 2 (0.30 Cu feed) Composite (-100 + 200 mesh)	0.06	7/8/2008	156
T55	-200	Pilot Plant 2 (0.30 Cu feed) Composite (-200 mesh)	0.09	7/8/2008	156
T56	Whole	Pilot Plant 3 (0.25 Cu feed) Composite Bulk Tailings (as received)	0.08	7/8/2008	156
T57	+100	Pilot Plant 3 (0.25 Cu feed) Composite (+100 mesh)	0.1	7/8/2008	156
T58	-100+200	Pilot Plant 3 (0.25 Cu feed) Composite (-100 + 200 mesh)	0.08	7/8/2008	156
T59	-200	Pilot Plant 3 (0.25 Cu feed) Composite (-200 mesh)	0.08	7/8/2008	156
T60	Whole	SCAV TAILS 9/30/09 1600	0.09	11/24/2009	84
T61	+100	SCAV TAILS 9/30/09 1600 +100	0.1	11/24/2009	84
T62	-100+200	SCAV TAILS 9/30/09 1600 -100+200	0.09	11/24/2009	84
T63	-200	SCAV TAILS 9/30/09 1600 -200	0.11	11/24/2009	84
T64	Whole	SCAV TAILS 10/1/09 09.00	0.13	11/24/2009	84
T65	+100	SCAV TAILS 10/1/09 09.00 +100	0.11	11/24/2009	84
T66	-100+200	SCAV TAILS 10/1/09 09.00 -100+200	0.14	11/24/2009	84
T67	-200	SCAV TAILS 10/1/09 09.00 -200	0.14	11/24/2009	84
T68	Whole	SCAV TAILS 10/1/09 17.00	0.12	11/24/2009	84
T69	+100	SCAV TAILS 10/1/09 17.00 +100	0.1	11/24/2009	84
T70	-100+200	SCAV TAILS 10/1/09 17.00 -100+200	0.1	11/24/2009	84
T71	-200	SCAV TAILS 10/1/09 17.00 -200	0.13	11/24/2009	84

# 2.2 Comparison of Solids Data

Solids data was compared between the three sets of humidity cells, (those initiated in 2005 & 2006, 2008 and 2009). Figure 1 shows the minimum, average and maximum values for key parameters.

Sulfur concentrations showed the greatest range in the early dataset due to evaluation of the use of copper sulfate to optimize recovery of sulfide minerals by flotation. Subsequent pilot plants have used copper sulfate. Metal concentrations were very similar between the three data sets with the exception of copper, which showed slightly higher average and maximum values in the cells initiated 2005 and 2006.



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Figure 1: Comparison of Solids data using Minimum, Average and Maximum Values – Key Results

06 2008		2009			
	Year Initiated				
06	2008 Year Initiated	2009			

# 2.3 Description of Humidity Cell Results

#### 2.3.1 Tests Started in 2005 & 2006

All humidity cell tests showed an initial decline in pH (Figure 2). The decline was greatest for the two coarser particles size fractions and least for the -200 mesh fraction samples. The trend for bulk tailings was between the coarse and fine fractions. The range in leachate pHs following the main initial decline was 6.0 to 7.8. Leachate pHs remain somewhat erratic but no decline to lower pHs has been apparent and pH appears to be stabilizing with time. Variation reflects whether copper sulfate was used in the pilot mineral processing circuit to improve recovery of sulfide minerals during flotation. Higher pH leachates are generally associated with samples with lower sulfur contents produced by the use of copper sulfate.

Sulfate release has shown a decline from week zero to 200. After week 200, sulfate release has generally stabilized (Figure 2). Major ions have followed sulfate and were generally decreasing followed by stabilization after week 200. Alkalinity leaching from the two coarser particle sizes declined sharply and then stabilized, with the stable period starting at approximately week 75. In contrast, alkalinity from the -200 mesh samples continued to decline until stabilization at approximately week 125. Bulk tailings with higher sulfur contents have shown the similar trends to the two coarser particle sizes whereas bulk tailings with lower sulfur contents were closer to the -200 mesh samples having values between the coarse and fine fractions.

The main distinctive feature of leachates has been the increase in leaching of nickel (Figure 2) cobalt and manganese from the two coarse tailings fractions. This positive trend was apparent in the RS46 Draft 01 reporting period and was confirmed by the RS82 report. Since the RS82 report leachates have shown a decrease in these metals following their peak leaching rates at approximately week 100. However, values remain elevated relative to the fine size fraction and bulk samples. In addition, an increase in leaching of these metals in bulk samples was observed at approximately week 140 followed by a general decline but at an order of magnitude below the comparable coarse fraction samples. Copper leaching rates are stable at low values (<0.002 mg/kg/week).



Tailings - Loadings in Humidity Cell Leachates



Tailings - Loadings in Humidity Cell Leachates



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Figure 2: Leachate pH, Sulfate and Nickel Loadings for 2005 & 2006 NorthMet Project Tailings

#### 2.3.2 Tests Started in 2008

All humidity cell tests showed a slight initial decline in pH (Figure 3). The typical range in leachate pHs following the main initial decline was 7.25 to 7.78. pH does not appear to be related to fraction size as all pH measurements fluctuate in range of values. Leachate pHs remain somewhat erratic but no decline to lower pHs has been apparent, pH appears to be stabilizing with time.

Sulfate release initially declined sharply followed by a gradual decline (Figure 3). Major ions have followed sulfate but with calcium having a larger declining trend. Alkalinity has shown a consistent decreasing trend and is highest in the coarse particle size (+100) and lowest in the medium (+100-200) particle size.

For all fraction sizes, nickel showed an initial decline until week 80 at which time nickel release increased slightly and stabilized at levels slightly above the lowest release rates (Figure 3). The exception to this is the +100 mesh samples which showed an increase in nickel release at weeks 80 to 140 followed by a decrease to the lowest values of the test period. Copper release rates were more erratic but remained at low levels throughout the testing period in the range of 0.0002 mg/kg/week.

Results from these tests are distinctively different from the similar tests started in 2005 and 2006. Leachate pHs have not decreased to the same degree when comparing the same test period (first three years). As a result, accompanying order-of-magnitude increases in nickel concentrations have not been observed. Sulfate release for the 2008 tests also stabilized earlier.

### 2.3.3 Tests Started in 2009

All humidity cell tests showed generally stable pH (Figure 4). However, a slight decline has occurred after 50 weeks of measurement in the -100 +200 mesh samples. The general trend is highest pHs are reported for the fine fraction and lowest for the -100 +200 mesh fraction with bulk tailings measurements between the coarse and fine fractions. The range in leachate pHs was 7.1 to 8.0.

Sulfate release initially declined sharply followed by a gradual decline (Figure 4). Major ions have followed sulfate but show a larger declining trend. Alkalinity showed an initial stable period from weeks 4 to 36 followed by a declining trend. This trend is most apparent in the coarse fraction.

The slight pH decrease at week 50 in the -200 +100 mesh tailings fractions was also accompanied by a slight rise in nickel (Figure4), cobalt and manganese release rates. All other size fractions have shown stable or decreasing release rates. Copper release rates have remained low for all cells throughout the test period in the range of 0.0001 mg/kg/week to 0.001 mg/kg/week.

Pilot Plant - Loadings in ASTM HCT



Pilot Plant - Loadings in ASTM HCT



#### Pilot Plant - Loadings in ASTM HCT



Source: \\VAN-SVR0\GE\_Projects\PolyMet Mining\1UP005.01\_Northmet\_project\_2004\Testwork\Tailings\3.KineticTests\Results\Charts\[load\_PP2PP3\_Tailings.xls

### Figure 3: Leachate pH, Sulfate and Nickel Loadings for NorthMet 2008 Pilot Plant



Scavenger Tailings - Concentrations in ASTM HCT

Scavenger Tailings - Concentrations in ASTM HCT





Source: \\VAN-SVR0\GE\_Projects\PolyMet Mining\1UP005.01\_Northmet\_project\_2004\Testwork\Tailings\3.KineticTests\Results\Charts\[Loadings\_Scavenger Tails\_Tailings.xlsx

#### Figure 4: Leachate pH, Sulfate and Nickel Loadings for NorthMet 2009 Scavenger Tailings

### 2.4 Discussion

The primary inputs to water quality modeling for the tailings are sulfide oxidation rates indicated by sulfate release from humidity cells. For the purpose of modeling, the sulfide oxidation reaction is assumed to be zero order, that is, the oxidation rate is independent of the amount of reactant (sulfide) remaining. This assumption was adopted to simplify the implementation of sulfide oxidation in the tailings water quality model and is conservative from the standpoint of estimating maximum expected concentrations of sulfate and other parameters. The current extended dataset provides an opportunity to evaluate the assumption and compare tailings produce by several metallurgical test programs.

Figure 5 shows sulfate release for all whole tailings samples being tested. Lines on the graph show the three different programs as different symbols and color-coding illustrates different initial sulfur concentrations. Sulfur concentrations exceeding 0.2% are shown as red; concentrations between 0.1 and 0.2% are shown as amber; and concentrations less than 0.1% are shown in green.

The overall distribution of rates shows that oxidation rates are correlated with sulfur content. Highest rates are associated with higher initial sulfur concentrations, and lowest rates are shown by samples with lowest sulfur concentrations.

Samples with sulfur concentrations exceeding 0.2% were only generated in the first pilot plant run when copper sulfate was not used at first to improve sulfide mineral flotation. Comparison between programs for the middle and lower sulfur ranges shows that there is little difference between results from the programs. In the middle sulfur range, oxidation rates for the initial pilot plant run samples were slightly higher than those in the same range produced in 2009, but the 2009 samples also had slightly lower initial sulfur concentrations. The same effect is seen in the lower sulfur range. The first pilot plant sample had the highest concentration of the four samples in this range and it appears yielded the highest sulfate release rates in that sulfur range. As a group, the testwork performed at various times shows similar relationships between sulfur content and sulfate release.

All tests showed that sulfate release declined over time. Mass balance indicates that the first and second sample set have been depleted of between 30% and 40% of the initial sulfur content indicating that the decline in sulfate release may be due to reduction in available oxidation rates. This implies the sulfide oxidation reaction is non-zero order and that the use of initial oxidation rates in modeling remains conservative.

Differences in pH trends and consequent release of nickel have been observed in the testwork. The initial dataset showed that pH decreased to a level at which nickel release could increase due to increased solubility of secondary nickel. This trend has not been observed to the same degree in subsequent testwork. The strong sensitivity of the test procedures to pH buffering by silicate mineral weathering has been observed previously and may be the reason for the observed differences. The 2008 tests suggest the tailings have greater buffering capacity than the 2005/2006 tests. Use of the first dataset to define sulfur concentrations which could result in significant metal leaching due to pH depression that could occur appears to be conservative.



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#### Figure 5: Comparison of Sulfate Leaching Rates as a Function of Sulfur Content

#### 2.5 Conclusions

Review of ongoing and new humidity cell data shows that the assumptions used for oxidation rates in the water quality modelling are conservative when assuming the reaction order for sulfide oxidation, and that oxidation rates shown by tailings produced at different times are comparable.

Differences in pH trends are apparent between tailings produced by the different rounds of metallurgical testwork. However, the differences do not indicate a need to re-visit assumptions about sulfur management criteria (tailings to contain less than 0.2% sulfur). Ongoing testwork on tailings containing more than 0.2% sulfur for six years has shown stable pH as sulfur content has depleted to 40% of the starting composition.

# 3 LTVSMC Tailings Samples

#### 3.1 Source of Samples

Twenty-nine samples of coarse LTVSMC tailings were obtained as part of a drilling program supervised by Barr Engineering to evaluate the geotechnical characteristics of the tailings. Ten drill holes were sampled in five different potential borrow areas (Figure 6).



#### Figure 6: LTVSMC Drilling Locations

### 3.2 Characteristics of Samples

Selected characteristics of the samples are shown in Table 2. Overall characteristics are similar to those for samples collected in an earlier drilling program and previously reported in RS46. Sulfur and trace element contents are very low. LTVSMC tailings samples are classified as non-acid generating due to the presence of carbonate minerals.

Results for the 29 samples were used to generate a sub-set of samples for humidity cell testing. In order to obtain sufficient sample for humidity cell testing (1 kg), composites were produced to represent coarse tailings in the four main borrow areas:

- 2E North Embankment
- 1E and 2E Separator
- 1E South Beach
- 2W North Embankment

Characteristics of the resulting composites are shown in Table 3. The sample from 2E North Embankment was tested in duplicate.

#### Table 2: Characteristics of LTVSMC Tailings

Statistic	As mg/kg	Co mg/kg	Cu mg/kg	Ni mg/kg	Carbonate %, C	Total S %, S
P5	14.88	5.94	5.28	2.78	0.638	<0.01
P50	25.5	7.9	7.3	4.1	1.45	0.03
P95	55.96	10.62	21.44	7.14	2.66	0.08

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### Table 3: Characteristics of LTVSMC Composite Tailings Samples Tested in Humidity Cells

HCT ID	As mg/kg	Co mg/kg	Cu mg/kg	Ni mg/kg	Total S %
2E North Embankment Composite	28.7	8	7.8	4.1	0.03
2E North Embankment Composite (Duplicate)	22.7	6.9	7.7	3.8	0.03
1E and 2E Separator Composite	31.9	9.8	16.1	5.1	0.04
1E South Beach Composite	21.1	8.4	20.1	7	0.01
2W North Embankment Composite	46.9	8.1	8.5	4.6	0.06

Source: \\Van-svr0.van.na.srk.ad\ge\_projects\PolyMet Mining\1UP005.01\_Northmet\_project\_2004\Reports\2011-10\_Tailings\_Update\Re Issue\[LTVSMC\_Tailings\_Data\_1UP005.01\_Id\_rev00.xlsx

#### 3.3 **Humidity Cell Procedure**

Shake flask testing of the samples prior to humidity cell testing indicated that the tailings were slightly oxidized due to weathering under field conditions. Since the purpose of humidity cells testing is to understand sulfide mineral oxidation rates, the samples were initially flushed with de-ionized water to remove soluble oxidation products. Following this procedure, the flushed samples were tested using the same procedures as used for NorthMet Project tailings.

#### 3.4 Results

Selected humidity cell results from about 65 weeks of testing are shown in Figures 7 and 8.

Leachate pH values from all tests have been consistently between 7.3 and 8.1 and result mainly from leaching carbonate minerals. One of the 2E North Embankment samples showed consistently lower pH than the other tests. Likewise alkalinity, Ca and Mg were not comparable for the duplicate pair. All other parameters showed good reproducibility for the pair implying that the differences are due to heterogeneity in the carbonate content which did not affect elements associated with sulfide minerals.

Initial differences in sulfate release were observed. Higher release rates were observed for the two samples containing higher sulfur concentrations (2W North Embankment, and 1E and 2E Separator) but after about 25 weeks, differences disappeared and all samples yielded comparable low sulfate release. Leaching of trace elements occurred at very low rates. Arsenic, cobalt, manganese, molybdenum, selenium showed an initial decline like sulfate but most elements, including copper, nickel and zinc indicated no trend.

#### 3.5 Conclusions

LTVSMC tailings leachate chemistry is dominated mainly by the buffering effects from dissolution of carbonate minerals. Initial differences in sulfate and some trace element release may be linked to differences in sulfide content but after about 25 weeks similar weathering behavior was shown regardless of sulfur content. Due to low sulfur content and expected long term effects of carbonate buffering, the tests have proceeded sufficiently to provide rates for input into water quality modeling. Release rates derived from these tests will be the average observed release over the 65-week testing period, which is conservative with respect to sulfate release.









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