

The Golder samples were submitted for the following tests:

- Chemical analysis of tailings solids by x-ray fluorescence (XRF);
- Mineralogical analysis by x-ray diffraction (XRD);
- Acid base accounting (ABA);
- Net acid generation (NAG) testing;
- Chemical analysis of decant (i.e. process) water;
- Short-term leach testing (Synthetic Precipitation Leaching Procedure – SPLP); and,
- Comprehensive analysis of NAG leachates.

The program was conducted in compliance with the Tier #1 requirements for material characterization under the Arizona Department of Environmental Quality's Aquifer Protection Permit Program (ADEQ-APP). ADEQ has published the Arizona Mining BADCT Guidance Manual (Guidance Manual) as part of their Aquifer Protection Program. In this manual, ADEQ recommends a two-tiered characterization approach for characterization of tailings, (spent) ore and waste rock, with Tier #2 being contingent upon the Tier #1 results. A detailed description of the various components of the Tier #1 and #2 testing is presented in Appendix B of the Guidance Manual (ADEQ, 1998).

3.0 RESULTS

Tables 1 through 6 present the results for the chemical analyses of solids, mineralogical analysis, ABA/NAG, process water, SPLP leach testing and NAG leachate analysis, respectively. The following sections provide an evaluation of those results and discussion of ARD/ML potential.

3.1 Chemical Analysis of Solids

The results from the chemical analysis of the tailings solids can be used to make an inference regarding elements of potential environmental concern. Table 1 presents a comparison against "approximate consensus" values for crustal abundance from Smith and Huyck (1999). Parameters that are significantly elevated relative to crustal abundance (arbitrarily defined as 5 times crustal abundance) for both the cleaner and scavenger tailings include sulfur, copper, molybdenum, lead, tin, thorium, uranium and tungsten. The cleaner tailings also show significant enrichment in iron, arsenic and cobalt.

A comparison of results for the Golder and KCB samples generally indicates higher trace metal concentrations in the Golder samples. This is due to the differences in analytical procedure used, with the aqua regia digest/ICP-MS analysis conducted by KCB representing partial digestion of the sample as opposed to the total measurements obtained from XRF. There is good agreement in terms of identification of parameters that occur in elevated concentrations relative to crustal abundance.

3.2 Mineralogical Analysis

The mineralogical results (Table 2) indicate that silicate minerals (quartz, mica, kaolinite, feldspar) make up the bulk of the scavenger tailings, while they contain little pyrite (< 1%) and no carbonates. In the cleaner tailings, pyrite accounts for approximately 47% of the total, with the remainder consisting of the same silicates. Carbonate minerals also are not identified in the cleaner tailings. It

should be noted that XRD is only capable of identifying crystalline mineral phases, and that the detection limit is around 1%.

The Golder results are in reasonable agreement with the mineralogical analyses presented in KCB (2007). Gypsum and calcite are identified in the KCB analyses in both tailings types at values less than approximately 1 to 1.5%. The most notable discrepancy is in the pyrite content of the cleaner tailings, with values of approximately 70% and 47% for the KCB and Golder samples, respectively.

3.3 Acid Base Accounting and Net Acid Generation Testing

The acid base accounting results (Table 3) indicate that both samples have a circumneutral paste pH, suggesting that the samples had not undergone any oxidation prior to analysis. The total sulfur contents of the scavenger and cleaner tailings differ significantly, with values of 0.4 and 36%, respectively. In the scavenger tailings, the majority of this sulfur is present in the form of sulfate sulfur (likely as gypsum as per the KCB mineralogical analysis), while in the cleaner tailings, the bulk of the sulfur consists of sulfide minerals (i.e., pyrite). Acid potential (AP) values for the scavenger and cleaner tailings were calculated from the sulfide sulfur concentrations, and are 2.5 and 960 kg CaCO₃/ton, respectively. The neutralization potentials (NP) for both samples are low (< 5 kg CaCO₃/ton), consistent with the low calcite values obtained in the KCB mineralogical analysis.

The results of the Golder and KCB analyses generally are in good agreement, although the paste pH for KCB's cleaner tailings was acidic due to some oxidation having occurred prior to testing (KCB, 2007). The Golder total sulfur analysis does not agree with the pyrite content from the Golder mineralogical analysis, but is consistent with the KCB mineralogical result.

The NAG test results indicate a very low NAG pH (2.2) for the cleaner tailings and a less acidic NAG pH (4.5) for the scavenger tailings. KCB did not conduct NAG testing as part of its geochemical characterization program.

3.3.1 Potential for Acid Rock Drainage

A number of criteria have been proposed for assigning an ARD potential to a material using ABA results. The most common approaches are those based on use of the neutralization potential ratio (NPR = NP/AP) and the net neutralization potential (NNP = NP - AP). For several reasons, no single ratio or NNP value has been identified to have universal applicability in terms of predicting acid generation. The actual threshold values for a particular solid are material-specific, and depend on many factors, including the amounts and types of acid generating and neutralizing minerals, their morphology, their grain size, their crystallinity, their chemical composition, their paragenesis, the material's texture, and the site-specific exposure conditions.

The most commonly used guidelines for classification of ARD potential are those promulgated by Price (1997). They are based on the NPR, and can be summarized as follows:

Potential for ARD	Criteria	Comments
Likely	NPR <1	Likely acid generating, unless sulfide minerals are non-reactive.
Possible (uncertain)	1 < NPR < 2	Possibly acid generating if NP is insufficiently reactive or is depleted at a rate faster than sulfides.
Low	2 < NPR < 4	Not potentially acid generating unless significant preferential exposure of sulfides along fractures planes, or extremely reactive sulfides in combination with insufficiently reactive NP.
None	NPR >4	

In addition to ABA results, NAG pH values can be used to determine the likelihood of acid generation. The NAG procedure uses a strong oxidant (hydrogen peroxide) to rapidly oxidize sulfide minerals in a crushed sample of the entire rock (AMIRA, 2002). The NP of the sample then can be directly challenged by the acidity generated by rapidly oxidizing sulfides. If the sample has sufficient available NP, the alkalinity of the whole rock will not be entirely depleted, and the system is expected to have the capacity to remain circum-neutral. If there is inadequate available NP, then the pH of the test solution (NAG pH) will fall below 4.5 and there will be net acidity rather than net alkalinity. In this case, a sample shows potential for acid generation.

The ABA and NAG results for the cleaner tailings indicate they are highly acid generating. Due to the large amount of reactive sulfur present and the lack of neutralization potential, the lag time to acid generation likely will be short. Kinetic testing is required to validate this assumption.

The ABA and NAG results for the scavenger tailings suggest a “possible” acid generation potential. The sulfur content is low, but so is the NP, while the NAG pH value is almost exactly at the threshold of 4.5. Due to the uncertain classification, kinetic testing of the scavenger tailings is also recommended to verify their acid generation potential as well as determine lag times to acid generation.

3.4 Process Water Quality

The results in Table 4 indicate that the process water is approximately neutral. Metal leachability generally is low, with most parameters not detected. Exceptions include aluminum, manganese, molybdenum and selenium, which are detected at low concentrations. Trace metal concentrations generally are highest in the process water from the cleaner tailings. Sulfate values are elevated in both process waters. The results generally are in agreement with supernatant data from KCB (2007), who identified the same parameters of potential concern plus cadmium based on a comparison against EPA Aquatic Life Standards and Drinking Water MCLs. The process waters represent aged solutions (by as much as 12 months – KCB (2007)). Therefore, the results are not representative of fresh process waters.

Table 4 also includes Arizona Aquifer Water Quality Standards (AAWQS) for comparison. No exceedances of the AAWQS are observed.

3.5 Synthetic Precipitation Leaching Procedure

The results of the SPLP testing are provided in Table 5. The SPLP tests is the preferred approach for leach testing under ADEQ's Tier #1 approach for characterization of mine wastes (ADEQ, 1998). The short-term nature of the SPLP test provides a snapshot in time of a material's environmental stability. Test results depend entirely on the present disposition of the sample (e.g., unoxidized vs. oxidized; oxidation products absent vs. present, etc.). For reactive rocks (e.g., material that contains oxidizable sulfur), the mechanisms that lead to changes in solution chemistry during water-rock interactions often develop over periods of time that are much greater than can be represented in a 18-hour extraction test. Therefore, the SPLP tests cannot be applied to predict long-term quality, but are instead used to get an initial indication of parameters of potential environmental concern. In the case of an unoxidized sample, SPLP results are indicative of leaching behavior shortly after placement and exposure of a mine waste. Long-term testing, such as kinetic testing, is required to evaluate environmental stability and weathering behavior of mining wastes over time.

The pH of the SPLP leachates is near-neutral as well. Sulfate and metal concentrations generally are lower than in the process water due to the higher degree of dilution (20 to 1 solution to solid ratio as per the standard protocol), and most trace metals are not detected. Exceptions include manganese, molybdenum and selenium. Concentration are lower than in shake flask extraction (SFE) leachates presented in KCB (2007) due to the greater dilution in the SPLP test (solution to solid ratio of 20 to 1 vs. 3 to 1 for the SFE).

Table 5 also includes AAWQS for comparison. However, it should be noted that this comparison is for illustrative purposes only, as short-term leach tests such as the SPLP generally are not capable of accurately simulating ambient conditions. Therefore, this comparison is primarily aimed at identifying constituents of potential environmental concern. No exceedances of AAWQS are observed.

3.6 NAG Leachate

Comprehensive analysis of the NAG leachates was conducted to evaluate leachate quality resulting from sulfide oxidation. NAG leachates represent a "short cut" to terminal conditions when reactive sulfides are present in a mine waste. However, since all available sulfides are oxidized during the NAG procedure, the leachate represents a worst-case scenario as, in reality; oxidation (and associated buffering by neutralizing minerals, if present) will be a more gradual process. Nevertheless, in the absence of kinetic testing information, analysis of NAG leachates is a useful surrogate for identifying parameters of potential environmental concern under pH conditions caused by sulfide oxidation.

The results in Table 6 indicate that both NAG leachates are acidic, with pH values of 2.0 and 4.8 for the cleaner and scavenger tailings, respectively. The sulfate concentration of the leachate from the cleaner tailings is higher than in the corresponding process water and SPLP leachate, indicative of sulfide oxidation. The sulfate concentration in the scavenger tailings leachate is lower than in the process water and SPLP leachate, likely due to the significant dilution associated with the NAG procedure (solution to solid ratio is 100 to 1). Due to the low pH, trace metal concentrations are significantly higher than in the process water and SPLP leachates, with the NAG leachate from the cleaner tailings generally having the highest concentrations. Virtually all parameters are detected in both the cleaner and scavenger NAG leachates, with the exception of beryllium and antimony. Highest trace metal concentrations are observed for aluminum and copper (11 and 38 mg/L, and 2.4 and 5 mg/L in leachates from the cleaner and scavenger tailings, respectively). Iron concentrations are elevated in the cleaner NAG leachate as well at 433 mg/L. KCB did not conduct NAG testing as part of its geochemical characterization program.

A comparison against AAWQS is also provided in Table 6. The same caveats as for the comparison against SPLP leachates results apply. Exceedances of AAWQS for NAG leachates from cleaner and scavenger tailings are observed for pH and fluoride, and for chromium and selenium for cleaner tailings only.

4.0 SUMMARY AND CONCLUSIONS

The Golder geochemical characterization program of the cleaner and scavenger tailings has indicated that the cleaner tailings have a considerable potential for acid generation. The scavenger tailings have a “possible” potential for acid generation, and there is some uncertainty as to the likelihood of acid generation occurring.

Under the neutral conditions present in the process water and SPLP leachates, metal leachability generally is low, with most parameters not detected in the leachates. No exceedances of AAWQS are observed. Comprehensive analysis of the NAG leachates identifies considerable leaching potential under acidic conditions, in particular for aluminum, copper and iron, with AAWQS exceedances for pH, fluoride, chromium and selenium.

It should be noted that any water quality impact analysis will have to take into account a number of site-specific additional factors, such as dilution, chemical attenuation and location of compliance points. Therefore, development of a water balance and mass balance as well as hydrogeochemical modeling are required before a defensible evaluation of potential water quality impacts can be conducted.

The results of the Golder geochemical characterization program generally are in good agreement and consistent with the results from the KCB (2007) effort.

5.0 RECOMMENDATIONS

Based on the results from the geochemical characterization program, kinetic testing of both tailings types is recommended. This will allow for determination of sulfide oxidation rates and verify the acid generation potential of the scavenger tailings. In addition, the kinetic testing will be useful to determine the lag times to the onset of acid generation for both the cleaner and scavenger tailings. If significant lag times are identified, this may allow for flexibility in tailings management during operation and after closure. The kinetic testing can further be used to evaluate the evolution of leachate chemistry as sulfide oxidation progresses, and will result in a more realistic understanding of leachate quality than can be achieved using static leach tests.

6.0 REFERENCES

- AMIRA International Ltd, 2002. ARD Test Handbook – Prediction and Kinetic Control of Acid Mine Drainage. Environmental Geochemistry International Pty. Ltd. and Ian Wark Institute, University of South Australia.
- Arizona Department of Environmental Quality (ADEQ), 1998. Arizona Mining Guidance Manual, Appendix B – Solution, Ore and Waste Characterization. September 1998.
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- Price, W.A., 1997. Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia, 1997. Reclamation Section, Energy and Minerals Division. April 1997.
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Chemical Composition Tailings Solids

Parameter	Unit	Crustal Abundance ¹	Cleaner	Scavenger
Al ₂ O ₃	wt%	15	8.8	14.9
BaO	wt%	0.05	0.02	0.03
CaO	wt%	4.2	0.46	0.68
Cl	wt%	0.05	< 0.02	< 0.02
Fe ₂ O ₃	wt%	7.1	37.5	1.88
K ₂ O	wt%	3.1	1.36	3.90
MgO	wt%	3.5	0.97	2.07
MnO	wt%	0.12	0.02	0.03
Na ₂ O	wt%	3.2	< 0.05	0.09
P ₂ O ₅	wt%	0.23	0.25	0.25
S	wt%	0.05	22.9	0.39
SiO ₂	wt%	58	30.8	75.5
TiO ₂	wt%	0.83	0.55	0.93
As	mg/kg	2	44	< 20
Co	mg/kg	25	241	< 10
Cr	mg/kg	200	193	99
Cu	mg/kg	60	4253	743
Mo	mg/kg	2	79	72
Nb	mg/kg	20	17	10
Ni	mg/kg	80	136	33
Pb	mg/kg	16	151	132
Rb	mg/kg	120	58	156
Sn	mg/kg	2.5	< 50	56
Sr	mg/kg	350	200	229
Th	mg/kg	10	116	47
U	mg/kg	3	35	20
V	mg/kg	150	58	188
W	mg/kg	1	16	44
Y	mg/kg	30	16	25
Zn	mg/kg	70	39	32
Zr	mg/kg	160	70	128

¹ Source: Smith and Huyck (1999)

 indicates concentration is greater than 5 times crustal abundance

Mineralogical Results

Mineral	Formula	Cleaner	Scavenger
Quartz	SiO ₂	22	53
Mica/Illite	(K,Na,Ca)(Al,Mg,Fe) ₂ (Si,Al) ₄ O ₁₀ (OH,F) ₂	15	34
Kaolinite	Al ₂ Si ₂ O ₅ (OH) ₄	10	7
K-feldspar	KAlSi ₃ O ₈	< 3?	< 5
Pyrite	FeS ₂	47	< 1
"Unidentified"	-	< 5	< 5

Acid Base Accounting (ABA) and Net Acid Generation (NAG) Results

	Parameter	Unit	Cleaner	Scavenger
Acid Base Accounting (ABA)	Paste pH	su	7.25	7.52
	Total S	%	36.1	0.38
	S(SO ₄)	%	5.30	0.26
	S(S ⁻²)	%	30.7	0.08
	S(residual)	%	0.08	0.04
	AP	kg CaCO ₃ /ton	960	2.5
	NP	kg CaCO ₃ /ton	2.2	4.4
	NNP	kg CaCO ₃ /ton	-958	1.9
	NPR		< 0.01	1.8
Net Acid Generation (NAG)	NAG pH after reaction	su	2.20	4.51
	NAG to pH 4.5	kg H ₂ SO ₄ /ton	49.8	-
	NAG to pH 7.0	kg H ₂ SO ₄ /ton	60.6	2.35

Process Water Chemistry

Parameter	Unit	AAWQS	Cleaner	Scavenger
Alkalinity	mg/L		11.6	50.3
Spec. Cond.	umhos/cm		1320	1920
pH	su	6 to 9	6.79	7.08
TDS	mg/L		1050	1620
Calcium	mg/L		258	383
Chloride	mg/L		39.3	47.4
Fluoride	mg/L	4.0	1.36	2.81
Hardness	mg/L		652	1030
Magnesium	mg/L		1.84	17
Potassium	mg/L		12.9	39.9
Sodium	mg/L		20.4	26.7
Sulfate	mg/L		598	979
Aluminum	mg/L		0.65	< 0.08
Antimony	mg/L	0.006	< 0.003	< 0.003
Arsenic	mg/L	0.05	< 0.003	< 0.003
Barium	mg/L	2.0	0.015	0.0278
Beryllium	mg/L	0.004	< 0.002	< 0.002
Cadmium	mg/L	0.005	< 0.0002	< 0.0002
Chromium	mg/L	0.1	< 0.006	< 0.006
Cobalt	mg/L		< 0.006	< 0.006
Copper	mg/L		< 0.01	< 0.01
Iron	mg/L		< 0.06	< 0.06
Lead	mg/L	0.05	< 0.003	< 0.003
Manganese	mg/L		< 0.004	0.147
Mercury	mg/L	0.002	< 0.0002	< 0.0002
Molybdenum	mg/L		0.1	0.073
Selenium	mg/L	0.05	0.0131	0.0046
Silicon	mg/L		1.55	1.93
Silver	mg/L		< 0.005	< 0.005
Thallium	mg/L	0.002	< 0.001	< 0.001
Uranium	mg/L		< 0.001	0.00118
Vanadium	mg/L		< 0.005	< 0.005
Zinc	mg/L		< 0.01	< 0.01


AAWQS - Arizona Aquifer Water Quality Standards

 indicates exceedance of AAWQS

ShortTerm Leach Testing (SPLP) Results

Parameter	Unit	AAWQS	Cleaner	Scavenger
Alkalinity	mg/L		41.9	11.8
Spec. Cond.	umhos/cm		349	512
pH	su	6 to 9	6.72	6.53
TDS	mg/L		186	294
Calcium	mg/L		62.9	94.2
Chloride	mg/L		0.34	1.63
Fluoride	mg/L	4.0	0.61	1.25
Hardness	mg/L		162	238
Magnesium	mg/L		1.09	0.611
Potassium	mg/L		2.08	3.29
Sodium	mg/L		1.58	2.01
Sulfate	mg/L		115	229
Aluminum	mg/L		< 0.08	< 0.08
Antimony	mg/L	0.006	< 0.003	< 0.003
Arsenic	mg/L	0.05	< 0.003	< 0.003
Barium	mg/L	2.0	0.0275	0.0122
Beryllium	mg/L	0.004	< 0.002	< 0.002
Cadmium	mg/L	0.005	< 0.0002	< 0.0002
Chromium	mg/L	0.1	< 0.006	< 0.006
Cobalt	mg/L		< 0.006	< 0.006
Copper	mg/L		< 0.01	< 0.01
Iron	mg/L		< 0.06	< 0.06
Lead	mg/L	0.05	< 0.003	0.0115
Manganese	mg/L		0.0313	0.0106
Mercury	mg/L	0.002	< 0.0002	< 0.0002
Molybdenum	mg/L		0.013	0.009
Selenium	mg/L	0.05	0.0043	< 0.003
Silicon	mg/L		0.55	0.57
Silver	mg/L		< 0.005	< 0.005
Thallium	mg/L	0.002	< 0.001	< 0.001
Uranium	mg/L		< 0.001	< 0.001
Vanadium	mg/L		< 0.005	< 0.005
Zinc	mg/L		< 0.01	< 0.01

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 indicates exceedance of AAWQS

NAG Leachate Results

Parameter	Unit	AAWQS	Cleaner	Scavenger
Alkalinity	mg/L		< 1	2.7
Spec. Cond.	umhos/cm		4350	215
pH	su	6 to 9	2.02	4.76
TDS	mg/L		1560	108
Calcium	mg/L		25.7	31.3
Chloride	mg/L		84.2	2.08
Fluoride	mg/L	4.0	7.2	4.12
Hardness	mg/L		87.8	81.7
Magnesium	mg/L		5.76	0.86
Potassium	mg/L		7.85	4.76
Sodium	mg/L		< 0.5	< 0.5
Sulfate	mg/L		1570	95.1
Aluminum	mg/L		11.2	2.37
Antimony	mg/L	0.006	< 0.003	< 0.003
Arsenic	mg/L	0.05	0.0309	< 0.003
Barium	mg/L	2.0	0.0521	0.0546
Beryllium	mg/L	0.004	< 0.002	< 0.002
Cadmium	mg/L	0.005	0.00339	0.00076
Chromium	mg/L	0.1	0.151	0.0089
Cobalt	mg/L		0.4	0.0164
Copper	mg/L		38.1	4.96
Iron	mg/L		433	0.095
Lead	mg/L	0.05	0.0416	< 0.003
Manganese	mg/L		0.434	0.329
Mercury	mg/L	0.002	0.0006	< 0.0002
Molybdenum	mg/L		0.099	0.149
Selenium	mg/L	0.05	0.128	0.0078
Silicon	mg/L		20.1	2.88
Silver	mg/L		0.0126	< 0.005
Thallium	mg/L	0.002	0.001	< 0.001
Uranium	mg/L		0.00193	< 0.001
Vanadium	mg/L		0.0463	< 0.005
Zinc	mg/L		0.359	0.121

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indicates exceedance of AAWQS