TECHNICAL MEMORANDUM

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CC

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TAILINGS LEACHABILITY ASSESSMENT

1.0 INTRODUCTION

As detailed in our proposal dated 1 September 2015, we have completed the following preliminary geochemical test work:

The objective of the testwork is to describe the minerals present within the tailings and to assess the potential for these minerals to release their constituents (metals and salts) to the environment over time using static analytical methods. Kinetic methods may be recommended following the completion of the static work if the solubility and potential mobility of elements of concern is found to be of moderate to high risk.

- Total elemental analysis using X-ray fluorescence (XRF) and four acid digest
- Mineralogical assessment using x-ray diffraction (XRD)
- Assessment of tailings leachability under relevant pH conditions (US EPA LEAF test 1314)
- Acid Base Accounting (ABA) and Single addition Net Acid Generation (NAG) testing.

2.0 SAMPLE INFORMATION

Four drums (10 kg each) of dry tailings were received by Golder Associates in September 2015. A 2 kg sub-sample of the tailings was sent to the Chemistry Centre of WA under Golder standard chain of custody conditions in November 2015.

3.0 RESULTS AND DISCUSSION

3.1 Elemental Composition

Total metal and whole rock analyses were conducted on the sample to determine the elemental composition of tailings material. Whole rock analyses were conducted using X-ray fluorescence (XRF). A bulk metals scan using Inductively coupled plasma (ICP) was also conducted on the sample following a 4-acid digest. The scan included the determination of major and trace metal components. Due to upper detection limit constraints in the ICP, lead was analysed using atomic absorption spectroscopy (AAS).

Concentrations were compared with average crustal abundance (after Smith and Huyck, 1999) to identify any elements (especially metals and metalloids) that occur at concentrations well above normal background values and may require further investigation to assess their environmental significance. The results are presented in **Figure 1** and **Figure 2**. For graphical purposes, values below detection limits are shown at half the detection limit.

The results from the whole rock chemical analysis show that SiO_2 accounts for the bulk of the total oxides (77.9%) while Al_2O_3 accounts for 6.66% and Fe_2O_3 accounts for 4.91%. Minor concentrations of CaO (1.08%) and MgO (1.33%) were also noted. Concentrations of Bi_2O_3 and MoO_3 are well above average crustal abundance.

Significant variability exists in the trace element compositions of the sample. In general, the trace metal concentrations are similar to or below the crustal abundance, with the exception of Ag, As, Cu, Se, Zn and Pb which exceed 6× crustal abundance. Trace elements highlighted here as being of potential environmental concern will be verified through leach testing.

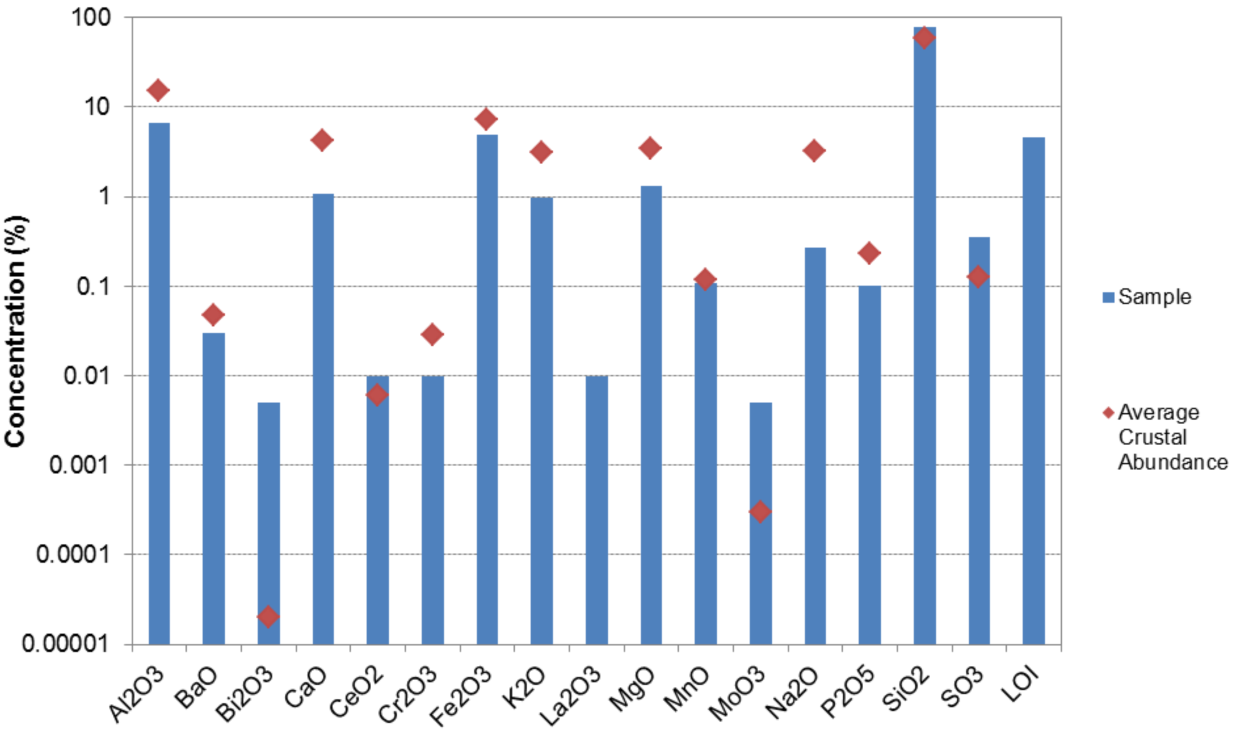

Figure 1: Major element composition of tailings sample

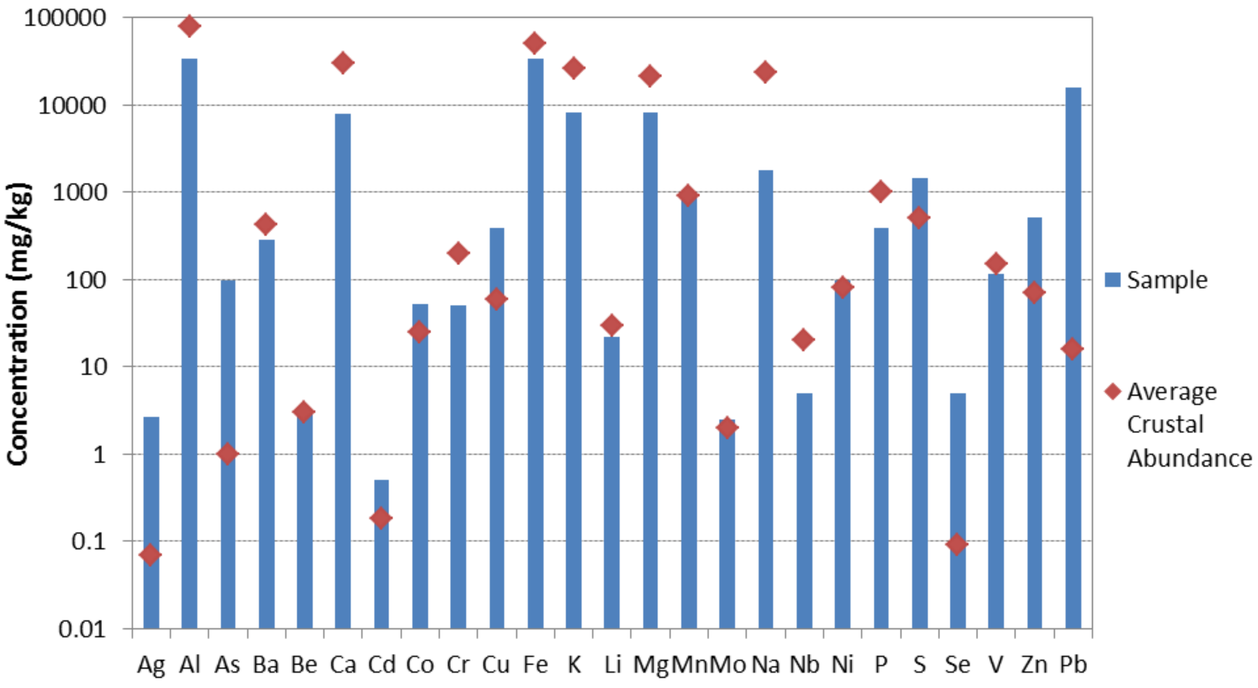

Figure 2: Trace element composition of tailings sample

3.2 Mineralogy

Mineralogy is essential for understanding the minerals and weathering processes that drive ARD generation, as agents of ARD neutralisation and as secondary minerals that both retard and promote acid release and toxic metal migration (DITR, 2007). A representative sub sample of the tailings material (Sample 15S1165) was analysed by the Chemistry Centre WA via x-ray diffraction.

The results of the analysis reported the presence of quartz (60–70%), kaolinite/halloysite (10–14%), ankerite/dolomite (5–7%), muscovite (4–6%), goethite (4–6%) and cerussite (2–3%). It was also noted that there were traces (<2%) of microcline feldspar, vermiculite/smectite, gypsum and other crandalite or alunite group minerals (possibly hindsdalite or plumbogummite) present in the sample. None of the minerals identified were sulfidic; however, carbonate minerals were recognized.

3.3 Acid forming potential

Acid forming potential was assessed using the results of acid base accounting (ABA) and net acid generating (NAG) tests according to AMIRA (2002). A summary table of the laboratory data and calculated parameters used to assess acid forming character is provided in **Table 1**.

Table 1: Summary of acid base accounting results for tailings solids

Results	Units	LOR	Sample 15S1165/001
Total Sulfur (combs)	%	0.01	0.14
Sulfur present as SO_4	%	0.01	0.15
ANC	kg H_2SO_4/tonne	0.5	39.0
NAG pH		0.1	6.3
NAG to pH 4.5	kg H_2SO_4/tonne	0.5	n.d.
NAG to pH 7	kg H_2SO_4/tonne	0.5	<0.5
Calculated Parameters			
MPA (oxidisable)	kg H_2SO_4/tonne		4.28
Net Acid Production Potential (NAPP)	kg H_2SO_4/tonne		-34.7
ANC/MPA ratio			9.11

Note: n.d. = not determined

The Maximum Potential Acidity (MPA) was estimated at 4.28 kg H_2SO_4/tonne. This is based on the total sulfur assay, and is a conservative approach since some sulfur may occur in forms other than pyrite.

The acid formed from pyrite oxidation will to some extent react with acid neutralising minerals contained within the sample. This inherent acid buffering is quantified in terms of the Acid Neutralising Capacity (ANC). The ANC of the material was measured using an industry standard titration method. Acid buffering capacity is moderate (39.0 kg H_2SO_4/tonne), and therefore the tailings material has the ability to buffer acid, if it is released.

In order to assess whether the tailings solids have potential to generate ARD, the Net Acid Producing Potential (NAPP) was calculated. The NAPP is -34.7 kg H_2SO_4/tonne. As the NAPP is negative, this indicates that the tailings are non-acid forming. This is confirmed by the ANC/MPA ratio being well above 1 (i.e. ANC/MPA = 9.11). As a general rule, an ANC/MPA ratio ≥2 generally signifies that there is a high probability that the material will remain circumneutral in pH.

The single addition NAG test is used in association with NAPP to classify the acid generation potential of the tailings sample. The NAG pH is 6.3, and the NAG capacity is <0.5 kg H_2SO_4/tonne. As NAG pH is greater than 4.5, and NAG capacity at pH 7.0 is less than 0.5 kg H_2SO_4/tonne, the sample of tailings tested is considered to be Non Acid Forming (NAF).

3.4 Leach testing

Leach testing was carried out in accordance with LEAF Method 1314. This test is designed to provide the liquid-solid partitioning of constituents in a granular solid material as a function of the liquid-to-solid ratio (L/S), under percolation conditions. A limited analysis approach was taken, in which nine eluate collections were taken with six analytical samples analysed. Evaluation is based on eluate concentrations. The eluent use was reagent water and the flow rate was maintained between 0.5 and 1.0 L/S per day to increase the likelihood of local equilibrium between the solid and liquid phases. The L/S ratios assessed included: 0.2, 0.5, 1, 2, 5 and 10 l/kg.

The results are presented in **Table 2**. All the leachates generated show near-neutral pH (7.7 to 8.1) regardless of the L/S ratio. Electrical conductivity (EC), however, increased significantly as the L/S ratio decreased. At the low L/S ratio of 0.2 l/kg, the EC was 1 730 mS/m, whilst at the high L/S ratio of 10 l/kg, the EC decreased to 76 mS/m. This concentration effect is not unexpected and indicates that during low rainfall periods, any leachate from the tailings is likely to be highly concentrated with salts. The results show that these salts are likely to comprise largely of sulfate (~8 530 mg/L), sodium (~3 790 mg/L) and chloride (~2 300 mg/L).

Copies of all laboratory data pertaining to these results are available upon request.

Table 2: Method 1314 leach test results for tailings

ChemCentre ID	Units	15S1165/007	15S1165/006	15S1165/005	15S1165/004	15S1165/003	15S1165/002
Client ID:		T9	T7	T5	T3	T2	T1
L/S ratio:		10	5	2	1	0.5	0.2
pH		7.9	7.9	8.1	8	7.9	7.7
EC	mS/m	7.6	18.1	80.9	353	932	1730
Redox (Eh)	mV	176	174	175	186	195	211
Br	mg/L	0	0	0	0	0	0
Cl	mg/L	0	0	22	470	830	2300
F	mg/L	0	0	0	0	0	0
SO_4	mg/L	5.1	37	236	1430	4080	8530
DOC	mg/L	1.4	6.3	18	19	23	29
Ag	mg/L	0	0	0	0	0	0
Al	mg/L	0	0	0	0	0	0
As	mg/L	0	0	0	0	0	0
B	mg/L	0.017	0.06	0.22	0.54	1.1	1.8
Ba	mg/L	0.088	0.053	0.028	0.024	0.03	0.037
Be	mg/L	0	0	0	0	0	0
Ca	mg/L	6.9	9	19	105	286	417
Cd	mg/L	0	0	0	0	0.0003	0.0006
Co	mg/L	0	0.0001	0.0005	0.0031	0.011	0.022
Cr	mg/L	0	0	0	0	0	0
Cu	mg/L	0.0002	0.0004	0.0004	0.001	0.0024	0.0068
Fe	mg/L	0	0	0	0	0	0
Hg	mg/L	0	0	0	0	0	0
K	mg/L	1.4	3.1	7.9	21.9	53.5	93
Mg	mg/L	3.3	4.4	9.8	53.2	190	411
Mn	mg/L	0.0007	0.002	0.0079	0.047	0.18	0.3
Mo	mg/L	0.002	0.003	0.003	0.003	0.004	0.009

ChemCentre ID	Units	15S1165/007	15S1165/006	15S1165/005	15S1165/004	15S1165/003	15S1165/002
Client ID:		T9	T7	T5	T3	T2	T1
L/S ratio:		10	5	2	1	0.5	0.2
Na	mg/L	1.8	18.2	131	643	2010	3790
Ni	mg/L	0	0	0	0.002	0.008	0.02
P	mg/L	0	0	0	0	0	0
Pb	mg/L	0.018	0.0084	0.0074	0.011	0.021	0.04
S	mg/L	1.7	13	91	470	1400	2500
Sb	mg/L	0	0	0	0	0	0
Se	mg/L	0	0	0	0.001	0.005	0.01
Sn	mg/L	0	0	0	0	0	0
Th	mg/L	0	0	0	0	0	0
Ti	mg/L	0	0	0	0	0	0
Tl	mg/L	0	0	0	0.0003	0.0008	0.0014
U	mg/L	0	0	0.0003	0.0007	0.0011	0.0012
V	mg/L	0	0	0	0	0	0
Zn	mg/L	0.001	0.002	0.003	0.003	0.008	0.011

4.0 COMPARISON OF RESULTS: LEACHATE AND GROUNDWATER QUALITY

Groundwater quality at the site must not exceed 0.1 mg/L Pb, all other parameters are to be assessed against the water quality criteria for livestock drinking water (ANZECC 2000).

Groundwater samples are collected quarterly from groundwater wells on site. At least one of these compliance bores, MTM001, is understood to be outside the footprint of the existing tailings storage facility (TSF). A review of the monitoring results for borehole MTM001 over the last two years shows a circumneutral pH (6.7 to 8.0) and an EC of 700 to 1 100 mS/cm. This suggests that the groundwater has a similar salt load to the leachate at a L:S ratio of 0.5 l/kg. A L:S ratio of 0.5 l/kg is the more concentrated end of the spectrum assessed in the leach tests, and would represent very low rainfall conditions at the site. Therefore, it can be said that the concentrated leachate is within the range seen in groundwater and changes to EC from the introduction of water from the tailings is not anticipated.

The tailings are effectively the waste product generated through the processing of lead carbonate (i.e. cerussite), and lead concentrations in the leachate are traces of the ore. Cerussite, and other lead-bearing minerals, were identified in the XRD analysis.

When available baseline groundwater quality is compared in more detail to the eluates generated from the tailings, the COPC's identified are, Pb, Cd, Ni and Zn as concentrations in the lower liquid to solid eluates are above levels recorded in the baseline groundwater quality assessment (Aquaterra 2004). It is noted that groundwater sampled from bores at the site, Cu values in the groundwater were higher than in the eluates.

The concentration of COPC's in the eluates were similar to those recorded in groundwater at the site during operation (Golder 2015).

5.0 MANAGEMENT MEASURES

The management measures recommended in the Surface Water and Drainage Management Plan (Rosslyn Hill Mining 2015) cover four broad categories; total containment, specific containment, engineering controls to contain, and no control.

- Pit Areas and Process Plant/Concentrate Handling – Total Containment
- Tailings Storage Facility – Specific Containment
- Site Infrastructure – Engineered Controls
- Undeveloped Areas – No Control.

It is understood that there is a network of bores at the site, around the existing TSF, more extensive than the compliance monitoring network.

Three monitoring bores have been in existence to the east of the TSF since 2006 and these wells have not recorded exceedances of the adopted screening criteria.

There are two wells slightly north of the pastoral well TOM001, these are MTM001 and MTM002, these well have not recorded Pb levels above the adopted screening criteria, and therefore no further actions are recommended other than continued monitoring.

Given that the proposed integrated waste landform (IWL) will be located in the area south of the TSF, the water in this area of the mine will be managed by the measures in place for the IWL; the groundwater quality will be monitored through a network of bores between the IWL and the pits. Surface water will be captured (engineered controls) and will report to the pond north of the TSF where it will evaporate.

The results of the leach tests do not change the management of water for the IWL: as it is site infrastructure, engineering controls will be put in place to capture any water and monitoring will be undertaken to assess potential impacts to groundwater from the identified COPC's. The measures to be implemented to meet this requirement are summarised in the Golder (2015), and Rosslyn Hill Mining (2015)documents.

6.0 SUMMARY

A tailings sample was submitted by Rosslyn Hill Mining for geochemical assessment.

The results from the whole rock chemical analysis show that SiO_2 accounts for the bulk of the total oxides (77.9%) while Al_2O_3 accounts for 6.66% and Fe_2O_3 accounts for 4.91%. Minor concentrations of CaO (1.08%) and MgO (1.33%) were also noted. Concentrations of Bi_2O_3 and MoO_3 are well above average crustal abundance in the tailings solids. In general, the trace metal concentrations are similar to or below the crustal abundance, with the exception of Ag, As, Cu, Se, Zn and Pb which exceed 6× crustal abundance.

The mineralogy of the sample comprised quartz (60–70%), kaolinite/halloysite (10–14%), ankerite/dolomite (5–7%), muscovite (4–6%), goethite (4–6%) and cerussite (2–3%). Traces (<2%) of microcline feldspar, vermiculite/smectite, gypsum and other crandalite or alunite group minerals (possibly hindsdalite or plumbogummite) were also present in the sample. None of the minerals identified were sulfidic; however, carbonate minerals were recognized.

Acid base accounting and short-term leach testing were carried out on the sample. The total sulfur content in the tailings sample was considered to be low (0.14% S), and therefore the MPA was low at 4.28 kg H_2SO_4/t. The ANC was found to be 39.0 kg H_2SO_4/t, and as such the sample has some capacity to buffer any acid should this be released. The NAPP is negative, and coupled with the near-neutral NAG pH (pH 6.3) and NAG capacity (<0.5 kg H_2SO_4/t) the sample is considered to be Non Acid Forming (NAF).

The leachate generated was near-neutral (pH 7.7–8.1) with significantly increasing electrical conductivity as the L:S ratio decreases (7.6 to 1 730 mS/m). This indicates that leachate will become highly concentrated with salts during low rainfall periods. These salts are likely to be dominated by sulfate (~8 530 mg/L), sodium (~3 790 mg/L) and chloride (~2 300 mg/L).

When compared to natural groundwater in the vicinity of the TSF, the salt lode in the concentrated leachate is within the range observed in the groundwater.

When available baseline groundwater quality is compared in more detail to the eluates generated from the tailings, Pb, Cd, Ni and Zn are the COPC's.

7.0 CONCLUSIONS

- The acid neutralising of the tailings is consistent with the description of carbonates being present in the surrounding geology.
- The waste tailings materials are non-acid forming and therefore consideration of acid generation does not have to be made.
- When eluates were compared to baseline water quality the following COPC's were identified as Pb, Cd, Ni, and Zn. This is consistent with the COPC's documented in the licensed monitoring requirements.
- All groundwater monitoring should include the basic water quality suite (pH, TDS, EC, Ca, Mg, K, Na, SO_4, Cl, and Alkalinity) with the additional metals (COPC's) Pb, Cd, Zn, and Ni. This will allow for an assessment of similarities in the trends in the basic water quality suite and the COPC's to minimise analytical costs in the future.
- Golder consider that the water management measures recommended for the TSF combined with those recommended for the IWL will be sufficient to manage the potential for impacts to groundwater quality from leachate generated from the tailings. The IWL design is therefore considered adequate.

8.0 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.

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Golder (2015) – **Rosslyn Hill Mining Ltd, Design Report for Integrated Waste Landform at Paroo Station Mine Site**. Draft, December 2015. 1537548 003 R RevA.

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