EARTH SYSTEMS
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GEOCHEMICAL ASSESSMENT OF BORROW MATERIALS FOR 2/5 TAILINGS DAM EXPANSION, MMG ROSEBERY, TASMANIA

Prepared for

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1. INTRODUCTION

This report describes the geochemical properties of proposed borrow material for expansion of the 2/5 tailings dam at the Rosebery Mine, and recommended management and testing procedures for its use.

This report includes:

- Review of the regional and local geology.
- Review of geochemical and bore log data provided by Pitt & Sherry (P&S).
- Assessment and interpretation of geochemical data for borrow materials.
- Development of a management strategy for avoiding and/or managing potentially acid forming (PAF) borrow materials.

Samples were collected and analytical parameters selected by ATC Williams. It is unclear how representative the samples are, and the selected static geochemical analytes provide limited information for determination of geochemical risk (a broader set of analyses would be recommended). Analytical work was conducted by ALS.

2. DATA

The following data and documents were provided by P&S:

- Excerpts from Coffey Environments, ENAUABTF06869AC-R01b, July 2012, 1/2/5 Dam TSF Hydrogeological Investigation, MMG Rosebery Mine, Tasmania;
- ALS analytical data (EB1514199);
- Map of sampling locations (ATC Williams);
- Borehole logs (ATC Williams).

The following resources were also consulted to prepare geological interpretations:

- Geology from Digital Geological Atlas 1:25000 Series. Sheet 3637 Rosebery. Mineral Resources Tasmania, 2003.
- Geology and Mineral Resources of Tasmania, Geological Society of Australia, 1989.
- Lees, T., Zaw, K., Large, R. R., Huston, D. L. Rosebery and Hercules copper-lead-zinc deposits. Geology of the Mineral Deposits of Australia and Papua New Guinea. Australian Institute of Mining and Metallurgy (AIMM), 1990.

3. REGIONAL AND LOCAL GEOLOGY

The geology of the area from Lees et al., (1990) is shown in Figure 1.

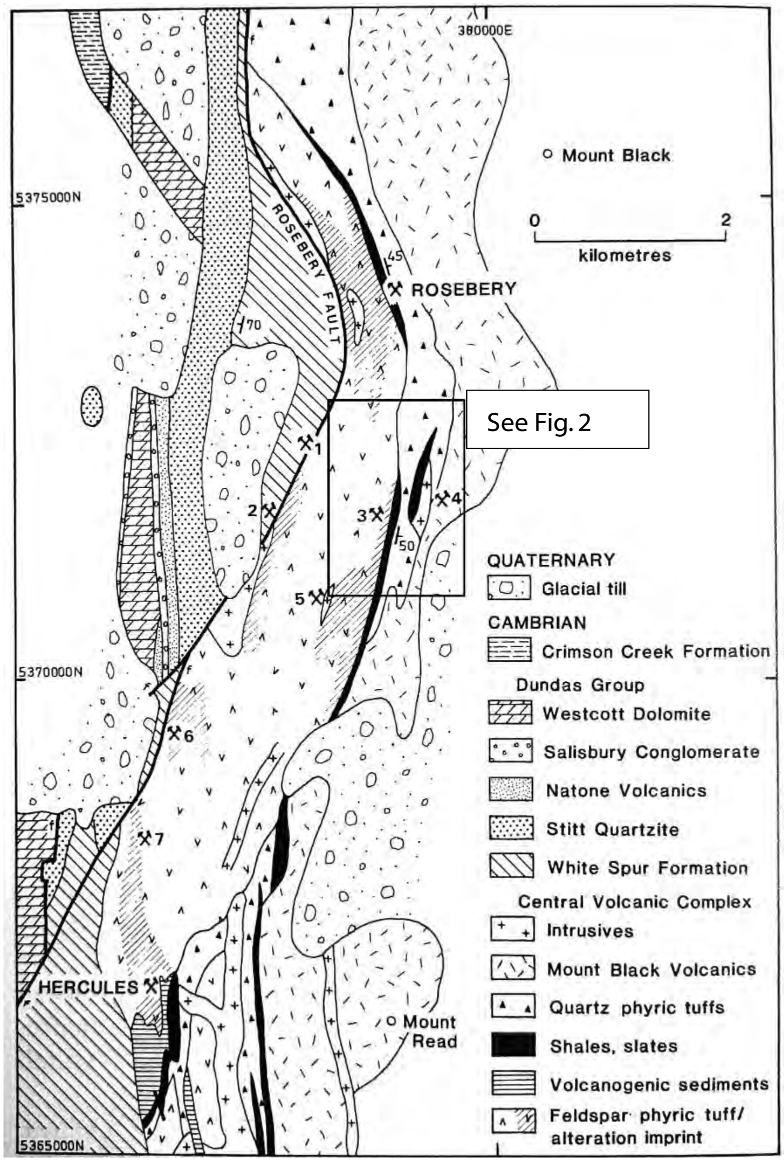

Figure 1: Geology map of Rosebery area (Lees et al. 1990).

The geology from MRT (2003) and the location of boreholes and surface samples are shown in Figure 2. Historic mine sites are indicated.

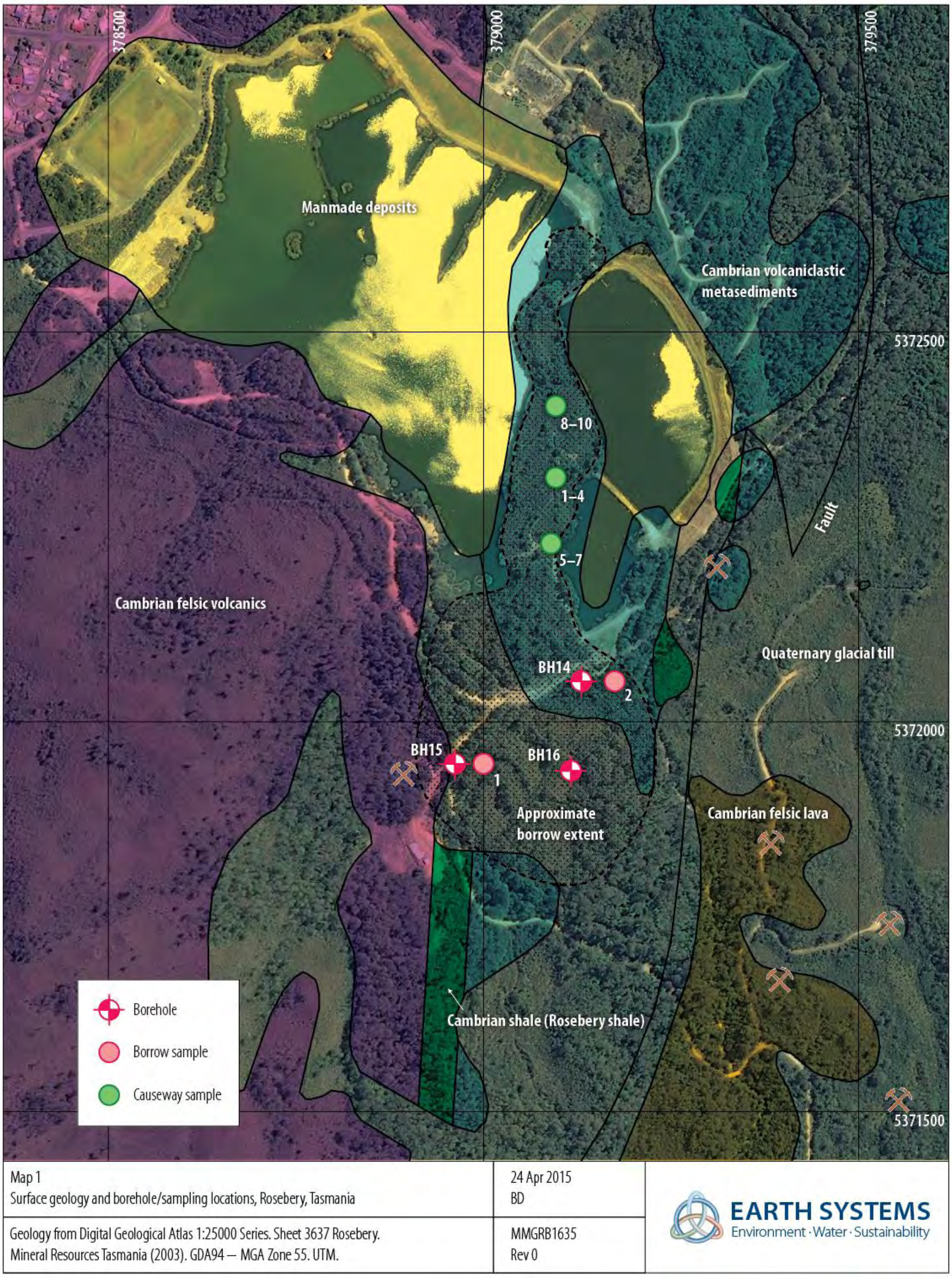

Figure 2: Map of geology (MRT, 2003) and borehole/sampling locations, Rosebery.

Coffey Environments (2012) reported an inferred geological cross-section extending into the Cambrian felsic volcanics, as shown in the cross section in Figure 3.

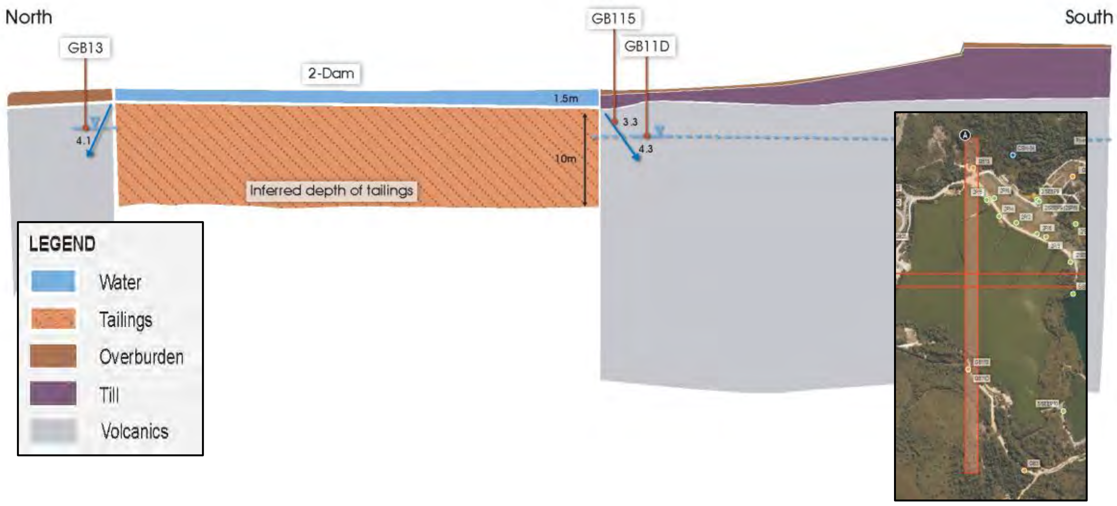

Figure 3: Inferred geological cross-section (Coffey Environments, 2012).

A summary of geology from the borehole logs provided by (ATC Williams) is depicted in Figure 4.

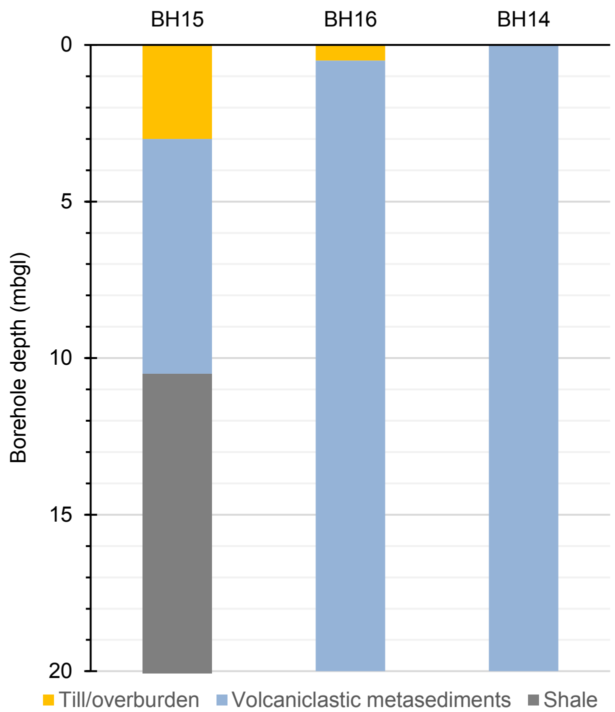

Figure 4: Borehole geology (ATC Williams, 2015).

The geology map in Figure 2 shows that the proposed borrow area (encompassing boreholes BH14–BH16) is located within surficial Quaternary glacial till and Cambrian volcaniclastic metasediments (Mount Black volcanics). It is important to note that the presence of proximal abandoned mines (from MRT, 2003) indicates that the area is mineralised (either Cambrian volcanogenic or Devonian hydrothermal) and may therefore be locally sulfidic.

BH15 (western borrow extent) is close to the contact between glacial till and the Cambrian felsic volcanics (Cfv; central volcanic complex), which are likely to be intersected at depth (eg. > 40 mbgl – metres below ground level) at that location (the felsic volcanics dip at 50–60° to the east). Cambrian shales (Cs; black shales and slates) present at the surface to the south of BH15 are intersected at ~10 m in BH15.

Note that the strike of lithologies in the area is north-south, consistent with the northward extension of shale outcropping to the south of BH15.

The interpreted geological section on chainage BH15–BH16–BH14 is shown in Figure 5.

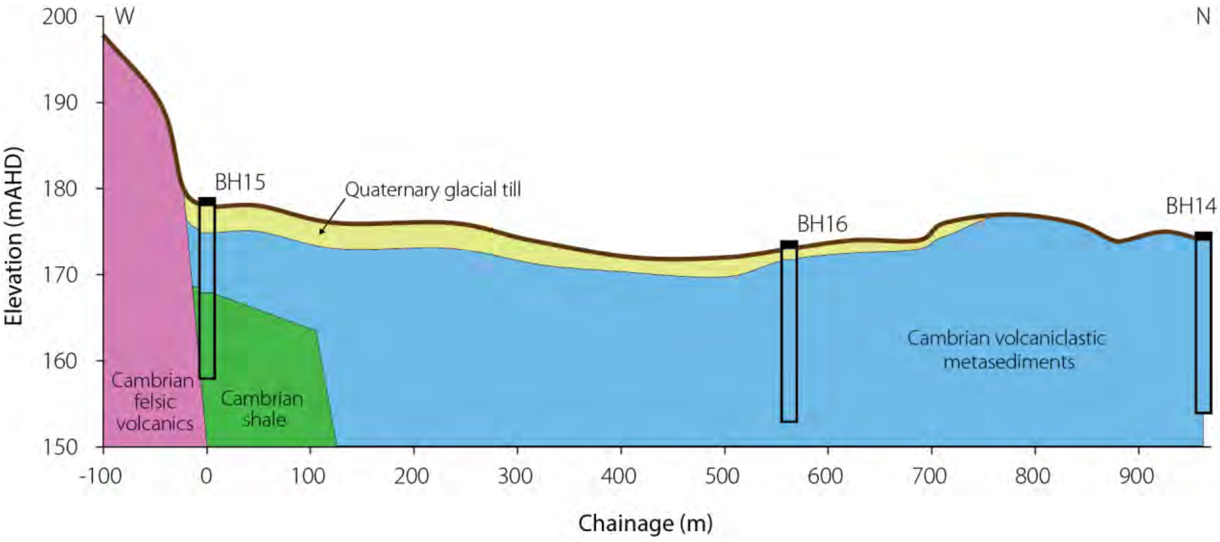

Figure 5: Interpreted subsurface geology on chainage BH15–BH16–BH14.

4. LITHOLOGIES PRESENT

The lithologies expected to be encountered in the proposed borrow area are listed in Table 1. Note that all Cambrian lithologies are indicated to have the potential to be pyritic.

Table 1: Lithologies present in the borrow area.

Lithology	Abbrev.	Description
Overburden / Quaternary glacial till	Qt	Unconsolidated overburden 0.1–5.4 m thick. Medium-plasticity, brown, silty and sandy clay (Coffey, 2012). Pleistocene glacial and glacigene deposits (MRT, 2003). Clay or silt matrix, enclosing larger particles of poorly sorted, well-rounded rock up to cobble size (Coffey, 2012).
Cambrian volcaniclastic metasediments (Mt Black volcanics)	Cv	Mainly volcaniclastic sandstone, typically crystal rich (quartz, feldspar), with some siltstone and mudstone (MRT, 2003). Dominantly feldspar-phyric rhyolite lava with subordinate felsic pyroclastic units and andesite lava and tuff (GSA, 1989). Typically sericite-chlorite-pyrite alteration (AIMM, 1990).
Cambrian felsic volcanics (Mt Black volcanics)	Cfv	Mainly felsic volcanic and pyroclastic rocks, dominantly feldspar-phyric, including pumice-bearing units (MRT, 2003). Dominantly feldspar-phyric rhyolite lava with subordinate felsic pyroclastic units and andesite lava and tuff (GSA, 1989). Typically sericite-chlorite-pyrite alteration (AIMM, 1990).
Cambrian shale	Cs	Shale–siltstone–minor sandstone units (includes Rosebery Shale) (MRT, 2003). Black shale and slate (Lees et al., 1990). Dominantly dark grey siltstone and slate containing biogenic pyrite and minor units of quartz-feldspar-phyric tuff and sandstone turbidites containing Precambrian-derived quartzite and quart-mica schist detritus (GSA, 1989).

5. GEOCHEMISTRY OF BORROW AREA

The geochemical data provided for the proposed borrow area are shown in Table 2.

Table 2: Geochemical data for borrow area.

Sample / Borehole / Depth (mbgl)	Parameter / Units													Risk class.
	NAG_{pH}	$NAG_{4.5}$	$NAG_{7.0}$	ANC	S_{KCl}	S_{HCl}	As	Ba	Cd	Cu	Mn	Pb	Zn	
	–	kg H_2SO_4/t			% S		mg/kg							
BH14														
0.2–4.0 m	7.8	<0.1	<0.1	4.4	<0.02	<0.02	8.4	122	<0.1	2.6	993	10.3	37.7	NAF
4.0–7.5 m	9.6	<0.1	<0.1	8.0	<0.02	<0.02	2.6	145	<0.1	3.8	659	7.8	36.3	NAF
7.5–8.5 m	8.7	<0.1	<0.1	9.2	<0.02	<0.02	2.1	195	0.4	5.3	2690	10.2	197	NAF
8.5–12.5 m	8.0	<0.1	<0.1	5.1	<0.02	0.03	4.2	156	0.3	2.3	669	10.6	132	NAF
12.5–16.5 m	7.5	<0.1	<0.1	5.2	<0.02	0.04	5.4	141	0.4	2	884	10.9	139	NAF
16.5–20.5 m	10.2	<0.1	<0.1	20.4	<0.02	<0.02	2	98.6	<0.1	2.2	668	8.6	31.4	NAF
BH15														
2.5–6.5 m	7.4	<0.1	<0.1	4.5	<0.02	<0.02	2.2	86.5	0.1	3.2	1540	10	136	NAF
6.5–10.5 m	6.8	<0.1	0.6	12.0	<0.02	0.29	3.8	98.6	0.1	8.1	2870	3.6	756	PAF
10.5–12.0 m	2.6	42.2	49.8	6.2	0.02	0.02	165	140	0.2	115	402	7.8	418	PAF
12.0–16.0 m	2.8	29.0	35.2	8.1	0.03	0.04	49	154	0.2	67.4	869	30.6	429	PAF
16.0–20.4 m	2.8	26.5	32.7	13.7	0.04	0.04	117	168	0.5	116	2620	39.7	249	PAF
BH16														
0.4–4.0 m	6.4	<0.1	2.7	3.8	<0.02	<0.02	8.4	132	0.5	36.5	126	12.8	141	NAF
4.0–8.0 m	7.1	<0.1	<0.1	5.2	<0.02	<0.02	15.4	136	0.2	6.6	697	13.1	58.3	NAF
8.0–12.0 m	7.2	<0.1	<0.1	7.6	<0.02	<0.02	4.9	112	<0.1	6.5	3700	10.8	35.9	NAF
12.0–16.0 m	7.7	<0.1	<0.1	10.0	<0.02	0.02	122	108	0.5	10.4	3190	18.1	148	NAF
16.0–20.4 m	7.9	<0.1	<0.1	8.6	<0.02	<0.02	31.2	91.4	<0.1	3.3	1940	7.2	34.3	NAF
Borrow area surface samples														
Sample 1	7.4	<0.1	<0.1	2.3	<0.02	<0.02	18.9	106	<0.1	4.5	547	12.2	33.6	NAF
Sample 2	7.6	<0.1	<0.1	2.5	<0.02	<0.02	15.2	87.5	0.2	9.3	936	13	44.1	NAF
Causeway borrow area surface samples														
1	7.4	<0.1	<0.1	1.8	<0.02	<0.02	5.4	75.9	<0.1	77.9	360	9.2	27.1	NAF
2	7.0	<0.1	<0.1	1.9	<0.02	<0.02	2.1	77.7	<0.1	19.4	192	7.8	22.8	NAF
3	7.1	<0.1	<0.1	1.8	<0.02	<0.02	1.9	69.6	<0.1	3.8	172	5.3	22.4	NAF
4	7.1	<0.1	<0.1	1.2	<0.02	<0.02	2.6	57.9	<0.1	3.2	218	4.6	20.2	NAF
5	6.7	<0.1	1.0	1.1	<0.02	<0.02	2.0	70.4	<0.1	2.3	142	5.2	23.6	NAF
6	6.8	<0.1	0.3	1.9	<0.02	<0.02	1.2	61.6	<0.1	2.0	153	4.6	19.5	NAF
7	7.0	<0.1	<0.1	1.3	<0.02	<0.02	0.8	64.4	<0.1	4.2	133	3.7	18.3	NAF
8	7.1	<0.1	<0.1	2.9	<0.02	<0.02	1.4	78.9	<0.1	3.9	135	7.5	19.4	NAF
9	6.9	<0.1	0.2	2.8	<0.02	<0.02	1.7	74.1	<0.1	5.0	195	6.9	23.2	NAF
10	7.2	<0.1	<0.1	2.4	<0.02	<0.02	1.9	74.5	<0.1	3.4	342	5.4	25.8	NAF
11	7.3	<0.1	<0.1	1.9	<0.02	<0.02	4.0	72.6	<0.1	2.7	212	4.9	13.8	NAF
12	6.0	<0.1	5.8	1.6	<0.02	<0.02	3.5	70.3	<0.1	4.8	221	5.2	15.9	NAF
13	5.9	<0.1	6.6	1.2	<0.02	<0.02	9.0	64	<0.1	3.4	69	4.9	11.5	NAF
14	7.2	<0.1	<0.1	2.4	<0.02	<0.02	37.7	60.3	<0.1	13.8	1450	5.7	26	NAF

Note: Orange highlighted cells indicate results suggesting potentially acid forming (PAF) characteristics; green highlights indicate neutral metalliferous drainage (NMD) potential.

6. GEOCHEMICAL RISK

6.1 Borrow materials, south of 2/5 dam

All sampled materials from BH14, BH16, and the surface are non-acid forming (NAF), with a small excess (<10 kg H_2SO_4/t) of acid neutralisation capacity (ANC).

Samples from BH15 at a depth of >10.5 m are potentially acid forming (PAF) with net acidity generation (NAG) potential of 30–50 kg H_2SO_4/t. This represents a moderate risk of acidity generation.

Based on the regional geology and geological logs, the PAF material intersected in BH15 corresponds to Cambrian shale, which is reported to contain pyrite (GCA, 1989; AIMM, 1990).

Unweathered rock to the west of BH15, mapped as Cambrian felsic volcanics, may also be PAF (although not sampled), as indicated by geology reports (GCA, 1989; AIMM, 1990).

6.2 Borrow materials, causeway

All causeway samples were NAF, and given the very low ANCs (<3 kg H_2SO_4/t), are unlikely to contain notable sulfides. However, as the depth of sampling is unknown, the acid forming potential of unweathered rocks at depth is unknown.

6.3 Summary of geochemical risk by lithology

A table summarising the geochemical risk of each of the local lithologies is provided in Table 3.

Table 3: Geochemical risk of lithologies present in the borrow area.

Lithology	AMD Risk Category	Geochemistry and Key mineralogy
Overburden / Quaternary glacial till	NAF	$NAG_{7.0}$ < 0.1 kg H_2SO_4/t ANC < 3 kg H_2SO_4/t No existing acidity
Cambrian volcaniclastic metasediments (Mt Black volcanics)	NAF (unknown at depth)	$NAG_{7.0}$ < 0.1 kg H_2SO_4/t ANC typically < 10 kg H_2SO_4/t No existing acidity
Cambrian felsic volcanics (Mt Black volcanics)	Likely PAF	Likely disseminated pyrite.
Cambrian shale	PAF	Biogenic pyrite. $NAG_{7.0}$ typically ~50 kg H_2SO_4/t.

7. INFERRED DISTRIBUTION OF GEOCHEMICAL RISK

The inferred geological cross-section and associated geochemical risk in the borrow area (chainage BH15–BH16–BH14) based on available data is shown in Figure 6.

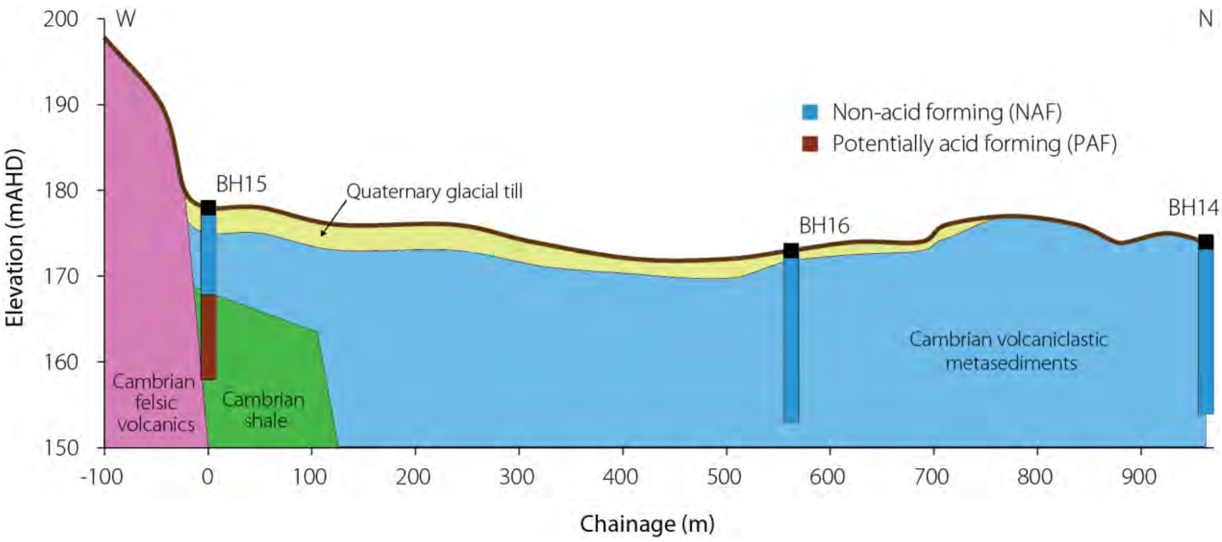

Figure 6: Inferred geology on a cross section through BH15, BH16 and BH14.

8. CONCLUSIONS

The key findings of this review are as follows:

- The majority of material in the proposed borrow area appears to be Cambrian volcaniclastic metasediment, which is categorised as NAF with a small excess of ANC. The sampled Cambrian volcaniclastic metasediments are geochemically suitable (non-PAF, non-NMD) for construction of the 2/5 dam expansion.
- PAF material was encountered at a depth of >10 mbgl at the western extent of the proposed borrow area (BH15), associated with Cambrian shale, which is known to contain pyrite.
- Excavation of borrow material should be conducted in a manner the reliably avoids all PAF materials. The most efficient means of avoiding PAF materials is to limit the extent of the borrow area to the zone known to include safe NAF materials (Quaternary glacial till, Cambrian volcaniclastic metasediments).
- If full utilisation of the borrow area is required, it may be necessary to conduct further drilling to identify the extent of safe NAF materials.
- Routine geological assessment is needed to visually identify and exclude PAF from the excavation volume.
- Routine geochemical testing of excavated materials is needed to confirm NAF properties.

9. RECOMMENDATIONS

The excavation or disturbance of PAF or potentially NMD-generating materials and their use for construction should be avoided. Recommended measures for ensuring the exclusion of PAF/NMD materials are as follows:

- Avoid excavation or disturbance of PAF materials by limiting the extent of the borrow area to the known extent of safe NAF materials (ie. Quaternary glacial till, Cambrian volcaniclastic metasediments).
  - » Lithologies identified as PAF are Cambrian shale and Cambrian felsic volcanics (likely PAF);
  - » For example, excavate no further west than UTM 37900 and no deeper than ~8 mbgl in the vicinity of BH15;
  - » If sufficient material can be won from the eastern side of the proposed borrow area, then avoid any excavation of materials on the western side;
  - » Consider borrowing material from further south or east rather than from the western side of the proposed borrow area.
- During excavation, the lithologies in the borrow area should be examined by a geologist to identify PAF/NMD lithologies.
- If PAF lithologies are visually apparent, then geochemical testing may be required.
- Additional drilling to identify the extent of safe NAF materials may be warranted if full utilisation of material in the borrow area is required.
- If PAF/NMD materials are encountered, they must not be used for 2/5 dam construction. If excavated or disturbed, PAF materials should be submerged either in the existing 2/5 dam or its extension.

Given the mineralised nature of the area (which may not be lithology-specific), routine sampling and analysis of borrow materials prior to or at the time of excavation is recommended to ensure that all material used for 2/5 dam construction is NAF. Sampling should be conducted as follows:

- Prior to or at the time of excavation, materials should be sampled routinely at a nominal frequency of one sample per ~1,000 tonnes.
- A minimum of 20 kg of material should be collected for each sample, ideally composited from 3–6 representative sampling points (subject to operational practicalities).
- The entire 20 kg sample (or a representative 2 kg split if suitable splitting facilities are available) should be despatched to a NATA-accredited laboratory for analysis.
- The sample should be analysed for the following parameters as a minimum:

Parameter	Unit	Method reference
NAG_{pH}	–	AMIRA 2002
$NAG_{4.5}$	kg H_2SO_4/t	
$NAG_{7.0}$		
ANC		

- <u>Suitable</u> NAF and non-NMD materials meet both of the following criteria:
  - » NAG_{pH} > 4.5 <u>AND</u>
  - » $NAG_{7.0}$ < 5 kg H_2SO_4/t