APPENDIX M Waste Characterisation Reports

HAVIERON PROJECT
WASTE CHARACTERISATION STUDY

Newcrest Mining Limited

January 2021

Disclaimer: All care and diligence has been exercised in testing, interpreting data and the development of recommendations presented in this report. The monitoring and testing have been undertaken in a skilled, professional manner, according to accepted practices. Specific circumstances and research findings after the date of publication may influence the accuracy of the data and recommendations within this report.

The landscape is not uniform. Because of this non-uniformity, no monitoring, testing or sampling technique can produce completely precise results for any site. Any conclusions based on the monitoring and/or testing presented in this report can therefore only serve as a 'best' indication of the environmental condition of the site at the time of preparing this document. It should be noted that site conditions can change with time.

The information that comprises this report should only be used within the limitations stipulated in this report. Landloch does not accept any risks and responsibilities for losses, damages, costs and other consequences resulting from using any information, material and recommendations in this report.

TOOWOOMBA
PO Box 57
HARLAXTON QLD 4350
Phone (07) 4613 1825

PERTH
PO Box 5175
SOUTH LAKE WA 6164
Phone (08) 9494 2835

NEWCASTLE
PO Box 1102
Warners Bay NSW 2282
Phone (02) 4965 7717

Landloch Pty Ltd
A.C.N. 011 032 803
A.B.N. 29011032803

Web site: www.landloch.com.au
Email: admin@landloch.com.au

Project Number: 2264.20a

Report Title: Havieron Project Waste Characterisation Study

Client: Newcrest Mining Limited

Review History

Version Number	Prepared by:	Reviewed by:	Date
0 (Draft)	C. Lison	E. Howard, L.Whitley	14/08/2020
1 (Draft)	C. Lison	E.Howard, L.Whitley	21/08/2020
2 (Draft)	C.Lison	E.Howard	07/09/2020
3 (Final)	C.Lison	E.Howard	22/01/2021

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Newcrest Mining Limited (Newcrest) are currently undertaking a feasibility study for the proposed Havieron Project. Landloch was engaged by Newcrest to undertake baseline soil and waste characterisation to support Newcrests's mining proposal application. This report relates to the results of the waste characterisation study.

The aim of this waste characterisation study is to:

- Identify the broad geology and different types of waste in the Project area;
- Determine the potential limitations of the different waste types; and
- Provide advice on management of each of those wastes for use as a rehabilitation material.

In order to complete the waste characterisation, the existing information relating to wastes was reviewed and a waste sampling methodology was developed. Landloch reviewed the drilling database in consultation with Newcrest's geologists. Geological units to be disturbed by mining were identified, and waste samples were selected from the drilling database that were deemed to be representative of wastes to be disturbed, including materials with a range of oxidation states (fresh and oxidised).

Sample selection was undertaken by Landloch in consultation with Newcrest. Samples were sourced from the diamond core drilling campaigns completed from 2019 and 2020. A total of 36 samples were assessed. Eight dominant lithologies were targeted during the sampling process including Lower Tillite (28% of samples), Saprock (17% of samples), Saprolite (17% of samples), Upper Mudstone (11% of samples), Upper and Lower Sandstone (11% of samples), Upper Tillite (8% of samples), Lower Sandstone (6% of samples) and Tertiary Cover (3% of samples).

All samples were assessed for pH, Electrical Conductivity, Total Sulphur, total metals and acid producing potential using acid-base accounting (ABA) techniques. Depending on the weathering state, materials that are oxidised and potentially prone to structural instability were further assessed for structural stability indices.

An outline of the methods used is given in Section 3 of the report, and results and their interpretation are presented in Section 4. Complete tabulation of the data is provided as appendices.

The results can be summarised as follows:

- For all waste materials there is a trend of increasing pH with depth. The pH of the Tertiary Cover is similar (slightly acidic to neutral) to those measured in naturally occurring soils and hence pH is not likely to pose a risk for rehabilitation success. All remaining materials are characterised as being slightly to highly alkaline (pH 7.87-9.38).
- The salinity ($EC_{1:5}$) for all materials ranges between 0.51-5.27 dS/m. The Saprolite material and unweathered materials of the Lower Tillite and Upper and Lower Sandstone are generally classed as saline with $EC_{1:5}$ ranging between 2.76-5.27 dS/m. Materials exposed to greater weathering such as the Tertiary Cover, Saprock, Upper Tillite, Upper Mudstone and Upper Siltstone generally recorded lower levels of salinity, with $EC_{1:5}$ ranging between 0.51 and 1.30

dS/m. At these levels, establishment of plant species is not expected to be significantly impacted by salinity (though some salt sensitive species may be impacted).

- Samples from the Lower Tillite lithology exhibited the highest rock density and lowest water absorption values, leading to some rocks within this waste type classed as having extremely strong rock strength. This indicates that these materials are highly suitable for use as rock armour on outer landform faces. Other materials tended to be less durable.
- All 36 waste samples were tested for Total S concentrations. Ten of the 36 waste samples returned elevated Total S (>0.15%). The proportion of these samples originated from Lower Tillite, Saprolite, Upper Mudstone, Upper Tillite and Lower and Upper Siltstone.
- The materials with Total S values >0.15% were further assessed for their ability to produce acid using static acid base accounting methods. Potentially acid forming materials were classified in the Upper Siltstone (1 sample). The potential for Saprolite and Upper Tillite material to be acid producing was deemed uncertain, although the Upper Tillite material is likely to be closer to potentially acid forming than non-acid forming, due to this material containing a considerable amount of Sulphide content.
- The results from total metal concentration analysis of the solids indicate that the Lower Tillite materials can have elevated:
    - Silver (1 sample);
- The results from total metal concentration analysis of the solids indicate that the Upper Siltstone materials can have elevated:
    - Arsenic (1 sample);
- The results from total metal concentration analysis of the solids indicate that all materials (except Lower Tillite) can have elevated:
    - Selenium (14/19 samples);
- The results from total metal concentration analysis of the leachates indicate that Aluminium (19/19 samples), Zinc (2/19 samples), Selenium (1/19 samples) and Molybdenum (9/19) are slightly mobilised in leachate but that concentrations of these metals/metalloids are likely to remain below recommended thresholds;
- A subset of fourteen waste samples were assessed for fibrous content. No fibrous materials were detected in the waste samples tested.
- All waste samples were assessed for naturally occurring radioactive material (NORM). None of the samples were found to give rise to enhanced exposures of NORM.
- A subset of eleven waste samples were assessed for structural stability. The assessment showed that all materials except the Tertiary Cover, are prone to structural decline based on elevated values of exchangeable sodium and effective cation exchange capacity. Further assessment of particle size distribution indicated that Saprolite, Saprock, Upper and Lower Siltstone and Lower and Upper Mudstone have greatest risk of structural decline, given these materials are prone to particle breakdown

1 INTRODUCTION

1.1 Overview

Landloch has been engaged by Newcrest to undertake a baseline waste characterisation study of the proposed Havieron Project.

The baseline waste characterisation will be used as part of the approval process, as well as in preparing the mine closure plan in accordance with the Department of Mines, Industry Regulation and Safety (DMIRS) *Statutory Guidelines for Mine Closure Plans* (DMIRS 2020a). The statutory guideline states that: *Comprehensive characterisation of materials (including soils and wastes) is critical to effective closure planning and successful progressive rehabilitation. This process should start during the exploration phase and continue throughout the life of the mine. Characterisation of material allows for separation and selective placement of materials considered beneficial to rehabilitation and materials that may inhibit rehabilitation.*

DMIRS provides additional information relating to materials characterisation in the *Draft Guidance for Materials Characterisation Baseline Data Requirements for Mining Proposals* (DMP 2016a). Broadly, characterisation of wastes should be undertaken to evaluate the physical stability and potential plant growth potential of wastes, and to identify risks associated with dispersive, asbestiform, or radioactive materials, and materials that may produce acidic, metalliferous, or saline drainage.

Additionally, the baseline characterisation has been undertaken consistent with Newcrest's *EN ST01 Acid and Metalliferous Drainage Management Standard.* This document outlines the requirement for baseline characterisation and sampling of wastes to be undertaken, in order to identify the geological setting and the potential for acid and metalliferous drainage.

1.2 Background

The Project area is located approximately 400km south east of Port Hedland within the Pilbara region of Western Australia (Figure 1). The Project area is defined within exploration tenement E45/4701. During mining, extraction of material is proposed to first be undertaken from within the Boxcut Area and then later, from the decline (Figure 2). Approximately 259,945m^3 of waste is proposed to be extracted during this process. Table 1 outlines the volumes (m^3) and tonnes (t) of waste estimated to be extracted from each lithology.

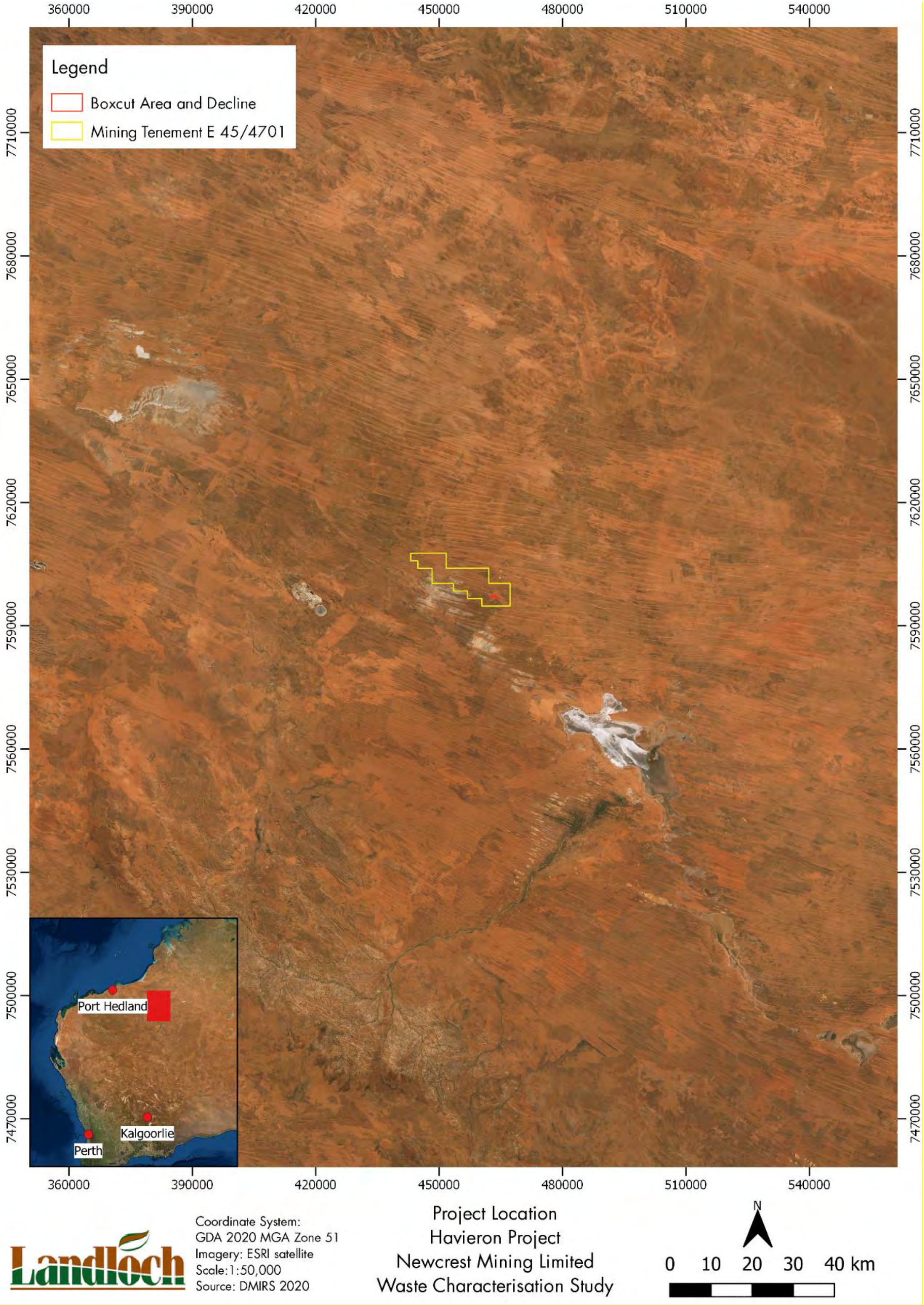


Figure 1: Project location

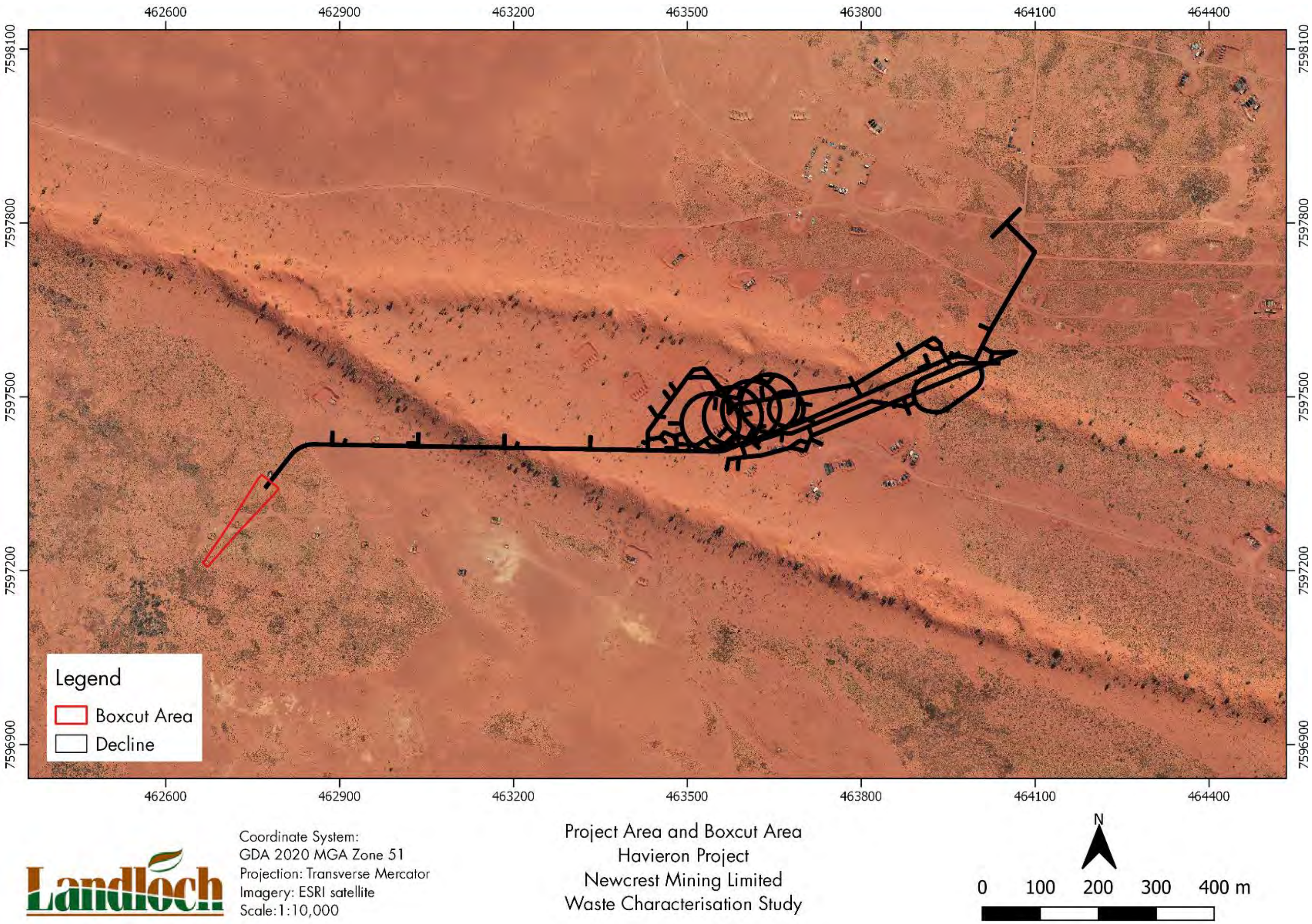


Figure 2: Boxcut Area and Decline

Table 1: Estimated volumes and tonnes of waste expected to be mined as part of Project

Project Stage	Lithology	Volume (m^3)	Mass (tonne)
Boxcut	Tertiary Cover	6,626	11,927
	Saprolite	37,815	75,631
	Saprock	18,371	36,741
Boxcut total volume		**62,812**	**124,299**
Decline	Tertiary Cover	533	959
	Saprolite	1,460	2,920
	Saprock	10,232	20,464
	Upper Mudstone	11,403	22,806
	Upper Tillite	37,811	79,403
	Upper and Lower Siltstone	47,005	103,411
	Lower Sandstone	13,248	29,146
	Lower Tillite	75,441	165,970
Decline total volume		**197,133**	**425,079**

1.3 Scope of works

In order to complete the waste characterisation, the following tasks were completed:

1. Information review and development of waste sampling methodology;
2. Waste characterisation; and
3. Reporting.

1.3.1 Information review and development of waste sampling methodology

An initial review of the drilling database was completed in consultation with Newcrest geologists to:

- Define the lithological units to be disturbed by mining, and
- Interrogate the drilling database to select waste samples that:
  - Are representative of the wastes to be disturbed; and
  - Include materials with a range of oxidation states (fresh, transitional, and oxidised).

1.3.2 Waste characterisation and reporting

Samples were supplied to Landloch for assessment and tested for:

- pH;
- Electrical Conductivity;
- Total S;
  Sulphide S.;
- Net Acid Generation (NAG);
- NAG pH;
- Maximum Potential Acidity;
- Acid Neutralising Capacity (ANC); and

- Net Acid Producing Potential (NAPP).

A subset of samples was tested for total metals (60 elements by ICP[1]). These samples were also flushed with water to assess quantities of metal leachate[2].

Depending on lithology and the level of weathering, materials that are potentially prone to structural instability were further assessed for:

- Particle size distribution;
- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+});
- Effective Cation Exchange Capacity; and
- Exchangeable Sodium Percentage.

Materials that were observed to have a coarse fraction were assessed for rock durability as a means of assessing the potential for these materials to be used as rock armour. Tests included:

- Rock water absorption;
- Rock particle density; and
- Schmidt hardness value.

A subset of samples were also tested for asbestiform materials via optical microscopy.

Naturally Occurring Radioactive Materials (NORMs) were also assessed using both a Geiger Muller and scintillator probe. The Geiger Muller probe, although capable of detecting gamma radiation, is particularly sensitive to the surface measurement of alpha and beta radiation. The scintillation probe utilises an inorganic scintillator crystal which is very sensitive to the detection of gamma radiation. In both cases, background NORM's was removed from the measurements.

The characterisation work is reported in this document.

---

[1] Solid metals included Ag, Al, As, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Eu, Er, Fe, Ga, Gd, Ge, Hf, Ho, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pr, Rb, Re, S, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr.

[2] Leachate metals included: Al, As, Ba, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, U, Zn.

2 ENVIRONMENTAL SETTING

2.1 Climate

2.1.1 Rainfall

The climate of the Project area is described as semi-arid with hot dry summers and mild winters (van Vreeswyk *et al.* 2004). Rainfall and temperature patterns were sourced from the nearest available weather station (Telfer Aero), located approximately 45 km to the west of the Project area. The mean annual rainfall is low and rainfall in August to November tends to be lower than for the remainder of the year (Table 2). Mean monthly pan evaporation is invariably higher than mean monthly rainfall, indicating that water is limited and landform surfaces are likely to be dry for much of the time. This further indicates that the movement of water to depth and its interaction with underlying wastes when they are placed within waste landforms may be limited.

Table 2: Mean monthly rainfall, pan evaporation, and daily maximum temperature for Telfer Aero weather station (013030) (BoM 2020).

Month	Mean Monthly Rainfall (mm)	Mean Monthly Pan Evaporation (mm)	Mean Daily Maximum Temperature (°C)
January	63.2	443.3	40.3
February	96.8	361.2	38.8
March	69.4	381.3	37.6
April	18.1	321.0	34.7
May	19.0	241.8	29.1
June	12.4	192.0	25.4
July	11.5	213.9	25.5
August	4.6	260.4	28.4
September	2.1	336.0	32.9
October	3.0	440.2	37.4
November	15.0	465.0	39.5
December	47.1	468.1	40.4
	364 (MEAN ANNUAL)	**4,124** (MEAN ANNUAL)	**34.2** (MEAN DAILY)

2.1.2 Rainfall erosivity

The erosive force of rain is expressed by rainfall erosivity. Historical rainfall erosivity mapping shows annual erosivity values for the Havieron area of 1,500MJ.mm/(ha.hr.yr) (Figure 3) (Rosewell 1993). By way of contrast, Port Hedland (Pilbara coast) has ~14% less annual rain than Havieron, but that lower total rainfall has 33% greater rainfall erosivity. Another arid mining area, Newman, has 13% less rainfall than Havieron and 40% less erosivity. Therefore, the Havieron climate could be considered more erosive than Newman. As a point of interest, Perth receives 100% more rain annually than Havieron and has 33% less erosivity, due to the less intense types of rainfall experienced in Perth. In terms of landform erosional stability, it can be expected that Havieron is located in a climate that makes erosion by water likely. This is particularly true on steep waste landform batter slopes, and even more important if slope lengths are long and are constructed from fine-grained and low cohesion soils or wastes.

Figure 3: Annual rainfall erosivity for Western Australia.

2.1.3 Large rainfall events

Although it is true that tropical cyclones and lows tend to weaken as they move inland, stronger systems are capable of producing intense rainfall events inland within the Pilbara region. The total rainfall that is produced is related to the weather system's path and speed. Rainfall totals in excess of 100mm are common with tropical lows that move over land. In February 1997 a slow moving low moved over the west Kimberley, Pilbara and Gascoyne causing rainfall in excess of 400mm in parts and one of the highest ever floods along the Ashburton River. A review of monthly rainfall for the Telfer Aero climate station during the period 2000-2019 found that many of the large rainfall months are associated with cyclones or tropical lows tracked by the Bureau of Meteorology (Figure 4).

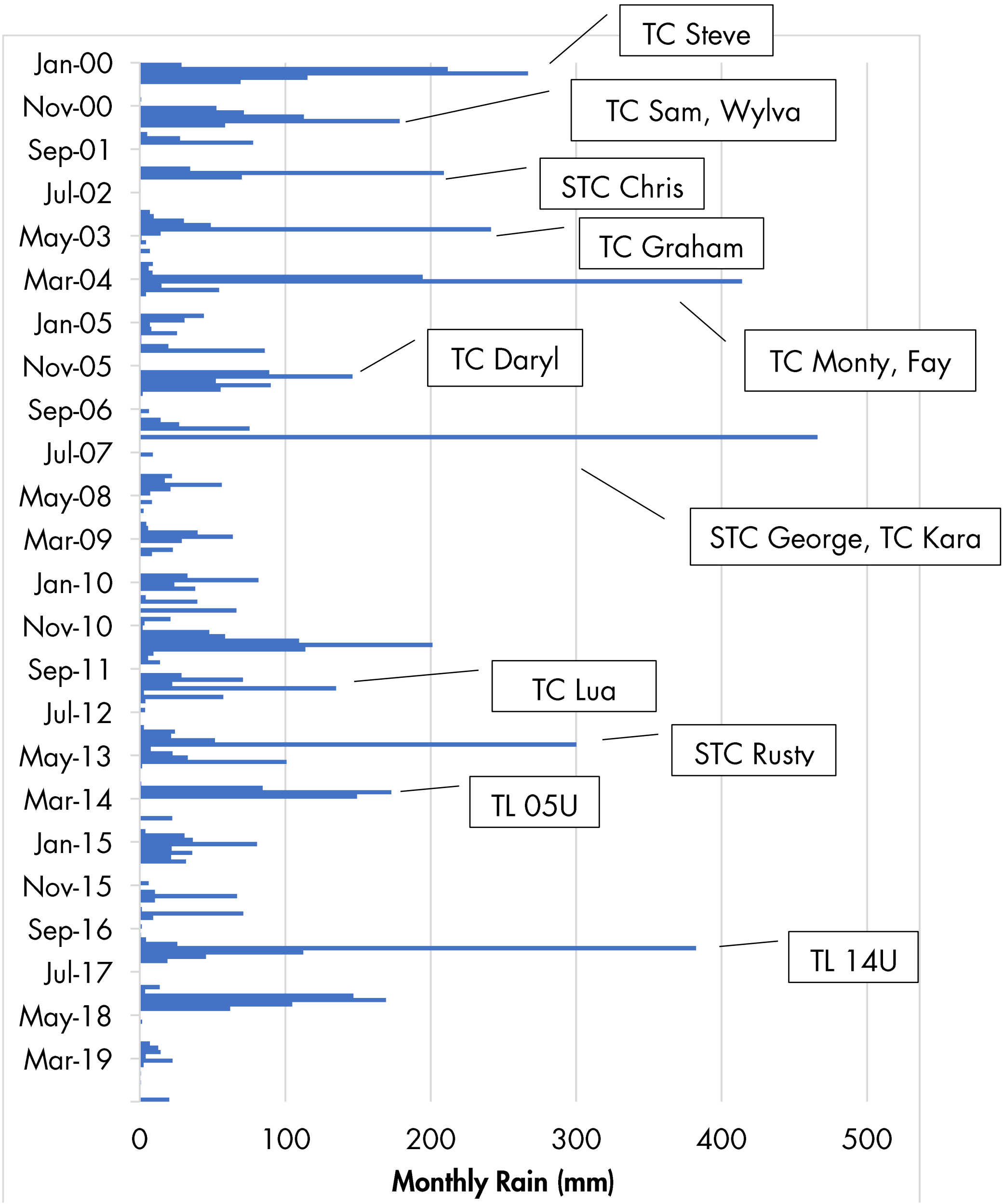


Figure 4: Monthly rainfall recorded at the Bureau of Meteorology's Telfer Aero weather station between January 2000 and December 2019.

It is also worth noting that months with rainfall totals greater than 100mm occurred 25 times in the last 20 years and daily rainfall amounts greater than 100mm occurred 5 times in the last 20 years. The last 2 years (since 2018) have been relatively quiet in terms of large rainfall events, with only 1 day recording rainfall total greater than 50mm (66.2mm). The annual rainfall in 2018 and 2019 was 169mm and 120mm, respectively. Notwithstanding any impacts of climate change, it is important to note that

Havieron has received below average rainfall in recent times and fewer than normal large rainfall events.

2.1.4 Wind

Wind is of potential importance at Havieron because of the presence of aeolian sand dunes that are essentially windblown deposits. Particle size data for the Deep Sands at Havieron indicate these soils generally contain ~10% clay, ~2% silt and ~40% fine sand with ~48% coarse sand. The Gradational Sands exhibit a similar particle size in the top 800mm, with an increase in at depth. The Gradational Loams contain up to 20% clay throughout the profile. This indicates that the Deep Sands and Gradational Sands may be prone to wind erosion.

The risk of wind erosion is also related to the direction of the prevailing winds and the typical wind speeds. Wind data for Telfer provides the observed range of wind speeds and directions. This data is given in Figure 5.

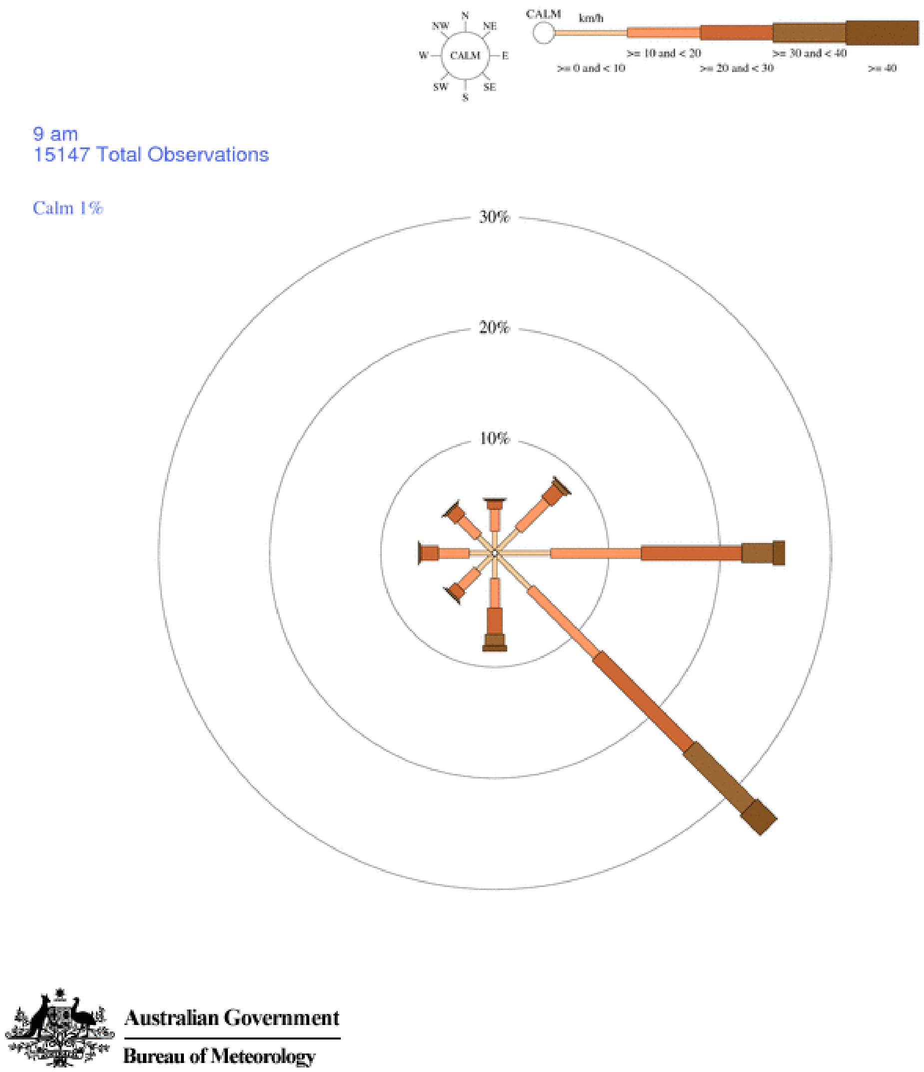


Figure 5: Wind rose data for Telfer from 1974 to 2016.

Winds at Telfer (assumed similar to Havieron) predominantly blow from the south east and east, and to a lesser degree from the east. This generally aligns with the orientation of the linear dunes, and from that it is inferred that the wind direction has a controlling influence on the orientation of the dunes. From the Telfer wind rose data, ~15% of the wind data is associated with winds >30km/h blowing from the south east or east. Winds greater than ~30km/h are typically required to move soil particles and lift dust over significant distances. Winds with speeds as low as 2km/h can cause localised erosion of unvegetated sandy surfaces. Therefore, it is concluded that the winds at Havieron occur at speeds that could potentially cause erosion of the surface sands.

2.2 Geological setting

2.2.1 Regional geology

The Project area is located in the Paterson and Quaternary Formations (Figure 6). The surface geology of the Paterson formation is dominated by mudstone, sandstone, and siltstone deposited by glaciation (DMIRS 2020b, DMP 2016b) and underlain by the Paleoproterozoic to Mesoproterozoic Rudall Complex, the Neoproterozoic Officer and Yeneena Basins, and the Phanerozoic Canning and Gunbarrel Basins (Rockwater 2020a). The surface geology of the Quaternary Formation is dominated by aeolian sand dunes and underlain by the fluvioglacial Permian Sediments of the Kidson Sub-basin of the Canning Basin. The Canning Basin sediments unconformably overlie the Neoproterozoic Yeneena Basin. The geological sequence of the Project area has been summarised by Rockwater (2020a) and included in Table 3.

Table 3: Geological Sequence (Rockwater 2020a)

Age	Geological Formation	Unit)	Thickness (m)	Depth to base of formation (m bgl)
Quaternary	Superficial	Aeolian deposits	49	49
Quaternary/Permian Unconformity				
Permian Paterson Formation	Package 3	Upper Sandstone	42	91
		Upper Conglomerate	49	140
		Upper Sandstone	70	210
	Package 2	Middle Siltstone	65	275
		Middle Sandstone	30	305
	Package 1	Lower Siltstone	57	362
		Lower Sandstone		474
		Lower Conglomerate		483
Unconformity				
Proterozoic Yeneena Basin	Undifferentiated	Undifferentiated	>517	>1000

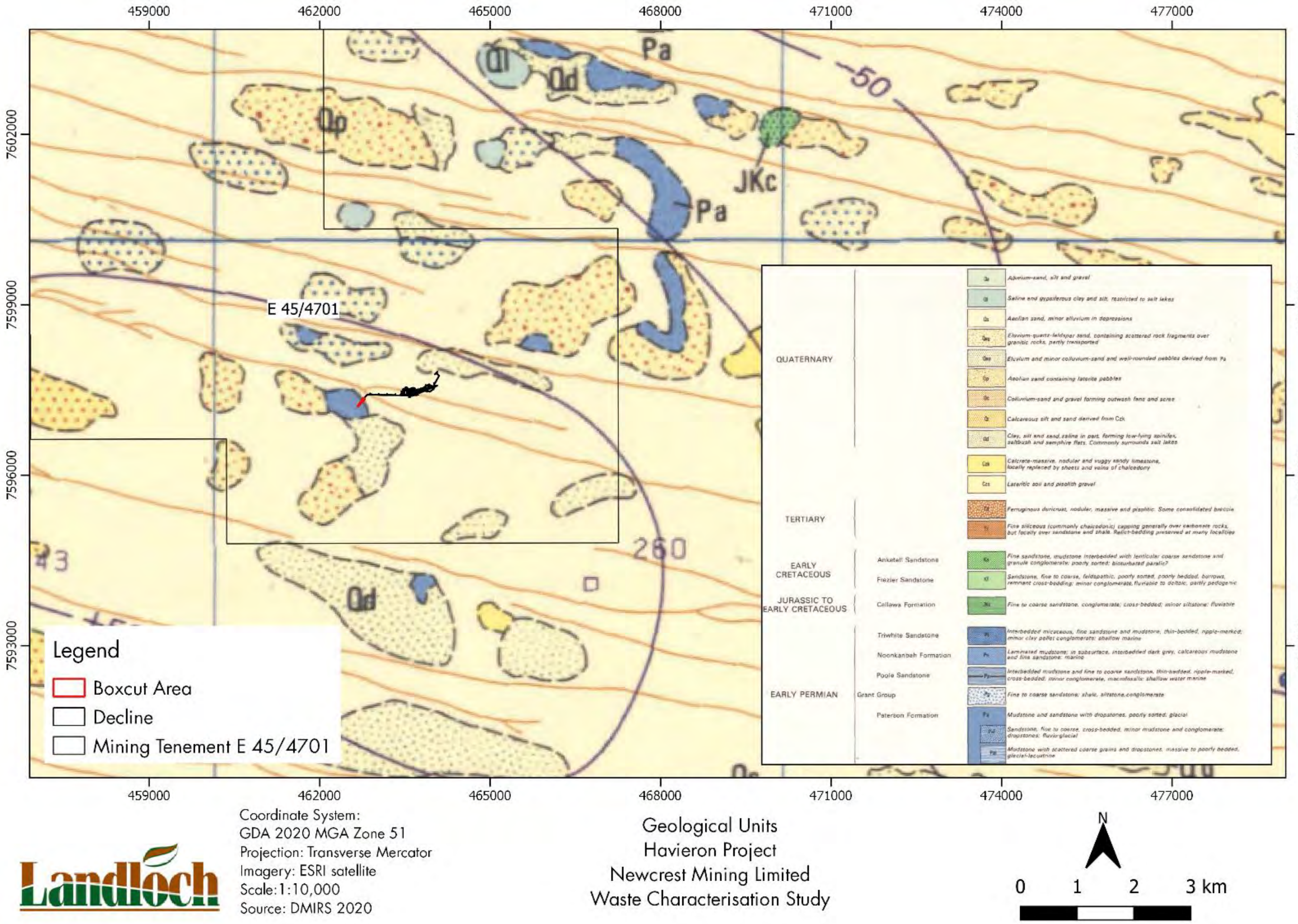


Figure 6: Regional geological setting of the Project

Newcrest has identified several major lithologies to be impacted by mining:

- Tertiary Cover;
- Saprolite;
- Saprock;
- Mudstone (upper);
- Tillite (upper and lower);
- Siltstone (upper and lower); and
- Sandstone (lower).

The majority of wastes will be disturbed and excavated during mining of these lithologies.

2.2.2 Weathering

Weathering profiles were established using Newcrest's drill hole database. The Boxcut Area consists of surface layers that have undergone soil forming processes (tertiary cover), and the saprolith positioned below the pedolith that has properties similar to those of the underlying parent material (fresh rock). There are two major horizons in the saprolith, Saprolite and Saprock (Completely Weathered/Oxidised). The base of complete oxidation (BOCO) tends to be approximately 10-50m below the surface, and the top of the fresh rock (TOFR) approximately 25-100m below the surface. Importantly, mining of the Boxcut Area is planned to mine oxidised waste material and mining within the decline in expected to extract fresh material.

3 METHODOLOGY

3.1 Sampling

Sample selection was undertaken by Landloch in consultation with Newcrest. Samples were sourced from diamond core available from drilling campaigns completed in 2019 and 2020. A total of 36 samples were assessed. The number of samples assessed was based on guidance given in the *Draft Guidance: Materials characterisation baseline data requirements for mining proposals* (DMP 2016a). Based on a total of ~900,000 tonnes of waste, a minimum number of samples ranging from 8-26 is suggested. A higher number of samples was selected in order to ensure that sampling of all of the waste lithologies to be disturbed was achieved.

Details of the samples provided are given in Table 4. The drill holes and the locations from which the samples were taken are shown in the 2D and 3D cross sections provided in Figure 7 and Figure 8. This cross section shows that all drill holes were in the vicinity of the Boxcut Area and the decline. This was done so that the samples collected are as representative of the wastes to be extracted going forward.

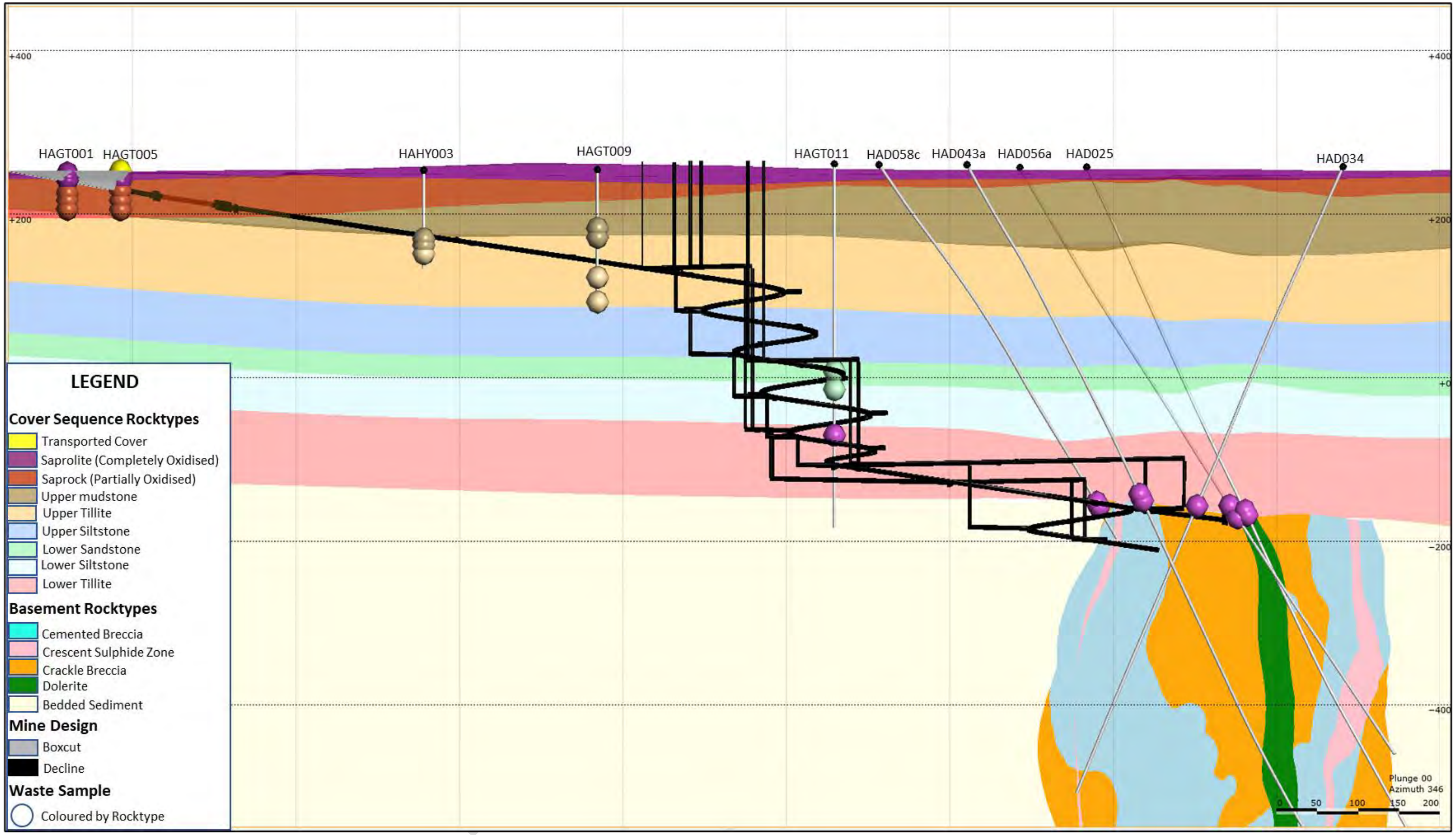


Figure 7: 2D schematic cross section of Boxcut Area and decline showing the intersection of different lithologies

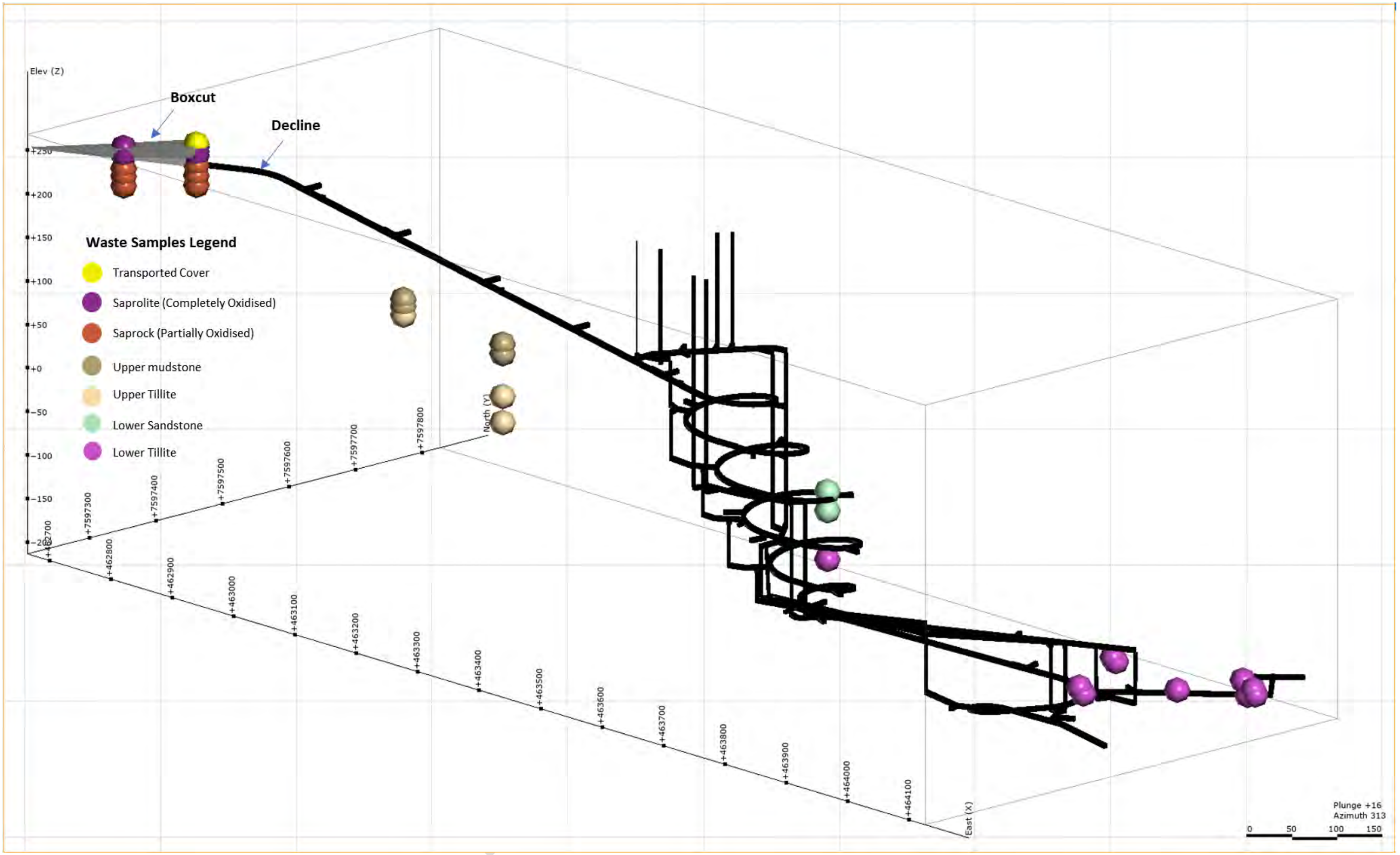


Figure 8: 3D schematic cross section of Boxcut Area and decline showing intersection of different lithologies

Table 4: Description of Havieron waste samples grouped by lithology

Sample Number	Sequence #	Lithology	Weathering	Location	Drill Hole ID	Depth (m)		Sample Point Co-ordinate	
						To	From	MGA_E (m)	MGA_N (m)
HW02	2	Tertiary Cover	Completely Weathered/Oxidised	Boxcut	HAGT005	0	0.5	462780.2	7597353.6
HW05	5	Saprolite	Completely Weathered/Oxidised	Boxcut	HAGT001	2.5	3	462729.0	7597291.6
HW06	6	Saprolite	Completely Weathered/Oxidised	Boxcut	HAGT001	7.5	8	462729.0	7597291.6
HW07	7	Saprolite	Completely Weathered/Oxidised	Boxcut	HAGT001	11.5	12	462729.0	7597291.6
HW08	8	Saprolite	Completely Weathered/Oxidised	Boxcut	HAGT005	3.5	4	462780.2	7597353.6
HW09	9	Saprolite	Completely Weathered/Oxidised	Boxcut	HAGT005	8.5	9	462780.2	7597353.6
HW10	10	Saprolite	Completely Weathered/Oxidised	Boxcut	HAGT005	13.5	14	462780.2	7597353.6
HW15	15	Saprock	Partially Weathered/Oxidised	Boxcut	HAGT001	26.5	27	462729.0	7597291.6
HW16	16	Saprock	Partially Weathered/Oxidised	Boxcut	HAGT001	35.5	36	462729.0	7597291.6
HW17	17	Saprock	Partially Weathered/Oxidised	Boxcut	HAGT001	46.5	47	462729.0	7597291.6
HW18	18	Saprock	Partially Weathered/Oxidised	Boxcut	HAGT005	24.5	25	462780.2	7597353.6
HW19	19	Saprock	Partially Weathered/Oxidised	Boxcut	HAGT005	36.5	37	462780.2	7597353.6
HW20	20	Saprock	Partially Weathered/Oxidised	Boxcut	HAGT005	47.5	48	462780.2	7597353.6
HW23	23	Upper Mudstone	Fresh rock	Decline	HAHY003	83.5	84	463177.4	7597298.0
HW24	24	Upper Mudstone	Fresh rock	Decline	HAHY003	91.5	92	463177.4	7597298.0

Sample Number	Sequence #	Lithology	Weathering	Location	Drill Hole ID	Depth (m)		Sample Point Co-ordinate	
						To	From	MGA_E (m)	MGA_N (m)
HW25	25	Upper Mudstone	Fresh rock	Decline	HAGT009	71.5	72	463414.5	7597228.2
HW26	26	Upper Mudstone	Fresh rock	Decline	HAGT009	82.5	83	463414.5	7597228.2
HW27	27	Upper Tillite	Fresh rock	Decline	HAHY003	101.5	102	463177.4	7597298.0
HW29	29	Upper Tillite	Fresh rock	Decline	HAGT009	131.5	132	463414.5	7597228.2
HW30	30	Upper Tillite	Fresh rock	Decline	HAGT009	161.5	162	463414.5	7597228.2
HW31	31	Upper Siltstone	Fresh rock	Decline	HAGT011	181.5	182	463643.4	7597505.3
HW32	32	Upper Siltstone	Fresh rock	Decline	HAGT011	241.5	242	463643.4	7597505.3
HW33	33	Lower Siltstone	Fresh rock	Decline	HAGT011	281.5	282	463643.4	7597505.3
HW34	34	Lower Siltstone	Fresh rock	Decline	HAGT011	301.5	302	463643.4	7597505.3
HW39	39	Lower Sandstone	Fresh rock	Decline	HAGT011	253.5	254	463643.4	7597505.3
HW40	40	Lower Sandstone	Fresh rock	Decline	HAGT011	275.5	276	463643.4	7597505.3
HW43	43	Lower Tillite	Fresh rock	Decline	HAGT011	331.5	332	463643.4	7597505.3
HW47	47	Lower Tillite	Fresh rock	Decline	HAD043a	470	471	463850.0	7597370.0
HW48	48	Lower Tillite	Fresh rock	Decline	HAD043a	479	480	463850.0	7597370.0
HW49	49	Lower Tillite	Fresh rock	Decline	HAD034	453	454	463845.7	7597367.9
HW51	51	Lower Tillite	Fresh rock	Decline	HAD056a	509	510	463800.0	7597800.0
HW52	52	Lower Tillite	Fresh rock	Decline	HAD056a	527	528	463800.0	7597800.0
HW53	53	Lower Tillite	Fresh rock	Decline	HAD025	464.5	465	463909.7	7597711.3
HW54	54	Lower Tillite	Fresh rock	Decline	HAD025	470.5	471	463909.7	7597711.3
HW57	57	Lower Tillite	Fresh rock	Decline	HAD058c	520	520.5	463719.2	7597439.4
HW58	58	Lower Tillite	Fresh rock	Decline	HAD058c	526	526.5	463719.2	7597439.4

3.2 Test work program

3.2.1 *Sample numbers*

A total of 36 waste samples were assessed. A summary of the samples tested grouped by weathering and lithology is given in Table 5. More than 28% of samples are representative of Lower Tillite. The remainder are representative of Saprock (17%), Saprolite (17%), Upper Mudstone (11%), Upper and Lower Siltstone (11%), Upper Tillite (8%), Lower Sandstone (6%), and Tertiary Cover (3%). Of the total number of samples analysed, 38% were oxides and 61% were fresh. The distribution of the samples within the lithologies and oxidation states was primarily based on the relative abundance of each of these materials within the Boxcut Area and the decline. For example, the Lower Tillite represents 29% of the waste mass and 28% of the samples and Saprolite represents 15% of the waste mass and 17% of the samples. The numbers of samples was also influenced by the availability of material. The Tertiary Cover material was not routinely recovered as part of drilling and only 1 sample was available.

Table 5: Number of samples from the different lithology and weathering states.

Lithology	Weathering State		% of Total
	Oxide	Fresh	
Lower Tillite		10	28
Tertiary Cover	1		3
Saprock	6		17
Upper Mudstone	1	3	11
Upper Tillite		3	8
Upper and Lower Siltstone		4	11
Lower Sandstone		2	6
Saprolite	6		17
% of Total	39	61	

3.2.2 *Testing performed*

All 36 samples were initially tested for the following:

- $pH_{1:5}$ (water);
- Electrical Conductivity ($EC_{1:5}$);
- Total S;
- Sulphide S.;
- Net Acid Generation (NAG);
- NAG pH;
- Maximum Potential Acidity;
- Acid Neutralising Capacity (ANC); and
- Net Acid Producing Potential (NAPP).

A subset of samples was tested for total metals (60 elements by ICP[3]). These samples were also flushed with water and the metals concentrations within the leachate assessed to consider seepage water quality[4].

Based on lithology and the level of weathering, a total of 11 samples that were potentially prone to structural instability were further assessed for:

- Particle size distribution;
- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+});
- Effective Cation Exchange Capacity; and
- Exchangeable Sodium Percentage.

Materials that were observed to have a coarse fraction were assessed for rock durability as a means of assessing the potential for these materials to be used as rock armour. Tests included:

- Rock water absorption;
- Rock particle density; and
- Schmidt hardness value.

A subset of samples were also tested for asbestiform materials via optical microscopy. The samples selected were those that contained exposed fresh faces on the core that allowed for ready detection using optical microscopy.

Naturally Occurring Radioactive Materials (NORMs) were also assessed using both a Geiger Muller and scintillator probe. The Geiger Muller probe, although capable of detecting gamma radiation, is particularly sensitive to the surface measurement of alpha and beta radiation. The scintillation probe utilises an inorganic scintillator crystal which is very sensitive to the detection of gamma radiation. In both cases, background NORMs was removed from the measurements. All samples were assessed for NORMs.

4 RESULTS

4.1 Acid generation potential

4.1.1 Total S and Sulphide S

Total S is a commonly used measure of the presence of acid producing materials. Typically, values greater than 0.1-0.3% Total S indicate material with sufficient Sulphur for there to be a risk of acid generation. For this project, a Total S values of 0.15% was used to indicate elevated Total S values. Total S values below 0.15% indicate a material that is considered benign in terms of acid producing potential.

---

[3] Solid metals included Ag, Al, As, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Eu, Er, Fe, Ga, Gd, Ge, Hf, Ho, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pr, Rb, Re, S, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr.

[4] Leachate metals included: Al, As, Ba, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, U, Zn.

All 36 waste samples were tested for Total S concentrations (Appendix A). Ten of the 36 waste samples returned elevated Total S (>0.15%) (Table 6). These samples originated from Lower and Upper Tillite, Saprolite, Upper Mudstone, and Upper and Lower Siltstone.

The Sulphide contents in samples with elevated Total S (calculated as the difference between Total S and Sulphate S) ranged from 0% to 0.83%. For fresh materials samples, there is typically more Sulphide than there is Sulphate, indicating that these materials have not yet undergone oxidation. For most of the more weathered materials (HW05), there are higher concentrations of Sulphate, indicating that oxidation has largely already occurred.

Nine out of the ten samples containing elevated levels of Total S were found in the decline area (Table 6). This indicates that the material within the Boxcut Area poses a lower risk in terms of acid producing potential.

Table 6: Waste samples returning Total S >0.15%

Sample	Lithology	Location	Weathering	S (%)	S-S^{2-} (%)	S-SO_4^{2-} (%)
HW48	Lower Tillite	Decline	Fresh	0.17	0.12	0.05
HW49	Lower Tillite	Decline	Fresh	0.16	0.13	0.03
HW51	Lower Tillite	Decline	Fresh	0.38	0.32	0.06
HW52	Lower Tillite	Decline	Fresh	0.34	0.09	0.25
HW58	Lower Tillite	Decline	Fresh	0.3	0.12	0.18
HW05	Saprolite	Boxcut	Completely Weathered/ Oxidised	0.31	0.00	0.31
HW26	Upper Mudstone	Decline	Fresh	0.2	0.18	0.02
HW30	Upper Tillite	Decline	Fresh	0.41	0.35	0.06
HW31	Upper Siltstone	Decline	Fresh	0.89	0.83	0.06
HW33	Lower Siltstone	Decline	Fresh	0.19	0.16	0.03

4.1.2 Acid-base account

The acid-base account involves static laboratory testing to evaluate the balance between acid generation processes and acid neutralising processes.

The acid generating potential is determined by assessing the Maximum Potential Acidity (MPA). The MPA is calculated using the formula: MPA = Total S (%) x 30.6. This offers a conservative estimate of acid generating potential because some of the Sulphur may not be in the form of pyrite. The acid neutralising capacity (ANC) is an indicator of the buffering capacity or acid consumption capacity of the material. The Net Acid Producing Potential (NAPP) is the difference between MPA and ANC. A negative NAPP indicates that the acid neutralising capacity exceeds the acid generating capacity. The ratio of ANC and MPA is often used to assess risk. ANC/MPA values greater than 3 indicate a negligible risk of acid generation, 2-3 indicates low risk, 1-2 a possible risk, and <1 an increased risk of acid generation.

The Net Acid Generation (NAG) test is used in conjunction with the NAPP to further classify acid generating potential. During the NAG test, acid generation and neutralising processes occur simultaneously. The final NAG pH is plotted against the NAPP, with NAG pH values >4.5 and negative NAPP values indicating NAF materials. Positive NAPP values and NAG pH values <4.5 indicate PAF materials. All other combinations are classed as uncertain as there is a conflict in the NAPP and NAG pH results. It is noted that the NAG test may not reliably reflect acid forming potential of sulphidic samples (>1% Total S) that also contain readily available neutralising materials. The classification scheme is summarised in Table 7. A material is classed as NAF or PAF based either on the combined NAPP and NAG test results or on the ANC/MPA ratio.

Table 7: Classification scheme

Classification	Total S (%)	NAPP (kgH_2SO_4/tonne)	Final NAG pH	ANC/MPA
NAF (Barren)	≤0.15	-	-	-
NAF	>0.15	<0	≥4.5	>2
PAF	>0.15	≥0	<4.5	<2
Uncertain	>0.15	≥0	>4.5	<2
	>0.15	<0	≤4.5	<2

4.1.2.1 NAPP and NAG results

For those samples with elevated Total S values (Table 6), the NAPP values for the Lower Tillite, Upper Mudstone, and Lower Siltstone samples are negative, indicating the there is greater neutralising capacity than there is acid generation capacity. NAPP values for the Upper Tillite, Saprolite and Upper Siltstone are close to zero or positive. When NAG pH is plotted against NAPP (Figure 9), the results indicate that the Upper Siltstone sample is potentially acid forming (PAF). The potential for Saprolite material and Upper Tillite to be acid forming is uncertain, most likely as due to these materials still having considerable acid neutralising capacity.

The Sulphide content in the Saprolite sample is close to zero, indicating that almost all sulphur has been oxidised in this material. In consideration of this, the Saprolite material is most likely to be non-acid forming rather than acid forming. A high proportion of Sulphide content was shown to remain in the Upper Tillite sample, indicating that this material is most likely to be acid forming rather than non-acid forming.

4.1.2.2 MPA and ANC results

For the samples with elevated Total S, Figure 10 shows the ANC plotted against the MPA. Materials with low Total S values are excluded from this figure. Those samples with an ANC:MPA ratio greater than 2 are considered to have low risk of acid generation. ANC:MPA ratio for the waste samples ranges from -0.6-14.4.

Samples from the Saprolite, Upper Tillite and Upper Siltstone recorded ANC:MPA ratio <2. In these materials there is considerably less neutralising capacity in the samples tested than there is potential to generate acid. All remaining materials generally recorded ANC:MPA ratios >2. This indicates that there is low to negligible risk of acid generation in these waste types. When coupled with a low NAG pH, the Upper Tillite and Upper Siltstone sample has been classed as PAF. For the Saprolite sample, almost all of the Sulphur is present as Sulphate and the NAG pH is >4.5. Therefore, although the class is uncertain, it is likely that the material is NAF.

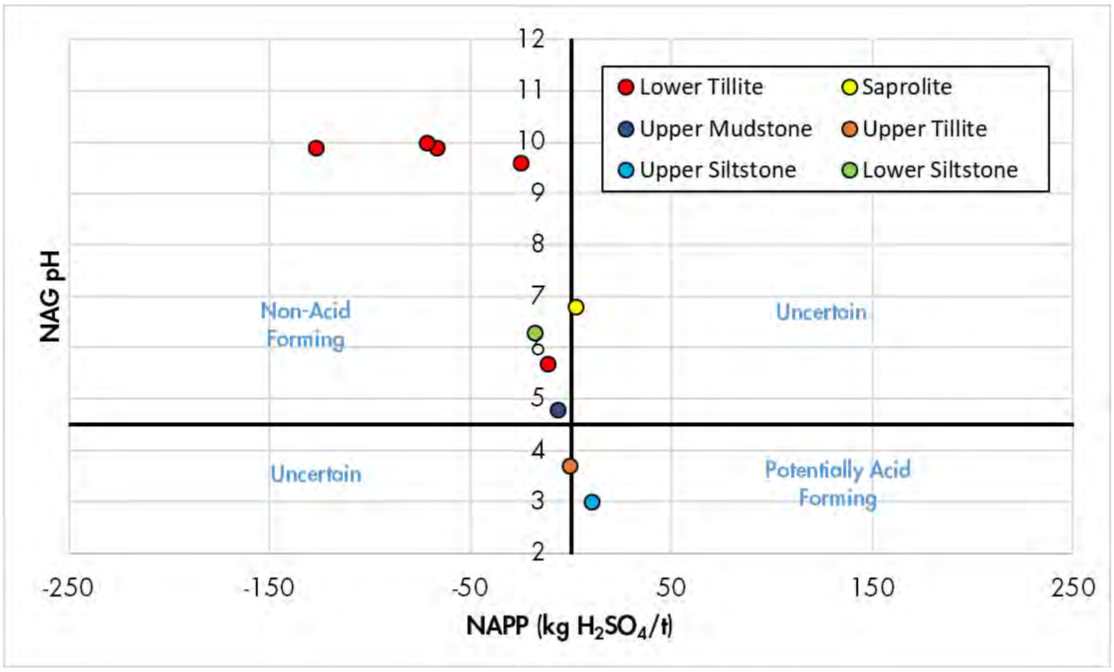


Figure 9: NAG pH versus NAPP for Havieron waste samples

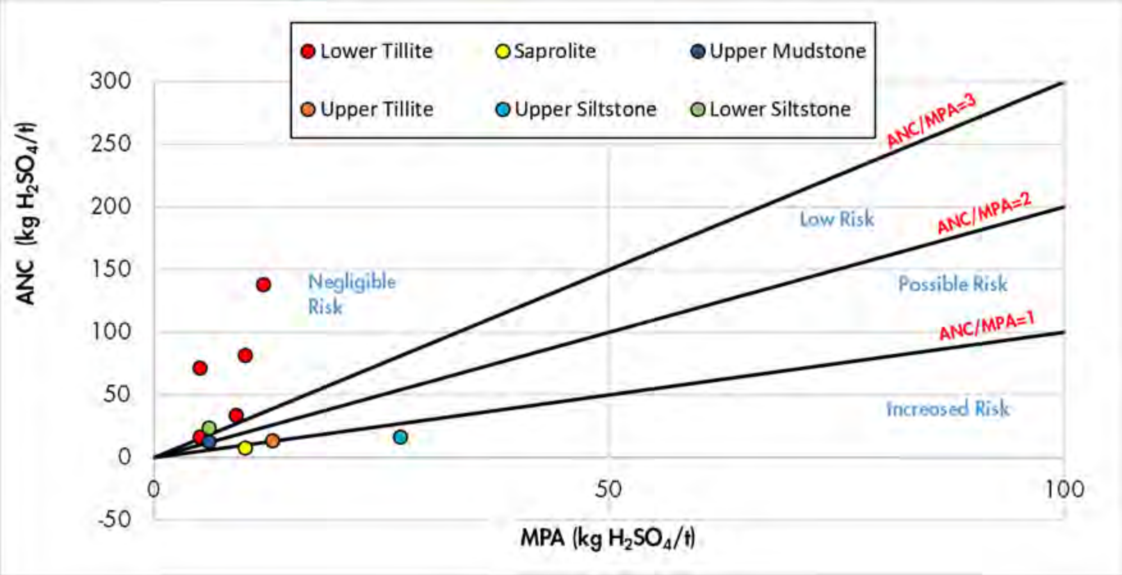


Figure 10: ANC and MPA values for Havieron waste samples

4.1.2.3 *Summary of results*

Full results of the acid-base account are provided in Table 8.

Considered as a whole, 94% of the Boxcut Area and decline samples were classed as NAF, and 6% were classed as PAF. Therefore, the risk of PAF materials from both the areas combined can be considered low.

Within the Boxcut Area materials, all but one sample are classed as NAF. Sample HW05 is classed as uncertain based on its elevated Total S content, low ANC/MPA ratio, but high NAG pH. The Sulphide content of this sample (i.e. sulphur available to be oxidised) is very low and Sulphate dominates this material. Considering this, although the material's class is uncertain, it is likely that the material is NAF. Therefore, it is concluded that the risk of acid generation from the Boxcut Area materials is low.

Of the 23 samples taken from the decline area, two samples are classed as PAF, a sample of Upper Tillite and a sample of Lower Siltstone. Looking broadly at the materials:

- 1 of 3 Upper Tillite samples were classed as PAF and the remaining 2 were classed as NAF (barren);
- 10 of 10 Lower Tillite samples were classed as NAF (barren) or NAF;
- 4 of 4 Upper Mudstone samples were classed as NAF (barren) or NAF;
- 1 of 2 Upper Siltstone samples were classed as PAF and the remaining 1 was classed as NAF (barren);
- 2 of 2 Lower Siltstone samples were classed as NAF (barren) or NAF; and
- 2 of 2 Lower Sandstone samples were classed as NAF (barren) or NAF.

Table 8: Acid base account results for all Havieron waste samples

Sample	Lithology	$EC_{1:5}$	$pH_{1:5}$ (water)	Total S	$S\text{-}SO_4^{2-}$	ANC	MPA	NAPP	NAG	NAG pH	Classification
		dS/m	-	%	%	kgH_2SO_4/t	kgH_2SO_4/t	kgH_2SO_4/t	kgH_2SO_4/t	-	
Boxcut Area Materials											
HW02	Tertiary Cover	0.623	6.4	<0.01	0.02	4	<1	-4	0	6.7	NAF (barren)
HW05	Saprolite	4.840	7.5	0.31	0.32	8	10	2	0	6.8	Uncertain
HW06	Saprolite	2.093	7.3	0.04	0.05	10	1	-9	2	6.5	NAF (barren)
HW07	Saprolite	1.220	7.1	0.02	0.03	15	<1	-14	0	6.8	NAF (barren)
HW08	Saprolite	1.363	8.8	0.04	0.05	13	1	-12	0	7.6	NAF (barren)
HW09	Saprolite	2.640	7.3	0.06	0.07	24	2	-22	1	6.6	NAF (barren)
HW10	Saprolite	1.922	7.3	0.05	0.04	27	2	-25	0	6.9	NAF (barren)
HW15	Saprock	0.295	7.5	<0.01	0.02	5	<1	-5	0	8.1	NAF (barren)
HW16	Saprock	0.262	7.4	0.02	0.02	6	<1	-5	2	6.4	NAF (barren)
HW17	Saprock	0.139	7.6	<0.01	<0.01	10	<1	-10	3	6.4	NAF (barren)
HW18	Saprock	0.504	7.1	0.08	0.08	3	2	-1	2	6	NAF (barren)
HW19	Saprock	0.418	7.2	<0.01	0.01	10	<1	-10	2	6.4	NAF (barren)
HW20	Saprock	0.557	6.9	0.04	0.05	4	1	-3	1	6.6	NAF (barren)
Decline Materials											
HW29	Upper Tillite	1.085	8.7	0.07	0.03	13	2	-11	0	6.7	NAF (barren)
HW30	Upper Tillite	1.097	7.2	0.41	0.06	14	13	-1	4	3.7	PAF
HW27	Upper Tillite	0.899	9.2	0.07	0.03	44	2	-42	0	9.0	NAF (barren)
HW53	Lower Tillite	0.741	9.6	0.1	0.02	135	3	-132	0	10.8	NAF (barren)
HW54	Lower Tillite	1.118	9.5	0.05	0.03	48	1	-47	0	10	NAF (barren)
HW47	Lower Tillite	1.048	8.1	0.06	0.03	11	2	-9	0	6.9	NAF (barren)
HW48	Lower Tillite	1.617	8.2	0.17	0.05	17	5	-12	1	5.7	NAF
HW49	Lower Tillite	1.356	9.3	0.16	0.03	72	5	-67	0	9.9	NAF

Sample	Lithology	$EC_{1:5}$	$pH_{1:5}$ (water)	Total S	$S\text{-}SO_4^{2-}$	ANC	MPA	NAPP	NAG	NAG pH	Classification
		dS/m	-	%	%	kgH_2SO_4/t	kgH_2SO_4/t	kgH_2SO_4/t	kgH_2SO_4/t	-	
HW51	Lower Tillite	1.660	9.3	0.38	0.06	139	12	-127	0	9.9	NAF
HW52	Lower Tillite	2.800	8.5	0.34	0.25	82	10	-72	0	10	NAF
HW57	Lower Tillite	2.440	8.4	0.15	0.06	17	4	-13	0	6.5	NAF (barren)
HW58	Lower Tillite	2.108	8.1	0.3	0.18	34	9	-25	0	9.6	NAF
HW43	Lower Tillite	0.311	9.9	0.09	0.02	257	3	-254	0	9.6	NAF (barren)
HW25	Upper Mudstone	0.914	9.1	0.11	0.03	22	3	-19	0	6.9	NAF (barren)
HW26	Upper Mudstone	0.501	8.8	0.20	0.02	13	6	-7	1	4.8	NAF
HW23	Upper Mudstone	0.841	9.1	0.04	0.02	10	1	-9	1	6.6	NAF (barren)
HW24	Upper Mudstone	1.006	7.8	0.07	0.03	14	2	-12	1	6.7	NAF (barren)
HW31	Upper Siltstone	1.614	8.2	0.89	0.06	17	27	10	13	3.0	PAF
HW32	Upper Siltstone	1.244	8.0	0.06	0.02	16	2	-14	0	6.7	NAF (barren)
HW33	Lower Siltstone	1.880	9.1	0.19	0.03	24	6	-18	0	6.3	NAF
HW34	Lower Siltstone	1.338	8.1	0.03	0.02	22	<1	-21	0	7.1	NAF (barren)
HW39	Lower Sandstone	1.298	8.7	0.03	0.02	24	<1	-23	0	6.9	NAF (barren)
HW40	Lower Sandstone	2.650	9.4	0.08	0.02	13	3	-10	0	7.1	NAF (barren)

4.2 Total metals analysis

Of the 36 samples assessed, a total of 19 samples were assessed for total metals in both the solids and in a leachate formed by flushing the sample with deionised water. The samples tested are given in Table 9.

Table 9: Samples assessed for total metals concentrations

Sample	Lithology	Sample	Lithology
HW54	Lower Tillite	HW02	Tertiary Cover
HW48	Lower Tillite	HW26	Upper Mudstone
HW52	Lower Tillite	HW24	Upper Mudstone
HW57	Lower Tillite	HW30	Upper Tillite
HW05	Saprolite	HW27	Upper Tillite
HW06	Saprolite	HW31	Upper Siltstone
HW10	Saprolite	HW34	Lower Siltstone
HW15	Saprock	HW39	Lower Sandstone
HW19	Saprock	HW40	Lower Sandstone
HW20	Saprock		

4.2.1 Total metals analysis (solids)

The total element (metals) test work seeks to identify any elements that may be of environmental concern with respect to revegetation and surface water/groundwater quality. Median concentrations of elements found in Havieron waste materials are provided in Table 10. Full results of the analysis are provided in Appendix B.

The results presented here can be used to target further investigation if needed. It is understood that the potential final land use of the mine following closure is likely to be a return to vacant crown land and (where practicable) native habitat.

The results were compared against the Geochemical Abundance Index (GAI) (AusIMM 2011), National Environmental Protection Council (NEPC) background concentrations for Health Investigation Level (HIL (C)) and Ecological Investigation Level (EIL (C)) ranges for soils (NEPC 2010, 2011).

The GAI compares the actual concentration of an element in a sample with the median abundance for that element in the most relevant media (in this case ultramafic rock, shale and soil). The main purpose of the GAI is to provide an indication of any elemental enrichment that may be of environmental importance. The GAI for an element is calculated as follows:

$$GAI = log_2\left[\left(\frac{C}{1.5 * S}\right)\right]$$

where C is the concentration of the element in the sample and S is the median content for that element in the reference material. The GAI values are truncated to integer increments (0-6) where a GAI of 0 indicates the element is present at a concentration similar to, or less than, median abundance, and a GAI of 6 indicates approximately a 100-fold, or greater, enrichment above median abundance.

As a general guide, a GAI of 3 or above is considered significant and such an enrichment would warrant further testing. Median abundance values are available for all elements except Aluminium (AusIMM 2011). For Aluminium, sample concentrations were compared against the relative content of the element in the earth's crust as given by Hazelton and Murphy (2016).

With respect to the HIL and EIL ranges for soils, the lesser of the two concentrations was used to determine whether the measured value warranted further consideration. Where criteria are not given in this guideline, Landloch cannot comment on the suitability of the values measured, but the data are supplied for the sake of completeness.

The results from total metals (Table 10) indicate that all materials have metals concentrations below the EIL and HIL thresholds (where provided). Comparison against the GAI index indicated that wastes may have elevated concentrations of the following:

- Lower Tillite: Silver (Ag) (1 of 4 samples);
- Upper Siltstone: Arsenic (As) (1 of 1 sample);
- All samples except Lower Tillite: Selenium (Se) (18 of 19 samples)

Table 10: Median total metal concentrations with GAI Index, EIL and HIL exceedances shown in red

Element	Ag	Al	As	Ba	Be	Bi	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er	Eu	Ga	Gd	Ge
Median	0.14	54,628	4.7	531.3	2.3	0.16	0.05	63.52	7.4	70	4.59	9.8	3.72	2.17	1.1	13.05	4.47	1.2
GAI Index	0.42	-1.18	1.06	-0.50	-0.76	1.15	-1.72	-0.68	-2.02	-1.10	0.03	-2.94	-1.27	-1.39	-1.52	-1.05	-1.37	-1.17
EIL			100									130						
HIL			300				90		300	300		17,000						

Element	Hf	Ho	In	La	Li	Lu	Mn	Mo	Nb	Nd	Ni	Pb	Pr	Rb	Re	Sb	Sc	Se
Median	3.94	0.68	0.04	31.45	22.9	0.31	313	0.55	9.7	26.6	16.5	21.2	7.28	98.2	0.0025	0.28	7.4	0.9
GAI Index	-1.01	-1.63	-0.88	-0.61	-0.39	-1.30	-2.19	-2.04	-1.63	-1.10	-2.86	0.01	-0.97	-0.46	2.03	-0.10	-1.70	3.58
EIL											60	1,100						
HIL							19,000				1,200							

Element	Sm	Sn	Sr	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Median	5.05	2	89.16	0.81	0.63	<0.2	11.8	2600	0.67	0.31	2.16	57	1.4	18.05	2.18	37	129.3
GAI Index	-1.23	-0.72	-2.64	-1.89	-1.39	-	-0.61	-1.69	-0.43	-1.22	-0.74	-2.07	-0.10	-1.32	-1.18	-1.60	-1.14
EIL																300	
HIL																30,000	

Assessment of metal concentrations in mineralisation zones – by their definition – is likely to yield elevated levels or particular metals. Naturally high levels of elements can particularly occur in rocks, where elements have become concentrated by natural processes. Determining the potential for materials to become a contaminant must also consider the solubility a material's metal concentration. For this reason, multi-element analysis of leached solutions was also undertaken. The following section provides results of this assessment.

4.2.2 Total metals analysis – leached solution

The results of the total metals analysis of the leach solutions are given in Table 11. Included for comparison are values found in local groundwater, trigger values for 95% protection of species in aquatic freshwater ecosystems (ANZECC 2000). Where no freshwater trigger values existed, comparison was made against livestock drinking water guidelines (ANZECC 2000) instead.

In all waste types, metal concentrations in the leach solution are typically higher than the comparative trigger values listed for Aluminium.

The following waste types also recorded concentrations of metals that typically exceeded the comparative trigger values:

Saprock

- Zinc (Zn) (1 of 3 samples).

Saprolite

- Selenium (Se) (1 of 3 samples);
- Zinc (Zn) (1 of 3 samples).

Siltstone (Upper and Lower), Upper Mudstone, Lower Sandstone and Upper and Lower Tillite

- Molybdenum (Mo) (9 of 12 samples)

Trigger levels were unavailable for Ba (Barium) and Antimony (Sb). Although no levels have been set for freshwater and livestock drinking water, concentrations of Ba and Sb remain below levels set by the National Health and Medical Research Council (NHMRC) for human drinking water (2.0 and 0.003 mg/L respectively) (NHMRC 2011).

For both Zinc and Selenium, concentrations in the leach solution were higher than the comparative trigger values listed for freshwater but consistent with concentrations found in local groundwater (Rockwater 2020a and 2020b). Samples with elevated concentrations of Aluminium, exceeded both local groundwater values and ANZECC (2000) freshwater trigger values, but remained within livestock drinking water values. Similarly, Molybdenum concentrations in fresh materials were slightly higher than local groundwater levels but remained within livestock drinking water trigger values. Consequently, the potential for waste materials to produce metalliferous drainage is considered to be low.

It is noted that a larger suite of metals was available for analysis in solids in comparison to leached solution. Consequently, concentrations of leached Silver were unavailable for analysis. Analysis of a larger suite of metals (including Silver) should be undertaken as part of future testing.

Table 11: Elemental composition of leachate solution for waste types at Havieron with trigger value exceedances shown in red

Elements		Al	As	Ba	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	U	Zn
Units		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Limit		0.01	0.0001	0.00005	0.00002	0.0001	0.01	0.01	0.0001	0.001	0.00005	0.01	0.0005	0.00001	0.0005	0.000005	0.01
HW54	Lower Tillite	0.46	0.0004	0.04671	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.006	0.00059	<0.01	<0.0005	0.00004	<0.0005	0.00003	<0.01
HW48	Lower Tillite	0.19	0.0005	0.00226	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.008	0.00042	<0.01	<0.0005	0.00011	<0.0005	0.00004	<0.01
HW52	Lower Tillite	0.21	0.0005	0.00967	<0.00002	0.00090	<0.01	<0.01	<0.0001	0.032	0.00317	<0.01	0.00050	0.00004	<0.0005	0.00009	<0.01
HW57	Lower Tillite	0.11	0.0011	0.00273	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.025	0.00097	<0.01	<0.0005	0.00015	<0.0005	0.00002	<0.01
HW05	Saprolite	0.15	<0.0001	0.02305	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.002	0.00081	<0.01	0.00060	0.00002	0.00510	0.00002	0.02
HW06	Saprolite	0.06	0.0001	0.01069	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.002	0.00055	<0.01	<0.0005	<0.00001	0.00130	0.00001	<0.01
HW15	Saprock	1.24	0.0013	0.00042	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.016	0.00114	<0.01	0.00050	0.00003	<0.0005	0.00001	0.02
HW02	Tertiary Cover	0.14	0.0002	0.12323	<0.00002	0.00030	<0.01	<0.01	<0.0001	0.064	<0.00005	<0.01	0.00050	<0.00001	<0.0005	0.00002	<0.01
HW10	Saprolite	0.33	0.0011	0.00385	<0.00002	0.00030	<0.01	<0.01	<0.0001	0.013	0.00492	<0.01	0.00070	0.00014	0.02350	0.00007	<0.01
HW19	Saprock	0.14	0.0005	0.00046	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.002	0.00036	<0.01	0.00080	0.00008	<0.0005	0.00004	<0.01
HW20	Saprock	0.13	0.0005	0.00045	<0.00002	<0.0001	<0.01	<0.01	<0.0001	<0.001	0.00540	<0.01	0.00110	0.00003	<0.0005	0.00002	<0.01
HW26	Upper Mudstone	0.51	0.0118	0.00134	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.007	0.00474	<0.01	<0.0005	0.00026	0.00850	0.00006	<0.01
HW30	Upper Tillite	0.27	0.0005	0.00327	<0.00002	0.00020	<0.01	<0.01	0.00020	0.005	0.00250	<0.01	0.00140	0.00016	0.00110	0.00006	<0.01
HW31	Upper Siltstone	0.16	0.0030	0.00297	<0.00002	0.00020	<0.01	<0.01	<0.0001	0.020	0.03567	<0.01	<0.0005	0.00098	0.00320	0.00012	<0.01
HW34	Lower Siltstone	0.34	0.0025	0.00238	<0.00002	0.00010	<0.01	<0.01	<0.0001	0.004	0.02090	<0.01	0.00220	0.00131	0.00260	0.00012	<0.01
HW39	Lower Sandstone	0.24	0.0023	0.00258	<0.00002	0.00010	<0.01	<0.01	<0.0001	0.003	0.03878	<0.01	0.00320	0.00201	0.00210	0.00011	<0.01
HW40	Lower Sandstone	0.10	0.0064	0.00534	<0.00002	<0.0001	<0.01	<0.01	<0.0001	0.002	0.00641	<0.01	<0.0005	0.00080	<0.0005	0.00012	<0.01
HW24	Upper Mudstone	0.23	0.0012	0.00520	<0.00002	0.00020	<0.01	<0.01	<0.0001	0.003	0.00673	<0.01	0.00090	0.00031	0.00480	0.00027	<0.01
HW27	Upper Tillite	0.39	0.0041	0.03450	<0.00002	0.00040	<0.01	<0.01	<0.0001	0.005	0.07438	<0.01	0.00350	0.00031	0.00310	0.00046	<0.01
Average local groundwater (Rockwater 2020)		0.03	<0.002	na	<0.0002	<0.002	<0.002	0.004	<0.0001	2.5	<0.002	<0.002	<0.002	na	<0.02	na	0.048
Freshwater (ANZECC 2000)		0.05	0.01	na	0.0002	na	0.001	0.001	0.001	1.90	na	0.01	0.003	na	0.01	na	0.01
Livestock Drinking ANZECC 2000)		5.00	0.50	na	0.01	1.00	1.00	1.00	0.002	Insufficiently toxic	0.15	1.00	0.10	na	0.02	0.20	20.00

na = value not assigned

4.3 Baseline plant growth properties

Baseline plant growth results for the different wastes from Havieron are provided in Table 12. A full listing of characterisation data is given in Appendix A. Interpretation of values for pH, Electrical Conductivity (EC), and exchangeable cations was based on available standards (e.g. Hazelton and Murphy 2016).

The suitability of materials for use as growth media was also assessed via comparison with chemical-physical characteristics of soils naturally occurring around the Havieron Project area (Table 12). Here, soils recently characterised for the same Project area were used as reference sites (Landloch 2020).

4.3.1 Sample pH$_{1:5}$

The acidity or alkalinity of a material is measured by the pH scale. Determination of guidelines for pH suitability relevant for a wide range of materials and sites is difficult, and the most rational approach is to consider naturally occurring soil pH values and the vegetation that is endemic on soil having these pH values. Waste materials that have similar pH values can be considered suitable for plant growth – at least with respect to material pH.

Soil characterisation work recently completed for the Project (Landloch 2020) showed surface soils (0.0-0.1m depth) having pH values ranging between 5.5-6.3. These findings indicate that surface soils commonly present around the Havieron Project area are slightly acidic to circum-neutral. Consequently, plant species endemic to this area are more likely to be tolerant of slightly acidic to neutral pH levels and are less likely to grow and survive within strongly acidic or alkaline material.

For all waste materials at Havieron, pH ranged between 6.1 and 9.4 (Figure 11). The Tertiary Cover exhibited pH levels closest to those commonly occurring in natural soils, with a pH of 6.1. At these levels, the material is likely to be supportive to plant growth, providing salinity levels remain low.

All remaining materials are characterised as being slightly to highly alkaline (pH 7.9-9.4). High alkalinity can limit the availability of some nutrients such as Nitrogen, Phosphorus, Calcium, Magnesium, and trace elements such as Iron, Manganese, Boron, Copper, and Zinc. Alkaline materials often form in unweathered and slightly weathered rock where leaching is limited, as occurs in arid environments where evaporation often exceeds rainfall.

These alkaline pH values may limit the ability of wastes to be used as growth media without amendment. Amendment could be achieved through the use of elemental Sulphur. However, any development of an amendment regime should first consider the actual impact of the elevates pH on plant growth. This could be done through use of pot trials and/or field trials in which plant establishment and growth into the wastes are tested.

Table 12: Baseline plant growth properties for materials at Havieron classed by lithology.

Analyses		Unit	Lower Tillite	Saprolite	Tertiary Cover	Saprock	Upper Tillite	Upper & Lower Siltstone	Lower Sandstone	Upper Mudstone	Reference Sites
pH$_{1:5}$ (water)		pH units	8.1-9.2	7.87	6.09	8.35	8.4	8.3-9.0	9.38	8.85	5.9-6.3
Electrical Conductivity, EC$_{1:5}$		dS/m	1.0-3.8	5.27	1.04	0.51	1.25	1.1-2.8	2.79	1.3	0.01-0.4
Chloride		mg/kg	2196-4321	4760	1196	620	1401	1545-4178	4074	1283	3.58-533
Exchange-able Cations	Extraction Method	Rayment& Lyons	15C1	15C1	15A2	15C1	15C1	15C1	15C1	15C1	15A1/15 A2
	ECEC	meq/100g	2.3-4.1	17.3	5	6.1	5.6	6.7-9.7	13.0	10.8	1.2-2.3
	Ex Sodium Percent	%	13.6-25.9	40.4	4.8	28.2	36.0	36.0-40.1	45.1	30.51	5.7-16.5
	Calcium	meq/100g	0.9-2.6	2.8	2.5	1.7	1.7	2.2-3.1	3.94	3.32	0.6-1.0
	Magnesium	meq/100g	0.8-1.0	6.5	2	2.5	1.67	1.7-2.5	2.9	3.86	0.3-0.7
	Potassium	meq/100g	0.03-0.05	1.01	0.21	0.2	0.22	0.4-0.2	0.31	0.35	0.1-0.2
	Sodium	meq/100g	0.6-0.7	7	0.24	1.72	2	2.4-3.9	5.87	3.31	0.08-0.38
	Aluminium	meq/100g	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02-0.08
	Ca/Mg Ratio	-	1.1	0.4	1.3	0.7	1	1.2-1.3	1.4	0.9	1.1-2.4
	ESI		0.04-0.3	0.1	0.2	0.02	0.03	0.03-0.1	0.06	0.04	
Particle Size Distribution of Fine Fractions (<2mm)	Coarse Sand 0.2-2.0mm	%	-	7.6	-	10.5	-	4.3-4.8	12.7	7.8	44.7-57.9
	Fine Sand 0.02-0.2mm	%	-	22.7	-	61.1	-	19.8-60.6	69.7	67.6	36.1-46.0
	Silt 0.002-0.02mm	%	-	25.1	-	12.6	-	15.7-32.8	5.4	7.1	0.1-1.1
	Clay <0.002mm	%	-	36.4	-	15.8	-	18.8-41.5	12.2	15.6	4.9-13.2

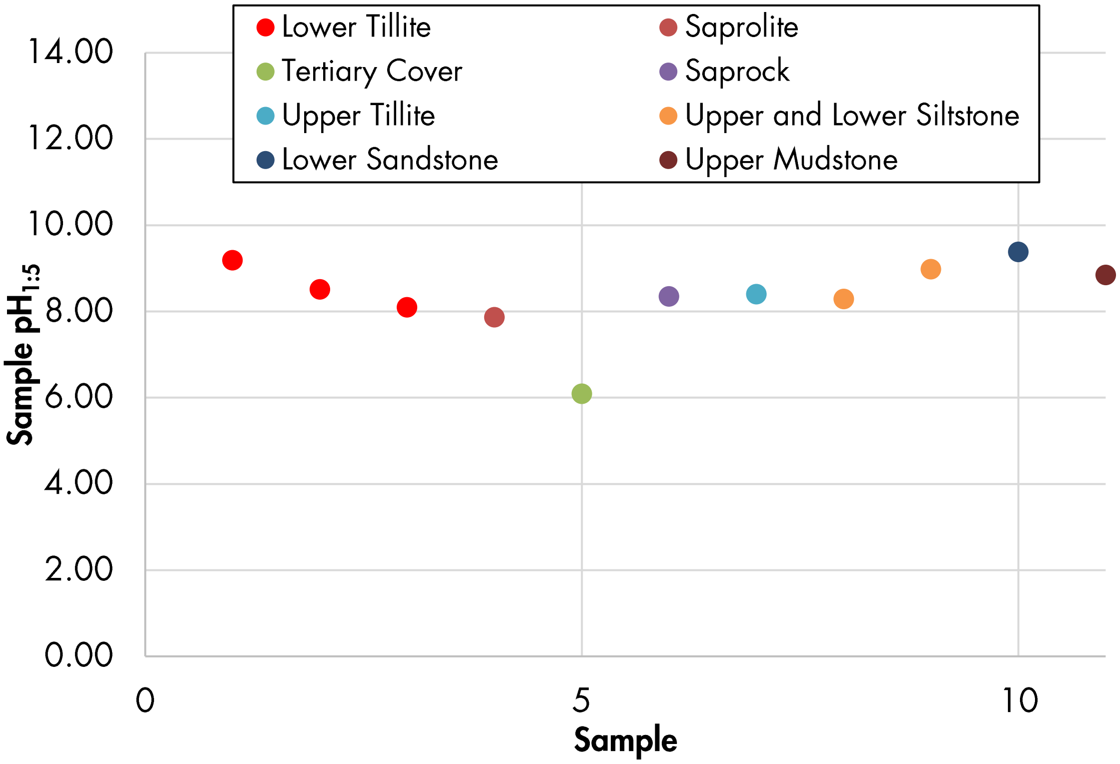


Figure 11: Sample $pH_{1:5}$ for Havieron waste materials.

4.3.2 *Sample salinity ($EC_{1:5}$)*

Soil salinity is often measured using the Electrical Conductivity of a solution containing 1 part soil to 5 parts of deionised water ($EC_{1:5}$). Salinity can be quite variable. For waste materials where leaching is infrequent and saline groundwater is not present, the salinity of the parent material will have a significant bearing on the salinity of the weathered zone.

Most published salinity suitability ranking systems assume agricultural vegetation, and application of these ranking systems has little significance to plant species used in arid zone rehabilitation. The Western Australian Department of Agriculture and Food provides a summary of published salinity tolerance values for a range of common species used in revegetation of disturbed lands in Western Australia (Department of Agriculture and Food, 2004). These tolerance values are given as EC values measured not using the common 1:5 soil:water solution method, but the less common saturation extract method (ECe). Conversion between $EC_{1:5}$ and ECe indicates growth of salt sensitive species is likely to be adversely effected at $EC_{1:5}$ values less than approximately 2.0dS/m and growth of salt tolerant species (e.g. *Atriplex* sp., *Maireana* sp.) is likely to be adversely effected at $EC_{1:5}$ values >2.0dS/m. Plants are particularly sensitive to salt during germination and establishment. Many eucalyptus species have salt tolerance values ($EC_{1:5}$) for germination ranging from 0.5-2.0dS/m.

In general, salinity across all materials was variable, ranging between 0.5-5.3dS/m (Figure 12). The Saprolite material and unweathered materials of the Lower Tillite and Upper and Lower Sandstone generally exhibited higher salinities than other waste types, with $EC_{1:5}$ ranging between 2.8-5.3dS/m. Growth of salt sensitive species is therefore likely to be restricted in these materials where they have potential to leach or break-down over time.

Materials exposed to greater weathering such as the Tertiary Cover, Saprock, Upper Tillite, Upper Mudstone, and Upper Siltstone generally recorded lower levels of salinity, with $EC_{1:5}$ ranging between 0.5dS/m and 1.3dS/m. These levels of salinity are lower in comparison to other materials, but higher than levels of salinity found in soils naturally occurring around the Project area (Table 12). Subsequently establishment of salt-sensitive plant species on these materials is likely to be lower. Salt tolerant species are still likely to establish.

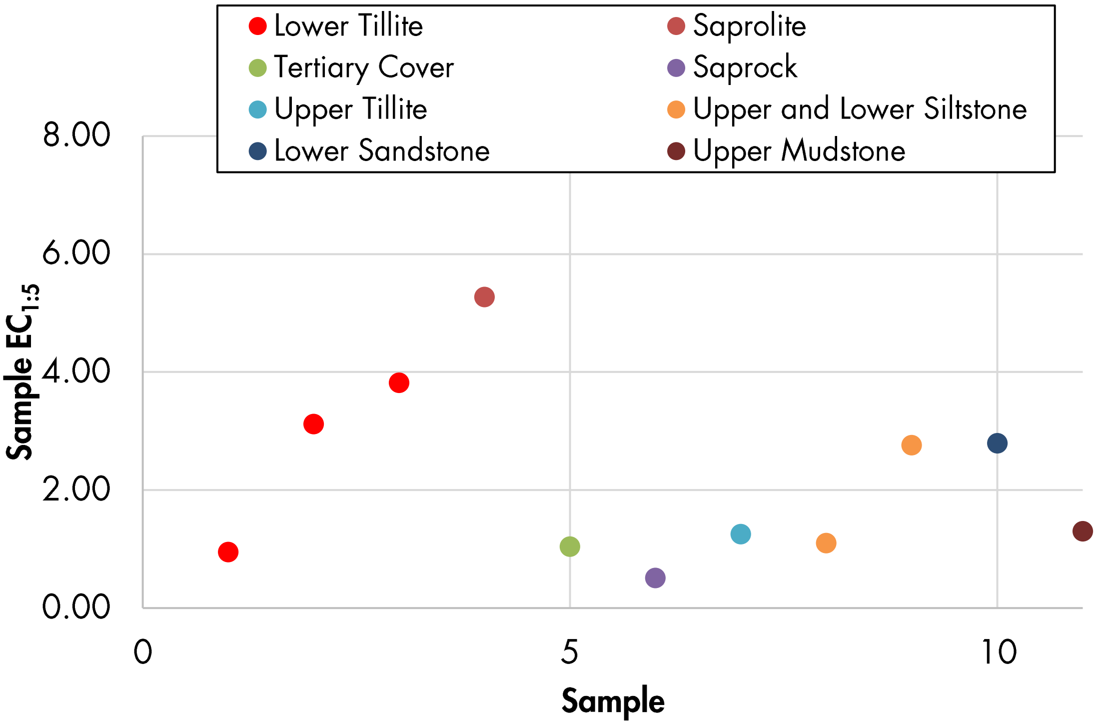


Figure 12: Sample $EC_{1:5}$ for Havieron waste materials.

4.3.3 Exchangeable cations, ECEC, and ESP

The ability of a material to absorb and retain cations is measured by Effective Cation Exchange Capacity (ECEC). Measurement of exchangeable cations provides information on the types of cations being held on the soil/material exchange complex. The type and proportion of exchangeable cations has a major impact on the physical stability of the material. Of particular importance is the proportion of Sodium (Na) held on the exchange complex in relation to other cations. This is referred to as the Exchangeable Sodium Percentage (ESP).

ECEC is calculated as the sum of the exchangeable cations – Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and Al^{3+}. Materials with ECEC values of less than approximately 3meq/100g are likely to be sandy or rocky, and have little ability to hold or retain nutrients. Materials with ECEC values greater than approximately 3meq/100g are likely to contain some clay and to have the ability to hold and retain nutrients. Further, ECEC values greater than approximately 40meq/100g indicate materials that have a high proportion of clays, and that these clays are likely to be reactive (typical of soils that shrink and swell).

Typically, soils with ESP values greater than 6% are classed as sodic and potentially dispersive. Materials with a tendency to disperse are generally not considered suitable for use as a growth medium as they are likely to be hard setting, potentially tunnel prone, and have low infiltration and water holding capacity. These physical characteristics can lead to increased runoff and potential erosion, which can limit vegetation establishment.

However, in practice, the potential for a soil to disperse is controlled by complex interactions between clay content, exchangeable cations, and soil salinity. Further, soils high in exchangeable magnesium can be dispersive even when the ESP is <6%. In addition to this, very low salinity can also increase the tendency for soil structural decline, even in materials that, by definition, are not otherwise dispersive. The interactions between ESP and salinity have important implications for rehabilitation activities. Materials that appear stable can become increasingly unstable (dispersive) as soil salinity decreases through leaching by rainfall. Therefore, materials that are "sodic" by definition should be treated as at least potentially dispersive, even if they appear initially stable.

The Electrochemical Stability Index (ESI) has recently been developed as a means of considering the relationship between sodicity and salinity. The ESI is defined as the ratio of $EC_{1:5}$ and ESP. A tentative critical ESI value for soils is 0.05. Materials with ESI <0.05 can be considered potentially prone to structural decline caused by clay dispersion.

The structural stability data for the 11 waste samples tested indicates that all materials except the Tertiary Cover are prone to structural decline based on elevated ESP values (Table 12). Susceptibility of materials to dispersion is influenced by the inherent particle size distribution of the materials. All materials except for the Tertiary Cover, Upper Tillite and Lower Tillite, have clay contents >10% in addition to a considerable proportion of silt and fine sand content. This indicates that these materials have the greatest risk of structural decline, given these materials are also prone to particle breakdown (refer Section 4.3.4).

Comparison of waste values with those recorded in natural reference sites, shows that the Tertiary Cover has physical and chemical characteristics most similar to topsoils located in the Project area. The low risk of dispersion associated with this material also makes it suitable for use as a growth media. The other wastes are not suitable for us as a growth media, with the exception of those found to contain durable rock. These could potentially be mixed with more suitable growth media as a means of increasing resistance to erosion for rehabilitation landform batters.

4.3.4 Rock particle density, absorption, and rock strength

Rock particle density, water absorption, and rock strength can provide an indication of how susceptible rock particles are to breakdown and their potential usefulness for use in rehabilitation as armouring.

Where rock particles are observed to be prone to breakdown, this can result in an increase in the proportion of fines over time, which would increase erosion potential in the long term. The breakdown of rock particles can occur during landform re-shaping using heavy machinery, whereby rock particles of a certain size become smaller as bulldozers and other machinery traverse over them, push them, and rip into them. Where rocks are shown to be durable, they could be considered for use as a rock armour to reduce erosion potential of rehabilitation landform batters. Density, water absorption and rock strength ranges for rock particles found within the different waste types at Havieron are provided in Table 13.

Table 13: Rock particle density and water absorption values classed by lithology

Lithology	Depth (m)		Range Rock Density (g/cm^3)	Range Water Absorption (%)	Durability	Rock strength	
	To	From				Grade	Term
Lower Tillite	527	528	2.6	5.6	Marginal	R2-R3	Weak-Medium Strong
Lower Tillite	470	526	1.9	11.8	Poor	R1-R2	Weak - Very Weak
Lower Tillite	453	471	2.3	5.9	Marginal	R3-R5	Medium Strong-Very Strong
Lower Tillite	331.5	332	3.1	2.5	Good	R5	Extremely Strong
Saprolite	All		0.0-2.4	10.4	Poor-Marginal	R0-R1	Extremely Weak to Very Weak
Tertiary Cover	All		-	-	Poor	R0	Extremely Weak
Saprock	All		0.0-2.1	14.3	Poor	R1-R2	Very Weak to Weak
Upper Tillite	All		0.0-2.2	11.3	Poor	R2	Weak
Upper and Lower Siltstone	All		Full disintegration		Poor	R2	Weak
Lower Sandstone	All		Full disintegration		Poor	R1-R2	Very Weak-Weak
Upper Mudstone	All		Full disintegration		Poor	R1	Very Weak

Lower Tillite exhibited the highest rock density in comparison to other materials. However, rock density and water absorption values within this waste type was variable, leading to rock particle rock strength varying between Very Weak and Extremely Strong. Rock strength was observed to vary based on depth, with Lower Tillite extracted from depths of ~330-470m exhibiting highest average rock density and lowest average water absorption (2.6g/cm^3 and 4.3% respectively). These values indicate that Lower Tillite at these depths is durable, not prone to rapid weathering, and highly suitable for use as armour on outer embankments.

Remaining materials (i.e. Saprolite, Tertiary Cover, Saprock, Upper Tillite, Sandstone and Mudstone) tended to be less durable as a result of being more weathered. This is evidenced by these materials exhibiting lower density and rock strength in comparison to the Lower Tillite. The low strength and high water adsorption values of rock particles indicate these materials are prone to breakdown over time and thus are not suitable for use on outer embankments.

4.4 Asbestiform materials

A subset of 14 waste samples were taken from drill cores for assessment of asbestiform materials via optical microscopy. Sampling was done using fractured faces of the available drill core. Samples were also inspected for actinolite, serpentine, and cummintonite-grunerite which have the potential to be present in a sample but not in asbestiform. No asbestos nor any other fibres were recorded in the samples tested (refer Appendix C).

4.5 Naturally Occurring Radioactive Materials

All minerals and raw materials contain radionuclides of natural origin. For most activities involving minerals and raw materials, the levels of exposure to these radionuclides are not significantly greater than normal background levels and are not of concern for radiation protection. However, some materials may give off radiant energy at levels higher than background levels. Human activity around these types of materials can increase the risk of radiological exposure. Material giving rise to these enhanced exposures is known as naturally occurring radioactive material (NORM).

All samples were assessed using both a Geiger Muller and scintillator probe. Background NORM's were removed from the readings of both equipment. Average surface activity of the samples was 0.10 Bq/cm^2 and average dose rate was 0.002 μSv/hr. These results fall within the dose limit and surface contamination for beta, gamma and low toxicity alpha emitters set by the Government of Western Australia (2019) and DMIRS (2010) respectively (Table 14).

Table 14: Results of NORM assessment

Measurement	Surface activity (Bq/cm^2)	Dose rate (μSv/hr)
Waste sample average	0.10	0.002
Specified limit	0.40	10

5 MANAGEMENT CONSIDERATIONS

5.1 Water erosion potential

5.1.1 Tertiary Cover and sandy soils

The Tertiary Cover and the surface sandy soils appear suitable for use as a growth medium. However, based on their fine-grained nature, there is a risk that they may be prone to both water and wind erosion. All other wastes except for the Lower Tillite were characterised as being prone to either physical breakdown or chemical dispersion (or both). These waste types are also likely to be prone to water erosion and potentially tunnel erosion (for the dispersive wastes).

Based on experience with similar materials in the vicinity of Havieron, the likely erosionally stable lift heights for the Tertiary Cover materials is in the order of 10-15m.

The properties of the materials that would underlie these materials on a waste landform are important. The Tertiary Cover and sandy soils are likely to have a high permeability compared to the finer-grained wastes. Field trials of placement of 0.5m of dune sands over an impermeable oxidised siltstone waste at Nifty Copper Mine showed that the surface soils 'slipped' from the oxidised waste surface during a single large rainfall event. This was caused by the reduced permeability of the oxidised waste that led to saturation of the sandy surface layer and a subsequent loss of cohesion of the surface soils. There is a risk that a similar outcome could occur at Havieron if shallow layers of sandy materials are placed over less permeable wastes.

The obvious response to this risk is to use thicker layers of permeable materials as a way of reducing the risk of the layer saturating. However, this response brings with it increased risks of wind and water erosion. Therefore, it is recommended that future rehabilitation planning include:

- Defining the permeability of the soils and wastes once disturbed (i.e. once extracted and placed within waste landforms);
- Assessment of water movement through the surface cover systems using a water balance model in order to define the risk of the surface layers becoming saturated and losing cohesion;
- Defining the required cover thickness to reduce the risk of saturation of the surface layers over impermeable wastes (if wastes are shown to be impermeable);
- Defining the risk posed by wind erosion of the soils and fin-grained wastes;
- Modelling the effect of landform shape on batter wind and water erosion (both on the windward face and the leeward face);
- Modelling the impacts of altered wind patterns around the landform on sensitive areas such as the adjacent sand dunes; and
- Trialling techniques for the rapid stabilisation of surfaces against wind erosion (e.g. temporary products to stabilise against wind, the use of potentially more durable wastes such as the Lower Tillite to provide increased erosion resistance).

5.1.2 Lower Tillite

The Lower Tillite has been shown to be the best candidate to contain a durable rock fraction once extracted. It has also been characterised as having elevated salinity and sodicity levels. This material should be assessed for its usefulness as a rock armour in order to increase the erosional stability of outer embankments. As part of this assessment, the impact of its salinity and sodicity on vegetation growth should also be considered. If the waste remains relatively blocky and contains a relatively small proportion of fines, when mixed with another growth medium, the salinity and sodicity of the Lower Tillite may not translate into a significant increase in salinity or sodicity of the material once mixed.

Water erosion modelling of similar materials – based on broad material properties such as particle size distribution – in the vicinity of Havieron indicate that erosionally stable heights of 20m are achievable for gradients of 12-18 degrees when a coarser waste is added into a finer-grained growth medium.

5.1.3 Other wastes

All other wastes appear unsuitable from a plant growth potential because of their elevated salinity and/or sodicity levels, coupled with their tendency to physically breakdown. In particular, all of the Boxcut Area materials are likely to breakdown and present as a mass of fine-grained waste (albeit with some coarse fraction). Their tendency to disperse poses challenges to rehabilitation when they are placed within a waste landform. Structures such as cross-slope benches and rock drains are at greater risk of failing with used within landforms dominated by dispersive wastes. For example, benches and crest bunding that allow water to pond close to the outer edge allows runoff to accumulate and pond for extended periods of time. This increases the risk of tunnel erosion occurring within these materials. Tunnel erosion that occurs near the outer face of a rehabilitation landform can result in the tunnel 'exiting' on the downslope batter. These tunnels tend to collapse over time and form large gullies the instant this occurs.

5.2 Wind erosion potential

5.2.1 Positioning dump relative to prevailing winds

Wind erosion at Havieron is currently limited by the erosion resistance provided by vegetation. The existing dunes are orientated in a similar direction to the prevailing winds. This orientation limits the movement of sand to within the dune area itself and is not likely to cause lateral migration of the crest of the dunes.

If the sands are disturbed and placed in a landform orientated perpendicular to the current prevailing wind, the risk of wind erosion (effectively causing dune migration) increases, and successful revegetation of the highly erodible crest of the landform will be particularly difficult. Orienting the landform within the long sides parallel with the prevailing wind would be desirable if practicable.

If this orientation is not possible, armouring of the windward side (and particularly the crest) will be required. This will be necessary until vegetation is established and able to provide surface erosion resistance. Without intervention, unvegetated sand susceptible to wind erosion cannot be expected to revegetate.

Increased surface resistance can be achieved by placement of vegetative debris on the surface, placement of gravel and/or rock on the surface, and/or application of temporary surface treatments (adhesives).

Ideally, if rock or vegetation debris is to be used, it should be applied to the entire slope. Chepil *et al.* (1963) found that rock need not be larger than approximately 5-10mm in diameter to be effective in limiting wind erosion. Approximately 20-40% of the soil surface should be covered. This is similar (though slightly lower) to the foliar cover required from vegetation to produce effective protection against wind (Carter 2002).

Also, where supplies of rock or vegetation are limited, a checkerboard pattern could be employed, with lines of these materials intersecting to form areas of 5–6m^2. Wind erosion can reach its maximum rates in less than 5m, and lines of rock and vegetation should be placed as close together as possible. The height of each line need not be greater than ~0.5-2m, but the required height will ultimately depend on the spacing adopted.

Application of temporary surface treatments is popular in the mineral sands industry. Products only offer temporary protection (3-12 months), after which reapplication is necessary if continued protection is required.

Increasing form roughness on the sand (e.g. rip lines or moonscaping) without application of any other surface treatment is unlikely to reduce erosion potential (Armbrust *et al.* 1964). This has been seen at Nifty Copper Mine where rip lines were all but erased by the wind after only a short period of time.

5.2.2 Vegetation and dune stabilisation

Establishment of vegetation is likely to be highly desirable and is likely to provide the long-term soil stability required. Chepil and Woodruff (1963) state that vegetation can reduce wind forces at the soil surface by as much as 99%, though the actual effectiveness is dependent on the amount, type, and orientation (standing or flat) of the vegetation.

For adequate protection against wind erosion, approximately >30% of foliar vegetation cover is required (Carter, 2002). The height of vegetation should be greater than 0.1m to offer significant improvements to erosion resistance (Leys 2003). However, establishment of vegetation is likely to require stabilisation of the soil surface using rock, vegetation debris, and/or temporary surface treatments.

Importantly, current vegetation on the dunes is likely to be dependent on the increasing clay content with depth. These deeper layers will hold water that is likely to be used by the vegetation, and successful rehabilitation of the dune materials must consider the water holding capacity of the soil profiles constructed. Failure to do so is likely to limit vegetation vigour and growth, and increase the susceptibility of the soils to erosion. Alternately, application of rock to the soil surface will provide erosion resistance, decreasing the importance of vegetation for stability.

5.3 Conceptual 2D batter designs

Havieron currently propose to construct waste landforms with a maximum height of 20m in order to be consistent with the height of the local dune systems. The total size of the dump will be 1-2ha (i.e. small). Based on the material characterisation results, two options for rehabilitation batter designs have been identified. The two options include:

1. 2 x 10m high lifts sheeted in sandy soils and/or Transported Cover, with a back sloping mid-slope berm (Figure 13).
2. 1 x 20m high lift sheeted in the mixture of Lower Tillite and Transport Cover (or sandy soil) (Figure 14).

These are conceptual in nature and must be considered in more detail once further characterisation occurs (e.g. water and wind erosion testing and modelling, vegetation impacts caused by salinity of Lower Tillite).

Use of the two lift option has significant limitations that make this option problematic:

- The Transported Cover and sands are prone to wind erosion and this design could lead to significant soil loss as a result;
- Creation of a surface that is prone to wind erosion will make establishment of vegetation difficult;
- The mid-slope berm represents a point where water can pond. Given the wastes as potentially tunnel prone, the berm would be a point at which tunnelling could be initiated; and
- Use of other options to remove the need for the berm (e.g. use of concave slope profiles) are unlikely to work in the sandy surface soils (concaves are useful for soils that have more cohesion and higher gravel contents).

The single lift option is preferred because it:

- Removes the risks posed by the berm (tunnel erosion);
- Incorporates the Lower Tillite into Transported Cover/Soil the surface layer as a means on addressing wind and water erosion;
- Can still potentially support vegetation, assuming that the salinity impacts of the Lower Tillite are adequately addressed;
- Could be used in conjunction with short-term products to stabilise the surface against wind (with long-term stability coming from the rockier Lower Tillite and vegetation).

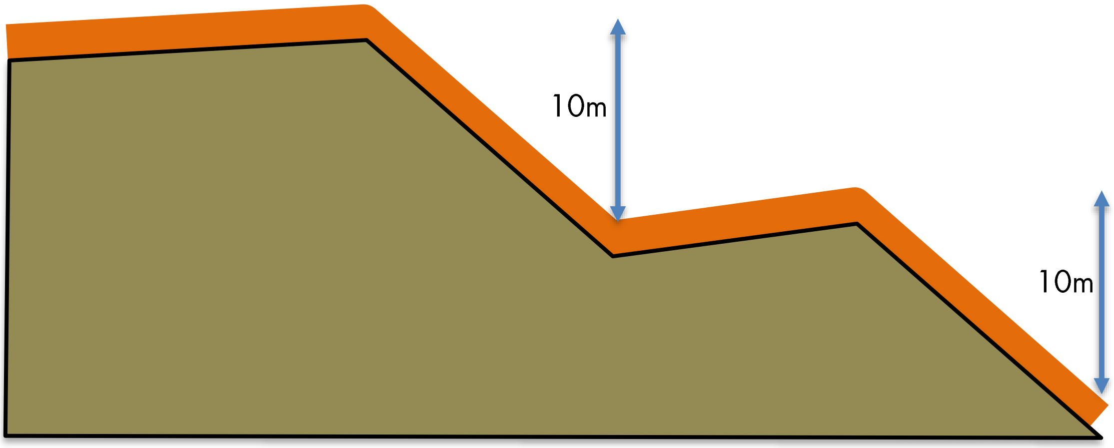


Figure 13: Conceptual landform batter design – two lift option

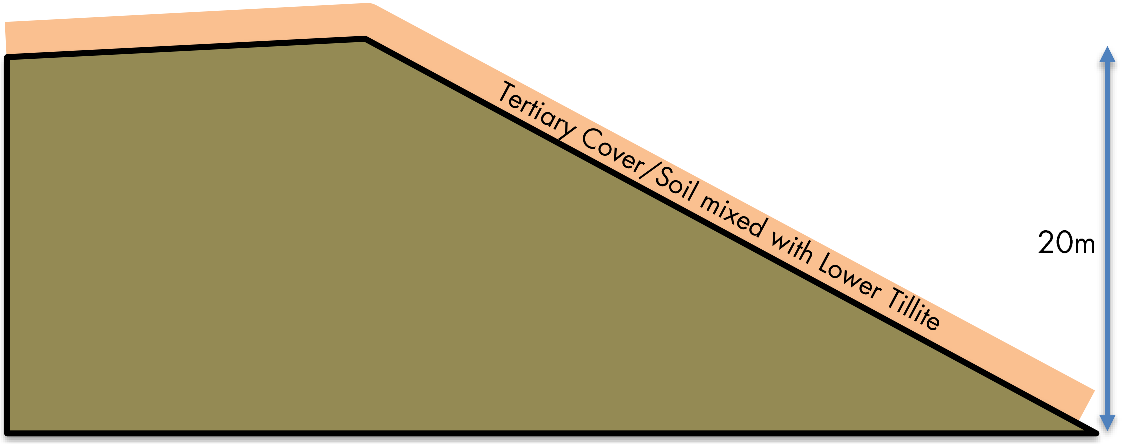


Figure 14: Conceptual landform batter design – single lift option

5.4 Sediment management

During operations there will be the need to place the fine-grained wastes within the waste dump without protection against erosion. This will mean that sediment will be produced. Havieron plan to manage this sediment by placement of the waste landform such that all runoff is discharged through a sediment basin and ultimately into an evaporation pond. This approach appears reasonable. The sediment basin can be used to settle out the larger particles generated by erosion of the waste, and if necessary, could be used as a point at which sediment could be flocculated to reduce suspended sediment loads. The eventual discharge of the runoff into the evaporation pond will mean there will be no discharge of sediment to the surrounding environment.

Once rehabilitated, sediment management would primarily be achieved through creation of a vegetated, erosionally stable waste landform that erodes at rates consistent with the surrounding environment. Therefore, there should not be the need for continual use of the sediment basin or evaporation pond. Construction of a toe bund may also not be required if the erosion from the landform can be shown to be occurring at acceptable rates. If it is shown that it is necessary to further reduce the risk of sediment movement from the rehabilitated dump beyond that which will be achieved through successful rehabilitation, a toe bund could be constructed. It could be built above the land surface from durable, low erosion potential wastes, or constructed below the land surface from the in situ materials. In either case, the sizing of the bund must accommodate rare rainfall events as the intent would be for this bund to remain in place for the long-term 300 years. An annual exceedance probability of <0.04% is suggested for use in the design of this bund.

5.5 Flood protection

Landloch is not aware that any of the landforms are located within a flood prone area. However, if landform batters that are located within the 100-year flood line, rock armour protection is recommended. This armouring should be sized according to a surface water flow study that calculates the potential flow velocities that will be experienced. These calculations cannot be performed at present as the shape and locations of the landforms are not yet set.

The required rock size will depend on the final placement of the waste landforms relative to the flood flows. Alternately, flood bunds are also used in some cases to divert water away from the waste landforms rather than allowing the water to interact with the landform batter.

Given that there is not significant volumes of durable waste present, identifying the need for these materials will be important.

5.6 Ramps

Ramps are a consistent source of failure in rehabilitated landforms. Where possible, ramps should be removed as part of the rehabilitation of the landform. Where they are left, their erosion potential must be assessed using a 3-D landform evolution model.

5.7 Landform shapes

Where batters are not a simple shape in plan view, there is potential for water-concentrating areas (indents) to be created (Figure 13). Indents may be large or quite small, but are of concern irrespective of magnitude. Such features should be avoided if at all possible.

From Landloch's experience with many waste dumps across Australia, one consistent observation is that erosion (rills, gullies) occurs most frequently on corners of waste dumps. Dozers are less successful at cross-ripping on-contour when the dozer works around corners, irrespective of the skill of the operator. Not surprisingly, the problem is accentuated when the corner is sharp. Ideally, all corners should have a radius of curvature of at least 100m.

Landform shape also influences the potential cost of rehabilitation. Rehabilitation of batter surfaces is considerably more expensive than rehabilitating flat waste landform tops (it is estimated that batters are four times more expensive that dump tops to rehabilitate). Therefore, wherever possible, the surface area of the landform top should be maximised and the perimeter of the batters minimised. This can be done by changing the landform shape.

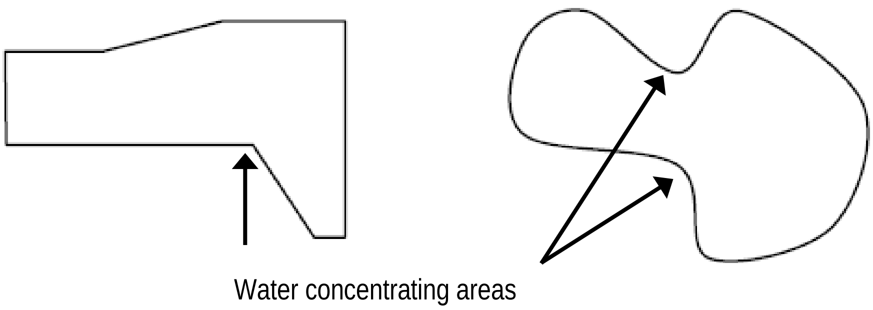


Figure 13: Conceptual plan view of a waste landform showing flow-concentrating features.

REFERENCES

ANZECC (Australia and New Zealand Environment and Conservation Council) and ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand) (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy Paper No. 4*, ANZECC and ARMCANZ, Canberra.

AusIMM (2011) Field Geologist's Manual, 5th Edition, Australasian Institute of Mining and Metallurgy, Carlton.

CSIRO and National Environment Protection Council (NEPC) (2010), Ecological Investigation Level Calculation Spreadsheet, Commonwealth of Australia.

Department of Agriculture and Food (DAF) (2004) *Soil salinity tolerance for agriculture and revegetation*, State of Western Australia.

Bureau of Meteorology (BoM) 2020. Monthly statistics, Telfer Aero weather station (013030), Commonwealth of Australia.

Department of Mines, Industry Regulation and Safety (DMIRS) (2020a). *Statutory guidelines for mine closure plans*, State of Western Australia.

Department of Mines, Industry Regulation and Safety (DMIRS) (2020b). 1:250,000 Geological Series: Paterson Range, GIS layer, State of Western Australia.

Department of Mines and Petroleum (DMP) (2016a). *Draft Guidance: Materials characterisation baseline data requirements for mining proposals*, March 2016, State of Western Australia.

Department of Mines and Petroleum (DMP) (2016b). 1:500 000 State interpreted bedrock geology, GIS layer, State of Western Australia.

Department of Mines and Petroleum (DMP) (2010). *Managing naturally occurring radioactive material (NORM) in mining and mineral processing – guideline. NORM-1. Applying the System of Radiation Protection to Mining Operations*, Government of Western Australia.

Government of Western Australia Radiological Council (2019)*, Radiation Safety Act: Dose Limits and Maximum Permissible Exposure Levels Fact Sheet*, Government of Western Australia

Hazelton P., and Murphy B. (2011) *Interpreting soil test results*, CSIRO Publishing.

Landloch (2020) *Havieron Soil Characterisation*, prepared for Newcrest Mining Ltd.

National Environment Protection Council (NEPC) (2011), Schedule B1, Guideline on Investigation Levels for Soil and Groundwater, Commonwealth of Australia.

NHMRC, NRMMC (2011) Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

Rockwater Pty Ltd (2020a) *Havieron Project Hydrogeological Assessment*, prepared for Newcrest Mining Ltd.

Rockwater Pty Ltd (2020b) *H3-Level Hydrogeological Assessment of the Havieron Project*, prepared for Newcrest Mining Ltd.

van Vreeswyk, A M, Leighton, K A, Payne, A L, and Hennig, P. (2004) *An inventory and condition survey of the Pilbara region*, Western Australia. Department of Agriculture and Food, Western Australia, Perth. Technical Bulletin 92.

APPENDIX A: BASIC MATERIAL PROPERTIES

Table A-1: pH, EC, exchangeable cations, and PSD for Havieron waste samples

Analyses		Unit	Lower Tillite	Lower Tillite	Lower Tillite	Saprolite	Tertiary Cover	Saprock	Upper Tillite	Upper and Lower Siltstone	Upper and Lower Siltstone	Lower Sandstone	Upper Mudstone
pH - Water		pH units	9.19	8.51	8.10	7.87	6.09	8.35	8.40	8.29	8.98	9.38	8.85
Electrical Conductivity		dS/m	0.95	3.12	3.82	5.27	1.04	0.51	1.25	1.10	2.76	2.79	1.30
Chloride		mg/kg	2196.00	4321.00	2618.00	4760.00	1196.00	620.00	1401.00	1545.00	4178.00	4074.00	1283.00
Exchangeable Cations	Cation Extraction Method	Rayment& Lyons	15C1	15C1	15C1	15C1	15A2	15C1	15C1	15C1	15C1	15C1	15C1
	Cation Exchange Capacity	meq/100g	2.26	2.56	4.13	17.30	5.00	6.09	5.55	6.70	9.74	13.03	10.84
	Ex Sodium Percent	%	25.42	25.94	13.59	40.44	4.80	28.20	35.95	35.97	40.07	45.05	30.51
	Exchangeable Calcium	meq/100g	0.86	0.94	2.58	2.76	2.54	1.67	1.66	2.20	3.10	3.94	3.32
	Exchangeable Magnesium	meq/100g	0.76	0.93	0.95	6.53	2.00	2.50	1.67	1.73	2.53	2.90	3.86
	Exchangeable Potassium	meq/100g	0.05	0.03	0.03	1.01	0.21	0.20	0.22	0.36	0.20	0.31	0.35
	Exchangeable Sodium	meq/100g	0.57	0.67	0.56	7.00	0.24	1.72	2.00	2.41	3.90	5.87	3.31
	Exchangeable Aluminium	meq/100g	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Calcium/Magnesium Ratio	-	1.13	1.01	2.71	0.42	1.27	0.67	1.00	1.27	1.23	1.36	0.86
	ESI		0.04	0.12	0.28	0.13	0.22	0.02	0.03	0.03	0.07	0.06	0.04
Particle Size Distribution of Fine Fractions (<2mm)	Coarse Sand 0.2-2.0mm	%	*	*	*	7.60	*	10.50	*	4.80	4.30	12.70	7.80
	Fine Sand 0.02-0.2mm	%	*	*	*	22.70	*	61.10	*	19.80	60.60	69.70	67.60
	Silt 0.002-0.02mm	%	*	*	*	25.10	*	12.60	*	32.80	15.70	5.40	7.10
	Clay <0.002mm	%	*	*	*	36.40	*	15.80	*	41.50	18.80	12.20	15.60

APPENDIX B: ACID BASE ACCOUNT AND TOTAL METAL CONCENTRATIONS

Table B-1: Total S results for all samples with values >0.15% shown in red

Element		S (%)
Limit		0.01
Method		/CSA
Sample	Lithology	
HW53	Lower Tillite	0.1
HW54	Lower Tillite	0.05
HW47	Lower Tillite	0.06
HW48	Lower Tillite	0.17
HW49	Lower Tillite	0.16
HW51	Lower Tillite	0.38
HW52	Lower Tillite	0.34
HW57	Lower Tillite	0.15
HW58	Lower Tillite	0.3
HW05	Saprolite	0.31
HW06	Saprolite	0.04
HW07	Saprolite	0.02
HW15	Saprock	<0.01
HW16	Saprock	0.02
HW17	Saprock	<0.01
HW02	Tertiary Cover	<0.01
HW08	Saprolite	0.04
HW09	Saprolite	0.06
HW10	Saprolite	0.05
HW18	Saprock	0.08
HW19	Saprock	<0.01
HW20	Saprock	0.04
HW25	Upper Mudstone	0.11
HW26	Upper Mudstone	0.2
HW29	Upper Tillite	0.07
HW30	Upper Tillite	0.41
HW31	Upper Siltstone	0.89
HW32	Upper Siltstone	0.06
HW33	Lower Siltstone	0.19
HW34	Lower Siltstone	0.03
HW39	Lower Sandstone	0.03
HW40	Lower Sandstone	0.08
HW43	Lower Tillite	0.09
HW23	Upper Mudstone	0.04
HW24	Upper Mudstone	0.07
HW27	Upper Tillite	0.07

Table B-2: Median total metal concentrations with GAI Index, EIL and HIL exceedances shown in red

Element	Units	Limit	Method	HW54	HW48	HW52	HW57	HW05	HW06	HW15	HW02	HW10	HW19	HW20	HW26	HW30	HW31	HW34	HW39	HW40	HW24	HW27
				Lower Tillite	Lower Tillite	Lower Tillite	Lower Tillite	Saprolite	Saprolite	Saprock	Tertiary Cover	Saprolite	Saprock	Saprock	Upper Mud-stone	Upper Tillite	Upper Siltstone	Lower Siltstone	Lower Sand-stone	Lower Sand-stone	Upper Mud-stone	Upper Tillite
Ag	ppm	0.05	4A/MS	<0.05	<0.05	1.88	<0.05	0.71	0.14	0.06	0.29	0.17	0.32	0.08	0.05	<0.05	0.06	0.05	<0.05	<0.05	<0.05	<0.05
GAI Index	ppm			-	-	4.16	-	2.76	0.42	-0.81	1.47	0.70	1.61	-0.39	-1.07	-	-0.81	-1.07	-	-	-	-
Al	ppm	50	4A/MS	33285	38680	30050	42649	62060	76527	57964	33953	79196	49160	48249	61877	54628	68900	77031	71312	49830	49109	70689
Abundance in crust	ppm			82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000	82,000
As	ppm	0.5	4A/MS	2.1	2.3	2	2.8	9.1	8.7	5.5	6.8	5.7	8.1	3.3	10.3	5	32	3.2	3	3.9	4.7	4.5
GAI Index	ppm			-0.10	0.03	-0.17	0.32	2.02	1.95	1.29	1.60	1.34	1.85	0.55	2.19	1.15	3.83	0.51	0.42	0.79	1.06	1.00
EIL	ppm			100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
HIL	ppm			300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
Ba	ppm	0.1	4A/MS	750.3	446.1	345.6	462.8	885	681.4	2217.9	223.3	722.5	485.6	532.2	592.8	548	499.4	472.4	442.9	476.3	531.3	642.7
GAI Index	ppm			0.00	-0.75	-1.12	-0.70	0.24	-0.14	1.56	-1.75	-0.05	-0.63	-0.49	-0.34	-0.45	-0.59	-0.67	-0.76	-0.66	-0.50	-0.22
Be	ppm	0.05	4A/MS	0.92	1.22	0.93	1.34	4.69	2.67	2.91	1.25	3.29	3.56	1.37	2.47	1.97	2.3	3.17	3.42	1.33	1.72	2.73
GAI Index	ppm			-2.08	-1.68	-2.07	-1.54	0.27	-0.55	-0.42	-1.64	-0.25	-0.13	-1.51	-0.66	-0.99	-0.76	-0.30	-0.19	-1.55	-1.18	-0.51
Bi	ppm	0.01	4A/MS	0.06	0.09	0.05	0.08	0.32	0.5	0.17	0.16	0.53	0.11	0.1	0.23	0.15	0.32	0.47	0.41	0.1	0.12	0.39
GAI Index	ppm			-0.26	0.32	-0.53	0.15	2.15	2.80	1.24	1.15	2.88	0.61	0.47	1.68	1.06	2.15	2.71	2.51	0.47	0.74	2.44
Cd	ppm	0.02	4A/MS	<0.02	0.02	<0.02	0.02	0.03	0.05	0.02	<0.02	0.1	0.04	<0.02	0.33	0.04	0.08	0.08	0.07	0.03	0.07	0.06
GAI Index	ppm			<0.02	-3.04	<0.02	-3.04	-2.46	-1.72	-3.04	<0.02	-0.72	-2.04	<0.02	1	-2.04	-1.04	-1.04	-1.24	-2.46	-1.24	-1.46
HIL	ppm			90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Ce	ppm	0.01	4A/MS	33.57	37.97	29	45.3	79	104.83	111.22	26.61	109.48	74.87	44.55	63.52	59.96	85.98	93.08	85.17	53.35	60.59	96.62
GAI Index	ppm			-1.60	-1.43	-1.81	-1.17	-0.37	0.04	0.12	-1.94	0.10	-0.45	-1.20	-0.68	-0.77	-0.25	-0.13	-0.26	-0.94	-0.75	-0.08
Co	ppm	0.1	4A/MS	4.9	4.3	3.8	3.9	48.2	6.5	32.7	9.9	17.4	3	2	9.9	7.4	12.1	10.9	9.7	4.3	6	10.1
GAI Index	ppm			-2.61	-2.80	-2.98	-2.94	0.68	-2.21	0.12	-1.60	-0.79	-3.32	-3.91	-1.60	-2.02	-1.31	-1.46	-1.63	-2.80	-2.32	-1.57
HIL	ppm			300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
Cr	ppm	1	4A/MS	85	100	105	94	68	70	38	103	81	26	66	41	103	52	63	60	85	99	58
GAI Index	ppm			-0.82	-0.58	-0.51	-0.67	-1.14	-1.10	-1.98	-0.54	-0.89	-2.53	-1.18	-1.87	-0.54	-1.53	-1.25	-1.32	-0.82	-0.60	-1.37
HIL	ppm			300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
Cs	ppm	0.05	4A/MS	1.22	2.23	1.19	1.86	7.05	10.91	5.08	2.32	9.37	3.9	3.62	5.23	3.57	17.05	12.88	10.21	3	4.59	7.95
GAI Index	ppm			-1.88	-1.01	-1.92	-1.27	0.65	1.28	0.17	-0.96	1.06	-0.21	-0.31	0.22	-0.33	1.92	1.52	1.18	-0.58	0.03	0.82
Cu	ppm	0.5	4A/MS	5.6	7.4	7.1	3.9	24.3	24.7	16.8	9.8	27	9.4	5.8	12.3	9.8	17.4	24.9	21.4	4.3	7.1	23.6
GAI Index	ppm			-3.74	-3.34	-3.40	-4.27	-1.63	-1.60	-2.16	-2.94	-1.47	-3.00	-3.69	-2.61	-2.94	-2.11	-1.59	-1.81	-4.12	-3.40	-1.67
EIL	ppm			130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
HIL	ppm			17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000
Dy	ppm	0.01	4A/MS	2.18	2.28	1.9	2.65	6.99	4.9	3.75	2.37	6.19	4.31	2.38	3.72	3.45	4.66	5.34	4.99	2.82	3.37	5.84
GAI Index	ppm			-2.05	-1.98	-2.24	-1.76	-0.36	-0.88	-1.26	-1.93	-0.54	-1.06	-1.92	-1.27	-1.38	-0.95	-0.75	-0.85	-1.67	-1.42	-0.62
Er	ppm	0.01	4A/MS	1.34	1.42	1.15	1.65	4.07	2.79	1.99	1.41	3.37	2.56	1.42	2.31	2.17	2.66	3.06	2.92	1.63	1.99	3.1
GAI Index	ppm			-2.09	-2.01	-2.31	-1.79	-0.49	-1.03	-1.52	-2.02	-0.76	-1.15	-2.01	-1.30	-1.39	-1.10	-0.90	-0.96	-1.81	-1.52	-0.88

Element	Units	Limit	Method	HW54	HW48	HW52	HW57	HW05	HW06	HW15	HW02	HW10	HW19	HW20	HW26	HW30	HW31	HW34	HW39	HW40	HW24	HW27
				Lower Tillite	Lower Tillite	Lower Tillite	Lower Tillite	Saprolite	Saprolite	Saprock	Tertiary Cover	Saprolite	Saprock	Saprock	Upper Mudstone	Upper Tillite	Upper Siltstone	Lower Siltstone	Lower Sandstone	Lower Sandstone	Upper Mudstone	Upper Tillite
Eu	ppm	0.01	4A/MS	0.63	0.71	0.56	0.83	1.67	1.46	1.26	0.55	1.58	1.13	0.77	1.1	0.95	1.29	1.44	1.31	0.79	0.91	1.51
GAI Index	ppm			-2.32	-2.15	-2.49	-1.92	-0.92	-1.11	-1.32	-2.52	-1.00	-1.48	-2.03	-1.52	-1.73	-1.29	-1.13	-1.27	-2.00	-1.79	-1.06
Ga	ppm	0.05	4A/MS	7.69	9.1	6.95	9.58	16.34	19.94	13.05	8.91	21.86	11.04	11	16.49	13.8	17.73	20.88	19.06	11.95	11.6	18.96
GAI Index	ppm			-1.81	-1.57	-1.96	-1.49	-0.72	-0.44	-1.05	-1.60	-0.30	-1.29	-1.30	-0.71	-0.97	-0.61	-0.37	-0.50	-1.18	-1.22	-0.51
Gd	ppm	0.01	4A/MS	2.53	2.62	2.15	3.18	8.21	6.35	5.07	2.71	7.35	5.24	3.02	4.47	3.97	5.9	6.7	6.22	3.44	4.02	6.67
GAI Index	ppm			-2.19	-2.14	-2.43	-1.86	-0.49	-0.86	-1.19	-2.09	-0.65	-1.14	-1.94	-1.37	-1.54	-0.97	-0.79	-0.89	-1.75	-1.52	-0.79
Ge	ppm	0.1	4A/MS	1.1	1.2	1	1.2	1.2	1.3	1.1	1.1	1.5	1.1	1	1.2	1.2	1.6	1.6	1.7	1.1	1.2	1.6
GAI Index	ppm			-1.30	-1.17	-1.43	-1.17	-1.17	-1.05	-1.30	-1.30	-0.85	-1.30	-1.43	-1.17	-1.17	-0.75	-0.75	-0.67	-1.30	-1.17	-0.75
Hf	ppm	0.05	4A/MS	3.16	3.14	2.65	4.3	3.6	4.25	4.11	1.82	3.87	6.25	3.5	3.76	4.35	4.28	4.23	3.96	3.15	4.53	3.94
GAI Index	ppm			-1.33	-1.34	-1.58	-0.89	-1.14	-0.90	-0.95	-2.13	-1.04	-0.35	-1.18	-1.08	-0.87	-0.89	-0.91	-1.01	-1.34	-0.81	-1.01
Ho	ppm	0.01	4A/MS	0.43	0.44	0.36	0.51	1.35	0.89	0.66	0.46	1.12	0.82	0.47	0.74	0.68	0.84	1.03	0.94	0.53	0.63	1.03
GAI Index	ppm			-2.29	-2.25	-2.54	-2.04	-0.64	-1.24	-1.67	-2.19	-0.91	-1.36	-2.16	-1.50	-1.63	-1.32	-1.03	-1.16	-1.99	-1.74	-1.03
In	ppm	0.01	4A/MS	0.02	0.02	0.01	0.02	0.05	0.07	0.04	0.03	0.07	0.03	0.03	0.05	0.04	0.06	0.06	0.07	0.03	0.02	0.05
GAI Index	ppm			-1.88	-1.88	-2.88	-1.88	-0.56	-0.07	-0.88	-1.29	-0.07	-1.29	-1.29	-0.56	-0.88	-0.29	-0.29	-0.07	-1.29	-1.88	-0.56
La	ppm	0.01	4A/MS	16.64	18.99	14.87	22.6	35.8	51.24	53.27	13.4	51.67	38.33	22.61	31.45	30.64	43.42	46.11	42.23	27.24	29.79	46.85
GAI Index	ppm			-1.53	-1.34	-1.69	-1.09	-0.42	0.09	0.15	-1.84	0.11	-0.32	-1.09	-0.61	-0.65	-0.14	-0.06	-0.18	-0.82	-0.69	-0.03
Li	ppm	0.1	4A/MS	13.8	15.7	16.9	17.7	26.1	36.5	9.1	18.2	61.3	10.1	9.2	27.7	27.7	44.8	56.2	50.7	18.5	22.9	49.2
GAI Index	ppm			-1.12	-0.93	-0.83	-0.76	-0.20	0.28	-1.72	-0.72	1.03	-1.57	-1.71	-0.12	-0.12	0.58	0.91	0.76	-0.70	-0.39	0.71
Lu	ppm	0.01	4A/MS	0.19	0.2	0.16	0.25	0.58	0.42	0.3	0.18	0.46	0.37	0.21	0.34	0.31	0.35	0.43	0.4	0.23	0.29	0.41
GAI Index	ppm			-2.01	-1.94	-2.26	-1.61	-0.40	-0.87	-1.35	-2.09	-0.73	-1.05	-1.87	-1.17	-1.30	-1.13	-0.83	-0.94	-1.73	-1.40	-0.90
Mn	ppm	1	4A/MS	466	166	869	170	2480	177	6499	545	572	72	192	255	271	313	345	319	163	225	790
GAI Index	ppm			-1.61	-3.10	-0.71	-3.07	0.80	-3.01	2.19	-1.39	-1.32	-4.31	-2.89	-2.48	-2.39	-2.19	-2.05	-2.16	-3.13	-2.66	-0.85
HIL	ppm			19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000
Mo	ppm	0.1	4A/MS	0.3	0.6	0.8	0.3	1	0.5	1	1	0.6	<0.1	0.3	0.4	1.7	0.8	0.2	0.4	0.3	0.4	1
GAI Index	ppm			-2.91	-1.91	-1.49	-2.91	-1.17	-2.17	-1.17	-1.17	-1.91	-	-2.91	-2.49	-0.40	-1.49	-3.49	-2.49	-2.91	-2.49	-1.17
Nb	ppm	0.05	4A/MS	4.53	5.72	3.96	6.81	11.78	15.87	9.7	7.02	16.92	10.1	6.92	10.85	9.5	12.37	13.44	12.8	7.64	8.24	12.62
GAI Index	ppm			-2.73	-2.39	-2.92	-2.14	-1.35	-0.92	-1.63	-2.10	-0.83	-1.57	-2.12	-1.47	-1.66	-1.28	-1.16	-1.23	-1.97	-1.86	-1.25
Nd	ppm	0.01	4A/MS	14.3	16.09	12.07	19.21	35.04	42.86	39.69	11.8	44.42	31.92	18.66	26.6	25.13	36.58	40.26	36.55	21.9	25.43	40.11
GAI Index	ppm			-1.99	-1.82	-2.24	-1.57	-0.70	-0.41	-0.52	-2.27	-0.36	-0.84	-1.61	-1.10	-1.18	-0.64	-0.50	-0.64	-1.38	-1.16	-0.51
Ni	ppm	0.5	4A/MS	10.3	9.9	8.2	9.4	41.7	49.9	15.1	16.5	34.8	10.9	4.9	20.3	17.3	27.9	26	21.3	7.3	12.4	22.5
GAI Index	ppm			-3.54	-3.60	-3.87	-3.67	-1.52	-1.27	-2.99	-2.86	-1.79	-3.46	-4.61	-2.56	-2.79	-2.10	-2.21	-2.49	-4.04	-3.27	-2.42
EIL	ppm			60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
HIL	ppm			1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Pb	ppm	0.5	4A/MS	10.3	15.2	11.1	14.7	21.2	31	31.5	10.9	35.2	18.9	25.7	27.1	18.3	26.3	25.7	24.6	19.3	18.9	25.3
GAI Index	ppm			-1.03	-0.47	-0.92	-0.51	0.01	0.56	0.58	-0.95	0.75	-0.15	0.29	0.37	-0.20	0.32	0.29	0.23	-0.12	-0.15	0.27
EIL	ppm			1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Pr	ppm	0.01	4A/MS	3.81	4.41	3.35	5.29	8.76	11.99	11.64	3.07	12.26	8.76	5.11	7.28	6.88	10.11	10.9	9.92	6.13	7.09	11.04
GAI Index	ppm			-1.90	-1.69	-2.09	-1.43	-0.70	-0.25	-0.29	-2.21	-0.22	-0.70	-1.48	-0.97	-1.05	-0.50	-0.39	-0.52	-1.22	-1.01	-0.37

Element	Units	Limit	Method	HW54	HW48	HW52	HW57	HW05	HW06	HW15	HW02	HW10	HW19	HW20	HW26	HW30	HW31	HW34	HW39	HW40	HW24	HW27
				Lower Tillite	Lower Tillite	Lower Tillite	Lower Tillite	Saprolite	Saprolite	Saprock	Tertiary Cover	Saprolite	Saprock	Saprock	Upper Mud-stone	Upper Tillite	Upper Siltstone	Lower Siltstone	Lower Sand-stone	Lower Sand-stone	Upper Mud-stone	Upper Tillite
Rb	ppm	0.05	4A/MS	60.02	78.03	56.43	78.71	194.27	235.42	88.71	42.52	194.15	95.98	81.45	131.4	101.53	139.67	167.04	153.57	92.13	98.2	171.11
GAI Index	ppm			-1.17	-0.79	-1.26	-0.78	0.53	0.80	-0.61	-1.67	0.52	-0.49	-0.73	-0.04	-0.41	0.05	0.31	0.19	-0.55	-0.46	0.34
Re	ppm	0.002	4A/MS	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
GAI Index	ppm			-	-	-	-	-	-	-	-	1.74	-	-	2.32	-	-	-	-	-	-	-
Sb	ppm	0.05	4A/MS	0.14	0.25	0.18	0.23	0.36	0.54	0.29	0.24	0.37	0.31	0.28	0.26	0.25	0.69	0.53	0.56	0.26	0.26	0.28
GAI Index	ppm			-1.10	-0.26	-0.74	-0.38	0.26	0.85	-0.05	-0.32	0.30	0.05	-0.10	-0.21	-0.26	1.20	0.82	0.90	-0.21	-0.21	-0.10
Sc	ppm	0.1	4A/MS	4.2	4.2	3.4	4.8	10	13	7.4	4.9	13.8	6.2	5.5	8.8	9.1	10.7	13.2	11.4	5.2	6.1	11.6
GAI Index	ppm			-2.51	-2.51	-2.82	-2.32	-1.26	-0.88	-1.70	-2.29	-0.80	-1.95	-2.13	-1.45	-1.40	-1.17	-0.86	-1.07	-2.21	-1.98	-1.05
Se	ppm	0.5	4A/MS	<0.5	<0.5	<0.5	<0.5	1.5	1.4	0.7	0.6	2	0.8	0.5	0.9	0.7	0.9	1.3	1	0.6	0.6	1.2
GAI Index	ppm			-	-	-	-	4.32	4.22	3.22	3.00	4.74	3.42	2.74	3.58	3.22	3.58	4.12	3.74	3.00	3.00	4.00
Sm	ppm	0.01	4A/MS	2.77	2.96	2.37	3.65	7.73	7.88	6.73	2.49	8.43	6	3.47	5.05	4.56	7.07	7.87	7.06	4.06	4.69	7.63
GAI Index	ppm			-2.10	-2.00	-2.32	-1.70	-0.62	-0.59	-0.82	-2.25	-0.49	-0.98	-1.77	-1.23	-1.38	-0.75	-0.59	-0.75	-1.55	-1.34	-0.64
Sn	ppm	0.1	4A/MS	0.8	1.2	1	1.3	2.9	3.7	2.1	1.6	4	1.7	1.5	2.3	1.9	3.3	4.2	3.9	2	1.6	3.2
GAI Index	ppm			-2.04	-1.46	-1.72	-1.34	-0.19	0.17	-0.65	-1.04	0.28	-0.96	-1.14	-0.52	-0.80	0.00	0.35	0.24	-0.72	-1.04	-0.04
Sr	ppm	0.05	4A/MS	125.19	93.95	89.16	108.29	424.75	85.42	203.54	20.89	86.73	86.71	84.41	106.08	115.98	87.38	82.57	83.68	85.98	98.77	100.86
GAI Index	ppm			-2.15	-2.56	-2.64	-2.36	-0.39	-2.70	-1.45	-4.73	-2.68	-2.68	-2.72	-2.39	-2.26	-2.67	-2.75	-2.73	-2.69	-2.49	-2.46
Ta	ppm	0.01	4A/MS	0.39	0.46	0.32	0.53	0.92	1.25	0.81	0.52	1.29	0.83	0.57	0.82	0.74	0.97	1.11	1.07	0.63	0.66	1
GAI Index	ppm			-2.94	-2.71	-3.23	-2.50	-1.71	-1.26	-1.89	-2.53	-1.22	-1.85	-2.40	-1.87	-2.02	-1.63	-1.43	-1.49	-2.25	-2.18	-1.58
Tb	ppm	0.01	4A/MS	0.36	0.38	0.32	0.44	1.14	0.84	0.67	0.39	1.04	0.72	0.41	0.63	0.56	0.79	0.93	0.85	0.48	0.56	0.93
GAI Index	ppm			-2.20	-2.12	-2.37	-1.91	-0.53	-0.97	-1.30	-2.08	-0.67	-1.20	-2.01	-1.39	-1.56	-1.06	-0.83	-0.96	-1.78	-1.56	-0.83
Te	ppm	0.2	4A/MS	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
GAI Index	ppm			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Th	ppm	0.01	4A/MS	5.7	6.55	5.08	7.4	15.03	20.49	10.06	7.03	21.19	15.02	8.08	12.59	11.8	14.26	18.13	16.82	10.84	10.56	18.36
GAI Index	ppm			-1.66	-1.46	-1.83	-1.28	-0.26	0.19	-0.84	-1.36	0.24	-0.26	-1.16	-0.52	-0.61	-0.34	0.01	-0.10	-0.73	-0.77	0.03
Ti	ppm	5	4A/MS	1483	1615	1227	1900	2917	3865	2540	2139	4048	2840	1770	2600	2731	3280	3580	3331	1688	2251	3256
GAI Index	ppm			-2.50	-2.38	-2.78	-2.14	-1.53	-1.12	-1.73	-1.97	-1.05	-1.56	-2.25	-1.69	-1.62	-1.36	-1.23	-1.33	-2.32	-1.90	-1.37
Tl	ppm	0.02	4A/MS	0.29	0.4	0.3	0.4	1.4	0.88	0.74	0.38	0.89	0.77	0.45	0.67	0.51	0.95	0.78	0.74	0.53	0.54	0.73
GAI Index	ppm			-1.63	-1.17	-1.58	-1.17	0.64	-0.03	-0.28	-1.24	-0.02	-0.23	-1.00	-0.43	-0.82	0.08	-0.21	-0.28	-0.76	-0.74	-0.30
Tm	ppm	0.01	4A/MS	0.19	0.2	0.16	0.23	0.57	0.4	0.28	0.19	0.53	0.36	0.2	0.32	0.31	0.36	0.41	0.4	0.24	0.28	0.41
GAI Index	ppm			-1.92	-1.85	-2.17	-1.65	-0.34	-0.85	-1.36	-1.92	-0.44	-1.00	-1.85	-1.17	-1.22	-1.00	-0.81	-0.85	-1.58	-1.36	-0.81
U	ppm	0.01	4A/MS	1.11	1.18	0.91	1.47	2.15	3.54	2.25	0.79	3.67	2.62	1.51	2.16	1.78	2.6	3.19	2.86	2.04	2.77	2.33
GAI Index	ppm			-1.70	-1.61	-1.98	-1.29	-0.74	-0.02	-0.68	-2.19	0.03	-0.46	-1.25	-0.74	-1.02	-0.47	-0.17	-0.33	-0.82	-0.38	-0.63
V	ppm	1	4A/MS	30	30	23	32	122	110	39	58	110	35	29	57	59	71	90	79	27	36	87
GAI Index	ppm			-3.00	-3.00	-3.38	-2.91	-0.98	-1.13	-2.62	-2.05	-1.13	-2.78	-3.05	-2.07	-2.02	-1.76	-1.42	-1.60	-3.15	-2.74	-1.46
W	ppm	0.1	4A/MS	0.8	0.7	0.6	0.8	3.9	2.5	1.3	2.4	2.8	3	1.1	1.3	1.4	1.9	2.3	2.3	1.4	1.1	1.6
GAI Index	ppm			-0.91	-1.10	-1.32	-0.91	1.38	0.74	-0.21	0.68	0.90	1.00	-0.45	-0.21	-0.10	0.34	0.62	0.62	-0.10	-0.45	0.09
Y	ppm	0.05	4A/MS	11.94	11.85	10.28	14.02	37.93	21.71	16.17	13.24	29.01	22.46	11.95	19.68	18.05	22.49	27.53	25.24	14.85	17.62	27.55
GAI Index	ppm			-1.91	-1.93	-2.13	-1.68	-0.25	-1.05	-1.48	-1.77	-0.63	-1.00	-1.91	-1.19	-1.32	-1.00	-0.71	-0.83	-1.60	-1.35	-0.71

Element	Units	Limit	Method	HW54	HW48	HW52	HW57	HW05	HW06	HW15	HW02	HW10	HW19	HW20	HW26	HW30	HW31	HW34	HW39	HW40	HW24	HW27
				Lower Tillite	Lower Tillite	Lower Tillite	Lower Tillite	Saprolite	Saprolite	Saprock	Tertiary Cover	Saprolite	Saprock	Saprock	Upper Mud-stone	Upper Tillite	Upper Siltstone	Lower Siltstone	Lower Sand-stone	Lower Sand-stone	Upper Mud-stone	Upper Tillite
Yb	ppm	0.01	4A/MS	1.21	1.26	1.1	1.51	3.42	2.73	1.84	1.21	3.12	2.39	1.42	2.21	2.18	2.32	2.78	2.52	1.49	1.84	2.7
GAI Index	ppm			-2.03	-1.97	-2.17	-1.71	-0.53	-0.86	-1.43	-2.03	-0.67	-1.05	-1.80	-1.16	-1.18	-1.09	-0.83	-0.97	-1.73	-1.43	-0.87
Zn	ppm	1	4A/MS	20	22	15	21	89	81	37	20	85	34	18	41	40	71	83	76	36	33	75
GAI Index	ppm			-2.49	-2.35	-2.91	-2.42	-0.34	-0.47	-1.60	-2.49	-0.40	-1.73	-2.64	-1.46	-1.49	-0.66	-0.44	-0.57	-1.64	-1.77	-0.58
EIL	ppm			330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330
HIL	ppm			30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Zr	ppm	0.1	4A/MS	115.7	110.8	91.1	153.4	129.3	131.6	135.7	62.8	123.8	203.6	117.4	123.9	150	137.1	139.7	128.9	100.7	157.3	131.2
GAI Index	ppm			-1.30	-1.36	-1.65	-0.89	-1.14	-1.11	-1.07	-2.18	-1.20	-0.49	-1.28	-1.20	-0.93	-1.06	-1.03	-1.14	-1.50	-0.86	-1.12

APPENDIX C: ASBESTOS RESULTS

Meta Maya Group Pty. Ltd.
Unit 5, 78-84 Catalano Circuit
Canning Vale, WA 6155
T: 1300 928 963

Certificate of Analysis

(Materials)

Job No.: 2021-001-0076 **No. of Samples:** 7 **Sampled by:** Client **Samples Received:** 16/07/2020 **Report Issued:** 17/07/2020

Client: Intertek Genalysis **Client Reference:** 1979.00 2012550 **Attention:** Damien Carter **Email/Tel. No:** Damien.carter@intertek.com

MMG Sample No.	Client ID	Location/Description	Physical Structure	Sample Description	Analysis of Fibrous Content	
					Asbestos Identified	Other Fibres Identified
CD08148	1979.00 2012550	HW47	Core Sample	1153 g	No Asbestos Detected	No Other Fibres Detected
CD08149	1979.00 2012550	HW49	Core Sample	1236 g	No Asbestos Detected	No Other Fibres Detected
CD08150	1979.00 2012550	HW57	Core Sample	1090 g	No Asbestos Detected	No Other Fibres Detected
CD08151	1979.00 2012550	HW30	Core Sample	1220 g	No Asbestos Detected	No Other Fibres Detected
CD08152	1979.00 2012550	HW31	Core Sample	1217 g	No Asbestos Detected	No Other Fibres Detected
CD08153	1979.00 2012550	HW34	Core Sample	1362 g	No Asbestos Detected	No Other Fibres Detected

Test Specification Employed: Analysis conducted in accordance with the Polarised Light Microscopy (PLM) and Dispersion Staining (DS) method established in *AS4964-2004 Method for the qualitative identification of asbestos in bulk samples*, as referenced in MMG in-house test *Procedure MMG-SD-P-001.LS.*

Client Received Samples: No responsibility is taken for errors that may have arisen during sampling or transportation of client supplied samples, as received by the laboratory.

Limit of Detection (LOD) & Limit of Report (LOR): Known limitations of the test procedure are:

- PLM is a qualitative technique
- The less encountered asbestos mineral fibres (i.e. actinolite, anthophyllite and tremolite) exhibit a wide range of optical properties that preclude unequivocal identification by PLM and Dispersion Staining (DS). The method is used to positively identify the three major asbestos minerals: amosite ("brown"), chrysotile ("white") and crocidolite ("blue")
- Valid identification requires that samples contain a sufficient quantity of the unknown fibres in excess of the practical detection limit used (i.e. practical detection limit of 0.01 - 0.1% w/w equivalent to 0.1 - 1g/kg (*AS4964-2004:App.A4*)
- Even after disintegration, it can be very difficult or impossible to detect the presence of asbestos in some materials using PLM and DS. This is due to the low grade, small length or diameter of fibres present in the material, or to the fact that very fine fibres have been distributed intimately throughout.
- Method does not cover identification of airborne or water-borne asbestos

SMF = Synthetic Mineral Fibres.
UMF = Unknown Mineral Fibres. Mineral fibres of unknown type and detected fibres may or may not be asbestos- Confirmation by another independent analytical technique may be necessary

Approved Identifier
Christine Smart

NATA

Accredited for compliance with ISO/IEC 17025 -Testing
Accreditation Number: 19429

Approved Signatory
Christine Smart

MMG Sample No.	Client ID	Location/Description	Physical Structure	Sample Description	Analysis of Fibrous Content Asbestos Identified	Other Fibres Identified
CD08154	1979.00 2012550	HW24	Core Sample	1294 g	No Asbestos Detected	No Other Fibres Detected

Comments/Observations:

Accredited for compliance with ISO/IEC 17025 -Testing
Accreditation Number: 19429
The results of the tests, calibrations and/or measurements included in this document are traceable to Australian and national standards

Landloch

TOOWOOMBA
PO Box 57 HARLAXTON QLD 4350
Phone 07 4613 1825 | **Fax** 07 4613 1826

PERTH
PO Box 5175 SOUTH LAKE WA 6164
Phone 08 9494 2835 | **Fax** 07 4613 1826

NEWCASTLE
PO Box 7017 REDHEAD NSW 2290
Phone 02 4965 7717 | **Fax** 07 4613 1826

Newcrest Mining Limited
Havieron Project Joint Venture
Level 1, 1 Centro Avenue
Subiaco, WA, 6008

7 December 2021

2664.21a (Rev 1)

Attn: Greg Barrett, Tara Garrood

Addendum: Havieron Tailings Geochemical Characterisation

A Waste Characterisation Study was completed by Landloch and Environmental Geochemistry International (EGi) in October 2021. Following completion of the Waste Characterisation Study, additional test work was completed on a metallurgical tailings sample to quantify the key geochemical attributes of tailings produced by the Havieron Project.

A memorandum detailing the results of the geochemical characterisation of the Havieron Project tailings can be found as an addendum to this report.

Overall, the results of the geochemical characterisation suggest that the tailings should not be a significant source of acidity, but may generate significant loadings of sulphate salinity and slightly elevated loadings of certain metals on exposure to oxidising conditions.

If you have any questions regarding this report, please contact me.

Regards

Christine Lison
Environmental Consultant
MPhil (Environment and Agriculture)
lison@landloch.com.au

HAVIERON PROJECT – STAGE 2 WASTE CHARACTERISATION STUDY

Newcrest Mining Limited

October 2021

Disclaimer: All care and diligence has been exercised in testing, interpreting data and the development of recommendations presented in this report. The monitoring and testing have been undertaken in a skilled, professional manner, according to accepted practices. Specific circumstances and research findings after the date of publication may influence the accuracy of the data and recommendations within this report.

The landscape is not uniform. Because of this non-uniformity, no monitoring, testing or sampling technique can produce completely precise results for any site. Any conclusions based on the monitoring and/or testing presented in this report can therefore only serve as a 'best' indication of the environmental condition of the site at the time of preparing this document. It should be noted that site conditions can change with time.

The information that comprises this report should only be used within the limitations stipulated in this report. Landloch does not accept any risks and responsibilities for losses, damages, costs and other consequences resulting from using any information, material and recommendations in this report.

TOOWOOMBA
PO Box 57
HARLAXTON QLD 4350
Phone (07) 4613 1825

PERTH
PO Box 5175
SOUTH LAKE WA 6164
Phone (08) 9494 2835

NEWCASTLE
PO Box 1102
Warners Bay NSW 2282
Phone (02) 4965 7717

Landloch Pty Ltd
A.C.N. 011 032 803
A.B.N. 29011032803

Web site: www.landloch.com.au
Email: admin@landloch.com.au

Project Number: 2264.21a

Report Title: Havieron Project Stage 2 Waste Characterisation Study

Client: Newcrest Mining Limited

Review History

Version Number	Prepared by:	Reviewed by:	Date
0 (Draft)	C. Lison, A. Botfield	R. Schumann, W. Stewart, E. Howard, G. Barrett	20/10/2021
1 (Final)	C. Lison		29/10/2021

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Newcrest Mining Limited (Newcrest) are undertaking a feasibility study for the proposed Havieron Project (the Project) that is targeting a gold-copper mineralisation contained within Proterozoic rocks which underlie a 420m thick Permian cover sequence. Extraction of the resource is planned to be undertaken via development of a boxcut and decline (Stage 1) and sub-level open stope underground mining methods (Stage 2).

Landloch was engaged by Newcrest to undertake a waste characterisation study for Stage 2 of the Project. The aim of this waste characterisation study is to:

- Identify the broad geology and different types of waste in the Project.
- Determine the potential limitations of the different waste types.
- Provide advice on management of each of those wastes for use as a rehabilitation material.

The existing information relating to wastes was reviewed and a waste sampling methodology was developed. Landloch reviewed the drilling database in consultation with Newcrest geologists. Geological units to be disturbed by mining were identified, and waste samples were selected from the drilling database that were deemed to be representative of waste types to be disturbed.

A total of 50 waste samples were assessed. Nine rock units within the deposit were targeted during the sampling process including Calcite Cemented Breccia (36% of samples), Siltstone (12% of samples), Crackle Breccia (10% of samples), Crescent Zone (massive sulphide) (10% of samples), Dolerite (6% of samples), Diorite (6% of samples), Conglomerate (6% of samples), Bedded Sediments (6% of samples), and Actinolite Cemented Breccia (4% of samples).

All samples were assessed for pH, Electrical Conductivity, Total sulphur, sulphide sulphur, acid-base accounting parameters, and Naturally Occurring Radioactive Material (NORM). Various subsets of samples were also tested for:

- Elemental concentrations in the solids. The same samples were then flushed with deionised water and elemental concentrations in the leachate were assessed to consider seepage water quality.
- Rock durability indices
- Structural stability indices for the fine fraction.
- Asbestiform materials.

Specialised geochemical test work was undertaken to help resolve any uncertainties in initial acid-base accounting classifications and provide more information on geochemical characteristics. This included:

- Sequential NAG tests;
- Acid-base characteristic curves (ABCC);
- Sulphur speciation;
- Kinetic NAG tests;
- Peroxide extraction and testing of metal concentrations; and
- Carbon forms.

An outline of the methods used is given in Section 3 of the report, and results and their interpretation are presented in Sections 4 and 5, respectively. Complete tabulation of the data is provided as appendices.

From the results of the test work it can be inferred that the following rock types appear suitable for use as rock armour or surface materials:

- Dolerite and Bedded Sediments (~59% of all waste rock). The majority of these rock units are expected to be NAF and are unlikely to generate adverse drainage water quality in the short or long term.
- Actinolite Cemented Breccia or Calcite Cemented Breccia (~14% of all waste rock). These materials could be used to supplement the Dolerite or Bedded Sediment as rock armour or cover material. The majority of these materials are expected to be NAF but greater rigor will be required for segregation and handling of these wastes, given the close proximity of these rock units to the high sulphide ore zone.

The following materials may require encapsulation or specific acid rock drainage (ARD) mitigation strategies:

- Crescent Zone material (~1% of all waste rock). This rock type has high levels of elemental enrichment and is likely to generate significant loadings of acidity, sulphate salinity, and metals and metalloids if placed at or near the surface of a waste rock landform. If this material does come to surface it will require a series of ARD mitigation strategies (e.g. material tracking and segregation, appropriately designed PAF cell and cover design.
- Diorite (proportion of all waste rock unknown). This rock type also has high levels of elemental enrichment and may generate moderate loadings acidity, sulphate salinity, and metals and metalloids if placed at or near the surface of a waste rock landform. This material should be treated as representing a lower ARD risk than Crescent Zone material, but where Diorite correlates with higher total sulphur waste rock, the same ARD mitigation strategies as those outlined for the crescent zone waste rock should apply.
- Crackle Breccia (4.8% of all waste rock). This material has high levels of elemental enrichment primarily in relation to copper.
- Conglomerate and Siltstone at the base of the Permian cover (expected to be a minor fraction of waste brought to surface). These materials are saline, have marginal to poor durability, and a high proportion of fines. They are unsuitable for use as rehabilitation rock armour or surface covers due to the higher risk of erosion. There is also potential for the materials to generate moderate loadings of acidity, sulphate salinity, and metals and metalloids if place at or near the surface of a waste rock landform.

1 INTRODUCTION

1.1 Overview

Landloch previously completed a baseline Waste Characterisation Study for Stage 1 of the Havieron Project Joint Venture which covered the development of a boxcut and decline (Landloch 2021). Newcrest Mining Limited (Newcrest) is now seeking to complete a waste material characterisation for Stage 2 of the proposed Havieron Project (the Project) which involves the development of a sub-level open stope underground mine and associated waste rock landforms.

Initial characterisation test work (Stage 1) was completed in July 2021. Since then, additional specialised geochemical test work has been undertaken to refine initial acid-base accounting classifications and further define the risk of metalliferous and saline drainage. This report provides an overview of results for all waste characterisation test work associated with Stage 2 of the Havieron Project.

This waste characterisation study is anticipated to be used as part of the approval process, as well as in preparing the mine closure plan in accordance with the Department of Mines, Industry Regulation and Safety (DMIRS) *Statutory Guidelines for Mine Closure Plans* (DMIRS 2020). The statutory guideline states that:

> *"Comprehensive characterisation of materials (including soils and wastes) is critical to effective closure planning and successful progressive rehabilitation. This process should start during the exploration phase and continue throughout the life of the mine. Characterisation of material allows for separation and selective placement of materials considered beneficial to rehabilitation and materials that may inhibit rehabilitation."*

DMIRS provides additional information relating to materials characterisation in the *Draft Guidance for Materials Characterisation Baseline Data Requirements for Mining Proposals* (DMP 2016a). Broadly, characterisation of wastes should be undertaken to evaluate the physical stability and potential plant growth potential of wastes, and to identify risks associated with dispersive, asbestiform, or radioactive materials, and materials that may produce acidic, metalliferous, or saline drainage.

Additionally, the characterisation work has been undertaken in accord with Newcrest's *Acid and Metalliferous Drainage Management Standard (EN ST01)* (Newcrest 2016). This standard outlines Newcrest's requirements for baseline characterisation and sampling of wastes to be undertaken, in order to identify the geological setting and the potential for acid and metalliferous drainage.

1.2 Scope of work

The aim of this Stage 2 waste characterisation study is to:

- Identify the broad geology and different types of waste associated with the development of the sub-level open stope underground mine.
- Determine the potential limitations of the different waste types.
- Provide advice on management of each waste type for use as a rehabilitation material.

2 ENVIRONMENTAL SETTING

2.1 Project location

The Project is located approximately 400km south-east of Port Hedland and approximately 350km north-west of Newman, within the Pilbara region of Western Australia (Figure 1). The Project is defined within mining tenement M45/1287.

2.2 Climate

2.2.1 Rainfall

The climate of the Project area is described as semi-arid with hot dry summers and mild winters (van Vreeswyk *et al.* 2004). Mean annual rainfall is low and rainfall in August to November tends to be lower than for the remainder of the year (Table 1)[1]. Mean monthly pan evaporation is invariably higher than mean monthly rainfall, indicating that water is limited and landform surfaces are likely to be dry for much of the time. This further indicates that the movement of water to depth and its interaction with more deeply placed wastes may be limited.

Table 1: Mean monthly rainfall, pan evaporation, and daily maximum temperature for Telfer Aero weather station (013030) (BoM 2021).

Month	Mean Monthly Rainfall (mm)	Mean Monthly Pan Evaporation (mm)	Mean Daily Maximum Temperature (°C)
January	63.2	443.3	40.3
February	95.1	361.2	38.7
March	69.4	381.3	37.6
April	17.7	321.0	34.7
May	18.7	241.8	29.1
June	12.1	192.0	25.4
July	11.2	213.9	25.6
August	4.7	260.4	28.5
September	2.0	336.0	33.0
October	2.9	440.2	37.4
November	15.0	465.0	39.6
December	47.1	468.1	40.3
	364.2 (MEAN ANNUAL)	**4,124** (MEAN ANNUAL)	**34.2** (MEAN DAILY)

---

[1] Rainfall and temperature patterns were sourced from the nearest available weather station (Telfer Aero), located approximately 45 km to the west of the Project.

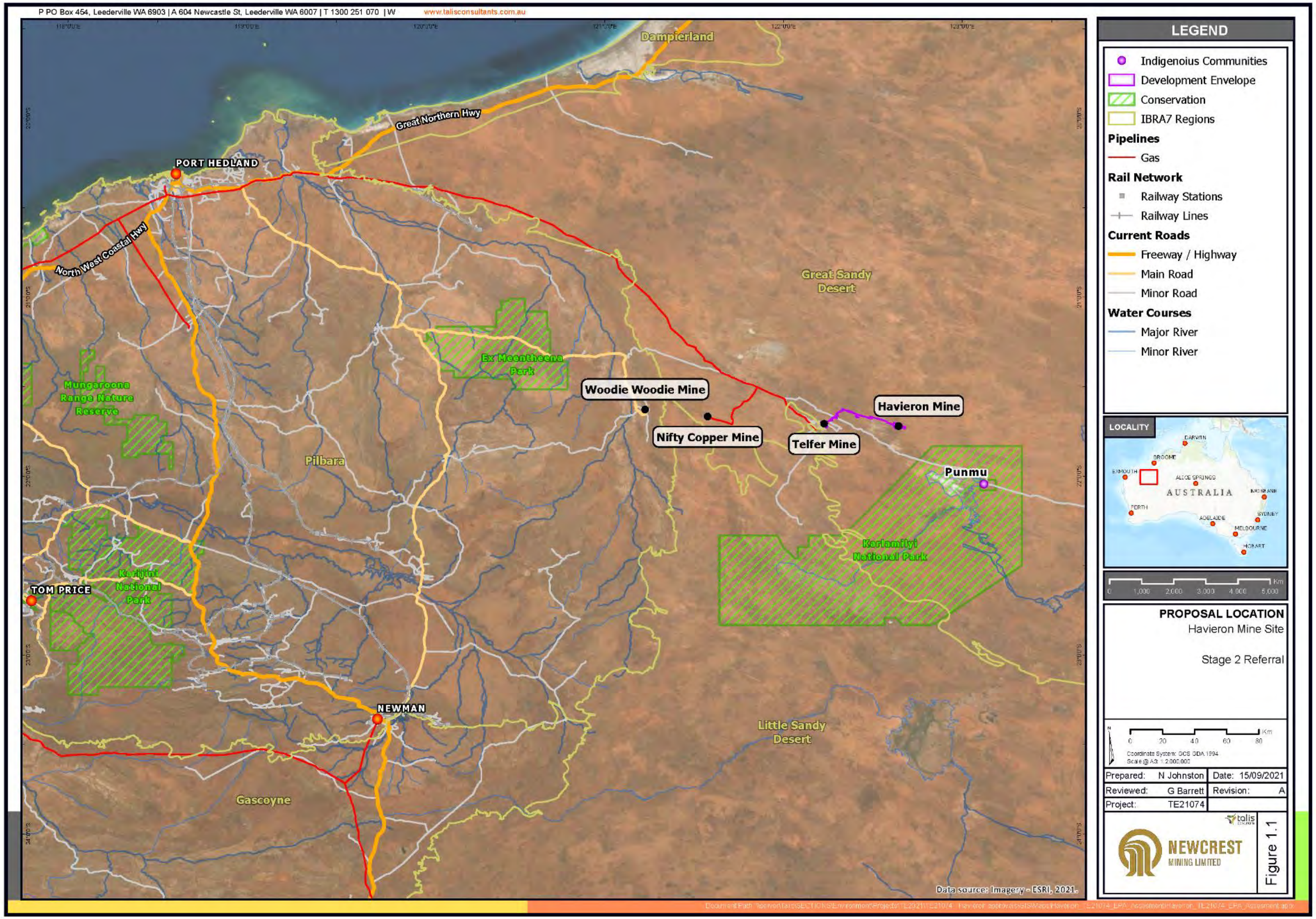


Figure 1: Project location

2.3 Geology and mineralogy

2.3.1 Regional geology

The Project is located in the Paleo to Neoproterozoic Paterson Province, a composite orogenic belt defined by outcrop-exposed geology and magnetic data that extends 2000km in a north-west to south-east direction from the northern Western Australian coast through to central Australia. The Paterson Province is flanked to the west and south-west by Archaean and Proterozoic rocks of the Pilbara Craton and are unconformably overlain to the north-east by sedimentary rocks of the Phanerozoic Canning Basin.

2.3.2 Project geology and mineralisation

The Project is targeting a gold-copper deposit contained within the Proterozoic Lamil group Puntapunta formation that was deposited in a marine carbonate-dominated shelf environment and comprises dolomitic siltstone, rare limestone, dolomitic sandstone, chert, and shale. It underlies a 420m thick cover of Permian fluvioglacial and diamictic sedimentary rocks (e.g. mudstones, tillites, siltstones, and mudstones).

The deposit is described as an ovoid-shaped zone of variable brecciation, alteration, and sulphide mineralisation. The zone is 650m by 350m and lies in a north-west orientation and extends from the basement contact with the Permian cover unconformity to greater than 1400m below surface (Figure 2).

The boundary of the deposit, defined by the presence of crackle brecciation, generally appears to be at the metamorphic contact between dominantly biotite-rich metasiltstone to meta-arenite (BS) facies outside, and dominantly calc silicate actinolite marble (CS) facies within.

The breccia zones can be defined as unmineralized crackle and mineralised cemented breccias. On the margins of the breccia exists a zone of sulphide mineralisation termed the Crescent Zone that is related to the highest grades in the system. The breccia is intruded by a 20-30m wide north-north-east trending, steeply east dipping, post-mineralisation dyke (Newcrest 2020).

Newcrest's exploration team has identified four key target regions within the deposit (Figure 3):

- South-East Crescent and Breccia;
- North-West Crescent;
- Northern Breccia; and
- Eastern Breccia.

The Crescent Zone is characterised by a series of massive to semi-massive sulphide replacement/open space infill units, that have a subvertical dip and trend parallel to the ovate breccia zone. The zone is best developed on the south-east closure creating a crescent like geometry. The massive sulphide units are separated from one another by variably mineralised calcite-cemented breccias which has inflated the rock package (Newcrest 2020).

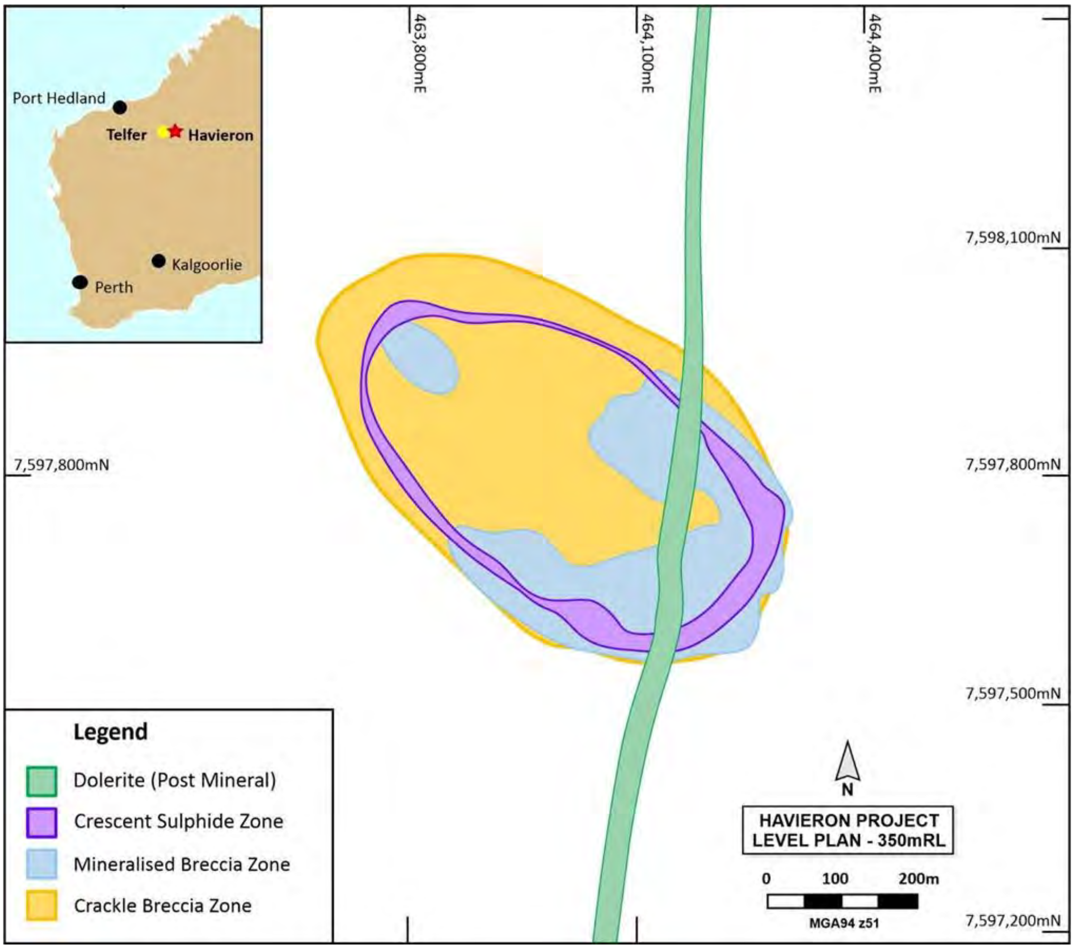


Figure 2: Plan view showing Crescent Sulphide, Crackle Breccia and mineralised Cemented Breccia zones at the -350mRL projected to surface. Also shown is the post-mineralisation Dolerite (Source: Newcrest).

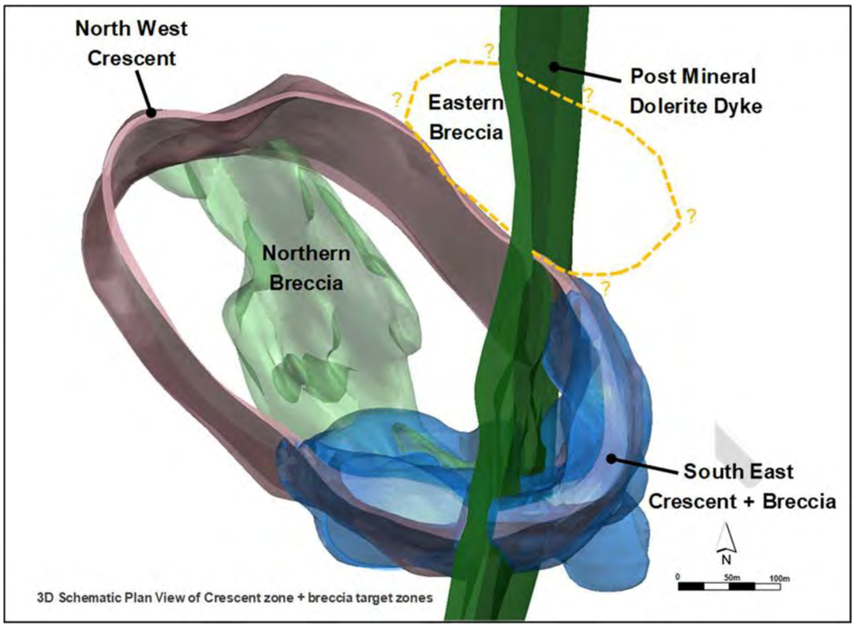


Figure 3: Schematic plan view of crescent and breccia zone target zones and post mineralisation targets (Source: Newcrest).

The crescent zone can be divided into four massive sulphide units (Figure 4) (Newcrest 2020):

- PYR – Coarse grained massive pyrite, with lesser marcasite and interstitial calcite, siderite, and white clay. PYR may contain minor amounts of chalcopyrite, sphalerite, and galena, as well as residual early pyrrhotite. It is better developed at higher levels close to the unconformity with the Permian cover.
- POR – Massive to locally banded pyrrhotite with locally abundant chalcopyrite.
- PCR – Like POR, but highly carbonate enriched, typically calcite, but may be dolomite or siderite.
- PQR – Like POR but can contain abundant chalcopyrite with local zones of quartz-chalcopyrite veins. PQR typically occurs on the footwall of the Crescent zone. It is associated with the highest gold grades at Havieron.

HAD013_488.3m – PYR

Coarse grained (>5mm), granular mass of massive pyrite, with lesser marcasite and interstitial calcite, siderite, white clay.

HAD014_864m – POR

Massive to locally banded pyrrhotite with locally abundant chalcopyrite.

HAD018_1106m – PCR

As POR but with >5% interstitial white to cream coloured carbonate, typically calcite but may be dolomite or siderite

HAD018_638.2m – PQR

As POR but with >5% grey to cloudy white quartz crystals, which locally may show euhedral crystal terminations.

Figure 4: Photograph examples of the sulphide units at Havieron (Source: Newcrest).

Ore samples from massive sulphide units POR, PQR and PCR, and mineralised breccia within the south-eastern crescent and breccia region of the deposit were the subject of the metallurgical test work for the program (Newcrest 2021). Specifically, ore samples from the eastern and western flanks of the south-eastern crescent zone and breccia immediate to south-eastern crescent zone (Figure 5).

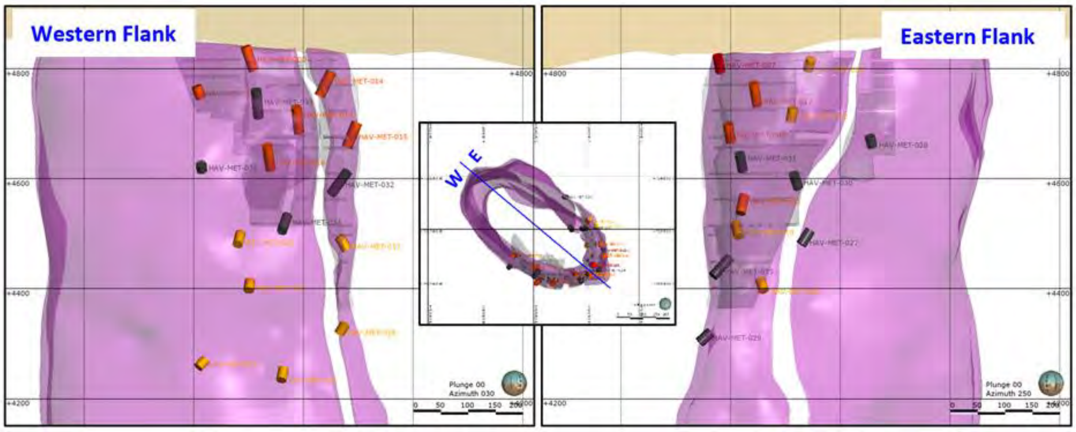


Figure 5: Location of samples from eastern and western flanks of south-eastern crescent zone (Source: Newcrest).

The following key aspects are evident from the modal mineralogy and sulphide distribution for ore materials within massive sulphide and breccia of the south-eastern crescent zone (Newcrest 2021):

- Although variable, there is a clear abundance of carbonate minerals throughout both the massive sulphide and breccia ore (10-50% within the massive sulphide and greater than 50% within the breccia) (Figure 6).
- Although there is a very high total sulphur content within the massive sulphide ore in the south-eastern crescent zone (in some cases over 50%), not all of the sulphide is pyrite (Figure 7). There appears to be a significant proportion of pyrrhotite (often in greater abundance than pyrite and in some cases greater than 90% of the total sulphide present) together with a significant proportion of chalcopyrite (although most often in less abundance than pyrite, sometimes as much as 10% of the total sulphide present). It is well established that pyrrhotite will produce significantly less acidity than pyrite (Gerson *et al*. 2019; Schumann *et al*. 2015). These aspects have been considered later in this report, particularly in relation to the interpretation of sulphide speciation results (Section 4.3.4).
- Although the breccia ore has significantly lower total sulphur content, there still appears to be a significant proportion of pyrrhotite (often in greater abundance than pyrite and in some cases greater than 90% of the total sulphide present) together with a significant proportion of chalcopyrite (although most often in less abundance than pyrite, sometimes as much as 35% of the total sulphide present).
- Although present in minor proportions (usually less than 1%) there is a wide variety of other sulphides present, including arsenopyrite, cobaltite, tennantite-enargite, covellite, chalcocite, and bornite.

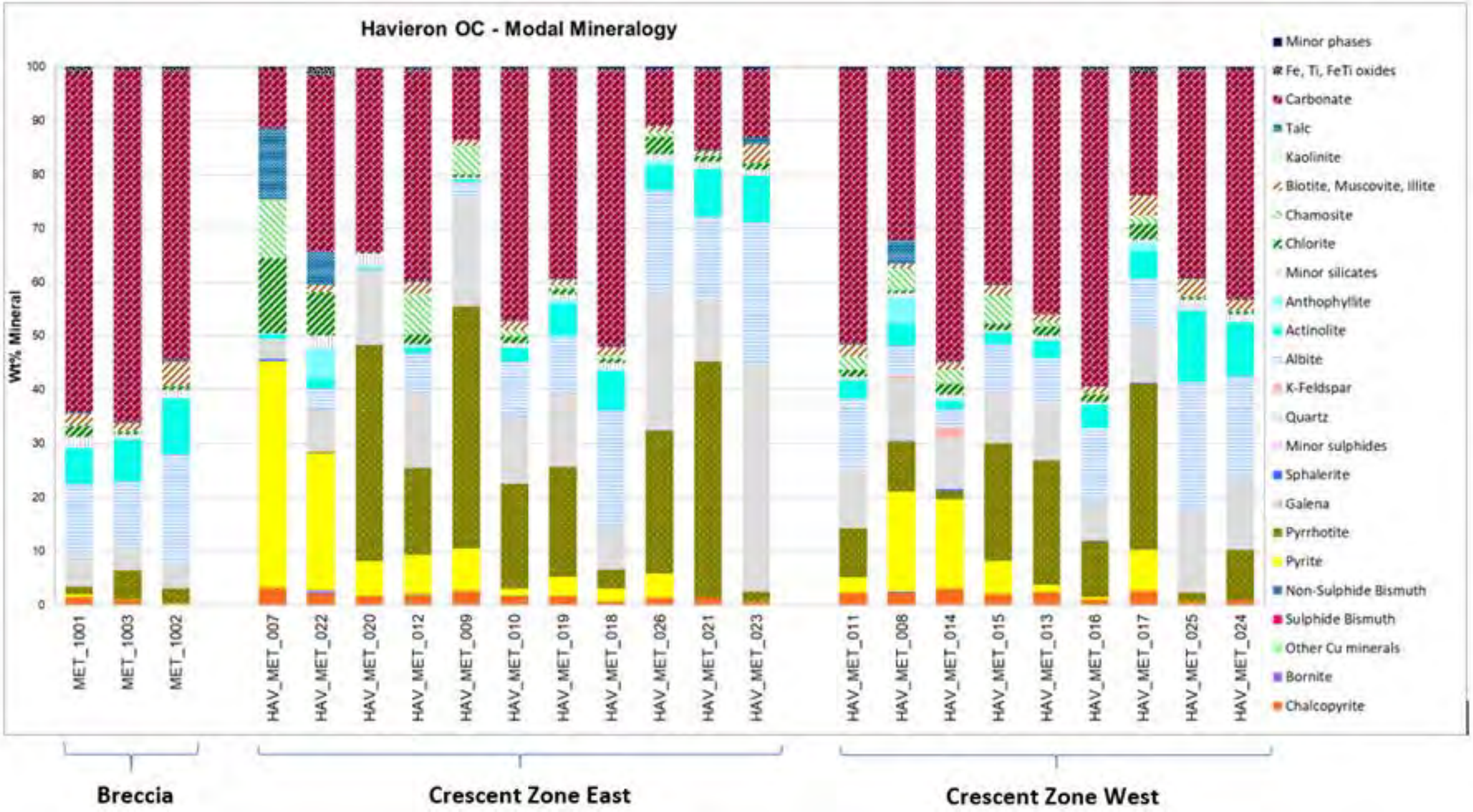


Figure 6: Modal Mineralogy for the massive sulphide and breccia of the south-eastern crescent zone (Source: Newcrest).

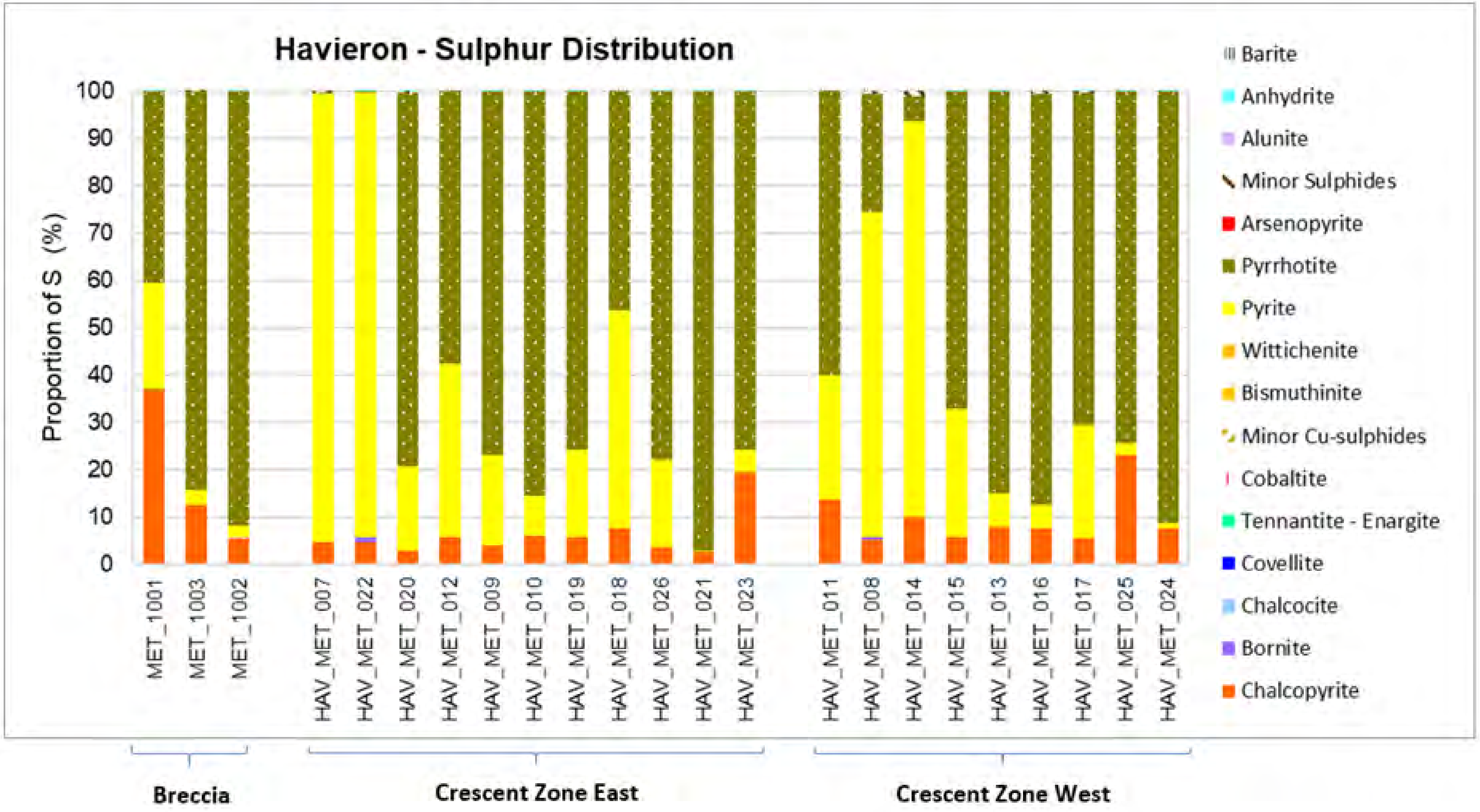
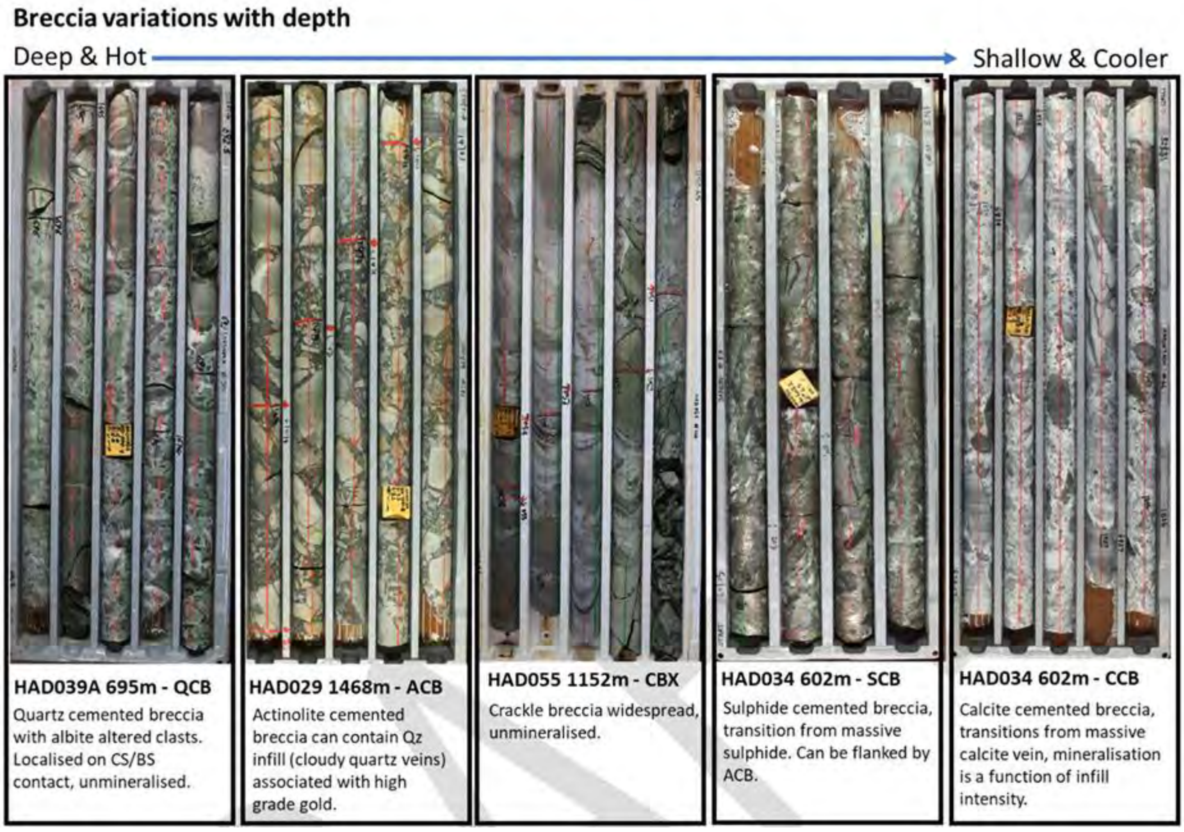


Figure 7: Sulphur distribution for the massive sulphide and breccia of the south-eastern crescent zone (Source: Newcrest).

Brecciation at Havieron can be divided into five main variations in chronological order of alteration (Newcrest 2020) (Figure 8):

- QCB – Quartz Cemented Breccia associated with albite alteration. It occurs at depth and is localised on the contact between the calc silicate actinolite marble (CS) and biotite-rich metasiltstone to meta-arenite (BS) metamorphic facies.
- ACB - Actinolite Cemented Breccia where clasts of CS, BS, and DIO (intrusive Diorite) are cemented by coarse grained acicular masses of pale green coloured amphibole (actinolite-tremolite) with less abundant intergrown calcite, quartz, and sulphides. Associated with cloudy quartz-actinolite open space infill which can host locally very high grade. Defines the northern and eastern breccia zones.
- CBX – Crackle breccia, widespread. It early and locally transitions to Actinolite Cemented Breccia (ACB).
- SCB – Sulphide Cemented Breccia where clasts of CS, BS, and DIO (diorite) are cemented by pyrrhotite +/- chalcopyrite. SCB commonly occurs on the margins of massive sulphide units, indicating that the pyrrhotite units are open-space infill, in addition to wall rock replacement.
- CCB – Calcite Cemented Breccia-Open-space Infill Breccia in which clasts of CS, BS and, DIO are cemented by coarse grained white to grey coloured calcite with locally abundant sulphides. It flanks the massive sulphide units generally as massive calcite vein with >80% infill on the margin decreasing in intensity away from the massive sulphide units, implying a genetic relationship and common timing of formation. The CCB can be seen overprinting the earlier ACB.



HAD039A 695m - QCB
Quartz cemented breccia with albite altered clasts. Localised on CS/BS contact, unmineralised.

HAD029 1468m - ACB
Actinolite cemented breccia can contain Qz infill (cloudy quartz veins) associated with high grade gold.

HAD055 1152m - CBX
Crackle breccia widespread, unmineralised.

HAD034 602m - SCB
Sulphide cemented breccia, transition from massive sulphide. Can be flanked by ACB.

HAD034 602m - CCB
Calcite cemented breccia, transitions from massive calcite vein, mineralisation is a function of infill intensity.

Figure 8: Breccia variations at Haverion (Source: Newcrest).

The Calcite Cemented Breccia defines a zone of massive calcite vein and Calcite Cemented Breccia, best developed in the south-east closure haloing the Crescent Zone. The intensity of zone is generally related to the intensity and proximity of the Crescent, forming as generally massive calcite vein on the contact, grading out into strongly cemented breccia (>50%) to weakly Cemented Breccia (<25%) on the outer margin. This forms a 70-120m wide mineralised breccia sleeve around the south-east Crescent.

An Actinolite Cemented Breccia zone occurring as a circa 300 by 100 m north-west trending zone within the Northern breccia. This zone is surrounded by Calcite Cemented Breccia. This breccia is generally higher grade in mineralisation, but has lower copper and sulphide compared to the Calcite Cemented Breccia.

There are two intrusive phases, including early diorite dyke intrusions that are thought to be the driver of brecciation and is closely associated with mineralisation, and a post-mineralisation dolerite phase. More specifically (Newcrest 2020) (Figure 9):

- DIO – Relatively small Dioritic intrusions with brecciated contacts, or as wall rock clasts within the breccias. The diorite dyke intercepts are discontinuous and cannot be modelled individually. However there appears to be a strong spatial relationship between the presence and abundance of the diorite dykes and/or clasts with mineralisation. The diorite shell margins closely represent the Crescent Zone and Crackle Breccia margins, suggesting the Crescent Zone may be a damage zone around the diorite intrusion(s) and was the driver for the brecciation at Havieron.
- DOL – 20-30m wide north-north-east trending dark grey to dark green coloured, aphanitic to finely porphyritic post mineral, magnetic dolerite dyke, with well-developed chilled margins.

HAD057W2 775m - DIO

Fine to medium grained crowded, equigrainular to weakly porphyritic feldspar-hornblende phyric diorite. strong biotite-actinolite alteration with quartz actinolite veining

HAD052 830m - DOL

Dark grey to black aphanitic dolerite. Moderately magnetic. Post Mineral.

Figure 9: Photographs of the two intrusive units at Haverion (Source: Newcrest).

2.3.3 Distribution of sulphur and carbonate minerals

2.3.3.1 Permian rock types

Overall, the Permian rock types are expected to have an absence of pyritic sulphur except for the base of the Permian where there has been a glacial re-working of the underlying Proterozoic rocks extending no further than 10-20m up from the unconformity (Newcrest 2021a). This is supported by the following lines of evidence:

- As shown in Figure 10, total sulphur values drop significantly within greater than 20m of from the unconformity (except outlier values between 200m and 250m). The total sulphur content greater than 20m from the unconformity can be considered negligible to low as reflected by a median total sulphur value of 0.07% and a 75th percentile total sulphur value of 0.14% (Table 2).
- The Permian glacial rock types were derived from evaporitic Cannington Basin sediments that did not have any anaerobic shale forming basins (i.e. where pyritic sulphides are likely to form).
- Black shale has not been noted in any drill core of the Permian rock types. Where sulphide has been observed, it has been limited to very close to the unconformity.
- Saprolite is completely weathered and highly leached and where sulphur is present, it is present as sulphate.
- For other rock types (mudstones/sandstone/siltstone/tillite/conglomerate) where sulphur is present, it is likely to be associated with magnesium/calcium sulphate minerals from groundwater-driven remobilisation and precipitation of evaporitic derived sulphate.

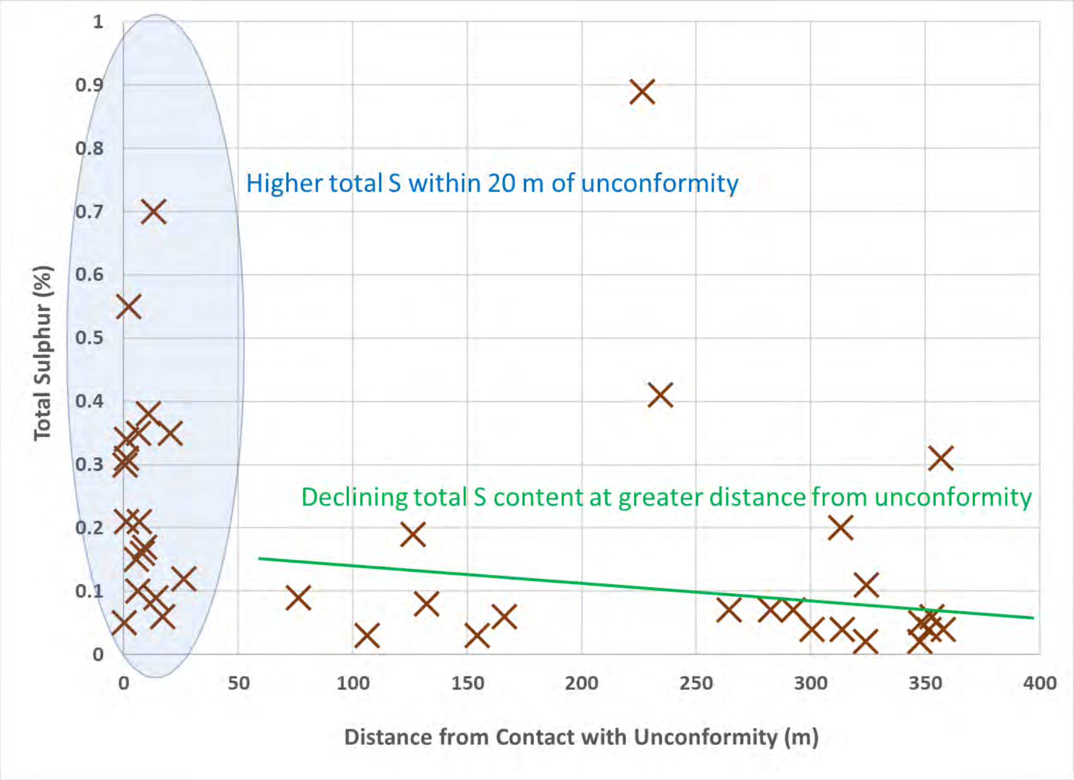


Figure 10: Higher total S (%) within 20m of the unconformity, except outlier values between 200m and 250m.

Table 2: Mean total sulphur (%) less than and greater than 20m from contact with the unconformity (Source: Newcrest).

Distance from Unconformity	25th Percentile	Median	75th Percentile	Number of Samples
Less than 20m	0.14	0.21	0.34	16
Greater than 20m	0.04	0.07	0.14	27

2.3.3.2 Proterozoic basement rock types

Two key aspects are quite apparent in relation to the Proterozoic basement rock types in terms of sulphide and carbonate mineral distribution (Newcrest 2021b). First, very high sulphide content is generally limited to the mineralised Crescent Zone (Figure 11). Second, all rock types within the brecciated ovate envelop that defines the deposit and beyond into the marine bedded sediments are generally enriched in carbonate minerals (Figure 12).

It should be noted that although a linear regression correlation between Ca% and bulk acid neutralising capacity has yet to be undertaken, Ca% should provide a reasonable indication of carbonate mineral content as the deposit is known to be highly enriched in Ca/Mg carbonate minerals (also refer to Section 4.3.3 of this report). Other suggested trends include Actinolite Cemented Breccia and Calcite Cemented Breccia having moderate enrichment in sulphide content as a result of their close proximity to the mineralised Crescent Zone, as well as Dolerite having the lowest sulphide and carbonate mineral content as a result of not being associated with the genesis of the deposit.

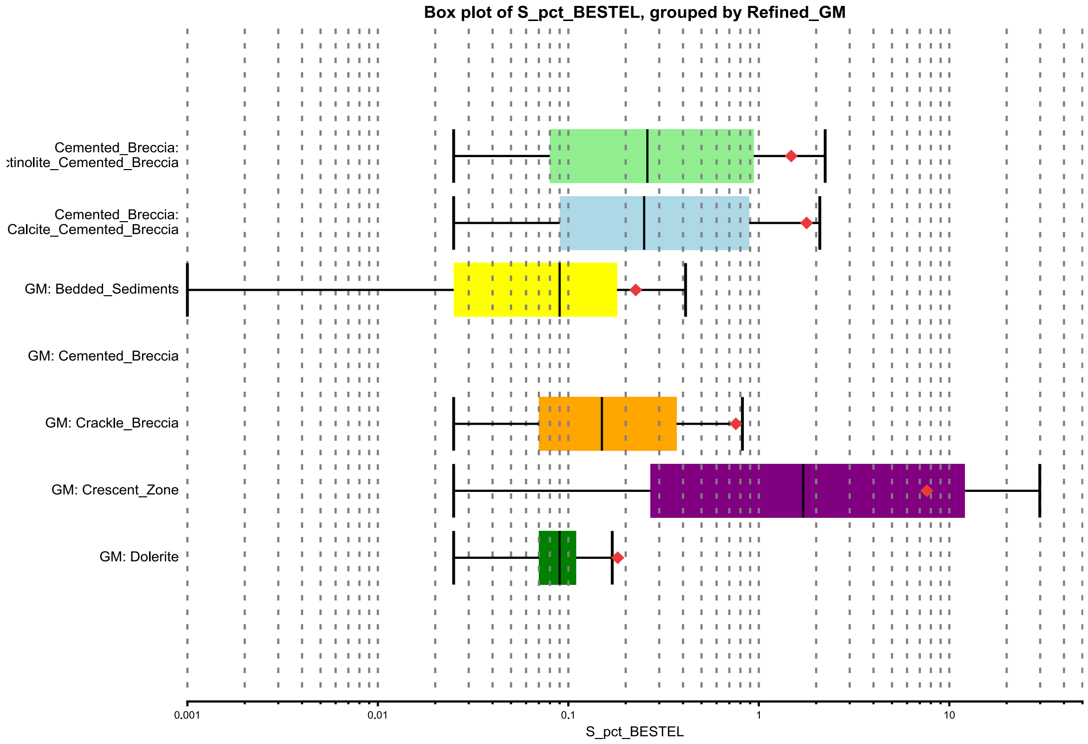


Figure 11: Total S (%) box plots for the Proterozoic basement rock types (Source: Newcrest).

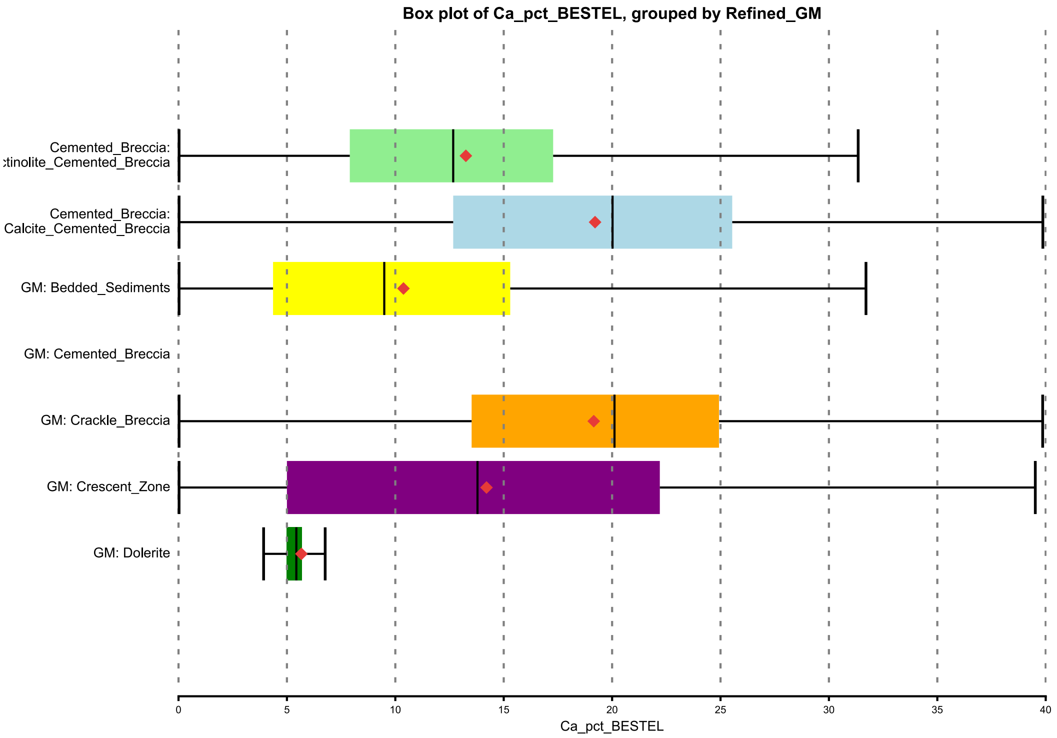


Figure 12: Total Ca (%) box plots for the Proterozoic basement rock types (Source: Newcrest).

2.3.4 Mine waste mass estimates

An estimated 3,546,796 tonnes of material are expected to be disturbed by mining (Table 3). The majority of waste to be extracted originates from the Proterozoic basement (79%). A small proportion of material will be extracted from the Permian cover.

For the purpose of estimation of the mass of mine waste materials:

- Proterozoic basement rock types are described as the following: actinolite cemented breccia, bedded sediments, calcite cemented breccia, crackle breccia, crescent zone, and dolerite. All ore is expected to originate from the Crescent Zone and a small portion of the Breccia units.
- Dioritic intrusions are also known to intercept the mining zone, but the intercepts are discontinuous and cannot be modelled individually. For this reason, the mass of Diorite expected to be extracted as waste is unknown.
- Permian cover rock types are described as the following: siltstone, conglomerate, lower and upper tillite, mudstone, sandstone, shale and saprolite.

Tailings will be produced from processing of the ore. Characterisation of the tailings is ongoing and will be reported in the future once results are at hand.

Table 3: Mass and proportion of waste split by geology and rock type.

Geology	Rock Type	Tonnes (t)	Proportion (%)
Proterozoic	Actinolite cemented breccia	52,969	1.5
	Bedded sediments	1,278,592	36.0
	Calcite cemented breccia	426,339	12.0
	Crackle breccia	170,053	4.8
	Crescent zone	37,283	1.1
	Dolerite	819,725	23.1
Permian	Siltstone	126,093	3.6
	Conglomerate	51,684	1.5
	Lower Tillite	143,415	4.0
	Upper Tillite	81,559	2.3
	Mudstone	10,100	0.3
	Sandstone	308,726	8.7
	Shale	37,073	1.0
	Saprolite	3,188	0.1
	Total	**3,546,796**	**100**

3 METHODOLOGY

3.1 Sampling

Sampling was based on the following key aspects (see Appendix A for further details):

- Guidance provided in the DMIRS *Draft guidance: Materials characterisation baseline data requirements for mining proposals* (DMP 2016). Approximately 50 samples were selected for preliminary characterisation test work.
- The proportion of samples selected for each rock type (Table 4) was broadly consistent with the mass of each waste to be extracted (Table 3). No samples were available for analysis of Lower and Upper Tillite, Mudstone, Sandstone, or Saprolite. These lithologies were analysed as part of the Stage 1 waste material characterisation (Landloch 2021a).
- Samples were selected from four drill holes: HAD055, HAD057W3, HAD061, and HAD112A. These drill holes were selected because they had good representation of key lithologies and alteration zones and more broadly the waste types to be extracted. Where the interval of a waste type was >10m, a greater number of samples (between 2-20) were taken from this interval and composited to capture any spatial variation in characteristics.
- A greater number of samples were selected from the Crescent Zone as assay data showed this unit to contain significant amounts of sulphur. A greater number of samples was also taken from the Siltstone, as Stage 1 test work showed 1 of 2 Siltstone samples to be potentially acid forming (PAF).
- Representation of the different regions of the deposit for each rock type where possible (e.g. south-east crescent and breccia region, north-west crescent zone, and the northern breccia zone), but also including Permian cover rock types at the base of the unconformity that are likely to be elevated in total sulphur; and
- Representation of the full range of total sulphur and acid neutralising capacity for each of the rock types.

Sampling was undertaken by Newcrest geologists in consultation with Landloch. Sample compositing was undertaken by Landloch. The drill holes and the locations from which the samples were taken are shown in the 2D cross section provided in Figure 13.

Table 4: Number and proportion of samples tested by geology and rock type

Geology	Rock Type	Number of Samples	Proportion of Total Number of Samples (%)	Proportion of Total Mass (%)
Proterozoic	Actinolite cemented breccia	4	8	1.5
	Bedded sediments	3	6	36.0
	Calcite cemented breccia	18	36	12.0
	Crackle breccia	5	10	4.8
	Crescent zone	5	10	1.1
	Dolerite	3	6	23.1
	Diorite	3	6	unknown
Permian	Siltstone	6	12	3.6
	Conglomerate	3	6	1.5
	Lower Tillite	0	0	4.0
	Upper Tillite	0	0	2.3
	Mudstone	0	0	0.3
	Sandstone	0	0	8.7
	Shale	0	0	1.0
	Saprolite	0	0	0.1
Total		**50**	**100**	**100**

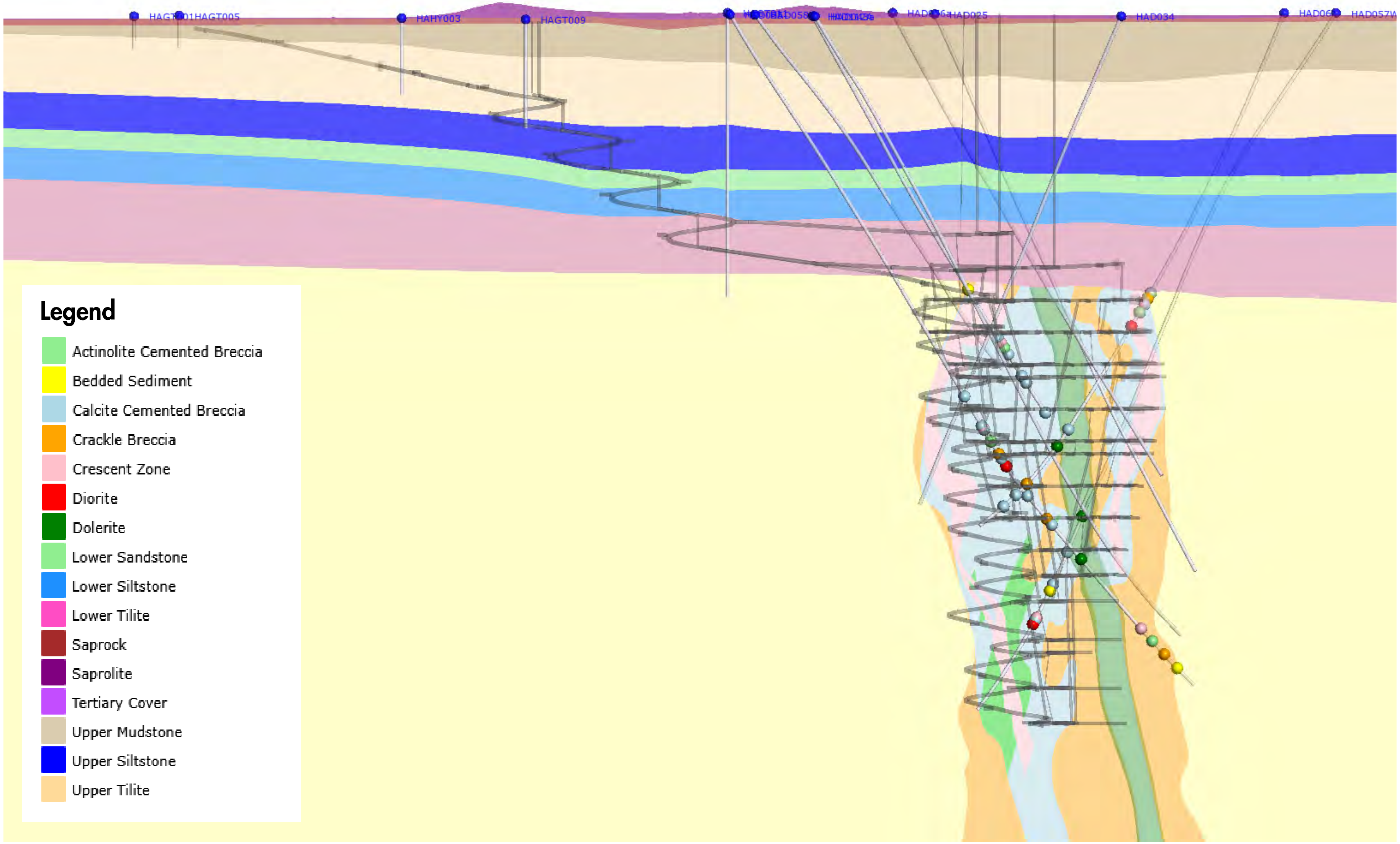


Figure 13: 2D schematic cross section of deposit showing intersection of different basement rock types and location of samples selected for this study

3.2 Test work program

3.2.1 General static test work

All 50 waste material samples were tested for the parameters:

- $pH_{1:5}$ (water).
- Electrical conductivity ($EC_{1:5}$).
- Total carbon (C).
- Total sulphur (S) (%) and proportion of Sulphide S (%).
- Acid Base Accounting (ABA) parameters including:
  - Net Acid Production Potential (NAPP).
  - Net Acid Generation (NAG) and NAG pH.
  - Acid Neutralising Capacity (ANC).
  - Maximum Potential Acidity (MPA).
- Naturally Occurring Radioactive Material (NORMs).

A subset of 37 samples were tested for rock durability indices including:

- Lithological classification;
- Weathering grade;
- Rock density;
- Water absorption; and
- Rock strength (Schmidt field strength test).

A subset of 5 samples were tested for structural stability indices for the fines including:

- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+})[2].
- Effective cation exchange capacity (ECEC).
- Exchangeable Sodium Percentage (ESP).
- Clay, silt, fine sand, and coarse sand fractions.
- Electrochemical Stability Index (ESI).

A subset of 10 samples were assessed for elemental enrichment with a 4 acid digest of 60[3] elements by ICP. The same 10 samples were then flushed with deionised water and the concentrations of 16 metals within the leachate were assessed to consider seepage water quality[4].

---

[2] Method 15C1 was used as the preferred method for assessment of exchangeable cations where EC1:5 of pre-treated samples exceeds 0.3dS/m. Use of this method results in a more accurate estimation of exchangeable cations as soluble salts have previously been removed as part of the pre-treatment.

[3] 60 elements assessed via 4-acid digest are: Ag, Al, As, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Eu, Er, Fe, Ga, Gd, Hf, Ho, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pr, Rb, Re, S, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Tm, Ti, Tl, U, V, W, Y, Yb, Zn, Zr,

[4] Leachate metals include: Al, As, B, Ba, Be, Cd, Cr, Co, Cu, Mn, Ni, Pb, Se, V, Zn and water leachable Hg

A subset of 7 samples were assessed for presence of asbestiform materials via optical microscopy.

3.2.2 Specialised geochemical test work

Some samples were subjected to specialised geochemical test work to help resolve any uncertainties in initial acid-base accounting classifications and provide more information on geochemical characteristics. Parameters tested as part of the specialised geochemical test work include:

- Sequential NAG test (6 samples);
- Acid-base characteristic curve (ABCC) (7 samples);
- Sulphur speciation (8 samples);
- Kinetic NAG test (8 samples);
- Peroxide extraction and metal concentrations (9 samples); and
- Carbon forms (21 samples).

3.3 Description of characterisation parameters

3.3.1 Sample pH and EC (1:5 solids to water solution)

The pH and EC of water extracts can be used as an indication of whether the sample is acidic, alkaline and/or saline at the time of testing. Note that this measurement reflects the readily available acidity/alkalinity/salinity at the time of testing. Although suitable for soils that are generally fully oxidised, they cannot be used in isolation for high sulphide waste materials, as their properties can change through time due to sulphide oxidation processes.

Landloch show that surface soils (0-100mm) that support vegetation are generally slightly acidic to neutral (typical range is 5.5-6.3) (Landloch 2020). Therefore, for this report, pH values of 5.5-6.3 were considered suitable for plant growth.

van Vreeswyk *et al.* (2004) established salinity class values as part of the inventory and condition survey of the Pilbara region. An $EC_{1:5}$ value >0.4dS/m was used to define a moderately saline topsoil and >0.8dS/m to define a highly saline topsoil. Landloch (2020) previously measured $EC_{1:5}$ values in surface soils of 0.01-0.4dS/m. Therefore, salinity values between <0.4dS/m were considered low salinity, 0.4 to 0.8dS/m were considered moderately saline and values >0.8dS/m were considered highly saline. Materials with low salinity have a low risk of adversely impacting a wide range of plants. Moderately saline materials will likely still support vegetation but the growth of salt sensitive species may be limited. Highly saline materials will likely adversely impact salt sensitive and moderately tolerant species (highly salt tolerant species would likely still grow). The density of vegetation in highly saline soils may also be reduced.

3.3.2 Structural stability

3.3.2.1 Factors affecting structural stability

A material's tendency for tunnel erosion is dependent of both its chemical and its physical characteristics.

From a chemical perspective, the type and proportion of exchangeable cations can affect the structural stability of the material by increasing the tendency for clay dispersion. Materials with a dispersive clay fraction are not considered suitable for use as a growth medium as they are likely to be hard setting, potentially tunnel prone, and likely have low infiltration and water holding capacities. These characteristics can lead to increased runoff and erosion potential, which can limit vegetation establishment (Sumner and Naidu 1998).

With respect to clay dispersion, the proportion of exchangeable Na held on the exchange complex in relation to other exchangeable cations (referred to as the ESP) is of particular importance. McKenzie *et al.* (2004) considers the measurement of ESP as suitable for indicating clay dispersion risk when ECEC is >3meq/100g, exchangeable Na >0.3meq/100g, and where appreciable clay (>10%) exists The impact of clay dispersion on the structure for sandier materials is less significant. For wastes with sufficiently high ECEC, exchangeable Na, and clay content, ESP values greater than 6% indicate the presence of a potentially dispersive clay fraction. These materials are classed as prone to structural decline.

The potential for a waste to disperse is also influenced by interactions between the clay content, ESP, and soil salinity ($EC_{1:5}$). The Electrochemical Stability Index (ESI) has been developed as a means of considering the relationship between ESP and $EC_{1:5}$. A tentative critical ESI value is 0.05 (NSW Agriculture 1998). ESI values <0.05 in a material with >10% clay indicate a material that is prone to structural decline.

Magnesic wastes (those with elevated exchangeable magnesium) can also be prone to clay dispersion. This is assessed using the ratio of exchangeable Ca and Mg. A Ca:Mg ratio of ≤0.5 is used to indicate a material that is prone to structural decline, assuming they also have sufficient clay.

From a physical perspective, materials with high combined proportions of fine sand, silt, and clay (particles less than ~0.2mm) are prone to structural decline, even if the clay fraction is relatively small and/or not dispersive. This is because these smaller particles can mobilise within the coarser sand matrix. For this reason, materials with a combined fine sand, silt, and clay fraction >70% are considered to be prone to structural decline (Vacher *et al.* 2004).

It should also be noted that a material can have a fine fraction that is prone to dispersion or structural instability, but if the fine fraction is a small fraction of the whole material mass (i.e. the material contains a large proportion of coarse fragments), then the risk of structural decline is reduced. A binary mixture with >30-40% fine materials and <60-70% coarse materials could be considered a fine material with some coarse particles, and a binary mixture with <30-40% fines and >60-70% coarse materials could be considered a coarse material with some fine particles. Based on this, a fines cut-off of >40% seems reasonable, with materials that contain >40% fines being prone to structural decline if it meets the other ESP, ESI, exchange Mg, or PSD criteria. If the fines fraction is <40%, the materials are classed as not prone to structural decline even if the any of the other criteria are met.

3.3.2.2 Assessment of structural stability

To capture interactions between physical and chemical properties and their effect on structural stability, the materials are assessed against four sets of conditions. If any of these sets of conditions are true, the material is classified as being prone to clay dispersion or structural instability, and at risk of resulting in tunnel erosion.

ESP-based criteria:

- Fines>40%,
- ESP >6%,
- Clay content >10% of fine fraction,
- ECEC >3meq/100g,
- Exchangeable Sodium concentration >0.3meq/100g, and
- Fine sand + silt + clay >70% of fine fraction.

Exchangeable Mg-based criteria:

- Fines>40%,
- Clay content >10% of fine fraction,

- ECEC >3meq/100g,
- Ratio of exchangeable Calcium to exchangeable Magnesium <0.5, and
- Fine sand + silt + clay >70% of fine fraction.

ESI-based criteria:

- Fines>40%,
- Clay content >10% of fine fraction, and
- ESI <0.05.

PSD-based criteria:

- Fines >40%, and
- Fine sand + silt + clay >70% of fine fraction.

3.3.3 Rock durability

Rock lithology, weathering grade, particle density, and water absorption values can provide an indication of how susceptible rock particles are to breakdown and their potential usefulness as armouring in rehabilitation. Where rock particles are observed to be prone to breakdown, this can result in an increase in the proportion of fines over time, which would either increase erosion potential in the long term or sustain elevated erosion rates for longer period (i.e. surface armouring by rainfall that can lead to reductions in erosion would be impeded).

The breakdown of rock particles can also occur during landform re-shaping using heavy machinery, whereby rock particles of a certain size become smaller as machinery traverse over them, push them, and rip into them. Where rocks are shown to be durable, they could be considered for use as a rock armour to reduce erosion potential of rehabilitation landform batters. It should be noted that sulphide oxidation can also have a significant impact on rock durability, with oxidation causing degradation of rock particles, through expansion with ARD salts and removal of soluble salts by leaching.

In this study the durability of rock particles is assessed as excellent, good, marginal, or poor based on their lithology, weathering grade, density, and water absorption properties (Table 5). This rating system is based on CIRIA (2007) criteria for determining the quality and durability of armourstone from a quarry source.

Table 5: Rock durability classification scheme (CIRIA 2007).

Criteria	Excellent	Good	Marginal	Poor
Mass density (g/cm^3)	>2.7	2.5-2.7	2.3-2.5	<2.3
Water absorption (%)	<0.5	0.5-2.0	2.0-6.0	>6.0
Strength rating^	ES	VS	S	MS-EW
Lithological classification	Unfoliated igneous and metamorphic rocks, quartzites and high silica cemented sandstones, compact crystalline limestones	Crystalline dolomites, crystalline limestone and moderately well cemented sandstones	Argillaceous limestones, poorly cemented sandstones, dolomite reef rock with void cavities	Shaly limestones, reef breccia, shale, siltstone, slate, schist, chalk, gypsiferous carbonates
Weathering grade	Fresh, unweathered	Faintly weathered (staining on major surfaces)	Slightly weathered (staining persists through a greater part of rock mass)	Moderately weathered (less than half the rock mass is decomposed)

^ES: Extremely strong, VS: Very strong, S: Strong, MS: Medium strong, W: Weak, VW: Very weak, EW: Extremely weak.

3.3.4 Acid-base accounting (ABA)

3.3.4.1 Acid Rock Drainage (ARD) classification scheme

Measurements of total sulphur (total S) were used to determine the presence of potentially acid producing materials. All materials were also assessed for the potential to produce acid via analysis of the following ABA parameters:

- Net Acid Generation (NAG); a measure of the sulphur released by reaction with strong hydrogen peroxide.
- Acid Neutralising Capacity (ANC); a measure of the natural ability of the material to neutralise acid.
- Maximum Potential Acidity (MPA); a measure of total sulphur, expressed in the same units as the ANC (kg H_2SO_4/t).
- Net Acid Producing Potential (NAPP); the difference between the MPA and ANC of the sample.

A preliminary cut-off of total S of >0.3% was used to screen samples for significant potential for acid generation (Price 1997). Samples with Total S <0.3% were inferred to be at lower risk of acid generation irrespective of the ABA test results. Materials with total S of >0.3% were inferred to be at higher risk of acid generation, and the ABA results were used to inform acid generation risk.

The classification scheme by which potentially acid forming (PAF) and non-acid forming (NAF) materials were identified is provided in Table 6. A material with a positive NAPP but low $NAG_{4.5}$ (<5kgH_2SO_4/tonne) is referred to a potentially acid forming-low capacity (PAF-LC). Materials with high levels of total sulphur (>1%) but low NAPP and $NAG_{4.5}$ values are classed as non-acid forming – high sulphur (NAF-HS). A classification of 'uncertain' is given to materials that have conflicting acid-base accounting (ABA) results.

The classification system and testing methodology is based on those developed by EGi, which have been incorporated into the Australian Government's (2016) *Guidelines on Preventing Acid and Metalliferous Drainage* and the AMIRA *ARD Test Handbook* (AMIRA International 2002). The latter is advocated by the *Global Acid Rock Drainage Guidelines* (INAP 2014).

Table 6: ARD classification scheme used for this study

Classification	Total S (%)	NAPP (kgH_2SO_4/tonne)	Final NAG pH	$NAG_{4.5}$ (kgH_2SO_4/tonne)	ANC/MPA
NAF	≤0.3	-	-	-	-
NAF	>0.3	<0	≥4.5	-	>2
NAF-HS	>1	<0	≥4.5	-	>2
PAF	>0.3	≥0	<4.5	>5	<2
PAF LC	>0.3	≥0	<4.5	<5	<2
Uncertain	>0.3	≥0	>4.5	-	<2
	>0.3	<0	≤4.5	-	<2

Additional analyses were undertaken on some samples to help resolve any uncertainties in initial acid-base accounting classifications and provide more information on geochemical characteristics including sequential NAG test, Acid-base characteristic curve, Sulphur speciation, Kinetic NAG test, and Carbon forms. A brief description of the rationale and methodology behind of each of these tests is provided below.

3.3.4.2 Sequential NAG test

Where samples have high sulphur content (e.g.>0.5%) it is common for oxidation to be incomplete with a single addition NAG test. Sequential NAG testing overcomes this limitation via successive additions of peroxide to the same sample and provides a more definitive ARD classification. It should be noted however that samples with very high carbonate mineral content may take multiple stages to reach a pH below 4.5.

3.3.4.3 Acid-base buffering characteristic curve (ABCC)

This test is used to determine the effective (readily available) ANC within a material as compared to the standard ANC measured by the modified Sobek method. The ABCC test involves slow titration of a sample with acid while measuring the solution pH. The acid buffering of a sample to pH 4 can be used as an estimate of the proportion of readily available ANC.

3.3.4.4 Sulphur speciation

Sulphur speciation is undertaken to determine the proportion of pyritic sulphur compared to other sulphur forms (sulphur present in non-pyritic forms is likely to generate less acid). Forms of sulphur in a material are determined via use of chromium reducible sulphur (CRS).

3.3.4.5 Kinetic NAG test

Kinetic NAG tests provide an indication of the kinetics of sulphide oxidation and acid generation for a sample. The time to pH 4 in the kinetic NAG test can be used to estimate the lag time before acid conditions develop in an acid forming sample under atmospheric oxidation conditions.

3.3.5 Elemental test work (solids)

The elemental test work seeks to identify any elements that may be of environmental concern with respect to revegetation and surface water/groundwater quality. The results can be used to target further investigation if needed. It is understood that the potential final land use of the mine following closure is likely to be a return to vacant crown land and (where practicable) native habitat.

Concentrations of metals within each sample were compared with the median elemental crustal abundance to determine if any environmentally sensitive metals are significantly enriched. The extent of element enrichment in samples was assessed via use of the Geochemical Abundance Index (GAI), which compares the measured concentration of a particular element with the estimated median crustal abundance (AusIMM 2011) using the following equation:

$$GAI = log_2\left[\left(\frac{C}{1.5 * S}\right)\right]$$

where C is the concentration of the element in the sample and S is the median concentration for that element in the reference material. The GAI values are truncated to integer increments (0 through to 6, respectively) where a GAI of 0 indicates the element is present at a concentration similar to, or less than the median abundance, and a GAI of 6 indicates approximately a 100-fold, or greater, enrichment above median abundance. As a general guide, a GAI of 3 or above is considered significant, and such an enrichment may warrant further examination.

Additionally, results were compared against the National Environmental Protection Council (NEPC) background concentrations for Health Investigation Level (HIL (C)) and Ecological Investigation Level (EIL (C)) ranges for soils (NEPC 2011a, 2011b). The lesser of the two concentrations was used to determine whether the measured value exceeded the threshold. EILs and HILs are designed to be used as an indicator for a more detailed risk assessment, and do not imply that a significant health or ecological risk is present.

Where criteria are not given in this guideline, Landloch/EGi cannot comment on the suitability of the values measured, but the data are supplied for the sake of completeness.

3.3.6 Elemental test work (leachate)

3.3.6.1 Deionised water extraction

Drainage from mine wastes containing elevated concentrations of soluble metals or metalloids, can have adverse impacts on downstream surface waters or groundwater. Heavy metals in particular, such as mercury, cadmium, arsenic, chromium, thallium, and lead can be toxic to biota at high concentrations.

Leachate test work is a useful method to provide an indication of whether a material may become a problematic mine waste contaminant source. Leachate tests can provide insight into aspects such as constituent solubility, mobility, bioavailability, and toxicity.

The deionised water extraction undertaken for this study seeks to provide an indication of the exchangeable (mobile) and soluble fraction under field conditions (an unbuffered water source). Evaluation of leachate data has been undertaken in the following manner:

- Comparison with ANZECC (2000) or Australian drinking water guidelines (NHMRC 2011) and British Columbia Freshwater Protection guidelines (British Columbia 2021) (where ANZECC values are not available) to identify constituents that may become soluble at elevated concentrations.
- Identification of constituents reporting slightly elevated concentrations (i.e. significantly above the detection limit but below the recommended trigger levels).
- Identification of constituents reporting elevated concentrations (i.e. above recommended trigger levels).
- Consideration of relevant ranges in pH within the material and its surrounds;
- Consideration of probable mineral phases that may control solubility in certain pH ranges.

3.3.6.2 Peroxide extraction test

Additionally, peroxide extraction tests were undertaken on samples determined to have acid generation potential (as part of the static geochemical test work). The intent of the peroxide extraction test work was to provide a preliminary indication of the mass release of sulphate and metals and metalloids upon exposure to strongly oxidising conditions. The peroxide extractions were based on the single-stage NAG test, which involves reaction of a sample with hydrogen peroxide to rapidly oxidise any sulphides that are present. Normally only the pH and acidity of the NAG solution are measured following the oxidation stage, but with these tests a sub-sample of the NAG solution was filtered and then assayed to determine the extent of mass release from the sample as a consequence of sulphide oxidation and potentially acidification.

When assessing the results, it should be noted that the actual concentrations of elements in a peroxide extract are directly related to the volume of peroxide used per unit weight of sample. The method involves a leach ratio of 100mL/g which is high in comparison to leach rates typically encountered under field conditions, as well as rates typically used in column leach tests. For example, the leach rates for columns routinely run by EGi typically average around 75mL/kg/week, which over a five-year period (for example) equates to a leach ratio of around 20mL/g. As such, it can be expected that the peroxide extracts represent a diluted condition in comparison to either column leachate test work or that in the field.

From past experience, EGi has determined that a nominal scaling factor of 5 applied to peroxide extraction tests provides a conservative indication of mass release in the field as a result of exposure of sulphidic materials to strongly oxidising conditions (i.e. order of magnitude concentrations of sulphate and other metals and metalloids). In the evaluation of results the terms 'slightly elevated'[5] and 'elevated' are used to describe the order of magnitude of the peroxide extract concentrations that have been scaled by a factor of 5. Similar to the deionised water extraction test, constituents are deemed to be elevated via comparison with ANZECC (2000) or Australian drinking water guidelines (NHMRC 2011) and British Columbia Freshwater Protection guidelines (British Columbia 2021) (where ANZECC values are not available).

3.3.7 NORMs

All minerals and raw materials contain radionuclides of natural origin. For most activities involving minerals and raw materials, the levels of exposure to these radionuclides are not significantly greater than normal background levels and are not of concern for radiation protection. However, some materials may give off radiant energy at levels higher than background levels. Human activity around these types of materials can increase the risk of radiological exposure. Material giving rise to these enhanced exposures is known as naturally occurring radioactive material (NORM).

The Government of Western Australia (2019) and the DMP (2010) require that the dose limit and surface concentration for betta, gamma and low toxicity alpha emitters falls below 10μSv/hr and 0.40Bq/cm^2, respectively. Dose limits and surface concentrations in samples are assessed against these criteria.

3.3.8 Asbestiform materials

"Asbestos" is a commercial term referring to six types of naturally occurring silicate mineral fibres that can be separated into two broad categories: amphibole and serpentine minerals. These minerals are hydrated silicates with varying metal compositions and are known as asbestiform minerals. Amphibole and serpentine minerals are major components of mafic and ultramafic rocks found in Western Australia's "greenstone belts", which contain the State's major gold and base metal deposits. Amphibole minerals may also be encountered in the banded iron formations

---

[5] The term 'slightly elevated' was based upon screening against relevant freshwater ecological protection guidelines (e.g. ANZECC) and in the absence of ecologically based guidelines alternate conservative values have been used [e.g. Australian Drinking Water Guidelines (ADWGs)]. The term 'elevated' was based upon less sensitive environmental criteria (e.g. ANZECC irrigation and livestock and ADWGs x a factor of 10).

of the Hamersley Basin (DMP 2015). Exposure to asbestiform minerals can have adverse impacts on human health, when fibres are of a size that can be airborne and respirable.

Assessment of asbestiform materials is undertaken in accordance with the Polarised Light Microscopy (PLM) and Dispersion Staining (DS) method established in AS:4964-2004 *Method for the qualitative identification of asbestos in bulk samples*. Here samples are scanned for the presence of fibrous materials, including actinolite, serpentine, and cummintonite-grunerite which have the potential to be present, but not in asbestiform.

4 RESULTS

The results of the waste rock characterisation test work are discussed below.

4.1 $pH_{1:5}$ (water)

The pH across all samples ranged between 6.7 and 10.3 (Table 7). Median pH was 9.45. Results show that the waste materials had moderately to very strong immediately available alkalinity at the time of testing.

Soil characterisation work completed by Landloch showed the pH of surface soils (0-100mm) within the survey area to range between 5.5-6.3 (Landloch 2000).

Each of the rock types are shown to have considerably greater alkalinity compared to surface soils within the project area. This is expected, given the known abundance of carbonate minerals either within or immediately above the marine Proterozoic basement and or relatively high abrasion pH of fresh rock calcium and magnesium silicate minerals that may be present. It should be noted that these results reflect only the available alkalinity at the time of testing, and do not account for the longer effects of sulphide oxidation or how quickly carbonate minerals may be depleted.

Table 7: pH median, average and standard deviation for each rock type

Geology	Rock Type	Median pH (unit)	Average pH (unit)	Standard Deviation
Proterozoic	Actinolite cemented breccia	9.95	9.93	0.33
	Bedded sediments	9.80	9.80	0.20
	Calcite cemented breccia	9.65	9.50	0.53
	Crackle breccia	9.20	9.30	0.47
	Crescent zone	8.60	8.26	0.92
	Dolerite	10.2	10.2	0.10
	Diorite	9.90	10.0	0.23
Permian	Siltstone	8.80	8.83	0.29
	Conglomerate	9.00	8.97	0.15

4.2 Electrical conductivity ($EC_{1:5}$)

The $EC_{1:5}$ across all samples ranged between 0.07 and 3.96dS/m (Table 8). There is a high correlation with $EC_{1:5}$ and depth. The Proterozoic rock types exhibit a lower salinity than Permian rock types with median $EC_{1:5}$ being 0.24dS/m and 1.97dS/m, respectively.

The salinity of Proterozoic rock types is considered to be low when compared with values found in natural soils (Section 3.3.1). That being said, these results only provide a reflection of the readily available salinity at the time of testing, as the salinity of high sulphide materials could be increased where sulphide oxidation occurs (driven by increased concentrations of sulphate salts).

Permian materials exhibit salinities considerably higher than the range typically encountered in natural soils. For this reason the Permian materials are considered to be highly saline. Use of the Permian material as growth media may have an adverse effect on the growth of plant species endemic to the Project, specifically where it is prone to leaching or further weathering over time.

Table 8: $EC_{1:5}$ median, average and standard deviation for each rock type

Geology	Rock Type	Median $EC_{1:5}$ (dS/m)	Average $EC_{1:5}$ (dS/m	Standard Deviation
Proterozoic	Actinolite cemented breccia	0.14	0.22	0.20
	Bedded sediments	0.10	0.14	0.10
	Calcite cemented breccia	0.12	0.20	0.14
	Crackle breccia	0.30	0.79	1.25
	Crescent zone	0.60	1.23	1.55
	Dolerite	0.41	0.35	0.10
	Diorite	0.30	0.33	0.12
Permian	Siltstone	1.61	1.72	0.85
	Conglomerate	2.94	2.90	1.03

4.3 Acid-base accounting

4.3.1 Preliminary ARD classifications

Measurements of total sulphur (total S) were used as an indication of the presence of potentially acid producing materials. A cut-off of total S of >0.3% was used as a preliminary way of screening samples for significant potential for acid generation, given the abundance of carbonate minerals in most rock types. Samples with total S <0.3% were inferred to be at lower risk of acid generation (Price 1997).

Assessment of total S concentrations showed that 29 of the 50 samples tested had total S <0.3%. These samples were classified Non-Acid Forming (NAF). 21 of the 50 samples had total S content >0.3%. The Acid Base Accounting (ABA) and NAG testing results for these materials were further considered to determine acid generation risk. Analysis of the general static geochemical test results in the 21 samples with total S >0.3% showed that:

- 4 of 5 samples from the Crescent Zone were classified as Potentially Acid Forming (PAF) and had an ANC:MPA ratio of <1.
- 1 Calcite Cemented Breccia sample, 2 Siltstone samples, and 1 Diorite sample were classified as Uncertain. Further analysis showed the 2 Siltstone samples classified as Uncertain have low potential for acid generation (suggested by NAG $pH_{4.5}$ of 1.5-2.5kg kgH_2SO_4/tonne) and are more likely to be PAF-Low Capacity (PAF-LC). The Diorite had a total S content >0.5% but a MPA ratio between 1 and 2 which means it is likely to be NAF-HS.
- The remainder of samples (14 of the 21 samples with total S >0.3%) were classified as NAF.

- Of the 14 samples classified as NAF, 10 samples had a NAPP lower than -100kgH_2SO_4/tonne. These materials have a high neutralising capacity and originate from the carbonate rich Breccia units (Calcite Cemented/Crackle) and the Actinolite Cemented Breccia. It is noted that the carbonate content in the Actinolite Cemented Breccia may be diminished to some extent as a result of hydrothermal alteration.
- Of the 14 samples classified as NAF, 6 samples had a total S content >1% but a MPA ratio between 1 and 2. These samples were classified as NAF-HS.

Figure 14 is an ABA plot showing ANC versus MPA for each of the rock types, and Figure 15 is an ARD classification plot showing NAPP versus NAG pH for each of the rock types.

The results indicate that there is likely to be significant acid generation potential in the Crescent Zone and low acid generation potential in the Siltstone units (reflected by the relative total sulphur content).

Further specialised geochemical test work was undertaken on some samples. The specialised geochemical test work included:

- Sulphur speciation to provide a guide to pyritic/pyrrhotitic S.
- Kinetic NAG to provide an indication of reaction rates and lag times.
- Sequential NAG to better define acid generation capacities and ARD classification of Uncertain samples.
- ABCC testing to confirm the effective neutralisation capacity of the Actinolite Cemented Breccia.

The results of the specialised geochemical test work are discussed below. The samples selected for testing are described in detail in Table 9.

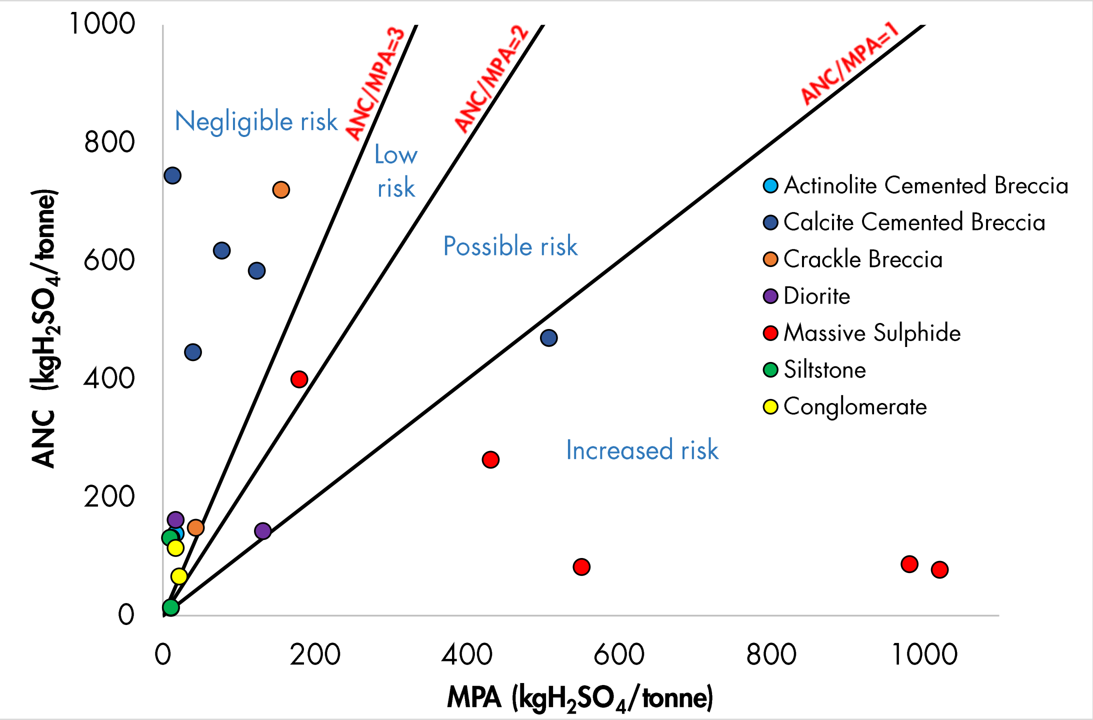


Figure 14: ABA plot showing ANC versus MPA for samples with Total S>0.3%

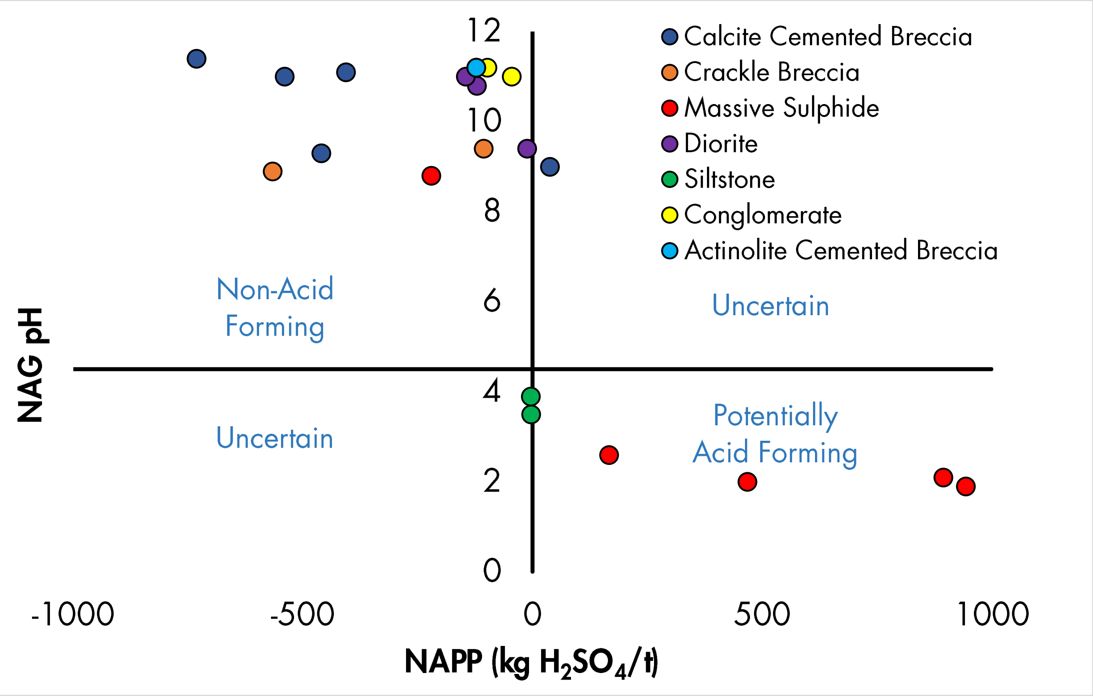


Figure 15: ARD classification plot showing NAG pH versus NAPP for samples with Total S>0.3%

Table 9: Samples subject to specialised geochemical test work

Sample ID	Rock Type	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type	ANC (kg H2SO4/t)	Relative Magnitude of ANC	Preliminary ARD classification	Sequential NAG	ABCC	Sulphur Speciation	Kinetic NAG	Peroxide Extraction
MWC052	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	0.35	Between 50th and 75th percentile	13.3	Very low generally, but typical for rock type.	Uncertain (PAF-LC)	X	X	X	X	X
MWC085	Crescent Zone	Crescent Sulphide Zone – South-East Crescent + Breccia	18	Between 75th to 95th percentile of Crescent Zone	83	Moderate generally but lower than typical for rock type.	PAF			X	X	X
MWC090	Actinolite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.55	Between 75th to 95th percentile	139	High generally but lower than typical for rock type.	NAF		X			
MWC104-MWC105	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	16.6	Very high S content, well above 95th percentile	470	Very high generally but typical for rock type.	Uncertain	X	X	X	X	X

Sample ID	Rock Type	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type	ANC (kg H2SO4/t)	Relative Magnitude of ANC	Preliminary ARD classification	Sequential NAG	ABCC	Sulphur Speciation	Kinetic NAG	Peroxide Extraction
MWC111	Crescent Zone	Crescent Sulphide Zone - South East Crescent & Breccia	14.1	Between 75th to 95th percentile of Cresent Zone	264	High generally, but slightly lower than typical for rock type.	PAF	X			X	X
MWC140	Conglomerate	Lower strata close to Permian Cover / Proterozoic Basement	0.7	Circa 95th percentile value	66.3	Moderate generally but higher than typical for rock type.	NAF	X		X		
MWC155	Crescent Zone	Crescent Sulphide Zone - Northern Breccia Zone	33.4	High S content, around 95th percentile of Crescent Zone	78	Moderate generally but lower than typical for rock type.	PAF			X	X	X
MWC157-MWC158	Actinolite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	0.28	Circa 50th percentile value	640	Very high generally and higher than typical for rock type.	NAF		X			
MWC161	Diorite	Mineralised Breccia / Crescent Sulphide Zone	4.3	Between 50th and 75th percentile of Crescent Zone	143	High generally and slightly lower than	Uncertain (NAF-HS)	X	X	X	X	X

Sample ID	Rock Type	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type	ANC (kg H2SO4/t)	Relative Magnitude of ANC	Preliminary ARD classification	Sequential NAG	ABCC	Sulphur Speciation	Kinetic NAG	Peroxide Extraction
		in Northern Breccia Zone				typical for rock type						
MWC189	Crescent Zone	Crescent Sulphide Zone - Northern Breccia Zone	32.1	High S content, around 95th percentile of Crescent Zone	87.5	Moderate generally but lower than typical for rock type.	PAF				X	X
MWC229	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	0.35	Between 50th and 75th percentile value	14.2	Low generally but typical for rock type.	Uncertain (PAF-LC)	X	X	X	X	X
MWC289	Crackle Breccia	Crackle Breccia Zone – South-East Cresent and Breccia	5.08	High S content, well above 95th percentile	721	Very high generally and higher than typical for rock type.	NAF-HS		X	X		

A total of 21 samples of varying ANC were subject to carbon form test work to confirm the absence of a significant amount of organic carbon and the relationship between ANC and inorganic carbon content.

4.3.2 Sequential NAG testing

Sequential NAG testing was undertaken on six samples plotting in the 'Uncertain' or 'PAF' domains of the ARD classification plot (Figure 15). These included 1 PAF Crescent Zone sample, 2 Uncertain Siltstone samples, 1 Uncertain Diorite sample, and 1 Uncertain Calcite Cemented Breccia sample. Additionally, sequential NAG testing was undertaken on 1 NAF Conglomerate sample that was shown to have elevated total S (close to the 95th percentile value).

The sequential NAG test seeks to provide a more definitive ARD classification by providing a better definition of acid forming potential. The results of the test work support retaining the initial ABA classifications for the 1 PAF Crescent Zone sample and 1 NAF Conglomerate sample, and re-classifying the 1 Uncertain Calcite Cemented Breccia sample to PAF and the 1 Uncertain Diorite sample and 2 Uncertain Siltstone samples to PAF-LC. The results of the test work for each of the samples tested is provided in further detail below and in Appendix B.

Sample MWC104-MWC105 represents a very highly elevated sulphur content Calcite Cemented Breccia (total S of 16.6%) in the mineralised breccia zone in the south-east crescent and breccia region of the deposit. This sample was previously classified as Uncertain due to a NAPP of 38kg H_2SO_4/t (based on total sulphur and standard ANC) and an ANC/MPA ratio of 0.9, but a single NAG pH of 9.0. This sample was subject to 4 sequential NAG stages and still maintained a pH above 7 and no NAG acidity. However, as this sample had a very high ANC (470 H_2SO_4/t), it was unlikely that all pyritic/pyrrhotitic S would have reacted after 4 sequential NAG stages. This was further supported by sulphur speciation (Section 4.3.4) and effective ANC (Section 4.3.3) results that suggested a NAPP of34 kg H_2SO_4/t. This sample is expected to be PAF, but with a very long lag time of many years before acid generation would develop.

Sample MWC111 represents a highly elevated sulphur content massive sulphide (total S of 14.1%) in the crescent sulphide zone in the south-east crescent and breccia region of the deposit. This sample was previously classified as PAF due to a NAPP of 167kg H_2SO_4/t (based on total sulphur and standard ANC) and ANC/MPA ratio of 0.9, but a single NAG pH of 2.6. Counter to the original single NAG pH result, this sample was subject to 11 sequential NAG stages and still maintained a pH above 7 and no NAG acidity. However, as this sample had a very high ANC (264kg H_2SO_4/t) it was unlikely that all pyritic/pyrrhotitic S would have reacted, and considering a significantly positive NAPP value, the sample retained its classification as PAF.

Sample MWC161 represents of a slightly elevated sulphur content diorite (as compared to the crescent zone) (total S of 4.3%) that is within the northern breccia region of the deposit. This sample was previously classified as Uncertain due to a NAPP of -11kg H_2SO_4/t (based on total sulphur and standard ANC), an ANC/MPA ratio of 1.1, and a single NAG pH of 9.4, but a high total sulphur content (where sulphide oxidation by a single NAG test is unlikely to be complete).This sample was subject to 4 sequential NAG stages and reported a pH of 4.3 at Stage 3 with a cumulative $NAG_{(pH4.5)}$ of 0.2kg H_2SO_4/t. Although the $NAG_{(pH4.5)}$ was negligible in magnitude, the corrected NAPP as determined by sulphur speciation (Section 4.3.4) and effective ANC (Section 4.3.3) did suggest a NAPP of 18kg H_2SO_4/t. On that basis this sample was re-classified as PAF-LC.

Sample MWC052 represents a Siltstone with slightly elevated sulphur content (total S of 0.35%) located at the base of the Permian where there has been a glacial re-working of the underlying the Proterozoic rocks. This sample was previously classified as Uncertain (likely to be PAF-LC) due to a NAPP of -3kg H_2SO_4/t (based on total sulphur and standard ANC), an ANC/MPA ratio of 1.2 and a single NAG pH of 3.5. This sample was subject to 4 sequential NAG stages and reported a pH of 3.8 at Stage 1 with an accumulative $NAG_{(pH4.5)}$ of 1kg H_2SO_4/t. This together with a corrected NAPP of 3kg H_2SO_4/t as determined by sulphur speciation (Section 4.3.4) and effective ANC (Section 4.3.3) provided sufficient basis for re-classification of the sample as PAF-LC.

Sample MWC229 represents a Siltstone with a typical sulphur content (total S of 0.35%) located at the base of the Permian where there has been a glacial re-working of the underlying the Proterozoic rocks. This sample was previously classified as Uncertain (likely to be PAF-LC) due to a NAPP of -3kg H_2SO_4/t (based on total sulphur and standard ANC), an ANC/MPA ratio of 1.3 and a single NAG pH of 3.9. This sample was subject to 4 sequential NAG stages and reported a pH of 3.9 at Stage 1 with a cumulative $NAG_{(pH4.5)}$ of 1kg H_2SO_4/t. This together with a corrected NAPP of 3kg H_2SO_4/t as determined by sulphur speciation (Section 4.3.4) and effective ANC (Section 4.3.3) provided sufficient basis for re-classification of the sample as PAF-LC.

Sample MWC140 represents Conglomerate with an elevated total sulphur content (total of 0.7%) located at the base of the Permian where there has been a glacial re-working of the underlying the Proterozoic rocks. This sample was previously classified as NAF due to a NAPP of -45kg H_2SO_4/t (based on total sulphur and standard ANC), an ANC/MPA ratio of 3.1 and a single NAG pH of 8.5. This sample was subject to 4 sequential NAG stages and still maintained a pH above 7 and no NAG acidity and on that basis maintained its original classification as NAF.

4.3.3 Acid Buffering Characteristic Curve (ABCC) testing

Acid buffering characteristic curve (ABCC) testing was undertaken on 7 samples to determine effective (readily available) ANC, as compared with standard ANC measured in the standard geochemical characterisation test work. The 7 samples tested included 2 Uncertain Siltstone, 2 NAF Actinolite Cemented Breccia, 1 Uncertain Calcite Cemented Breccia, 1 Uncertain Diorite, and 1 NAF-HS Crackle Breccia.

Results of the ABCC test work are provided in Appendix C. Carbonate types are provided as reference in Figures D-1 to D-7 of Appendix C. Calcite and dolomite readily dissolve in acid and exhibit strongly buffered pH curves in the ABCC test, rapidly dropping once the effective ANC value is reached. Siderite provides very poor acid buffering, reflected in a very steep pH curve in the ABCC test. Ferroan dolomite has an acid buffering availability between siderite and dolomite.

Based on the ABCC curves, samples can be split into those exhibiting a high or low proportion of readily available ANC.

The following samples show strong effective buffering capacity similar to the ferroan dolomite standard curves, with a very high standard ANC and high proportion of readily available ANC:

- Sample MWC157-MWC158 had an effective ANC of 582kg H_2SO_4/t which is 90% of the standard ANC.
- Sample MWC104-MWC105 had an effective ANC of 459kg H_2SO_4/t which is 98% of the standard ANC.
- Sample MWC289 had an effective ANC of 710kg H_2SO_4/t which is 99% of the standard ANC.
- Sample MWC090 had an effective ANC of 86kg H_2SO_4/t which is 85% of the standard ANC.
- Sample MWC161 had an effective ANC of 113kg H_2SO_4/t which is 80% of the standard ANC.

The following samples show poor effective buffering capacity similar to the ferroan dolomite standard curves, with a low standard ANC and lower proportion of readily available ANC:

- Sample MWC052 had an effective ANC of 5kg H_2SO_4/t which is 40% of the bulk ANC.
- Sample MWC229 had an effective ANC of 14kg H_2SO_4/t which is 40% of the bulk ANC.

Additionally, across the various rock types at Haverion, ANC estimated from inorganic carbon (calcite equivalent) appears to provide a reasonable estimate of standard ANC, at least for higher ANC samples (Figure 16). It should be noted however that most samples were associated with the carbonate-rich deposit within the Proterozoic basement and not the overlying Permian cover that is known to be highly depleted in carbonate minerals.

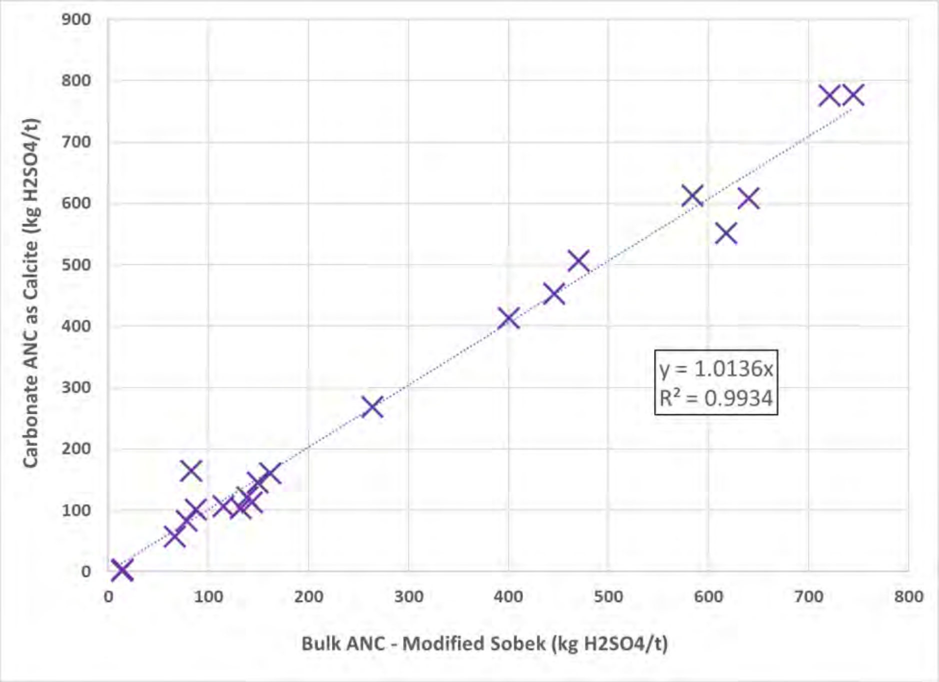


Figure 16: Carbonate ANC as calcite Vs standard ANC based upon 21 samples tested for carbon forms.

4.3.4 Sulphur speciation

Sulphur speciation analysis was carried out on 8 samples initially classified as PAF or Uncertain. These included 2 PAF Crescent Zone samples, 2 Uncertain Siltstone samples, 1 Uncertain Diorite sample, 1 NAF-HS Crackle Breccia samples, and 1 Uncertain Calcite Cemented Breccia sample. Additionally, sulphur speciation was undertaken on 1 NAF Conglomerate sample that was shown to have elevated total S (close to the 95th percentile value).

The results of the test work, in addition to the sequential NAG testing, support retaining the initial ABA classifications for the 2 PAF Crescent Zone sample, 1 NAF Conglomerate sample, and 1 NAF-HS Crackle Breccia sample, and re-classifying the 1 Uncertain Calcite Cemented Breccia sample to PAF and 1 Uncertain Diorite sample and 2 Uncertain Siltstones samples to PAF-LC.

The following aspects should be noted regarding the manner in which the data were evaluated:

- Final ARD classification was conservatively based on NAPP values derived from total S and effective ANC with consideration also of specialised testing results.
- The chromium reducible sulphur (CRS) values were used together with effective ANC to estimate revised NAPP values.
- Consideration was also made to the use of MPA calculated via accounting for a large proportion of pyrrhotite known to be present in the south-east crescent and breccia region of the deposit (median value of 75% of the total sulphide present based upon 23 ore samples that were subject to detailed mineralogical test work (Newcrest 2021)). The associated MPA value was based on an MPA calculated using the equation MPA=((pyritic sulphur wt%) + (0.2 × pyrrhotite sulphur wt%)) × 30.6 (Gerson *et al.* 2019). This is considered a conservative estimate for potential acid generation capacity of pyrrhotite. NAPP values were calculated in a similar manner and conservatively assumed a 25th percentile pyrrhotite proportion of 59% of the total sulphide present.

The results of the sulphur speciation are presented in Appendix D. From the results it can be inferred that sulphur is pyritic/pyrrhotitic in Permian cover materials close to the basement of the unconformity and in materials in the northern breccia or crescent zone. Further detail on determination of acid potential and adjustment of NAPP based on sulphur speciation follows.

Total sulphur is likely to provide a suitably conservative estimate for acid potential for the Permian cover materials close to the basement of the unconformity as well as the higher sulphide materials in the northern breccia/crescent zone. In the case of the Permian cover materials close to the basement of the unconformity, it should be assumed that all sulphur could be present as pyrite. In the case of the higher sulphide materials in the northern breccia/crescent zone it should be assumed that all sulphur could be present as pyrite and the recovery of S estimated by the chromium reducible sulphur (CRS) is known to diminish at higher sulphur levels (Schumann *et al.* 2012).

Although rock types within the Proterozoic basement are generally enriched in carbonate minerals and effective ANC appears close to bulk ANC values, the overlying Permian cover is known to be highly depleted in carbonate minerals and thus the effective ANC should be considered in the estimation of NAPP values and ARD classification for these materials.

In terms of specific samples:

- Sample MWC104-MWC105 has a revised NAPP of 34kg H_2SO_4/t and has been conservatively classified PAF, but with a very long lag time of many years before acid conditions (if they occur) would develop. Whether this sample is PAF or NAF-HS, it is considered potentially problematic.
- Sample MWC289 has a revised NAPP of -548kg H_2SO_4/t and retains its original classification as NAF-HS.
- Sample MWC161 has a revised NAPP of 18kg H_2SO_4/t but has been re-classified as PAF-LC based on sequential NAG results in Section 4.3.2.
- Sample MWC085 has a revised NAPP of 474kg H_2SO_4/t and retains its classification as PAF.
- Sample MWC155 has a revised NAPP of 1,070kg H_2SO_4/t and retains its classification as PAF.
- Sample MWC052 has a revised NAPP of 4kg H_2SO_4/t and was re-classified as PAF-LC, supported by the sequential NAG results in Section 4.3.2.
- Sample MWC140 has a revised NAPP of -4kg H_2SO_4/t and retains its classification as NAF, supported by sequential NAG results in Section 4.3.2.
- Sample MWC229 has a revised NAPP of 3kg H_2SO_4/t and was re-classified as PAF-LC, supported by the sequential NAG results in Section 4.3.2.

4.3.5 Kinetic NAG Testing

All 8 samples initially classified as 'Uncertain' or 'PAF' were subjected to kinetic NAG testing. The test is used as an indication of lag time before acid conditions would develop under atmospheric oxidation conditions. Samples tested included 1 Uncertain Calcite Cemented Breccia sample, 1 Uncertain Diorite samples, 2 Uncertain basement Permian cover Siltstone samples and 4 PAF Crescent Zone samples. Results of the kinetic NAG testing are provided in Appendix E.

Sample MWC104-MWC105 showed a distinctive temperature peak above 80°C is consistent with the presence of a significant amount of pyrite/pyrrhotite (as also inferred by the sulphur speciation results). The sample did not acidify in the time of the test, indicating long lag times, consistent with sequential NAG results.

Sample MWC161 did not show a distinct temperature peak, indicating slow rates of pyrite/pyrrhotite oxidation in the time of the test. The sample did not acidify in the time of the test, indicating long lag times, consistent with sequential NAG results.

Sample MWC085 showed a distinctive temperature peak above 60°C, consistent with the presence of a significant amount of pyrite/pyrrhotite (as also inferred by the sulphur speciation results). The timeframe to reach a pH below 4 (166 minutes) infers a long lag time of 1 to 2 years.

Sample MWC111 showed a distinctive temperature peak above 80°C, consistent with the presence of a significant amount of pyrite/pyrrhotite (as also inferred by the sulphur speciation results). The sample did not acidify in the time of the test, indicating long lag times, consistent with sequential NAG results.

Sample MWC155 showed a distinctive temperature peak above 80°C, consistent with the presence of a significant amount of pyrite (as also inferred by the sulphur speciation results). The time to reach a pH below 4 (7 minutes) infers a short lag time of 1 to 2 months.

Sample MWC189 showed a distinctive temperature peak above 80°C, consistent with the presence of a significant amount of pyrite (as also inferred by mineralogy in the northern breccia region). The time to reach a pH below 4 (49 minutes) infers a moderate lag time of 4 to 6 months.

Sample MWC052 showed only a subdued temperature peak consistent with a low total S of 0.35%. The time to reach a pH below 4 (358 minutes) infers a long lag time of greater than two years.

Sample MWC229 showed only a subdued temperature peak consistent with a low total S of 0.35%. The time to reach a pH below 4 (1,000 minutes) infers a long lag time of greater than two years.

4.3.6 Final ARD classifications

The ARD classification for all samples, including classifications modified based on the results of specialised geochemical test work, are provided in Table 10.

Table 10: Acid-base accounting results for all samples, including ARD classification that was modified based on specialised geochemical test work

Sample ID	Rock Type	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC	ARD classification*	Revised NAPP (kg H_2SO_4/t)^	ANC/MPA	Single NAGpH	NAG (pH 4.5)	NAG (pH 7.0)
MWC010-MWC019	Dolerite	Post Mineral Dolerite Dyke, South-East Crescent and Breccia	0.08	Between 25th and 50th percentile	22.1	Low generally and very much lower than typical for rock type.	NAF	-20	9	7.9	<0.1	<0.1
MWC023-MWC027	Crackle Breccia	Crackle Breccia Zone – South-East Crescent and Breccia	1.42	Above 95th percentile	149	High generally, but lower than typical for rock type.	NAF-HS	-106	3	9.4	<0.1	<0.1
MWC028-MWC047	Dolerite	Post Mineral Dolerite Dyke, South-East Crescent and Breccia	0.07	Circa 25th percentile	58.7	Moderate generally, very much lower than typical for rock type.	NAF	-57	27	10.4	<0.1	<0.1
MWC048-MWC051	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.11	Between 50th and 75th percentile	656	Very high generally and moderately higher than typical for rock type.	NAF	-653	195	11.6	<0.1	<0.1
MWC052	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	0.35	Between 50th and 75th percentile	13.3	Very low generally, but typical for rock type.	^PAF-LC	^4	1.2	3.5	2.4	5.5
MWC060	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	0.31	Between 50th and 75th percentile	132	High generally and very much higher than typical for rock type.	NAF	-123	14	11.2	<0.1	<0.1
MWC062	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	<0.01	Below 5th percentile	423	Very high generally, but slightly lower than typical for rock type.	NAF	-423	1382	11.7	<0.1	<0.1
MWC063	Diorite	Diorite – South-East Crescent & Breccia	0.37	Between 25th and 50th percentile of Cresent Zone	132	High generally, but slightly lower than typical for rock type.	NAF	-121	12	10.8	<0.1	<0.1
MWC066	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.06	Between 5th and 25th percentile	840	Very high generally and higher than typical for rock type.	NAF	-838	458	11.7	<0.1	<0.1
MWC085	Crescent Zone	Crescent Sulphide Zone – South-East Crescent + Breccia	18	Between 75th to 95th percentile of Cresent Zone	83	Moderate generally but lower than typical for rock type.	PAF	474	0.2	2	174	218
MWC090	Actinolite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.55	Between 75th to 95th percentile	139	High generally but lower than typical for rock type.	NAF	-122	8	11.2	<0.1	<0.1

Sample ID	Rock Type	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC	ARD classification*	Revised NAPP (kg H_2SO_4/t)^	ANC/MPA	Single NAGpH	NAG (pH 4.5)	NAG (pH 7.0)
MWC091	Bedded Sediment	Bedded Sediment – South-East Crescent & Breccia	0.11	Between 50th and 75th percentile	69.1	Moderate generally but lower than typical for rock type.	NAF	-66	21	9.9	<0.1	<0.1
MWC104-MWC105	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	16.6	Very high S content, well above 95th percentile	459	Very high generally but typical for rock type.	^PAF	^34	0.9	9	<0.1	<0.1
MWC107	Bedded Sediment	Bedded Sediment – South-East Crescent & Breccia	0.02	Between 5th and 25th percentile value of bedded sediments	506	Very high generally and higher than typical for rock type.	NAF	-505	827	11.6	<0.1	<0.1
MWC111	Crescent Zone	Crescent Sulphide Zone – South-East Crescent & Breccia	14.1	Between 75th to 95th percentile of Cresent Zone	264	High generally, but slightly lower than typical for rock type.	PAF	167	0.6	2.6	61	82
MWC112	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.14	Between 25th and 50th percentile value	690	Very high generally and higher than typical for rock type.	NAF	-686	161	11.5	<0.1	<0.1
MWC113	Diorite	Diorite – South-East Crescent & Breccia	0.55	Between 5th and 25th percentile value	162	High generally, but slightly lower than typical for rock type.	NAF	-145	10	11	<0.1	<0.1
MWC140	Conglomerate	Lower strata close to Permian Cover / Proterozoic Basement	0.7	Circa 95th percentile value	66.3	Moderate generally but higher than typical for rock type.	NAF	-4	3	11	<0.1	<0.1
MWC142	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	0.21	Circa 50th percentile value	80.5	Moderate generally but higher than typical for rock type.	NAF	-74	13	11	<0.1	<0.1
MWC145-MWC146	Conglomerate	Lower strata close to Permian Cover / Proterozoic Basement	0.55	Between 75th and 95th percentile value.	115	High generally and very much higher than typical for rock type.	NAF	-98	7	11.2	<0.1	<0.1
MWC147-MWC150	Calcite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	0.24	Circa 50th percentile value	600	Very high generally and slightly higher than typical for rock type.	NAF	-593	82	11.5	<0.1	<0.1
MWC151	Crackle Breccia	Crackle Breccia Zone – North-West Crescent	0.09	Between 25th and 50th percentile value	134	High generally but lower than typical for rock type.	NAF	-131	49	9.7	<0.1	<0.1

Sample ID	Rock Type	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC	ARD classification*	Revised NAPP (kg H_2SO_4/t)^	ANC/MPA	Single NAGpH	NAG (pH 4.5)	NAG (pH 7.0)
MWC155	Crescent Zone	Crescent Sulphide Zone - Northern Breccia Zone	33.4	High S content, around 95th percentile of Crescent Zone	78	Moderate generally but lower than typical for rock type.	PAF	1,070	0.1	1.9	189	258
MWC157-MWC158	Actinolite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	0.28	Circa 50th percentile value	640	Very high generally and higher than typical for rock type.	NAF	-631	75	11.1	<0.1	<0.1
MWC161	Diorite	Mineralised Breccia / Crescent Sulphide Zone in Northern Breccia Zone	4.3	Between 50th and 75th percentile of Crescent Zone	143	High generally and slightly lower than typical for rock type	^PAF-LC	^18	1.1	^4.3	^0.15	^4.1
MWC186	Calcite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	0.07	Between 5th and 25th percentile value	940	Very high generally and higher than typical for rock type.	NAF	-938	439	11.4	<0.1	<0.1
MWC189	Crescent Zone	Crescent Sulphide Zone - Northern Breccia Zone	32.1	High S content, around 95th percentile of Crescent Zone	87.5	Moderate generally but lower than typical for rock type.	PAF	895	0.1	2.1	195	239
MWC190-MWC191	Actinolite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	0.04	Between 5th and 25th percentile value	605	Very high generally and higher than typical for rock type.	NAF	-604	494	11.6	<0.1	<0.1
MWC193	Calcite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	<0.01	Less than 5th percentile value	948	Very high generally and higher than typical for rock type.	NAF	-948	3098	11.5	<0.1	<0.1
MWC200	Calcite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	0.42	Between 50th and 75th percentile value	745	Very high generally and higher than typical for rock type.	NAF	-732	58	11.4	<0.1	<0.1
MWC203-MWC204	Calcite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	0.2	Between 25th and 50th percentile value	435	Very high generally but slightly lower than typical for rock type.	NAF	-429	71	11.6	<0.1	<0.1
MWC214-MWC215	Calcite Cemented Breccia	Crackle Breccia Zone – North-West Crescent	0.02	Less than 5th percentile value	816	Very high generally and higher than typical for rock type.	NAF	-815	1333	11.5	<0.1	<0.1
MWC216	Conglomerate	Lower strata close to Permian Cover / Proterozoic Basement	0.21	Circa 50th percentile value	21.4	Low generally but slightly higher than typical for rock type.	NAF	-15	3	8.5	<0.1	<0.1

Sample ID	Rock Type	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC	ARD classification*	Revised NAPP (kg H_2SO_4/t)^	ANC/MPA	Single NAGpH	NAG (pH 4.5)	NAG (pH 7.0)
MWC217-MWC218	Bedded Sediment	Bedded Sediment – North-West Crescent	0.14	Circa 5th percentile value	437	Very high generally and slightly higher than typical for rock type.	NAF	-433	102	11.7	<0.1	<0.1
MWC221-MWC222	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	0.12	Between 25th and 50th percentile value	13.2	Low generally and slightly lower than typical for rock type	NAF	-10	4	6.9	<0.1	0.2
MWC226	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	0.09	Between 25th and 50th percentile value	16.1	Low generally but slightly higher than typical for rock type.	NAF	-13	6	10.1	<0.1	<0.1
MWC229	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	0.35	Between 50th and 75th percentile value	14.2	Low generally but typical for rock type.	^PAF-LC	^3	1.3	3.9	1.4	3.9
MWC248-MWC250	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	2.54	Above 95th percentile	618	Very high generally and slightly higher than typical for rock type.	NAF-HS	-540	8	11	<0.1	<0.1
MWC251	Dolerite	Post Mineral Dolerite Dyke, South-East Crescent and Breccia	0.12	Above 95th percentile	28.6	Low generally but higher than typical for rock type	NAF	-25	8	8	<0.1	<0.1
MWC256-MWC257	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.23	Circa 50th percentile value	616	Very high generally and slightly higher than typical for rock type.	NAF	-609	88	11.7	<0.1	<0.1
MWC270	Crackle Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.14	Circa 50th percentile value	592	Very high generally and slightly higher than typical for rock type.	NAF	-588	138	11.5	<0.1	<0.1
MWC276-MWC277	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Cresent & Breccia	0.04	Between 5th and 25th percentile value	563	Very high generally and slightly higher than typical for rock type.	NAF	-562	460	11.6	<0.1	<0.1
MWC283	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.18	Between 25th and 50th percentile value	938	Very high generally and higher than typical for rock type.	NAF	-932	170	11.6	<0.1	<0.1
MWC284	Crescent Zone	Crescent Sulphide Zone – South-East Crescent & Breccia	5.87	Between 50th and 75th percentile of Crescent Zone	400	Very high generally, but slightly lower than typical for rock type.	NAF-HS	-220	2.2	8.8	<0.1	<0.1

Sample ID	Rock Type	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC	ARD classification*	Revised NAPP (kg H_2SO_4/t)^	ANC/MPA	Single NAGpH	NAG (pH 4.5)	NAG (pH 7.0)
MWC285	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.18	Between 25th and 50th percentile value	623	Very high generally and slightly higher than typical for rock type.	NAF	-617	113	11.6	<0.1	<0.1
MWC286-MWC287	Actinolite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.15	Between 25th and 50th percentile value	603	Very high generally and higher than typical for rock type.	NAF	-598	131	11.6	<0.1	<0.1
MWC289	Crackle Breccia	Crackle Breccia Zone – South-East Crescent and Breccia	5.08	High S content, well above 95th percentile	721	Very high generally and higher than typical for rock type.	NAF-HS	-548	5	8.9	<0.1	<0.1
MWC290-MWC291	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	1.3	Between 75th to 95th percentile	446	Very high generally but slightly lower than typical for rock type.	NAF-HS	-406	11	11.1	<0.1	<0.1
MWC293	Crackle Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	0.13	Circa 50th percentile value	700	Very high generally and higher than typical for rock type.	NAF	-696	176	11.3	<0.1	<0.1
MWC294-MWC296	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Cresent & Breccia	4.04	High S content, well above 95th percentile	584	Very high generally and slightly higher than typical for rock type.	NAF-HS	-460	5	9.3	<0.1	<0.1

Notes: *These modified ARD classifications and key values are based upon specialised geochemical test work.

^ Revised NAPPs are been based upon effective ANC (kg H_2SO_4)

4.4 Elemental test work (solids)

To determine if elements in solid samples were significantly enriched, concentrations of elements in the 10 samples tested for 60 elements by ICP were compared with median crustal abundance. The extent of elemental enrichment in samples was assessed using the Geochemical Abundance Index (GAI). Additionally, results were compared against the National Environmental Protection Council (NEPC) background concentrations for Health Investigation Level (HIL) (NEPC 2011a) and Ecological Investigation Level (EIL) (NEPC 2011b) ranges for soils[6]. Full results of this assessment are provided in Appendix F. Elements typically shown to be significantly enriched in samples are outlined in Table 11.

Table 11: Elements typically shown to be significantly enriched in waste samples

GAI = 3-4	GAI = 5	GAI>6
Silver	Cobalt	Bismuth
Arsenic	Lead	Iron
Indium		Copper
Lutetium		Selenium
Thallium		Tellerium
Thulium		Iron
Ytterbium		

---

[6] EIL land-uses include national parks and areas with high ecological value. HIL land-uses include developed open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths.

Further analysis of elemental concentrations in solids showed that:

- Material from the Crescent Zone was shown to be significantly enriched in Bismuth, Cobalt, Copper, Nickel and Lead when compared to other wastes. Concentrations of elements in this material exceeded EIL and HIL values.
- All wastes types (except for Bedded Sediments and Dolerite) were significantly enriched in Copper, with concentrations of Copper typically exceeding EIL and HIL values.

Determining the potential for materials to become a contaminant source must also consider a material's leachable fraction of potential contaminants. For this reason, multi-element analysis of leached solutions (de-ionised water and peroxide extractions) was also undertaken for waste samples. Leachable concentrations were assessed against guideline limits for freshwater and livestock (beef cattle) drinking water (ANZECC 2000) or, Australian drinking water (NHMRC, NRMMC, 2011) or British Columbia Freshwater Protection (British Columbia 2021) where freshwater and livestock limits did not exist.

The following section provides results of the multi-element analysis of solutions leached from waste materials.

4.5 Elemental test work (leachate)

4.5.1 Deionised water extraction

10 samples of waste rock types Actinolite Cemented Breccia, Calcite Cemented Breccia, Crackle Breccia, Crescent Zone, and Conglomerate were subject to a deionised water extract (1:20 solid:water). The de-ionised water extract provides a preliminary indication of leachable loadings of a freshly mined material upon short term contact with an unbuffered water source (e.g. surface rainfall run-off). Results of elemental test work for leachate is provided in Appendix F.

Results of the assessment indicate that flushing of all waste rock materials tested with an unbuffered water source was not likely to generate significant loadings of metals and metalloids immediately after mining and surface exposure. Reported concentrations of aluminium across all rock types, except the Crescent Zone, were slightly elevated when compared with the guideline limits for freshwater. The slightly elevated aluminium may be associated with the formation of soluble $Al(OH)_4^-$ as a result of the alkalinity of the leachate solution (as supported by the 1:5 pH results).

The potential for elevated levels of aluminium to have an adverse effect on the receiving environment is primarily where pH is <5 and aluminium is more likely to be present as trivalent Al^{3+}, which is the form of aluminium known to be most toxic to natural organisms (Bojórquez-Quintal *et al.* 2017). Where the pH is >5 up to moderately alkaline conditions (circa pH 8.5), soluble Al concentrations are expected to remain low, be predominantly non- soluble $Al(OH)_3$ and $Al(OH)_4^-$, and not represent a significant toxicity issue.

4.5.2 Peroxide extraction

Peroxide extraction tests were undertaken on 9 samples shown to have elevated levels of total S including 1 Uncertain Calcite Cemented Breccia sample (re-classified to PAF), 1 NAF-HS Crackle Breccia sample, 1 Uncertain (re-classified to PAF-LC) Diorite sample, 2 Uncertain (re-classified to PAF-LC) basement Permian cover Siltstone samples, and 4 PAF Crescent Zone samples.

The results suggest that upon exposure to strongly oxidising conditions, the drainage water from the Calcite Cemented Breccia, Crackle Breccia, and Diorite sample, is likely to be slightly alkaline, potentially elevated in sulphate, and slightly elevated in some metals and metalloids. Drainage water from Crescent Zone and Permian cover Siltstone samples is likely to be acidic, and potentially or slightly elevated in sulphate and some metals and metalloids.

- Calcite cemented breccia as represented by Uncertain sample MWC104-MWC105 (highly elevated total S and very high ANC but within an expected range for this rock type) – results infer drainage water may be slightly alkaline, potentially elevated in selenium and sulphate, slightly elevated in nickel and zinc and with probable low concentrations of all other metals and metalloids (noting this would be representative of the lag phase before any onset of net acidity (if that were to occur)).
- Crackle Breccia as represented by NAF-HS sample MWC289 (highly elevated total S and very high ANC but within an expected range for this rock type) – results infer drainage water may be slightly alkaline, potentially elevated in sulphate, slightly elevated in chromium, copper, nickel, selenium and zinc and with probable low concentrations of all other metals and metalloids.
- Diorite as represented by PAF-LC sample MWC161 (slightly elevated total S and moderate ANC as compared to the most sulphur enriched Crescent Zone rock type) – results infer that for at least the initial lag phase, drainage water may be slightly alkaline, potentially elevated in sulphate, slightly elevated in aluminium, chromium and selenium, and with probable low concentrations of all other metals and metalloids.
- Crescent Zone PAF samples (MWC189 and MWC155) within the crescent sulphide zone of the north-west crescent region of the deposit that have highly elevated total S content (total S of 32.1 to 33.4% respectively, which is around the 95th percentile for that rock type) and a relatively low ANC (88 to 78kg H_2SO_4/t respectively) for this rock type – results infer drainage water may be acidic, potentially elevated in sulphate, cobalt, copper, iron, manganese, lead, selenium and zinc, slightly elevated in aluminium, arsenic, boron, cadmium and chromium and with low concentrations of all other metals and metalloids.
- Crescent Zone (PAF) samples (MWC111 and MWC085) within the crescent sulphide zone of the south-east crescent and breccia region of the deposit that have elevated total S content (total S of 14.1 to 18.0% respectively, which is between the 75th and 95th percentile values for this rock type) and moderate to low ANC (264 to 83kg H_2SO_4/t respectively) for this rock type – results infer drainage water quality may be more adverse with lower ANC (represented by MWC 085), specifically acidic, potentially elevated in sulphate, aluminium, cobalt, copper, iron, manganese, selenium and zinc and slightly elevated in boron, cadmium, nickel and antimony. Conversely results infer that drainage

water for the high ANC PAF materials (represented by MWC111) in the initial lag phase is likely to remain alkaline, elevated in sulphate, iron and manganese and slightly elevated in aluminium, cobalt, copper, nickel, lead, selenium and zinc.

- Basement Permian Cover siltstone as represented by PAF-LC samples MWC052 and MWC229 (moderately elevated total S and depleted ANC) – results infer drainage water may be acidic, potentially elevated in aluminium and molybdenum and slightly elevated in boron, barium, cadmium, chromium, cobalt, copper, manganese, nickel and zinc and with probable low concentrations of all other metals and metalloids.

4.6 Structural stability

A subset of 5 samples of Permian material, including 4 Siltstone and 1 Conglomerate samples were analysed for physico-chemical indicators of structural stability. These materials were selected for structural stability testing because a high proportion of the material matrix consisted of fines, making these materials more prone to breakdown. The materials' tendency for structural decline was assessed based on the conditions defined in Section 3.3. The results of the assessment are included in Table 12. This assessment assumes that the coarse fraction is low, and that the materials are dominated by fines, as is the case for the 5 samples studied here.

Table 12: Assessment of Permian waste types against structural stability parameters

Analysis	Unit	MWC052	MWC060	MWC142	MWC219	MWC229
		SST	SST	SST	CON	SST
ECEC	meq/100g	2.2	2.4	2.6	2.9	3.1
ESP	%	39.1	25.1	15.7	24.6	35.2
Ex Sodium	meq/100g	0.84	0.60	0.41	0.72	1.09
Ca:Mg	-	1.0	6.9	3.5	6.0	2.9
ESI	-	0.05	0.03	0.05	0.06	0.05
FS+S+C	%	79.1	19.7	80.5	49.4	95.5
Clay	%	7.6	3.9	7.5	9.3	5.7
ESP Result		✗	✗	✗	✗	✗
Ex. Mg Result		✗	✗	✗	✗	✗
ESI Result		✗	✗	✗	✗	✗
PSD Result		✓	✗	✓	✗	✓
Prone to structural decline		Yes	No	Yes	No	Yes

Notes: SST = Siltstone, CON = Conglomerate, ECEC= Effective Cation Exchange Capacity, ESP = Exchangeable Sodium Percentage, Ex Sodium = Exchangeable Sodium, Ca:Mg = Calcium:Magnesium ratio, ESI = Electrochemical Stability Index, FS+S+C = Fine sand + Silt + Clay fractions.

It can be inferred from the results of the assessment, that in the Siltstone materials, there is high availability of sodium on the exchange complex but the ECEC and clay fraction is low, reducing the risk of structural decline via clay dispersion. However there still remains a risk of structural decline in these materials, given the high proportion of fine particles (combined proportion of fine sands, silts and clays). This is because these smaller particles can mobilise within the coarser sand matrix, making the material more prone to tunnel erosion, even if the clay fraction is not dispersive. For this reason, the Siltstone material is not considered suitable for use as a growth medium or surface cover.

The increased risk of structural decline in Permian materials is consistent with previous structural stability testing undertaken on 11 samples from the Permian sequence as part of the Stage 1 characterisation testwork (Landloch 2021). The results of the testwork showed most Permian materials, except for the Tertiary cover, and Upper and Lower Tillites to be prone to structural decline based on elevated exchangeable sodium values and a high proportion of fine particles.

4.7 Rock durability

In order to gain insight into the durability of the different waste materials and the potential for their use as a rock armour in rehabilitation, waste samples were tested for rock particle density, water absorption, and rock strength. For each sample, a minimum of three rock pieces were tested and averaged. A durability rating was assigned based on rock particle density, water absorption, and rock strength values, in addition to lithology and weathering grade of each of the materials. Results of the durability assessment are provided in Table 13.

Table 13: Lithology, weathering, rock strength ratings and average rock particle density and water absorption values for each rock type

Geology	Lithology*	Weathering	No samples tested	Average rock density (g/cm^3)	Average water absorption (%)	Strength rating^	Durability rating
Proterzoic	ACB	Fresh	4	7.15	0.25	S-VS	Excellent
	BS	Fresh	4	6.05	0.25	MS-ES	Excellent
	CCB	Fresh	5	6.33	0.23	MS-ES	Excellent
	CB	Fresh	7	6.73	0.03	VS-ES	Excellent
	DIO	Fresh	2	6.70	0.00	VS-ES	Excellent
	DOL	Fresh	11	6.23	1.31	MS-ES	Good
Permian	CON	Slightly to moderately weathered	1	4.80	3.50	W	Poor
	SST	Slightly to moderately weathered	3	4.15	8.65	VW-W	Poor

*ACB: Actinolite Cemented Breccia, BS: Bedded Sediments, CCB: Calcite Cemented Breccia, CB: Crackle Breccia, CON: Conglomerate, SST: Siltstone, DIO: Diorite, DOL: Dolerite.
^ES: Extremely strong, VS: Very strong, S: Strong, MS: Medium strong, W: Weak, VW: Very weak.

Based on the assessment all rock types from the Proterozoic exhibited good to excellent durability. Materials from the Permian sequence tended to have poorer durability based on increased exposure to weathering, lower rock strength, and increased water absorption. These materials are less suitable for use as rehabilitation rock armour as compared to the Proterozoic basement rock types.

4.8 Asbestiform materials

A subset of 7 waste samples, were assessed for presence of asbestiform materials via optical microscopy. A minimum of 1 sample was assessed for each of the different rock types. Sampling was done using fractured faces of the available drill core. No fibrous materials were detected in the waste samples tested (Appendix H).

4.9 Naturally occurring radioactive materials

All minerals and raw materials contain radionuclides of natural origin. For most activities involving minerals and raw materials, the levels of exposure to these radionuclides are not significantly greater than normal background levels and are not of concern for radiation protection. However, some materials may give off radiant energy at levels higher than background levels. Human activity around these types of materials can increase the risk of radiological exposure. Material giving rise to these enhanced exposures is known as naturally occurring radioactive material (NORM).

The Government of Western Australia (2019) and the DMP (2010) require that the dose limit and surface concentration for betta, gamma and low toxicity alpha emitters falls below 10μSv/hr and 0.40Bq/cm^2, respectively.

None of the samples were found to give rise to enhanced exposures of NORM when assessed against these criteria (Table 14).

Table 14: Results of NORM assessment

Measurement	Surface activity (Bq/cm^2)	Dose rate (μSv/hr)
Waste sample average	0.02	0.17
Specified limit	0.40	10

5 GEOCHEMICAL ATTRIBUTES OF WASTE ROCK TYPES

The following summary of geochemical attributes for each waste rock type is based on what can be inferred from projected mineral waste masses, the mineralogy and distribution of sulphur and carbonate minerals within the deposit, and geochemical test work results on a total of 50 samples intended to represent key rock types.

5.1 Actinolite Cemented Breccia

Actinolite Cemented Breccia waste rock can be summarised as follows:

- Expected to comprise ~1.5% of the total waste rock brought to surface.

- Very high[7] and readily available Ca/Mg carbonate mineral ANC and most of the rock type has a total sulphur content less than 1%.
- All samples that were subjected to detailed geochemical testing were classified as NAF.
- Although geochemical test work showed all samples tested to be NAF based on sulphur distributions, 25% or less of this rock type is likely to be NAF-HS. This is due to a portion of this unit being in close proximity to the ore zone.
- ACB is durable fresh rock, highly suitable for use as rehabilitation rock armour that is also free of asbestos fibres or radioactivity beyond background levels.
- In relation to elemental enrichment, significant enrichment in relation to the following elements of environmental interest: bismuth. No element significantly exceeded the adopted ecological/health investigation levels (greater than 5 times the threshold).
- In relation to leachability:
    - Short term contact with an unbuffered water source such as rainfall runoff may generate non-saline drainage water that is alkaline and slightly elevated in aluminium. However, the predominant soluble form will be $Al(OH)_4^-$ which does not represent a significant toxicity issue to either flora or fauna.
    - Upon exposure to strongly oxidising conditions NAF-HS materials may generate drainage water that is potentially elevated in sulphate salinity.

5.2 Bedded Sediment

Bedded Sediment waste rock can be summarised as follows:

- Expected to comprise ~36% of the total waste rock brought to surface.
- This waste rock type has moderate to very high and readily available Ca/Mg carbonate mineral ANC (slightly below 100 to often greater than 300kg H_2SO_4/t) and most of the rock type has a total sulphur content less than 0.2% (as suggested by the 75th percentile value, which is just below 0.2%, equivalent of circa 6kg H_2SO_4/t).
- All samples subjected to detailed geochemical testing were classified as NAF.
- Durable fresh rock material, highly suitable for use as rehabilitation rock armour that is also free of asbestos fibres or radioactivity beyond background levels.
- No significant enrichment in relation to any elements of environmental interest. All elements reported below the adopted ecological/health investigation levels.
- In relation to leachability:
    - Short term contact with an unbuffered water source may generate non-saline drainage water that is alkaline and slightly elevated in aluminium.

---

[7] Relative magnitude of Ca/Mg carbonate mineral ANC based upon the following descriptors: ‘low’ (below 10kg H_2SO_4/t); ‘moderate’ (between 30 and 100kg H_2SO_4/t); ‘high’ (between 100 and 300kg H_2SO_4/t); very high (greater than 300kg H_2SO_4/t). It should be noted that these are order of magnitude descriptors and are based upon a limited set of samples subject to ABCC test work and Ca% content distribution data (Newcrest 2021b). The actual correlation between Ca% and bulk ANC has yet to be determined.

However, the predominant soluble form will be $Al(OH)_4^-$ which does not represent a significant toxicity issue to either flora or fauna.

5.3 Crackle Breccia

Crackle Breccia waste rock can be summarised as follows:

- Expected to comprise ~4.8% of the total waste rock brought to surface.
- This waste rock type has high to very high and readily available Ca/Mg carbonate mineral ANC (greater than 100kg H_2SO_4/t and often greater than 300kg H_2SO_4/t) and most of the rock type has a total sulphur content less than 0.4% (as suggested by the 75Th percentile value, which is just below 0.4%, equivalent of circa 12kg H_2SO_4/t).
- 3 of 5 samples (~60%) subjected to detailed geochemical testing were classified as NAF.
- Samples that were not classified as NAF (>1% total S) were limited to rock materials very close to the ore zone, specifically the mineralised breccia zone in the south-east crescent and breccia region of the deposit where additionally the lower acid generating sulphide pyrrhotite is often present in greater abundance than pyrite. These rock materials are expected to comprise a minor fraction (i.e. <10%) of crackle breccia that will be brought to surface. These samples comprised two NAF-HS samples (total S >1%).
- A durable fresh rock material, highly suitable for use as rehabilitation rock armour that is also free of asbestos fibres or radioactivity beyond background levels.
- In relation to elemental enrichment, significant enrichment in relation to the following elements of environmental interest: arsenic, cobalt, copper and selenium. The only element to significantly exceed the adopted ecological/health investigation level (greater than 5 times the threshold) was copper.
- In relation to leachability:
    - Short term contact with an unbuffered water source such as rainfall runoff may generate non-saline drainage water that is alkaline and slightly elevated in aluminium, however the predominant soluble form will be $Al(OH)_4^-$ which does not represent a significant toxicity issue to either flora or fauna.
    - Upon exposure to strongly oxidising conditions NAF-HS materials (which are expected to be a minor fraction of this rock type) may generate drainage water may that is slightly alkaline, potentially elevated in sulphate, slightly elevated in chromium, copper, nickel, selenium and zinc and probable low concentrations of all other metals and metalloids.

5.4 Calcite Cemented Breccia

Calcite Cemented Breccia waste rock can be summarised as follows:

- Expected to comprise ~12% of the total waste rock brought to surface.
- This waste rock type has very high and readily available Ca/Mg carbonate mineral ANC (often greater than 300kg H_2SO_4/t) and most of the rock type has

a total sulphur content less than 1% (as suggested by the 75th percentile value, which is just below 1%, equivalent of circa 30kg H_2SO_4/t).

- 14 of 18 samples (~78%) subjected to detailed geochemical testing were classified as NAF.
- Samples that were not classified as NAF (>1% total S) were limited to rock materials very close to the ore zone (specifically the mineralised breccia zone in the south-east crescent and breccia region of the deposit where additionally the lower acid generating sulphide pyrrhotite is often present in greater abundance than pyrite). These rock materials are expected to comprise a minor fraction of the calcite cemented breccia that will be brought to surface. These samples comprised:
    - Three NAF-HS samples (total S >1%); and
    - One Uncertain sample with a very high total sulphur content (16.6% which is almost an order of magnitude greater than the 95th percentile total S content for that rock type).
- A durable material fresh rock material, highly suitable for use as rehabilitation rock armour that is also free of asbestos fibres or radioactivity beyond background levels.
- In relation to elemental enrichment, significant enrichment in relation to the following elements of environmental interest: copper, iron, and selenium. In relation to elemental enrichment, significant enrichment in relation to the following elements of environmental interest: copper and selenium. No element significantly exceeded the adopted ecological/health investigation levels (greater than 5 times the threshold).
- In relation to leachability:
    - Short term contact with an unbuffered water source such as rainfall runoff may generate non-saline drainage water that is alkaline and slightly elevated in aluminium, however the predominant soluble form will be $Al(OH)_4^-$ which does not represent a significant toxicity issue to either flora or fauna.
    - Upon exposure to strongly oxidising conditions NAF-HS materials (which are expected to be a minor fraction of this rock type) may generate drainage water may that is slightly alkaline, potentially elevated in selenium and sulphate, slightly elevated in nickel and zinc and probably has low concentrations of all other metals and metalloids.

5.5 Crescent Zone

Crescent Zone waste rock can be summarised as follows:

- Expected to comprise ~1.1% of the total waste rock brought to surface.
- Although this waste rock type has moderate to very high and readily available Ca/Mg carbonate mineral ANC (below 100 to greater than 300kg H_2SO_4/t) most of the rock type has a total sulphur content between 0.3 and 15% (as suggested by the 25th to 75th percentile band, which is equivalent of circa 10 to 460kg H_2SO_4/t).
- 4 out of 5 of samples subjected to detailed geochemical testing were classified as PAF and one samples was classified as NAF-HS.

- Crescent zone waste rock originating from the northern breccia zone contains a significantly greater proportion of pyrite over the lower acid generating sulphide pyrrhotite which is predominant in the south-east crescent and breccia region of the deposit. As such, material from the northern breccia zone represents the highest risk in terms of ARD.
- In relation to elemental enrichment, significant enrichment in relation to the following elements of environmental interest: silver, bismuth, cobalt, iron, lead and selenium. There were several elements that significantly exceeded the adopted ecological/health investigation levels (greater than 5 times the threshold): bismuth, copper, and nickel.
- In relation to leachability:
    - Short term contact with an unbuffered water source such as rainfall runoff may generate non-saline drainage water that is alkaline and slightly elevated in aluminium. However, the predominant soluble form will be $Al(OH)_4^-$ which does not represent a significant toxicity issue to either flora or fauna.
    - Upon exposure to strongly oxidising conditions PAF materials may generate drainage water may that is acidic, potentially elevated in sulphate, aluminium, cobalt, copper, iron, manganese, lead, selenium, and zinc and slightly elevated in arsenic, boron, cadmium, chromium, nickel, and antimony.
    - Similarly, although NAF-HS materials may not generate drainage water that is acidic, it is likely to generate a similar range of metals and metalloids at slightly lower concentrations.

5.6 Diorite

Diorite waste rock can be summarised as follows:

- Although the specific proportion of total waste rock brought to surface is unknown for diorite, what is known is that there is a strong spatial relationship between the presence and abundance of the diorite dykes and/or clasts with mineralisation, generally within the crescent zone and thus this rock type could generally be considered to be positioned very close to the ore zone and have close association with the crescent zone rock type.
- Based upon a very limited set of three representative samples, although diorite has relatively high readily available Ca/Mg carbonate mineral ANC (between 100 and 200kg H_2SO_4/t), total sulphur content varies from moderate to high (0.37 to 4.3%, equivalent of circa 11 to 131kg H_2SO_4/t). As such the two lower total sulphur content samples were classified as NAF and the higher total sulphur content sample was classified as PAF-LC.
- In relation to elemental enrichment, significant enrichment in relation to the following elements of environmental interest: bismuth, copper, iron, and selenium. The only element to significantly exceed the adopted ecological/health investigation level (greater than 5 times the threshold) was copper.
- In relation to leachability:
    - Short term contact with an unbuffered water source such as rainfall runoff may generate non-saline drainage water that is alkaline and slightly

    - elevated in aluminium. However, the predominant soluble form will be $Al(OH)_4^-$ which does not represent a significant toxicity issue to either flora or fauna.
    - Upon exposure to strongly oxidising conditions PAF-LC materials may generate drainage water in the initial lag phase that is slightly alkaline, potentially elevated in sulphate, slightly elevated in aluminium, chromium and selenium. Beyond the lag period drainage water is expected to become more adverse (i.e. acidic and metals and metalloids at greater concentration).

5.7 Dolerite

Dolerite waste rock can be summarised as follows:

- Expected to comprise ~23.1% of the total waste rock brought to surface.
- It is a post mineralisation intrusive rock at Haverion and thus has a significantly lower total sulphur content than other waste rock types. Most of this rock type has total sulphur of ~0.1% or less (as reflected by a 75th percentile value around 0.1%). Although Ca/Mg carbonate mineral content is expected to be significantly less than the other rock types, only low to moderate effective ANC is likely to be required to render most of the rock types as NAF. To illustrate, the single sample that was subject to test work was classified as NAF with a total sulphur content of 0.12% (equivalent of 3.6kg H_2SO_4/t) and a bulk ANC of 28.6kg H_2SO_4/t).
- A durable fresh rock material, highly suitable for use as rehabilitation rock armour that is also free of asbestos fibres or radioactivity beyond background levels.
- No significant enrichment in relation to any elements of environmental interest other than iron. All elements reported below the adopted ecological/health investigation levels.
- In relation to leachability:
    - Short term contact with an unbuffered water source such as rainfall runoff may generate non-saline drainage water that is alkaline and slightly elevated in aluminium. However, the predominant soluble form will be $Al(OH)_4^-$ which does not represent a significant toxicity issue to either flora or fauna.

5.8 Permian rock types (within 20m of base of unconformity)

Lower tillite/conglomerate/siltstone/sandstone at the base of the Permian cover and within circa 20m of the unconformity with the Proterozoic basement can be summarised as follows:

- Although not specifically quantified, they are expected to be a minor fraction as limited to an approximate 20m vertical interval of mining.
- Where pyritic sulphur is present, it is because of re-working of the underlying the Proterozoic rocks. Although moderate ANC may be present as an artefact of the same process, these rocks may be more typically depleted in readily available

Ca/Mg carbonate mineral ANC content as was the case for two samples that ABCC test work confirmed had only 40% effective ANC as compared to the bulk ANC. These two samples were classified as PAF-LC. The other 9 were classified as NAF due to sufficient ANC.

- In relation to elemental enrichment, significant enrichment in relation to iron. All elements reported below the adopted ecological/health investigation levels.
- Although free of asbestos fibres or radioactivity beyond background levels these materials have marginal to poor durability and a high proportion of fines making them significantly less suitable for use as rehabilitation rock armour as compared to the Proterozoic basement rock types.
- In relation to leachability:
  - Short term contact with an unbuffered water source such as rainfall runoff may generate non-saline drainage water that is alkaline and slightly elevated in aluminium. However, the predominant soluble form will be $Al(OH)_4^-$ which does not represent a significant toxicity issue to either flora or fauna.
  - Upon exposure to strongly oxidising conditions PAF-LC materials may generate drainage that is acidic, potentially elevated in aluminium and molybdenum, and slightly elevated in boron, barium, cadmium, chromium, cobalt, copper, manganese, nickel and zinc and with probable low concentrations of all other metals and metalloids.
  - Lower total sulphur materials are likely to initially generate saline drainage on event short-term contact with an unbuffered water source such as rainfall.

6 WASTE LANDFORM CONSIDERATIONS

In overview, the following materials appear useful based upon mineralogy and distribution of sulphur and carbonate minerals within the deposit, geochemical test work results, and physico-chemical results:

- Both Dolerite and Bedded Sediments appear suitable for use in rehabilitation as a rock armour. These rock types represent ~59% of all waste rock material that will be brought to surface. The vast majority is expected to be NAF and are unlikely to generate adverse drainage water quality in the shorter or longer term (including salinity).
- Both Actinolite Cemented Breccia and Calcite Cemented Breccia could be used to supplement the above rock types as rehabilitation rock armour or near surface materials. These rock types collectively represent ~14% of all waste rock materials, and although the majority of these materials are expected to be NAF, NAF-HS materials will be present in close proximity to the ore zone and thus more rigor is likely to be required around material segregation and handling than is required for the Dolerite and Bedded Sediments. NAF materials associated with these rock types are unlikely to generate adverse drainage water quality in the shorter or longer term (including salinity).

In overview the following materials appear to require encapsulation and specific ARD mitigation strategies:

- Crescent Zone waste rock – potentially problematic due to elemental enrichment in relation to bismuth, copper and nickel that may represent a significant toxicity issue as well as the presence of NAF-HS/PAF materials that dominate this rock type. They will generate significant loadings of acidity, sulphate salinity and metals and metalloids if left upon the surface of a waste landform. Although only representing ~1% of total waste rock, the amount of this material brought to surface should be minimised (i.e. remain in the underground) where possible. If this material does come to surface it will require a series of ARD mitigation strategies (e.g. material tracking and segregation, appropriately designed PAF cell and cover design).
- Diorite waste rock – potentially problematic due to elemental enrichment in relation to copper that may represent a significant toxicity issue as well as the presence of NAF-HS/PAF-LC materials that may generate moderate loadings of acidity, sulphate salinity and metals and metalloids if left upon the surface of a waste landform. This material should be treated as representing a lower ARD risk than Crescent Zone waste, but where diorite exists with higher total S waste rock, the diorite should be subject to the same ARD mitigation strategies as that of the high total S material.
- Crackle Breccia waste rock – potentially problematic, primarily due to elemental enrichment in relation to copper that may represent a significant toxicity issue; ~4.8% of the total waste rock brought to surface.
- All NAF-HS waste rock materials from all rock types (e.g. Actinolite Cemented Breccia and Calcite Cemented Breccia) are potentially problematic and should be encapsulated beneath a waste dump cover system, primarily because these materials may generate moderate loadings of sulphate salinity and metals and metalloids if left upon the surface of a waste landform.
- Lower tillite/conglomerate/siltstone/sandstone at the base of the Permian cover within 20m of the unconformity – potentially problematic primarily due to the presence of PAF-LC materials that may generate moderate loadings of acidity, sulphate salinity and metals and metalloids if left upon the surface of a waste landform.

Key geochemistry information gaps that should be addressed to better inform materials segregation, rehabilitation waste landform design and construction aspects include:

- Expanded geochemical test work to better represent the properties and variation of the main rock types to be mined, with particular focus on:
    - Developing reliable segregation criteria for use in block modelling based on key indicator geological and assay parameters that can be readily and rapidly determined on site.
    - Assessment of whether parameters such as total C, inorganic C and/or Ca can be used as a proxy for effective ANC.
    - Expanding total S testing of the Permian materials to better define the distribution and variability of pyritic materials and confirm the mainly benign nature of this unit and thickness of the problematic basement materials.

  - Undertaking water extraction test work on additional samples from potential cover materials to provide further certainty around the leaching behaviour of the potentially useful surface cover materials.
  - Carrying out leach column testing of potentially problematic materials to better understand relative ARD risks, and what operational controls may be required before implementation of closure management controls. Results will also be used to assess opportunities to reclassify some of these materials initially classed as potentially problematic where leaching kinetics downgrades the risk of acid/salt/metal release.
- Further work to confirm the volume of higher ARD risk materials in the block model to inform mine planning and methods of problematic material identification and modes of segregation and handling.
- Further work to confirm feasibility of useful material segregation. For example, continuity of rock types in the block model and the alignment with the mine schedule as well as development of a means for visual identification by site geologists and the requirement for grade control validation upon placement (e.g. supplementary total sulphur test work). Note that optimising material segregation to minimise materials classed as potentially problematic will reduce the footprint of materials requiring management at surface and cover system design requirements.
- Conceptual landform cover system design informed by appropriate modelling (e.g. soil-atmosphere flux modelling of cover layer scenarios to determine probable cover system performance, landform shape erosion modelling, etc).
- Development of rehabilitation material quantity estimates based upon rehabilitated waste landform design and construction methods.

In addition to the above, predictive hydrogeochemical water quality modelling should be considered to determine probable groundwater quality at closure as even if the period prior to inundation of the subsurface is brief there may be significant loadings of acidity, sulphate salinity and metals associated with shorter term exposure of the residual higher sulphide Crescent Zone materials. This would typically be informed by both kinetic column test work to define the rock type source terms and pertinent aspects of groundwater dynamics at closure (e.g. rates of groundwater influx and mixing and timeframes prior to inundation).

Table 15 presents a summary of the potential usefulness of waste rock types within a waste landform versus requirements for encapsulation.

Table 15: Summary of potential usefulness versus requirements for encapsulation in relation to waste rock types.

Waste rock type and proportion of mine waste to brought to surface	Potentially useful as a WRD cover medium	Potential Requirements for Encapsulation
Actinolite cemented breccia waste rock, approximately 1.5% of the total waste rock brought to surface.	Suitable for use as rehabilitation rock armour providing it was confirmed as NAF prior to emplacement at surface which is expected to be most of the rock type. Although only 1.5% of the overall expected waste rock tonnage, if material segregation is feasible, stockpiling for later rehabilitation use should be considered.	Any higher ARD risk materials (which appears to be limited to NAF-HS that comprises less than 25% of the rock type) should be encapsulated beneath WRD cover system.
Bedded sediment waste rock, approximately 36% of the total waste rock brought to surface.	Suitable for use as rehabilitation rock armour providing it was confirmed as NAF prior to emplacement (which appears to be the vast majority of this rock type). As 36% of the overall expected waste rock tonnage, if material segregation is feasible, stockpiling for later rehabilitation use should be considered.	No requirement based upon what is currently known of the geology, distribution of sulphur and carbonate minerals within the deposit and geochemical test work.
Crackle breccia waste rock, approximately 4.8% of the total waste rock brought to surface.	Not suitable, primarily due to elemental enrichment in relation to copper that may represent a significant toxicity issue.	This material should be encapsulated beneath WRD cover system.
Calcite cemented breccia waste rock, approximately 12% of the total waste rock brought to surface.	Suitable for use as rehabilitation rock armour providing it was confirmed as NAF prior to emplacement at surface which is expected to be most of the rock type. As 12% of the overall expected waste rock tonnage, if material segregation is feasible, stockpiling for later rehabilitation use should be considered.	Any higher ARD risk materials (which appears to be limited to NAF-HS that comprises less than 25% of the rock type) should be encapsulated beneath WRD cover system.
Crescent zone waste rock, approximately 1.1% of the total waste rock brought to surface.	Not suitable due to elemental enrichment in relation to bismuth, copper and nickel that may represent a significant toxicity issue as well as the presence of NAF-HS / PAF that predominates this rock type and will generate significant loadings of acidity, sulphate salinity and metals and metalloids if left upon the surface of the WRD landform.	Where possible the amount of this material brought to surface should be minimised (i.e. remain in the underground). If this material does come to surface it will require a series of ARD mitigation strategies (e.g. material tracking and segregation, appropriately designed PAF cell and cover design).

Waste rock type and proportion of mine waste to brought to surface	Potentially useful as a WRD cover medium	Potential Requirements for Encapsulation
Diorite waste rock, unknown proportion of the total waste rock brought to surface, although thought to be low as that there is a strong spatial relationship between the presence and abundance of the diorite dykes and/or clasts with mineralisation, generally within the crescent zone.	Not suitable due to elemental enrichment in relation to copper that may represent a significant toxicity issue as well as the presence of NAF-HS / PAF-LC that may generate moderate loadings of acidity, sulphate salinity and metals and metalloids if left upon the surface of the WRD landform.	This material should be treated as representing a lower ARD risk than crescent zone waste rock, but where diorite correlates with higher total sulphur waste rock, the same ARD the same ARD mitigation strategies used for the Crescent Zone should apply.
Dolerite waste rock, approximately 23.1% of the total waste rock brought to surface.	Highly suitable for use as rehabilitation rock armour providing it was confirmed as NAF prior to emplacement (which appears to be the vast majority of this rock type). As 23.1% of the overall expected waste rock tonnage, if material segregation is feasible, stockpiling for later rehabilitation use should be considered. Further work is required to better establish the distribution of effective ANC within this rock type.	No requirement based upon what is currently known of the geology, distribution of sulphur and carbonate minerals within the deposit and geochemical test work.
Lower tillite / conglomerate / siltstone / sandstone at the base of the Permian cover, although not specifically quantified, expected to be a minor fraction as limited to an approximate 20 metre vertical interval of mining.	Not suitable primarily due to PAF-LC that may generate moderate loadings of acidity, sulphate salinity and metals and metalloids if left upon the surface of the WRD landform.	Should be encapsulated beneath WRD cover system.

7 CLOSING

If you require any clarifications regarding the content of this report, don't hesitate to contact the undersigned.

Regards

Christine Lison
Environmental Consultant

MPhil (Environment and Agriculture)

lison@landloch.com.au

Andrew Botfield
Principal Environmental Geochemist

PhD MRACI CChem CEnvP MAusIMM

andrew.botfield@geochemistry.com.au

REFERENCES

ANZECC (Australia and New Zealand Environment and Conservation Council) and ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand) (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy Paper No. 4, ANZECC and ARMCANZ, Canberra.

Bojórquez-Quintal, E, Escalante-Magaña, C, Echevarría-Machado, I, Martínez-Estévez, M (2017). *Aluminum, a Friend or Foe of Higher Plants in Acid Soils*, Frontiers in Plant Science, 8:1767

Berkman (2011) Field Geologists Manual. 5th edition. Carlton, VIC, Australia: Australasian Institute of Mining and Metallurgy.

British Columbia Ministry of Environment and Climate Change Strategy (2021). British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture - Guideline Summary. Water Quality Guideline Series, WQG-20. Prov. B.C., Victoria B.C.

CIRIA, CUR, CETMEF (2007) The Rock Manual, The use of rock in hydraulic engineering, 2nd ed, C683, CIRIA, London.

CSIRO and National Environment Protection Council (NEPC) (2010), Ecological Investigation Level Calculation Spreadsheet, Commonwealth of Australia.

Department of Agriculture and Food (DAF) (2004) Soil salinity tolerance for agriculture and revegetation, State of Western Australia.

Bureau of Meteorology (BoM) 2021. Monthly statistics, Telfer Aero weather station (013030), Commonwealth of Australia.

Department of Mines, Industry Regulation and Safety (DMIRS) (2020). Statutory guidelines for mine closure plans, State of Western Australia.

Department of Mines and Petroleum (DMP) (2016). Draft Guidance: Materials characterisation baseline data requirements for mining proposals, March 2016, State of Western Australia.

Department of Mines and Petroleum (DMP) (2015). Management of fibrous minerals in Western Australian mining operations, State of Western Australia.

Department of Mines and Petroleum (DMP) (2010). Managing naturally occurring radioactive material (NORM) in mining and mineral processing – guideline. NORM-1. Applying the System of Radiation Protection to Mining Operations, Government of Western Australia.

Government of Western Australia Radiological Council (2019), Radiation Safety Act: Dose Limits and Maximum Permissible Exposure Levels Fact Sheet, Government of Western Australia

Gerson, et al. (2019). Unexpected Non-acid Drainage from Sulfidic Rock Waste. Andrea R. Gerson, Peter J. Rolley, Catherine Davis, Sandrin T. Feig, Stephen Doyle & Roger Smart. Scientific Reports online: published 13 March 2019.

Hazelton P., and Murphy B. (2011) *Interpreting soil test results,* CSIRO Publishing.

Landloch (2020) Havieron Soil Characterisation, prepared for Newcrest Mining Ltd.

Landloch (2021) Memorandum: Geochemical and baseline characterisation of mine waste, Havieron Project – Stage 2, prepared for Newcrest Mining Limited.

Landloch (2021a) Newcrest Havieron Waste Characterisation Study, prepared for Newcrest Ltd.

McKenzie, N, Grundy, M, Webster, R, and Ringrose-Voase, A (2008), Guidelines for Surveying Soil and Land Resources, CSIRO Publishing, Collingwood.

National Environment Protection Council (NEPC) (2011a), Schedule B1, Guideline on Investigation Levels for Soil and Groundwater, Commonwealth of Australia.

National Environment Protection Council (NEPC) (2011b), Schedule B(5)b. Guidelines on the Australian methodology to derive Ecological Investigation Levels in contaminated soils, Commonwealth of Australia.

Newcrest (2020). Mineral Resource Report Haverion, Patterson, Western Australia November 2020. Newcrest Mining Limited.

Newcrest (2021). Haverion Pre-Feasibility Study Volume 6.4. Technical – Metallurgy & Processing. PRJ-720-20-01. June 2021.

Newcrest (2021a). Geological details and sulphur and ANC distribution statistics provided by Newcrest geologists David Finn and Anthony Harris. 7 September 2021.

Newcrest (2016). EN ST01 Acid and Metalliferous Drainage Management Standard.

NHMRC, NRMMC (2011) Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

NSW Agriculture (1998), SOILpak for Cotton Growers, Third Edition, Government of New South Wales.

Price (1997). Draft Guidelines and Recommended Methods for Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia.

Schumann et al. (2012). Acid–base accounting assessment of mine wastes using the chromium reducible sulfur method. Russell Schumann, Warwick Stewart, Stuart Miller b, Nobuyuki Kawashima, Jun Li, Roger Smart. Science of the Total Environment 424 (2012) 289–296.

Schumann et al. (2015). Iron Sulfides Ain't iron Sulfides. A comparison of acidity generated during oxidation of pyrite and pyrrhotite in waste rock and tailings materials. Russell Schumann, Alan Robertson, Andrea Gerson, Rong Fan, Nobuyuki Kawashima, Jun Li, Roger Smart. 10th International Conference on Acid Rock Drainage & IMWA Annual Conference.

Sumner and Naidu (1998) Sodic soils, distribution, properties, management and environmental consequences, Oxford University Press.

Vacher, C.A., Loch, R.J., and Raine, S.R. (2004) Identification and management of dispersive mine spoils, Australian Centre for Mining Environmental Research.

van Vreeswyk, A M, Leighton, K A, Payne, A L, and Hennig, P. (2004) An inventory and condition survey of the Pilbara region, Western Australia. Department of Agriculture and Food, Western Australia, Perth. Technical Bulletin 92.

APPENDIX A: DESCRIPTION OF SAMPLES SELECTED FOR TEST WORK

Table A-1: Detailed sample descriptions including the region of the deposit represented and what was represented in the sulphur and ANC distribution for the respective rock type.

Hole ID	Sample ID	Rock Type	From (m)	To (m)	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type[1]	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC[2]
HAD055	MWC090	Actinolite Cemented Breccia	1205	1205	Mineralised Breccia Zone – South-East Crescent & Breccia	0.55	Between 75th to 95th percentile	139	High generally but lower than typical for rock type.
HAD061	MWC157-MWC158	Actinolite Cemented Breccia	543	556	Crackle Breccia Zone – North-West Crescent	0.28	Circa 50th percentile value	640	Very high generally and higher than typical for rock type.
HAD112A	MWC190-MWC191	Actinolite Cemented Breccia	617	628	Crackle Breccia Zone – North-West Crescent	0.04	Between 5th and 25th percentile value	605	Very high generally and higher than typical for rock type.
HAD055	MWC286-MWC287	Actinolite Cemented Breccia	795	802	Mineralised Breccia Zone – South-East Crescent & Breccia	0.15	Between 25th and 50th percentile value	603	Very high generally and higher than typical for rock type.
HAD055	MWC091	Bedded Sediment	1260	1264	Bedded Sediment – South-East Crescent & Breccia	0.11	Between 50th and 75th percentile	69.1	Moderate generally but lower than typical for rock type.
HAD057W3	MWC107	Bedded Sediment	1022	1030	Bedded Sediment – South-East Crescent & Breccia	0.02	Between 5th and 25th percentile value of bedded sediments	506	Very high generally and higher than typical for rock type.
HAD112A	MWC217-MWC218	Bedded Sediment	498	524	Bedded Sediment – North-West Crescent	0.14	Circa 5th percentile value	437	Very high generally and slightly higher than typical for rock type.
HAD057W3	MWC048-MWC051	Calcite Cemented Breccia	944	973	Mineralised Breccia Zone – South-East Crescent & Breccia	0.11	Between 50th and 75th percentile	656	Very high generally and moderately higher than typical for rock type.

Hole ID	Sample ID	Rock Type	From (m)	To (m)	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type[1]	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC[2]
HAD055	MWC062	Calcite Cemented Breccia	712	716	Mineralised Breccia Zone – South-East Crescent & Breccia	<0.01	Below 5th percentile	423	Very high generally, but slightly lower than typical for rock type.
HAD055	MWC066	Calcite Cemented Breccia	903	905	Mineralised Breccia Zone – South-East Crescent & Breccia	0.06	Between 5th and 25th percentile	840	Very high generally and higher than typical for rock type.
HAD057W3	MWC104-MWC105	Calcite Cemented Breccia	1008	1020	Mineralised Breccia Zone – South-East Crescent & Breccia	16.6	Very high S content, well above 95th percentile	470	Very high generally but typical for rock type.
HAD057W3	MWC112	Calcite Cemented Breccia	1075	1080	Mineralised Breccia Zone – South-East Crescent & Breccia	0.14	Between 25th and 50th percentile value	690	Very high generally and higher than typical for rock type.
HAD061	MWC147-MWC150	Calcite Cemented Breccia	506	520	Crackle Breccia Zone – North-West Crescent	0.24	Circa 50th percentile value	600	Very high generally and slightly higher than typical for rock type.
HAD112A	MWC186	Calcite Cemented Breccia	600	606	Crackle Breccia Zone – North-West Crescent	0.07	Between 5th and 25th percentile value	940	Very high generally and higher than typical for rock type.
HAD112A	MWC193	Calcite Cemented Breccia	633	636	Crackle Breccia Zone – North-West Crescent	<0.01	Less than 5th percentile value	948	Very high generally and higher than typical for rock type.
HAD112A	MWC200	Calcite Cemented Breccia	674	677	Crackle Breccia Zone – North-West Crescent	0.42	Between 50th and 75th percentile value	745	Very high generally and higher than typical for rock type.
HAD112A	MWC203-MWC204	Calcite Cemented Breccia	684	693	Crackle Breccia Zone – North-West Crescent	0.2	Between 25th and 50th percentile value	435	Very high generally but slightly lower than typical for rock type.

Hole ID	Sample ID	Rock Type	From (m)	To (m)	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type[1]	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC[2]
HAD112A	MWC214-MWC215	Calcite Cemented Breccia	741	751	Crackle Breccia Zone – North-West Crescent	0.02	Less than 5th percentile value	816	Very high generally and higher than typical for rock type.
HAD061	MWC248-MWC250	Calcite Cemented Breccia	769	780	Mineralised Breccia Zone – South-East Crescent & Breccia	2.54	Above 95th percentile	618	Very high generally and slightly higher than typical for rock type.
HAD061	MWC256-MWC257	Calcite Cemented Breccia	934	944	Mineralised Breccia Zone – South-East Crescent & Breccia	0.23	Circa 50th percentile value	616	Very high generally and slightly higher than typical for rock type.
HAD061	MWC276-MWC277	Calcite Cemented Breccia	909	914	Mineralised Breccia Zone – South-East Crescent & Breccia	0.04	Between 5th and 25th percentile value	563	Very high generally and slightly higher than typical for rock type.
HAD055	MWC283	Calcite Cemented Breccia	768	771	Mineralised Breccia Zone – South-East Crescent & Breccia	0.18	Between 25th and 50th percentile value	938	Very high generally and higher than typical for rock type.
HAD055	MWC285	Calcite Cemented Breccia	774	779	Mineralised Breccia Zone – South-East Crescent & Breccia	0.18	Between 25th and 50th percentile value	623	Very high generally and slightly higher than typical for rock type.
HAD055	MWC290-MWC291	Calcite Cemented Breccia	826	837	Mineralised Breccia Zone – South-East Crescent & Breccia	1.3	Between 75th to 95th percentile	446	Very high generally but slightly lower than typical for rock type.
HAD055	MWC294-MWC296	Calcite Cemented Breccia	954	972	Mineralised Breccia Zone – South-East Crescent & Breccia	4.04	High S content, well above 95th percentile	584	Very high generally and slightly higher than typical for rock type.
HAD061	MWC140	Conglomerate	490	490	Lower strata close to Permian Cover / Proterozoic Basement	0.7	Circa 95th percentile value	66.3	Moderate generally but higher than typical for rock type.

Hole ID	Sample ID	Rock Type	From (m)	To (m)	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type[1]	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC[2]
HAD061	MWC145-MWC146	Conglomerate	501	506	Lower strata close to Permian Cover / Proterozoic Basement	0.55	Between 75th and 95th percentile value.	115	High generally and very much higher than typical for rock type.
HAD112A	MWC216	Conglomerate	495	498	Lower strata close to Permian Cover / Proterozoic Basement	0.21	Circa 50th percentile value	21.4	Low generally but slightly higher than typical for rock type.
HAD055	MWC023-MWC027	Crackle Breccia	1205	1260	Crackle Breccia Zone – South-East Crescent and Breccia	1.42	Above 95th percentile	149	High generally, but lower than typical for rock type.
HAD061	MWC151	Crackle Breccia	522	524	Crackle Breccia Zone – North-West Crescent	0.09	Between 25th and 50th percentile value	134	High generally but lower than typical for rock type.
HAD061	MWC270	Crackle Breccia	882	889	Mineralised Breccia Zone – South-East Crescent & Breccia	0.14	Circa 50th percentile value	592	Very high generally and slightly higher than typical for rock type.
HAD055	MWC289	Crackle Breccia	822	824	Crackle Breccia Zone – South-East Crescent and Breccia	5.08	High S content, well above 95th percentile	721	Very high generally and higher than typical for rock type.
HAD055	MWC293	Crackle Breccia	948	954	Mineralised Breccia Zone – South-East Crescent & Breccia	0.13	Circa 50th percentile value	700	Very high generally and higher than typical for rock type.
HAD055	MWC063	Diorite	845	847	Diorite – South-East Crescent & Breccia	0.37	Between 25th and 50th percentile of Crescent Zone	132	High generally, but slightly lower than typical for rock type.

Hole ID	Sample ID	Rock Type	From (m)	To (m)	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type[1]	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC[2]
HAD057W3	MWC113	Diorite	1081	1090	Diorite – South-East Crescent & Breccia	0.55	Between 5th and 25th percentile value	162	High generally, but slightly lower than typical for rock type.
HAD061	MWC161	Diorite	571	582	Mineralised Breccia / Crescent Sulphide Zone in Northern Breccia Zone	4.3	Between 50th and 75th percentile of Crescent Zone	143	High generally and slightly lower than typical for rock type
HAD055	MWC010-MWC019	Dolerite	1000	1069	Post Mineral Dolerite Dyke, South-East Crescent and Breccia	0.08	Between 25th and 50th percentile	22.1	Low generally and very much lower than typical for rock type.
HAD057W3	MWC028-MWC047	Dolerite	848	944	Post Mineral Dolerite Dyke, South-East Crescent and Breccia	0.07	Circa 25th percentile	58.7	Moderate generally, very much lower than typical for rock type.
HAD061	MWC251	Dolerite	780	834	Post Mineral Dolerite Dyke, South-East Crescent and Breccia	0.12	Above 95th percentile	28.6	Low generally but higher than typical for rock type
HAD055	MWC085	Crescent Zone	1178	1179	Crescent Sulphide Zone – South-East Crescent + Breccia	18	Between 75th to 95th percentile of Crescent Zone	83	Moderate generally but lower than typical for rock type.
HAD057W3	MWC111	Crescent Zone	1073	1075	Crescent Sulphide Zone – South-East Crescent & Breccia	14.1	Between 75th to 95th percentile of Crescent Zone	264	High generally, but slightly lower than typical for rock type.
HAD061	MWC155	Crescent Zone	532	535	Crescent Sulphide Zone - Northern Breccia Zone	33.4	High S content, around 95th	78	Moderate generally but lower than typical for rock type.

Hole ID	Sample ID	Rock Type	From (m)	To (m)	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type[1]	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC[2]
							percentile of Crescent Zone		
HAD112A	MWC189	Crescent Zone	612	614	Crescent Sulphide Zone - Northern Breccia Zone	32.1	High S content, around 95th percentile of Crescent Zone	87.5	Moderate generally but lower than typical for rock type.
HAD055	MWC284	Crescent Zone	774	774	Crescent Sulphide Zone – South-East Crescent & Breccia	5.87	Between 50th and 75th percentile of Crescent Zone	400	Very high generally, but slightly lower than typical for rock type.
HAD055	MWC052	Siltstone	471	473	Lower strata close to Permian Cover / Proterozoic Basement	0.35	Between 50th and 75th percentile	13.3	Very low generally, but typical for rock type.
HAD055	MWC060	Siltstone	494	496	Lower strata close to Permian Cover / Proterozoic Basement	0.31	Between 50th and 75th percentile	132	High generally and very much higher than typical for rock type.
HAD061	MWC142	Siltstone	497	499	Lower strata close to Permian Cover / Proterozoic Basement	0.21	Circa 50th percentile value	80.5	Moderate generally but higher than typical for rock type.
HAD112A	MWC221-MWC222	Siltstone	464	470	Lower strata close to Permian Cover / Proterozoic Basement	0.12	Between 25th and 50th percentile value	13.2	Low generally and slightly lower than typical for rock type

Hole ID	Sample ID	Rock Type	From (m)	To (m)	Region of Deposit Represented	Total S	S Distribution Representation for Rock Type[1]	ANC (kg H_2SO_4/t)	Relative Magnitude of ANC[2]
HAD112A	MWC226	Siltstone	481	482	Lower strata close to Permian Cover / Proterozoic Basement	0.09	Between 25th and 50th percentile value	16.1	Low generally but slightly higher than typical for rock type.
HAD112A	MWC229	Siltstone	489	492	Lower strata close to Permian Cover / Proterozoic Basement	0.35	Between 50th and 75th percentile value	14.2	Low generally but typical for rock type.

Notes: [1] Distribution statistics based upon block model total S data for Proterozoic Basement [same as presented in Section 2.3.2 (Newcrest 2021b)] and total S data for the Permian Cover derived from this investigation [same as presented in Section 2.3.3 (Newcrest 2021a)]. [2] Relative magnitude based upon the following descriptors: 'low generally' (below 10 kg/H_2SO_4); 'moderate generally' (between 30 and 100 kg/H_2SO_4); 'high generally' (between 100 and 300 kg/H_2SO_4); 'very high generally' (greater than 300 kg/H_2SO_4). The term 'typical for rock type' for Proterozoic Basement rocks was based upon circa median Ca% content and terms slightly lower and slightly higher ranging from 25th to 75th percentile Ca% content and 'lower' and 'higher' between 5th and 25th percentile bands and 75th and 95th percentile bands Ca% content and 'very low' and 'very high', beyond the 5th and 95th percentile bands respectively. These terms are similar for the Permian Cover rock types however the percentile ranges were based upon actual ANC values derived from this investigation.

APPENDIX B: SEQUENTIAL NAG RESULTS

Table C-1: Sequential NAG test work results

Sample ID	Rock Type	Previous Test Work and Initial ARD Classification						Stage 1			Stage 2			Stage 3			Stage 4			Cumulative NAG		Suggested ARD Classification
		Preliminary ARD classification	NAPP (kg H2SO4/t)	ANC/ MPA	Single NAGpH	NAG (pH 4.5)	NAG (pH 7.0)	NAG pH	NAG(pH4.5) (kg H2SO4/t)	NAG(pH7.0) (kg H2SO4/t)	NAG pH	NAG(pH4.5) (kg H2SO4/t)	NAG(pH7.0) (kg H2SO4/t)	NAG pH	NAG(pH4.5) (kg H2SO4/t)	NAG(pH7.0) (kg H2SO4/t)	NAG pH	NAG(pH4.5) (kg H2SO4/t)	NAG(pH7.0) (kg H2SO4/t)	NAG(pH4.5) (kg H2SO4/t)	NAG(pH7.0) (kg H2SO4/t)	
MWC052	Siltstone	Uncertain (PAF-LC)	-3	1.2	3.5	2.4	5.5	3.8	1.0	3.0	4.6	0.0	1.4	5.0	0.0	3.3	5.3	0.0	4.9	1.0	12.7	PAF-LC
MWC104-MWC105	Calcite Cemented Breccia	Uncertain	38	0.9	9.0	<0.1	<0.1	7.8	0.0	0.0	7.9	0.0	0.0	8.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0	Uncertain
MWC111	Massive Sulphide	PAF	167	0.6	2.6	61	82	8.0	0.0	0.0	7.7	0.0	0.0	8.0	0.0	0.0	7.9	0.0	0.0	0.0	0.0	PAF
MWC140	Conglomerate	NAF	-45	3.1	11.0	<0.1	<0.1	8.5	0.0	0.0	8.8	0.0	0.0	8.9	0.0	0.0	8.4	0.0	0.0	0.0	0.0	NAF
MWC161	Diorite	Uncertain (NAF-HS)	-11	1.1	9.4	<0.1	<0.1	7.7	0.0	0.0	4.8	0.0	2.2	4.3	0.1	1.4	5.0	0.0	0.6	0.15	4.1	PAF-LC
MWC229	Siltstone	Uncertain (PAF-LC)	-3	1.3	3.9	1.4	3.9	3.9	0.8	2.6	4.6	0.0	2.9	5.0	0.0	4.8	5.3	0.0	6.4	0.77	16.7	PAF-LC

APPENDIX C: ABCC RESULTS

Table C-1: Description of samples subjected to ABCC test work

Sample ID	Figure Number	Type of Carbonate Buffering	Effective ANC (to pH 4)	Sample Description	ANC	Effective ANC as % of Measured ANC
21671	D-1	Calcite	120	MWC090	139	86
21672	D-2	Ferroan Dolomite	582	MWC157-MWC158	640	91
21684	D-3	Ferroan Dolomite	459	MWC104-MWC105	470	98
21695	D-4	Dolomite/Ferroan Dolomite	710	MWC289	721	99
21702	D-5	Calcite/Dolomite	113	MWC161	143	79
21711	D-6	Ferroan Dolomite	5	MWC052	13	41
21718	D-7	Ferroan Dolomite	6	MWC229	14	45

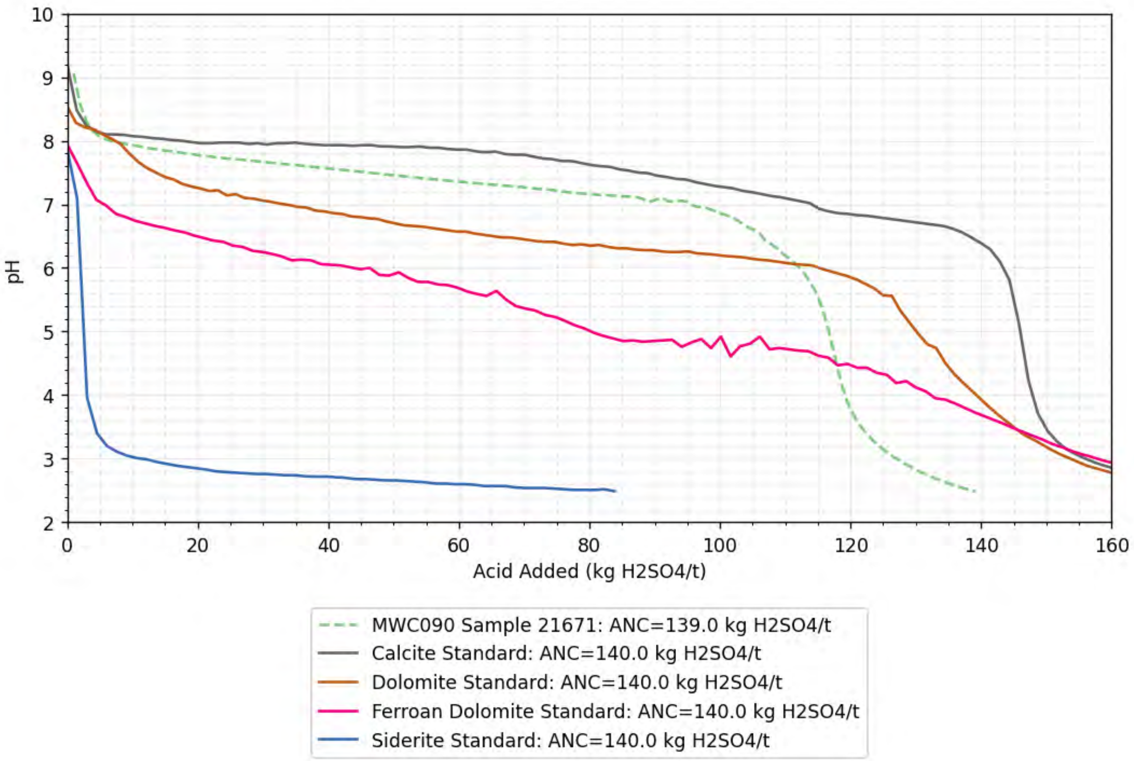


Figure C-11: ABCC profile for sample 21671 with an ANC value close to 140.0 kg H2SO4/t. Carbonate standard curves are included for reference.

Sample ID	Type of Carbonate Buffering	Effective ANC (to pH 4)	Sample Description	ANC	Effective ANC as % of Measured ANC
21671	Calcite	120	MWC090	139	86

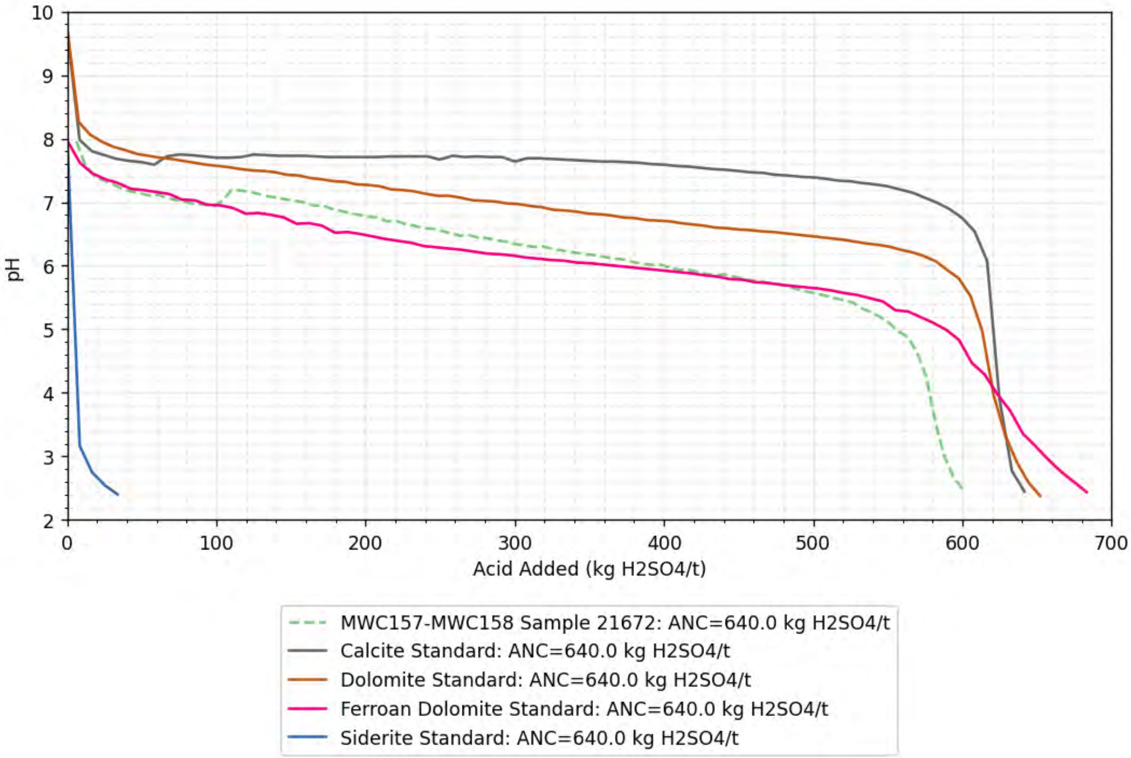


Figure C-22: ABCC profile for sample 21672 with an ANC value close to 640.0 kg H2SO4/t. Carbonate standard curves are included for reference.

Sample ID	Type of Carbonate Buffering	Effective ANC (to pH 4)	Sample Description	ANC	Effective ANC as % of Measured ANC
21672	Ferroan Dolomite	582	MWC157-MWC158	640	91

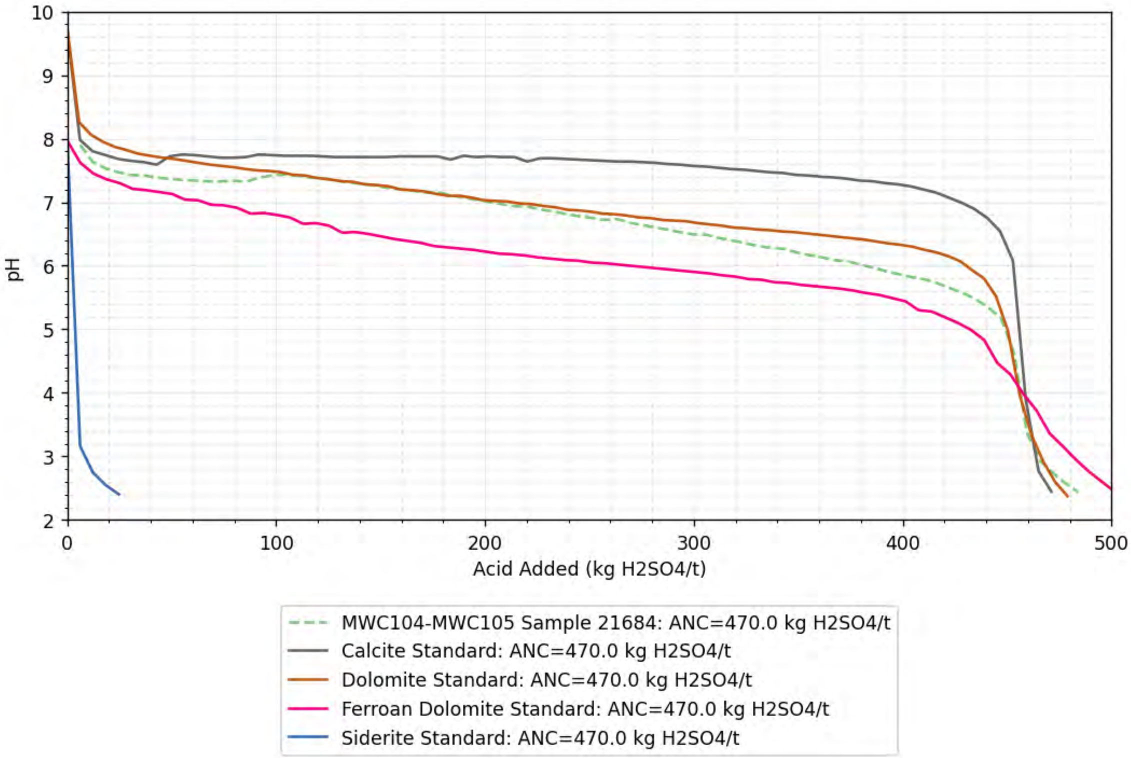


Figure C-33: ABCC profile for sample 21684 with an ANC value close to 470.0 kg H2SO4/t. Carbonate standard curves are included for reference.

Sample ID	Type of Carbonate Buffering	Effective ANC (to pH 4)	Sample Description	ANC	Effective ANC as % of Measured ANC
21684	Ferroan Dolomite	459	MWC104-MWC105	470	98

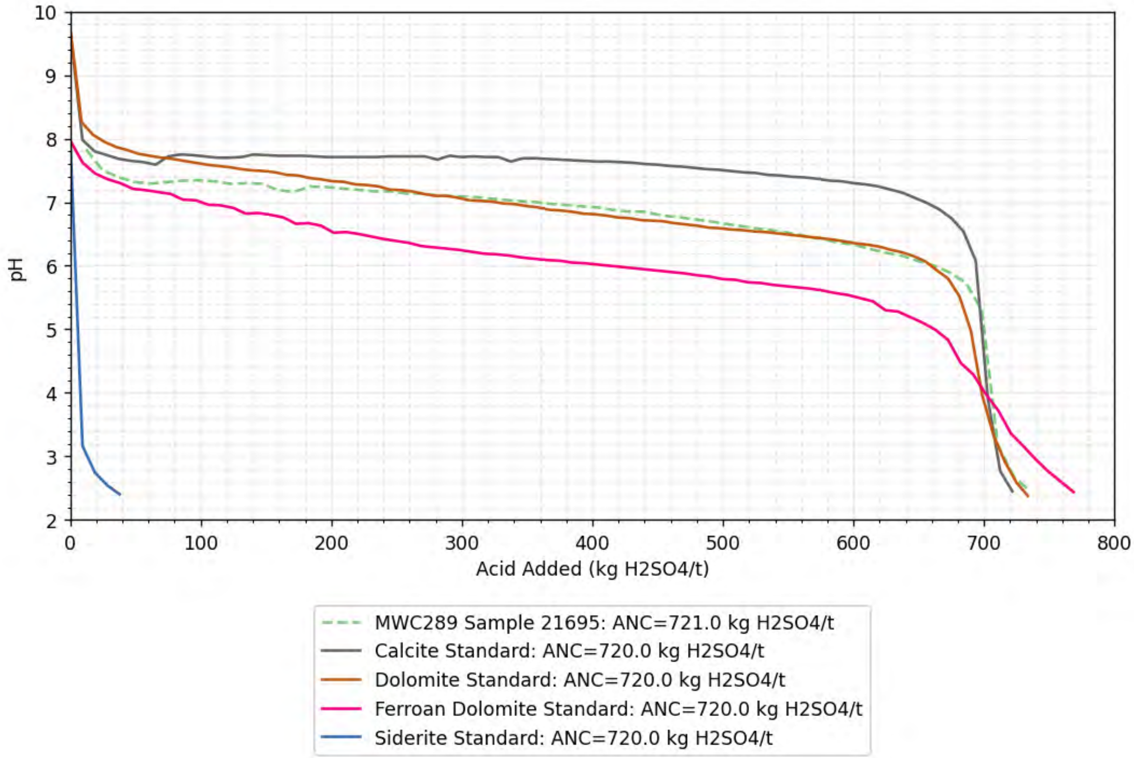


Figure C-44: ABCC profile for sample 21695 with an ANC value close to 720.0 kg H2SO4/t. Carbonate standard curves are included for reference.

Sample ID	Type of Carbonate Buffering	Effective ANC (to pH 4)	Sample Description	ANC	Effective ANC as % of Measured ANC
21695	Dolomite/Ferroan Dolomite	710	MWC289	721	99

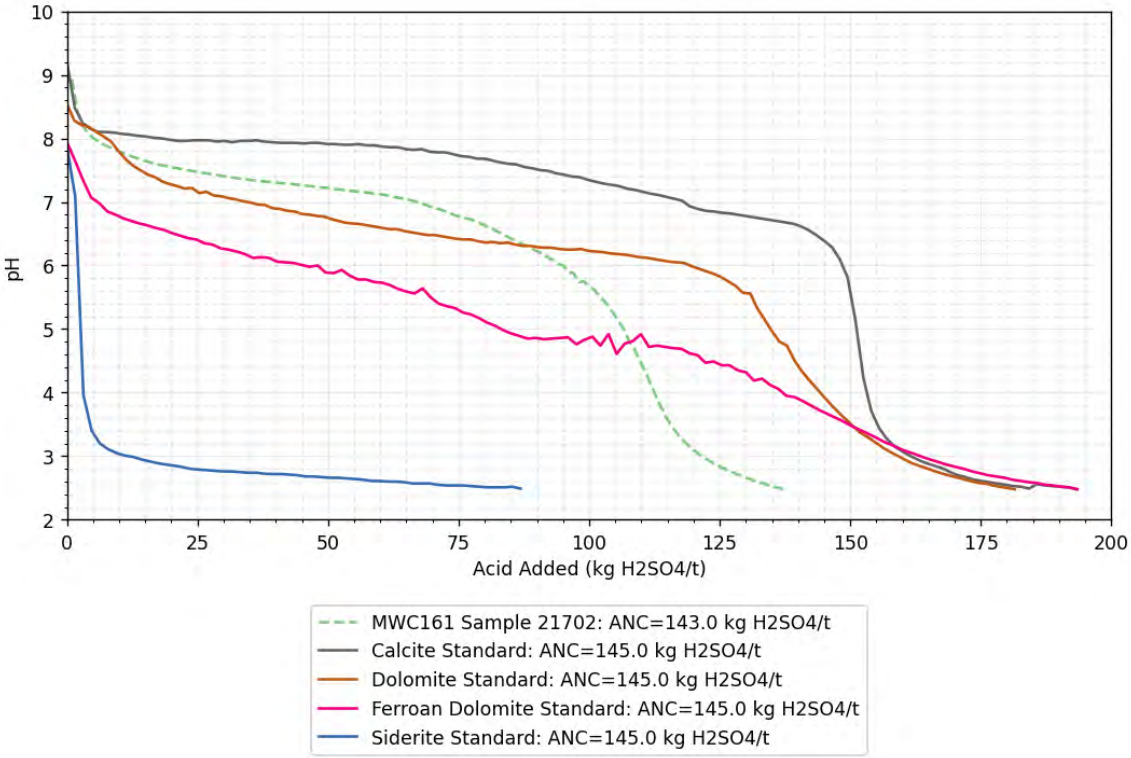


Figure C-55: ABCC profile for sample 21702 with an ANC value close to 145.0 kg H2SO4/t. Carbonate standard curves are included for reference.

Sample ID	Type of Carbonate Buffering	Effective ANC (to pH 4)	Sample Description	ANC	Effective ANC as % of Measured ANC
21702	Calcite/Dolomite	113	MWC161	143	79

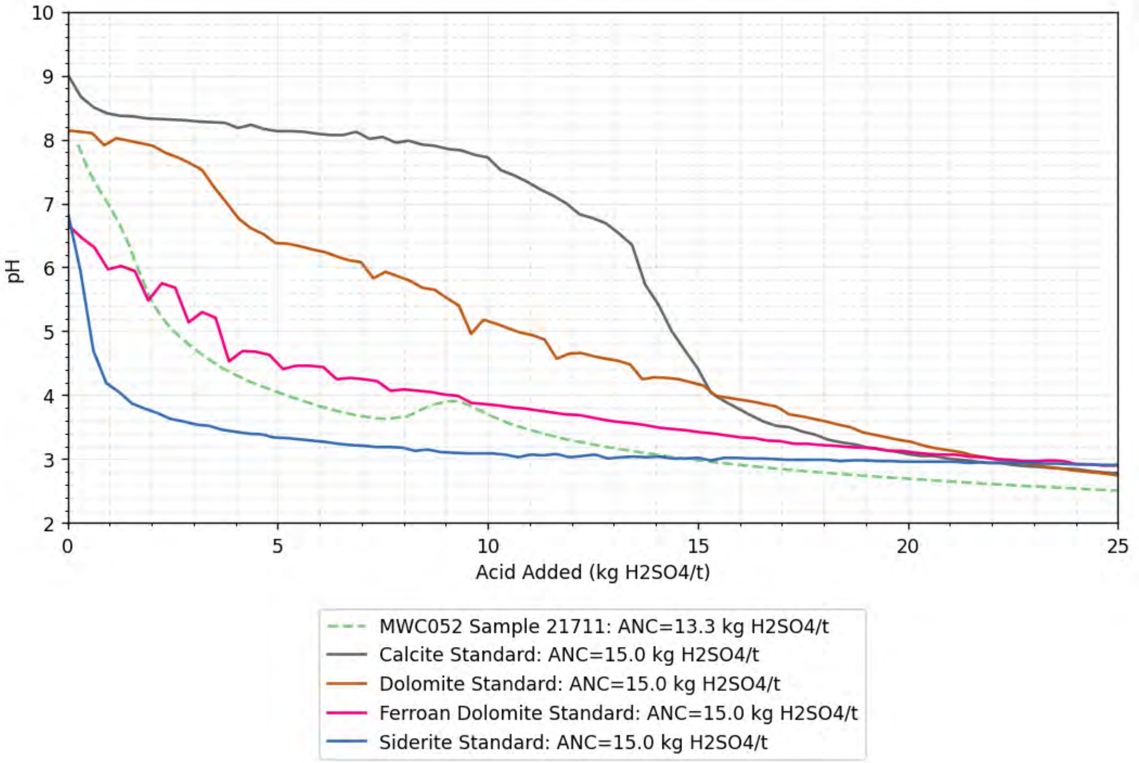


Figure C-66: ABCC profile for sample 21711 with an ANC value close to 15.0 kg H2SO4/t. Carbonate standard curves are included for reference.

Sample ID	Type of Carbonate Buffering	Effective ANC (to pH 4)	Sample Description	ANC	Effective ANC as % of Measured ANC
21711	Ferroan Dolomite	5	MWC052	13	41

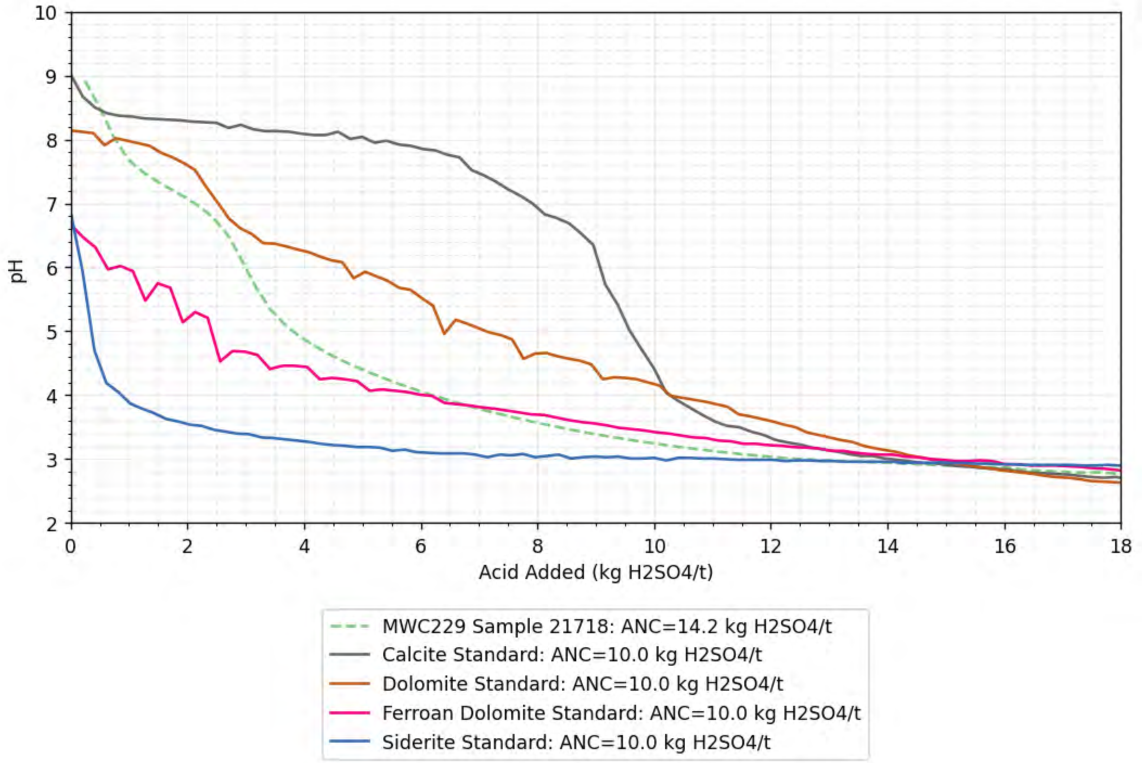


Figure C-77: ABCC profile for sample 21718 with an ANC value close to 10.0 kg H2SO4/t. Carbonate standard curves are included for reference.

Sample ID	Type of Carbonate Buffering	Effective ANC (to pH 4)	Sample Description	ANC	Effective ANC as % of Measured ANC
21718	Ferroan Dolomite	6	MWC229	14	45

APPENDIX D: SULPHUR SPECIATION RESULTS

Table D-1: Sulphur Speciation Results

Sample ID	Rock Type	Region of Deposit Represented	Preliminary ARD classification	Total S	MPA (kg H2SO4/t)	CRS S%	Acid Sulphate %S	Proportion of Acid Generating Total S inferred from CRS S%	MPA based upon CRS S% + Acid Sulphate (kg H2SO4/t)	[1]Estimated proportion of pyrrhotite %S based upon region of deposit geology and mineralogical work	[1]MPA based upon pyrrhotite %S based upon region of deposit geology and mineralogical work (kg H2SO4/t)	[2]Effective ANC (kg H2SO4)	NAPP based upon Total S and Effective ANC (kg H2SO4)	[3]Final ARD classification	NAPP based upon CRS S% and Effective ANC (kg H2SO4)	NAPP based Pyrrhotite S% and Effective ANC (kg H2SO4)
MWC052	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	Uncertain (PAF-LC)	0.30	9.2	0.27	0.00	90.0%	8.3	Not Applicable	NA	5	4	PAF-LC	3	Not Applicable
MWC085	Massive Sulphide	Crescent Sulphide Zone – South-East Crescent + Breccia	PAF	17.6	540.1	6.00	0.00	34.0%	183.6	10.4	286.2	66	474	PAF	117	219.8
MWC104-MWC105	Calcite Cemented Breccia	Mineralised Breccia Zone – South-East Crescent & Breccia	Uncertain	16.1	492.7	12.7	0.00	78.9%	388.6	9.5	261.1	459	34	Uncertain	-70	-197.9
MWC140	Conglomerate	Lower strata close to Permian Cover / Proterozoic Basement	NAF	0.65	19.9	0.12	0.00	18.5%	3.7	Not Applicable	NA	27	-7	NAF	-23	Not Applicable
MWC155	Massive Sulphide	Crescent Sulphide Zone-Northern Breccia Zone	PAF	37.0	1132.2	30.3	0.00	81.9%	927.2	Not Applicable	NA	62	1070	PAF	865	Not Applicable
MWC161	Diorite	Mineralised Breccia / Crescent Sulphide Zone in Northern Breccia Zone	Uncertain (NAF-HS)	4.28	131.0	3.75	0.00	87.6%	114.8	Not Applicable	NA	113	18	PAF-LC	2	Not Applicable

Sample ID	Rock Type	Region of Deposit Represented	Preliminary ARD classification	Total S	MPA (kg H2SO4/t)	CRS S%	Acid Sulphate %S	Proportion of Acid Generating Total S inferred from CRS S%	MPA based upon CRS S% + Acid Sulphate (kg H2SO4/t)	[1]Estimated proportion of pyrrhotite %S based upon region of deposit geology and mineralogical work	[1]MPA based upon pyrrhotite %S based upon region of deposit geology and mineralogical work (kg H2SO4/t)	[2]Effective ANC (kg H2SO4)	NAPP based upon Total S and Effective ANC (kg H2SO4)	[3]Final ARD classification	NAPP based upon CRS S% and Effective ANC (kg H2SO4)	NAPP based Pyrrhotite S% and Effective ANC (kg H2SO4)
MWC229	Siltstone	Lower strata close to Permian Cover / Proterozoic Basement	Uncertain (PAF-LC)	0.31	9.5	0.11	0.00	35.5%	3.4	Not Applicable	NA	6	3	PAF-LC	-3	Not Applicable
MWC289	Crackle Breccia	Crackle Breccia Zone – South-East Crescent and Breccia	NAF-HS	5.29	161.9	4.74	0.00	89.6%	145.0	3.1	85.8	710	-548	NAF-HS	-565	-624.2

APPENDIX E: KINETIC NAG RESULTS

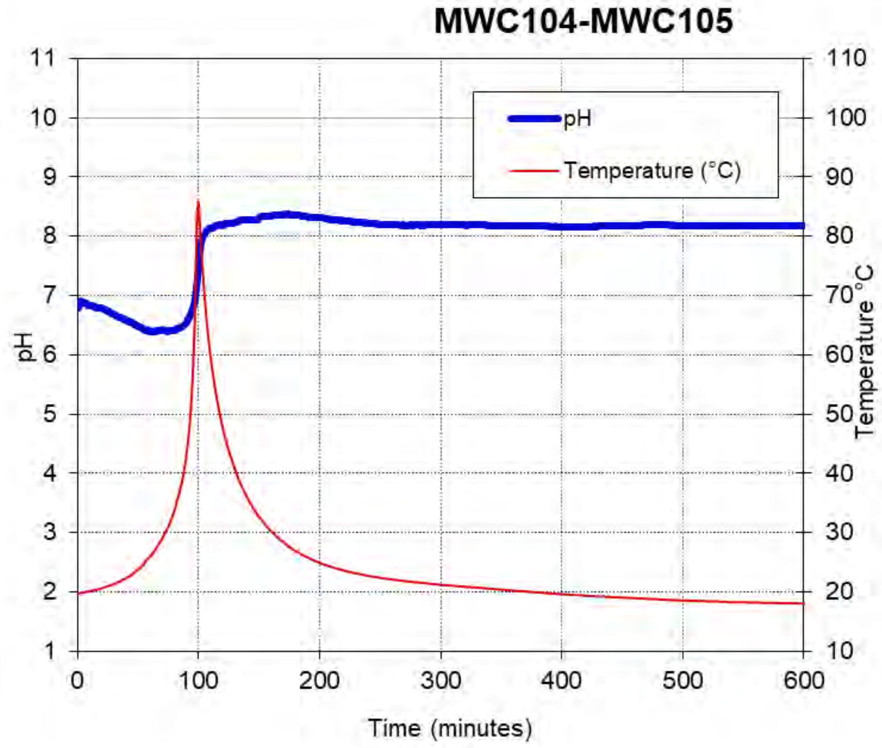


Figure E-1: Kinetic NAG for MWC104-MWC105

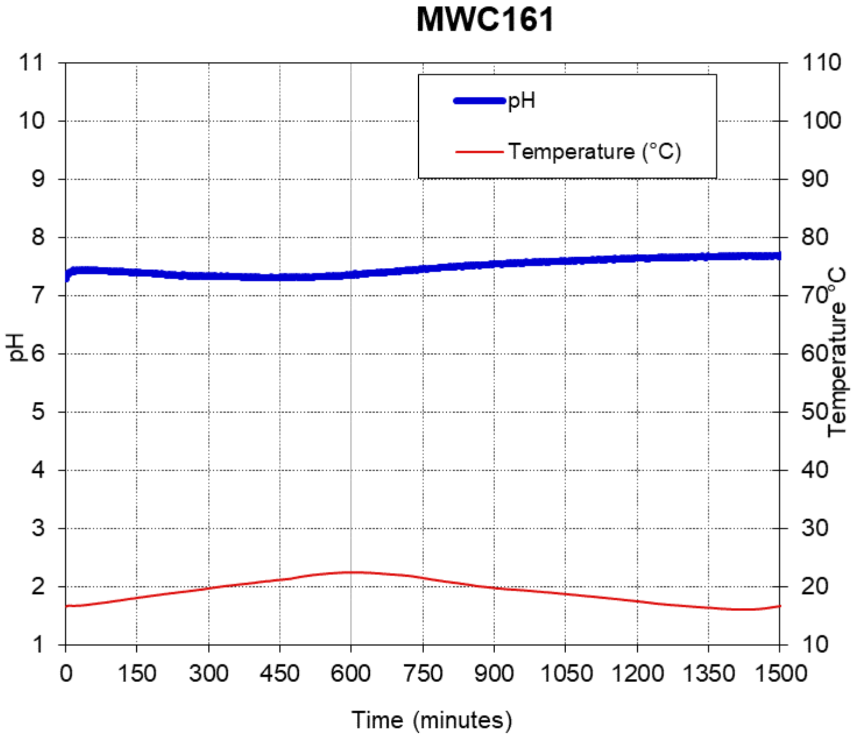


Figure E-2: Kinetic NAG for MWC161

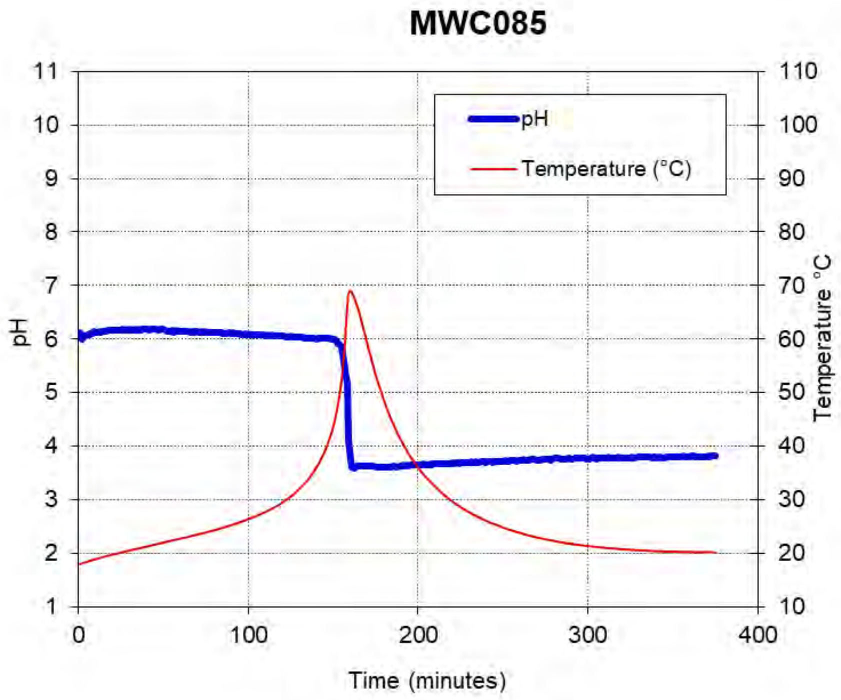


Figure E-3: Kinetic NAG for MWC161

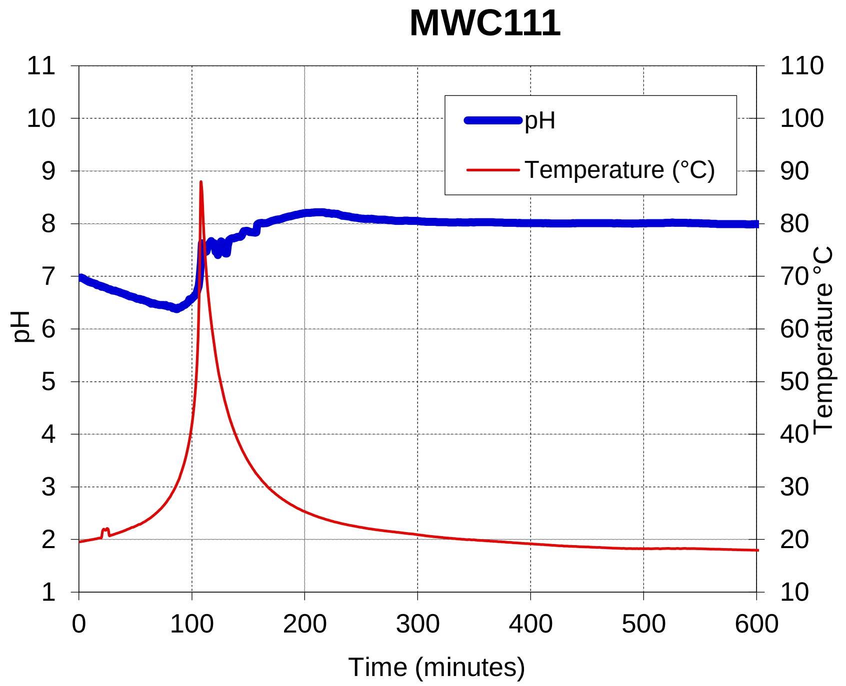


Figure E-4: Kinetic NAG for MWC111

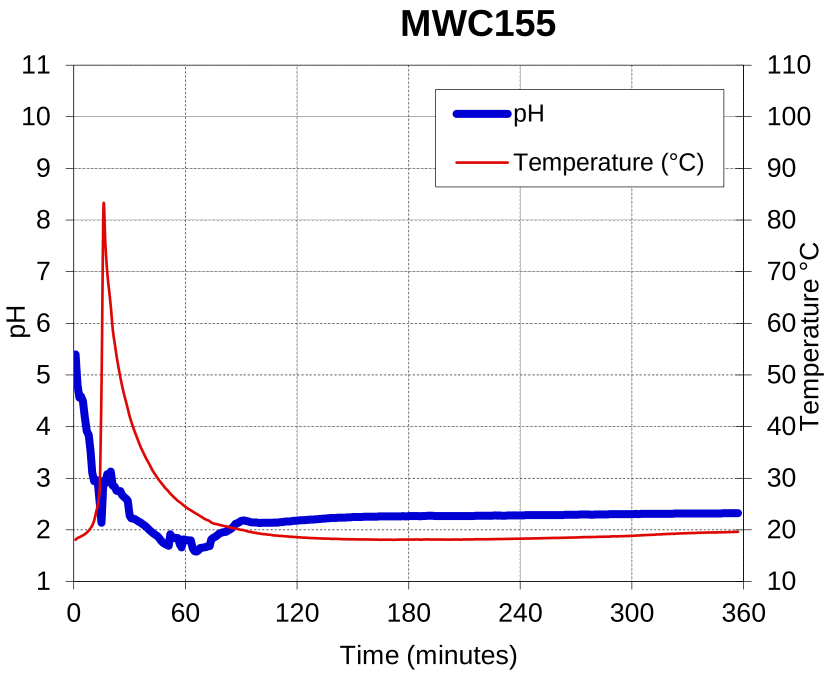


Figure E-5: Kinetic NAG for MWC155

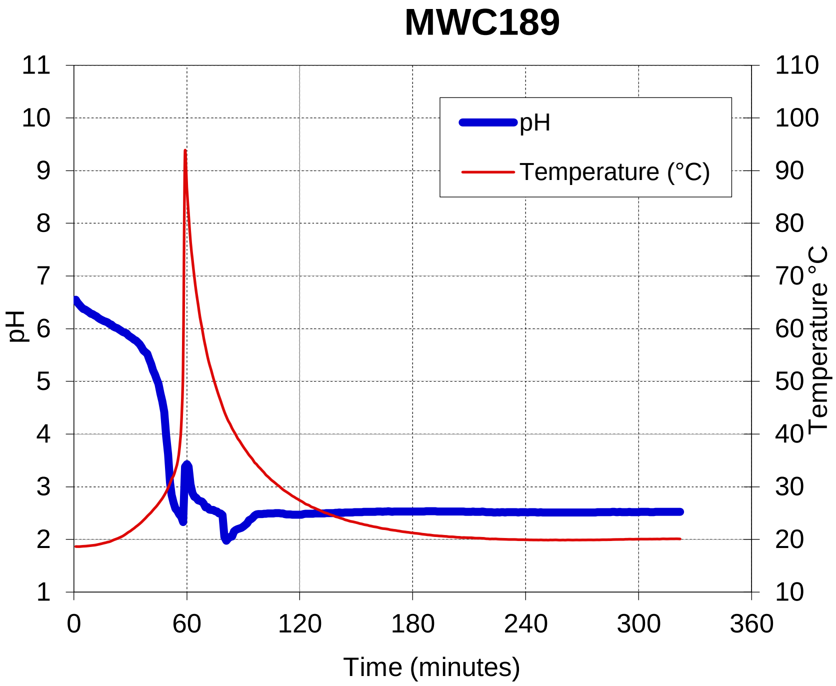


Figure E-6: Kinetic NAG for MWC189

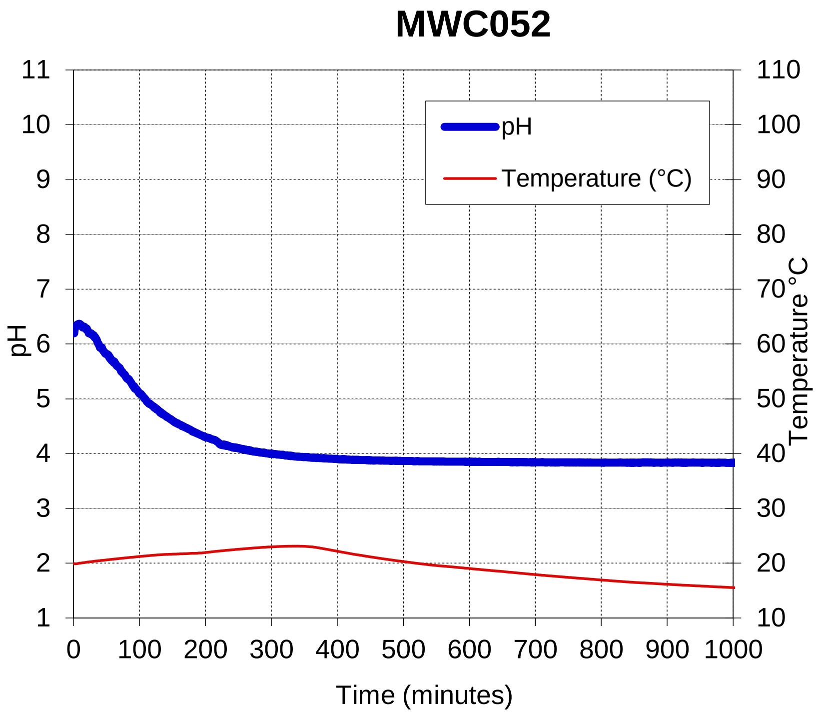


Figure E-7: Kinetic NAG for MWC052

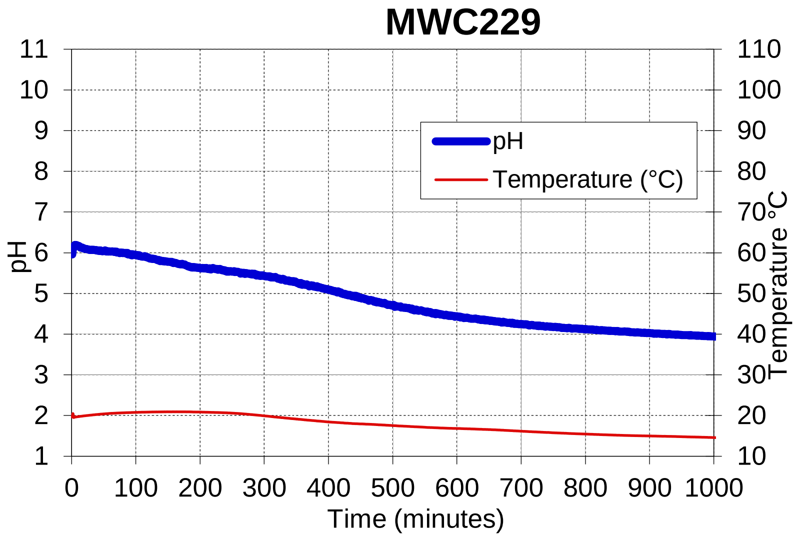


Figure E-8: Kinetic NAG for MWC229

APPENDIX F: ELEMENTAL AND DEIONISED WATER EXTRACTION RESULTS

Table F-1: GAI values for subset 10 waste samples with GAI values >3 in yellow

Element	Unit	Median Crustal Abundance	MWC286-MWC287	MWC107	MWC290-MWC291	MWC186	MWC289	MWC063	MWC251	MWC155	MWC189	MWC145-MWC146
			ACB	BS	CCB	CCB	CB	Diorite	Dolerite	CZ	CZ	CON
Ag	ppm	0.07	1	0	0	0	2	0	0	4	2	0
Al	ppm	82000	0	0	0	0	0	0	0	0	0	0
As	ppm	1.5	0	0	0	0	4	0	0	0	0	0
Ba	ppm	500	0	0	0	0	0	0	0	0	0	0
Be	ppm	2.6	0	0	0	0	0	0	0	0	0	0
Bi	ppm	0.048	8	2	5	1	8	5	1	15	10	2
Cd	ppm	0.11	0	0	0	0	1	0	0	0	0	0
Ce	ppm	68	0	0	0	0	0	0	0	0	0	0
Co	ppm	20	0	0	1	0	3	0	1	5	5	0
Cr	ppm	100	0	0	0	0	0	0	0	0	0	0
Cs	ppm	3	1	0	0	0	0	2	0	0	0	0
Cu	ppm	50	2	0	3	2	6	4	0	8	4	0
Dy	ppm	6	2	0	0	2	2	0	0	0	0	0
Er	ppm	3.8	2	0	0	2	2	0	0	0	0	0
Eu	ppm	2.1	0	0	0	2	1	0	0	0	0	0
Fe	ppm	950	3	2	4	3	6	5	6	8	8	4
Ga	ppm	18	0	0	0	0	0	0	0	0	0	0
Gd	ppm	7.7	1	0	0	2	1	0	0	0	0	0
Ge	ppm	1.8	0	0	0	0	0	0	0	0	0	0
Hf	ppm	5.3	0	0	0	0	0	0	0	0	0	0
Ho	ppm	1.4	2	0	0	2	2	0	0	0	0	0

Element	Unit	Median Crustal Abundance	MWC286-MWC287	MWC107	MWC290-MWC291	MWC186	MWC289	MWC063	MWC251	MWC155	MWC189	MWC145-MWC146
			ACB	BS	CCB	CCB	CB	Diorite	Dolerite	CZ	CZ	CON
In	ppm	0.049	0	0	0	2	3	0	0	1	0	0
La	ppm	32	0	0	0	1	0	0	0	0	0	0
Li	ppm	20	0	0	0	0	0	0	0	0	0	0
Lu	ppm	0.51	3	0	0	2	3	0	0	0	0	0
Mn	ppm	950	0	0	0	0	0	0	0	0	0	0
Mo	ppm	1.5	0	0	0	0	0	0	0	0	0	0
Nb	ppm	20	0	0	0	0	0	0	0	0	0	0
Nd	ppm	38	0	0	0	0	0	0	0	0	0	0
Ni	ppm	80	0	0	0	0	0	0	0	2	2	0
Pb	ppm	14	0	0	0	0	0	0	0	5	0	0
Pr	ppm	9.5	0	0	0	0	0	0	0	0	0	0
Rb	ppm	90	0	0	0	0	0	0	0	0	0	0
Re	ppm	0.0004	0	0	0	0	0	0	0	0	0	0
Sb	ppm	0.2	0	0	0	0	0	0	0	1	0	0
Sc	ppm	16	1	0	0	0	2	1	1	1	0	0
Se	ppm	0.05	2	1	5	0	6	4	4	7	6	0
Sn	ppm	2.2	0	0	0	0	0	1	0	0	0	0
Sm	ppm	7.9	0	0	0	2	1	0	0	0	0	0
Sr	ppm	370	0	0	0	0	0	0	0	0	0	0
Ta	ppm	2	0	0	0	0	0	0	0	0	0	0
Tb	ppm	1.1	1	0	0	2	2	0	0	0	0	0
Te	ppm	0.005	9	2	6	0	9	6	0	9	6	0

Element	Unit	Median Crustal Abundance	MWC286-MWC287	MWC107	MWC290-MWC291	MWC186	MWC289	MWC063	MWC251	MWC155	MWC189	MWC145-MWC146
			ACB	BS	CCB	CCB	CB	Diorite	Dolerite	CZ	CZ	CON
Th	ppm	12	0	0	0	0	0	0	0	0	0	0
Ti	ppm	5600	0	0	0	0	0	0	1	0	0	0
Tl	ppm	0.6	0	0	0	0	0	0	0	3	0	0
Tm	ppm	0.48	3	0	0	3	3	0	0	0	1	0
U	ppm	2.4	0	0	0	0	0	0	0	0	0	0
V	ppm	160	0	0	0	0	0	0	1	0	0	0
W	ppm	1	0	0	0	0	0	0	0	0	0	0
Y	ppm	30	0	0	0	2	2	0	0	0	0	0
Yb	ppm	3.3	3	0	0	2	3	0	0	0	0	0
Zn	ppm	75	0	0	0	0	0	0	0	0	0	0
Zr	ppm	190	0	0	0	0	0	0	0	0	0	0

*ACB:Actonolite Cemented Breccia, BS:Bedded Sediment, CCB:Calcite Cemented Breccia, CB:Crackle Breccia, CZ:Crescent Zone, SST:Siltstone, CON:Conglomerate

Table F-2: Total metals concentrations in solid component of subset 10 waste samples with EIL and HIL exceedances in yellow

Element	Unit	MWC286-MWC287	MWC107	MWC290-MWC291	MWC186	MWC289	MWC063	MWC251	MWC155	MWC189	MWC145-MWC146	EIL	HIL
		ACB	BS	CCB	CCB	CB	Diorite	Dolerite	CZ	CZ	CON		
Ag	ppm	0.22	<0.01	0.07	0.02	0.53	0.14	0.02	1.68	0.44	0.05		
Al	ppm	2500	700	2300	100	500	59200	62400	100	200	39000		
As	ppm	0.4	0.2	0.5	0.2	37.5	1	0.7	1.6	0.2	2.9	40	300
Ba	ppm	10	<10	<10	<10	<10	50	200	60	10	430		
Be	ppm	0.1	<0.05	<0.05	<0.05	<0.05	0.78	1.22	1.17	<0.05	1.05		
Bi	ppm	21.1	0.22	2.32	0.14	18.65	2.43	0.14	2020	68.4	0.35		100
Ca	ppm	211000	2200	23200	>250000	>250000	65200	55700	29700	32200	44600		
Cd	ppm	0.02	0.01	0.01	0.01	0.26	0.05	0.13	0.21	<0.02	0.05		90
Ce	ppm	20.6	37.6	28.9	51.2	20.5	35.5	36.8	20.6	16.25	40.4		
Co	ppm	8.4	1.4	61.6	2.8	248	34.4	53.2	793	1270	5.3		300
Cr	ppm	10	6	8	8	6	189	23	12	6	25	140	240
Cs	ppm	7.5	0.32	2.51	0.18	0.41	24.9	2.57	0.05	<0.05	1.61		
Cu	ppm	281	14.8	445	304	4970	1210	67.5	23100	1610	12	90	20,000
Dy	ppm	28.4	2.51	5.72	50.9	36.2	6.36	6.62	4.72	9.7	2.23		
Er	ppm	25	1.76	4.36	28.8	31.8	3.69	4.03	4.02	7.12	1.39		
Eu	ppm	3.68	0.55	1.28	10.85	4.85	1.37	1.77	0.33	0.83	0.72		
Fe	ppm	8400	5200	29500	13200	83700	57800	113500	319000	>500000	17900		
Ga	ppm	4.41	0.7	1.95	1.4	0.99	18.7	22.5	0.31	0.26	9.17		
Gd	ppm	21.1	2.44	4.88	46.5	25.2	6.12	6.53	2.99	7	2.73		
Ge	ppm	0.17	0.06	0.06	0.34	0.17	0.13	0.15	0.14	0.21	0.05		
Hf	ppm	0.06	0.11	0.08	<0.02	<0.02	2	4.8	<0.1	<0.1	3.2		
Ho	ppm	7.28	0.59	1.39	10.55	9.25	1.35	1.46	1.18	2.29	0.5		

Element	Unit	MWC286-MWC287	MWC107	MWC290-MWC291	MWC186	MWC289	MWC063	MWC251	MWC155	MWC189	MWC145-MWC146	EIL	HIL
		ACB	BS	CCB	CCB	CB	Diorite	Dolerite	CZ	CZ	CON		
In	ppm	0.086	0.007	0.034	0.239	0.808	0.04	0.093	0.105	0.021	0.018		
K	ppm	2300	300	1500	100	200	16400	8800	100	<100	15300		
La	ppm	41.4	19.2	13.1	96.3	40.8	14.4	16.6	7.7	5.9	19.9		
Li	ppm	5	0.7	1.9	0.8	1.1	13.2	15.1	42	0.7	15.4		
Lu	ppm	5.56	0.27	0.71	2.89	6.62	0.41	0.55	0.89	1.04	0.22		
Mg	ppm	5200	3800	5700	4600	4300	48200	25400	27100	3700	5500		
Mn	ppm	384	912	771	843	880	655	1470	330	161	942		9,000
Mo	ppm	0.09	0.05	0.2	<0.05	0.09	0.4	0.44	0.54	0.13	0.46		
Na	ppm	<100	300	300	400	400	30100	17100	900	300	14300		
Nb	ppm	0.08	0.73	0.18	<0.05	0.11	5.4	5.6	<0.1	<0.1	5		
Nd	ppm	56.4	13.8	15.8	145.5	60.6	19.7	20.1	9.9	11	16.3		
Ni	ppm	11.5	1.5	44.3	1.4	132	122.5	37.2	355	499	12.3	75	800
P	ppm	40	190	170	10	70	510	670	<10	10	280		
Pb	ppm	0.8	1.2	0.7	0.7	0.9	0.9	8.6	616	1.6	15.1	470	600
Pr	ppm	13.65	4.07	3.91	35	14.15	4.91	4.97	2.76	2.49	4.78		
Rb	ppm	80.6	2.9	26.3	0.8	3.6	265	54.4	0.3	0.3	66.6		
Re	ppm	0.002	<0.001	<0.001	0.002	0.003	<0.002	0.003	<0.002	<0.002	<0.002		
S	ppm	500	200	8800	600	26700	3800	1300	>100000	>100000	6100		
Sb	ppm	<0.05	<0.05	<0.05	<0.05	<0.05	0.17	0.06	0.82	0.06	0.28		
Sc	ppm	37.6	1.8	3.7	16.3	70.5	35.3	39	45.2	20.9	5.4		
Se	ppm	0.4	0.2	1.7	<0.2	6	1	1	11	6	<1		
Sn	ppm	0.7	1.1	0.8	<0.2	2.7	5.1	2.2	0.4	0.2	1		
Sm	ppm	16.75	2.52	3.98	42.3	18.85	5.63	5.55	2.5	4.3	3.14		
Sr	ppm	97	181	139	293	229	99.6	158	23.4	18.4	139		

Element	Unit	MWC286-MWC287	MWC107	MWC290-MWC291	MWC186	MWC289	MWC063	MWC251	MWC155	MWC189	MWC145-MWC146	EIL	HIL
		ACB	BS	CCB	CCB	CB	Diorite	Dolerite	CZ	CZ	CON		
Ta	ppm	<0.01	0.01	<0.01	<0.01	<0.01	0.34	0.49	<0.05	<0.05	0.43		
Tb	ppm	4.23	0.39	0.84	8.03	5.23	1.07	1.1	0.68	1.5	0.41		
Te	ppm	3.45	0.03	0.37	0.01	2.79	0.42	<0.05	5.15	0.65	<0.05		
Th	ppm	2.8	4.9	2.8	0.2	0.4	1.39	6.82	0.08	0.06	6.14		
Ti	ppm	290	550	410	<50	90	7630	14050	<50	<50	1720		
Tl	ppm	0.31	0.02	0.11	<0.02	0.02	1.1	0.21	6.16	0.02	0.7		
Tm	ppm	4.56	0.28	0.69	4.24	5.72	0.5	0.53	0.66	1.03	0.19		
U	ppm	0.48	0.65	0.5	<0.05	0.05	0.7	1.3	<0.1	0.1	1.5		
V	ppm	21	7	18	38	21	283	547	20	8	30		
W	ppm	0.09	0.58	0.29	<0.05	0.1	2	1	0.1	0.1	0.8		
Y	ppm	42.1	15.25	34.2	241	251	32.9	35.6	28.8	63.1	13.2		
Yb	ppm	30.5	1.75	4.53	22.8	37	3.07	3.61	5.59	6.99	1.35		
Zn	ppm	3	<2	2	<2	41	25	127	38	<2	21	250	30,000
Zr	ppm	2.3	3	3.2	<0.5	0.5	71.2	155	<0.5	<0.5	104.5		

*ACB:Actonolite Cemented Breccia, BS:Bedded Sediment, CCB:Calcite Cemented Breccia, CB:Crackle Breccia, CZ:Crescent Zone, SST:Siltstone, CON:Conglomerate

Table F-3: Elemental concentrations in leachate component of subset 10 samples with slightly elevated concentrations in yellow and elevated concentrations in red

Parameter	Unit	Detection Limit	Slightly Elevated	Screening Guideline	Elevated	Screening Guideline	MWC286-MWC287	MWC107	MWC290-MWC291	MWC186	MWC289	MWC063	MWC251	MWC155	MWC189	MWC145-MWC146
							ACB	BS	CCB	CCB	CB	Diorite	Dolerite	CZ	CZ	CON
Al	mg/l	0.01	0.055	ANZECC 95% Freshwater Protection	5	ANZECC livestock	0.28	0.24	0.22	<0.1	0.12	0.45	1.26	<0.1	<0.1	0.31
As	mg/l	0.001	0.013	ANZECC 95% Freshwater Protection	0.5	ANZECC livestock	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
B	mg/l	0.05	0.37	ANZECC 95% Freshwater Protection	5	ANZECC livestock	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Ba	mg/l	0.001	2	Australian Drinking Water	20	Australian Drinking Water (x10)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Be	mg/l	0.001	0.06	Australian Drinking Water	0.1	ANZECC long term irrigation	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cd	mg/l	0.0001	0.0002	ANZECC 95% Freshwater Protection	0.02	Australian Drinking Water (x10)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Co	mg/l	0.001	0.11	British Columbia Freshwater Protection	1	ANZECC livestock	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01
Cr	mg/l	0.001	0.001	ANZECC 95% Freshwater Protection	0.5	ANZECC long term irrigation	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	mg/l	0.001	0.0014	ANZECC 95% Freshwater Protection	20	Australian Drinking Water (x10)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	mg/l	0.0001	0.0006	ANZECC 95% Freshwater Protection	0.01	Australian Drinking Water (x10)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mn	mg/l	0.001	1.9	ANZECC 95% Freshwater Protection	5	Australian Drinking Water (x10)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.29	<0.01	<0.01
Ni	mg/l	0.001	0.011	ANZECC 95% Freshwater Protection	1	ANZECC livestock	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	<0.01
Pb	mg/l	0.001	0.0034	ANZECC 95% Freshwater Protection	0.1	Australian Drinking Water (x10)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Se	mg/l	0.01	0.011	ANZECC 95% Freshwater Protection	0.2	Australian Drinking Water (x10)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
V	mg/l	0.01	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	0.13	<0.01	<0.01	<0.01
Zn	mg/l	0.005	0.008	ANZECC 95% Freshwater Protection	2	ANZECC long term irrigation	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

*ACB:Actonolite Cemented Breccia, BS:Bedded Sediment, CCB:Calcite Cemented Breccia, CB:Crackle Breccia, CZ:Crescent Zone, SST:Siltstone, CON:Conglomerate
NA= Investigation level not available

APPENDIX G: PEROXIDE EXTRACTION RESULTS

Table G-1: Peroxide Extraction Results (x5) with slightly elevated concentrations in yellow and elevated concentrations in red

Parameter	Unit	Detection Limit	Slightly Elevated	Screening Guideline	Elevated	Screening Guideline	MWC104 - MWC105	MWC289	MWC161	MWC085	MWC155	MWC111	MWC189	MWC052	MWC229	Blank
							CCB	CB	Diorite	CZ	CZ	CZ	CZ	SST	SST	
							Uncertain	NAF-HS	PAF-LC	PAF	PAF	PAF	PAF	PAF-LC	PAF-LC	
pH	-	0.1	<5.0	Slightly acidic	<4	Moderately acidic	7.9	7.6	7.8	3.2	2.2	7.8	2.6	3.8	3.9	5.5
Ag	mg/l	0.001	0.1	Australian Drinking Water	1	Australian Drinking Water (x10)	0.015	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Al	mg/l	0.01	0.055	ANZECC 95% Freshwater Protection	5	ANZECC livestock	<0.01	0.05	4.3	8.85	2.9	0.4	1	12.8	12.1	<0.01
As	mg/l	0.001	0.013	ANZECC 95% Freshwater Protection	0.5	ANZECC livestock	<0.001	<0.001	0.005	<0.001	0.08	<0.001	0.025	0.015	0.015	0.12
B	mg/l	0.05	0.37	ANZECC 95% Freshwater Protection	5	ANZECC livestock	<0.05	0.3	<0.05	0.9	0.65	<0.05	0.7	0.4	0.75	<0.05
Ba	mg/l	0.001	2	Australian Drinking Water	20	Australian Drinking Water (x10)	0.33	0.77	1.46	1.14	0.27	0.455	0.22	1.725	3.055	<0.001
Be	mg/l	0.001	0.06	Australian Drinking Water	0.1	ANZECC long term irrigation	<0.001	<0.001	<0.001	<0.001	0.045	<0.001	<0.001	<0.001	0.005	<0.001
Ca	mg/l	1	NA	NA	NA	NA	2245	980	540	1190	1480	2210	1905	60	90	<1
Cd	mg/l	0.0001	0.0002	ANZECC 95% Freshwater Protection	0.02	Australian Drinking Water (x10)	<0.0001	<0.0001	<0.0001	0.0005	0.0065	<0.0001	0.002	<0.0001	0.001	0.0005
Cl	mg/l	1	NA	NA	NA	NA	75	20	20	35	50	30	30	155	100	5
Co	mg/l	0.001	0.11	British Columbia Freshwater Protection	1	ANZECC livestock	0.015	0.015	<0.001	4.5	10.55	0.455	26.6	0.155	0.135	<0.001
Cr	mg/l	0.001	0.001	ANZECC 95% Freshwater Protection	0.5	ANZECC long term irrigation	<0.001	0.005	0.055	<0.001	0.05	<0.001	0.015	0.03	0.065	0.015
Cu	mg/l	0.001	0.0014	ANZECC 95% Freshwater Protection	20	Australian Drinking Water (x10)	<0.001	0.01	<0.001	275	473.5	15.85	31.1	1.74	0.105	0.035
F	mg/l	0.1	1.5	Australian Drinking Water	15	Australian Drinking Water (x10)	0.5	<0.1	0.5	1	0.5	<0.1	<0.1	1	1	<0.1
Fe	mg/l	0.05	0.3	Australian Drinking Water	3	Australian Drinking Water (x10)	<0.05	<0.05	<0.05	700	1820	63	4665	<0.05	<0.05	<0.05
Hg	mg/l	0.0001	0.0006	ANZECC 95% Freshwater Protection	0.01	Australian Drinking Water (x10)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
K	mg/l	1	NA	NA	NA	NA	5	10	180	40	5	10	5	30	40	<1
Mg	mg/l	1	NA	NA	NA	NA	45	25	<1	185	175	50	125	40	45	<1

Parameter	Unit	Detection Limit	Slightly Elevated	Screening Guideline	Elevated	Screening Guideline	MWC104 - MWC105	MWC289	MWC161	MWC085	MWC155	MWC111	MWC189	MWC052	MWC229	Blank
							CCB	CB	Diorite	CZ	CZ	CZ	CZ	SST	SST	
							Uncertain	NAF-HS	PAF-LC	PAF	PAF	PAF	PAF	PAF-LC	PAF-LC	
Mn	mg/l	0.001	1.9	ANZECC 95% Freshwater Protection	5	Australian Drinking Water (x10)	0.07	0.12	<0.001	26.95	17.7	0.955	10.2	1.03	2.04	0.015
Mo	mg/l	0.001	0.05	Australian Drinking Water	0.15	ANZECC livestock	<0.001	0.015	<0.001	<0.001	<0.001	<0.001	<0.001	0.025	0.175	0.085
Na	mg/l	1	NA	NA	NA	NA	90	105	130	165	110	95	95	220	340	95
Ni	mg/l	0.001	0.011	ANZECC 95% Freshwater Protection	1	ANZECC livestock	0.015	0.01	<0.001	0.62	4.095	0.18	10.3	0.14	0.23	0.01
P	mg/l	1	NA	NA	NA	NA	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pb	mg/l	0.001	0.0034	ANZECC 95% Freshwater Protection	0.1	Australian Drinking Water (x10)	<0.001	<0.001	<0.001	0.02	2.865	0.03	0.2	<0.001	<0.001	0.075
Sb	mg/l	0.001	0.003	Australian Drinking Water	0.03	Australian Drinking Water (x10)	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.18
Se	mg/l	0.01	0.011	ANZECC 95% Freshwater Protection	0.2	Australian Drinking Water (x10)	0.6	0.15	0.1	0.3	0.3	0.1	0.55	<0.01	<0.01	<0.01
Si	mg/l	0.1	NA	NA	NA	NA	0.3	1.5	19.6	124.5	48.6	2.9	36.1	38.7	38.9	0.45
Sn	mg/l	0.001	NA	NA	NA	NA	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.325
SO4	mg/l	1	429	British Columbia Freshwater Protection	1000	ANZECC livestock	4465	1705	1110	5100	10550	5050	13350	355	370	<1
Sr	mg/l	0.001	NA	NA	NA	NA	1.485	0.96	0.565	1.275	1.005	1.355	1.08	0.285	0.415	<0.001
Th	mg/l	0.001	NA	NA	NA	NA	<0.001	<0.001	<0.001	0.01	0.01	<0.001	<0.001	<0.001	<0.001	<0.001
Tl	mg/l	0.001	NA	NA	NA	NA	<0.001	<0.001	<0.001	<0.001	0.05	0.005	<0.001	<0.001	<0.001	<0.001
U	mg/l	0.001	0.0085	British Columbia Freshwater Protection	0.2	ANZECC livestock	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zn	mg/l	0.005	0.008	ANZECC 95% Freshwater Protection	2	ANZECC long term irrigation	0.27	0.385	<0.005	2.955	2.745	0.9	2.045	1.3	1.48	0.175

*CCB:Calcite Cemented Breccia, CB:Crackle Breccia, CZ:Crescent Zone, SST:Siltstone

APPENDIX H: ASBESTOS RESULTS

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **EB2114864**
Client : **LANDLOCH**
Contact : Christine Lison
Address : PO BOX 5175
SOUTH LAKE WESTERN AUSTRALIA 6164
Telephone : 08 9494 2835
Project : 2264.21a
Order number : ----
C-O-C number : ----
Sampler : Christine Lison
Site : HAVIERON
Quote number : EP/480/21
No. of samples received : 7
No. of samples analysed : 7

Page : 1 of 4
Laboratory : Environmental Division Brisbane
Contact : Customer Services EB
Address : 2 Byth Street Stafford QLD Australia 4053
Telephone : +61-7-3243 7222
Date Samples Received : 28-May-2021 12:00
Date Analysis Commenced : 01-Jun-2021
Issue Date : 01-Jun-2021 15:19

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Descriptive Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Uyen Dalkin	Approved Asbestos Identifier	Melbourne Asbestos, Springvale, VIC

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EA200: Asbestos Identification Samples were analysed by Polarised Light Microscopy including dispersion staining.
- **EA200 Legend**
- EA200 'Am' Amosite (brown asbestos)
- EA200 'Cr' Crocidolite (blue asbestos)
- EA200 'Ch' Chrysotile (white asbestos)
- EA200: 'UMF' Unknown Mineral Fibres. "-" indicates fibres detected may or may not be asbestos fibres. Confirmation by alternative techniques is recommended.
- EA200: N/A - Not Applicable

Analytical Results

Sub-Matrix: **SOLID** (Matrix: **SOLID**)			*Sample ID*	**MWC090** **Act Cem Breccia**	**MWC217-MWC218** **Bed Sediment**	**MWC048-MWC051** **Cal Cem Breccia**	**MWC256-MWC257** **Cal Cem Breccia**	**MWC023-MWC027** **Crackle Breccia**
			Sampling date / time	26-May-2021 00:00	26-May-2021 00:00	26-May-2021 00:00	26-May-2021 00:00	26-May-2021 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**EB2114864-001**	**EB2114864-002**	**EB2114864-003**	**EB2114864-004**	**EB2114864-005**
				Result	Result	Result	Result	Result
EA200: AS 4964 - 2004 Identification of Asbestos in bulk samples								
Asbestos Detected	1332-21-4	0.1	g/kg	**No**	**No**	**No**	**No**	**No**
Asbestos Type	1332-21-4	-	--	**-**	**-**	**-**	**-**	**-**
Asbestos (Trace)	1332-21-4	5	Fibres	**No**	**No**	**No**	**No**	**No**
Sample weight (dry)	----	0.01	g	**288**	**674**	**508**	**619**	**724**
Synthetic Mineral Fibre	----	0.1	g/kg	**No**	**No**	**No**	**No**	**No**
Organic Fibre	----	0.1	g/kg	**No**	**No**	**No**	**No**	**No**
APPROVED IDENTIFIER:	----	-	--	**U.DALKIN**	**U.DALKIN**	**U.DALKIN**	**U.DALKIN**	**U.DALKIN**

Analytical Results

Sub-Matrix: **SOLID** (Matrix: **SOLID**)			*Sample ID*	**MWC111** **Massive Sulphide**	**MWC140** **CON**	----	----	----
			Sampling date / time	26-May-2021 00:00	26-May-2021 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EB2114864-006**	**EB2114864-007**	--------	--------	--------
				Result	Result	----	----	----
EA200: AS 4964 - 2004 Identification of Asbestos in bulk samples								
Asbestos Detected	1332-21-4	0.1	g/kg	**No**	**No**	----	----	----
Asbestos Type	1332-21-4	-	--	**-**	**-**	----	----	----
Asbestos (Trace)	1332-21-4	5	Fibres	**No**	**No**	----	----	----
Sample weight (dry)	----	0.01	g	**268**	**83.2**	----	----	----
Synthetic Mineral Fibre	----	0.1	g/kg	**No**	**No**	----	----	----
Organic Fibre	----	0.1	g/kg	**No**	**No**	----	----	----
APPROVED IDENTIFIER:	----	-	--	**U.DALKIN**	**U.DALKIN**	----	----	----

Analytical Results

Descriptive Results

Sub-Matrix: **SOLID**

Method: Compound	*Sample ID - Sampling date / time*	*Analytical Results*
EA200: AS 4964 - 2004 Identification of Asbestos in bulk samples		
EA200: Description	MWC090Act Cem Breccia - 26-May-2021 00:00	Grey fragment approx 115 x 50 x 30mm.
EA200: Description	MWC217-MWC218Bed Sediment - 26-May-2021 00:00	Grey fragments approx 100 x 65 x 30mm.
EA200: Description	MWC048-MWC051Cal Cem Breccia - 26-May-2021 00:00	Grey fragments approx 50 x 55 x 20mm.
EA200: Description	MWC256-MWC257Cal Cem Breccia - 26-May-2021 00:00	Grey fragments approx 90 x 50 x 30mm.
EA200: Description	MWC023-MWC027Crackle Breccia - 26-May-2021 00:00	Grey fragments approx 80 x 50 x 25mm.
EA200: Description	MWC111Massive Sulphide - 26-May-2021 00:00	Grey fragment approx 105 x 50 x 25mm.
EA200: Description	MWC140CON - 26-May-2021 00:00	Grey fragment approx 50 x 20 x 35mm.

Inter-Laboratory Testing

Analysis conducted by ALS Melbourne, NATA accreditation no. 825, site no. 13778 (Chemistry).

(SOLID) EA200: AS 4964 - 2004 Identification of Asbestos in bulk samples

ADDENDUM: HAVIERON TAILINGS GEOCHEMICAL CHARACTERISATION

Environmental Geochemistry International

ENVIRONMENTAL GEOCHEMISTRY
INTERNATIONAL PTY LTD

ABN 48 600 298 271

81A COLLEGE STREET
BALMAIN, NSW 2041 AUSTRALIA

T +61 2 9810 8100
E EGI@GEOCHEMISTRY.COM.AU
W WWW.GEOCHEMISTRY.COM.AU

TECHNICAL MEMORANDUM

TO:	Landloch Pty Ltd (Landloch)
ATTENTION:	Christine Lison, Environmental Consultant, PGDip, MPhil
FROM:	Andrew Botfield and John Jeffery
DATE:	7 December 2021
DOCUMENT NO:	J000606 / R1458
SUBJECT:	Havieron Tailings Geochemical Characterisation

1. INTRODUCTION

This technical memorandum relates to geochemical characterisation of a metallurgical tailings sample produced from a laboratory scale test circuit simulating the preferred gold – copper recovery process for the Havieron Project (the Project). The work was undertaken for Landloch on behalf of Newcrest Mining Limited (Newcrest).

1.1. Background

The Project is located approximately 400km south-east of Port Hedland within the Pilbara region of Western Australia, approximately 45 km north-east of Newcrest's Telfer mine. The Project involves a high-grade underground gold-copper deposit that will be developed in two stages. The first stage of work (Stage 1) is the development of a box cut and decline extending to 400m below ground level. The second stage of work (Stage 2) involves the development of a sub-level open stope underground mine. Ore will be transported by road from Havieron to Telfer for processing and tailings storage. Details relating to deposit geology, ore mineralogy and the currently preferred process circuit are provided in Section 2.

1.2. Objective

The objective of this work was to quantify the key geochemical characteristics of tailings that will be produced by the Havieron Project.

2. MINEROLOGY AND ORE PROCESSING

2.1. Project geology and mineralisation

The Havieron Project is targeting a gold-copper deposit contained within the Proterozoic Lamil group Puntapunta formation that was deposited in a marine carbonate-dominated shelf environment and comprises dolomitic siltstone, rare limestone, dolomitic sandstone, chert, and shale. It underlies a 420m cover of Permian fluvioglacial and diamictic sedimentary rocks (e.g. mudstones, tillites, siltstones and mudstones).

The deposit is described as an ovoid shaped zone of variable brecciation, alteration and sulphide mineralisation that is approximately 650m by 350m, trending in a north-west orientation, and extending from the basement contact with the Permian cover unconformity to greater than 1400m below surface (refer to Figure 1). The boundary, defined by the presence of crackle brecciation, generally appears to be at the metamorphic contact between dominantly biotite-rich metasiltstone to meta-arenite facies outside and dominantly calc silicate actinolite marble facies within.

The breccia zones can be defined as unmineralized crackle and mineralised cemented breccias. On the margins of the breccia exists a zone of sulphide mineralisation termed the Crescent Zone related to the highest grades in the system. The breccia is intruded by a 20-30m wide NNE trending steeply east dipping post mineralisation dyke (Newcrest 2020).

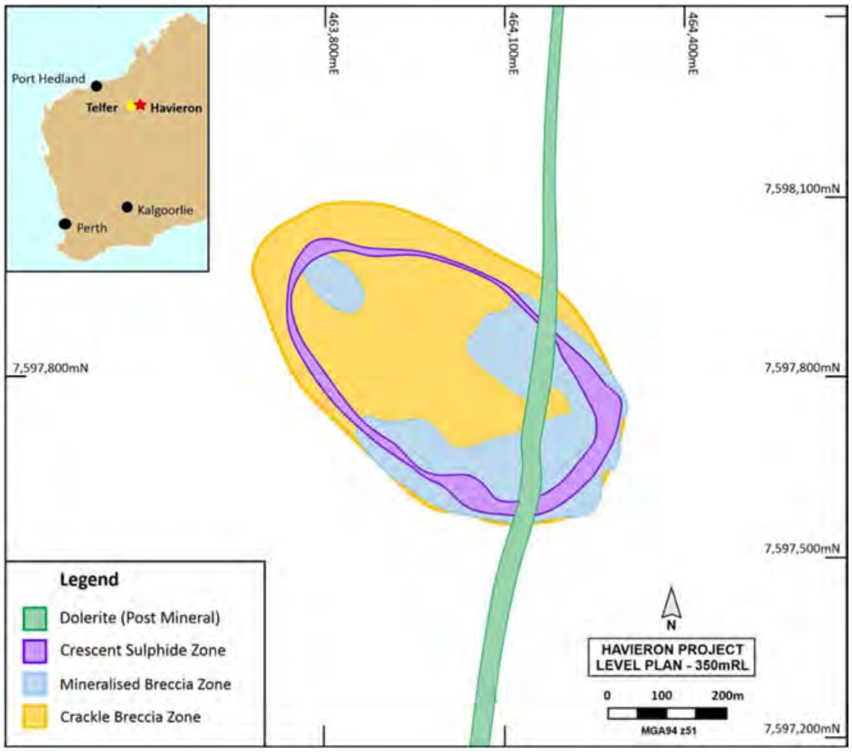


Figure 1: Plan viewing showing the ovoid shaped zone of variable brecciation showing crescent zone, crackle breccia and mineralised cemented breccia at the -350mRL projected to surface (Newcrest 2020).

Exploration has identified the following four key target regions within the deposit (refer to Figure 2):

- South-East Crescent and Breccia.
- North-West Crescent.
- Northern Breccia.
- Eastern Breccia.

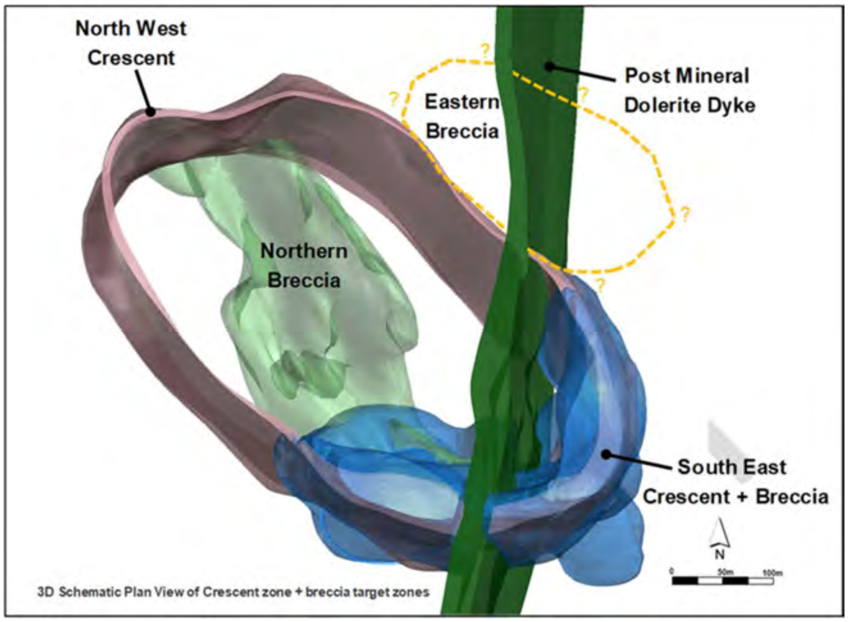
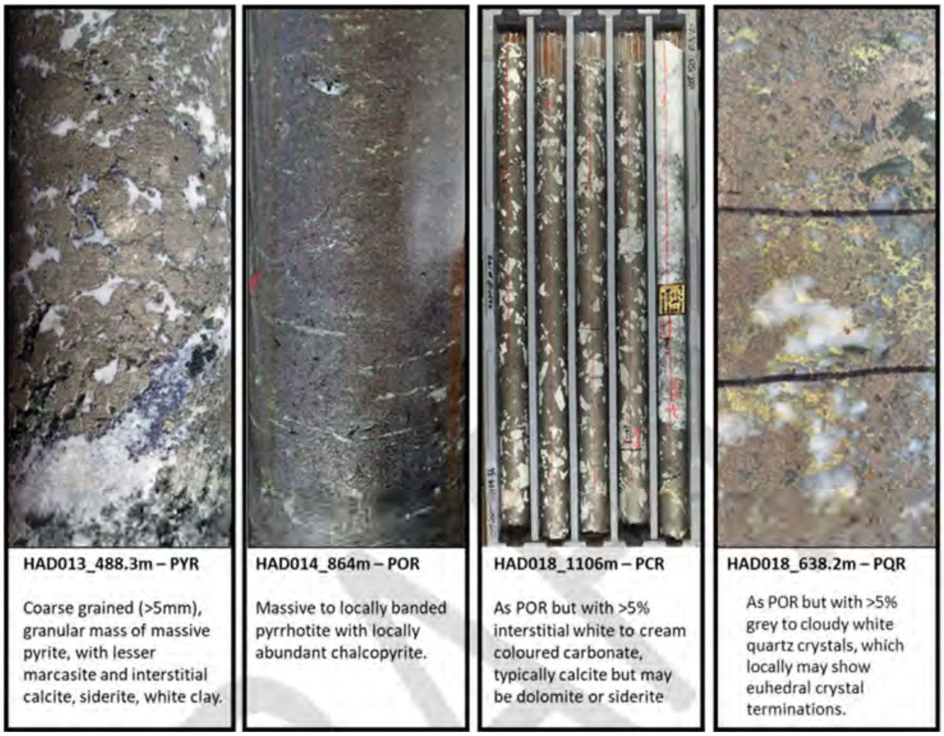


Figure 2: 3D schematic of the key target regions within the deposit (Newcrest 2020).

The crescent zone is characterised by a series of massive to semi-massive sulphide replacement/open space infill units, that have a subvertical dip and trend parallel ovate breccia zone. The zone is best developed on the SE closure creating a crescent like geometry. The massive sulphide units are separated from one another by variably mineralised calcite-cemented breccias which has inflated the rock package (Newcrest 2020).

The crescent zone can be divided into four massive sulphide units (refer to Figure 3) (Newcrest 2020):

- POR - Massive to locally banded pyrrhotite with locally abundant chalcopyrite.
- PQR - Like POR but can contain abundant chalcopyrite with local zones of quartz- chalcopyrite veins. Typically occurs on the footwall of the crescent zone. Associated with the highest gold grades at Havieron.
- PCR – Like POR but highly carbonate enriched, typically calcite, but may be dolomite or siderite.
- PYR – coarse grained massive pyrite, with lesser marcasite and interstitial calcite, siderite, and white clay. May contain minor amounts of chalcopyrite, sphalerite, galena, as well as residual early pyrrhotite. Better developed at higher levels close to the unconformity with the Permian cover.


HAD013_488.3m – PYR

Coarse grained (>5mm), granular mass of massive pyrite, with lesser marcasite and interstitial calcite, siderite, white clay.

HAD014_864m – POR

Massive to locally banded pyrrhotite with locally abundant chalcopyrite.

HAD018_1106m – PCR

As POR but with >5% interstitial white to cream coloured carbonate, typically calcite but may be dolomite or siderite

HAD018_638.2m – PQR

As POR but with >5% grey to cloudy white quartz crystals, which locally may show euhedral crystal terminations.

Figure 3: Photograph examples of the sulphide units at Havieron (Newcrest 2020).

Ore samples from massive sulphide units POR, PQR and PCR and mineralised breccia within the south-eastern crescent and breccia region of the deposit were the subject of the metallurgical test work for the program (Newcrest 2021). The ore samples were taken from the eastern and western flanks of the south-eastern crescent zone and breccia adjacent to south-eastern crescent zone (refer to Figure 4).

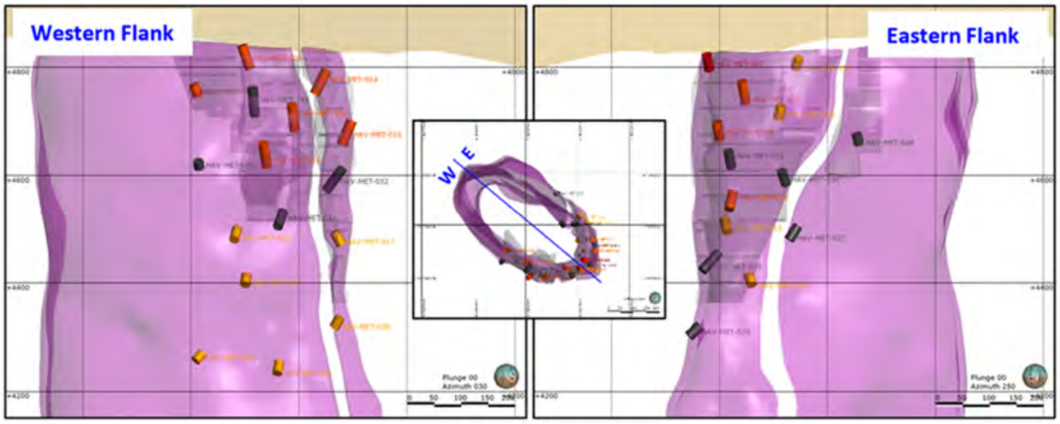


Figure 4: Location of samples from eastern and western flanks of south-eastern crescent zone (Newcrest 2021).

The modal mineralogy and sulphide distributions for ore materials within massive sulphide and breccia of the south-eastern crescent zone (Newcrest 2021) indicate the following:

- There is an abundance of carbonate minerals throughout both the massive sulphide and breccia rock ore (10 to 50% within the massive sulphide; and greater than 50% within the breccia) (refer to Figure 5).
- There appears to be a significant proportion of pyrrhotite (often in greater abundance than pyrite and in some cases greater than 90% of the total sulphide present), as well as a significant proportion of chalcopyrite (although most often in less abundance than pyrite, sometimes as much as 10% of the total sulphide present) (refer to Figure 6).
- Breccia ore has a much lower total sulphur content, but still has a significant proportion of pyrrhotite (often in greater abundance than pyrite and in some cases greater than 90% of the total sulphide present) together with chalcopyrite (although most often in less abundance than pyrite, sometimes as much as 35% of the total sulphide present).
- There is a wide variety of other sulphides present in minor proportions (usually less than 1%), including: arsenopyrite, cobaltite, tennantite, enargite, covellite, chalcocite and bornite.

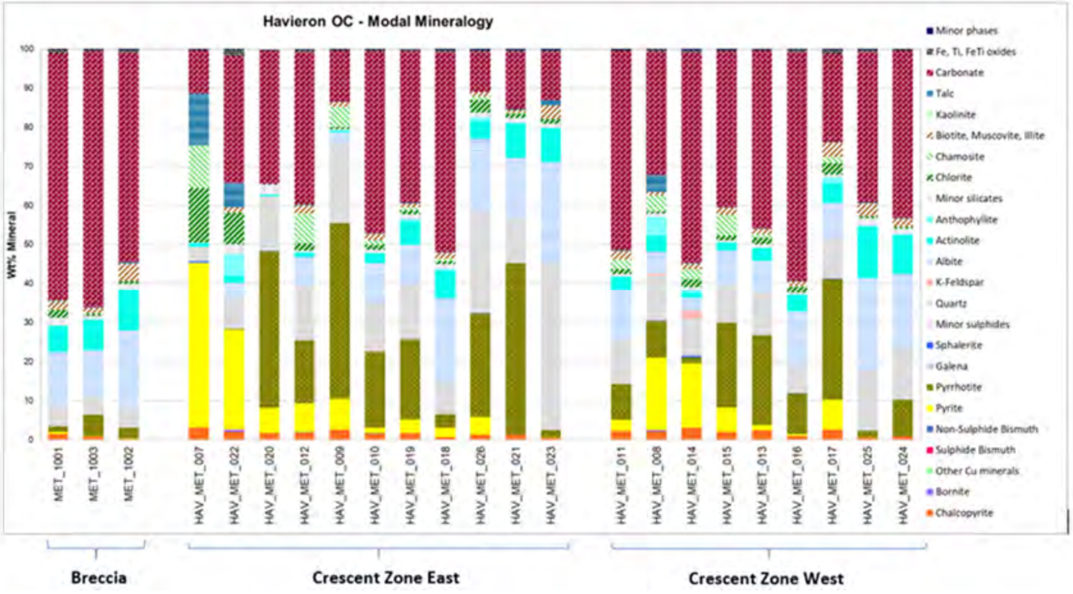


Figure 5 Modal Mineralogy for the massive sulphide and breccia of the south-eastern crescent zone (Newcrest 2021).

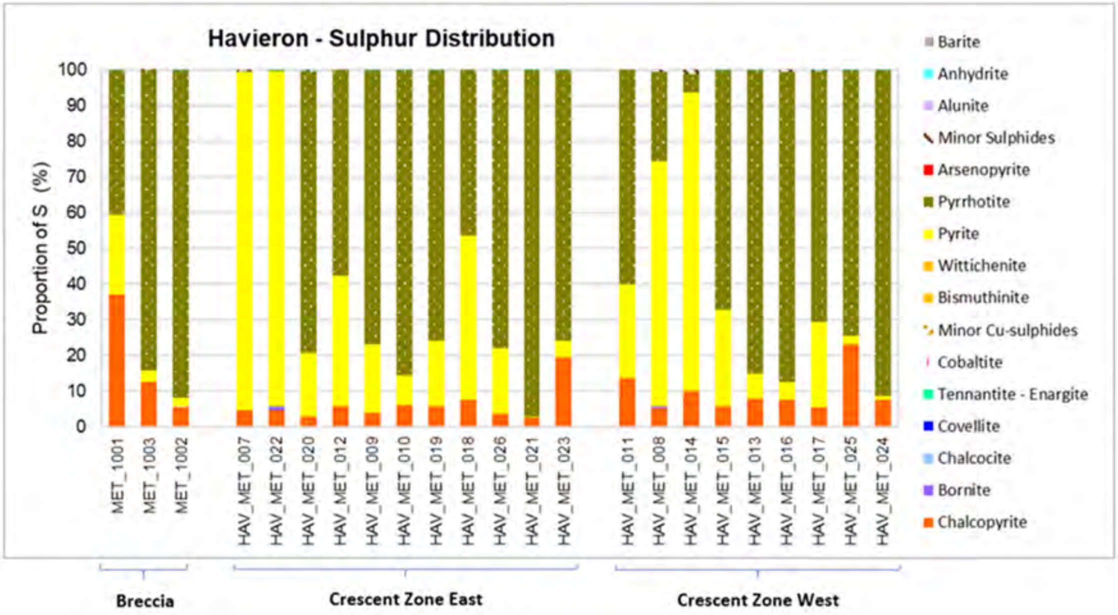


Figure 6 Sulphur distribution for the massive sulphide and breccia of the south-eastern crescent zone (Newcrest 2021).

2.2. Process Plant Overview

The proposed process plant for gold-copper recovery based upon metallurgical test work comprises the following key elements (Newcrest 2021) (as refer to Figure 7):

- Crushing and grinding of ore.
- Copper concentration via flotation, magnetite separation to remove magnetic (monoclinic) pyrrhotite and thickening via filtration.
- Gold extraction via oxidation, liming, cyanidation, and carbon-in-leach (CIL).
- Cyanide destruction via an air/SO_2 circuit.
- Tailings thickening to produce an assumed underflow density of 60% solids.

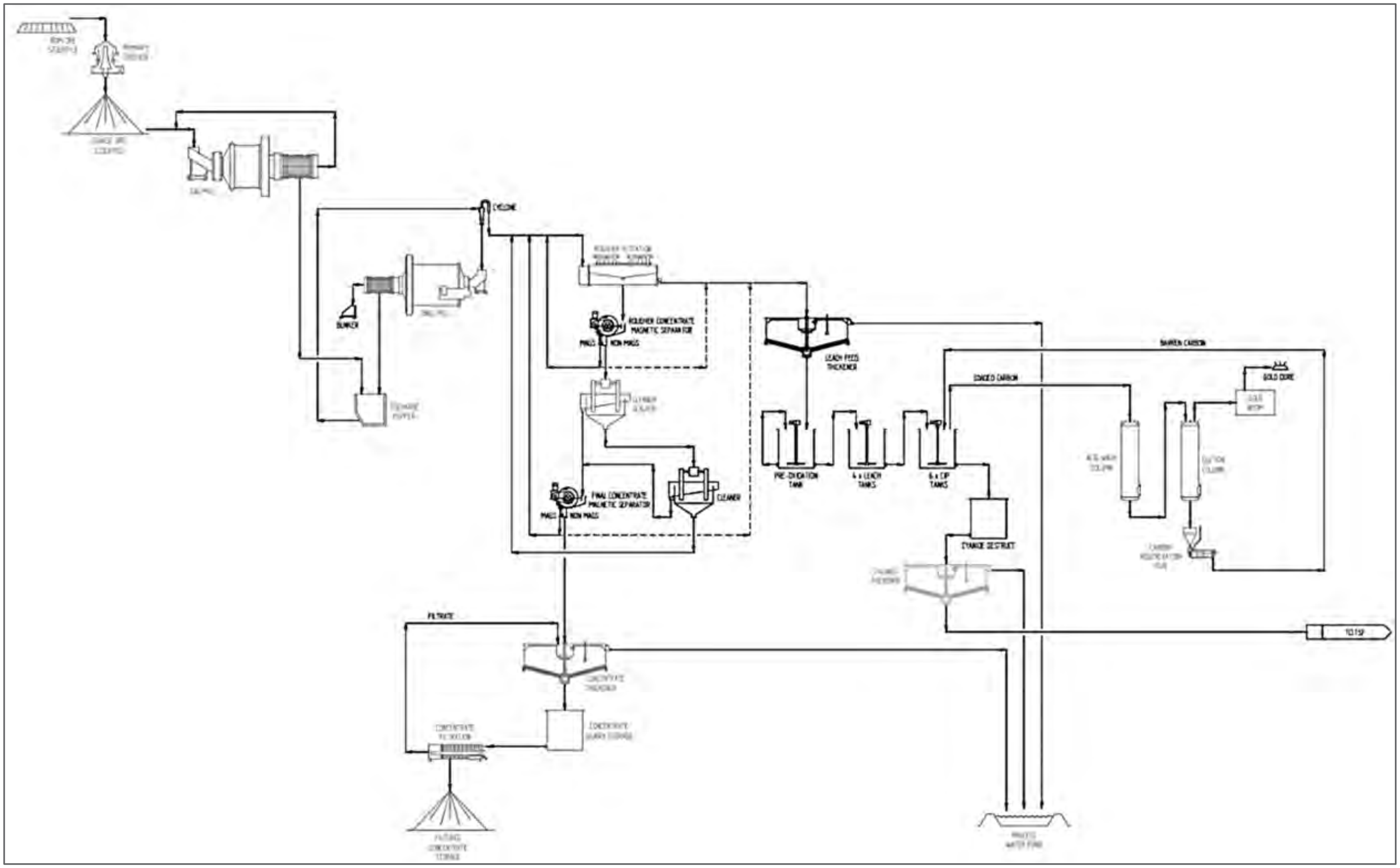


Figure 7 Proposed process plant for gold-copper recovery

3. SAMPLE DETAILS AND LABORATORY PROGRAM

The tailings sample was representative of metallurgical tailings material produced from a process test circuit analogous to the gold – copper recovery process described in Section 2.2. It was supplied by Landloch on behalf of Newcrest Technical Services. The tailings sample was received as a wet slurry at EGi's Balmain Laboratory on 29 July 2021. The sample was then prepared for laboratory analysis via the following:

- Decanting off excess water.
- Oven dried for 3 days at relatively low temperature (circa 50 degrees Celsius).
- Pulverised by hand mortar and pestle.

The tailings were then subject to the following laboratory analysis:

- Standard acid-base accounting used to inform initial acid-rock drainage (ARD) classification. This included:
    - Total sulphur content.
    - Standard acid neutralising capacity (ANC) using the modified Sobek method.
    - Single Net-Acid Generation (NAG) pH.
- Specialised geochemical test work to further probe the nature of potentially acid producing and neutralisation minerals present. This included:
    - Sequential NAG test.
    - Acid-Base Characteristic Curve (ABCC) test.
    - Sulphur speciation test work.
    - Kinetic NAG test.
    - Total organic carbon.
- General chemistry and exchangeable cations, including:
    - Paste pH and electrical conductivity (1:2 solid/water ratio).
    - Exchangeable calcium, sodium, potassium, magnesium and aluminium.
- Four-acid digest and multi element analysis to provide an indication of any elements that may be significantly enriched.
- X-ray diffraction mineralogical analysis to confirm key residual minerals after processing.
- Asbestos fibre screening by polarised light microscopy (PLM) and dispersion staining (DS) techniques to confirm the presence / absence of asbestos fibres.
- Water extraction (1:2) and analysis to provide a preliminary indication of potentially leachable constituents upon short term contact with an unbuffered water source. Leachate was analysed for a range of general chemistry parameters including pH, electrical conductivity (EC), alkalinity and major cations and anions, trace metals and metalloids, and total and weak-acid dissociable (WAD) cyanide [where WAD cyanide represents both free cyanide and various metal-cyanide complexes (e.g. Cu, Ni and Zn)].
- Peroxide extraction and analysis to provide a preliminary indication of the mass release of sulphate and metals and metalloids upon exposure to strongly oxidising conditions.

The supernatant associated with the tailings sample was subject to the same suite of analysis as the water extraction upon the tailings sample. The purpose was to provide a preliminary indication of the water quality of the process water fraction of the tailings slurry.

4. TEST WORK RESULTS

4.1. Acid-base characteristics

The acid forming characteristics of the tailings sample are given in Table 1 and Attachment 1. Based on the available results the tailings are considered to be non-acid forming (NAF), but due to the high sulphide content could potentially generate neutral saline drainage if exposed to atmospheric conditions (i.e. loadings of sulphate salinity and certain metals and metalloids). Specific characteristics of the tailings were as follows:

- ARD (acid-rock drainage) classification = NAF-HS (non-acid forming – high sulphide).
- NAPP (net acid producing potential) - Definitively negative, specifically:
    - -162 kg H_2SO_4/t - based on total sulphur and standard ANC (i.e. conservative).
    - -233 kg H_2SO_4/t based on sulphur speciation and effective ANC as indicated by ABCC curve.
- ANC/MPA ratio between 1.8 to 2.7 (based upon above).
- NAG pH of 8.0 and zero NAG values for both single and sequential NAG testing.
- A kinetic NAG temperature and pH profile consistent with the NAF-HS classification (i.e. pH remained well above pH 4 but with a distinct, albeit subdued, rise in temperature).

Table 1: Results of standard and specialised acid-base testing of tailing

Acid-Base Parameter		Result
Sulphur forms and suggested potential acidity	Total S (%)	6.76
	Maximum Potential Acidity (MPA) (kg H_2SO_4/t)	207
	Non-Acid Sulphate S (%)	0.03
	Acid Sulphate S (%)	0.00
	Chromium Reducible S (%)	4.60
	Other Sulphur Forms (%)	2.13
	Proportion of Acid Generating Total S (%)	68
	Potential acidity based on sulphur speciation (kg H_2SO_4/t)	141
Carbon forms and suggested acid neutralisation capacity	Standard ANC (modified Sobek) (kg H_2SO_4/t)	369
	Total C (%)	4.60
	Organic C (%)	0.0
	Inorganic C (%)	4.60
	Carbonate equivalent ANC (kg H_2SO_4/t)	375
	Effective ANC - based on ABCC to pH 4 (kg H_2SO_4/t)	374
Acid-base accounting	Standard NAPP - based upon MPA-Standard ANC (kg H_2SO_4/t)	-162
	NAPP - based on sulphur speciation and effective ANC (kg H_2SO_4/t)	-233
	ANC/MPA ratio	1.8
	Effective ANC/Actual Potential Acidity ratio	2.7
Net Acid Generation (NAG) pH values	Single NAG pH	8.0
	Single stage NAG acidity to pH 7.0	0
	Sequential NAG (4 stages) cumulative acidity to pH 7.0	0

4.2. Elemental composition

The elemental composition of the tailings sample is given in Table 2. The main findings are as follows:

- Significant enrichment [i.e. Geochemical Abundance Index (GAI) ≥3] relative to median soil abundance with bismuth, calcium, cobalt, copper, molybdenum, and sulphur.
- The enrichments are consistent with acid-base accounting results (high sulphur and carbonate mineral content) as well as a similar suite of enriched elements observed in ore materials in metallurgical test work (Newcrest 2021).

Table 2: Four acid digest multi-element analysis

Element	Detection Limit	Unit	Concentration (ppm or %)	Median Soil Abundance[1]	GAI Value[2]
Ag	0.01	mg/kg	0.23	0.05	2
Al	0.01	%	2.5	7.1	0
As	0.2	mg/kg	37	6	2
Ba	10	mg/kg	10	500	0
Be	0.05	mg/kg	0.27	0.3	0
Bi	0.01	mg/kg	271	0.2	**10**
Ca	0.01	%	16.0	1.5	**3**
Cd	0.02	mg/kg	0.23	0.35	0
Co	0.1	mg/kg	188	8	**4**
Cr	1	mg/kg	257	70	1
Cu	0.2	mg/kg	350	30	**3**
Fe	0.01	%	9.3	4.0	1
Hg	0.005	mg/kg	<0.005	0.06	0
K	0.01	%	0.19	1.4	0
La	0.5	mg/kg	29	40	0
Li	0.2	mg/kg	5.2	25	0
Mg	0.01	%	2.0	0.5	1
Mn	5	mg/kg	860	1000	0
Mo	0.05	mg/kg	26	1.2	**4**
Na	0.01	%	1.7	0.5	1
Ni	0.2	mg/kg	215	50	2
Pb	0.5	mg/kg		35	0
S	0.01	%	3.5	0.07	**5**
Se	1	mg/kg	2	0.4	2
Sn	0.2	mg/kg	2.7	4	0
Sr	0.2	mg/kg	163	250	0
U	0.1	mg/kg	1.4	2	0
V	1	mg/kg	60	90	0
W	0.1	mg/kg	80	1.5	**10**
Zn	2	mg/kg	152	90	0

Notes: [1]Average crustal abundance for soils value based upon Bowen H.J.M. (1979) Environmental Chemistry of the Elements. [2]Geochemical Abundance Index (GAI) value based upon GAI = $\log_2$[C/1.5 x average crustal abundance for soils value)]. As a general guide, a GAI of 3 or above is considered significant enrichment (highlighted in bold text and grey).

4.3. X-ray diffraction (XRD) mineralogical test work and asbestos screening

The mineral phases detected using XRD and results of the asbestos screening are given in Table 3. The results infer the following:

- Significant carbonate mineral content (predominantly calcite with a smaller proportion of ankerite).
- Significant iron sulphide mineral content (predominantly pyrrhotite with a smaller proportion of pyrite).
- Significant silicate mineral content (predominance of albite, quartz and actinolite and minor proportions of biotite, kaolinite, talc, chlinochlore and montmorillonite).

- Low clay mineral content as suggested by minor proportions of kaolinite, talc and montmorillonite.
- Absence of asbestos fibres.

These findings are consistent with acid-base characteristics (high sulphur and carbonate mineral content), and a similar suite of minerals was observed in XRD and QEMScan (Quantitative Electron Microprobe – Scan) analysis of ore materials that was undertaken as part of the metallurgical test work (Newcrest 2021) (refer to Figures 4 and 5). The absence of asbestos fibres confirms amphibole minerals such as actinolite are not in a hazardous respirable form.

Table 3: Summary of X-ray diffraction (XRD) and asbestos screening results

Mineral Phase	Weight %
Calcite	31.9
Albite low	24.3
Quartz	16
Actinolite	10.5
Pyrrhotite 4C	7.4
Ankerite	3.7
Biotite	2.5
Pyrite	1.4
Kaolinite	1.3
Talc	0.5
Clinochlore	0.3
Montmorillonite	0.2
Asbestos Screening	**Reportable Limit of 0.01% w/w**
Presence / absence of asbestos fibres	Absence

4.4. General chemistry and exchangeable cations

General chemistry and exchangeable cations for the tailings sample are provided in Table 4. The results infer the following:

- Paste pH and EC results infer the tailings contain a moderate amount of residual alkalinity and a moderate amount of residual salinity. These results are consistent with the de-ionised water extract results (refer to Section 5) that suggest short term contact of the tailings with an unbuffered water source is likely to generate a leachate that is slightly alkaline with concentrations of sulphate and chloride of 434 and 139 mg/L respectively (i.e. moderate salinity predominated by sulphate).
- Exchangeable cation results infer the tailings have a high amount of exchangeable calcium, a low amount of exchangeable magnesium and a negligible amount of exchangeable potassium, sodium and aluminium. Furthermore:
    - The negligible exchangeable sodium and associated ESP value together with the low clay mineral content (refer to Section 3) infer the tailings are non-sodic and non-dispersive.
    - The high exchangeable calcium is consistent with the high carbonate mineral content of the tailings.
    - The negligible exchangeable aluminium results suggest aluminium won't be made bioavailable to plants and or micro-biota by the tailings. These results are further supported by negligible de-ionised water and peroxide extractable alumimium concentrations (refer to Sections 5 and 6) which reflect the leachable

fraction of aluminium upon exposure of the tailings to an unbuffered water source and conditions conducive to sulphide oxidation respectively.

Table 4: Summary of general chemistry and exchangeable cations results

Parameter	Result
Paste pH (1:2)	8.1
Paste Electrical Conductivity (1:2)	1120 µS/cm
Aluminium (exchangeable) meq/100g	0.01 meq/100g
Calcium (exchangeable) meq/100g	24 meq/100g
Magnesium (exchangeable) meq/100g	1.2 meq/100g
Potassium (exchangeable) meq/100g	<0.1 meq/100g
Sodium (exchangeable)	<0.1 meq/100g
Exchangeable Sodium Percentage (ESP)	0.4%

4.5. De-ionised water extraction

The results of the de-ionised water extraction (1:2 solids to water) are given in Table 5. The purpose of the extraction test was to provide an indication of constituents within the tailings that might be released upon short term contact with an unbuffered water source (e.g. rainfall).

Reported parameter concentrations in Table 4 are described as either low, slightly elevated, or elevated. The terms 'slightly elevated' and 'elevated' are used within the context of a range of local and international environmental guideline values (ANZECC 2000; NHMRC 2011; IFC 2007; World Bank 1995, BC WQG. 2021; and DoRET 2008).

The term 'slightly elevated' infers concentration greater than lower-end environmental guideline values (e.g. protection of aquatic life) and the term 'elevated' infers concentration greater than upper end environmental guideline values (e.g. livestock drinking water guidelines). It should also be noted that both terms are used merely as order of magnitude descriptors and neither term implies potential environmental risk as leachate concentrations alone do not represent any indication of probable water quality issues[1]:

Results infer tailings may generate the following drainage water quality upon short term contact with an unbuffered water source (e.g. rainfall):

- Slightly alkaline.
- Slightly elevated total cyanide and negligible WAD cyanide (which includes free cyanide and Cu, Ni and Zn cyanide complexes).
- Slightly elevated concentrations of copper and zinc and low concentrations of all other metals and metalloids.
- Slightly elevated concentrations of sulphate.

---

[1] An assessment of potential environmental risk would need to be based upon probable water quality in the receiving environment as well as consideration of the nature of the environmental receptor. Water quality prediction requires an estimation of mass loadings from the leached material (which can be based on leachate concentrations relevant to field conditions) and quantification of water volumes (both in contact and not in contact with the leachable materials) that determine concentrations in the receiving environment.

Table 5: Water extraction (1:2) test results

Parameter		Detection Limit	Slightly Elevated	Screening Guideline	Elevated	Screening Guideline	Tailings
pH	-	0.1	<5.0	Slightly acidic	<4	Moderately acidic	8.1
EC	µS/cm	1	1493	Mayer et al 2005[2]	5970	ANZECC livestock[3]	1120
Total Cyanide	mg/l	0.1	1.0	IFC 2007	50	DoRET 2008	1.33
WAD Cyanide	mg/l	0.1	0.5	World Bank 1995	30	DoRET 2008[1]	<0.1
Ag	mg/l	0.001	0.1	ADWG	1	ADWG (x10)	<0.001
Al	mg/l	0.01	0.055	ANZECC 95% FW Protection	5	ANZECC livestock	<0.01
As	mg/l	0.001	0.013	ANZECC 95% FW Protection	0.50	ANZECC livestock	<0.001
B	mg/l	0.05	0.37	ANZECC 95% FW Protection	5.00	ANZECC livestock	<0.05
Ba	mg/l	0.001	2	ADWG	20	ADWG (x10)	0.209
Be	mg/l	0.001	0.06	ADWG	0.1	ANZECC long term irrigation	<0.001
Ca	mg/l	1	NGV	NGV	NGV	NGV	72
Cd	mg/l	0.0001	0.0002	ANZECC 95% FW Protection	0.02	ADWG (x10)	<0.0001
Cl	mg/l	1	NGV	NGV	NGV	NGV	149
Co	mg/l	0.001	0.11	BC Freshwater Protection	1	ANZECC livestock	0.023
Cr	mg/l	0.001	0.001	ANZECC 95% FW Protection	0.5	ANZECC long term irrigation	<0.001
Cu	mg/l	0.001	0.0014	ANZECC 95% FW Protection	20	ADWG (x10)	0.03
F	mg/l	0.1	1.5	ADWG	15	ADWG (x10)	0.1
Fe	mg/l	0.05	0.3	ADWG	3	ADWG (x10)	0.07
Hg	mg/l	0.0001	0.0006	ANZECC 95% FW Protection	0.01	ADWG (x10)	<0.0001
K	mg/l	1	NGV	NGV	NGV	NGV	9
Mg	mg/l	1	NGV	NGV	NGV	NGV	5
Mn	mg/l	0.001	1.9	ANZECC 95% FW Protection	5	ADWG (x10)	0.011
Mo	mg/l	0.001	0.05	ADWG	0.15	ANZECC livestock	0.008
Na	mg/l	1	NGV	NGV	NGV	NGV	110
Ni	mg/l	0.001	0.011	ANZECC 95% FW Protection	1	ANZECC livestock	<0.001
P	mg/l	1	NGV	NGV	NGV	NGV	<1
Pb	mg/l	0.001	0.0034	ANZECC 95% FW Protection	0.1	ADWG (x10)	<0.001
Sb	mg/l	0.001	0.003	ADWG	0.03	ADWG (x10)	<0.001
Se	mg/l	0.01	0.011	ANZECC 95% FW Protection	0.2	ADWG (x10)	<0.01
Si	mg/l	0.1	NGV	NGV	NGV	NGV	1.1
Sn	mg/l	0.001	NGV	NGV	NGV	NGV	<0.001
Sulphate	mg/l	1	429	BC Freshwater Protection	1000	ANZECC livestock	434
Sr	mg/l	0.001	NGV	NGV	NGV	NGV	0.181
Th	mg/l	0.001	NGV	NGV	NGV	NGV	<0.001
Tl	mg/l	0.001	NGV	NGV	NGV	NGV	<0.001
U	mg/l	0.001	0.0085	BC Freshwater Protection	0.2	ANZECC livestock	<0.001
Zn	mg/l	0.005	0.008	ANZECC 95% FW Protection	2	ANZECC long term irrigation	0.048

Notes: [1]Value based upon Cowal Gold Operations Cyanide Management Plan (Evolution Mining 2018) to which the Cyanide Management Handbook (DoRET 2008) refers. ADWG – Australian Drinking Water Guidelines (NHMRC 2011). Exceedance of slightly elevated criteria highlighted in light green. Exceedance of elevated criteria highlighted in orange.[2]Equivalent total dissolved solids of brackish water as per salinity status classifications by total salt concentration (Mayer et al. 2005). [3]Equivalent total dissolved solids where there are no adverse effects upon cattle, horse and pigs (ANZECC 2000).

4.6. Peroxide extraction

The intent of the peroxide extraction test was to provide an indication of the potential for release of sulphate, metals and metalloids in the event the tailings solids were exposed to conditions conducive to sulphide oxidation. The peroxide extraction was based on the single-stage NAG test, which involves reaction of a sample with hydrogen peroxide to rapidly oxidise any sulphides that are present. Normally only the pH and acidity of the NAG solution are measured following the oxidation stage, but with the peroxide extraction a sub-sample of the NAG solution was filtered then assayed to determine the extent of elemental release from the tailings sample.

When assessing the results, it should be noted that the actual concentrations of elements in a peroxide extract are directly related to the volume of peroxide used per unit weight of sample. The method involves a leach ratio of 100 mL/g which is high in comparison to leach rates typically encountered under field conditions, as well as rates typically used in column leach tests. For example, the leach rates for columns routinely run by EGi typically average around 75 mL/kg/week, which over a five-year period (for example) equates to a leach ratio of around 20 mL/g. As such, it can be expected that the peroxide extracts represent a diluted condition in comparison to either column leachate test work or that in the field. From past experience, EGi has determined that a nominal scaling factor of 5 to 10 should be applied to peroxide extraction tests to better represent elemental mass release in the field as a result of exposure of sulphidic materials to oxidising conditions.

The results of the peroxide extraction test with a scaling factor of 5 applied are given in Table 6. The terms low, slightly elevated, and elevated have been used in the same manner as described Section 4.5. The results suggest the following drainage water quality may be generated upon exposure of the tailings to oxidising conditions:

- Slightly alkaline.
- Elevated concentrations of sulphate.
- Slightly elevated concentrations of molybdenum, selenium, and zinc.
- Low concentrations of all other metals and metalloids.

Table 6: Peroxide extraction test results

Parameter		Detection Limit	Slightly Elevated	Screening Guideline	Elevated	Screening Guideline	Tailings
pH	-	0.1	<5.0	Slightly acidic	<4	Moderately acidic	8.0
Ag	mg/l	0.001	0.1	ADWG	1	ADWG (x10)	<0.001
Al	mg/l	0.01	0.055	ANZECC 95% FW Protection	5	ANZECC livestock	<0.01
As	mg/l	0.001	0.013	ANZECC 95% FW Protection	0.50	ANZECC livestock	<0.001
B	mg/l	0.05	0.37	ANZECC 95% FW Protection	5.00	ANZECC livestock	<0.05
Ba	mg/l	0.001	2	ADWG	20	ADWG (x10)	0.58
Be	mg/l	0.001	0.06	ADWG	0.1	ANZECC long term irrigation	<0.001
Ca	mg/l	1	NGV	NGV	NGV	NGV	1100
Cd	mg/l	0.0001	0.0002	ANZECC 95% FW Protection	0.02	ADWG (x10)	<0.0001
Cl	mg/l	1	NGV	NGV	NGV	NGV	15
Co	mg/l	0.001	0.11	BC Freshwater Protection	1	ANZECC livestock	0.015
Cr	mg/l	0.001	0.001	ANZECC 95% FW Protection	0.5	ANZECC long term irrigation	0.06
Cu	mg/l	0.001	0.0014	ANZECC 95% FW Protection	20	ADWG (x10)	<0.001
F	mg/l	0.1	1.5	ADWG	15	ADWG (x10)	1
Fe	mg/l	0.05	0.3	ADWG	3	ADWG (x10)	<0.05
Hg	mg/l	0.0001	0.0006	ANZECC 95% FW Protection	0.01	ADWG (x10)	<0.0001
K	mg/l	1	NGV	NGV	NGV	NGV	65
Mg	mg/l	1	NGV	NGV	NGV	NGV	30
Mn	mg/l	0.001	1.9	ANZECC 95% FW Protection	5	ADWG (x10)	0.085
Mo	mg/l	0.001	0.05	ADWG	0.15	ANZECC livestock	0.055
Na	mg/l	1	NGV	NGV	NGV	NGV	110
Ni	mg/l	0.001	0.011	ANZECC 95% FW Protection	1	ANZECC livestock	<0.001
P	mg/l	1	NGV	NGV	NGV	NGV	<1
Pb	mg/l	0.001	0.0034	ANZECC 95% FW Protection	0.1	ADWG (x10)	<0.001
Sb	mg/l	0.001	0.003	ADWG	0.03	ADWG (x10)	<0.001
Se	mg/l	0.01	0.011	ANZECC 95% FW Protection	0.2	ADWG (x10)	0.1
Si	mg/l	0.1	NGV	NGV	NGV	NGV	1.6
Sn	mg/l	0.001	NGV	NGV	NGV	NGV	<0.001
Sulphate	mg/l	1	429	BC Freshwater Protection	1000	ANZECC livestock	2050
Sr	mg/l	0.001	NGV	NGV	NGV	NGV	1.005
Th	mg/l	0.001	NGV	NGV	NGV	NGV	<0.001
Tl	mg/l	0.001	NGV	NGV	NGV	NGV	<0.001
U	mg/l	0.001	0.0085	BC Freshwater Protection	0.2	ANZECC livestock	<0.001
Zn	mg/l	0.005	0.008	ANZECC 95% FW Protection	2	ANZECC long term irrigation	0.21

Notes: ADWG – Australian Drinking Water Guidelines (NHMRC 2011). Exceedance of slightly elevated criteria highlighted in light green. Exceedance of elevated criteria highlighted in orange.

4.7. Supernatant Water Quality

Supernatant water quality is provided in Table 7. The purpose was to provide a preliminary indication of the water quality of the process water fraction of the tailings slurry.

The terms low, slightly elevated, and elevated have been used in the same manner as described Section 4.5. Results infer the process water quality fraction may have the following attributes:

- Slightly alkaline.
- Elevated concentrations of sulphate.
- Slightly elevated salinity as reflected by electrical conductivity (sulphate the predominant anion).
- Slightly elevated total cyanide and WAD cyanide (which includes free cyanide and Cu, Ni and Zn cyanide complexes).
- Slightly elevated concentrations of cobalt, copper, iron and molybdenum.
- Low concentrations of all other metals and metalloids.

Table 7: Supernatant water quality

Parameter		Detection Limit	Slightly Elevated	Screening Guideline	Elevated	Screening Guideline	Tailings
pH	-	0.1	<5.0	Slightly acidic	<4	Moderately acidic	8.2
EC	µS/cm	1	1493	Mayer et al 2005[2]	5970	ANZECC livestock[3]	5210
Total Cyanide	mg/l	0.1	1.0	IFC 2007	50	DoRET 2008	11.4
WAD Cyanide	mg/l	0.1	0.5	World Bank 1995	30	DoRET 2008[1].	3.48
Ag	mg/l	0.001	0.1	ADWG	1	ADWG (x10)	0.0013
Al	mg/l	0.01	0.055	ANZECC 95% FW Protection	5	ANZECC livestock	0.021
As	mg/l	0.001	0.013	ANZECC 95% FW Protection	0.50	ANZECC livestock	0.0018
B	mg/l	0.05	0.37	ANZECC 95% FW Protection	5.00	ANZECC livestock	0.083
Ba	mg/l	0.001	2	ADWG	20	ADWG (x10)	0.0195
Be	mg/l	0.0001	0.06	ADWG	0.1	ANZECC long term irrigation	<0.0001
Ca	mg/l	1	NGV	NGV	NGV	NGV	80
Cd	mg/l	0.00001	0.0002	ANZECC 95% FW Protection	0.02	ADWG (x10)	<0.00005
Cl	mg/l	1	NGV	NGV	NGV	NGV	680
Co	mg/l	0.001	0.11	BC Freshwater Protection	1	ANZECC livestock	0.409
Cr	mg/l	0.0001	0.001	ANZECC 95% FW Protection	0.5	ANZECC long term irrigation	<0.0002
Cu	mg/l	0.001	0.0014	ANZECC 95% FW Protection	20	ADWG (x10)	0.0187
F	mg/l	0.1	1.5	ADWG	15	ADWG (x10)	0.1
Fe	mg/l	0.05	0.3	ADWG	3	ADWG (x10)	1.94
Hg	mg/l	0.0001	0.0006	ANZECC 95% FW Protection	0.01	ADWG (x10)	<0.0001
K	mg/l	1	NGV	NGV	NGV	NGV	52
Mg	mg/l	1	NGV	NGV	NGV	NGV	22
Mn	mg/l	0.001	1.9	ANZECC 95% FW Protection	5	ADWG (x10)	0.0019
Mo	mg/l	0.001	0.05	ADWG	0.15	ANZECC livestock	0.0631
Na	mg/l	1	NGV	NGV	NGV	NGV	1270
Ni	mg/l	0.0001	0.011	ANZECC 95% FW Protection	1	ANZECC livestock	0.0008
P	mg/l	1	NGV	NGV	NGV	NGV	<1
Pb	mg/l	0.0001	0.0034	ANZECC 95% FW Protection	0.1	ADWG (x10)	0.0001
Sb	mg/l	0.0001	0.003	ADWG	0.03	ADWG (x10)	0.0008
Se	mg/l	0.001	0.011	ANZECC 95% FW Protection	0.2	ADWG (x10)	0.0059
Si	mg/l	0.1	NGV	NGV	NGV	NGV	2.1
Sn	mg/l	0.0001	NGV	NGV	NGV	NGV	0.0002
Sulphate	mg/l	1	429	BC Freshwater Protection	1000	ANZECC livestock	3480
Sr	mg/l	0.001	NGV	NGV	NGV	NGV	0.535
Th	mg/l	0.0001	NGV	NGV	NGV	NGV	<0.0001
Tl	mg/l	0.00001	NGV	NGV	NGV	NGV	<0.00002
U	mg/l	0.0001	0.0085	BC Freshwater Protection	0.2	ANZECC livestock	0.00075
Zn	mg/l	0.005	0.008	ANZECC 95% FW Protection	2	ANZECC long term irrigation	<0.001

Notes: [1]Value based upon Cowal Gold Operations Cyanide Management Plan (Evolution Mining 2018) to which the Cyanide Management Handbook (DoRET 2008) refers. ADWG – Australian Drinking Water Guidelines (NHMRC 2011). Exceedance of slightly elevated criteria highlighted in light green. Exceedance of elevated criteria highlighted in orange.[2]Equivalent total dissolved solids of brackish water as per salinity status classifications by total salt concentration (Mayer et al. 2005). [3]Equivalent total dissolved solids where there are no adverse effects upon cattle, horse and pigs (ANZECC 2000).

5. SUMMARY OF GEOCHEMICAL ATTRIBUTES OF TAILINGS

The results of laboratory test work suggest that tailings produced by the currently preferred process circuit for the Haverion Project are likely to have the following key attributes:

- Non-acid forming but classified as NAF-HS because of a high iron sulphide content, and an abundance of reactive net neutralising carbonate minerals.
- Significant elemental enrichment (relative to median soil abundances) with a few elements (e.g. bismuth, cobalt, copper, molybdenum, and tungsten).
- Short term contact of the tailings with an unbuffered water source may generate drainage with the following characteristics:
    - Slightly alkaline.
    - Slightly elevated concentrations of total cyanide, sulphate and copper and zinc.
    - A moderate amount of first flush salinity (predominated by sulphate) as reflected by a paste EC value of 1120 µS/cm which would diminish over time providing the tailings are not exposed to oxidising conditions.
    - Negligible concentrations WAD cyanide (that includes both free cyanide and copper, nickel and zinc cyanide complexes).
    - Negligible concentrations of most metals and metalloids.
- If there is extended exposure of the tailings to oxidising conditions then drainage should remain slightly alkaline but would likely have an elevated concentration of sulphate and possibly slightly elevated concentrations of molybdenum, selenium and zinc.
- Negligible bioavailable aluminium regardless of the conditions that the tailings are exposed (supported by the exchangeable cation test work as well as water and peroxide extract results).

Overall, the results suggest the tailings should not be a significant source of acidity, however significant loadings of sulphate salinity and slightly elevated loadings of certain metals (as above) may be generated under certain conditions (e.g. upon exposure to oxidising conditions).

Supernatant water quality results suggests the process water quality fraction entering the tailings storage facility may have the following attributes: alkaline, slightly elevated in salinity (sulphate the predominant anion), total and WAD cyanide, cobalt, copper, iron and molybdenum, but negligible concentrations of most metals and metalloids.

It should be noted that these inferences of probable geochemical behaviour are based on testing of a single metallurgical tailings sample. The following additional work is recommended to provide greater certainty and understanding of the geochemical behaviour of the tailings as the Project develops:

- Kinetic, column leach testing over an extended period (i.e. year) to quantify the reactivities of residual iron sulphides and the rates of release of sulphate salinity and elements that are potentially of environmental interest (i.e. metals and metalloids).
- Regular sampling and geochemical test work of tailings materials produced by the process circuit once in operation.
- Surface and groundwater monitoring in and immediately beyond the TSF (tailings storage facility) to ground truth the actual behaviour of the tailings.

REFERENCES

ANZECC, & ARMCANZ. 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

BC WQG. 2021. British Columbia Ministry of Environment and Climate Change Strategy (2021). British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture - Guideline Summary. Water Quality Guideline Series, WQG-20. Prov. B.C., Victoria B.C

DoRET 2008. Cyanide Management Handbook (2008). Australian Government Department of Resources Energy and Tourism.

Evolution Mining 2018. Cowal Gold Operations Cyanide Management Plan. July 2018.

IFC 2007. Environmental, Health and Safety Guidelines for Mining. International Finance Corporation. World Bank Group. December 10, 2007.

Landloch 2021. Haverion Project - Stage 2 Waste Characterisation Study. Newcrest Mining Limited. October 2021.

Mayer et al. 2005. Stream salinity status and trends in south-west Western Australia, Department of Environment, Salinity and land use impacts series, Report No. SLUI 38.

Newcrest. 2020. Mineral Resource Report Haverion, Patterson, Western Australia November 2020. Newcrest Mining Limited.

Newcrest. 2021. Haverion Pre-Feasibility Study Volume 6.4. Technical – Metallurgy & Processing. PRJ-720-20-01. June 2021.

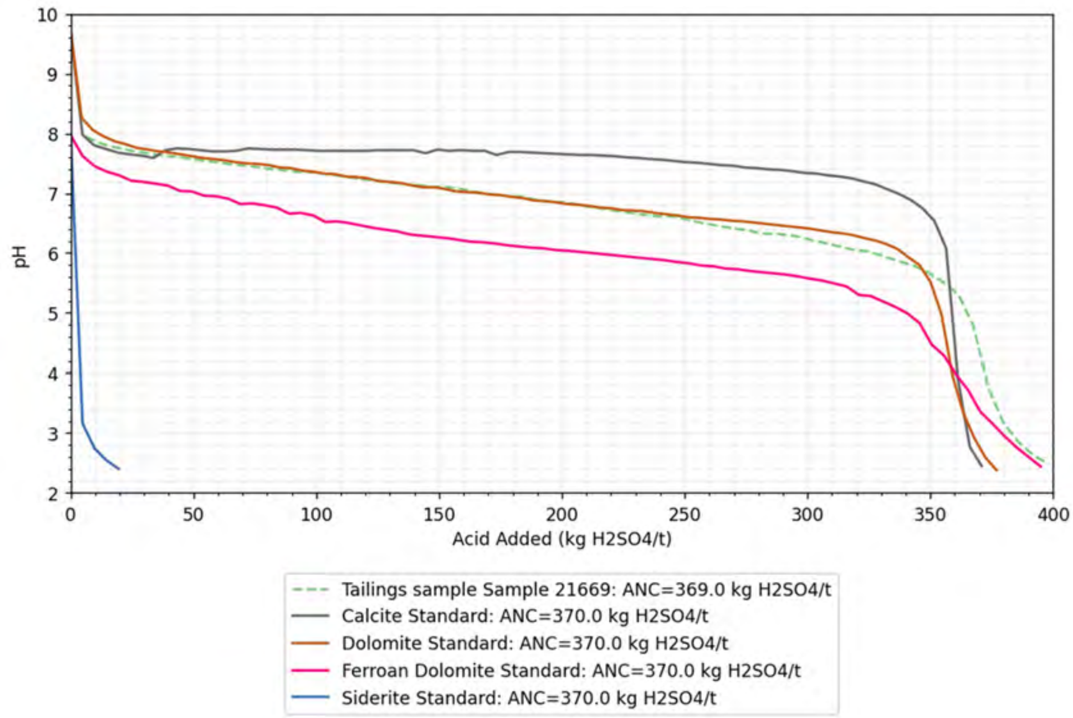
NHMRC. 2011. Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra

World Bank 1995. World Bank Environment, Health and Safety Guidelines. Mining and Milling - Underground. August 11, 1995.

Attachment 1 – ABCC Test Curve and Kinetic NAG

Acid-Base Characteristic Curve Profile

Sample ID	Sample Description	Measured ANC (Sobek)	Effective ANC (to pH 4)	Effective ANC as % of Measured ANC	Type of Carbonate Buffering
21669	Tailings	369	374	101	Dolomite



Kinetic NAG Profile