



## **APPENDIX S**

Geochemical Assessment  
(AECOM)



# Project Martha Geochemical Assessment

Geochemistry of Martha Phase 4 Pit, Martha Underground and Rex  
Orebody

## Project Martha Geochemical Assessment

Geochemistry of Martha Phase 4 Pit, Martha Underground and Rex Orebody

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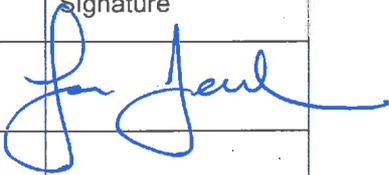
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## Glossary

ANC	Acid Neutralising Capacity
ARD	Acid Rock Drainage
CAF	Cement Aggregate Fill
HFO	Hydrous Ferric Oxide
MP4	Martha Phase 4 Pit
MPA	Maximum Potential Acidity
NAF	Non-Acid Forming
NAPP	Net Acid Producing Potential
NPR	Net Potential Ratio
PAF	Potentially Acid Forming
ROM	Run of Mine
RTSA	Rock and Tailings Storage Area
SUPA	Slevin Underground Project Area
TSF	Tailings Storage Facility
UCL	Upper Confidence Limit

## Executive Summary

The proposed Martha Phase 4 (MP4) and Martha Underground including the Rex vein (collectively known as Project Martha) will include the recovery and processing of approximately 4,000,000 tonnes of ore and approximately 8,000,000 tonnes of overburden.

The relevant ore bodies are considered of similar mineralogy to the existing Martha, Favona, Trio, Correnso and Slevin Underground Project Area (SUPA) mines, owing to the shared geological setting and mode of mineralisation. The existing Martha Mine overburden and ore have been conservatively adopted as representative of overburden likely to be encountered in Project Martha as the open pit dataset exhibits the highest average and maximum sulphur and maximum potential acidity (MPA) values as well as exhibiting a low acid neutralisation capacity (ANC).

The overall overburden management strategy is based on continued use of the existing storage facilities and the current overburden management practices which have shown to be effective at preventing acid rock drainage. The specific recommended mitigation outlined, depends on the overburden's source and ultimate end state and is broadly discussed in three broad categories:

- Temporary storage of overburden sourced from Project Martha in existing stockpiles prior to placement within permanent disposal structures;
- Disposal of overburden to underground backfill; and
- Disposal of overburden sourced from the slip material within Martha Pit.

Potentially acid forming (PAF) overburden placed into temporary stockpiles at the Rock and Tailings Storage Area (RTSA) should be amended with limestone to ensure the introduction of a 30 week lag period. This will ensure that PAF overburden material is neutralised until the material is placed permanently outside of the zone of oxidation. For overburden that will potentially be exposed for a period in excess of this, additional amendment may be required as it is currently.

The potential for ongoing oxidation of overburden placed as underground backfill is considered negligible for overburden material of similar acid producing properties to the current geochemical dataset. However, as there is potential for some leaching of sulphate and trace metals into the groundwater, this potential impact on groundwater quality within the vicinity of the workings has been assessed by undertaking geochemical equilibrium modelling. The results suggest that mixing of acidified porewater with groundwater results in a reasonably unchanged groundwater quality. This is primarily driven by concentrations of sulphate currently being at (or near) the limits of saturation and a high degree of attenuation on trace elements due to sorption to ion-hydroxide minerals. For overburden material exhibiting acid producing properties in excess of the current dataset, it is recommended that amendment of the material with limestone is required prior to placing the overburden underground as backfill.

Overburden contained within the slip material (within the Martha Pit) has been exposed for an extended period of time (over a three year period) and is likely to have resulted in the generation of acidity and production of acid rock drainage (ARD) during this time as its natural neutralising capacity would have been consumed. Amendment with limestone at a rate that will sufficiently neutralise the residual sulphate mass is recommended, before being placed in permanent disposal structures (eg. The existing Central and Eastern Stockpiles or the Tailings Storage Facilities (TSFs)).

The amendment rates outlined are considered conservative and within the current operating limits of the site. Monitoring of the overburden material will enable refinement to those calculated and outlined and will be part of ongoing operations.

The geochemistry of the ore for Project Martha is considered to be similar in characteristics to the Martha Mine. The current tailings storage facilities (TSF1A and TSF2) are dominated by ore from this area and therefore it is unlikely that the ore deposited from Project Martha will alter the current decant or leachate water quality significantly. Furthermore, consolidation of existing tails over time result in a lower seepage velocity and improved seepage quality through retardation of trace-element migration from adsorption onto secondary mineral precipitates.

## 1.0 Introduction

### 1.1 Introduction

Project Martha is a development proposed by Oceana Gold (New Zealand) Limited (OGNZL) that has the potential to extend the current life of mine from mid-2019 to 2030 by adding 0.7 million ounces of gold production to its Waihi operations. The project consists of two key components:

- The Martha Phase 4 pit; and
- The Martha Underground, including the Rex vein.

Anderson Lloyd has engaged AECOM New Zealand Limited (AECOM) to carry out a geochemical study of the ore, tailings and overburden expected to be recovered from the proposed mine areas, and to assess the potential influence these materials may have on the environment.

The purpose of this study is to determine the following in order to support the consenting process:

- Undertake geochemical assessment of overburden material and ore.
- Undertake analysis of treatment requirements to mitigate potential acid generating conditions.

The project utilises the existing mine infrastructure and additional consents for the conveyor and the Rock and Tailings Storage Area (RTSA) are not required.

### 1.2 Background

The Phase 4 pit and the underground mines can provide a total ore tonnage of 4.5 Mt which is more than the remaining consented tailings capacity. The Company will decide based on the prevailing economics at that time, whether to process the open pit feed in preference to the underground feed or alternatively to complete the underground mine in preference to completing the open pit.

#### 1.2.1 Martha Phase 4 Pit (MP4)

Up to nine hundred thousand tonnes of ore and 7 Mt of overburden could be mined from the MP4 component of the project. This includes material associated with two main slip events in the vicinity of the north wall of the existing Martha Pit which occurred during April 2015 and April 2016 (estimated to contain approximately 2 Mt of overburden).

Overburden material excavated will comprise similar geologies to that mined from the Martha Pit over the previous three decades. Overburden from MP4 will provide a source of backfill to the Martha Underground. The existing Central and Eastern stockpiles located in the RTSA and the existing Tailings Storage Facilities (TSF) will provide permanent disposal for the bulk of the material balance.

#### 1.2.2 Martha Underground

Up to approximately 3.7 Mt of ore and 1.6 Mt of overburden could be mined from the Martha Underground project.

Overburden material excavated from the Martha Underground is expected to comprise similar geologies to that mined from the Martha Pit over the previous three decades. Where possible, overburden will remain underground and be used to backfill excavated voids. During the initial stages of excavation, it is proposed overburden will be stored temporarily in the vicinity of the Favona portal or in the Polishing Pond Stockpile which are designed to collect and manage seepage and runoff before being returned later as underground backfill. Ore is proposed to be stored at the existing Run Of Mine (ROM) stockpile to await processing.

#### 1.2.3 Tailings and Overburden Storage Facilities

##### TSF1A

TSF1A is expected to have approximately 1.7 Mm<sup>3</sup> of spare capacity following the current life of mine when raised to the consented height of 177.25 mRL to incorporate additional material sourced from

the Martha Ore. The crest raise will utilise a combination of both potentially acid forming (PAF) and non-acid forming (NAF) overburden sourced from Project Martha.

## TSF2

TSF2 is expected to have approximately 1.6 Mm<sup>3</sup> of spare capacity when raised by 5 metres to 161 mRL to incorporate additional material sourced from the Martha Ore. The crest raise will utilise NAF overburden (0.19 Mm<sup>3</sup>) sourced primarily from existing stockpiles.

## Underground Disposal

Overburden will be utilised within the underground workings for stope backfill and it is estimated that 2.39 Mm<sup>3</sup> of overburden material will be deposited in this way.

## Overburden Storage Facility

Overburden not used for the TSF embankment crest raises or rehabilitation will be permanently disposed of in the existing Central and Eastern stockpiles which are designed to collect and manage seepage and runoff and are located within the RTSA.

## 1.3 Geochemistry of Mine Wastes

Acid Rock Drainage (ARD) is a broad term incorporating the natural process of sulphide oxidation (which occurs when rocks containing sulphide minerals such as pyrite are exposed to air and water) leading to the formation of acid (ie. low pH) drainage and metalliferous drainage (which may have a neutral drainage (ie. pH 6-7)). The potential for environmental effects from ARD due to a depressed pH and/or elevated trace metal concentrations can be avoided by overburden characterisation, overburden removal and handling practices, and adopted overburden storage and/or treatment strategies.

Pyrite (FeS<sub>2</sub>) is the most predominant “acid” forming sulphide mineral present in the Waihi mining situation. When pyrite is exposed to air and water, it decomposes into water-soluble components, including ferrous iron (Fe<sup>2+</sup>), sulphate (SO<sub>4</sub>) and acid (H<sup>+</sup>). The relatively reduced water-soluble components are further oxidised to form ferric iron (Fe<sup>3+</sup>) and water. The formation of ferric iron (Fe<sup>3+</sup>) in water takes the form of ferric hydroxide (Fe(OH)<sub>3</sub> - an orange precipitate) and additional acidity (H<sup>+</sup>). Once sulphides have been oxidised to sulphates, it is extremely difficult to avoid oxidation of aqueous ferrous species to ferric species and subsequent hydroxide precipitation. Acidic waters increase the mobility of trace elements that can be elevated as a result of the mineralisation.

The actual potential for, and rate of oxidation of pyrite (and other sulphide minerals), and the potential impact to the receiving environment (notwithstanding the importance of the adopted overburden management practices) is dependent on many factors, including the concentration of the sulphides in the overburden, morphology of the sulphides, oxygen concentration and exposure time, wetting and drying cycles, presence of bacteria, and acid consuming materials (neutralisation capacity).

The following analytical testing methods are commonly used to characterise overburden with respect to its acid generating potential:

- Multi-element analysis - whole-rock testing for a range of trace and major elements to allow characterisation of the rock for potential contaminants that may leach and adversely influence water quality.
- Static testing – whole-rock testing for parameters indicative of the potential for acid generation.
- Kinetic testing – accelerated weathering of selected crushed overburden samples to assess the rate of potential acid generation and trace element leaching.
- Column testing – on site weathering of selected crushed overburden samples exposed to atmospheric conditions and to assess management practices.

The geochemistry of the Martha Mine ore and overburden is well understood and characterised. This knowledge has come as a result of the past 30 years of mining, during which time existing ore and waste management practices on site have been developed. These practices have proven to be appropriate for controlling ARD and are the basis for the practices recommended and outlined in this report for managing overburden from Project Martha.

## 1.4 Report Structure

This report is structured in the following manner:

- Section 2: Geology and Mineralogy – describes the geological setting of the greater Waihi epithermal area and the corresponding mineralogy associated with hydrothermal alteration and ore deposits in the area.
- Section 3: Geochemical Assessment – describes the analysis and assessment of ore and overburden undertaken to characterise the geochemistry of these materials.
- Section 4: Overburden Management – describes the proposed management of overburden for the proposed developments, including stockpiling, backfilling of material and management of material contained within the Martha Pit slip.
- Section 5: Mine Tailings and Tailings Management – describes management of mine tailings and impacts to the decant and seepage waters associated with the placement of tailings from the proposed mining development into the existing tailings storage facilities.
- Section 6: Conclusion – summarises the findings of this assessment.

## 2.0 Geology and Mineralogy

### 2.1 Local Geology

The mineralised overburden types at Waihi, encountered in Martha have been divided into the following main groups:

- **Andesite Host Rock** primarily consists of fine to medium porphyritic andesite flows with varying degrees of clay alteration and silicification. Also included within this category are volcanic ash and tephra deposits stratified within the main body of the andesite host rock. This host rock is prevalent throughout the wider area. Characteristic alteration assemblages include quartz, albite, adularia, calcite, pyrite, illite, chlorite, interlayered illite-smectite and chlorite-smectite clays extending over tens of metres laterally from major veins. There is also an association of quartz + interlayered chlorite-smectite (corrensite) + chlorite, producing a distinctive pale green colouration. The system is locally oxidised to depths in excess of 350 m below ground level along fractures.
- **Quartz Andesite** is the dominant host lithology for the Martha Vein system and in the Union Hill epithermal vein system which includes the Trio, Amaranth and Union veins. This lithology is described as a quartz-feldspar phyric andesite lava.

Ignimbrite, volcanic ash and alluvial sediments overlie the andesite. These rocks were formed subsequent to the mineralisation phase, and analyses have confirmed that these rocks are NAF.

The various component mining areas of Project Martha form part of the greater Waihi epithermal vein system. The Waihi vein system, including Martha Hill, Union Hill, Favona, Correnso and Slevin Underground Project Area (SUPA), has been interpreted as located within a series of sub-regional scale NE-trending grabens. The quartz andesite unit attains thicknesses in excess of 400 m in the Union Hill – Waihi East area with only minor variation in texture or modal composition. The quartz andesite is overlain by a fine-grained tuff, which forms a distinctive marker horizon and is overlain in turn by a series of feldspar-phyric andesite flows and volcanoclastics.

The geology and mineralogy of the proposed project areas, as with the greater Waihi epithermal vein system, is expected to be generally consistent with that encountered in the existing Martha, Favona, Trio and Correnso mines.

## 3.0 Geochemical Assessment

### 3.1 Introduction

Data from geochemical assessments of ore, tailings and overburden produced from previously mined areas associated with the Waihi Vein system and the current site operations at Martha (Martha Pit, Favona underground, Trio underground and Correnso underground) are summarised in the various technical reports that were produced for these mining operations. The source of this information is summarised in Table 1.

**Table 1 Geochemistry Source Data Summary**

			Total Element	Acid Base Accounting	NAG	Kinetics	Column
Overburden	Martha		(4) GCNZ, 1986	(2) EGI, 1994	(2) EGI, 1994		
Overburden	Favona		(6) URS, 2001	(6) URS, 2001	(6) URS, 2001		
Overburden	Trio		(5) URS, 2010	(5) URS, 2010	(5) URS, 2010		
Overburden	Correnso Deep		(1) URS, 2012	(1) URS, 2012	(1) URS, 2012	(1) URS, 2012	
Tailings	Martha			(2) EGI, 1994	(2) EGI, 1994		(5) EGI, 2012b
Tailings	Favona		(6) URS, 2001	(6) URS, 2001	(6) URS, 2001		(3) EGI, 2012a
Tailings	Trio						
Tailings	Correnso Deeps						
			Existing				
			Unknown				
			No Data				

GCNZ, 1986 Groundwater Consultants (NZ) Ltd. And Stuart D Miller & Associates Pty Ltd. Geochemical Evaluation of leachates from Waste Rock and Tailings. August 1986.

EGI, 1994 Environmental Geochemistry International Pty Ltd. Waihi Gold Mining Company. Acid forming characteristics of waste rock and tailings and implications for waste disposal. Stage 1 Report. March 1994.

URS, 2001 URS New Zealand Ltd. Favona Reef, Waihi. Underground Mining Consent Geochemistry. 30 November 2001.

URS, 2010 URS New Zealand Ltd. Trio Development Project - Geochemistry of Waste Rock. 08 June 2010.

EGI, 2012a Environmental Geochemistry International Pty Ltd. Martha Mine. Column Leach Testing of Favona Tailings. Progress Report - Year 3. June 2012

EGI, 2012b Environmental Geochemistry International Pty Ltd. Martha Mine. Column Leach Testing of a composite tailings sample from storage 2: Progress Report Year 8. June 2012.

URS, 2012 URS New Zealand Ltd. Correnso Underground Mine and Golden Link Project, Area - Geochemistry of Ore, Tailings and Waste Rock. 5 June 2012

## 3.2 Characterisation Philosophy

The geology and mineralogy of Project Martha (MP4, Rex and the remainder of the Martha Underground) is expected to be generally consistent with that encountered in the existing mine. Therefore the geochemical characteristics and behaviour of the ore and overburden (once mined) is well understood.

Geochemical analytical results from the three main areas associated with Project Martha are currently scheduled for multi element analysis and static testing. The number of required analyses from both the Martha Underground and the MP4 cutback areas has been calculated based on the minimal sample size required to categorise the mean concentration (from the existing datasets). The calculation in the existing datasets was focused on the variable concentrations of sulphur, antimony, selenium and arsenic as they are the four analytes which currently exhibit a geochemical abundance index of greater than 3.

The assessment given here (in lieu of receiving the targeted analytical results) is undertaken on the premise that as the ore bodies of Project Martha are of similar mineralogy to the Martha, Favona, Correnso and Trio ore bodies, a conservative approach has been adopted in characterising overburden and ore from Project Martha to account for potential variation in overburden geochemical properties. The adopted approach is outlined below.

### 3.2.1 Project Martha

Historic static overburden data from previously mined areas is summarised and presented in Table 2. Data from the Martha Mine overburden (highlighted) has been conservatively adopted as representative of overburden likely to be encountered in Project Martha as the dataset exhibits the highest average and maximum sulphur and MPA values as well as exhibiting a low ANC.

Long term column leach tests of Martha overburden sourced from the Martha Pit walls have been considered to provide the best indication of acidification kinetics for overburden from the proposed project.

Kinetic testing comprised daily leaching at a rate equivalent to rainfall, with leachate samples collected at regular intervals to allow characterisation of changing leachate quality. This methodology is considered sufficiently robust to allow assessment of the kinetics of acidification for these samples and it is considered that these kinetic test results provide a suitable proxy for overburden produced for the current project for the following reasons:

- The mineralogy in Martha, Favona, Correnso and Trio overburden rock is similar, with the degree to which acidification occurs primarily a function of total sulphur content and any inherent neutralisation potential that may be present in the overburden. The total sulphur and neutralisation potential differs spatially across the ore body, however adopting the full variability within the Martha, Favona, Correnso and Trio dataset is considered a conservative approach in terms of representing the variability present within the Project Martha rock and ore.
- The testing of overburden rock samples for total sulphur allows the calculated dosage rates to be scaled in accordance with overburden rock sulphur content, on the assumption that the mineralogy is approximately equivalent and acid generation rates are a function of sulphur content.
- The column testing results were not scaled for particle size, providing a conservatively high rate of acidification as a function of the significantly greater surface area of the crushed sample relative to overburden rock.
- The use of sulphate generation rates is conservative in that not all sulphide minerals generate acidity on oxidation.

### 3.2.2 Slip Material

During April 2015 and April 2016, two main slip events occurred in the vicinity of the north wall of the Martha Pit. These events released and exposed a significant volume of rock into the open pit. The combined slip cut haul road access to the bottom of the pit and extended to the base of the pit (RL – 885 mRL).

Due to the exposure period (ca. 2-3 years+), this material is likely to have resulted in the generation of acidity and production of acid rock drainage (ARD). Some of this ARD production has reported to the underground workings and currently this ARD (generated from the slip material) is being managed via the underground dewatering and water treatment processes. As part of the MP4 and Martha Underground projects, this material will have to be removed, treated and disposed of accordingly.

Due to the nature and exposure time of this material (to oxidising processes), an assessment of the acid producing characteristics of this material and its likely in-pit geochemical status has been carried out with a view of developing a management strategy for this material which will be removed and disposed of as part of the proposed development of the Martha Pit. This assessment methodology is summarised in Figure 1 and detailed in Appendix A.

In summary, the methodology adopted is based on conservatively calculating the volume of oxidised products based on likely whole rock geochemistry, expected sulphate oxidation rates and exposure period. The assessment undertaken was considered conservative based on the following:

- Adopted Net Acid Producing Potential NAPP values representative of the material contained within the slip are based on the 95th percent Upper Confidence Limit UCL of analytical data sourced from the north wall of Martha Pit before the slip event;
- A likely scaling factor of 5 has been calculated in the assessment based on likely differences in porosity and particle size distribution between column tests and material contained within the slip, however amendment rates have been calculated based on a scaling factor of 1 (ie. column sulphate generation rates have been assumed to be reflective of field sulphate generation rates);
- A maximum oxidation depth of 5 m below the surface has been assumed over the total surface of the slip; and
- No lag has been taken into account.

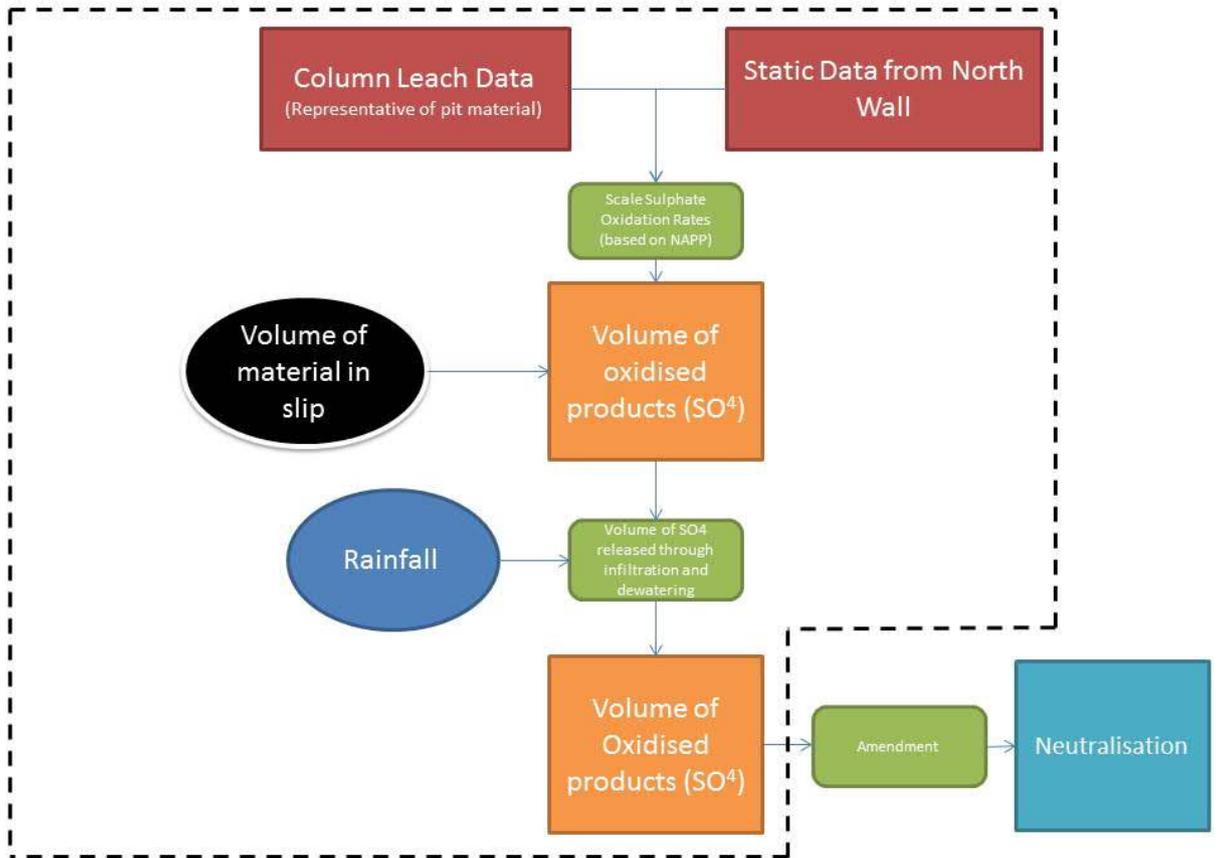


Figure 1 Conceptualised Assessment Methodology for Slip Material

**Table 2 Summary of Geochemical Results for Overburden**

Parameter	Trio Andesite Waste Rock		Favona Andesite Waste Rock		Martha Mine Waste Rock		Correnso Andesite Waste Rock		North Wall Data		Mean Concentration in Earths Crust <sup>1</sup>	Geochemical Abundance Index <sup>2</sup>					
	25 Samples		85 Samples		46 Samples		27 Samples		15 Samples			Trio	Favona	Martha	Correnso		
	Arithmetic Mean	Range	Arithmetic Mean	Range	Arithmetic Mean	Range	Arithmetic Mean	Range	Arithmetic Mean	Range							
<b>Acid Generating Potential</b>																	
Total Sulphur (%)	2.1	0.5 - 5.1	2.3	0.01 – 6.0	3.0	0.01 – 9.3	2.15	0.47 - 3.39	3.3	0.58 - 4.5	0.03	5	5	5	5		
Total Carbon (%)	0.3	0.02 - 0.7	-	-	-	-	0.70	0.21 - 1.53	-	-	-	-	-	-	-	-	-
MPA (%CaCO <sub>3</sub> )	6.5	1.5 – 15.9	7.0	0.03 – 19	9.5	0.03 – 29	6.7	1.5 - 10.6	10.0	1.8 - 14.1	-	-	-	-	-	-	-
ANC (%CaCO <sub>3</sub> )	7.8	<2 – 15.0	1.5	0.03 – 13	3.1	<2 – 16	7.3	2.0 - 15	4.7	0 - 32	-	-	-	-	-	-	-
ANC/MPA	1.6	0.13 - 8.12	1	0.004 – 32	0.9	0 – 18	1.36	0.2 - 4.6	0.45	0 - 2.7	-	-	-	-	-	-	-
AP (kg CaCO <sub>3</sub> /tonne)	65	15 - 159	70	0.3 - 190	112	0.3 - 291	67	14.7 - 106	102	18 - 140	-	-	-	-	-	-	-
NP (kg CaCO <sub>3</sub> /tonne)	53 (26) <sup>2</sup>	20 - 150 (1.7 - 58.7) <sup>2</sup>	15	0.3 - 130	31	<2 - 155	58	17.5 - 127	-	-	-	-	-	-	-	-	-
NNP (kg CaCO <sub>3</sub> /tonne)	-41	-152 - 43	-54	-181 - 114	-73	-252 – 63	-15	-87.8 - 72.5	-	-	-	-	-	-	-	-	-
NAG pH	-	-	-	-	3.4	2.1 - 7.5	8.7	2.3 - 11.2	4.1	2.3 - 8.5	-	-	-	-	-	-	-

Notes:  
 1. Bowen, HJM, 1979, Environmental Geochemistry of the Elements.  
 2. Values based on total carbon.

## 4.0 Overburden Management

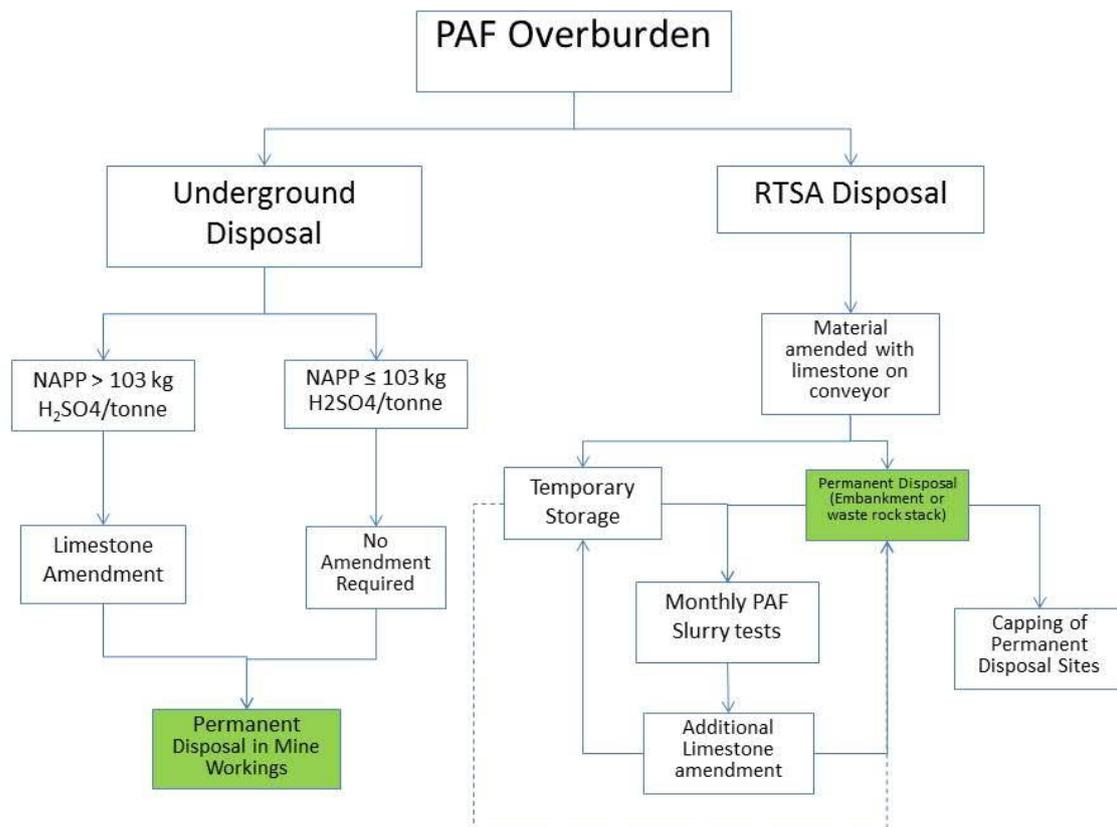
During development and mining, overburden is to be managed to minimise the requirement for surface stockpiling and the need for externally sourced backfill materials. Overburden used as backfill will be permanently stored within the underground workings, limiting the potential for oxidation of the overburden prior to flooding of the workings at some point in the future.

Overall the overburden management strategy for underground backfill is to monitor the material and to add limestone if necessary prior to placement. Based on current data, the requirement to add limestone to underground backfill is expected to be minimal.

Likewise, overburden in the Central and Eastern stockpiles, or used within the TSF embankments will be compacted upon deposition in order to limit oxygen ingress within these storage facilities. Overburden placed within the zone of oxidation for the final proposed landforms (typically within the final 2 metres of directly placed and/or stockpiled material) should comprise NAF material only. Within temporary stockpiles stored at the RTSA, appropriate mitigation measures in the form of limestone amendment will be required to limit sulphide oxidation rates and/or limit the effects of already oxidised material.

Overall the overburden management strategy at the RTSA is based on current overburden management practices adopted on site and is summarized in Figure 2. The overriding philosophy is:

- The overburden will likely be consistent with the materials produced by the current mining operations;
- Addition of limestone to PAF material is required to create a lag in acid generation until overburden is encapsulated within a permanent repository;
- The refinements to the management practices over the past decades are based on maintaining a pH of above 5.5 until final capping is complete to control the rate of sulphate release;
- Testing of the material prior to conveying allows the limestone addition via the lime silo on the conveyor belt to be adjusted as necessary;
- Regular (monthly) PAF slurry testing and regular surface limestone application after placement have proven to be effective at managing the material prior to placement of a permanent cover; and
- The current overburden management practices are effective at controlling the mine overburden materials and preventing acid rock drainage.



**Figure 2 Conceptualised Overburden Management**

The mitigation measures outlined here relate largely to limestone amendment which has been widely used on site in the past. The actual management of overburden (and amendment rates) will depend on its source and its ultimate end state. As such, overburden management is discussed in three broad categories:

- Disposal of freshly mined overburden to temporary stockpiles at the RTSA prior to permanent disposal;
- Disposal of freshly mined overburden to backfill (underground); and
- Disposal of overburden sourced from the slip material within Martha Pit.

#### 4.1 Overburden disposal to temporary stockpiles (RTSA Disposal)

While OGNZL prefers to place overburden directly into the permanent repositories, there are times of the year (generally during the winter) when that is not possible, and the material needs to be stored temporarily prior to permanent placement.

Sulphate generation rates for overburden from Project Martha, excluding the slip material have been conservatively estimated by utilising the adopted static geochemical results (refer Table 2) and kinetic testing of Martha overburden collected within the open Martha Pit. The 95th percent UCL NAPP has been adopted for conservatism and is the basis for calculating the predicted sulphate generation rates.

The rate of sulphate generation has been calculated from selected Martha Overburden Columns. Selected columns including oxidation state, NAPP and calculated sulphate generation rate of a mix of oxidised and unoxidised material are presented in Table 3. In calculating the sulphate generation rate,

the initial 20 weeks of data was excluded to exclude any lag from the sulphate generation rate calculation.

**Table 3 Selected Martha Overburden Columns**

Sample	Location within Martha Pit	Oxidation State	Sulphate Generation Rate (Calculated)	
			NAPP	mg SO <sub>4</sub> /kg/day
			kg H <sub>2</sub> SO <sub>4</sub> /t	
WR2	South Wall	Unoxidised	65	4
WR3	South Wall	Oxidised / Unoxidised	20	41
WR4	South Wall	Oxidised	17	16
WR6	South Wall	Unoxidised	65	5
WR7	South Wall	Oxidised / Unoxidised	20	51
WR8	South Wall	Oxidised	20	18
WR17	North of Martha Lode	Unoxidised	16	20
WR18	North of Martha Lode	Partially Oxidised	123	56
WR20	North of Martha Lode	Oxidised	47	20
WR29	Waste	Oxidised	23	1
Mean			42	23
95% UCL	Martha Static Data (Refer to Table 2)	103		
Scaled Sulphate Generation Rate				57

#### 4.1.1 Limestone dosing requirements

The limestone amendment required for overburden placed within the temporary stockpiles at the RTSA is proposed to be dependent upon the results of testing of the material prior to it leaving the open pit. Current operational practises see daily testing of the overburden for NAG pH and NAPP. Depending on the results, material is then classified as PAF or NAF, a limestone amendment rate is calculated and application rate is adjusted accordingly. These same practices are proposed for calculating limestone amendment rates for overburden sourced from Project Martha.

Overburden to be placed in temporary storage structures and left exposed for a period of no more than 30 weeks should be blended with crushed limestone at a rate designed to provide a lag period appropriate to mitigate generation of ARD for a 30 week period (Table 4). It is proposed that limestone amendment occurs on the conveyor while moving overburden out of the pit area as per current practice.

Monitoring of placed rock will ensure these dosing rates are appropriate and enable refinement as part of ongoing operations. The dosing rate given in Table 4 are considered conservative based on the assumptions outlined in Section 4.1.2.

**Table 4 Overburden Limestone Dosing Requirements – Short Term Exposure**

Item	Value
NAPP (95 <sup>th</sup> percent UCL)	103 kg H <sub>2</sub> SO <sub>4</sub> /tonne
Adopted Sulphate Generation Rate	0.06 kg SO <sub>4</sub> /tonne/day
Limestone Dosing Requirement (for 200 day lag)	12 kg CaCO <sub>3</sub> /tonne overburden
Limestone Amendment Rate	1.2 %

#### 4.1.2 Key Assumptions

The calculated limestone dosage rates given in Table 4 are considered to provide a high degree of conservatism in that it is assumed that all sulphur is present as acid generating pyrite (FeS<sub>2</sub>), with no allowance for other sulphide minerals that do not generate equivalent acidity, such as sphalerite. In addition, the use of a 95<sup>th</sup> UCL NAPP provides a degree of conservatism that on average, the given dosing rate requirement should provide sufficient excess limestone to account for any variation encountered.

Refinement of the predicted dosage rates for overburden will be undertaken as additional information from routine monitoring becomes available. Specific information requirements to allow such a review may include:

- Determination of a period of exposure
- Static data for overburden

The derivation of the rates for limestone dosing has proven to be effective in managing rock stockpiles at the site to date. The method is conservative and waste specific dose rates are effectively revised as part of the current operation on site.

The key assumptions used in assessing and calculating the amendment requirements are as follows:

- That collected static data and calculated NAPP (based on the 95th percent UCL of the Martha overburden geochemical dataset) is representative of the mass of the overburden material.
- Overburden used within the kinetic column tests is representative of overburden from the proposed mining areas (with calculated sulphate generation rates proportional to calculated NAPP values).
- No scaling factors have been applied to the sulphate generation rates calculated from the column leachate tests. This is considered a conservative assumption as it does not take into account likely differences in porosity and particle size distribution.
- No inherent lag within the overburden material has been taken into account and it is assumed that sulphides within overburden will oxidise immediately upon removal. This is considered a conservative approach as it is likely an inherent lag period will exist within the overburden.

## 4.2 Freshly Mined Overburden Disposal to Backfill Underground

Approximately half of the overburden from Project Martha will be utilised to backfill the underground workings and voids. The potential for ongoing oxidation of overburden once the materials are at their final destinations is considered to be negligible. Furthermore, approximately 30% of total backfill will compromise cement aggregate fill (CAF) which will introduce a source of alkalinity with the overburden mitigating adverse seepage.

To date additional mitigation (aside from limestone amendment during temporary storage prior to permanent disposal) has not been required by existing underground operations at the site and it is not considered necessary for Project Martha based on the assumed overburden acid base accounting

properties (95<sup>th</sup> % UCL NAPP of 103 kg H<sub>2</sub>SO<sub>4</sub>/tonne). However in the event that overburden to be disposed to backfill has acid producing properties higher than this assumed NAPP of 103 kg H<sub>2</sub>SO<sub>4</sub>/tonne, it is recommended that amendment of the material with limestone is considered prior to placing the overburden underground as backfill. Therefore two different amendment scenarios are recommended depending on the acid producing properties of the overburden. These properties will be redefined based on the geochemical analytical results from overburden associated with Project Martha.

In both scenarios, it is recommended the backfilling of overburden should be completed with minimum stockpiling following exposure, such that the overburden's inherent lag will ensure that material is placed before the onset of acidification.

#### 4.2.1 Limestone amendment prior to backfill

It is expected that the majority of the backfill will not require limestone addition (assuming Project Martha overburden is within the 95<sup>th</sup> percent UCL of the Martha overburden geochemical dataset). For overburden material with acid producing characteristics in excess of this, amendment with limestone prior to backfilling may be appropriate. The rate of amendment would depend on the monitoring results of the backfill material. To ensure appropriate mixing of limestone and overburden, one option is to place limestone on top of the benches prior to removal.

#### 4.2.2 No amendment requirement prior to backfill

For material geochemically similar to the current Martha dataset (ie. NAPP of 103 kg H<sub>2</sub>SO<sub>4</sub>/tonne or below) no limestone amendment prior to backfill is required. This is based on the potential for acidification of this material being low (due to the minimisation of long term temporary storage within the pit), and the existing groundwater geochemistry in the area of backfill which is already impacted by historic mine drainage. An assessment on the potential effects to groundwater based on the acidification of the placed overburden and a subsequent release of trace metals to groundwater has been undertaken.

#### 4.2.3 Assessment of Effects on Groundwater

Once the backfilled overburden material is saturated, there is the potential for some leaching of oxidation products and trace metals into the groundwater within the vicinity of the workings. As stated previously, due to a preference for overburden material to be placed directly underground and/or amendment of overburden prior to backfilling; the volume of oxidised products available for leaching is likely to be low. However for means of comparison, it is assumed here that backfilled overburden is in an advanced oxidised state and that the porewater chemistry within is elevated with respect to sulphate and trace elements. This assessment is therefore considered 'worst case'. The assessment does not assess potential effects of backfilling overburden that is considered outside the current Martha dataset (ie. NAPP > 103 kg H<sub>2</sub>SO<sub>4</sub>/tonne). In the event that the geochemical analytical results for the overburden are greater than the conservatively assumed 95% UCL NAPP, the need for amendment with limestone prior to backfilling should be evaluated (refer to Section 4.2.1)

Despite the conservatism of the assessment, it is not expected that backfilled overburden will impact the water quality of the groundwater due to the current over saturation of elements. For means of illustration geochemical modelling was undertaken utilising the geochemical modelling software PHREEQC version 3.3.12 and the Minteq.v4 database.

The modelling utilised the following steps and process:

1. Equilibrate leachate from the Martha column tests with a range of minerals that typically influence the solubility of the various contaminants of concern. The minerals considered include sulphides, hydroxides, carbonates and sulphates.
2. Determine the influence of changing groundwater conditions on the adsorption/desorption of trace elements to iron oxy-hydroxides or hydrous ferric oxides (HFO). The insoluble iron mass ( is assumed to be present as ferrihydrite), is provided for sorption reactions. In this manner a new equilibrium between adsorbed and soluble trace elements can be modelled.
3. The removal of trace elements via adsorption to ferrihydrite can change the ionic strength of the water and this can lower the solubility of the iron remaining in solution. To ensure solubility limits for iron minerals are not being exceeded following the adsorption reactions, and to

address the overall solubility of goethite, mineral equilibrium for goethite was carried out subsequent to surface adsorption.

Modelled groundwater quality is considered to reflect an average chemistry that would be expected to occur within the underground backfill upon flooding (assuming porewater is reflective of raw column leachate). Localised differences are expected, with these the result of the variability of overburden material, the degree of oxidation, the presence of neutralising minerals and the availability of ion-hydroxide minerals for adsorption of trace elements.

The range of predicted contaminant concentrations (mixed at ratios of 9:1, 8:2 and 7:3 for existing groundwater / porewater respectively) are generally consistent with the background groundwater quality and are characteristically high in sulphate, with elevated concentrations of some analytes such as iron and manganese due to the reducing conditions present (Table 5). Concentrations of trace elements arsenic, cadmium, chromium, copper, lead, nickel and zinc are predicted to be relatively low due to the high degree of attenuation provided by sorption to ion-hydroxide minerals.

Selenium which is present in groundwater as an anion, is predicted to be elevated in concentration relative to background. This is primarily a function of the poor adsorption of selenium under the conditions assessed. Iron and cadmium, which are also elevated under the anaerobic conditions modelled, are expected to precipitate under aerobic conditions. Therefore there is likely to be no discernible difference in concentration of these elements within the discharge of the Martha Pit Lake when formed (refer to AECOM Report Martha Pit Lake Management Strategy, 2018).

Table 5 Predicted Groundwater Concentration

Input	Existing Groundwater	Porewater of backfilled material	Predicted Groundwater Quality	Predicted Groundwater Quality	Predicted Groundwater Quality
Source	Shaft No.7 <sup>#</sup>	Raw Column Data <sup>#</sup>	90 % Groundwater	80% Groundwater	70% Groundwater
pH	6.5	2.5	7.1	7.1	7.1
SO <sub>4</sub>	1230	1153	1223	1214	1206
Ca	370	39	4	1	1
Mg	90.2	45	61	44	30
Na	46	5	42	38	34
K	9	6	9	9	8
Fe	0.4	196	20	39	59
As	0.01	0.006	<0.002	<0.002	<0.002
Cd	0.0002	0.02	0.002	0.003	0.005
Cr	0.0002	0.01	<0.0001	<0.0001	<0.0001
Cu	0.001	1.4	<0.0001	<0.0001	<0.0001
Pb	0.0002	0.01	<0.0001	<0.0005	<0.0005
Ni	0.03	1.4	<0.0001	<0.0001	<0.0001
Zn	0.1	1.7	0.0005	0.0005	0.0005
Mn	11	2	2.5	2.7	2.9
Hg	0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008
Sb	0.001	0.001	0.0001	0.0001	0.0002
Se	0.001	0.02	0.003	0.005	0.007
Co	0.01	2	< 0.0001	< 0.0001	< 0.0001

\*All concentrations in mg/l (pH = pH units)

<sup>#</sup>Based on mean recorded concentrations

Overall, the mixing of porewater within the backfilled overburden subject to acidification with the 'natural' groundwater results in a reasonably unchanged groundwater quality. It is therefore considered that the potential for the backfilled overburden to negatively impact groundwater quality within the vicinity of the workings is negligible based on the following:

- The assessment assumes that overburden will be subject to oxidation and is not placed in a way that limits oxidation properties.
- Overburden used within the kinetic column tests is representative of overburden from the proposed mining areas.
- No scaling factors have been applied to the sulphate generation rates calculated from the column leachate tests. This is considered a conservative assumption as it does not take into account likely differences in porosity and particle size distribution.
- No inherent lag within the overburden material has been taken into account and it is assumed that sulphides within overburden will oxidise immediately upon removal. This is considered a conservative approach as it is likely an inherent lag period will exist within the overburden.
- Concentrations of sulphate in groundwater are currently at (or near) saturation limits.

- A high degree of attenuation on trace elements is expected by sorption to ion-hydroxide minerals.

### 4.3 Overburden Disposal (Slip Material)

The assessment methodology adopted is outlined in Section 3.2.2 and provided in Appendix A. The slip material may be used as underground backfill, stored temporarily at the RTSA, or the material may be placed in permanent above ground storage structures. It is recommended that the slip material at the RTSA be blended with limestone at a rate sufficient to fully neutralise the residual oxidation products. Slip material to be disposed of underground will require testing as outlined in Section 4.2.3.

#### 4.3.1 Limestone Application Rate (for disposal outside of pit)

The recommended mass of alkalinity (in the form of limestone) to be blended with material potentially exposed to oxidation (estimated to be the top 5 metres of the slip material) has been calculated based on the mass of PAF rock present within the slip material, exposure period and sulphate oxidation rate. Actual measurements on slip material have not been undertaken, however theoretical acid base accounting estimates suggest that the maximum potential limestone amendment rates required to be blended with the oxidised slip material could be up to 21 kg/CaCO<sub>3</sub> per tonne of material or at a rate of 2.1 % per volume, per year of exposure based on achieving a net potential ratio (NPR) of 1.2. It should be noted that ongoing onsite waste management practices at the site have refined amendment rates from the theoretical levels to approximately 25% to 50% of these rates, and these lower rates have been shown to adequately control acid rock drainage.

The maximum potential application rates are summarised in Table 6. This rate of amendment only accounts for the exposure period up until the time of disposal. It does not account for additional oxidation and sulphate generation from the period of disposal until oxidation controls are fully in place (i.e. material is no longer subject to oxidation through either permanent placement underground as backfill or placed in an engineered fill and capped). Therefore the requirements for monitoring and additional limestone application should be followed as outlined in Section 4.1.1.

Monitoring of the slip material will ensure that dosing rates are appropriate and enable refinement as part of ongoing operations. The dosing rate given here is an indicative rate based on the assumptions outlined in Section 3.2.2 and are therefore expected to represent an upper bound for limestone amendment rates.

**Table 6 Recommended Rate of Amendment – Slip Material When Disposed of out of Pit**

Item	Value
Residual Sulphate Production Rate	24,000 t/SO <sub>4</sub> /year
NPR	1.2
Volume of Oxidised Material	1,170,000 tonne
Volume of amendment required (per tonne of material per year of exposure)	21 kg CaCO <sub>3</sub>
Maximum Potential Rate of amendment (per year of exposure)*	2.1%

\*Based on a linear relationship between sulphate production rate and time

## 5.0 Mine Tailings Management

Current tailings storage facilities (TSF1A and TSF2) contain a high proportion of tailings sourced from the Martha Pit area (approximately 70% and 100% for TSF1A and TSF2 respectively). The balance of TSF1A is made up from processed ore from the underground Favona, Trio, Correnso and SUPA mines. Following current mining activities, TSF1A is expected to have approximately 1.7 Mm<sup>3</sup> of spare capacity. TSF2 will allow an additional 1.6 Mm<sup>3</sup> of spare capacity. Collectively, this spare capacity will be utilised for processed ore from Project Martha and once in place, ore from the project will comprise approximately 5% of the material balance stored within each of these facilities.

Current TSF seepage water quality from both TSF1A and TSF2 is presented in Table 7.

**Table 7 Actual TSF Seepage Water Quality**

	TSF1A (Actual) <sup>2</sup>	TSF2 (Actual) <sup>1</sup>
pH	6.3	6.4
SO <sub>4</sub>	492	97
Al	0.005	0.01
Fe	21	5
Ca	51	21
Mg	27	9.1
Na	154	73
K	16	8
Sb	0.0002	0.0002
As	0.002	0.001
Ba	0.05	0.14
Cd	0.0001	0.00005
Co	0.17	0.11
Cr	0.001	0.001
Cu	0.002	0.002
Pb	0.0001	0.0001
Hg	0.0001	0.0001
Mn	8.7	3.8
Ni	0.014	0.005
Zn	0.03	0.004

All concentrations reported in mg/L (where actual data was below the method detection limit, the detected limit has been taken as the recorded concentration).

<sup>1</sup> Mean Underdrainage Data (U1-U4), 2014 to July 2017

<sup>2</sup> Mean Underdrainage Data (TU), 2014 to August 2017

When processed ore is deposited at the top of the tailings facilities, the tailings porewater will be exposed to atmospheric conditions and saturated with respect to a number of trace elements and via the formation of Ferrihydrite, Gibbsite and hydrous ferrous oxygen compounds resulting in trace elements Al, Cd, Ca, Cr, As, Pb, Hg, Co and Zn largely precipitating out of solution. In addition, as

porewater seeps through the consolidated tailings, attenuation of trace elements through adsorption onto secondary mineral precipitates will occur. The resultant tailings leachate geochemistry as shown in Table 7 is largely depressed with respect to trace elements of concern

The geochemistry of the ore for Project Martha is considered to be of similar characteristics to Martha Mine. As both current tailings storage facilities are dominated by ore from this area (approximately 70 to 100% for TSF1A and TSF2 respectively) it is unlikely that the geochemistry of the ore deposited from Martha will differ significantly to what is already present and the resultant leachate should not differ significantly from the data presented Table 7. In addition to the material balance, the likely leachate is unlikely to change significantly from current concentrations due to the following:

- The consolidation of existing tailings will reduce hydraulic conductivities and thereby result in a lower seepage velocity; and
- This lower seepage velocity coupled with a longer flow path will attenuate changes in seepage quality through retardation of trace element migration from adsorption onto secondary mineral precipitates.

Any variance in geochemistry (between ore from Project Martha and ore from previously mined areas) is likely to be more pronounced in the decant water quality. However, as the geochemistry of both is considered to be similar, and current decant water quality is well within the operational constraints of the water treatment plant, no significant changes to the decant water (that would affect consent compliance) are considered likely. It is recommended that once the ore geochemistry data is available, the similarity with the current geochemistry dataset is confirmed and a reassessment of any key variances that could result in the ultimate tailings pore and seepage water quality is made.

## 6.0 Conclusions

Overburden and ore material excavated from MP4 and the Martha Underground mines will comprise similar geology to that mined from the Martha Pit over the previous three decades and as such no significant difference to the overburden management or philosophy from past practices is expected.

Overburden backfilled into the underground workings is unlikely to impact groundwater based on a limited potential for oxidation once the materials are at their final destinations assuming that the overburden material has similar acid producing characteristics to the current known dataset. The current oversaturation of groundwater in respect to sulphate and a likely high degree of attenuation on trace elements via the sorption to ion-hydroxide minerals will ensure that any impacts of groundwater quality within the vicinity of the workings as a result of oxidised overburden should be minimal. For overburden material exhibiting acid producing properties in excess of the current dataset, it is recommended that amendment of the material with limestone is required prior to placing the overburden underground as backfill.

For the slip material contained within the Martha Pit, disposal directly underground or to the RTSA (either temporary stockpiles or permanent placement) is possible. For slip material at the RTSA, amendment with limestone at a rate that will sufficiently neutralise the residual sulphate mass is recommended. Additional amendment measures may be required prior to final disposal if this material is placed in temporary storage.

The dosing rates outlined for the temporary storage of overburden material and for the slip material are considered conservative and within the current operating limits of the site. Monitoring of the overburden material will ensure that dosing rates given are appropriate and will enable refinement to those calculated here as part of ongoing operations.

Current tailings storage facilities (TSF1A and TSF2) are dominated by ore mined from the Martha pit to date and which is expected to be reflective of the characteristics of the ore from Project Martha. Coupled with reduced porewater release from the consolidated tailings, a resultant lower seepage velocity, and improved seepage water quality, as well as current decant water quality being within the operating constraints of the water treatment plant, no additional management measures are recommended for the disposal of ore into these existing facilities.

## 7.0 Standard Limitations

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# Appendix A

Martha Pit Slip Material -  
Geochemical  
Assessment

## A.1 Geochemical Properties of Slip Material

Static data from a 2011 survey of the north wall area has been assumed to be reflective of material contained within the slip material (Table 8). The 95<sup>th</sup> percent UCL NAPP has been calculated as 86 kg/H<sub>2</sub>SO<sub>4</sub>/t (84 kg CaCO<sub>3</sub>/t) and has been conservatively adopted as representative of overburden contained within the slip material.

Table 8 Static Data Summary

Sample Collection Date	Site ID	NAPP kg H <sub>2</sub> SO <sub>4</sub> /t
28-Jun-11	NU7 E	-45
28-Jun-11	NU7 D	52
28-Jun-11	NU7 C	91
28-Jun-11	NU7 B	82
28-Jun-11	NU7 A	94
28-Jun-11	NU6 E	124
28-Jun-11	NU6 D	128
28-Jun-11	NU6 C	109
28-Jun-11	NU6 B	93
28-Jun-11	NU6 A	75
27-Jun-11	NU5 E	32
27-Jun-11	NU5 D	23
27-Jun-11	NU5 C	-198
27-Jun-11	NU5 B	26
27-Jun-11	NU5 A	75
<b>Mean</b>		<b>53</b>
<b>95<sup>th</sup> percent UCL</b>		<b>86</b>

## A.2 Sulphate Generation Rate of Slip Material

Selected kinetic data has been summarised from column testing undertaken on Martha Overburden. The initial 20 weeks of data has been excluded in order to exclude initial lag periods which were present in the column tests, which is deemed applicable due to the exposure of the former pit wall to a period of oxidation prior to the slip event. However any lag associated with rock previously not exposed to the oxidation front (ie. unoxidised and unweathered rock within the pit wall exposed by the slip event) has not been taken into account; the approach is therefore considered conservative.

### A.2.1 Scaling Factors

In order to account for the scaling effect between the column tests and the slip material (and their respective expected sulphate oxidation rates), a scaling factor is considered appropriate. The actual scaling factor will depend upon the estimated differences in waste-rock particle size (between lab samples and slip material) and hence total surface area and overall porosity of the material noting the following:-

- The material used in the column tests had a maximum particle size in the order of 4 mm diameter, whereas the slip material likely consists of material of greater than 1m in diameter.

- The slip material also likely contains a large volume of fines, the overall difference between the overburden in the column data and the overburden contained within the slip material cannot therefore be defined.
- Based on the slip morphology and pre-slip pit wall contours, a bulking factor of 1.13 is estimated which equates to a slip material porosity of 18% (assuming an initial in-situ porosity of 5%). The porosity of the column tests are likely to have been in the order of 30%.

Due to the uncertainties in applicable scaling factor, a scaling factor of between 1 (no scaling factor) and 5 (which conservatively takes into account porosity and particle size distribution) is considered appropriate, however the adopted sulphate generation rate and resultant amendment rate is based on a scaling factor of 1 (ie. no scaling applied) with the potential to refine the estimate when further data becomes available.

The scaling factors applied suggest a calculated sulphate generation rate of between 10 to 50 mg/SO<sub>4</sub> per kilogram of oxidising slip material per day of exposure (based 95% UCL NAPP value).

The adopted values are outlined in Table 9.

**Table 9 Overburden Sulphate Generation Rate – Slip Material**

Item	Value
NAPP (95 <sup>th</sup> percent UCL)	84 kg CaCO <sub>3</sub> /tonne
Column Sulphate Generation Rate	0.05 kg SO <sub>4</sub> /tonne/day
Calculated Scaling Factor	1 – 5
Calculated Sulphate Generation Rate	0.01 – 0.05 kg SO <sub>4</sub> /tonne/day
Adopted Scaling Factor	1
Adopted Sulphate Generation Rate	0.05 g SO <sub>4</sub> /tonne/day

### A.3 Volume of Oxidising Material in Slip

Generally PAF overburden is placed in engineered embankment structures with lifts of well compacted overburden. This reduces the permeability of the overburden, which limits the rate of oxygen ingress into the overburden which limits the rate of sulphate oxidation. Sulphate generation rates of between 3 and 4 kg(SO<sub>4</sub>)/ha/day have been predicted from the analysis of oxygen data in compacted and covered overburden stacks at site (SRK, 2011).

As the material in the slip is considered 'loose' and has not been placed in a controlled manner, it is assumed that initially permeability is high and the depth of the oxidation will be greater. However as the base portion of the overburden is likely to become saturated and oxidation advances deeper into the waste rock, the concentration gradient (of oxygen) diminishes which should limit advective flow (and transport of additional oxygen) into deeper portions of the overburden, limiting oxidation of the lower portions of the slip material. Previous investigations by SRK (2011) suggest that in uncompacted and/or covered overburden stacks, the oxidation ingress is limited to the top 5 m below the surface. This depth has been adopted here in order to estimate the volume of material likely to be influenced by oxidation.

The volume of material within the slip available for oxidation has been based on the total surface area of the slip. It is assumed that at depths of below 5 m, oxygen infiltration is minimal and that the slip material is at least 5 metres deep over its total surface area. The total material available of oxidation has therefore been calculated as 1,170,000 tonnes out of a total assumed mass of 2,000,000 tonnes (Table 10).

**Table 10 Slip Overburden Volume Calculation**

Item	Value
Volume of PAF Overburden in Slip	920,000 m <sup>3</sup>
Tonnes of PAF Material	2,000,000 t
Area of Exposed Overburden	107,358 m <sup>2</sup>
Depth of Oxidation	5 m
Volume of Material Available for Oxidation	536,790 m <sup>3</sup>
Tonnes of Material Available for Oxidation	1,170,000 t

#### A.4 Total Sulphate Oxidation in Slip Material

The annual mass load of sulphate generated through the oxidation process has been adopted based on the tonnes of material available for oxidation 1,170,000 tonnes (0) and the calculated sulphate production rate per kg of material (0.05 kg SO<sub>4</sub>/tonne/day) (0). The total annual sulphate production load is therefore estimated to be 24,450 tonnes per annum (Table 11). A lag period has not been taken into account, although as material within the former pit wall was previously exposed, it is assumed that a significant quantity of this material was oxidised / partially oxidised before the slip events occurred.

**Table 11 Sulphate Generation Rate per Annum - Slip Material**

Item	Value
Tonnes of Material Available for Oxidation	1,170,000 t
Adopted Sulphate Generation Rate	0.05 kg SO <sub>4</sub> /tonne/day
Sulphate Production Rate	24,450 tonne SO <sub>4</sub> /year

When compared to estimates given in ANSTO (1994) and SRK (2011), estimated sulphate generation rates for uncompacted scenarios vary from 1,400 kg(SO<sub>4</sub>)/ha/day (ANSTO, 1994) to 1,991 kg(SO<sub>4</sub>)/ha/day (SRK, 2011) which calculate to between 5500 to 8000 tonne of SO<sub>4</sub> per annum (Table 12) based on the calculated area of the slip material. These numbers are based on processed overburden – which will likely have a larger surface area than overburden within the slip material. Furthermore the permeable toe in the slip material has water and sediment covering it further reducing sulphate oxidation potential. The estimate calculated here is therefore considered conservative.

**Table 12 Sulphate Production Rate Comparison**

Source	kg/SO <sub>4</sub> /Ha per day	Tonne/SO <sub>4</sub> /per annum
Calculated Sulphate Production Rate	5,200	24,450 t/SO <sub>4</sub> /year
ANTSO 1994	1,400	5,500 t/SO <sub>4</sub> /year
SRK 2011	1,991	8,000 t/SO <sub>4</sub> /year

## A.5 Residual Sulphate mass

Combined with frequent wetting and drying cycles, (depending on whether water infiltrates or flows over), oxidised material will frequently be flushed out of the overburden (or not). Over time, consolidation of the slip material is likely which would reduce the permeability of the slip material, however this has not been taken into account during this assessment and it is conservatively assumed the rate of sulphate oxidation has remained constant throughout the exposure period.

In order to calculate the residual sulphate mass – after removal through infiltration and seepage, the residual mass of sulphate within the slip material has been calculated by subtracting the potential mass of sulphate leaching from the total sulphate oxidation mass calculated.

Based on an assumed average yearly rainfall for the site (2084 mm/year) and assuming all of this rainfall with the addition of runoff from the area of pit immediately above the slip material infiltrates the slip material, the calculated horizontal surface area of the combined slip material and pit wall immediately above the slip material is 92,592 m<sup>2</sup>. This equates to a calculated volume of infiltrating rainfall of 192,922 m<sup>3</sup> per annum.

Based on the theoretical maximum concentration of sulphate in water of 2300 mg/L – controlled by the solubility of gypsum, it is estimated that approximately 450 tonne of sulphate is released to the pit through infiltrating rainfall per annum.

The residual sulphate mass is therefore 24,450 t/SO<sub>4</sub>/year less 450 t/SO<sub>4</sub>/year representing sulphate mass removed through the pit dewatering processes per annum resulting in a residual sulphate mass of 24,000 t/SO<sub>4</sub>/year (Table 13).

**Table 13 Residual Sulphate Production – Slip Material**

Item	Value
Annual Average Rainfall	2084 mm/year
Horizontal Surface Area of Slip	92,593 m <sup>2</sup>
Volume of Infiltrating Rainfall	192,922 m <sup>3</sup>
Theoretical Maximum Concentration of SO <sub>4</sub> in Water	2,300 mg/L
SO <sub>4</sub> released per annum	450 t/SO <sub>4</sub> /year
Calculated Sulphate Production Rate	24,450 t/SO <sub>4</sub> /year
Residual Sulphate Production Rate	24,000 t/SO <sub>4</sub> /year

## A.6 Key Assumptions

The key assumptions used in assessing and calculating the residual sulphate mass are as follows:

- That collected static data and calculated NAPP (based on the 95th percent UCL) is representative of the mass of the slip material.
- Overburden used within the kinetic column tests is representative of overburden contained within the slip material (with calculated sulphate generation rates proportional to calculated NAPP values).
- A scaling factor of between 1 and 5 applied to the sulphate generation rates calculated from the column leachate is applicable and takes into account differences in porosity and particle size distribution. However the scaling factor of 1 (ie. no scaling factor) has been adopted for this assessment.
- No lag has been taken into account.
- Rainfall infiltrates the mass of material

- The concentration of sulphate in water draining from the slip mass is 2300 mg/L
- No groundwater infiltrates the slip mass material
- Rock within the slip mass has an oxidation profile down to a depth of 5 m
- The depth of the slip mass is at least 5 m over its surface area

## A.7 References

ANTSO, 1994. Oxidation and Sulphate Generation Rates in the Waste Rock Dump at the Martha Hill Mine Site. ANTSO/c400 Australian Nuclear Science and Technology Organisation.

SRK, 2011. Waste Rock Oxidation in Storage 2. NEM009. SRK Consulting (Australia) Pty Ltd.