Appendix O

Residue Characterisation

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O.1 Background

O.1.1 Residue Treatment

All material to be placed within the RSF will undergo initial treatment in the final neutralisation circuit. In this process, the pH is raised to 7.0[1], allowing most of the heavy metals to be precipitated. Limestone will be added as a reactant to the first stage, raising the pH of the slurry to approximately 5.5[1]. Lime slurry will be added as reactant to the second stage, raising the pH of the final slurry to 7.0. The neutralised slurry containing residues from ore and other process inputs in addition to gypsum generated during neutralisation, will be pumped to the RSF thickeners located at the RSF.

O.2 Testing

A bulk residue sample was geochemically tested in April 2006 by Australian Laboratory Services Pty Ltd and SGS Lakefield Oretest. The residue sample analysed by these laboratories had been neutralised to a pH of 7.0, in order to generally replicate the chemistry of residue material potentially entering the RSF. However, discussions with GPN personnel indicate that some aspects of residue treatment are still to be finalised and a more representative sample of residue material will be available for validation test work from combined Marlborough and overseas ore in 2007.

O.2.1 Acid Generation and Prediction

Acid generation from (process residue) materials is caused by the exposure of sulfide minerals, most commonly pyrite (FeS2), to atmospheric oxygen and water. Sulfur assay results are used to calculate the maximum potential acid (MPA) that could be generated by a waste, either directly from pyritic sulfur content, or by assuming that all sulfur not present as sulfate occurs as pyrite. Pyrite oxidises to generate acid according to the following overall reaction:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \ \text{--->}\ Fe(OH)_3 + 2\ H_2SO_4$$

The chemical components of the acid generation process consist of the above sulfide oxidation reaction and acid neutralisation, which is mainly provided by inherent carbonates and to a lesser extent silicate materials. The amount and rate of acid generation is determined by the interaction and overall balance of the acid generation and neutralisation components.

The net acid producing potential (NAPP) is used as an indicator of materials that may be of concern with respect to acid generation and represents the balance between the MPA and the acid neutralising capacity (ANC) of the material, which is determined experimentally. By convention, the NAPP result is expressed in units of kg H2SO4/t sample. If the ANC exceeds the MPA, then the NAPP of the material is negative. Conversely, if the MPA exceeds the ANC, the NAPP of the material is positive.

The net acid generation (NAG) test involves direct hydrogen peroxide oxidation of a sample of a material to oxidise reactive sulfide, then measurement of pH and titration of any net acidity produced by the acid generation and neutralisation reactions occurring in the sample. A final NAGpH < 4 can confirm that the sample is PAF, and a final NAGpH ≥ 4 can confirm that the sample is Non-Acid Forming (NAF).

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[1] Lisa Park (GPN) personal communication, July 2006.

O.2.2 Assessment of Element Enrichment and Solubility

Multi-element scans are carried out to identify any elements (particularly metals) that are present in a material at concentrations that may be of environmental concern with respect to surface water quality and revegetation. The assay result for each element is compared to relevant environmental investigation levels to determine any concerns related to TSF operation and final rehabilitation. Elements identified as enriched may not necessarily be a concern for revegetation, drainage water quality, or public health but their significance should be evaluated. Similarly, because an element is not enriched does not mean it will never be a concern, because under some conditions (e.g. low pH) the geochemical behaviour of common environmentally important elements such as Al, Cu, Cd, Fe and Zn increases significantly. Water extracts are used to determine the immediate solubility and potential mobility of elements under existing pH conditions. Soluble element concentrations are generally compared with those recommended in relevant surface water and groundwater guidelines in order to determine their environmental significance.

There are no specific guidelines and/or regulatory criteria specifically related to total metal concentrations in process residue materials, apart from those associated with Queensland EPA acceptance criteria for Hazardous Dams (QLD-EPA, 2006). In the absence of these and to provide relevant context, URS has compared the total concentration of each element reported in residue solids to QLD-EPA (1998) environmental investigation levels (for soils) and NEPC (1999a) health-based investigation levels (HIL's) for parks and recreation (open spaces). The QLD-EPA (1998) guidelines are primarily aimed at soil investigations and provide a suitable guideline for an industrial facility, such as an RSF. The NEPC (1999a) guidelines for 'open spaces' are less stringent than the QLD-EPA guidelines, however their applicability stems from the potential final land use of the RSF following closure (e.g. grass cover and low intensity livestock grazing). Geochemical results are also compared to Queensland EPA acceptance criteria for Hazardous Dams, to provide additional context.

The total metals concentration for individual elements in residue materials can be relevant for revegetation activities and/or where the potential exists for human contact (e.g. if the material was to be used off-site). Of more relevance is the potential for residue material to leach soluble metals at concentrations that may impact the environment or human health. The water extract tests go some way to addressing this issue.

Water extracts are used to determine the immediate solubility and potential mobility of elements under existing pH conditions. Soluble element concentrations are generally compared with those recommended in relevant surface water and groundwater guideline criteria in order to determine their environmental significance. Again, there are no specific guidelines and regulatory criteria specifically related to seepage from residue materials, apart from those associated with Queensland EPA acceptance criteria for Hazardous Dams (QLD-EPA, 2006). Therefore, to provide relevant context, URS has compared the soluble concentration of each element extracted from overburden and potential reject materials to NEPC (1999b) investigation levels for groundwater and ANZECC (2000) livestock drinking water guidelines. These guidelines allow for higher concentrations of individual parameters (appropriate for an industrial facility), are less prescriptive than guidelines designed for water to be used for human consumption or being directly discharged into an aquatic environment (e.g. stream, river, lake, etc.), and allow the end-use and receiving environment of any seepage to be included in the comparison.

O.2.3 Sodicity and Dispersion

The relative proportion of the various exchangeable cations (e.g. calcium, magnesium, potassium and sodium) in a material can have a significant effect on the physical properties of that material. Potential effects can be indicated by assessment of material sodicity, as measured by the Exchangeable Sodium Percentage (ESP[2]). ESP is calculated from the effective cation exchange capacity (eCEC) of the material. When the ESP is high or the calcium/magnesium ratio is low, the material is more likely to disperse upon wetting. As the percentage of sodium in the material increases, the tendency for dispersion increases, resulting in crusting, reduced infiltration and

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[2] ESP can be defined as the proportion of sodium adsorbed onto a material surface as a proportion of the total cation exchange capacity.

consequent reduced plant growth, high runoff and erosion. In general terms, ESP values of less than 6 indicate that a material has a low risk of dispersion and ESP values greater than 12 indicate that a material has a higher risk of dispersion. The effect of ESP on dispersion is also influenced by other soil properties such as organic matter content, clay mineralogy, cation composition, and particularly electrolyte concentration of the soil and of any applied irrigation water (Isbell, 2002). Materials with a high risk of dispersion generally require management strategies to be put in place to ensure that slopes are stabilised against erosion.

The structural stability of a soil aggregate upon wetting can have significant implications on the infiltration rate, hydraulic conductivity and soil strength of that particular material. Potential effects can be indicated by assessment of aggregate cohesion, as measured by the Emerson Class Number Test (Standards Australia, 1997). Soils are generally divided into six classes on the basis of their coherence in water. The lower the Emerson Class Number, the greater the likelihood that the soil will readily disperse in water, resulting in crusting, reduced infiltration and consequent reduced plant growth, high runoff and erosion. The higher the Emerson Class number, the greater the likelihood that the soil will not disperse in water. Materials with a high risk of dispersion (e.g. ECN 1 or 2) generally require management strategies to be put in place to ensure that slopes are stabilised against erosion.

O.2.4 Organic Carbon and Nutrients

Total organic carbon in soil comprises a variety of carbonaceous materials including humus, soil micro-organisms, plant and animal residues, coal, charcoal, coke and graphite, and carbonate minerals such as calcite and dolomite. Australian soils generally contain less than 5% organic carbon but higher levels are common in some surface soils and coal mines. The total organic carbon content of a soil (taken in context and in conjunction with a variety of other parameters) can provide an indication of its potential suitability as a growth medium.

Soil nutrients include nitrogen and phosphorous and deficiencies in these elements can also present a potential plant-growth issue, which may have implications for reduced vegetative cover, reduced plant species variability and erosion. Nitrogen and phosphorous deficiencies can generally be overcome in soils by fertilizer addition, however other soil characteristics (e.g. pH, salinity, sodicity, and metals) can impact soil fertility.

O.3 Residue Characteristics

The characteristics of the residue sample are given in Tables 1.3.1 and 1.3.2.

Table 1.3.1 Acid Base Test Results for Process Residue Sample

Table 1 Acid-Base Test Results for Process Residue Sample - Gladstone Pacific Nickel Ltd

Sample Description	Sample Matrix	pH[1]	Net Alkalinity	EC[1]	Total Sulfur	Sulfate Sulfur	TOS[2,3]	TOC[2]	MPA[2]	ANC[2]	NAPP[2]	NAG[2] capacity	NAGpH[2]	Sample Classification[4]
			(kg H_2SO_4/t)	(µS/cm)	(%)				(kg H_2SO_4/t)					
Tailings	Solid	7.00	1.20	83,600	5.30	5.26	0.04	0.19	1.2	9.7	-8	<0.1	7.5	Non Acid Forming (NAF)

Notes:

1. Natural pH and EC provided for 1:5 sample:water extracts
2. TOS = Total oxidisable sulfur; TOC = Total Organic Carbon; MPA = Maximum potential acidity; ANC = Acid neutralising capacity; NAPP = Net acid producing potential; and NAG = Net Acid Generating capacity
3. TOS concentration is calculated from the difference between total S and sulfate sulfur concentrations. It is assumed that the organic S concentration is negligible.
4. Sample has low TOS content, negative NAPP and NAGpH > 4; and is therefore classified as Non-Acid Forming (NAF).

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Table 1.3.2 Multi-Element Concentration in Process Residue Neutralised Solids

Parameters	Units[1]	Detection Limit	QLD-EPA[2] Environmental Investigation Level	NEPC[3] Health-Based Investigation Level	Process Residue (Solid)
Major Elements					
Ca	mg/kg	100	-	-	31,000
Mg	mg/kg	100	-	-	24,000
Na	mg/kg	100	-	-	11200
K	mg/kg	100	-	-	2,200
Fe	mg/kg	100	-	-	147,000
Minor Elements					
Ag	mg/kg	0.5	-	-	<0.5
Al	mg/kg	100	-	-	18,600
As	mg/kg	1	20	200	3
B	mg/kg	20	1 to 75 (Background)	6,000	20
Be	mg/kg	0.1	-	40	0.1
Cd	mg/kg	0.5	3	40	<0.5
Cl	mg/kg	100			300
Co	mg/kg	2	2 to 170 (background)	200	98
Cr	mg/kg	50	50[4]	200	6,350
Cu	mg/kg	2	60	2,000	26
F	mg/kg	100	-	-	<100
Hg	mg/kg	0.00001	1	30	30
Mn	mg/kg	5	500	3,000	2,110
Mo	mg/kg	0.5	<1 to 20 (background)	-	3
N	mg/kg	50			<50
Ni	mg/kg	5	60	600	2,950
Pb	mg/kg	1	300	600	2
S	mg/kg	100			53,000
Sb	mg/kg	0.2	20	-	0.400
Se	mg/kg	5	-	-	<5
Si	mg/kg	100	-	-	197,000
Sn	mg/kg	0.5	50	-	1.000
Sr	mg/kg	0.5	-	-	92
Tl	mg/kg	0.1	-	-	<0.1
U	mg/kg	0.5			0.500
Zn	mg/kg	2	200	14,000	86
Other parameters					
Extractable P (Colwell)	mg/kg	2			<2
Exchangeable Ca	meq/100g	0.1	-	-	190.0
Exchangeable Mg	meq/100g	0.1	-	-	160.0
Exchangeable K	meq/100g	0.1	-	-	1.3
Exchangeable Na	meq/100g	0.1	-	-	56.7
eCEC	meq/100g	0.1	-	-	408.0
Exchangeable Na %	%	0.1	-	-	13.9
SAR	%		-	-	20.6
Emerson Class Number	-	-	-	-	4

Notes:

▨ Shaded cells indicate values which exceed relevant QLD-EPA or NEPC guideline values.

< indicates less than the analytical detection limit.

1. Result values presented here are reported to mg/kg, having been converted from lab reported values of ppm, % and ppb using an assumed bulk density of
2. Queensland Government. Department of Environment. Draft Guidelines for the Assessment & Management of Contaminated Land in Queensland. May 1998.
3. National Environmental Protection Council (NEPC). National Environmental Protection (Assessment of Site Contamination) Measure (NEPM). Guideline on Investigation Levels for Soil and Groundwater (1999). HIL(E): parks, recreational open spaces and playing fields.
4. Cr (III). No background or QLD-EPA EIL's are available for Cr (VI).

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Table 1.3.3 Multi-Element Concentrations in Process Residue Neutralised Liquor

		Material Group -->	**Process Residue**
		Sample No. --->	**1**
Parameters	Detection Limit	ANZECC^2/NEPC^3 Guidelines	Liquor
Major Elements	(mg/L)	(mg/L)	(mg/L)
Ca	1	1,000	96
Mg	1	-	3,660
Na	5	-	2,500
K	5	-	41
Cl	400	-	5,040
SO$_4$	10	1,000	69,000
Minor Elements	(mg/L)	(mg/L)	(mg/L)
Ag	0.02	-	<0.02
Al	0.5	5	0.5
As	0.1	0.5	<0.1
B	0.5	5	2.5
Be	0.005	0.1	<0.005
Cd	0.05	0.01	<0.05
Co	0.2	1	0.8
Cr	0.2	1	<0.2
Cu	0.2	0.5	<0.2
F	2	2	2
Fe	0.5	1 (irrigation)	<0.5
Hg	0.005	0.002	<0.005
Mn	0.2	2 (irrigation)	407
Mo	0.05	0.15	<0.05
N	50	5 (irrigation)	<50
Ni	0.5	1	31.5
Pb	0.5	0.1	<0.5
S	5	-	23000
Sb	0.01	-	<0.01
Se	0.5	0.02	<0.5
Si	2	-	32
Sn	0.1	-	<0.1
Sr	0.05	-	8.75
Tl	0.005	-	<0.005
U	0.005	0.2	<0.005
Zn	0.2	20	0.2

Notes:

< Indicates concentration less than the detection limit.

\- Indicates no specified guideline parameter

1. Natural pH and EC provided for 1:5 sample:water extracts
2. ANZECC and ARMCANZ, Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT (2000). Livestock drinking water.
3. National Environmental Protection Council (NEPC). National Environmental Protection (Assessment of Site Contamination) Measure (NEPM). Guideline on Investigation Levels for Soil and Groundwater (1999). Groundwater Investigation Levels (Livestock drinking water)

▨ Shaded cells indicate values which exceed recommended ANZECC/NEPC guideline values.