
Report on Static Test Data for Vardocube Samples

1 Introduction

This report describes the geochemical characterisation of nine samples obtained from drill cores within the Vardocube Prospecting Right area. The Vardocube area is adjacent to the Repli area, which is currently being mined. The Vardocube body will be mined from the Repli side and will make use of the existing infrastructure on the Repli site. The nine samples represent lithologies associated with the ore body and are characteristic of the waste rock material that will be disposed of on the surface during mining operations.

2 Background to geochemical characterisation

The primary purpose of the geochemical characterisation of mine materials is to guide management decisions. Therefore, it is critical that a phased assessment program is carried out to ensure sufficient data are available at all stages of the project cycle. Best practice environmental management can only be achieved through the early recognition of the potential for acid drainage and metal leaching.

Geochemical characterisation aims to identify the distribution and variability of key geochemical parameters (such as sulphur content, acid neutralising capacity and elemental composition) and acid generating and metal leaching characteristics. A basic screening level investigation is essential and should commence at the earliest possible stage. The necessity and scope for detailed investigations will depend on the findings of initial screening.

2.1 Sample selection

Sample selection is critical and must be given due consideration at all stages of the process. For waste material the samples must represent each geological type that will be mined or exposed and each waste type. The number of samples must be sufficient to adequately cover the variability within each geological unit and waste type.

2.2 Sample number

The number of samples required for the characterisation of each material type depends on a number of factors, including:

- The amount of disturbance (i.e. the volume or mass of material extracted for each material type).
- Compositional variability within the material type.
- The degree of statistical confidence required.

While the number of samples required is likely to be site-specific, country specific guidelines do exist. The GARD guide describes the Australian Government's Department of Industry guidelines.

These suggest at least 3-5 representatives of each material type during the prospecting phase, increasing to 5-10 per material type during resource scoping. During the pre-feasibility they recommend several hundred representatives of high and low grade ore, waste rock and tailings, with the number dependent on the complexity of the deposit geology and host rock. This should be followed by kinetic testing of 1-2 representatives of each material type. In reality, this number is often reduced due to time and budget constraints

The goal of waste management is to prevent or reduce ARD generation, so characterisation programmes must provide sufficient information to make sustainable and cost-effective decisions regarding the management and disposal of waste materials. The number of samples needs to be sufficient to meet this minimum requirement.

2.3 Testing programme overview

Laboratory and field-testing are designed to characterise the acid generating and leaching potential of mine and waste materials. Typically, a phased approach is adopted and this is likely to be dynamic, with changes informed by data as they become available.

The laboratory phase of geochemical characterisation typically includes the following analyses:

Static tests

- Whole rock and elemental analysis
- Mineralogical analysis
- Acid base accounting (ABA)
- Net acid generation (NAG)
- Short term leaching tests

Kinetic tests

- Humidity cells
- Laboratory leach columns

This report will focus on the static tests.

3 Materials and methods

3.1 Sample materials

A total of nine (9) samples, as drill cores, were provided. The lithological code, dominant lithology and a description are summarised in Table 1, below.

Table 1: Description of the dominant lithologies of the samples provided

Lith code	Lithology	Description
AMP	Amphibolite	Coarse grained weakly sheared amphibolite -Intrusive at all levels
VBA	Gneissic amphibolite	Banded amphibolite-in mining footwall of ore
PEG	Pegmatite	Massive intrusive pegmatite in both FW and HW of ore
PBG	Biotite Gneiss	Altered sheared amphibolite with disseminated pyrite
PT	Quartz tourmaline Rock	Banded schorl with disseminated pyrite, In lateration zone above and below ore zone
PPG	Quartz-Sillimanite-Phlogopite rock	Predominant alteration rock in immediate FW and HW of ore, pyritiferous , mylonitic
SMG	Dacitic Gneiss	Gneissic qtz-hornblende-feldspar rock with minor pyrite and magnetite, in mining HW of ore above alteration Zone
VBG	Felsic gneiss	Gneissic qtz-feldspar-Biotite rock with minor pyrite and magnetite, in mining FW of ore
PGF	Gedrite-Sillimanite-Phlogopite Rock	Massive weakly pyritiferous coarse grained tourmalinous rock in alteration unit around the ore FW and HW

The samples were crushed in a jaw crusher, then pulverised and sieved to obtain a representative - 75 µm fraction that was used for geochemical characterisation.

3.1.1 Whole rock analysis

Major element analysis was performed by XRF (Thermo ICap) with trace elements quantified by Laser Ablation ICP-MS (Agilent 7700 ICP-MS) and ICP-MS on acid digested material.

3.1.2 Static tests

3.1.2.1 Leach tests

The leaching of cations and anions from the samples was determined by a reagent water leach, following the Australian Standard Leaching Procedure (AS 4439.1), as the residues represent non-putrescible waste to be disposed of without any other waste. The AS 4439.1 test is based on the US EPA TCLP test, which is not appropriate for mine residues as nitric and acetic acids used to prepare the leach solutions are not representative of mining environments. A recent review (August 2018) of Australian Standards has resulted in AS 4439 being withdrawn for being obsolete.

In addition to the reagent water leach test a second series of leach tests were conducted using a dilute sulphuric acid solution at pH 2.88. The pH value corresponds to the low range for the TCLP test, but replaces the inappropriate acetic acid with sulphuric acid, which is the acid generated during the oxidation of sulphide minerals in mining residues. Two of the samples tested were characterised as potentially acid forming, justifying the addition of the sulphuric acid leach.

The leach tests were performed at a solids loading of 5% (m/v), equivalent to a liquid:solid ratio of 20:1. Flasks were gently agitated at 25°C for 24 hours after which the solids were allowed to settle and subsamples were removed and filtered through a 0.45 µm membrane filter ahead of cation and anion analysis by ICP and IC. The results are considered against the Leachable Concentration Threshold (LCT) values (Government Gazette No. 36784)

3.1.2.2 Acid base accounting (ABA)

Acid base accounting utilises information on the maximum potential acidity and acid neutralising capacity of the material in order to classify it as potentially acid forming, non-acid forming or uncertain. The maximum potential acidity was calculated based on the total sulphur content, determined using an Elementar Vario EL Cube Elemental Analyzer. The acid neutralising capacity was determined using the standard method (Appendix A1)

3.1.2.3 Net acid generation (NAG) test

The NAG test is described in detail in Appendix A2. The sample (2.5 g) was exposed to 250 ml of 15% hydrogen peroxide and allowed to react until gas evolution ceased. The flask was then heated for a minimum of two hours to ensure the decomposition of any residual peroxide. Once the contents had cooled the volume was made up to 250 ml with deionised water, the pH recorded and the solution titrated to pH 4.5 and pH 7.0.

4 Results and discussion

4.1 Whole rock analysis

The whole rock analysis provides an indication of the elemental composition of the material. The major elements are represented in terms of standard mineral types (Table 2).

Table 2: Summary of major element analysis by XRF. Values expressed as mass %.

Sample	Al ₂ O ₃	CaO	Cr ₂ O ₃	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	P ₂ O ₅	SiO ₂	TiO ₂	LOI ¹	Sum
AMP	12.29	10.94	0.02	13.72	0.74	12.08	0.78	1.48	0.28	46.63	0.49	1.46	100.9
PBG	14.34	3.99	0.04	18.84	2.53	9.72	0.34	1.48	0.11	45.29	0.98	2.11	99.77
PEG	18.70	0.45	0.01	0.67	4.59	0.01	0.04	3.25	0.11	70.12	0.02	1.15	99.13
PGF	15.34	3.51	0.03	14.15	1.11	12.77	0.28	0.88	0.20	47.35	0.57	2.84	99.03
PPG	12.96	0.33	0.03	5.28	3.64	9.44	0.05	0.34	0.02	61.95	0.16	5.02	99.23
PT	14.99	2.02	0.04	7.32	0.77	2.60	0.16	1.16	1.31	65.53	0.20	2.59	98.68
SMG	15.50	6.20	0.02	8.18	1.43	3.42	0.16	2.90	0.37	59.58	0.72	0.59	99.07
VBA	14.13	6.66	0.02	12.75	0.92	3.71	0.26	2.54	0.47	55.59	1.22	1.02	99.29
VBG	12.97	2.21	0.03	3.38	2.63	0.93	0.07	2.51	0.04	73.33	0.25	0.88	99.22

¹ Loss on ignition – includes total volatile content (including water contained in lattice of silicate material)

The XRF analysis was able to account for all the major elements in all nine of the samples, with the data consistent the description of the lithologies provided.

The trace element data were determined by laser ablation ICP-MS and total acid digestion, followed by ICP analysis, for those elements degraded by laser ablation. The results are presented in Table 3.

Sample Element	TCT0 mg/kg	TCT1 mg/kg	TCT2 mg/kg	AMP mg/kg	PBG mg/kg	PEG mg/kg	PGF mg/kg	PPG mg/kg	PT mg/kg
As	5.8	500	2000	2.67	12.87	7.23	4.77	4.66	9.23
V	150	2680	10720	216.60	269.15	21.08	283.75	38.43	45.56
Cr	46000	80000	N/A	148.10	269.95	150.25	224.55	240.75	284.35
Co	50	5000	20000	46.41	47.90	1.05	40.89	9.16	15.27
Ni	91	10600	42400	64.60	102.25	9.40	59.60	9.44	16.40
Cu	16	19500	78000	112.40	511.10	34.00	69.85	141.20	603.60
Zn	240	16000	64000	144.20	127.90	16.00	130.00	118.00	154.95
B	150	15000	60000	77.34	84.83	33.30	164.07	112.42	341.84
Sr	-	-	-	77.95	109.80	18.55	53.15	45.45	82.20
Cd	7.5	260	1040	4.12	3.75	2.07	3.22	6.03	2.55
Zr	-	-	-	31.97	111.75	13.80	44.27	264.25	194.00
Hg	0.93	160	640	0.67	1.22	0.45	0.32	0.79	1.34
Mo	40	1000	4000	3.87	4.01	7.93	5.44	41.25	13.30
Cs	-	-	-	22.05	41.91	7.02	66.08	13.28	6.43
Ba	62.5	6250	25000	65.85	1205.00	301.00	437.60	3099.50	512.75
La	-	-	-	18.68	11.70	1.78	27.15	44.40	69.14
Ce	-	-	-	36.43	21.13	3.26	55.35	93.71	147.05
Nd	-	-	-	15.44	9.63	0.90	26.27	42.20	63.20
Sb	10	75	300	4.23	7.15	3.08	4.45	6.22	2.85

Se	10	50	200	3.85	4.22	7.18	5.05	12.58	14.23
Gd	-	-	-	3.45	2.93	0.31	4.15	10.47	11.73
Pb	20	1900	7600	10.17	49.12	108.50	12.66	42.89	25.77
Th	-	-	-	6.31	1.72	1.19	6.24	23.67	21.71
U	-	-	-	4.48	0.57	9.45	1.16	9.43	7.97

The unit is mg of the element per kg of material, rather than as a mass % for predicted mineral phases. The trace element values are considered against the Total Concentration Threshold (TCT) limits used to classify the hazard level of elements in waste material.

Table 3: Summary of trace element concentrations represented against TCT limits. Data in bold exceed TCT0, but are less than TCT1

Sample Element	TCT0 mg/kg	TCT1 mg/kg	TCT2 mg/kg	AMP mg/kg	PBG mg/kg	PEG mg/kg	PGF mg/kg	PPG mg/kg	PT mg/kg	SMG mg/kg	VBA mg/kg	VBG mg/kg
As	5.8	500	2000	2.67	12.87	7.23	4.77	4.66	9.23	3.17	4.28	4.67
V	150	2680	10720	216.60	269.15	21.08	283.75	38.43	45.56	133.50	202.15	39.77
Cr	46000	80000	N/A	148.10	269.95	150.25	224.55	240.75	284.35	152.50	151.05	210.00
Co	50	5000	20000	46.41	47.90	1.05	40.89	9.16	15.27	18.50	24.16	3.01
Ni	91	10600	42400	64.60	102.25	9.40	59.60	9.44	16.40	15.14	21.60	9.57
Cu	16	19500	78000	112.40	511.10	34.00	69.85	141.20	603.60	45.95	77.60	57.00
Zn	240	16000	64000	144.20	127.90	16.00	130.00	118.00	154.95	90.90	136.10	51.20
B	150	15000	60000	77.34	84.83	33.30	164.07	112.42	341.84	75.16	82.09	62.73
Sr	-	-	-	77.95	109.80	18.55	53.15	45.45	82.20	355.35	196.00	136.55
Cd	7.5	260	1040	4.12	3.75	2.07	3.22	6.03	2.55	3.18	3.76	2.11
Zr	-	-	-	31.97	111.75	13.80	44.27	264.25	194.00	152.75	57.71	141.80
Hg	0.93	160	640	0.67	1.22	0.45	0.32	0.79	1.34	0.62	0.48	0.45
Mo	40	1000	4000	3.87	4.01	7.93	5.44	41.25	13.30	8.03	6.43	13.36
Cs	-	-	-	22.05	41.91	7.02	66.08	13.28	6.43	5.40	5.50	2.66
Ba	62.5	6250	25000	65.85	1205.00	301.00	437.60	3099.50	512.75	795.40	195.00	1069.50
La	-	-	-	18.68	11.70	1.78	27.15	44.40	69.14	39.38	11.68	40.64
Ce	-	-	-	36.43	21.13	3.26	55.35	93.71	147.05	81.94	25.89	78.80
Nd	-	-	-	15.44	9.63	0.90	26.27	42.20	63.20	37.86	15.40	31.95
Sb	10	75	300	4.23	7.15	3.08	4.45	6.22	2.85	5.33	3.06	4.73
Se	10	50	200	3.85	4.22	7.18	5.05	12.58	14.23	4.86	3.52	4.54
Gd	-	-	-	3.45	2.93	0.31	4.15	10.47	11.73	6.81	4.49	6.10
Pb	20	1900	7600	10.17	49.12	108.50	12.66	42.89	25.77	15.73	16.56	15.14
Th	-	-	-	6.31	1.72	1.19	6.24	23.67	21.71	7.87	1.25	14.61
U	-	-	-	4.48	0.57	9.45	1.16	9.43	7.97	1.29	0.37	3.51

The data show that all nine samples exceed the TCT0 limit with respect to at least one element, but all parameters are well below the TCT1 limits. Copper and barium exceed the TCT0 limits in all cases. The copper data are not surprising, given that the material is associated with a copper bearing deposit.

4.2 Acid base accounting

Table 4 presents the summarised data from the acid base accounting (ABA). The ABA approach uses a calculated maximum potential acidity value (MPA), based on the amount of oxidisable sulphur, against a measured acid neutralising capacity (ANC) value to provide an estimation of the overall potential of the material to generate acidic leachate upon oxidation.

The data presented in Table 4 indicates that the sulphur grades for all but PPG and PT are below the 0.3% value used to define “acid generating tailings”. The PPG and PT reported moderate sulphur grades, which were consistent with the geological description of the material, as containing disseminated pyrite. The SMG and VBG samples were described as having “minor pyrite”, but the measured reduced sulphur values suggest very limited amounts.

Table 4: Total sulphur and acid base accounting data for the three samples tested

Sample	Total S (%)	MPA (kg H ₂ SO ₄ /t)	ANC (kg H ₂ SO ₄ /t)	NAPP (kg H ₂ SO ₄ /t)	ANC:MPA
AMP	0.11	3.37	46.56	-43.20	13.8
PBG	0.15	4.59	40.50	-35.91	8.8
PEG	0.08	2.45	5.22	-2.78	2.1
PGF	0.07	2.14	32.26	-30.11	15.1
PPG	1.88	57.53	43.25	14.28	0.8
PT	1.25	38.25	35.00	3.25	0.9
SMG	0.09	2.75	25.15	-22.40	9.1
VBA	0.15	4.59	37.06	-32.47	8.1
VBG	0.08	2.45	26.36	-23.91	10.8

The acid neutralising capacity is determined experimentally by reacting the material with an acid solution and back titrating to determine acid consumption. The volume and concentration of acid are determined using a subjective “fizz rating” based on observing the reaction between the tailings and a concentrated acid solution. The fizz rating of all samples were either 1 or 2, indicating low to moderate acid neutralising capacity and this was confirmed by the analysis, with all but the PEG sample yielding ANC values between 25 and 47 kg H₂SO₄/t. The whole rock analysis revealed very low levels of calcium (0.45%) and magnesium (0.01%), elements typically consistent with acid neutralising capacity, in the PEG sample.

The ratio between the MPA and the ANC is often used to characterise the acid generating potential of mine waste. If the ratio is > 2 there is a strong possibility that the material will remain circum-neutral and not generate acidity. Based on the NAPP value and ANC:MPA ratio it is clear that only the PPG and PT samples have significant potential to be acid generating. The PEG sample is on the threshold, due to both the MPA and ANC values being very low, so this does not represent a significant risk. The net acid generation test data provide a more realistic picture.

4.3 Net acid generation

The net acid generation test relies on the addition of hydrogen peroxide to accelerate the oxidation of reduced sulphur minerals, generating acidity. Where samples have acid neutralising capacity, some or all of the acid generated may be neutralised. Once the reactions are complete and the residual peroxide has been decomposed the NAG pH is measured. Thereafter, a standard hydroxide solution is used to titrate to specific end points (pH 4.5 and pH 7).

A low NAG pH value is indicative of material that has an acid generating capacity in excess of the acid neutralising capacity. The results of the assay are consistent with the outcome of the ABA tests, with only the PPG and PT samples yielding a NAG pH below 4.5.

The NAG 7 values are determined by titrating the solution back to pH 7, so any test that returns a NAG pH below represents some acid generating potential. However, most peroxide solutions are stabilised with small amounts of phosphoric acid, so blank reactions are performed and the NAG 7 value subtracted from the experimental data, which explains the negative value for the AMP sample, despite the NAG pH being lower than pH 7.

Table 5 compares the acid generating potential based on the NAG tests to the NAPP value determined during the ABA test. While the trend is consistent, there is a difference in the magnitude of the data, with the NAG tests seeming to underestimate the acid neutralising potential. This can most likely be accounted for by the nature of the acid consuming minerals. The fizz tests indicated relatively low short-term reactivity, which indicates the absence of meaningful concentrations of carbonate or oxide minerals (which react rapidly). The ANC test uses strong acid at elevated temperature, so less reactive silicate minerals are more likely to contribute to the ANC under these conditions. In the NAG test, the material is not subjected to low pH unless there is significant acid generation, so the less reactive acid consuming minerals are unlikely to react, hence the lower apparent acid neutralising capacity.

Table 5: Summary of NAG data

Sample	NAG pH	NAG 7 (kg H ₂ SO ₄ /t)	NAPP (kg H ₂ SO ₄ /t)
AMP	6.61	-0.09	-43.20
PBG	5.07	0.89	-35.91
PEG	5.45	0.69	-2.78
PGF	7.54	-0.29	-30.11
PPG	2.57	34.21	14.28
PT	2.74	22.25	3.25
SMG	6.18	0.69	-22.40
VBA	6.19	0.49	-32.47
VBG	6.57	0.20	-23.91

Based on the results of the NAG test it is clear that only the PPG and PT samples have acid generating potential. What is also apparent is that a significant portion of the acid neutralising

capacity across all the samples is in the form of less reactive silicates, which may have implications from a kinetic perspective.

A geochemical classification plot (Figure 1) confirms that only the PPG and PT samples are potentially acid forming (PAF), while the remainder of the samples are classified as non-acid forming (NAF).

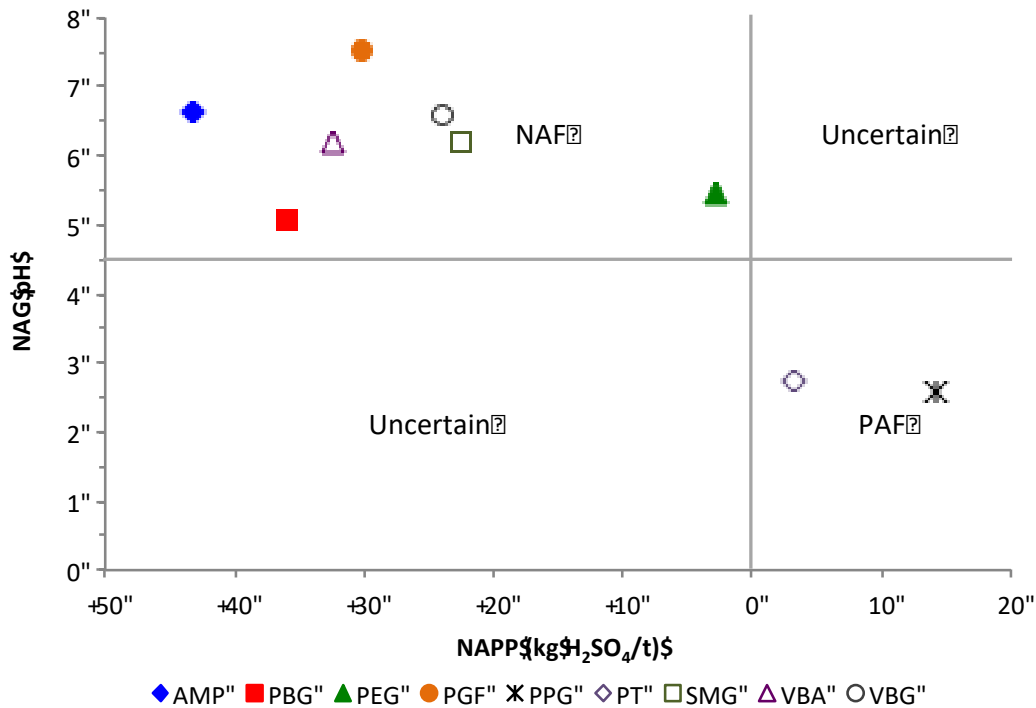


Figure 1: Geochemical classification plot based on ABA and NAG test data

4.4 Deionised water leach

A number of protocols exist to assess metal leaching from mine waste material. The synthetic precipitation leach procedure (SPLP; EPA Method 1312) is most widely used to assess the risk of water contamination posed by leaching of mine wastes (Hageman *et al.*, 2000). The validity of the SPLP test procedure for assessing mine wastes (and other waste products) for their metal leaching has been challenged on a number of points. These include the selection of nitric acid to prepare the leach solutions, which does not reflect actual AMD, the mildly acidic pH values (pH 4.2 and 5.0) and the particle size (-9.5 mm). In their critical review of prediction tests Parbhaker-Fox and Lottermoser (2015) conclude that the SPLP can be used as a screening tool, but its application as a waste classification tool appears to be limited.

As an alternative to the SPLP, a reagent (deionised) water leach was selected for this investigation. This is prescribed by the National Norms and Standards for Assessment of Waste for Landfill Disposal, under the National Environmental Management: Waste Act of 2008 and follows the AS 4439.1 protocol. The ABA analysis confirmed that the majority of the samples did not have acid generating potential, so reagent water was appropriate. Two of the samples did have significant acid generation potential so an additional leach was included. This is permitted under AS 4439.1,

but in this case sulphuric acid, rather than acetic acid, was used to acidify the water as it represents the acidity generated by sulphide mineral oxidation. The acid leach data are presented in Section 4.5.

The data represent solution concentrations of anions (Table 6) and cations (Table 7) in the leachate after agitation for 24 hours (solid liquid ratio of 1:20).

The results show that solution pH at the end of the experiment was in the alkaline range (pH 8.3-9) for all samples tested, even the PPG and PT samples that have acid generating potential. This result was expected, as the samples were prepared from drill cores that had not been subjected to oxidative weathering. The acid generating potential will only be realised when the material undergoes oxidation.

The total dissolved solids (TDS) values were relatively low in all cases, again consistent with material that is not weathered, or contains relatively small amounts of readily soluble alkaline minerals. In all cases the TDS values were substantially lower than the LCT0 limits.

The individual anion concentrations are consistent with the low TDS values and in all cases the values are below the LCT0 limits. The fluoride concentration in solution from some of the tests was close to the LCT0 limit, but all other anions were well below the limit.

The cation data (Table 7) is also consistent with the low TDS, with sodium and potassium as the dominant cations. The relatively low concentrations of calcium and magnesium are consistent with the acid neutralising data described above, supporting the assertion that much of the acid neutralising potential is tied up in silicate minerals, rather than carbonates or oxides.

The whole rock analysis suggested that elements such as iron, aluminium, copper, lead and barium were present at levels that could represent an environmental risk, but the reagent water leach data suggest that these are present in stable, mineral form.

While the concentrations of the majority of the elements in the leach solution were below the LCT0 limit, the vanadium concentration for all samples exceeded the LCT0 limit of 0.2 mg/l, while the boron concentration in the PT sample leachate also exceeded the LCT0 limit of 0.5 mg/l. These concentrations remained well below the LCT1 threshold.

4.5 Acidified water leach

The cation data for the acidified water leach tests are summarised in Table 8. The most significant difference between the reagent water leach data and the acidified water leach data is in the calcium and magnesium concentrations, indicating that the mineral phases containing these elements are more acid labile.

With respect to the LCT values, the vanadium concentrations were lower in the acid leach, with values falling below the LCT0 limit, but there was an increase in manganese leaching, with the PT and SMG samples exceeding the LCT0 value of 0.5 mg/l.

Table 6: Solution chemistry and anion data generated during reagent water leach tests, compared to Leach Concentration Threshold Limits

Sample Element	LCT0 mg/l	LCT1 mg/l	AMP mg/l	PBG mg/l	PEG mg/l	PGF mg/l	PPG mg/l	PT mg/l	SMG mg/l	VBA mg/l	VBG mg/l
pH	-	-	8.61	8.98	8.61	8.76	8.54	8.33	8.66	8.77	8.85
TDS	1000	12500	126	242	109	131	210	121	76	90	85
F⁻	1.5	75	0.90	1.38	0.47	1.04	1.44	1.03	0.79	0.58	1.34
Cl⁻	300	15000	2.48	1.23	3.64	0.97	2.47	1.66	1.32	2.48	5.26
NO₃⁻	11	550	0.36	0.19	1.18	0.63	0.27	0.17	0.37	0.18	0.27
SO₄²⁻	250	12500	6.90	15.28	11.11	7.98	38.01	18.92	6.07	11.08	6.85
PO₄³⁻	-	-	0.81	0.84	1.15	0.00	0.00	1.03	0.72	0.00	1.16

Table 7: Cation concentration data generated during reagent water leach tests, compared to Leach Concentration Threshold Limits

Sample Element	LCT0 mg/l	LCT1 mg/l	AMP mg/l	PBG mg/l	PEG mg/l	PGF mg/l	PPG mg/l	PT mg/l	SMG mg/l	VBA mg/l	VBG mg/l
Be	-:	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B	0.5	25	0.030	0.041	0.021	0.343	0.075	1.032	0.042	0.027	0.023
Al	-	-	0.436	1.364	1.030	0.582	0.669	0.205	1.220	0.543	0.571
V	0.2	10	0.436	1.364	1.030	0.582	0.669	0.205	1.220	0.543	0.571
Cr	0.1	5	0.002	0.048	0.002	0.003	0.001	0.001	0.002	0.001	0.001
Mn	0.5	25	0.024	0.029	0.016	0.009	0.010	0.052	0.021	0.012	0.017
Fe	-	-	0.288	2.460	0.125	0.537	0.324	0.047	0.713	0.240	0.176
Co	0.5	25	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.07	3.5	0.001	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Cu	2	100	0.003	0.004	0.018	0.002	0.003	0.003	0.002	0.001	0.002
Zn	5	250	0.005	0.005	0.016	0.004	0.003	0.004	0.005	0.004	0.003
As	0.01	0.5	0.001	0.005	0.003	0.002	0.001	0.000	0.001	0.002	0.001
Se	0.01	0.5	0.000	0.002	0.000	0.000	0.002	0.002	0.000	0.000	0.000
Sr	-	-	0.024	0.014	0.010	0.021	0.018	0.063	0.022	0.040	0.029
Mo	0.07	3.5	0.004	0.003	0.014	0.004	0.037	0.015	0.007	0.005	0.007
Cd	0.003	0.15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sb	0.02	1	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ba	0.7	35	0.004	0.026	0.005	0.016	0.093	0.009	0.017	0.007	0.020
Hg	0.006	0.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pb	0.01	0.5	0.001	0.007	0.006	0.001	0.003	0.001	0.004	0.001	0.001
U	-	-	0.001	0.000	0.008	0.000	0.000	0.002	0.000	0.000	0.004
Ca	-	-	11.88	3.06	7.04	6.07	1.50	14.90	6.79	12.39	9.93
K	-	-	13.59	20.70	13.02	15.31	10.37	6.38	9.13	5.52	10.45
Mg	-	-	3.23	2.04	0.32	1.91	2.32	2.41	1.51	1.48	1.19
Na	-	-	18.22	67.28	20.92	27.10	55.44	17.71	12.20	15.98	11.94
Si	-	-	5.77	6.16	3.88	4.23	6.16	2.59	4.82	2.97	3.95

Table 8: Cation concentration data generated during acidified water leach tests, compared to Leach Concentration Threshold Limits

Sample Element	LCT0 mg/l	LCT1 mg/l	AMP mg/l	PBG mg/l	PEG mg/l	PGF mg/l	PPG mg/l	PT mg/l	SMG mg/l	VBA mg/l	VBG mg/l
Be	-:	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B	0.5	25	0.035	0.049	0.030	0.463	0.089	1.361	0.064	0.038	0.032
Al	-	-	0.043	0.053	0.015	0.056	0.041	0.021	0.214	0.097	0.094
V	0.2	10	0.008	0.006	0.001	0.007	0.001	0.000	0.001	0.005	0.002
Cr	0.1	5	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Mn	0.5	25	0.097	0.027	0.709	0.046	0.103	2.469	1.148	0.015	0.228
Fe	-	-	0.010	0.005	0.007	0.004	0.019	0.005	0.007	0.004	0.004
Co	0.5	25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.07	3.5	0.001	0.001	0.000	0.000	0.000	0.001	0.002	0.000	0.000
Cu	2	100	0.003	0.004	0.001	0.001	0.001	0.001	0.001	0.001	0.000
Zn	5	250	0.011	0.008	0.006	0.004	0.007	0.008	0.007	0.005	0.003
As	0.01	0.5	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.001	0.000
Se	0.01	0.5	0.000	0.001	0.000	0.000	0.004	0.001	0.000	0.000	0.000
Sr	-	-	0.094	0.207	0.065	0.142	0.124	0.219	0.100	0.149	0.103
Mo	0.07	3.5	0.012	0.009	0.043	0.016	0.179	0.087	0.041	0.031	0.016
Cd	0.003	0.15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sb	0.02	1	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.001	0.000
Ba	0.7	35	0.017	0.228	0.013	0.141	0.071	0.052	0.082	0.023	0.074
Hg	0.006	0.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pb	0.01	0.5	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
U	-	-	0.003	0.002	0.001	0.002	0.000	0.000	0.000	0.001	0.007
Ca	-	-	90.12	54.92	42.43	70.07	15.27	73.13	31.56	80.36	78.60
K	-	-	21.52	37.92	20.38	24.17	21.17	10.10	13.89	8.55	13.33
Mg	-	-	7.40	6.02	1.39	8.43	16.59	7.44	7.44	4.28	3.19
Na	-	-	17.00	66.33	22.83	30.75	57.17	17.64	12.71	15.77	11.61
Si	-	-	5.95	3.76	10.60	4.14	6.40	8.71	11.32	3.99	4.23

5 Conclusions

The interpretation of the data generated during the static test programme allows a number of conclusions to be drawn:

1. Seven of the nine samples tested can be classified as non-acid generating, based their acid generating and neutralising capacity. The PPG and PT samples can be classified as potentially acid forming, although the potential for acid generation is relatively low (34 and 22 kg H₂SO₄/t respectively, based on NAG data).
2. The magnitude of the acid generating potential predicted from the NAG test was higher than that calculated from the acid-base accounting. This is most likely due to the relatively low reactivity of the silicate minerals, which account for much of the acid neutralising capacity.
3. The acid neutralising capacity of most of the non-acid forming samples, with the exception of PEG, is of similar magnitude to the acid generating potential of the PPG and PT material, suggesting co-disposal may be an option.
4. The whole rock analysis showed that all samples contained at least two elements (copper and barium) at concentrations in excess of the TCT0 limit.
5. None of the samples contained any elements at concentrations in excess of the TCT1 limits, so all the material tested falls can be considered between TCT0 and TCT1.
6. Reagent water leach tests were performed and the leachate from all samples contained vanadium concentrations that exceeded the LCT0 limit. In addition, the leachate from the PT sample contained boron at a concentration in excess of the LCT0 limit. For all other elements the concentrations in the leachate were below the LCT0 limit for all samples.
7. An acidified water leach test, using sulphuric acid, was performed as two of the samples could be classified as potentially acid forming. The results showed that the calcium and magnesium concentrations in the leachate were substantially higher than for the corresponding reagent water leach. The PT and SMG samples yielded manganese concentrations in the leachate that exceeded the LCT0 limit.
8. All nine samples tested exceeded the TCT0 limit in and least two parameters and the LCT0 limit in at least one, but no samples exceeded either a TCT1 or LCT1 limit. Therefore, all samples can be classified as Type 3 waste, according to the National Norms and Standards for Assessment of Waste for Landfill Disposal, under the National Environmental Management: Waste Act of 2008.

6 References

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7 Appendices

Appendix A – Static test procedures

Static test procedures have been adapted from the AMIRA International ARD Test Handbook (2002).

Appendix A1 - Acid Neutralising Capacity (ANC)

The ANC test is used to measure the buffering capacity or inherent neutralising capacity of the material. This is determined by adding a known amount of standardised hydrochloric acid (HCl) to an accurately weighed sample, allowing the sample time to react (with heating), then back titrating with standardised sodium hydroxide (NaOH).

Procedure:

Step 1:

To determine the amount and concentration of acid to be used in the analysis, the sample is given a subjective “fizz rating”, determined by adding a few (2-3) drops of concentrated HCl to a small sample of pulverised material. A rating is assigned according to the scale of the reaction, as indicated in Table A1.

Table A1: Fizz ratings and associated volume and concentrations of reagent to be used in ANC test.

Reaction	Fizz rating	HCl (M)	HCl volume (ml)	NaOH (M)
No reaction	0	0.5	4	0.1
Slight reaction	1	0.5	8	0.1
Moderate reaction	2	0.5	20	0.5
Strong reaction	3	0.5	40	0.5
Very strong reaction	4	1.0	40	0.5
	5 ¹	1.0	60	0.5

¹ 5 is used for very high ANC material (>400kg H₂SO₄/t) e.g. limestone

Step 2:

Weigh 2.00g of dried, pulverised material into a clean, dry 250ml beaker and add the required amount of HCl. Add approximately 20ml of deionised water. Prepare duplicate blanks by adding acid to clean, dry beakers without any sample and add 20 ml deionised water.

Step 3:

Cover each beaker with a watch glass and heat to 80-90°C, stirring occasionally, for 2-3 hours or until the reaction is complete (no further evolution of gas).

Step 4:

Cool the beaker to room temperature and add deionised water to a final volume of 125ml. Measure the pH of the mixture. If the pH is in the range of 0.8 – 1.5, proceed with the titration.

If the pH is greater than 1.5, additional acid is required (unless the fizz rating is 0). For all other fizz ratings, additional acid must be added such that the total acid is equivalent to the next fizz rating, or the test must be repeated using the next highest fizz rating.

If the pH of the mixture is less than pH 0.8, too much acid may have been added (unless the fizz rating is 5) and the test should be run again at the next lowest fizz rating.

Step 5:

Titrate against standardised sodium hydroxide, using the concentration shown in Table A1, with constant mixing. Interrupt the titration around pH 5.0 and add two drops of 30% hydrogen peroxide to oxidise any soluble ferrous iron. Continue the titration to pH 7.0 and record the volume added.

Titrate the duplicate blank samples using NaOH as indicated in Table A1.

$$\text{ANC} = [Y \times M_{\text{HCl}} / \text{wt}] \times C$$

Where :Y = (vol of HCl added) – (vol of NaOH titrated xB)

$$B = (\text{vol of HCl in blank}) / (\text{vol of NaOH titrated in blank})$$

M_{HCl} = molarity of HCl

wt = sample weight (g)

C = conversion factor (49.0 to express results as kg H₂SO₄/t)

Appendix A2 - Net Acid Generation (NAG)

The NAG test involves the addition of a solution of hydrogen peroxide to a prepared sample of mine rock or process residue to oxidise reactive sulphide minerals contained therein. This is followed by measurement of pH and titration of net acidity produced by the acid generation and neutralisation reactions occurring in the sample.

Single addition NAG procedure

Accurately weigh 2.5g of pulverised material into a 250ml beaker.

Carefully add 250ml of a 15% H₂O₂ solution (30% H₂O₂ diluted 1:1 with deionised water and adjusted to pH 4.5).

Cover the beaker with a watch glass and place in a well ventilated area.

Allow the sample to react until effervescence ceases. This may require the sample to be left overnight.

After the reaction, place the beaker on a hot plate and gently heat the sample until the effervescence stops or for a minimum of 2 hours. Do not allow the sample to boil dry and add deionised water as required to maintain the volume approximately constant.

Allow the sample to cool to room temperature.

Rinse any sample that has adhered to the sides of the flask down into the solution using deionised water. Add deionised water to give a final volume of 250ml.

Record the pH of the solution. This pH measurement is referred to as the NAGpH.

Titrate the solution to pH 4.5 and 7.0, while stirring, with the appropriate NaOH concentration, based on the NAGpH as follows:

When NAGpH > 2 Titrate with 0.10M NaOH

When NAGpH < 2 Titrate with 0.50M NaOH

Calculation of NAG

$$\text{NAG (kg H}_2\text{SO}_4\text{/t)} = (49 \times V \times M) / W$$

Where: V = volume of NaOH used in titration (ml)

M = concentration of NaOH used in titration (moles/l)

W = mass of sample (g)

If the NAG value exceeds 25kg H₂SO₄ per ton, the procedure may need to be repeated using a lower sample mass (i.e. 1.0g).

Interpretation of NAG results

An indication of the acid potential of a sample can be obtained from the NAGpH and NAG results as follows:

Table A2: Interpretation of NAG results

NAG pH	NAG (kg H ₂ SO ₄ /t)	Acid Potential of Sample
= 4.5	0	Non-acid forming (NAF)
< 4.5	5 ¹	Potentially acid forming – lower capacity (PAF-LC)
< 4.5	> 5	Potentially acid forming (PAF)

¹ the NAG criteria used to specify PAF-LC materials may vary from site to site. The PAF-LC classification is used to describe materials that may be amenable to treatment with lime or blending with NAF or acid consuming material