

FORTESCUE METALS GROUP LTD

MINDY MINDY DEPOSIT

GEOCHEMICAL CHARACTERISATION OF

MINE-WASTE SAMPLES

['STATIC-TESTWORK']

Implications for Mine-Waste Management

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EXECUTIVE SUMMARY

In this study, a range of regolith and waste-bedrock samples derived from the wall-waste-zone of the Mindy Mindy Deposit have been geochemically characterised.

All lithotypes should be classified as Non-Acid Forming (NAF), due to minute/negligible amounts of sulphide-minerals. Enrichments in minor-elements in the NAF-lithotypes should only be slight (or non-existent), and soluble-salt contents should be low-to-moderate.

In brief, no geochemical concerns are foreseen for the mine-waste materials to be produced during open-pit mining of the Mindy Mindy Deposit.

SUMMARY OF TECHNICAL TERMS EMPLOYED IN THIS REPORT

ACRONYM	PARAMETER	DEFINITION/DETERMINATION	UNIT
AFP	Acid-Formation Potential		
ARD	Acid-Rock Drainage		
Total-S	Total Sulphur	Analysis Result	% (w/w)
Sulphide-S	Sulphide Sulphur	Testwork Result [i.e. Sulphide-S = Total-S - Sulphate-S]	% (w/w)
ANC	Acid-Neutralisation Capacity	Testwork Result	kg H ₂ SO ₄ /tonne
MPA	Maximum-Potential Acidity	Calculation	kg H ₂ SO ₄ /tonne
NAPP	Net-Acid-Producing Potential	Calculation	kg H ₂ SO ₄ /tonne
NAG	Net-Acid Generation	Testwork Result	kg H ₂ SO ₄ /tonne
NAF	Non-Acid Forming	Calculation:	kg H ₂ SO ₄ /tonne
		<ul style="list-style-type: none"> • Sulphide-S < 0.3 % • Sulphide-S ≥ 0.3 %, and negative-NAPP value with ANC/MPA ≥ 2.0 	
PAF	Potentially-Acid Forming	Calculation:	kg H ₂ SO ₄ /tonne
		<ul style="list-style-type: none"> • Sulphide-S ≥ 0.3 %, and any positive-NAPP value • Sulphide-S ≥ 0.3 %, and a negative-NAPP value with ANC/MPA < 2.0 	
PAF-[SL]	PAF-[Short-Lag]	Estimation [e.g. inferred from 'kinetic' testing]	
PAF-[LL]	PAF-[Long-Lag]	Estimation [e.g. inferred from 'kinetic' testing]	
SOR	Sulphide-Oxidation Rate	Testwork Result [e.g. obtained from 'kinetic' testing]	mg SO ₄ /kg/week,

Notes:

The **PAF-[SL]** classification applies to (initially circum-neutral) PAF-materials that may acidify (viz. pH less than 5) within a matter of weeks-to-months when subjected to "**aggressive-ambient-weathering**", corresponding to periods of at least a few days during which unsaturated-conditions prevail (via drainage/evaporation processes) between successive inundations that, in turn, occur semi-regularly (e.g. weekly-to-fortnightly "on-average" during most of the annual hydrological-cycle).

The **PAF-[LL]** classification applies to PAF-materials where exposure to the atmosphere for years (even decades, or longer) may be needed before acidification develops. Circum-neutral-pH during the "lag-phase" for such lithotypes is chiefly due to buffering reactions involving carbonate-minerals.

Climate directly influences the duration of the "lag-phase", and a sulphide-gangue assemblage classified as PAF-[SL] in a "humid" environment where the SOR is controlled by **O₂-supply**, may instead be classified as PAF-[LL] in semi-arid/arid environments where the SOR is controlled by **water-supply** (viz. frequency of "flushing-episodes") [Campbell 2004]. The formation of "secondary-oxidation-products" (e.g. Fe-oxyhydroxides) as protective-coatings is generally enhanced during the "lag-phase-stage" of mine-waste weathering in semi-arid/arid environments, and so further curtails sulphide-oxidation rates.

1.0 INTRODUCTION

Fortescue Metals Group Ltd is proposing to produce iron-ore from the Mindy Mindy Deposit located *c.* 70 kms north-west of Newman, Western Australia.

Ore will be produced through open-pit mining, and the excavated waste-rock materials (viz. various types of regoliths and bedrocks) placed on waste-dumps located in the vicinity of the Pit.

Graeme Campbell & Associates Pty Ltd (GCA) was commissioned to carry out geochemical testwork on a range of regolith, and waste-bedrock, samples derived from the Mindy Mindy Deposit.

The 'Static-Testwork' Programme focused on Acid-Formation Potential (AFP), Multi-Element Composition, and Mineralogy.¹

The testwork results are presented and discussed in this report, and implications for mine-waste management highlighted.

¹ A 'Static-Testwork' Programme comprises "whole-rock" analyses and tests.

2.0 STUDY APPROACH

Details of the sampling and testwork programmes, and the calculations and criteria employed for classifying the mine-waste samples into AFP categories, are presented and discussed in the following sections.

2.1 Testwork Programme

2.1.1 Samples

Details of the samples are presented in Appendix A.

The tested samples were derived from down-hole intervals of *c.* 1.0 m, and so allow assessment of mine-waste geochemistry, at the "metre-scale", in terms of sulphide/carbonate abundances, and minor-element content.

It is assumed that the samples submitted for testing herein are representative of the major types of mine-waste materials to be produced during open-pit mining of the Mindy Mindy Deposit.

2.1.2 Testwork

The samples were assigned GCA Sample-Numbers, and relevant details recorded in the GCA Sample-Register. All samples were crushed (nominal 2 mm), and pulped (nominal 75 µm), for specific tests.

The testwork methods employed in this study are based on recognised procedures for the geochemical characterisation of mine-waste materials (e.g. AMIRA 2002; Morin and Hutt 1997; Smith 1992; Coastech Research 1991; BC AMD Task Force 1989).

Part of the testwork was carried out by SGS Environmental Service [SGS] (Welshpool), and Genalysis Laboratory Services [GLS] (Maddington). The analyses performed by SGS and GLS have NATA endorsement.²

Specialised testing (viz. Net-Acid-Generation [NAG] Tests) was undertaken by Dr. Graeme Campbell in the GCA Testing-Laboratory (Bridgetown).

Details of the testwork methods are presented in Appendix B, and copies of the laboratory reports are presented in Appendix C.

2.2 Calculated Parameters

The Maximum-Potential-Acidity (MPA) values (in kg H₂SO₄/tonne) of the samples were calculated by multiplying the Sulphide-S values (in %) by 30.6. The multiplication-factor of 30.6 reflects both the reaction stoichiometry for the complete-oxidation of pyrite by O₂ to "Fe(OH)₃" and H₂SO₄, and the different weight-based units of % and kg H₂SO₄/tonne. The stoichiometry of pyrite-oxidation is discussed further in Appendix B.

Net-Acid-Producing-Potential (NAPP) values (in kg H₂SO₄/tonne) of mine-waste samples are usually calculated from the corresponding MPA and Acid-Neutralisation-Capacity (ANC) values (i.e. NAPP = MPA - ANC). However, since the Sulphide-S contents of all samples tested in this study were less than 0.1 %, no NAPP calculations were performed herein.

² NATA = National Association of Testing Authorities.

2.3 Classification Criteria

In terms of AFP, mine-waste materials may be classified into one of the following categories, viz.

- Non-Acid Forming (NAF).
- Potentially-Acid Forming (PAF).

There are **no** unifying, "standard" criteria for classifying the AFP of mine-waste materials (Campbell 2002a,b; Smith 1992), and reflects the diversity of sulphide and gangue-mineral assemblages within (un)mineralised-lithotypes of varying weathering- and alteration-status. Rather, criteria for classifying AFP may need to be tailored to deposit-specific geochemistry, and mineralogy.

The AFP-classification criteria often employed at mining-operations worldwide are:

- **NAF**: Sulphide-S < 0.3 %. For Sulphide-S \geq 0.3 %, both a negative NAPP value, and an ANC/MPA ratio \geq 2.0.
- **PAF**: For Sulphide-S \geq 0.3 %, any positive-NAPP value; negative-NAPP value with an ANC/MPA ratio < 2.0.

In assessing the AFP of mine-waste materials, there is consensus (e.g. mining/environmental regulators in British Columbia, Canada) that lithotypes with Sulphide-S contents less than 0.3 % are unlikely to oxidise at rates fast enough to result in acidification (e.g. pH less than 4-5) [Soregaroli and Lawrence 1997]. This position assumes that the groundmass hosting such "trace-sulphides" is not simply quartz, and/or clays (Price *et al.* 1997), and that for a carbonate-deficient gangue, the sulphides are not unusually reactive (e.g. sulphide-oxidation rates [SORs] less than *c.* 20-40 mg

SO₄/kg/week) [= c. 1-2 kg SO₄/tonne/year].³ A "cut-off" of 0.3 % for Sulphide-S also accords with the findings of 'kinetic' testing conducted, since the late-1980s, by Dr. Graeme Campbell for mine-waste samples of diverse mineralogy in terms of AFP.

The ANC/MPA criteria for the NAF category reflects the need to compensate for "less-than-perfect" availability of alkalinity-forms (e.g. carbonates) for neutralisation of acid produced through pyrite-oxidation. A "less-than-perfect" availability of alkalinity-forms may arise from:

- (a) Restricted accessibility of acid to carbonate-grains.
- (b) Rate-limiting dissolution of carbonates-grains near pH=7.
- (c) Depletion of carbonate-minerals through rainfall-fed leaching within waste-dumps.⁴

Restricted accessibility of acid to the surfaces of carbonate-grains may occur at different spatial-scales (viz. at the "whole-rock-scale" in which Acid-Rock Drainage [ARD] "bypasses" carbonate-bearing materials via preferential-flow pathways within a waste-dump, and at the "grain-scale" in which the surfaces of individual carbonate-grains are "blinded/rimmed" by precipitates of Fe(III)-oxyhydroxides [e.g. ferrihydrite-type phases]). As shown by Li (1997), ferroan-carbonates (especially "Fe-rich" varieties) are prone to "surface-armouring/rimming" during dissolution: weathering of tailings-solids containing pyrite, ankerites and Mg-siderites produced acidic leachates when less than one-third of the carbonate-grains had dissolved.

³ Although 'steady-state' SORs (at circum-neutral-pH) for Sulphide-S contents less than 0.3 % may indeed exceed 1-2 kg SO₄/tonne/year, such rates are generally restricted to either sedimentary forms (e.g. framboidal-pyrite), or hydrothermal-sulphides that are atypically reactive.

⁴ Depletion of carbonate-minerals through dissolution in meteoric-waters is minimal in semi-arid settings, especially within the "hydrologically-active-zone" (e.g. top 2-3 m) of a waste-dump, since re-precipitation occurs during evapo-concentration when desiccating conditions return after "wet-spells".

To compensate for the effects of (a) to (c) above, some authors advocate that, for a mine-waste sample to be classified as NAF, it must have an ANC/MPA ratio of at least 3.0 (see review of earlier literature by Smith [1992]). In recent years, fundamental-research (especially estimation of reaction-rates for diverse sulphide/gangue-mineral assemblages), and field-experience at mining operations world-wide, have shown that the potential for ARD production is very low for mine-waste materials with ANC/MPA ratios greater than 2.0 (AMIRA 2002; Price *et al.* 1997, Currey *et al.* 1997, and Murray *et al.* 1995).⁵ This ANC/MPA ratio is employed in the present work.⁶

The risk posed by handling PAF-lithotypes during the working of a deposit is governed primarily by the duration of the "lag-phase" (i.e. the period during which sulphide-oxidation occurs, but acidification does not develop, due to buffering near pH=7 by gangue-phases).⁷ Although the "lag-phase" applicable to exposed mine-wastes at "field-scale" cannot be accurately predicted *a priori*, estimates (albeit approximate) are still needed to identify the exposure-times for the safe handling of PAF-lithotypes, and so reduce the risk for ARD production. Estimates of the "lag-phase" are invariably obtained through programmes of 'kinetic' testing (viz. Weathering-Columns). However, based on experience, "first-pass" estimates of the "lag-phase" may be made, and thereby used to further classify PAF-lithotypes into **PAF-[Short-Lag]** and **PAF-[Long-Lag]** sub-categories. Such "first-pass" estimates are necessarily provisional, and subject to revision, in the light of the outcomes of 'kinetic' testing, and field observations.

⁵ Such ANC/MPA ratios are consistent with those indicated from SORs, and carbonate-depletion rates, as reported in the International-Kinetic Database for mine-waste materials from around the world (Morin and Hutt 1997).

⁶ It should be noted that mining-regulators in Nevada (USA) classify a mine-waste sample as NAF, if it is characterised by an ANC/MPA ratio greater than 1.2 (US EPA 1994). This lower ANC/MPA ratio reflects the semi-arid conditions typically encountered at mine-sites in Nevada. Although utilised in the early-1990s, it is understood that an ANC/MPA ratio of 1.2 is still entertained by regulators in Nevada for "screening" PAF and NAF varieties of mine-wastes in semi-arid settings.

⁷ SO₄ is still produced by sulphide-oxidation during the "lag-phase", and appreciable amounts of soluble-forms of certain minor-elements (e.g. As) may be released at circum-neutral-pH during the "within-lag-phase-stage" of mine-waste weathering.

3.0 ACID-BASE CHEMISTRY AND SALINITY OF MINE-WASTE SAMPLES

The testwork results on the acid-base chemistry and salinity of the regolith and waste-bedrock samples are presented in Table 3.1.⁸ These results are discussed in the following sections.

3.1 Regoliths

3.1.1 pH and Salinity

The samples had pH-(1:2) values of 6.3-7.5, and EC-(1:2) values of 0.073-0.31 mS/cm (Table 3.1).⁹

Although not measured, the soluble-salts in the samples should be dominated by chlorides.

The testwork results indicate that the samples were circum-neutral (viz. pH 6-8), with low contents of soluble-salts.

3.1.2 Sulphur Forms

The samples had Total-S values that ranged from less than 0.01 %, to 0.05 % (Table 3.1).

The testwork results indicate that the samples contained negligible amounts of sulphide-minerals (viz. Sulphide-S contents less than 0.1 %).

⁸ For the purposes of this report, the regoliths correspond to the detritals from the Quaternary-Alluvium.

⁹ EC= Electrical-Conductivity. The pH-(1:2) and EC-(1:2) Tests (and other testwork) are described in Appendix B.

3.1.3 Acid-Consuming Properties

The samples had ANC values of 1.2-3.9 kg H₂SO₄/tonne (Table 3.1).¹⁰

The testwork results indicate that the samples had a very-low capacity to consume acid.

3.1.4 Acid-Formation Potential

The samples had NAG-pH values of 6.9-7.3, and NAG values less than 0.5 kg H₂SO₄/tonne (Table 3.1).¹¹ Therefore, under the strongly-oxidising conditions of the NAG-testwork, the samples did not acidify.

The testwork results indicate that the samples were classified as NAF.

3.2 Waste-Bedrocks

3.2.1 pH and Salinity

The samples had pH-(1:2) values of 5.9-7.1, and EC-(1:2) values of 0.052-1.1 mS/cm (Table 3.1).

The testwork results indicate that the samples were circum-neutral (viz. pH 8-9), with low-to-moderate contents of soluble-salts.

¹⁰ ANC values of 1.2-3.9 kg H₂SO₄/tonne is equivalent to c. 0.12-0.39 % (as "CaCO₃").

¹¹ It should be noted that the "Single-Addition" version of the NAG Test (AMIRA 2002) was employed in this study.

3.2.2 Sulphur Forms

The samples had Total-S values that ranged from less than 0.01 %, to 0.09 % (Table 3.1).

The testwork results indicate that all samples contained negligible amounts of sulphide-minerals (viz. Sulphide-S contents less than 0.1 %).

3.2.3 Acid-Consuming Properties

The samples had ANC values that ranged from less than 0.5 kg H₂SO₄/tonne, to 2.6 kg H₂SO₄/tonne (Table 3.1).¹²

The testwork results indicate that the samples had a very-low capacity to consume acid.

3.2.4 Acid-Formation Potential

All samples had NAG values less than 0.5 kg H₂SO₄/tonne, and NAG-pH values of 6.6-7.2 (Table 3.1).

The testwork results indicate that all samples were classified as NAF.

¹² An ANC values of 2.6 kg H₂SO₄/tonne is equivalent to c. 0.26 % (as "CaCO₃").

4.0 MULTI-ELEMENT COMPOSITION OF MINE-WASTE SAMPLES

The multi-element composition of selected samples is indicated by the data presented in Tables 4.1 and 4.2.¹³ The corresponding element-enrichments, as indicated by the values of the Geochemical-Abundance Index (GAI), are also presented in these Tables.¹⁴ It should be noted that these element-enrichments are relative enrichments, based on the element contents typically recorded for unmineralised soils, regoliths and bedrocks (Bowen 1979).

The assayed samples had contents of most environmentally-significant elements below, or close to, those typically recorded for unmineralised soils and regoliths. Slight enrichments were apparent in some samples for As, Bi, Sb and Se.

The analysis results indicate that, geochemically, the assayed samples were "clean" with low contents of environmentally-significant elements.

¹³ The suite of elements listed in Tables 4.1 and 4.2 is grouped into (a) the major-elements (viz. Na, K, Mg, Ca, Al and Fe) making-up the lattices of primary-silicates, clays, sesquioxides and carbonates, and (b) minor-elements. A distinction is made between minor-elements which, under neutral-to-alkaline conditions, occur (i) as cationic-hydrolysis forms (e.g. Cu), and (ii) as anions/oxyanions (e.g. As). Anionic forms may exhibit moderate solubility under neutral-to-alkaline conditions.

¹⁴ The GAI is defined in Appendix B.

5.0 CONCLUSIONS

Based on the testwork results obtained in this study, it is concluded that the regoliths and waste-bedrocks to be produced during open-pit mining of the Mindy Mindy Deposit should be classified as NAF, due to minute/negligible amounts of sulphide-minerals.¹⁵ Enrichments in minor-elements in the NAF-lithotypes should only be slight (or non-existent), and soluble-salt contents should be low-to-moderate.

In brief, no geochemical concerns are foreseen for the mine-waste materials to be produced during open-pit mining of the Mindy Mindy Deposit.

¹⁵ NAF = Non-Acid Forming.

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TABLES

Table 3.1: Acid-Base-Analysis, Salinity and Net-Acid-Generation Results for Regolith and Waste-Bedrock Samples

GCA-SAMPLE NO.	LITHOTYPE	DRILLHOLE & DOWN-HOLE INTERVAL (m)	pH-(1:2)	EC-(1:2) [mS/cm]	TOTAL-S (%)	ANC	NAPP	NAG	NAG-pH	AFP
						kg H ₂ SO ₄ /tonne				CATEGORY
Sample of Quaternary-Alluvial (QA)										
GCA5612	Clay	MM44, 0-1	7.5 (7.5)	0.29 (0.28)	<0.01	3.4	nc	<0.5 (<0.5)	7.1 (7.1)	NAF
GCA5606	Clay	MM56, 8-9	7.2	0.31	0.05	2.2	nc	<0.5	7.1	NAF
GCA5603	Clay	MM18, 3-4	7.0 (7.2)	0.11 (0.11)	<0.01	3.9 (3.9)	nc	<0.5	6.9	NAF
GCA5599	Clay	MM12, 16-17	6.6	0.15	0.02	1.6	nc	<0.5	7.1	NAF
GCA5600	Banded-Iron Formation	MM39, 5-6	6.3	0.073	<0.01	1.2	nc	<0.5	7.3	NAF
Samples of Channel-Iron Deposits (CID)										
GCA5594	Goethite/Maghemite	MM04, 50-51	6.8	0.094	0.09	1.5	nc	<0.5	7.0	NAF
GCA5597	Goethite/Maghemite	MM34, 32-33	6.3	0.37	0.03	<0.5	nc	<0.5	7.1	NAF
GCA5604	Goethite/Maghemite	MM18, 15-16	6.8	0.26	0.02	1.8	nc	<0.5	6.6	NAF
GCA5609	Goethite/Maghemite	MM48, 4-5	7.1	0.25	0.03	2.6	nc	<0.5	6.6	NAF
GCA5610	Goethite/Maghemite	MM48, 18-19	7.0	0.22	0.02	1.4	nc	<0.5	7.1	NAF
GCA5607	Goethite/Hematite	MM56, 20-21	6.7	1.1	0.03	2.1	nc	<0.5	6.6	NAF
GCA5601	Limonite/Goethite	MM39, 25-26	5.9	0.12	0.02	0.6	nc	<0.5	7.0	NAF
GCA5596	Limonite/Goethite	MM50, 53-54	6.5	0.16	0.04	1.1	nc	<0.5	7.0	NAF
Samples of Paleochannel-Basal-Zone (BZ)										
GCA5595	Banded-Iron Formation	MM04, 73-74	6.7	0.078	0.10	0.9	nc	<0.5	7.1	NAF
GCA5611	Banded-Iron Formation	MM48, 35-36	6.4	0.30	<0.01	0.6	nc	<0.5	6.8	NAF
Sample of Archaean-Chert (AC)										
GCA5598	Calcite/Limonite	MM34, 50-51	6.1	0.052	<0.01	<0.5 (<0.5)	nc	<0.5	7.2	NAF
Sample of Bedrock (BD)										
GCA5602	Banded-Iron Formation	MM39, 44-45	6.0	0.19	0.02	<0.5	nc	<0.5	7.0	NAF
Sample of Archaean-Sediment (AS)										
GCA5605	Shale/Calcite	MM18, 25-26	7.1	0.11	0.07	0.7	nc	<0.5	6.6	NAF
Sample of Archaean-Iron-Formation (Ai)										
GCA5608	Banded-Iron Formation	MM56, 35-36	6.7	0.40	<0.01	0.6	nc	<0.5	6.9	NAF

Notes:
 EC = Electrical Conductivity; ANC = Acid-Neutralisation Capacity; NAPP = Net-Acid-Producing Potential; AFP = Acid-Formation Potential; NAF = Non-Acid Forming; nc = not calculated.
 pH-(1:2) and EC-(1:2) values correspond to pH and EC measured on sample slurries prepared with deionised-water, and a solid:solution ratio of c. 1:2 (w/w).
 All results expressed on a dry-weight basis, except for pH-(1:2) and EC-(1:2).
 Values in parentheses represent duplicates.

N.B. No NAPP values were calculated since the Total-S values were less than, or equal to, 0.10 %.

Table 4.1: Multi-Element-Analysis Results for Regolith and Waste-Bedrock Samples

Note: Refer Appendix B for the definition of the Geochemical-Abundance-Index (GAI) indicated in this table.

ELEMENT	TOTAL-ELEMENT CONTENT (mg/kg or %)			AV.-CRUSTAL- ABUNDANCE (mg/kg or %)	GEOCHEMICAL-ABUNDANCE INDEX (GAI)		
	Clay (GCA5612)	Banded-Iron Formation (GCA5600)	Goethite/ Maghemite (GCA5604)		Clay (GCA5612)	Banded-Iron Formation (GCA5600)	Goethite/ Maghemite (GCA5604)
Al	2.5%	3.1%	1.1%	8.2%	0	0	0
Fe	25.6%	32.5%	57.9%	4.1%	2	2	3
Na	0.045%	0.027%	0.019%	2.3%	0	0	0
K	0.44%	0.42%	0.020%	2.1%	0	0	0
Mg	0.14%	0.14%	0.072%	2.3%	0	0	0
Ca	0.15%	0.046%	0.039%	4.1%	0	0	0
Ag	<0.1	<0.1	<0.1	0.07	0	0	0
Cu	21	23	<1	50	0	0	0
Zn	34	35	22	75	0	0	0
Cd	<0.1	<0.1	<0.1	0.11	0	0	0
Pb	14	22	6	14	0	0	0
Cr	65	58	15	100	0	0	0
Ni	25	23	12	80	0	0	0
Co	5.7	6.1	5.8	20	0	0	0
Mn	330	360	220	950	0	0	0
Hg	0.05	0.06	0.06	0.05	0	0	0
Sn	1.0	1.1	0.4	2.2	0	0	0
Sr	21	12	4.3	370	0	0	0
Ba	97	85	26	500	0	0	0
Th	4.5	5.5	2.1	12	0	0	0
U	1.1	1.7	0.95	2.4	0	0	0
Tl	0.21	0.22	0.09	0.6	0	0	0
V	88	120	40	160	0	0	0
As	11	11	16	1.5	2	2	3
Bi	0.16	0.19	0.07	0.048	1	1	0
Sb	1.6	2.5	0.52	0.2	2	3	1
Se	0.28	0.36	0.56	0.05	2	2	3
Mo	1.3	1.9	1.4	1.5	0	0	0
B	<50	<50	<50	10	0	0	0
P	270	390	480	1,000	0	0	0
F	78	110	130	950	0	0	0

Note: Average-crustal abundance of elements based on Bowen (1979).

Table 4.2: Multi-Element-Analysis Results for Waste-Bedrock Samples

Note: Refer Appendix B for the definition of the Geochemical-Abundance-Index (GAI) indicated in this table.

ELEMENT	TOTAL-ELEMENT CONTENT (mg/kg or %)					AVERAGE-CRUSTAL-ABUNDANCE (mg/kg or %)	GEOCHEMICAL-ABUNDANCE INDEX (GAI)				
	Banded-Iron Formation (GCA5595)	Calcite/Limonite (GCA5598)	Banded-Iron Formation (GCA5602)	Shale/Calcite (GCA5605)	Banded-Iron Formation (GCA5608)		Banded-Iron Formation (GCA5595)	Calcite/Limonite (GCA5598)	Banded-Iron Formation (GCA5602)	Shale/Calcite (GCA5605)	Banded-Iron Formation (GCA5608)
Al	1.4%	2.9%	5.6%	2.9%	0.97%	8.2%	0	0	0	0	0
Fe	45.7%	6.5%	43.3%	4.3%	38.9%	4.1%	3	0	3	0	3
Na	0.008%	0.011%	0.012%	0.026%	0.026%	2.3%	0	0	0	0	0
K	0.019%	0.075%	0.004%	0.043%	0.029%	2.1%	0	0	0	0	0
Mg	0.049%	0.036%	0.047%	0.028%	0.074%	2.3%	0	0	0	0	0
Ca	0.020%	0.042%	0.019%	0.022%	0.037%	4.1%	0	0	0	0	0
Ag	<0.1	0.2	0.4	0.3	<0.1	0.07	0	1	2	2	0
Cu	7	6	8	4	<1	50	0	0	0	0	0
Zn	21	31	25	12	29	75	0	0	0	0	0
Cd	<0.1	<0.1	<0.1	1.9	<0.1	0.11	0	0	0	4	0
Pb	7	8	29	21	7	14	0	0	0	0	0
Cr	28	31	84	27	15	100	0	0	0	0	0
Ni	12	11	44	10	15	80	0	0	0	0	0
Co	3.7	1.4	7.6	1.4	4.6	20	0	0	0	0	0
Mn	220	31	470	41	320	950	0	0	0	0	0
Hg	0.13	0.17	0.03	0.10	0.49	0.05	1	1	0	0	3
Sn	1.0	1.1	5.0	1.7	0.7	2.2	0	0	1	0	0
Sr	1.7	4.7	5.8	13	4.6	370	0	0	0	0	0
Ba	8.6	39	36	120	26	500	0	0	0	0	0
Th	2.2	3.7	18	3.0	1.8	12	0	0	0	0	0
U	0.89	0.50	2.3	0.28	1.4	2.4	0	0	0	0	0
Tl	0.03	0.03	0.16	0.03	0.08	0.6	0	0	0	0	0
V	56	25	220	14	37	160	0	0	0	0	0
As	15	2	8	1	5	1.5	3	0	2	0	1
Bi	0.15	0.13	0.47	0.17	0.08	0.048	1	1	3	1	0
Sb	1.6	0.99	11	2.3	1.4	0.2	2	2	5	3	2
Se	0.42	0.04	0.09	0.04	0.12	0.05	2	0	0	0	1
Mo	3.6	0.8	2.4	0.6	0.7	1.5	1	0	0	0	0
B	<50	<50	<50	<50	<50	10	0	0	0	0	0
P	700	160	950	110	840	1,000	0	0	0	0	0
F	120	57	100	73	70	950	0	0	0	0	0

Note: Average-crustal abundance of elements based on Bowen (1979).

APPENDIX A

DETAILS OF SAMPLING PROGRAMME

Sample Number	RC Hole ID	Easting	Northing	Sample Depth		End of RC hole depth/m	Stratigraphy	Min 1	Min 2	Min 3	Min 4	Standing Water Level/m below collar	Comments
				From	To								
	MM04	742251	7479483	50	51	84	CID	GO (50)	MH (50)				
	MM04	742251	7479483	73	74	84	BZ	Bi(100)					
	MM50	742390	7479619	53	54	76	CID	LO (50)	GO (45)	Mh (5)			
	MM34	742287	7478753	32	33	52	CID	GO (90)	Mh (10)				
	MM34	742287	7478753	50	51	52	AC	Ct (80)	LO (20)				
	MM12	742389	7478763	16	17	36	Qa	Cy (50)	Bi (45)	Mh (5)			
	MM39	742872	7477235	5	6	46	Qa	Bi (50)	Cy (40)	Mh (10)			
	MM39	742872	7477235	25	26	46	CID	LO (70)	GO (30)				
	MM39	742872	7477235	44	45	46	BD	Bi (99)	Cy (1)				
	MM18	743653	7475847	3	4	30	Qa	Cy (50)	Bi (45)	Mh (5)			
	MM18	743653	7475847	15	16	30	CID	GO (94)	Mh (5)	Cy (1)			
	MM18	743653	7475847	25	26	30	As	Sh (50)	Ct (50)				
	MM56	744124	7474314	8	9	40	Qa	Cy (50)	Bi (30)	Mh (20)			
	MM56	744124	7474314	20	21	40	CID	GO (60)	HO (30)	Mh (10)			
	MM56	744124	7474314	35	36	40	Ai	Bi (100)					
	MM48	745543	7473472	4	5	40	CID	GO (90)	Mh (10)				
	MM48	745543	7473472	18	19	40	CID	GO (85)	Mh (10)	Cy (5)			
	MM48	745543	7473472	35	36	40	BZ	Bi (100)					
	MM44	744076	7475144	0	1	34	Qa	Cy (60)	Bi (30)	Mh (10)			

VALIDATION CODES

STRATIGRAPHY

AI	Alluvium	SWP	Surface Weathered Profile
SC	Scree	MOZ	Main ore Zone
FeSC	Enriched Scree	BDZ	Basal denatured Zone
CA	Canga	BCG	Basal Conglomerate
CID	Channel Iron Deposits	BD	Bedrock

LITHOLOGY

BI	Banded Iron-formation	GO	Goethite	OP	Opalite
BS	Black shale	GP	Gypsum	PI	Pisolite
CF	Cavity fill	HO	Hematite	PD	Pedolith
CH	Chert	HS	Hematised shale	PY	Pyrite
CL	Clay	LG	Limonic goethite	OZ	Quartz
CT	Calcite	LO	Limonite	RO	Red Ochre
CV	Cavity Fill	MH	Maghemite	SH	Shale
DM	Dolomite	MN	Manganese	ST	Silcrete
DT	Dolerite	MO	Magnetite	VG	Vitreous goethite
FS	Ferruginous shale	MS	Manganiferous shale	SD	Siderite
GL	Goethitic limonite	MT	Magnetite		

SHAPE OF CHIPS

VA	Very angular	SA	Sub angular	RR	Rounded
AA	Angular	SR	Sub rounded	WR	Well rounded

HARDNESS

VS	Very soft	MS	Moderately soft	H	Hard
S	Soft	MH	Moderately hard	VH	Very hard

MAGNETISM

VS	Very strong	M	Medium	TR	Trace
S	Strong	W	Weak	-	None detected

COLOUR

As per Munsell Colour Charts

APPENDIX B

TESTWORK METHODS

APPENDIX B

TESTWORK METHODS

B1.0 ACID-BASE-CHEMISTRY AND SALINITY TESTWORK

The acid-base chemistry and salinity of the regolith and waste-bedrock samples was assessed by determining:

- pH and Electrical-Conductivity (EC) on sample slurries.
- Total-Sulphur (Total-S) and Sulphate-Sulphur (SO₄-S).
- Acid-Neutralisation-Capacity (ANC).
- Net-Acid-Generation (NAG).

Relevant details of the testwork methods employed are discussed briefly below. Further details are presented in the laboratory reports (see Appendix C).

B1.1 pH-(1:2) and EC-(1:2) Tests

Measurements of pH and EC were performed on slurries prepared using deionised-water, and a solid:water ratio of *c.* 1:2 (w/w). The sample slurries were allowed to age in contact with the air for *c.* 24 hours, prior to measuring pH and EC.¹

¹ The sample slurries were stirred at the beginning of the testwork, and once again immediately prior to measuring pH and EC.

The resulting pH-(1:2) and EC-(1:2) values provide a measure of the inherent acidity/alkalinity and salinity of the samples.²

B1.2 Total-S and SO₄-S Tests

The Total-S values were measured by Leco combustion (@ 1300 °C) with detection of evolved SO_{2(g)} by infra-red spectroscopy.

The SO₄-S values were determined by the Na₂CO₃-Extraction Method (Lenahan and Murray-Smith 1986).³ The difference between the Total-S and SO₄-S values indicates the Sulphide-S (strictly Non-Sulphate-S) content.

B1.3 ANC Tests

The ANC values of the samples were determined by a procedure based on that of Sobek *et al.* (1978). This procedure is essentially the "standard" method employed for estimating the ANC values of mine-waste materials (Morin and Hutt 1997; BC AMD Task Force 1989).

The samples were reacted with dilute HCl for *c.* 2 hours at 80-90 °C, followed by back-titration with NaOH to a pH=7 end-point to determine the amount of acid consumed.⁴ The simmering step for *c.* 2 hours differs slightly from the heating treatment of the

² The pH-(1:2) values approximate the "Abrasion-pH" values employed for identifying minerals in the field (Stevens and Carron 1948).

³ The Na₂CO₃-reagent extracts SO₄-S which occurs as soluble sulphates, and calcium sulphates (e.g. gypsum and anhydrite). It also extracts SO₄ sorbed to the surfaces of sesquioxides, clays and silicates. However, SO₄ present as barytes (BaSO₄) is not extracted, and SO₄ associated with jarositic-type and alunitic-type compounds are incompletely extracted.

⁴ Two drops of 30 % (w/w) H₂O₂ were added to the test mixtures as the pH=7 end-point was approached, so that any Fe(II) forms released by the acid-attack of ferroan-carbonates and -silicates are oxidised to Fe(III) forms (which then hydrolyse to "Fe(OH)₃"). This step ensures that the resulting ANC values are not unduly biased "on-the-high-side", due to the release of Fe(II) during the acidification/digestion step. Such potential bias in ANC values may be marked for mine-waste samples in which "Fe-rich" ferroan-carbonates (e.g. siderite) dominate acid consumption. The addition of the H₂O₂ reagent is not part of the methodology described by Sobek *et al.* (1978).

Sobek *et al.* procedure wherein the test mixtures are heated to near boiling until reaction is deemed to be complete (viz. gas evolution not visually apparent), followed by boiling for one minute. In terms of dissolution of carbonate, primary-silicate and oxyhydroxide minerals, this variation to the Sobek *et al.* method is inconsequential.

The Sobek *et al.* (1978) procedure exposes mine-waste samples to both strongly-acidic conditions (e.g. pH of 1-2), and a near-boiling temperature. Provided excess acid is added, this method ensures that carbonate-minerals (including ferroan and manganoan varieties) are dissolved quantitatively, and that at least traces of ferro-magnesian silicates (e.g. amphiboles, pyroxenes, chlorites, micas, etc.), and feldspars, are dissolved. However, under circum-neutral (viz. pH 6-8) conditions required for mine-waste and environmental management, the dissolution of ferro-magnesian silicates is kinetically extremely slow (e.g. see review-monograph by White and Brantley [1995]). Near pH=7, the dissolution rates (under 'steady-state' conditions, and in the absence of inhibiting alteration-rims) of mafic-silicates and feldspars generally correspond to H₂SO₄-consumption rates 'of-the-order' 10⁻¹¹/10⁻¹² moles/m²/s (White and Brantley 1995). As a guide, for minerals of sub-mm grading, such silicate-dissolution rates correspond to Sulphide-Oxidation Rates (SORs) ranging up to 'of-the-order' 1-10 mg SO₄/kg/week (= c. 0.1-1.0 kg H₂SO₄/tonne/year).⁵ Maintenance of circum-neutral-pH through dissolution/hydrolysis of primary-silicates is therefore restricted to both "mineral-fines", and slow rates of pyrite weathering.

Despite the aggressive-digestion conditions employed, the ANC values determined by the Sobek *et al.* (1978) method allow an informed, initial "screening" of mine-waste materials in terms of acid-consuming and pH-buffering properties, especially when due account is taken of gangue mineralogy (Morin and Hutt 1997). Jambor *et al.* (2000, 2002) have presented a compendium of 'Sobek-ANC' values for specific classes of primary-silicates, and assists interpretation of the ANC values recorded for mine-waste materials of varying mineralogy.

⁵ SORs of this magnitude (at circum-neutral-pH) would typically only be recorded for the oxidation of "trace-sulphides" (e.g. Sulphide-S contents less than 0.5 %).

B1.4 NAG Tests

The NAG Test is a direct measure of a sample's potential to produce acid through sulphide oxidation, and also provides an indication of the reactivity of the sulphides, and the availability of the alkalinity-forms contributing to the ANC (AMIRA 2002; Miller *et al.* 1997, 1994).

In this test, the sample is reacted with H₂O₂ to rapidly oxidise contained sulphides, and allow the produced acid to react with the acid-neutralising materials (e.g. carbonates). The NAG Test supplements the NAPP-based assessment of the acid-formation potential of mine-waste materials (Morin and Hutt 1997).

The procedure employed in this study is based on that for the 'Static-NAG Test' (AMIRA 2002; Miller *et al.* 1994, 1997). The Start-pH of the 15 % (w/w) H₂O₂ solution (prepared from A.R.-grade H₂O₂) was adjusted to pH=4.5 using dilute NaOH. In addition, the boiling treatment to decompose residual, unreacted-H₂O₂ following overnight reaction was carried out in two stages (*viz.* boiling for *c.* 2 hours initially, cooling and addition of 1 mL of 0.02 M-CuSO₄ to the test mixtures, followed by boiling again for *c.* 2 hours). The addition of Cu(II) salts catalyses the decomposition of residual H₂O₂, and thereby prevents "positive-blank" values being obtained (O'Shay *et al.* 1990).⁶ Pulped K-feldspar was employed for the blanks run for the NAG testwork.

Prior to the boiling steps, the pH values of the test-mixture suspensions are measured, and invariably correspond to an "overnight-period" of reaction. Such pH values reflect buffering under ambient conditions without accelerated dissolution of gangue-phases through boiling to decompose any unreacted-H₂O₂. In the interpretation of NAG-testwork data, it is important to take note of the pH values recorded prior to the boiling steps, especially for mine-waste samples that have both Sulphide-S contents less than 1

⁶ Where mine-waste samples contain sufficient Cu, then Cu(II) forms will be released to solution during the NAG Test, especially at low pH.

%, and ANC values less than *c.* 10 kg H₂SO₄/tonne (as typically recorded for a felsic/mafic-gangue that is void of carbonates). Furthermore, oxidation by H₂O₂ is generally at least 10³ faster than the SORs recorded during 'kinetic' testing (e.g. Weathering-Columns) of mine-waste samples. If circum-neutral conditions are to prevail during NAG testwork, then the rate of acid consumption by gangue-phases must be proportionately faster (c.f. rates for 'ambient-weathering'), and is essentially restricted to pH-Buffering by carbonates (viz. calcites, dolomites and ankerites) that are not unduly ferroan. This aspect must also be borne in mind when interpreting NAG-testwork data, especially for mine-waste materials that contain "trace-sulphides" in a carbonate-void gangue, since the dissolution/hydrolysis kinetics of primary-silicates (both felsic- and mafic-silicates) are strongly pH-dependent.

B2.0 MULTI-ELEMENT ANALYSES

The total content of a wide range of major- and minor-elements in selected samples was determined through the use of various digestion and analytical techniques. The detection-limits employed in these analyses are appropriate for environmental investigations.

Element enrichments were identified using the *Geochemical Abundance Index (GAI)*.⁷

The GAI quantifies an assay result for a particular element in terms of the average-crustal-abundance of that element.⁸

⁷ The GAI was developed by Förstner *et al* (1993), and is defined as:

$$\text{GAI} = \log_2 [C_n / (1.5 \times B_n)]$$

where:

C_n = measured content of n-th element in the sample.

B_n = "background" content of the n-th element in the sample.

⁸ The average-crustal-abundances of the elements for the GAI calculations are based on the values listed in Bowen (1979).

The GAI (based on a log-2 scale) is expressed in 7 integer increments (viz. 0 to 6). A GAI of 0 indicates that the content of the element is less than, or similar to, the average-crustal-abundance; a GAI of 3 corresponds to a 12-fold enrichment above the average-crustal-abundance; and so forth, up to a GAI of 6 which corresponds to a 96-fold, or greater, enrichment above average-crustal-abundances.

APPENDIX C

LABORATORY REPORTS



9 December, 2004

Graeme Campbell & Associates Pty Ltd
Attn: Dr G Campbell
PO Box 247
BRIDGETOWN WA 6255

Our Reference: 85270
Your Reference: GCA0417/4
NATA Accreditation: 2562(1705)

Dear Sir

On the 16th November 2004 you forwarded test work instructions for nineteen (19) waste rock samples that were received on the 17th November 2004 at our laboratory. As per your instructions all samples were crushed and pulped. Approximately 50 grams of pulps were sent to Graeme Campbell and Associates.

Results of all test work performed follow:

Sample Number	pH (1:2) (pH Units)	Conductivity (1:2) µs/cm	Total Sulphur, S (%w/w)
GCA5594	6.8	94	0.09
GCA5595	6.7	78	0.10
GCA5596	6.5	160	0.04
GCA5597	6.3	370	0.03
GCA5598	6.1	52	<0.01
GCA5599	6.6	150	0.02
GCA5600	6.3	73	<0.01
GCA5601	5.9	120	0.02
GCA5602	6.0	190	0.02
GCA5603	7.0	110	<0.01
RPT GCA 5603	7.2	110	-
GCA5604	6.8	260	0.02
GCA5605	7.1	110	0.07
GCA5606	7.2	310	0.05
GCA5607	6.7	1,100	0.03
GCA5608	6.7	400	<0.01
GCA5609	7.1	250	0.03
GCA5610	7.0	220	0.02
GCA5611	6.4	300	<0.01
GCA5612	7.5	290	<0.01
RPT GCA5612	7.5	280	-

NOTE:

- Total sulphur was determined on dried pulped sample by LECO induction furnace, IR detection, and is reported on that basis. This test work was performed by SGS Minerals Services, Welshpool, report number WM082662 (NATA1936).*

CLIENT: Graeme Campbell & Associates Pty Ltd **OUR REFERENCE:** 85270
PROJECT NO: GCA0417/4

Acid Neutralisation Capacity (ANC):

Sample Number	Fizz Rating	Sample Weight (g)	Titre NaOH (mL)	Normality HCl/NaOH (N)	Initial Effervescence	Effervescence on Warming	ANC Solution pH	ANC (kg H ₂ SO ₄ /tonne)
GCA5594	0	5.04	23.50	0.1	Nil	Nil	1.5	1.5
GCA5595	0	4.97	24.20	0.1	Nil	Nil	1.6	0.9
GCA5596	0	5.02	24.00	0.1	Nil	Nil	2.2	1.1
GCA5597	0	5.05	24.70	0.1	Nil	Nil	1.5	<0.5
GCA5598	0	5.04	24.80	0.1	-	-	1.7	<0.5
RPT GCA 5598	0	5.03	24.70	0.1	Nil	Nil	1.6	<0.5
GCA5599	0	4.99	23.50	0.1	Nil	Nil	2.1	1.6
GCA5600	0	5.02	23.90	0.1	Nil	Nil	1.8	1.2
GCA5601	0	5.03	24.50	0.1	Nil	Nil	1.8	0.6
GCA5602	0	2.0079	25.00	0.1	Nil	Nil	2.3	<0.5
GCA5603	0	2.0074	23.50	0.1	Nil	Nil	1.6	3.9
RPT GCA 5603	0	2.0130	23.50	0.1	-	-	1.6	3.9
GCA5604	0	4.99	23.30	0.1	Nil	Nil	1.5	1.8
GCA5605	0	4.99	24.40	0.1	Nil	Nil	1.9	0.7
GCA5606	0	5.03	22.80	0.1	Nil	Nil	1.8	2.2
GCA5607	0	4.9788	23.00	0.1	Nil	Nil	1.5	2.1
GCA5608	0	4.9819	24.50	0.1	Nil	Nil	1.7	0.6
GCA5609	0	5.0387	22.40	0.1	Nil	Nil	2.0	2.6
GCA5610	0	4.9976	23.70	0.1	Nil	Nil	1.8	1.4
GCA5611	0	5.0414	24.50	0.1	Nil	Nil	1.9	0.6
GCA5612	0	5.0397	21.60	0.1	Nil	Nil	2.0	3.4
ANC Std 20	-	2.0445	17.00	0.1	-	-	1.6	19.3

NOTES:

1. *Acid neutralisation capacity was determined on the nominal 2mm crushed sample. Unless otherwise stated, 25mL of HCl is used. Reagent blank titre of 0.5N NaOH was 25.00mL and 0.1N NaOH was 25.10mL.*
2. *ANC Std20 is an internally produced standards of CaCO₃ and quartz pulped to a nominal 75µm particle size which has nominal ANC of 20kg of H₂SO₄/tonne.*
3. *This procedure is based on Sobek et al, 1978.*

CLIENT: Graeme Campbell & Associates Pty Ltd **OUR REFERENCE:** 85270
PROJECT NO: GCA0417/4



NATA Endorsed Test Report

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NATA Accredited Laboratory No. 2562

Yours faithfully,

Steven Edmatt.

STEVEN EDMETT
Client Liaison Manager

A handwritten signature in black ink that reads 'J. Venning'.

JANICE VENNING
Manager, Perth

This report supersedes our preliminary results sent by facsimile on the 7th December 2004.

Graeme Campbell & Associates Pty Ltd Laboratory Report
NET-ACID-GENERATION (NAG) TESTWORK

Sample Number	Sample Weight (g)	Comments	pH of Test Mixture Before Boiling Step	Test Mixture After Boiling Step		Titre [0.1 M-NaOH] (mL)	NAG (kg H ₂ SO ₄ /tonne)
				pH	EC (µS/cm)		
GCA5594	4.0	Reaction peaked overnight (?)	5.8	7.0	53	-	<0.5
GCA5595	4.5	Reaction peaked overnight (?)	5.7	7.1	51	-	<0.5
GCA5596	4.0	Reaction peaked overnight (?)	5.9	7.0	41	-	<0.5
GCA5597	3.6	Reaction peaked overnight (?)	4.9	7.1	47	-	<0.5
GCA5598	4.6	Reaction peaked overnight (?)	5.4	7.2	51	-	<0.5
GCA5599	4.2	Reaction peaked overnight (?)	5.9	7.1	56	-	<0.5
GCA5600	3.7	Reaction peaked overnight (?)	5.8	7.3	52	-	<0.5
GCA5601	4.7	Reaction peaked overnight (?)	5.4	7.0	53	-	<0.5
GCA5602	5.2	Reaction peaked overnight (?)	5.5	7.0	54	-	<0.5
GCA5603	5.3	Reaction peaked overnight (?)	6.3	6.9	57	-	<0.5
GCA5604	4.2	Reaction peaked overnight (?)	5.8	6.6	60	0.30	<0.5
GCA5605	5.3	Reaction peaked overnight (?)	5.6	6.6	57	0.30	<0.5
GCA5606	4.8	Reaction peaked overnight (?)	5.6	7.1	70	-	<0.5
GCA5607	5.1	Reaction peaked overnight (?)	5.7	6.6	97	0.40	<0.5
GCA5608	4.3	Reaction peaked overnight (?)	6.2	6.9	61	-	<0.5
GCA5609	4.6	Reaction peaked overnight (?)	6.0	6.6	63	0.30	<0.5
GCA5610	5.5	Reaction peaked overnight (?)	6.0	7.1	58	0.30	<0.5
GCA5611	4.1	Reaction peaked overnight (?)	5.6	6.8	54	-	<0.5
GCA5612	4.4	Reaction peaked overnight (?)	6.6	7.1	57	-	<0.5
GCA5612 (Repeat)	4.10	Reaction peaked overnight (?)	6.6	7.1	63	-	<0.5
Blank	8.7		5.3	7.2	50	-	<0.5

Notes: Test conditions based on those described by Miller *et al.* (1997). The pH of the 15 % (v/v) H₂O₂ solution was adjusted to 4.5 using 0.1 M-NaOH prior to commencing the NAG Tests. Test mixtures boiled for *c.* 2 hours to accelerate reaction with H₂O₂. Then, after allowing the test mixtures to cool, 1.0 mL of 0.016 M-CuSO₄ solution was added, and the test mixtures again boiled for *c.* 2 hours. The addition of Cu(II) catalyses the decomposition of any residual, unreacted H₂O₂ in the test mixtures (O'Shay *et al.* 1990). K-Feldspar was employed for the Blanks. Samples labelled with an asterisk signifies that 0.5 M-NaOH employed.

Dr GD Campbell
2nd January 2005

ANALYTICAL REPORT

Dr G. CAMPBELL
CAMPBELL, GRAEME and ASSOCIATES
 PO Box 247
 BRIDGETOWN, W.A. 6255
 AUSTRALIA

JOB INFORMATION

JOB CODE : 143.0/0409671
 No. of SAMPLES : 8
 No. of ELEMENTS : 32
 CLIENT O/N : GCA0417/4
 SAMPLE SUBMISSION No. :
 PROJECT : Mindy Mindy Iron Ore Project
 STATE : Solid
 DATE RECEIVED : 03/12/2004
 DATE COMPLETED : 30/12/2004
 DATE PRINTED : 30/12/2004

LEGEND

X = Less than Detection Limit
 N/R = Sample Not Received
 * = Result Checked
 () = Result still to come
 I/S = Insufficient Sample for Analysis
 E6 = Result X 1,000,000
 UA = Unable to Assay
 > = Value beyond Limit of Method

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SAMPLE DETAILS

DISCLAIMER

Genalysis Laboratory Services Pty Ltd wishes to make the following disclaimer pertaining to the accompanying analytical results.

Genalysis Laboratory Services Pty Ltd disclaims any liability, legal or otherwise, for any inferences implied from this report relating to either the origin of, or the sampling technique employed in the collection of, the submitted samples.

SIGNIFICANT FIGURES

It is common practice to report data derived from analytical instrumentation to a maximum of two or three significant figures. Some data reported herein may show more figures than this. The reporting of more than two or three figures in no way implies that the third, fourth and subsequent figures may be real or significant.

Genalysis Laboratory Services Pty Ltd accepts no responsibility whatsoever for any interpretation by any party of any data where more than two or three significant figures have been reported.

SAMPLE STORAGE DETAILS

GENERAL CONDITIONS

SAMPLE STORAGE OF SOLIDS

Bulk Residues and Pulps will be stored for 60 DAYS without charge. After this time all Bulk Residues and Pulps will be stored at a rate of \$1.50 per cubic metre per day until your written advice regarding collection or disposal is received. Expenses related to the return or disposal of samples will be charged to you at cost. Current disposal cost is charged at \$50.00 per cubic metre.

SAMPLE STORAGE OF SOLUTIONS

Samples received as liquids, waters or solutions will be held for 60 DAYS free of charge then disposed of, unless written advice for return or collection is received.

NOTES

*** NATA ENDORSED DOCUMENT ****

Company Accreditation Number 3244

The contents of this report have been prepared in accordance with the terms of NATA accreditation and as such should only be reproduced in full.

The analysis results reported herein have been obtained using the following methods and conditions:

The 8 samples, as listed in the report, were received as being waste rocks.

The samples required drying at 45 degrees Celcius prior to being fine pulverised in a zirconia bowl.

The results have been determined according to Genalysis method numbers :
SL_W001 (A/), SL_W007 (BP/), ENV_W012 (DH/SIE), SL_W013 (D/) and SL_W012 (CM/)
for the digests and ICP_W004 (/OES), ICP_W005 (/MS) and AAS_W004 (/CVAP).

The results included the assay of blanks and international reference standards WGB-1 and SO-3 and Genalysis in-house standards TKC4, AE12 and HgSTD-3.

The results are expressed as parts per million or percent by mass in the dried and prepared material.

NATA Signatory: T K Chan

Date: 30th December 2004

ANALYSIS

ELEMENTS	Ag	Al	As	B	Ba	Bi	Ca	Cd	Co	Cr
UNITS	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
DETECTION	0.1	20	1	50	0.1	0.01	10	0.1	0.1	2
DIGEST	A/	A/	A/	D/	A/	A/	A/	A/	A/	A/
ANALYTICAL FINISH	MS	OES	MS	OES	MS	MS	OES	MS	MS	OES
SAMPLE NUMBERS										
0001 GCA5595	X	1.40%	15	X	8.6	0.15	198	X	3.7	28
0002 GCA5598	0.2	2.83%	2	X	38.1	0.13	412	X	1.4	31
0003 GCA5600	X	3.02%	11	X	84.9	0.19	453	X	6.1	58
0004 GCA5602	0.4	5.54%	8	X	35.8	0.47	190	X	7.6	84
0005 GCA5604	X	1.06%	16	X	25.2	0.07	390	X	5.8	15
0006 GCA5605	0.3	2.83%	1	X	112.3	0.17	216	1.9	1.4	27
0007 GCA5608	X	9661	5	X	25.7	0.08	367	X	4.6	15
0008 GCA5612	X	2.48%	11	X	96.6	0.16	1493	X	5.7	65

CHECKS

0001 GCA5595	X	1.43%	15	X	8.8	0.13	265	X	3.7	28
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STANDARDS

0001 AE12										
0002 HgSTD-3										
0003 SO-3										
0004 TKC4				811						
0005 WGB-1	0.1	6.83%	2		811.1	0.02	12.07%	X	28.6	319

BLANKS

0001 Control Blank	X	X	X	X	X	X	16	X	X	X
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ANALYSIS

ELEMENTS	V	Zn
UNITS	ppm	ppm
DETECTION	2	1
DIGEST	A/	A/
ANALYTICAL FINISH	OES	OES

SAMPLE NUMBERS

0001 GCA5595	56	21
0002 GCA5598	25	31
0003 GCA5600	111	35
0004 GCA5602	211	25
0005 GCA5604	40	22

0006 GCA5605	14	12
0007 GCA5608	37	29
0008 GCA5612	88	34

CHECKS

0001 GCA5595	58	22
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STANDARDS

0001 AE12		
0002 HgSTD-3		
0003 SO-3		
0004 TKC4		
0005 WGB-1	273	30

BLANKS

0001 Control Blank	X	2
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METHOD CODE DESCRIPTION

A/MS

Multi-acid digest including Hydrofluoric, Nitric, Perchloric and Hydrochloric acids in Teflon Beakers. Analysed by Inductively Coupled Plasma Mass Spectrometry.

A/OES

Multi-acid digest including Hydrofluoric, Nitric, Perchloric and Hydrochloric acids in Teflon Beakers. Analysed by Inductively Coupled Plasma Optical (Atomic) Emission Spectrometry.

BP/MS

Aqua-Regia digest followed by Precipitation and Concentration. Specific for Selenium. Analysed by Inductively Coupled Plasma Mass Spectrometry.

D/OES

Sodium peroxide fusion (Zirconium crucibles) and Hydrochloric acid to dissolve the melt. Analysed by Inductively Coupled Plasma Optical (Atomic) Emission Spectrometry.

DH/SIE

Alkaline fusion (Nickel crucible) specific for Fluorine. Analysed by Specific Ion Electrode.

CM/CVAP

Low temperature Perchloric acid digest specific for Mercury. Analysed by Cold Vapour Generation Atomic Absorption Spectrometry.