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# Wonarah Phosphate Project

ACID FORMING CHARACTERISTICS OF WASTE ROCK COMPOSITE SAMPLES FROM THE ARRUWURRA PROSPECT AND MAIN ZONE AND LOW GRADE ORE
FINAL

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# 1.0 Introduction

Environmental Geochemistry International Pty Ltd (EGi) were commissioned by Coffey Natural Systems Pty Ltd on behalf of Minemakers Australia Pty Ltd to carry out geochemical characterisation of composite waste rock samples from the Wonarah Phosphate Project in the Northern Territory. The project consists of two deposits, Main Zone and Arruwurra, with mining likely to begin with the Arruwurra Prospect. Testing of samples from the Wonarah Phosphate Project was undertaken in two separate stages. The first consisting of samples from the Arruwurra Prospect and the second consisting of samples from the Main Zone together with low-grade ore (from both deposits).

The objectives of the testing program were to:

- Determine the acid-forming characteristics of the samples;
- Evaluate the acid rock drainage (ARD) potential of the materials;
- Assess the availability of acid neutralising capacity (ANC) within the materials; and.
- Determine the elemental composition and enrichment of elements of environmental concern.

This report presents the results and findings of the geochemical test work conducted on all the samples.

# 2.0 Sample Description and Test Programme

The samples were provided in two batches with the first consisting of 47 composite waste rock samples from the Arruwurra Prospect (received by EGi on the 19$^{th}$ March 2009). The second batch comprised of 51 composite waste rock samples from the Main Zone and 20 low-grade ore samples (from both deposits), which was received by EGi on the 28$^{th}$ July 2009.

The composite waste rock samples were prepared on site using the following criteria:

- Sample holes selected to cover spatial and depth variation in geological units within the mining area.
- All lithological units within the mining area to be represented in the composite samples.
- Individual samples included in each composite should not transcend across different lithological boundaries or across different holes.
- Where possible for each hole, 4 composites should be made from overburden and 1 composite made from basement material. Composites should comprise no greater than 5 m intervals combined together.

- Composite samples should be about 1.5 to 2 kg each.

Upon receipt of samples, a 200 g split was sent to Sydney Environmental and Soil Laboratory (SESL) to pulverise to -75µm.

The testing program was as follows:

- Total sulphur analysis (all samples);
- Acid neutralising capacity (ANC) determination (all samples);
- $pH_{1:2}$ and $EC_{1:2}$ on water extracts (all Arruwurra Prospect samples, selected samples from the Main Zone and selected low grade ore samples);
- Single addition net acid generation (NAG) testing (all Arruwurra Prospect samples, selected samples from the Main Zone and selected low grade ore samples);
- Acid buffering characteristic curve (ABCC) testing (selected samples from the Arruwurra Prospect);
- Multi-element scans on liquors (selected samples from both batches); and
- Multi-element scans on solids (selected samples from both batches).

Samples from the second batch were selected for $pH_{1:2}$ and $EC_{1:2}$ and single addition NAG testing as results from testing of the Arruwurra Prospect samples indicated that waste rock would not be problematic with respect to ARD and metal leaching and it was expected that samples from the second batch would have similar characteristics.

Water extracts for pH, EC and multi-element scans on liquors were carried out on the as received samples. All other test work was carried out on pulverised samples.

Leco total sulphur assays were carried out by SESL, multi-element scans on solids were conducted by Australian Laboratory Services (ALS) in Brisbane and multi-element scans on water extracts was conducted by ALS in Sydney. All other analyses were carried out by EGi.

A general description of the pH/EC, total S, ANC and NAG test methods is included in Appendix A.

# 3.0 Results

## 3.1 Arruwurra Prospect

The geochemical test results of the Arruwurra Prospect composites are presented in Table 1 and comprise pH and EC of water extracts, total S, MPA, ANC, NAPP, ANC/MPA ratio and single addition NAG.

### *3.1.1 pH and EC*

The $pH_{1:2}$ and $EC_{1:2}$ tests were carried out by equilibrating as received solid sample in deionised water for approximately 16 hours at a solid to water ratio of 1:2 (w/w). This gives an indication of the inherent acidity and salinity of the waste material when initially exposed in a waste emplacement area.

All samples tested had a circum-neutral $pH_{1:2}$ ranging from 6.7 to 8.5 and correspondingly low electrical conductivities ($EC_{1:2}$) of 0.1 to 0.7 dS/m, indicating that the samples were non-saline to slightly saline.

### *3.1.2 Acid-Base Account and Net Acid Generation (NAG)*

The acid-base and net acid generation (NAG) test results for the samples are presented in Table 1.

The results show that all samples had a low total S content ranging from <0.01 to 0.1%S, with the majority of the samples having a value <0.05%S. The acid neutralising capacities (ANC's) of the samples were variable, ranging from 3 to 848 kg $H_2SO_4$/t. About 40% of the samples had moderate to high ANC values greater than 20 kg $H_2SO_4$/t.

All the samples have a negative net acid producing potential (NAPP[1]) varying from -3 to -848 kg $H_2SO_4$/t.

The NAPP value is used in conjunction with single addition net acid generation (NAG) test results to geochemically classify samples in relation to their ARD potential. Samples are classified as barren, non-acid forming (NAF), potentially acid forming (PAF) and uncertain (UC) according to the following characteristics:

- Barren: Total S ≤ 0.05%S and ANC ≤ 5 kg $H_2SO_4$/t.
- NAF: Non-Acid Forming. NAPP negative and NAGpH greater than or equal to 4.5.
- PAF: Potentially Acid Forming. NAPP positive and NAGpH less than 4.5.
- UC: Uncertain. Conflicting NAPP and NAG results (i.e., NAPP positive and NAGpH greater than 4.5 or NAPP negative and NAGpH less than 4.5).

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[1] The net acid producing potential (NAPP) is a theoretical calculation that represents the balance between the capacity of a sample to generate acid (MPA) and its capacity to neutralise acid (ANC). The NAPP is expressed in units of kg $H_2SO_4$/t and is calculated as follows:

NAPP = MPA – ANC

Where MPA = Maximum potential acidity (total %S x 30.6 = MPA in units of kg $H_2SO_4$/t)
ANC = Acid Neutralising Capacity

The single addition NAG test involves reaction of a sample with hydrogen peroxide to rapidly oxidise any sulphide minerals present. Both acid generation and acid neutralisation occur simultaneously during the NAG test, hence the end result represents a direct measurement of the net amount of acid generated.

Figure 1a is an ARD classification plot showing the pH after reaction with hydrogen peroxide (NAGpH) and the NAPP of the samples and Figure 1b is the same as Figure 1a, except with an expanded NAPP scale. Potentially acid forming (PAF), non-acid forming (NAF) and uncertain (UC) classification domains are indicated.

The results show that the samples have a negative NAPP and NAGpH greater than 4.5 and plot in the top left hand quadrant. These samples are classified as non-acid forming (NAF). About 30% of the samples are further classified as barren as they have a total S content < 0.1%S and ANC ≤ 5 kg $H_2SO_4$/t and are thus barren with respect to acid generation and neutralisation.

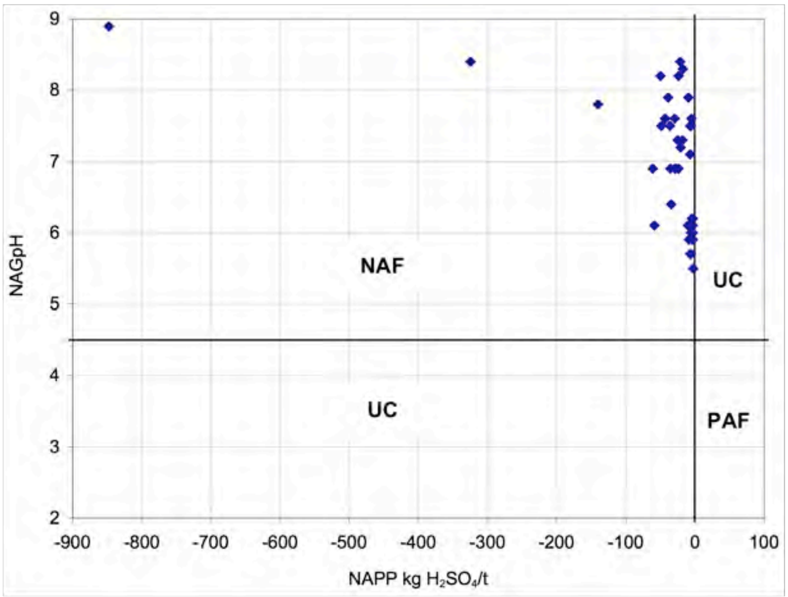


*Figure 1a: ARD classification plot of composite samples – Arruwurra Prospect.*

Three samples have a NAPP value less than -100 kg $H_2SO_4$/t. These include composite 4, with a NAPP of -848 kg $H_2SO_4$/t, composite 5 with a NAPP of -325 kg $H_2SO_4$/t and composite 6 with a NAPP of -140 kg $H_2SO_4$/t. These three samples are carbonates and described as dolomite, calcrete and phosphatic carbonate, respectively. They have high ANC values and negligible total S contents ranging from 0.01 to 0.04%S.

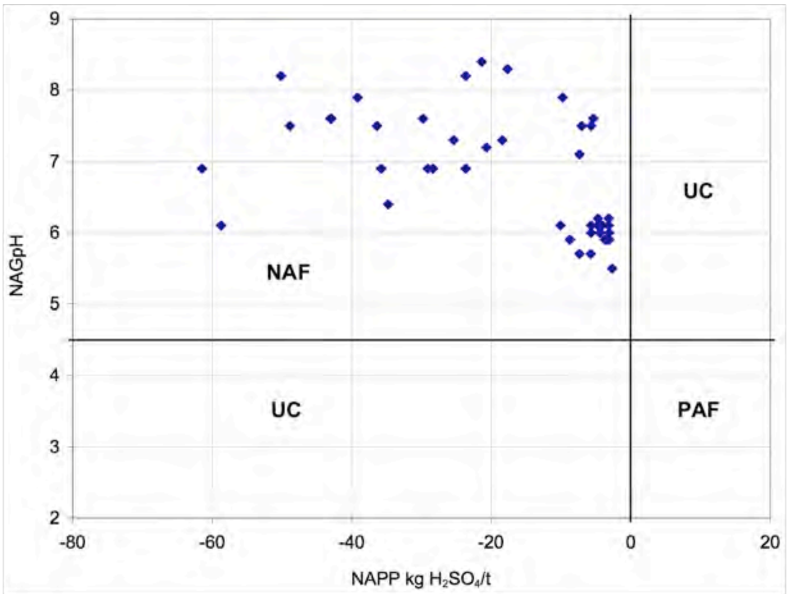


*Figure 1b: Same as for Figure 1a, but with expanded NAPP scale.*

### *3.1.3 ABCC Results*

An acid buffering characteristic curve (ABCC) is produced by slow titration of a sample with acid, and provides an indication of the relative reactivity of the measured ANC. The acid buffering of a sample to pH 4 can be used as an estimate of the proportion of readily available ANC. Calcite, dolomite, ferroan dolomite and siderite standard curves are also plotted for reference. Calcite and dolomite readily dissolve in acid and exhibit strongly buffered pH curves in the ABCC test, rapidly dropping once the ANC value is reached. The siderite standard provides very poor acid buffering, exhibiting a very steep pH curve in the ABCC test. Ferroan dolomite is between siderite and dolomite in acid buffering availability.

Three samples (Composite 5, 30 and 42) were selected to undergo ABCC testing and had ANC values of 326, 26 and 52 kg $H_2SO_4$/t, respectively. The samples were selected to encompass the range in ANC values that were observed in the results. The results are presented in Figures 2 to 4.

Figure 2 presents the curve for Composite 5, which plots between the dolomite and ferroan dolomite standard curves. The sample has a strong initial pH plateau above pH 6 and has a readily available ANC, which is about 60% of the measured ANC of the sample. The results indicate that the ANC of this sample is dominated by dolomitic and ferroan dolomitic minerals with about 50% fast reacting.

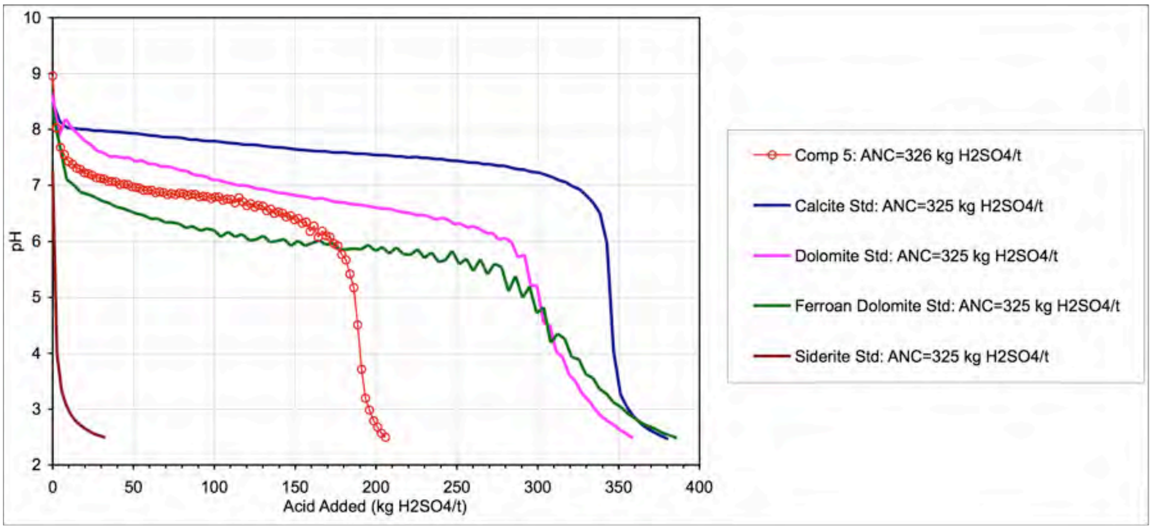


*Figure 2: Acid buffering characteristic curve of composite 5, with ANC close to 325 kg $H_2SO_4$/t. Carbonate standard curves are included for reference.*

Figures 3 and 4 present the ABCC plots for Composite 30 and 42, respectively. Both curves decrease rapidly from the beginning of the test and plot close to the siderite standard curve. The results indicate that the ANC of these two samples was ineffective and only about 10% of the measured ANC was readily available. The shapes of the curves suggest that the ANC of the samples is dominated by siderite. Siderite is known to cause interference with the standard ANC test (caused by incomplete oxidation of ferrous iron released during the ANC digest), resulting in overestimation of effective acid buffering.

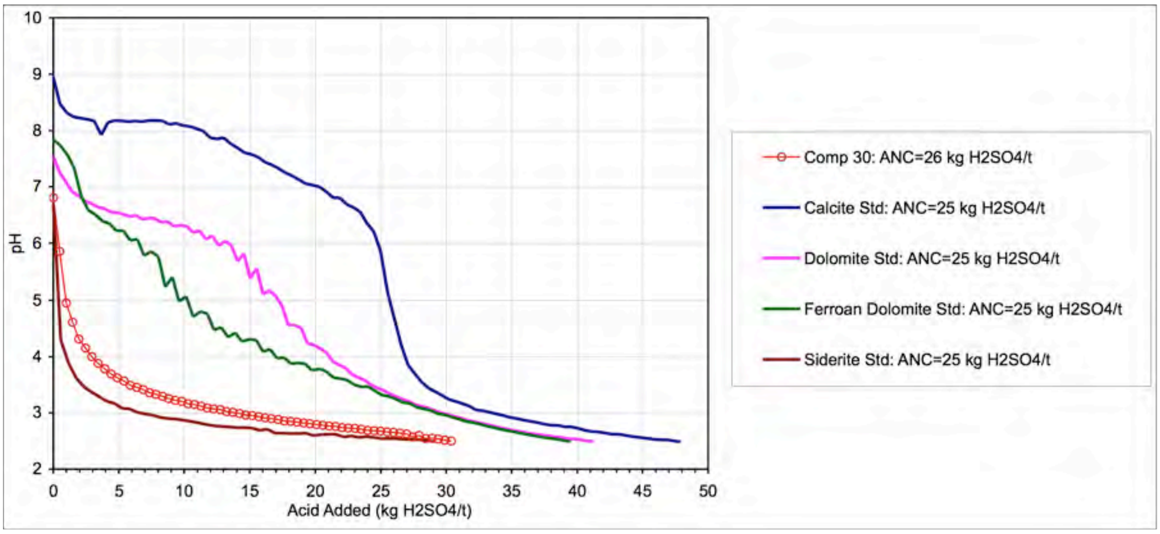


*Figure 3: Acid buffering characteristic curve of composite 30, with ANC close to 25 kg $H_2SO_4$/t. Carbonate standard curves are included for reference.*

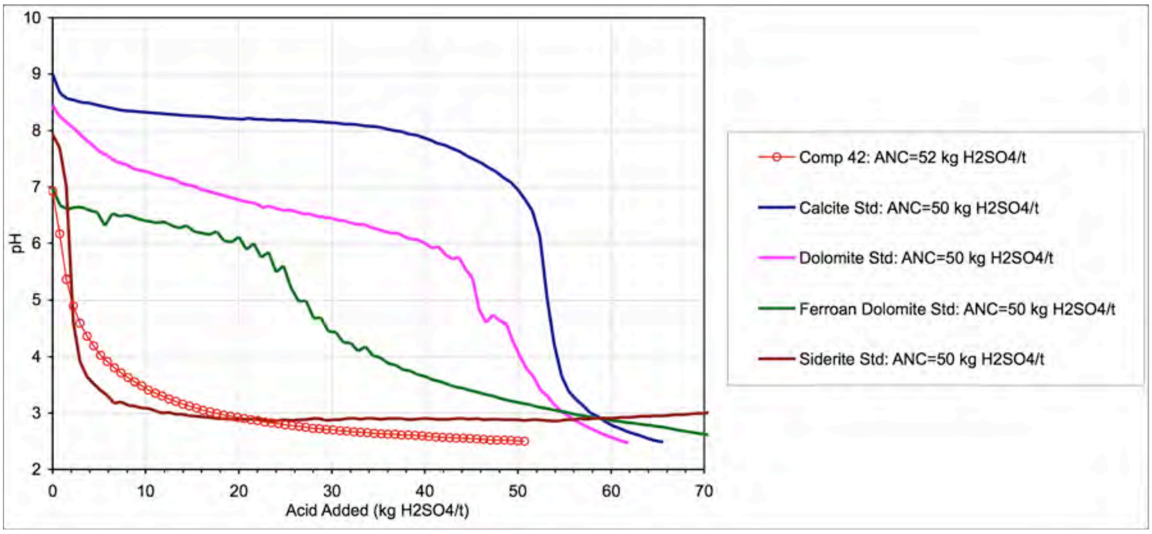


*Figure 4: Acid buffering characteristic curve of composite 42, with ANC close to 50 kg $H_2SO_4$/t. Carbonate standard curves are included for reference.*

Overall, ABCC testing indicates that in materials represented by Composite 5, 30 and 42, a large proportion of the ANC would not be available to neutralise pyrite generated acidity and hence the NAPP value can not be relied on to indicate the ARD risk. However, due to the low total S content and high NAGpH, all samples are classified as NAF and the lack of effective ANC would only be a concern if higher sulphide material were encountered.

### *3.1.4 Element Enrichment and Solubility*

Multi-element scans were conducted on 8 samples and the elements included in the multi-element testing program were:

> Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, Hg, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Se, Sn, Sr, Th, Ti, Tl, U, V, W and Zn.

Geochemical Abundance Indices (GAIs) were also calculated for each element. The GAI compares the actual concentration of an element in a sample with the median abundance in the selected reference material (world soil[2] concentrations used in this report) for that element. The main purpose of the GAI is to provide an indication of any elemental enrichment that may be of environmental importance. The GAI for an element is calculated as follows:

$$GAI = \log_2 [ C / (1.5*S) ]$$

where C is the concentration of the element in the sample and S is the median soil content for that element. The GAI are truncated to integer increments (0 through to 6,

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[2] References for median soil data were: (1) Bowen, H.J.M. (1997) Environmental Chemistry of the Elements. Academic Press, London. (2) Berkman, D.A. (1976) Field Geologists' Manual, The Australian Institute of Mining and Metallurgy, Parkville, Victoria, Australia

respectively) where a GAI of 0 indicates the element is present at a concentration similar to, or less than, median soil abundance and a GAI of 6 indicates approximately a 100-fold, or greater, enrichment above median soil abundance. The enrichment ranges for the GAI are as follows:

*Little or No Enrichment*
GAI=0 < 3 times median soil

*Slightly Enrichment*
GAI=1 3 to <6 times median soil
GAI=2 6 to <12 times median soil

*Significant Enrichment*
GAI=3 12 to <24 times median soil
GAI=4 24 to <48 times median soil
GAI=5 48 to <96 times median soil
GAI=6 ≥ 96 times median soil

The multi-element results and geochemical abundance indices are presented in Tables 2 and 3, respectively. The results show that phosphorous (P) is significantly enriched in many samples with concentrations exceeding 5% P. Beryllium (Be) is significantly enriched in 7 of the 8 samples and Ca, Cu, Ce, Tl and U are significantly enriched in 1 or 2 of the samples. Although the GAI for Be exceeds 3 relative to median soil concentrations, the actual concentrations are not enriched compared to mean crustal abundance (2.6 mg/kg) and is unlikely to be a concern. The enrichment of P is to be expected given the mineralogy of the deposit.

The potential for dissolution and leaching of enriched elements is the main environmental concern during mining operations. To evaluate element solubility, the same samples that underwent multi-element scans on solids also underwent multi-element analyses of water extracts to provide an indication of the immediate solubility of these enriched elements as well as other environmentally important elements.

The results are presented in Table 4 and show only low concentrations of dissolved constituents. Phosphorous shows very low solubility with concentrations less than the detection limit of 1 mg/l in all samples. Na, Cl and $SO_4$ are the main ions in solution and there is some solubility of F. Fluorine (F) is typically associated with phosphate and leaching of F would be expected. The results indicate that routine water quality monitoring programmes should include F.

## 3.2 Main Zone

The acid forming characteristics of the Main Zone composite waste rock samples are presented in Table 5. A total of 51 samples were included in the program. All samples were assayed for total S and ANC and selected samples assayed for pH, EC, single addition NAG and multi-element scans on solids and water extracts.

### *3.2.1 pH & EC*

Twelve (12) samples were selected for $pH_{1:2}$ and $EC_{1:2}$ testing. The samples were selected to encompass a range in total S and ANC values observed in the samples.

The samples had a circum-neutral $pH_{1:2}$ ranging from 7.1 to 7.7. The corresponding electrical conductivities ranged from 0.09 to 0.15 dS/m, indicating that the samples were non-saline.

### *3.2.2 Acid-Base Accounting and Net Acid Generation (NAG)*

The total S contents of the composite waste rock samples was low, ranging from <0.01 to 0.13%S. More than two thirds of the samples had a value that was less than or equal to 0.05%S.

The acid neutralising capacity (ANC) of the composites ranged from 0 to 19 kg $H_2SO_4$/t, with about three quarters of the samples having a value less than or equal to 5 kg $H_2SO_4$/t. The samples had a net acid producing potential (NAPP) ranging from -19 to 2 kg $H_2SO_4$/t, with the majority of the samples having a value close to zero.

Twelve (12) samples, which had total S contents ≥ 0.04%S, were selected for single addition NAG testing. The results show that all samples had a NAGpH > 4.5. Eight of the samples have a positive NAPP value close to zero and are classified as uncertain (UC). However, it is unlikely that these samples will be acid generating, therefore the samples are further classified as UC (NAF), i.e., uncertain but likely to be non-acid forming. The remaining four samples that were NAG tested have a negative NAPP value and are classified as NAF.

Table 5 shows that overall about 50% of the samples (29 of 51) are classified as barren with respect to acid generation and have total S of less than or equal to 0.05%S and ANC less than 5 kg $H_2SO_4$/t. Of the remaining 22 samples, 18 are classified UC (NAF) and 4 are classified NAF. No samples were classified as PAF.

Based on the samples provided, these results indicate that ARD will not be an issue for the Main Zone waste rock.

### *3.2.3 Element Enrichment and Solubility*

Multi-element composition and geochemical abundance indices (GAI) of selected solids samples from the Main Zone are presented in Tables 6 and 7, respectively. A description of the GAI was presented in Section 3.1.4.

The results show that phosphorus (P) is significantly enriched in 3 of the 12 samples tested, however, concentrations are not as high as in the Arruwurra Prospect. Beryllium (Be) is significantly enriched in 5 of the samples when compared with the median soil concentrations. However, similar to the Arruwurra Prospect samples, the actual concentrations are not enriched compared to mean crustal abundance (2.6 mg/kg) and are unlikely to be a concern. Ag, Cd, Mg, Mn, Pb, U and Zn were significantly enriched in 1 or 2 of the samples as identified on Table 7

Water extractions were performed to determine the solubility of these elements and other environmentally important constituents. The results are presented in Table 8 and show that the majority of the elements are at low concentrations or below the detection limit.

Phosphorous shows low solubility with concentrations at or less than the detection limit of 1 mg/l, except for sample 31 with a concentration of 4 mg/l. There is some solubility of F, which is expected as fluorine is typically associated with phosphate, with concentrations ranging from 0.2 to 2.0 mg/l. Ten (10) of the samples had F concentrations in the range of 1 to 2 mg/l.

One sample, composite 16, also had a high concentration of Mn (1.26 mg/l). This sample was significantly enriched in Mn having a GAI of 4. Fe (0.36 mg/l) and Zn (0.17 mg/l) are also slightly soluble in this sample.

As for the Arruwurra Prospect, it is recommended that F is included in routine water quality monitoring programmes.

## 3.3 Low Grade Ore

Twenty low-grade ore samples were provided for geochemical testing and the acid forming characteristics of the samples is presented in Table 9. The samples are labelled as Comp No. 52 to 71. All the samples underwent total S and ANC testing and selected samples were assayed for pH, EC, single addition NAG and multi-element scans on solids and water extracts.

### *3.3.1 pH & EC*

$pH_{1:2}$ and $EC_{1:2}$ was conducted on eight selected samples (4 from the Arruwurra Prospect and 4 from the Main Zone), which covered a range in total S and ANC values. The results show that the low grade ore samples had a circum-neutral to alkaline pH ranging from 7.2 to 7.9.

The electrical conductivities of the selected samples were low, ranging from 0.09 to 0.15 dS/m, indicating that the samples were non-saline.

### *3.3.2 Acid-Base Accounting and Net Acid Generation (NAG)*

The low grade ore samples had low total S contents, which varied from 0.03 to 0.19%S, with the majority of the samples having a value less than 0.1%S. The acid neutralising capacity (ANC) of the samples was moderate, ranging from 14 to 28 kg $H_2SO_4$/t.

All the samples had a negative NAPP value and high ANC/MPA ratios indicating a high factor of safety for prevention of acid generation.

Eight (8) samples were selected for single addition NAG testing. The results show that the samples had a NAGpH greater than 4.5 confirming the non-acid forming (NAF) nature of the low grade ore samples.

Table 9 shows that all low grade ore samples from the Arruwurra Prospect and Main Zone are classified as NAF.

### *3.3.3 Element Enrichment and Solubility*

The multi-element composition and geochemical abundance indices (GAI) of selected solids samples is presented in Tables 10 and 11, respectively. The results show that Be and P are highly enriched in all the samples with Ca and U significantly enriched in half of the samples. Phosphorous (P) enrichment is to be expected given the mineralogy of the deposit. In addition, Ag, Co, Pb and Sr are enriched in 1 of he Main Zone samples.

The enrichment of P, Ca, Be and U is typical of phosphate ores. As expected, P is highly enriched in the low grade ore and although Be is also significantly enriched, the actual concentrations only slightly exceed the typical range in soils (0.1 to 15 mg/kg[3]) in 1 of 8 samples.

The enrichment of uranium is also typical of phosphate deposits. The average content of U in rock phosphate is 120 mg/kg[3], which is greater than the maximum concentration of 63 mg/kg determined in the Main Zone and Arruwurra low grade ore samples.

As for the waste rock samples, water extractions were conducted to determine the solubility of environmentally important elements and the results are presented in Table 12. The results show only low concentrations of dissolved constituents with Ca and Na the main cations and Cl and $SO_4$ the main anions. Phosphorous has low solubility with concentrations being less than or equal to 2 mg/l. There is some solubility of F in the low-grade ore samples with concentrations ranging from 0.4 to 2.5 mg/l.

Ba was slightly soluble in sample 53 from the Arruwurra Prospect, having a concentration of 0.6 mg/l. The remaining elements were at low concentrations or below the detection limit.

# 4.0 Summary and Recommendations

Geochemical characterisation of composite waste rock samples from the Arruwurra Prospect and Main Zone, and low-grade ore from both deposits has shown that materials

[3] István Pais and J. Benton Jones, Jr. (1997), *The Handbook of Trace Elements.* St Lucie Press, Boca Raton Fl, USA.

represented by the samples will not be problematic with respect to ARD. All samples tested were classified as non-acid forming (NAF) and about 40% of the waste rock composites were also barren with respect to S and ANC contents, having a total S less than or equal to 0.05%S and ANC less than or equal to 5 kg $H_2SO_4$/t.

The average total S and ANC of samples are presented in Table 13. The average total S contents of waste rock composites from the Arruwurra Prospect and Main Zone were the same, while the average ANC of the waste rock from the Arruwurra Prospect was almost an order of magnitude higher than in the Main Zone samples.

Table 13 shows that the Arruwurra Prospect and Main Zone low-grade ore samples had similar average total S contents that were slightly higher than waste rock composites and similar ANC values.

*Table 13: Average total S, ANC and NAPP of composite waste rock and low grade ore samples.*

| Sample Type | Deposit | Total S (%) | ANC (kg $H_2SO_4$/t) |
|---|---|---|---|
| Waste Rock | Arruwurra Prospect | 0.03 | 46 |
| | Main Zone | 0.03 | 5 |
| Low Grade Ore | Arruwurra Prospect | 0.09 | 25 |
| | Main Zone | 0.07 | 19 |

Elemental analysis of selected waste rock composites indicated that P and Be were significantly enriched (i.e. GAI ≥3) in most samples from the Arruwurra Prospect and Main Zone. Phosphorous (P) enrichment is to be expected given the mineralogy of the deposit and although Be was enriched when compared against median soil concentrations (0.3 mg/kg), the actual concentrations were not enriched compared to mean crustal abundance (2.6 mg/kg). Other elements showing significant enrichment in 1 or 2 of the samples were Ag, Ca, Cd, Cu, Mg, Pb, Tl, U and Zn.

Testing showed that all the low grade ore samples were significantly enriched in Be and P and half of the samples were also significantly enriched in Ca and U. The actual concentration of U in the low grade ore is lower than typically observed in rock phosphate ore.

Water extractions carried out on waste rock and low grade ore samples indicated only low solubility of dissolved constituents and that the majority of the environmentally significant elements were either at low concentrations or below the detection limit. Phosphorous showed very low solubility with the concentrations being close to or less than the detection limit of 1 mg/l. There was some solubility of F in the samples. Fluorine (F) is typically associated with phosphate and leaching of F would be expected in these samples.

Overall, the results of the current investigation indicated that ARD will not be a concern for the Wonarah Phosphate Project. However, there are some elements that occur at elevated concentrations in waste rock and low grade ore. Although their solubilities are expected to be low, it is recommended that $PO_4$, F and Be, be included in site water quality monitoring programmes.

Table 1: Acid forming characteristics of composite waste rock samples from the Arruwurra Prospect.

| Composite Number | Hole No. | Lithology | Depth (m) | | Interval (m) | $pH_{1:2}$ | $EC_{1:2}$ | ACID-BASE ANALYSIS | | | | | NAG TEST | | | ARD Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | From | To | | | | Total %S | MPA | ANC | NAPP | ANC/MPA Ratio | NAGpH | $NAG_{(pH4.5)}$ | $NAG_{(pH7.0)}$ | |
| 1 | WNRC009 | mudstone | 5 | 9 | 4.0 | 7.6 | 0.112 | 0.02 | 1 | 5 | -4 | 8 | 6.0 | 0 | 8 | NAF (Barren) |
| 2 | WNRC009 | silty mudstone | 9 | 12 | 3.0 | 8.3 | 0.216 | 0.01 | 0 | 5 | -5 | 16 | 6.1 | 0 | 9 | NAF (Barren) |
| 3 | WNRC009 | silty mudstone | 12 | 17 | 5.0 | 7.5 | 0.146 | 0.01 | 0 | 6 | -6 | 20 | 6.0 | 0 | 8 | NAF |
| 4 | WNRC009 | dolomite | 26 | 32 | 6.0 | 8.3 | 0.104 | 0.01 | 0 | 848 | -848 | 2771 | 8.9 | 0 | 0 | NAF |
| 5 | WNRC013 | calcrete | 1 | 4 | 3.0 | 8.2 | 0.156 | 0.04 | 1 | 326 | -325 | 266 | 8.4 | 0 | 0 | NAF |
| 6 | WNRC013 | phosphatic carbonate | 4 | 9 | 5.0 | 7.8 | 0.152 | 0.03 | 1 | 141 | -140 | 154 | 7.8 | 0 | 0 | NAF |
| 7 | WNRC089 | muddy siltstone | 3 | 6 | 3.0 | 7.7 | 0.232 | 0.04 | 1 | 11 | -10 | 9 | 7.9 | 0 | 0 | NAF |
| 8 | WNRC089 | phosphatic muddy siltstone | 6 | 11 | 5.0 | 8.1 | 0.214 | 0.07 | 2 | 51 | -49 | 24 | 7.5 | 0 | 0 | NAF |
| 9 | WNRC089 | basaltic sediments | 14 | 16 | 2.0 | 8.0 | 0.211 | 0.06 | 2 | 41 | -39 | 22 | 7.9 | 0 | 0 | NAF |
| 10 | WNRC089 | basalt | 16 | 20 | 4.0 | 7.8 | 0.176 | 0.01 | 0 | 18 | -18 | 59 | 8.3 | 0 | 0 | NAF |
| 11 | WNRC090 | ferricrete | 1 | 3 | 2.0 | 7.6 | 0.189 | 0.02 | 1 | 6 | -5 | 10 | 7.6 | 0 | 0 | NAF |
| 12 | WNRC090 | siltstone | 3 | 8 | 5.0 | 7.5 | 0.259 | <0.01 | 0 | 6 | -6 | 20 | 6.1 | 0 | 9 | NAF |
| 13 | WNRC091 | siltstone/mudstone | 4 | 8 | 4.0 | 6.8 | 0.166 | <0.01 | 0 | 9 | -9 | 29 | 5.9 | 0 | 9 | NAF |
| 14 | WNRC091 | mudstone/siltstone | 8 | 12 | 4.0 | 7.6 | 0.179 | 0.02 | 1 | 4 | -3 | 7 | 5.9 | 0 | 9 | NAF (Barren) |
| 15 | WNRC091 | mudstone | 20 | 24 | 4.0 | 8.3 | 0.181 | <0.01 | 0 | 24 | -24 | 78 | 6.9 | 0 | 0 | NAF |
| 16 | WNRC091 | basalt | 24 | 27 | 3.0 | 7.8 | 0.192 | 0.01 | 0 | 21 | -21 | 69 | 7.2 | 0 | 0 | NAF |
| 17 | WNRC094 | aeolian sand | 0 | 4 | 4.0 | 6.7 | 0.215 | 0.01 | 0 | 3 | -3 | 10 | 5.5 | 0 | 9 | NAF (Barren) |
| 18 | WNRC094 | siltstone | 5 | 10 | 5.0 | 7.9 | 0.176 | 0.02 | 1 | 5 | -4 | 8 | 6.0 | 0 | 9 | NAF (Barren) |
| 19 | WNRC094 | siltstone | 10 | 14 | 4.0 | 8.2 | 0.236 | 0.03 | 1 | 4 | -3 | 4 | 6.0 | 0 | 9 | NAF (Barren) |
| 20 | WNRC094 | phosphatic siltstone | 15 | 20 | 5.0 | 8.4 | 0.213 | 0.03 | 1 | 44 | -43 | 48 | 7.6 | 0 | 0 | NAF |
| 21 | WNRC094 | basalt | 25 | 28 | 3.0 | 7.6 | 0.248 | 0.02 | 1 | 22 | -21 | 36 | 8.4 | 0 | 0 | NAF |
| 22 | WNRC197 | pisolitic | 2 | 4 | 2.0 | 8.3 | 0.376 | 0.01 | 0 | 6 | -6 | 20 | 7.5 | 0 | 0 | NAF |
| 23 | WNRC197 | mudstone-siltstone | 4 | 8 | 4.0 | 8.2 | 0.276 | 0.01 | 0 | 5 | -5 | 16 | 6.1 | 0 | 9 | NAF (Barren) |
| 24 | WNRC197 | mudstone c chert | 8 | 12 | 4.0 | 8.1 | 0.311 | 0.03 | 1 | 4 | -3 | 4 | 5.9 | 0 | 10 | NAF (Barren) |
| 25 | WNRC197 | cherty sandstone | 12 | 14 | 2.0 | 7.8 | 0.198 | 0.03 | 1 | 11 | -10 | 12 | 6.1 | 0 | 6 | NAF |
| 26 | WNRC197 | basalt | 21 | 25 | 4.0 | 8.4 | 0.416 | 0.02 | 1 | 19 | -18 | 31 | 7.3 | 0 | 0 | NAF |
| 27 | WNRC203 | mudstone c chert | 3 | 7 | 4.0 | 7.7 | 0.321 | 0.03 | 1 | 5 | -4 | 5 | 6.1 | 0 | 7 | NAF (Barren) |
| 28 | WNRC203 | mudstone c chert | 7 | 11 | 4.0 | 8.2 | 0.412 | 0.06 | 2 | 5 | -3 | 3 | 6.2 | 0 | 7 | NAF |
| 29 | WNRC203 | chert sandstone | 11 | 14 | 3.0 | 7.5 | 0.329 | 0.06 | 2 | 5 | -3 | 3 | 6.1 | 0 | 6 | NAF |
| 30 | WNRC203 | phosphatic mudstone | 14 | 17 | 3.0 | 8.4 | 0.407 | 0.02 | 1 | 26 | -25 | 42 | 7.3 | 0 | 0 | NAF |
| 31 | WNRC203 | weathered basalt | 19 | 24 | 5.0 | 7.7 | 0.311 | <0.01 | 0 | 24 | -24 | 78 | 8.2 | 0 | 0 | NAF |

Table 1: Acid forming characteristics of composite waste rock samples from the Arruwurra Prospect.

| Composite Number | Hole No. | Lithology | Depth (m) | | Interval (m) | $pH_{1:2}$ | $EC_{1:2}$ | ACID-BASE ANALYSIS | | | | | NAG TEST | | | ARD Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | From | To | | | | Total %S | MPA | ANC | NAPP | ANC/MPA Ratio | NAGpH | $NAG_{(pH4.5)}$ | $NAG_{(pH7.0)}$ | |
| 32 | WNRC210 | mudstone | 3 | 8 | 5.0 | 6.8 | 0.276 | <0.01 | 0 | 5 | -5 | 16 | 6.2 | 0 | 7 | NAF (Barren) |
| 33 | WNRC210 | mudstone | 8 | 12 | 4.0 | 7.8 | 0.356 | <0.01 | 0 | 4 | -4 | 13 | 5.9 | 0 | 10 | NAF (Barren) |
| 34 | WNRC210 | cherty sandstone and mudstone | 12 | 16 | 4.0 | 8.5 | 0.281 | 0.04 | 1 | 37 | -36 | 30 | 6.9 | 0 | 0 | NAF |
| 35 | WNRC210 | mudstone c chert | 16 | 19 | 3.0 | 7.9 | 0.198 | 0.04 | 1 | 36 | -35 | 29 | 6.4 | 0 | 6 | NAF |
| 36 | WNRC210 | weathered basalt | 22 | 25 | 3.0 | 7.8 | 0.235 | 0.02 | 1 | 29 | -28 | 47 | 6.9 | 0 | 0 | NAF |
| 37 | WNRC212 | mudstone | 1 | 4 | 3.0 | 7.7 | 0.324 | 0.02 | 1 | 37 | -36 | 60 | 7.5 | 0 | 0 | NAF |
| 38 | WNRC212 | mudstone-siltstone | 4 | 8 | 4.0 | 8.2 | 0.276 | 0.02 | 1 | 8 | -7 | 13 | 7.1 | 0 | 0 | NAF |
| 39 | WNRC212 | mudstone-siltstone | 8 | 12 | 4.0 | 6.9 | 0.319 | 0.03 | 1 | 30 | -29 | 33 | 6.9 | 0 | 0 | NAF |
| 40 | WNRC212 | cherty sandstone and mudstone | 12 | 15 | 3.0 | 7.5 | 0.415 | 0.10 | 3 | 46 | -43 | 15 | 7.6 | 0 | 0 | NAF |
| 41 | WNRC217 | ferricrete | 1 | 3 | 2.0 | 6.9 | 0.266 | 0.03 | 1 | 8 | -7 | 9 | 7.5 | 0 | 0 | NAF |
| 42 | WNRC217 | mudstone | 3 | 8 | 5.0 | 7.8 | 0.346 | 0.06 | 2 | 52 | -50 | 28 | 8.2 | 0 | 0 | NAF |
| 43 | WNRC217 | mudstone c chert | 8 | 11 | 3.0 | 7.9 | 0.309 | 0.04 | 1 | 60 | -59 | 49 | 6.1 | 0 | 10 | NAF |
| 44 | WNRC252 | mudstone | 4 | 9 | 5.0 | 8.3 | 0.235 | 0.04 | 1 | 31 | -30 | 25 | 7.6 | 0 | 0 | NAF |
| 45 | WNRC252 | mudstone>siltstone | 9 | 14 | 5.0 | 6.7 | 0.616 | 0.05 | 2 | 63 | -61 | 41 | 6.9 | 0 | 0 | NAF |
| 46 | WNRC252 | mudstone-siltstone | 14 | 19 | 5.0 | 6.8 | 0.529 | 0.04 | 1 | 7 | -6 | 6 | 5.7 | 0 | 11 | NAF |
| 47 | WNRC252 | palaeoregolith/weathered basalt | 30 | 34 | 4.0 | 6.9 | 0.721 | 0.02 | 1 | 8 | -7 | 13 | 5.7 | 0 | 8 | NAF |

**KEY**

$pH_{1:2}$ = pH of 1:2 extract
$EC_{1:2}$ = Electrical Conductivity of 1:2 extract (dS/m)
MPA = Maximum Potential Acidity ($kgH_2SO_4/t$)
ANC = Acid Neutralising Capacity ($kgH_2SO_4/t$)
NAPP = Net Acid Producing Potential ($kgH_2SO_4/t$)

NAGpH = pH of NAG liquor
$NAG_{(pH4.5)}$ = Net Acid Generation capacity to pH 4.5 ($kgH_2SO_4/t$)
$NAG_{(pH7.0)}$ = Net Acid Generation capacity to pH 7.0 ($kgH_2SO_4/t$)

NAF = Non-Acid Forming
PAF = Potentially Acid Forming
PAF-LC = PAF - lower capacity
UC = Uncertain Classification
(expected classification in brackets)

Table 2: Multi-element composition of selected solids samples (mg/kg except where shown) - Arruwurra Prospect.

| Element | Detection Limit | Composite Number / Hole ID / Lithology | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 5 | 8 | 13 | 21 | 25 | 40 | 42 | 45 |
| | | WNRC013 | WNRC089 | WNRC091 | WNRC094 | WNRC197 | WNRC212 | WNRC217 | WNRC252 |
| | | calcrete | phosphatic muddy siltstone | siltstone/ mudstone | basalt | cherty sandstone | cherty sandstone and mudstone | mudstone | mudstone> siltstone |
| Ag | 0.02 | 0.18 | 0.36 | 0.19 | 0.12 | 0.55 | 0.33 | 0.38 | 0.42 |
| Al | 0.01% | 2.73% | 5.61% | 5.55% | 6.78% | 3.70% | 3.82% | 6.47% | 2.12% |
| As | 0.2 | 2 | 1.2 | 2 | 6.5 | 2.3 | 3.5 | 3.7 | 4 |
| Ba | 10 | 730 | 1550 | 520 | 230 | 500 | 210 | 780 | 160 |
| Be | 0.05 | 1.44 | 4.21 | 3.04 | 6.91 | 3.44 | 6.71 | 9.52 | 4.54 |
| Bi | 0.01 | 0.15 | 0.3 | 0.2 | 0.07 | 0.12 | 0.16 | 0.23 | 0.1 |
| Ca | 0.01% | 9.18% | 6.39% | 0.12% | 0.99% | 0.20% | 16.25% | 3.83% | 13.30% |
| Cd | 0.02 | 0.12 | 0.31 | <0.02 | 0.29 | <0.02 | 0.42 | 0.12 | 0.63 |
| Co | 0.1 | 5 | 5.1 | 1.6 | 51.4 | 1.3 | 15.2 | 31.5 | 6.1 |
| Cr | 1 | 28 | 43 | 48 | 49 | 65 | 61 | 113 | 27 |
| Cu | 0.2 | 26.4 | 51.4 | 11.7 | 309 | 29 | 72.1 | 83.8 | 22.3 |
| Fe | 0.01% | 0.73% | 0.40% | 0.47% | 9.03% | 0.45% | 0.65% | 0.51% | 0.84% |
| Ga | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | <10 |
| Hg | 0.01 | 0.011 | 0.024 | 0.007 | 0.031 | 0.01 | 0.052 | 0.027 | 0.013 |
| K | 0.002% | 0.54% | 0.82% | 1.24% | 2.54% | 0.34% | 0.21% | 0.18% | 0.44% |
| La | 10 | 30 | 30 | 40 | 20 | 30 | 40 | 40 | 10 |
| Mg | 0.002% | 0.36% | 0.52% | 0.36% | 0.73% | 0.16% | 0.22% | 0.41% | 0.14% |
| Mn | 1.0 | 315 | 334 | 40 | 1330 | 20 | 472 | 1220 | 148 |
| Mo | 0.1 | 0.84 | 0.31 | 0.17 | 0.66 | 3.39 | 1.39 | 2.06 | 0.9 |
| Na | 0.002% | 0.03% | 0.09% | 0.04% | 0.05% | 0.05% | 0.11% | 0.10% | 0.04% |
| Ni | 1.0 | 15.1 | 10.6 | 7.7 | 89.9 | 8.6 | 21.3 | 15.8 | 21.5 |
| P | 20 | 9390 | 29000 | 850 | 3530 | 1710 | >50000 | 24500 | >50000 |
| Pb | 2.0 | 44.4 | 135.5 | 35.2 | 22.7 | 70.7 | 57.8 | 123.5 | 18.1 |
| S | 0.001% | 0.05% | 0.07% | 0.02% | 0.02% | 0.04% | 0.12% | 0.06% | 0.05% |
| Sb | 0.05 | 1.08 | 0.57 | 0.61 | 0.49 | 0.29 | 0.61 | 0.47 | 0.37 |
| Sc | 1 | 9 | 13 | 10 | 35 | 19 | 10 | 28 | 11 |
| Se | 0.01 | 2.2 | 2.3 | 1.3 | 1.9 | 2.5 | 2.6 | 4.3 | 1.4 |
| Sn | 0.1 | 1.5 | 2.5 | 3 | 1.3 | 1.2 | 1 | 2.3 | 1.1 |
| Sr | 0.05 | 79 | 112 | 190 | 55 | 328 | 150 | 735 | 66 |
| Th | 0.2 | 7 | 10.7 | 12 | 5.7 | 7.4 | 6.8 | 9.7 | 6.3 |
| Ti | 0.01% | 0.14% | 0.26% | 0.26% | 0.55% | 0.12% | 0.07% | 0.23% | 0.04% |
| Tl | 0.02 | 0.18 | 0.41 | 0.33 | 1.08 | 0.13 | 0.2 | 1.93 | 0.2 |
| U | 0.01 | 2.6 | 11.6 | 3.3 | 2.6 | 4.7 | 12.1 | 13.1 | 24.1 |
| V | 2.0 | 43 | 68 | 80 | 292 | 53 | 64 | 62 | 56 |
| W | 0.1 | 1.3 | 2 | 2 | 1.2 | 2.4 | 1 | 2.2 | 0.9 |
| Zn | 1.0 | 66 | 38 | 19 | 205 | 39 | 52 | 22 | 99 |

< element at or below analytical detection limit.

Table 3: Geochemical abundance indices (GAI) of selected solids samples - Arruwurra Prospect.

| Element | Median Soil Abundance* | Sample Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 5 | 8 | 13 | 21 | 25 | 40 | 42 | 45 |
| | | WNRC013 | WNRC089 | WNRC091 | WNRC094 | WNRC197 | WNRC212 | WNRC217 | WNRC252 |
| | | calcrete | phosphatic muddy siltstone | siltstone/ mudstone | basalt | cherty sandstone | cherty sandstone and mudstone | mudstone | mudstone> siltstone |
| Ag | 0.05 | 1 | 2 | 1 | 1 | 3 | 2 | 2 | 2 |
| Al | 7.1% | - | - | - | - | - | - | - | - |
| As | 6 | - | - | - | - | - | - | - | - |
| Ba | 500 | - | 1 | - | - | - | - | - | - |
| Be | 0.3 | 2 | 3 | 3 | 4 | 3 | 4 | 4 | 3 |
| Bi | 0.2 | - | - | - | - | - | - | - | - |
| Ca | 1.5% | 2 | 2 | - | - | - | 3 | 1 | 3 |
| Cd | 0.35 | - | - | - | - | - | - | - | - |
| Co | 8 | - | - | - | 2 | - | - | 1 | - |
| Cr | 70 | - | - | - | - | - | - | - | - |
| Cu | 30 | - | - | - | 3 | - | 1 | 1 | - |
| Fe | 4.0% | - | - | - | 1 | - | - | - | - |
| Ga | 20 | - | - | - | - | - | - | - | - |
| Hg | 0.06 | - | - | - | - | - | - | - | - |
| K | 1.4% | - | - | - | - | - | - | - | - |
| La | 40 | - | - | - | - | - | - | - | - |
| Mg | 0.5% | - | - | - | - | - | - | - | - |
| Mn | 1000 | - | - | - | - | - | - | - | - |
| Mo | 1.2 | - | - | - | - | 1 | - | - | - |
| Na | 0.5% | - | - | - | - | - | - | - | - |
| Ni | 50 | - | - | - | - | - | - | - | - |
| P | 800 | 3 | 5 | - | 2 | 1 | >5 | 4 | >5 |
| Pb | 35 | - | 1 | - | - | - | - | 1 | - |
| S | 0.07% | - | - | - | - | - | - | - | - |
| Sb | 1 | - | - | - | - | - | - | - | - |
| Sc | 7 | - | - | - | 2 | 1 | - | 1 | - |
| Se | 0.4 | 2 | 2 | 1 | 2 | 2 | 2 | 3 | 1 |
| Sn | 4 | - | - | - | - | - | - | - | - |
| Sr | 250 | - | - | - | - | - | - | 1 | - |
| Th | 9 | - | - | - | - | - | - | - | - |
| Ti | 0.50% | - | - | - | - | - | - | - | - |
| Tl | 0.2 | - | - | - | 2 | - | - | 3 | - |
| U | 2 | - | 2 | - | - | 1 | 2 | 2 | 3 |
| V | 90 | - | - | - | 1 | - | - | - | - |
| W | 1.5 | - | - | - | - | - | - | - | - |
| Zn | 90 | - | - | - | 1 | - | - | - | - |

*Bowen H.J.M.(1979) Environmental Chemistry of the Elements.

Table 4: Chemical composition of water extracts of selected samples - Arruwurra Prospect.

| Parameter | | Detection Limit | Composite Number / Hole ID / Lithology | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 5 | 8 | 13 | 21 | 25 | 40 | 42 | 45 |
| | | | WNRC013 | WNRC089 | WNRC091 | WNRC094 | WNRC197 | WNRC212 | WNRC217 | WNRC252 |
| | | | calcrete | phosphatic muddy siltstone | siltstone/ mudstone | basalt | cherty sandstone | cherty sandstone and mudstone | mudstone | mudstone> siltstone |
| pH | | 0.01 | 8.1 | 8.3 | 6.7 | 7.5 | 7.9 | 7.6 | 7.6 | 6.8 |
| EC | dS/m | 0.01 | 0.149 | 0.219 | 0.161 | 0.251 | 0.21 | 0.429 | 0.355 | 0.626 |
| Ag | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Al | mg/l | 0.01 | 0.80 | 0.67 | 3.93 | 0.96 | 0.36 | 0.12 | 0.20 | 0.22 |
| As | mg/l | 0.001 | 0.001 | 0.001 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 |
| B | mg/l | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ba | mg/l | 0.001 | 0.115 | 0.054 | 0.106 | 0.019 | 0.037 | 0.022 | 0.030 | 0.006 |
| Be | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Ca | mg/l | 1 | 19 | 6 | 3 | 6 | 3 | 12 | 8 | 2 |
| Cd | mg/l | 0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Cl | mg/l | 1 | 3 | 56 | 16 | 23 | 48 | 63 | 97 | 7 |
| Co | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | 0.002 | <0.001 | <0.001 | <0.001 | <0.001 |
| Cr | mg/l | 0.001 | 0.001 | <0.001 | 0.005 | <0.001 | <0.001 | <0.001 | 0.001 | <0.001 |
| Cu | mg/l | 0.001 | 0.003 | 0.002 | 0.004 | 0.013 | 0.004 | 0.002 | 0.002 | 0.002 |
| F | mg/l | 0.1 | 2.4 | 2.9 | 1.1 | 0.8 | 1.1 | 2.1 | 2.2 | 2.6 |
| Fe | mg/l | 0.05 | 0.23 | 0.17 | 0.52 | 0.48 | 0.36 | 0.09 | <0.05 | 0.36 |
| Hg | mg/l | 0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | mg/l | 1 | 8 | 5 | 7 | 6 | 6 | 6 | 4 | 5 |
| Mg | mg/l | 1 | 2 | 3 | 2 | 5 | 4 | 5 | 7 | 2 |
| Mn | mg/l | 0.001 | 0.010 | 0.004 | 0.031 | 0.075 | 0.008 | 0.001 | 0.004 | 0.004 |
| Mo | mg/l | 0.001 | 0.001 | <0.001 | <0.001 | <0.001 | 0.004 | 0.003 | 0.003 | 0.001 |
| Na | mg/l | 1 | 2 | 57 | 16 | 19 | 26 | 35 | 59 | 9 |
| Ni | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | 0.002 | <0.001 | <0.001 | <0.001 | <0.001 |
| P | mg/l | 1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Pb | mg/l | 0.001 | 0.001 | <0.001 | 0.003 | 0.002 | <0.001 | <0.001 | <0.001 | <0.001 |
| $SO_4$ | mg/l | 1 | 12 | 26 | 10 | 39 | 16 | 17 | 25 | 10 |
| Sb | mg/l | 0.001 | 0.006 | 0.002 | 0.002 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Se | mg/l | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | mg/l | 0.1 | 7.5 | 6.9 | 7.7 | 9.3 | 4.6 | 5.4 | 7.1 | 3.0 |
| Sn | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sr | mg/l | 0.001 | 0.044 | 0.041 | 0.046 | 0.054 | 0.079 | 0.116 | 0.092 | 0.017 |
| Th | mg/l | 0.001 | <0.001 | <0.001 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| U | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Zn | mg/l | 0.005 | <0.005 | <0.005 | 0.050 | 0.013 | 0.006 | <0.005 | <0.005 | <0.005 |

< element at or below analytical detection limit.

Table 5: Acid forming characteristics of waste rock composite samples from the Main Zone.

| Comp. No. | Hole No. | Lithology | Depth (m) | | Interval (m) | $pH_{1:2}$ | $EC_{1:2}$ (dS/m) | ACID-BASE ANALYSIS | | | | | NAG TEST | | | ARD Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | From | To | | | | Total %S | MPA | ANC | NAPP | ANC/MPA Ratio | NAGpH | $NAG_{(pH4.5)}$ | $NAG_{(pH7.0)}$ | |
| 1 | WNRC295 | aeolian sand | 0 | 3 | 3.0 | | | <0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 2 | WNRC295 | silty mudstone | 5 | 10 | 5.0 | | | 0.03 | 1 | 1 | 0 | 1.1 | | | | NAF (Barren) |
| 3 | WNRC295 | cherty sandstone | 22 | 27 | 5.0 | 7.3 | 0.107 | 0.04 | 1 | 0 | 1 | 0.0 | 5.1 | 0 | 12 | UC (NAF) |
| 4 | WNRC295 | cherty sandstone/mudstone | 30 | 35 | 5.0 | | | 0.02 | 1 | 1 | 0 | 1.6 | | | | NAF (Barren) |
| 5 | WNRC295 | mudstone c chert | 44 | 48 | 4.0 | | | 0.03 | 1 | 14 | -13 | 15.3 | | | | UC (NAF) |
| 6 | WNRC313 | mudstone/siltstone | 4 | 9 | 5.0 | | | 0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 7 | WNRC313 | mudstone/siltstone | 12 | 17 | 5.0 | | | <0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 8 | WNRC313 | cherty sandstone and mudstone | 25 | 30 | 5.0 | | | 0.02 | 1 | 0 | 1 | 0.0 | | | | NAF (Barren) |
| 9 | WNRC313 | mudstone/siltstone c chert | 36 | 40 | 4.0 | 7.4 | 0.114 | 0.02 | 1 | 3 | -2 | 4.9 | | | | NAF (Barren) |
| 10 | WNRC313 | weathered basalt | 51 | 54 | 3.0 | | | <0.01 | 0 | 18 | -18 | 58.8 | | | | UC (NAF) |
| 11 | WNRC326 | pisolitic regolith | 0 | 3 | 3.0 | | | <0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 12 | WNRC326 | cherty/ferruginous silty mudstone | 8 | 13 | 5.0 | | | 0.04 | 1 | 4 | -3 | 3.3 | | | | NAF (Barren) |
| 13 | WNRC326 | cherty mudstone | 17 | 22 | 5.0 | | | 0.04 | 1 | 1 | 0 | 0.8 | | | | NAF (Barren) |
| 14 | WNRC326 | weakly phosphatic mudstone | 27 | 31 | 4.0 | 7.5 | 0.092 | 0.04 | 1 | 9 | -8 | 7.4 | | | | UC (NAF) |
| 15 | WNRC326 | weakly phosphatic c breccia | 44 | 49 | 5.0 | | | 0.05 | 2 | 12 | -10 | 7.8 | 5.6 | 0 | 10 | NAF |
| 16 | WNRC326 | cherty mudstone | 49 | 53 | 4.0 | 7.6 | 0.121 | 0.13 | 4 | 12 | -8 | 3.0 | 7.8 | 0 | 0 | NAF |
| 17 | WNRC346 | silcrete breccia | 0 | 5 | 5.0 | | | <0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 18 | WNRC346 | siltstone-sandstone | 7 | 12 | 5.0 | | | 0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 19 | WNRC346 | mudstone-siltstone | 13 | 18 | 5.0 | 7.7 | 0.146 | 0.07 | 2 | 0 | 2 | 0.0 | 5.2 | 0 | 12 | UC (NAF) |
| 20 | WNRC346 | mudstone-cherty sandstone | 20 | 25 | 5.0 | | | 0.03 | 1 | 1 | 0 | 1.1 | | | | NAF (Barren) |
| 21 | WNRC346 | phosphatic mudstone | 41 | 46 | 5.0 | | | 0.02 | 1 | 14 | -13 | 22.9 | | | | UC (NAF) |
| 22 | WNRC372 | ferruginous silty mudstone | 6 | 11 | 5.0 | | | 0.02 | 1 | 1 | 0 | 1.6 | | | | NAF (Barren) |
| 23 | WNRC372 | mudstone | 11 | 16 | 5.0 | 7.2 | 0.109 | 0.05 | 2 | 1 | 1 | 0.7 | 5.8 | 0 | 10 | UC (NAF) |
| 24 | WNRC372 | mudstone | 16 | 21 | 5.0 | | | 0.03 | 1 | 1 | 0 | 1.1 | | | | NAF (Barren) |
| 25 | WNRC372 | mudstone and cherty sandstone | 26 | 31 | 5.0 | | | <0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 26 | WNRC372 | weakly phosphatic mudstone | 42 | 46 | 4.0 | | | 0.02 | 1 | 16 | -15 | 26.1 | | | | UC (NAF) |
| 27 | WNRC389 | muddy siltstone | 4 | 9 | 5.0 | | | 0.02 | 1 | 2 | -1 | 3.3 | | | | NAF (Barren) |
| 28 | WNRC389 | mudstone with chert sandstone | 13 | 18 | 5.0 | | | 0.04 | 1 | 1 | 0 | 0.8 | | | | NAF (Barren) |
| 29 | WNRC389 | mudstone with minor siltstone | 19 | 24 | 5.0 | | | 0.03 | 1 | 1 | 0 | 1.1 | | | | NAF (Barren) |
| 30 | WNRC389 | phosphatic cherty mudstone | 25 | 27 | 2.0 | 7.4 | 0.111 | 0.10 | 3 | 6 | -3 | 2.0 | 5.2 | 0 | 15 | NAF |

Table 5: Acid forming characteristics of waste rock composite samples from the Main Zone.

| Comp. No. | Hole No. | Lithology | Depth (m) | | Interval (m) | $pH_{1:2}$ | $EC_{1:2}$ (dS/m) | ACID-BASE ANALYSIS | | | | | NAG TEST | | | ARD Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | From | To | | | | Total %S | MPA | ANC | NAPP | ANC/MPA Ratio | NAGpH | $NAG_{(pH4.5)}$ | $NAG_{(pH7.0)}$ | |
| 31 | WNRC389 | weakly phosphatic chert breccia | 33 | 38 | 5.0 | 7.1 | 0.131 | 0.08 | 2 | 15 | -13 | 6.1 | 5.6 | 0 | 11 | NAF |
| 32 | WNRC389 | phosphatic mudstone | 38 | 41 | 3.0 | | | 0.05 | 2 | 18 | -16 | 11.8 | | | | UC (NAF) |
| 33 | WNRC418 | silcrete breccia | 0 | 5 | 5.0 | | | <0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 34 | WNRC418 | mudstone with minor siltstone | 10 | 15 | 5.0 | 7.3 | 0.124 | 0.07 | 2 | 1 | 1 | 0.5 | 4.9 | 0 | 14 | UC (NAF) |
| 35 | WNRC418 | mudstone with minor chert | 17 | 22 | 5.0 | | | 0.05 | 2 | 1 | 1 | 0.7 | 5.0 | 0 | 15 | UC (NAF) |
| 36 | WNRC418 | mudstone-siltstone | 22 | 28 | 6.0 | | | 0.02 | 1 | 1 | 0 | 1.6 | | | | NAF (Barren) |
| 37 | WNRC418 | clay-rich phosphatic mudstone | 42 | 45 | 3.0 | | | 0.04 | 1 | 14 | -13 | 11.4 | | | | UC (NAF) |
| 38 | WNRC429 | mudstone | 9 | 14 | 5.0 | | | 0.04 | 1 | 1 | 0 | 0.8 | | | | NAF (Barren) |
| 39 | WNRC429 | mudstone with minor chert | 22 | 27 | 5.0 | 7.2 | 0.122 | 0.06 | 2 | 1 | 1 | 0.5 | 5.1 | 0 | 14 | UC (NAF) |
| 40 | WNRC429 | mudstone with minor chert | 37 | 42 | 5.0 | | | 0.02 | 1 | 1 | 0 | 1.6 | | | | NAF (Barren) |
| 41 | WNRC429 | weathered basalt | 53 | 58 | 5.0 | | | <0.01 | 0 | 19 | -19 | 62.1 | | | | UC (NAF) |
| 42 | WNRC481 | ferruginous silcrete | 0 | 3 | 3.0 | 7.5 | 0.088 | 0.01 | 0 | 1 | -1 | 3.3 | | | | NAF (Barren) |
| 43 | WNRC481 | silty mudstone | 7 | 12 | 5.0 | | | 0.03 | 1 | 1 | 0 | 1.1 | | | | NAF (Barren) |
| 44 | WNRC481 | silty-mudstone c cherty sandstone | 19 | 24 | 5.0 | | | 0.05 | 2 | 1 | 1 | 0.7 | 5.0 | 0 | 17 | UC (NAF) |
| 45 | WNRC481 | mudstone | 30 | 35 | 5.0 | | | 0.03 | 1 | 1 | 0 | 1.1 | | | | NAF (Barren) |
| 46 | WNRC481 | cherty phosphatic mudstone | 48 | 51 | 3.0 | | | 0.02 | 1 | 15 | -14 | 24.5 | | | | UC (NAF) |
| 47 | WNRC532 | silcrete breccia | 2 | 6 | 4.0 | | | <0.01 | 0 | 2 | -2 | 6.5 | | | | NAF (Barren) |
| 48 | WNRC532 | mudstone c minor cherty sandstone | 6 | 11 | 5.0 | | | 0.02 | 1 | 1 | 0 | 1.6 | | | | NAF (Barren) |
| 49 | WNRC532 | silty mudstone | 15 | 20 | 5.0 | | | 0.04 | 1 | 1 | 0 | 0.8 | | | | NAF (Barren) |
| 50 | WNRC532 | cherty mudstone | 25 | 30 | 5.0 | | | 0.05 | 2 | 1 | 1 | 0.7 | 5.4 | 0 | 11 | UC (NAF) |
| 51 | WNRC532 | weathered basalt | 55 | 59 | 4.0 | 7.4 | 0.125 | <0.01 | 0 | 13 | -13 | 42.5 | | | | UC (NAF) |

**KEY**

MPA = Maximum Potential Acidity ($kgH_2SO_4/t$)
ANC = Acid Neutralising Capacity ($kgH_2SO_4/t$)
NAPP = Net Acid Producing Potential ($kgH_2SO_4/t$)

NAGpH = pH of NAG liquor
$NAG_{(pH4.5)}$ = Net Acid Generation capacity to pH 4.5 ($kgH_2SO_4/t$)
$NAG_{(pH7.0)}$ = Net Acid Generation capacity to pH 7.0 ($kgH_2SO_4/t$)

NAF = Non-Acid Forming
PAF = Potentially Acid Forming
PAF-LC = PAF - lower capacity
UC = Uncertain Classification
(expected classification in brackets)

Table 6: Multi-element composition of selected solids samples (mg/kg except where shown) - Main Zone.

| Element | Detection Limit | Composite Number/ Hole ID/ Lithology | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3 | 9 | 14 | 16 | 19 | 23 | 30 | 31 | 34 | 39 | 42 | 51 |
| | | WNRC295 | WNRC313 | WNRC326 | WNRC326 | WNRC346 | WNRC372 | WNRC389 | WNRC389 | WNRC418 | WNRC429 | WNRC481 | WNRC532 |
| | | cherty sandstone | mudstone/silt stone c chert | weakly phosphatic mudstone | cherty mudstone | mudstone-siltstone | mudstone | phosphatic cherty mudstone | weakly phosphatic chert breccia | mudstone with minor siltstone | mudstone with minor chert | ferruginous silcrete | weathered basalt |
| Ag | 0.02 | 0.11 | 0.43 | 0.26 | 0.23 | 0.03 | <0.01 | 1.69 | 0.38 | 0.03 | 0.05 | 0.23 | 0.04 |
| Al | 0.01% | 4.10% | 4.70% | 2.50% | 4.05% | 5.52% | 4.84% | 5.77% | 3.92% | 3.54% | 2.97% | 3.74% | 7.17% |
| As | 0.2 | 1.1 | 0.9 | 1.9 | 12.6 | 0.6 | 3.5 | 3.7 | 2.2 | 0.3 | 0.8 | 7.7 | 0.3 |
| Ba | 10 | 280 | 420 | 360 | 880 | 580 | 330 | 940 | 280 | 660 | 330 | 450 | 150 |
| Be | 0.05 | 1.51 | 7.55 | 4.34 | 4.38 | 1.74 | 2.15 | 11.30 | 5.26 | 1.10 | 1.42 | 1.15 | 1.14 |
| Bi | 0.01 | 0.13 | 0.20 | 0.10 | 0.22 | 0.13 | 0.12 | 0.33 | 0.14 | 0.04 | 0.06 | 0.17 | 0.06 |
| Ca | 0.01% | 0.10% | 0.51% | 1.17% | 1.06% | 0.11% | 0.08% | 1.82% | 8.57% | 0.09% | 0.11% | 0.03% | 0.52% |
| Cd | 0.02 | 0.04 | 0.05 | 0.13 | 4.45 | <0.02 | <0.02 | 0.07 | 1.17 | <0.02 | <0.02 | <0.02 | 0.37 |
| Co | 0.1 | 2.2 | 18.5 | 17.8 | 26.6 | 0.5 | 0.9 | 0.8 | 5.9 | 0.4 | 1.0 | 2.9 | 48.5 |
| Cr | 1 | 35 | 37 | 21 | 55 | 23 | 30 | 42 | 41 | 21 | 18 | 127 | 31 |
| Cu | 0.2 | 17.5 | 37.7 | 29.4 | 85.0 | 2.1 | 3.2 | 44.2 | 44.5 | 6.1 | 9.8 | 12.3 | 142.5 |
| Fe | 0.01% | 0.33% | 0.38% | 0.39% | 2.83% | 0.32% | 0.36% | 0.57% | 0.94% | 0.30% | 0.27% | 5.16% | 5.94% |
| Ga | 10 | 8.50 | 12.35 | 6.54 | 14.15 | 14.80 | 12.45 | 13.70 | 9.44 | 8.19 | 6.93 | 13.55 | 17.75 |
| Hg | 0.01 | 0.007 | 0.007 | 0.007 | 0.052 | 0.006 | <0.005 | 0.097 | 0.014 | <0.005 | 0.005 | 0.009 | 0.032 |
| K | 0.002% | 0.37% | 0.97% | 0.46% | 0.78% | 0.55% | 0.59% | 0.73% | 0.66% | 0.34% | 0.42% | 0.13% | 2.44% |
| La | 10 | 46 | 58 | 27 | 26 | 79 | 58 | 104 | 28 | 55 | 32 | 20 | 16 |
| Mg | 0.002% | 0.07% | 0.17% | 0.09% | 0.41% | 0.10% | 0.11% | 0.12% | 0.18% | 0.06% | 0.08% | 0.04% | 5.21% |
| Mn | 1.0 | 15 | 177 | 325 | 18100 | 18 | 43 | 26 | 185 | 8 | 28 | 73 | 905 |
| Mo | 0.1 | 0.91 | 0.49 | 1.03 | 2.81 | 0.40 | 0.21 | 1.15 | 1.94 | 0.13 | 0.53 | 0.99 | 0.27 |
| Na | 0.002% | 0.03% | 0.04% | 0.03% | 0.05% | 0.03% | 0.04% | 0.04% | 0.04% | 0.03% | 0.03% | 0.02% | 0.04% |
| Ni | 1.0 | 11.1 | 7.1 | 14.6 | 135.5 | 3.3 | 5.1 | 4 | 13.9 | 3.8 | 5.4 | 13.1 | 88.5 |
| P | 20 | 1370 | 5520 | 7630 | 4470 | 1670 | 1110 | 23300 | 43400 | 1330 | 1370 | 150 | 830 |
| Pb | 2.0 | 30 | 51 | 44 | 455 | 17 | 9 | 482 | 243 | 8 | 8 | 32 | 7 |
| S | 0.001% | 0.05% | 0.02% | 0.05% | 0.02% | 0.08% | 0.06% | 0.13% | 0.09% | 0.07% | 0.05% | 0.03% | 0.01% |
| Sb | 0.05 | 0.41 | 0.19 | 0.25 | 2.05 | 0.41 | 0.38 | 1.34 | 0.97 | 0.18 | 0.24 | 0.52 | <0.05 |
| Sc | 1 | 5.7 | 22.0 | 7.1 | 12.1 | 7.1 | 7.0 | 31.3 | 13.1 | 6.5 | 15.1 | 6.8 | 38.3 |
| Se | 0.01 | 1 | 1 | <1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 |
| Sn | 0.1 | 2.3 | 1.9 | 1.4 | 2.4 | 4.6 | 4.2 | 3.5 | 1.8 | 2.1 | 2.2 | 2.1 | 1.3 |
| Sr | 0.05 | 326 | 506 | 450 | 43 | 534 | 323 | 1690 | 673 | 729 | 450 | 59 | 25 |
| Th | 0.2 | 15.1 | 10.3 | 4.4 | 9.7 | 20.4 | 17.2 | 13.9 | 10.4 | 17.2 | 8.7 | 8.0 | 5.0 |
| Ti | 0.01% | 0.21% | 0.14% | 0.10% | 0.26% | 0.39% | 0.35% | 0.23% | 0.15% | 0.17% | 0.19% | 0.32% | 0.58% |
| Tl | 0.02 | 0.13 | 0.35 | 0.69 | 0.87 | 0.14 | 0.18 | 0.31 | 0.30 | 0.11 | 0.18 | 0.13 | 0.36 |
| U | 0.01 | 5.2 | 16.7 | 6.0 | 4.8 | 5.3 | 3.6 | 50.4 | 21.8 | 4.1 | 3.3 | 1.4 | 1.1 |
| V | 2.0 | 29 | 68 | 49 | 232 | 31 | 60 | 68 | 90 | 26 | 23 | 119 | 234 |
| W | 0.1 | 1.6 | 1.2 | 1.2 | 2.4 | 1.9 | 1.8 | 1.8 | 2.2 | 1.2 | 1.3 | 1.6 | 0.7 |
| Zn | 1.0 | 27 | 30 | 66 | 1120 | 7 | 8 | 76 | 112 | 8 | 12 | 11 | 472 |

< element at or below analytical detection limit.

Table 7: Geochemical abundance indices (GAI) of selected solids samples - Main Zone.

| Element | Median Soil Abundance* | Composite Number/ Drill Hole/ Lithology | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3 | 9 | 14 | 16 | 19 | 23 | 30 | 31 | 34 | 39 | 42 | 51 |
| | | WNRC295 | WNRC313 | WNRC326 | WNRC326 | WNRC346 | WNRC372 | WNRC389 | WNRC389 | WNRC418 | WNRC429 | WNRC481 | WNRC532 |
| | | cherty sandstone | mudstone/silt stone c chert | weakly phosphatic mudstone | cherty mudstone | mudstone-siltstone | mudstone | phosphatic cherty mudstone | weakly phosphatic chert breccia | mudstone with minor siltstone | mudstone with minor chert | ferruginous silcrete | weathered basalt |
| Ag | 0.05 | 1 | **3** | 2 | 2 | - | - | **4** | 2 | - | - | 2 | - |
| Al | 7.1% | - | - | - | - | - | - | - | - | - | - | - | - |
| As | 6 | - | - | - | - | - | - | - | - | - | - | - | - |
| Ba | 500 | - | - | - | - | - | - | - | - | - | - | - | - |
| Be | 0.3 | 2 | **4** | **3** | **3** | 2 | 2 | **5** | **4** | 1 | 2 | 1 | 1 |
| Bi | 0.2 | - | - | - | - | - | - | - | - | - | - | - | - |
| Ca | 1.5% | - | - | - | - | - | - | - | 2 | - | - | - | - |
| Cd | 0.35 | - | - | - | **3** | - | - | - | 1 | - | - | - | - |
| Co | 8 | - | 1 | 1 | 1 | - | - | - | - | - | - | - | 2 |
| Cr | 70 | - | - | - | - | - | - | - | - | - | - | - | - |
| Cu | 30 | - | - | - | 1 | - | - | - | - | - | - | - | 2 |
| Fe | 4.0% | - | - | - | - | - | - | - | - | - | - | - | - |
| Ga | 20 | - | - | - | - | - | - | - | - | - | - | - | - |
| Hg | 0.06 | - | - | - | - | - | - | - | - | - | - | - | - |
| K | 1.4% | - | - | - | - | - | - | - | - | - | - | - | - |
| La | 40 | - | - | - | - | - | - | 1 | - | - | - | - | - |
| Mg | 0.5% | - | - | - | - | - | - | - | - | - | - | - | **3** |
| Mn | 1000 | - | - | - | **4** | - | - | - | - | - | - | - | - |
| Mo | 1.2 | - | - | - | 1 | - | - | - | - | - | - | - | - |
| Na | 0.5% | - | - | - | - | - | - | - | - | - | - | - | - |
| Ni | 50 | - | - | - | 1 | - | - | - | - | - | - | - | - |
| P | 800 | - | 2 | **3** | 2 | - | - | **4** | **5** | - | - | - | - |
| Pb | 35 | - | - | - | **3** | - | - | **3** | 2 | - | - | - | - |
| S | 0.07% | - | - | - | - | - | - | - | - | - | - | - | - |
| Sb | 1 | - | - | - | - | - | - | - | - | - | - | - | - |
| Sc | 7 | - | 1 | - | - | - | - | 2 | - | - | 1 | - | 2 |
| Se | 0.4 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| Sn | 4 | - | - | - | - | - | - | - | - | - | - | - | - |
| Sr | 250 | - | - | - | - | 1 | - | 2 | 1 | 1 | - | - | - |
| Th | 9 | - | - | - | - | 1 | - | - | - | - | - | - | - |
| Ti | 0.50% | - | - | - | - | - | - | - | - | - | - | - | - |
| Tl | 0.2 | - | - | 1 | 2 | - | - | - | - | - | - | - | - |
| U | 2 | 1 | 2 | 1 | 1 | 1 | - | **4** | **3** | - | - | - | - |
| V | 90 | - | - | - | 1 | - | - | - | - | - | - | - | 1 |
| W | 1.5 | - | - | - | - | - | - | - | - | - | - | - | - |
| Zn | 90 | - | - | - | **3** | - | - | - | - | - | - | - | 2 |

*Bowen H.J.M.(1979) Environmental Chemistry of the Elements.

Table 8: Chemical composition of water extracts of selected waste rock composite samples from the Main Zone.

| Parameter | | Detection Limit | Composite Numer/ Hole ID/ Lithology | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3 | 9 | 14 | 16 | 19 | 23 | 30 | 31 | 34 | 39 | 42 | 51 |
| | | | WNRC295 | WNRC313 | WNRC326 | WNRC326 | WNRC346 | WNRC372 | WNRC389 | WNRC389 | WNRC418 | WNRC429 | WNRC481 | WNRC532 |
| | | | cherty sandstone | mudstone/ siltstone c chert | weakly phosphatic mudstone | cherty mudstone | mudstone-siltstone | mudstone | phosphatic cherty mudstone | weakly phosphatic chert breccia | mudstone with minor siltstone | mudstone with minor chert | ferruginous silcrete | weathered basalt |
| pH | | 0.01 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.2 | 7.4 | 7.1 | 7.3 | 7.2 | 7.5 | 7.4 |
| EC | dS/m | 0.01 | 0.107 | 0.114 | 0.092 | 0.121 | 0.146 | 0.109 | 0.111 | 0.131 | 0.124 | 0.122 | 0.088 | 0.125 |
| | | | | | | | | | | | | | | |
| Ag | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Al | mg/l | 0.01 | 0.50 | 0.24 | 0.29 | 0.54 | 0.32 | 0.14 | 0.45 | 0.97 | 0.52 | 0.60 | 0.24 | 0.43 |
| As | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| B | mg/l | 0.05 | 0.68 | <0.05 | <0.05 | <0.05 | <0.05 | 0.28 | <0.05 | <0.05 | <0.05 | <0.05 | 0.31 | <0.05 |
| Ba | mg/l | 0.001 | 0.009 | 0.016 | 0.010 | 0.067 | 0.006 | 0.035 | 0.008 | 0.016 | 0.010 | 0.008 | 0.046 | 0.010 |
| Be | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Ca | mg/l | 1 | <1 | 6 | 2 | 5 | <1 | 7 | <1 | 9 | <1 | <1 | <1 | 2 |
| Cd | mg/l | 0.0001 | 0.0001 | <0.0001 | <0.0001 | 0.0007 | <0.0001 | <0.0001 | <0.0001 | 0.0002 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Cl | mg/l | 1 | 8 | 13 | 22 | 14 | 6 | 24 | 14 | 13 | 6 | 6 | 5 | 12 |
| Co | mg/l | 0.001 | <0.001 | <0.001 | 0.001 | 0.004 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Cr | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | 0.007 | <0.001 | <0.001 | <0.001 | 0.001 | 0.001 | 0.001 | <0.001 | <0.001 |
| Cu | mg/l | 0.001 | 0.008 | 0.002 | 0.004 | 0.014 | 0.003 | 0.001 | 0.006 | 0.009 | 0.002 | 0.004 | 0.002 | 0.003 |
| F | mg/l | 0.1 | 0.6 | 2.0 | 1.0 | 1.0 | 1.1 | 2.0 | 1.3 | 1.6 | 1.0 | 1.4 | 0.2 | 1.0 |
| Fe | mg/l | 0.05 | <0.05 | <0.05 | <0.05 | 0.36 | <0.05 | <0.05 | <0.05 | 0.17 | 0.05 | 0.06 | <0.05 | <0.05 |
| Hg | mg/l | 0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | mg/l | 1 | 3 | 2 | 5 | 6 | 2 | 3 | 5 | 5 | 2 | 2 | 2 | 4 |
| Mg | mg/l | 1 | <1 | 2 | 2 | 4 | <1 | 3 | <1 | 1 | <1 | <1 | <1 | 1 |
| Mn | mg/l | 0.001 | 0.005 | 0.007 | 0.032 | 1.26 | 0.012 | 0.003 | 0.002 | 0.01 | 0.002 | 0.003 | 0.006 | 0.011 |
| Mo | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 | <0.001 | 0.001 | <0.001 | <0.001 |
| Na | mg/l | 1 | 7 | 12 | 12 | 14 | 6 | 19 | 7 | 8 | 7 | 8 | 6 | 10 |
| Ni | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | 0.018 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| P | mg/l | 1 | <1 | 1 | <1 | <1 | <1 | <1 | <1 | 4 | <1 | <1 | <1 | <1 |
| Pb | mg/l | 0.001 | <0.001 | 0.002 | 0.001 | 0.008 | <0.001 | <0.001 | 0.002 | 0.007 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sb | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Se | mg/l | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | mg/l | 0.05 | 8.79 | 4.53 | 12.8 | 3.84 | 31.6 | 3.84 | 11.4 | 3.01 | 3.21 | 2.64 | 4.82 | 16.4 |
| Sn | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| $SO_4$ | mg/l | 1 | 7 | 6 | 7 | 11 | <1 | 14 | 9 | 11 | 3 | 2 | 3 | 5 |
| Sr | mg/l | 0.001 | 0.019 | 0.030 | 0.025 | 0.012 | 0.006 | 0.070 | 0.015 | 0.050 | 0.012 | 0.023 | 0.014 | 0.021 |
| Th | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | 0.003 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| U | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.002 | <0.001 | <0.001 | <0.001 | <0.001 |
| Zn | mg/l | 0.005 | 0.02 | <0.005 | 0.013 | 0.174 | 0.006 | <0.005 | 0.008 | 0.018 | 0.005 | 0.006 | 0.007 | 0.005 |

< element at or below analytical detection limit.

Table 9: Acid forming characteristics of low-grade ore from the Arruwurrua Prospect and Main Zone.

| Comp. No. | Hole No. | Deposit | Lithology | Depth (m) | | Interval (m) | $pH_{1:2}$ | $EC_{1:2}$ (dS/m) | ACID-BASE ANALYSIS | | | | | NAG TEST | | | ARD Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | From | To | | | | Total %S | MPA | ANC | NAPP | ANC/MPA Ratio | NAGpH | $NAG_{(pH4.5)}$ | $NAG_{(pH7.0)}$ | |
| 52 | WNRC210 | Arruwurra Prospect | non-DSO phosphorite | 15 | 18 | 3.0 | | | 0.03 | 1 | 16 | -15 | 17.4 | | | | UC (NAF) |
| 53 | WNRC211 | | non-DSO phosphorite | 12 | 16 | 4.0 | 7.8 | 0.092 | 0.09 | 3 | 24 | -21 | 8.7 | 6.1 | 0 | 7 | NAF |
| 54 | WNRC217 | | non-DSO phosphorite | 8 | 10 | 2.0 | | | 0.05 | 2 | 27 | -25 | 17.6 | | | | UC (NAF) |
| 55 | WNRC218 | | non-DSO phosphorite | 14 | 18 | 4.0 | | | 0.07 | 2 | 26 | -24 | 12.1 | | | | UC (NAF) |
| 56 | WNRC219 | | non-DSO phosphorite | 9 | 13 | 4.0 | 7.2 | 0.129 | 0.15 | 5 | 28 | -23 | 6.1 | 7.2 | 0 | 0 | NAF |
| 57 | WNRC226 | | non-DSO phosphorite | 4 | 9 | 5.0 | | | 0.09 | 3 | 28 | -25 | 10.2 | | | | UC (NAF) |
| 58 | WNRC227 | | non-DSO phosphorite | 13 | 17 | 4.0 | 7.9 | 0.146 | 0.11 | 3 | 25 | -22 | 7.4 | 7.4 | 0 | 0 | NAF |
| 59 | WNRC726 | | non-DSO phosphorite | 10 | 12 | 2.0 | | | 0.14 | 4 | 25 | -21 | 5.8 | 5.9 | 0 | 12 | NAF |
| 60 | WNRC752 | | non-DSO phosphorite | 7 | 11 | 4.0 | | | 0.10 | 3 | 25 | -22 | 8.2 | | | | UC (NAF) |
| 61 | WNRC756 | | non-DSO phosphorite | 9 | 11 | 2.0 | 7.2 | 0.096 | 0.04 | 1 | 24 | -23 | 19.6 | | | | UC (NAF) |
| 62 | WNRC290 | Main Zone | non-DSO phosphorite | 32 | 34 | 2.0 | | | 0.06 | 2 | 23 | -21 | 12.5 | | | | UC (NAF) |
| 63 | WNRC313 | | non-DSO phosphorite | 40 | 42 | 2.0 | 7.5 | 0.117 | 0.07 | 2 | 23 | -21 | 10.7 | 5.7 | 0 | 10 | NAF |
| 64 | WNRC326 | | non-DSO phosphorite | 31 | 35 | 4.0 | 7.6 | 0.124 | 0.03 | 1 | 22 | -21 | 24.0 | | | | UC (NAF) |
| 65 | WNRC330 | | non-DSO phosphorite | 38 | 41 | 3.0 | | | 0.04 | 1 | 28 | -27 | 22.9 | | | | UC (NAF) |
| 66 | WNRC337 | | non-DSO phosphorite | 30 | 32 | 2.0 | | | 0.09 | 3 | 15 | -12 | 5.4 | 5.6 | 0 | 10 | NAF |
| 67 | WNRC345 | | non-DSO phosphorite | 37 | 39 | 2.0 | | | 0.06 | 2 | 14 | -12 | 7.6 | | | | UC (NAF) |
| 68 | WNRC346 | | non-DSO phosphorite | 29 | 31 | 2.0 | 7.6 | 0.099 | 0.19 | 6 | 14 | -8 | 2.4 | 5.3 | 0 | 12 | NAF |
| 69 | WNRC408 | | non-DSO phosphorite | 30 | 38 | 8.0 | | | 0.06 | 2 | 15 | -13 | 8.2 | | | | UC (NAF) |
| 70 | WNRC477 | | non-DSO phosphorite | 44 | 47 | 3.0 | | | 0.07 | 2 | 23 | -21 | 10.7 | | | | UC (NAF) |
| 71 | WNRC533 | | non-DSO phosphorite | 41 | 43 | 2.0 | 7.7 | 0.087 | 0.05 | 2 | 16 | -14 | 10.5 | 7.2 | 0 | 0 | NAF |

**KEY**

MPA = Maximum Potential Acidity ($kgH_2SO_4/t$)
ANC = Acid Neutralising Capacity ($kgH_2SO_4/t$)
NAPP = Net Acid Producing Potential ($kgH_2SO_4/t$)

NAGpH = pH of NAG liquor
$NAG_{(pH4.5)}$ = Net Acid Generation capacity to pH 4.5 ($kgH_2SO_4/t$)
$NAG_{(pH7.0)}$ = Net Acid Generation capacity to pH 7.0 ($kgH_2SO_4/t$)

NAF = Non-Acid Forming
UC = Uncertain Classification
(expected classification in brackets)

Table 10: Multi-element composition of selected low grade ore samples (mg/kg except where shown).

| Element | Detection Limit | Composite Number/ Hole ID/ Lithology | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Arruwurra Prospect** | | | | **Main Zone** | | | |
| | | 53 | 56 | 58 | 61 | 63 | 64 | 68 | 71 |
| | | WNRC211 | WNRC219 | WNRC227 | WNRC756 | WNRC313 | WNRC326 | WNRC346 | WNRC533 |
| | | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite |
| Ag | 0.02 | 0.26 | 0.33 | 0.28 | 0.30 | 0.79 | 0.17 | 0.36 | 0.33 |
| Al | 0.01% | 1.61% | 1.97% | 1.07% | 3.19% | 2.70% | 2.32% | 7.91% | 2.77% |
| As | 0.2 | 5.0 | 5.0 | 5.0 | 5.0 | 9.0 | 5 | 0.9 | 7.0 |
| Ba | 10 | 170 | 280 | 240 | 120 | 140 | 210 | 1060 | 910 |
| Be | 0.05 | 4.06 | 6.15 | 4.40 | 4.58 | 9.87 | 6.24 | 27.70 | 12.50 |
| Bi | 0.01 | 0.06 | 0.07 | 0.04 | 0.13 | 0.17 | 0.13 | 0.16 | 0.10 |
| Ca | 0.01% | 11.15% | 19.30% | 18.05% | 17.90% | 14.05% | 16.70% | 6.84% | 18.85% |
| Cd | 0.02 | 0.49 | 0.34 | 0.59 | 0.86 | 1.84 | 1.58 | 0.63 | 2.51 |
| Co | 0.1 | 20.1 | 15.0 | 14.8 | 2.6 | 2.6 | 5.7 | 1.8 | 87.8 |
| Cr | 1 | 23 | 30 | 16 | 35 | 27 | 71 | 81 | 55 |
| Cu | 0.2 | 31.4 | 18.4 | 33.9 | 19.9 | 53.5 | 18.5 | 26.8 | 47.4 |
| Fe | 0.01% | 0.16% | 0.31% | 0.28% | 0.19% | 0.29% | 0.27% | 0.42% | 0.64% |
| Ga | 10 | 3.53 | 5.33 | 2.63 | 6.84 | 7.90 | 6.1 | 13.15 | 8.29 |
| Hg | 0.01 | 0.016 | 0.024 | 0.034 | 0.014 | 0.017 | 0.02 | 0.034 | 0.031 |
| K | 0.002% | 0.22% | 0.20% | 0.15% | 0.31% | 0.55% | 0.32% | 0.62% | 0.29% |
| La | 10 | 20 | 46 | 20 | 25 | 55 | 47.3 | 81 | 39 |
| Mg | 0.002% | 0.10% | 0.15% | 0.08% | 0.22% | 0.11% | 0.06% | 0.08% | 0.11% |
| Mn | 1.0 | 268 | 599 | 1040 | 98 | 101 | 191 | 84 | 2510 |
| Mo | 0.1 | 0.42 | 0.73 | 1.47 | 0.24 | 0.30 | 1.65 | 0.84 | 0.92 |
| Na | 0.002% | 0.07% | 0.14% | 0.09% | 0.05% | 0.06% | 0.03% | 0.05% | 0.06% |
| Ni | 1.0 | 5.5 | 7.9 | 5.7 | 7 | 4.6 | 24 | 3.6 | 61.1 |
| P | 20 | >50000 | >50000 | >50000 | >50000 | >50000 | >50000 | >50000 | >50000 |
| Pb | 2.0 | 78 | 126 | 44 | 100 | 345 | 82.3 | 93 | 106 |
| S | 0.001% | 0.08% | 0.16% | 0.09% | 0.03% | 0.06% | 0.03% | 0.14% | 0.05% |
| Sb | 0.05 | 0.17 | 0.15 | 0.09 | 0.25 | 0.24 | 0.4 | 0.54 | 0.51 |
| Sc | 1 | 3.8 | 8.0 | 5.5 | 10.0 | 10.4 | 13 | 50.5 | 41.2 |
| Se | 0.01 | <1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 |
| Sn | 0.1 | 0.5 | 0.8 | 0.5 | 1.1 | 1.3 | 1.2 | 2.5 | 1.5 |
| Sr | 0.05 | 81 | 244 | 125 | 47 | 162 | 332 | 2200 | 1670 |
| Th | 0.2 | 2.8 | 3.5 | 2.4 | 6.0 | 6.7 | 6.5 | 16.7 | 6.5 |
| Ti | 0.01% | 0.02% | 0.02% | 0.02% | 0.04% | 0.05% | 0.02% | 0.14% | 0.06% |
| Tl | 0.02 | 0.12 | 0.26 | 0.19 | 0.17 | 0.20 | 0.29 | 0.36 | 0.97 |
| U | 0.01 | 8.7 | 9.9 | 8.7 | 18.8 | 21.5 | 15.9 | 62.7 | 54.1 |
| V | 2.0 | 26 | 30 | 33 | 34 | 43 | 37 | 45 | 109 |
| W | 0.1 | 0.6 | 0.7 | 0.5 | 0.9 | 0.9 | 1.2 | 1.6 | 1.6 |
| Zn | 1.0 | 20 | 30 | 66 | 23 | 76 | 153 | 124 | 275 |

< element at or below analytical detection limit.

Table 11: Geochemical abundance indices (GAI) of selected low grade ore samples.

| Element | Median Soil Abundance* | Composite Number/ Hole ID/ Lithology | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Arruwurra Prospect** | | | | **Main Zone** | | | |
| | | 53 | 56 | 58 | 61 | 63 | 64 | 68 | 71 |
| | | WNRC211 | WNRC219 | WNRC227 | WNRC756 | WNRC313 | WNRC326 | WNRC346 | WNRC533 |
| | | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite |
| Ag | 0.05 | 2 | 2 | 2 | 2 | **3** | 1 | 2 | 2 |
| Al | 7.1% | - | - | - | - | - | - | - | - |
| As | **6** | - | - | - | - | - | - | - | - |
| Ba | **500** | - | - | - | - | - | - | - | - |
| Be | 0.3 | **3** | **4** | **3** | **3** | **4** | **4** | **6** | **5** |
| Bi | 0.2 | - | - | - | - | - | - | - | - |
| Ca | 1.5% | 2 | **3** | **3** | **3** | **3** | **3** | 2 | **3** |
| Cd | 0.35 | - | - | - | 1 | 2 | 2 | - | 2 |
| Co | **8** | 1 | - | - | - | - | - | - | **3** |
| Cr | **70** | - | - | - | - | - | - | - | - |
| Cu | **30** | - | - | - | - | - | - | - | - |
| Fe | 4.0% | - | - | - | - | - | - | - | - |
| Ga | **20** | - | - | - | - | - | - | - | - |
| Hg | 0.06 | - | - | - | - | - | - | - | - |
| K | 1.4% | - | - | - | - | - | - | - | - |
| La | **40** | - | - | - | - | - | - | - | - |
| Mg | 0.5% | - | - | - | - | - | - | - | - |
| Mn | **1000** | - | - | - | - | - | - | - | 1 |
| Mo | 1.2 | - | - | - | - | - | - | - | - |
| Na | 0.5% | - | - | - | - | - | - | - | - |
| Ni | **50** | - | - | - | - | - | - | - | - |
| P | **800** | **5** | **5** | **5** | **5** | **5** | **5** | **5** | **5** |
| Pb | **35** | 1 | 1 | - | 1 | **3** | 1 | 1 | 1 |
| S | 0.07% | - | 1 | - | - | - | - | - | - |
| Sb | 1 | - | - | - | - | - | - | - | - |
| Sc | **7** | - | - | - | - | - | - | 2 | 2 |
| Se | 0.4 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| Sn | **4** | - | - | - | - | - | - | - | - |
| Sr | **250** | - | - | - | - | - | - | **3** | 2 |
| Th | **9** | - | - | - | - | - | - | - | - |
| Ti | 0.50% | - | - | - | - | - | - | - | - |
| Tl | 0.2 | - | - | - | - | - | - | - | 2 |
| U | 2 | 2 | 2 | 2 | **3** | **3** | 2 | **4** | **4** |
| V | **90** | - | - | - | - | - | - | - | - |
| W | 1.5 | - | - | - | - | - | - | - | - |
| Zn | **90** | - | - | - | - | - | - | - | 1 |

*Bowen H.J.M.(1979) Environmental Chemistry of the Elements.

Table 12: Chemical composition of water extracts of selected low-grade ore samples.

| Parameter | | Detection Limit | Composite Numer/ Hole ID/ Lithology | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Aruwurra Prospect** | | | | **Main Zone** | | | |
| | | | 53 | 56 | 58 | 61 | 63 | 64 | 68 | 71 |
| | | | WNRC211 | WNRC219 | WNRC227 | WNRC756 | WNRC313 | WNRC326 | WNRC346 | WNRC533 |
| | | | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite | non-DSO phosphorite |
| pH | | 0.01 | 7.8 | 7.2 | 7.9 | 7.2 | 7.5 | 7.6 | 7.6 | 7.7 |
| EC | dS/m | 0.01 | 0.092 | 0.129 | 0.146 | 0.096 | 0.117 | 0.124 | 0.099 | 0.087 |
| Ag | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Al | mg/l | 0.01 | 0.01 | 0.16 | 0.09 | 0.05 | 0.28 | 0.27 | 0.26 | 0.32 |
| As | mg/l | 0.001 | <0.001 | <0.001 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| B | mg/l | 0.05 | 0.09 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ba | mg/l | 0.001 | 0.565 | 0.030 | 0.056 | 0.027 | 0.011 | 0.004 | 0.002 | 0.052 |
| Be | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Ca | mg/l | 1 | 11 | 8 | 7 | 7 | 7 | 5 | 2 | <1 |
| Cd | mg/l | 0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Cl | mg/l | 1 | 94 | 35 | 20 | 15 | 19 | 7 | 5 | 7 |
| Co | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Cr | mg/l | 0.001 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Cu | mg/l | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 | 0.002 | 0.009 | 0.004 | 0.002 |
| F | mg/l | 0.1 | 1.9 | 1.4 | 2.5 | 2.1 | 2.5 | 1.2 | 1.2 | 0.4 |
| Fe | mg/l | 0.05 | <0.05 | 0.07 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.1 |
| Hg | mg/l | 0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K | mg/l | 1 | 7 | 3 | 4 | 2 | <1 | 5 | 3 | 2 |
| Mg | mg/l | 1 | 8 | 4 | 3 | 2 | 2 | 1 | <1 | <1 |
| Mn | mg/l | 0.001 | <0.001 | 0.002 | 0.002 | 0.009 | 0.001 | 0.003 | 0.003 | 0.006 |
| Mo | mg/l | 0.001 | 0.003 | 0.001 | <0.001 | 0.002 | <0.001 | <0.001 | <0.001 | <0.001 |
| Na | mg/l | 1 | 70 | 24 | 17 | 13 | 18 | 8 | 6 | 6 |
| Ni | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| P | mg/l | 1 | <1 | <1 | <1 | <1 | 2 | 2 | <1 | <1 |
| Pb | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.002 | 0.006 | 0.001 | <0.001 |
| Sb | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Se | mg/l | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Si | mg/l | 0.05 | 7.87 | 4.59 | 4.03 | 3.36 | 6.53 | 7.46 | 8.38 | 4.65 |
| Sn | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| $SO_4$ | mg/l | 1 | 60 | 23 | 8 | 8 | 4 | 7 | <1 | 4 |
| Sr | mg/l | 0.001 | 0.185 | 0.103 | 0.065 | 0.041 | 0.03 | 0.006 | 0.005 | 0.013 |
| Th | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| U | mg/l | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Zn | mg/l | 0.005 | 0.013 | <0.005 | <0.005 | <0.005 | <0.005 | 0.005 | 0.006 | 0.006 |

< element at or below analytical detection limit.

# APPENDIX A

## Assessment of Acid Forming Characteristics

# Assessment of Acid Forming Characteristics

## Introduction

Acid rock drainage (ARD) is produced by the exposure of sulphide minerals such as pyrite to atmospheric oxygen and water. The ability to identify in advance any mine materials that could potentially produce ARD is essential for timely implementation of mine waste management strategies.

A number of procedures have been developed to assess the acid forming characteristics of mine waste materials. The most widely used methods are the Acid-Base Account (ABA) and the Net Acid Generation (NAG) test. These methods are referred to as static procedures because each involves a single measurement in time.

## Acid-Base Account

The acid-base account involves static laboratory procedures that evaluate the balance between acid generation processes (oxidation of sulphide minerals) and acid neutralising processes (dissolution of alkaline carbonates, displacement of exchangeable bases, and weathering of silicates).

The values arising from the acid-base account are referred to as the potential acidity and the acid neutralising capacity, respectively. The difference between the potential acidity and the acid neutralising capacity value is referred to as the net acid producing potential (NAPP).

The chemical and theoretical basis of the ABA are discussed below.

*Potential Acidity*

The potential acidity that can be generated by a sample is calculated from an estimate of the pyrite ($FeS_2$) content and assumes that the pyrite reacts under oxidising conditions to generate acid according to the following reaction:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \Rightarrow Fe(OH)_3 + 2\ H_2SO_4$$

Based on the above reaction, the potential acidity of a sample containing 1 %S as pyrite would be 30.6 kilograms of $H_2SO_4$ per tonne of material (i.e. kg $H_2SO_4$/t). The pyrite content estimate can be based on total S and the potential acidity determined from total S is referred to as the maximum potential acidity (MPA), and is calculated as follows:

$$\text{MPA (kg } H_2SO_4/t) = (\text{Total \%S}) \times 30.6$$

The use of an MPA calculated from total sulphur is a conservative approach because some sulphur may occur in forms other than pyrite. Sulphate-sulphur, organic sulphur and native sulphur, for example, are non-acid generating sulphur forms. Also, some sulphur may occur as other metal sulphides (e.g. covellite, chalcocite, sphalerite, galena) which yield less acidity than pyrite when oxidised or, in some cases, may be non-acid generating. The total sulphur content is commonly used to assess potential acidity because of the difficulty, costs and uncertainty involved in routinely determining the speciation of sulphur forms within samples, and determining reactive sulphide-sulphur contents. However, if the sulphide mineral forms are known then allowance can be made for non- and lesser acid generating forms to provide a better estimate of the potential acidity.

*Acid Neutralising Capacity (ANC)*

The acid formed from pyrite oxidation will to some extent react with acid neutralising minerals contained within the sample. This inherent acid buffering is quantified in terms of the ANC.

The ANC is commonly determined by the Modified Sobek method. This method involves the addition of a known amount of standardised hydrochloric acid (HCl) to an accurately weighed sample, allowing the sample time to react (with heating), then back-titrating the mixture with standardised sodium hydroxide (NaOH) to determine the amount of unreacted HCl. The amount of acid consumed by reaction with the sample is then calculated and expressed in the same units as the MPA (kg $H_2SO_4$/t).

*Net Acid Producing Potential (NAPP)*

The NAPP is a theoretical calculation commonly used to indicate if a material has potential to produce acidic drainage. It represents the balance between the capacity of a sample to generate acid (MPA) and its capacity to neutralise acid (ANC). The NAPP is also expressed in units of kg $H_2SO_4$/t and is calculated as follows:

$$\text{NAPP} = \text{MPA} - \text{ANC}$$

If the MPA is less than the ANC then the NAPP is negative, which indicates that the sample may have sufficient ANC to prevent acid generation. Conversely, if the MPA exceeds the ANC then the NAPP is positive, which indicates that the material may be acid generating.

*ANC/MPA Ratio*

The ANC/MPA ratio is frequently used as a means of assessing the risk of acid generation from mine waste materials. The ANC/MPA ratio is another way of looking at the acid base account. A positive NAPP is equivalent to an ANC/MPA ratio less than 1, and a negative NAPP is equivalent to an ANC/MPA ratio greater than 1. A NAPP of zero is equivalent to an ANC/MPA ratio of 1.

The purpose of the ANC/MPA ratio is to provide an indication of the relative margin of safety (or lack thereof) within a material. Various ANC/MPA values are reported in the literature for indicating safe values for prevention of acid generation. These values typically range from 1 to 3. As a general rule, an ANC/MPA ratio of 2 or more signifies that there is a high probability that the material will remain circum-neutral in pH and thereby should not be problematic with respect to acid rock drainage.

*Acid-Base Account Plot*

Sulphur and ANC data are often presented graphically in a format similar to that shown in Figure A-1. This figure includes a line indicating the division between NAPP positive samples from NAPP negative samples. Also shown are lines corresponding to ANC/MPA ratios of 2 and 3.

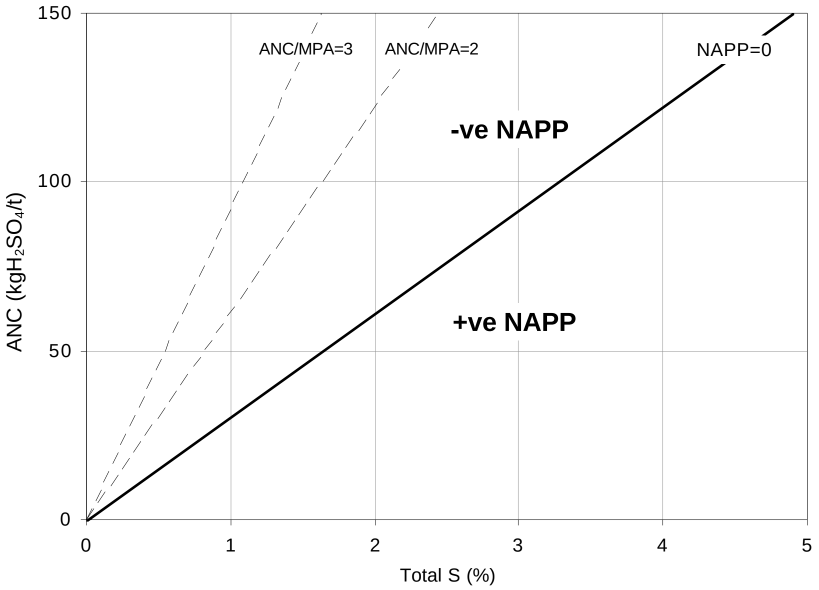


Figure A-1: Acid-base account (ABA) plot

## Net Acid Generation (NAG) Test

The NAG test is used in association with the NAPP to classify the acid generating potential of a sample. The NAG test involves reaction of a sample with hydrogen peroxide to rapidly oxidise any sulphide minerals contained within a sample. During the NAG test both acid generation and acid neutralisation reactions can occur simultaneously. The end result represents a direct measurement of the net amount of acid generated by the sample. The final pH is referred to as the NAGpH and the amount of acid produced is commonly referred to as the NAG capacity, and is expressed in the same units as the NAPP (kg $H_2SO_4$/t).

Several variations of the NAG test have been developed to accommodate the wide geochemical variability of mine waste materials. The four main NAG test procedures currently used by EGi are the single addition NAG test, the sequential NAG test, the kinetic NAG test, and the extended boil and calculated NAG test.

*Single Addition NAG Test*

The single addition NAG test involves the addition of 250 ml of 15% hydrogen peroxide to 2.5 g of sample. The peroxide is allowed to react with the sample overnight and the following day the sample is gently heated to accelerate the oxidation of any remaining sulphides, then vigorously boiled for several minutes to decompose residual peroxide. When cool, the NAGpH and NAG capacity are measured.

An indication of the form of the acidity is provided by initially titrating the NAG liquor to pH 4.5, then continuing the titration up to pH 7. The titration value at pH 4.5 includes acidity due to free acid (i.e. $H_2SO_4$) as well as soluble iron and aluminium. The titration value at pH 7 also includes metallic ions that precipitate as hydroxides at between pH 4.5 and 7.

*Sequential NAG Test*

When testing samples with high sulphide contents it is not uncommon for oxidation to be incomplete in the single addition NAG test. This can sometimes occur when there is catalytic breakdown of the hydrogen peroxide before it has had a chance to oxidise all of the sulphides in a sample. To overcome this limitation, a sequential NAG test is often carried out. This test may also be used to assess the relative geochemical lag of PAF samples with high ANC.

The sequential NAG test is a multi-stage procedure involving a series of single addition NAG tests on the one sample (i.e. 2.5 g of sample is reacted two or more times with 250 ml aliquots of 15% hydrogen peroxide). At the end of each stage, the sample is filtered and the solution is used for measurement of NAGpH and NAG capacity. The NAG test is then repeated on the solid residue. The cycle is repeated until such time that there is no further catalytic decomposition of the peroxide, or when the NAGpH is greater than pH 4.5. The overall NAG capacity of the sample is then determined by summing the individual acid capacities from each stage.

*Kinetic NAG Test*

The kinetic NAG test is the same as the single addition NAG test except that the temperature and pH of the liquor are recorded. Variations in these parameters during the test provide an indication of the kinetics of sulphide oxidation and acid generation. This, in turn, can provide an insight into the behaviour of the material under field conditions. For example, the pH trend gives an estimate of relative reactivity and may be related to prediction of lag times and oxidation rates similar to those measured in leach columns. Also, sulphidic samples commonly produce a temperature excursion during the NAG test due to the decomposition of the peroxide solution, catalysed by sulphide surfaces and/or oxidation products.

*Extended Boil and Calculated NAG Test*

Organic acids may be generated in NAG tests due to partial oxidation of carbonaceous materials[1] such as coal washery wastes. This can lead to low NAGpH values and high acidities in standard single addition NAG tests unrelated to acid generation from sulphides. Organic acid effects can therefore result in misleading NAG values and misclassification of the acid forming potential of a sample.

The extended boil and calculated NAG tests can be used to account for the relative proportions of pyrite derived acidity and organic acidity in a given NAG solution, thus providing a more reliable measure of the acid forming potential of a sample. The procedure involves two steps to differentiating pyritic acid from organic derived acid:

| | |
|---|---|
| Extended Boil NAG | decompose the organic acids and hence remove the influence of non-pyritic acidity on the NAG solution. |
| Calculated NAG | calculate the net acid potential based on the balance of cations and anions in the NAG solution, which will not be affected by organic acid. |

The extended boiling test is carried out on the filtered liquor of a standard NAG test, and involves vigorous boiling of the solution on a hot plate for 3-4 hours. After the boiling step the solution is cooled and the pH measured. An extended boil NAGpH less than 4.5 confirms the sample is potentially acid forming (PAF), but a pH value greater than 4.5 does not necessarily mean that the sample is non acid forming (NAF), due to some loss of free acid during the extended boiling procedure. To address this issue, a split of the same filtered NAG solution is assayed for concentrations of S, Ca, Mg, Na, K and Cl, from which a calculated NAG value is determined[2].

The concentration of dissolved S is used to calculate the amount of acid (as $H_2SO_4$) generated by the sample and the concentrations of Ca, Mg, Na and K are used to estimate the amount of acid neutralised (as $H_2SO_4$). The concentration of Cl is used to correct for soluble cations associated with Cl salts, which may be present in the sample and unrelated to acid generating and acid neutralising reactions.

The calculated NAG value is the amount of acid neutralised subtracted from the amount of acid generated. A positive value indicates that the sample has excess acid generation and is likely to be PAF, and a zero or negative value indicates that the sample has excess neutralising capacity and is likely to be NAF.

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[1] Stewart, W., Miller, S., Thomas, J.E., and Smart R. (2003), 'Evaluation of the Effects of Organic Matter on the Net Acid Generation (NAG) Test', in *Proceedings of the Sixth International Conference on Acid Rock drainage (ICARD), Cairns, 12-18th July 2003*, 211-222.

[2] Environmental Geochemistry International, Levay and Co. and ACeSSS, 2008. *ACARP Project C15034: Development of ARD Assessment for Coal Process Wastes*, EGi Document No. 3207/817, July 2008.

## Sample Classification

The acid forming potential of a sample is classified on the basis of the acid-base and NAG test results into one of the following categories:

- Barren;
- Non-acid forming (NAF);
- Potentially acid forming (PAF); and
- Uncertain (UC).

*Barren*

A sample classified as barren essentially has no acid generating capacity and no acid buffering capacity. This category is most likely to apply to highly weathered materials. In essence, it represents an 'inert' material with respect to acid generation. The criteria used to classify a sample as barren may vary between sites, but for hard rock mines it generally applies to materials with a total sulphur content ≤ 0.1 %S and an ANC ≤ 5 kg $H_2SO_4$/t.

*Non-acid forming (NAF)*

A sample classified as NAF may, or may not, have a significant sulphur content but the availability of ANC within the sample is more than adequate to neutralise all the acid that theoretically could be produced by any contained sulphide minerals. As such, material classified as NAF is considered unlikely to be a source of acidic drainage. A sample is usually defined as NAF when it has a negative NAPP and the final NAG pH ≥ 4.5.

*Potentially acid forming (PAF)*

A sample classified as PAF always has a significant sulphur content, the acid generating potential of which exceeds the inherent acid neutralising capacity of the material. This means there is a high risk that such a material, even if pH circum-neutral when freshly mined or processed, could oxidise and generate acidic drainage if exposed to atmospheric conditions. A sample is usually defined as PAF when it has a positive NAPP and a final NAGpH < 4.5.

*Uncertain (UC)*

An uncertain classification is used when there is an apparent conflict between the NAPP and NAG results (i.e. when the NAPP is positive and NAGpH > 4.5, or when the NAPP is negative and NAGpH ≤ 4.5). Uncertain samples are generally given a tentative classification that is shown in brackets e.g. UC(NAF).

Figure A-2 shows the format of the classification plot that is typically used for presentation of NAPP and NAG data. Marked on this plot are the quadrats representing the NAF, PAF and UC classifications.

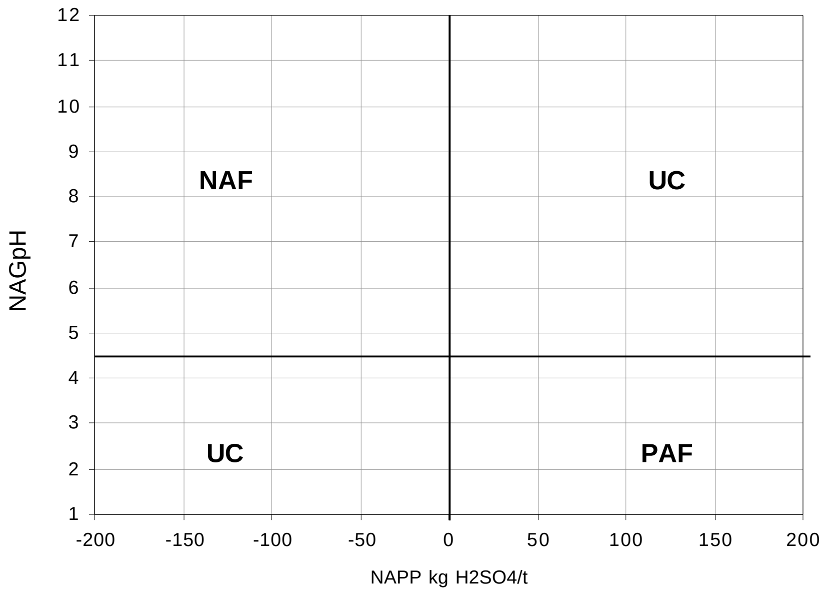


Figure A-2 ARD classification plot

## Other Methods

Other test procedures may be used to define the acid forming characteristics of a sample.

*pH and Electrical Conductivity*

The pH and electrical conductivity (EC) of a sample is determined by equilibrating the sample in deionised water for a minimum of 12 hours (or overnight), typically at a solid to water ratio of 1:2 (w/w). This gives an indication of the inherent acidity and salinity of the waste material when initially exposed in a waste emplacement area.

*Acid Buffering Characteristic Curve (ABCC) Test*

The ABCC test involves slow titration of a sample with acid while continuously monitoring pH. These data provides an indication of the portion of ANC within a sample that is readily available for acid neutralisation.