



MOOLARBEN COAL PROJECT

Stage 2

A P P E N D I X 17

Geochemical Assessment

Prepared by:

**ENVIRONMENTAL GEOCHEMISTRY
INTERNATIONAL PTY LTD**

81A College Street, Balmain, NSW 2041 Australia

Telephone: (61-2) 9810 8100 Facsimile: (61-2) 9810 5542

Email: egi@geochemistry.com.au

ACN 003 793 486 ABN 12 003 793 486

For:

Moolarben Coal Mines Pty Limited

C/- Wells Environmental Services
PO Box 205, East Maitland NSW 2323

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**Geochemical Assessment of the
Moolarben Coal Project Stage 2**

Contents

<i>List of Tables</i>	<i>ii</i>
<i>List of Figures</i>	<i>iii</i>
<i>List of Appendices</i>	<i>iii</i>
<i>Executive Summary</i>	<i>iv</i>
1.0 INTRODUCTION	1
2.0 BACKGROUND DATA	1
3.0 SAMPLE COLLECTION AND PREPARATION	2
4.0 METHODOLOGY	3
5.0 GEOCHEMICAL CHARACTERISATION RESULTS	4
5.1 pH and EC	4
5.2 Acid Base (NAPP) Results	4
5.3 Single Addition NAG Results	5
5.4 Kinetic NAG Results	6
6.0 LEACH COLUMN RESULTS	7
7.0 SAMPLE CLASSIFICATION AND DISTRIBUTION OF GEOCHEMICAL ROCK TYPES	9
8.0 CONCLUSIONS	10

List of Tables (after text)

Table 1:	Acid forming characteristics of overburden, coal and floor samples.
Table 2:	Extended boil NAG and calculated NAG test results for selected samples.
Table 3:	Geochemical characteristics of individual samples used to make up composite samples for column testing. Samples were selected from the Moolarben Stage 1 sample set.
Table 4:	Acid forming characteristics of the composite samples used in column testing.
Table 5:	Multi-element composition (mg/kg except where shown) and geochemical abundance indices (GAI) of column samples.
Table 6:	Column leach test results for the PAF-LC composite sample.
Table 7:	Column leach test results for the PAF-LC composite (1 Part) and NAF composite (2 Parts) blended sample.

List of Figures (after text)

- Figure 1: Arial photo and mine layout showing drill holes sampled for geochemical testing.
- Figure 2: Box plot showing the distribution of pH_{1.2} split by rock types. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 3: Box plot showing the distribution of EC_{1.2} split by rock types. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 4: Box plot showing the distribution of total S split by rock type. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 5: Box plot showing the distribution of ANC split by rock type. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 6: Acid-base account (ABA) plot showing ANC versus total S.
- Figure 7: As for Figure 6 but with a re-scaled y axis.
- Figure 8: Kinetic NAG graph for sample 35912.
- Figure 9: Kinetic NAG graph for sample 35948.
- Figure 10: Kinetic NAG graph for sample 35949.
- Figure 11: Kinetic NAG graph for sample 35975.
- Figure 12: Leach column pH profiles for PAF and composite co-disposed reject/tailings samples from the Stage 1 facility.
- Figure 13: Leach column SO₄ profiles for PAF and composite co-disposed reject/tailings samples from the Stage 1 facility.
- Figure 14: PAF-LC leach column SO₄ release rate, CO₃ dissolution rate (assuming all Ca and Mg released to leachates is due to dissolution of Ca-Mg carbonates), and CO₃/SO₄ molar ratio trends.
- Figure 15: Downhole total S profiles for holes PZ130, PZ133 and PZ150, with PAF samples (including UC(PAF)) indicated.

List of Appendices (after text)

Appendix A – Assessment of Acid Forming Characteristics (after Tables and Figures)

Executive Summary

Environmental Geochemistry International Pty Ltd (EGi) were commissioned by Moolarben Coal Mines Pty Limited to carry out a geochemical assessment of the Moolarben Coal Project Stage 2, located in the Hunter Valley, NSW, approximately 3km east of the village of Ulan. The objective of the work was to assess the acid rock drainage (ARD) potential of the Stage 2 development for inclusion in an environmental assessment.

The Moolarben project stratigraphy comprises a sequence of Permian sandstone, siltstone, mudstone, tuff and coal, of which the Ulan Seam is the only seam of economic significance. Sub economic seams intersected within the mine stratigraphy include Moolarben and Bungaba.

A total of 107 samples were tested from 3 chip holes drilled for groundwater investigations (PZ130, PZ133 and PZ150). All holes drilled to the base of the Ulan Seam, and were selected to best represent the full mine stratigraphic section.

Results of geochemical testing suggest that the bulk of the Moolarben overburden and floor material from the Stage 2 operations is likely to be non acid forming (NAF), with potentially acid forming (PAF) overburden materials mainly associated with the Moolarben Seam, and roof and floor of the Ulan Seam. The Ulan Seam appears to have a greater proportion of PAF than overburden or floor, indicating possible ARD issues associated with rejects, tailings and coal stockpiles.

There are uncertainties in ARD classification due to the combined effects of varying sulphur forms and organic acid effects on characterisation test work, and further investigation would be required to fully assess the relative distribution of PAF and NAF materials, and the overall acid potential. However, findings to date have the following implications for materials management:

- Rejects and tailings may be partly PAF and should be managed as PAF material.
- PAF overburden appears to make up only a small proportion of overburden, and operational mixing may be sufficient to control ARD from these materials, depending on the overall distribution of PAF materials and the acid potential. Alternatively the PAF overburden materials may need to be selectively handled as with the rejects.
- Possible closure strategies for PAF waste materials (including rejects and overburden) include placement in pit and below long term stable water table levels, and/or construction of a cover system that prevents flushing of PAF materials by infiltrating water. The PAF materials can also be treated with limestone.
- During operations, monitoring of seepage and runoff from pits and overburden dumps should be carried out to determine whether limestone/lime treatment or other ARD controls are required prior to implementation of closure strategies.
- Coal materials may be acid generating and moderately saline, and containment of runoff and leachate from coal stockpiles and underground operations may be required to

monitor water quality, with provision for acid treatment as needed. Minor addition of crushed limestone to exposed surfaces may also mitigate ARD generation.

- A routine system of ARD testing should be established during operations to check the ARD potential of mine materials and identify any need to modify materials management strategies.
- Routine site water quality monitoring programmes should include pH, EC, acidity/alkalinity, SO₄, Al, As, Co, Cu, Fe, Mn, Ni and Zn to monitor for effects of ARD.

The following work should be carried out to finalise materials management requirements:

- More widespread sampling and testing of overburden materials to determine the distribution and to quantify the production and scheduling of PAF materials. Testing should include sulphur speciation, extended boil NAG and calculated NAG methods in addition to standard geochemical tests. The feasibility for selective mining, segregation and possible co-disposal with reject should be evaluated.
- Geochemical characterisation of representative rejects and tailings is required to determine whether ARD is a significant issue for these materials.
- Leach column testing of PAF coal, overburden and reject materials to determine lag times and acid release rates, which in turn can be used to determine management requirements such as the need for limestone treatment, appropriate treatment rates (if necessary), and whether selective handling is likely to be required.

1.0 Introduction

Environmental Geochemistry International Pty Ltd (EGi) were commissioned by Moolarben Coal Mines Pty Limited to carry out a geochemical assessment of the Moolarben Coal Project Stage 2, located in the Hunter Valley, NSW, approximately 3km east of the village of Ulan. The objective of the work was to assess the acid rock drainage (ARD) potential of the Stage 2 development for inclusion in an environmental assessment.

The work carried out included the following:

- Review of background data and discussions with relevant site personnel;
- Selection of samples in conjunction with site personnel, and assistance in organising sample preparation prior to delivery to the EGi laboratory;
- Characterisation of materials in terms of ARD potential;
- Leach column testing of samples collected as part of Stage 1 investigations; and
- Evaluation of results and completion of a technical report, detailing results and implications for mine operations and overburden management.

2.0 Background Data

The Moolarben project stratigraphy comprises a sequence of Permian sandstone, siltstone, mudstone, tuff and coal, of which the Ulan Seam is the only seam of economic significance. Sub economic seams intersected within the mine stratigraphy include Moolarben and Bungaba. The Permian sediments appear to have been deposited in a mainly fluvial dominated environment, although worm burrows are observed in some of the sandstone horizons, suggesting occasional marine influence. Pyrite is not generally observed in the drill core. Quaternary/Tertiary alluvial erosion channels cut through portions of the Permian sequence. Small Tertiary basaltic intrusive plugs and flows also occur within the mine area. Siderite is the main carbonate observed, and application of 10% HCl to the core during the Stage 1 investigations showed only minor and occasional fizzing, suggesting a lack of acid neutralising minerals.

Stage 1 of the Moolarben Coal Project was previously investigated by EGi¹, in which samples from 3 proposed open cuts (Open Cut 1, 2 and 3) and a proposed underground development to the north (Underground No. 4) were tested and geochemically assessed. Stage 2 involves development of an additional open cut pit (Open Cut 4) in the catchment immediately east of the Stage 1 area, and development of underground mines (Underground No. 1 and 2) between the Stage 1 and Stage 2 open cut pits. It is understood that the target seams and stratigraphy of the Stage 2 development will be essentially the same as the Stage 1 development.

¹ *Geochemical Assessment of the Moolarben Coal Project*, EGi Document No. 2350/710, April 2006.

Mining will comprise both open cut and underground development operating concurrently, with all coal potentially being washed on site. The full Ulan seam will be recovered in the open cut operations, and a partial section will be recovered in the underground operations.

Out of pit placement of overburden will be required during initial pit development, but it is understood that most overburden will be backfilled into the pits.

Underground mining will use longwall mining methods. Development waste extracted as part of access drives, ventilation shafts and other underground workings will be deposited with overburden.

It is understood that the open cut operations will mine the full Ulan seam in two passes, with separate processing to produce two products: a high ash domestic thermal product; and an export thermal product. Underground coal mining will be restricted mainly to the D section of the Ulan seam.

3.0 Sample Collection and Preparation

A total of 3 chip holes drilled for groundwater investigations (PZ130, PZ133 and PZ150) were sampled for geochemical testing, with all holes drilled to the base of the Ulan Seam. Hole locations are shown in Figure 1. Hole PZ130 was drilled in the southwest portion of Underground No 1, PZ133 in the western part of Open Cut 4, and PZ150 in the eastern part of Open Cut 4. The holes were selected to best represent the full mine stratigraphic section.

All holes were sampled in continuous 1m intervals by Moolarben project consultants, placed in labelled sample bags, and dispatched to ACTest in Newcastle NSW for sample preparation. Continuous intervals were sampled to ensure the full stratigraphic section was represented, and the individual 1m samples were later composited according to geological intervals. Composite sample intervals were selected in conjunction with Moolarben project personnel based on geological descriptions provided.

EGi provided sample preparation guidelines to ACTest as follows:

- Dry individual 1m samples, crush to -5mm and rotary split sub sample for compositing;
- Prepare composites of 1m samples on an equal weight basis according to the composite list provided;
- Rotary split composites into two 300g sub-samples and store all residual individual 1m samples and composite samples;
- Pulverise one 300g split; and
- Dispatch the 300g coarse and 300g pulverised splits to EGi.

A total of 107 composite samples were prepared from 274 individual 1m samples. Pulverising to $-75\mu\text{m}$ of 37 of the composite samples was arranged by EGi and carried out by Sydney Environmental and Soil Laboratory (SESL). ACTest pulverised the remaining 70 composite samples to $-212\mu\text{m}$.

4.0 Methodology

The following tests were carried out on all samples:

- $\text{pH}_{1:2}$ and electrical conductivity (EC)_{1:2} on deionised water extracts;
- Leco total S;
- Acid neutralising capacity (ANC); and
- Net acid producing potential (NAPP) calculated from total S and ANC results.

The following tests were carried out on selected samples:

- Single addition net acid generation (NAG) test.
- Extended boil NAG and calculated NAG testing for samples with high organic carbon contents; and
- Kinetic NAG.

The $\text{pH}_{1:2}$ and $\text{EC}_{1:2}$ determinations were carried out on -5mm crushed samples. All other characterisation testing was carried out on pulverised samples. A general description of the pH/EC, total S, ANC and NAG test methods is included in Appendix A.

High organic carbon contents ($>7\%C$) can cause generation of organic acids in the NAG test, which can cause misleading low NAGpH values. The combination of extended boiling and NAG solution assay (calculated NAG) helps identify and quantify any effects of organic acid generation on NAG test results.

In addition to characterisation work, leach column testing was carried out on two overburden samples from the Moolarben Stage 1 investigations: a potentially acid forming low capacity (PAF-LC) composite sample; and a blend of the PAF-LC composite with a non acid forming (NAF) overburden composite. Column operations involved subjecting 2kg crushed samples to weekly wet-dry cycles and monthly leaching cycles. The samples were wetted by applying deionised water to the surface, and the resulting leachates were collected through the funnel at the base. Water was added to the columns once per week in four-weekly cycles. In the first three weeks of each cycle, water was added at a rate of 100 ml/kg. In the fourth week of each cycle, water was added at a rate of 400 ml/kg to flush the oxidation products into the leachate collection vessels. Heat lamps were used to dry the samples between water additions to promote oxidation throughout the samples.

Column leachates were analysed for pH, electrical conductivity (EC), acidity/alkalinity and a suite of 32 elements as follows:

Ag, Al, As, B, Ba, Be, Ca, Cd, Cl, Co, Cr, Cu, F, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, P, Pb, S (as SO₄), Sb, Se, Si, Sn, Sr, Th, U and Zn

Total sulphur assays were carried out by Sydney Environmental and Soil Laboratory (SESL). Multi-element analyses for column leachates to week 8 were carried out by Genalysis Pty Ltd (Perth), and after week 8 were carried out by ALS Laboratory Group (Sydney). Analyses of NAG solutions were carried out by Levay & Co. Environmental Services (Adelaide). All other analyses were carried out by EGi.

5.0 Geochemical Characterisation Results

Acid forming characteristics for the Moolarben Stage 2 samples are provide in Table 1.

5.1 pH and EC

The pH_{1:2} and EC_{1:2} tests were carried out by equilibrating crushed 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.

Figure 2 is a box plot showing the distribution of pH_{1:2} values split by broad rock type. The basalt rock type comprises samples from basalt intersected in the top 34m of drill hole PZ130. The coal rock type includes all samples of coal seams and partings, and the sedimentary overburden rock type includes samples of all non-coal sedimentary units, including Ulan Seam floors. The plot shows that most samples (70%) had pH_{1:2} values above 6, and no samples indicated significant existing acidity, with all pH_{1:2} values above 4. Slightly acidic samples with pH_{1:2} values less than 6 were only associated with coal seam samples.

Figure 3 is a box plot showing the distribution of EC_{1:2} values split by rock type. Most samples (80%) were non-saline to slightly saline at less than 0.8 dS/m, and moderately saline samples (0.8 to 1.4 dS/m) were restricted to coal samples. Results indicate low salinity in overburden and floor materials, but moderate salinity from coal seams.

The coal seam samples also have elevated S (see below) and the slightly acidic pH_{1:2} and moderately saline EC_{1:2} values most likely reflect partial oxidation of pyrite.

5.2 Acid Base (NAPP) Results

Figure 4 is a box plot showing the distribution of total S split by rock type. Total S is generally low for overburden and basalt samples, but distinctly elevated in coal samples. The few overburden samples with elevated S greater than 0.2%S are carbonaceous materials from the roof and floor of Moolarben and Ulan coal seams.

Figure 5 is a box plot showing the distribution of ANC split by rock type. The basalt has moderate to high ANC, which is typical of this type of lithology. The ANC of the sedimentary overburden is mainly low, having a median ANC less than 10 kg H₂SO₄/t, but with a number of moderate ANC values greater than 20 kg H₂SO₄/t. The ANC for the coal samples are distinctly low, with a median of 3 kg H₂SO₄/t.

The NAPP value is an acid-base account calculation using measured total S and ANC values. It represents the balance between the maximum potential acidity (MPA) calculated from the total S and ANC. A negative NAPP value indicates that the sample may have sufficient ANC to prevent acid generation. Conversely, a positive NAPP value indicates that the material may be acid generating.

Figure 6 is an acid base accounting plot showing total S versus ANC, with NAPP positive and NAPP negative domains indicated. Figure 7 is the same plot but with the y-axis rescaled to better represent ANC values less than 50 kg H₂SO₄/t. The plot shows that total S and ANC generally show mutually exclusive distribution, with higher S samples showing low ANC and high ANC samples showing low S.

5.3 Single Addition NAG Results

Single addition NAG testing was carried out on 59 selected samples, focusing on samples with NAPP positive values or total S greater than 0.05%S. A NAGpH less than 4.5 generally indicates the sample is acid producing, but in carbonaceous samples organic acid can be generated and a low NAGpH may be due to interference by organic acids rather than acid generated by pyrite. Standard NAG test results are a reliable indicator of acid potential if the NAGpH is greater than or equal to 4.5, or if the samples are non-carbonaceous.

Standard NAGpH values ranged from 2.2 to 8.2. All NAGpH values less than 4.5 are restricted to coal or carbonaceous samples, but in these cases it is uncertain what proportion of the acid generated in the standard NAG test was due to pyrite or partial oxidation of organic compounds. For most of the samples with NAGpH less than 4.5, the NAG to pH 4.5 acidity exceeds the maximum potential acidity (MPA), indicating overestimation of acid capacity in the NAG test due to carbonaceous materials. NAG test results that appear to be influenced by organic acid effects are highlighted yellow in Table 1.

Extended boil NAG and calculated NAG testing was carried out on 18 selected samples to help resolve uncertainty in classification of solids based on standard NAG test results. Results are presented in Table 2. All samples show an increase in the NAGpH value after the extended boiling step, confirming the effects of organic acids. Note that the extended boil NAGpH value can be used to confirm samples are potentially acid forming (PAF), but does not necessarily mean that samples with a pH greater than 4.5 are non acid forming (NAF), due to some loss of free acid during the extended boiling procedure. To address this issue, a calculated NAG value is determined from assays of anions and

cations released to the NAG solution. A calculated NAG value of 0 kg H₂SO₄/t or less is equivalent to a NAGpH of greater than or equal to pH 4.5 from pyrite alone.

Sample 35975 had an extended boil NAGpH less than 4.5, indicating the sample may be PAF, but a negative calculated NAG value. The extended boil and NAG solution assay are carried out on separate solutions, and only 8% of the S present in the solid was accounted for in the solution assay. The apparent conflict in results may be due to incomplete recovery of S during solution assay. Kinetic NAG testing (see Section 5.4) indicates that a significant portion of the acid generated by this sample in the NAG test is likely to be due to pyrite.

Four of the samples (35936, 35948, 35949 and 35969) have positive calculated NAG values, and are likely to be PAF.

The calculated NAG value for the remaining 13 samples was less than or equal to 0, indicating that all acid generated in the standard NAG test for these samples is organic, and that these samples are unlikely to generate acid.

Results indicate that much of the total S measured in the carbonaceous and coal samples is likely to be in non acid generating forms and that most of the acid generated in the standard NAG test is likely to be due to organic acid effects. Hence both the NAPP and standard NAGpH value will tend to overestimate the acid potential. Results also indicate that higher S materials with 0.7%S or more may be acid producing.

5.4 Kinetic NAG Results

Kinetic NAG tests provide an indication of the kinetics of sulphide oxidation and acid generation for a sample. Kinetic NAG testing was carried out on 3 selected samples with total S values greater than 0.8%S. Results are presented in Figures 8 to 11.

Typically, there will be a distinct temperature peak of greater than 50°C in the kinetic NAG profile for samples with pyritic S greater than 0.7%S. None of the kinetic NAG profiles show a strong temperature peak, despite total S values of up to 1.15%S. This indicates that a significant proportion of the total S measured in these samples is likely to be in non-pyrite form, and hence the NAPP values are likely to overestimate the acid potential. The kinetic profiles for sample 35975 (Figure 11) shows a small temperature peak indicating a pyritic S content of close to 0.5%S, and also has a rapid pH drop typical of pyritic samples. The pH profiles of the other samples are more typical of acid release due to slower partial oxidation of organic materials, indicating most of the acid generated in these samples is controlled by organic acid effects.

Results suggest that much of the total S measured in the higher S samples is likely to be due to organic S or other non acid generating S forms, but also indicate these materials may be partly pyritic.

6.0 Leach Column Results

Results of EGi investigations for Stage 1 of the Moolarben Coal project² indicated a small portion of overburden samples may be potentially acid forming with low capacity (PAF-LC). The PAF-LC materials appeared to have low ARD potential and were likely to represent only a small proportion of overburden to be mined. It was expected that normal run-of-mine operational blending of Stage 1 overburden materials would be sufficient to control ARD from materials represented by the samples tested without the need for any further materials management. Leach column testing of blended PAF-LC and non acid forming (NAF) materials was carried out to confirm that operational blending is a valid approach for managing PAF-LC overburden materials. The results of these investigations have implications for both Stage 1 and Stage 2 development, and results after 8 months of leaching are included in this report.

Two composite samples were prepared to represent PAF-LC and NAF overburden from Stage 1 samples. Table 3 shows the geochemical characteristics of the individual samples used to make up the composites. Samples were combined on an equal weight basis, with the PAF-LC sample made up of 6 individual samples, and the NAF sample made up of 15 individual samples.

Splits of these two composite samples were blended in a ratio of 1 part PAF-LC to two parts NAF to approximate the product of operational blending of PAF-LC and NAF materials. Geochemical characteristics of the PAF-LC composite, NAF composite, and PAF-LC/NAF blended samples are shown in Table 4. Calculated NAG and NAPP results of the PAF-LC and NAF composite samples are consistent with results for individual samples in Table 3, confirming the PAF-LC and NAF classification. Results also indicate that the blended PAF-LC/NAF sample is likely to be NAF.

Multi-element analysis was carried out on the PAF-LC composite and PAF-LC/NAF blended sample. Results of multi-element scans were compared to the median soil abundance (from Bowen, 1979³) to highlight enriched elements. The extent of enrichment is reported as the Geochemical Abundance Index (GAI), which relates the actual concentration with an average abundance on a log 2 scale. The GAI is expressed in integer increments where a GAI of 0 indicates the element is present at a concentration similar to, or less than, average abundance; and a GAI of 6 indicates approximately a 100-fold enrichment above average abundance. As a general rule, a GAI of 3 or greater signifies enrichment that warrants further examination.

Results of multi-element analysis and the corresponding GAI values are presented in Table 5. Results show enrichment of Be in both samples but with a maximum of 5.2 mg/kg, which is within normal ranges for soils. No other elements were significantly enriched compared to normal soils. These results are consistent with multi-element results for individual samples reported as part of the Stage 1 geochemical assessment².

² *Geochemical Assessment of the Moolarben Coal Project*, EGi Document No. 2350/710, April 2006.

³ Bowen, H.J.M. (1979) *Environmental Chemistry of the Elements*. Academic Press, New York, p 36-37.

Leach column results for the PAF-LC composite and PAF-LC/NAF blended sample are shown in Tables 6 and 7, and plots of pH and sulphate trends are shown in Figures 12 and 13.

The pH of leachates from both columns was circum neutral for the 32 weeks of operation. Sulphate trends show a sharp decrease from initial concentrations (week 0) to week 8, but then show a gradual decrease to low concentrations of less than 20 mg/L by week 32. The high initial concentrations reflect flushing of readily soluble sulphate minerals, which could be either originally present in the materials before sampling (primary), or derived from pyrite oxidation and neutralisation reactions between sampling and testing (secondary). The subsequent decrease to low concentrations after the initial peak suggests a lack of subsequent significant pyrite oxidation in either column.

Figure 14 is a plot of the SO₄ release rate, CO₃ dissolution rate (assuming all Ca and Mg released to leachates is due to dissolution of Ca-Mg carbonates), and CO₃/SO₄ molar ratio trends for the PAF-LC column leachates. The SO₄ release and CO₃ dissolution trends closely match until week 20, where SO₄ release rates decrease and CO₃ dissolution is relatively stable. The results suggest that long term SO₄ release rates will be low from materials represented by this sample, and at these rates background silicates are generally capable of neutralising any acid produced. Although geochemical characterisation work suggested that the PAF-LC materials would be acid producing with low capacity, under atmospheric oxidation conditions it appears that any sulphate release due to pyrite oxidation is matched by neutralisation reactions, and it is likely that this sample is actually NAF.

Leachates from the PAF-LC and PAF-LC/NAF blended columns have low EC values of 0.31 to 0.82 dS/m, suggesting overburden materials represented by these samples are likely to produce only slightly saline leachate in the short term, and are expected to be non saline in the long term.

There was no significant release of environmentally important elements from either column, apart from elevated Al (>1 mg/L) in a number of cases. Al has low solubility at circum neutral pH, and the elevated Al is most likely due to the presence of small amounts of fine particulates in the leachate solutions tested.

Overall results indicate that open cut overburden materials represented by the samples tested in the Stage 1 assessment are unlikely to produce significant acid, salinity or leach metals/metalloids of environmental significance. However, results from Stage 2 testing indicate that carbonaceous overburden materials and sub-economic coal may have higher acid potential.

Both columns have reached low sulphate release rates and it is unlikely that additional information will be obtained by continuation of these columns. It is recommended that both columns be terminated. However, column testing of higher S samples from the Stage 2 testing would help resolve uncertainties in the ARD classification of these materials and better determine the overall ARD risks from Moolarben overburden materials.

7.0 Sample Classification and Distribution of Geochemical Rock Types

Prediction of ARD potential for carbonaceous samples using standard NAG and NAPP techniques can be unreliable due to interferences associated with organic matter and mineralogy common in these types of materials. The NAPP test may overestimate the acid potential if organic S is present in significant amounts, and the NAG test may overestimate acid potential due to partial oxidation of organic matter. Follow up testing including kinetic NAG, extended boil NAG and calculated NAG indicated that most of the total S measured in the carbonaceous overburden and coal materials is likely to be in non acid generating forms, but also indicated that some carbonaceous materials may be partly pyritic.

Samples in which the NAGpH is greater than or equal to 4.5 are expected to be NAF, but samples with a NAGpH less than 4.5 may be PAF or NAF depending on the relative contribution of pyrite derived acidity to the test result. NAPP positive samples may also be PAF or NAF, depending on how much of the total S is present as pyrite. Of the samples tested to date, only those with total S greater than 0.7%S appeared to have acid generating potential based on extended boil NAG and calculated NAG results. Hence for samples with a NAGpH less than 4.5 where extended boil NAG and calculated NAG testing was not carried out, a preliminary cut off of 0.5%S is used to distinguish between samples with that are expected to be NAF from those expected to be PAF. Classification of samples in Table 1 was carried out on the following basis:

Non Acid Forming (NAF)

- Total S $\leq 0.05\%$ (due to the very low risk of acid formation); ***or***
- NAPP ≤ 0 kg H₂SO₄/t and NAGpH ≥ 4.5 ; ***or***
- Extended boil NAGpH ≥ 4.5 and calculated NAG value ≤ 0 kg H₂SO₄/t.

Potentially Acid Forming (PAF)

- Extended boil NAGpH < 4.5 or calculated NAG value > 0 kg H₂SO₄/t.

Uncertain Expected to be NAF (UC(NAF))

- NAPP ≤ 0 kg H₂SO₄/t and NAGpH < 4.5 ; ***or***
- NAPP > 0 kg H₂SO₄/t and NAGpH < 4.5 and total S $\leq 0.5\%S^*$.

Uncertain Expected to be PAF (UC(PAF))

- NAPP > 0 kg H₂SO₄/t and NAGpH < 4.5 and total S $> 0.5\%S^*$.

**Note: applies only to samples NOT assayed by the extended boil and calculated NAG procedure.*

Results of testing to date indicate that around 95% of the overburden (including thinner sub-economic seams such as Moolarben, Bungaba and others) is likely to be non acid forming (NAF), and the remaining 5% may be potentially acid forming (PAF). Coal seams appear to have higher ARD potential with around 40% classified PAF/UC(PAF). Only 1 of the 5 Ulan Seam floor samples were classified PAF.

Figure 15 is a plot of downhole S profiles for the three holes tested, with PAF/UC(PAF) samples indicated. The plot clearly shows that the higher S values greater than 0.5%S are restricted to samples of coal seams, or floor and roof within a few meters of the coal seam boundary.

8.0 Conclusions

Overall, results suggest that the bulk of the Moolarben overburden and floor material is likely to be NAF, with PAF overburden materials apparently mainly associated with the Moolarben Seam, and roof and floor of the Ulan Seam. The Ulan Seam appears to have a greater proportion of PAF than overburden or floor, indicating possible ARD issues associated with rejects, tailings and coal stockpiles.

There are uncertainties in ARD classification due to the combined effects of varying S forms and organic acid effects on characterisation test work, and further investigation would be required to fully assess the relative distribution of PAF and NAF materials, and the overall acid potential. However, findings to date have the following implications for materials management:

- Rejects and tailings may be partly PAF and should be managed as PAF material.
- PAF overburden appears to make up only a small proportion of overburden, and operational mixing may be sufficient to control ARD from these materials, depending on the overall distribution of PAF materials and the acid potential. Alternatively the PAF overburden materials may need to be selectively handled as with the rejects.
- Possible closure strategies for PAF waste materials (including rejects and overburden) include placement in pit and below long term stable water table levels, and/or construction of a cover system that prevents flushing of PAF materials by infiltrating water. The PAF materials can also be treated with limestone.
- During operations, monitoring of seepage and runoff from pits and overburden dumps should be carried out to determine whether limestone/lime treatment or other ARD controls are required prior to implementation of closure strategies.
- Coal materials may be acid generating and moderately saline, and containment of runoff and leachate from coal stockpiles and underground operations may be required to monitor water quality, with provision for acid treatment as needed. Minor addition of crushed limestone to exposed surfaces may also mitigate ARD generation.
- A routine system of ARD testing should be established during operations to check the ARD potential of mine materials and identify any need to modify materials management strategies.

- Routine site water quality monitoring programmes should include pH, EC, acidity/alkalinity, SO₄, Al, As, Co, Cu, Fe, Mn, Ni and Zn to monitor for effects of ARD.

The following work should be carried out to finalise materials management requirements:

- More widespread sampling and testing of overburden materials to determine the distribution and to quantify the production and scheduling of PAF materials. Testing should include sulphur speciation, extended boil NAG and calculated NAG methods in addition to standard geochemical tests. The feasibility for selective mining, segregation and possible co-disposal with reject should be evaluated.
- Geochemical characterisation of representative rejects and tailings is required to determine whether ARD is a significant issue for these materials.
- Leach column testing of PAF coal, overburden and reject materials to determine lag times and acid release rates, which in turn can be used to determine management requirements such as the need for limestone treatment, appropriate treatment rates (if necessary), and whether selective handling is likely to be required.

Table 1: Acid forming characteristics of overburden, coal and floor samples.

Hole Name	EGi Sample No	Depth (m)			Lithology	Description	Seam	Ply	pH _{1,2}	EC _{1,2}	ACID-BASE ANALYSIS				STANDARD NAG TEST			ARD Classification	
		From	To	Interval							Total %S	MPA	ANC	NAPP	ANC/MPA	NAGpH	NAG _(pH4.5)		NAG _(pH7.0)
PZ130	35870	0.00	1.00	1.00	BASALT	Red/brown, highly weathered, soft.			7.6	0.12	0.02	1	22	-21	35.95				NAF
PZ130	35871	1.00	6.00	5.00	BASALT	Black to dark grey, generally massive and hard, variable fracturing evident.			7.5	0.10	<0.01	0	50	-50	326.80				NAF
PZ130	35872	6.00	10.00	4.00	BASALT	Black to dark grey, generally massive and hard, variable fracturing evident.			8.2	0.12	<0.01	0	56	-56	366.01				NAF
PZ130	35873	10.00	15.00	5.00	BASALT	Black to dark grey, generally massive and hard, variable fracturing evident.			7.8	0.22	<0.01	0	108	-108	705.88				NAF
PZ130	35874	15.00	20.00	5.00	BASALT	Black to dark grey, generally massive and hard, variable fracturing evident.			6.6	0.15	<0.01	0	76	-76	496.73				NAF
PZ130	35875	20.00	25.00	5.00	BASALT	Black to dark grey, generally massive and hard, variable fracturing evident.			7.5	0.16	0.01	0	72	-72	235.29				NAF
PZ130	35876	25.00	30.00	5.00	BASALT	Black to dark grey, generally massive and hard, variable fracturing evident.			8.3	0.11	0.01	0	79	-79	258.17				NAF
PZ130	35877	30.00	34.00	4.00	BASALT	Black to dark grey, generally massive and hard, variable fracturing evident.			7.7	0.20	0.01	0	169	-169	552.29				NAF
PZ130	35878	34.00	39.00	5.00	SHALE	medium grey, soft, slightly silty.			7.9	0.19	0.01	0	135	-135	441.18				NAF
PZ130	35879	39.00	41.00	2.00	MUDSTONE	Medium brown, soft, silty.			7.6	0.15	0.02	1	7	-6	11.44				NAF
PZ130	35880	41.00	44.00	3.00	SANDSTONE	Light to medium brown, fine to medium grained, argillaceous.			8.1	0.15	<0.01	0	1	-1	6.54				NAF
PZ130	35881	44.00	47.00	3.00	SANDSTONE	Light to medium brown, fine to medium grained, argillaceous.			7.9	0.14	<0.01	0	0	0	0.00				NAF
PZ130	35882	47.00	50.00	3.00	SHALE	Black, friable, carbonaceous.			8.4	0.12	0.05	2	1	1	0.65	4.3	0.3	9	NAF
PZ130	35883	50.00	53.00	3.00	SHALE	Medium grey, friable, silty and sandy.			8.3	0.10	0.03	1	2	-1	2.18				NAF
PZ130	35884	53.00	58.00	5.00	SANDSTONE	Medium brown to buff coloured, coarse to very coarse grained, angular to sub-angular, quartzose.			8.3	0.10	<0.01	0	1	-1	6.54				NAF
PZ130	35885	58.00	61.00	3.00	SHALE	Dark grey to black, friable, variably carbonaceous.			7.8	0.20	0.04	1	6	-5	4.90				NAF
PZ130	35886	61.00	64.00	3.00	SHALE	Dark grey to black, friable, variably carbonaceous.			6.8	0.15	0.09	3	7	-4	2.54	4.7	0	5	NAF
PZ130	35887	64.00	65.00	1.00	CLAYSTONE	Medium grey, soft.			6.6	0.13	0.28	9	5	4	0.58	2.7	22	41	NAF
PZ130	35888	65.00	66.00	1.00	COAL	Black, soft.	Moolarben	A	5.2	0.82	0.25	8	4	4	0.52	2.5	46	78	NAF
PZ130	35889	66.00	67.00	1.00	COAL	Black, soft.	Moolarben	A	5.1	0.32	0.03	1	2	-1	2.18	3.1	8	21	NAF
PZ130	35890	67.00	68.00	1.00	SHALE	Medium grey, friable.			7.4	0.09	0.06	2	8	-6	4.36	7.2	0	0	NAF
PZ130	35891	68.00	69.00	1.00	SHALE	Medium grey, friable.			7.6	0.09	0.05	2	9	-7	5.88				NAF
PZ130	35892	69.00	70.00	1.00	COAL	Black, friable to soft.	Moolarben	B	4.9	0.53	0.10	3	2	1	0.65	2.7	18	34	NAF
PZ130	35893	70.00	71.00	1.00	SHALE	Medium grey, friable.			6.7	0.41	0.01	0	1	-1	3.27				NAF
PZ130	35894	71.00	76.00	5.00	SANDSTONE	Light grey, coarse to very coarse grained, sub-angular to angular, lightly argillaceous.			7.4	0.09	0.01	0	0	0	0.00	6.2	0	6	NAF
PZ130	35895	76.00	80.00	4.00	SANDSTONE	Light grey, coarse to very coarse grained, sub-angular to angular, lightly argillaceous.			7.5	0.11	0.02	1	0	1	0.00	6.2	0	5	NAF
PZ130	35896	80.00	85.00	5.00	SHALE	medium grey, friable, silty and sandy.			8.1	0.12	0.05	2	5	-3	3.27				NAF
PZ130	35897	85.00	87.00	2.00	SANDSTONE	Medium grey, friable, very argillaceous.			7.8	0.12	0.03	1	31	-30	33.77				NAF
PZ130	35898	87.00	92.00	5.00	SHALE	Medium to dark grey, friable, variably silty and sandy, carbonaceous.			7.6	0.12	0.03	1	7	-6	7.63				NAF
PZ130	35899	92.00	95.00	3.00	SHALE	Medium to dark grey, friable, variably silty and sandy, carbonaceous.			7.8	0.12	0.05	2	9	-7	5.88				NAF
PZ130	35900	95.00	96.00	1.00	SHALE	Medium to dark grey, friable, variably silty and sandy, carbonaceous.			7.5	0.10	0.14	4	4	0	0.93	3.0	11	26	NAF
PZ130	35901	96.00	97.00	1.00	COAL	Black, friable, occasionally vitreous, minor shale bands.	Ulan		5.1	0.42	0.46	14	0	14	0.00	3.7	3	15	UC(NAF)
PZ130	35902	97.00	102.00	5.00	COAL	Black, friable, occasionally vitreous, minor shale bands.	Ulan		5.5	0.48	0.38	12	1	11	0.09	2.4	31	52	UC(NAF)
PZ130	35903	102.00	107.00	5.00	COAL	Black, friable, occasionally vitreous, minor shale bands.	Ulan		5.4	0.52	0.53	16	1	15	0.06	2.2	53	79	UC(PAF)
PZ130	35904	107.00	108.00	1.00	COAL	Black, friable, occasionally vitreous, minor shale bands.	Ulan		5.3	0.68	0.58	18	0	18	0.00	2.2	50	73	UC(PAF)
PZ130	35905	108.00	109.00	1.00	SHALE	Medium grey to dark grey, friable, silty, sandy.			8.2	0.15	0.16	5	2	3	0.41	2.7	13	28	NAF
PZ130	35906	109.00	111.00	2.00	SHALE	Medium grey to dark grey, friable, silty, sandy.			7.6	0.12	0.02	1	2	-1	3.27				NAF
PZ133	35907	0.00	1.00	1.00	SHALE	Light grey, highly weathered, sandy.			7.3	0.11	<0.01	0	1	-1	6.54				NAF
PZ133	35908	1.00	6.00	5.00	MUDSTONE	Light grey to medium brown, soft, silty.			6.8	0.12	0.02	1	34	-33	55.56				NAF
PZ133	35909	6.00	8.00	2.00	MUDSTONE	Light grey to medium brown, soft, silty.			7.2	0.15	0.01	0	14	-14	45.75				NAF
PZ133	35910	8.00	9.00	1.00	MUDSTONE	Light grey to medium brown, soft, silty.			7.4	0.16	0.02	1	68	-67	111.11				NAF
PZ133	35911	9.00	10.00	1.00	COAL	Black to brown / black, soft.	Moolarben		5.7	0.92	0.11	3	4	-1	1.19	3.8	3	17	NAF
PZ133	35912	10.00	12.00	2.00	COAL	Black to brown / black, soft.	Moolarben		5.5	1.24	0.82	25	3	22	0.12	2.2	63	95	UC(PAF)
PZ133	35913	12.00	13.00	1.00	COAL	Black to brown / black, soft.	Moolarben		5.3	1.11	0.67	21	2	19	0.10	2.3	34	58	UC(PAF)
PZ133	35914	13.00	14.00	1.00	MUDSTONE	Variable light to dark grey, mostly soft (occasional friable horizons - particularly from 22 - 26m).			6.5	0.17	0.03	1	2	-1	2.18				NAF
PZ133	35915	14.00	18.00	4.00	MUDSTONE	Variable light to dark grey, mostly soft (occasional friable horizons - particularly from 22 - 26m).			7.4	0.18	0.02	1	4	-3	6.54				NAF
PZ133	35916	18.00	23.00	5.00	MUDSTONE	Variable light to dark grey, mostly soft (occasional friable horizons - particularly from 22 - 26m).			7.3	0.19	0.03	1	22	-21	23.97				NAF
PZ133	35917	23.00	28.00	5.00	MUDSTONE	Variable light to dark grey, mostly soft (occasional friable horizons - particularly from 22 - 26m).			7.4	0.19	0.09	3	8	-5	2.90	7.6	0	0	NAF
PZ133	35918	28.00	32.00	4.00	MUDSTONE	Variable light to dark grey, mostly soft (occasional friable horizons - particularly from 22 - 26m).			7.6	0.15	0.02	1	3	-2	4.90				NAF
PZ133	35919	32.00	35.00	3.00	MUDSTONE	Variable light to dark grey, mostly soft (occasional friable horizons - particularly from 22 - 26m).			6.7	0.14	0.02	1	1	0	1.63				NAF
PZ133	35920	35.00	40.00	5.00	SHALE	Medium grey to dark grey, friable, becoming increasingly carbonaceous with depth (particularly from 46 - 52m).			7.8	0.13	0.12	4	19	-15	5.17	7.5	0	0	NAF
PZ133	35921	40.00	45.00	5.00	SHALE	Medium grey to dark grey, friable, becoming increasingly carbonaceous with depth (particularly from 46 - 52m).			7.7	0.13	0.04	1	43	-42	35.13				NAF
PZ133	35922	45.00	50.00	5.00	SHALE	Medium grey to dark grey, friable, becoming increasingly carbonaceous with depth (particularly from 46 - 52m).			6.8	0.14	0.04	1	59	-58	48.20				NAF
PZ133	35923	50.00	51.00	1.00	SHALE	Medium grey to dark grey, friable, becoming increasingly carbonaceous with depth (particularly from 46 - 52m).			6.7	0.15	0.10	3	49	-46	16.01	8.1	0	0	NAF
PZ133	35924	51.00	52.00	1.00	SHALE	Medium grey to dark grey, friable, becoming increasingly carbonaceous with depth (particularly from 46 - 52m).			6.6	0.16	0.05	2	14	-12	9.15				NAF
PZ133	35925	52.00	53.00	1.00	COAL	Black, soft.	Bungaba		5.5	0.88	0.08	2	8	-6	3.27	7.6	0	0	NAF
PZ133	35926	53.00	54.00	1.00	SHALE	Medium grey, friable, carbonaceous.			6.7	0.12	0.06	2	15	-13	8.17	7.4	0	0	NAF
PZ133	35927	54.00	57.00	3.00	SHALE	Medium grey, friable, carbonaceous.			7.2	0.14	0.06	2	51	-49	27.78	7.8	0	0	NAF
PZ133	35928	57.00	58.00	1.00	SHALE	Medium grey, friable, carbonaceous.			7.4	0.13	0.05	2	24	-22	15.69				NAF
PZ133	35929	58.00	59.00	1.00	COAL	Black, friable, occasionally vitreous appearance.	Ulan	A	5.4	1.16	0.45	14	3	11	0.22	2.5	23	44	UC(NAF)
PZ133	35930	59.00	60.00	1.00	SHALE	Black, friable, carbonaceous.	Ulan	A	5.3	1.02	0.35	11	3	8	0.28	2.6	25	46	UC(NAF)

Table 1: Acid forming characteristics of overburden, coal and floor samples.

Hole Name	EGi Sample No	Depth (m)			Lithology	Description	Seam	Ply	pH _{1:2}	EC _{1:2}	ACID-BASE ANALYSIS				STANDARD NAG TEST			ARD Classification		
		From	To	Interval							Total %S	MPA	ANC	NAPP	ANC/MPA	NAGpH	NAG _(pH4.5)		NAG _(pH7.0)	
PZ133	35931	60.00	62.00	2.00	COAL	Black, hard to friable	Ulan	BEBT	5.1	1.21	0.51	16	4	12	0.26	2.2	63	96	UC(PAF)	
PZ133	35932	62.00	64.00	2.00	COAL	Black, hard to friable	Ulan	BEBT	5.2	1.11	0.47	14	5	9	0.35	2.2	66	103	UC(NAF)	
PZ133	35933	64.00	65.00	1.00	COAL	Black, hard to friable shale interbeds	Ulan	BEBT	5.0	1.35	0.20	6	15	-9	2.45	5.0	0	11	NAF	
PZ133	35934	65.00	70.00	5.00	COAL	Black, hard to friable	Ulan	BEBT	5.3	0.98	0.55	17	6	11	0.36	2.3	58	98	UC(PAF)	
PZ133	35935	70.00	71.00	1.00	COAL	Black, hard to friable	Ulan	BEBT	5.5	1.41	0.48	15	3	12	0.20	2.2	71	105	UC(NAF)	
PZ133	35936	71.00	72.00	1.00	SHALE	Medium to dark grey, friable, silty and sandy, variably carbonaceous.			6.7	0.22	0.75	23	2	21	0.09	2.2	32	54	PAF	
PZ133	35937	72.00	74.00	2.00	SHALE	Medium to dark grey, friable, silty and sandy, variably carbonaceous.			6.8	0.11	0.34	10	3	7	0.29	3.4	3	11	UC(NAF)	
PZ150	35938	0.00	1.00	1.00	TOPSOIL	medium brown to buff, clayey, silty.			7.5	0.33	0.01	0	1	-1	3.27				NAF	
PZ150	35939	1.00	6.00	5.00	MUDSTONE	Light grey to buff, soft, occasionally silty.			7.6	0.42	0.02	1	0	1	0.00	5.2	0	12	NAF	
PZ150	35940	6.00	11.00	5.00	MUDSTONE	Light grey to buff, soft, occasionally silty.			7.3	0.51	0.02	1	1	0	1.63				NAF	
PZ150	35941	11.00	14.00	3.00	SHALE	Medium to dark grey, friable, silty.			7.2	0.63	0.08	2	14	-12	5.72	7.1	0	0	NAF	
PZ150	35942	14.00	15.00	1.00	SHALE	Black, friable, sandy, carbonaceous.			6.6	0.24	0.19	6	4	2	0.69	3.2	8	20	NAF	
PZ150	35943	15.00	18.00	3.00	SHALE	Medium to dark grey, silty, friable.			7.4	0.18	0.08	2	13	-11	5.31	6.9	0	0	NAF	
PZ150	35944	18.00	22.00	4.00	SHALE	Black, friable, sandy, very carbonaceous.			7.5	0.43	0.20	6	10	-4	1.63	5.1	0	3	NAF	
PZ150	35945	22.00	24.00	2.00	SANDSTONE	Light grey, fine to medium grey, friable, argillaceous.			6.7	0.19	0.03	1	44	-43	47.93				NAF	
PZ150	35946	24.00	25.00	1.00	SANDSTONE	Light grey, fine to medium grey, friable, argillaceous.			7.2	0.19	0.04	1	17	-16	13.89				NAF	
PZ150	35947	25.00	26.00	1.00	COAL	Black, friable, shaley.	Moolarben		5.1	0.89	0.31	9	9	0	0.95	6.9	0	0	NAF	
PZ150	35948	26.00	28.00	2.00	COAL	Black, friable, shaley.	Moolarben		5.4	0.93	0.91	28	3	25	0.11	2.5	28	44	PAF	
PZ150	35949	28.00	29.00	1.00	COAL	Black, friable, shaley.	Moolarben		5.5	1.08	1.15	35	1	34	0.0	2.4	25	42	PAF	
PZ150	35950	29.00	30.00	1.00	SANDSTONE	Medium grey, fine grained, friable, silty, argillaceous.			6.8	0.22	0.05	2	1	1	0.7	6.9	0	0	NAF	
PZ150	35951	30.00	35.00	5.00	SANDSTONE	Medium grey, fine grained, friable, silty, argillaceous.			7.2	0.13	0.03	1	6	-5	6.5				NAF	
PZ150	35952	35.00	40.00	5.00	SHALE	Dark grey, friable, silty, carbonaceous.			6.6	0.24	0.05	2	8	-6	5.2				NAF	
PZ150	35953	40.00	41.00	1.00	SHALE	Dark grey, friable, silty, carbonaceous.			7.2	0.14	0.07	2	20	-18	9.3	7.2	0	0	NAF	
PZ150	35954	41.00	42.00	1.00	COAL	Black, soft, silty.	Bungaba		6.8	0.43	0.07	2	4	-2	1.9	7.1	0	0	NAF	
PZ150	35955	42.00	43.00	1.00	COAL	Black, soft, silty.	Bungaba		5.5	1.26	0.51	16	25	-9	1.6	5.1	0	7	NAF	
PZ150	35956	43.00	44.00	1.00	COAL	Black, soft, silty.	Bungaba		5.6	1.31	0.18	5	3	2	0.6	3.0	8	22	NAF	
PZ150	35957	44.00	45.00	1.00	SHALE	Dark grey, friable, silty.			8.2	0.09	0.03	1	8	-7	8.7				NAF	
PZ150	35958	45.00	49.00	4.00	SANDSTONE	Light grey, friable, slightly argillaceous.			7.2	0.23	0.03	1	6	-5	6.5				NAF	
PZ150	35959	49.00	52.00	3.00	SANDSTONE	Light grey, friable, slightly argillaceous.			7.4	0.09	0.02	1	1	0	1.6				NAF	
PZ150	35960	52.00	53.00	1.00	SANDSTONE	Light grey, friable, slightly argillaceous.			7.5	0.09	0.03	1	1	0	1.1				NAF	
PZ150	35961	53.00	54.00	1.00	COAL	Black, soft.			5.2	1.32	0.60	18	3	15	0.2	2.5	35	56	NAF	
PZ150	35962	54.00	55.00	1.00	SHALE	Black, friable, carbonaceous.			7.3	0.09	0.04	1	5	-4	4.1				NAF	
PZ150	35963	55.00	58.00	3.00	SHALE	Black, friable, carbonaceous.			6.6	0.42	0.04	1	53	-52	43.3				NAF	
PZ150	35964	58.00	59.00	1.00	SHALE	Black, friable, carbonaceous.			7.1	0.12	0.04	1	51	-50	41.7				NAF	
PZ150	35965	59.00	60.00	1.00	COAL	Black, soft.			5.3	1.27	0.10	3	12	-9	3.9	7.2	0	0	NAF	
PZ150	35966	60.00	61.00	1.00	SHALE	Dark grey to black, friable, variably carbonaceous - but becoming very carbonaceous from 64m.			6.7	0.15	0.08	2	11	-9	4.5	7.7	0	0	NAF	
PZ150	35967	61.00	66.00	5.00	SHALE	Dark grey to black, friable, variably carbonaceous - but becoming very carbonaceous from 64m.			7.5	0.14	0.06	2	58	-56	31.6	7.8	0	0	NAF	
PZ150	35968	66.00	70.00	4.00	SHALE	Dark grey to black, friable, variably carbonaceous - but becoming very carbonaceous from 64m.			7.6	0.10	0.09	3	19	-16	6.9	8.2	0	0	NAF	
PZ150	35969	70.00	74.00	4.00	SHALE	Dark grey to black, friable, variably carbonaceous - but becoming very carbonaceous from 64m.			7.7	0.15	0.78	24	3	21	0.1	2.3	44	70	PAF	
PZ150	35970	74.00	75.00	1.00	SHALE	Dark grey to black, friable, variably carbonaceous - but becoming very carbonaceous from 64m.			7.8	0.08	0.11	3	13	-10	3.9	7.4	0	0	NAF	
PZ150	35971	75.00	76.00	1.00	COAL	Black, soft to friable.	Ulan		5.5	1.26	0.56	17	3	14	0.2	3.0	10	23	NAF	
PZ150	35972	76.00	80.00	4.00	COAL	Black, soft to friable.	Ulan		5.2	0.93	0.54	17	5	12	0.3	2.7	24	48	NAF	
PZ150	35973	80.00	84.00	4.00	COAL	Black, soft to friable.	Ulan		6.2	0.73	0.04	1	49	-48	40.0	7.3	0	0	NAF	
PZ150	35974	84.00	87.00	3.00	COAL	Black, soft to friable.	Ulan		5.4	1.14	0.20	6	4	2	0.7	2.5	33	58	UC(NAF)	
PZ150	35975	87.00	88.00	1.00	COAL	Black, soft to friable.	Ulan		5.3	1.18	1.14	35	0	35	0.0	2.4	30	44	PAF	
PZ150	35976	88.00	88.50	0.50	SHALE	Dark grey, friable, carbonaceous.			7.1	0.43	0.07	2	2	0.1	0.9	3.1	3	13	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 (kgH₂SO₄/t)

ANC = Acid Neutralising Capacity (kgH₂SO₄/t)

NAPP = Net Acid Producing Potential (kgH₂SO₄/t)

NAGpH = pH of NAG liquor

NAG_(pH4.5) = Net Acid Generation capacity to pH 4.5 (kgH₂SO₄/t)

NAG_(pH7.0) = Net Acid Generation capacity to pH 7.0 (kgH₂SO₄/t)

Standard NAG results overestimate acid potential due to organic acid effects

- NAF = Non-Acid Forming
- UC(NAF) = Uncertain Expected to be NAF
- PAF = Potentially Acid Forming
- UC(PAF) = Uncertain Expected to be PAF

Table 2: Extended boil NAG and calculated NAG test results for selected samples.

EGi Code	Lithology	Seam	ACID-BASE ANALYSIS					STANDARD NAG TEST			Extended Boil NAGpH	Calculated NAG
			Total %S	MPA	ANC	NAPP	ANC/MPA	NAGpH	NAG _(pH4.5)	NAG _(pH7.0)		
35887	CLAYSTONE		0.28	9	5	4	0.58	2.7	22	41	6.9	-4
35888	COAL	Moolarben	0.25	8	4	4	0.52	2.5	46	78	7.1	-3
35892	COAL	Moolarben	0.10	3	2	1	0.65	2.7	18	34	6.9	-3
35900	SHALE		0.14	4	4	0	0.93	3.0	11	26	7.3	-3
35905	SHALE		0.16	5	2	3	0.41	2.7	13	28	7.1	-1
35911	COAL	Moolarben	0.11	3	4	-1	1.19	3.8	3	17	7.3	-5
35936	SHALE		0.75	23	2	21	0.09	2.2	32	54	6.9	15
35942	SHALE		0.19	6	4	2	0.69	3.2	8	20	7.1	-2
35948	COAL	Moolarben	0.91	28	3	25	0.11	2.5	28	44	6.1	7
35949	COAL	Moolarben	1.15	35	1	34	0.03	2.4	25	42	6.9	2
35956	COAL	Bungaba	0.18	5	3	2	0.56	3.0	8	22	7.2	-2
35961	COAL		0.60	18	3	15	0.16	2.5	35	56	7.1	0
35969	SHALE		0.78	24	3	21	0.13	2.3	44	70	6.9	9
35971	COAL	Ulan	0.56	17	3	14	0.18	3.0	10	23	7.4	0
35972	COAL	Ulan	0.54	17	5	12	0.30	2.7	24	48	7.5	-1
35975	COAL	Ulan	1.14	35	0	35	0.00	2.4	30	44	3.4	-3
35976	SHALE		0.07	2	2	0	0.93	3.1	3.4	13	7.5	-1

KEY
MPA = Maximum Potential Acidity (kgH₂SO₄/t)
ANC = Acid Neutralising Capacity (kgH₂SO₄/t)
NAPP = Net Acid Producing Potential (kgH₂SO₄/t)
NAGpH = pH of NAG liquor
NAG_(pH4.5) = Net Acid Generation capacity to pH 4.5 (kgH₂SO₄/t)
NAG_(pH7.0) = Net Acid Generation capacity to pH 7.0 (kgH₂SO₄/t)
Extended Boil NAGpH = pH of NAG liquor after extended heating
Calculated NAG = The net acid potential based on assay of anions and cations released to the NAG solution (kgH₂SO₄/t)

Table 3: Geochemical characteristics of individual samples used to make up composite samples for column testing. Samples were selected from the Moolarben Stage 1 sample set.

Column Composite	Hole No	Open Cut Pit No	EGi Code	Moolarben Sample No	Depth (m)			pH _{1:2}	EC _{1:2}	ACID-BASE ANALYSIS				NAG TEST			ARD Classification	
					From	To	Interval			Total %S	MPA	ANC	NAPP	ANC/MPA	NAGpH	NAG _(pH4.5)		NAG _(pH7.0)
PAF-LC Column Composite Sample No 34466	WMLB24	OC1	28490	WMLB24-E1	14.95	15.45	0.50	6.82	0.09	0.19	6	3	3	0.52	2.3	76	122	PAF-LC
	WMLB24	OC1	28491	WMLB24-E2	15.45	16.60	1.15	6.88	0.09	0.11	3	3	0.4	0.89	2.5	37	66	PAF-LC
	WMLB24	OC1	28493	WMLB24-E4	18.59	19.04	0.45	6.66	0.06	0.14	4	2	2	0.47	2.2	45	79	PAF-LC
	WMLB24	OC1	28503	WMLB24-E14	40.21	40.86	0.65	7.35	0.11	0.20	6	2	4	0.33	2.4	43	73	PAF-LC
	WMLB15	OC2	28508	WMLB15-E3	8.50	9.64	1.14	7.66	0.13	0.21	6	5	1	0.78	2.4	68	109	PAF-LC
	WMLB15	OC2	28514	WMLB15-E9	13.91	14.83	0.92	7.73	0.14	0.20	6	2	4	0.33	2.4	37	68	PAF-LC
NAF Column Composite Sample No 34467	WMLB24	OC1	28492	WMLB24-E3	16.60	18.59	1.99	6.76	0.06	0.03	1	15	-14	16.34	7.3	0	0	NAF
	WMLB24	OC1	28494	WMLB24-E5	19.04	19.91	0.87	6.59	0.04	0.03	1	2	-1	2.18	2.5	12	33	NAF
	WMLB24	OC1	28495	WMLB24-E6	19.91	24.00	4.09	7.12	0.04	<0.01	0	1	-1	-	5.6	0	17	NAF
	WMLB24	OC1	28500	WMLB24-E11	33.65	36.45	2.80	6.88	0.06	0.02	1	14	-13	22.88	7.6	0	0	NAF
	WMLB24	OC1	28501	WMLB24-E12	36.45	39.45	3.00	6.91	0.06	0.02	1	8	-7	13.07	7.7	0	0	NAF
	WMLB24	OC1	28502	WMLB24-E13	39.45	39.80	0.35	7.32	0.09	0.09	3	3	0	1.09	2.6	20	40	UC(NAF)
	WMLB24	OC1	28504	WMLB24-E15	40.86	42.45	1.59	7.46	0.08	0.01	0	1	-1	3.27	5.7	0	1	NAF
	WMLB15	OC2	28506	WMLB15-E1	6.00	8.12	2.12	7.55	0.08	0.02	1	7	-6	11.44	6.1	0	6	NAF
	WMLB15	OC2	28507	WMLB15-E2	8.12	8.50	0.38	7.62	0.10	0.06	2	8	-6	4.36	7.2	0	0	NAF
	WMLB15	OC2	28509	WMLB15-E4	9.64	10.28	0.64	7.86	0.18	0.03	1	13	-12	14.16	7.1	0	0	NAF
	WMLB15	OC2	28512	WMLB15-E7	11.90	13.58	1.68	7.71	0.13	0.05	2	24	-22	15.69	7.4	0	0	NAF
	WMLB15	OC2	28513	WMLB15-E8	13.58	13.91	0.33	7.79	0.11	0.04	1	5	-4	4.08	4.7	0	12	NAF
	WMLB15	OC2	28515	WMLB15-E10	14.83	15.35	0.52	7.62	0.12	<0.01	0	2	-2	-	5.2	0	4	NAF
	WMLB15	OC2	28516	WMLB15-E11	15.35	17.98	2.63	7.32	0.14	<0.01	0	1	-1	-	5.7	0	14	NAF
WMLB15	OC2	28517	WMLB15-E12	17.98	20.15	2.17	7.46	0.13	0.02	1	12	-11	19.61	7.4	0	0	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 (kgH₂SO₄/t)

ANC = Acid Neutralising Capacity (kgH₂SO₄/t)

NAPP = Net Acid Producing Potential (kgH₂SO₄/t)

NAGpH = pH of NAG liquor

NAG_(pH4.5) = Net Acid Generation capacity to pH 4.5 (kgH₂SO₄/t)

NAG_(pH7.0) = Net Acid Generation capacity to pH 7.0 (kgH₂SO₄/t)

NAF = Non-Acid Forming

PAF = Potentially Acid Forming

PAF-LC = PAF - lower capacity

UC = Uncertain Classification (expected classification in brackets)

Table 4: Acid forming characteristics of the composite samples used in column testing.

EGi Sample Number	Sample Description	ACID-BASE ANALYSIS*					STANDARD NAG TEST			Extended Boil NAGpH	Calculated NAG	ARD Classification
		Total %S	MPA	ANC	NAPP	ANC/MPA	NAGpH	NAG _(pH4.5)	NAG _(pH7.0)			
34466	PAF-LC Column Composite	0.22	7	2	5	0.3	2.2	67	113	5.7	2	PAF
34467	NAF Column Composite	0.04	1	6	-5	4.9	7.1	0	0			NAF
34468	Blend of PAF-LC Composite (1 Part) and NAF Composite (2 Parts)	0.09	3	5	-2	1.8	3.5	2	18	6.9	-2	NAF

KEY

MPA = Maximum Potential Acidity (kgH₂SO₄/t)

ANC = Acid Neutralising Capacity (kgH₂SO₄/t)

NAPP = Net Acid Producing Potential (kgH₂SO₄/t)

NAGpH = pH of NAG liquor

NAG_(pH4.5) = Net Acid Generation capacity to pH 4.5 (kgH₂SO₄/t)

NAG_(pH7.0) = Net Acid Generation capacity to pH 7.0 (kgH₂SO₄/t)

NAF = Non-Acid Forming

PAF = Potentially Acid Forming

PAF-LC = PAF - lower capacity

UC = Uncertain Classification

(expected classification in brackets)

**Note: acid-base calculations are based on the average total S and ANC from individual samples used to make up the composite.*

Table 5: Multi-element composition (mg/kg except where shown) and geochemical abundance indices (GAI) of column samples.

Element	Detection Limit	Elemental Composition		Median Soil Abundance*	GAI	
		PAF-LC Column Sample	PAF-LC/NAF Blend Column Sample		PAF-LC Column Sample	PAF-LC/NAF Blend Column Sample
Ag	0.1	<0.1	<0.1	0.05	-	-
Al	0.002%	4.16%	6.51%	7.1%	-	-
As	0.2	2.3	9.2	6	-	-
Ba	0.1	171	221	500	-	-
Be	0.1	5.2	3.4	0.3	4	3
Ca	0.001%	0.04%	0.07%	1.5%	-	-
Cd	0.1	0.2	0.2	0.35	-	-
Co	0.1	4.6	7.1	8	-	-
Cr	2	15	33	70	-	-
Cu	1	17	20	30	-	-
Fe	0.01%	0.32%	1.20%	4.0%	-	-
Hg	0.01	<0.01	<0.01	0.06	-	-
K	0.002%	0.49%	1.14%	1.4%	-	-
Mg	0.002%	0.10%	0.24%	0.5%	-	-
Mn	1	39	169	1000	-	-
Mo	0.1	2.6	1.6	1.2	1	-
Na	0.002%	0.02%	0.03%	0.5%	-	-
Ni	1	49	34	50	-	-
P	20	75	120	800	-	-
Pb	2	20	26	35	-	-
S	0.001%	0.22%	0.09%	0.07%	-	-
Sb	0.05	2.08	1.11	1	-	-
Se	0.5	0.8	1	0.4	-	1
Sn	0.1	3	4.4	4	-	-
Sr	0.05	29.1	55.6	250	-	-
Th	0.01	10.9	16.2	9	-	-
U	0.01	4.18	4.28	2	-	1
Zn	1	44	74	90	-	-

< element at or below analytical detection limit.

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

Table 6: Column leach test results for the PAF-LC composite sample.

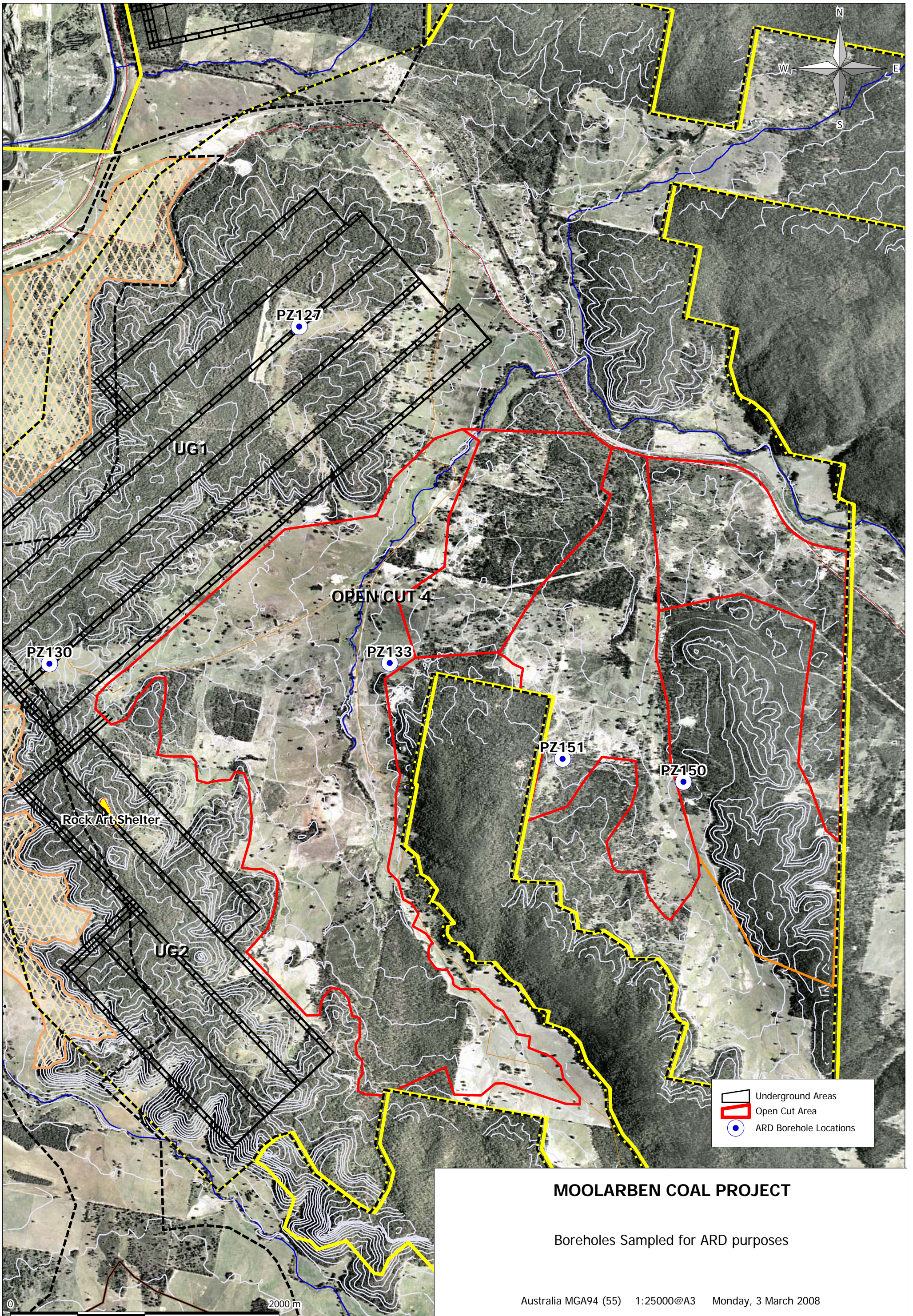
Sample Characteristics						
Sulphur	ANC	NAPP	NAG _{Calc}	Weight	Start	Sample
%S	kgH ₂ SO ₄ /t	kgH ₂ SO ₄ /t	kgH ₂ SO ₄ /t	g	Date	Code
0.22	2	5	2	2000	16/11/07	34466

Parameters		Week													
		0	4	8	12	16	20	24	28	32	36	40	44	48	52
Volume	ml	416	420	421	423	425	429	429	428	431					
pH	-	7.21	6.91	6.92	6.55	6.54	7.31	7.51	7.54	7.55					
EC	dS/m	0.32	0.33	0.35	0.34	0.35	0.31	0.32	0.31	0.31					
Alkalinity	mg/l	43	35	31	21	20	24	29	29	43					
Acidity	mg/l														
Ag	mg/l	0.00001	<0.00001	0.00020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Al	mg/l	<0.01	0.02	0.20	0.12	1.21	0.86	0.24	1.39	0.15					
As	mg/l	0.0099	0.0051	0.0338	0.0020	0.0020	<0.001	0.0090	0.0010	<0.001					
B	mg/l	<0.01	0.06	0.05	0.07	0.08	0.05	<0.05	<0.05	<0.05					
Ba	mg/l	0.033	0.026	0.019	0.021	0.018	0.020	0.022	0.029	0.031					
Be	mg/l	<0.0001	<0.0001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Ca	mg/l	18	11	9	8	6	6	6	5	5					
Cd	mg/l	0.0003	0.0001	0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001					
Cl	mg/l	35	28	29	30	37	52	66	77	80					
Co	mg/l	0.057	0.018	0.008	0.004	0.002	0.001	<0.001	<0.001	<0.001					
Cr	mg/l	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Cu	mg/l	0.010	<0.01	0.020	0.006	0.010	0.004	0.023	0.007	0.004					
F	mg/l	0.2	0.3	0.3	0.3	0.5	0.6	0.9	1.0	1.3					
Fe	mg/l	<0.01	<0.01	0.07	<0.05	0.06	0.12	0.08	0.08	0.06					
Hg	mg/l	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001					
K	mg/l	30	13	11	11	9	10	7	9	8					
Mg	mg/l	22	15	12	11	8	9	8	8	8					
Mn	mg/l	0.34	0.22	0.14	0.09	0.05	0.04	0.03	0.02	0.03					
Mo	mg/l	0.006	0.003	0.003	0.003	0.005	0.003	0.004	0.005	0.007					
Na	mg/l	48	22	22	20	18	27	28	32	35					
Ni	mg/l	0.17	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01					
P	mg/l	<0.1	<0.1	<0.1	<1	<1	<1	<1	<1	<1					
Pb	mg/l	0.003	0.039	0.002	<0.001	0.001	<0.001	0.001	<0.001	0.002					
SO ₄	mg/l	177	97	74	66	46	40	22	17	13					
Sb	mg/l	0.0010	0.0003	0.0003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Se	mg/l	0.16	0.08	0.08	0.06	0.04	0.02	<0.01	<0.01	<0.010					
Si	mg/l	2.46	2.41	2.67	2.45	2.70	2.46	1.02	2.42	2.16					
Sn	mg/l	<0.0001	<0.0001	0.0019	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Sr	mg/l	0.10	0.07	0.03	0.04	0.03	0.04	0.03	0.03	0.04					
Th	mg/l			<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					
Zn	mg/l	0.14	0.09	0.04	0.04	0.03	0.02	0.02	0.02	0.02					

Table 7: Column leach test results for the PAF-LC composite (1 Part) and NAF composite (2 Parts) blended sample.

Sample Characteristics						
Sulphur	ANC	NAPP	NAG _{Calc}	Weight	Start	Sample
%S	kgH ₂ SO ₄ /t	kgH ₂ SO ₄ /t	kgH ₂ SO ₄ /t	g	Date	Code
0.09	5	-2	-2	2000	16/11/07	34468

Parameters		Week													
		0	4	8	12	16	20	24	28	32	36	40	44	48	52
Volume	ml	393	397	394	396	397	397	410	412	416					
pH	-	7.41	6.96	6.93	7.11	7.41	7.71	7.83	7.95	7.96					
EC	dS/m	0.71	0.82	0.81	0.82	0.79	0.61	0.61	0.59	0.58					
Alkalinity	mg/l	57	50	47	50	65	74	80	83	87					
Acidity	mg/l														
Ag	mg/l	0.00002	0.00001	0.00005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Al	mg/l	0.01	0.10	3.82	2.34	1.64	0.64	0.22	1.24	0.12					
As	mg/l	0.012	0.006	0.006	0.004	0.003	<0.001	0.001	0.014	0.0020					
B	mg/l	<0.01	0.03	0.02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05					
Ba	mg/l	0.042	0.020	0.018	0.016	0.015	0.016	0.018	0.021	0.0250					
Be	mg/l	<0.0001	0.0001	0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Ca	mg/l	45	15	9	7	7	9	10	11	12					
Cd	mg/l	0.00043	0.00004	0.00002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001					
Cl	mg/l	102	33	21	16	24	39	61	68	83					
Co	mg/l	0.081	0.009	0.003	0.003	0.002	<0.001	<0.001	0.001	0.0010					
Cr	mg/l	<0.01	<0.01	<0.01	0.0020	0.0010	<0.001	<0.001	<0.001	<0.001					
Cu	mg/l	<0.01	<0.01	<0.01	0.022	0.012	0.010	0.004	0.003	0.03					
F	mg/l	0.5	1.0	2.0	2.6	3.6	3.3	3.5	3.5	3.3					
Fe	mg/l	<0.01	<0.01	0.32	0.27	0.20	0.06	<0.05	0.10	<0.05					
Hg	mg/l	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001					
K	mg/l	34	16	13	10	9	9	9	10	9					
Mg	mg/l	63	22	14	11	11	14	16	17	20					
Mn	mg/l	0.51	0.20	0.10	0.04	0.04	0.01	0.01	0.01	0.01					
Mo	mg/l	0.019	0.018	0.021	0.021	0.017	0.013	0.011	0.008	0.00800					
Na	mg/l	104	32	22	16	15	22	24	29	34					
Ni	mg/l	0.240	0.030	<0.01	0.014	0.011	0.003	0.003	0.005	0.004					
P	mg/l	<0.1	<0.1	<0.1	<1	<1	<1	<1	<1	<1					
Pb	mg/l	0.0057	0.0086	0.0029	0.0040	0.0060	<0.001	<0.001	0.0020	0.0010					
SO ₄	mg/l	401	135	74	43	27	21	12	11	11					
Sb	mg/l	0.0011	0.0007	0.0009	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Se	mg/l	0.20	0.07	0.04	0.02	<0.01	<0.01	<0.01	<0.01	<0.010					
Si	mg/l	3.21	2.22	8.67	1.62	1.51	1.10	<0.10	1.12	0.88					
Sn	mg/l	<0.0001	0.0001	0.0004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
Sr	mg/l	0.28	0.09	0.05	0.04	0.04	0.05	0.05	0.06	0.07					
Th	mg/l			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					
Zn	mg/l	0.10	0.02	<0.01	0.01	0.01	<0.005	<0.005	0.01	<0.005					



MOOLARBEN COAL PROJECT

Boreholes Sampled for ARD purposes

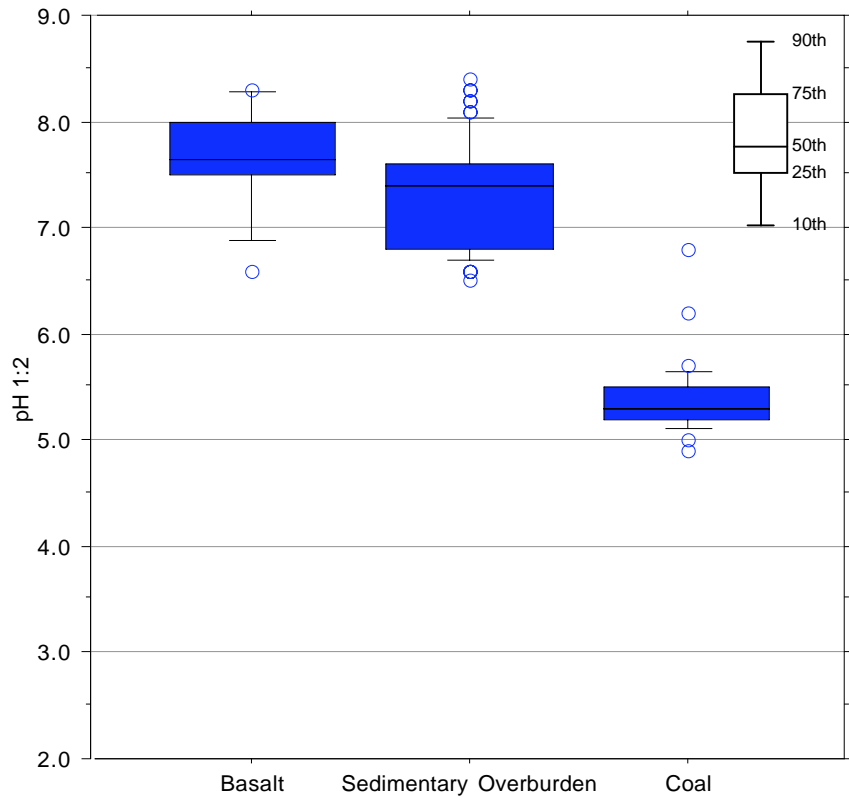


Figure 2: Box plot showing the distribution of $pH_{1:2}$ split by rock types. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

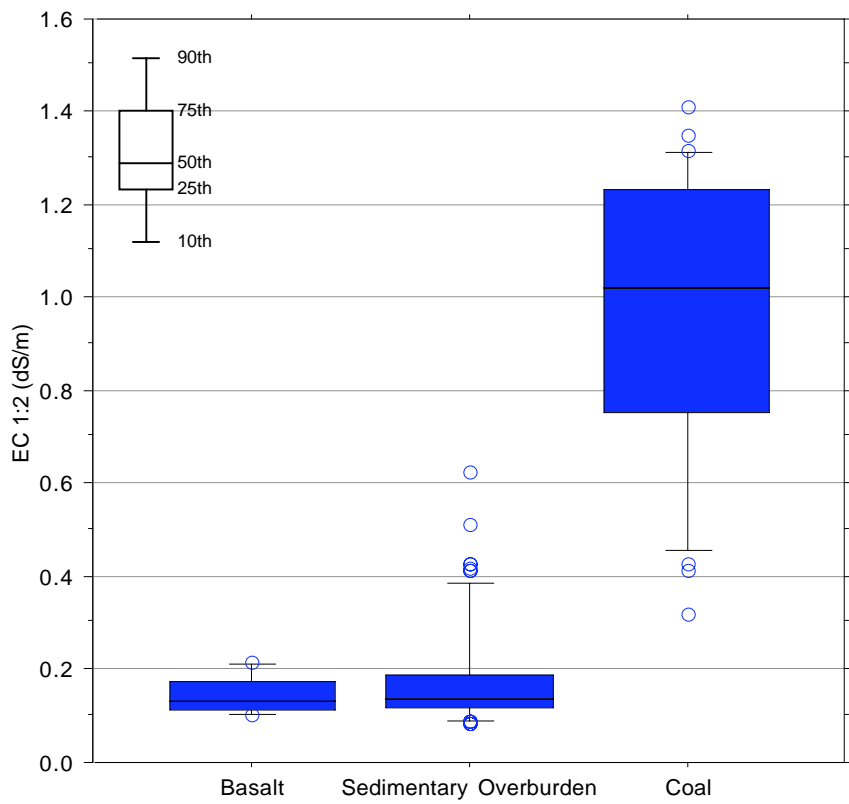


Figure 3: Box plot showing the distribution of $EC_{1:2}$ split by rock types. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

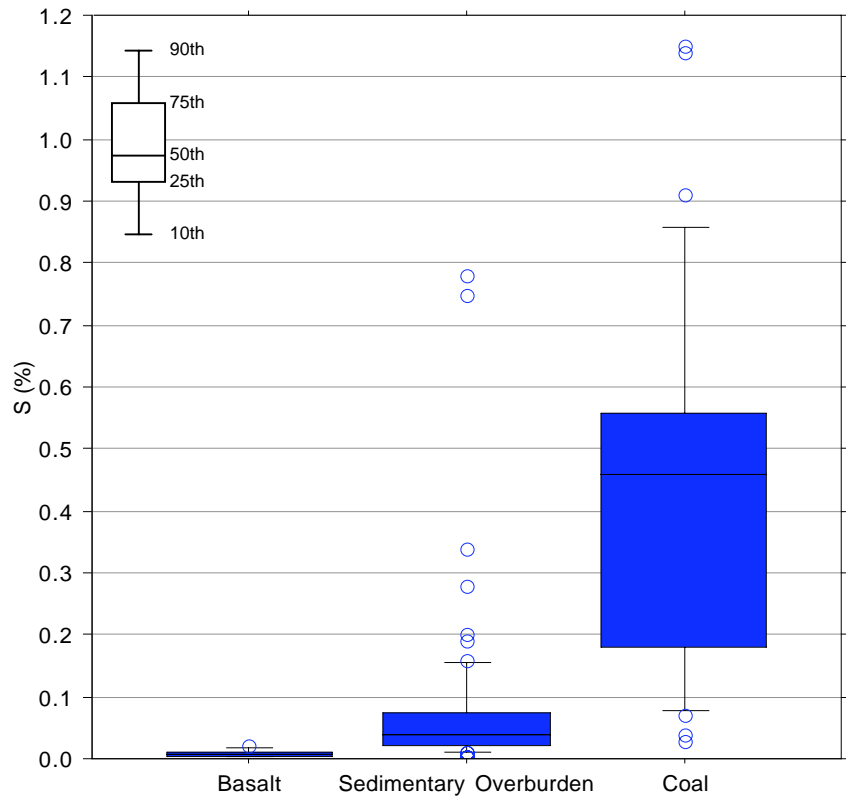


Figure 4: Box plot showing the distribution of total S split by rock type. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

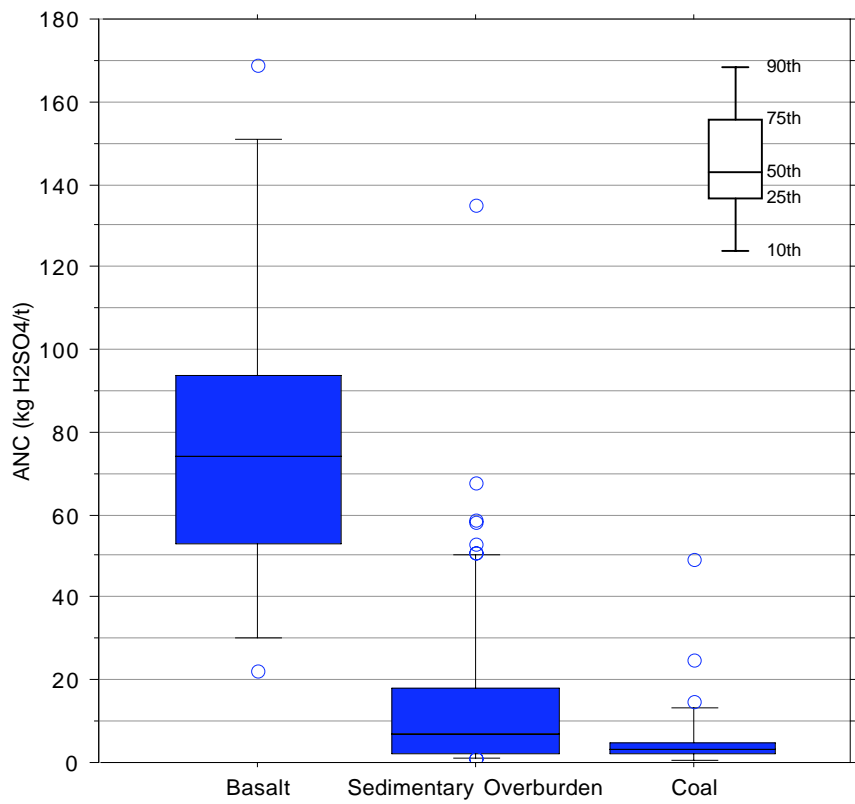


Figure 5: Box plot showing the distribution of ANC split by rock type. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

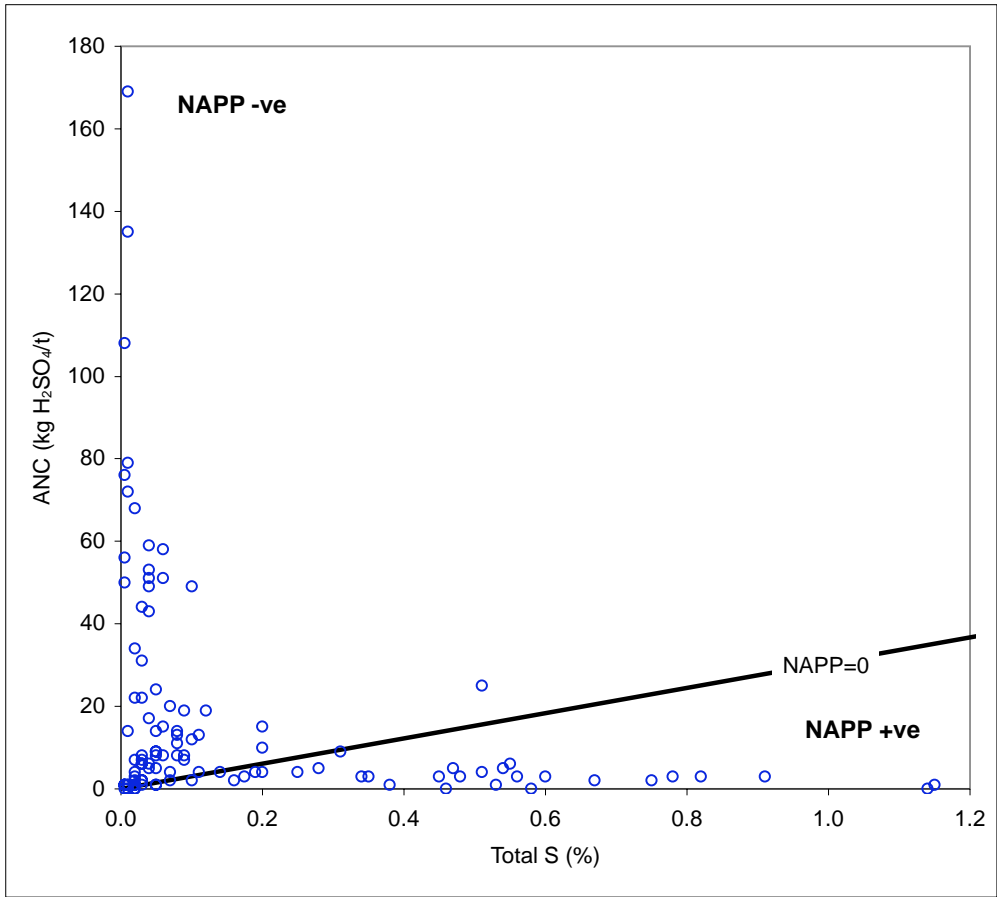


Figure 6: Acid-base account (ABA) plot showing ANC versus total S.

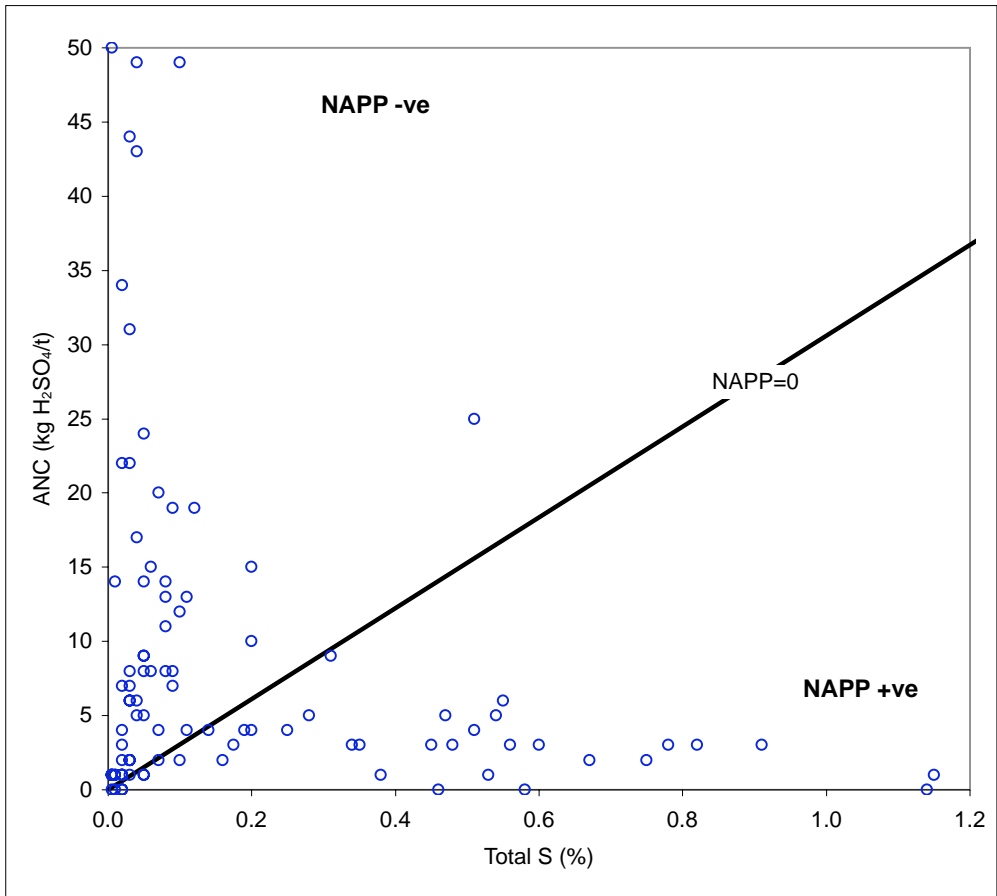


Figure 7: As for Figure 6 but with a re-scaled y axis.

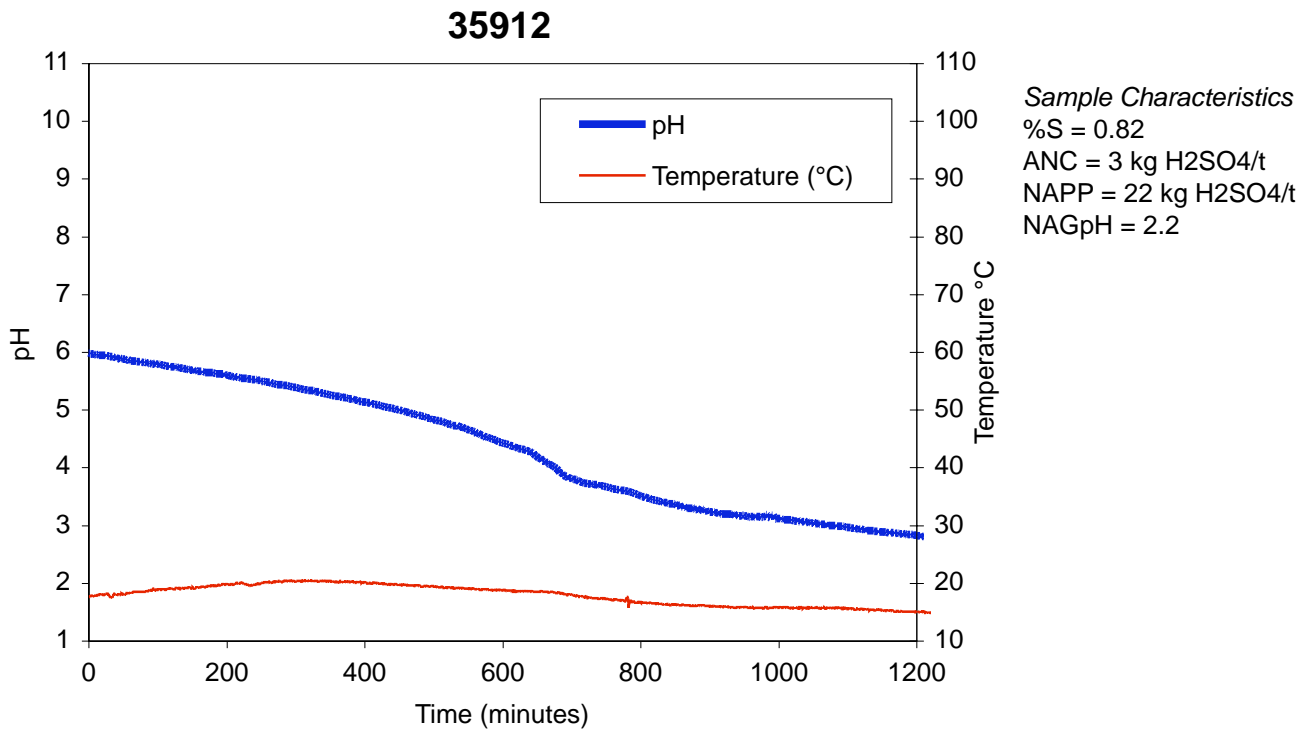


Figure 8: Kinetic NAG graph for sample 35912.

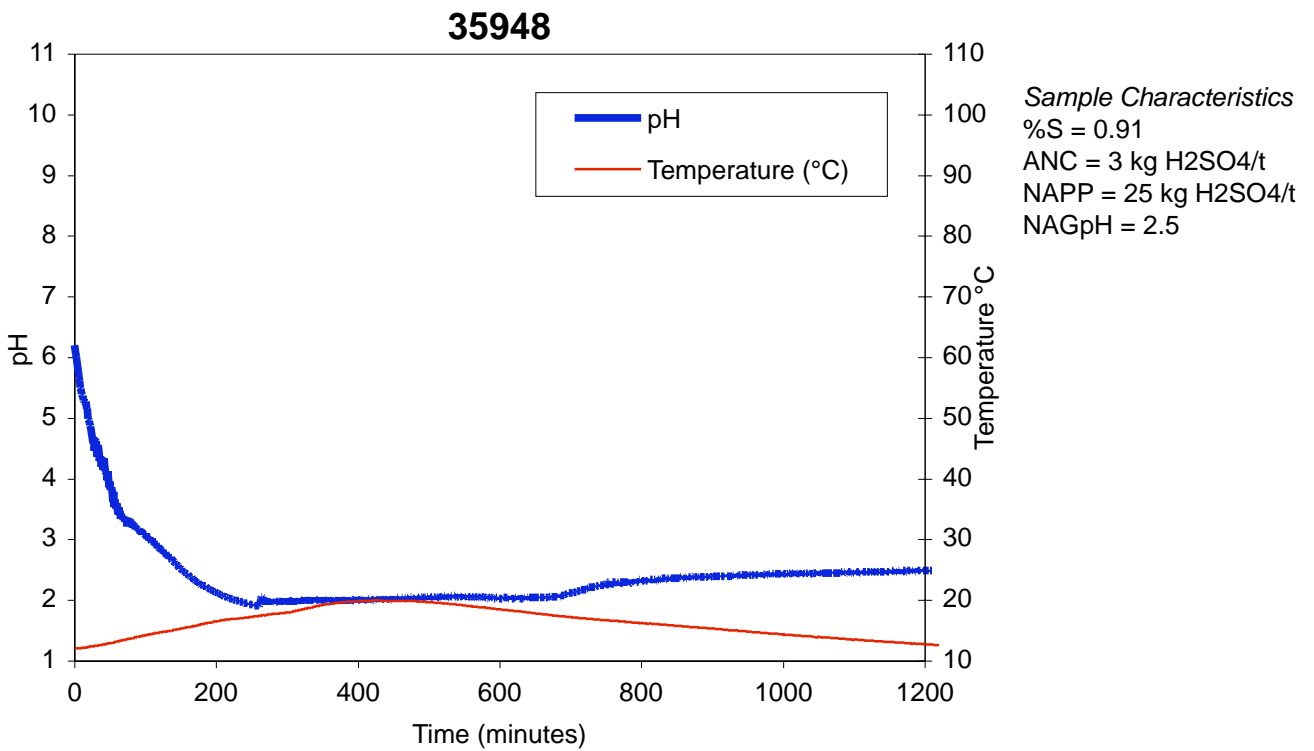


Figure 9: Kinetic NAG graph for sample 35948.

35949

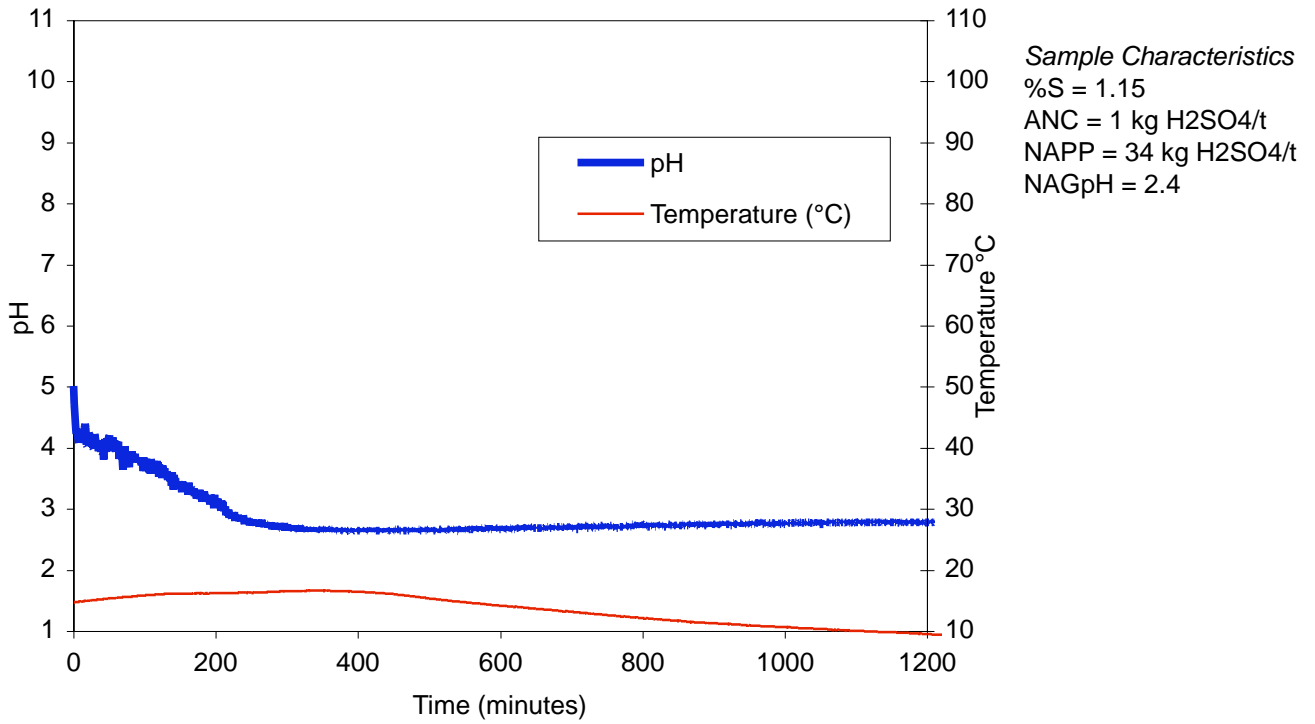


Figure 10: Kinetic NAG graph for sample 35949.

35975

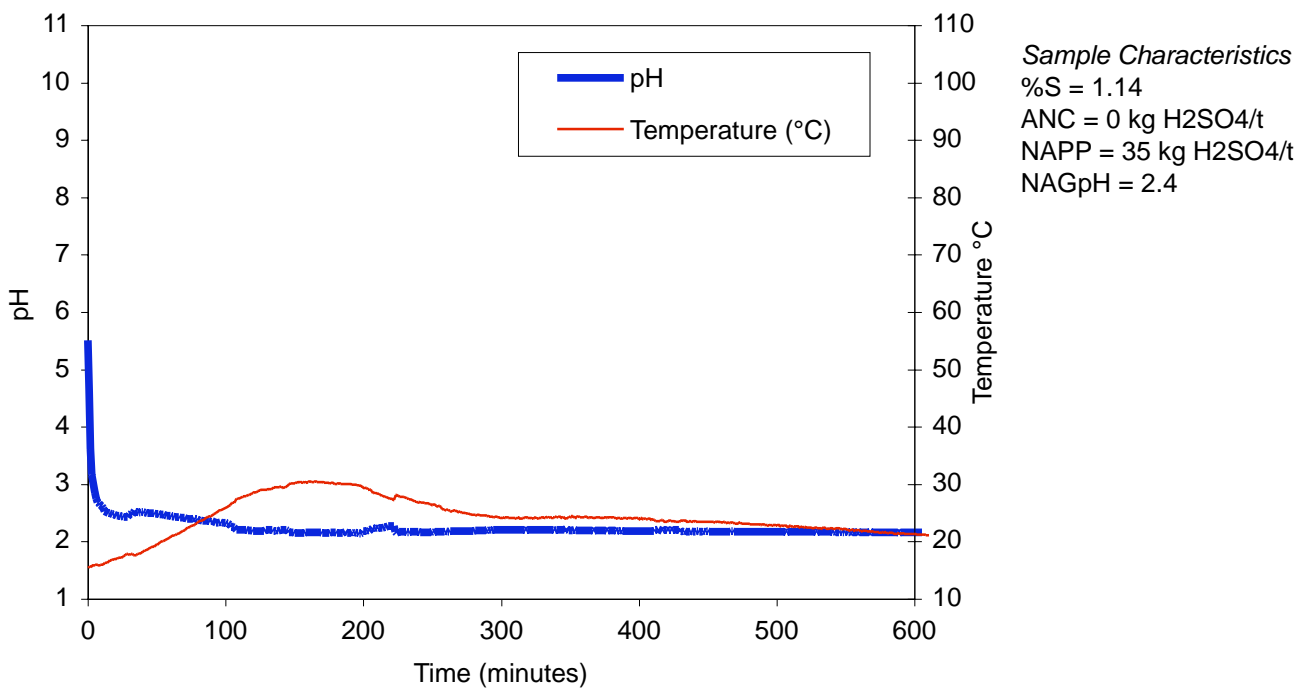


Figure 11: Kinetic NAG graph for sample 35975.

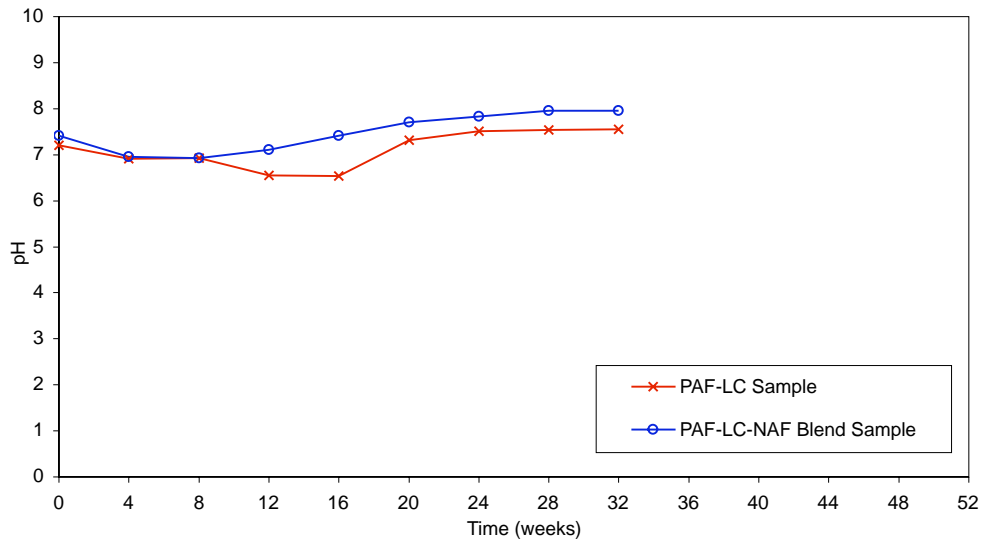


Figure 12: Leach column pH profiles for PAF and composite co-disposed reject/tailings samples from the Stage 1 facility.

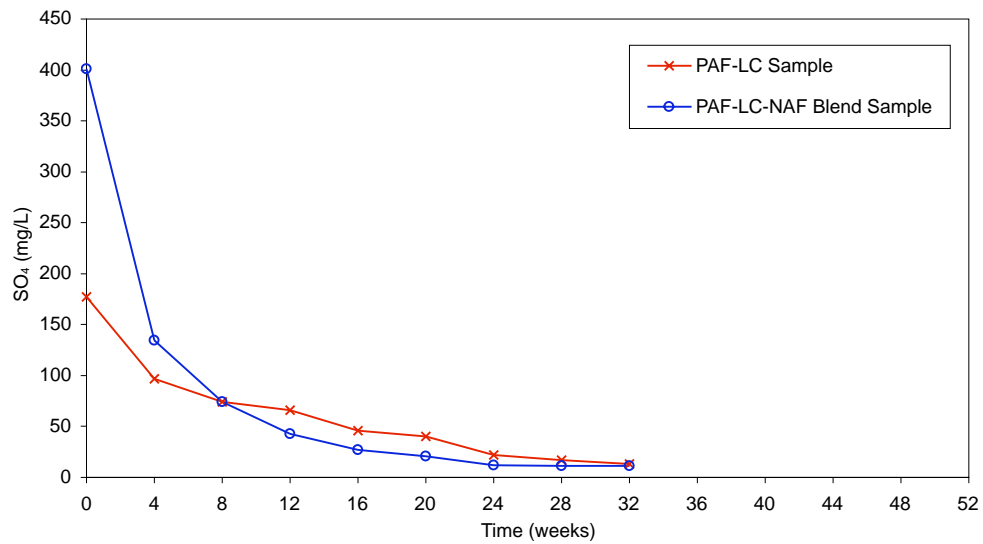


Figure 13: Leach column SO₄ profiles for PAF and composite co-disposed reject/tailings samples from the Stage 1 facility.

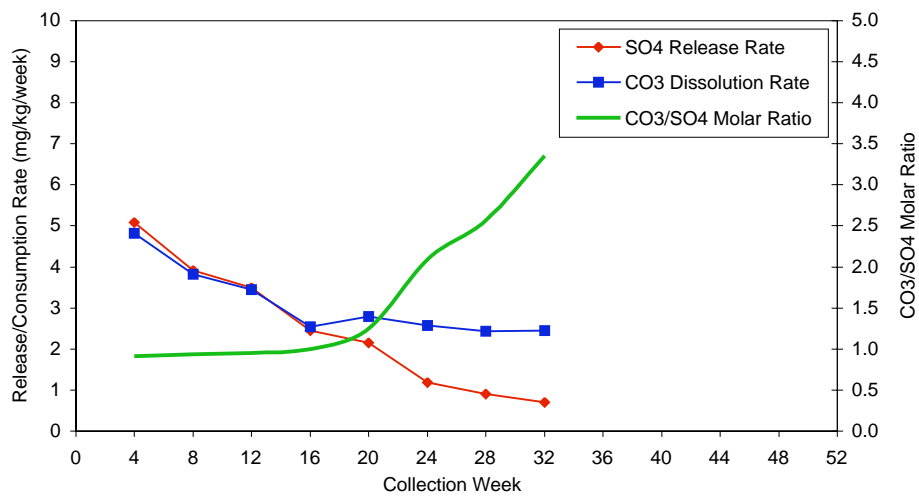


Figure 14: PAF-LC leach column SO₄ release rate, CO₃ dissolution rate (assuming all Ca and Mg released to leachates is due to dissolution of Ca-Mg carbonates), and CO₃/SO₄ molar ratio trends.

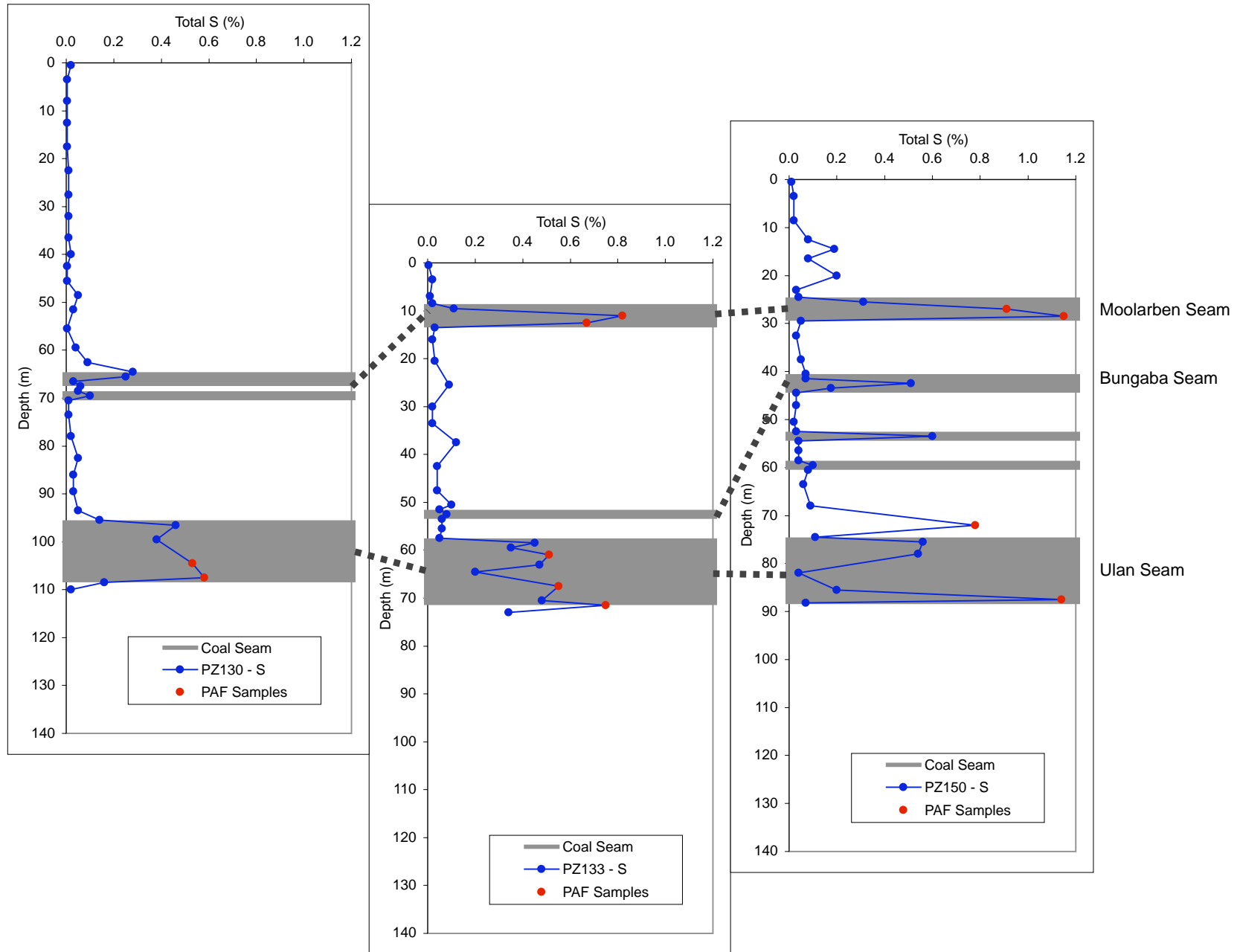


Figure 15: Downhole total S profiles for holes PZ130, PZ133 and PZ150, with PAF samples (including UC(PAF)) indicated.

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 help assess the acid forming characteristics of mine waste materials. The most widely used assessment methods for ARD characterisation 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 maximum potential acidity (MPA) and the acid neutralising capacity (ANC), respectively. The difference between the MPA and ANC value is referred to as the net acid producing potential (NAPP).

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

Maximum Potential Acidity

The MPA that can be generated by a sample is determined from the sample sulphur content. The total sulphur content of a sample is commonly determined by the Leco high temperature combustion method. The calculation assumes that all the sulphur measured in the sample occurs as pyrite (FeS₂) and that the pyrite reacts under oxidising conditions to generate acid according to the reaction:



According to this reaction, the MPA of a sample containing 1 %S as pyrite would be 30.6 kilograms of H₂SO₄ per tonne of material (*i.e.* kg H₂SO₄/t). Hence the MPA of a sample is calculated from the total sulphur content using the following formula:

$$\text{MPA (kg H}_2\text{SO}_4\text{/t)} = (\text{Total \%S}) \times 30.6$$

The use of the total sulphur assay to estimate the MPA is a conservative approach because some sulphur may occur in forms other than pyrite. Sulphate-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 sulfur content is commonly used to assess MPA because of the difficulty and costs involved in routinely determining the speciation of sulfur forms within samples and determining reactive sulphide-sulfur contents. However, if the sulphide mineral forms are known then allowance can be made for non- and lesser acid generating sulfur forms to provide a better estimate of the MPA.

Acid Neutralising Capacity

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, that is kg H₂SO₄/t.

Net Acid Producing Potential

This 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 H₂SO₄/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, a ANC/MPA ratio of 2 or more generally 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 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.

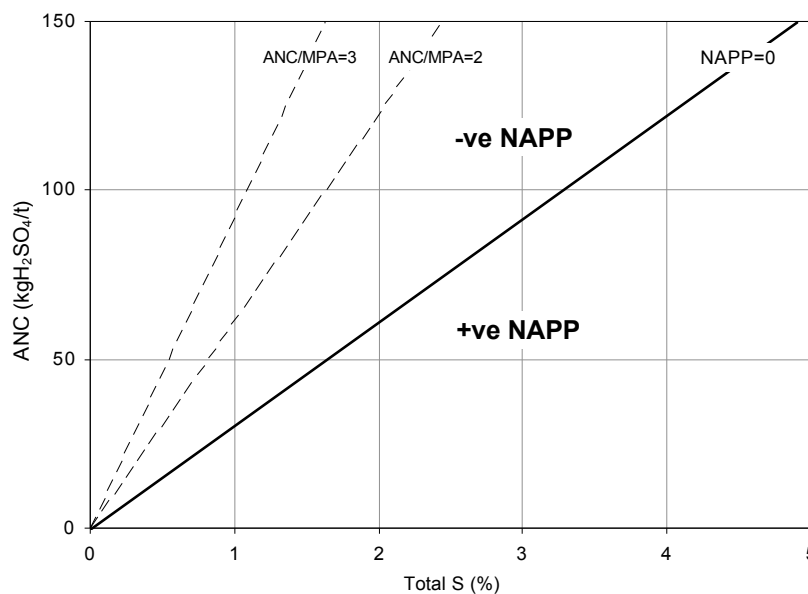


Figure A-1. Acid-base account (ABA) plot

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. Therefore, the end result represents a direct measurement of the net amount of acid generated by the sample. This value is commonly referred to as the NAG capacity and is expressed in the same units as NAPP, that is kg H₂SO₄/t.

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

Single Addition NAG Test

The single addition NAG test involves the addition of 250 mL of 15% hydrogen peroxide to 2.5 gm 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 pH and acidity of the NAG liquor are measured. The acidity of the liquor is then used to estimate the net amount of acidity produced per unit weight of sample.

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.* H₂SO₄) as well as soluble iron and aluminium. The titration value at pH 7 also includes metallic ions that precipitate as hydroxides at pHs between 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 multi-stage 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, pH and sometimes EC of the liquor are recorded. Variations in these parameters during the test provide an indication of the kinetics of sulphide oxidation and acid generation during the test. This, in turn, can provide an insight into the behaviour of the material field 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.

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 sulfur content ≤ 0.1 %S and an ANC ≤ 5 kg H₂SO₄/t.

Non-acid forming (NAF)

A sample classified as NAF may, or may not, have a significant sulfur 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 sulfur 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 $\text{NAGpH} \leq 4.5$). 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 geochemical data. Marked on this plot are the quadrats representing the NAF, PAF and UC classifications.

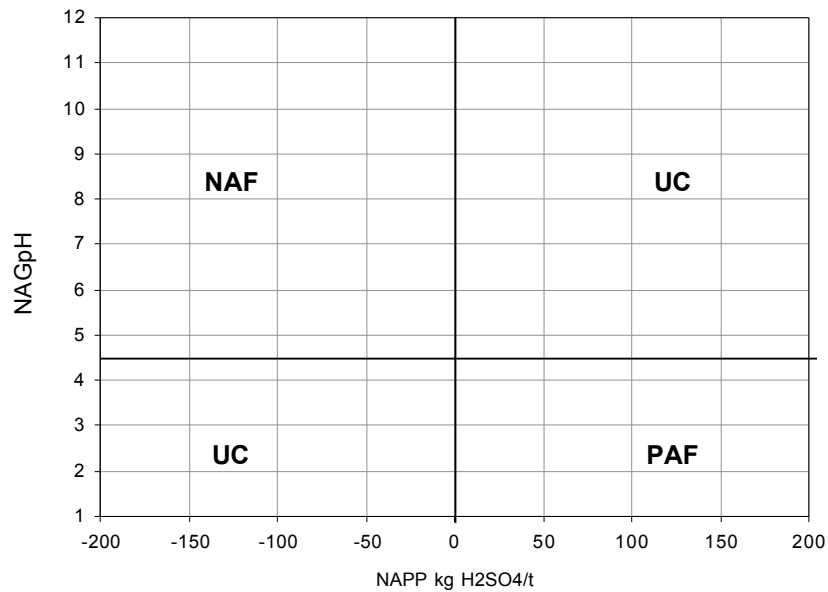


Figure A-2 Geochemical classification plot

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 1 hour, 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. This data provides an indication of the portion of ANC within a sample that is readily available for acid neutralisation.

