

Appendix G: ARD Assessment for Colton Mine Project



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](mailto:egi@geochemistry.com.au)  
ACN 003 793 486 ABN 12 003 793 486

For:

**NORTHERN ENERGY CORPORATION LIMITED**

GPO Box 5283  
Brisbane QLD 4001

August 2009

Document No. 5051/867

**ARD Assessment of the Colton Mine Project**

---

# Contents

<i>List of Tables</i> .....	<i>iii</i>
<i>List of Figures</i> .....	<i>iii</i>
<i>List of Appendices</i> .....	<i>iv</i>
<i>Executive Summary</i> .....	<i>v</i>
<b>1.0 INTRODUCTION</b> .....	<b>1</b>
<b>2.0 SAMPLE DESCRIPTIONS AND PREPARATION</b> .....	<b>1</b>
<b>3.0 METHODOLOGY</b> .....	<b>2</b>
<b>4.0 STANDARD GEOCHEMICAL RESULTS</b> .....	<b>3</b>
4.1 pH and EC .....	3
4.2 Acid Base (NAPP) Results.....	3
4.3 Single Addition NAG Results .....	4
<b>5.0 SPECIALISED GEOCHEMICAL CHARACTERISATION RESULTS</b> .....	<b>5</b>
5.1 Extended Boil and Calculated NAG Results .....	5
5.2 Acid Buffering Characteristic Curve (ABCC) Testing .....	6
5.3 Kinetic NAG Testing.....	7
5.4 Sulphur Speciation.....	7
5.5 Multi-Element Analysis of Solids and Water Extracts.....	7
<b>6.0 SAMPLE CLASSIFICATION AND DISTRIBUTION OF ARD ROCK TYPES</b> ...	<b>8</b>
<b>7.0 CONCLUSIONS AND RECOMMENDATIONS</b> .....	<b>9</b>

---

**List of Tables** (after text)

- Table 1: Acid forming characteristics.
- Table 2: Extended boil NAG and calculated NAG test results for selected samples.
- Table 3: Sulphur speciation results for selected samples.
- Table 4: Multi-element composition of selected sample solids (mg/kg except where shown).
- Table 5: Geochemical abundance indices (GAI) of selected sample solids.
- Table 6: Chemical composition of water extracts of selected samples.

**List of Figures** (after tables)

- Figure 1: Schematic stratigraphic column for the Colton Deposit.
- Figure 2: Box plot showing the distribution of pH<sub>1.2</sub> split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 3: Box plot showing the distribution of EC<sub>1.2</sub> split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 4: Box plot showing the distribution of S split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 5: Box plot showing the distribution of ANC split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 6: Acid-base account (ABA) plot showing ANC versus total S split by lithology.
- Figure 7: Box plot showing the distribution of NAGpH split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.
- Figure 8: ARD classification plot showing NAGpH versus NAPP split by lithology, with ARD classification domains indicated.
- Figure 9: ABCC profiles for samples with an ANC value close to 5 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.
- Figure 10: ABCC profiles for samples with an ANC value close to 10 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.
- Figure 11: ABCC profiles for samples with an ANC value close to 15 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.
- Figure 12: ABCC profiles for samples with an ANC value close to 20 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.
- Figure 13: ABCC profiles for samples with an ANC value close to 30 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.
- Figure 14: ABCC profiles for sample 37665 with an ANC value close to 60 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.
- Figure 15: ABCC profile for sample 37688 with an ANC value close to 75 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.
- Figure 16: Kinetic NAG graph for sample 37640 (Mudstone).
- Figure 17: Kinetic NAG graph for sample 37657 (Carb Mudstone/Coal).

- 
- Figure 18: Kinetic NAG graph for sample 37659 (Carb Mudstone/Coal).  
Figure 19: Kinetic NAG graph for sample 37701 (Carb Mudstone/Coal).  
Figure 20: Kinetic NAG graph for sample 37702 (Carb Mudstone/Coal).  
Figure 21: Kinetic NAG graph for sample 37703 (Siltstone).  
Figure 22: Kinetic NAG graph for sample 37708 (Carb Mudstone/Coal).  
Figure 23: Kinetic NAG graph for sample 37718 (Carb Mudstone/Coal).  
Figure 24: Kinetic NAG graph for sample 37714 (Carb Mudstone/Coal).  
Figure 25: Kinetic NAG graph for sample 37715 (Carb Mudstone/Coal).  
Figure 26: Kinetic NAG graph for sample 37716 (Mudstone).  
Figure 27: Total S, ANC, NAGpH and NAPP profiles for hole NMB-031.  
Figure 28: Total S, ANC, NAGpH and NAPP profiles for hole NMB-037.  
Figure 29: Total S, ANC, NAGpH and NAPP profiles for hole NMB-038.

### **List of Appendices** (after text)

Appendix A – Assessment of Acid Forming Characteristics

---

## Executive Summary

Environmental Geochemistry International Pty Ltd (EGi) were commissioned by Northern Energy Corporation Limited to carry out a geochemical assessment of the Colton Mine Project, located 11km north of the town of Maryborough, and 280 km north of Brisbane, Queensland.

The Colton coking coal deposit is multi-seamed and thinly bedded, and part of the Early Cretaceous Burrum Coal Measures. It is understood the deposit will be mined as an open cut pit, with out of pit dumping planned initially, followed by open pit backfill as space becomes available. Coal washing will occur on site, with tailings de-watered and combined with rejects for placement with overburden.

The objective of the work was to assess the acid rock drainage (ARD) potential of overburden, interburden, floor rock and process wastes to support an Environmental Management Plan.

A total of 83 samples from three core holes (NMB-031, NMB-037 and NMB-038) were geochemically tested, with intervals ranging from less than 0.5m to over 5m. Sample intervals were selected by Colton geologists in conjunction with EGi to match geological boundaries. The holes were spaced approximately 500m apart across the deposit, and the samples tested included overburden and interburden from just below the Jubilee Seam to the base of the A3L Seam.

Results of testing indicate that the bulk of the overburden and interburden represented by the samples tested is likely to be NAF, but that coal seams, seam roof, seam floor, rejects and tailings are likely to be mainly PAF. Results indicate a significant excess of NAF overburden, which will greatly assist materials management and is likely to provide flexibility in selective handling and placement of ARD material types. Kinetic net acid generation (NAG) testing indicates that PAF materials are likely to be fast reacting, producing acid within weeks of exposure to atmospheric oxidation conditions. Constituents associated with ARD are likely to include Al, Co, Cu, Fe, Ni, SO<sub>4</sub> and Zn. Some slight enrichment of As in PAF materials was also indicated.

Results have the following implications for mine materials management:

- Most of the overburden and interburden is expected to be NAF and will not require special handling for ARD control, and can be used to assist management of PAF materials.
- PAF horizons appear to be mainly associated with coal seams and immediate roof and floor.
- Washery waste materials are likely to be mainly PAF and special handling and management is likely to be required.
- Pit floor and wall materials may also be a source of ARD, and provision for capture of runoff/leachate, monitoring and lime treatment may be required.

- 
- Possible management strategies for PAF washery waste and any PAF overburden/interburden materials include:
    - limestone treatment and interim compaction of PAF materials to increase lag times before onset of acid conditions to manage ARD during operations or until implementation of closure strategies;
    - placement of PAF materials below the water table to allow inundation and prevent further exposure to atmospheric oxidation; and
    - construction of a NAF cover zone designed to limit oxygen diffusion and infiltration into PAF materials (water and oxygen flux modelling will be required to determine the best approach under the local climatic conditions).
  - ROM and product coal stockpiles may generate ARD depending on residence times and reaction rates, and again provision for capture of runoff/leachate, monitoring and lime treatment may be required.
  - A programme of routine sampling and testing of washery wastes and overburden/interburden materials will be required during operations to monitor variation in acid potential and to reconcile the predicted distribution of ARD rock types in overburden.
  - Water quality monitoring of seepage and runoff from pit walls and floors, waste rock dumps, ROM stockpiles and washery waste disposal areas should be carried out to check for ARD generation, assess the performance of management strategies, and determine and/or refine lime and limestone treatment requirements.
  - Routine site water quality monitoring programmes should include pH, EC, acidity/alkalinity, SO<sub>4</sub>, Al, As, Co, Cu, Fe, Mn, Ni and Zn to monitor for effects of pyrite oxidation and ARD generation.

Testing completed to date at Colton indicates mine materials will be mainly NAF, and is sufficient to determine the main implications and approaches to manage waste materials. However, it is recommended that additional investigations be carried out prior to mining to confirm the distribution of ARD waste rock types and refine management strategies for PAF materials. These investigations should include the following:

- Geochemical characterisation of additional drill holes should be carried out to expand the ARD database and confirm the distribution of ARD rock types in overburden and interburden. This should include testing of the surface weathered zone and Tertiary sediments to confirm the expected benign nature of these materials.
- Overburden and interburden samples tested to date cover the stratigraphy from below the Jubilee Seam to the base of the AL3 Seam. ARD assessment of additional stratigraphy will be required if the proposed mine development includes materials from outside of the stratigraphic range tested.
- Testing of washery waste materials should be carried out once suitable materials become available.

- Leach column testing should be carried out on representative PAF floor, ROM coal, product coal, and washery wastes to determine lag times before onset of acid conditions, and short and long term ARD potential to refine disposal and long term management strategies.
- The possibility of disposing PAF materials below the water table should be investigated, as this is likely to represent the most secure long term ARD control option. Considerations include the likely duration of exposure and the reaction kinetics of PAF materials, and the sensitivity of the water table to any ARD generated during operations and before inundation (inundation will mobilise any accumulated ARD products and could potentially result in lateral contamination of the water table).
- Conceptual level (desk top) modelling of water and oxygen flux in dumped materials should be carried out to determine a minimum cover requirement for long term control of ARD from PAF overburden. This would provide a basis for comparison of the cover option with other management strategies such as disposal below the water table.

## **1.0 Introduction**

Environmental Geochemistry International Pty Ltd (EGi) were commissioned by Northern Energy Corporation Limited to carry out a geochemical assessment of the Colton Mine Project, located 11km north of the town of Maryborough, and 280 km north of Brisbane, Queensland.

The objective of the work was to assess the acid rock drainage (ARD) potential of overburden, interburden, floor rock and process wastes to support an Environmental Management Plan.

The Colton coking coal deposit is multi-seamed and thinly bedded, with the main potentially economic seams split into A-Series and B-Series groups. These coal seams are part of the Early Cretaceous Burrum Coal Measures, which are unconformably overlain by the Tertiary Elliot Formation. A schematic stratigraphic column is shown in Figure 1.

It is understood the deposit will be mined as an open pit, with out of pit dumping planned initially, followed by backfill as space becomes available. Coal washing will occur on site, with tailings de-watered and combined with rejects for placement with overburden.

The scope of work comprised the following:

- Selection of drill holes and sample intervals in consultation with site geologists based on geological logs, cross-sections and plans;
- Collection of samples and sample preparation arranged by site personnel;
- Geochemical testing; and
- Assessment of results and reporting.

## **2.0 Sample Descriptions and Preparation**

A total of 83 samples from three core holes (NMB-031, NMB-037 and NMB-038) were geochemically tested, with intervals ranging from less than 0.5m to over 5m. Sample intervals were selected by Colton geologists in conjunction with EGi to match geological boundaries. An effort was made to represent the full stratigraphic section proposed to be mined in three holes spaced approximately 500m apart across the deposit.

Continuous sampling from the top to the base of each hole was carried out where possible, but missing intervals were common due to core loss, and previous sampling for coal quality and geotechnical testing. Around 70% of the total overburden intersected in the three holes was available for sampling. Coal seams were generally not represented and the immediate coal seam roof and floor were also commonly missing. The open hole pre-collars representing the first 5-10m of each hole were also not available although these materials (including Tertiary cover) are expected to be strongly weathered and any pyrite originally present is likely to have

been largely oxidised. Although the mine stratigraphy is not fully represented, results are expected to provide an indication of the general distribution of ARD rock types.

Overburden and interburden from the three holes tested cover the stratigraphic range from just below the Jubilee Seam to the base of the A3L Seam. Samples from Holes NMB-031 and NMB-038 intercepted overburden from 11-18m above the A1U Seam, and down to floor material below the A3L Seam. Hole NMB-037 was located higher in the stratigraphic sequence, intercepting the top of the Jubilee Seam, and overlapping with Seam A1U overburden intercepted in holes NMB-031 and NMB-038.

Initial sample preparation of core was arranged by Northern Energy, which involved drying (as required), crushing to a nominal -4mm, splitting, pulverising a 500g split to -212 $\mu$ m (size fraction limit of the equipment at the laboratory used), and dispatch of 500g of -212 $\mu$ m pulverised samples and -4mm crushed samples to EGi. The -212 $\mu$ m pulverised samples were dispatched to Sydney Environmental and Soil Laboratory (SESL) for pulverising to -75 $\mu$ m.

### 3.0 Methodology

Standard geochemical characterisation was completed on all samples as follows:

- pH and electrical conductivity (EC) of deionised water extracts at a ratio of 1 part solid to 2 parts water (pH<sub>1:2</sub> and EC<sub>1:2</sub>);
- Leco total S;
- acid neutralising capacity (ANC); and
- standard single addition net acid generation (NAG) test.

Further testing was carried out on selected samples to help resolve uncertainties in the above test results, as follows:

- extended boil and calculated NAG testing to account for high organic carbon contents;
- sulphur speciation testing;
- kinetic NAG test;
- acid buffering characteristic curve (ABCC) test; and
- multi-element scans of solids and water extracts.

A general description of ARD test methods and calculations used is provided in Appendix A.

The -4mm crushed samples were used for pH<sub>1:2</sub> and EC<sub>1:2</sub> testing and water extracts. Pulverised samples were used for all other tests.

The sulphur speciation procedure involved Leco total S, chromium reducible sulphur (CRS) and KCl digestion to help differentiate pyritic S, acid forming sulphate, non-acid forming sulphate and lower risk S forms (including organic S, jarosite S and elemental S).

Leco total sulphur assays were carried out by SESL. Multi-element analyses and CRS of sample solids were carried out by ALS Laboratory Group (Brisbane). Multi-element analyses of water extracts were carried out by ALS Laboratory Group (Sydney). Analyses of NAG solutions and S analysis of KCl digest solutions were carried out by Levay & Co. Environmental Services (Adelaide). All other analyses were carried out by EGi.

## 4.0 Standard Geochemical Results

Results of standard geochemical characterisation are presented in Table 1, comprising pH and EC of water extracts, total S, maximum potential acidity (MPA), ANC, NAPP, ANC/MPA ratio and single addition NAG.

### 4.1 pH and EC

The pH<sub>1:2</sub> and EC<sub>1:2</sub> results were determined by equilibrating the 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 and 3 are box plots showing the distribution of pH<sub>1:2</sub> and EC<sub>1:2</sub> values, respectively, split by major lithology.

The pH<sub>1:2</sub> values ranged from 4.3 to 8.4, with most samples (80%) showing no inherent acidity with a pH greater than 6. Ten of the samples tested had a slightly acidic pH of less than 5.0, and Figure 2 shows they are associated with mudstone and carbonaceous mudstone/coal samples.

EC<sub>1:2</sub> values ranged from 0.13 to 1.91 dS/m with most samples (80%) falling within the non-saline to slightly saline range with an EC of less than 0.8 dS/m. The remaining samples were moderately saline (0.8 to 1.6 dS/m) to saline (>1.6 dS/m). Figure 3 shows that the carbonaceous mudstone/coal samples account for all of the saline samples and most of the moderately saline samples.

Results indicate a general lack of immediately available acidity and salinity in the samples tested, but minor acidity and moderate salinity is associated with some of the carbonaceous samples.

### 4.2 Acid Base (NAPP) Results

Total S ranges from below detection up to 3.39%S. Figure 4 is a box plot of the distribution of S split by lithology. The plot shows that the higher S samples (>1%S) are associated with

mudstone and carbonaceous mudstone and coal samples, and shows a general increase in S with grain size, with sandstone having the lowest median S and carbonaceous mudstone/coal showing the highest.

ANC ranges up to 99 kg H<sub>2</sub>SO<sub>4</sub>/t. Figure 5 is a box plot of the distribution of ANC split by lithology, which shows that sandstone and siltstone samples tend to have higher ANC than the mudstone and carbonaceous mudstone/coal samples, with moderate ANC values of close to 20 kg H<sub>2</sub>SO<sub>4</sub>/t in the sandstone and siltstone samples, compared to low median ANC values of 15 and 9 kg H<sub>2</sub>SO<sub>4</sub>/t for the mudstone and carbonaceous mudstone/coal samples, respectively.

The net acid producing potential (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) 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 account plot of ANC versus total S, with samples split by lithology. The NAPP zero line is shown which defines the NAPP positive and NAPP negative domains, and the line representing an ANC/MPA ratio value of 2 is also plotted. Note that the NAPP = 0 line is equivalent to an ANC/MPA ratio of 1. The ANC/MPA ratio is used as an indication of the relative factor of safety within the NAPP negative domain. Usually a ratio of 2 or more signifies a high probability that the material will remain circum-neutral in pH and thereby should not be problematic with respect to ARD.

Results show that 75% of samples are NAPP negative, with 60% also having ANC/MPA ratios of greater than 2. Figure 6 shows that most of the samples plotting in the PAF domain are mudstone and carbonaceous mudstone/coal samples.

### 4.3 Single Addition NAG Results

Figure 7 is a box plot of the distribution of NAGpH, split by lithology. Generally a NAGpH value greater than or equal to 4.5 indicates a sample is unlikely to be net acid generating. The figure shows that the majority of low NAGpH values are associated with the carbonaceous mudstone/coal samples. However, most samples (75%) have NAGpH values greater than 4.5.

NAG test results are used in conjunction with NAPP values to classify samples according to acid forming potential. Figure 8 is an ARD classification plot showing NAGpH versus NAPP value, with results split according to major rock unit groupings. Potentially acid forming (PAF), non-acid forming (NAF) and uncertain (UC) classification domains are indicated. A sample is classified PAF when it has a positive NAPP and NAGpH < 4.5, and NAF when it has a negative NAPP and NAGpH ≥ 4.5. Samples are classified uncertain 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.

Figure 8 shows that most samples have consistent NAPP and NAGpH results, plotting in either the PAF or NAF domain. Only 4 of the 83 samples tested had conflicting NAPP and NAGpH results. The PAF domain comprises mainly carbonaceous mudstone and coal samples, and the NAF domain is dominated by sandstone samples.

Two samples plot in the upper right uncertain domain. These samples have moderate total S of 0.46%S and 0.63%S and low ANC of less than or equal to 10 kg H<sub>2</sub>SO<sub>4</sub>/t, and the NAG test would normally account for all pyritic S in the sample. These samples are expected to be NAF in accordance with the NAG results, and it is likely that the total S value includes non acid generating S forms, and hence the NAPP value may overestimate the acid generating potential.

Two samples plot in the bottom left hand uncertain domain, with slightly acidic NAGpH values of 3.4 and 4.1 and NAPP values of 0 and -6 kg H<sub>2</sub>SO<sub>4</sub>/t. The uncertainty may be due to either organic acid effects on the NAG test causing overestimation of acid potential, or poorly available ANC causing underestimation of the NAPP result. Follow up testing was carried out to resolve these uncertainties.

In addition to the above uncertain samples, the low NAGpH values for carbonaceous samples plotting in the PAF domain needs to be checked with further testing to determine whether organic acids have affected the NAG results.

## 5.0 Specialised Geochemical Characterisation Results

### 5.1 Extended Boil and Calculated NAG Results

Samples with high organic carbon contents (such as coal and carbonaceous sedimentary materials) can cause interference with standard NAG tests due to partial oxidation of carbonaceous materials. This can lead to low NAGpH values and high acidities in standard single addition NAG tests unrelated to acid generation from sulphides. Hence standard NAGpH values of  $\geq 4.5$  are an indication that samples are non acid forming (NAF), but NAGpH values less than 4.5 for carbonaceous samples may be inconclusive in isolation due to potential organic acid effects.

Extended boil and calculated NAG testing was carried out on 10 selected samples to check for effects of organic acids on the NAG test and help resolve uncertainties described in the previous section. Results are presented in Table 2.

Extended boil NAGpH values were less than 4.5 for six samples, confirming these samples are likely to be PAF. Note that the extended boil NAGpH value can be used to confirm samples are PAF, but does not necessarily mean that samples with a pH greater than 4.5 are 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 less than or equal to 0 kg H<sub>2</sub>SO<sub>4</sub>/t indicates the

sample is likely to be NAF, and a value of more than 0 kg H<sub>2</sub>SO<sub>4</sub>/t indicates the sample may be PAF.

The calculated NAG values for all 10 samples are positive, indicating that these samples are likely to be acid producing. This includes two uncertain samples (37664 and 37660) with NAPP values of less than or equal to 0 kg H<sub>2</sub>SO<sub>4</sub>/t, indicating the total ANC may overestimate the effective acid buffering.

Note also that the calculate NAG value is significantly less than the NAPP value for three samples (37641, 37662 and 37646), which indicates that a portion of the S measured in these samples is likely to be in non acid generating forms.

Calculated NAG test results are consistent with NAPP and NAGpH results for samples plotting in the PAF domain, although it appears the NAPP value may overestimate the acid potential in some samples due to the presence of non acid generating S forms. Results also show that the two samples plotting in the lower left uncertain domain are likely to be PAF, consistent with NAGpH results, but only have a low capacity to generate acid.

## 5.2 Acid Buffering Characteristic Curve (ABCC) Testing

Acid buffering characteristic curve (ABCC) testing was carried out on 19 selected samples to evaluate the availability of the ANC measured. The ABCC test involves slow titration of a sample with acid while measuring the solution pH. The acid buffering of a sample to pH 4 can be used as an estimate of the proportion of readily available ANC. Results are presented in Figures 9 to 15, with calcite, dolomite, ferroan dolomite and siderite standard curves as 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.

The ABCC profiles for samples 37688 (Figure 15) and 37689 (Figure 13) were the only samples showing strong buffering similar to dolomite, with the results indicating 70% to 85% of the ANC was readily available.

Other samples show profiles indicating a ferroan carbonate portion, with profiles plotting between dolomite and ferroan dolomite standard curves to siderite standard curves. Although the total ANC values ranged from 4 to 61 kg H<sub>2</sub>SO<sub>4</sub>/t, ABCC testing indicates the readily available portion is much lower ranging from 5 to 14 kg H<sub>2</sub>SO<sub>4</sub>/t.

ABCC results suggest that the acid buffering minerals within the samples tested are partly sideritic and poorly reactive overall, with ANC values generally overestimating the effective ANC. This is consistent with the common observation of siderite in the core by site geologists.

### 5.3 Kinetic NAG Testing

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 11 selected samples with S values greater than 0.7%S. Results are presented in Figures 16 to 26.

All samples show distinct temperature peaks of greater than 80°C in the kinetic NAG profile, typical of samples with pyritic S greater than 0.7%S. The pH profiles for all samples show a rapid decrease, reaching pH 4 in less than 5 minutes, indicating lag times of days to a few weeks before onset of acid conditions after exposure to atmospheric oxidation.

Results confirm the pyritic nature of the higher S samples, and indicate a rapid generation of ARD under atmospheric oxidation conditions for PAF materials represented by these samples.

### 5.4 Sulphur Speciation

Sulphur speciation testing was carried out on 17 selected samples as a guide to the proportion of the total S present in acid generating forms. Results are shown in Table 3. Note that the pyritic S value should only be treated as a guide to the pyrite content in the sample due to issues with repeatability in the chromium reducible sulphur (CRS) method<sup>1</sup>.

The CRS values confirm the presence of significant acid generating S (mainly pyritic S with minor contribution of acid sulphate S) in most of the samples, with the estimated proportion of acid generating S ranging from 25% to 80% of the total S. The remainder occurs in the form of non-acid sulphate and low risk S forms such as organic S.

Results confirm the presence of pyrite in these samples but also indicate that MPA values may overestimate the acid potential due to the presence of non-acid generating S forms. Conversely, ABCC testing (Section 5.2) indicates that the measured ANC may overestimate the effective ANC.

### 5.5 Multi-Element Analysis of Solids and Water Extracts

Results of multi-element scans of solids from 11 selected samples were compared to the median soil abundance (from Bowen, 1979<sup>2</sup>) to highlight enriched elements. The extent of enrichment is reported as the Geochemical Abundance Index (GAI), which relates the actual concentration with an average or median 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, median soil abundance; and a GAI of 6 indicates approximately a 100-fold enrichment above median soil abundance. As a general rule, a GAI of 3 or greater signifies enrichment that warrants further examination.

---

<sup>1</sup> 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. [www.acarp.com.au](http://www.acarp.com.au).

<sup>2</sup> Bowen, H.J.M. (1979) *Environmental Chemistry of the Elements*. Academic Press, New York, p 36-37.

Results of multi-element analysis of solids are presented in Table 4, and the corresponding GAI values are presented in Table 5. Results show that in addition to S (which was discussed earlier in relation to acid forming potential), slight enrichment of Be is indicated for a number of samples, and individual samples show enrichment of As, Tl and W compared to natural soils. Enrichment of Be and Tl is common for coals and carbonaceous samples, and the recorded values are within normal ranges for these materials. Although W is elevated, it is within normal ranges for soils and is unlikely to be of environmental significance. The As enrichment shows some correlation with S, and it is likely to be due to small amounts arsenopyrite associated with the pyrite.

Ten of the above sample solids were subjected to water extraction at a solids:liquor ratio of 1:2 and results are shown in Table 6.

A number of the samples have high S in the solid (shown in Table 6), and partial oxidation of pyrite in these samples was expected between sampling and testing, so that water extracts should provide a guide to metals and metalloids likely to be mobilised if ARD develops. Samples 37646, 37657, 37701 and 37708 have elevated S greater than 1%S and show slightly acidic pH values of less than 5. These extracts show elevated Al, Co, Fe and Zn, and slightly elevated Cu and Ni. Sulphate concentrations are also elevated, confirming the influence of pyrite oxidation on the water extracts.

A number of other samples have elevated Al and Fe concentrations at circum neutral pH associated with a generally higher Si concentration, which is most likely due to the presence of fine or colloidal particulates in the solution after filtering.

Results indicate that initial metal/metalloid release associated with any ARD generated from pyritic materials will include Al, Co, Cu, Fe, Ni, and Zn. The solubility of metals/metalloids will largely be determined by pH and therefore control of acid generation will effectively control metal leaching. Some slight enrichment in As was also indicated for pyritic materials.

## 6.0 Sample Classification and Distribution of ARD Rock Types

ARD classifications are provided in Table 1 based on results and discussions above. Classification of samples was carried out on the following basis:

### **Non Acid Forming (NAF)**

- Total S  $\leq$  0.05% (due to the negligible risk of acid formation from these samples); *or*
- NAPP  $\leq$  0 kg H<sub>2</sub>SO<sub>4</sub>/t and NAGpH  $\geq$  4.5.

### **Potentially Acid Forming (PAF)**

- NAPP  $>$  0 kg H<sub>2</sub>SO<sub>4</sub>/t and NAGpH  $<$  4.5; *or*
- Calculated NAG  $>$  0 kg H<sub>2</sub>SO<sub>4</sub>/t.

**Uncertain and expected to be NAF (UC(NAF))**

- NAPP > 0 kg H<sub>2</sub>SO<sub>4</sub>/t and NAGpH ≥ 4.5 (since NAG testing will generally account for pyritic S in these types of materials).

Figures 27 to 29 show down hole profiles of total S, ANC, NAGpH and NAPP values for each of the holes tested. Samples classified PAF are indicated on the NAPP profiles. The profiles for holes NMB-031 and NMB-038 show that total S is distinctly elevated in samples close to the coal seams, with PAF samples mainly associated with coal, roof and floor materials. Results suggest that overburden above the A1U Seam and below the Jubilee Seam will be mainly NAF, with NAF horizons likely to occur between many of the seam interburden. In particular, the NAF interburden below A2L and above A3U shows apparent continuity between holes NMB-031 and NMB-038.

Based on results to date, around 90% of the overburden tested was NAF, indicating a significant excess of NAF overburden, which will greatly assist materials management and is likely to provide flexibility in selective handling and placement of PAF material types for ARD control. However, additional sampling and testing is recommended prior to mining to better define the distribution and relative abundance of PAF rock types across the deposit for final design.

Approximately 75% of coal samples tested were PAF, indicating coal seams, immediate roof and floor horizons, and rejects and tailings are potential sources of ARD and will require specific management. The salinity and acidity in these samples noted in Section 4.1 is associated with PAF materials, and is related to partial oxidation of pyrite between sample collection and testing, supporting the rapid reaction rates indicated in kinetic NAG testing (Section 5.3).

## 7.0 Conclusions and Recommendations

Results of testing indicate that the bulk of the overburden and interburden represented by the samples tested is likely to be NAF, but that coal seams, seam roof, seam floor, rejects and tailings are likely to be mainly PAF. Results indicate a significant excess of NAF overburden, which will greatly assist materials management and is likely to provide flexibility in selective handling and placement of ARD material types.

Kinetic NAG testing indicates that PAF materials are likely to be fast reacting, producing acid within weeks of exposure to atmospheric oxidation conditions. Constituents associated with ARD are likely to include Al, Co, Cu, Fe, Ni, SO<sub>4</sub> and Zn. Some slight enrichment of As in PAF materials was also indicated.

Results have the following implications for mine materials management:

- Most of the overburden and interburden is expected to be NAF and will not require special handling for ARD control, and can be used to assist management of PAF materials.
- PAF horizons appear to be mainly associated with coal seams and immediate roof and floor.
- Washery waste materials are likely to be mainly PAF and special handling and management is likely to be required.
- Pit floor and wall materials may also be a source of ARD, and provision for capture of runoff/leachate, monitoring and lime treatment may be required.
- Possible management strategies for PAF washery waste and any PAF overburden/interburden materials include:
  - limestone treatment and interim compaction of PAF materials to increase lag times before onset of acid conditions to manage ARD during operations or until implementation of closure strategies;
  - placement of PAF materials below the water table to allow inundation and prevent further exposure to atmospheric oxidation; and
  - construction of a NAF cover zone designed to limit oxygen diffusion and infiltration into PAF materials (water and oxygen flux modelling will be required to determine the best approach under the local climatic conditions).
- ROM and product coal stockpiles may generate ARD depending on residence times and reaction rates, and again provision for capture of runoff/leachate, monitoring and lime treatment may be required.
- A programme of routine sampling and testing of washery wastes and overburden/interburden materials will be required during operations to monitor variation in acid potential and to reconcile the predicted distribution of ARD rock types in overburden.
- Water quality monitoring of seepage and runoff from pit walls and floors, waste rock dumps, ROM stockpiles and washery waste disposal areas should be carried out to check for ARD generation, assess the performance of management strategies, and determine and/or refine lime and limestone treatment requirements.
- Routine site water quality monitoring programmes should include pH, EC, acidity/alkalinity, SO<sub>4</sub>, Al, As, Co, Cu, Fe, Mn, Ni and Zn to monitor for effects of pyrite oxidation and ARD generation.

Testing completed to date at Colton indicates mine materials will be mainly NAF, and is sufficient to determine the main implications and approaches to manage waste materials. However, it is recommended that additional investigations be carried out prior to mining to confirm the distribution of ARD waste rock types and refine management strategies for PAF materials. These investigations should include the following:

- Geochemical characterisation of additional drill holes should be carried out to expand the ARD database and confirm the distribution of ARD rock types in overburden and interburden. This should include testing of the surface weathered zone and Tertiary sediments to confirm the expected benign nature of these materials.
- Overburden and interburden samples tested to date cover the stratigraphy from below the Jubilee Seam to the base of the AL3 Seam. ARD assessment of additional stratigraphy will be required if the proposed mine development includes materials from outside of the stratigraphic range tested.
- Testing of washery waste materials should be carried out once suitable materials become available.
- Leach column testing should be carried out on representative PAF floor, ROM coal, product coal, and washery wastes to determine lag times before onset of acid conditions, and short and long term ARD potential to refine disposal and long term management strategies.
- The possibility of disposing PAF materials below the water table should be investigated, as this is likely to represent the most secure long term ARD control option. Considerations include the likely duration of exposure and the reaction kinetics of PAF materials, and the sensitivity of the water table to any ARD generated during operations and before inundation (inundation will mobilise any accumulated ARD products and could potentially result in lateral contamination of the water table).
- Conceptual level (desk top) modelling of water and oxygen flux in dumped materials should be carried out to determine a minimum cover requirement for long term control of ARD from PAF overburden. This would provide a basis for comparison of the cover option with other management strategies such as disposal below the water table.

Table 1: Acid forming characteristics.

Hole Name	Depth (m)			Lithology	Seam	Material Type	Weathering	Comments	Maryborough Sample Number	EGi Sample Number	pH <sub>1-2</sub>	EC <sub>1-2</sub>	ACID-BASE ANALYSIS				SINGLE ADDITION NAG			ARD Classification		
	From	To	Interval										Total %S	MPA	ANC	NAPP	ANC/MPA	NAGpH	NAG <sub>(pH4.5)</sub>		NAG <sub>(pH7.0)</sub>	
NMB-031	0.00	2.00	2.00	Sand		Overburden																
NMB-031	2.00	12.00	10.00	Clay		Overburden																
NMB-031	12.00	14.60	2.60	Sandstone		Overburden	W															
NMB-031	14.60	14.68	0.08	Core Loss		Overburden																
NMB-031	14.68	15.84	1.16	Sandstone/Siltstone		Overburden	P		P214598	37667	7.9	0.22	0.03	1	20	-19	21.79	7.6	0	0	NAF	
NMB-031	15.84	17.67	1.83	Sandstone		Overburden	W	base of weathering 17.67m	P214599	37668	8.2	0.23	<0.01	0	19	-19	124.18	7.4	0	0	NAF	
NMB-031	17.67	17.94	0.27	Sandstone		Overburden	F															
NMB-031	17.94	19.77	1.83	Sandstone		Overburden	F	siderite	P214600	37669	7.6	0.24	0.06	2	16	-14	8.71	7.5	0	0	NAF	
NMB-031	19.77	20.11	0.34	Sandstone		Overburden	F	siderite														
NMB-031	20.11	20.34	0.23	Sandstone		Overburden	F		P214701	37636	7.6	0.22	0.14	4	22	-18	5.14	7.9	0	0	NAF	
NMB-031	20.34	20.58	0.24	Sandstone		Overburden	F															
NMB-031	20.58	22.93	2.35	Sandstone		Overburden	F	siderite, mudstone at base	P214702	37637	8.2	0.33	0.11	3	20	-17	5.94	7.6	0	0	NAF	
NMB-031	22.93	23.23	0.30	Sandstone/Mudstone		Overburden	F															
NMB-031	23.23	24.03	0.80	Sandstone		Overburden	F	calcite	P214703	37638	7.5	0.34	0.07	2	32	-30	14.94	7.7	0	0	NAF	
NMB-031	24.03	24.24	0.21	Mudstone		Overburden	F															
NMB-031	24.24	25.06	0.82	Sandstone/Mudstone		Overburden	F		P214704	37639	7.4	0.42	0.12	4	7	-3	1.91	6.0	0	1	NAF	
NMB-031	25.06	25.32	0.26	Mudstone		Overburden	F															
NMB-031	25.32	25.63	0.31	Mudstone		Overburden	F	minor coal	P214705	37640	4.6	1.24	2.56	78	0	78	0.00	2.3	46	53	PAF	
NMB-031	25.63	26.03	0.40	Coal	A1U	Coal	F															
NMB-031	26.03	26.34	0.31	Carb Mudstone	A1U	Coal	F															
NMB-031	26.34	26.56	0.22	Coal	A1U	Coal																
NMB-031	26.56	26.57	0.01	Core Loss	A1U	Coal																
NMB-031	26.57	27.50	0.93	Core Loss/Siltstone/Mudstone		Coal	F	core loss interval 0.78m														
NMB-031	27.50	27.99	0.49	Coal	A1L	Coal																
NMB-031	27.99	28.43	0.44	Carb Mudstone		Overburden	F		P214706	37641	5.5	1.02	0.58	18	4	14	0.23	3.2	3	6	PAF	
NMB-031	28.43	29.51	1.08	Siltstone		Overburden	F	claystone at base	P214707	37642	6.7	0.23	0.60	18	13	5	0.71	3.5	2	5	PAF	
NMB-031	29.51	29.90	0.39	Claystone		Overburden	F															
NMB-031	29.90	30.59	0.69	Claystone		Overburden	F		P214708	37643	7.2	0.33	0.10	3	16	-13	5.23	7.1	0	0	NAF	
NMB-031	30.59	30.84	0.25	Sandstone		Overburden	F		P214709	37644	8.0	0.53	0.30	9	6	3	0.65	3.2	3	5	PAF	
NMB-031	30.84	31.39	0.55	Carb Mudstone/Coal	A2U	Coal	F		P214727	37662	5.6	1.04	0.65	20	6	14	0.30	2.7	19	37	PAF	
NMB-031	31.39	31.77	0.38	Claystone/Siltstone/Coal		Coal	F															
NMB-031	31.77	31.87	0.10	Siltstone		Coal	F		P214710	37645	6.8	0.62	0.25	7	3	4	0.40	3.9	1	4	PAF	
NMB-031	31.87	32.23	0.36	Siltstone/Mudstone		Coal	F															
NMB-031	32.23	32.35	0.12	Mudstone		Coal	F		P214711	37646	4.5	1.36	1.17	36	3	33	0.08	2.7	12	22	PAF	
NMB-031	32.35	32.57	0.22	Coal	A2L	Coal																
NMB-031	32.57	33.46	0.89	Siltstone/Carb Mudstone		Overburden	F		P214712	37647	6.8	0.23	0.46	14	10	4	0.71	4.6	0	5	UC(NAF)	
NMB-031	33.46	33.49	0.03	Core Loss		Overburden																
NMB-031	33.49	35.03	1.54	Mudstone/Carb Mudstone/Coal		Overburden			P214713	37648	7.5	0.23	0.11	3	14	-11	4.16	6.9	0	0	NAF	
NMB-031	35.03	35.33	0.30	Mudstone		Overburden																
NMB-031	35.33	35.86	0.53	Mudstone		Overburden			P214714	37649	8.3	0.31	0.09	3	20	-17	7.26	6.9	0	0	NAF	
NMB-031	35.86	36.14	0.28	Mudstone		Overburden																
NMB-031	36.14	37.95	1.81	Siltstone/Mudstone		Overburden			P214715	37650	7.6	0.33	0.32	10	18	-8	1.84	6.9	0	0	NAF	
NMB-031	37.95	38.18	0.23	Mudstone		Overburden																
NMB-031	38.18	38.48	0.30	Mudstone		Overburden																
NMB-031	38.48	39.66	1.18	Mudstone		Overburden			P214716	37651	8.1	0.34	0.14	4	15	-11	3.50	7.1	0	0	NAF	
NMB-031	39.66	40.01	0.35	Mudstone		Overburden																
NMB-031	40.01	40.10	0.09	Mudstone		Overburden			P214717	37652	7.9	0.53	0.40	12	6	6	0.49	3.5	2	7	PAF	
NMB-031	40.10	40.28	0.18	Coal	A3U	Coal																
NMB-031	40.28	40.71	0.43	Carb Mudstone/Clay	A3U	Coal																
NMB-031	40.71	40.91	0.20	Coal	A3U	Coal																
NMB-031	40.91	41.26	0.35	Carb Mudstone		Coal																
NMB-031	41.26	41.84	0.58	Coal	A3U	Coal																
NMB-031	41.84	42.18	0.34	Carb Mudstone		Overburden																
NMB-031	42.18	42.48	0.30	Carb Mudstone		Overburden																
NMB-031	42.48	42.81	0.33	Mudstone		Overburden		siderite														
NMB-031	42.81	43.37	0.56	Mudstone		Overburden		siderite	P214718	37653	7.8	0.48	0.15	5	15	-10	3.27	6.9	0	0	NAF	
NMB-031	43.37	43.73	0.36	Mudstone		Overburden																
NMB-031	43.73	44.03	0.30	Mudstone		Overburden																



Table 1: Acid forming characteristics.

Hole Name	Depth (m)			Lithology	Seam	Material Type	Weathering	Comments	Maryborough Sample Number	EGi Sample Number	pH <sub>1,2</sub>	EC <sub>1,2</sub>	ACID-BASE ANALYSIS				SINGLE ADDITION NAG			ARD Classification		
	From	To	Interval										Total %S	MPA	ANC	NAPP	ANC/MPA	NAGpH	NAG <sub>(pH4.5)</sub>		NAG <sub>(pH7.0)</sub>	
NMB-038	0.00	1.00	1.00	Sand		Overburden																
NMB-038	1.00	2.00	1.00	Clay		Overburden																
NMB-038	2.00	5.80	3.80	Clay		Overburden																
NMB-038	5.80	8.80	3.00	Sandstone		Overburden		siderite	P214548	37692	7.5	0.23	<0.01	0	9	-9	58.82	6.3	0	9	NAF	
NMB-038	8.80	9.30	0.50	Core Loss		Overburden																
NMB-038	9.30	9.97	0.67	Clay		Overburden			P214549	37693	8.0	0.31	0.04	1	8	-7	6.54	5.9	0	18	NAF	
NMB-038	9.97	13.75	3.78	Sandstone		Overburden			P214550	37694	7.8	0.43	<0.01	0	12	-12	78.43	7.4	0	0	NAF	
NMB-038	13.75	15.20	1.45	Core Loss		Overburden																
NMB-038	15.20	16.94	1.74	Sandstone		Overburden	W	siderite, base of weathering	P214551	37695	8.4	0.42	0.01	0	12	-12	39.22	5.6	0	11	NAF	
NMB-038	16.94	18.30	1.36	Sandstone		Overburden	F		P214552	37696	7.7	0.63	0.05	2	22	-20	14.38	7.3	0	0	NAF	
NMB-038	18.30	19.01	0.71	Mudstone		Overburden			P214553	37697	7.6	0.54	0.07	2	15	-13	7.00	7.5	0	0	NAF	
NMB-038	19.01	21.30	2.29	Sandstone		Overburden		siderite	P214554	37698	8.3	0.62	0.05	2	26	-24	16.99	7.6	0	0	NAF	
NMB-038	21.30	24.05	2.75	Core Loss		Overburden																
NMB-038	24.05	24.30	0.25	Sandstone		Overburden			P214555	37699	7.5	0.20	0.05	2	24	-22	15.69	7.8	0	0	NAF	
NMB-038	24.30	24.42	0.12	Core Loss		Overburden																
NMB-038	24.42	24.58	0.16	Sandstone		Overburden			P214556	37700	7.6	0.24	0.11	3	11	-8	3.27	5.3	0	1	NAF	
NMB-038	24.58	24.98	0.40	Carb Mudstone/Coal	A1U	Coal			P214557	37701	4.4	1.79	3.39	104	0	104	0.00	2.2	58	66	PAF	
NMB-038	24.98	25.72	0.74	Coal	A1U	Coal																
NMB-038	25.72	26.04	0.32	Carb Mudstone	A1U	Coal			P214558	37702	4.6	1.91	1.17	36	5	31	0.14	2.5	19	25	PAF	
NMB-038	26.04	26.20	0.16	Core Loss	A1U	Coal																
NMB-038	26.20	26.38	0.18	Coal	A1U	Coal																
NMB-038	26.38	27.39	1.01	Core Loss		Coal																
NMB-038	27.39	28.24	0.85	Siltstone		Coal		sandy laminations throughout	P214559	37703	5.5	1.14	0.87	27	11	16	0.41	2.8	9	15	PAF	
NMB-038	28.24	28.49	0.25	Coal	A1L	Coal																
NMB-038	28.49	29.92	1.43	Mudstone/Carb Mudstone		Overburden			P214560	37704	7.3	0.51	0.10	3	15	-12	4.90	6.9	0	0	NAF	
NMB-038	29.92	32.92	3.00	Siltstone		Overburden			P214561	37705	8.2	0.36	0.08	2	15	-13	6.54	7.2	0	0	NAF	
NMB-038	32.92	34.30	1.38	Mudstone/Coal	A2U	Overburden			P214562	37706	7.9	0.43	0.09	3	33	-30	11.98	7.4	0	0	NAF	
NMB-038	34.30	35.61	1.31	Carb Mudstone/Coal	A2U	Coal			P214563	37707	7.6	0.24	0.30	9	9	0	0.98	4.5	0	3	NAF	
NMB-038	35.61	36.65	1.04	Core Loss		Overburden																
NMB-038	36.65	38.16	1.51	Carb Mudstone		Overburden			P214564	37708	4.3	1.28	1.17	36	6	30	0.17	2.8	9	17	PAF	
NMB-038	38.16	38.81	0.65	Carb Mudstone/Coal	A2L	Coal			P214732	37718	4.4	1.36	2.25	69	0	69	0.00	2.3	31	42	PAF	
NMB-038	38.81	39.21	0.40	Core Loss	A2L	Coal																
NMB-038	39.21	40.89	1.68	Carb Mudstone/Siderite		Overburden		siderite	P214565	37709	6.7	0.18	0.51	16	23	-7	1.47	5.1	0	4	NAF	
NMB-038	40.89	42.07	1.18	Mudstone		Overburden			P214566	37710	7.4	0.33	0.22	7	19	-12	2.82	7.1	0	0	NAF	
NMB-038	42.07	42.17	0.10	Core Loss		Overburden																
NMB-038	42.17	43.48	1.31	Carb Mudstone		Overburden			P214567	37711	7.5	0.33	0.22	7	8	-1	1.19	6.4	0	0	NAF	
NMB-038	43.48	45.27	1.79	Mudstone/Siltstone/Carb Mudstone		Overburden		siderite	P214568	37712	7.7	0.41	0.23	7	15	-8	2.13	6.9	0	0	NAF	
NMB-038	45.27	45.32	0.05	Core Loss		Overburden																
NMB-038	45.32	45.96	0.64	Mudstone/Carb Mudstone		Overburden			P214569	37713	6.5	0.28	0.63	19	6	13	0.31	4.8	0	8	UC(NAF)	
NMB-038	45.96	46.10	0.14	Coal	A3U	Coal																
NMB-038	46.10	47.24	1.14	Carb Mudstone	A3U	Coal			P214570	37714	4.5	1.88	1.30	40	4	36	0.10	2.5	22	32	PAF	
NMB-038	47.24	47.37	0.13	Coal	A3U	Coal																
NMB-038	47.37	47.76	0.39	Carb Mudstone		Coal			P214571	37715	5.8	1.06	0.89	27	6	21	0.22	2.8	7	14	PAF	
NMB-038	47.76	48.21	0.45	Coal	A3L	Coal																
NMB-038	48.21	49.28	1.07	Core Loss	A3L	Coal																
NMB-038	49.28	49.90	0.62	Mudstone/Coal	A3L	Coal																
NMB-038	49.90	51.81	1.91	Mudstone		Overburden			P214572	37716	5.9	1.02	0.78	24	10	14	0.42	2.9	6	11	PAF	
NMB-038	51.81	52.68	0.87	Sandstone		Overburden			P214573	37717	6.8	0.72	0.42	13	17	-4	1.32	6.9	0	0	NAF	

**KEY**

pH<sub>1,2</sub> = pH of 1:2 extract  
 EC<sub>1,2</sub> = Electrical Conductivity of 1:2 extract (dS/m)  
 MPA = Maximum Potential Acidity (kgH<sub>2</sub>SO<sub>4</sub>/t)  
 ANC = Acid Neutralising Capacity (kgH<sub>2</sub>SO<sub>4</sub>/t)  
 NAPP = Net Acid Producing Potential (kgH<sub>2</sub>SO<sub>4</sub>/t)

NAGpH = pH of NAG liquor  
 NAG<sub>(pH4.5)</sub> = Net Acid Generation capacity to pH 4.5 (kgH<sub>2</sub>SO<sub>4</sub>/t)  
 NAG<sub>(pH7.0)</sub> = Net Acid Generation capacity to pH 7.0 (kgH<sub>2</sub>SO<sub>4</sub>/t)

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

Coal seam interval

Overburden intervals from open hole and core (including loss core) not available for sampling

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

Maryborough Sample Number	EGi Sample Number	Lithology	ACID-BASE ANALYSIS					STANDARD NAG TEST			Extended Boil NAGpH	Calculated NAG
			Total %S	MPA	ANC	NAPP	ANC/MPA	NAGpH	NAG <sub>(pH4.5)</sub>	NAG <sub>(pH7.0)</sub>		
P214706	37641	Carb Mudstone	0.58	18	4	14	0.23	3.2	3	6	4.5	5
P214727	37662	Carb Mudstone/Coal	0.65	20	6	14	0.30	2.7	19	37	6.9	1
P214711	37646	Mudstone	1.17	36	3	33	0.08	2.7	12	22	3.9	15
P214717	37652	Mudstone	0.40	12	6	6	0.49	3.5	2	7	6.9	2
P214729	37664	Mudstone/Carb Mudstone/Coal	0.39	12	12	0	1.01	3.4	3	9	6.2	4
P214725	37660	Carb Mudstone/Mudstone	0.37	11	17	-6	1.50	4.1	1	7	6.9	1
P214559	37703	Siltstone	0.87	27	11	16	0.41	2.8	9	15	3.7	18
P214564	37708	Carb Mudstone	1.17	36	6	30	0.17	2.8	9	17	3.5	29
P214571	37715	Carb Mudstone	0.89	27	6	21	0.22	2.8	7	14	4.1	16
P214572	37716	Mudstone	0.78	24	10	14	0.42	2.9	6	11	4.0	10

**KEY**

MPA = Maximum Potential Acidity (kgH<sub>2</sub>SO<sub>4</sub>/t)

ANC = Acid Neutralising Capacity (kgH<sub>2</sub>SO<sub>4</sub>/t)

NAPP = Net Acid Producing Potential (kgH<sub>2</sub>SO<sub>4</sub>/t)

NAGpH = pH of NAG liquor

NAG<sub>(pH4.5)</sub> = Net Acid Generation capacity to pH 4.5 (kgH<sub>2</sub>SO<sub>4</sub>/t)

NAG<sub>(pH7.0)</sub> = Net Acid Generation capacity to pH 7.0 (kgH<sub>2</sub>SO<sub>4</sub>/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 (kgH<sub>2</sub>SO<sub>4</sub>/t)

Table 3: Sulphur speciation results for selected samples.

Hole Name	Depth (m)			Lithology	Seam	EGi Sample No	Total %S	Pyritic S (%)	Acid Sulphate S (%)	Acid Generating S (%)	Non-Acid Sulphate S (%)	Low Risk S Forms (%)
	From	To	Interval									
NMB-031	27.99	28.43	0.44	Carb Mudstone		37641	0.58	0.31	0.00	0.31	0.04	0.23
NMB-031	30.84	31.39	0.55	Carb Mudstone/Coal	A3L	37662	0.65	0.17	0.00	0.17	0.02	0.46
NMB-031	32.23	32.35	0.12	Mudstone		37646	1.17	0.36	0.01	0.37	0.10	0.70
NMB-031	32.57	33.46	0.89	Siltstone/Carb Mudstone		37647	0.46	0.16	0.00	0.16	0.00	0.30
NMB-031	52.11	53.19	1.08	Mudstone/Carb Mudstone/Coal		37664	0.39	0.28	0.00	0.28	0.05	0.06
NMB-031	53.28	53.57	0.29	Carb Mudstone/Mudstone		37660	0.37	0.24	0.00	0.24	0.03	0.10
NMB-037	14.70	15.43	0.73	Carb Mudstone/Coal	UNC	37665	0.66	0.44	0.00	0.44	0.00	0.22
NMB-038	24.58	24.98	0.40	Carb Mudstone/Coal	AA1	37701	3.39	1.41	0.08	1.49	0.25	1.65
NMB-038	25.72	26.04	0.32	Carb Mudstone	AA1	37702	1.17	0.89	0.02	0.91	0.11	0.15
NMB-038	27.39	28.24	0.85	Siltstone		37703	0.87	0.71	0.00	0.71	0.04	0.12
NMB-038	34.30	35.61	1.31	Carb Mudstone	A2L	37707	0.30	0.18	0.00	0.18	0.06	0.06
NMB-038	36.65	38.16	1.51	Carb Mudstone		37708	1.17	0.38	0.02	0.40	0.17	0.60
NMB-038	38.16	38.81	0.65	Carb Mudstone/Coal	AA3	37718	2.25	0.67	0.05	0.72	0.19	1.34
NMB-038	39.21	40.89	1.68	Carb Mudstone/Siderite		37709	0.51	0.36	0.00	0.36	0.10	0.05
NMB-038	45.32	45.96	0.64	Mudstone/Carb Mudstone		37713	0.63	0.37	0.00	0.37	0.06	0.20
NMB-038	47.37	47.76	0.39	Carb Mudstone	BB1	37715	0.89	0.50	0.06	0.56	0.16	0.17
NMB-038	49.90	51.81	1.91	Mudstone		37716	0.78	0.55	0.01	0.56	0.19	0.04

Pyritic S (%) = CRS (%)

Acid Sulphate S = KCl Acid Sulphate S

Acid Generating S = Pyritic S + Acid Sulphate S

Non-Acid Sulphate S = KCl S – KCl Acid Sulphate S

Low Risk S Forms = Total S - (CRS + KCl S)

Table 4: Multi-element composition of selected sample solids (mg/kg except where shown).

Element	Detection Limit	Sample No./Lithology										
		37638 Sandstone	37641 Carb Mudstone/ Coal	37646 Mudstone	37647 Siltstone	37657 Carb Mudstone/ Coal	37689 Siltstone	37696 Sandstone	37697 Mudstone	37701 Carb Mudstone/ Coal	37708 Carb Mudstone/ Coal	37716 Mudstone
Ag	0.02	0.23	0.09	0.11	0.10	0.06	0.09	0.09	0.12	0.08	0.09	0.10
Al	0.01%	7.16%	8.83%	8.64%	8.99%	6.23%	8.07%	7.71%	7.48%	7.03%	8.36%	8.52%
As	0.2	5	12	17	20	63	6	8	7	74	28	17
Ba	10	110	180	150	160	120	150	160	160	150	130	1850
Be	0.05	2.0	2.3	2.2	2.1	1.6	1.7	1.8	1.6	2.4	3.0	2.4
Bi	0.01	0.13	0.34	0.43	0.31	0.35	0.27	0.22	0.24	0.32	0.32	0.40
Ca	0.01%	0.59%	0.06%	0.07%	0.18%	0.05%	0.81%	0.30%	0.28%	0.10%	0.11%	0.20%
Cd	0.02	0.09	0.09	0.16	0.12	0.10	0.07	0.13	0.09	0.08	0.11	0.09
Co	0.1	10.3	13.0	16.2	10.7	11.1	12.6	18.9	14.0	24.1	11.8	18.8
Cr	1	17	34	23	28	16	24	19	22	27	28	28
Cu	0.2	54.4	29.4	34.9	37.4	21.1	36.2	23.2	24.6	29.9	28.9	27.8
Fe	0.01%	13.15%	1.18%	1.61%	2.24%	1.70%	4.13%	5.38%	4.62%	3.35%	2.15%	3.48%
Ga	10	10	20	20	20	10	20	20	20	20	20	20
Hg	0.01	0.024	0.063	0.080	0.047	0.200	0.024	0.023	0.027	0.332	0.078	0.071
K	0.002%	1.05%	1.68%	1.34%	1.36%	0.98%	1.48%	1.38%	1.33%	1.32%	1.21%	1.32%
La	10	20	20	20	20	20	20	20	20	20	20	20
Mg	0.002%	0.73%	0.44%	0.47%	0.51%	0.30%	0.71%	0.69%	0.60%	0.35%	0.42%	0.52%
Mn	1.0	3510	38	27	294	26	763	1715	1355	57	161	726
Mo	0.1	1.0	0.7	0.6	2.0	1.6	1.5	1.1	1.4	1.7	1.3	1.1
Na	0.002%	1.06%	0.20%	0.20%	0.31%	0.12%	1.35%	1.14%	1.03%	0.56%	0.61%	0.33%
Ni	1.0	7.4	11.9	11.4	11.0	9.8	11.2	11.4	10.8	18.0	13.1	15.6
P	20	780	170	190	520	170	610	580	560	270	350	530
Pb	2.0	13.2	15.4	24.2	18.1	17.9	16.7	15.7	17.3	19.7	18.6	20.9
S	0.001%	0.07%	0.58%	1.17%	0.46%	2.08%	0.06%	0.05%	0.07%	3.39%	1.17%	0.78%
Sb	0.05	0.17	0.2	0.35	0.27	0.32	0.24	0.26	0.24	0.37	0.25	0.26
Sc	1	14	19	18	17	14	18	16	16	14	18	19
Se	0.01	1.4	1.6	1.7	1.8	1.6	1.6	1.7	1.6	1.6	1.7	1.9
Sn	0.1	4.7	2.9	3.3	3.0	2.4	2.4	2.3	2.2	2.3	2.5	2.5
Sr	0.05	93	97	109	127	103	149	108	114	98	156	151
Th	0.2	6.1	9.5	9.7	8.9	7	7.8	7.4	7.2	6.9	8.5	9.3
Ti	0.01%	0.32%	0.53%	0.53%	0.53%	0.35%	0.51%	0.45%	0.45%	0.43%	0.52%	0.53%
Tl	0.02	0.17	0.28	0.23	0.26	0.35	0.29	0.25	0.25	1.7	0.25	0.35
U	0.01	1.7	2.3	2.3	2.2	1.5	1.9	2.1	2.0	2.0	2.1	2.3
V	2.0	80	150	124	115	86	116	96	98	109	108	133
W	0.1	22	2	11	6	4	4	4	4	2	1	2
Zn	1.0	90	98	95	89	58	103	98	96	54	100	98

< element at or below analytical detection limit.

Table 5: Geochemical abundance indices (GAI) of selected sample solids.

Element	Median Soil Abundance*	Sample No./Lithology										
		37638 Sandstone	37641 Carb Mudstone/ Coal	37646 Mudstone	37647 Siltstone	37657 Carb Mudstone/ Coal	37689 Siltstone	37696 Sandstone	37697 Mudstone	37701 Carb Mudstone/ Coal	37708 Carb Mudstone/ Coal	37716 Mudstone
Ag	0.05	2	-	1	-	-	-	-	1	-	-	-
Al	7.1%	-	-	-	-	-	-	-	-	-	-	-
As	6	-	-	1	1	3	-	-	-	3	2	1
Ba	500	-	-	-	-	-	-	-	-	-	-	1
Be	0.3	2	2	2	2	2	2	2	2	2	3	2
Bi	0.2	-	-	1	-	-	-	-	-	-	-	-
Ca	1.5%	-	-	-	-	-	-	-	-	-	-	-
Cd	0.35	-	-	-	-	-	-	-	-	-	-	-
Co	8	-	-	-	-	-	-	1	-	1	-	1
Cr	70	-	-	-	-	-	-	-	-	-	-	-
Cu	30	-	-	-	-	-	-	-	-	-	-	-
Fe	4.0%	1	-	-	-	-	-	-	-	-	-	-
Ga	20	-	-	-	-	-	-	-	-	-	-	-
Hg	0.06	-	-	-	-	1	-	-	-	2	-	-
K	1.4%	-	-	-	-	-	-	-	-	-	-	-
La	40	-	-	-	-	-	-	-	-	-	-	-
Mg	0.5%	-	-	-	-	-	-	-	-	-	-	-
Mn	1000	1	-	-	-	-	-	-	-	-	-	-
Mo	1.2	-	-	-	-	-	-	-	-	-	-	-
Na	0.5%	-	-	-	-	-	1	1	-	-	-	-
Ni	50	-	-	-	-	-	-	-	-	-	-	-
P	800	-	-	-	-	-	-	-	-	-	-	-
Pb	35	-	-	-	-	-	-	-	-	-	-	-
S	0.07%	-	2	3	2	4	-	-	-	5	3	3
Sb	1	-	-	-	-	-	-	-	-	-	-	-
Sc	7	-	1	1	1	-	1	1	1	-	1	1
Se	0.4	1	1	2	2	1	1	2	1	1	2	2
Sn	4	-	-	-	-	-	-	-	-	-	-	-
Sr	250	-	-	-	-	-	-	-	-	-	-	-
Th	9	-	-	-	-	-	-	-	-	-	-	-
Ti	0.50%	-	-	-	-	-	-	-	-	-	-	-
Tl	0.2	-	-	-	-	-	-	-	-	3	-	-
U	2	-	-	-	-	-	-	-	-	-	-	-
V	90	-	-	-	-	-	-	-	-	-	-	-
W	1.5	3	-	2	2	1	1	1	1	-	-	-
Zn	90	-	-	-	-	-	-	-	-	-	-	-

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

Table 6: Chemical composition of water extracts of selected samples.

Parameter	Detection Limit	Sample No./Lithology/%S in Solid										
		37638 Sandstone 0.07%S	37641 Carb Mudstone/ Coal 0.58%S	37646 Mudstone 1.17%S	37647 Siltstone 0.46%S	37657 Carb Mudstone/ Coal 2.08%S	37689 Siltstone 0.06%S	37696 Sandstone 0.05%S	37701 Carb Mudstone/ Coal 3.39%S	37708 Carb Mudstone/ Coal 1.17%S	37716 Mudstone 0.78%S	
pH	0.01	7.4	5.4	4.6	7.1	4.5	8.3	7.9	4.4	4.4	5.7	
EC	dS/m	0.01	0.34	1.06	1.41	0.24	1.85	0.28	0.12	1.76	1.24	1.04
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
Al	mg/l	0.01	3.46	0.26	0.66	0.78	4.93	4.28	4.76	8.46	0.57	0.20
As	mg/l	0.001	0.003	0.003	0.006	0.002	0.047	0.008	0.008	0.021	0.003	<0.001
B	mg/l	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ba	mg/l	0.001	0.016	0.011	0.006	0.004	0.007	0.012	0.014	0.005	0.004	0.011
Be	mg/l	0.001	0.001	0.006	0.010	<0.001	0.020	<0.001	<0.001	0.059	0.014	<0.001
Ca	mg/l	1	4	8	14	2	29	5	4	26	13	11
Cd	mg/l	0.0001	<0.0001	0.0006	0.0010	<0.0001	0.0036	<0.0001	0.0001	0.0026	0.0007	0.0005
Cl	mg/l	1	47	79	69	76	39	64	44	40	44	70
Co	mg/l	0.001	0.01	0.15	0.22	0.00	0.61	0.02	0.04	1.73	0.14	0.11
Cr	mg/l	0.001	0.001	<0.001	<0.001	<0.001	0.003	0.002	0.002	0.007	<0.001	<0.001
Cu	mg/l	0.001	0.01	0.05	0.05	0.01	0.26	0.01	0.02	0.12	0.04	0.01
F	mg/l	0.1	1.4	0.2	0.4	1.0	0.9	1.3	1.5	1.1	0.4	0.1
Fe	mg/l	0.05	22.0	0.9	3.4	2.0	39.2	11.5	15.8	47.8	2.7	0.8
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
K	mg/l	1	4	4	3	3	3	3	3	2	1	4
Mg	mg/l	1	5	20	31	3	80	6	6	95	26	21
Mn	mg/l	0.001	0.6	0.1	0.1	0.1	0.7	0.3	0.7	1.1	1.1	1.2
Mo	mg/l	0.001	0.001	<0.001	<0.001	0.002	<0.001	0.028	0.005	<0.001	<0.001	<0.001
Na	mg/l	1	72	170	187	118	159	88	84	123	148	186
Ni	mg/l	0.001	0.01	0.10	0.10	0.00	0.39	0.01	0.02	0.78	0.10	0.07
P	mg/l	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pb	mg/l	0.001	0.014	0.008	0.006	0.002	0.016	0.011	0.016	0.028	0.003	<0.001
SO4	mg/l	1	39	356	470	132	783	42	60	828	381	401
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
Se	mg/l	0.01	<0.01	0.02	0.02	<0.01	0.01	0.01	0.01	<0.01	<0.01	0.02
Si	mg/l	0.1	1.31	2.48	3.22	1.86	3.29	1.68	1.54	3.34	2.42	2.23
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
Sr	mg/l	0.001	0.054	0.193	0.275	0.031	0.576	0.072	0.053	0.384	0.184	0.241
Th	mg/l	0.001	0.005	<0.001	0.004	0.002	0.003	0.003	0.004	0.003	<0.001	<0.001
U	mg/l	0.001	<0.001	<0.001	0.002	<0.001	0.007	<0.001	<0.001	0.010	<0.001	<0.001
Zn	mg/l	0.01	0.06	0.50	0.35	0.01	1.54	0.05	0.07	1.17	0.57	0.18

< element at or below analytical detection limit.

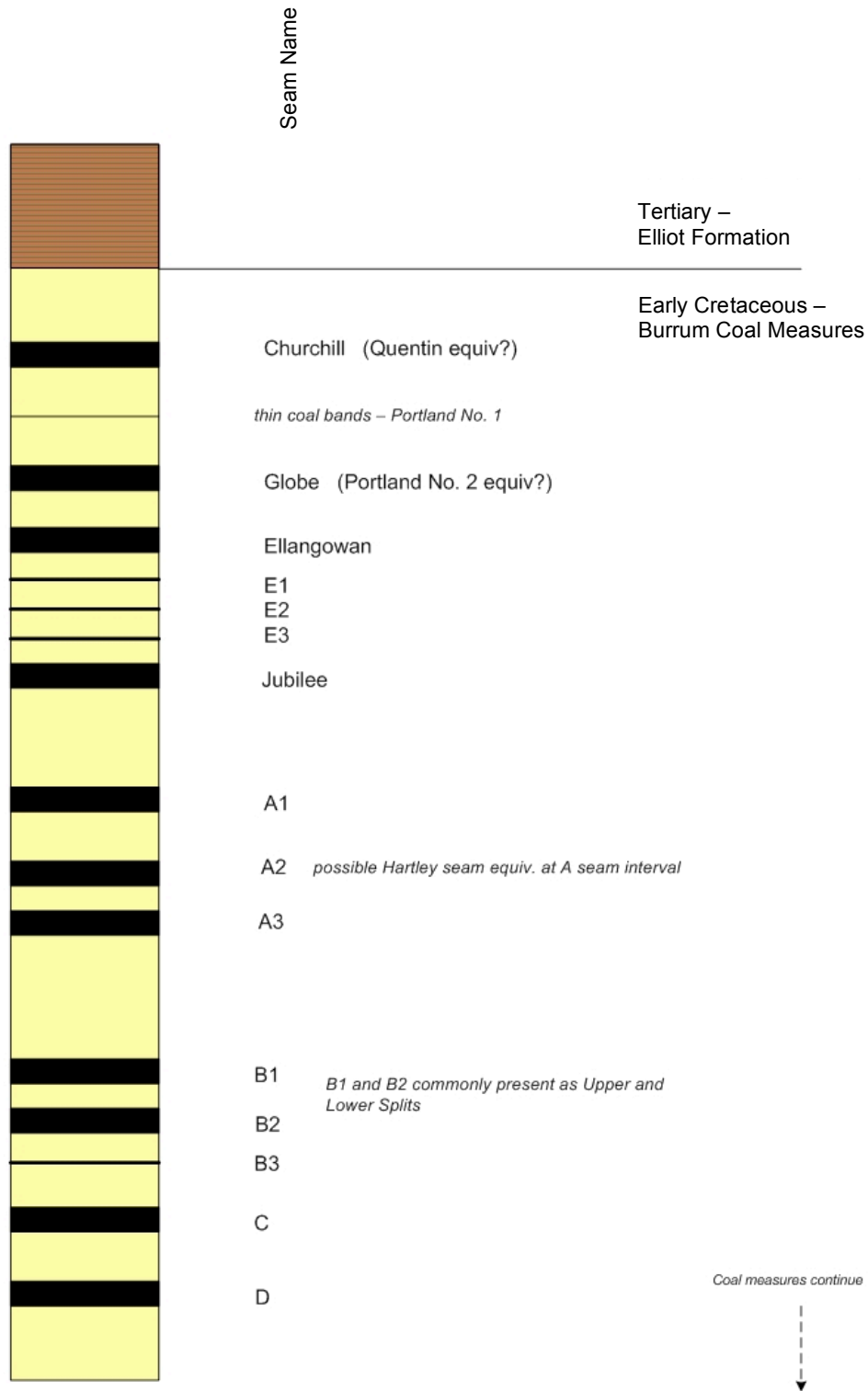


Figure 1: Schematic stratigraphic column for the Colton Deposit.

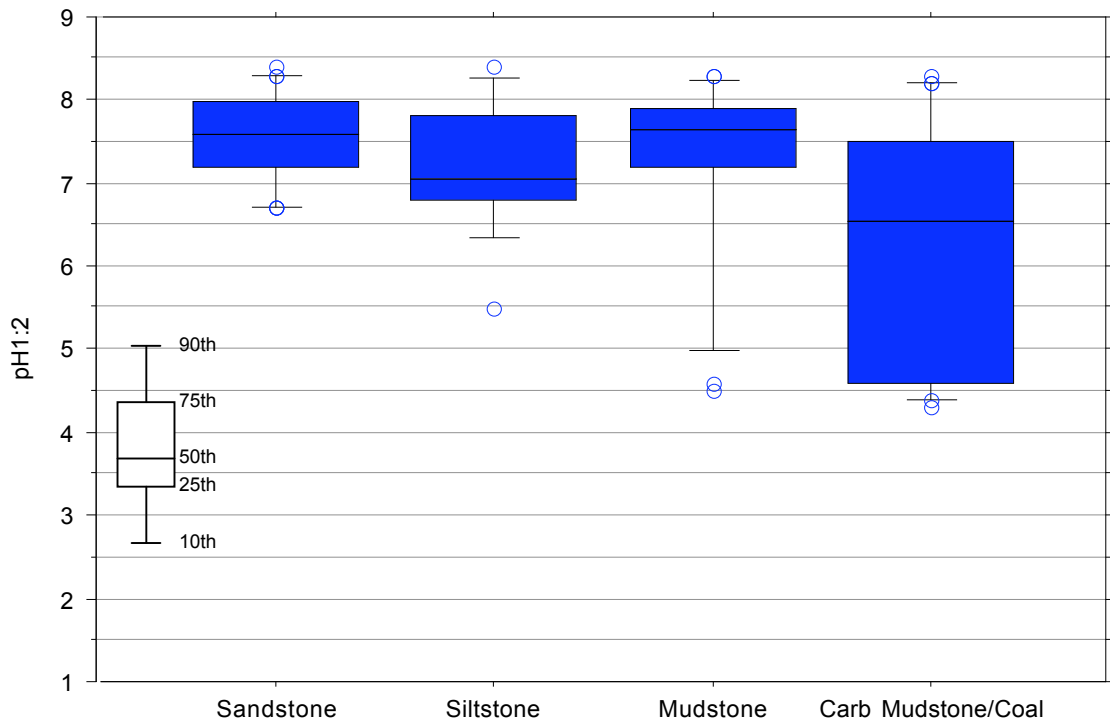


Figure 2: Box plot showing the distribution of pH<sub>1:2</sub> split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

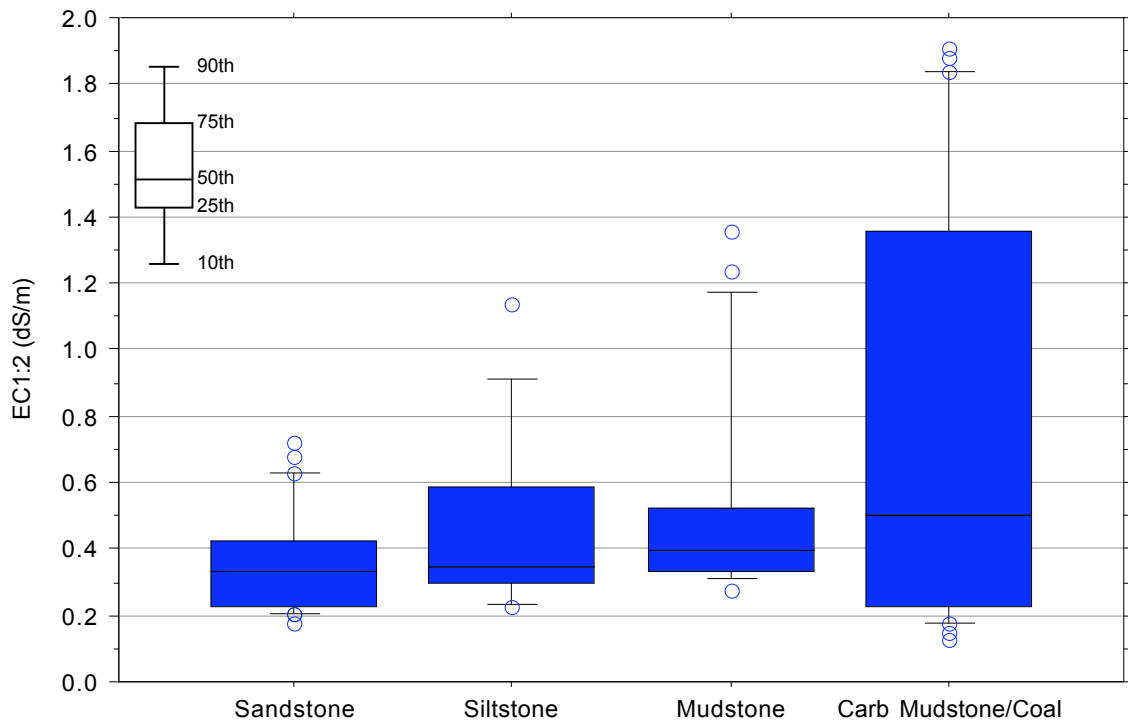


Figure 3: Box plot showing the distribution of EC<sub>1:2</sub> split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

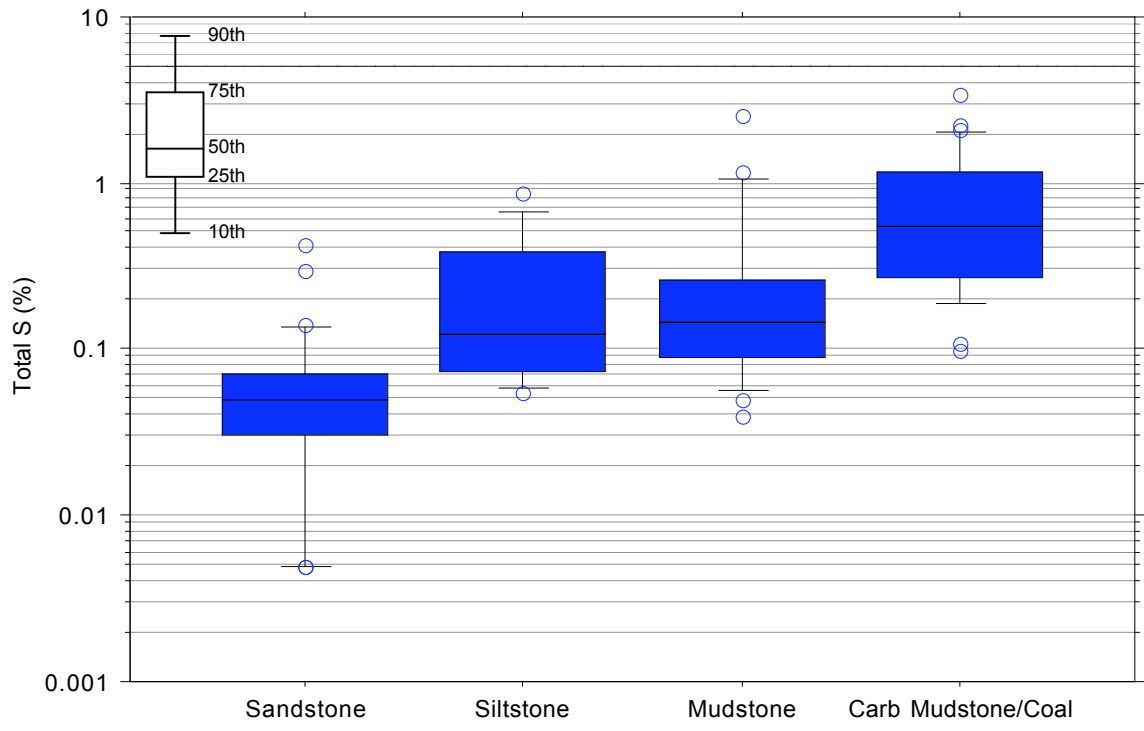


Figure 4: Box plot showing the distribution of S split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

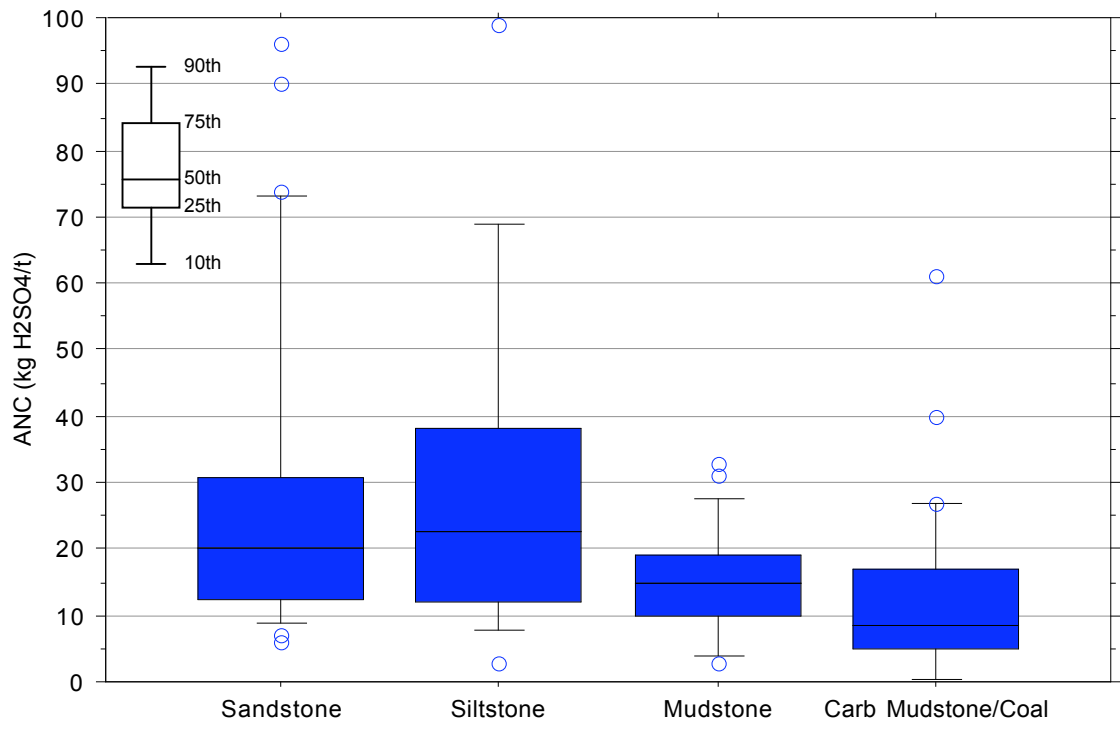


Figure 5: Box plot showing the distribution of ANC split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

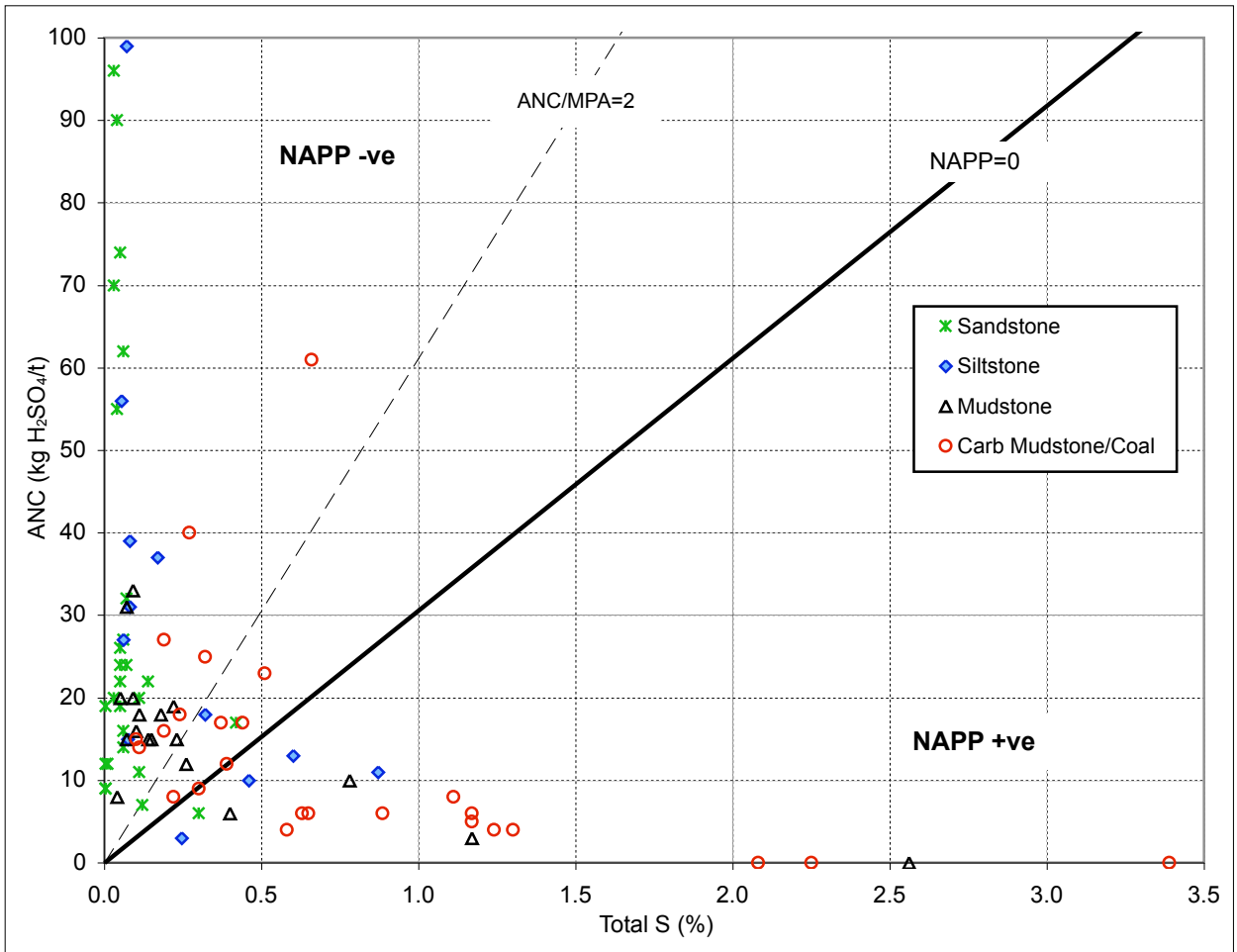


Figure 6: Acid-base account (ABA) plot showing ANC versus total S split by lithology.

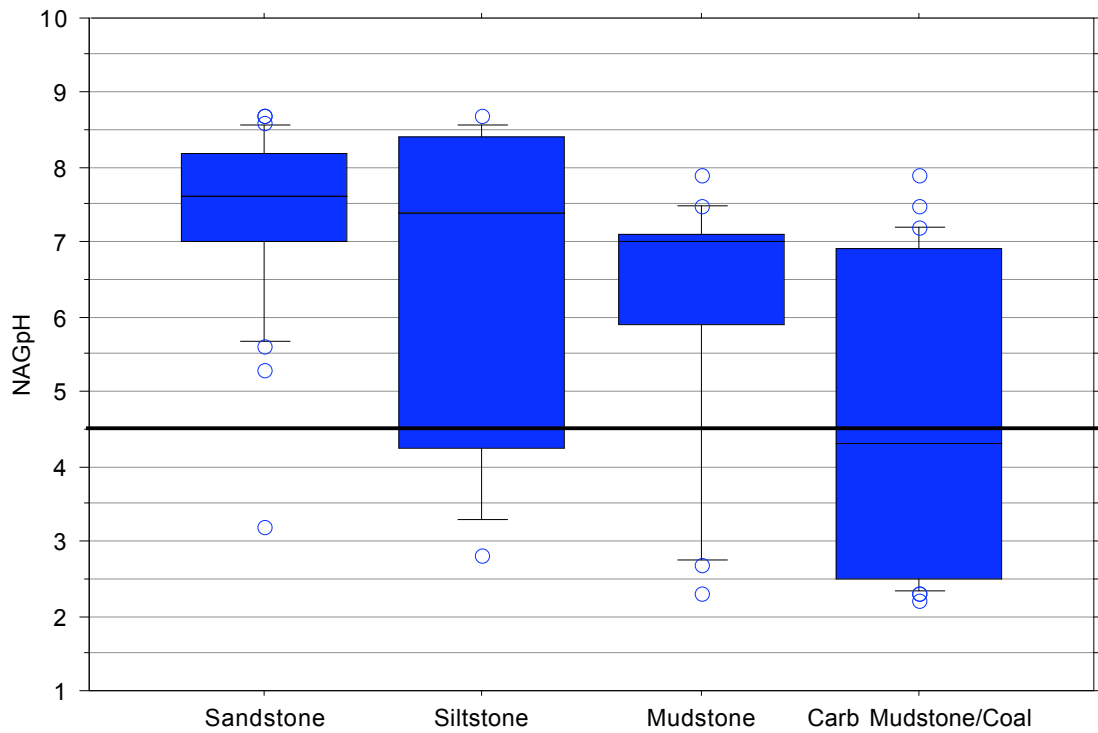


Figure 7: Box plot showing the distribution of NAGpH split by lithology. Box plots have 10th, 25th, 50th (median), 75th and 90th percentiles marked.

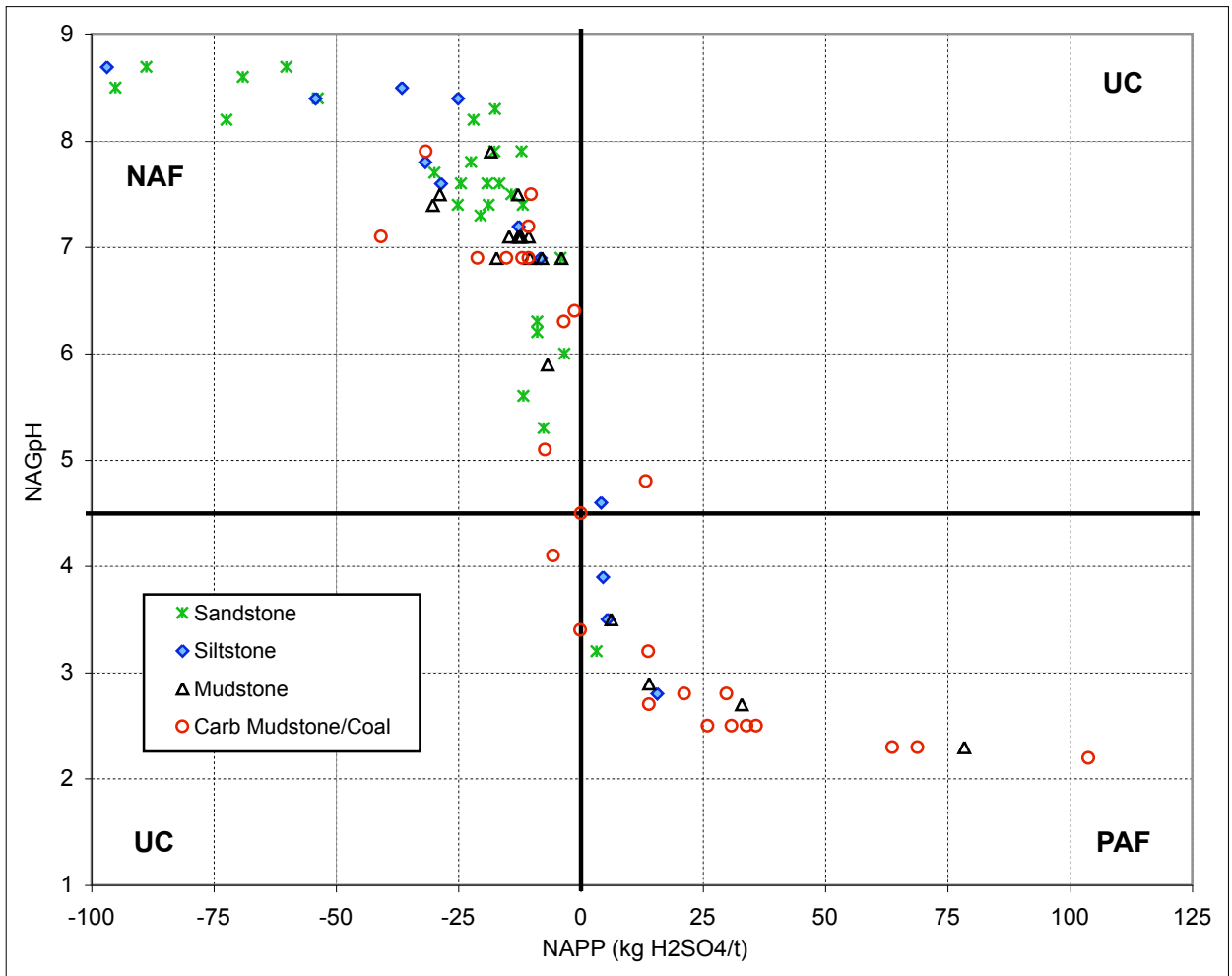


Figure 8: ARD classification plot showing NAGpH versus NAPP split by lithology, with ARD classification domains indicated.

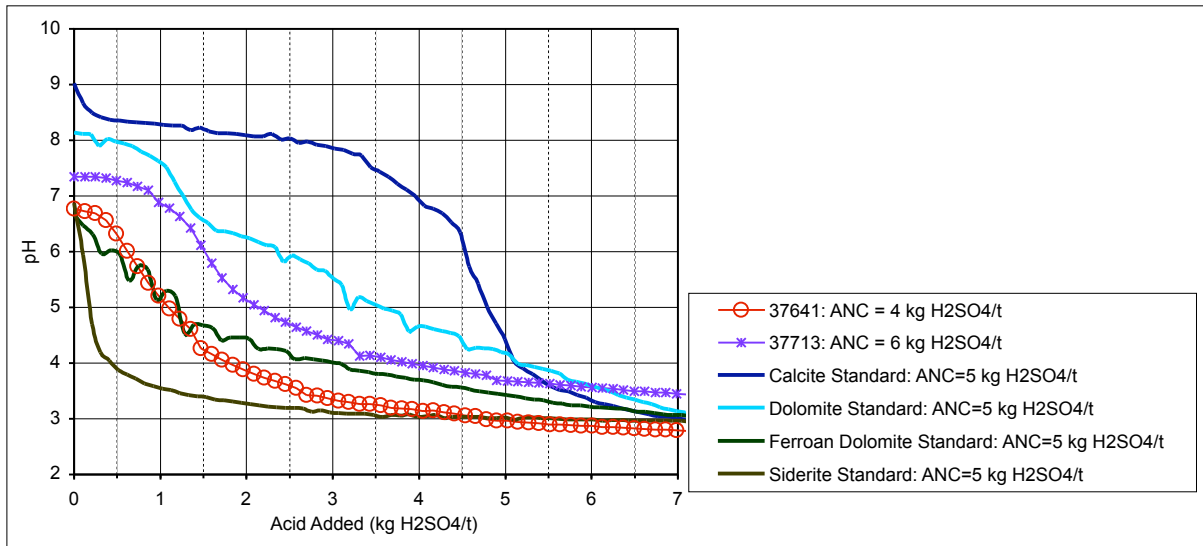


Figure 9: ABCC profiles for samples with an ANC value close to 5 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.

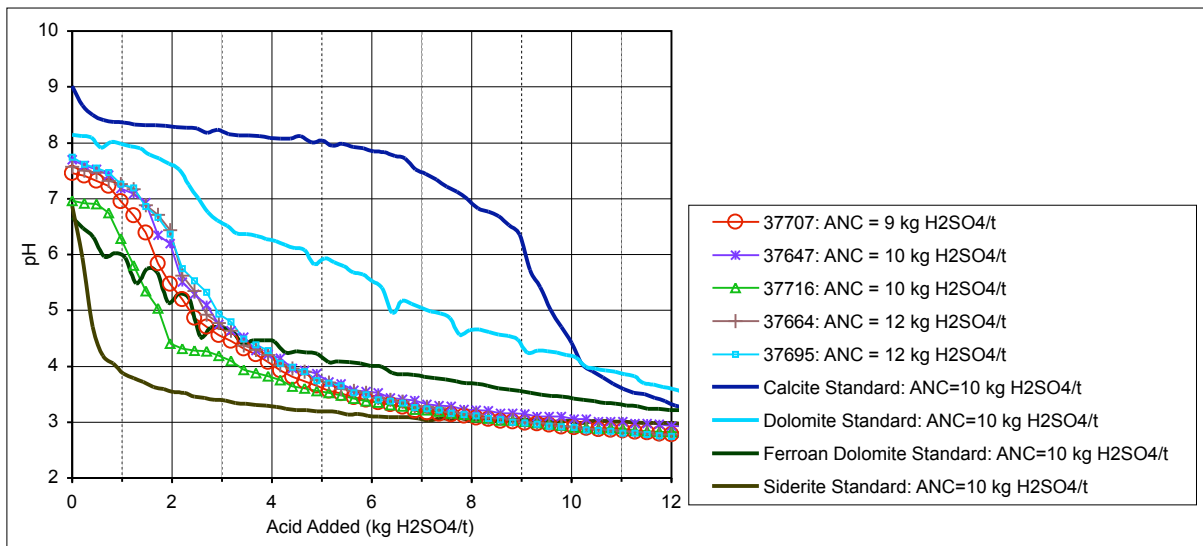


Figure 10: ABCC profiles for samples with an ANC value close to 10 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.

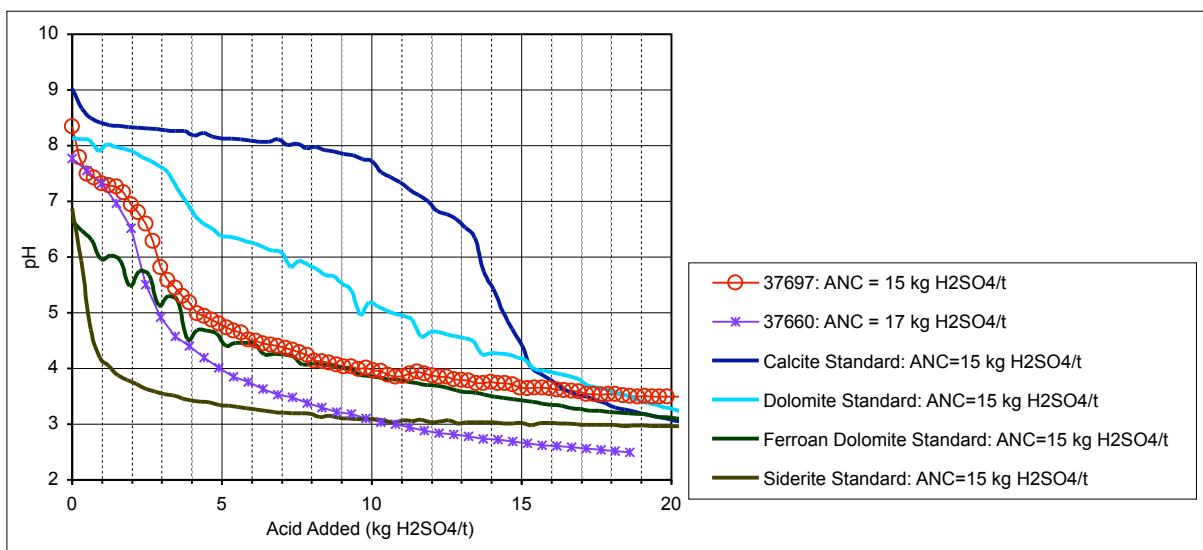


Figure 11: ABCC profiles for samples with an ANC value close to 15 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.

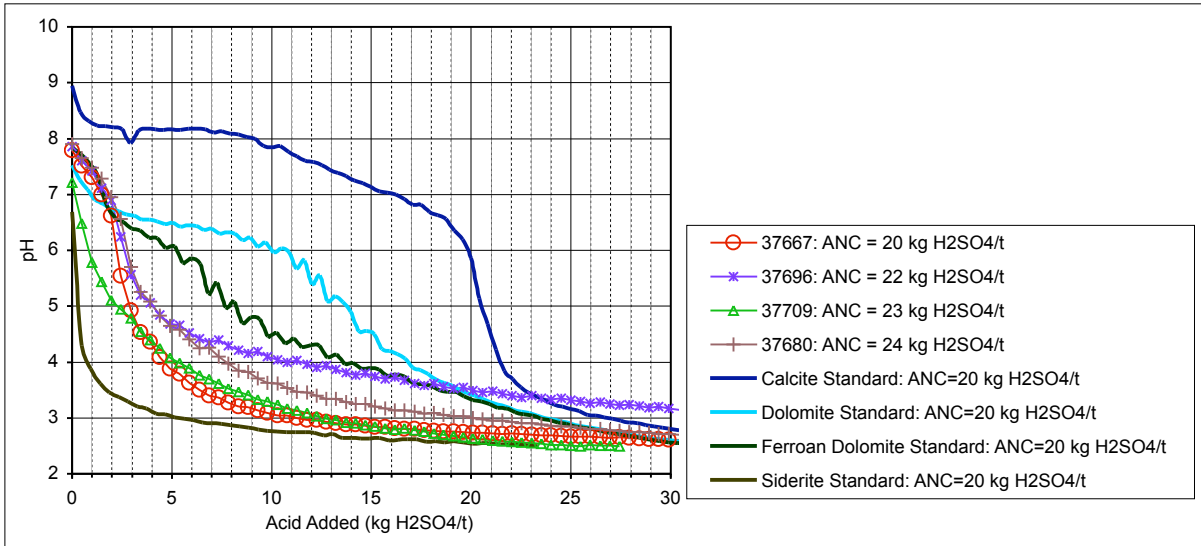


Figure 12: ABCC profiles for samples with an ANC value close to 20 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.

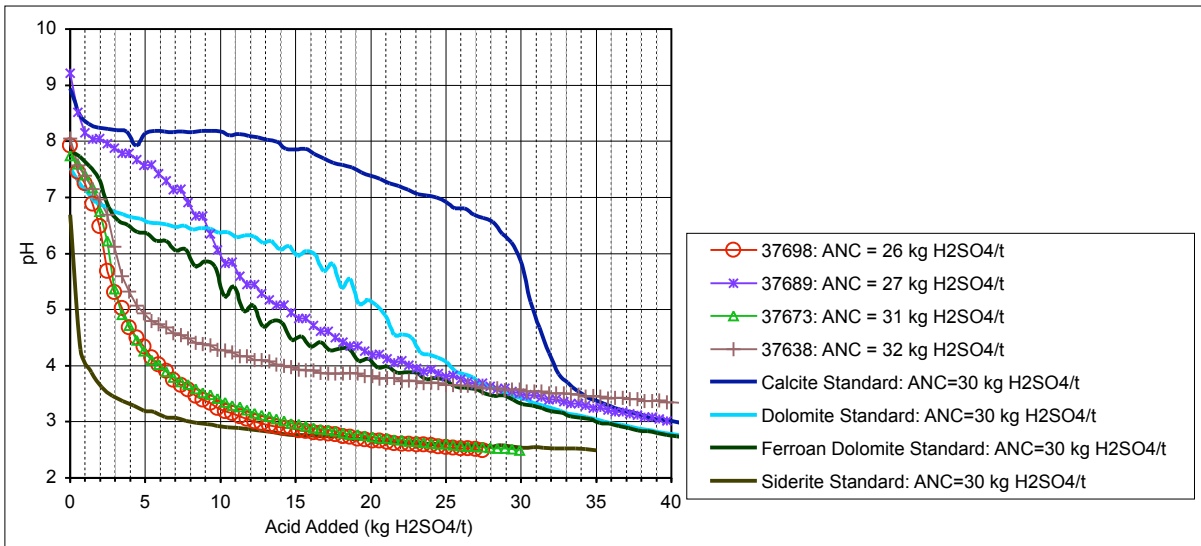


Figure 13: ABCC profiles for samples with an ANC value close to 30 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.

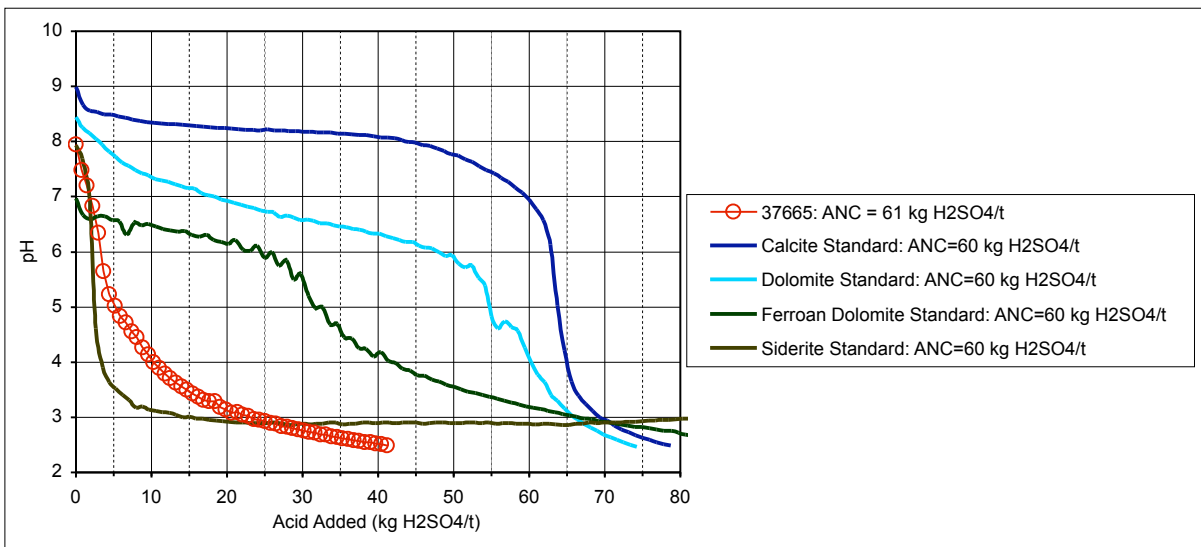


Figure 14: ABCC profiles for sample 37665 with an ANC value close to 60 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.

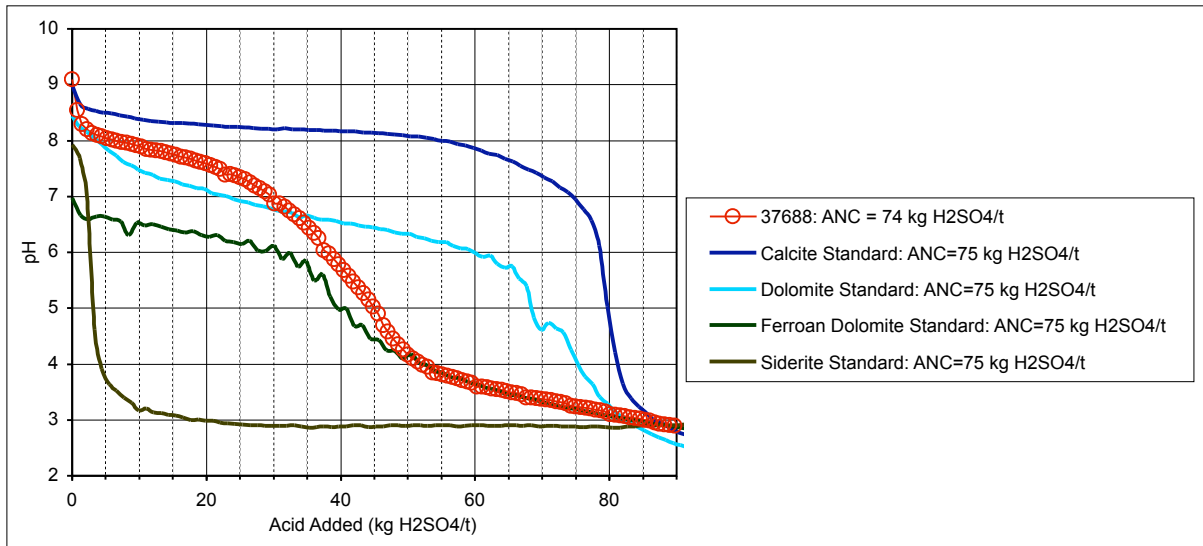


Figure 15: ABCC profile for sample 37688 with an ANC value close to 75 kg H<sub>2</sub>SO<sub>4</sub>/t. Carbonate standard curves are included for reference.

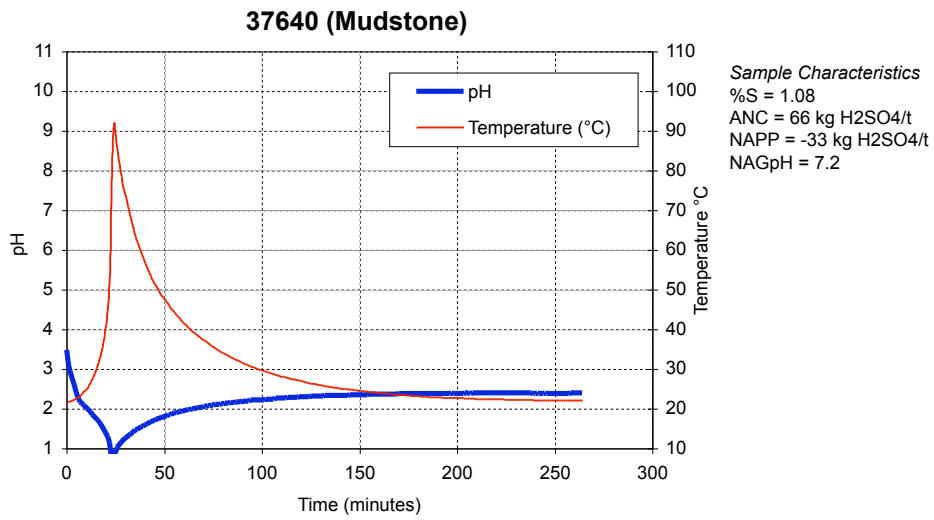


Figure 16: Kinetic NAG graph for sample 37640 (Mudstone).

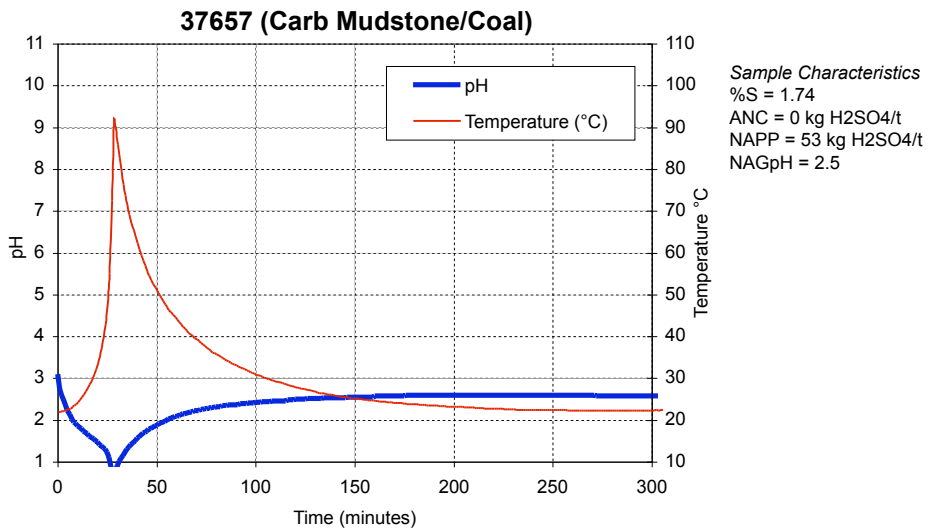


Figure 17: Kinetic NAG graph for sample 37657 (Carb Mudstone/Coal).

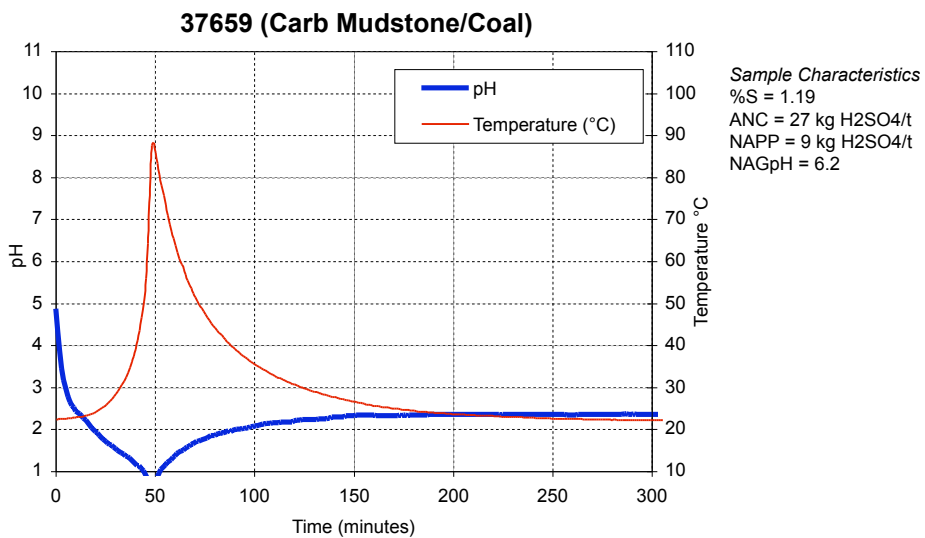


Figure 18: Kinetic NAG graph for sample 37659 (Carb Mudstone/Coal).

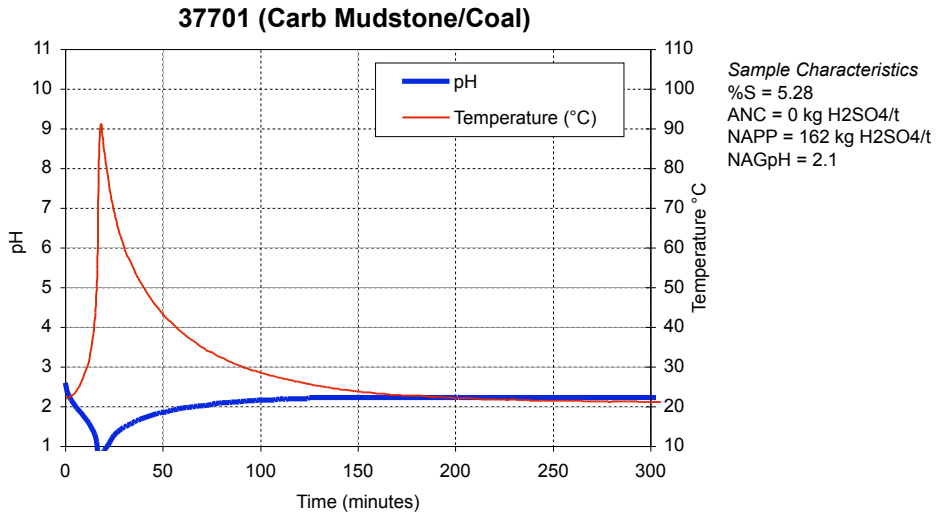


Figure 19: Kinetic NAG graph for sample 37701 (Carb Mudstone/Coal).

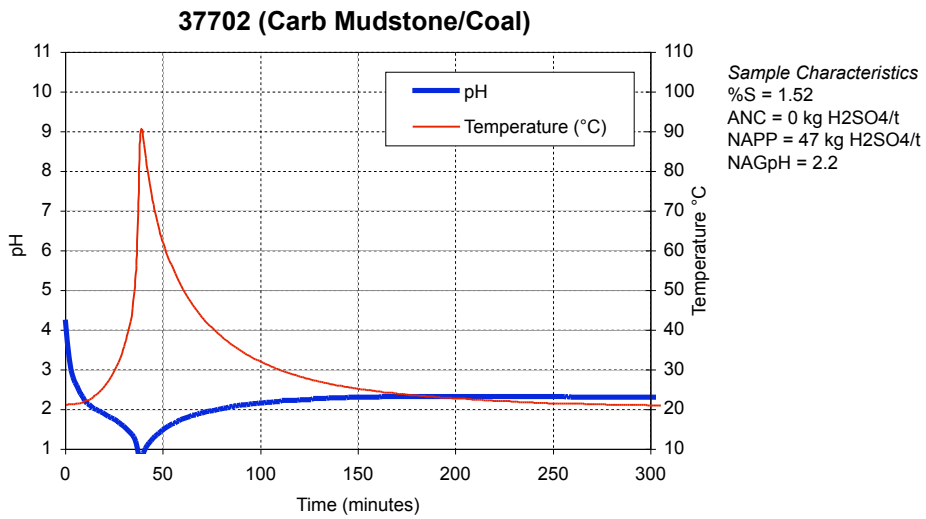


Figure 20: Kinetic NAG graph for sample 37702 (Carb Mudstone/Coal).

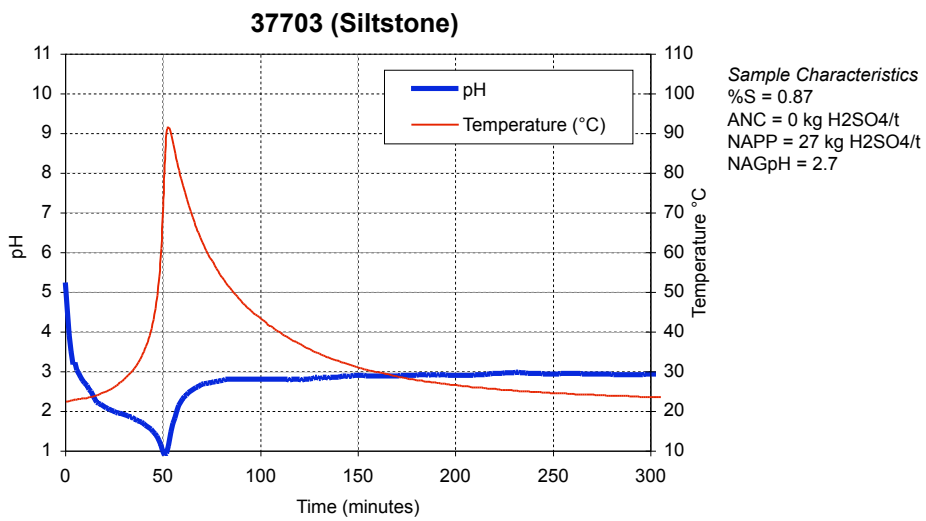


Figure 21: Kinetic NAG graph for sample 37703 (Siltstone).

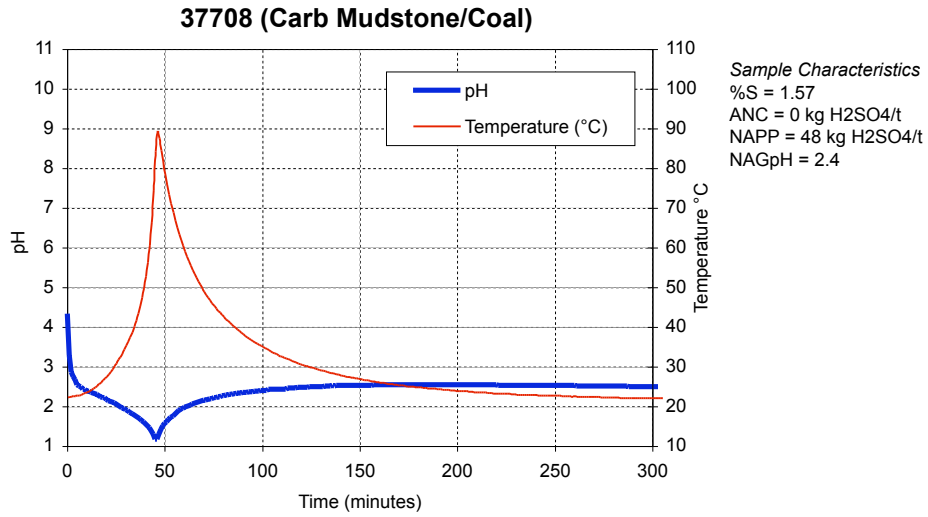


Figure 22: Kinetic NAG graph for sample 37708 (Carb Mudstone/Coal).

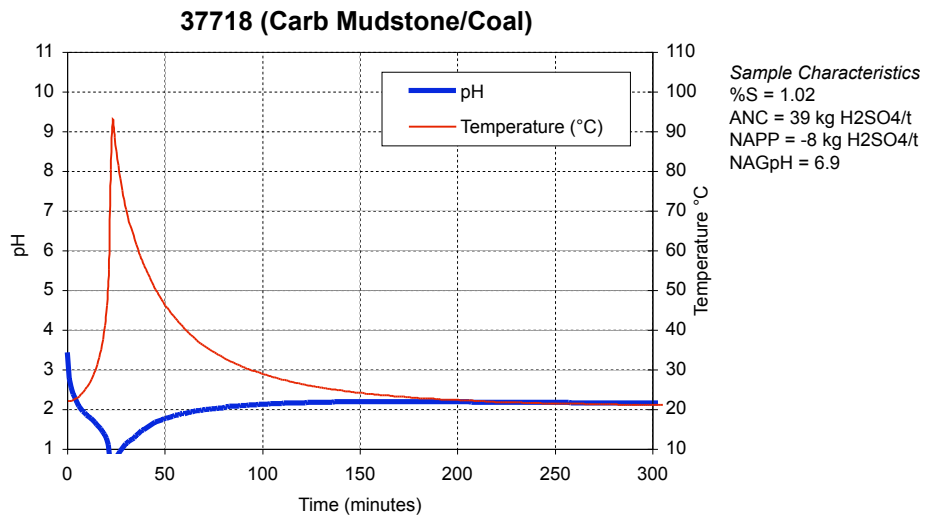


Figure 23: Kinetic NAG graph for sample 37718 (Carb Mudstone/Coal).

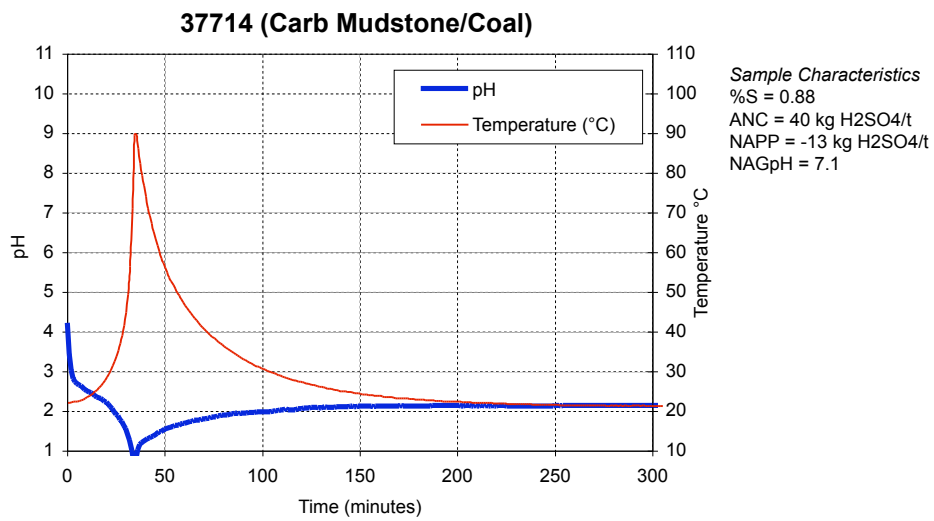


Figure 24: Kinetic NAG graph for sample 37714 (Carb Mudstone/Coal).

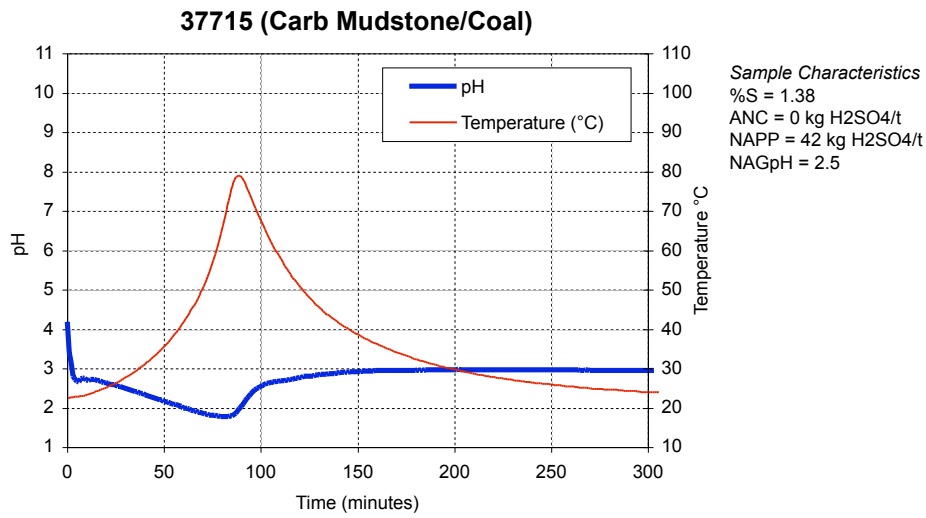


Figure 25: Kinetic NAG graph for sample 37715 (Carb Mudstone/Coal).

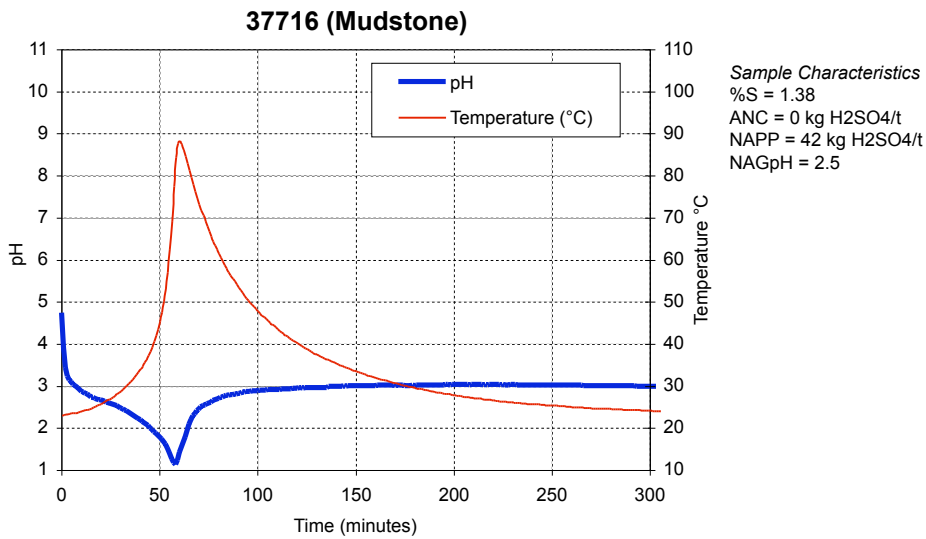


Figure 26: Kinetic NAG graph for sample 37716 (Mudstone).

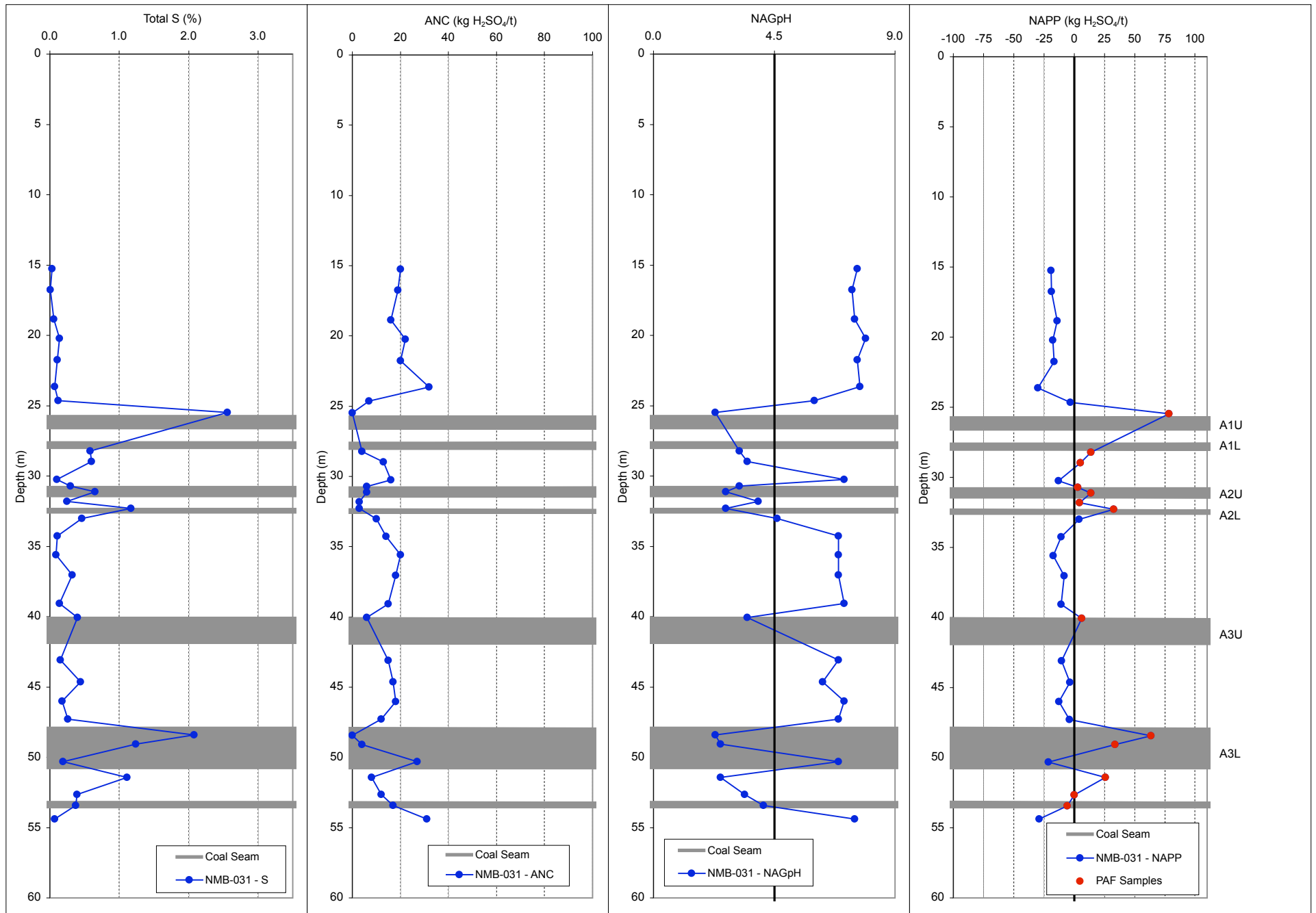


Figure 27: Total S, ANC, NAGpH and NAPP profiles for hole NMB-031.

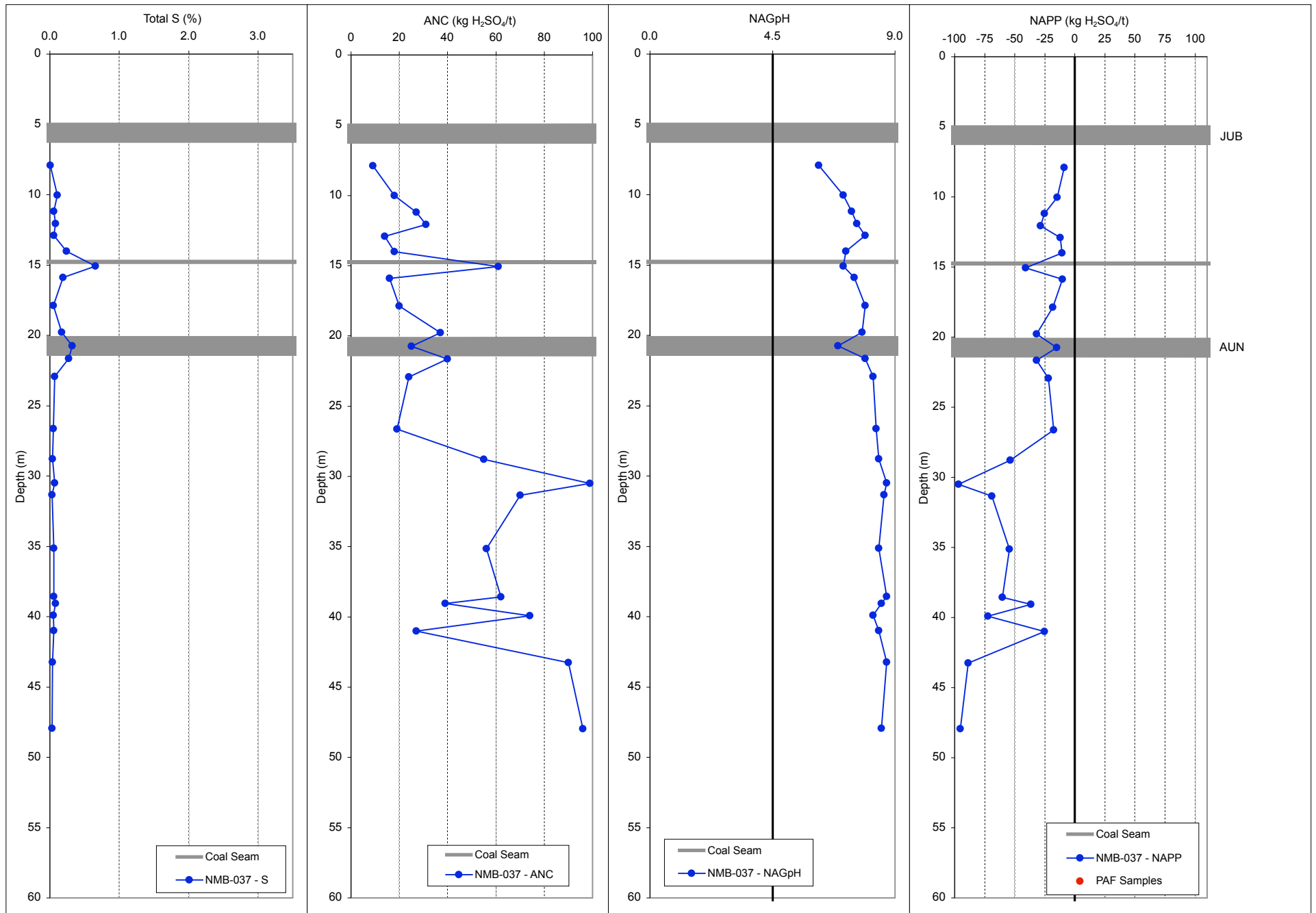


Figure 28: Total S, ANC, NAGpH and NAPP profiles for hole NMB-037.

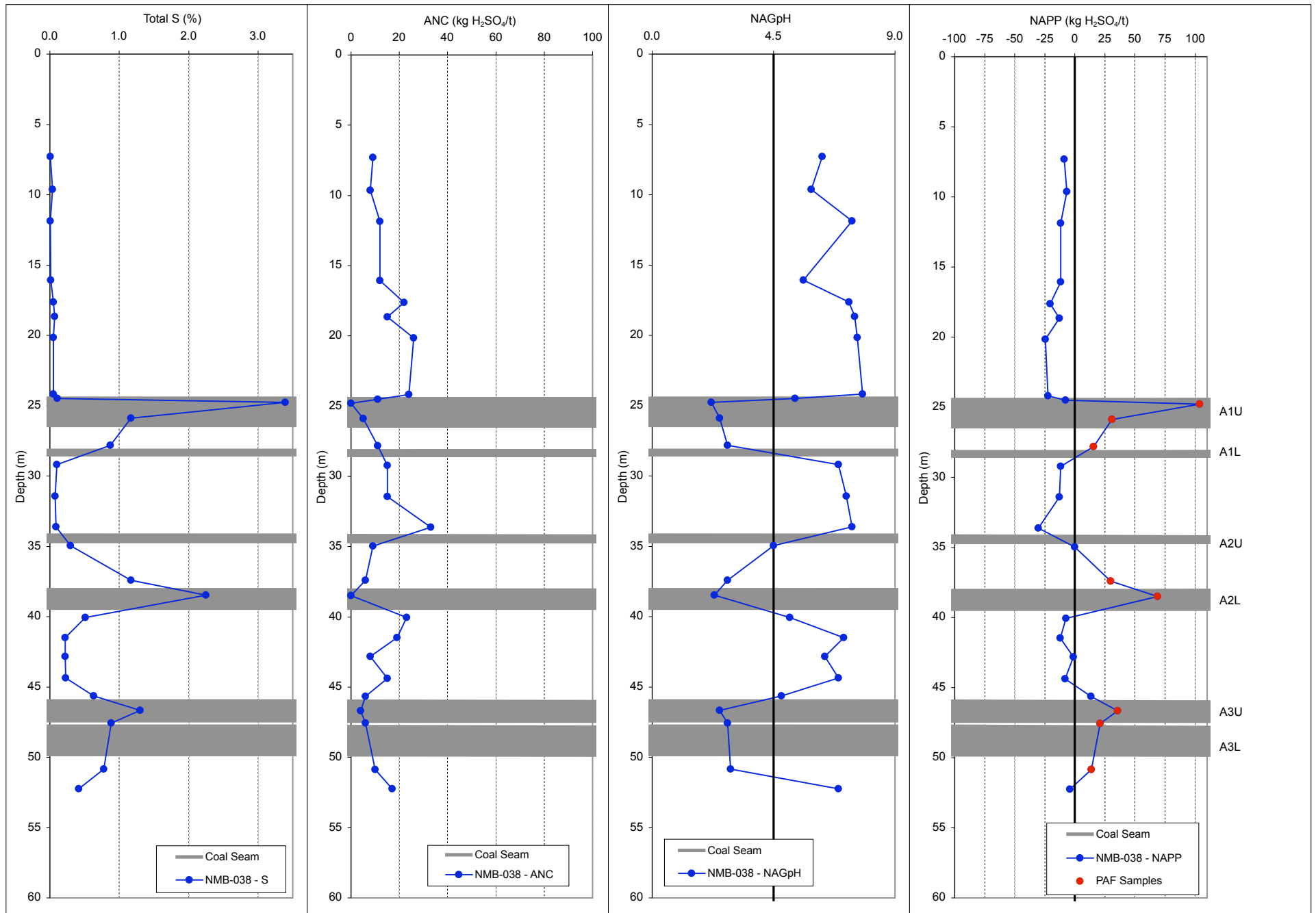


Figure 29: Total S, ANC, NAGpH and NAPP profiles for hole NMB-038.

## **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

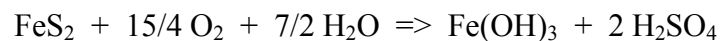
The acid-base account involves static laboratory procedures that evaluate the balance between acid generation processes (oxidation of sulphide minerals) and acid neutralising processes (dissolution of alkaline carbonates, displacement of exchangeable bases, and weathering of silicates).

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<sub>2</sub>) content and assumes that the pyrite reacts under oxidising conditions to generate acid according to the following reaction:



Based on the above reaction, the potential acidity of a sample containing 1 %S as pyrite would be 30.6 kilograms of H<sub>2</sub>SO<sub>4</sub> per tonne of material (i.e. kg H<sub>2</sub>SO<sub>4</sub>/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:

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

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<sub>2</sub>SO<sub>4</sub>/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<sub>2</sub>SO<sub>4</sub>/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.

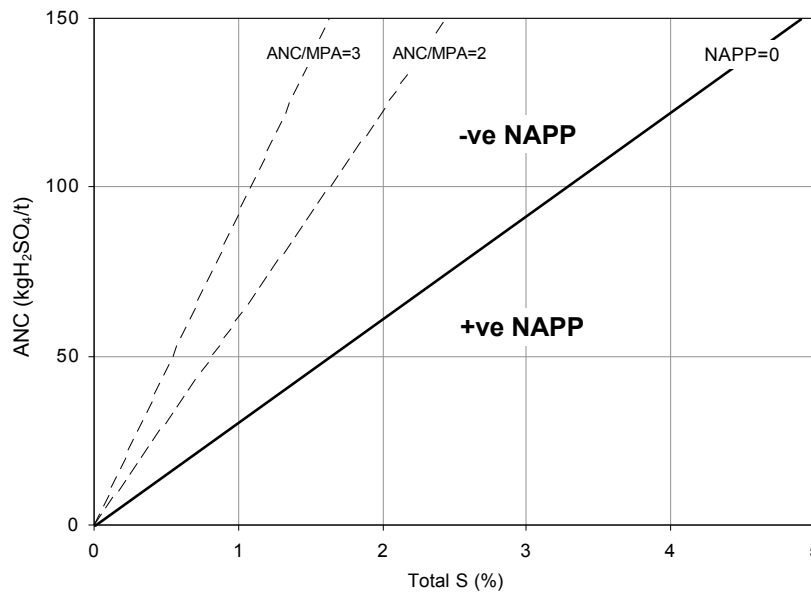


Figure A-1: Acid-base account (ABA) plot

### **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<sub>2</sub>SO<sub>4</sub>/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<sub>2</sub>SO<sub>4</sub>) 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<sup>1</sup> 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<sup>2</sup>.

The concentration of dissolved S is used to calculate the amount of acid (as H<sub>2</sub>SO<sub>4</sub>) generated by the sample and the concentrations of Ca, Mg, Na and K are used to estimate the amount of acid neutralised (as H<sub>2</sub>SO<sub>4</sub>). 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.

---

<sup>1</sup> 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, 12-18<sup>th</sup> July 2003*, 211-222.

<sup>2</sup> 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  $\leq 0.1$  %S and an ANC  $\leq 5$  kg H<sub>2</sub>SO<sub>4</sub>/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  $\geq 4.5$ .

### *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  $\leq 4.5$ ). 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 NAPP and NAG data. Marked on this plot are the quadrats representing the NAF, PAF and UC classifications.

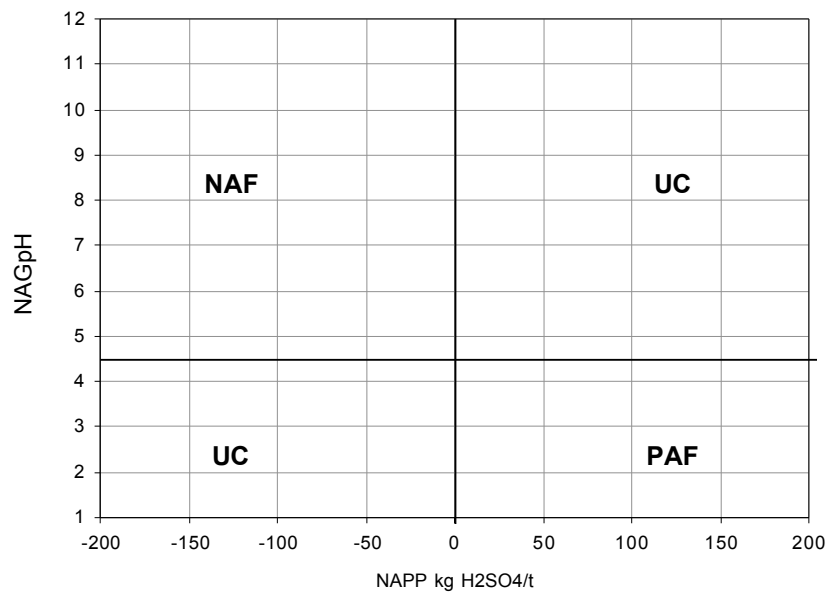


Figure A-2 ARD classification plot

## 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.