Appendix 6.
Geochemical Characterisation of Waste Rock & Ore – Fountain Head

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Geochemical Characterisation of Waste Rock & Ore

Fountain Head

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FOUNTAIN HEAD

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LIST OF ABBREVIATIONS

ABBREVIATIONS USED IN GEOCHEMICAL ASSESSMENT

ARD	Acid Rock Drainage
AMD	Acid, Metalliferous and Saline Drainage
NMD	Neutral and Metalliferous Drainage
ABA	Acid Base Account
$pH_{1:2}$	pH of a sample slurry with a solid to water ratio of 1:2 (by weight)
$EC_{1:2}$	Electrical Conductivity of a sample slurry with a solid to water ratio of 1:2 (by weight)
ESP	Exchangeable Sodium Percentage
ECEC	Effective Cation Exchange Capacity
S	Sulphur
CRS	Chromium Reducible Sulphur
KCl	Potassium Chloride
H_2SO_4	Sulphuric Acid
SO_4	Sulphate
$CaCO_3$	Calcium Carbonate
ANC	Acid Neutralising Capacity in kg H_2SO_4/t
ANC_{ABCC}	Acid Neutralising Capacity in kg H_2SO_4/t estimated from ABCC testing
CNV	Carbonate Neutralising Value in kg H_2SO_4/t
MPA	Maximum Potential Acidity, calculated from total S in kg H_2SO_4/t
NAPP	Net Acid Producing Potential, calculated from ANC and total S (or MPA) in kg H_2SO_4/t.
NAG	Net Acid Generation (test)
NAGpH	pH of NAG solution before titration
$NAG_{(pH4.5)}$	NAG acidity titrated to pH 4.5 in kg H_2SO_4/t
$NAG_{(pH7.0)}$	NAG acidity titrated to pH 7.0 in kg H_2SO_4/t
ABCC	Acid Buffering Characteristic Curve
GAI	Geochemical Abundance Index based on multi-elements of solids
PAF	Potentially Acid Forming
PAF-LC	Potentially Acid Forming - Low Capacity
NAF	Non-Acid Forming
NAF-HS	Non-Acid Forming – High Sulphur
UC	Uncertain
AC	Acid Consuming

UNITS OF MEASUREMENTS

%	Percentage
°C	Degrees Celsius
dS	Deci Siemen
µm	Micrometre
mm	Millimetre
m	Metre
mg	Milligram
M	Million
g	Gram
kg	Kilogram
t	Tonne
L	Litre
ml	Millilitre

OTHER ABBREVIATIONS

ALS	Australian Laboratory Services
EGi	Environmental Geochemistry International Pty Ltd
Project	Fountain Head Gold Heap Leach Project
pXRF	Portable X-Ray Fluorescence
ROM	Run-of-Mine

EXECUTIVE SUMMARY

Environmental Geochemistry International were engaged by ERIAS Group Pty Ltd to undertake a study of the geochemical properties of mine materials at PNX Metal's proposed Fountain Head Gold Heap Leach project in the Northern Territory, Australia. This investigation is a component of an EIS which is being prepared by ERIAS as a part of the licencing of the Fountain Head project.

The proposed Fountain Head Project will involve a cutback of the existing pit. Approximately 15 Mt of waste rock and 3 Mt of ore will be mined over the 2.5 year operation. Waste rock will be placed in the existing waste rock stockpile (WRS). The existing WRS encroaches onto the proposed pit cutback and therefore a section of the waste stockpile will need to be relocated prior to cutting back in this region. Ore will be processed using cyanide heap leaching with the heap leach pads to be left in situ following closure. The gold bearing ore from the mining operation will be stockpiled on the ROM until it is required to be crushed and screened and stockpiled onto the heap leach pads.

Geochemical testing included waste rock that will be removed from the pit during the cutback, waste rock from the existing WRS, including material that will be removed to allow pit development, and ore samples before processing and cyanide leached ore to represent ore stored on the ROM pad and remaining in heap leach pads at closure, respectively.

In order to obtain rock samples which would satisfactorily represent the distribution of waste rock types to be mined during the expansion of the existing Fountain Head pit, a number of drill holes were selected from the many drilled during resource definition drilling. Samples from these drill holes were selected to cover variation in lithology, oxidation and chemical composition of the waste rock, while also achieving appropriate spatial coverage of the proposed expanded pit. A value of 1 ppm Au (fire assay results) was used in most instances to delineate between ore (Au >1 ppm) and waste rock.

Correlations of data sets, including lithology, oxidation and elemental composition between the whole sample and tested sample sets, showed the tested samples were representative of the larger sample set. However, for some elements, particularly sulphur, the tested sample set was slightly biased toward the upper end of the concentration range in comparison to the full sample set for all selected drill holes. This was deliberate to obtain sufficient samples containing elevated sulphur concentrations which may lead to acid formation, and thereby allow clear definition of possible sulphur cut-off grades which might define PAF wastes.

In total 111 drill hole samples, 18 WRS samples and 3 ore and 3 cyanide leached samples were tested for the following:

- Total sulphur (S);
- Paste (1:2) pH and EC;
- single addition net acid generation (NAG) test; and
- acid neutralising capacity (ANC)

For a number of samples, additional geochemical testing was conducted to provide better definition of their geochemical properties including:

- acid buffering characteristic curve (ABCC) testing to define the relative availability of the measured ANC;
- carbon speciation analysis (Total C, organic C and inorganic C) to determine carbonate content; and
- chromium reducible sulphur (CRS) to quantify the amount of sulphide sulphur.

In addition to the above tests, leach tests were conducted on a number of samples to provide information on the leaching characteristics of various metals and other elements of concern. Testing included:

- Multi-element testing of the sample solid (19 drill hole samples, multi-element assay results were available for WRS and metallurgical samples)

- Peroxide extraction testing including multi-element assay of the extract (9 drill hole samples)
- Water extraction testing including multi-element assay of the extract (19 drill hole samples, 3 WRS samples and 2 metallurgical samples)

This report describes the results of static geochemical testing which were used to define acid rock drainage (ARD) classification for the various mine materials tested, and the results of water and peroxide extractions. The report also describes methods that may be used to identify and segregate mine wastes according to their potential to generate ARD.

Results of geochemical testing of samples obtained from drilling in the Fountain Head pit show:

- There is no immediately available acidity and low salinity in these samples when contacted with water, indicating that freshly mined rock is unlikely to provide low pH or saline drainage.
- Total S analysis showed a broad range up to 3%S, but with the vast majority (90%) having a relatively low S value of 0.5%S or less, suggesting the occurrence of pyritic rock is not widespread.
- ANC was relatively low, ranging up to 33 kg H_2SO_4/t, indicating a general lack of excess buffering.
- Carbon speciation analysis indicates carbonate content is negligible, with the total carbon content of these samples generally low. This is consistent with ABCC test results which also suggest little carbonate content, and that the small amount of carbonate present in these samples is predominantly iron carbonates (ferroan dolomite, siderite), which will react relatively slowly.
- Most samples were NAPP negative, with the majority of these having ANC/MPA ratios of 2 or more, indicating a high factor of safety.
- The majority (70%) of NAGpH values were 4.5 or greater, corroborating the ABA results which indicated most samples are likely to be NAF.
- CRS measurements show that greater than 90% of Total S is contained in sulphide minerals, suggesting that Total S measurements can be used as suitable guide to the sulphide (pyrite) content of these materials.
- Test results were used to classify samples as NAF, PAF, PAF-LC or UC. Around 80% of samples tested were classified NAF (including UC equivalents), 15% PAF-LC (including UC equivalents) and 5% PAF. Overall results indicate most waste materials to be mined will be NAF, with a minor proportion of PAF.

Results of geochemical testing of samples obtained from the existing WRS at Fountain Head show:

- The WRS samples contain very little sulphur (<0.08%) and consequently are unlikely to generate any acidity.
- The WRS samples generally contain small amounts of neutralising material (ANC <20 kg H_2SO_4/t).
- The majority of WRS samples were clearly classified as NAF (one sample only as UC(PAF-LC)).
- Samples taken from locations in the WRS close to where rock will be excavated prior to pit cutback, were all classified as NAF with ANC/MPA ratios well above 2, indicating that waste rock represented by these samples is very unlikely to produce any ARD and therefore suitable for construction purposes, such as roads, pads and embankments.

Results of geochemical testing of ore and cyanide leached ore show:

- The three metallurgical samples used as feed for bottle roll cyanide leach tests, all contained negligible sulphur (<0.1 %) and ANC (<10 kg H_2SO_4/t) and were classified as NAF.
- The corresponding residues following cyanide leaching of the head samples contained increased neutralising capacity (15 - 20 kg H_2SO_4/t), presumably because of lime addition during leaching.

- These results indicate that heap leach pads remaining after closure which contain ore samples of the type tested here are very unlikely to produce ARD in the longer-term.

Given the relatively low ANC and poor reactivity, criteria based on Total S was selected as the best potential option for routine classification of ARD rock types. Using the results from detailed geochemical testing, sulphur distributions were determined for each of NAF, PAF-LC or PAF ARD classifications. The results show:

- NAF samples can be differentiated from PAF/PAF-LC samples by applying a Total S cut-off of 0.2%S
- 95% of samples classified NAF have a Total S value of 0.2% or less, and all PAF samples and 60% of PAF-LC samples have a Total S value of greater than 0.2%S.
- Although using a ≤0.2%S criteria for NAF waste rock includes 40% PAF-LC material, these have low acid potential and operational blending with NAF materials would be expected to account for any minor acidity generated.

Geological observations (logging) was also investigated as a screening tool for ARD rock types, but the information to date is not sufficient to calibrate reliable geological criteria. Based on the available information the following observations can be made:

- Lithology does not appear to be a significant control on S or ANC distribution.
- Quartz veining, observed sulphide occurrence, and oxidation are potential geological parameters that may be used in conjunction with Total S to differentiate ARD rock types.
- PAF and PAF-LC materials are generally associated with logged quartz veining and/or observed sulphide, but not exclusively. There are intervals where sulphides were observed but Total S was low.
- Quartz veining was also common in NAF materials.

Using Total S values to distinguish between NAF and PAF/PAF-LC rock types it may be possible to estimate volumes of each rock type that will be mined from the Fountain Head pit. However, the only sulphur data available for a sufficient number of samples to provide such an estimate were derived from pXRF analysis. Comparison of pXRF sulphur data with Total S data indicated very poor correlation, suggesting the pXRf data were of insufficient quality to allow an estimate of the volume of PAF rock to be made.

In addition to the above testing, water and peroxide extractions were conducted on selected samples to understand the likely quality of drainage from freshly mined and oxidised waste rock respectively. The results of these tests show:

- All water extracts produced circum-neutral to mildly alkaline solutions with low salinity. Metal concentrations in water extracts were also very low to non-detectable.
- These results suggest leachates from freshly mined waste rock from the Fountain Head pit will, in general, be of reasonable quality. However, segregation of the PAF waste rock using a Total S value of 0.2% may improve leachate quality for the majority of fresh waste rock containing ≤0.2%S.
- Water extracts for WRS samples had neutral pH and low salinity. Metal/metalloid concentrations were also very low or non-detectable.
- Water extractions conducted on an ore sample and the same sample following cyanidation showed that cyanide leaching has significantly increased arsenic mobility in this sample.
- Arsenic is significantly enriched in the majority of samples tested relative to average crustal and soil abundance. This suggests that increased arsenic solubility as a result of cyanide leaching may lead to drainage containing elevated arsenic concentrations from heap leach pads remaining after closure.

- Iron, copper, cobalt, nickel and arsenic concentrations in peroxide leachates correlated with Total S content of the samples, indicating that segregation of samples with significant sulphur content is likely to reduce the concentration of these heavy metals/metalloids in drainage from oxidised waste rock in the WRS.
- Peroxide leachates suggest drainage from oxidised waste rock containing more than 0.2% sulphur may contain substantial concentrations of Al, Co, Mn, Ni, Pb, Zn and waste rock with Total S concentrations above this value should be managed to minimise oxidation and release of heavy metals.

The results summarised above suggest that further investigations are required to confirm the conclusions made to date and to provide more confidence in applying the results to the management of mine wastes during and post-operations. Consequently, the following are recommended as future geochemical investigations:

- Although the proportion of PAF materials is likely to be minor, quantification of the distribution of PAF materials will be required ahead of mining and selective handling and management carried out during mining to ensure PAF materials are not a source of ARD during operations and at closure. Quantifying the proportion of PAF will require more extensive testing and it is recommended that any further drilling for resource definition, should include Total S analysis (high temperature combustion method e.g. LECO method, or ICP S analysis) as a part of the suite of analyses conducted on the samples tested.
- Only a limited number of WRS samples were tested, and more widespread follow up testing (S only required initially) is recommended for rock from the WRS.
- It is expected that some ore processed at Fountain Head may have higher sulphide content associated with pyrite than the samples tested during this study. Such materials could potentially generate ARD, depending on the balance between the acid generating potential of the sulphide and the ANC in the material and the alkalinity added through lime addition. It is therefore recommended that ore samples with higher sulphur content should be tested for ARD generating potential.
- Currently available geological information is not sufficient to calibrate reliable geological criteria for waste handling and management. Definition of geological criteria would require inspection of representative drill core through the deposit to better understand controls on sulphide and carbonate distribution, including the oxidation profile to check for the presences of residual sulphides in oxide and transition zones. It is recommended that this inspection should be undertaken as a part of a site visit.
- If a ≤0.2%S criteria for NAF waste rock is to be utilised as a waste segregation and handling criterium, it is recognised that the NAF rock will likely contain a small portion of PAF-LC rock. While these materials have low acid potential and operational blending with NAF materials could be expected to account for any minor acidity generated, this assumption should be validated. It is recommended that kinetic leach column testing be undertaken on samples of PAF-LC material and mixtures of NAF and PAF-LC materials to determine the likely nature of drainage of such materials stored permanently in the WRS.
- It is recommended that the increase in water solubility of arsenic in cyanide leached ores should be further investigated to determine the likely concentrations of arsenic in drainage from heap leach pads after closure.
- Because of the elevated concentrations of several metals (Al, Co, Mn, Ni, Pb, Zn) in peroxide extracts of samples containing relatively low Total S (<0.35%), it is recommended that further testing of the leaching behaviour of these types of samples should be investigated further.

1. INTRODUCTION

The Fountain Head Gold Heap Leach Project lies approximately 15 km to the north of the Iron Blow and Mt Bonnie volcanogenic massive sulphide (VMS) deposits, which form the Hayes Creek Project in the Pine Creek region of the Northern Territory (Figure 1). The proposed Fountain Head Project will involve a cutback of the existing pit at Fountain Head to access gold mineralisation in the Fountain Head and Tally Ho ore bodies (Figure 2). Approximately 15 Mt of waste rock and 3 Mt of ore will be mined over the 2.5 year operation. Waste rock will be placed in the existing waste rock stockpile (WRS) to the west and south of the pit. The existing waste dump encroaches onto the proposed pit cutback and therefore a section of the waste dump will need to be relocated prior to cutting back in this region. The relocated waste rock will be used for the construction of haul roads and laydown areas to reduce costs.

Ore will be processed using cyanide heap leaching with the heap leach pads to be left in situ following closure. The gold bearing ore from the mining operation will be stockpiled on the ROM until it is required to be crushed and screened and stockpiled onto the heap leach pads. The Heap Leach Facility will be constructed in multiple stages with each stage having a heap leach pad capacity of 3 Mt. It is proposed that additional gold bearing ore be sourced from within the local area to unlock low grade resources that otherwise may not be mined.

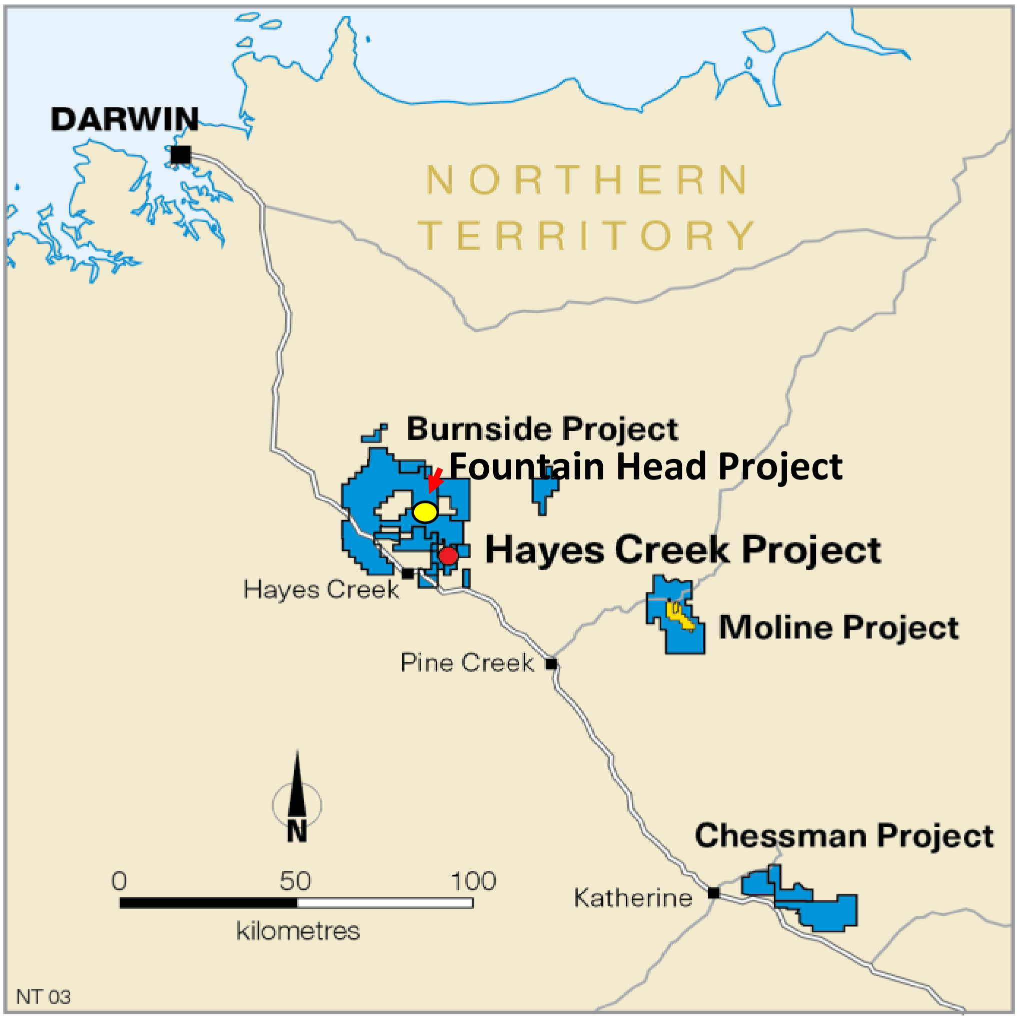

Figure 1:Location of Fountain Head gold project.

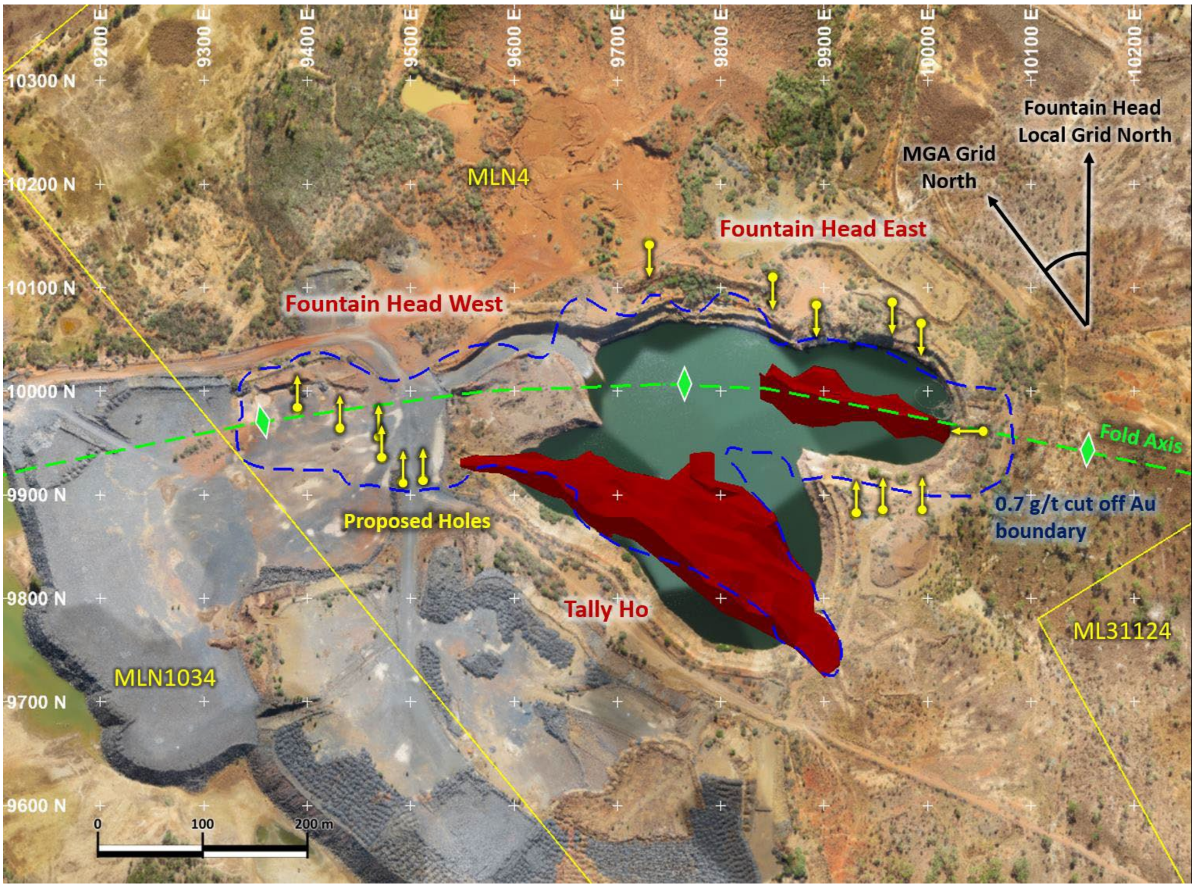

Figure 2: Plan view of the Fountain Head mineral resource (lodes in red and outline in blue) with the existing WRS to the south west of the existing pit. The Fountain Head anticline is shown in green.

The mineralisation at Fountain Head occurs within the upper units of the Mount Bonnie Formation, the uppermost division of the South Alligator Group. This comprises cyclic siltstone, mudstone and greywacke packages that have been metamorphosed to greenschist facies. In the region of the Fountain Head deposit, stratigraphy is folded along axes that strike NW-SE and plunge to the SE at shallow angles.

Gold mineralisation at Fountain Head occurs in veins as either conformable anticlinal lodes (with flanking mineralisation) or subvertical “ladder vein” styled mineralisation associated with brittle failure sub-parallel to the fold axis, and is found within mudstones, greywackes and phyllite units. Sheeted quartz vein stock-works occur mainly in the axial zone with veins predominantly dipping northeast, and some saddle reefs occur in the axial zone. The Tally Ho deposit strikes sub-parallel to the Fountain Head deposit and consists of a linear zone of mineralisation striking northwest-southeast and plunging to the southeast. The quartz veins are 1–20 cm thick and host gold with a minor pyrite-arsenopyrite association (Figure 3).

In November 2009 Crocodile Gold acquired the Fountain Head group of tenements and subsequently conducted a campaign of Acid Rock Drainage (ARD) sampling over the Fountain Head/Tally Ho waste rock stockpile to determine the acid generating potential of the waste rock. A total of 30 samples were collected and sent to MPL Laboratories (Envirolab). Results showed that all samples were classified as Non-Acid Forming (NAF) with a high safety factor. However, none of these samples originated from the current WRS, which had not been constructed at that time. The current WRS is in good condition with little to no erosion evident and the dump materials appears to have low sulphide content.

Figure 3: FHRC077D (left) from 191m showing mineralised zone, and FHRC090D (right) at 375 metres showing arsenopyrite within quartz.

Since 2018, PNX Metals have conducted a series of drilling campaigns to define the gold resource at Fountain Head. A large number of holes were drilled between June 2018 and February 2020 (Figure 4), principally using reverse circulation drilling. The drill samples generated provided a set from which appropriate samples could be selected to investigate the geochemical properties of waste rock from the proposed expanded Fountain Head pit. Samples were also excavated from the existing WRS to assess the geochemistry of material stored in the WRS, some of which is proposed to be excavated and repurposed for site construction. In addition to these samples, samples of feed stock and leached ore from batch leach testing were sourced to provide material to test the geochemical properties of ore and the residue from heap leaching which will remain in situ following completion of mining and processing.

This report details findings of geochemical test work conducted on RC drill hole samples as representative of waste rock generated during the mining operation, and rock from the existing WRS. It also provides results from test work conducted on ore and processed ore samples from metallurgical testing as representative of ore that will be stockpiled prior to processing and cyanide leached residues remaining in leach pads post treatment, respectively. Testing focused on the determining the potential of these samples to generate acid rock drainage and leach metals and metalloids under oxidative and non-oxidative conditions. Recommendations are provided as to appropriate segregation criteria that can be applied to separate potentially environmentally hazardous materials from non-hazardous rock, and possible management options to minimise adverse environmental impacts from surface storage of these materials.

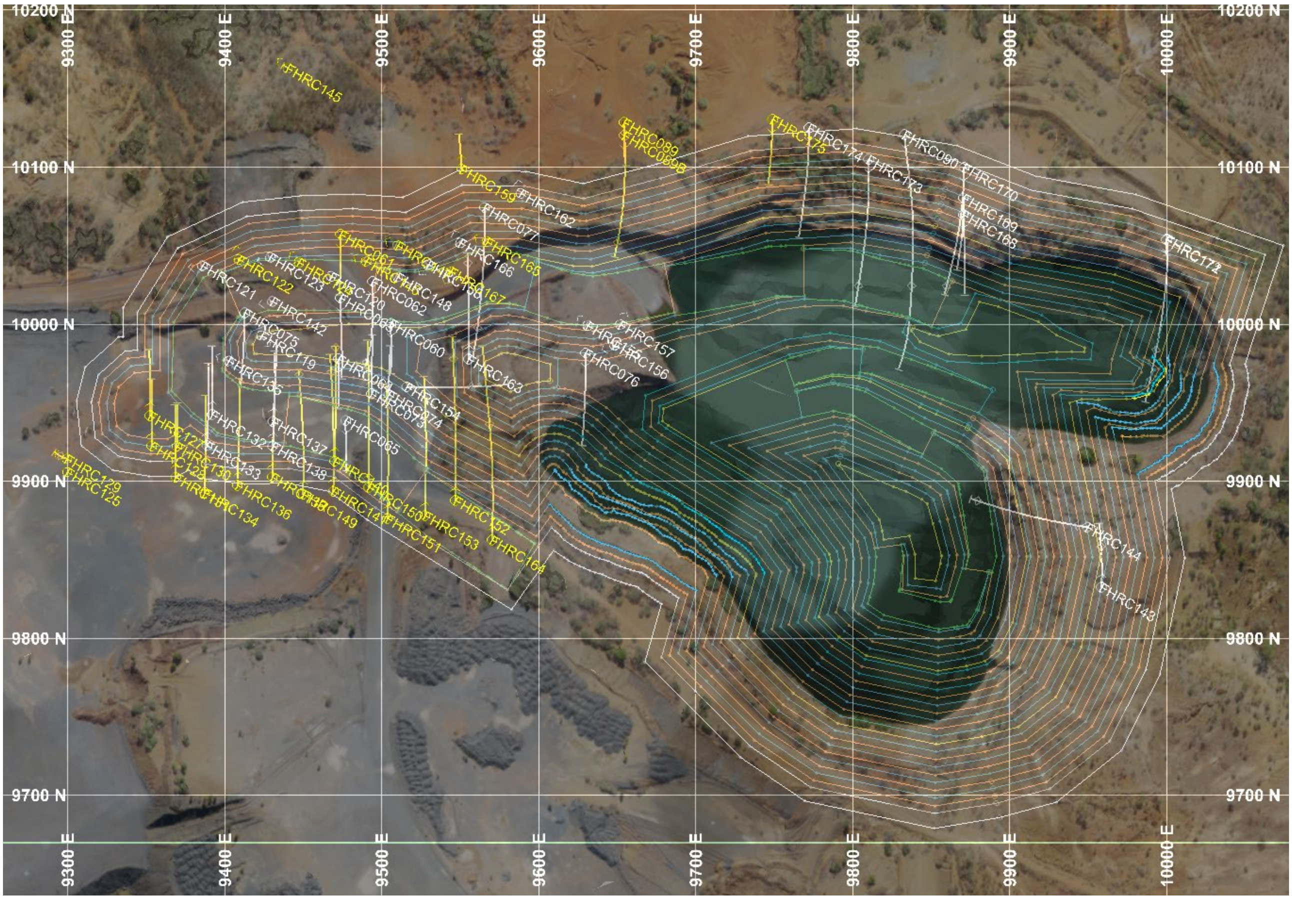

Figure 4: Traces for holes drilled in the period between June 2018 and February 2020 around the existing Fountain Head pit from which samples were selected for geochemical testing.

2. SAMPLE SELECTION

2.1. Fountain Head Pit Drill Hole Samples

To obtain rock samples which would satisfactorily represent the distribution of rock types to be mined during the expansion of the existing Fountain Head pit, a sectional based drill sample selection process was carried out. First, a set of drill holes were selected from the many drilled during resource definition drilling on key representative sections to provide a spatial representation of the materials to be mined. A combined database containing the geological logs from drilling together with assay results (portable XRF only) was then generated for the selected holes (Figure 5), and this was used as a database to select a representative sample subset for geochemical testing.

The selected drill holes provided around 1500 samples representing 1 m intervals from each hole. A value of 1 ppm Au (fire assay results) was used in most instances to delineate between ore (Au >1 ppm) and waste rock. It is understood that this value is currently used for mine planning. A subset of 216 samples was selected from the broader sample set to span the range of materials that will remain in permanent emplacements following mine closure, and cover the variation in lithology, oxidation and chemical composition of the waste rock, while also covering the entire depth of the hole contained within the proposed expanded pit. Note that samples were selected to represent the variation in geochemical properties of the different waste rock types, but not necessarily to accurately represent the overall proportion and distribution of geochemical types that may be mined. However, the results would still provide an indication of ARD potential for the different waste material types.

A smaller set of 111 samples were selected from the 216 samples for initial testing.

Figures 6 and 7 show distributions of rock types and oxidation for the full set, selected and tested sample sets respectively, demonstrating the representativeness of the tested sample set regarding lithology and oxidation profiles. Figures 8 to 13 show the distributions concentrations of various elements in the various sample sets, based on portable XRF analysis. These figures demonstrate good correlation between the selected and tested sample sets, showing the tested samples were representative of the larger selected sample set. However, for some elements, particularly sulphur, the tested sample set was slightly biased toward the upper end of the concentration range in comparison to the full sample set for all selected drill holes. This was deliberate to obtain sufficient samples containing elevated sulphur concentrations which may lead to acid formation, and thereby allow clear definition of possible sulphur cut-off grades which might define PAF wastes.

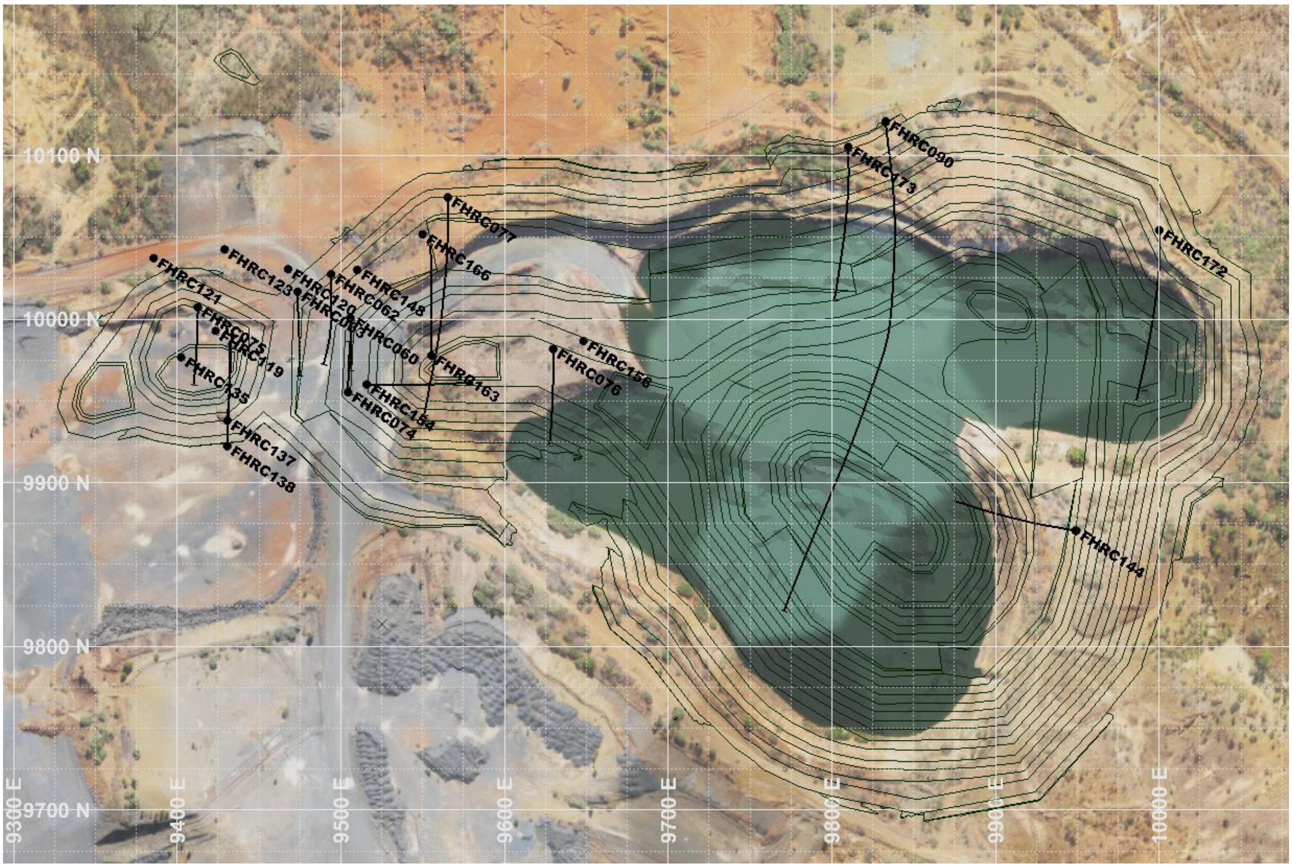

Figure 5: Traces for drill holes from which samples were selected for geochemical testing.

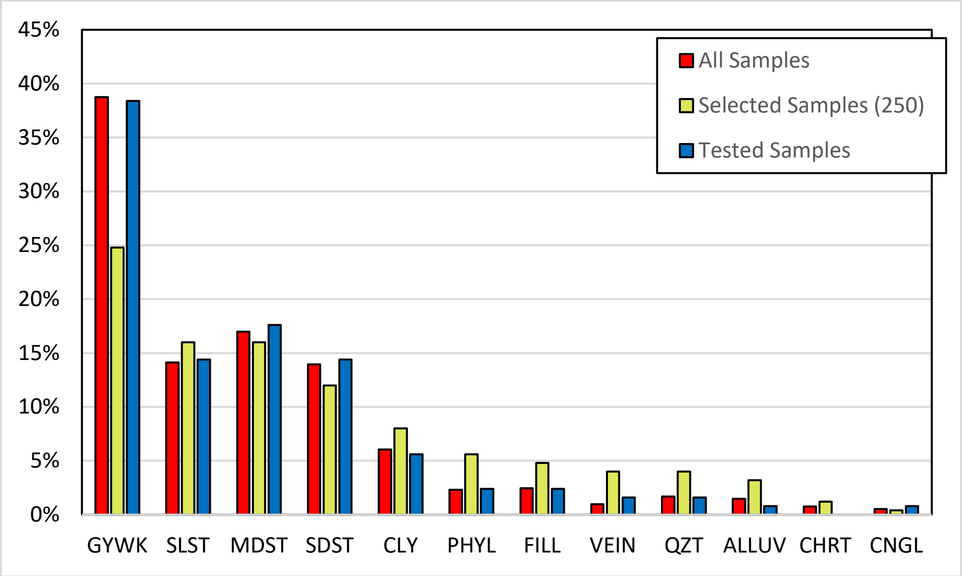

Figure 6: Percent samples from each lithology for all samples from the drill holes shown in Figure 5, samples initially selected for testing and the sub-set of samples which underwent testing. Lithology codes for Fountain Head are provided in Appendix A.

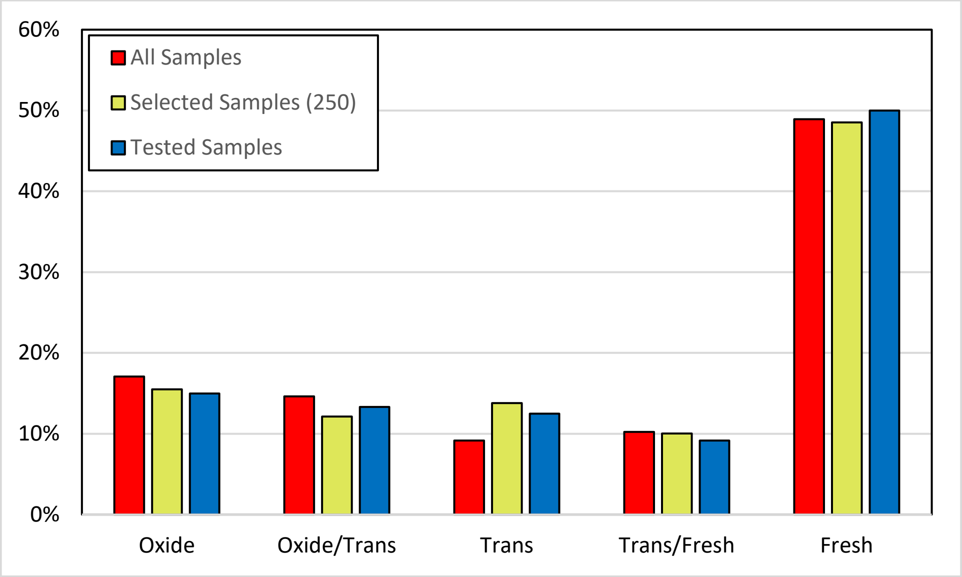

Figure 7: Percent samples from each oxidation state (fully oxidised to fresh) for all samples from the drill holes shown in Figure 5, samples initially selected for testing, and the sub-set of samples which underwent testing.

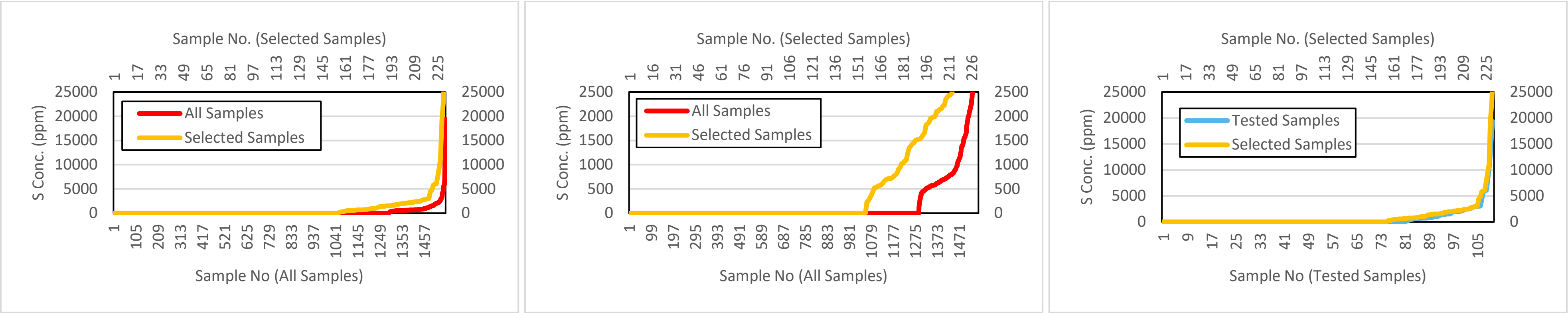

Figure 8: Sulphur concentrations in all samples from the drill holes shown in Figure 5 together with samples initially selected for testing (left), same figure with expanded y-axis (middle), and samples initially selected for testing together with the sub-set of samples which underwent testing (right).

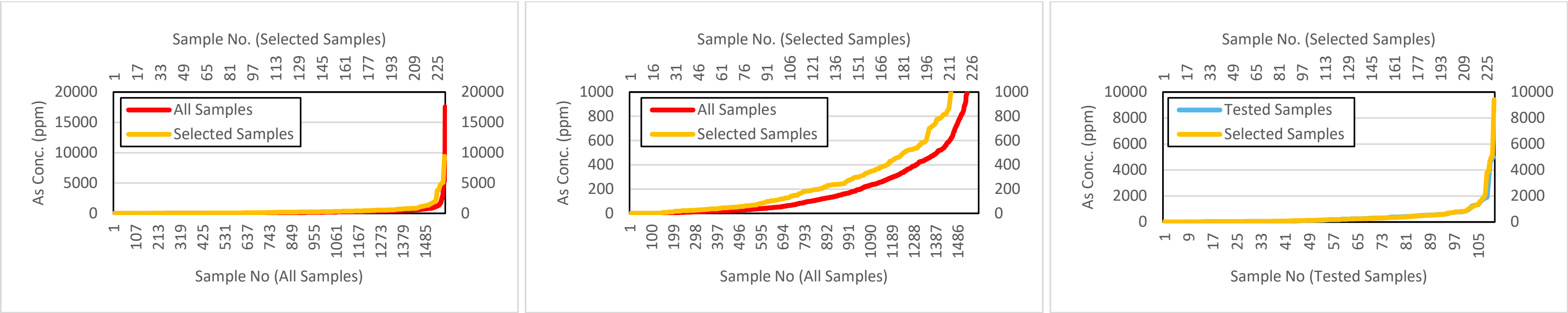

Figure 9: Arsenic concentrations in all samples from the drill holes shown in Figure 5 together with samples initially selected for testing (left), same figure with expanded y-axis (middle), and samples initially selected for testing together with the sub-set of samples which underwent testing (right).

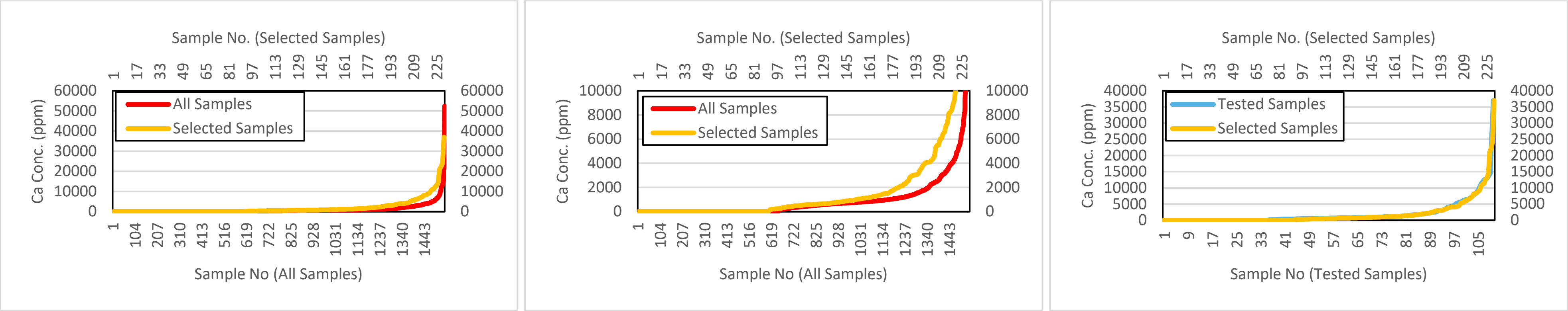

Figure 10: Calcium concentrations in all samples from the drill holes shown in Figure 5 together with samples initially selected for testing (left), same figure with expanded y-axis (middle), and samples initially selected for testing together with the sub-set of samples which underwent testing (right).

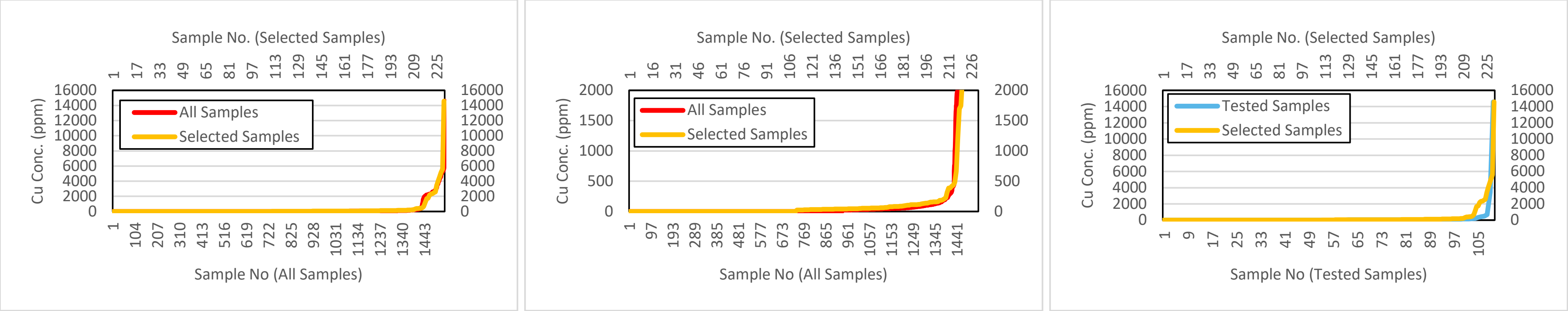

Figure 11: Copper concentrations in all samples from the drill holes shown in Figure 5 together with samples initially selected for testing (left), same figure with expanded y-axis (middle), and samples initially selected for testing together with the sub-set of samples which underwent testing (right).

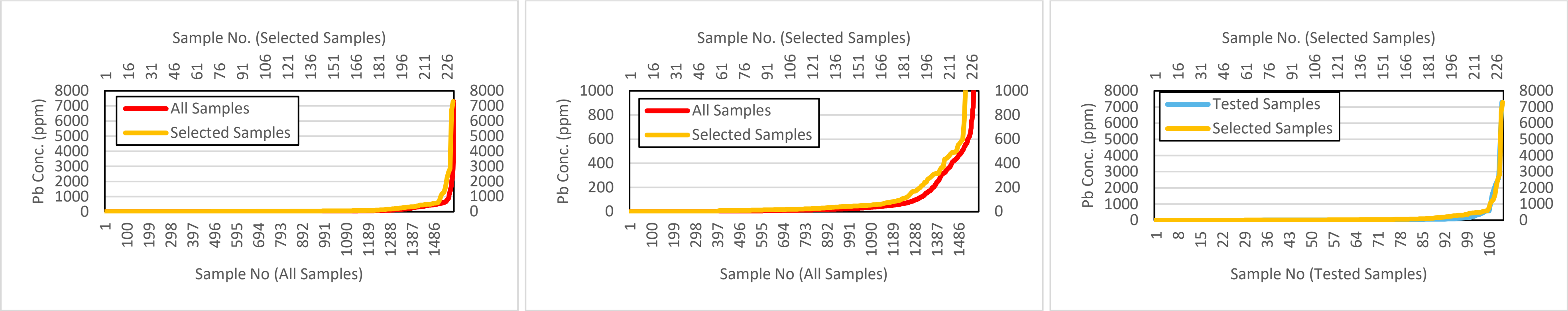

Figure 12: Lead concentrations in all samples from the drill holes shown in Figure 5 together with samples initially selected for testing (left), same figure with expanded y-axis (middle), and samples initially selected for testing together with the sub-set of samples which underwent testing (right).

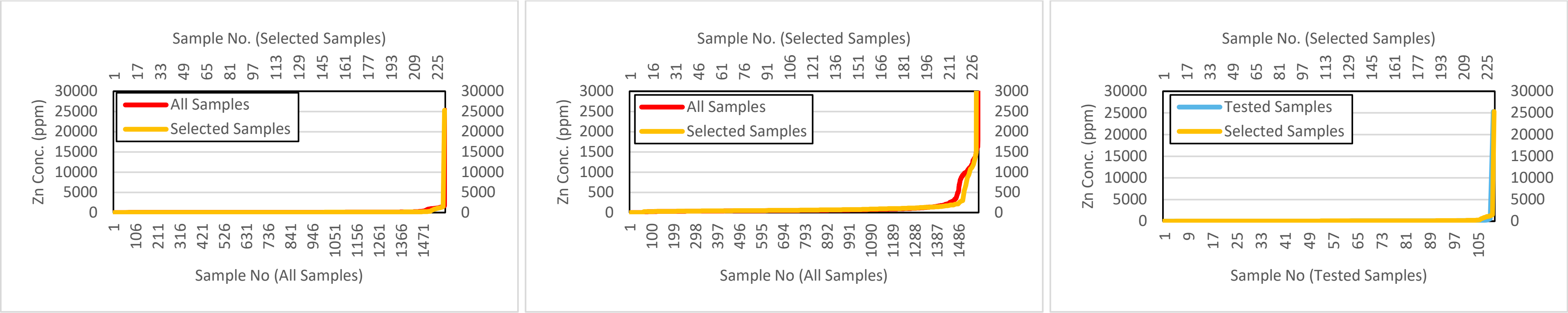

Figure 13: Zinc concentrations in all samples from the drill holes shown in Figure 5 together with samples initially selected for testing (left), same figure with expanded y-axis (middle), and samples initially selected for testing together with the sub-set of samples which underwent testing (right).

2.2. Existing Fountain Head WRS Samples

Some material from the existing waste rock stockpile will be used for the construction of haul roads and other mine infrastructure, and the remaining waste rock will be contained in the final WRS to be rehabilitated at closure. Hence samples were collected from the existing dump for geochemical testing to better understand the ARD potential of these placed materials. Sampling locations for the WRS samples are shown in Figure 14. Samples were collected using an excavator at 1 m intervals to a depth of 3 m at each of 15 locations. Subsequently, samples from each depth at six of these locations (red circles Figure 14) were selected for geochemical testing (total 18 samples). Locations were selected to cover the majority of the WRS and visual variations in rock types within the stockpile. Two sampling locations (FHWR 08 and FHWR10) were specifically targeted for testing, as these locations are closest to the waste rock that will be removed and used for construction purposes prior to expansion of the pit.

Figures 15 and 16 show box plots for concentrations of various elements in samples collected from all the locations shown in Figure 14, and for samples selected for geochemical testing. Comparison of the box plots for the two sets show the tested samples were in general chemically similar to all of the sampled rock, although the significantly higher mean sulphur concentration for the complete sample set, reflects the presence of several samples with significantly higher sulphur than occur in the test sample set.

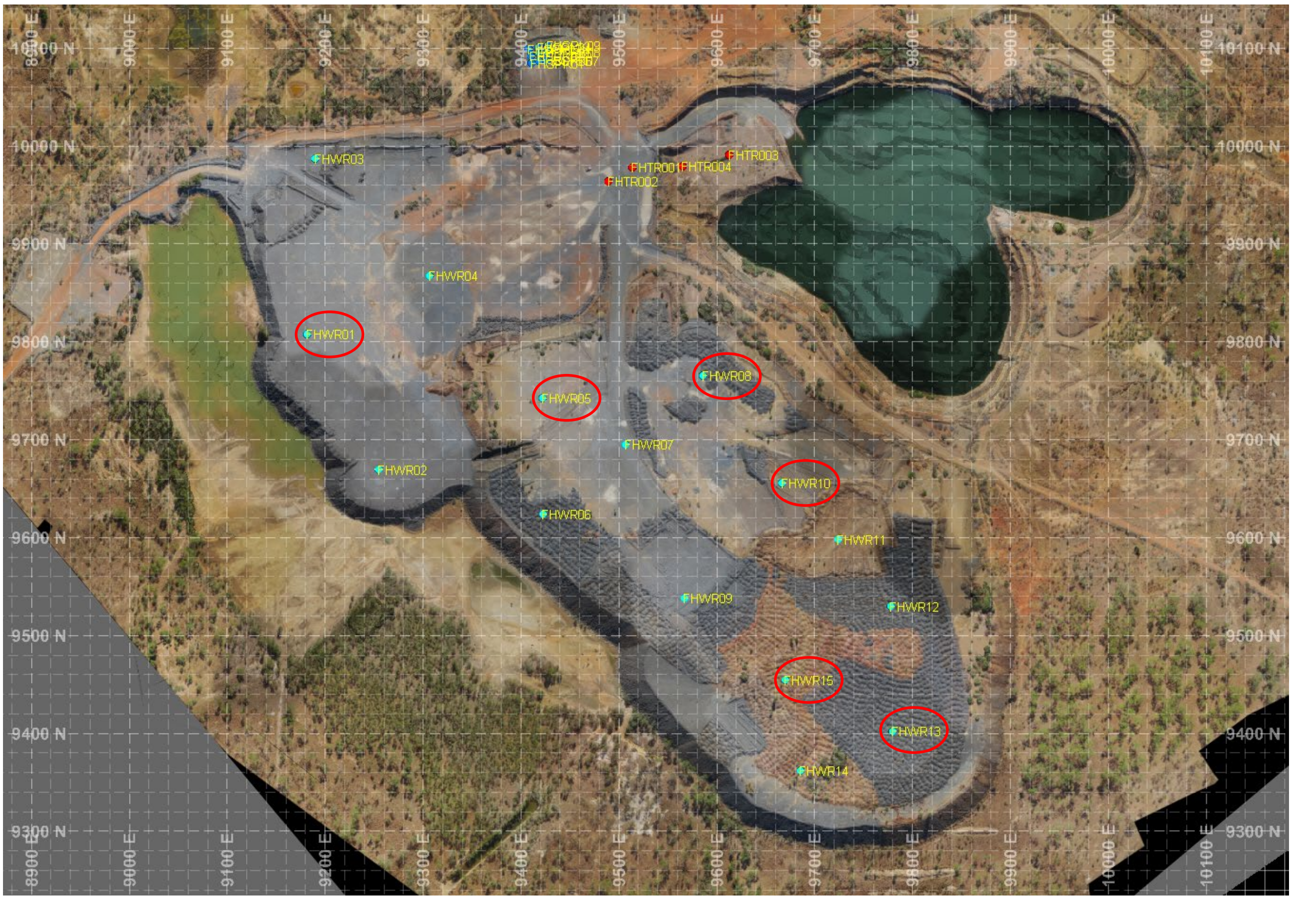

Figure 14: Sampling locations for samples collected from the existing Fountain Head WRS for geochemical testing (blue dots). Samples from locations circled in red were selected for testing.

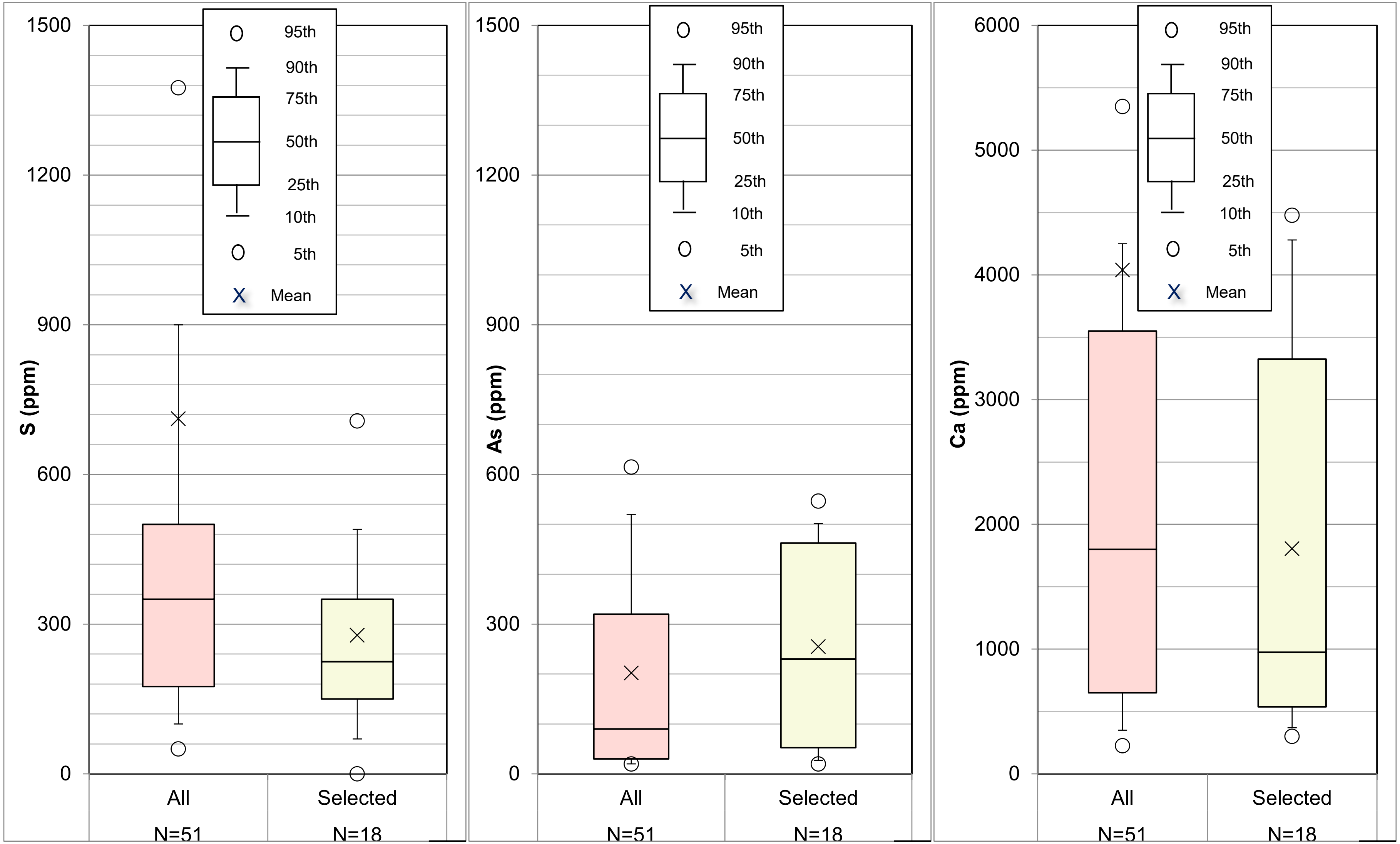

Figure 15: Box plots showing sulphur (left), arsenic (middle) and calcium (right) concentrations in all samples collected from excavation of the Fountain Head WRS and samples selected for testing.

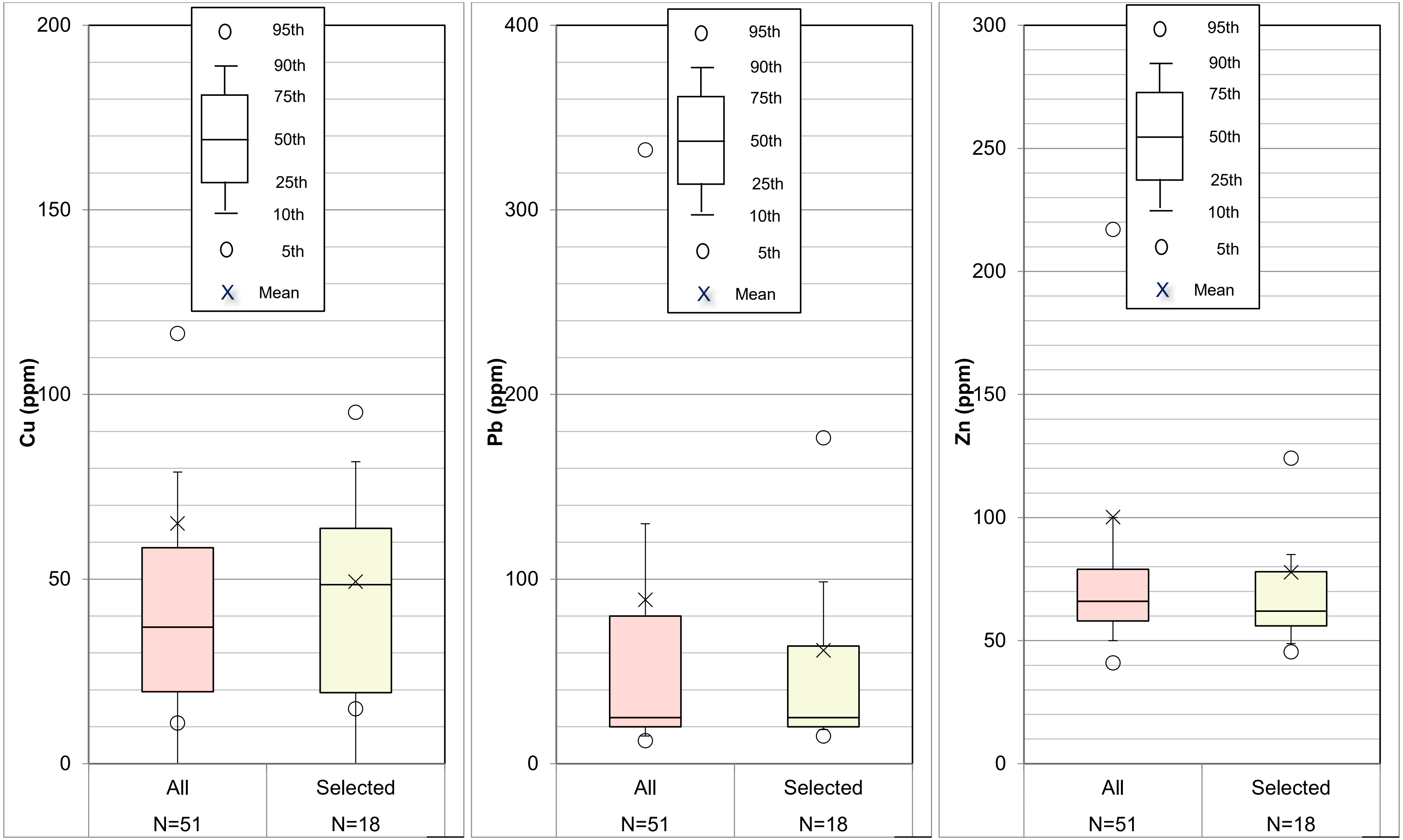

Figure 16: Box plots showing copper (left), lead (middle) and zinc (right) concentrations in all samples collected from excavation of the Fountain Head WRS and samples selected for testing.

2.3. Ore and Metallurgical Test Samples

It is proposed that mined ore will be stored in a ROM stockpile prior to construction of the heap leaching pads. Following leaching, heap leach pads will remain in place and will be rehabilitated at closure. Consequently, materials were sought which would be representative of typical ore which will be stored in the ROM stockpile and cyanide leached ore as representative of material remaining within the heap leach pads at closure.

Three composite samples were available from metallurgical testing, which were used for investigating the geochemical properties of ore and leached ore. These samples were made by compositing rock collected from trenches which were dug to a depth of 2 to 3 m at the locations shown in Figure 17. For each of the three locations, untreated samples (Head samples) and the same samples following bottle roll cyanide leach tests (Residue) were obtained for geochemical testing.

Figure 17: Sampling locations for samples used for cyanide leach tests. Composite samples from sites UB#1, UB#2 and LB#3, together with the corresponding cyanide leached samples, were used for geochemical testing.

3. METHODOLOGY

3.1. Sample Preparation

RC drill samples were collected and prepared by PNX Metals personnel in accordance with JORC compliant methods. All samples, including WRS and ore/metallurgical samples were received by EGi from third party laboratories as pulp samples and were used for all test work as received.

3.2. Analytical Programme

The following tests were carried out on all 111 drill hole samples, 18 WRS samples and 6 ore/metallurgical samples:

- Total sulphur (S);
- pH and EC on deionised water extracts at a ratio of 1 part solid to 2 parts water ($pH_{1:2}$ and $EC_{1:2}$);
- Single addition net acid generation (NAG) test; and
- Acid neutralising capacity (ANC)

Replicate analyses for NAG and ANC determinations were made for 12 samples (approximately 1 in 10 samples).

To assist in understanding the ARD characteristics of samples where ARD classification was not clear based on the above tests, more detailed testing was conducted on 12 selected samples (11 drill hole samples and 1 WRS sample). Tests included:

- Acid buffering characteristic curve (ABCC) testing to define the relative availability of the measured ANC;
- Carbon speciation analysis (Total C, organic C and inorganic C) to determine carbonate content; and
- Chromium reducible sulphur (CRS) to quantify the amount of pyritic sulphur.

In addition to the above tests, leach tests were conducted on a number of samples to provide information on the leaching characteristics of various metals and other elements of concern. Testing included:

- Multi-element testing of the sample solid (19 drill hole samples, multi-element assay results were available for WRS and ore/metallurgical samples);
- Peroxide extraction testing including multi-element assay of the extract (9 drill hole samples); and
- Water extraction testing including multi-element assay of the extract (19 drill hole samples, 3 WRS samples and 2 ore/metallurgical samples).

Total sulphur and carbon speciation analyses were conducted using a combustion furnace method (LECO). CRS analyses were conducted using an in-house method based on the method of Burton et al. (2008)[1] and were carried out by ALS Laboratory Group (Brisbane) using NATA registered procedures.

Multi-element analyses of solid samples and water and peroxide extracts were also carried out by ALS Laboratory Group (Brisbane) using NATA registered procedures. Solids were digested using 4-acid digest method (hydrofluoric, nitric, perchloric and hydrochloric acids) or aqua regia. The aqua regia digests were analysed for Hg by inductively coupled plasma mass spectrometry (ICP-MS), and the multi-acid digests were analysed for a suite of 35 elements using a combination of ICP-MS and inductively coupled plasma atomic emission spectrometry (ICP-AES).

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[1] Burton, E.D., Sullivan, L.A., Bush, R.T., Johnston, S.G., Keene, A.F., 2008. A simple and inexpensive chromium-reducible sulfur method for acid-sulfate soils. Applied Geochemistry 23, 2759-2766.

Water extracts were produced by mixing 70 g of sample in 350 g of deionised water (i.e. a solid:liquor ratio of 1:5) and agitating the slurry for 16 hours. At completion, the pH and electrical conductivity of the extract were recorded, and the liquor fraction was filtered through a 0.45 micron membrane filter. A portion of the filtrate was used to measure alkalinity and a second portion preserved with a few drops of high purity nitric acid and dispatched to ALS. Samples were analysed for a suite of 32 elements using a combination of ICP-MS, ICP-AES, and specific methods for Cl, Hg and F.

Peroxide extracts were produced by following the NAG procedure where 2.5 g of sample is mixed with 250 ml of 15% hydrogen peroxide (i.e. a solid:liquor ratio of 1:100) and allowed to react overnight. The sample was then gently heated to accelerate the oxidation of any remaining sulphides, then vigorously boiled for several minutes to decompose residual peroxide. After cooling, the pH of the solution was measured (NAGpH) and the liquor fraction was filtered through a 0.45 micron membrane filter. The filtrate was preserved with a few drops of high purity nitric acid and dispatched to ALS. Samples were analysed as per the water extracts.

All other analyses were carried out by EGi. A general outline of ARD methods and approaches used by EGi is provided in Appendix B.

4. GEOCHEMICAL CHARACTERISATION RESULTS

4.1. Pit Expansion Drill Samples

Acid forming characteristics of pit expansion drill samples are presented in Appendix C, Table C1, comprising pH and EC of water extracts, total S, CRS, maximum potential acidity (MPA), ANC, ABCC readily available ANC, total C, organic C, inorganic C, NAPP, ANC/MPA ratio and single addition NAG.

The $pH_{1:2}$ values showed no inherent acidity, ranging from 6.6 to 9.2. $EC_{1:2}$ values ranged from 0.08 to 0.62 dS/m with all samples falling within the non-saline to slightly saline range with an EC of 0.8 dS/m or less. Results indicate no immediately available acidity and low salinity in these samples.

Total S showed a broad range up to 3%S, but with the vast majority (90%) having a relatively low S value of 0.5%S or less.

ANC was relatively low, ranging up to 33 kg H_2SO_4/t, indicating a general lack of excess buffering.

The NAPP value is an acid-base account calculation using measured total S and ANC values. It represents the balance between the 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. Note that sulphidic materials with sufficient ANC to prevent acid generation may still produce saline and metalliferous drainage under circum-neutral pH conditions.

Figure 18 is an acid-base account plot of ANC verses total S. Figure 19 is the same as Figure 18, but re-scaled to better represent S below 1%S and ANC values below 50 kg H_2SO_4/t. 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 acid drainage.

The plots highlight the narrow clustering of ANC values for a range of S values, with most samples plotting in the NAPP negative domain, and most of those having ANC/MPA ratios of 2 or more, indicating a high factor of safety. Only 10 samples plotted in the NAPP positive domain.

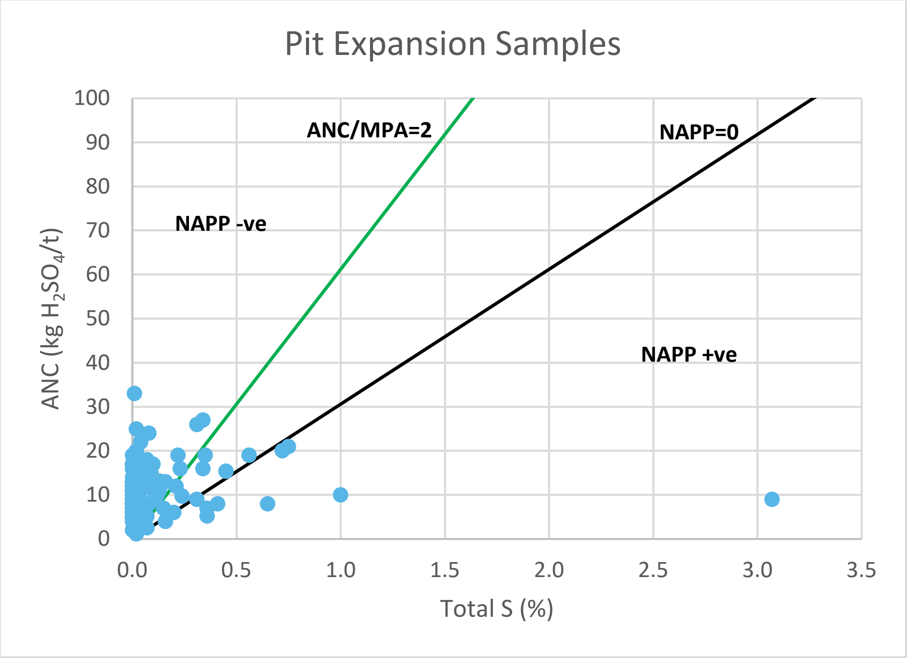

Figure 18: Acid-base account (ABA) plot for drill hole samples from the Fountain Head pit.

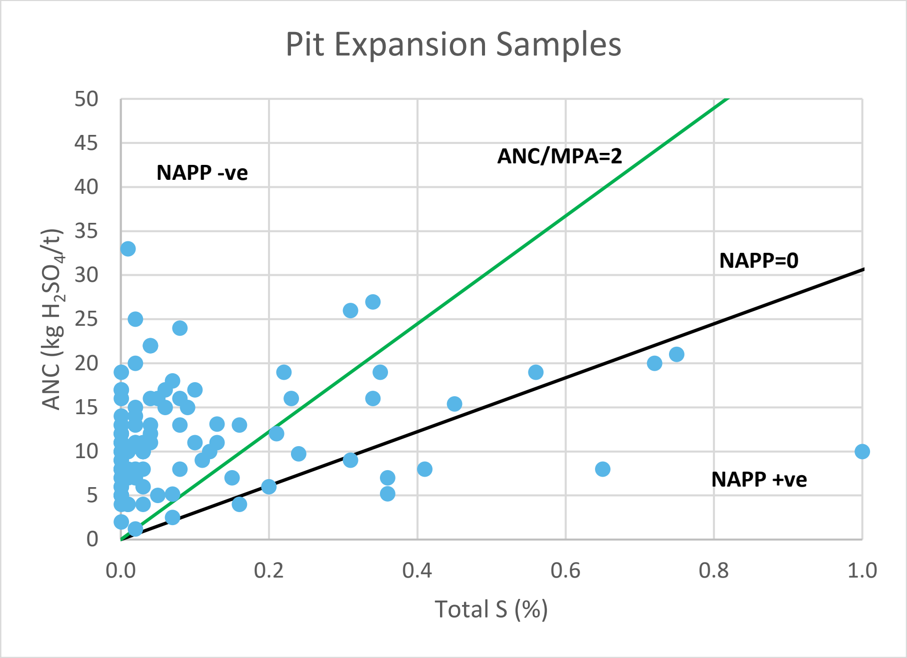

Figure 19: As for Figure 18 with expanded axes.

NAG test results are used in conjunction with NAPP values to classify samples according to acid forming potential. The majority (70%) of NAGpH values were 4.5 or greater, indicating most samples are likely to be NAF. Generally, a NAGpH value less than 4.5 indicates a sample may be acid forming, but where a sample is non-reactive with low ANC, residual peroxide in the NAG solution can give a marginally acidic result unrelated to ARD.

Figure 20 is an ARD classification plot showing NAGpH versus NAPP value. 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.

Most (77) of the samples plotted in the NAF quadrant, with 10 samples plotting in the PAF region. However, a significant number of samples (24) plotted in the lower left uncertain quadrant, where ABA analysis suggested NAF classification (NAPP -ve) and NAGpH was <4.5. Of the 24 samples classified as UC, 14 gave a NAGpH of between 4 and 4.5 (circled in red in Fig. 18). A significant number (6) of these samples had a Total S content of less than 0.1%, which would not normally provide a NAGpH below 4.5. Analysis of a "blank" NAG sample, gave a NAGpH of 4.1, suggesting the hydrogen peroxide used in the NAG tests contained a small amount of acidity. Where samples had a low S of 0.5%S or less, an ANC/MPA ratio of 2 or more (indicating a high factor of safety), and a NAGpH of between 4.0 and 4.5 the samples was classified NAF due to the low potential for generation of significant acidity.

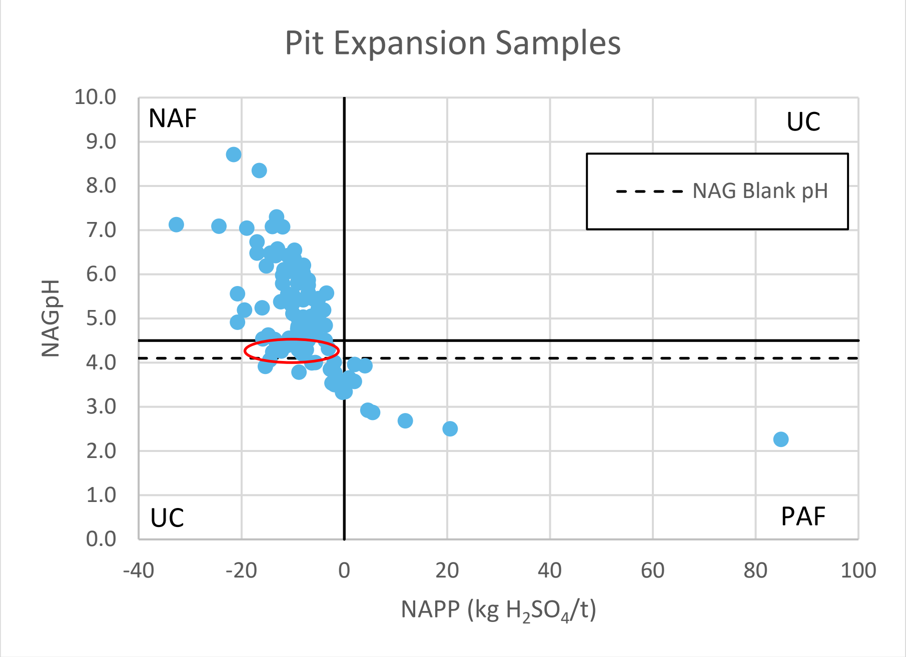

Figure 20: ARD classification plot for drill hole samples from the Fountain Head pit.

For the remaining samples plotting in the UC region of the ARD plot, further detailed testing was undertaken to help understand the geochemical properties of these materials. Testing included CRS analysis to determine the sulphide content, C speciation to establish the carbonate content and ABCC testing to determine readily available neutralising capacity of these materials. In addition to these tests, replicate analyses were conducted for these samples including Total S, ANC and NAG tests. This was done to confirm the original results used to determine ARD classifications, and to provide an indication of the precision of the analysis. The results of these additional tests are shown below in Tables 1 to 5. Note, in addition to the samples plotting in the UC quadrant, sample (EGi Code 18960) was also included in the set of samples that underwent additional testing, because this sample reacted vigorously in the NAG test, despite a Total S of 0.35%. Typically, samples with relatively low sulphur content such as this would not show significant reaction in the NAG test, and additional testing was expected to provide further understanding of the ARD properties of this material.

Replicate NAG test results (Table 1.) demonstrate excellent reproducibility (RSD <4%) and confirm the NAGpH of the UC samples. The reproducibility of the ANC test (Table 2) was not as good as the NAG test, with RSD up to 30%. However, results confirm that in many instances, there is only moderate to low ANC available in these samples, ranging from 1 to 27 kg H2SO4/t. The very low ANC, in many instances close to the detection limit of the ANC measurement, in part explains the higher RSD for replicate measurements made for these samples.

Replicate Total S results (Table 3.) demonstrate good reproducibility (RSD <10%) and confirm the sulphur content of samples classified as UC. CRS measurements demonstrate that greater than 90% of sulphur is contained in sulphide minerals for all but one sample. This sample (EGi Code 18955) gave a CRS value which was only about 20% of the Total S value, suggesting the presence of non-acidic sulphate salts (paste pH 7.7).

Carbon speciation analysis results (Table 4) indicate the carbonate content of UC samples is negligible, with the total carbon content of these samples generally low. These results are consistent with ABCC test results which also suggest little carbonate content. Consequently, it appears that a significant proportion of the ANC measured for these samples is provided by dissolution of relatively reactive silicate minerals rather than carbonate minerals. It is likely that much of this silicate ANC may not be available under the much milder NAG test conditions, where only carbonates are likely to dissolve at an appreciable rate[2].

ABCC test results are provided in Table 5. ABCC plots are provided in Appendix F. The results indicate there is very limited carbonate neutralising capacity available in the UC samples, with the maximum measured effective ANC of 11 kg H_2SO_4/t and most samples well below 10 kg H_2SO_4/t. ABCC test results also indicate that the small amount of carbonate present in these samples is predominantly iron carbonates (ferroan dolomite, siderite), which will react relatively slowly.

For the sample (EGi Code 18960) that also underwent additional testing because it reacted vigorously in the NAG test despite a relatively low Total S of 0.35%, results from detailed testing demonstrated that all sulphur was likely pyritic, and that this material contained virtually no readily available neutralising capacity. Consequently, the sample underwent rapid oxidation of the sulphides, accompanied by a decrease in pH and dissolution of lead-containing minerals, resulting in elevated concentrations of lead ions in the NAG liquor. Hydrogen peroxide decomposition is known to be particularly rapid in the presence of lead ions[3], usually resulting in a vigorous reaction with elevated temperatures due to the exothermic nature of the decomposition. Other samples which underwent significant reaction during the NAG test also gave elevated concentrations of lead in the liquor, indicating this was likely a significant contributor to the observed reactivity.

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[2] Dyantyi, N., 2014. Application of mineralogy in the interpretation of laboratory scale acid rock drainage (ARD) prediction tests: A gold case study, Department of Chemical Engineering. University of Cape Town, Cape Town, South Africa.

[3] Ian Wark Research Institute and Environmental Geochemistry International, 2002. AMIRA Project P387A Prediction & Kinetic Control of Acid Mine Drainage, Final Progress Report, January 2002.

Table 1: Results from replicate NAG analyses.

EGI CODE	HOLE ID	SAMPLE ID	DEPTH (m)		NAGpH			
			From	**To**	**Original**	**Replicate**	**Average**	**RSD**
18929	FHRC060	183084	5	6	3.5	3.6	3.6	1%
18955	FHRC063	183413	76	77	3.8	3.6	3.7	3%
18960	FHRC074	184543	40	41	2.9	2.9	2.9	1%
18983	FHRC077	184853	51	52	3.3	3.4	3.4	1%
18984	FHRC077	184860	58	59	3.9	4.0	4.0	2%
19049	FHRC163	196511	20	21	3.5	3.5	3.5	1%
19052	FHRC163	196558	62	63	3.9	3.9	3.9	1%
19077	FHRC173	197685	43	44	3.6	3.6	3.6	1%
19078	FHRC173	197707	63	64	3.5	3.4	3.5	2%
19202	FHRC138	193833	37	38	3.8	3.8	3.8	0%
19359	FHRC148	194984	39	40	3.9	3.9	3.9	1%

Table 2: Results from replicate ANC analyses. Units are kg H_2SO_4/t unless otherwise indicated. Replicate results shown in italics were made using a different fizz rating to the original measurement and are therefore not true replicate measurements

EGI CODE	HOLE ID	SAMPLE ID	DEPTH (m)		ANC					
			From	**To**	**Original**		**Replicate**		**Average**	**RSD**
					Fizz	**Result**	**Fizz**	**Result**		
18929	*FHRC060*	*183084*	*5*	*6*	*1*	*1*	*0*	*1*	*1*	*32%*
18955	FHRC063	183413	76	77	1	19	1	19	19	1%
18960	*FHRC074*	*184543*	*40*	*41*	*1*	*12*	*0*	*5*	*9*	*55%*
18983	*FHRC077*	*184853*	*51*	*52*	*1*	*10*	*0*	*3*	*6*	*83%*
18984	FHRC077	184860	58	59	1	32	1	21	27	29%
19049	FHRC163	196511	20	21	1	8	1	11	10	19%
19052	*FHRC163*	*196558*	*62*	*63*	*0*	*7*	*1*	*9*	*8*	*22%*
19077	FHRC173	197685	43	44	1	9	1	10	9	6%
19078	FHRC173	197707	63	64	1	14	1	17	15	12%
19202	FHRC138	193833	37	38	1	11	1	15	13	18%
19359	*FHRC148*	*194984*	*39*	*40*	*1*	*6*	*0*	*4*	*5*	*36%*

Table 3: Results from replicate S analyses and CRS analyses. Units are % unless otherwise indicated.

EGI CODE	HOLE ID	SAMPLE ID	DEPTH (m)		TOTAL S			CRS	CRS/ TOTAL S
			From	To	Original	Replicate	RSD		
18929	FHRC060	183084	5	6	0.01	0.01	0%	0.02	2.0
18955	FHRC063	183413	76	77	0.56	0.62	7%	0.11	0.19
18960	FHRC074	184543	40	41	0.35	0.37	4%	0.36	1.0
18983	FHRC077	184853	51	52	0.07	0.08	9%	0.07	0.93
18984	FHRC077	184860	58	59	0.38	0.39	2%	0.34	0.88
19049	FHRC163	196511	20	21	0.24	0.23	3%	0.24	1.0
19052	FHRC163	196558	62	63	0.15	0.14	5%	0.15	1.0
19077	FHRC173	197685	43	44	0.28	0.32	9%	0.31	1.0
19078	FHRC173	197707	63	64	0.44	0.49	8%	0.45	1.0
19202	FHRC138	193833	37	38	0.14	0.14	0%	0.13	0.93
19359	FHRC148	194984	39	40	0.08	0.07	9%	0.07	0.93

Table 4: Results from carbon speciation analyses. Units are % unless otherwise indicated.

EGI CODE	HOLE ID	SAMPLE ID	DEPTH (m)		TOTAL C	ORGANIC C	INORGANIC C	ANC$_{IC}$[1]
			From	To				
18929	FHRC060	183084	5	6	0.12	0.15	<0.02	<2
18955	FHRC063	183413	76	77	0.10	0.11	<0.02	<2
18960	FHRC074	184543	40	41	0.18	0.19	<0.02	<2
18983	FHRC077	184853	51	52	0.05	0.07	<0.02	<2
18984	FHRC077	184860	58	59	0.25	0.26	<0.02	<2
19049	FHRC163	196511	20	21	0.20	0.21	<0.02	<2
19052	FHRC163	196558	62	63	0.05	0.06	<0.02	<2
19077	FHRC173	197685	43	44	0.07	0.09	<0.02	<2
19078	FHRC173	197707	63	64	0.08	0.09	<0.02	<2
19202	FHRC138	193833	37	38	0.04	0.05	<0.02	<2
19359	FHRC148	194984	39	40	0.05	0.06	<0.02	<2

1. ANC$_{IC}$ (kg H_2SO_4/t) = INORGANIC C (%) x 81.7 and assumes all inorganic C is present as calcite

Table 5: Results from ABCC analyses. Units are kg H_2SO_4/t unless otherwise indicated.

EGI CODE	HOLE ID	SAMPLE ID	DEPTH (m)		EFFECTIVE ANC (to pH4)	ANC	EFFECTIVE ANC	TYPE OF CARBONATE BUFFERING
			From	**To**				
18929	FHRC060	183084	5	6	3	1	270%	Ferroan Dolomite
18955	FHRC063	183413	76	77	11	19	55%	Ferr Dol/ Siderite
18960	FHRC074	184543	40	41	2	5	42%	Ferr Dol/ Siderite
18983	FHRC077	184853	51	52	2	3	78%	Ferr Dol/ Siderite
18984	FHRC077	184860	58	59	6	27	22%	Ferr Dol/ Siderite
19049	FHRC163	196511	20	21	6	10	65%	Ferroan Dolomite
19052	FHRC163	196558	62	63	5	7	70%	Dol/ Ferroan Dol
19077	FHRC173	197685	43	44	3	9	33%	Ferr Dol/ Siderite
19078	FHRC173	197707	63	64	5	15	35%	Ferroan Dolomite
19202	FHRC138	193833	37	38	6	13	47%	Ferroan Dolomite
19359	FHRC148	194984	39	40	4	5	76%	Ferroan Dolomite

The results and discussions presented above were used to classify samples as NAF, PAF, PAF-LC or UC in Table C1. PAF-LC samples are defined as having an acid capacity of 5 kg H_2SO_4/t or less. All samples with S values of less than or equal to 0.05%S were classified NAF due to the negligible risk of acid formation. Around 80% of samples tested were classified NAF (including UC equivalents), 15% PAF-LC (including UC equivalents) and 5% PAF. Overall results indicate most waste materials to be mined will be NAF, with a minor proportion of PAF. Although the proportion of PAF materials is likely to be minor, quantification of the distribution of PAF materials will be required ahead of mining and selective handling and management carried out during mining to ensure PAF materials are not a source of ARD during operations and at closure. Quantifying the proportion of PAF will require more extensive testing and block modelling.

4.2. WRS Samples

The full set of test results and final ARD classifications for the Fountain Head WRS samples are provided in Table D1.

An ARD Classification plot for the WRS samples is provided in Figure 21. The majority of WRS samples were clearly classified as NAF. The tested samples contained very little sulphur (<0.08%) and consequently are unlikely to generate any acidity, despite the generally low level of neutralising material (ANC <20 kg H_2SO_4/t). Several samples gave a NAGpH between 4.0 and 4.5 but very low titrated acidity, suggesting the NAGpH below 4.5 reflects the low level of acidity present in the peroxide used for the tests. One sample (WRD015) gave a low NAGpH (3.6) with very little sulphur and ANC. This sample was included with the drill hole samples for more detailed testing as described above. The results of these tests are provided in Table 6.

Results confirm the low concentration of sulphur in this sample, which is essentially all present as sulphide S. The low amount of neutralising capacity in this sample was also confirmed with negligible ANC measured when the test was repeated at fizz rating 0. It is likely the lack of any neutralising minerals in this material that resulted in acidic pH in the sample during NAG testing despite the low sulphur content. The sample was therefore conservatively classified as UC(PAF-LC), but is likely to have very little reactivity.

Notably, all samples taken from locations FHWR08 and FHWR10 were all classified as NAF with ANC/MPA ratios well above 2, indicating that waste rock represented by the samples tested is very unlikely to produce any ARD and therefore suitable for infrastructure construction. Note that only limited samples were tested, and more widespread follow up testing (S only required initially) is recommended.

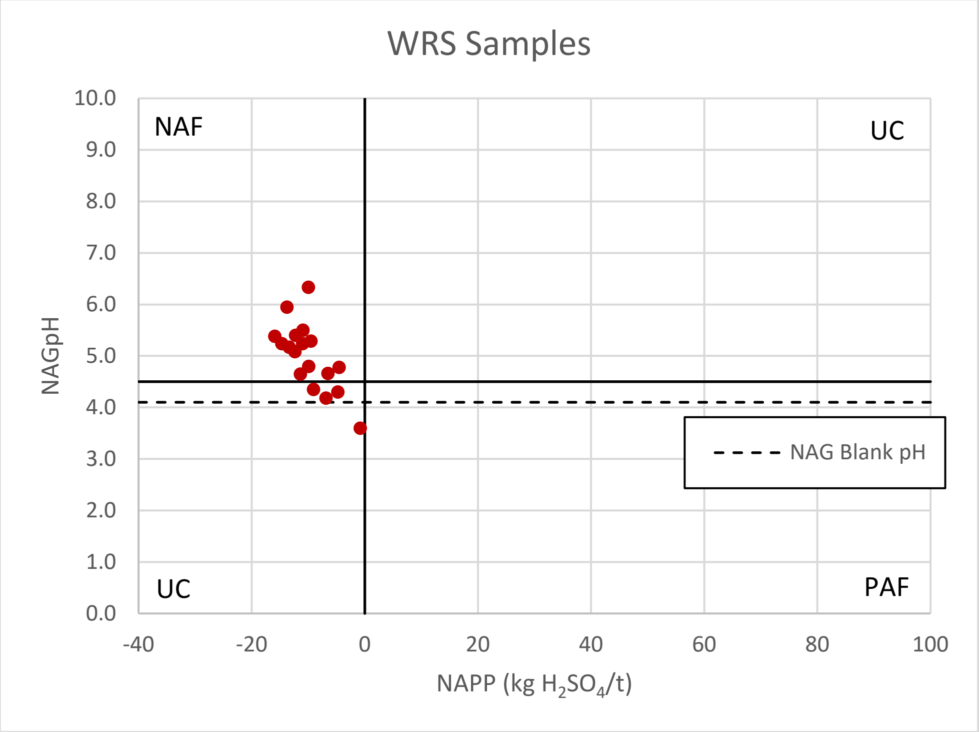

Figure 21: ARD classification plot for WRS samples from Fountain Head.

Table 6: Results for geochemical testing of sample WRD015 from the Fountain Head WRS. Values in parentheses show the fizz rating used in the ANC test.

TEST	UNIT	ORIGINAL RESULT	REPLICATE RESULT
ANC	kg H_2SO_4/t	9 (1)	3 (0)
NAGpH	-	3.6	3.6
NAG $_{(pH4.5)}$	kg H_2SO_4/t	1	1
NAG $_{(pH7)}$	kg H_2SO_4/t	1	3
Total S	%	0.08	0.08
CRS	%	0.07	-
ABCC	kg H_2SO_4/t	4	-
Total C	%	0.14	-
Organic C	%	0.14	-
Inorganic C	%	<0.02	-

4.3. Ore and Metallurgical Samples

The full set of test results and final ARD classifications for the Fountain Head ore/metallurgical samples are provided in Table E1.

An ARD Classification plot for the ore/metallurgical samples is provided in Figure 22. The three ore samples (UB1, UB2 and LB3) used as feed for the bottle roll leach tests, all contained negligible sulphur (<0.1 %) and ANC (<10 kg H_2SO_4/t) and were classified as NAF. The corresponding residues following cyanide leaching of the head samples contained increased neutralising capacity (15 - 20 kg H_2SO_4/t), presumably because of lime addition during leaching. These results indicate that heap leach pads remaining after closure which contain ore samples of the type tested here are very unlikely to produce ARD in the longer-term. However, it is noted that some ore processed at Fountain Head may have higher sulphide content associated with pyrite and could potentially generate ARD, depending on the balance between the acid generating potential of the sulphide and the ANC in the material and the alkalinity added through lime addition. It is therefore recommended that ore samples with higher sulphur content should be tested for ARD generating potential.

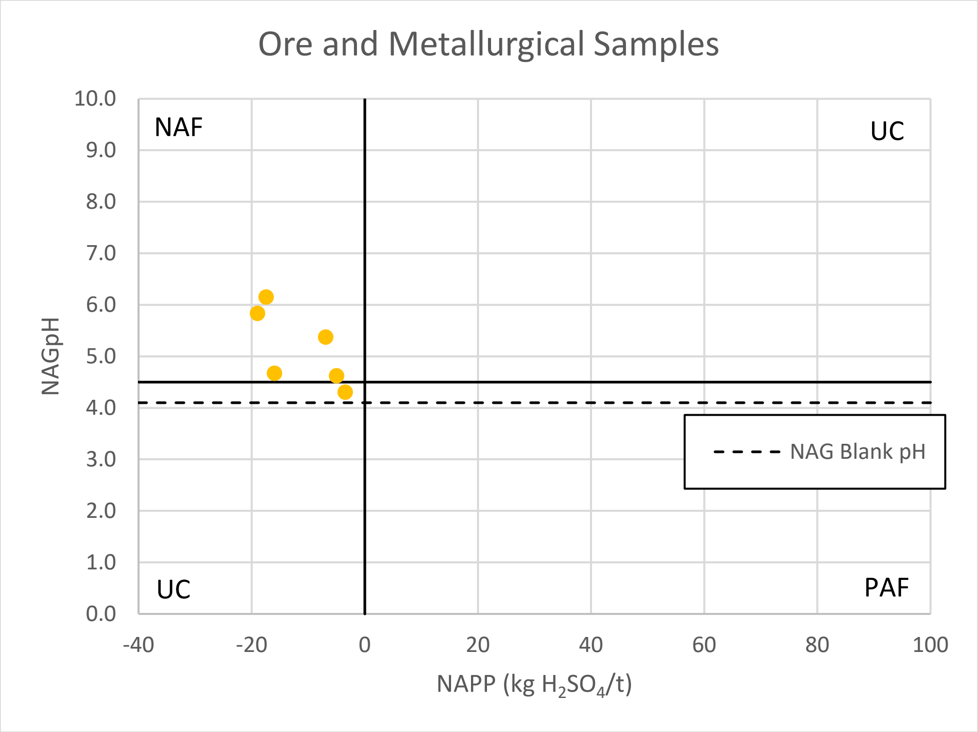

Figure 22: ARD classification plot for ore/metallurgical samples from Fountain Head.

5. WASTE SEGREGATION CRITERIA

Given the relatively low ANC and poor reactivity, criteria based on Total S was selected as the best potential option for routine classification of ARD rock types. Figure 23 presents box plots showing the distributions of Total S in samples from the Fountain Head pit drill holes which were used for ARD classification (Section 4.1). Sulphur distributions were split according to ARD classification as NAF, PAF-LC or PAF. The results show that NAF samples can be differentiated from PAF/PAF-LC samples by applying a Total S cut-off of 0.2%S, with 95% of samples classified NAF having a Total S value of 0.2% or less, and all PAF samples and 60% of PAF-LC samples having a Total S value of greater than 0.2%S.

Although the less than or equal to 0.2%S criteria includes 40% PAF-LC materials, these have low acid potential and operational blending with NAF materials would be expected to account for any minor acidity generated.

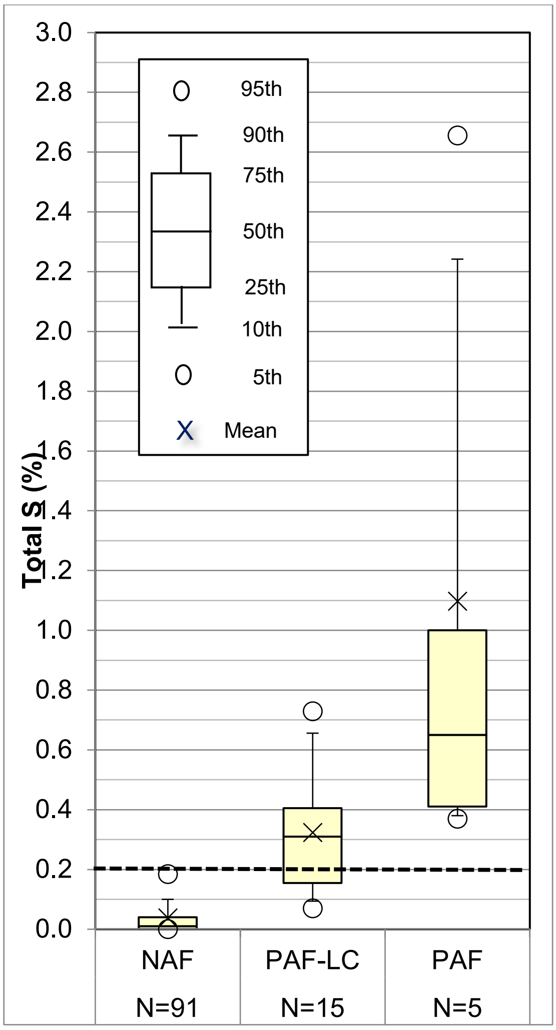

Figure 23: Box plots showing % Total S for NAF, PAF-LC and PAF samples from drill holes in the Fountain Head pit. The broken line shows Total S = 0.2%.

The only available S data for the Fountain Head pit is the Leco S analysis carried out on a limited number of samples as part of the EGi test programme, and handheld portable XRF (pXRF) S data, which is available for the majority of the drill samples. In EGi's experience, pXRF S data is unreliable and unsuitable for waste segregation or block modelling at the relatively low S values proposed for these initial cut offs, even with extensive calibration. Figure 24 is a plot of sulphur concentrations measured using pXRF plotted against measurements made on the same samples using the Leco Total S method. The results confirm the poor correlation between the two methods, with the sulphur concentrations measured by Total S generally higher than those measured by pXRF (Figure 25). Sulphur determined by ICP or Leco S or similar method is recommended for classifying waste rock materials.

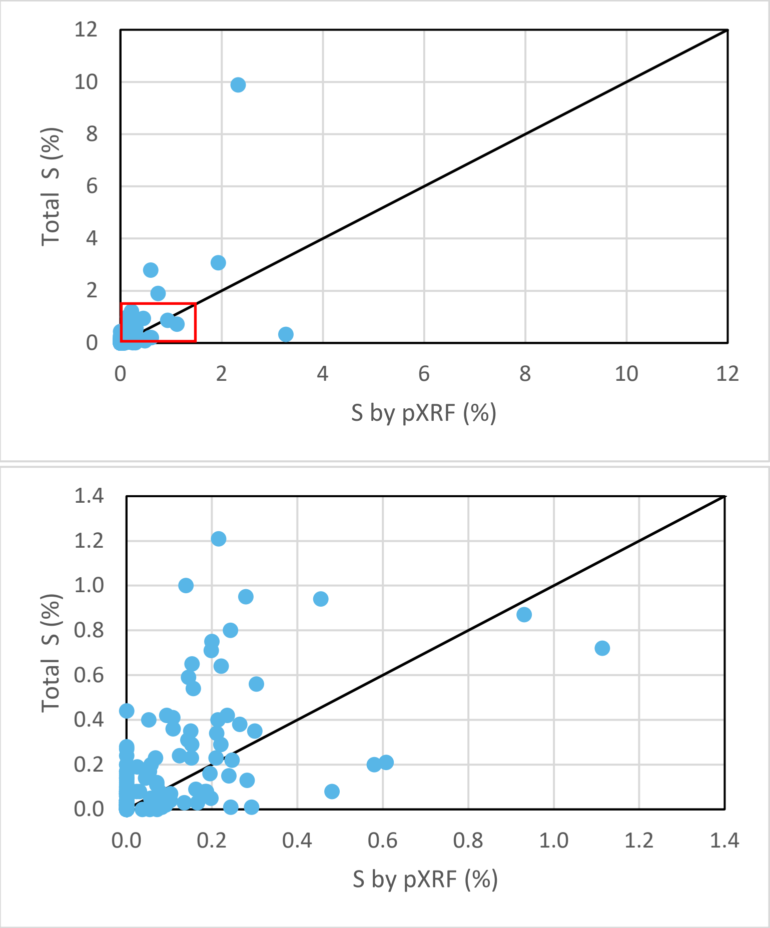

Figure 24: Sulphur measured in samples from the test set from Fountain Head pit measured using handheld portable XRF vs high temperature combustion analysis (top) and expanded to show the area inside the red box (bottom).

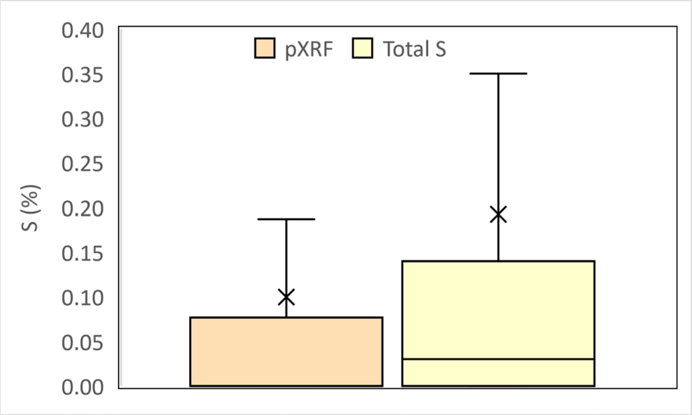

Figure 25: Box plots showing the distributions of sulphur in samples from the test set from Fountain Head pit measured using handheld portable XRF and high temperature combustion.

Geological observations (logging) could also assist with screening ARD rock types, but the information to date is not sufficient to calibrate reliable geological criteria. Based on the available information, lithology does not appear to be a significant control on S or ANC distribution, but quartz veining, observed sulphide occurrence, and oxidation are potential geological parameters that could be used in conjunction with Total S to differentiate ARD rock types. PAF and PAF-LC materials are generally associated with logged quartz veining and/or observed sulphide, but not exclusively. There are intervals where sulphides were observed but S was low, and quartz veining was also common in NAF materials. The samples tested are RC chip samples, and hence geological differentiation is not precise. Definition of geological criteria would require inspection of representative drill core through the deposit to better understand controls on sulphide and carbonate distribution (including the oxidation profile to check for the presences of residual sulphides in oxide and transition zones) supported with continuous/semi-continuous ICP or Leco S testing and ANC testing.

Based on the investigations conducted to date on the Fountain Head pit samples, it is proposed that PAF waste could be defined as material with a Total S concentration greater than 0.2% (Table 7). If the site contains an area close to the pit where this material could be temporarily stored during mining operations, then following cessation of mining, PAF waste could be relocated to the pit where, on groundwater recharge, it could be permanently stored under water with little risk of sulphide oxidation and generation of acid and dissolved metals/metalloids. Waste rock with a Total S concentration below or equal to 0.2% is likely to have low risk of ARD when stored permanently with the existing waste in the current WRS.

Note, this classification system is based on a limited number of samples, especially in the PAF classification. Management options are also suggested without an estimate of the volume of PAF waste, which may impact how it can be managed. Increased testing of drill hole samples using Total S analysis, combined with geological observations will provide improved definition of PAF waste, facilitating estimation of the volume of PAF waste requiring management. Management options are also suggested with limited data available on the leaching properties of these materials and further kinetic leach testing is recommended to provide more information on which to base waste management options.

Table 7: Suggested waste segregation criteria and possible management options.

TOTAL S	**ARD CLASSIFICATION**	**MANAGEMENT**	
		During Mining	**Post Mining**
>0.2%	PAF/PAF-LC	Segregate and store in bunded area, capture and treat run-off before discharge as required.	Sub-aqueous disposal in the Fountain Head pit.
≤0.2%	Low risk	Segregate and place in permanent WRS.	WRS closure as per mine plan.

6. WATER AND PEROXIDE EXTRACTABLE ELEMENTS

Batch water extraction tests provide an insight into elemental solubilities within recently mined rock. The samples were extracted with deionised water at a solid to liquid ratio of 1:5 for 16 hours, which is generally sufficient for chemical equilibrium to be established. Extract pHs were recorded after the equilibration period, then the liquors were filtered and analysed for a suite of elements, the results of which are given in Appendix G (Table G1).

A series of accelerated oxidation tests based on the NAG test procedure were also carried out to provide indicative data on metals and metalloids that are likely to occur in acidic runoff from waste rock that is subject to oxidation processes following surface storage. The NAG test involves reaction of a sample with hydrogen peroxide to rapidly oxidise any sulphides that are present. Normally only the pH and acidity of the NAG solution are measured following the oxidation stage, but elemental analysis of the NAG liquor can also be carried out to provide data on the release of elements that may be of interest. The NAG test is conducted using a solid to liquid ratio of 1:100, so the results from multielement analysis of the NAG liquors were multiplied by a factor of ten to provide comparable results to those of the water extract (solid to liquid ratio of 1:5) following multiplication by a factor of 0.5. Past experience has also suggested NAG test concentrations typically need to be multiplied by between 3 to 10 times to provide a reasonable guide to what might be expected from column leach tests, so multiplication by a factor of ten will also give indicative metal/metalloids concentrations from column tests. The results for multielement analysis of NAG liquors are provided in Appendix G (Table G2).

These tests represent the two extremes of the leaching process for PAF materials. The results of water extraction provide an indication of chemical mobility for a material that is freshly mined and exposed to atmospheric conditions, whereas the results of the peroxide extractions provide information of metal mobility for sulphidic materials that undergo oxidation and acidification. These two tests represent the extremes of the leaching process. In practice, oxidation of waste rock stored in a WRS will progress over time, and so leachates from the WRS will be derived from contact of infiltrating water with waste rock covering the spectrum of oxidised rock.

6.1. Water extracts

Water extractions were conducted on a number of Fountain Head pit samples covering a Total S range from <0.01 to 3.1%S, including PAF, PAF-LC and NAF materials. All water extracts produced circum-neutral to mildly alkaline solutions (pH 7.2 – 9.2), with low salinity (EC = 0.1 – 0.13 dS/m). Metal concentrations in water extracts were also very low to non-detectable. Figure 26 shows box plots of metal/metalloid concentrations in water extracts. Samples are split according to the sulphur content as either >0.2% or ≤0.2%S to discriminate between NAF (≤0.2%S) and PAF/PAF-LC (>0.2%S). This figure shows that metal concentrations in water extracts for the NAF samples were significantly lower than for the samples with Total S >0.2%, with the exception of aluminium. While these results suggest leachates from freshly mined waste rock from the Fountain Head pit will, in general, be of reasonable quality, segregation of the PAF waste rock using a Total S value of 0.2%, may improve leachate quality for the majority of waste rock containing ≤0.2%S.

Figure 26: Box plots showing the distributions of metals and metalloids in water extracts of samples from Fountain Head pit. Samples are split according to Total S concentration. Note concentrations have been multiplied by a factor of 0.5 to normalise to a solid to liquid ratio of 1:10.

Water extractions were also carried out on several samples from the existing Fountain Head WRS. Extracts had neutral pH (7.8 – 7.9) and low salinity (EC = 0.1 – 0.13 dS/m). Metal/metalloid concentrations were also very low or non-detectable (Figure 27). These results are not unexpected, since these materials have been stored in the current waste rock stockpile for a number of years and will have been subject to leaching by infiltration of incident rainfall.

Two samples representing ore (19019) and the same ore sample following cyanide leaching (19022) were also subjected to water extraction. This ore sample contained a significant concentration of arsenic (1.06%), which was essentially unchanged following cyanide treatment (1.03% As). Despite the similar concentrations of arsenic in the ore and the leached ore sample, the water solubility of arsenic in these samples appears to be very different, with the concentration of arsenic in the water extract of cyanide leached sample approximately 7 times higher than in the water extract of the ore sample (Figure 27). That cyanide leaching has significantly increased arsenic mobility is clear from the data shown in Figure 28. This figure shows that there is a reasonable correlation between the amount of arsenic in the samples and the amount which can be extracted by water, suggesting that arsenic in these samples is similar in nature for all samples. However, the solubility of arsenic in the cyanide leached samples does not fit this pattern, suggesting the nature of the arsenic following cyanidation has changed significantly. The reason for increased solubility of arsenic following cyanide treatment is not clear, but this phenomenon has been observed previously, where tailings from cyanide treated gold ore was found to contain readily soluble arsenic compounds[4].

While the ore sample used here contained a higher than average concentration of arsenic in comparison to many of the samples tested, multi-element assay of Fountain Head pit, WRS and ore samples suggest arsenic is significantly enriched in the majority of samples tested relative to average crustal and soil abundance (Appendix H). This suggests that increased arsenic solubility as a result of cyanide leaching, may lead to drainage containing elevated arsenic concentrations from heap leach pads after closure. It is recommended that the water solubility of arsenic in cyanide leached ores should be further investigated to determine the likely concentrations of arsenic in drainage from the heap leach pads after closure.

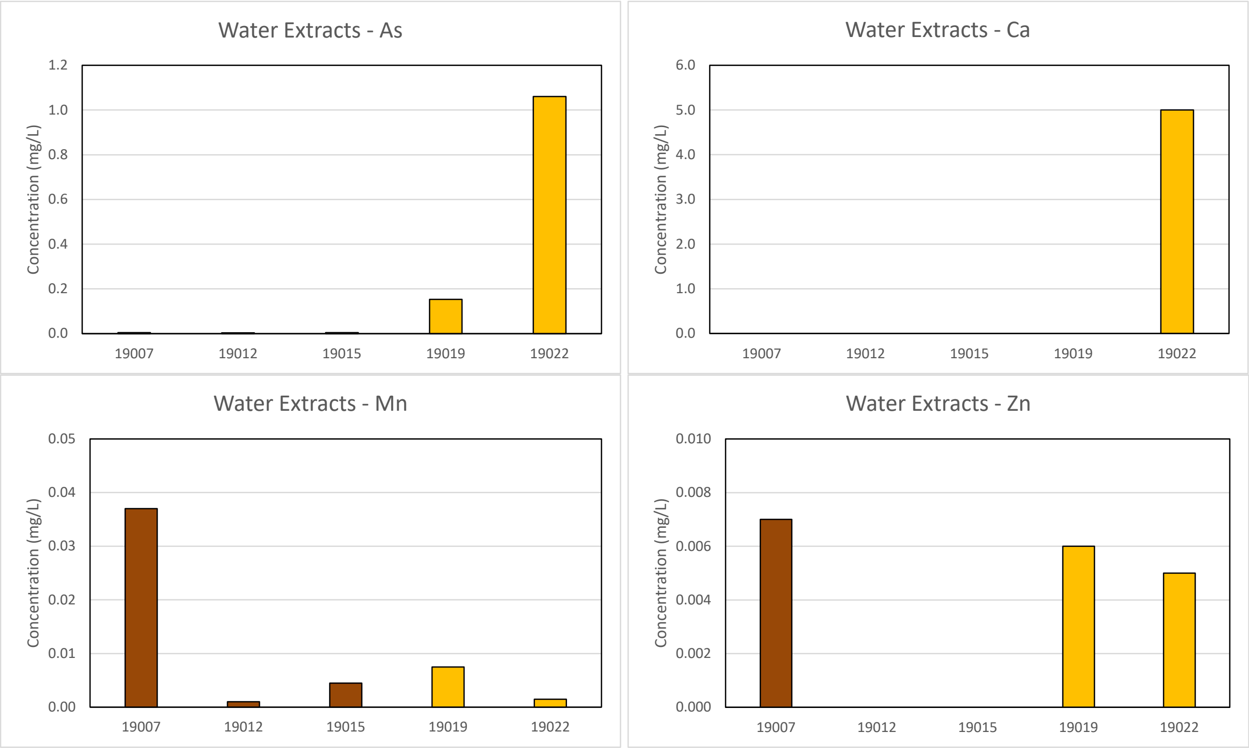

Figure 27: Concentrations of metals and metalloids in water extracts of samples from the Fountain Head pit WRS (brown bars) and ore and leached ore (gold bars). Note concentrations have been multiplied by a factor of 0.5 to normalise to a solid to liquid ratio of 1:10.

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[4] Paktunc, D., Foster, A., Heald, S. and Laflamme, G., 2004. Speciation and characterisation of arsenic in gold ore and cyanidation tailings using X-ray absorption spectroscopy. Geochim. Cosmochim. Acta, 68 (5), 969-983.

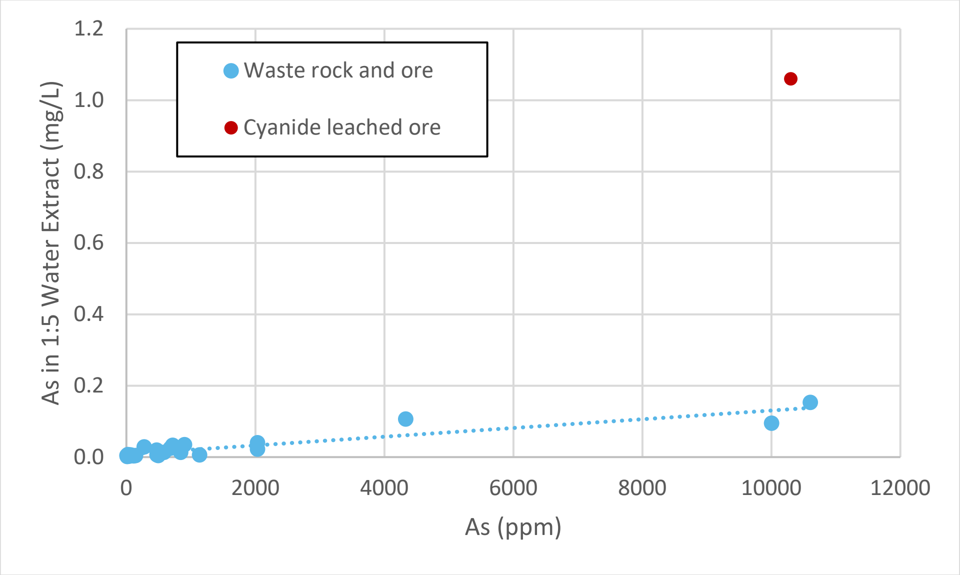

Figure 28: Concentrations of arsenic in water extracts of samples from the Fountain Head pit, existing WRS and ore and leached ore samples as a function of arsenic content of the sample. Note concentrations have been multiplied by a factor of 0.5 to normalise to a solid to liquid ratio of 1:10.

6.2. Peroxide extracts

Peroxide extractions were conducted on samples from the Fountain Head pit only, as WRS samples and the ore samples all contained very little sulphur and would not undergo significant oxidation. Pit samples containing sulphur in the range of 0.16 to 3.1%S, including 3 PAF, 3 PAF-LC and 3 NAF samples, were treated with peroxide and the liquors assayed.

Figure 29 shows the concentrations of sulphate, iron, copper, cobalt, nickel and arsenic in peroxide leachates as a function of the Total S content of the sample. There is a significant correlation between the Total S content of a sample and the amount of these metals/metalloids dissolved during treatment with peroxide. This suggests that copper, cobalt and to a lesser extent nickel are, in the main, associated with sulphides in these samples, and are dissolved as a result of oxidative dissolution during treatment with peroxide. It is also likely that arsenic is associated with sulphides, possibly arsenopyrite, in some samples. These results indicate that segregation of samples with significant sulphide content is also likely to reduce the concentration of several heavy metals/metalloids in drainage from oxidised waste rock in the WRS.

Figure 30 shows the concentrations of aluminium, manganese, lead and zinc in peroxide leachates as a function of the Total S content of the sample. The correlation of these metals in peroxide extracts with Total S appears to much less significant, suggesting that these metals are less likely to be associated with sulphides. Nevertheless, the results show that leachates from oxidised waste rock containing more than 0.2% sulphur may contain substantial concentrations of these metals and waste rock with Total S concentrations above this value should be managed to minimise oxidation/acidification and release of heavy metals.

Because of the elevated concentrations of several metals (Al, Co, Mn, Ni, Pb, Zn), in peroxide extracts of samples containing relatively low Total S (<0.35%), it is recommended that testing of the leaching behaviour of these types of samples should be investigated further.

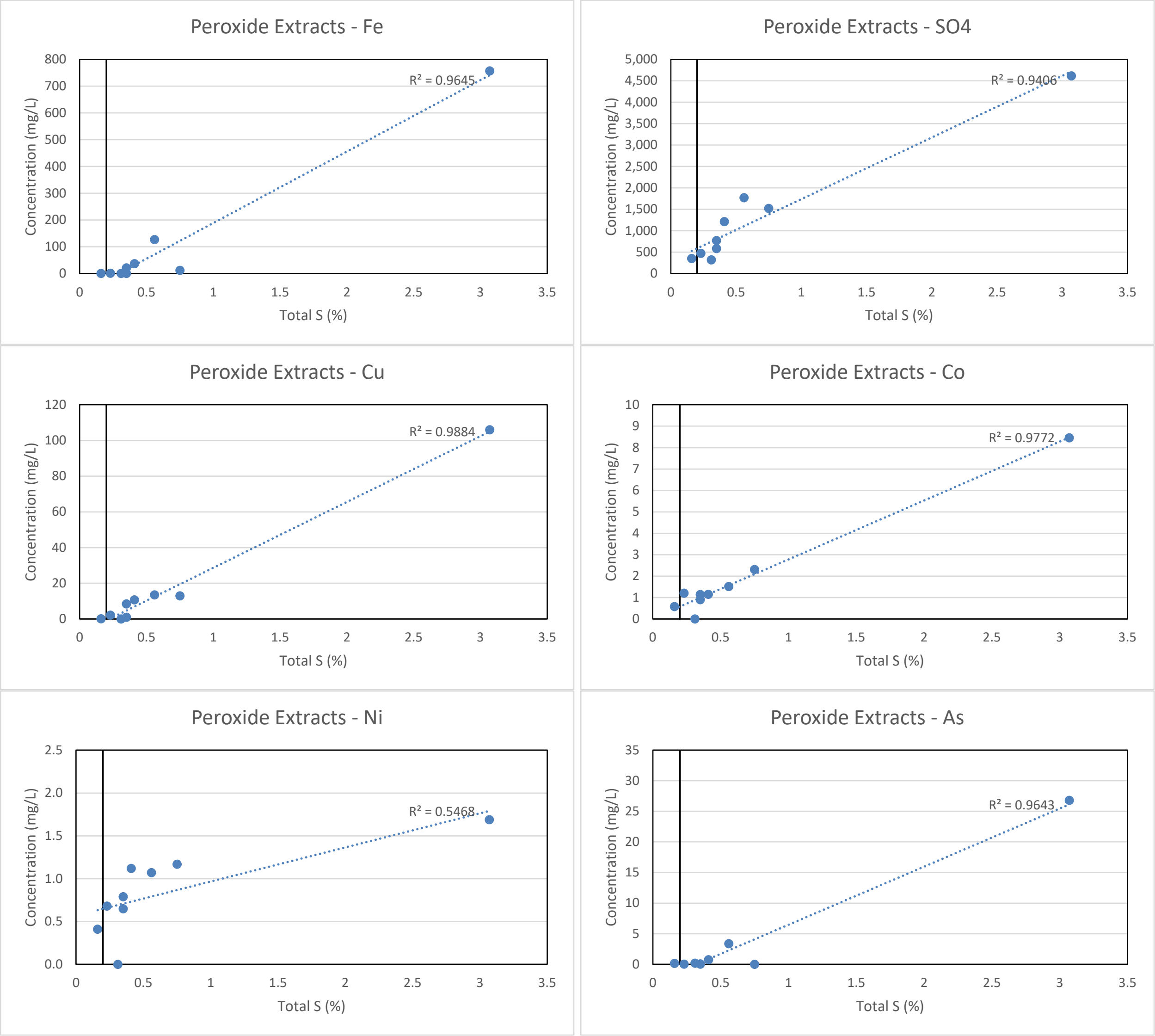

Figure 29: Concentrations of sulphate and metals/metalloids in peroxide extracts of samples from the Fountain Head pit WRS as a function of Total S concentration. The solid black line shows a Total S content of 0.2%. The dotted blue line shows the linear regression line of best fit. Note, concentrations have been multiplied by a factor of 10 to normalise to a solid to liquid ratio of 1:10.

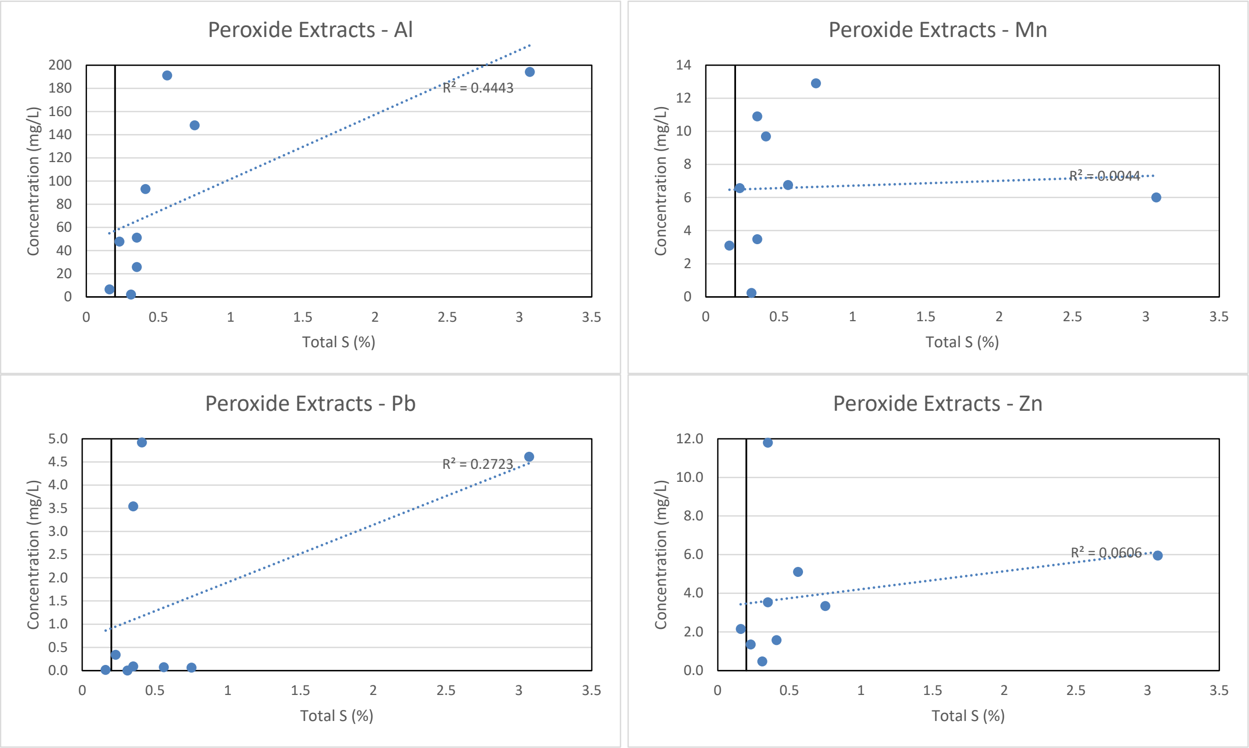

Figure 30: Concentrations of several metals in peroxide extracts of samples from the Fountain Head pit WRS as a function of Total S concentration. The solid black line shows a Total S content of 0.2%. The dotted blue line shows the linear regression line of best fit. Note, concentrations have been multiplied by a factor of 10 to normalise to a solid to liquid ratio of 1:10.

7. CONCLUSIONS AND RECOMMENDATIONS

Geochemical testing has been conducted on materials that were selected to represent waste rock that will be removed from the pit during the cutback, waste rock from the existing WRS, including rock that will be removed to allow pit development, and ore samples before processing and cyanide leached ore to represent ore stored on the ROM pad and remaining in heap leach pads at closure, respectively. This testing was designed to obtain information on the potential of these materials to generate ARD during and post-mining at the Fountain Head operation.

Results of geochemical testing of samples obtained from drilling in the Fountain Head pit show:

- There is no immediately available acidity and low salinity in these samples when contacted with water, indicating that freshly mined rock is unlikely to provide low pH or saline drainage.
- Total S analysis showed a broad range up to 3%S, but with the vast majority (90%) having a relatively low S value of 0.5%S or less, suggesting the occurrence of pyritic rock is not widespread.
- ANC was relatively low, ranging up to 33 kg H_2SO_4/t, indicating a general lack of excess buffering.
- Carbon speciation analysis indicates carbonate content is negligible, with the total carbon content of these samples generally low. This is consistent with ABCC test results which also suggest little carbonate content, and that the small amount of carbonate present in these samples is predominantly iron carbonates (ferroan dolomite, siderite), which will react relatively slowly.
- Most samples were NAPP negative, with the majority of these having ANC/MPA ratios of 2 or more, indicating a high factor of safety.
- The majority (70%) of NAGpH values were 4.5 or greater, corroborating the ABA results which indicated most samples are likely to be NAF.
- CRS measurements show that greater than 90% of Total S is contained in sulphide minerals, suggesting that Total S measurements can be used as suitable guide to the sulphide (pyrite) content of these materials.
- Test results were used to classify samples as NAF, PAF, PAF-LC or UC. Around 80% of samples tested were classified NAF (including UC equivalents), 15% PAF-LC (including UC equivalents) and 5% PAF. Overall results indicate most waste materials to be mined will be NAF, with a minor proportion of PAF.

Results of geochemical testing of samples obtained from the existing WRS at Fountain Head show:

- The WRS samples contain very little sulphur (<0.08%) and consequently are unlikely to generate any acidity.
- The WRS samples generally contain small amounts of neutralising material (ANC <20 kg H_2SO_4/t).
- The majority of WRS samples were clearly classified as NAF (one sample only as UC(PAF-LC)).
- Samples taken from locations in the WRS close to where rock will be excavated prior to pit cutback, were all classified as NAF with ANC/MPA ratios well above 2, indicating that waste rock represented by these samples is very unlikely to produce any ARD and therefore suitable for construction purposes, such as roads, pads and embankments.

Results of geochemical testing of ore and cyanide leached ore show:

- The three metallurgical samples (UB1, UB2 and LB3) used as feed for the bottle roll leach tests, all contained negligible sulphur (<0.1 %) and ANC (<10 kg H_2SO_4/t) and were classified as NAF.
- The corresponding residues following cyanide leaching of the head samples contained increased neutralising capacity (15 - 20 kg H_2SO_4/t), presumably because of lime addition during leaching.

- These results indicate that heap leach pads remaining after closure which contain ore samples of the type tested here are very unlikely to produce ARD in the longer-term.

Given the relatively low ANC and poor reactivity, criteria based on Total S was selected as the best potential option for routine classification of ARD rock types. Using the results from detailed geochemical testing, sulphur distributions were determined for each of NAF, PAF-LC or PAF ARD classifications. The results show:

- NAF samples can be differentiated from PAF/PAF-LC samples by applying a Total S cut-off of 0.2%S
- 95% of samples classified NAF have a Total S value of 0.2% or less, and all PAF samples and 60% of PAF-LC samples have a Total S value of greater than 0.2%S.
- Although using a ≤0.2%S criteria for NAF waste rock includes 40% PAF-LC material, these have low acid potential and operational blending with NAF materials would be expected to account for any minor acidity generated.

Geological observations (logging) was also investigated as a screening tool for ARD rock types, but the information to date is not sufficient to calibrate reliable geological criteria. Based on the available information the following observations can be made:

- Lithology does not appear to be a significant control on S or ANC distribution.
- Quartz veining, observed sulphide occurrence, and oxidation are potential geological parameters that may be used in conjunction with Total S to differentiate ARD rock types.
- PAF and PAF-LC materials are generally associated with logged quartz veining and/or observed sulphide, but not exclusively. There are intervals where sulphides were observed but Total S was low.
- Quartz veining was also common in NAF materials.

The Total S cut off could be used to distinguish between NAF and PAF/PAF-LC rock types and estimate volumes of each rock type that will be mined from the Fountain Head pit. However, the only sulphur data available for a sufficient number of samples to provide such an estimate were derived from pXRF analysis. Comparison of pXRF sulphur data with Total S data indicated very poor correlation, suggesting the pXRF data were of insufficient quality to allow an estimate of the volume of PAF rock to be made.

In addition to the above testing, water and peroxide extractions were conducted on selected samples to understand the likely quality of drainage from freshly mined and oxidised waste rock respectively. The results of these tests show:

- All water extracts produced circum-neutral to mildly alkaline solutions with low salinity. Metal concentrations in water extracts were also very low to non-detectable.
- These results suggest leachates from freshly mined waste rock from the Fountain Head pit will, in general, be of reasonable quality. However, segregation of the PAF waste rock using a Total S value of 0.2%, may improve leachate quality for the majority of fresh waste rock containing ≤0.2%S.
- Water extracts for WRS samples had neutral pH and low salinity. Metal/metalloid concentrations were also very low or non-detectable.
- Water extraction conducted on an ore sample and the same sample following cyanidation showed that cyanide leaching has significantly increased arsenic mobility in this sample.
- Arsenic is significantly enriched in the majority of samples tested relative to average crustal and soil abundance. This suggests that increased arsenic solubility as a result of cyanide leaching may lead to drainage containing elevated arsenic concentrations from heap leach pads remaining after closure.

- Iron, copper, cobalt, nickel and arsenic concentrations in peroxide leachates correlated with Total S content of the samples, indicating that segregation of samples with significant sulphur content is likely to reduce the concentration of these heavy metals/metalloids in drainage from oxidised waste rock in the WRS.
- Peroxide leachates suggest drainage from oxidised waste rock containing more than 0.2% sulphur may contain substantial concentrations of Al, Co, Mn, Ni, Pb, Zn and waste rock with Total S concentrations above this value should be managed to minimise oxidation and release of heavy metals.

The results summarised above suggest that further investigations are required to confirm the conclusions made to date and to provide more confidence in applying the results to the management of mine wastes during and post-operations. Consequently, the following are recommended as future geochemical investigations:

- Although the proportion of PAF materials is likely to be minor, quantification of the distribution of PAF materials will be required ahead of mining and selective handling and management carried out during mining to ensure PAF materials are not a source of ARD during operations and at closure. Quantifying the proportion of PAF will require more extensive testing and it is recommended that any further drilling for resource definition, should include Total S analysis (high temperature combustion method e.g. LECO method, or ICP S analysis) as a part of the suite of analyses conducted on the samples tested.
- Only a limited number of WRS samples were tested, and more widespread follow up testing (S only required initially) is recommended for rock from the WRS.
- It is expected that some ore processed at Fountain Head may have higher sulphide content associated with pyrite than the samples tested during this study. Such materials could potentially generate ARD, depending on the balance between the acid generating potential of the sulphide and the ANC in the material and the alkalinity added through lime addition. It is therefore recommended that ore samples with higher sulphur content should be tested for ARD generating potential.
- Currently available geological information is not sufficient to calibrate reliable geological criteria for waste handling and management. Definition of geological criteria would require inspection of representative drill core through the deposit to better understand controls on sulphide and carbonate distribution, including the oxidation profile to check for the presences of residual sulphides in oxide and transition zones. It is recommended that this inspection should be undertaken as a part of a site visit.
- If a ≤0.2%S criteria for NAF waste rock is to be utilised as a waste segregation and handling criterium, it is recognised that the NAF rock will likely contain a small portion of PAF-LC rock. While these materials have low acid potential and operational blending with NAF materials could be expected to account for any minor acidity generated, this assumption should be validated. It is recommended that kinetic leach column testing be undertaken on samples of PAF-LC material and mixtures of NAF and PAF-LC materials to determine the likely nature of drainage of such materials stored permanently in the WRS.
- It is recommended that the increase in water solubility of arsenic in cyanide leached ores should be further investigated to determine the likely concentrations of arsenic in drainage from heap leach pads after closure.
- Because of the elevated concentrations of several metals (Al, Co, Mn, Ni, Pb, Zn) in peroxide extracts of samples containing relatively low Total S (<0.35%), it is recommended that further testing of the leaching behaviour of these types of samples should be investigated further.

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APPENDIX A

Fountain Head Lithology Codes

Table A1. Fountain Head Lithology Codes

LITH-CODE	LITHOLOGY	LITH-CODE	LITHOLOGY
ALUV	alluvium	LOM	loam
AMP	amphibolite	LPR	lamproite
ANT	andesite	LPY	lamprophyre
ARKS	arkose	LTUF	lapilli tuff
ARNT	arenite	MBL	marble
BIF	banded iron formation	MDST	mudstone
BIOM	biomicrite	METB	metabasite
BLT	basalt	MGST	magnesite
BX	breccia	MIG	migmatite
CALR	calcarenite	MSU	massive sulphide
CBIF	carbonate iron formation	MUD	mud
CBRK	carbonate rock	MYL	mylonite
CBSH	carbonaceous shale	MZG	Monzogranite
CHRT	chert	NSMP	No Sample
CLCR	calcrete	OXIF	Oxide Iron Formation
CLY	clay	PEG	Pegmatite
CNGL	conglomerate	PHYL	Phyllite
DAC	dacite	QZT	Quartzite
DLT	dolerite	REG	Regolith
FILL	unspecified fill	RHD	Rhyodacite
FIRK	felsic intrusive	RHY	Rhyolite
FRCT	ferricrete	SCHT	Schist
FVOL	felsic volcanic	SDST	Sandstone
GAB	gabbro	SHLE	Shale
GNS	gneiss	SIF	Ironstone
GO	gossan	SKN	Skarn
GOUG	gouge	SLA	slate
GRD	granodiorite	SLCT	Silcrete
GRP	granophyre	SLST	Siltstone
GRSN	greisen	SND	sand
GRT	granite	SOIL	soil
GYWK	greywacke	SPLT	saprolite
HFL	hornfels	SPRK	saprock
IGM	ignimbrite	SRP	serpentinite
JASP	jasper	TRC	trachyte
LAG	lag	TUF	tull
LAT	laterite	VEBX	vein breccia
LITF	lithic tuff	VEIN	vein
LMST	limestone		

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APPENDIX B

ARD Assessment Approach and EGi Test Methods

ARD Assessment Approach and EGi Test Methods

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 NAG test. These methods are referred to as static procedures because each involves a single measurement in time.

Acid-Base Account

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

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

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

Potential Acidity

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

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

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

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

The use of an MPA calculated from total sulphur is a conservative approach because some sulphur may occur in forms other than pyrite. Ca and Mg sulphate, organic sulphur and native sulphur, for example, are non-acid generating sulphur forms. Also, some sulphur may occur as other metal sulphides (e.g. covellite, chalcocite, sphalerite, galena), which yield less acidity than pyrite when oxidised or, in some cases, may be non-acid generating.

The total sulphur content is commonly used to assess potential acidity because of the difficulty, costs and uncertainty involved in routinely determining the speciation of sulphur forms within samples and determining reactive sulphide-sulphur contents. However, if the sulphide mineral forms are known then allowance can be made for non- and lesser acid generating forms to provide a better estimate of the potential acidity.

Acid Neutralising Capacity (ANC)

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

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

Net Acid Producing Potential (NAPP)

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

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

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

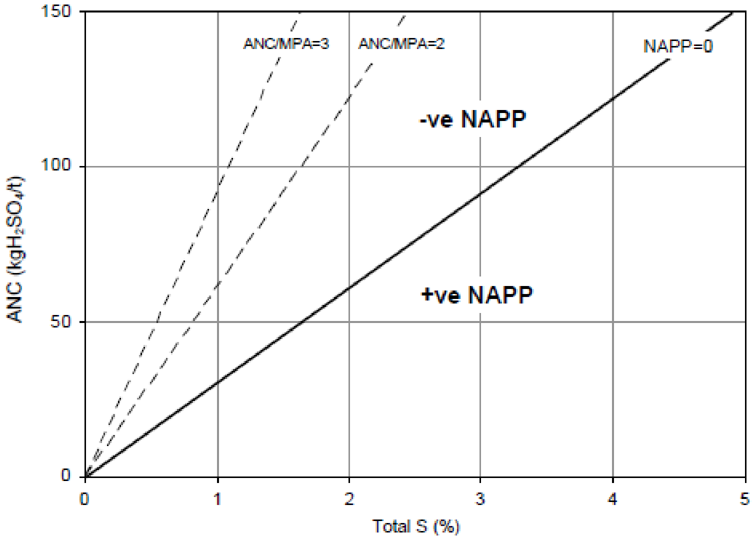
ANC/MPA Ratio

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

The purpose of the ANC/MPA ratio is to provide an indication of the relative margin of safety (or lack thereof) within a material. Various ANC/MPA values are reported in the literature for indicating safe values for prevention of acid generation. These values typically range from 1 to 3. Generally, 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 the figure below. 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.



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 result represents a direct measurement of the net amount of acid generated by the sample. The final pH is referred to as the NAGpH and the amount of acid produced is commonly referred to as the NAG capacity and is expressed in the same units as the NAPP (kg H_2SO_4/t).

Several variations of the NAG test have been developed to accommodate the wide geochemical variability of mine waste materials, which include 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 g of sample. The peroxide is allowed to react with the sample overnight and the following day the sample is gently heated to accelerate the oxidation of any remaining sulphides, then vigorously boiled for several minutes to decompose residual peroxide. When cool, the NAGpH and NAG capacity are measured.

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

Sequential NAG Test

When testing samples with high sulphide contents it is not uncommon for oxidation to be incomplete in the single addition NAG test. This can sometimes occur when there is catalytic breakdown of the hydrogen peroxide before it has had a chance to oxidise all 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 peroxide, catalysed by sulphide surfaces and/or oxidation products.

Sample Classification

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

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

Barren

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

Non-acid forming (NAF)

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

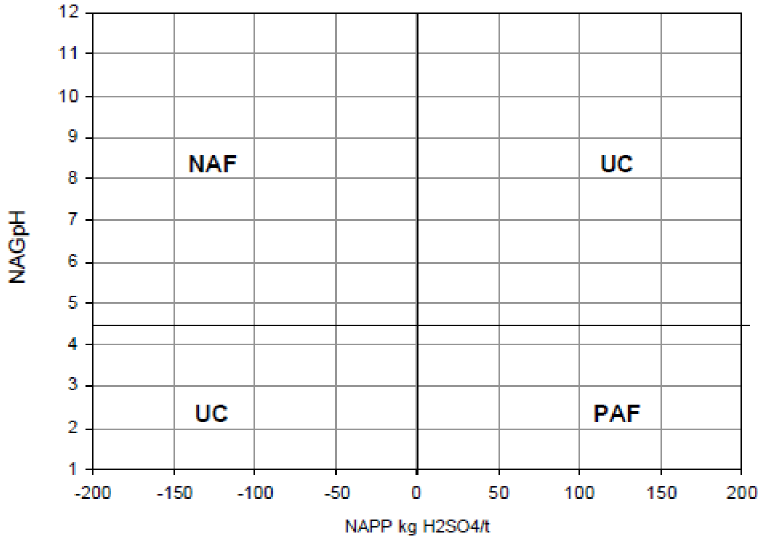
Potentially acid forming (PAF)

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

Uncertain (UC)

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

The figure below 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.



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 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 provide an indication of the portion of ANC within a sample that is readily available for acid neutralisation.

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APPENDIX C

Acid Forming Characteristics – Pit Samples

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APPENDIX D

Acid Forming Characteristics – WRS Samples

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APPENDIX E

Acid Forming Characteristics – Ore/Metallurgical Samples

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APPENDIX F
ABCC Plots

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APPENDIX G

Water and Peroxide Extract Results

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APPENDIX H

Multi-Element Assay Results and Geochemical Abundance Indices

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