# Browns Range Rare Earth Element (REE) Project – Waste Rock Geochemical Characterisation

**Report Prepared for**

## Northern Minerals Limited

**Report Prepared by**

srk consulting

SRK Consulting (Australasia) Pty Ltd

NML003

February 2014

# Browns Range Rare Earth Element (REE) Project – Waste Rock Geochemical Characterisation

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# Executive Summary

Northern Minerals Limited (NML) is currently conducting baseline studies for the Browns Range rare earths elements (REE) project, a potential future mine and mineral processing operation at a site located approximately 150 km southeast of Halls Creek, Western Australia (WA). The project is in an early stage of developing strategies for handling and storage of its waste rock, tailings, and the transportation of mineral concentrate. NML has conducted preliminary geochemical characterisation activities to inform its assessment of potential environmental impacts of project implementation, and support planning for mine closure and rehabilitation.

In 2013 NML commissioned SRK to undertake a preliminary review of existing geochemical datasets (Geochemical Characterisation Review, SRK, 2013). The current assessment addresses some of the gaps identified – namely an examination of the representivity of waste rock geochemical dataset (in terms of lithology and sulfur content) and a supplementary leach test programme to obtain data describing the long-term weathering characteristics of the waste rock.

## Sample Representivity

### Wolverine Deposit

SRK assessed Wolverine geochemical dataset in light of the geological database and the current pit shell, and concluded as follows:

- The two dominant waste rock lithologies (arenite and arkose) comprise a significant proportion of the geochemical dataset. However, some minor lithologies (present in proportions of less than 1.5%) have not been sampled.
- The majority (>99%) of the drilled waste rock contains negligible sulfur (<0.1 wt% S); five waste lithologies were found to have 95$^{th}$ percentile sulfur contents equal to, or greater than 0.1 wt% S. It is therefore considered that the potential for acid generation from waste rock from the Wolverine deposit is low.
- The geochemical static sample set is sufficiently representative in terms of the range of sulfur contents represented.

### Other Deposits

Following review of the logged proportions and sulfur content of the waste lithologies at the Area 5, Area 5 North, Gambit West and Gambit Central deposits, SRK identified that:

- The lithologies and logged proportions of waste rock at the four additional deposits demonstrate variability. Whilst the dominant waste lithologies are arenite and arkose (in keeping with the Wolverine waste rock), their relative proportions change at each of the four deposits.
- Higher proportions of a few of the minor waste lithologies were also identified, including conglomerate (3.4%, Area 5), schist unclassified (4.6%, Area 5 North), interbedded fine and coarse grained arenite (3.7%, Gambit West), hematite breccia (2.9%, Gambit West) and colluvial gravel (2.1%).
- Sulfur contents encountered within the assayed waste rock are typically low and in keeping with the S content characteristics at the Wolverine deposit. However, a number of waste lithologies were identified with maximum sulfur contents above 0.1 wt% S, including arenite, arkose, hematite breccia, siltstone, interbedded arenite and argillite, gravelstone, interbedded fine and coarse grained arenite and conglomerate.

## Supplementary Leach Test Programme

A supplementary assessment of the leaching characteristics of the Wolverine geochemical samples incorporated the use of static deionised water leach tests, mild acid leach tests and NAG liquor analyses.

Generally, the leachable trace metal concentrations of the waste rock samples were low, and often below detection limits. The leachable REE concentrations from waste rock sampled from above the ore zone were predominantly below detection limit (<0.001 mg/L).

The assessment identified that acidic leachates were only encountered in the case of samples from the ore zone and sub-ore zone, where S contents were higher (<0.01-0.44 wt% S). Where acidic solutions were observed, higher quantities of a greater range of elements were found to be leachable, including Fe, K, Mg, Ca, Al, Be, Co, Cu, Li, Mn, Ni, Rb, Sr, U and REE.

Of the total elemental mass present in the waste materials, only a small proportion is in a form that is readily leachable under the geochemical conditions expected in a waste rock dump – less than 1% under neutral pH conditions and less than 6% under acidic conditions.

For sulfidic samples (which have been found to be primarily associated with the mineralised zone (ore zone), but also within the sub-ore zone (0.44 wt% S) there is likely to be a significant proportion of metal release as a result of oxidation. For these sample types, NAG testing showed that higher proportions of some elements could be leached under oxidising acidic conditions (up to 100% for trace metals associated with sulfide mineralogy (e.g. Ni, Co), and up to 22% for certain REE (e.g. Dy, Er, Y). This source of metalliferous drainage is of secondary concern in the overall assessment of waste rock characterisation as (i) most waste rock contains very low or negligible sulfur, and it is not anticipated that appreciable sulfidic material from the mineralised zone would report to the waste rock dumps, and (ii) associated metal release would occur over a long period of time (due to kinetic controls on sulfide oxidation).

## Recommendations

Following this assessment, the following recommendations are made:

- While the supplemental leach assessment has determined that leachable trace metal concentrations of the waste rock samples were generally low, higher solute concentrations are liable to result from materials from the mineralised (ore) zone, where sulfur contents and the potential to generate acid are more significant. This should be taken into consideration with regard to the management of ore stockpiles, and should such materials be exposed on pit walls.
- In absence of recognised environmental REE assessment criteria (e.g. water quality standards), a baseline assessment may be advisable with respect to the REE chemistry in local surface and groundwater.

**Further Sampling**

- SRK recommends that static geochemical characterisation of the Wolverine siltstone, sericite breccia and polymict breccia waste zone lithologies is undertaken, to assess potential acid and metalliferous drainage potential.
- Additional drillcore sampling for static geochemical characterisation assessment is recommended at the deposits where mining is proposed. Focus during sample selection should be placed on lithologies that are present within the additional deposits in higher proportions than encountered at the Wolverine deposit, and are therefore possibly under-represented within the existing geochemical sample set.

- When pit shell outlines have been determined for Area 5, Area 5 North, Gambit West and Gambit Central a more rigorous assessment of spatial representivity should be undertaken.
- On the basis of the database interrogation, and the low sulfur contents identified at the additional Browns Range deposits (Area 5, Area 5 North, Gambit West and Gambit Central), kinetic column testwork may not be required to assess the long-term weathering and leaching potentials of waste rock generated at these deposits. A similar static batch-testwork programme to the proposed and completed Wolverine testwork programme may be more appropriate. This could be confirmed following an initial phase of static testwork.

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# Disclaimer

The opinions expressed in this Report have been based on the information supplied to SRK Consulting (Australasia) Pty Ltd (SRK) by Northern Minerals Limited (NML). The opinions in this Report are provided in response to a specific request from NML to do so. SRK has exercised all due care in reviewing the supplied information. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them. Opinions presented in this Report apply to the site conditions and features as they existed at the time of SRK's investigations, and those reasonably foreseeable. These opinions do not necessarily apply to conditions and features that may arise after the date of this Report, about which SRK had no prior knowledge nor had the opportunity to evaluate.

# List of Abbreviations

| Abbreviation | Meaning |
|---|---|
| ABA | acid base accounting |
| ABCC | Acid base characteristics curve |
| AMD | acid and metalliferous drainage |
| ANC | acid neutralisation capacity |
| ANZECC | Australian and New Zealand Environmental Conservation Council |
| BoM | Bureau of Meteorology |
| Carb NP | Carbonate Neutralisation Potential |
| DMP | Department of Mines and Petroleum |
| EC | electrical conductivity |
| EPA | Environmental Protection Authority |
| GAI | Global Abundance Index |
| GARD | Global Acid and Metalliferous Drainage (Guide) |
| HREE | Heavy Rare Earth Elements |
| mg/L | milligram per litre |
| IGLS | Intertek Genalysis Laboratory Services (IGLS) |
| INAP | International Network of Acid Prevention |
| L | litre |
| LG | lithological group |
| LREE | Light Rare Earth Elements |
| MPA | Maximum Potential Acidity |
| NAF | non-acid forming |
| NAF-Barren | non-acid forming (with low acid neutralisation capacity (≤5 kg $H_2SO_4$/t) |
| NAG | net acid generation |
| NAPP | Net Acid Production Potential |
| NATA | National Association of Testing Authorities |
| NML | Northern Minerals Limited |
| NT | Northern Territory |
| PAF | potentially acid forming |
| PAF-LC | PAF materials associated with low NAG acidities ($NAG_{pH4.5}$ < 5 kg $H_2SO_4$/t) |
| REE | Rare Earth Elements |
| SFE | Shake Flask Extraction |
| SRK | SRK Consulting (Australasia) Pty Ltd |
| t | tonne (s) |
| TREO | Total Rare Earth Oxide |
| TSF | Tailings Storage Facility |
| wt% | weight as a% |
| WA | Western Australia |
| WRD | waste rock dump |
| XRD | X-ray diffraction |

# 1 Introduction

## 1.1 Project Background

Northern Minerals Limited (NML) is currently conducting baseline studies for the Browns Range rare earths elements (REE) project, a potential future mine and mineral processing operation at a site located approximately 150 km southeast of Halls Creek, Western Australia (WA). The project is in an early stage of developing strategies for handling and storage of its waste rock, tailings, and the transportation of mineral concentrate. NML has conducted preliminary geochemical characterisation activities to inform its assessment of potential environmental impacts of project implementation, and support planning for mine closure and rehabilitation.

In March 2013, NML commissioned SRK to conduct a review[1] of the existing Browns Range geochemical data for the Browns Range Project. The assessment was to identify any significant information gaps or uncertainties which exist, and make recommendations for a programme of work to address these uncertainties. Following this review, SRK recommended that further work include an assessment of sample representivity and examination of the long-term leaching characteristics of the waste rock.

## 1.2 Scope of Work

In August 2013, NML commissioned SRK to undertake the following:

- Conduct an assessment to determine whether the geochemical characterisation undertaken to date provides adequate representation of the waste rock to be generated at Browns Range;
- If warranted, develop recommendations for further static geochemical characterisation to ensure representative sampling of the Browns Range waste rock; and
- Design and implement a supplementary leach test programme to obtain data describing the long-term weathering characteristics of the waste rock.

The assessments provided within this report were undertaken in the light of Western Australian Environmental Protection Authority (EPA) objectives for acid and metalliferous drainage (AMD) and soils and landforms[2].

- *To maintain the integrity, ecological functions and environmental values of the soil and landform.*
- *To ensure that emissions do not adversely affect environment values or the health, welfare and amenity of people and land uses by meeting statutory requirements and acceptable standards.*
- *To ensure that rehabilitation achieves an acceptable standard compatible with the intended land use, and consistent with appropriate criteria.*

[1] *Browns Range Rare Earth Element (REE) Project – Geochemical Data Review,* SRK, 2013.
[2] *Guide to EIA Environmental Principles, Factors and Objectives, Environmental Protection Authority, 2010.*

Additionally, appropriate reference was made to the relevant Australian and International guidelines, including:

- Managing Acid and Metalliferous Drainage, February 2007, developed by the Australian Government, Department of Industry Tourism and Resource;
- Acid Mine Drainage – Environmental Notes of Mining, 2009, Department of Mines and Petroleum (DMP), Government of Western Australia;
- Waste Rock Dumps – Environmental Notes of Mining, 2009, Department of Mines and Petroleum (DMP), Government of Western Australia;
- The Global Acid and Metalliferous Drainage (GARD) Guide, May 2012, developed by the International Network of Acid Prevention (INAP); and
- The Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand 2000, Australian Water Guidelines for Fresh and Marine Waters and its updates.

## 1.3 Report Structure

An introduction to the project and scope of work is given in Section 8, followed by an overview of the project setting (Section 2) and a summary of the previous waste rock geochemical characterisation assessment undertaken for the Browns Range project (Section 3). The assessment of the representivity of the existing geochemical dataset (as reviewed in SRK (2013)) is presented in Section 4, and the supplemental leach test programme is reported in Section 5. Conclusions are provided in Section 6 and recommendations, including future work recommendations to address identified geochemical sampling data gaps, are given in Section 7.

# 2 Project Overview

## 2.1 Project Location and Summary

The Browns Range rare earths elements (REE) project site is located approximately 150 km southeast of Halls Creek in Western Australia (WA), adjacent to the WA/Northern Territory (NT) border (Figure 2-1).

The ore targeted at Browns Range is xenotime ($YPO_4$), a rare earth phosphate mineral and a rich source of yttrium and high value Heavy Rare Earths Element (HREE).

Xenotime was first identified in the Browns Range area in the 1980s by PNC Exploration while exploring for uranium. PNC named the area of quartz-xenotime mineralisation “Area 5 Prospect” and tested one of the larger quartz-xenotime veins (10-30cm wide, 15m long) by costeaning and shallow drilling, obtaining results up to 16% yttrium (Y), 0.2% uranium (U), 0.5% light REE (LREE) and 12% HREE.

The project will comprise open-pit mining at four deposits (Wolverine, Gambit Central, Gambit West and Area 5), with subsequent underground mining to be undertaken at the Wolverine and Gambit deposits (Figure 2-1). It is anticipated that Area 5 North, a fifth deposit, will not be mined.

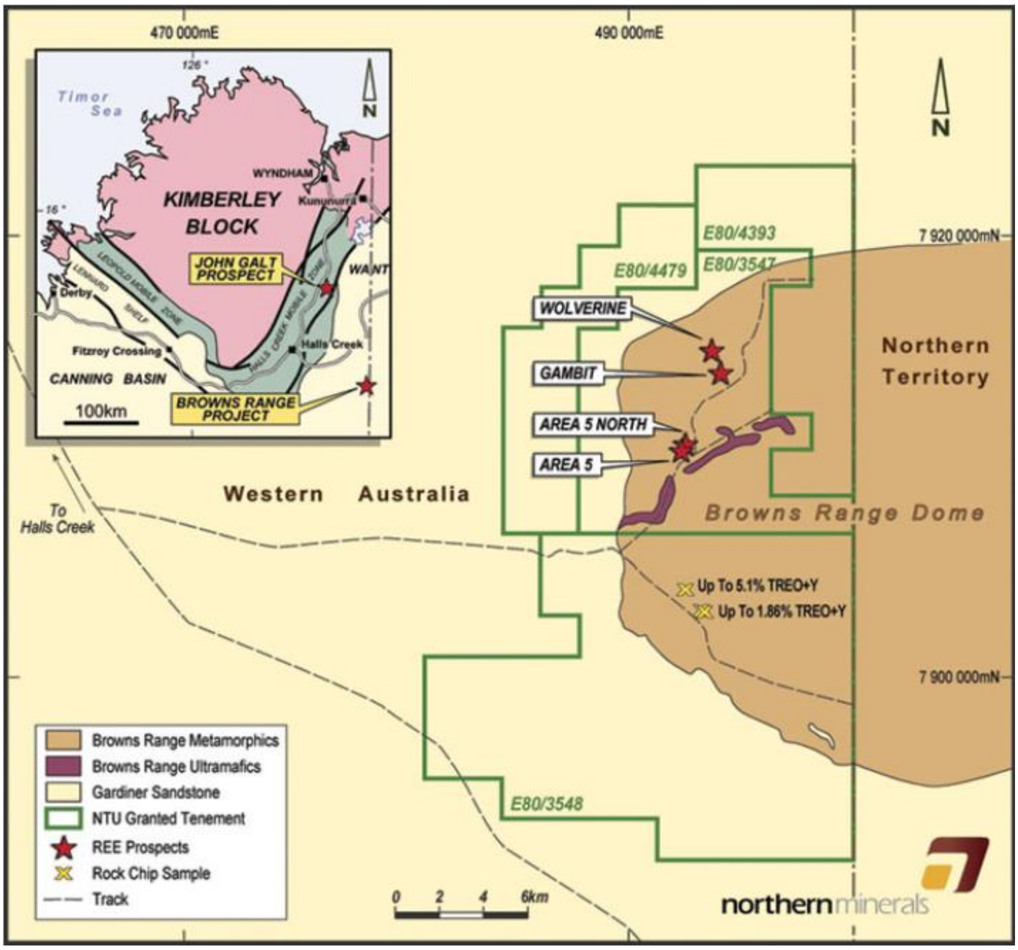


**Figure 2-1: Location of Browns Range deposits**

The proposed open pits are likely to be constructed to depths of 200 m, with pit floor radii of 50 m and a strip ratio of 30%. A Tailings Storage Facility (TSF) is proposed (location yet to be finalised) and Waste Rock Dump(s) (WRD) are anticipated to be located adjacent to the open pits.

### 2.1.1 Geological Setting

The Browns Range prospects are located on the western side of the Browns Range Dome, a Paleoproterozoic dome formed by a granitic core intruding the Paleoproterozoic "Browns Range Metamorphics" (meta-arkoses, feldspathic metasandstones and schists) and an Archaean orthogneiss and schist unit to the south. The dome and its aureole of metamorphics are surrounded by the Mesoproterozoic Gardiner Sandstone (Birrindudu Group).

### 2.1.2 Climate

The Browns Range site is located within a semi-arid climate zone with a monsoonal influence. Most of the rainfall occurs during the wet season between November and March and is associated with the passage of tropical monsoonal activity and cyclones. Bureau of Meteorology (BoM) data indicates that approximately 80% of the rainfall occurs from December to March (NML, 2013). The absence of these cyclones, during the wet season, can lead to drought conditions.

# 3 Previous Geochemical Characterisation

An outline of the previous geochemical characterisation review undertaken in 2013 (SRK, 2013) is presented below.

## 3.1 Waste Rock Sample Selection and Collection

A total of 33 waste rock samples (from six drillholes located at the Wolverine deposit) were selected for static geochemical testing by Northern Minerals Limited. The rock types, drillhole ID and sampling intervals for individual samples are provided in Appendix A. The drillhole locations are shown in Figure 3-1.

Composite samples, comprising sub-samples from all of the samples within each respective lithological grouping, based on the Northern Minerals Limited sample selection rationale as outlined in Table 3-1, were subjected to leach testing and radionuclide testing (solid and leachate).

All samples were dispatched to Intertek Genalysis Laboratory Services (IGLS) in Perth for the geochemical characterisation programme test work. IGLS has National Association of Testing Authorities (NATA) accreditation for the analyses carried out.

**Table 3-1: Lithological Grouping Summary and Rationale**

| Lithological grouping | Number of samples | Sampled depth range (m) | Rationale |
|---|---|---|---|
| 1 | 4 | 0.8-2.4 m | Transported material (including alluvial sand, colluvial sand and alluvial clay) |
| 2 | 5 | 4.0-22.6 m | Weathered *in situ* materials – including mottled saprolite |
| 3 | 12 | 13.5-100.1 m | Weathered *in situ* materials – predominantly moderately weathered sedimentary rocks (siltstones, arenites, arkoses) |
| 4 | 8 | 109.9-145 m | Ore zone deposits (brecciation or alteration common) |
| 5 | 4 | 117.2-173.5 m | Arkose wallrock (comprising arkose or arenite – rarely brecciated) |

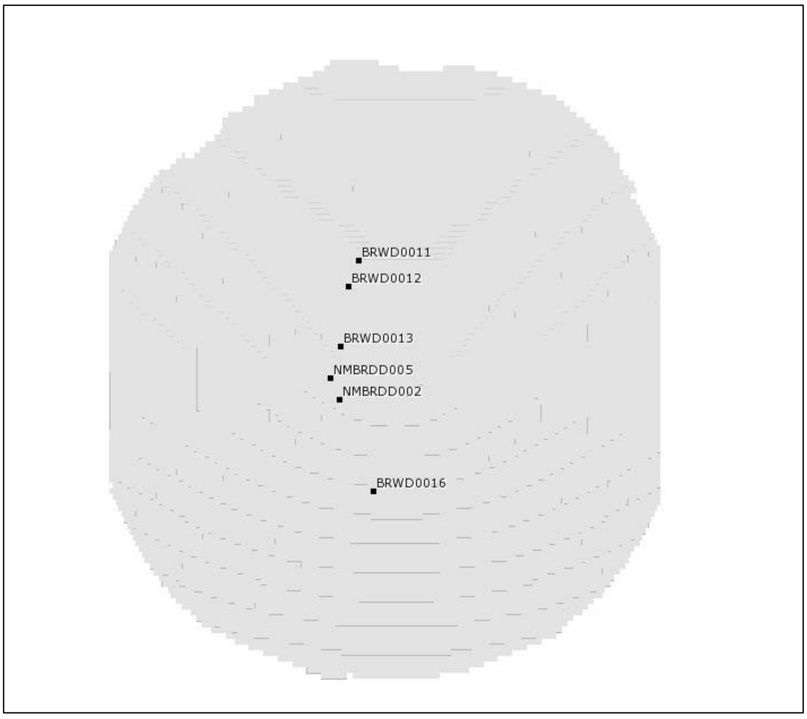


**Figure 3-1: Drillhole location plan - Wolverine Pit (orientated towards the East)**

## 3.2 Laboratory Programme

A programme of static testing laboratory work was initiated by NML to characterise the overall balance between acid generating and acid consuming minerals in the waste rock. Total metal analyses together with composite sample leach tests were also included in the test regime to investigate potential solute release and identify potential contaminants of concern.

The following test methods were included in the initial laboratory test work programme:

- Paste pH and EC;
- Acid base accounting (ABA) incorporating sulphur analysis, sulphide-sulphur analysis (chromium reducible sulphur), determination of acid neutralisation capacity (ANC) and definition of maximum potential acidity (MPA) and net-acid producing potential (NAPP);
- Net acid generation (NAG) tests;
- Multi-element solids content determination;
- Cation exchange capacity and exchangeable sodium percentage;
- Leach testing (1:5, solid: water) on composite samples (incorporating pH, EC, trace elements, major cations and anions, alkalinity);
- Mineralogical identification by x-ray diffraction (XRD); and
- Radionuclide assays of composite samples used for leach testing, and the leach test solutions.

The analytical methods employed are described in Appendix B.

## 3.3 Summary of Previous Characterisation Results

The following conclusions were made following review of the results obtained during the first phase of Browns Range waste rock geochemical programme:

- The sulfur content of the waste rock was low, ranging between <0.01 and 0.44 wt% S (median <0.01 wt% S). Sulfide-sulfur was shown to contribute between 20%-88% of the total sulfur content (in the eight samples analysed for sulfide-sulfur).
- Overall, the results of static ABA and NAG testing indicated that the rock samples possess both low acid generating potential and low acid neutralising capacity, and potential acid generation is considered to be of low environmental significance at the site.
- Qualitative mineral determination by x-ray diffraction (XRD) on 15 samples indicated that the dominant mineral was quartz with major quantities (>10 wt%) of illite/muscovite, potassium feldspar and kaolin. Minor (<10 wt%) or trace (<2 wt%) quantities of hematite, barite, xenotime, goethite, pyrophyllite, florencite[3] (REE bearing, with dominant Ce) and siderite were identified. Xenotime was present as a major constituent mineral (>10 wt%) within the arkose sample BR020024 collected from within the ore zone. No carbonate or sulphide bearing minerals identified (with the exception of presence of siderite in one sample, BR020022, <2 wt%), suggesting that the assessed lithologies contain limited acid generating or acid neutralising potential.
- “Enriched” elements were identified based on comparison of the multi-element analysis of the waste rock, compared against mean elemental crustal abundances using Global Abundance Indices (GAI). The “enriched” elements, which had a GAI of 3 or more, included: Ag, As, B, Bi, Ce, Dy, Er, Gd, Ho, La, Lu, Nd, Pr, S, Se, Sm, Tb, Te, Te, Tm, Y and Yb. The highest incidence of enriched elements occurred within lithological group 4 (sampled from the ore zone). Boron and selenium were identified as the elements most widely enriched in the sample dataset and additionally were enriched outside the ore zone.
- Leach testwork (utilising a 1:5 solid to liquid)[4] determined leachable concentrations of Al, B, Ba, Co, Cu, Er, Eu, Fe, Gd, Li, Lu, Mn, Pr, Rb, Sr, Tb, U, Y and Zn, with detectable REE leached concentrations generally coincident with the ore zone. It was noted that the Cu concentration in the leach extract from waste rock collected from the ore zone was above the ANZECC livestock drinking water guideline value. Water quality monitoring programs developed for the Browns Range project should be designed to include these analytes.
- Nine shallow depth waste rock samples were assessed for sodicity. Two samples were identified as sodic, and as a general recommendation, suitable precautions should be taken to prevent water flow over or ponding on the waste dumps to minimise physical erosion of materials, and also to minimise waste rock deterioration.
- Radionuclide assessment of leachate extracts from five composite waste rock samples (representing each of the lithological groupings including the ore zone (lithological group 4)) indicated that the radioactivity is below the mandatory DMP naturally occurring radioactive material investigation levels.
- It was considered that the waste rock materials present a low risk of acidic or metalliferous drainage and based on the initial static testwork data, and that no special handling, such as encapsulation of specific litho-types will be necessary. However, further studies were recommended to verify this conclusion (including assessment of sample representivity and long-term leaching characteristics).

[3] Florencite ($CeAl_3(PO_4)_2(OH)_6$, is a REE bearing mineral, in which cerium (Ce) is the dominant REE.
[4] The leach testwork comprised Shake Flask Extraction (batch) leach tests, using deionised water, at a solid to liquid ratio of 1:5, with shaking on for 24 hours.

# 4 Representivity of Geochemical Dataset

## 4.1 Wolverine Waste Rock

SRK reviewed the geological database provided by NML (SRK_NM_BR_DrillData, 22/8/2013). The geological logging and assay data were merged to allow interrogation of the assay data as a function of lithology.

Particular attention was given to examination of the distribution of sulfur assays, i.e. as an indicator of the distribution of sulfide within the rocks. In the previous geochemical characterisation testwork undertaken, sulfide-sulfur was shown to contribute between 20%-88% of the total sulfur content (in the eight samples analysed for sulfide-sulfur). Therefore, total sulfur has been used as a (conservative) surrogate to assess the acid generating potential of the assayed waste rock within the Wolverine database.

The *Leapfrog* geological modelling software package was used to select drillcore data from within the Wolverine pit shell (*br3pitshell74.dxf*). Waste rock was defined as the material present within the pit shell and outside the mineralised zone wireframes (main mineralised zone, footwall mineralised zone and hanging wall mineralised zone, which define the “mineralised zone”). The total waste drillcore length reviewed was 16,974 m, comprising 191 drillholes and 3679 assay samples.

As described in the previous section, the existing geochemical dataset was derived from testing of samples collected from six drillholes within the Wolverine deposit. The samples comprised the following:

- 33 rock samples; and
- Five composite waste rock samples (including one composite representative of the ore zone), which were subjected to static leach testing.

The distribution of the geochemical samples within the Wolverine pit shell is shown in Figure 4-1. The spatial density of NML drilling within the Wolverine pit shell, within the waste rock (non-mineralised zone) and the mineralised zones, are shown in Figure 4-2 and Figure 4-3, respectively. The drillholes are bias to the mineralised zones with less drillhole coverage towards the edge of the pit shell.

Based on the mineralisation wireframes, seven of the 33 waste rock samples were collected from within the mineralised zone. Of these samples, three have associated assay data indicating that they are of ore-grade (Total Rare Earth Oxide (TREO) >0.15 wt%; 0.23-1.90 wt% TREO).

Based on the review of the NML geological database, the geochemical sample set was further assessed in terms of lithological representivity and the distribution of sulfur.

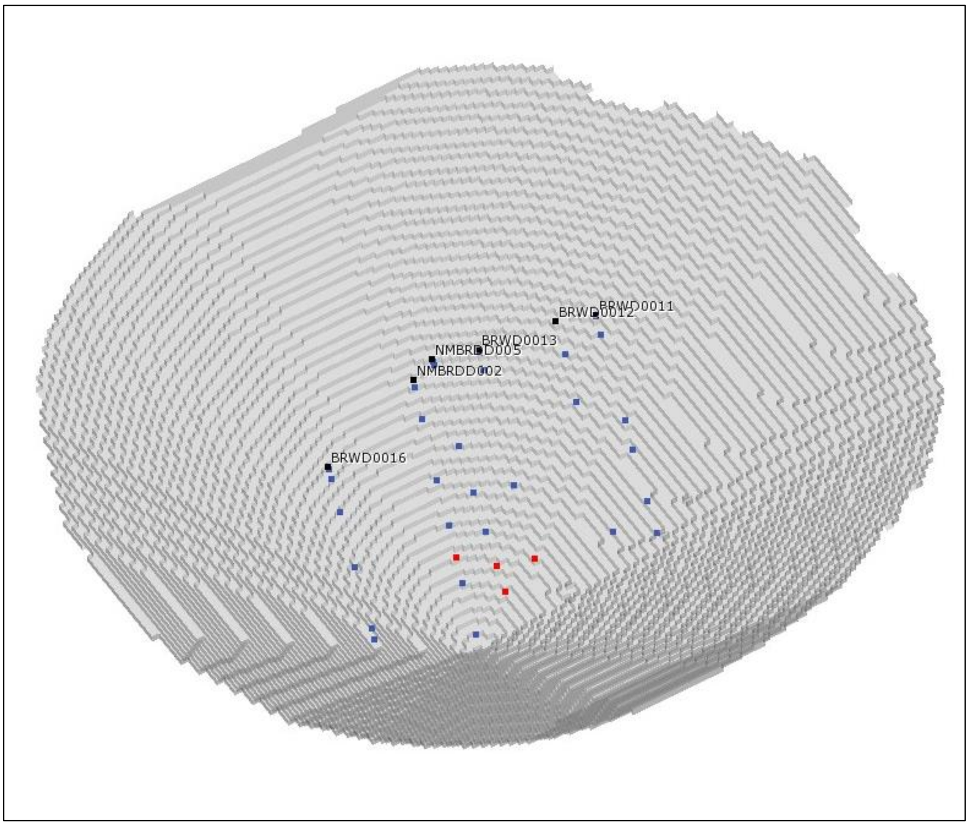


**Figure 4-1: Geochemical samples sulfur distribution – Wolverine Pit**

Note: Total sulfur data >0.1 wt% S shown in red; total sulfur data ≤0.1 wt% S shown in blue.

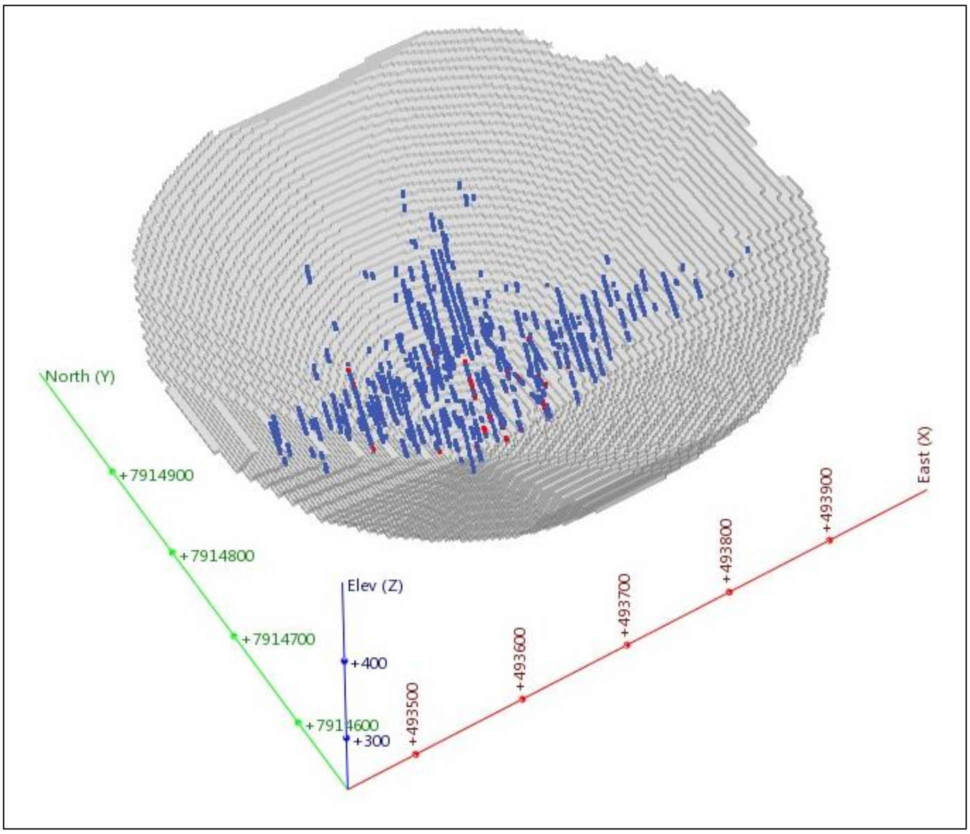


**Figure 4-2: Waste rock assay sulfur distribution – Wolverine Pit**

Note: Sulfur assay data >0.1 wt% S shown in red; sulfur data ≤0.1 wt% S shown in blue.

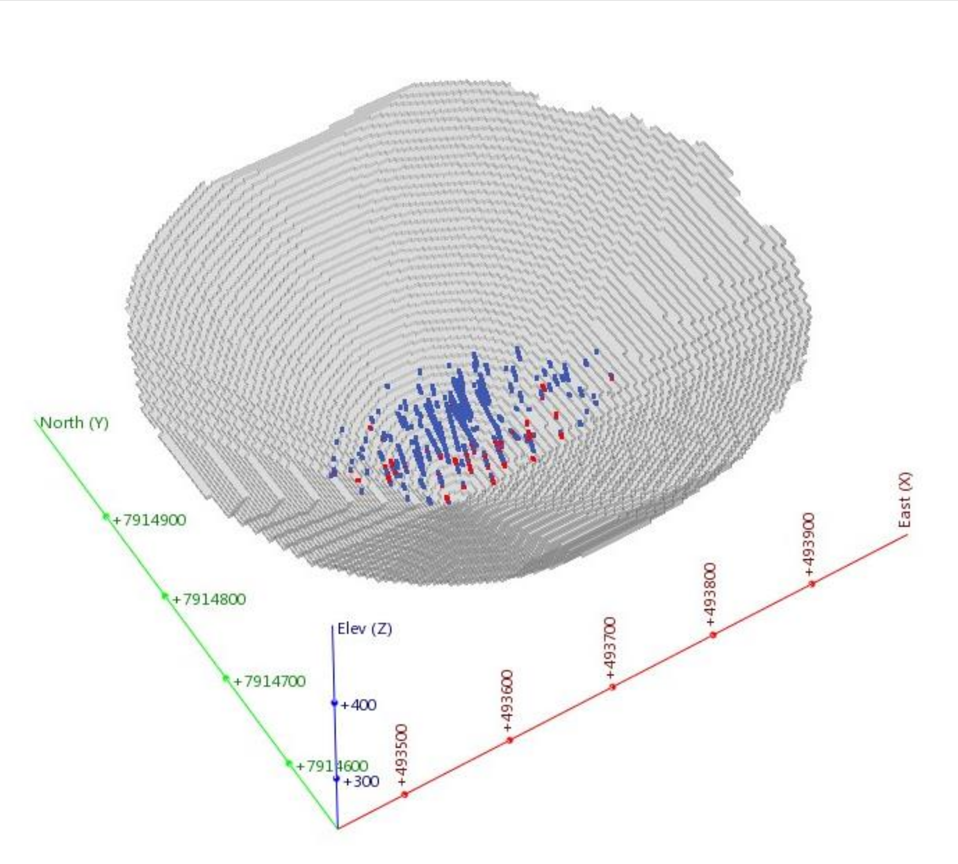


**Figure 4-3: Ore assay sulfur distribution – Wolverine Pit**

Note: Sulfur assay data >0.1 wt% S shown in red; sulfur data ≤0.1 wt% S shown in blue.

### 4.1.1 Lithological Representivity

The relative proportions of different waste rock lithological units were estimated based on the comparison of the cumulative lengths logged for each lithology (within the pit shell and outside the mineralised zones), as shown in Table 4-1. It should be noted that these proportions are indicative and may not be representative of the final volumes of waste rock that could report to a waste rock facility. More accurate representation of the composition of mined waste rock would require detailed waste rock production schedules and 3D volumetric modelling of the waste units.

**Table 4-1: Lithological representation of waste rock**

| Lithology | Code | Lithological representation logged within database drill-core | | Geochemical samples | |
|---|---|---|---|---|---|
| | | m | % | Count* | % of sample dataset |
| Arenite | SAN | 10009.5 | 59% | 8 | 24.2% |
| Arkose | SAK | 4253.29 | 25% | 8 (waste); 3 (ore) | 33.3% |
| Hematite Breccia | BH | 235.15 | 1.4% | 1 (waste); 1 (ore) | 6.1% |
| Argillite | SAR | 229.3 | 1.4% | - | - |
| Colluvial Gravel | TCG | 212.42 | 1.3% | - | - |
| Gravelstone | SGS | 194.23 | 1.1% | - | - |
| Siltstone | SST | 190.39 | 1.1% | - | - |
| Sandstone | SS | 187.7 | 1.1% | - | - |

| Lithology | Code | Lithological representation logged within database drill-core | | Geochemical samples | |
|---|---|---|---|---|---|
| | | m | % | Count* | % of sample dataset |
| Mottled Saprolite | RMS | 163.47 | 1.0% | 2 | 6.1% |
| Interbedded arenite and argillite (arenite dominant) | SIAS | 128.68 | 0.8% | 1 | 3.0% |
| Colluvial Clay | TCC | 94.05 | 0.6% | 2 | 6.1% |
| Schist Unclassified | XSC | 87.2 | 0.51% | 1 (ore) | 3.0% |
| Breccia (Generic Monomict) | B | 62.8 | 0.37% | 1 (ore) | 3.0% |
| Clay | RCY | 56.77 | 0.33% | 1 | 3.0% |
| Mottled No Relict Texture | RMO | 33.02 | 0.19% | 1 | 3.0% |
| Alluvial Clay - Lake Clay | TAC | 25.25 | 0.15% | 1 | 3.0% |
| Xenotime Breccia | BX | 14.8 | 0.09% | 1 (ore) | 3.0% |
| Alluvial Sand | TAV | 2.4 | 0.014% | 1 | 3.0% |

Note: All lithologies present within the Wolverine pit shell, and outside the mineralised zones (hanging wall, footwall and main) in logged length >1% are detailed (shaded grey cells), along with additional lithologies that were sampled for geochemical characterisation.

* Sample numbers detailed within the Count column detail waste zone samples unless otherwise stated.

In previous studies, it is noted that the NML sampling rationale was based on different lithological groupings, as detailed in Table 4-2, in part based on the identified weathering profile at Wolverine. A summary of the number of geochemical samples, per waste lithology, as sampled from each of the NML lithological groupings is provided in Appendix A.

**Table 4-2: NML lithological grouping summary and sampling rationale**

| Lithological grouping | Number of samples | Sampled depth range (m) | Rationale |
|---|---|---|---|
| 1 | 4 | 0.8-2.4 | Transported material (including alluvial sand, colluvial sand and alluvial clay) |
| 2 | 5 | 4.0-22.6 | Weathered in situ materials – including mottled saprolite |
| 3 | 12 | 13.5-100.1 | Weathered *in situ* materials – predominantly moderately weathered sedimentary rocks (siltstones, arenites, arkoses) |
| 4 | 8 | 109.9-145 | Ore zone deposits (brecciation or alteration common) |
| 5 | 4 | 117.2-173.5 | Arkose footwall (comprising arkose or arenite – rarely brecciated) |

The dominant waste lithologies within the pit shell are arenite (59%) and arkose (25%), with the remaining waste rock lithologies present in total logged lengths of less than 1.5%. The complete list of estimated lithological proportions, including lithologies present in proportions less than 1% of the total core length, are detailed in Appendix A.

Based on the total logged length waste rock proportions, arenite is under-represented within the geochemical sample set (comprising 24% of the samples, and 59% of the total logged waste length), and arkose is slightly over-represented (comprising 33% of the samples, and only 25% of the total logged waste length).

There are a further 43 minor waste lithologies, which are present in proportions of less than 1.5% of the total logged length of waste rock. Of these minor lithologies, only 11 have been included in the geochemical characterisation study. In order to assess if further geochemical characterisation of the minor lithologies is prudent, a review of the sulfur distribution of the waste rock lithologies has been undertaken, and is presented in the next section.

### 4.1.2 Distribution of Sulfur

Of the total logged length of waste within the drillcore (16,974 m), 19% has been assayed for sulfur. A total of 28 of the 45 waste lithologies are represented in the assay dataset. A summary of sulfur statistics is presented in Table 4-3.

The sulfur content within the waste lithologies is generally low, ranging between <0.0025 wt% S and 1.33 wt% S (breccia (generic monomict)). Median S contents were below detection limits (<0.0025-<0.025 wt% S), in all lithologies with the exception of the vein lithology, which had a median S content of 0.05 wt% S.

The highest average sulfur concentrations occurred within the breccia (generic monomict) (0.082 wt% S), polymict breccia (0.073 wt% S) and siltstone (0.070 wt% S) lithologies.

In order to assess whether any waste lithologies require further assessment in terms of potential acid generation, a sulfur cut-off threshold has been applied (0.1 wt% S). Materials with sulfur content below the threshold are considered to represent a low risk of acid generation. Application of a 0.1 wt% S threshold is often used for materials that contain little or no neutralisation potential (e.g. Green and Borden, 2011). The neutralisation potential offered by the previously assessed Wolverine waste lithologies was found to be low, with ANC values of 1-17 kg$H_2SO_4$/t.

Five waste lithologies have 95$^{th}$ percentile sulfur contents equal to, or greater than 0.1 wt% S, including siltstone, interbedded arenite and argillite, breccia (generic monomict), sericite breccia and polymict breccia. Of these lithologies, sericite breccia and polymict breccia have not yet been geochemically characterised. Siltstone was present as a minor lithology in an arenite sample (BR020008).

A total of 51.85m of waste zone assayed drillcore has sulfur content above 0.1 wt% S, which represents 1.6% of the total length of waste rock assayed drillcore, and 0.3% of the total length of waste rock drillcore.

**Table 4-3: Database waste rock lithology sulfur statistics**

| Lithology | Lith. code | Assay count | Sulfur assay length (m) | Sulfur content,% | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Min. | Med. | Ave. | 95th percentile | 99th percentile | Max. |
| Arenite | SAN | 1378 | 1336 | <0.0025 | <0.025 | 0.03 | 0.07 | 0.16 | 1.04 |
| Arkose | SAK | 1246 | 1226 | <0.0025 | <0.025 | 0.02 | 0.05 | 0.09 | 0.19 |
| Hematite Breccia | BH | 185 | 173 | <0.025 | <0.025 | 0.03 | 0.06 | 0.08 | 0.09 |
| Argillite | SAR | 10 | 10 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Colluvial Gravel | TCG | 41 | 41 | <0.025 | <0.025 | 0.03 | <0.025 | 0.04 | 0.05 |
| Gravelstone | SGS | 60 | 51 | <0.0025 | <0.025 | 0.03 | 0.08 | 0.09 | 0.09 |
| Siltstone | SST | 25 | 21 | <0.025 | <0.025 | 0.07 | 0.10 | 0.75 | 0.96 |
| Sandstone | SS | 29 | 29 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Mottled Saprolite | RMS | 3 | 3 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Interbedded arenite and argillite (arenite dominant) | SIAS | 38 | 36 | <0.025 | <0.025 | 0.04 | 0.10 | 0.13 | 0.14 |
| Quartz Breccia | BQ | 109 | 104 | <0.025 | <0.025 | 0.03 | 0.06 | 0.10 | 0.13 |
| Vein Quartz | VQ | 57 | 27 | <0.0025 | <0.025 | 0.03 | 0.08 | 0.15 | 0.19 |
| Colluvial Clay | TCC | 1 | 1 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Interbedded fine and coarse grained arenite | SIAA | 35 | 33 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Schist Unclassified | XSC | 25 | 16 | <0.0025 | <0.025 | 0.02 | <0.025 | <0.025 | <0.025 |
| Saprolite | RSP | 4 | 4 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Conglomerate | SCG | 11 | 8.1 | <0.025 | <0.025 | 0.03 | 0.04 | 0.06 | 0.06 |
| Breccia (Generic Monomict) | B | 71 | 63 | <0.025 | <0.025 | 0.08 | 0.17 | 1.13 | 1.33 |
| Soil (transported) | TSO | 2 | 2 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Clay | RCY | 2 | 2 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Sericite breccia | BS | 24 | 16.1 | <0.025 | <0.025 | 0.04 | 0.11 | 0.11 | 0.11 |
| Xenotime Breccia | BX | 18 | 14.8 | <0.025 | <0.025 | 0.04 | 0.07 | 0.09 | 0.1 |
| Vein | VN | 3 | 3 | <0.025 | 0.05 | 0.05 | 0.08 | 0.08 | 0.08 |
| Polymict Breccia | BP | 14 | 11.8 | <0.025 | <0.025 | 0.07 | 0.28 | 0.55 | 0.62 |
| Mudstone | SMS | 4 | 2.9 | <0.0025 | <0.0025 | 0.004 | 0.007 | 0.01 | 0.01 |
| Quartzite | XSQ | 2 | 2 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |
| Colluvial Silt | TCS | 6 | 3.5 | <0.025 | <0.025 | 0.031 | 0.05 | 0.06 | 0.06 |
| Clay Fault | CF | 1 | 0.4 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 | <0.025 |

The sulfur statistics calculated from the geochemical samples, separated into waste zone and ore zone sub-sets, are in good agreement with the statistics for equivalent samples within the assay dataset (Table 4-4).

Review of the waste zone and ore zone assay datasets has shown that the ore-grade samples contain more sulfur than the waste-grade samples. This would suggest that the ore zone may have a greater propensity to generate acid. The higher density of drillholes closer to the ore zone will possibly result in a general bias toward higher sulfur contents, and the current datasets may be conservative (with respect to acid generation potential) compared with the total waste rock volume generated from the pit shell.

Mineralised material would generally report to the plant and ultimately to the TSF. However, as a small portion of mineralised material may report to the waste rock dump, and some mineralised material may remain on the pit walls and on underground exposed faces, it was considered prudent to characterise material from within the mineralised zone.

[SRK understand that NML has commissioned Golder Associates to undertake a companion study concerning the physical and geochemical properties of the Browns Range beneficiation rejects and hydrometallurgical tailings, which is currently in progress.]

Figure 4-2 and Figure 4-3 highlight the database assay samples with sulfur contents >0.1 wt% S, in the waste rock and mineralised zones, respectively, and show that there is a higher proportion of material above the sulfur cut-off threshold( >0.1 wt%) within the mineralised zones.

As summarised in Table 4-4, the average and 95$^{th}$ percentile sulfur contents of the geochemical samples are reasonably consistent with the corresponding assay sample data (from within the waste zone and ore zone), and corroborate the observation that higher S contents are generally associated within the ore zone materials.

Comparison of the sulfur statistics calculated for the dominant lithologies, arenite and arkose, also demonstrate good agreement between the geochemical samples and equivalent samples (from the waste zone and ore zone) within the assay dataset (Table 4-5).

**Table 4-4: Database assay and geochemical sample set sulfur content summary**

| Dataset | Zone | Count | Min. | Median | Ave. | Max. | 95$^{th}$ percentile |
|---|---|---|---|---|---|---|---|
| Geochemical Samples | Waste zone | 26 | <0.01 | 0.01 | 0.03 | 0.44 | 0.04 |
| Geochemical Samples | Ore zone | 7 | 0.01 | 0.06 | 0.12 | 0.36 | 0.31 |
| Database S assay data | Waste zone | 3404 | <0.0025 | <0.025 | 0.03 | 1.33 | 0.06 |
| Database S assay data | Ore zone | 1191 | <0.0025 | <0.025 | 0.07 | 3.51 | 0.31 |

**Table 4-5: Arenite and arkose (assay and geochemical sample set) sulfur statistics**

| Lithology | Dataset | Zone | Count | Min. | Median | Ave. | Max. | 95th percentile |
|---|---|---|---|---|---|---|---|---|
| Arenite | Static Samples | Waste zone | 8 | <0.01 | <0.01 | 0.02 | 0.04 | 0.04 |
| Arenite | Static Samples | Ore zone | - | - | - | - | - | - |
| Arenite | Database S assay data | Waste zone | 1378 | <0.0025 | <0.025 | 0.03 | 1.04 | 0.07 |
| Arenite | Database S assay data | Ore zone | 144 | <0.025 | <0.025 | 0.09 | 2.08 | 0.31 |
| Arkose | Static Samples | Waste zone | 8 | <0.01 | 0.01 | 0.10 | 0.44 | 0.40 |
| Arkose | Static Samples | Ore zone | 3 | 0.01 | 0.19 | 0.19 | 0.36 | 0.34 |
| Arkose | Database S assay data | Waste zone | 1246 | <0.0025 | <0.025 | 0.024 | 0.19 | 0.05 |
| Arkose | Database S assay data | Ore zone | 741 | <0.0025 | <0.025 | 0.04 | 3.51 | 0.11 |

## 4.2 Review of Other Deposits (Area 5, Area 5 North, Gambit West, Gambit Central)

Geology, waste rock lithological composition, mineralogy and the propensity to generate AMD can vary significantly within a single deposit. Available geological information and assay data have been reviewed to provide a preliminary assessment of whether the Area 5, Area 5 North, Gambit West and Gambit Central deposits can be regarded as analogous to the Wolverine deposit and to determine whether further geochemical sampling is required.

NML has indicated that the Area 5 North deposit may not be mined.

The geological database provided by NML (SRK_NM_BR_DrillData, 22/8/2013) was reviewed, and the geological logging and assay data were merged to allow review of the assay data by lithology. A summary of the number of drillholes, drillhole lengths and the number of assay samples reviewed is provided in Table 4-6.

**Table 4-6: Drillhole data summary**

| Deposit | No. of Drillholes | Total logged length (m) | No. of assay samples |
|---|---|---|---|
| Gambit Central | 77 | 6731 | 2454 |
| West Gambit | 142 | 9035 | 2501 |
| Area 5 | 99 | 11011 | 4308 |
| Area 5 N | 37 | 2531 | 716 |

Pit shells for the Area 5, Area 5 North, Gambit West and Gambit Central deposits have not yet been developed. Approximate pit footprints for each of the deposits were provided by NML.

*Leapfrog* was used to identify which drillholes occur within the indicative pit footprints, by projecting the surface footprint vertically and selecting the drillhole data within the resultant footprint “cylinder”. Lithological proportions calculated using this method are intrinsically more uncertain than those calculated for the Wolverine area, which was based on the available pit shell.

Ore-grade material was separated using the ore-grade TREO threshold of 0.15 wt% TREO, and the remaining data were defined as waste (i.e. data with assay TREO ≤ 0.15%, or with no TREO assay data and assumed as waste rock).

The relative proportions of different waste rock lithological units at Area 5, Area 5 North, Gambit West and Gambit Central, were estimated based on the comparison of the cumulative lengths logged for each lithology, as shown in Table 4-7, Table 4-8, Table 4-9 and Table 4-10, respectively.

Following review of the lithological proportions and associated lithological sulfur statistics, the following points are highlighted:

- Arenite and/or arkose are the dominant waste lithologies, as at the Wolverine deposit, comprising a combined proportion of over 85% of the total logged waste drillcore at each of the four deposits;
- Arkose is the dominant waste lithology (90% of the logged waste drillcore length) at the Area 5 N deposit, with minor arenite (0.1%);
- Arenite is the dominant waste lithology (85%) at the Gambit West, with a minor arkose (1.4%);
- Slighter higher proportions of certain minor waste lithologies were identified, compared with the lithological proportions present at Wolverine, including, conglomerate (3.4%, Area 5), schist unclassified (4.6%, Area 5 North), interbedded fine and coarse grained arenite (3.7%, Gambit West), hematite breccia (2.9%, Gambit West) and colluvial gravel (2.1%); and
- Sulfur contents were found to be typically low; however, a number of waste lithologies were identified with maximum sulfur contents greater than 0.1 wt% S, including:
  - Arenite and arkose (Area 5)
  - Arkose (Area 5 North)
  - Arenite, hematite breccia and siltstone (Gambit West)
  - Arkose, arenite, interbedded arenite and argillite, gravelstone, interbedded fine and coarse grained arenite and conglomerate (Gambit Central).

**Table 4-7: Lithological representation and sulfur content of waste rock at Area 5**

| Lithology | Code | Lithological representation | | Database assay S wt% statistics | | | |
|---|---|---|---|---|---|---|---|
| | | m | % | Assayed length (m) | Min. | Ave. | Max. |
| Arenite* | SAN | 6967.9 | 70.3% | 2308 | <0.025 | 0.026 | 0.82 |
| Arkose | SAK | 1843.2 | 18.6% | 462 | <0.025 | 0.026 | 0.28 |
| Conglomerate* | SCG | 338.37 | 3.4% | 147 | <0.025 | 0.025 | 0.05 |
| Clay | RCY | 165 | 1.7% | 35 | <0.025 | <0.025 | <0.025 |
| Schist Unclassified | XSC | 108.2 | 1.1% | 43 | <0.025 | <0.025 | <0.025 |
| Colluvial Gravel | TCG | 87 | 0.9% | 9 | <0.025 | <0.025 | <0.025 |
| Interbedded fine and coarse grained arenite | SIAA | 85.01 | 0.9% | 20 | <0.025 | <0.025 | <0.025 |
| Saprolite | RSP | 56.78 | 0.6% | 4 | <0.025 | 0.0425 | 0.06 |
| Vein Quartz | VQ | 52.21 | 0.5% | 25.8 | <0.025 | <0.025 | <0.025 |
| Gravel | TGV | 37 | 0.4% | - | - | - | - |
| **Total** | **-** | **9906.6** | **-** | **-** | **-** | **-** | **-** |

Note: All waste lithologies (with TREO <0.15 wt%, or with no associated assay data) that are present within the Area 5 footprint and in logged length >0.2% of the total Area 5 waste lithology logged length are detailed. Waste lithologies present in proportions greater or equal to 1% are shaded grey. * Maximum sulfur contents of 60 wt% S were reported for arenite and conglomerate samples from drillcore BRAD0003, which are considered anomalous and most likely typographical errors. These sulfur values have been removed from the datasets and not incorporated in the statistical calculations.

**Table 4-8: Lithological representation and sulfur content of waste rock at Area 5 North**

| Lithology | Code | Lithological representation | | Database assay S wt% Statistics | | | |
|---|---|---|---|---|---|---|---|
| | | m | % | Assayed length (m) | Min. | Ave. | Max. |
| Arkose | SAK | 2151 | 89.9% | 530 | <0.025 | 0.025642 | 0.1 |
| Schist Unclassified | XSC | 110 | 4.6% | 30 | <0.025 | 0.0315 | 0.08 |
| Colluvial Gravel | TCG | 41 | 1.7% | 5 | <0.025 | <0.025 | <0.025 |
| Vein Quartz | VQ | 26 | 1.1% | 3 | <0.025 | <0.025 | <0.025 |
| Meta Sediment Unclassified | XMS | 24 | 1.0% | 3 | <0.025 | <0.025 | <0.025 |
| - | NL | 15 | 0.6% | 4 | <0.025 | <0.025 | <0.025 |
| Greywacke | SGW | 12 | 0.5% | 3 | <0.025 | <0.025 | <0.025 |
| Quartzite | XSQ | 11 | 0.5% | - | - | - | - |
| Arenite | SAN | 3 | 0.1% | - | - | - | - |
| **Total** | **-** | **2393** | **-** | **-** | **-** | **-** | **-** |

Note: All waste lithologies (with TREO <0.15 wt%, or with no associated assay data) that are present within the Area 5 North footprint and in logged length >0.2% of the total Area 5 North waste lithology logged length are detailed. Waste lithologies present in proportions greater or equal to 1% are shaded grey.

**Table 4-9: Lithological representation and sulfur content of waste rock at Gambit West**

| Lithology | Code | Lithological representation | | Database assay S wt% statistics | | | |
|---|---|---|---|---|---|---|---|
| | | m | % | Assayed length (m) | Min. | Ave. | Max. |
| Arenite | SAN | 7195.7 | 85% | 1538.8 | <0.025 | 0.026 | 0.21 |
| Interbedded fine and coarse grained arenite | SIAA | 315.03 | 3.7% | 59.7 | <0.025 | 0.026 | 0.06 |
| Hematite Breccia | BH | 244.36 | 2.9% | 105.4 | <0.025 | 0.026 | 0.1 |
| Colluvial Gravel | TCG | 179 | 2.1% | 15 | <0.025 | 0.031 | 0.09 |
| Arkose | SAK | 119.19 | 1.4% | 4.5 | <0.025 | <0.025 | <0.025 |
| Siltstone | SST | 77.4 | 0.9% | 7.3 | <0.025 | 0.045 | 0.12 |
| Quartz Breccia | BQ | 37 | 0.44% | 8 | <0.025 | <0.025 | <0.025 |
| Mottled Saprolite | RMS | 36.3 | 0.43% | 1 | <0.025 | <0.025 | <0.025 |
| Breccia (Generic Monomict) | B | 32.2 | 0.38% | 24 | <0.025 | <0.025 | <0.025 |
| Colluvium | TCO | 26.9 | 0.32% | 2.1 | <0.025 | <0.025 | <0.025 |
| Schist Unclassified | XSC | 23.27 | 0.28% | 7 | <0.025 | <0.025 | <0.025 |
| Saprolite | RSP | 23 | 0.27% | 1 | 0.06 | 0.06 | 0.06 |
| Gravel | TGV | 22 | 0.26% | 3 | <0.025 | <0.025 | <0.025 |
| Sericite breccia | BS | 19.12 | 0.23% | 17.9 | <0.025 | <0.025 | <0.025 |
| **Total** | | **8421.4** | | | | | |

Note: All waste lithologies (with TREO <0.15 wt%, or with no associated assay data) that are present within the Gambit West footprint and in logged length >0.2% of the total Gambit West waste lithology logged length are detailed. Waste lithologies present in proportions greater or equal to 1% are shaded grey.

**Table 4-10: Lithological representation and sulfur content of waste rock at Gambit Central**

| Lithology | Code | Lithological representation | | Database assay S wt% statistics | | | |
|---|---|---|---|---|---|---|---|
| | | m | % | Assayed length (m) | Min. | Ave. | Max. |
| Arkose | SAK | 3230 | 51.6% | 1039 | <0.025 | 0.0296 | 0.2 |
| Arenite | SAN | 2630.2 | 42.0% | 739 | <0.025 | 0.0296 | 0.31 |
| Interbedded arenite and argillite (arenite dominant) | SIAS | 82.6 | 1.3% | 22 | <0.025 | 0.0292 | 0.1 |
| Colluvial Gravel | TCG | 55.0 | 0.88% | 12 | <0.025 | <0.025 | <0.025 |
| Gravelstone | SGS | 47.1 | 0.75% | 13.2 | <0.025 | 0.075 | 0.69 |
| Quartz Breccia | BQ | 38.2 | 0.61% | 32.2 | <0.025 | 0.0260 | 0.06 |
| Interbedded fine and coarse grained arenite | SIAA | 28.1 | 0.45% | 14.3 | <0.025 | 0.03 | 0.1 |
| Hematite Breccia | BH | 27.8 | 0.44% | 15.6 | <0.025 | <0.025 | <0.025 |
| Quartzite | XSQ | 26.0 | 0.42% | - | - | - | - |
| Siltstone | SST | 19.0 | 0.30% | 2.6 | <0.025 | <0.025 | <0.025 |
| Soil (transported) | TSO | 16.0 | 0.26% | 2 | <0.025 | <0.025 | <0.025 |
| Vein Quartz | VQ | 12.7 | 0.20% | 4 | <0.025 | <0.025 | <0.025 |
| Mudstone | SMS | 6.00 | 0.10% | 5 | 0.025 | 0.03 | 0.05 |
| Conglomerate | SCG | 4.48 | 0.07% | 6 | 0.025 | 0.16 | 0.69 |
| Fault Breccia | XFB | 2.10 | 0.03% | 3 | 0.025 | 0.04 | 0.08 |
| **Total** | | **6261.3** | | | | | |

Note: All waste lithologies (with TREO <0.15 wt%, or with no associated assay data) that are present within the Gambit Central footprint and in logged length >0.2% of the total Gambit Central waste lithology logged length, or detectable sulfur content, are detailed. Waste lithologies present in proportions greater or equal to 1% are shaded grey.

# 5 Supplemental Waste Rock Leach Test Assessment

## 5.1 Introduction

The use of kinetic testing (i.e. free draining column methodologies) is widely adopted within the mining industry as part of the geochemical assessment of mine wastes in support of the mining proposal. These techniques are designed specifically for study of weathering and leaching behaviour in sulfidic samples. The geological assay database, combined with static geochemical data obtained to date, indicate that mined materials contain low sulfur levels. SRK considers that alternative methods may be better suited to generate data describing potential long-term weathering behaviour – e.g. static leach testing under a wider range of geochemical conditions.

A static leach testwork programme was designed and implemented to assess the potential drainage chemistry from the Wolverine waste rock samples, and incorporated the following testwork:

- 11 Shake Flask Extraction tests (using deionised water as the extractant);
- 5 Mild Acid Leach Shake Flask Extraction tests (using dilute sulfuric acid as the extractant); and
- 5 Single-Addition NAG tests, with subsequent analysis of the NAG liquor.

A summary of the analytical methods employed in the leach assessment is detailed in Appendix B.

Further details of the samples selected for leach testing are given in Table 5-1. Details of the geochemical properties of the samples are provided in Appendix B.

Results from the laboratory test work are presented in the following three sections.

**Table 5-1: Selected Samples for Long-Term Leachability Assessment**

| Sample ID | Drillhole ID | Sampled Interval (m) | Lithology Group | Lithology | Total S (%) | SFE | Mild Acid Leach SFE | NAG (with NAG solution analysis) |
|---|---|---|---|---|---|---|---|---|
| BR020006 | BRWD0011 | 0.8-1.3 | 1 | Colluvial Clay | 0.01 | x | | |
| BR020020 | NMBRDD002 | 5.1-5.5 | 2 | Arkose | 0.01 | x | x | |
| BR020017 | BRWD0016 | 8.37-9.0 | 2 | Mottled Saprolite | 0.01 | x | | |
| BR020023 | NMBRDD002 | 99.4-100.0 | 3 | Arkose | 0.02 | x | | |
| BR020003 | BRWD0011 | 92-92.6 | 3 | Arenite | 0.04 | x | x | |
| BR020011 | BRWD0013 | 92.25-92.75 | 3 | Arenite | 0.04 | x | | x |
| BR020024 | NMBRDD002 | 120.3-121.3 | 4 | Arkose | 0.36 | x | x | x |
| BR020032 | NMBRDD005 | 143-144 | 4 | Arkose | 0.19 | x | | x |
| BR020010 | BRWD0013 | 142.1-142.7 | 4 | Hematite Breccia | 0.16 | x | | x |
| BR020014 | BRWD0016 | 109.9-110.9 | 4 | **Arenite** / Sericite Breccia | *0.01* | x | x | |
| BR020033 | NMBRDD005 | 161-161.6 | 5 | Quartz / **Arkose** | 0.44 | x | x | x |

Notes: Shaded cells indicated selected samples. Values in *italics* are below the reported detection limit. Dominant lithologies within a sampled interval are shown in **bold**.

## 5.2 Shake Flask Extraction Results

Static de-ionised water leach extraction tests were undertaken to provide an indication of the readily leachable elements that may be present within waste rock. Note that the test results reflect the condition of the samples at the time they were tested and may not represent the material behaviour following weathering (when solutes may be more readily available to leach dependent on the stage of weathering, mineralogy, solubility controls, kinetics etc.).

Leach tests were carried out on eleven waste rock samples, incorporating at least one sample from each of the five Northern Mineral lithological sampling groups (as described in Table 3-1). The leach tests involved roughly crushed samples and were conducted at a 1:5 solid to liquid ratio with a 24-hour contact time (during which the sample was tumbled). This method was selected in order to be consistent with the methodology utilised previously by NML during the previous static leach testing of composite waste rock samples (Section 0).

A summary of the detectable concentration ranges from the leach extraction tests are given in Table 5-2, with full laboratory results in Appendix C.

The ANZECC livestock drinking water guideline values are also listed for reference. The laboratory results cannot be used directly to represent leachate quality expected to seep from a stockpile of the material. Depending on field conditions, seepage water quality might be better or worse than indicated by these leach tests. Thus, while comparison with the guidelines may help identify some parameters of concern, it does not allow determination of which elements will remain below, or exceed, the guidelines in the field-scale system.

The trends observed from the de-ionised water static leach tests on individual samples are generally consistent with earlier composite sample testing, however higher maximum REE concentrations are observed within the individual sample dataset (sub-ore zone sample BR020033).

The final pH values obtained in the recent leachates were predominantly circum-neutral (pH 6.9-7.3), with more acidic leachates associated with samples collected from the ore zone (pH 4.9-5.2) and sub-ore zone (pH 3.9). The more acidic pH values obtained from the ore zone and sub-ore zone samples are coincident with higher sulfur contents (0.16-0.44 wt% S). The composite leachate sample final pH values were also circum-neutral in waste rock from above the ore zone (pH 6.7-7.6), and (mildly) acidic in the ore zone (pH 5.7) and sub-ore zone (pH 5.0).

The leachable trace metal concentrations of the waste rock samples were generally low, and often below detection limits. The leachable REE concentrations from waste rock sampled from above the ore zone were predominantly below detection limit (<0.001 mg/L).

Higher dissolved concentrations of certain trace metals (e.g. Co, Cu, Ni, U) and the REE are evident in the acidic leachates, corresponding with the ore zone and sub-ore zone samples, and appear to be controlled by a pH-dependent solubility control, with higher dissolved concentrations occurring below pH 5.5. Conversely, the dissolved concentrations of Ba and F increase in more alkaline conditions (from pH 7), as encountered at shallower depth above the ore zone (LG 1-3). While the highest REE concentrations were obtained in the leachate of the sub-ore zone sample in the recent extracts, the highest concentrations from the previous testing on composite samples were obtained from the ore zone composite sample.

Although selenium was identified as one of the two most "enriched" elements on the basis of the GAI assessment of the solid samples (*SRK, 2013*), no leachable selenium concentrations above detection level were obtained. Boron, the most commonly "enriched" element within the solid samples, was present in nine of the eleven leach extractions.

The proportions of trace metals and REE that were leachable in solution, compared with the total masses present in the samples, were generally low. The maximum proportion of REE that became soluble equated to approximately 5% of the total mass (e.g. Tb (4.8%), Y (4.1%), Dy (4.2%), while certain REE were demonstrated low solubility (Ce, 0.1%). Similarly, the leachable copper from sample BR020024, (6.5 mg/L), equated to approximately 5% of the mass of copper present within the sample. Dissolved phosphate concentrations indicate limited phosphate solubility.

When compared to the available ANZECC livestock drinking water guideline values, the highest two leached concentrations of copper (6.54 mg/l, BR020024, ore zone, 99.7$^{th}$ percentile of the Wolverine Cu assays; 0.84 mg/l, composite sample LG 4) were above the guideline value (0.4 mg/l), and the fluoride concentrations leached from samples BR020020 (3.4 mg/l; arkose) and BR020017 (2.8 mg/l; mottled saprolite) from LG 2 were above the guideline value of 2 mg/l.

It is noted that no recognised environmental REE assessment criteria (e.g. water quality standards) were identified.

**Table 5-2: Leachate composition (elements present above detection limits)**

| Element/ Analyte | Units | Static SFE Concentration Ranges | | | | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|
| | | Individual samples (n=11) | | Composite samples (n=5) [1] | | |
| | | Minimum | Maximum | Minimum | Maximum | |
| pH | pH Unit | 3.88 | 9.11 | 5 | 7.6 | - |
| Al | mg/L | 1 | 2.4 | 0.042 | 0.91 | 5 |
| As | µg/L | *1* | 17 | *1* | 6 | 50 |
| B | mg/L | 0.1 | 1.53 | 0.01 | 0.44 | 5 |
| Ba | µg/L | 50 | 1380 | 14.2 | 308 | - |
| Be | mg/L | *0.001* | 0.004 | *0.001* | *0.001* | - |
| Bi | µg/L | *1* | *1* | *0.06* | *0.06* | - |
| Ca | mg/L | *1* | 10 | - | - | 1000 |
| Cd | mg/L | *0.0001* | 0.0036 | *0.0002* | *0.0002* | 0.01 |
| Cl | mg/L | 0.01 | 14 | - | - | - |
| Co | mg/L | *0.001* | 0.265 | *0.001* | 0.018 | 1 |
| Cr | mg/L | *0.001* | 0.006 | *0.01* | *0.01* | 1 |
| Cu | mg/L | 0.001 | **6.54** | *0.01* | 0.168 | 0.4 / 1 (sheep/cattle) |
| F | mg/L | *0.1* | **3.4** | - | - | 2 |
| Fe | mg/L | 0.05 | 7.68 | *0.01* | 0.51 | - |
| K | mg/L | 0.009 | 16 | - | - | - |
| Li | µg/L | 1 | 13 | 0.0016 | 0.007 | - |
| Mg | mg/L | *1* | 8 | - | - | - |
| Mn | mg/L | 0.001 | 0.589 | *0.01* | 0.066 | - |
| Mo | mg/L | *0.001* | 0.021 | *0.0006* | 0.0218 | 0.15 |
| Na | mg/L | 0.001 | 96 | - | - | - |
| Ni | mg/L | *0.001* | 0.151 | *0.01* | 0.014 | 1 |
| P | mg/L | *0.01* | 0.07 | *0.1* | *0.1* | - |
| Pb | mg/L | *0.001* | 0.001 | *0.006* | *0.006* | 0.1 |
| Rb | mg/L | 0.001 | 0.016 | 0.0044 | 0.019 | - |
| Si | mg/L | 0.001 | 55.4 | - | - | - |
| Sn | mg/L | *0.001* | 0.001 | *0.001* | *0.001* | - |

| Element/ Analyte | Units | Static SFE Concentration Ranges | | | | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|
| | | Individual samples (n=11) | | Composite samples (n=5) [1] | | |
| | | Minimum | Maximum | Minimum | Maximum | |
| $SO_4$ | mg/L | 0.002 | 103 | - | - | 1000 |
| Sr | mg/L | 0.008 | 0.114 | 0.0046 | 0.0736 | - |
| Th | mg/L | *0.001* | 0.002 | *0.00006* | 0.00062 | - |
| Ti | mg/L | *0.01* | 0.04 | - | - | - |
| U | mg/L | *0.001* | 0.012 | *0.00006* | 0.0014 | 0.2 |
| V | mg/L | *0.01* | 0.09 | *0.01* | *0.01* | - |
| W | mg/L | *0.001* | 0.013 | - | - | - |
| Zn | mg/L | *0.005* | 0.504 | *0.01* | 0.35 | 20 |
| **Rare Earth Elements** | | | | | | |
| Ce | mg/L | *0.001* | 0.019 | 0.0001 | 0.00074 | - |
| Dy | mg/L | *0.001* | 0.025 | *0.00002* | 0.00046 | - |
| Er | mg/L | *0.001* | 0.015 | 0.000009 | 0.00052 | - |
| Eu | mg/L | *0.001* | 0.003 | *0.000002* | 0.00004 | - |
| Gd | mg/L | *0.001* | 0.016 | 0.000016 | 0.00044 | - |
| Ho | mg/L | *0.001* | 0.005 | 0.0000024 | 0.000148 | - |
| La | mg/L | *0.001* | 0.006 | 0.00002 | 0.00038 | - |
| Lu | mg/L | *0.001* | 0.002 | 0.0000016 | 0.000047 | - |
| Nd | mg/L | *0.001* | 0.019 | 0.000025 | 0.00025 | - |
| Pr | mg/L | *0.001* | 0.003 | 0.00012 | 0.00125 | - |
| Sm | mg/L | *0.001* | 0.009 | 0.000012 | 0.00015 | - |
| Tb | mg/L | *0.001* | 0.004 | 0.0000036 | 0.000072 | - |
| Tm | mg/L | *0.001* | 0.002 | 0.000002 | 0.000061 | - |
| Yb | mg/L | *0.001* | 0.012 | *0.00002* | 0.00028 | - |
| Y | mg/L | *0.001* | 0.156 | *0.0001* | 0.003 | - |

Notes: The leachate extractions were performed using a 1:5 (solid:liquid) ratio, with a 24 hr tumble. Values in *italics* are below the reported detection limit. Cells shaded in grey indicate leachable concentrations greater than the Livestock Drinking Guideline Value.

[1] The composite SFE leachate concentrations have been updated to reflect the concentrations reported in the revised Genalysis Intertek laboratory report (11/02/2014).

## 5.3 Mild Acid Shake Flask Extractions

Mild acid leach SFE tests provide an indication of the potential leachability of elements under acid conditions. Whilst the potential for acid generation from the NML waste rock is considered low, it is prudent to collect some data pertinent to such conditions, allowing assessment of leaching under 'worst case' conditions.

Rough crushed (particle size less than 2 mm) samples were leached using dilute sulfuric acid (pH 4) at a solid: liquid ratio of 1:5 for 24 hours. In the initial stages of the tests, the pH was monitored and adjusted to maintain the pH of the leachates in the target range of between pH 3 and pH 4. Once the solution pH stabilised, the samples were agitated for 24 hours. The liquor of the final solutions was filtered (0.45 $\mu$m) and then submitted for analyses.

Five samples were selected, including samples from both the waste and ore zone. The selected samples incorporated materials classed as non-acid forming (NAF), NAF with low neutralisation capacity (NAF-Barren) and (low capacity) potentially acid forming (PAF-LC). Due to the presence of measureable acid neutralising capacity, it was considered likely that 'standard' shake flask extractions involving these samples would generate circum neutral leachates and the mild acid testing was intended to complement the shake flask extractions by providing directly comparable leach data at acidic conditions. The two PAF-LC samples (BR020024 and BR020033) were found to give acidic or mildly acidic leachate in the shake flask extractions – diminishing the range of pH values studied for these samples (to meet tight project timelines, the shake flask extractions and the mild acid leach testing were initiated simultaneously – otherwise this scenario would have been avoided).

A summary of the detectable concentration ranges from the leach extraction tests are given in Table 5-3 with full laboratory results in Appendix D.

**Table 5-3: Mild acid leachate results (elements present above detection limits)**

| Element/ Analyte | LG | 2 | 3 | 4 | 4 | 5 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|
| | Sample ID | BR0200020 | BR020003 | BR020024 | BR020014 | BR020033 | |
| | Units | Arkose | Arenite | Arkose | **Arenite**/ Sericite Breccia | Quartz/ **Arkose** | |
| pH* | pH Unit | 4.56 | 3.95 | 4.18 | 3.1 | 3.64 | - |
| Al | mg/L | *0.1* | *0.1* | 0.4 | **5.9** | 2.1 | 5 |
| As | mg/L | *0.005* | *0.005* | *0.005* | *0.005* | 0.013 | 0.5 |
| B | mg/L | 0.8 | 0.1 | *0.1* | *0.1* | 0.1 | 5 |
| Be | mg/L | *0.001* | 0.004 | 0.002 | 0.001 | 0.004 | - |
| Ca | mg/L | 328 | 6 | 7 | 10 | 6 | 1000 |
| Cd | mg/L | *0.001* | *0.001* | 0.008 | *0.001* | *0.001* | 0.01 |
| Cl | mg/L | 8 | 3 | 3 | 3 | 2 | - |
| Co | mg/L | *0.01* | 0.01 | 0.15 | *0.01* | 0.24 | 1 |
| Cr | mg/L | *0.01* | *0.01* | *0.01* | 0.1 | *0.01* | 1 |
| Cu | mg/L | *0.01* | *0.01* | **22.7** | 0.03 | 0.05 | 0.4/1 (sheep/cattle) |
| F | mg/L | 1 | 0.1 | 0.3 | 0.2 | 0.2 | 2 |
| Fe | mg/L | *0.05* | 1.33 | 1.15 | 7.45 | 7.91 | - |
| K | mg/L | 37 | 47 | 13 | 12 | 29 | - |
| Li | mg/L | 0.015 | 0.004 | 0.009 | 0.005 | 0.006 | - |
| Mg | mg/L | 70 | 6 | 8 | 7 | 5 | - |
| Mn | mg/L | 0.21 | 0.22 | 0.74 | 0.74 | 0.47 | - |
| Mo | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | 0.15 |
| Na | mg/L | 125 | 5 | 8 | 7 | 6 | - |
| Ni | mg/L | *0.01* | 0.01 | 0.1 | 0.04 | 0.14 | 1 |
| Pd | mg/L | *0.001* | *0.001* | 0.034 | 0.005 | 0.008 | - |
| Rb | mg/L | 0.028 | 0.034 | 0.01 | 0.014 | 0.012 | - |
| Se | mg/L | *0.01* | *0.01* | 0.01 | *0.01* | *0.01* | 0.02 |
| Sr | mg/L | 1.62 | 0.12 | 0.18 | 0.11 | 0.1 | - |
| Te | mg/L | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | - |
| Th | mg/L | *0.001* | *0.001* | *0.001* | 0.002 | *0.001* | - |
| Ti | mg/L | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Tl | mg/L | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| U | mg/L | 0.001 | 0.002 | 0.04 | 0.005 | 0.011 | 0.2 |
| V | mg/L | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Zn | mg/L | *0.1* | *0.1* | *0.1* | *0.1* | 0.1 | 20 |

| **Element/ Analyte** | **LG** | **2** | **3** | **4** | **4** | **5** | **ANZECC Livestock Drinking Water Guideline Value** |
|---|---|---|---|---|---|---|---|
| | **Sample ID** | **BR0200020** | **BR020003** | **BR020024** | **BR020014** | **BR020033** | |
| | **Units** | Arkose | Arenite | Arkose | **Arenite/** Sericite Breccia | Quartz/ **Arkose** | |
| **Rare Earth Elements** | | | | | | | |
| Ce | mg/L | *0.001* | *0.001* | 0.018 | 0.038 | 0.022 | - |
| Dy | mg/L | *0.001* | *0.001* | 0.096 | 0.012 | 0.021 | - |
| Er | mg/L | *0.001* | *0.001* | 0.068 | 0.007 | 0.012 | - |
| Eu | mg/L | *0.001* | *0.001* | 0.005 | 0.002 | 0.002 | - |
| Gd | mg/L | *0.001* | *0.001* | 0.044 | 0.011 | 0.014 | - |
| Ho | mg/L | *0.001* | *0.001* | 0.021 | 0.002 | 0.004 | - |
| La | mg/L | *0.001* | *0.001* | 0.006 | 0.018 | 0.006 | - |
| Lu | mg/L | *0.001* | *0.001* | 0.009 | *0.001* | 0.001 | - |
| Nd | mg/L | *0.001* | 0.001 | 0.016 | 0.028 | 0.019 | - |
| Pr | mg/L | *0.001* | *0.001* | 0.003 | 0.006 | 0.004 | - |
| Sm | mg/L | *0.001* | *0.001* | 0.016 | 0.008 | 0.007 | - |
| Tb | mg/L | *0.001* | *0.001* | 0.012 | 0.002 | 0.003 | - |
| Tm | mg/L | *0.001* | *0.001* | 0.011 | *0.001* | 0.002 | - |
| Yb | mg/L | *0.001* | *0.001* | 0.069 | 0.005 | 0.01 | - |
| Y | mg/L | *0.001* | 0.005 | 0.557 | 0.079 | 0.136 | - |

Notes: The leachate extractions were performed using a 1:5 (solid:liquid) ratio, with a 24 hr tumble. Values in *italics* are below the reported detection limit. Cells shaded in grey indicate leachable concentrations greater than the Livestock Drinking Guideline Value. * pH measured following leachate extraction, in advance of filtration.

The final pH in the mild acid leach tests ranged from pH 3.1 to 4.6, compared to pH 3.9 to 9.1 in the equivalent de-ionised water leach tests (Figure 5-1).

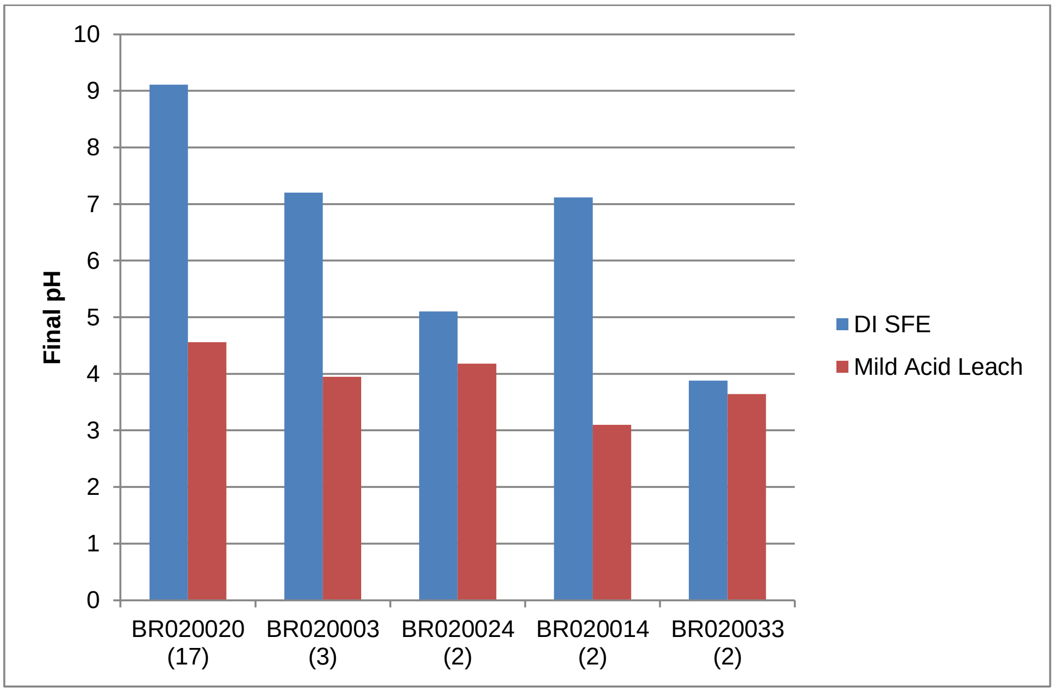


**Figure 5-1: Shake Flask Extraction final pH values**

Notes: ANC (kg $H_2SO_4$/t) are given in brackets after the sample ID numbers.

Following the mild acid leach, the final pH for most samples was in the target range, pH 3 to 4. The final pH obtained by the leach test of sample BR020020 (arkose; LG 2) was slightly higher (pH 4.6) and is considered due to higher neutralisation capacity offered by the sample (17 kg $H_2SO_4$/t). The higher concentrations of calcium (328 mg/L), magnesium (70 mg/L) and strontium (1.62 mg/L; chemically analogous to calcium) present in the mild acid leach extract, compared to the equivalent deionised water extraction, suggest the dissolution of carbonate content within the sample.

As was expected, the dissolved concentrations of certain elements were observed to be higher under more acidic conditions (e.g. Fe, K, Mg, Ca, Al, Be, Co, Cu, Li, Mn, Ni, Rb, Sr, U). For example, Figure 5-2, Figure 5-3 and Figure 5-4 compare the dissolved Cu, Ni and U concentrations in standard de-ionised water leach tests with those observed in the equivalent mild acid leach tests. Higher dissolved concentrations under acidic conditions likely reflect increased mineral solubility, perhaps combined with desorption from mineral surfaces (sorption of many metals is weaker at acid pH). Note that in the case of sample BR020033 – the pH of both the shake flask extraction and the mild acid tests was similarly acidic (pH 3.9 and pH 3.6, respectively).

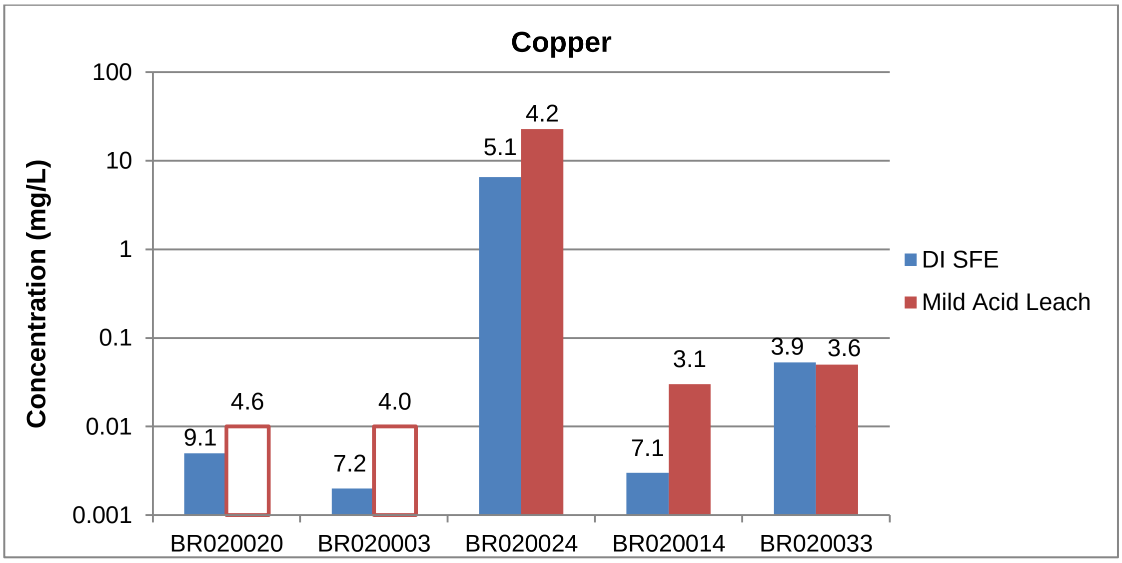


**Figure 5-2: Dissolved copper concentrations in standard static and mild acid leach tests**

Note: The y-axis (concentration) has been plotted using a logarithmic scale. Due to the matrix interferences, detection limits were often higher for the mild acid leachates. The mild acid leach copper concentrations for samples BR020020 and BR020003 were reported below the detection limit (<0.01 mg/l), and have been plotted equivalent to the detection limit. The final pH values of the leachate solutions are given above the data bars.

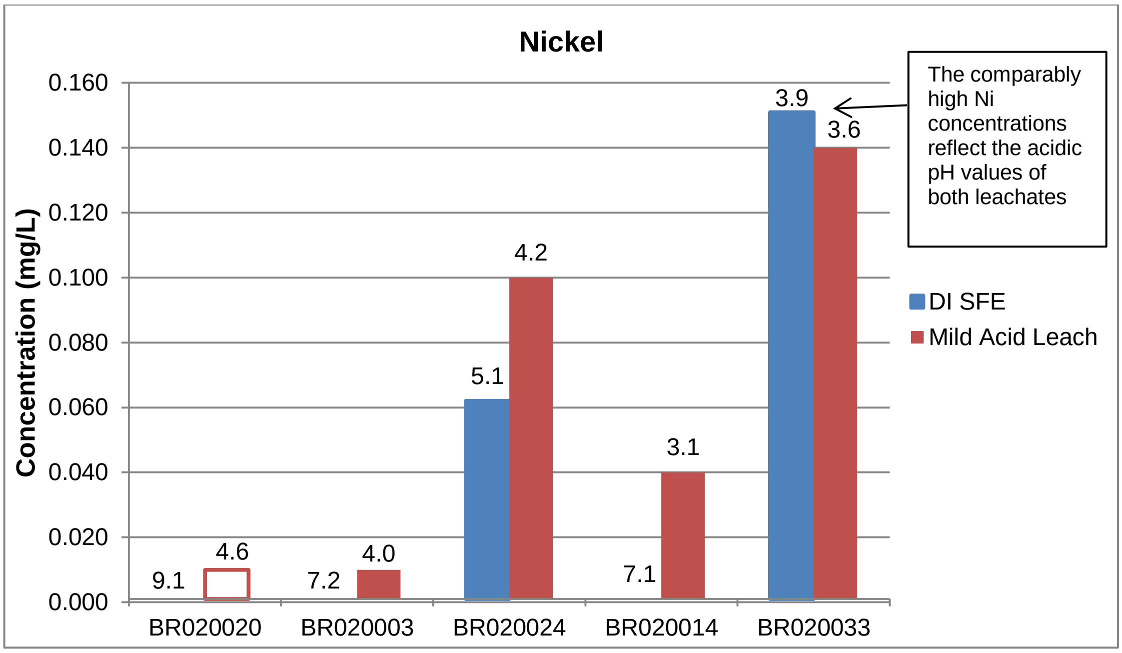


**Figure 5-3: Dissolved nickel concentrations in standard static and mild acid leach tests**

Note: Due to the matrix interferences, detection limits were often higher for the mild acid leachates. The mild acid leach nickel concentration for sample BR020020 was reported below the detection limit (<0.01 mg/l), and has been plotted equivalent to the detection limit. The de-ionised leach concentrations for samples BR020020, BR020003 and BR020014 were reported below the detection limit (<0.001 mg/l). The final pH values of the leachate solutions are given above the data bars.

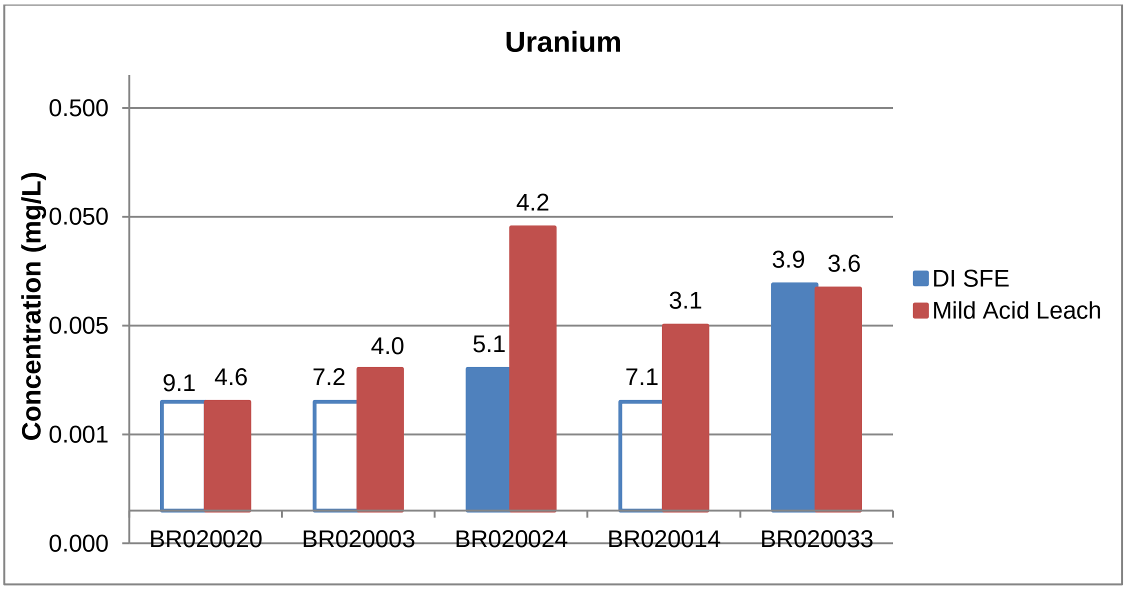


**Figure 5-4: Dissolved uranium concentrations in standard static and mild acid leach tests**

Note: The de-ionised leach concentrations for samples BR020020, BR020003 and BR020014 were reported below the detection limit (<0.001 mg/l). The final pH values of the leachate solutions are given above the data bars.

The acid leach of sample BR020014 (arenite with minor sericite breccia) resulted in the lowest end solution pH value of pH 3.1. Comparatively high concentrations of aluminium and iron were observed in the acid leach solution of this sample, which may be due to increase dissolution of aluminium and iron silicates at this low pH.

Trends for some elements (e.g. As, Mo) were difficult to discern, due to proximity with detection limits (which were higher for the mild acid leachates due to matrix interferences).

The dissolved REE concentrations following mild acid extraction were predominantly below the detection limit (<0.001 mg/l) for waste rock samples collected above the ore zone (LG 2-3). The only exceptions were the dissolved neodymium (0.001 mg/l) and yttrium (0.005 mg/l) concentrations obtained from sample (BR020003, LG 3).

In contrast, the dissolved REE concentrations obtained from the mild acid leach tests on samples from the ore zone and sub-ore zone were generally above detection limits, and at higher concentrations than their equivalent higher pH deionised water extract tests (by up to 20 times).

Although higher dissolved concentrations of certain elements were observed in acidic conditions, the leachable proportions (compared with the total mass present in the sample) generally remained low. For the REE, the maximum dissolved proportion observed was 5.9% (Y, BR020013, pH 3.1) was approximately 2% higher than within the de-ionised water leach test (pH 7.1, BR020014). Many REE solubilities appeared to remain low (e.g Ce <1% leachable).

In summary, mild acid leach testing has shown that the leaching of certain metals (Fe, K, Mg, Ca, Al, Be, Co, Cu, Li, Mn, Ni, Rb, Sr, U and REE) from non-acid forming samples can be appreciable should those samples be exposed to acid conditions. However, the total proportion of solutes leached from the samples generally remains low.

Samples collected from the ore zone and sub-ore zone, with higher REE content, gave significantly higher dissolved REE concentrations when exposed to more acidic conditions.

When data from the mild acid testing are considered there are several elements that gave maximum dissolved concentrations that were significantly greater than those listed in Table 5-2 (i.e. had increased by more than a factor of two).

These were:

- Ca, Al, Fe, K, Mg, and Mn – the greater concentrations of these major elements probably reflect greater dissolution of carbonates and silicates in response to the acidic conditions. Including data from the mild acid leach tests, maximum dissolved concentrations for these elements were Ca (328 mg/L), Al (5.9 mg/L), Fe (7.9 mg/L), K (47 mg/L)), Mg (70 mg/L) and Mn (0.74 mg/L), respectively.
- Minor or trace elements (greatest dissolved concentration detailed in brackets), Be (0.004 mg/L), Co (0.27 mg/L), Cu (22.7 mg/L), Li (0.015 mg/L), Ni (0.1 mg/L), Rb (0.034 mg/L), Sr (1.6 mg/L) and U (0.04 mg/L).
- Rare earth elements (greatest dissolved concentration detailed in brackets), Ce (0.038 mg/L), Dy (0.096 mg/L), Er (0.068 mg/L), Gd (0.044 mg/L), Ho (0.021 mg/L), La (0.018 mg/L), Lu (0.009 mg/L), Nd (0.028 mg/L), Pr (0.006 mg/L), Sm (0.016 mg/L), Tb (0.012 mg/L), Tm (0.011 mg/L), Yb (0.069 mg/L) and Y (0.557mg/L).

## 5.4 Net Acid Generating (NAG) Liquor Analysis

Single addition net acid generating (NAG) tests were undertaken with subsequent analysis of the NAG liquor to identify solutes that may be released as a result of the waste rock samples being exposed to oxidising conditions.

The single addition NAG test subjects a sample to highly oxidising conditions (through the addition of hydrogen peroxide). The oxidation of any sulfides contained in the sample generates acidity and a portion (or all) of the acidity may then be consumed by any neutralising minerals present.

The five samples selected for NAG liquor analyses were selected to incorporate the range of detectable sulfur contents within the sample set (0.04-0.44 wt% S). The median sulfur content of the overall sample set was <0.01 wt% S.

The NAG pH values obtained ranged between pH 3.1 and 6.0, and the results are given in Table 5-4, along with the equivalent sample NAG test results reported in the Geochemical Review (SRK, 2013), which show good agreement. (The sulfur content of each sample is also detailed for reference.)

A summary of the NAG liquor analysis results, for elements present above detection limits, is given in Table 5-4, with the full NAG liquor analysis results detailed in Appendix E.

**Table 5-4: NAG liquor analysis results (elements present above detection limits)**

| Analyte | Sample ID | BR020011 | BR020024 | BR020032 | BR020010 | BR020033 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|
| | Units | Arkose | Arenite | Arkose | Arenite/ Sericite Breccia | Quartz/ Arkose | |
| Lithological Group | - | 3 | 4 | 4 | 4 | 5 | - |
| NAG pH (2014)[1] | pH Unit | 6.0 | 3.3 | 3.2 | 3.6 | 3.1 | - |
| NAG pH (2013)[2] | pH Unit | 5.9 | 3.2 | 3.5 | 3.3 | 3.2 | - |
| Total Sulfur[2] | wt% | 0.04 | 0.36 | 0.19 | 0.16 | 0.44 | - |
| EC | µS/cm | 28 | 381 | 322 | 204 | 381 | - |
| Acidity | mg/L | 651 | 89 | 63 | 49 | 78 | - |
| Al | mg/L | *0.01* | 2.3 | 3 | 2.48 | 2.02 | 5 |
| As | mg/L | *0.001* | 0.002 | 0.002 | *0.001* | *0.001* | 0.5 |
| B | mg/L | 0.2 | 0.23 | 0.18 | 0.15 | 0.28 | 5 |
| Ba | mg/L | 0.896 | 0.022 | 0.044 | 0.176 | 0.021 | - |
| Br | mg/L | *0.1* | 0.1 | 0.1 | *0.1* | *0.1* | - |
| Ca | mg/L | *1* | 4 | 2 | 2 | 10 | 1000 |
| Cd | mg/L | *0.0001* | 0.0009 | *0.0001* | *0.0001* | *0.0001* | 0.01 |
| Cl | mg/L | 14 | *1* | *1* | *1* | 1 | - |
| Co | mg/L | *0.001* | 0.069 | 0.051 | 0.053 | 0.031 | 1 |
| Cr | mg/L | 0.032 | 0.008 | 0.017 | 0.022 | 0.065 | 1 |
| Cu | mg/L | *0.001* | 7.4 | 0.053 | 0.076 | 0.024 | 0.4/1 (sheep/ cattle) |
| F | mg/L | 1.8 | 0.4 | 0.6 | 0.9 | 1.4 | 2 |
| Fe | mg/L | <0.05 | 0.39 | 0.19 | 0.06 | 0.23 | - |
| Ga | mg/L | *0.001* | 0.003 | 0.002 | 0.002 | *0.001* | - |
| Ge | mg/L | *0.001* | 0.002 | 0.001 | 0.001 | *0.001* | - |
| K | mg/L | 7 | 12 | 13 | 13 | 14 | - |
| Li | mg/L | *0.001* | 0.002 | 0.002 | 0.002 | 0.001 | - |
| Mg | mg/L | *1* | 5 | 2 | 2 | 8 | - |
| Mn | mg/L | 0.005 | 0.077 | 0.043 | 0.05 | 0.048 | - |
| Mo | mg/L | 0.001 | *0.001* | 0.001 | 0.002 | 0.005 | 0.15 |
| Ni | mg/L | *0.001* | 0.072 | 0.04 | 0.074 | 0.03 | 1 |
| Rb | mg/L | 0.005 | 0.006 | 0.009 | 0.008 | 0.004 | - |

| Analyte | Sample ID | BR020011 | BR020024 | BR020032 | BR020010 | BR020033 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|
| | Units | Arkose | Arenite | Arkose | Arenite/ Sericite Breccia | Quartz/ Arkose | |
| Se | mg/L | *0.01* | 0.07 | 0.09 | 0.04 | *0.01* | 0.02 |
| Si | mg/L | *0.1* | 15.6 | *0.1* | *0.1* | *0.1* | - |
| SO4 | mg/L | 5 | 81 | 62 | 37 | 65 | 1000 |
| Sr | mg/L | 0.011 | 0.072 | 0.03 | 0.056 | 0.027 | - |
| U | mg/L | 0.001 | 0.046 | 0.008 | 0.007 | 0.002 | 0.2 |
| V | mg/L | 0.02 | *0.01* | *0.01* | *0.01* | *0.01* | - |
| W | mg/L | 0.001 | 0.001 | 0.002 | *0.001* | *0.001* | - |
| Zn | mg/L | *0.005* | 0.014 | 0.016 | 0.024 | 0.011 | 20 |
| Rare Earth Elements | | | | | | | |
| Ce | mg/L | *0.001* | 0.042 | 0.018 | 0.024 | 0.012 | - |
| Dy | mg/L | *0.001* | 0.129 | 0.154 | 0.057 | 0.006 | - |
| Er | mg/L | *0.001* | 0.096 | 0.105 | 0.037 | 0.004 | - |
| Eu | mg/L | *0.001* | 0.007 | 0.008 | 0.003 | *0.001* | - |
| Gd | mg/L | *0.001* | 0.071 | 0.088 | 0.037 | 0.004 | - |
| Ho | mg/L | *0.001* | 0.03 | 0.035 | 0.013 | 0.001 | - |
| La | mg/L | *0.001* | 0.013 | 0.006 | 0.01 | 0.005 | - |
| Lu | mg/L | *0.001* | 0.014 | 0.012 | 0.005 | *0.001* | - |
| Nd | mg/L | *0.001* | 0.031 | 0.029 | 0.022 | 0.007 | - |
| Pr | mg/L | *0.001* | 0.005 | 0.004 | 0.004 | 0.002 | - |
| Sm | mg/L | *0.001* | 0.021 | 0.029 | 0.012 | 0.002 | - |
| Tb | mg/L | *0.001* | 0.017 | 0.022 | 0.008 | *0.001* | - |
| Tm | mg/L | *0.001* | 0.016 | 0.015 | 0.006 | *0.001* | - |
| Yb | mg/L | *0.001* | 0.103 | 0.092 | 0.033 | 0.003 | - |
| Y | mg/L | *0.001* | 0.775 | 0.985 | 0.349 | 0.041 | - |

Notes: Values in *italics* are below the reported detection limit. Cells shaded in grey indicate leachable concentrations greater than the Livestock Drinking Guideline Value.

1 Analysed at Genalysis Laboratory Services
2 Analysed at ALS Environmental

The NAG liquor analysis of the sample from Lithological Group 3 (above the ore zone) demonstrated limited solutes were present above detection limits, with a lower EC (28 µS/cm) than the analyses of the ore zone and sub-ore zone samples (204-381 µS/cm). Note that the contact ratio for the NAG test was approximately 100: 1 (liquid:solid) as opposed to the 5:1 ratio applicable to the deionised and mild acid SFE tests.

The most significant solute concentrations were obtained from the ore zone samples, with notable concentrations of REE, including yttrium (Y) of up to a maximum concentration of 0.985 mg/L.

Of the 21 elements identified as being “enriched” on the basis of their Global Abundance Indices (GAI) (SRK, 2013) (Ag, As, B, Bi, Ce, Dy, Er, Gd, Ho, La, Lu, Nd, Pr, S, Se, Sm, Tb, Te, Tm, Y, Yb), only 3 elements did not leach in detectable concentrations (Ag, Bi, and Te).

The NAG liquor analyses indicated that between 40-100% of the sulfide mineral content of the samples was oxidised during the single stage peroxide addition. The results indicate that if the sulfide containing samples (primarily from the ore zone and sub-ore zone) are exposed to atmospheric conditions and allowed to oxidise, localised acidic conditions are likely to develop, with associated higher solute release rates.

Significant concentrations of metals associated with sulfides (e.g. Cu, Co, Ni and Zn) were present in the NAG liquor, which constitute high proportions of the total element content in the solid samples. For example, leached concentrations equivalent to the total content of Ni and Co were obtained from sample BR020032 (0.19 wt% S).

The proportion of certain REE present in the NAG liquor solutions accounts for up to a maximum of 22% of the total content of the solid samples (Dy (20.1%), Er (21.5%), Y (21.5%)). Other REE show significantly lower proportions are liable to be released by oxidation of waste (e.g. Ce, 1.1%).

It is noted that the waste rock with limited sulfur (e.g. from non-mineralised zones) demonstrate near neutral median NAG pH values (around pH 6) and would not be anticipated to generate acidity or associated increased solute release.

# 6 Conclusions

Conclusions are provided below in relation to geochemical sample representivity, sulfur distribution and long-term leaching potentials of waste rock generated at Browns Range.

## 6.1 Sample Representivity and Sulfur Distribution

**Wolverine Deposit**

Having assessed the Wolverine geochemical dataset in light of the geological database and the current pit shell, SRK concluded as follows:

- The two dominant waste rock lithologies (arenite and arkose) comprise a significant proportion of the geochemical dataset. However, some minor lithologies (present in proportions of less than 1.5%) have not been sampled and subjected to geochemical characterisation.
- The majority (>99%) of the drilled waste rock contains negligible sulfur (<0.1 wt% S); five waste lithologies were found to have $95^{th}$ percentile sulfur contents equal to, or greater than 0.1 wt% S, including siltstone, interbedded arenite and argillite, breccia (generic monomict), sericite breccia and polymict breccia. Of these lithologies, sericite breccia and polymict breccia have not yet been geochemically characterised. Siltstone was present as a minor lithology in an arenite sample (BR020008).
- The available geochemical samples and drillhole samples are spatially biased towards the ore zone, and possibly biased towards higher sulfur and will therefore lead to a 'conservative' dataset in the sense that acid potential could be overestimated, with respect to the projected waste rock volume generated at Wolverine.
- The geochemical static sample set is sufficiently representative in terms of the range of sulfur contents represented.

**Other Deposits**

Following review of the logged proportions and sulfur content of the waste lithologies at the Area 5, Area 5 North, Gambit West and Gambit Central deposits, the following points are highlighted:

- The lithologies and logged proportions of waste rock at the four additional deposits demonstrate variability – whilst the dominant waste lithologies are arenite and arkose (in keeping with the Wolverine waste rock), their relative proportions change at each of the four deposits. Higher proportions of a few of the minor waste lithologies were also identified, including conglomerate (3.4%, Area 5), schist unclassified (4.6%, Area 5 North), interbedded fine and coarse grained arenite (3.7%, Gambit West), hematite breccia (2.9%, Gambit West) and colluvial gravel (2.1%).
- Sulfur contents encountered within the assayed waste rock are typically low and in keeping with the S content characteristics at the Wolverine deposit. However, a number of waste lithologies were identified with maximum sulfur contents above 0.1 wt% S, including arenite, arkose, hematite breccia, siltstone, interbedded arenite and argillite, gravelstone, interbedded fine and coarse grained arenite and conglomerate.
- A slightly higher proportion of assayed samples with sulfur greater or equal to 0.1 wt% S was encountered at Gambit Central (1.9%) compared with the other deposits (including Wolverine (1.8%); Gambit West (0.4%), Area 5 (0.3%), Area 5 North (0.2%)). The median S contents in all the deposits were less than the detection limit of 0.025 wt% S. Average sulfur contents were approximately 0.03 wt% S for most areas; the highest average was calculated for the Area 5 deposit (0.06 wt% S).

## 6.2 Supplemental Waste Rock Leach Test Assessment

Following supplementary assessment of the leaching characteristics of the Wolverine geochemical samples, incorporating the use of static deionised water leach tests, mild acid leach tests and NAG liquor analyses, the following conclusions are made.

- Typically, waste rock material (from the non-mineralised zone) resulted in circa-neutral/mildly alkaline leachate solutions, with low concentrations of leached elements (often below detection limits).
- Acidic leachates were only encountered in the case of samples from the ore zone and sub-ore zone, where S contents were higher (<0.01-0.44 wt% S).
- Higher quantities of a greater range of elements leach in acidic solution, including Fe, K, Mg, Ca, Al, Be, Co, Cu, Li, Mn, Ni, Rb, Sr, U and REE, as demonstrated by acidic leachates in the de-ionised water SFE testing and NAG liquors, and direct comparison of equivalent de-ionised water SFE and mild acid leach tests.
- Instances of elevated Cu leaching in acidic solutions (< pH 5.5, from the de-ionised water and mild acid leach tests) were observed from a particularly Cu-rich sample from the ore zone containing veined quartz. This sample is considered to have high Cu and S content in comparison to the Wolverine assay dataset (occurring at the 99.7$^{th}$ percentile for Cu, and the 98.6$^{th}$ percentile for sulfur). A pH-dependent solubility control appears to occur for Cu (and several other metals including the REE), limiting solubility above pH 5.5.
- It appears as though elements that are not subject to pH-dependent solubility controls (e.g. Se, Mo) do not leach in detectable quantities despite being present within the waste rock at quantities in excess of crustal averages.
- Of the total elemental mass present in the waste materials, only a small proportion is in a form that is readily leachable under the geochemical conditions expected in a waste rock dump – less than 1% under neutral pH conditions and less than 6% under acidic conditions.
- NAG liquor analysis on sulfur-bearing samples (typically associated with the mineralised zone) suggests that the following elements (As, B, Ce, Dy, Er, Gd, Ho, La, Lu, Nd, Pr, S, Se, Sm, Tb, Tm, Y, Yb and REE) could be released in the long-term, following oxidation of sulfides.
- For sulfidic samples there is likely to be a significant proportion of metal release as a result of oxidation. For these sample types, NAG testing showed that higher proportions of some elements could be leached under oxidising acidic conditions (up to 100% for trace metals associated with sulfide mineralogy (e.g. Ni, Co), and up to 22% for certain REE (e.g. Dy, Er, Y). This source of metalliferous drainage is of secondary concern in the overall assessment of waste rock characterisation as (i) most waste rock contains very low or negligible sulfur, and it is not anticipated that appreciable sulfidic material from the mineralised zone would report to the waste rock dumps, and (ii) associated metal release would occur over a long period of time (due to kinetic controls on sulfide oxidation).

# 7 Recommendations

The following recommendations are made with respect to the findings of the supplementary waste rock leach test assessment work for the Browns Range Project:

- While the supplemental leach assessment has determined that leachable trace metal concentrations of the waste rock samples were generally low, higher solute concentrations are liable to result from the mineralised zone, where sulfur contents and the potential to generate acid are more significant. This should be taken into consideration with regard to the management of ore stockpiles.
- In absence of recognised environmental REE assessment criteria (e.g. water quality standards), a baseline assessment may be advisable with respect to the REE chemistry in local surface and groundwater.

The following recommendations are made with respect to further geochemical characterisation assessment work for the Browns Range Project:

- SRK recommends that static geochemical characterisation of the Wolverine siltstone, sericite breccia and polymict breccia waste zone lithologies is undertaken as part of the detailed project design, to assess potential acid and metalliferous drainage potential.
- Based on the variations of lithological proportions identified (mostly relating to the minor waste lithologies), additional drillcore sampling for static geochemical characterisation assessment is recommended at the deposits where mining is proposed. Focus during sample selection should be placed on lithologies that are present within the additional deposits in higher proportions than encountered at the Wolverine deposit, and are therefore possibly under-represented within the existing geochemical sample set. Examples of these lithologies include conglomerate (3.4%, Area 5) and interbedded fine and coarse grained arenite (3.7%, Gambit West). Those minor lithologies that showed sulfur ranges extending to higher maximum values should be prioritised.
- When pit shell outlines have been determined for Area 5, Area 5 North, Gambit West and Gambit Central a more rigorous assessment of spatial representivity should be undertaken.
- On the basis of the database interrogation, and the low sulfur contents identified at the additional Browns Range deposits (Area 5, Area 5 North, Gambit West and Gambit Central), kinetic column testwork may not be required to assess the long-term weathering and leaching potentials of waste rock generated at these deposits. A similar static batch-testwork programme to the proposed Wolverine testwork programme may be more appropriate. This could be confirmed following an initial phase of static testwork.

**Project Code:** **NML003**

**Report Title:** **Browns Range Rare Earth Element (REE) Project – Waste Rock Geochemical Characterisation**

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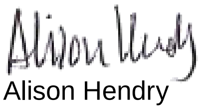

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# Appendices

# Appendix A: Sample List and Description

**Appendix A -Sample List and Description**

| Lithological Grouping | Laboratory ID | Drillhole ID | Depth from (m) | Depth to (m) | Lithology** | Lithology Code** |
|---|---|---|---|---|---|---|
| 1 | BR020027 | NMBRDD005 | 2 | 2.4 | Alluvial Sand | TAV |
| 1 | BR020006 | BRWD0011 | 0.8 | 1.3 | Colluvial Clay | TCC |
| 1 | BR020019 | BRWD0013 | 1.5 | 2 | Colluvial Clay | TCC |
| 1 | BR020018 | BRWD0016 | 1.5 | 2 | Alluvial Clay - Lake Clay | TAC |
| 2 | BR020020 | NMBRDD002 | 5.1 | 5.5 | Arkose | SAK |
| 2 | BR020028 | NMBRDD005 | 4 | 4.4 | **Clay**/Arkose | **RCY (4-4.3)**, SAK (4.3-4.4) |
| 2 | BR020005 | BRWD0011 | 13 | 13.6 | Mottled Saprolite | RMS |
| 2 | BR020009 | BRWD0012 | 22 | 22.6 | **Mottled No Relict Texture**/Mottled Saprolite | **RMO (22-22.5)**, RMS (22.5-22.6) |
| 2 | BR020017 | BRWD0016 | 8.37 | 9 | Mottled Saprolite | RMS |
| 3 | BR020021 | NMBRDD002 | 26.3 | 26.8 | Arkose | SAK |
| 3 | BR020022 | NMBRDD002 | 68 | 68.6 | Arkose | SAK |
| 3 | BR020023 | NMBRDD002 | 99.4 | 100.1 | Arkose | SAK |
| 3 | BR020029 | NMBRDD005 | 60.1 | 60.6 | Arkose | SAK |
| 3 | BR020030 | NMBRDD005 | 92.1 | 92.7 | Arkose | SAK |
| 3 | BR020004 | BRWD0011 | 71.6 | 72.2 | Arenite | SAN |
| 3 | BR020003 | BRWD0011 | 92 | 92.6 | Arenite | SAN |
| 3 | BR020008 | BRWD0012 | 55 | 55.7 | **Arenite**/Siltstone | **SAN (55-55.53)**, SST (55.53-55.7) |
| 3 | BR020012 | BRWD0013 | 13.5 | 14 | Arenite | SAN |
| 3 | BR020011 | BRWD0013 | 92.25 | 92.75 | Arenite | SAN |
| 3 | BR020016 | BRWD0016 | 31.1 | 31.6 | Interbedded arenite and agrillite (arenite dominant) | SIAS |
| 3 | BR020015 | BRWD0016 | 68.23 | 68.8 | Hematite Breccia | BH |
| 4 | BR020024 | NMBRDD002 | 120.3 | 121.3 | Arkose | SAK |
| 4 | BR020025 | NMBRDD002 | 138.3 | 139.3 | Arkose | SAK |
| 4 | BR020031 | NMBRDD005 | 119.3 | 120.2 | **Schist Unclassified**/Arkose | **XSC (119.3-119.9)**, SAK (119.9-120.2) |
| 4 | BR020032 | NMBRDD005 | 143 | 144 | Arkose | SAK |
| 4 | BR020002 | BRWD0011 | 127.1 | 128.1 | Xenotime Breccia | BX |
| 4 | BR020007 | BRWD0012 | 144.2 | 145 | Hematite Breccia/**Breccia (generic monomict)** | BH (144.2-144.5), **B (144.5-145)** |
| 4 | BR020010 | BRWD0013 | 142.1 | 142.7 | Hematite Breccia | BH |
| 4 | BR020014 | BRWD0016 | 109.9 | 110.9 | **Arenite**/Sericite Breccia | **SAN (109.9-110.7)**, BS (110.7-110.9) |
| 5 | BR020026 | NMBRDD002 | 173 | 173.5 | Arkose | SAK |
| 5 | BR020033 | NMBRDD005 | 161 | 161.6 | Quartz/**Arkose** | Q (161-161.1), **SAK (161.1-161.6)** |
| 5 | BR020001 | BRWD0011 | 149.6 | 150.3 | Arenite | SAN |
| 5 | BR020013 | BRWD0016 | 117.2 | 117.7 | Arenite | SAN |

Notes:

*Lithological grouping rationale described in Table 3.1 of report.

**Lithological description based on NML database "Lithology 1" description. Where two lithologies are present over a sample length, the dominanat lithology is detailed in **bold**.

# Appendix B: Summary of Test Methods (with Geochemical Review and Supplementary Leachability Assessment)

The tests carried out as part of the geochemical characterisation programme and calculations used to assist in evaluating the acid base accounting parameters of the samples are shown in Table B-1 and Table B-2 respectively.

**Table B-1: Parameters measured and description of method**

| Parameter | Description |
|---|---|
| Paste pH (1:5) | pH measurements are performed on a 1:5 solid/water extract. |
| Paste EC (1:5) | Electrical conductivity measurements are performed on a 1:5 solid/water extract. |
| Acid neutralising capacity (ANC) | Determined by adding HCl to the sample, heating it, and then back-titrating the mixture with NaOH in order to determine the amount of HCl that remains on completion of the reaction. The amount of acid consumed in the initial reaction is calculated and expressed as the ANC. Details of the procedure are outlined in the AMIRA International ARD Test Handbook (AMIRA, 2002). |
| Total carbon/sulfur | The sample is combusted in oxygen at 1350°C. Carbon/sulfur present in the sample is evolved as carbon dioxide and swept to a measurement cell for quantification by infrared detection (LECO). |
| Chromium reducible sulfur | Dried pulped sample is mixed with acid and chromium metal in a rapid distillation unit to produce hydrogen sulfide which is collected and titrated with iodine to measure CRS. |
| Single addition net acid generation (NAG) test | The NAG test involves addition of hydrogen peroxide to prepared samples (to oxidise any reactive sulfides). The NAG pH is the pH of the final solution. The resultant acidity is then titrated (using NaOH) to pH 4.5 and then to pH 7. Details of the procedure are outlined in the AMIRA International ARD Test Handbook (AMIRA, 2002). |
| Whole rock multi element assay | Involves the near total dissolution of most elements using a variety of digestion techniques (e.g. aqua regia, four acid digest and lithium borate fusion). Analytical techniques are selected depending on the elements under investigation and include ICP-AES, ICP-MS, AAS, ISE and TGA. |
| De-ionised Water Leach Test (or Shake Flask Extraction, SFE) | Simple leach extraction involves dissolution of elements from the solid matrix using de-ionised water. The water and solids are mixed at a ratio of 1:5 (solids: water) and agitated for a period of 24 hours. The leachates are filtered by 0.45µm filters prior to analysis. Analytical techniques are selected depending on the elements under investigation and include ICP-AES and ICP-MS. |
| Mild Acid Leach Test | A pH modified (acidic) leach extraction involves dissolution of elements from the solid matrix using de-ionised water which has been adjusted to a target of pH 4, by addition of sulphuric acid. The stock solution and solids were mixed at a ratio of 5:1 (solution: solids), incorporating any further $H_2SO_4$ addition required to adjust the pre-agitated sample (water: solids) to pH 4, and agitated for a period of 24 hours. The leach solution is filtered through a 0.45µm filter prior to analysis. Analytical techniques are selected depending on the elements under investigation and include ICP-AES and ICP-MS. |
| Acid buffering characterisation curve (ABCC) | Involves a slow titration of the sample with acid, whilst monitoring the pH readings. Details of the procedure are outlined in the AMIRA International ARD Test Handbook (AMIRA, 2002) |
| Mineralogical assessment | XRD carried out on a powdered sample containing an internal standard. |

**Table B-2: Calculated data**

| Parameter | Description |
|---|---|
| Maximum potential acidity (MPA) | Calculated by multiplying the total sulfur content (wt%) by 30.6. Approach assumes that all sulfur is present as pyrite. |
| Total inorganic carbon | Calculated as the difference between the total carbon content and total organic carbon content of the sample. |
| Net acid producing potential (NAPP) | NAPP is the difference between MPA[1] and ANC of the sample:<br>NAPP = MPA – ANC |

[1] MPA has been adopted here rather than AP so that the calculations will be conservative with respect to acid generation potential, i.e. over-estimate rather than under-estimate acid generation potential.

# Appendix C: De-ionised Water Static Leach Tests

## Appendix C: De-ionised Water Static Leach Test Results

| Analyte | Analyte Symbol | **Lithology Group** | | 1 | 2 | 2 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Waste/Ore Zone** | | Waste Zone | Waste Zone | Waste Zone | Waste Zone | Waste Zone | Waste Zone | Ore Zone | Ore Zone | Ore Zone | Ore Zone | Waste Zone | |
| | | **Sample ID** | | BR020006 | BR020020 | BR020017 | BR020023 | BR020003 | BR020011 | BR020024 | BR020032 | BR020010 | BR020014 | BR020033 | |
| | | **Units** | **LOR** | Colluvial Clay | Arkose | Mottled Saprolite | Arkose | Arenite | Arenite | Arkose | Arkose | Hematite Breccia | **Arenite/** Sericite Breccia | Quartz/ **Arkose** | |
| pH Value | pH | pH Unit | 0.01 | 6.94 | 9.11 | 7.29 | 7.18 | 7.2 | 6.95 | 5.1 | 5.24 | 4.89 | 7.12 | 3.88 | - |
| Electrical Conductivity @ 25°C | EC | µS/cm | 1 | 92 | 404 | 87 | 80 | 106 | 80 | 153 | 107 | 107 | 52 | 272 | - |
| Hydroxide Alkalinity as CaCO3 | OH Alkalinity | mg/L | 1 | *1* | *1* | *1* | *1* | *1* | *1* | *1* | *1* | *1* | *1* | *1* | - |
| Carbonate Alkalinity as CaCO3 | CaCO3 alk | mg/L | 1 | *1* | 57 | *1* | *1* | *1* | *1* | *1* | *1* | *1* | *1* | *1* | - |
| Bicarbonate Alkalinity as CaCO3 | HCO3 alk | mg/L | 1 | 22 | 105 | 15 | 11 | 10 | 6 | 2 | 3 | 2 | 11 | *1* | - |
| Total Alkalinity as CaCO3 | Total alk | mg/L | 1 | 22 | 162 | 15 | 11 | 10 | 6 | 2 | 3 | 2 | 11 | *1* | - |
| Acidity as CaCO3 | Acidity | mg/L | 1 | 6 | *1* | 2 | 2 | 2 | 2 | 24 | 5 | 2 | 2 | 48 | - |
| **Major Elements** | | | | | | | | | | | | | | | |
| Sulfate as SO4 - Turbidimetric | SO4 | mg/L | 1 | 4 | 17 | 4 | 10 | 22 | 13 | 51 | 34 | 35 | 2 | 103 | 1000 |
| Calcium | Ca | mg/L | 1 | 4 | 2 | 1 | *1* | *1* | *1* | 4 | 2 | 2 | *1* | 10 | 1000 |
| Chloride | Cl | mg/L | 1 | 3 | 14 | 3 | 4 | 3 | 4 | 3 | 3 | 3 | 3 | 2 | - |
| Fluoride | F | mg/L | 0.1 | 0.2 | **3.4** | **2.8** | 0.7 | 0.4 | 0.6 | *0.1* | *0.1* | *0.1* | 0.3 | *0.1* | 2 |
| Iron | Fe | mg/L | 0.05 | 0.89 | 0.68 | 0.54 | 0.07 | 0.11 | 0.09 | *0.05* | 0.22 | 0.1 | 0.11 | 7.68 | - |
| Potassium | K | mg/L | 1 | 5 | 7 | 7 | 7 | 16 | 6 | 10 | 10 | 11 | 4 | 12 | - |
| Magnesium | Mg | mg/L | 1 | 1 | *1* | *1* | *1* | *1* | *1* | 5 | 2 | 2 | *1* | 8 | - |
| Sodium | Na | mg/L | 1 | 10 | 96 | 11 | 11 | 10 | 11 | 5 | 4 | 6 | 8 | 4 | - |
| Reactive Phosphorus as P | P | mg/L | 0.01 | *0.01* | 0.05 | *0.01* | 0.02 | *0.01* | *0.01* | *0.01* | 0.07 | 0.04 | 0.02 | *0.01* | - |
| Reactive Silica | Si | mg/L | 0.1 | 12.1 | 23.9 | 55.4 | 11 | 9.1 | 9.05 | 10.2 | 9.56 | 12.2 | 8.9 | 13.2 | - |
| **Trace Elements** | | | | | | | | | | | | | | | |
| Silver | Ag | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Aluminium | Al | mg/L | 0.01 | 1.55 | 0.56 | 0.84 | 0.7 | 0.94 | 0.55 | 0.02 | 0.02 | 0.07 | 1.17 | 2.4 | 5 |
| Arsenic | As | mg/L | 0.001 | *0.001* | 0.013 | *0.001* | 0.002 | *0.001* | *0.001* | 0.004 | 0.006 | 0.005 | 0.002 | 0.017 | 0.5 |
| Boron | B | mg/L | 0.05 | 0.67 | 1.53 | 0.97 | 0.82 | 0.73 | 0.8 | 0.05 | *0.05* | *0.05* | 0.75 | 0.07 | 5 |
| Barium | Ba | mg/L | 0.001 | 0.8 | 1.38 | 1.32 | 1.03 | 1.28 | 1.21 | 0.06 | 0.009 | 0.065 | 1.11 | 0.048 | - |
| Beryllium | Be | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.004 | - |
| Bismuth | Bi | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Cadmium | Cd | mg/L | 0.0001 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | 0.0036 | *0.0001* | *0.0001* | *0.0001* | 0.0003 | 0.01 |
| Cobalt | Co | mg/L | 0.001 | 0.003 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.088 | 0.027 | 0.05 | *0.001* | 0.265 | 1 |
| Chromium | Cr | mg/L | 0.001 | 0.002 | 0.001 | 0.002 | *0.001* | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.006 | 1 |
| Caesium | Cs | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Copper | Cu | mg/L | 0.001 | 0.01 | 0.005 | 0.003 | 0.002 | 0.002 | 0.002 | **6.54** | 0.004 | 0.055 | 0.003 | 0.053 | 0.4/1 (sheep/cattle) |
| Gallium | Ga | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Hafnium | Hf | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Mercury | Hg | mg/L | 0.0001 | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | 0.002 |
| Lithium | Li | mg/L | 0.001 | 0.007 | 0.001 | 0.013 | 0.002 | *0.001* | 0.003 | 0.007 | 0.006 | 0.008 | 0.001 | 0.006 | - |
| Manganese | Mn | mg/L | 0.001 | 0.154 | 0.006 | 0.008 | 0.002 | 0.003 | 0.009 | 0.589 | 0.221 | 0.137 | 0.003 | 0.52 | - |

**Appendix C: De-ionised Water Static Leach Test Results (Continued)**

| Analyte | Analyte Symbol | Lithology Group | | 1 | 2 | 2 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Waste/Ore Zone** | | Waste Zone | Waste Zone | Waste Zone | Waste Zone | Waste Zone | Waste Zone | Ore Zone | Ore Zone | Ore Zone | Ore Zone | Waste Zone | |
| | | **Sample ID** | | BR020006 | BR020020 | BR020017 | BR020023 | BR020003 | BR020011 | BR020024 | BR020032 | BR020010 | BR020014 | BR020033 | |
| | | **Units** | **LOR** | Colluvial Clay | Arkose | Mottled Saprolite | Arkose | Arenite | Arenite | Arkose | Arkose | Hematite Breccia | **Arenite/** Sericite Breccia | Quartz/ **Arkose** | |
| pH Value | pH | pH Unit | 0.01 | 6.94 | 9.11 | 7.29 | 7.18 | 7.2 | 6.95 | 5.1 | 5.24 | 4.89 | 7.12 | 3.88 | - |
| Molybdenum | Mo | mg/L | 0.001 | *0.001* | 0.021 | *0.001* | 0.006 | *0.001* | 0.002 | 0.005 | 0.002 | 0.001 | 0.002 | *0.001* | 0.15 |
| Nickel | Ni | mg/L | 0.001 | 0.003 | *0.001* | 0.006 | *0.001* | *0.001* | 0.003 | 0.062 | 0.016 | 0.031 | *0.001* | 0.151 | 1 |
| Lead | Pb | mg/L | 0.001 | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.1 |
| Rubidium | Rb | mg/L | 0.001 | 0.008 | 0.004 | 0.003 | 0.002 | 0.01 | 0.002 | 0.01 | 0.016 | 0.012 | 0.002 | 0.014 | - |
| Antimony | Sb | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Selenium | Se | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | 0.02 |
| Tin | Sn | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.001 | *0.001* | - |
| Strontium | Sr | mg/L | 0.001 | 0.04 | 0.018 | 0.017 | 0.009 | 0.011 | 0.012 | 0.114 | 0.048 | 0.071 | 0.008 | 0.108 | - |
| Tantalum | Ta | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Tellurium | Te | mg/L | 0.005 | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | - |
| Thorium | Th | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | 0.002 | *0.001* | - |
| Titanium | Ti | mg/L | 0.01 | 0.04 | 0.02 | 0.01 | *0.01* | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Thallium | Tl | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Uranium | U | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.002 | *0.001* | 0.004 | *0.001* | 0.012 | 0.2 |
| Vanadium | V | mg/L | 0.01 | *0.01* | 0.09 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Tungsten | W | mg/L | 0.001 | *0.001* | 0.013 | *0.001* | 0.002 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Zinc | Zn | mg/L | 0.005 | 0.504 | 0.101 | 0.312 | 0.164 | 0.27 | 0.241 | 0.014 | *0.005* | 0.044 | 0.263 | 0.044 | 20 |
| Zirconium | Zr | mg/L | 0.005 | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | |
| **Rare Earth Elements** | | | | | | | | | | | | | | | |
| Cerium | Ce | mg/L | 0.001 | 0.002 | *0.001* | 0.001 | *0.001* | *0.001* | *0.001* | 0.002 | *0.001* | *0.001* | 0.002 | 0.019 | - |
| Dysprosium | Dy | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.008 | 0.003 | 0.002 | *0.001* | 0.025 | - |
| Erbium | Er | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.005 | 0.002 | 0.001 | *0.001* | 0.015 | - |
| Europium | Eu | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.003 | - |
| Gadolinium | Gd | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.004 | 0.002 | 0.001 | *0.001* | 0.016 | - |
| Holmium | Ho | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.002 | *0.001* | *0.001* | *0.001* | 0.005 | - |
| Lanthanum | La | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.001 | 0.006 | - |
| Lutetium | Lu | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.002 | - |
| Neodymium | Nd | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.001 | *0.001* | *0.001* | 0.002 | 0.019 | - |
| Praseodymium | Pr | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.003 | - |
| Samarium | Sm | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.001 | *0.001* | *0.001* | *0.001* | 0.009 | - |
| Terbium | Tb | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.004 | - |
| Thulium | Tm | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.002 | - |
| Ytterbium | Yb | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.005 | 0.002 | 0.001 | *0.001* | 0.012 | - |
| Yttrium | Y | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | 0.003 | 0.002 | 0.001 | 0.048 | 0.02 | 0.012 | 0.004 | 0.156 | - |

Notes: Concentrations below detection limits are given in italics. Concentrations above the stock drinking water guideline values are shown in red.

# Appendix D: Mild Acid Static Leach Tests

## Appendix D: Mild Acid Leach Test Results

| Analyte | Analyte Symbol | Lithology Group | | 2 | 3 | 4 | 4 | 5 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|---|---|
| | | Waste/Ore Zone | | Waste Zone | Waste Zone | Ore Zone | Ore Zone | Waste Zone | |
| | | Sample ID | | BR020020 | BR020003 | BR020024 | BR020014 | BR020033 | |
| | | Units | LOR | Arkose | Arenite | Arkose | **Arenite**/ Sericite Breccia | Quartz/ **Arkose** | |
| pH Value (before filtration) | pH | pH Unit | 0.01 | 4.56 | 3.95 | 4.18 | 3.1 | 3.64 | - |
| pH Value (after filtration) | pH | pH Unit | 0.01 | 7.82 | 5.18 | 4.71 | 3.77 | 4.22 | |
| EC @ 25°C | EC | µS/cm | 1 | 2100 | 245 | 262 | 326 | 247 | - |
| Acidity as CaCO3 | Acidity | mg/L | 1 | 6 | 6 | 50 | 77 | 45 | - |
| **Major Elements** | | | | | | | | | |
| Calcium | Ca | mg/L | 1 | 328 | 6 | 7 | 10 | 6 | 1000 |
| Chloride | Cl | mg/L | 1 | 8 | 3 | 3 | 3 | 2 | - |
| Fluoride | F | mg/L | 0.1 | 1 | 0.1 | 0.3 | 0.2 | 0.2 | 2 |
| Iron | Fe | mg/L | 0.05 | *0.05* | 1.33 | 1.15 | 7.45 | 7.91 | - |
| Potassium | K | mg/L | 1 | 37 | 47 | 13 | 12 | 29 | - |
| Magnesium | Mg | mg/L | 1 | 70 | 6 | 8 | 7 | 5 | - |
| Sodium | Na | mg/L | 1 | 125 | 5 | 8 | 7 | 6 | - |
| Total Phosphorus as P | P | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Reactive Silica | Si | mg/L | 0.1 | - | - | - | - | - | - |
| **Trace Elements** | | | | | | | | | |
| Silver | Ag | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Aluminium | Al | mg/L | 0.1 | *0.1* | *0.1* | 0.4 | **5.9** | 2.1 | 5 |
| Arsenic | As | mg/L | 0.005 | *0.005* | *0.005* | *0.005* | *0.005* | 0.013 | 0.5 |
| Boron | B | mg/L | 0.1 | 0.8 | 0.1 | *0.1* | *0.1* | 0.1 | 5 |
| Barium | Ba | mg/L | 0.1 | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | - |
| Beryllium | Be | mg/L | 0.001 | *0.001* | 0.004 | 0.002 | 0.001 | 0.004 | - |
| Bismuth | Bi | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Cadmium | Cd | mg/L | 0.001 | *0.001* | *0.001* | 0.008 | *0.001* | *0.001* | 0.01 |
| Cobalt | Co | mg/L | 0.01 | *0.01* | 0.01 | 0.15 | *0.01* | 0.24 | 1 |
| Chromium | Cr | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | 0.1 | *0.01* | 1 |
| Caesium | Cs | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Copper | Cu | mg/L | 0.01 | *0.01* | *0.01* | **22.7** | 0.03 | 0.05 | 0.4/1 (sheep/cattle) |
| Gallium | Ga | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Germanium | Ge | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Hafnium | Hf | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Mercury | Hg | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.002 |
| Lithium | Li | mg/L | 0.001 | 0.015 | 0.004 | 0.009 | 0.005 | 0.006 | - |
| Manganese | Mn | mg/L | 0.01 | 0.21 | 0.22 | 0.74 | 0.74 | 0.47 | - |
| Molybdenum | Mo | mg/L | 0.01 | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | 0.15 |
| Niobium | Nb | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Nickel | Ni | mg/L | 0.01 | *0.01* | 0.01 | 0.1 | 0.04 | 0.14 | 1 |
| Lead | Pb | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | 0.1 |
| Palladium | Pd | mg/L | 0.001 | *0.001* | *0.001* | 0.034 | 0.005 | 0.008 | - |
| Platinum | Pt | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Rubidium | Rb | mg/L | 0.001 | 0.028 | 0.034 | 0.01 | 0.014 | 0.012 | - |
| Rhenium | Re | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Antimony | Sb | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Selenium | Se | mg/L | 0.01 | *0.01* | *0.01* | 0.01 | *0.01* | *0.01* | 0.02 |
| Tin | Sn | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Strontium | Sr | mg/L | 0.01 | 1.62 | 0.12 | 0.18 | 0.11 | 0.1 | - |
| Tantalum | Ta | mg/L | 0.001 | - | - | - | - | - | - |
| Tellurium | Te | mg/L | 0.005 | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | - |
| Thorium | Th | mg/L | 0.001 | *0.001* | *0.001* | *0.001* | 0.002 | *0.001* | - |
| Titanium | Ti | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Thallium | Tl | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Uranium | U | mg/L | 0.001 | 0.001 | 0.002 | 0.04 | 0.005 | 0.011 | 0.2 |
| Vanadium | V | mg/L | 0.01 | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Tungsten | W | mg/L | 0.001 | - | - | - | - | - | - |
| Zinc | Zn | mg/L | 0.1 | *0.1* | *0.1* | *0.1* | *0.1* | 0.1 | 20 |
| Zirconium | Zr | mg/L | 0.005 | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | - |

Notes: Concentrations below detection limits are given in italics. Concentrations above the stock drinking water guideline values are shown in red. pH values measured after filtration were recorded at pH values of 0.5-3.3 higher. This cause of this discrepancy has not yet been resolved.

**Appendix D: Mild Acid Leach Test Results (Continued)**

| Analyte | Analyte Symbol | Lithology Group | | 2 | 3 | 4 | 4 | 5 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|---|---|
| | | **Waste/Ore Zone** | | Waste Zone | Waste Zone | Ore Zone | Ore Zone | Waste Zone | |
| | | **Sample ID** | | BR020020 | BR020003 | BR020024 | BR020014 | BR020033 | |
| | | **Units** | **LOR** | Arkose | Arenite | Arkose | **Arenite**/ Sericite Breccia | Quartz/ **Arkose** | |
| pH Value (before filtration) | pH | pH Unit | 0.01 | 4.56 | 3.95 | 4.18 | 3.1 | 3.64 | - |
| pH Value (after filtration) | pH | pH Unit | 0.01 | 7.82 | 5.18 | 4.71 | 3.77 | 4.22 | |
| **Rare Earth Elements** | | | | | | | | | |
| Cerium | Ce | mg/L | 0.001 | *0.001* | *0.001* | 0.018 | 0.038 | 0.022 | - |
| Dysprosium | Dy | mg/L | 0.001 | *0.001* | *0.001* | 0.096 | 0.012 | 0.021 | - |
| Erbium | Er | mg/L | 0.001 | *0.001* | *0.001* | 0.068 | 0.007 | 0.012 | - |
| Europium | Eu | mg/L | 0.001 | *0.001* | *0.001* | 0.005 | 0.002 | 0.002 | - |
| Gadolinium | Gd | mg/L | 0.001 | *0.001* | *0.001* | 0.044 | 0.011 | 0.014 | - |
| Holmium | Ho | mg/L | 0.001 | *0.001* | *0.001* | 0.021 | 0.002 | 0.004 | - |
| Lanthanum | La | mg/L | 0.001 | *0.001* | *0.001* | 0.006 | 0.018 | 0.006 | - |
| Lutetium | Lu | mg/L | 0.001 | *0.001* | *0.001* | 0.009 | *0.001* | 0.001 | - |
| Neodymium | Nd | mg/L | 0.001 | *0.001* | 0.001 | 0.016 | 0.028 | 0.019 | - |
| Praseodymium | Pr | mg/L | 0.001 | *0.001* | *0.001* | 0.003 | 0.006 | 0.004 | - |
| Samarium | Sm | mg/L | 0.001 | *0.001* | *0.001* | 0.016 | 0.008 | 0.007 | - |
| Terbium | Tb | mg/L | 0.001 | *0.001* | *0.001* | 0.012 | 0.002 | 0.003 | - |
| Thulium | Tm | mg/L | 0.001 | *0.001* | *0.001* | 0.011 | *0.001* | 0.002 | - |
| Ytterbium | Yb | mg/L | 0.001 | *0.001* | *0.001* | 0.069 | 0.005 | 0.01 | - |

Notes: Concentrations below detection limits are given in italics. Concentrations above the stock drinking water guideline values are shown in red. pH values measured after filtration were recorded at pH values of 0.5-3.3 higher. This cause of this discrepancy has not yet been resolved.

# Appendix E: NAG Liquor Analyses

## Appendix E: NAG Liquor Analysis

| Analyte | Sample ID | BR020011 | BR020024 | BR020032 | BR020010 | BR020033 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|
| | **Units** | Arkose | Arenite | Arkose | **Arenite**/ Sericite Breccia | Quartz/ **Arkose** | |
| NAG pH | pH Unit | 5.9 | 3.2 | 3.5 | 3.3 | 3.2 | - |
| EC | µS/cm | 28 | 381 | 322 | 204 | 381 | - |
| Acidity | mg/L | 651 | 89 | 63 | 49 | 78 | - |
| Ag | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Al | mg/L | *0.01* | 2.3 | 3 | 2.48 | 2.02 | 5 |
| As | mg/L | *0.001* | 0.002 | 0.002 | *0.001* | *0.001* | 0.5 |
| Au | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| B | mg/L | 0.2 | 0.23 | 0.18 | 0.15 | 0.28 | 5 |
| Ba | mg/L | 0.896 | 0.022 | 0.044 | 0.176 | 0.021 | - |
| Be | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Bi | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Br | mg/L | *0.1* | 0.1 | 0.1 | *0.1* | *0.1* | - |
| Ca | mg/L | *1* | 4 | 2 | 2 | 10 | 1000 |
| Cd | mg/L | *0.0001* | 0.0009 | *0.0001* | *0.0001* | *0.0001* | 0.01 |
| Cl | mg/L | 14 | *1* | *1* | *1* | 1 | - |
| Co | mg/L | *0.001* | 0.069 | 0.051 | 0.053 | 0.031 | 1 |
| Cr | mg/L | 0.032 | 0.008 | 0.017 | 0.022 | 0.065 | 1 |
| Cs | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Cu | mg/L | *0.001* | **7.4** | 0.053 | 0.076 | 0.024 | 0.4/1 (sheep/cattle) |
| F | mg/L | 1.8 | 0.4 | 0.6 | 0.9 | 1.4 | 2 |
| Fe | mg/L | <0.05 | 0.39 | 0.19 | 0.06 | 0.23 | - |
| Ga | mg/L | *0.001* | 0.003 | 0.002 | 0.002 | *0.001* | - |
| Ge | mg/L | *0.001* | 0.002 | 0.001 | 0.001 | *0.001* | - |
| Hf | mg/L | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Hg | mg/L | *0.0001* | *0.0001* | *0.0001* | *0.0001* | *0.0001* | 0.002 |
| I | mg/L | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | - |
| K | mg/L | 7 | 12 | 13 | 13 | 14 | - |
| Li | mg/L | *0.001* | 0.002 | 0.002 | 0.002 | 0.001 | - |
| Mg | mg/L | *1* | 5 | 2 | 2 | 8 | - |
| Mn | mg/L | 0.005 | 0.077 | 0.043 | 0.05 | 0.048 | - |
| Mo | mg/L | 0.001 | *0.001* | 0.001 | 0.002 | 0.005 | 0.15 |
| Nb | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Ni | mg/L | *0.001* | 0.072 | 0.04 | 0.074 | 0.03 | 1 |

Notes: Concentrations below detection limits are given in italics. Concentrations above the stock drinking water guideline values are shown in red.

## Appendix E: NAG Liquor Analysis (Continued)

| Analyte | Sample ID | BR020011 | BR020024 | BR020032 | BR020010 | BR020033 | ANZECC Livestock Drinking Water Guideline Value |
|---|---|---|---|---|---|---|---|
| | **Units** | Arkose | Arenite | Arkose | **Arenite**/ Sericite Breccia | Quartz/ **Arkose** | |
| NAG pH | pH Unit | 5.9 | 3.2 | 3.5 | 3.3 | 3.2 | - |
| Pb | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | 0.1 |
| Pd | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Pt | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Rb | mg/L | 0.005 | 0.006 | 0.009 | 0.008 | 0.004 | - |
| Re | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Sb | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Se | mg/L | *0.01* | 0.07 | 0.09 | 0.04 | *0.01* | 0.02 |
| Si | mg/L | *0.1* | 15.6 | *0.1* | *0.1* | *0.1* | - |
| Sn | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| $SO_4$ | mg/L | 5 | 81 | 62 | 37 | 65 | - |
| Sr | mg/L | 0.011 | 0.072 | 0.03 | 0.056 | 0.027 | - |
| Ta | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Te | mg/L | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | - |
| Th | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| Ti | mg/L | *0.01* | *0.01* | *0.01* | *0.01* | *0.01* | - |
| Tl | mg/L | *0.001* | *0.001* | *0.001* | *0.001* | *0.001* | - |
| U | mg/L | 0.001 | 0.046 | 0.008 | 0.007 | 0.002 | 0.2 |
| V | mg/L | 0.02 | *0.01* | *0.01* | *0.01* | *0.01* | - |
| W | mg/L | 0.001 | 0.001 | 0.002 | *0.001* | *0.001* | - |
| Zn | mg/L | *0.005* | 0.014 | 0.016 | 0.024 | 0.011 | 20 |
| Zr | mg/L | *0.005* | *0.005* | *0.005* | *0.005* | *0.005* | - |
| **Rare Earth Elements** | | | | | | | |
| Ce | mg/L | *0.001* | 0.042 | 0.018 | 0.024 | 0.012 | - |
| Dy | mg/L | *0.001* | 0.129 | 0.154 | 0.057 | 0.006 | - |
| Er | mg/L | *0.001* | 0.096 | 0.105 | 0.037 | 0.004 | - |
| Eu | mg/L | *0.001* | 0.007 | 0.008 | 0.003 | *0.001* | - |
| Gd | mg/L | *0.001* | 0.071 | 0.088 | 0.037 | 0.004 | - |
| Ho | mg/L | *0.001* | 0.03 | 0.035 | 0.013 | 0.001 | - |
| La | mg/L | *0.001* | 0.013 | 0.006 | 0.01 | 0.005 | - |
| Lu | mg/L | *0.001* | 0.014 | 0.012 | 0.005 | *0.001* | - |
| Nd | mg/L | *0.001* | 0.031 | 0.029 | 0.022 | 0.007 | - |
| Pr | mg/L | *0.001* | 0.005 | 0.004 | 0.004 | 0.002 | - |
| Sm | mg/L | *0.001* | 0.021 | 0.029 | 0.012 | 0.002 | - |
| Tb | mg/L | *0.001* | 0.017 | 0.022 | 0.008 | *0.001* | - |
| Tm | mg/L | *0.001* | 0.016 | 0.015 | 0.006 | *0.001* | - |
| Yb | mg/L | *0.001* | 0.103 | 0.092 | 0.033 | 0.003 | - |
| Y | mg/L | *0.001* | 0.775 | 0.985 | 0.349 | 0.041 | - |

Notes: Concentrations below detection limits are given in italics. Concentrations above the stock drinking water guideline values are shown in red.

# SRK Report Client Distribution Record

Project Number: NML003

Report Title: Browns Range Rare Earth Element (REE) Project – Waste Rock Geochemical Characterisation

Date Issued: 26 February 2014

| Name/Title | Company |
|---|---|
| Robin Jones | Northern Minerals Limited |

| Rev No. | Date | Revised By | Revision Details |
|---|---|---|---|
| 0 | 03/02/2014 | Alison Hendry | Draft Report |
| 1 | 26/02/2914 | Alison Hendry | Final Report |