THUNDERBIRD MINERAL SANDS PROJECT
MINE RESIDUES CHARACTERISATION

PREPARED FOR:

SHEFFIELD RESOURCES LIMITED

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TABLE OF CONTENTS

TABLES

FIGURES

CHARTS

APPENDICES

1. INTRODUCTION

1.1 PROJECT BACKGROUND

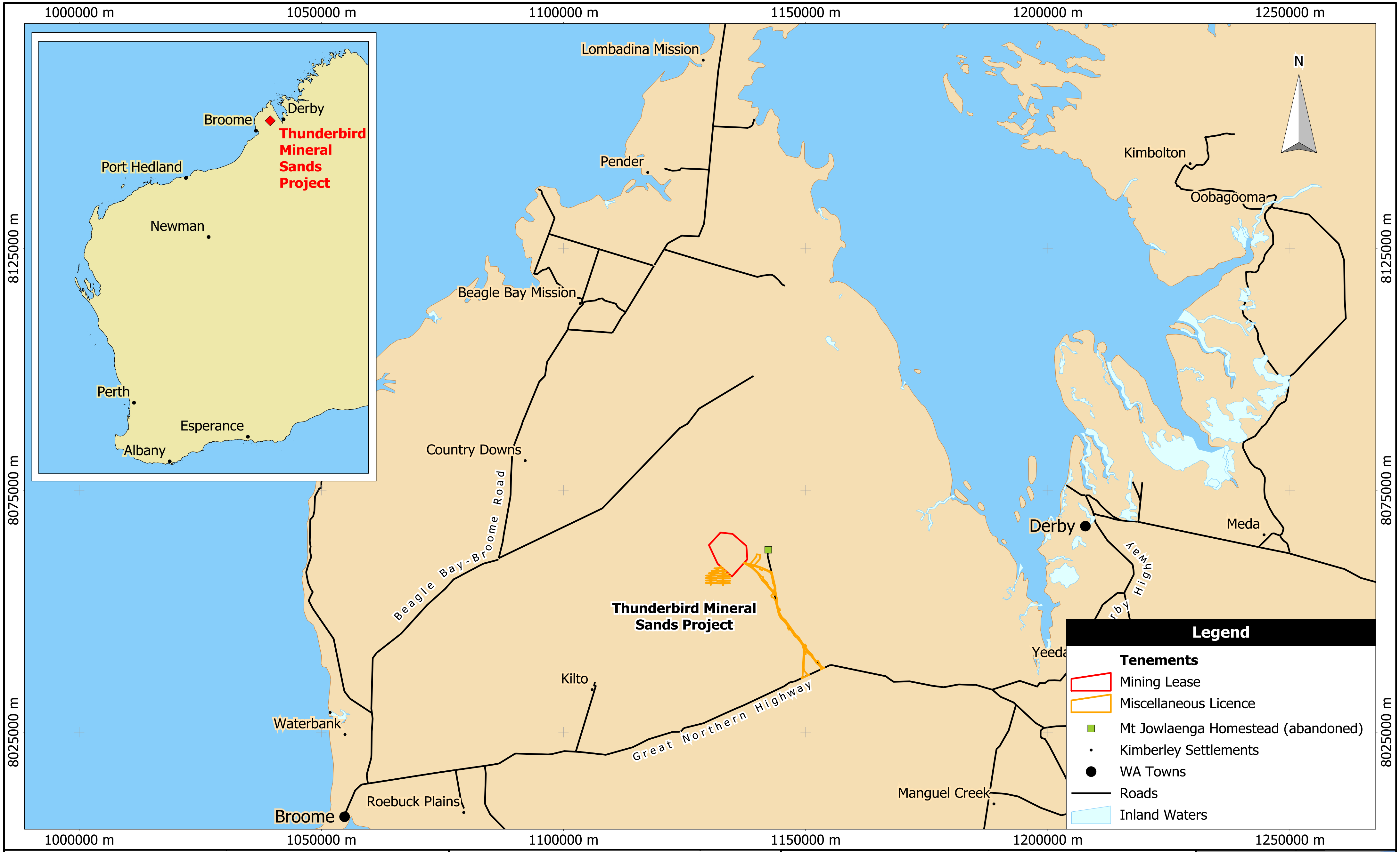
Sheffield Resources Limited (Sheffield Resources) is proposing to develop the Thunderbird Mineral Sands Project (the project), located on the Dampier Peninsula within the west Kimberley region of Western Australia (Figure 1). The project will involve the mining of heavy mineral sands to produce various products (ilmenite, zircon, and high titanium (HiTi88) leucoxene) and subsequent export to overseas markets from Derby Port.

Sheffield Resources is investigating development options for the project and commissioned MBS Environmental (MBS) to undertake geochemical characterisation of process waste streams likely to be generated. The outcomes of this study will be used to support future environmental impact assessment processes. This report details the methodology, processes and results of the assessment and provides recommendations for the management and storage of the project's process wastes.

1.2 OBJECTIVE AND SCOPE OF WORK

The objective of the study was to determine the potential for acid and metalliferous drainage (AMD), neutral or saline drainage to occur from process waste streams and if these materials are likely to pose a significant risk to the environment. The scope of work involved the following:

- Liaise with Sheffield Resources personnel to obtain samples of metallurgical trial residues representing all proposed process waste streams.
- Liaise with relevant geochemical and environmental testing laboratories to ensure use of appropriate methods of testwork for process waste characterisation.
- Classification of various residue types based on their potential to generate AMD according to the procedures published by the Federal Department of Industry, Tourism and Resources (DITR, 2007 and the International Network for Acid Prevention (INAP).
- Determine by analysis those metals and metalloids of environmental significance which are enriched in process residues relative to natural levels and the relative environmental significance of this enrichment.
- Determine by analysis of water and dilute acid leachates, the potential for seepage from waste residues to contaminate local surface and groundwater resources and identify general strategies for mitigation of risk as required.
- Assess the potential for any clay rich material to be dispersive in nature and hence pose any possible physical instability and runoff contamination risks from constructed landforms with such materials.
- Preparation of a geochemical characterisation report with respect to the processing residues predicted to be produced at the project outlining to Sheffield Resources the likely properties and any potential significant environmental risks to the environment posed by these materials.



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Sheffield Resources Limited
Thunderbird Mineral Sands Project

Figure 1

Location Plan

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MBS ENVIRONMENTAL

W:\Sheffield Resources\Drawings\Location Plan.map 12/10/2016 F1 Location Plan Layout

2. PROJECT DESCRIPTION

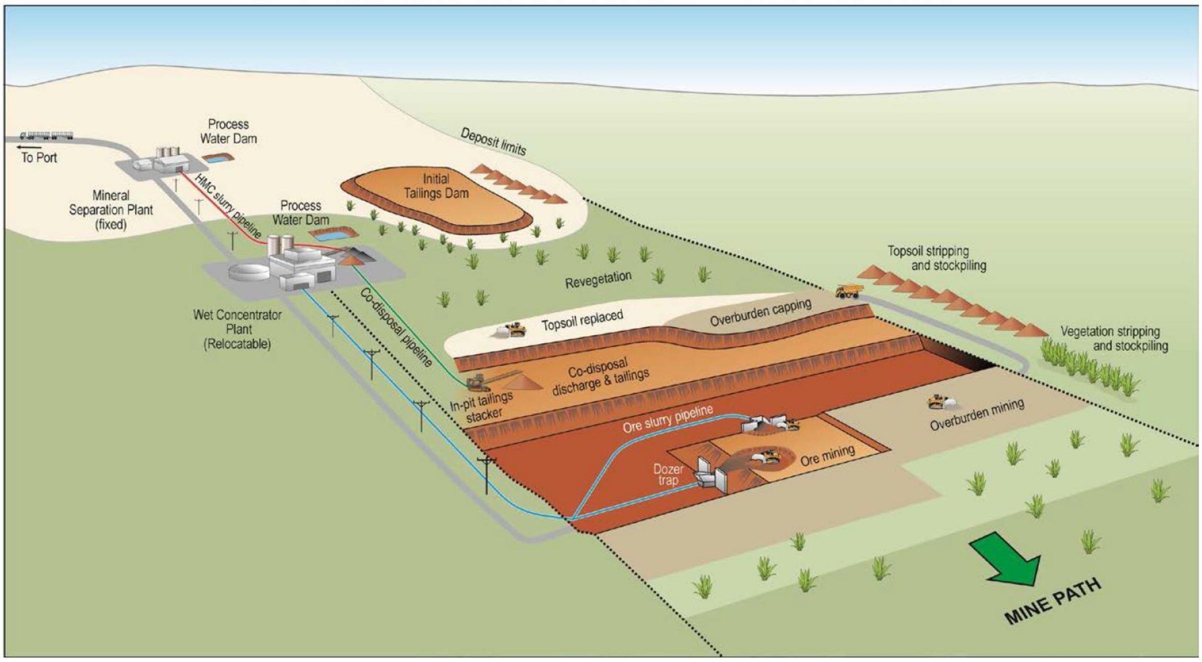
2.1 PROJECT SUMMARY

The project is located approximately 95 km northeast of Broome and 75 km west of Derby at the southeast edge of the Dampier Peninsula in Western Australia. It is located within Pastoral Lease H910623 (Mt Jowlaenga) held by Yeeda Pastoral Company Pty Ltd (used for cattle grazing). The project will be accessed via the Great Northern Highway and then via a proposed 30 km long site access road. The project includes:

- Progressive mining of heavy mineral sands over a 47 year period from the Thunderbird deposit. The initial rate of mining will allow for excavation of 7.5 Mtpa (nominal) to year 5 and then increasing to 15 Mtpa for the remainder of the project life.
- Onsite primary and secondary processing of ore to produce a range of saleable mineral products (ilmenite, zircon, and HiTi88 Leucoxene). Construction of processing facilities will be staged to match mining rates as above.
- Abstraction and injection of groundwater from the Broome Aquifer to allow mining and supply ore processing needs.
- Supporting infrastructure including an accommodation village, power generation, waste storage and disposal facilities, communications infrastructure and internal roadways.
- Upgrade and extension of the existing pastoral track (Mt Jowlaenga Road) from the Great Northern Highway to form a 30 km site access road.
- An initial Tailings Storage Facility (TSF).
- Progressive backfilling and rehabilitation of mined pits.
- Transport of mineral products from the Mine Site via the Site Access Road and Great Northern Highway to Derby Port for storage prior to export via King Sound. As required packaged mineral product from Broome Port to international customers.

The project will comprise mining of heavy mineral sands from the Thunderbird deposit over a 47 year mine life, processing onsite and transportation of final concentrates (ilmenite, zircon, and HiTi88 leucoxene) by road to Derby Port for storage and subsequent export to overseas markets. Sheffield Resources proposes to extract mineral products using conventional mineral sand mining techniques. Mining will be undertaken progressively, with approximately 200 ha of the proposed 1,510 ha pit disturbance open at any one time. Mined areas will undergo progressive backfilling and rehabilitation. A summary of the proposed mining, ore processing and export operations is detailed below and shown in Figure 2.

Figure 2: Proposed Mining Schematic for Thunderbird



2.2 MINING

Sheffield Resources proposes to use standard mineral sands strip mining with progressive backfilling and rehabilitation. The large, relatively thick and sheet-like characteristics of the host sand unit allow for bulk mining techniques employing heavy earthmoving equipment to achieve the proposed processing rate of 7.5 Mtpa (years 1 – 5) and 15 Mtpa (year 5 onwards). Mining will commence in the northern section of the pit area and will progressively expand southwards.

The top of mineralisation starts at the surface in the northernmost section of the pit and dips towards the south. The overburden is weakly mineralised and includes intermittent zones of induration (minor ferricrete and calcrete areas) relating to a lateritic weathering profile of older Cretaceous sediments. These are thin enough to enable free digging with standard heavy earthmoving equipment, although some dozer ripping may be required with the more competent overburden. The majority of overburden will be removed using scrapers and/or excavators and dump trucks and immediately returned to mined sections of the pit. Approximately 34% of the Thunderbird deposit occurs above the water table, 37% in the transitional zone, and 29% below.

Dozers will be used to push ore into dozer traps where the sand will be screened of coarse oversize material and the remaining undersize material slurried and pumped for further scrubbing and screening prior to wet concentration and processing.

2.3 PROCESSING

Processing methods and equipment are conventional within the mineral sands industry. Mineral sands will initially be screened at the active mine face using mobile mining unit plants (MUP) before being transferred in a slurry form to a primary processing plant. The primary processing plant will be located in close proximity to the active mining face. This plant, referred to as a Wet Concentrator Plant (WCP), separates the heavy minerals from the sand by means of water and gravity to produce a crude heavy mineral concentrate (HMC) plus rejected sand and slimes (WCP tails – clays). The WCP will be moved a number of times during the project life to minimise slurry piping distances as the mining area changes over time. Process water will be supplied from local groundwater resources adjacent to the pit and recycled using a nearby dam for storage.

A secondary processing plant will be used to separate out the different minerals within the HMC. This plant, referred to collectively as the Mineral Separation Plant (MSP) will be located away from the mining area and incorporate a combination of gravity, magnetic, chemical, low temperature roasting and electrostatic separation processes. Initial processing of the HMC is through the Concentrate Upgrade Plant (CUP) which uses magnetic separation to separate magnetic ilmenite from the HMC. The ilmenite is then roasted with imported coal (Becher process) and re-screened (magnetic) to produce primary ilmenite. Non-magnetic zircon and high titanium leucoxene/rutile from the CUP will undergo a hot sulfuric acid leach (HAL) process to leach iron (including iron cemented coatings) from the concentrate. The waste acid from this process is neutralised using agricultural lime to produce a relatively small quantity of gypsum (calcium sulfate) residue. Acid leached zircon and high titanium leucoxene/rutile are then separated by dry electrostatic separation in the Zircon Separation Plant (ZSP).

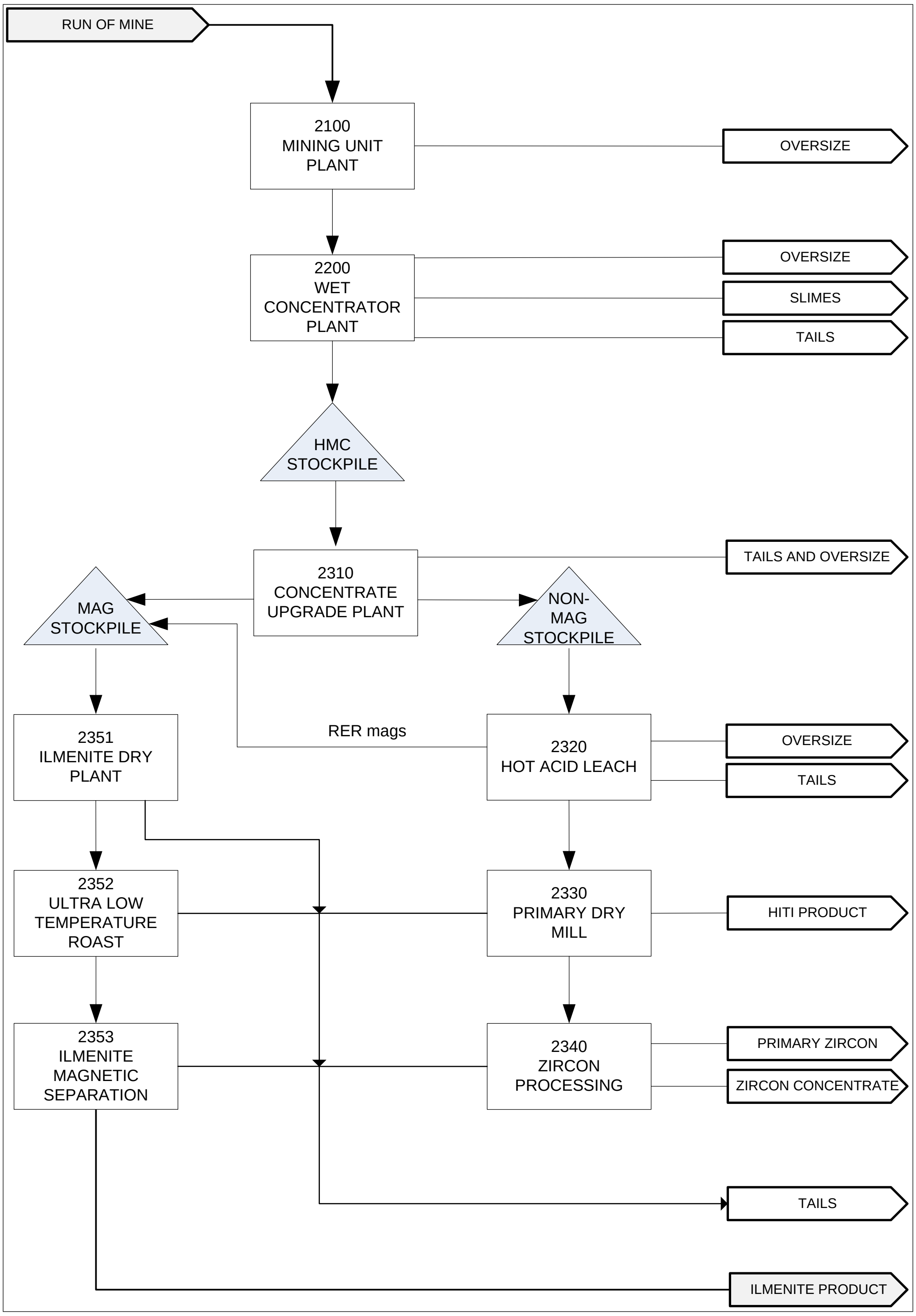
Uneconomic sands and other waste streams from the WCP and MSP will initially be stored within a TSF until a sufficient mine void is created which will then be used for waste and residue storage for the remainder of the project. The TSF will be rehabilitated once back filling of the pit void has commenced.

A description of the residue streams and quantities versus mined material is presented in Table 1 in approximate order (top to bottom) of production for the project. A summary conceptual processing flow chart is shown in Figure 3.

Table 1: Residue Descriptions and Proportions to Processed Material

Residue Stream	Description and Fate	Stage I (7.5 Mtpa)	Stage II (15 Mtpa)	Percentage of Processed Material
MUP >5.0mm Oversize	Mining Unit Plant Oversize (> 5 mm). Stockpiled for use as roadbase/construction or returned to mine void.	300 ktpa	600 ktpa	4%
MUP/WCP >2.0 mm Oversize	Mining Unit Plant Oversize (> 2 mm). Stockpiled for use as roadbase/construction or returned to mine void.	750 ktpa	1,500 kpta	10%
MUP/WCP sand rejects	Waste non heavy mineral sand returned to mine void or initial TSF. Assessed in mine waste report (MBS 2016).	5,097 ktpa	10,194 ktpa	68%
WCP tails (slimes)	Wet Concentrate Plant Tails (initial gravity separation slimes/clay fraction). Returned to mine void or initial TSF	565 ktpa	1,130 ktpa	7.5%
CUP MSP tails	Concentrate Upgrade Plant Combined Tails (magnetic separation) and MSP tails. Returned to mine void or initial TSF.	325 kpta	649 kpta	4.3%
MSP rejects	Minerals Separation Plant Rejects (includes zircon plant rejects and ilmenite processing rejects). Returned to mine void or initial TSF.	142 ktpa	283 ktpa	1.9%
Gypsum	Acid neutralisation residue from HAL circuit. Gypsum evaporation pond and/or mine void.	1.9 ktpa	3.7 ktpa	0.025%
Products exported (ilmenite, zircon, and HiTi88) or stockpiled (magnetic concentrate)		322 ktpa	644 ktpa	4.3%

Figure 3: Conceptual Processing Flow Chart



3. ENVIRONMENTAL SETTING

3.1 CLIMATE

The project is located on the Dampier Peninsula in the western part of the Kimberley region. Most rainfall occurs during the wet season between November and April. Potential evapotranspiration for the area is very high, averaging 1980 mm per year and varies moderately across seasons. It generally remains higher than rainfall even in the wet season, resulting in water limited conditions for vegetation (CSIRO 2009).

Weather data has been collected from an automatic weather station at the project site since November 2014. Maximum and minimum temperatures and mean humidity are shown in Chart 1. Maximum temperatures are generally between 35 and 45°C. Minimum temperature rarely drops below 15°C. Average humidity is around 40% in the dry season and approaches 80% in the wet season. Days with maximum humidity over 90% were observed in all months.

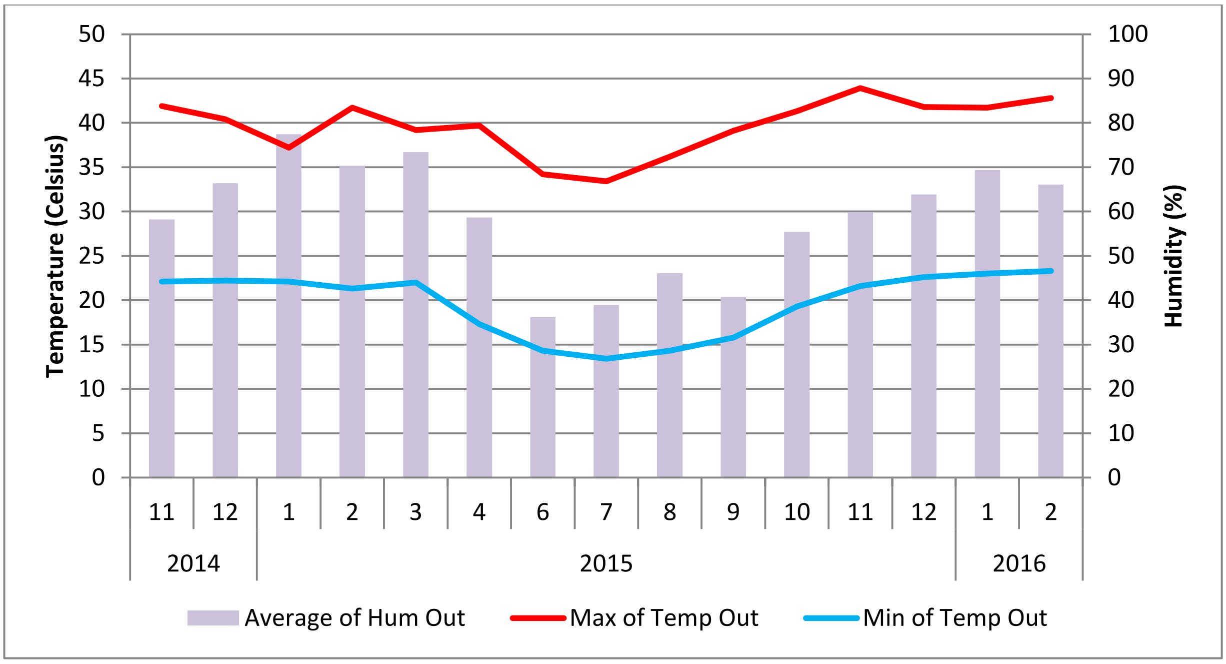


Chart 1: Temperature and Humidity at Thunderbird

Spatially extrapolated rainfall data is available for the project location from the SILO Data Drill data set. This data is calculated by extrapolation from all available BoM data including the closest BoM sites (Thunderbird, Mount Jowlaenga, Country Downs, Beagle Bay, Yeeda and Derby Aero) to give a continuous estimated record for a specific location. Comparison with local stations shows that, the Data Drill closely matches Mount Jowlaenga rainfall records when they were available, and is similar to Country Downs and other nearby stations at other times. It is recommended this dataset be used as an indication of long term rainfall patterns for the site.

Monthly rainfall statistics for the Thunderbird project area based on the Data Drill dataset from 1889 to 2015 are shown in Table 2 and Chart 2. The annual figures presented are based on a rainfall year from September to August. Mean annual rainfall is 694 mm. Rainfall is very variable with the lowest annual rainfall of 153 mm and maximum of 1,503 mm. Median annual rainfall is 675 mm. Median monthly rainfall is 1.2 mm or less during the dry season from May to October. Zero or very low rainfall may occur in any month.

Table 2: Rainfall Statistics (mm) for Thunderbird Project Site 1889 to 2015 (Data Drill)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
Mean	1.0	3.9	17.8	92.4	193.1	181.0	128.9	29.9	23.4	14.9	6.5	3.5	695.3
Highest	48.5	53.9	229.1	668.5	1031.8	556.9	535.1	261.7	308.4	159.4	157.6	56.1	1502.7
90th percentile	1.1	12.0	44.3	181.4	365.3	334.9	288.1	73.5	80.6	53.7	19.8	5.9	1003.6
Median	0.0	0.3	8.4	66.1	156.6	164.7	96.7	12.4	0.9	0.3	0.0	1.2	675.2
10th percentile	0.0	0.0	0.3	10.8	54.7	47.0	26.0	0.0	0.0	0.0	0.0	0.7	401.2
Lowest	0.0	0.0	0.0	1.1	21.0	12.7	1.8	0.0	0.0	0.0	0.0	0.5	152.6

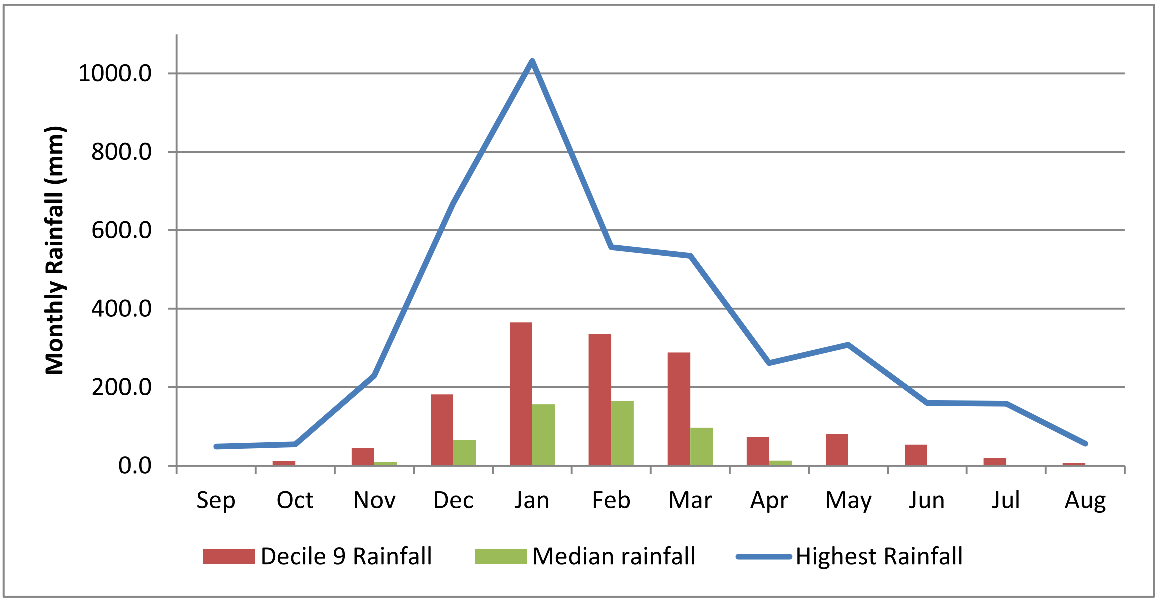


Chart 2: Monthly Rainfall Statistics for Thunderbird

3.2 GEOLOGY

3.2.1 Regional Geology

Stratigraphic units present within or adjacent to the project comprise sand units of the Upper Jurassic to the Lower Cretaceous, including the Jarlemai Siltstone, the Broom Sandstone and the Melligo Sandstone (Table 3). These formations are dipping at a shallow angle of less than 5° to the southwest.

Table 3: Stratigraphic Units

Unit Name	Description
Jarlemai Siltstone	• Dated as Upper Jurassic but may extend up to the Early Cretaceous (Crowe et al. 1978). • Deposited at the height of the Jurassic-Cretaceous marine transgression in the Canning Basin. • Lithology varies from siltstone to claystone and sandstone and is glauconitic to ferruginous in part (Towner and Gibson 1983).
Broome Sandstone	• Originally defined to cover sandstone cropping out along the west coast of the Dampier Peninsula near Broome and overlying the Jarlemai Siltstone (Brunnschweiler 1957). • Contains a wide variety of sandstone lithologies and sedimentary structures, consistent with deposition in a shallow-marine (tidal) environment as the Early Cretaceous sea regressed (Towner and Gibson 1980). • Lithology varies from a fine to very coarse sandstone to a mudstone with some minor conglomerate. • Sedimentary features such as ripple-marks, cross-bedding and bioturbation can be observed. • The topmost part contains well rounded heavy minerals (Towner and Gibson 1983).
Melligo Sandstone	• Conformably to disconformably overlies the Broome Sandstone. • High silicified unit but unsilicified Melligo Sandstone has been recognised in the Mount Jowlaenga area on the basis of sedimentary structures and fabric (Brunnschweiler 1957, McWhae et al. 1958, Towner and Gibson 1980). • Good sorting and rounding of the constituent grains, which include heavy minerals, coupled with thin bedding, flat to low-angle cross bedding and parting lineation indicate that it is a beach deposit, laid down as the sea in which the Broome Sandstone was deposited regressed. • Lithology of the Melligo Sandstone is fine to medium, well-sorted, thin-bedded to laminated sandstone that is pebbly in places. • Contains heavy minerals (Towner and Gibson 1983). • Considered by Sheffield Resources geologists to be an equivalent unit to the Broome Sandstone and therefore the primary target lithology for heavy mineral concentrations.

3.2.2 Project Geology

The Thunderbird deposit is a heavy mineral sands deposit containing valuable heavy minerals ilmenite, zircon, leucoxene and rutile. The Thunderbird deposit is hosted by deeply weathered Cretaceous-aged formations. Mineralisation is in a thick, broad anticlinal sheet-like body striking northwest. The areal extent, width, grade, geological continuity and grain size of the Thunderbird deposit are interpreted to indicate an off-shore sub-wave base depositional environment.

Five stratigraphic units have been defined by Sheffield Resources geologists via a combination of surface mapping and drillhole lithological logs. These are locally referred to as the Fraser Beds, Reeves, Melligo, Thunderbird and Jowlaenga Formations. Of these the Thunderbird Formation is the main mineralised unit with the Fraser Beds acting as a distinct marker unit toward the base of the Thunderbird Formation.

The Thunderbird Formation is a medium to dark brown/orange, fine to very fine sand unit. The Formation has a thickness of up to 90 m (average of 38 m) and is very rich in heavy minerals (up to 40%). The Formation has been modelled to be at least 8.5 km along strike and more than 2.5 to 5.5 km wide. The following features are present within the Formation:

- Layers of siliceous and iron cemented sandstone. The layers are interpreted to have been formed by post-deposition chemical processes of ferruginisation from ancient water table movements with iron oxides leached from the sand (e.g. from ilmenite). These cemented mineralised layers occur throughout the formation in a patchy nature, with extents rarely continuous between holes at 60 and 250 m spacing. This cemented mineralised sandstone is estimated to comprise no more than 10% of the deposit.
- Continuous, very high grade heavy mineral (greater than 7.5%) zone named the GT Zone. The GT Zone is up to 29 m thick (average 15 m) over an area of at least 7 km by 3.5 km, striking approximately north-south, open along strike and following the dip of the Thunderbird Formation. The high grade of heavy minerals in the GT Zone is interpreted to result from deposition in off-shore higher wave energy shoals.

3.3 LANDFORM AND SOILS

Project landforms and soils were the subject of a separate baseline report (MBS Environmental 2016b) which has additional information and mapping relevant to the project area.

The project is located within four land systems (Payne and Schoknecht 2011):

- The Fraser land system - characterised by sandplains and dunes. Relief less than nine metres.
- The Reeves land system - characterised by sandplains, scattered hills and minor plateaus. Relief to 60 metres.
- The Waganut land system - characterised by low-lying sandplains and dunefields with through-going drainage. Relief less than nine metres.
- The Yeeda land system - characterised by sandplains and occasional dunes with little organised drainage.

The four main soil types (Bettenay et al. 1967) within the land systems described above and located within the project area are as follows:

- Red earthy sands with associated hummocks of siliceous sands.
- Red earthy sands associated with soils on the plains, with dunes and hummocks of red sands. Some soils in lower sites often have a heavy surface layer of ferruginous gravel.
- Neutral red earths and sandy neutral red soils on plains with minor sandstone residuals on which there is extensive rocky outcrops.
- Neutral red earths and red earthy sands within sand plains with irregular dunes/active drainage systems.

3.4 SURFACE WATER DRAINAGE AND QUALITY

The project lies within the upper catchments of Fraser River (including Fraser River South) and Logue River (including Little Logue River). While the Fraser River enters King Sound from the west, the Logue River discharges to King Sound at Jarrananga Plain, immediately adjacent to the Fitzroy River. The Fitzroy River Basin is a much larger river basin extending approximately 500 km inland and representing the primary surface water inflow to King Sound.

Other than pastoral dams, there are no permanent water bodies at or near the project. A small depression is located approximately 3 km southeast of the Thunderbird deposit and a number of small drainage lines exist within the development envelope. However, these features contain water only during the wet season. No surface water quality monitoring data is available for the mine site development envelope or elsewhere on the Dampier Peninsula. Given the lack of industry and other sources of potential contamination, surface runoff is expected to be of good quality, suitable for livestock and agricultural use.

3.5 REGIONAL HYDROGEOLOGY AND WATER QUALITY

Five distinctive hydrogeological units have been identified within the project area:

- Superficial sediments ‘Pindan’.
- Broome upper aquifer.
- Heavy mineral sands (HMS) ore zone.
- Broome lower aquifer.
- Jarlemai Siltstone .

Ground level elevations within the mining area range from 89 m AHD in the south to 119 m AHD in the north, while the water table ranges from 66 m AHD in the south to 75 m AHD in the north (Rockwater 2016). The resulting depth to water is between 44 m BGL on elevated ground and 23 m BGL in local areas adjacent to drainage lines. The hydraulic gradient in the project region is approximately 1.6 m per km and decreases in the southwest to about 0.7 m per km. The steeper groundwater gradient near the project area is the result of lower permeability material where the ore occurs and at the base of the Broome aquifer.

Groundwater salinity in the Broome aquifer ranges from less than 100 to more than 30 000 mg/L TDS (GSWA 1991). It is generally low in elevated landscapes, including the project area, with saline groundwater only recorded towards discharge areas along the coast and Roebuck Plains above the saltwater wedge. Groundwater in the Broome Sandstone is essentially a sodium chloride type, with occasional high levels of bicarbonate.

4. DESCRIPTION OF SAMPLES

Six composite samples of processing residue samples were received from Sheffield Resources pilot processing trials. These compromised the following:

- Two samples of oversize material from MUP screening of the silicified mineral sands (>2 mm and >5 mm size fractions).
- Individual samples of MSP, CUP and WCP tailings/reject material.
- A ‘gypsum’ waste stream generated from neutralisation of the hot acid leach residue using agricultural lime (calcium carbonate). A hot sulfuric acid leach process is utilised to remove surface iron coatings from the zircon concentrate, which may also include iron cemented monazite (refer Glossary) which will then report to this fraction.

These samples were considered to be representative of material produced for the majority of mine life. Sample descriptions are presented in Table 4

Table 4: Sample Descriptions

Sample	Description
MUP >2.0 mm Oversize	Mining Unit Plant Oversize (> 2 mm)
MUP >5.0mm Oversize	Mining Unit Plant Oversize (> 5 mm)
MSP Rejects	Minerals Separation Plant Rejects
CUP MSP tails	Combined Concentrate Upgrade Plant Tails (magnetic separation) and MSP tails
WCP tails	Wet Concentrate Plant Tails (initial gravity separation - slimes)
Gypsum residue	Acid neutralisation residue from Hot Acid Leach circuit

5. GEOCHEMICAL CHARACTERISATION METHODS

5.1 ACID BASE ACCOUNTING CLASSIFICATION BACKGROUND

The aim of quantitative laboratory testing for acid base accounting (ABA) is to estimate the net potential for acid formation if the waste material is disturbed and any oxidisable sulfur species (sulfides) present allowed to oxidise by exposure to atmospheric oxygen to generate sulfuric acid. Pyrite (FeS_2) forms naturally under reduced oxygen (anaerobic) conditions in soils and sediment from biological reduction of sulfate to sulfide by sulfate reducing bacteria (SRB). Anaerobic conditions for the generation of pyrite in acid sulfate soils (ASS) occur in areas of waterlogging and organic rich soils and sediments such as swamps and wetlands. Pyrite and other potentially acid forming sulfides can also be present as primary minerals in rocks formed by volcanic activity and typically associated with hard rock mining. When exposed by physical disturbance or a lowering of the water table, pyrite reacts with oxygen and water to produce acidity (H^+) according to the chemical equation:

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 16H^+ + 8SO_4^{2-}$$

Oxidation of one mole of pyrite will produce two moles of sulfuric acid or alternatively, 30.6 kg of sulfuric acid will be produced by oxidation of one tonne of ASS containing 1% by weight sulfur. This potential acidity will be in addition to any existing acidity already present but can also be counteracted by any acid neutralising capacity (ANC) present.

There is no simple method to define whether mine waste containing small quantities of sulfides will produce sulfuric acid. For AMD, a combination of approaches is often applied to more accurately classify mine waste. These approaches are listed below in order of increasing data requirements (and therefore increased reliability):

- The “Analysis Concept”, which only requires data for total sulfur content. Its adoption is based on long term experience of wastes from Western Australian mine sites in arid and semi-arid conditions. Experience has shown that hard rock waste containing very low sulfur contents (less than 0.2 to 0.3%), rarely produces significant amounts of acidic seepage. In the case of potential ASS material however, a more suitable conservative screening criteria for total sulfur is 0.05% (DMP - Department of Mines and Petroleum 2016). ASS methods are a modified form of acid base accounting as used in AMD procedures for hard rock mine waste, but are tailored specifically for soils where the concentrations of sulfides are normally lower, significant levels of organic materials are often present, ANC is often low and other forms of acidity (collectively called retained acidity) are more common.
- The “Ratio Concept”, which compares the relative proportions of acid neutralising minerals (measured by the ANC) to acid generating minerals (measured by the Acid Production Potential (AP)). The risk of generating acidic seepage is generally low when this ratio (the Neutralisation Potential Ratio – NPR) is above a value of two.
- Acid-Base Accounting, in which the calculated value for Nett Acid Producing Potential (NAPP) is used to classify the acid generating potential of mine waste. NAPP is equal to the AP minus the ANC.
- Procedures recommended by AMIRA (2002), which take into consideration measured values provided by the Nett Acid Generation (NAG) test and calculated NAPP values.
- Use of chromium-reducible sulfur (CRS or S_{CR}) as a direct measure of oxidisable sulfur, as a preferred alternative to indirect measurement of oxidisable sulfur by AMIRA (2002) methodology.
- Kinetic leaching column test data, which provides information for the relative rates of acid generation under controlled laboratory conditions, intended to simulate those within a waste material stockpile or tailings storage facility.

A sound knowledge of geological and geochemical processes must also be employed in the application of the above methods.

Classification of wastes in this report follows the Australian Government's Guidelines on Managing Acidic and Metalliferous Drainage (DITR 2007) and AMIRA (2002) and is based on NAPP and NAG pH results. However selection of samples for full ABA parameters (ANC, NAG, AP and NAPP) was also based on the ASS based criteria of 0.05% total sulfur (DMP 2016) or pH_{OX} (refer Section 9) of less than 3.0 (DER 2012, DER 2013) in order to cover any potential for such material at or below the groundwater table within the project in the samples received. The adopted methodology therefore included the following assessments:

- Analysis for total sulfur (Tot_S) and pH_{OX} on all samples.
- Analysis for ANC (quoted in kg H_2SO_4/t), NAG (quoted in kg H_2SO_4/t), NAGpH and CRS if total sulfur was greater than 0.05% or pH_{OX} is less than 3.0.
- Calculation of AP based on total sulfur and sulfate sulfur = [(Tot_S – SO_4_S) * 30.6] kg H_2SO_4/t.
- Secondary check calculation of AP based on chromium reducible sulfur = [(S_{CR}) * 30.6] kg H_2SO_4/t.
- Calculation of NAPP = [AP – ANC] kg H_2SO_4/t.
- Calculation of NPR = ANC/AP.

When assessing data for AP and NAPP, it must be noted that both parameters are based on the assumption that all sulfur contained in the sample is acid producing (sourced from pyrite and other iron sulfide minerals). However, this represents a worst case scenario as not all minerals containing sulfur will result in acid production. Conversely, the NAPP calculation also assumes that the acid neutralising material measured in ANC is rapid-acting. In practice, some neutralising capacity is supplied by silicate and aluminosilicate minerals which can be much slower to react. Further still, iron carbonate minerals such as siderite ($FeCO_3$) have limited or no capacity to neutralise acidity due to acid producing reactions resulting from oxidation of the dissolved ferrous iron component. Despite these assumptions, NAPP remains a suitable conservative prediction of potential acid generation when used in conjunction with mineralogical data.

A combined acid generation classification scheme based on NAPP and NAG determinations is presented in Table 5.

Table 5: ABA Classification Criteria for Samples

Primary Geochemical Waste Type Class	NAPP Value kg H_2SO_4/t	NAGpH
Potentially Acid Forming (PAF)	≥10	< 4.5
Potentially Acid Forming – Low Capacity (PAF-LC)	0 to 10	< 4.5
Uncertain (UC)	0 to 5	> 4.5
	-10 to 0	< 4.5
Non Acid Forming (NAF) (Subclass 'Barren' if estimates of oxidisable sulfur are < 0.05%)	-100 to 0	> 4.5
Acid Consuming (AC)	< -100	> 4.5

Table 5 is based on the Australian Government's Guidelines on Managing Acidic and Metalliferous Drainage (DITR 2007) and is in turn based on an earlier classification system included within the AMIRA ARD Test Handbook (AMIRA 2002), which is advocated by the Global Acid Rock Drainage Guidelines (GARD) published by the International Network for Acid Prevention (INAP 2009). This classification system, based on static acid base accounting procedures and used in conjunction with geological, geochemical and mineralogical analysis can still leave materials classified as 'uncertain' where there is conflicting NAGpH and NAPP results. Uncertain materials demonstrating a NAG pH above 4.5 may be tentatively assigned as potentially NAF and those below pH 4.5 as potentially PAF. However, in such cases further assessment, such as the use of kinetic leaching columns may be required to provide a definitive classification. Classification criteria for pH of potentially ASS material is normally based on an oxidised pH (pH_{FOX} equivalent to NAGpH) of less than 3 so a classification criteria of pH 4.5 for NAG pH is therefore more conservative for acid generation.

5.2 ACID BASE ACCOUNTING LABORATORY METHODOLOGY

Sample analysis was performed by a NATA accredited laboratory (Intertek Genalysis). Preliminary analysis was conducted for total sulfur measured by combustion infra-red analysis. As none of the residue samples other than the acid neutralised 'gypsum' residue had a total sulfur content of more than 0.05%, further analysis for S_{CR}, ANC and NAG was not conducted for these samples. An estimation of sulfate-sulfur was taken from water leachates (5.4) to calculate the AP. The 'gypsum' residue of neutralised sulfuric acid leachate results from a high temperature sulfuric acid leach and neutralisation with agricultural lime (calcium carbonate). As all sulfur present would already be in an oxidised form (sulfate) with no further acid generation potential, no ABA parameters were assessed for this sample.

5.3 ELEMENTAL COMPOSITION AND GAI

A range of major and trace metals and metalloids were measured by inductively coupled plasma (ICP) spectrometry following digestion of a finely ground sample with a four acid (HF, HCl, HNO_3 and $HClO_4$) mixture, which is considered to be a near total determination for the elements measured.

Digest solutions were analysed for a general suite of potential toxicants determined by ICP optical emission spectroscopy (ICP-OES) or ICP mass spectroscopy (ICP-MS). Samples were analysed for aluminium (Al), arsenic (As), barium (Ba), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), tin (Sn), thorium (Th), uranium (U), vanadium (V) and zinc (Zn).

From this data, the global abundance index (GAI) for each element was calculated by comparison to the average earth crustal abundance (Bowen 1979 and AIMM 2001). The main purpose of the GAI is to provide an indication of any elemental enrichment that could be of environmental significance. The GAI (based on a log-2 scale) is expressed in integer increments from zero to six (GARD Guide). A GAI of zero indicates that the content of the element is less than or up to three times the average crustal abundance; a GAI of one corresponds to a three to six fold enrichment; a GAI of two corresponds to a six to 12 fold enrichment and so forth, up to a GAI of six which corresponds to a 96-fold, or greater, enrichment above average crustal abundances. A GAI of more than three is considered significant and may warrant further investigation.

5.4 WATER LEACHATE CHARACTERISATION METHODOLOGY

Samples examined during this investigation were subject to a water leach according to the Australian Standards Leaching Procedure (ASLP) 4439.3 Class 1 specification using a 1:20 weight/weight, sample to water. Analytical finish was via ICP-OES or ICP-MS, as necessary. Samples were analysed for Al, As, Ba, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sn, Th, U, V and Zn.

Water extracts of samples were simultaneously tested for Electrical Conductivity (EC), pH, alkalinity (bicarbonate, carbonate and hydroxide forms), sulfate and chloride. Fluoride concentrations were measured by Ion Selective Electrode (ISE).

5.5 DILUTE ACID LEACHATE CHARACTERISATION METHODOLOGY

Samples were subject to analysis using dilute acetic acid as the leaching fluid (initial pH 2.9) according to ASLP 4439.3 specification (1:20). Analytical finish of the filtered (0.45 µm) extract was via ICP-OES or ICP-MS finish, as necessary, for the same metals and metalloids as performed for the water leachable fraction. Analysis of this leachate can provide:

- An indication of the relative abundance of acid-consuming minerals. High concentrations of calcium (and magnesium) in conjunction with higher ANC values would indicate the presence of calcite ($CaCO_3$). High concentrations of soluble silicon and/or aluminium would indicate reactive silicates and/or aluminosilicates are responsible for ANC.
- An indication of the amount of non-acid forming sulphate sulfur present in the sample.
- Heavy metals and metalloids that may be leachable over extended periods if acidic conditions were to prevail. It should be noted that the pH for this test (2.9) is lower than NAG pH and pH_{OX} data recorded for all samples (Section 6.1.1).

5.6 MINERALOGICAL ASSESSMENT

The 'gypsum' residue sample was assessed for mineralogical composition. The sample was submitted to Intertek Genalysis Laboratory Services for a quantitative powder X-Ray diffraction analysis (XRD) of the crystalline and amorphous contents. Samples were further ground to a very fine powder in an agate mortar and pestle and subsampled for analysis with and without addition of zinc oxide (solid dilution 10% by weight) to determine amorphous content. XRD patterns were then collected on PANalytical Cubix wavelength dispersive XRD with quantitative analysis performed using an automated Rietveld method of correction. Full experimental details are provided in Appendix 2.

5.7 PARTICLE SIZE ANALYSIS

Particle size analysis on tailings samples (MSP rejects, CUP MSP tails and WCP tails) was performed by light (laser) scattering using a Beckman Coulter Particle Size Analyser by Intertek Genalysis Laboratory Services. Results are provided in Appendix 2.

6. RESULTS AND DISCUSSION

6.1 ACID BASE ACCOUNTING

Laboratory results for total sulfur, water soluble sulfate sulfur, and ABA parameters of the five residue samples (as discussed previously, in Section 5.2, the 'gypsum' residue was not assessed) are collated in Table A1-1 of Appendix 1. The original laboratory reports are provided in Appendix 2.

6.1.1 Sulfur Assay and Forms

Based on the data in Table A1-1 of Appendix 1, the following are noted as key points for the five residue samples:

- Total sulfur concentrations were very low in all samples (0.05% or less). MSP rejects had the highest result at 0.05% total sulfur and 0.013% sulfate sulfur (indicating only 0.04% was present in the non-oxidised sulfide). Further analysis of MSP rejects indicated less than 0.02% chromium reducible sulfur.
- The natural pH of samples (1:20 leachate) was marginally acidic with pH ranging from 5.7 (MSP rejects) to 6.5 (CUP MSP tails). These values are typical of highly weathered and leached soils such as the pindan soils of the project.
- Oxidised pH values (pH_{OX}) for the tails and reject samples were lower (pH 4.1 to 4.8), but above pH 3.0. These values are attributed to retained/exchangeable acidity (Section 9) in the residue, as well as hydrolysis of iron (formation of additional ferric ions) under strong laboratory oxidising conditions in the iron rich soils and clays. Some organic matter may also be present and contribute to a lowering of pH when artificially oxidised (formation of organic acids). The NAG pH of MSP rejects used for AMIRA based classification (Table 5) was 4.9.
- As a result of the low sulfur concentrations, calculated AP values were low (<0.3 to 1.5 kg H_2SO_4/t).

6.1.2 Acid Drainage Classification

Based upon measured total sulfur, sulfate sulfur and chromium reducible sulfur concentrations in MSP rejects (the highest sulfur content sample) and other ABA parameters, the following aspects were evident:

- All samples had very low levels of potentially oxidisable sulfur and were classified as NAF.
- ANC measured on the MSP rejects was very low (3 kg H_2SO_4/t). Based on pH and soluble alkalinity data, all tailings/reject samples are expected to have similar low levels of available acid neutralisation capacity. The 'gypsum' residue (Section 6.3) is noted as having some soluble alkalinity and a slightly alkaline pH (7.6) for acid neutralisation but will form a very small portion of mine waste (0.025% of mineralised material processed excluding overburden).
- As a result of the low levels of potentially oxidisable sulfur and ANC, samples assessed are given a sub-classification of 'Barren', having neither acid producing nor acid neutralisation potential.

6.2 ELEMENTAL COMPOSITION

Laboratory results for analysis of total metals and metalloids by strong acid digestion for the six residue samples are collated in Table A1-2 of Appendix 1 and the calculated GAI values, as outlined in Section 5.3, are presented in Table A1-3.

Mineral deposits by their nature are anticipated to have some elements present in concentrations above the average crustal abundance. The GAI does, however, provide a useful screening tool for identifying elements requiring further assessment by more specific test methods. Examination of the total element concentrations and the corresponding GAI values for these samples indicates the following:

- The WCP tails, being the primary rejection stream from gravity separation of heavy minerals to produce the raw HMC, was found to have low concentrations of all elements tested, consistent with a composition of mostly quartz sand and clays.
- As expected for tailings residues from a mineral sand placer deposit, samples were enriched in thorium – which is normally mostly present in the mineral monazite. Concentrations in the MUP oversize fraction materials (largely cemented mineralised sandstone) were approximately 100 mg/kg (GAI 3) versus a crustal abundance of 10 mg/kg. A slightly higher concentration (136 mg/kg, GAI 3) was present in the CUP MSP tails and the highest concentration was present in the 'gypsum' sample (261 mg/kg, GAI 4). Thorium enrichment in the 'gypsum' residue is consistent with the result of release of iron cemented monazite adhered to the zircon particles during acid leaching of the zircon concentrate.
- Uranium concentrations were highest in the MSP rejects (371 mg/kg, GAI 6) and CUP MSP tails (136 mg/kg, GAI 3) versus the global abundance of 2.7 mg/kg. The oversize fraction material contained between 10 and 11 mg/kg uranium.
- The MSP rejects sample was enriched in selenium (4 mg/kg, GAI 4) versus the average soil concentration of 0.2 mg/kg. Selenium concentrations in other samples were less than or equal to 0.7 mg/kg.
- The MSP rejects sample was also enriched in lead (357 mg/kg, GAI 4) versus an average crustal abundance of 12.5 mg/kg. This is consistent with the enrichment of uranium in this material as lead is a radioactive decay product of uranium.
- Vanadium was noted as being generally elevated in all samples (139 to 548 mg/kg), compared to the average crustal abundance of 135 mg/kg, but insufficient to be considered 'enriched' (GAI values were a maximum of 1).
- Concentrations of all other environmentally relevant elements tested did not significantly exceed average crustal abundances.

6.3 WATER LEACHATE CHARACTERISATION

The use of a tumbled water extract of a finely ground sample allows the laboratory water extraction test to mimic weathering conditions that may be expected in a temperate, semi-arid environment over a period of several years. It is not suitable for predicting long term release rates.

Observed concentrations of minerals and metalloids in the extract may not represent maximum potential concentrations. This test method can be limited by the rates of dissolution, desorption and solubility (especially for sparingly soluble minerals such as gypsum ($CaSO_4.2H_2O$), barite ($BaSO_4$) and fluorite (CaF_2)). Hence an understanding of mineral phases present is important when interpreting the results.

6.3.1 pH, Salinity and Soluble Alkalinity

Results for pH, EC and soluble alkalinity in the 1:20 water extracts are given in Table A1-4 of Appendix 1. Results indicate:

- The MUP, MSP, CUP and WCP waste streams generated circumneutral to marginally acidic leachates (pH values ranging from 5.7 to 6.5) in the un-oxidised state. The 'gypsum' neutralised sample had a marginally higher leachate pH of 7.6.
- All leachates contained low to very low soluble alkalinity (range 3 to 29 mg/L as $CaCO_3$), with samples other than the 'gypsum' residue having between 3 and 5 mg/L as $CaCO_3$.
- The MUP, MSP, CUP and WCP waste streams generated leachates with low to very low EC and soluble salt concentrations (EC <10 to 60 µS/cm). The 'gypsum' residue leachate EC was considerably higher (2,436 µS/cm) having effectively reached saturation with calcium and sulfate in the water extract.
- All leachates contained very low levels of soluble fluoride.

These results suggest the MUP, MSP, CUP and WCP waste streams contain only very low levels of any soluble salts or alkalinity. The 'gypsum' residue had low levels of soluble alkalinity.

6.3.2 Soluble Metals and Metalloids

Results for water soluble metals and metalloids in the 1:20 ASLP extracts are given in Table A1-5 of Appendix 1. ANZECC livestock drinking water guidelines (cattle), ANZECC/DEC freshwater guidelines, and Human Drinking Water Guidelines (NHMRC 2011) are provided for comparison. The primary use of groundwater in the regional area is for cattle and hence results are compared to livestock drinking water guidelines. Comparison to human drinking water guidelines are also provided. Key observations for soluble metals and metalloids data are summarised below.

- All metals and metalloid concentrations in water leachates for all residue samples were below the corresponding ANZECC livestock drinking water guidelines, indicating a low risk of material adversely impacting groundwater quality by a process of leaching from rainfall or in contact with groundwater/process water. Only aluminium and chromium (see below) exceeded human drinking water quality guidelines.
- The aluminium concentration in CUP MSP tails leachate (0.79 mg/L) was above the aesthetic human drinking water guideline (0.2 mg/L), which is consistent with the slightly lower pH of this sample (pH 5.7) versus others. There is no applicable human health guideline for aluminium. This waste stream represents a low contribution to total waste volume (approximately 4.3% of mined mineralised material) and these concentrations are not considered of environmental significance in the overall project.
- The chromium concentration in leachate from the 'gypsum' residue was above the human drinking water guideline value (0.18 mg/L versus a guideline value of 0.05 mg/L). Based on previous work by MBS Environmental staff, it is known that Western Australian lime contains moderate levels of soluble (hexavalent) chromium. It is considered that the source of chromium in the present 'gypsum' residue is from the source of lime used for acid neutralisation rather the mineral deposit itself. Soluble chromium does not persist in the groundwater environment under normal conditions and this is expected to be immobilised rapidly without risk to any potential receptors, particularly given the low volumes of this residue material in the mine void/initial TSF.
- Metals (thorium, uranium, vanadium and lead) and metalloids (selenium) that were geochemically enriched in these materials (Section 6.2) were well below both livestock and drinking water guidelines, indicating they are present in very stable, insoluble forms.

Overall, water soluble concentrations of all metals and metalloids assessed were very low to non-detectable for all elements of environmental significance. This indicates there is a very low risk of leachates generated from Thunderbird process residues impacting the surrounding environment.

6.4 DILUTE ACID LEACHATE CHARACTERISATION

Dilute acid leachate results for all samples are presented in Tables A1-6 and A1-7 of Appendix 1.

Under the strongly acidic conditions of this test, the following properties were identified:

- Metal and metalloid concentrations in the acetic acid leachates of all residue samples were below the corresponding ANZECC livestock drinking water guidelines, indicating a very low risk of material adversely impacting groundwater quality even if localised acid conditions were to prevail.
- Concentrations of major ions (Na, K, Ca, Mg and SO_4) in samples other than the 'gypsum' residue were very low indicating very little available buffering capacity in the form of calcium or magnesium carbonates.
- Aluminium concentrations in acid leachates for the MUP, MSP, CUP and WCP residue samples were low (1.5 mg/L to 4.2 mg/L), but above the human drinking water guideline of 0.2 mg/L. Iron (no health guideline values) was also present at low concentrations. This reflects natural presence of some hydrated aluminium and iron oxides from weathering and groundwater interactions. These soluble concentrations under worst case acidic conditions are not considered of environmental significance in the overall project.
- Nickel present in the MSP rejects acid leachate was marginally above the human drinking water guideline (0.03 mg/L versus a guideline value of 0.02 mg/L).
- The 'gypsum' residue was very different in composition with soluble calcium and sulfate dominating as expected. No metals or metalloids in this sample were above ANZECC livestock drinking water guidelines, but nickel (0.06 mg/L) and manganese (1.88 mg/L) were marginally above human drinking water guidelines (0.02 and 0.5 mg/L respectively). This waste stream represents only 0.025% of the expected waste streams.

It is important to reiterate the fact that elemental concentrations presented in Table A1-7 are not a prediction of expected concentrations of actual seepage. They represent a worst case scenario of possible leaching under rapidly generated acidic conditions which, based on available oxidisable sulfur, are not expected to be present in the field.

6.5 MINERALOGICAL ASSESSMENT OF GYPSUM RESIDUE

Results of XRD mineralogy for the 'gypsum' residue (lime neutralised sulfuric acid process leachate) are provided in Appendix 2. Result of this analysis indicate that:

- The largest components by weight are unreacted calcium and magnesium carbonates from the source lime (calcite, 41% and dolomite, 10%).
- The gypsum (calcium sulfate, $CaSO_4.2H_2O$) expected to be formed as part of the neutralisation is actually amorphous (none detected in crystalline form). A small quantity of crystalline basanite ($CaSO_4.0.5H_2O$, 7%) was either formed or present in the original lime.
- Magnesium silicate and trace quartz, zircon and kaolin made up the remainder of the material.

Reaction of sulfuric acid with agricultural lime (calcium/magnesium carbonates) tends to form a layer of calcium sulfate which physically prevents further reaction with the calcium carbonate (calcite) underneath. Hence the distribution of material as a whole is not uniform and this would be consistent with the mineralogy findings above (i.e. unreacted calcite comprising 41% of the material after neutralisation). Left as a bulk material and depending on exposure to water, amorphous calcium sulfate present is expected to dissolve and re-crystallise in a crystalline (less soluble) form over time but this may also expose more of the calcite and dolomite as a source of alkalinity. The total proportion of this residue to processed mine waste (0.025%) means such effects on the overall mine void pore water will be very minimal.

6.6 PARTICLE SIZE ANALYSIS AND POTENTIAL FOR DISPERSION

Particle size distribution results for CUP MSP and WCP tails samples are provided in Appendix 2. Summary statistics of particle sizing are presented in Table 6. These results can also be combined with analysis of cation exchange capacity (CEC) and calculated exchangeable sodium percentage (ESP) presented in Table A1-8 of Appendix 1 to give an indication of the potential for dispersion of the tailings materials. An ESP of more than 15% is generally classified 'highly sodic' while a result of 6 to 15% indicates 'moderately sodic' (Northcote and Skene 1972). Key points are summarised as follows:

- The CUP MSP tails sample was almost entirely comprised of silt (<20 µm) and clay (2 µm) fraction material. This sample also had low EC levels (Section 5.4) and an ESP of 22%, indicating that it is sodic and prone to being highly dispersive.
- WCP tails (a broad spread of clay, silt and very fine sand) and MSP rejects (a very broad spread across the clay, silt and very fine sand fractions), were both slightly broader in distribution that CUP MSP tails. Both samples also contained sufficient clay/silt fraction material and recorded low EC and elevated ESP's (15.4% for MSP Rejects and 12.6% for WCP Tails) to indicate that they are sodic and potentially dispersive.
- Placement of these materials back into the initial TSF or mine void as a slurry has the potential to result in the supernatant water remaining highly turbid with suspended clay, limiting options for discharge of any excess mine water during high rainfall events. In practice, it is understood this will be managed by addition of flocculent to the process water which in turn will assist in settling of the clay/silt material in the mine void/initial TSF and lowering the turbidity of water which is mostly re-circulated into the plant for use in processing.

Table 6: Summary of Particle Size Analysis Results (µm)

Sample	10th Percentile	50th Percentile (Median)	90th Percentile
MSP Rejects	0.965	10.97	72.17
CUP MSP Tails	1.043	4.76	27.15
WCP Tails	1.3	9.34	50.56

7. CONCLUSIONS AND RECOMMENDATIONS

Geochemical assessment of four residue samples and two oversize ore streams from metallurgical trials for the project indicated the following:

- The MUP oversize, MSP rejects, CUP MSP tails, and WCP tails samples contained very low concentrations of total sulfur and were all classified as NAF-Barren, having neither acid forming or acid neutralising capacity.
- All sulfur contained in the 'gypsum' residue sample would be in the fully oxidised (sulfate) form following a sulfuric acid leach and subsequent neutralisation. This sample was also classified as NAF-Barren.
- Natural pH values for samples other than 'gypsum' were marginally acidic (5.7 to 6.5 pH) with essentially no soluble alkalinity. This is typical of the highly weathered pindan soils present in the project area. The 'gypsum' residue sample had low levels of residual alkalinity (29 mg/L as $CaCO_3$) and a slightly higher pH (7.6).
- With the exception of the 'gypsum' residue sample (a minor waste stream but source of soluble calcium sulfate), all samples had extremely low levels of soluble salts.
- Thorium was the most commonly enriched element and is likely to be associated with naturally elevated concentrations of monazite present in the Thunderbird deposit. GAI values for thorium in oversize ore (MUP oversize, two samples), CUP MSP tails and 'gypsum' residue ranged from three to four, with a maximum concentration of 261 mg/kg ('gypsum' residue). Both water and dilute acid leachate testing indicated these total concentrations will not be mobilised under any expected mining conditions.
- Enrichment in uranium was observed for MSP rejects (371 mg/kg, GAI of 6) and CUP MSP Tails (136 mg/kg, GAI 3), versus the global abundance of 2.7 mg/kg. Lead (357 mg/kg) and selenium (4 mg/kg) were also enriched in MSP rejects as a result of mineral separation from the source ore material. Again water and dilute acid leaching indicated this natural uranium enrichment was in a highly insoluble and environmentally unavailable form.
- Water soluble concentrations of elements of environmental significance in residue and oversize ore samples were very low to non-detectable and below ANZECC livestock drinking water guidelines. Concentrations of aluminium in CUP MSP tails (0.79 mg/L) and chromium in gypsum (0.18 mg/L) just exceeded corresponding human drinking water guidelines but are not considered of risk to the receiving environment at the concentrations and proposed waste volumes. Overall, results indicate there is an extremely low risk of process residue leachates adversely impacting the surrounding environment by rainfall/groundwater/process water interaction.
- Dilute acid leach results confirmed negligible levels of calcium and magnesium carbonates were available for buffering capacity/acid neutralisation. Low levels of aluminium and iron were the primary elements solubilised, which is consistent with a natural presence of hydrated aluminium and iron oxides from weathering and groundwater interactions. The 'gypsum' sample also released low concentrations of manganese and nickel but these were below the corresponding ANZECC livestock drinking water guidelines. Concentrations of all other environmentally significant metals and metalloids (including geochemically enriched thorium, uranium, lead and selenium) were very low in all samples and below corresponding ANZECC livestock drinking water guidelines.
- Analysis of the 'gypsum' residue by X-Ray Diffraction indicated the presence of significant unreacted calcium and magnesium carbonates (calcite and dolomite total 51%) in the lime being used for neutralisation of the sulfuric acid leach of the zircon concentrate. Both gypsum and underlying calcite and dolomite are expected to gradually dissolve following co-disposal of this minor waste stream (0.025%) with other mine waste by interaction with rainfall/groundwater.
- Particle size analysis conducted on the MSP rejects, CUP MSP tails and WCP tails confirmed a significant portion of clay materials were present in these residue streams. Cation exchange capacity results also indicated these samples were slightly to moderately sodic (ESP values of 12.6 to 22%) and low in salinity.

These materials are therefore expected to have a dispersive tendency and make water turbid by remaining suspended. As processing involves the use of flocculants, slurries of these materials should still reasonably settle upon placement in the mine void or initial TSF.

Overall, results indicate that project tailings will be NAF and Barren with essentially no capacity for acid generation or acid neutralisation. Predicted concentrations of soluble salts, metals and metalloids in any seepage are expected to be extremely low. Low overall (in relation to waste volumes) levels of calcium sulfate and calcium carbonate will gradually be mobilised by leaching from the 'gypsum' residue, however seepage water quality will mostly reflect process groundwater quality as drawn from local aquifers. Although various residues are geochemically enriched in thorium, uranium, lead and selenium, these elements were not found to be mobile, even under artificially applied acidic conditions. All process waste streams are thus considered environmentally benign for the project, but will have a tendency towards dispersive behaviour – however this will be managed on site by use of flocculants in process waters.

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9. GLOSSARY OF TECHNICAL TERMS

Term	Explanation
Acid fizz test	A field test used to test for the presence of carbonate minerals in soil and sediment. Dilute hydrochloric acid is added to the sample and an effervescent reaction indicates the presence of carbonate minerals.
ACM	Acid consuming material.
Action criteria	The critical net acidity values (expressed as % pyrite sulfur or the equivalent moles H^+/t) for different soil texture groups and sizes of soil disturbance that trigger the need for ASS management.
Actual acidity	The soluble and exchangeable acidity already present in the soil, often as a result of previous oxidation of sulfides. It is measured in the laboratory using the TAA method but does not include the less soluble acidity (i.e. residual acidity) held in minerals such as alunite and jarosite.
alunite	A hydrated aluminium potassium sulfate mineral, formula $KAl_3(SO_4)_2(OH)_6$. It is an analogue of jarosite where aluminium has replaced iron and can hydrate to aluminium hydroxide and release soluble free acidity. It is thus a source of stored or 'retained' acidity.
ANC	Acid Neutralising Capacity. A process where a sample is reacted with excess 0.5 m HCl at a pH of about 1.5, for 2-3 hours at 80-90ºC followed by back-titration to pH=7 with sodium hydroxide. This determines the acid consumed by soluble materials in the sample.
ANC_E	Acid Neutralising Capacity (Excess). Found in soils with acid neutralising capacity in excess of that needed to neutralise acid generation from sulfides. Measured by titration down to pH 6.5 after oxidation of the sample with peroxide. If ANC_E of a soil is positive then the TPA is zero and vice versa.
AP	Acid Potential. Similar to MPA, but only is based on the amount of sulfide-sulfur (calculated at the difference between total sulfur and sulfate-sulfur (SO_4-S)) rather than total sulfur. AP (kg H_2SO_4/t) = (Total S – SO_4-S) x 30.6
ASS	Acid Sulfate Soils.
calcite	Calcium carbonate $CaCO_3$
CEC	Cation Exchange Capacity of a soil is defined as the total sum of exchangeable cations that it can adsorb at a specific pH. Cation exchange of exchangeable cations in reversible chemical reactions is a quality important in terms of soil fertility, erosion and plant nutritional studies.
Chromium suite	The approach of calculating net acidity using the chromium reducible sulfur method to determine potential sulfidic acidity. It is combined with a decision process based on pH_{KCl} to determine the other components of acid-base accounting (TAA, ANC).
Circum-neutral pH	pH value near 7.
CRS	Chromium Reducible Sulfur. A measurement of reactive sulfide sulfur normally applied to acid sulfate soils using reaction with metallic chromium and hydrochloric acid to liberate hydrogen sulfide gas, which is trapped and then measured by iodometric titration.
Dolerite	A mafic, holocrystalline, subvolcanic rock equivalent to volcanic basalt or plutonic gabbro
Dolomite	Calcium magnesium carbonate $CaMg(CO_3)_2$
EC	Electrical conductivity. A measurement of solution salinity. Conversion: 1000 µS/cm = 1 dS/m = 1 mS/cm
Effective NAPP	NAPP calculated using CarbNP rather than traditional ANC. Effective NAPP (kg H_2SO_4/t) = AP – CarbNP

Term	Explanation
ENV	Effective neutralising value of a liming product (normally calcite) which takes into account the chemical purity of the lime, particle size and solubility in its ability to neutralise acid.
Existing or Exchangeable acidity	The acidity already present in soils, usually as a result of oxidation of sulfides, but which can also be from organic material or ions which release acid upon hydrolysis (Fe and Al). Existing acidity is the sum of actual acidity and retained acidity.
Fineness factor	A factor applied to the amount of acid neutralising material required to neutralise the acid potential due to the poor reactivity of coarser carbonate or other acid neutralising material. The minimum factor is 1.5 for finely divided pure agricultural lime (calcium carbonate), but may be as high as 3.0 for coarser shell material.
Fulvic acid	A complex mixture of small organic molecules derived from biological breakdown of plant matter (humus). They are organic acids (carboxyl and phenolate groups) which remain soluble in water below pH 2 (compare with Humic acid).
Humic acid	A complex mixture of large (high molecular weight) organic molecules derived from biological breakdown of plant matter (humus). They are organic acids (carboxyl and phenolate groups) which are insoluble in water below pH 2.
Ilmenite	Iron Titanium Oxide ($FeTiO_3$). It can be processed (removal of iron) to produce synthetic rutile (TiO_2).
Jarosite	A hydrated iron potassium sulfate mineral, formula $KFe_3(SO_4)_2(OH)_6$. It can hydrate to iron (III) hydroxide and release soluble free acidity. It is thus a source of stored or 'retained' acidity. Jarosite is often distinguished by its yellow colouration among dark sediments exposed to oxygen. A sodium form is known as natrojarosite.
Laterite	Highly weathered soils/subsoils developed by extensive leaching of iron and aluminium rich parent rocks in tropical climates to leave soils rich in hydrous iron and aluminium oxides.
Leucoxene	An industry applied name (not an official mineral name) to describe highly weathered ilmenite where the iron has been leached to leave a higher titanium content ilmenite (70 to 93% titanium dioxide content).
Monazite	A normally highly insoluble mineral of $(Ce, La)PO_4$ which also contains thorium (approximately 5%) and uranium (0.3 to 0.5%) and is a naturally occurring radioactive material (NORM). It can be 'cracked' by high temperature sulfuric acid and dissolved leaving behind the insoluble minerals zircon (ZrO_2), rutile (TiO_2) and $ZrSiO_4$
MBO	Monsulfidic Black Ooze. Black, oily in appearance gel-like substances highly enriched (up to 27%) in monosulfides and organic matter which can form thick deposits in waterways in acid sulfate soil landscapes.
Mg_A	Reacted magnesium. The magnesium solubilised after reaction with peroxide that was not soluble in 1M KCl (i.e. Mg_P minus Mg_{KCl}). It is a measure of the magnesium present and available for acid neutralisation in the form of carbonates (e.g. dolomite, magnesite).
Mg_{KCl}	Magnesium soluble in 1 M KCl. It is a measure of the soluble and exchangeable magnesium.
Mg_P	Peroxide magnesium. Magnesium measured after peroxide oxidation, it includes soluble and exchangeable magnesium as well as magnesium dissolved by acid produced from oxidation of sulfides.
Monosulfides	The term given to highly reactive iron sulfide minerals found in ASS of approximate formula 'FeS' and are soluble in hydrochloric acid which distinguishes them from disulfides such as pyrite which are insoluble in hydrochloric acid.
MPA	Maximum Potential Acidity. A calculation where the total sulfur in the sample is assumed to all be present as pyrite. This value is multiplied by 30.6 to produce a value known as the Maximum Potential Acidity reported in units of kg H_2SO_4/t. MPA should include only the non-sulfate sulfur to avoid over-estimation of acid production in which case it may be

Term	Explanation
	referred to as AP.
NAF	Non Acid Forming
NAG	Net Acid Generation. A process where a sample is reacted with 15% hydrogen peroxide solution at pH = 4.5 to oxidise all sulfides and then time allowed for the solution to react with acid soluble materials. This is a direct measure of the acid generating capacity of the sample but can be affected by the presence of organic materials.
NAGpH	Net Acid Generation pH. The pH of the NAG test solution after oxidation.
NAPP	Net Acid Producing Potential. NAPP (kg H_2SO_4/t) = AP – ANC
Net acidity	Result obtained after accounting for all forms of soil acidity and neutralising capacity. Net acidity = Potential acidity + Existing acidity – (ANC/Fineness Factor)
PAF	Potentially Acid Forming.
PAF-HC	Potentially Acid Forming – High Capacity. Classification for samples with NAPP values greater than 10 kg H_2SO_4/t.
PAF-LC	Potentially Acid Forming – Low Capacity. Classification for samples with NAPP values less than or equal to 10 kg H_2SO_4/t.
pH_F	pH field of a 1:2 soil:water paste
pH_{FOX}	pH field after addition of a few drops of strong oxidant (hydrogen peroxide).
pH_{KCl}	pH in a 1M potassium chloride solution (laboratory measured).
pH_{OX}	pH in a peroxide oxidised suspension as per the SPOCAS method (laboratory measured).
Potential acidity	The latent acidity in ASS that can be generated if the sulfide minerals present are fully oxidised to generate sulfuric acid. It is estimated by measurement of S_{POS} (SPOCAS Suite) or SCR (Chromium Suite).
pyrite	Iron (II) sulfide, FeS_2. Pyrite is the most common sulfide minerals and the major acid forming mineral oxidising to produce sulfuric acid
Retained acidity	The less available fraction of existing acidity which is not measured as part of TAA and is due to hydrolysis of relatively insoluble minerals such alunite and jarosite.
Rutile	Titanium Dioxide (TiO_2)
SAR	Sodium Absorption Ratio.
S_{CR}	The symbol often given to the result for sulfur measured by the chromium reducible sulfur method i.e. CRS.
TAA	Titratable actual acidity. Used in both the SCR and SPOCAS suites; it determines the present soil acidity by titration with sodium hydroxide after extraction in potassium chloride up to pH 6.5.
Zircon	Zirconium Dioxide (ZrO_2). Often used to also describe Zirconium Silicate ($ZrSiO_4$)

APPENDICES

APPENDIX 1: COLLATED RESULTS

LIST OF APPENDIX TABLES

Table A1-1: Acid Base Accounting Residue Samples

Sample Number	Waste Type	Total S %	SO4_S* %	S_{CR} %	AP	ANC	NAPP	NAG	pH	NAG pH	pH_{OX}	Classification
					kg H_2SO_4/t	kg H2SO4/t	kg H2SO4/t	kg H2SO4/t	pH units			
MUP >2.0 mm Oversize	Residue	0.02	0.0001	N/A	0.6	N/A	N/A	N/A	6.2	N/A	4.8	NAF/Barren
MUP >5.0mm Oversize	Residue	0.02	0.0001	N/A	0.6	N/A	N/A	N/A	6.3	N/A	4.3	NAF/Barren
MSP Rejects	Residue	0.05	0.013	<0.02	1.5	3	-2	1	5.7	4.9	4.4	NAF/Barren
CUP MSP Tails	Residue	0.01	0.0011	N/A	0.3	N/A	N/A	N/A	6.5	N/A	4.1	NAF/Barren
WCP Tails	Residue	<0.01	0.0002	N/A	<0.3	N/A	N/A	N/A	6.3	N/A	4.4	NAF/Barren

** This is not a true Sulfate Sulfur measurement as data is provided from the ASLP extract data. The sulfate sulfur is known to be significantly underestimated by this method.*

N/A indicates not analysed (sulfur content insufficient for acid generation)

Table A1-2: Metals and Metalloids

Sample	Waste Type	Al	As	Ba	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn
		%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	mg/kg	mg/kg	mg/kg
MUP >2.0 mm Oversize	Residue	1.71	54	30	399	0.08	348	17	25	318	800	1400
MUP >5.0mm Oversize	Residue	1.37	58	26	168	0.04	227	2	23	239	300	1360
MSP Rejects	Residue	1.71	67	27	997	<0.02	431	4	22	159	1,800	1880
CUP MSP Tails	Residue	0.76	16	49	370	<0.02	72	6	5.2	199	800	441
WCP Tails	Residue	0.74	12	23	125	<0.02	60	3	5.0	165	200	392
Gypsum	Lime/Gypsum	1.28	15	33	240,000	0.16	97	48	6.7	853	21,800	397
2010 DER EIL		**N/G**	**20**	**300**	**N/G**	**3**	**400 Cr(III)**	**100**	**N/G**	**N/G**	**N/G**	**500**
Crustal Average		**8.2**	**25**	**425**	**4.1**	**0.2**	**100**	**55**	**4.1**	**2.1**	**2.3**	**950**

All units of measure are mg/kg unless otherwise specified

Table A1-2: Metals and Metalloids, continued

Sample	Waste Type	Mo	Na	Ni	Pb	Sb	Se	Sn	Th	U	V	Zn
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
MUP >2.0 mm Oversize	Residue	1.1	142	18	30.5	0.51	0.7	2.9	104	10.3	481	158
MUP >5.0mm Oversize	Residue	0.9	95	12	29	0.34	0.5	2.6	103	11.0	385	168
MSP Rejects	Residue	2.2	877	26	357	1.58	4	11.2	4.31	371	548	266
CUP MSP Tails	Residue	0.7	373	6	26.4	0.67	0.6	4.2	136	20.5	139	54
WCP Tails	Residue	0.3	60	5	14.3	0.23	<0.5	1.2	41	3.5	147	34
Gypsum	Lime/Gypsum	0.6	776	20	15.9	N/A	<0.5	1.7	261	11.9	152	118
2010 DER EIL		**40**	**N/G**	**60**	**600**	**N/G**	**N/G**	**50**	**N/G**	**N/G**	**50**	**200**
Crustal Average		**1.5**	**2.3**	**75**	**12.5**	**0.2**	**0.2**	**2**	**10**	**2.7**	**135**	**70**

All units of measure are mg/kg unless otherwise specified, N/A indicates not analysed

Table A1-3: Global Abundance Index (GAI)

Sample	Waste Type	Al	As	Ba	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn
MUP >2.0 mm Oversize	Residue	0	1	0	0	0	1	0	2	0	0	0
MUP >5.0mm Oversize	Residue	0	1	0	0	0	1	0	2	0	0	0
MSP Rejects	Residue	0	1	0	0	0	2	0	2	0	0	0
CUP MSP Tails	Residue	0	0	0	0	0	0	0	0	0	0	0
WCP Tails	Residue	0	0	0	0	0	0	0	0	0	0	0
Gypsum	Lime/Gypsum	0	0	0	2	0	0	0	0	0	0	0
Crustal Average (mg/kg)		**82,000**	**25**	**425**	**41,000**	**0.2**	**100**	**55**	**4.1**	**21000**	**23000**	**950**

Table A1-3: Global Abundance Index (GAI), continued

Sample	Waste Type	Mo	Na	Ni	Pb	Sb	Se	Sn	Th	U	V	Zn
MUP >2.0 mm Oversize	Residue	0	0	0	1	1	1	0	3	2	1	0
MUP >5.0mm Oversize	Residue	0	0	0	0	0	1	0	3	2	1	1
MSP Rejects	Residue	0	0	0	4	2	4	2	0	6	1	1
CUP MSP Tails	Residue	0	0	0	0	1	1	0	3	3	0	0
WCP Tails	Residue	0	0	0	0	0	1	0	1	0	0	0
Gypsum	Lime/Gypsum	0	0	0	0	N/A	1	0	4	2	0	0
Crustal Average (mg/kg)		**1.5**	**23,000**	**75**	**12.5**	**0.2**	**0.2**	**2**	**10**	**2.7**	**135**	**70**

Highlighted values of GAI greater than or equal to 3. N/A indicates not analysed

Table A1-4: ASLP Water Leachate (1:20), Major Ions

Sample	Waste Type	pH	EC	Ca	Mg	Na	K	Cl	SO$_4$	F	HCO$_3$	CO$_3$
			µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg CaCO$_3$/L	
MUP >2.0 mm Oversize	Residue	6.2	<10	0.12	0.09	0.6	<0.1	<2	0.2	<0.1	4	<1
MUP >5.0mm Oversize	Residue	6.3	<10	0.06	0.07	0.6	<0.1	<2	<0.2	<0.1	4	<1
MSP Rejects	Residue	5.7	60	4.7	2.0	1.5	<0.1	<2	19	<0.1	3	<1
CUP MSP Tails	Residue	6.5	14	0.94	0.48	0.7	0.1	3	1.6	<0.1	5	<1
WCP Tails	Residue	6.3	<10	0.29	0.15	0.5	0.2	<2	0.3	<0.1	4	<1
Gypsum	Lime/Gypsum	7.6	2436	687	49	32	3.6	46	1798	0.3	29	<1

Table A1-5: ASLP Water Leachate (1:20) Metals and Metalloids (mg/L)

Sample Number	Waste Type	Al	As	B	Ba	Cd	Cr	Cu	Fe	Mn	Mo
MUP >2.0 mm Oversize	Residue	<0.01	0.0002	<0.01	0.00076	<0.00002	<0.01	<0.01	<0.01	0.002	<0.00005
MUP >5.0mm Oversize	Residue	<0.01	0.0001	<0.01	0.00073	<0.00002	<0.01	<0.01	<0.01	0.002	<0.00005
MSP Rejects	Residue	<0.01	<0.0001	<0.01	0.041	<0.00002	0.02	<0.01	<0.01	0.005	<0.00005
CUP MSP Tails	Residue	0.79	0.0009	<0.01	0.0040	<0.00002	0.01	<0.01	2.01	0.008	0.00014
WCP Tails	Residue	0.16	0.0005	<0.01	0.0006	<0.00002	<0.01	<0.01	0.13	<0.001	<0.00005
Gypsum	Lime/Gypsum	0.05	0.0006	<0.01	0.0191	<0.00002	0.18	<0.01	0.01	0.018	0.0012
Freshwater		0.055	0.013	0.37	N/G	0.0002	0.01	0.0014	N/G	1.9	N/G
Livestock Drinking Water (Cattle)		5	0.5	5	N/G	0.01	1	1	N/G	N/G	0.15
Human Drinking Water		0.2	0.01	4	2	0.002	0.05	2	N/G	0.5	0.05

N/G = No Guideline

Table A1-5: ASLP Water Leachate (1:20) Metals and Metalloids (mg/L), continued (mg/L)

Sample Number	Lithology	Ni	Pb	Sb	Se	Sn	Th	U	V	Zn
MUP >2.0 mm Oversize	Residue	<0.01	<0.0005	<0.00001	<0.0005	0.0001	<0.000005	<0.000005	<0.01	<0.01
MUP >5.0mm Oversize	Residue	<0.01	<0.0005	<0.00001	<0.0005	0.0001	<0.000005	<0.000005	<0.01	<0.01
MSP Rejects	Residue	<0.01	0.0006	<0.00001	<0.0005	0.0001	<0.000005	<0.000005	<0.01	<0.01
CUP MSP Tails	Residue	<0.01	0.0017	0.00053	<0.0005	0.0002	0.0017	0.00009	0.01	<0.01
WCP Tails	Residue	<0.01	0.0042	<0.00001	<0.0005	0.0001	<0.000005	<0.000005	<0.01	<0.01
Gypsum	Lime/Gypsum	<0.01	<0.0005	0.00016	<0.0005	<0.0001	0.00024	0.00276	<0.01	<0.01
Freshwater		0.011	0.0034	N/A	0.005	N/G	N/G	N/G	N/G	0.008
Livestock Drinking Water (Cattle)		1	0.1	N/A	0.02	N/G	N/G	0.2	N/G	20
Human Drinking Water		0.02	0.01	0.003	0.01	N/G	N/G	0.017	N/G	N/G

N/G = No Guideline

Table A1-6: Dilute Acid (1:20 Acetic Acid, pH 2.9) Leachate, Major Ions

Sample	Waste Type	Na	K	Ca	Mg	SO_4
		mg/L	mg/L	mg/L	mg/L	mg/L
MUP >2.0 mm Oversize	Residue	0.6	0.2	1.12	0.72	<0.2
MUP >5.0mm Oversize	Residue	0.6	0.4	0.69	0.63	<0.2
MSP Rejects	Residue	1.9	0.4	7.16	2.51	3.9
CUP MSP Tails	Residue	0.8	0.2	2.49	0.9	0.4
WCP Tails	Residue	0.6	<0.1	1.1	0.5	0.2
Gypsum	Lime/Gypsum	32	5.7	2467	80	1023

Table A1-7: Dilute Acid Leachate (1:20 Acetic Acid, pH 2.9), Metals and Metalloids (mg/L)

Sample Number	Waste Type	Al	As	B	Ba	Cd	Cr	Cu	Fe	Mn	Mo
MUP >2.0 mm Oversize	Residue	1.87	<0.0001	<0.01	0.052	<0.00002	0.01	<0.01	0.51	0.036	<0.00005
MUP >5.0mm Oversize	Residue	3.5	0.0002	<0.01	0.05	0.00003	0.03	<0.01	0.85	0.058	<0.00005
MSP Rejects	Residue	4.22	0.0002	<0.01	0.48	0.00024	0.04	0.26	0.19	0.18	<0.00005
CUP MSP Tails	Residue	1.54	<0.0001	<0.01	0.13	0.00013	0.02	0.03	2.1	0.071	<0.00005
WCP Tails	Residue	2.56	<0.0001	<0.01	0.023	0.00006	<0.01	<0.01	0.36	0.026	<0.00005
Gypsum	Lime/Gypsum	<0.01	N/A	0.01	N/A	N/A	0.03	N/A	0.03	1.88	N/A
Freshwater		0.055	0.013	0.37	N/G	0.0002	0.01	0.0014	N/G	1.9	N/G
Livestock Drinking Water (Cattle)		5	0.5	5	N/G	0.01	1	1	N/G	N/G	0.15
Human Drinking Water		0.2	0.01	4	2	0.002	0.05	2	N/G	0.5	0.05

N/G = No Guideline, NA = Not Analysed

Table A1-7: Dilute Acid Leachate (1:20 Acetic Acid, pH 2.9), Metals and Metalloids (mg/L), continued (mg/L)

Sample Number	Lithology	Ni	Pb	Sb	Se	Sn	Th	U	V	Zn
MUP >2.0 mm Oversize	Residue	<0.01	0.0029	<0.00001	<0.0005	0.0001	0.0031	0.0036	<0.01	0.05
MUP >5.0mm Oversize	Residue	<0.01	0.0028	<0.00001	<0.0005	<0.0001	0.0050	0.0043	<0.01	0.09
MSP Rejects	Residue	0.03	0.0018	<0.00001	0.0026	0.0001	0.0054	0.017	<0.01	0.53
CUP MSP Tails	Residue	<0.01	0.0045	<0.00001	<0.0005	0.0001	0.0040	0.0047	<0.01	0.24
WCP Tails	Residue	<0.01	0.0026	<0.00001	<0.0005	<0.0001	0.0062	0.0019	<0.01	0.10
Gypsum	Lime/Gypsum	0.06	N/A	N/A	N/A	N/A	N/A	N/A	<0.01	0.01
Freshwater		0.011	0.0034	N/A	0.005	N/G	N/G	N/G	N/G	0.008
Livestock Drinking Water (Cattle)		1	0.1	N/A	0.02	N/G	N/G	0.2	N/G	20
Human Drinking Water		0.02	0.01	0.003	0.01	N/G	N/G	0.017	N/G	N/G

Table A1-8: Exchangeable Cations, Process Residues Samples

Sample	Ca	Mg	Na	K	ECEC	ESP
	centimoles (+)/kg					%
MSP Rejects	0.65	0.21	0.20	0.21	1.30	15.4
CUP MSP Tails	0.40	0.05	0.17	0.05	0.79	22.0
WCP Tails	0.22	0.11	0.05	0.11	0.43	12.6

APPENDIX 2: LABORATORY REPORTS

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Quantitative X-Ray Diffraction Analysis

REPORT PREPARED FOR	DR DAVE ALLEN SHEFFIELD RESOURCES LTD
CLIENT CODE	1628.0
JOB CODE	1603523
No. of SAMPLES	1
CLIENT O/N	SRWAS
SAMPLE SUBMISSION No.	N/A
PROJECT	THUDERBIRD MINERAL SANDS PROJECT
STATE	PULPS
DATE RECEIVED	4-Apr-16
DATE COMPLETED	13-Apr-16
DATE WRITTEN	13-Apr-16
WRITTEN BY	Dr Sharon Ness
ANALYSING LABORATORY	Perth

Sample Details

DISCLAIMER

This report relates specifically to the sample(s) that were drawn and/or provided by the client or their nominated third party. The reported results(s) provide no warranty or verification on the sample(s) representing any specific goods and/or shipment and only relate to the sample(s) as received and tested. This report is prepared solely for the use of the client named in this report. Intertek accepts no responsibility for any loss, damage or laibility suffered by a third party as a result of any reliance upon or use of this report.

The results provided are not intended for commercial settlement purposes.

SIGNIFICANT FIGURES

The method detection limit is 1 wt%.

Uncertainty in the analysis should reflect errors (absolute) of no greater than: +/- 10% for phases 50-95%, +/- 5% for phases 10-50% and +/- 2% for phases 3-10%. Phases of < 3% are approaching detection limit and normally no refinements are made on these.

Please note that results are rounded off to integer values

LEGEND

ND	Not Detected

Job Information

Preparation

XRD15 (dry 50C, mill < 60um, micronised)

Analytical Method

XRDQUANT01 - Quantitative analysis, crystalline and amorphous content

Sampling

Sample(s) coned and quartered, then grab(s) taken

Amorphous content determination

Internal standard single scan

Additions

Internal standard ZnO (zincite)

Method

Sample(s) packed and presented as unoriented powder mount(s) of the total sample

Job Information

Instrumentation and Parameters

Instrument:

PANalytical Cubix^3 XRD
Copper radiation (operating at 45 kV and 40 mA)
Graphite monochromator (diffracted beam)

Parameters:

Parameter	Setting
Start angle (deg 2θ)	4
End angle (deg 2θ)	65
Step size (deg 2θ)	0.02
Time/active length (secs)	150
Active length (deg 2θ)	4.01

Software

Qualitative analysis:	Bruker Diffrac.EVA 4.1 Search/Match ICDD PDF-2 (2011) database
Quantitative analysis:	SIROQUANT Version 4

Results

The quantitative analysis of the crystalline and amorphous content of the sample is given below.

Calculation of the phase abundances has been based on the Brindley contrast corrections using a particle diameter of 4 µm.

Sample ID **1145 Gypsum**

		original	duplicate
Phase	**Formula**	**wt%**	**wt%**
Amorphous content*		30	30
Bassanite	CaSO4.0.5H2O	7	7
Calcite	CaCO3	41	41
Dolomite	CaMg(CO3)2	10	10
Kaolin	Al2Si2O5(OH)4	<1	<1
Palygorskite**	Mg5(Si4O10)2(OH)2(H2O)8	9	9
Quartz	SiO2	2	2
Zircon	ZrSiO4	<1	<1

* see Note 1
** see Note 2

Notes

1

The amorphous content may contain some of the more poorly crystalline clay phases and conversely the clay phase content may contain some poorly crystalline or amorphous material. Where there is a significant presence of clay material, the distinction between poorly crystalline material and amorphous content can be imprecise.

2

For confirmation of the clay mineralogy, a clay separation followed by analysis of oriented clay mounts (glycol and heat treated) would be required.

Quality Control

NIST Standard Reference Material (SRM) 656

This standard is used for quality control on the instrument and software.

The standard reference material is a powder which consists of sub-micrometer, equi-axial, non-aggregated grains that do not display the effects of absorption contrast, extinction or preferred orientation.

An aliquot of this SRM, spiked with 10% Al_2O_3 (SRM 676a) for the amorphous content determination, was prepared as un-oriented powder mount of the total sample and the pattern analysed with SIROQUANT^{TM}

Sample ID **α 656 (High α Phase Powder)**

		1603523	method std dev	SRM certified	SRM uncert
Phase	**Formula**	**wt%**	**wt%**	**wt%**	**wt%**
Amorphous content		9.2	0.7	9.6	0.61
Si3N4, alpha	Si3N4	87.4	0.8	87.3	0.59
Si3N4, beta	Si3N4	3.4	0.2	3.1	0.05

Each interval defined by the certified value and its uncertainty is a 95% confidence interval for the true value of the mean in the absence of systematic error.

Method Description

Quantification is determined from the chosen software package: this uses the full-profile Rietveld method of refining the profile of the calculated XRD pattern against the profile of the measured XRD pattern. The total calculated pattern is the sum of the calculated patterns of the individual phases.

Results are given as weight % of the total crystalline phases and amorphous content.

The amorphous content quantifies the amorphous material and unknown minerals or known minerals for which there is not a suitable crystal structure.

Corrections are incorporated into the process that allows for a more accurate description of the mineral's contribution to the measured pattern and to allow for variation due to atomic substitution, layer disordering, preferred orientation, and other factors that affect the acquisition of the XRD scan.

The limitations of qualitative XRD analysis are as follows:

There is a limit of detection of approximately 1 wt% on the crystalline phases.

The detection of a phase may be dependent on its crystallinity.

Where there exist multiple phases, overlap of diffracted reflections can occur, thus rendering some ambiguity into the interpretation.

Overlapping reflections of a major phase can mask the presence of minor or trace phases.

Some phases cannot be unambiguously identified as they are present in minor or trace amounts.

The limitations of quantitative XRD analysis by a full-profile Rietveld method are as follows:

The limitations for qualitative XRD analysis apply

The method as described is standardless: it relies solely on the published crystallographic data available for each phase. Some data may not exactly describe the phases present.

Particle size is important with respect to the absorption of the X-rays by the sample. Micronising reduces the particle size to that more suitable for quantitative analysis.

The accuracy of the analysis is dependent on sampling and sample preparation in addition to the calculated profiles being exactly representative of the chemistry of the component phases and their crystallinity. Some preferred orientation effects and reflection overlaps may occur which cannot be adequately resolved.

Amorphous Content

Internal standard method

Single scan (SIROQUANT^{TM} and TOPAS)

The amorphous content is determined from the addition of a known spike of a well-crystalline internal standard to each sample.

When amorphous material is present, the weight percentage of the spike found is larger than actually weighed out. The amount of amorphous material that causes the difference in the spike weight percentages is then calculated and all weight percentages are normalised to include the amorphous content.

Double scan (SIROQUANT only)

SIROQUANT^{TM} also allows the choice of using the spiked pattern completely, or combining the run with a previous unspiked pattern result. This choice is given because the weight percentages from an unspiked pattern are more accurate since the intensities are not diluted by the spike addition. The percentages from the unspiked sample are normalised to the amorphous content calculated from the spiked sample pattern.

External standard method

The amorphous content is determined from the external standard method[1]

The normalisation constant is determined from the external standard which allows the calculated weight fractions to be placed on an absolute scale.

Reference:

1. O’Connor, B.H., and Raven, M.D., “Application of the Rietveld Refinement Procedure in Assaying Powdered Mixtures”, Powder Diffraction 3(1), (1988), 2-6.

Modelling of amorphous content

A pattern representing a poorly crystalline form of silica is used in the SIROQUANT program.[2]

Reference:

2. Ward, C.R. and French, D., "Determination of glass content and estimation of glass composition in fly ash using quantitative X-ray diffractometry." Fuel 85 (2006), 2268-2277.

XRD Analysis Standard Report Conditions

1. The work for and preparation of this report are governed by the Standard Report Conditions listed below and Intertek Minerals Terms and Conditions 2010, a copy of which is available online at www.intertek.com. The Standard Report Conditions also govern use and reproduction of this report and any extract of it. This endorsement highlights some of the Standard Report Conditions but does not override or vary them.

2. The analytical methods and procedures used in carrying out the work are summarised in the report. Any interpretations of data are also identified as such in the report. Intertek accepts no responsibility for any further or other interpretations. Any questions relating to the work or the report or about inferences to be drawn from them, should be referred to the author of the report.

3. The report must not be disseminated in any way which is likely to mislead or deceive any person, including by disseminating an extract of the report without including relevant qualifications contained in the report without limitation.

4. Subject to condition 17, the Client indemnifies Intertek against all Claims arising in any way of or in connection with:

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c) the use of any part of the Works or Report by any person other than the Client; and
d) any breach of any of these conditions by the client

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a) the supplying of services again; or
b) the cost of having those services supplied again.

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Intertek GENALYSIS LABORATORY SERVICES

ANALYTICAL REPORT

SHEFFIELD RESOURCES LTD
PO Box 205
WEST PERTH, W.A. 6872
AUSTRALIA

JOB INFORMATION

JOB CODE : 1628.0/1602467
No. of SAMPLES : 5
No. of ELEMENTS : 24
CLIENT O/N : SRWAS (Job 1 of 0)
SAMPLE SUBMISSION No. :
PROJECT : THUNDERBIRD MINERAL SANDS PR
STATE : Residue
DATE RECEIVED : 26/02/2016
DATE COMPLETED : 05/04/2016
DATE PRINTED : 05/04/2016
ANALYSING LABORATORY : Intertek Genalysis Perth

LEGEND

X = Less than Detection Limit
N/R = Sample Not Received
* = Result Checked
( ) = Result still to come
I/S = Insufficient Sample for Analysis
E6 = Result X 1,000,000
UA = Unable to Assay
> = Value beyond Limit of Method
OV = Value over-range for Package

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TOWNSVILLE LABORATORY

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SAMPLE DETAILS

DISCLAIMER

Intertek Genalysis wishes to make the following disclaimer pertaining to the accompanying analytical results.

All work is performed in accordance with the Intertek Minerals Standard Terms and Conditions of work http://www.intertek.com/terms/

This report relates specifically to the sample(s) that were drawn and/or provided by the client or their nominated third party. The reported result(s) provide no warranty or verification on the sample(s) representing any specific goods and/or shipment and only relate to the sample(s) as received and tested. This report was prepared solely for the use of the client named in this report. Intertek accepts no responsibility for any loss, damage or liability suffered by a third party as a result of any reliance upon or use of this report.

The results provided are not intended for commercial settlement purposes.

SIGNIFICANT FIGURES

It is common practice to report data derived from analytical instrumentation to a maximum of two or three significant figures. Some data reported herein may show more figures than this. The reporting of more than two or three figures in no way implies that the third, fourth and subsequent figures may be real or significant.

Intertek Genalysis accepts no responsibility whatsoever for any interpretation by any party of any data where more than two or three significant figures have been reported.

SAMPLE STORAGE DETAILS

GENERAL CONDITIONS

SAMPLE STORAGE OF SOLIDS

Bulk Residues and Pulps will be stored for 60 DAYS without charge. After this time all Bulk Residues and Pulps will be stored at a rate of $4.00 per cubic metre per day until your written advice regarding collection or disposal is received. Expenses related to the return or disposal of samples will be charged to you at cost. Current disposal cost is charged at $150.00 per cubic metre.

SAMPLE STORAGE OF SOLUTIONS

Samples received as liquids, waters or solutions will be held for 60 DAYS free of charge then disposed of, unless written advice for return or collection is received.

ANALYSIS

ELEMENTS	Al	As	Ba	Ca	Ca	Cd	Cr	Cu	Fe	K
UNITS	ppm	ppm	ppm	ppm	mg/Kg	ppm	ppm	ppm	%	ppm
DETECTION LIMIT	50	0.5	0.1	50	10	0.02	5	1	0.01	20
DIGEST	4A/	4A/	4A/	4A/	AmCl7/	4A/	4A/	4A/	4A/	4A/
ANALYTICAL FINISH	OE	MS	MS	OE	OE	MS	OE	OE	OE	OE
SAMPLE NUMBERS										
0001 SFX +2.0 mm Oversize	1.71%	53.9	29.7	399		0.08	348	17	25.20	318
0002 SFX +5.0 mm Oversize	1.37%	57.6	25.9	168		0.04	227	2	22.97	239
0003 SFX MSP Rejects	1.70%	67.1	26.9	997	130	X	431	4	21.59	159
0004 SFX CUP MSP Tails	7562	16.2	49.4	370	80	X	72	6	5.17	199
0005 SFX WCP Tails	7410	11.6	23.1	125	44	X	60	3	5.01	165
CHECKS										
0001 SFX CUP MSP Tails	7824	16.9	48.8	380		0.03	74	12	5.26	230
0002 SFX CUP MSP Tails					81					
STANDARDS										
0001 ASS1511-2					2595					
0002 OREAS 24b										
0003 OREAS 925	7.03%	10.3	425.7	4632		0.58	75	6123	6.87	2.35%
BLANKS										
0001 Control Blank					X					
0002 Control Blank	X	X	X	X		X	X	X	X	X

ANALYSIS

ELEMENTS	K	Mg	Mg	Mn	Mo	Na	Na	Ni	Pb	pH
UNITS	mg/Kg	ppm	mg/Kg	ppm	ppm	ppm	mg/Kg	ppm	ppm	NONE
DETECTION LIMIT	20	20	20	1	0.1	20	10	1	0.5	0.1
DIGEST	AmCl7/	4A/	AmCl7/	4A/	4A/	4A/	AmCl7/	4A/	4A/	pHox/
ANALYTICAL FINISH	OE	OE	OE	OE	MS	OE	OE	OE	MS	MTR
SAMPLE NUMBERS										
0001 SFX +2.0 mm Oversize		779		1405	1.1	142		18	30.5	4.8
0002 SFX +5.0 mm Oversize		335		1360	0.9	95		12	29.0	4.3
0003 SFX MSP Rejects	42	1763	48	1883	2.2	877	40	26	356.5	4.4
0004 SFX CUP MSP Tails	X	833	34	441	0.7	373	35	6	26.4	4.1
0005 SFX WCP Tails	22	170	X	392	0.3	60	11	5	14.3	4.4
CHECKS										
0001 SFX CUP MSP Tails		894		444	0.7	385		5	26.1	4.1
0002 SFX CUP MSP Tails	30		34				20			
STANDARDS										
0001 ASS1511-2	127		1049				176			
0002 OREAS 24b										
0003 OREAS 925		1.75%		1022	1.0	2754		34	109.6	
BLANKS										
0001 Control Blank	X		X				X			
0002 Control Blank		X		17	X	X		X	X	3.1

ANALYSIS

ELEMENTS	S	S	Sb	Se	Sn	Th	U	V	Zn
UNITS	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
DETECTION LIMIT	50	0.01	0.05	0.5	0.1	0.01	0.01	1	1
DIGEST	4A/		4A/	4A/	4A/	4A/	4A/	4A/	4A/
ANALYTICAL FINISH	OE	/CSA	MS	MS	MS	MS	MS	OE	OE
SAMPLE NUMBERS									
0001 SFX +2.0 mm Oversize	189	0.02	0.51	0.7	2.9	103.68	10.33	481	158
0002 SFX +5.0 mm Oversize	207	0.02	0.34	0.5	2.6	103.18	10.99	385	168
0003 SFX MSP Rejects	439	0.05	1.58	4.0	11.2	4.31	371.07	548	266
0004 SFX CUP MSP Tails	75	0.01	0.67	0.6	4.2	135.87	20.52	139	54
0005 SFX WCP Tails	X	X	0.23	X	1.2	41.08	3.47	147	34
CHECKS									
0001 SFX CUP MSP Tails	85	0.01	0.65	0.5	4.2	128.75	20.17	146	56
0002 SFX CUP MSP Tails									
STANDARDS									
0001 ASS1511-2									
0002 OREAS 24b		0.21							
0003 OREAS 925	9912		1.37	9.3	15.1	15.97	2.97	89	439
BLANKS									
0001 Control Blank									
0002 Control Blank	X	X	X	X	X	X	X	X	X

METHOD CODE DESCRIPTION

Method Code	Analysing Laboratory **NATA Laboratory Accreditation**	**NATA Scope of Accreditation**
/CSA	Intertek Genalysis Perth **3244 3237**	**MPL_W043, CSA : MPL_W043**
Induction Furnace Analysed by Infrared Spectrometry		
4A/MS	Intertek Genalysis Perth **3244 3237**	**4A/ : MPL_W002, MS : ICP_W003**
Multi-acid digest including Hydrofluoric, Nitric, Perchloric and Hydrochloric acids in Teflon Tubes. Analysed by Inductively Coupled Plasma Mass Spectrometry.		
4A/OE	Intertek Genalysis Perth **3244 3237**	**4A/ : MPL_W002, OE : ICP_W004**
Multi-acid digest including Hydrofluoric, Nitric, Perchloric and Hydrochloric acids in Teflon Tubes. Analysed by Inductively Coupled Plasma Optical (Atomic) Emission Spectrometry.		
AmCl7/OE	Intertek Genalysis Perth **3244 3237**	
Extraction with 1M NH4Cl. Analysed by Inductively Coupled Plasma Optical (Atomic) Emission Spectrometry.		
pHox/MTR	Intertek Genalysis Perth **3244 3237**	
Oxidised pH. Analysed with Electronic Meter Measurement		

ANALYTICAL REPORT

SHEFFIELD RESOURCES LTD
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AUSTRALIA

JOB INFORMATION

JOB CODE	:	1628.0/1603315
No. of SAMPLES	:	10
No. of ELEMENTS	:	32
CLIENT O/N	:	SRWAS (Job 1 of 1)
SAMPLE SUBMISSION No.	:	
PROJECT	:	THUNDERBIRD MINERAL SANDS PR
STATE	:	Ex-Pulp
DATE RECEIVED	:	26/02/2016
DATE COMPLETED	:	18/04/2016
DATE PRINTED	:	18/04/2016
ANALYSING LABORATORY	:	Intertek Genalysis Perth

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SAMPLE STORAGE OF SOLUTIONS

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ANALYSIS

ELEMENTS	Al	As	B	Ba	CO3	Ca
UNITS	mg/l	ug/l	mg/l	ug/l	mgCaCO3/L	mg/l
DETECTION LIMIT	0.01	0.1	0.01	0.05	1	0.01
DIGEST	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/
ANALYTICAL FINISH	OE	MS	OE	MS	VOL	OE
SAMPLE NUMBERS						
0001 SFX +2.0 mm Oversize natural pH	X	0.2	X	0.76	X	0.12
0002 SFX +5.0 mm Oversize natural pH	X	0.1	X	0.73	X	0.06
0003 SFX MSP Rejects natural pH	X	X	X	40.88	X	4.67
0004 SFX CUP MSP Tails natural pH	0.79	0.9	X	3.96	X	0.94
0005 SFX WCP Tails natural pH	0.16	0.5	X	0.60	X	0.29
0006 SFX +2.0 mm Oversize pH 2.9	1.87	X	X	52.25		1.12
0007 SFX +5.0 mm Oversize pH 2.9	3.50	0.2	X	50.04		0.69
0008 SFX MSP Rejects pH 2.9	4.22	0.2	X	482.81		7.16
0009 SFX CUP MSP Tails pH 2.9	1.54	X	X	128.78		2.49
0010 SFX WCP Tails pH 2.9	2.56	X	X	23.37		1.10
CHECKS						
0001 SFX +2.0 mm Oversize natural pH	X	0.2	X	1.09	X	0.15
BLANKS						
0001 Control Blank	X	X	X	X	X	X
0002 Control Blank	X	X	X	0.49	X	0.04
0003 Control Blank	X	X	X	X		X

ANALYSIS

ELEMENTS	Cd	Cl	Cr	Cu	EC	F
UNITS	ug/l	mg/l	mg/l	mg/l	uS/cm	mg/L
DETECTION LIMIT	0.02	2	0.01	0.01	10	0.1
DIGEST	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/
ANALYTICAL FINISH	MS	COL	OE	OE	MTR	SIE
SAMPLE NUMBERS						
0001 SFX +2.0 mm Oversize natural pH	X	X	X	X	X	X
0002 SFX +5.0 mm Oversize natural pH	X	X	X	X	X	X
0003 SFX MSP Rejects natural pH	X	X	0.02	X	60	X
0004 SFX CUP MSP Tails natural pH	X	3	0.01	X	14	X
0005 SFX WCP Tails natural pH	X	X	X	X	X	X
0006 SFX +2.0 mm Oversize pH 2.9	X		0.01	X		
0007 SFX +5.0 mm Oversize pH 2.9	0.03		0.03	X		
0008 SFX MSP Rejects pH 2.9	0.24		0.04	0.26		
0009 SFX CUP MSP Tails pH 2.9	0.13		0.02	0.03		
0010 SFX WCP Tails pH 2.9	0.06		X	X		
CHECKS						
0001 SFX +2.0 mm Oversize natural pH	X	X	X	X	X	X
BLANKS						
0001 Control Blank	X	X	X	X	X	X
0002 Control Blank	X	143	X	X		
0003 Control Blank	X		X	X		

ANALYSIS

ELEMENTS	Fe	HCO3	K	Mg	Mn	Mo
UNITS	mg/l	mgCaCO3/L	mg/l	mg/l	mg/l	ug/l
DETECTION LIMIT	0.01	2	0.1	0.01	0.001	0.05
DIGEST	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/
ANALYTICAL FINISH	OE	VOL	OE	OE	OE	MS
SAMPLE NUMBERS						
0001 SFX +2.0 mm Oversize natural pH	X	4	X	0.09	0.002	X
0002 SFX +5.0 mm Oversize natural pH	X	4	X	0.07	0.002	X
0003 SFX MSP Rejects natural pH	X	3	X	1.96	0.005	X
0004 SFX CUP MSP Tails natural pH	2.01	5	0.1	0.48	0.008	0.14
0005 SFX WCP Tails natural pH	0.13	4	0.2	0.15	X	X
0006 SFX +2.0 mm Oversize pH 2.9	0.51		0.2	0.72	0.036	X
0007 SFX +5.0 mm Oversize pH 2.9	0.85		0.4	0.63	0.058	X
0008 SFX MSP Rejects pH 2.9	0.19		0.4	2.51	0.177	X
0009 SFX CUP MSP Tails pH 2.9	0.21		0.2	0.90	0.071	X
0010 SFX WCP Tails pH 2.9	0.36		X	0.50	0.026	X

CHECKS						
0001 SFX +2.0 mm Oversize natural pH	X	4	X	0.11	0.003	X

BLANKS						
0001 Control Blank	X	X	0.1	X	X	X
0002 Control Blank	X	94	X	X	X	X
0003 Control Blank	X		X	X	0.001	X

ANALYSIS

ELEMENTS	Na	Ni	OH	Pb	pH	S
UNITS	mg/l	mg/l	mgCaCO3/L	ug/l	NONE	mg/l
DETECTION LIMIT	0.1	0.01	5	0.5	0.1	0.05
DIGEST	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/
ANALYTICAL FINISH	OE	OE	VOL	MS	MTR	OE
SAMPLE NUMBERS						
0001 SFX +2.0 mm Oversize natural pH	0.6	X	X	X	6.2	0.06
0002 SFX +5.0 mm Oversize natural pH	0.6	X	X	X	6.3	X
0003 SFX MSP Rejects natural pH	1.5	X	X	0.6	5.7	6.44
0004 SFX CUP MSP Tails natural pH	0.7	X	X	1.7	6.5	0.54
0005 SFX WCP Tails natural pH	0.5	X	X	4.2	6.3	0.10
0006 SFX +2.0 mm Oversize pH 2.9	0.6	X		2.9		X
0007 SFX +5.0 mm Oversize pH 2.9	0.6	X		2.8		X
0008 SFX MSP Rejects pH 2.9	1.9	0.03		1.8		1.30
0009 SFX CUP MSP Tails pH 2.9	0.8	X		4.5		0.14
0010 SFX WCP Tails pH 2.9	0.6	X		2.6		0.05
CHECKS						
0001 SFX +2.0 mm Oversize natural pH	0.6	X	X	X	6.8	0.08
BLANKS						
0001 Control Blank	X	X	X	X		X
0002 Control Blank	X	X	X	1.8		0.05
0003 Control Blank	X	X		X		X

ANALYSIS

ELEMENTS	SO4	Sb	Se	Sn	Th	U
UNITS	mg/l	ug/l	ug/l	ug/l	ug/l	ug/l
DETECTION LIMIT	0.2	0.01	0.5	0.1	0.005	0.005
DIGEST		ASLP/	ASLP/	ASLP/	ASLP/	ASLP/
ANALYTICAL FINISH	/CALC	MS	MS	MS	MS	MS
SAMPLE NUMBERS						
0001 SFX +2.0 mm Oversize natural pH	0.2	X	X	0.1	X	X
0002 SFX +5.0 mm Oversize natural pH	X	X	X	0.1	X	X
0003 SFX MSP Rejects natural pH	19.3	X	X	0.1	X	X
0004 SFX CUP MSP Tails natural pH	1.6	0.53	X	0.2	1.746	0.090
0005 SFX WCP Tails natural pH	0.3	X	X	0.1	X	X
0006 SFX +2.0 mm Oversize pH 2.9	X	X	X	0.1	3.059	3.579
0007 SFX +5.0 mm Oversize pH 2.9	X	X	X	X	4.957	4.302
0008 SFX MSP Rejects pH 2.9	3.9	X	2.6	0.1	5.361	16.818
0009 SFX CUP MSP Tails pH 2.9	0.4	X	X	0.1	4.017	4.681
0010 SFX WCP Tails pH 2.9	0.2	X	X	X	6.239	1.858
CHECKS						
0001 SFX +2.0 mm Oversize natural pH	0.2	X	X	X	X	X
BLANKS						
0001 Control Blank	X	X	X	X	X	X
0002 Control Blank	0.2	X	X	0.1	X	X
0003 Control Blank	X	X	X	X	X	X

ANALYSIS

ELEMENTS	V	Zn
UNITS	mg/l	mg/l
DETECTION LIMIT	0.01	0.01
DIGEST	ASLP/	ASLP/
ANALYTICAL FINISH	OE	OE
SAMPLE NUMBERS		
0001 SFX +2.0 mm Oversize natural pH	X	X
0002 SFX +5.0 mm Oversize natural pH	X	X
0003 SFX MSP Rejects natural pH	X	X
0004 SFX CUP MSP Tails natural pH	0.01	X
0005 SFX WCP Tails natural pH	X	X
0006 SFX +2.0 mm Oversize pH 2.9	X	0.05
0007 SFX +5.0 mm Oversize pH 2.9	X	0.09
0008 SFX MSP Rejects pH 2.9	X	0.53
0009 SFX CUP MSP Tails pH 2.9	X	0.24
0010 SFX WCP Tails pH 2.9	X	0.10
CHECKS		
0001 SFX +2.0 mm Oversize natural pH	X	X
BLANKS		
0001 Control Blank	X	X
0002 Control Blank	X	X
0003 Control Blank	X	X

METHOD CODE DESCRIPTION

Method Code	Analysing Laboratory **NATA Laboratory Accreditation**	**NATA Scope of Accreditation**	
/CALC	Intertek Genalysis Perth **3244 3237**		No digestion or other pre-treatment undertaken. Results Determined by calculation from other reported data.
ASLP/COL	Intertek Genalysis Perth **3244 3237**		AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils. Analysed by UV-Visible Spectrometry.
ASLP/MS	Intertek Genalysis Perth **3244 3237**	**ASLP/ : ENV_W037, MS : ICP_W003**	AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils. Analysed by Inductively Coupled Plasma Mass Spectrometry.
ASLP/MTR	Intertek Genalysis Perth **3244 3237**		AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils. Analysed with Electronic Meter Measurement
ASLP/OE	Intertek Genalysis Perth **3244 3237**	**ASLP/ : ENV_W037, OE : ICP_W004**	AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils. Analysed by Inductively Coupled Plasma Optical (Atomic) Emission Spectrometry.
ASLP/SIE	Intertek Genalysis Perth **3244 3237**		AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils. Analysed by Specific Ion Electrode.
ASLP/VOL	Intertek Genalysis Perth **3244 3237**		AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils. Analysed by Volumetric Technique.

ANALYTICAL REPORT

SHEFFIELD RESOURCES LTD
PO Box 205
WEST PERTH, W.A. 6872
AUSTRALIA

JOB INFORMATION

JOB CODE : 1628.0/1603913
No. of SAMPLES : 1
No. of ELEMENTS : 22
CLIENT O/N : SRWAS (Job 1 of 0)
SAMPLE SUBMISSION No. :
PROJECT : THUNDERBIRD MINERAL SANDS PR
STATE : Ex-Pulp
DATE RECEIVED : 17/03/2016
DATE COMPLETED : 14/04/2016
DATE PRINTED : 14/04/2016
ANALYSING LABORATORY : Intertek Genalysis Perth

LEGEND

X = Less than Detection Limit
N/R = Sample Not Received
* = Result Checked
( ) = Result still to come
I/S = Insufficient Sample for Analysis
E6 = Result X 1,000,000
UA = Unable to Assay
> = Value beyond Limit of Method
OV = Value over-range for Package

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15 Davison Street, Maddington 6109, Western Australia
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KALGOORLIE SAMPLE PREPARATION DIVISION

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Tel: +61 8 8162 9714 Fax: +61 8 8349 7444

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TOWNSVILLE LABORATORY

9-23 Kelli Street, Mt St John, Bohle, Queensland, Australia 4818
Tel: +61 7 4774 3655 Fax: +61 7 4774 4692

SAMPLE DETAILS

DISCLAIMER

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SAMPLE STORAGE DETAILS

GENERAL CONDITIONS

SAMPLE STORAGE OF SOLIDS

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SAMPLE STORAGE OF SOLUTIONS

Samples received as liquids, waters or solutions will be held for 60 DAYS free of charge then disposed of, unless written advice for return or collection is received.

ANALYSIS

ELEMENTS	Al	As	Ba	Ca	Cd	Cr	Cu	Fe	K	Mg
UNITS	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm
DETECTION LIMIT	50	0.5	0.1	50	0.02	5	1	0.01	20	20
DIGEST	4A/	4A/	4A/	4A/	4A/	4A/	4A/	4A/	4A/	4A/
ANALYTICAL FINISH	OE	MS	MS	OE	MS	OE	OE	OE	OE	OE
SAMPLE NUMBERS										
0001 1145 Gypsum	1.28%	14.9	33.2	24.01%	0.16*	97	48	6.67	853	2.18%
CHECKS										
0001 1145 Gypsum	1.30%	15.8	33.7	23.44%	0.18	89	59	6.58	974	2.14%
STANDARDS										
0001 OREAS 72a										
0002 OREAS 928	6.05%	9.3	303.3	4485	0.56	55	1.48%	9.06	1.81%	1.66%
BLANKS										
0001 Control Blank	X	X	X	X	X	X	X	X	X	X

ANALYSIS

ELEMENTS	Mn	Mo	Na	Ni	Pb	S	Se	Sn	Th	U
UNITS	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm
DETECTION LIMIT	1	0.1	20	1	0.5	0.01	0.5	0.1	0.01	0.01
DIGEST	4A/	4A/	4A/	4A/	4A/		4A/	4A/	4A/	4A/
ANALYTICAL FINISH	OE	MS	OE	OE	MS	/CSA	MS	MS	MS	MS
SAMPLE NUMBERS										
0001 1145 Gypsum	397	0.6	776	20	15.9	1.75	X	1.7	261.00	11.87
CHECKS										
0001 1145 Gypsum	395	0.6	755	19	16.9	1.75	X	1.8	270.45	12.37
STANDARDS										
0001 OREAS 72a						1.70				
0002 OREAS 928	1029	1.2	1760	28	121.3		18.7	26.0	13.07	2.40
BLANKS										
0001 Control Blank	4	X	X	X	X	X	X	X	X	X

ANALYSIS

ELEMENTS	V	Zn
UNITS	ppm	ppm
DETECTION LIMIT	1	1
DIGEST	4A/	4A/
ANALYTICAL FINISH	OE	OE
SAMPLE NUMBERS		
0001 1145 Gypsum	152	118
CHECKS		
0001 1145 Gypsum	150	123
STANDARDS		
0001 OREAS 72a		
0002 OREAS 928	73	417
BLANKS		
0001 Control Blank	X	X

METHOD CODE DESCRIPTION

Method Code	Analysing Laboratory **NATA Laboratory Accreditation**	**NATA Scope of Accreditation**
/CSA	Intertek Genalysis Perth **3244 3237**	**MPL_W043, CSA : MPL_W043**
Induction Furnace Analysed by Infrared Spectrometry		
4A/MS	Intertek Genalysis Perth **3244 3237**	**4A/ : MPL_W002, MS : ICP_W003**
Multi-acid digest including Hydrofluoric, Nitric, Perchloric and Hydrochloric acids in Teflon Tubes. Analysed by Inductively Coupled Plasma Mass Spectrometry.		
4A/OE	Intertek Genalysis Perth **3244 3237**	**4A/ : MPL_W002, OE : ICP_W004**
Multi-acid digest including Hydrofluoric, Nitric, Perchloric and Hydrochloric acids in Teflon Tubes. Analysed by Inductively Coupled Plasma Optical (Atomic) Emission Spectrometry.		

ANALYTICAL REPORT

SHEFFIELD RESOURCES LTD
PO Box 205
WEST PERTH, W.A. 6872
AUSTRALIA

JOB INFORMATION

JOB CODE : 1628.0/1604166
No. of SAMPLES : 2
No. of ELEMENTS : 32
CLIENT O/N : SRWAS (Job 1 of 0)
SAMPLE SUBMISSION No. :
PROJECT : THUNDERBIRD MINERAL SANDS PR
STATE : Pulp
DATE RECEIVED : 05/04/2016
DATE COMPLETED : 30/04/2016
DATE PRINTED : 30/04/2016
ANALYSING LABORATORY : Intertek Genalysis Perth

LEGEND

X = Less than Detection Limit
N/R = Sample Not Received
* = Result Checked
( ) = Result still to come
I/S = Insufficient Sample for Analysis
E6 = Result X 1,000,000
UA = Unable to Assay
> = Value beyond Limit of Method
OV = Value over-range for Package

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9-23 Kelli Street, Mt St John, Bohle, Queensland, Australia 4818
Tel: +61 7 4774 3655 Fax: +61 7 4774 4692

SAMPLE DETAILS

DISCLAIMER

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SAMPLE STORAGE DETAILS

GENERAL CONDITIONS

SAMPLE STORAGE OF SOLIDS

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SAMPLE STORAGE OF SOLUTIONS

Samples received as liquids, waters or solutions will be held for 60 DAYS free of charge then disposed of, unless written advice for return or collection is received.

ANALYSIS

ELEMENTS	Al	As	B	Ba	CO3	Ca	Cd	Cl	Cr	Cu
UNITS	mg/l	ug/l	mg/l	ug/l	gCaCO3/L	mg/l	ug/l	mg/l	mg/l	mg/l
DETECTION LIMIT	0.01	0.1	0.01	0.05	1	0.01	0.02	2	0.01	0.01
DIGEST	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/
ANALYTICAL FINISH	OE	MS	OE	MS	VOL	OE	MS	COL	OE	OE
SAMPLE NUMBERS										
0001 1145 Gypsum natural pH	0.05	0.6	X	19.09	X	687.20	X	46	0.18	X
0002 1145 Gypsum pH 2.9	X		0.01			2466.90			0.03	X
CHECKS										
0001 1145 Gypsum natural pH	0.05	0.8	X	18.79	X	654.23	X	44	0.18	X
STANDARDS										
0001 N191								102		
BLANKS										
0001 Control Blank	X	X	X	X	X	X	X	X	X	X

ANALYSIS

ELEMENTS	EC	F	Fe-Sol	HCO3	K	Mg	Mn	Mo	Na	Ni
UNITS	uS/cm	mg/L	mg/l	ʒCaCO3/L	mg/l	mg/l	mg/l	ug/l	mg/l	mg/l
DETECTION LIMIT	10	0.1	0.01	2	0.1	0.01	0.001	0.05	0.1	0.01
DIGEST	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/	ASLP/
ANALYTICAL FINISH	MTR	SIE	OE	VOL	OE	OE	OE	MS	OE	OE
SAMPLE NUMBERS										
0001 1145 Gypsum natural pH	2436	0.3	0.01	29	3.6	48.90	0.018	1.24	32.0	X
0002 1145 Gypsum pH 2.9			0.03		5.7	79.87	1.876		32.0	0.06
CHECKS										
0001 1145 Gypsum natural pH	2433	0.3	0.02	30	3.6	48.90	0.015	1.17	31.6	X
STANDARDS										
0001 N191										
BLANKS										
0001 Control Blank	X	X	X	X	X	X	X	X	X	X

ANALYSIS

ELEMENTS	OH	Pb	pH	S	SO4	Sb	Se	Sn	Th	U
UNITS	ɡCaCO3/L	ug/l	NONE	mg/l	mg/l	ug/l	ug/l	ug/l	ug/l	ug/l
DETECTION LIMIT	5	0.5	0.1	0.05	0.2	0.01	0.5	0.1	0.005	0.005
DIGEST	ASLP/	ASLP/	ASLP/	ASLP/		ASLP/	ASLP/	ASLP/	ASLP/	ASLP/
ANALYTICAL FINISH	VOL	MS	MTR	OE	/CALC	MS	MS	MS	MS	MS
SAMPLE NUMBERS										
0001 1145 Gypsum natural pH	X	X	7.6	600.21	1798.1	0.16	X	X	0.241	2.759
0002 1145 Gypsum pH 2.9				341.34	1022.6					
CHECKS										
0001 1145 Gypsum natural pH	X	X	7.5	625.56	1874.0	0.17	X	X	0.213	2.869
STANDARDS										
0001 N191										
BLANKS										
0001 Control Blank	X	X		X	X	X	X	X	X	X

ANALYSIS

ELEMENTS	V	Zn
UNITS	mg/l	mg/l
DETECTION LIMIT	0.01	0.01
DIGEST	ASLP/	ASLP/
ANALYTICAL FINISH	OE	OE
SAMPLE NUMBERS		
0001 1145 Gypsum natural pH	X	X
0002 1145 Gypsum pH 2.9	X	0.01
CHECKS		
0001 1145 Gypsum natural pH	X	X
STANDARDS		
0001 N191		
BLANKS		
0001 Control Blank	X	X

METHOD CODE DESCRIPTION

Method Code	Analysing Laboratory NATA Laboratory Accreditation	NATA Scope of Accreditation
/CALC	Intertek Genalysis Perth **3244 3237**	

No digestion or other pre-treatment undertaken. Results Determined by calculation from other reported data.

ASLP/COL	Intertek Genalysis Perth **3244 3237**	

AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils.
Analysed by UV-Visible Spectrometry.

ASLP/MS	Intertek Genalysis Perth **3244 3237**	**ASLP/ : ENV_W037, MS : ICP_W003**

AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils.
Analysed by Inductively Coupled Plasma Mass Spectrometry.

ASLP/MTR	Intertek Genalysis Perth **3244 3237**	

AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils.
Analysed with Electronic Meter Measurement

ASLP/OE	Intertek Genalysis Perth **3244 3237**	**ASLP/ : ENV_W037, OE : ICP_W004**

AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils.
Analysed by Inductively Coupled Plasma Optical (Atomic) Emission Spectrometry.

ASLP/SIE	Intertek Genalysis Perth **3244 3237**	

AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils.
Analysed by Specific Ion Electrode.

ASLP/VOL	Intertek Genalysis Perth **3244 3237**	

AS4439.3-1997: Australian Standard Leachates Protocol for Wastes, Sediments & Contaminated Soils.
Analysed by Volumetric Technique.

ANALYTICAL REPORT

SHEFFIELD RESOURCES LTD
PO Box 205
WEST PERTH, W.A. 6872
AUSTRALIA

JOB INFORMATION

JOB CODE : 1628.0/1604260
No. of SAMPLES : 1
No. of ELEMENTS : 8
CLIENT O/N : SRWAS (Job 1 of 1)
SAMPLE SUBMISSION No. :
PROJECT : THUNDERBIRD MINERAL SANDS PR
STATE : Ex-Pulp
DATE RECEIVED : 05/04/2016
DATE COMPLETED : 26/05/2016
DATE PRINTED : 26/05/2016
ANALYSING LABORATORY : Intertek Genalysis Perth

LEGEND

X = Less than Detection Limit
N/R = Sample Not Received
* = Result Checked
( ) = Result still to come
I/S = Insufficient Sample for Analysis
E6 = Result X 1,000,000
UA = Unable to Assay
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SAMPLE DETAILS

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SAMPLE STORAGE DETAILS

GENERAL CONDITIONS

SAMPLE STORAGE OF SOLIDS

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SAMPLE STORAGE OF SOLUTIONS

Samples received as liquids, waters or solutions will be held for 60 DAYS free of charge then disposed of, unless written advice for return or collection is received.

ANALYSIS

ELEMENTS	ANC	ColourChange	Final-pH	Fizz-Rate	NAG	NAGpH
UNITS	kgH2SO4/t	NONE	NONE	NONE	kgH2SO4/t	NONE
DETECTION LIMIT	1	0	0.1	0	1	0.1
DIGEST	ANCx/	ANCx/	ANCx/	ANCx/	NAGx/	NAGx/
ANALYTICAL FINISH	VOL	QUAL	MTR	QUAL	VOL	MTR
SAMPLE NUMBERS						
0001 SFX MSP Rejects	3	No	1.6	0.0000000	1	4.9
CHECKS						
0001 SFX MSP Rejects	2	No	1.6	0.0000000	1	4.9
BLANKS						
0001 Control Blank	0		1.5		6	4.5

ANALYSIS

ELEMENTS	NAG(4.5)	S
UNITS	kgH2SO4/t	%
DETECTION LIMIT	1	0.02
DIGEST	NAGx/	SCR/
ANALYTICAL FINISH	VOL	VOL
SAMPLE NUMBERS		
0001 SFX MSP Rejects	0	X

CHECKS		
0001 SFX MSP Rejects	0	

BLANKS		
0001 Control Blank	0	

METHOD CODE DESCRIPTION

Method Code Analysing Laboratory **NATA Scope of Accreditation**
NATA Laboratory Accreditation

ANCx/MTR Intertek Genalysis Perth
3244 3237

Acid Neutralizing Capacity Digestion Procedure. Analysed with Electronic Meter Measurement

ANCx/QUAL Intertek Genalysis Perth
3244 3237

Acid Neutralizing Capacity Digestion Procedure. Analysed by Qualitative Inspection

ANCx/VOL Intertek Genalysis Perth
3244 3237

Acid Neutralizing Capacity Digestion Procedure. Analysed by Volumetric Technique.

NAGx/MTR Intertek Genalysis Perth
3244 3237

Net Acid Generation Extraction of samples with H2O2 Analysed with Electronic Meter Measurement

NAGx/VOL Intertek Genalysis Perth
3244 3237

Net Acid Generation Extraction of samples with H2O2 Analysed by Volumetric Technique.

SCR/VOL Intertek Genalysis Perth
3244 3237

Chromium Reducible Suplhur Analysed by Volumetric Technique.

Intertek

Beckman Coulter LS Particle Size Analyzer

4 Apr 2016 13:22

1628.0/1602467

File name:	C:\LS13320\Samples\1628.01602467_03_01.$ls 1628.01602467_03_01.$ls
File ID:	1628.0/1602467
Sample ID:	SFX CUP MSP Tails
Comment 1:	Alexis
Optical model:	RI18PS100.rf780z
Start time:	11:43 4 Apr 2016

Volume Statistics (Arithmetic) 1628.01602467_03_01.$ls

Calculations from 0.375 µm to 2000 µm

Volume:	100%
Mean:	10.37 µm
Median:	4.762 µm

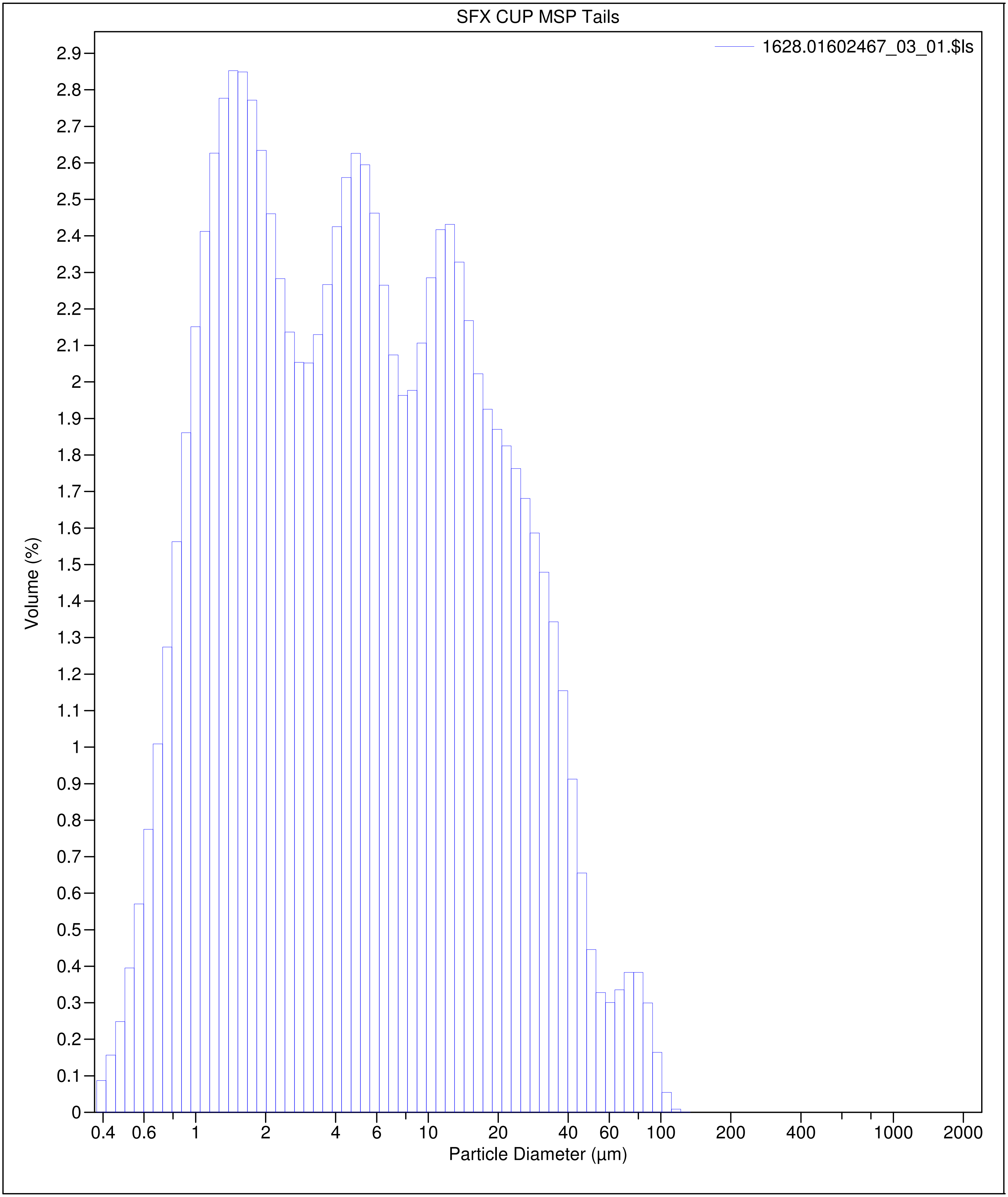
d_{10}: 1.043 µm d_{50}: 4.762 µm d_{90}: 27.15 µm

-45 µm	-63 µm	-75 µm	-90 µm	-100 µm	-106 µm	-150 µm
96.8%	98.3%	99.0%	99.7%	99.9%	99.96%	100%
+45 µm	+63 µm	+75 µm	+90 µm	+100 µm	+16 µm	+150 µm
3.15%	1.65%	0.99%	0.30%	0.084%	20.5%	0%

Beckman Coulter LS Particle Size Analyzer

4 Apr 2016 13:22

1628.0/1602467



Beckman Coulter LS Particle Size Analyzer

4 Apr 2016 13:22

1628.0/1602467

File name:	C:\LS13320\Samples\1628.01602467_02_01.$ls 1628.01602467_02_01.$ls
File ID:	1628.0/1602467
Sample ID:	SFX MSP Rejects
Comment 1:	Alexis
Optical model:	RI18PS100.rf780z
Start time:	11:39 4 Apr 2016

Volume Statistics (Arithmetic) 1628.01602467_02_01.$ls

Calculations from 0.375 µm to 2000 µm

Volume:	100%
Mean:	25.58 µm
Median:	10.97 µm

d_{10}: 0.965 µm d_{50}: 10.97 µm d_{90}: 72.17 µm

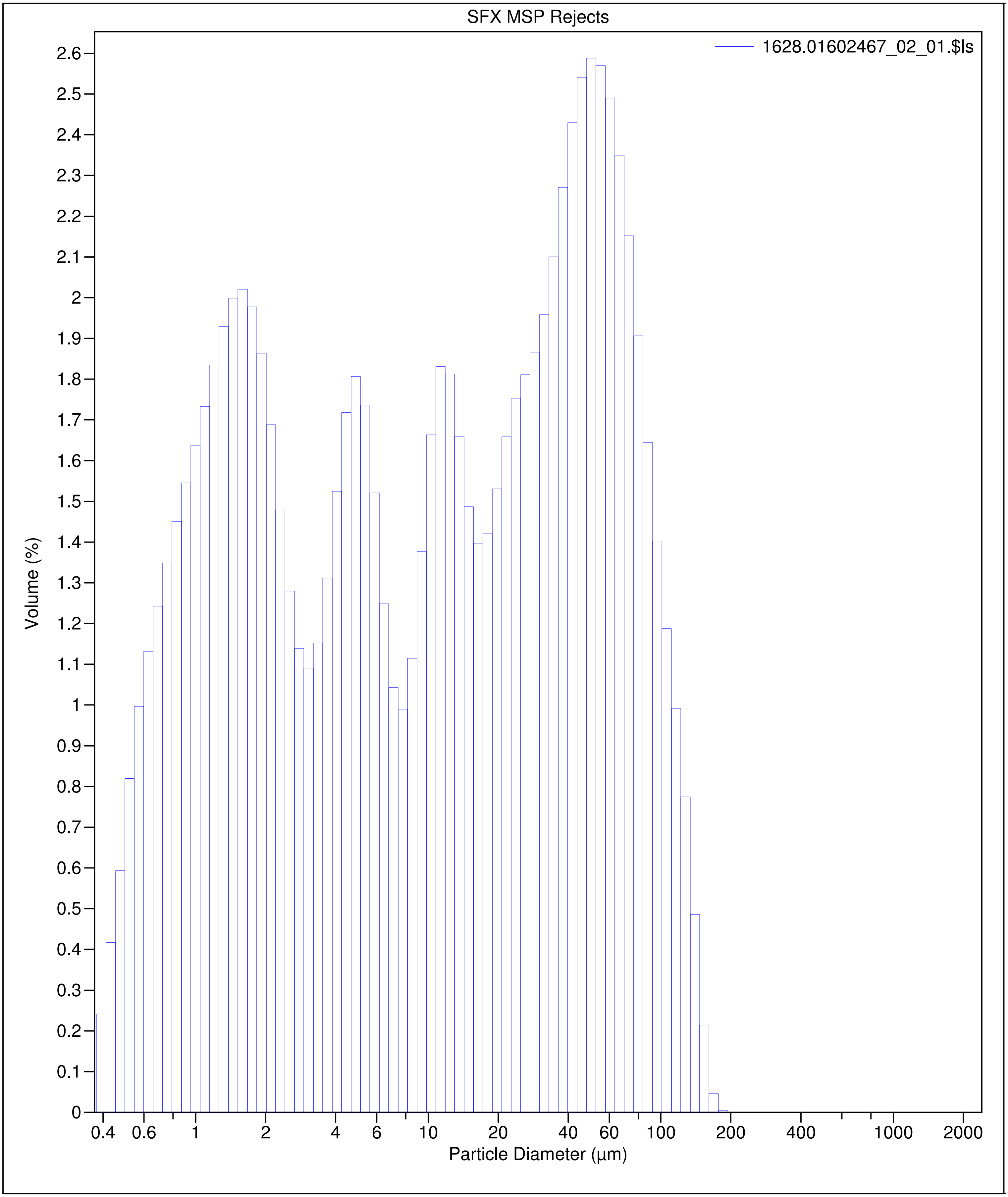
-45 µm	-63 µm	-75 µm	-90 µm	-100 µm	-106 µm	-150 µm
77.4%	86.7%	90.9%	94.5%	96.1%	96.9%	99.8%

+45 µm	+63 µm	+75 µm	+90 µm	+100 µm	+16 µm	+150 µm
22.6%	13.3%	9.10%	5.52%	3.87%	43.2%	0.22%

Beckman Coulter LS Particle Size Analyzer

4 Apr 2016 13:22

1628.0/1602467



Beckman Coulter LS Particle Size Analyzer

4 Apr 2016 13:22

1628.0/1602467

File name:	C:\LS13320\Samples\1628.01602467_04_01.$ls 1628.01602467_04_01.$ls
File ID:	1628.0/1602467
Sample ID:	SFX WCP Tails
Comment 1:	Alexis
Optical model:	RI18PS100.rf780z
Start time:	11:48 4 Apr 2016

Volume Statistics (Arithmetic)   1628.01602467_04_01.$ls

Calculations from 0.375 µm to 2000 µm

Volume:	100%
Mean:	18.65 µm
Median:	9.344 µm

d_{10}: 1.343 µm d_{50}: 9.344 µm d_{90}: 50.56 µm

-45 µm	-63 µm	-75 µm	-90 µm	-100 µm	-106 µm	-150 µm
87.5%	94.0%	96.5%	98.6%	99.4%	99.7%	100%
+45 µm	+63 µm	+75 µm	+90 µm	+100 µm	+16 µm	+150 µm
12.5%	6.04%	3.50%	1.39%	0.58%	37.1%	0%

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4 Apr 2016 13:22

1628.0/1602467