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Internal Memo

From	Lisa Terrusi
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To	Melinda Brand
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Number of pages	12

Mesa H 2017 AMD Risk Assessment Update Summary

Introduction

A review of the acid and metalliferous drainage (AMD) risk associated with mining in the Mesa H project area has been completed to support the referral of the Mesa H Iron Ore Project Proposal under Section 38 of the *Environmental Protection Act 1986*. This review considers recently available (July 2017) drillhole data and mine planning data.

The overall AMD risk for the Mesa H area remains low following an update to the initial assessment [RTIO, 2016]. This memorandum presents a summary of information as documented in the *AMD Risk Assessment for the Robe Valley* [RTIO, 2017].

Background Information

Rio Tinto has undertaken an extensive program of geochemical testing over several years to understand the potential for acidification and/or metalliferous drainage to occur as a result of exposing various waste rock types common to mining operations in the Pilbara. The geochemical characterisation process aims to assess sulfur content as an indicator of acid generation potential, and to undertake static (acid base accounting) and, if appropriate, kinetic testing of materials. This information is applied to the geological and mining models to ensure materials posing potential geochemical risks are identified prior to mining and managed appropriately. This work is in accordance with the *Rio Tinto Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* and the *Spontaneous Combustion and Acid Rock Drainage (SCARD) Management Plan*.

The most significant geochemical risk posed by mining iron ore deposits in the Pilbara is associated with the sulfide mineral pyrite (FeS_2), which can form sulfuric acid when exposed to oxygen and water. The unoxidised Mount McRae Shale, most commonly associated with pyrite and AMD, will not be exposed during mining at Mesa H. However, pyrite may also occur in Banded Iron Formation (BIF) of the Marra Mamba Iron Formation (MM), as well as within the Wittenoom Formation (WD), which are known to underlie the channel iron deposit (CID) in the Mesa H area. Other sulfate minerals, such as alunite and jarosite, may also pose a geochemical risk, albeit the risk is usually lower due to self-limiting chemical processes.

Total Sulfur Analysis of Mesa H Drillhole Samples

A sulfur cut-off value of 0.3% is generally relevant to rock types associated with the Robe Valley area (e.g., BIF and detritals). However, for rock types containing black shale, where sulfur is likely to be in the form of pyrite and containing minimal acid neutralising capacity, a sulfur cut-off of 0.1% is applicable. In addition, material associated with elevated-sulfate (where sulfur values may range from 0.1% to greater than 1%) is also considered to be potentially acid forming in a low capacity. Sulfur cut-off values of both 0.1% and 0.3% are considered in this assessment.

The analysis of total sulfur content in drillhole data (covering historical drilling to 2017) was undertaken to identify the rock types which require further investigation relating to AMD risk. The risk is assessed by comparing the occurrence of total sulfur content greater than 0.1% and 0.3% in drillhole samples against the total number of samples which have been assayed for sulfur. This task was completed for all Mesa H project area drillhole samples, as well as those drillhole samples located within the proposed final pit shell. These results are summarised in Table 1, and documented in *Robe Valley AMD Risk Assessment* [RTIO, 2017]. **The risk of acid drainage being generated during operations and upon closure is low for Mesa H.**

In the Mesa H project area, 0.5% of approximately 81,650 drillhole samples have a sulfur content greater than 0.1%. Less than 1% of *waste* drillhole samples have sulfur values greater than 0.1%. If exposed during mining in this area, Wittenoom Formation located below the water table (BWT), which may include black shale, is considered to pose an AMD risk. This is based on the association of pyrite and relatively high sulfur content. However, based on the current final pit shell for the BWT pit, it is unlikely that this rock type will be exposed in significant (if any) volumes.

Table 1: Acid-forming potential risk based on sulfur values of drillhole samples.

Project Area	All waste drillholes		In-pit waste drillholes*		AMD Risk	Comments
	Rel.% with S>0.1%	Rel.% with S>0.3%	Rel.% with S>0.1%	Rel.% with S>0.3%		
Mesa H	0.7%	0.3%	0.3%	0.1%	Low	WD located BWT poses an AMD risk if exposed.

* *mesah_kn_ult_cf01* final pit shell considered (July 2017).

Geochemical Analysis of Mesa H (Robe Valley) Drillhole Samples

Drillhole data from various Robe Valley mining and project areas were combined to assess the geochemical characteristics of rock types that may be exposed in the greater Robe Valley area. When compared to the *average crustal abundance* [Bowen, 1979], most rock types are enriched or elevated in iron, correlating with the iron mineralisation. As with many Hamersley Group deposits, arsenic is enriched in all rock types, while tin is enriched or elevated.

Drillhole data were also contrasted with Ecological Investigation Levels (EILs) and Health Investigation Levels (HILs) provided in the *Contaminated Sites Management Series Assessment Levels for Soil, Sediment and Water* [DEC, 2010], as well as *US EPA Ecological Soil Screening Levels* (Eco-SSLs) [US EPA 2005, 2010]. In general, all Mesa H rock types (CID ore and waste, and basement lithologies) are considered to have higher levels of Co, Cr, Mn, Pb and V compared to these guideline values. However, it should be noted that these guideline values may not be the most appropriate for Pilbara-specific receptors. Furthermore, material from RTIO mine sites is mostly rock, and not soil, and therefore whilst the EILs, HILs and Eco-SSLs discussed above are useful for screening purposes, they may not be appropriate to use as management triggers.

In summary, the elements **Fe, As, Co, Cr, Cu, Mn, Pb, Se and Zn** have been identified as being enriched in some Robe Valley rock types and should be considered in any source-path-receptor modelling related to potential AMD impacts. However, it should be noted that whilst some elements of potential environmental concern are considered enriched, these elements will not necessarily mobilise into groundwater. For instance, iron oxy-hydroxides such as hematite and magnetite have high sorption capacities for arsenic, and the release of manganese may be limited by solubility controls.

As part of a recent characterisation programme with a focus on elevated-sulfur samples and certain elemental enrichments, 191 samples collected from the greater Robe Valley area have been submitted for acid base accounting (ABA) and geochemical test work. Samples were collected from Mesa J, Mesa A/Warramboo, Mesa B, Mesa F, Mesa H and the Middle Robe areas and represent a range of rock types considered to be analogous across the greater Robe Valley.

A total of 96 (of 191) samples were collected from the Mesa H project area and the adjacent Mesa J mining area. Results are provided in *Robe Valley Geochemical Assessment* [O'Kane, 2016] and sample collar locations relative to drillhole locations at Mesa H are shown in Figure 1.

The 96 Mesa H/Mesa J samples submitted for ABA and geochemical test work comprise a variety of rock types including alluvium/detritals (ALL) waste rock (19 samples), pisolite/CID ore and waste rock (42 samples), Wittenoom Formation (WD) waste rock (32 samples) and Marra Mamba Iron Formation (MM) waste rock (3 samples). The CID samples have been further sub-divided based on ore-type/position within the orebody (i.e., hardcap (HTP), hard pisolite (TPH), mixed pisolite (TPM), clayey pisolite (TPC) and basal pisolite (TPB)).

Sulfur content for the 96 Mesa H/Mesa J samples range from 0.001% to 5.4%, where 23 of those samples have sulfur content greater than 0.1%. Eleven (11) of the 23 elevated-sulfur samples are classified as potentially acid forming (PAF) and represent the WD rock type (10 samples) and MM rock type (one sample). A summary of the total sulfur analysis compiled for all 191 geochemical samples is shown in Figure 2. Relatively higher *average* sulfur values for certain rock types (i.e., WD and MM) are indicative of sampling bias towards elevated-sulfur samples; the average total sulfur content for each rock type based on all Mesa H drillhole data is also shown and is more representative of the calculated *median* values (median values have been considered in this assessment).

A summary of the rock types tested relative to the tonnes of waste material expected during mining at Mesa H is shown in Table 2. The majority of Mesa H waste is expected to represent the TPC, TPM, ALL and HTP rock types, and basement lithologies including WD and MM are not expected to be exposed in significant quantities. **Waste material associated with elevated-sulfur is not expected to be mined in bulk at Mesa H.**

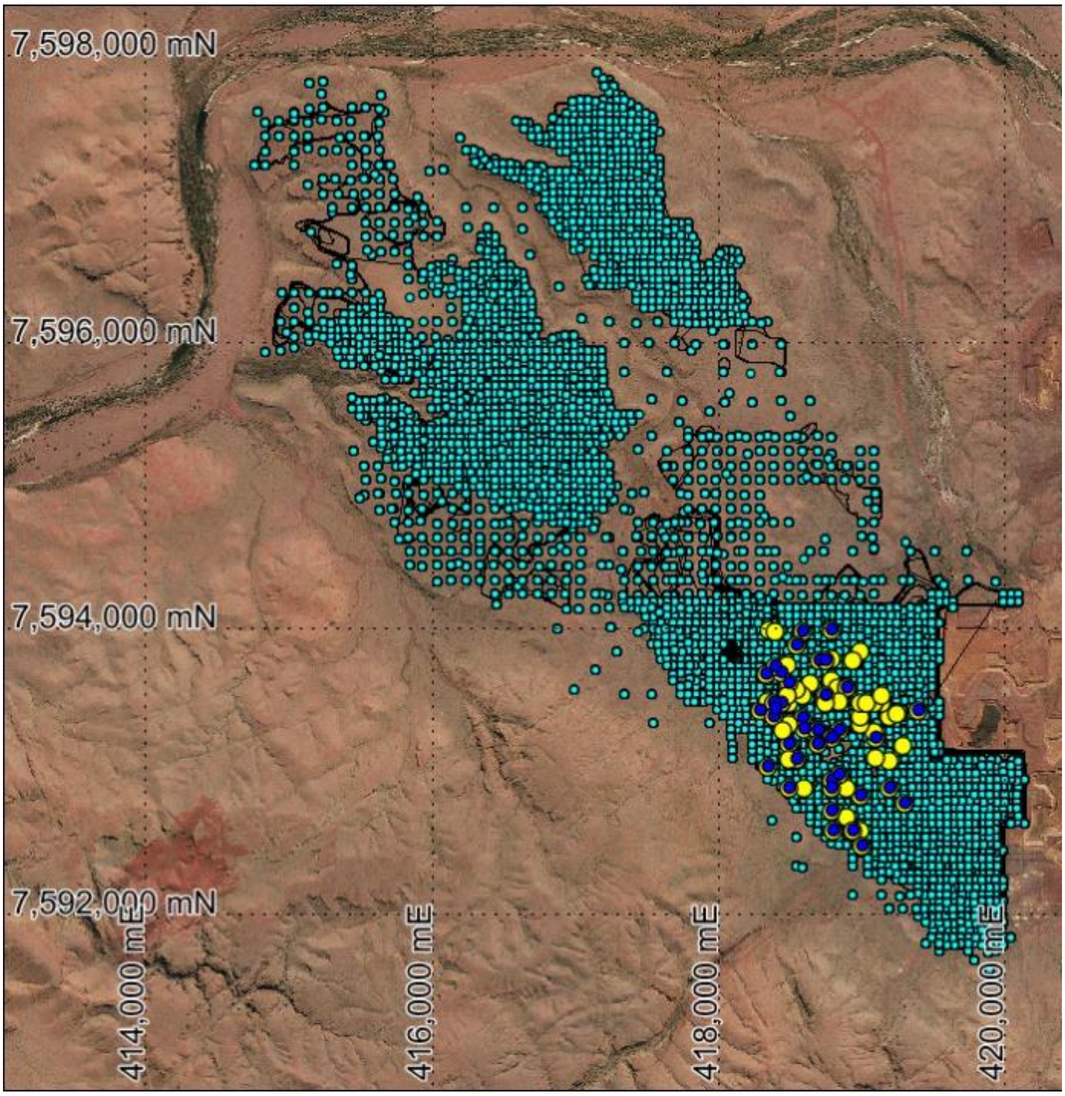

Figure 1: Plan view of Mesa H project area showing proposed final pit shell outline, drillhole locations (blue dots), collar locations of ABA/geochemical samples (yellow dots) and collar locations of samples associated with static leach tests (dark blue dots).

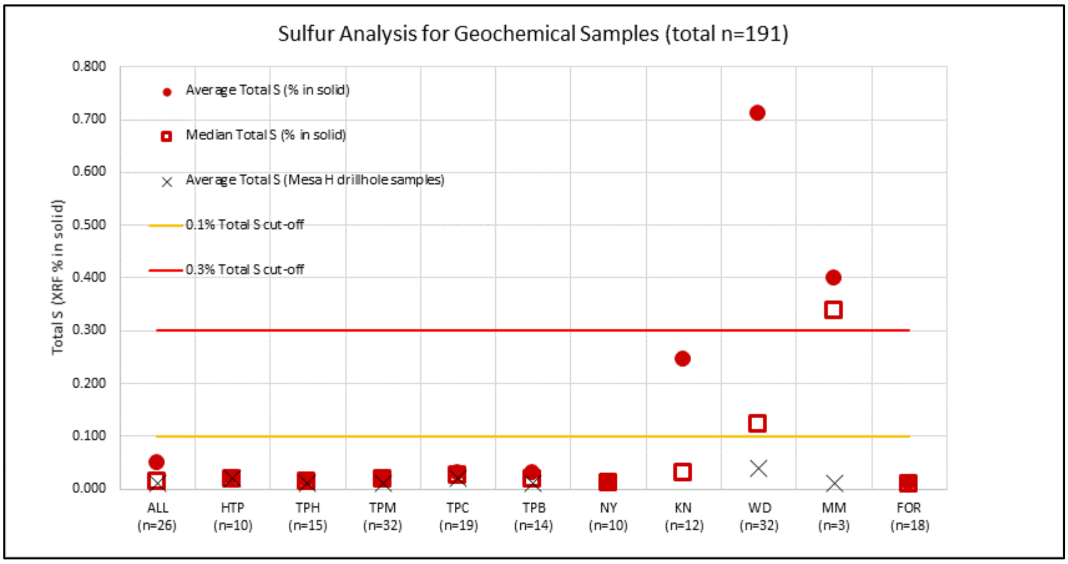

Figure 2: Total sulfur analysis compiled for all 191 geochemical samples, relative to total sulfur analysis of Mesa H drillhole data.

Table 2: Mesa H waste rock types relative to total waste expected to be mined, and number of ABA/geochemical characterisation samples collected from greater Robe Valley area.

Waste Rock Type[1]	Rel.% of total waste[2]	# ABA/geochemical test work samples[3]	Comments
TPC	49%	19	13 samples specific to Mesa H
TPM	24%	32	11 samples specific to Mesa H
ALL	13%	26	19 samples specific to Mesa H
HTP	11%	10	2 samples specific to Mesa H
TPH	2%	15	8 samples specific to Mesa H
TPB	1%	14	8 samples specific to Mesa H
MM	0.1%	3	3 samples specific to Mesa H
WD	0.01%	32	32 samples specific to Mesa H
NY		10	NY not represented at Mesa H
KN		12	KN not represented at Mesa H
FOR		18	FOR not represented at Mesa H
Total waste:	**100%**	**191**	

[1] waste rock types include material flagged with mp_dest = w or ltlg

[2] source rbvipr3pf_mesah_20170707_001

[3] samples from *Robe Valley Geochemical Assessment* [O'Kane, 2016]

Static Leach Test Analysis of Mesa H (Robe Valley) Samples

In addition to the ABA test work described above, static leach tests using deionised water were also carried out on 100 selected samples from the greater Robe Valley area [O'Kane, 2016]. Considering the finding that Fe, As, Co, Cr, Cu, Mn, Pb, Se and Zn may be enriched in Robe Valley rock types, the leach data has been analysed to focus on those parameters in addition to sulfate, nitrate, Al, B, Hg, Mo, Ni and U which also correspond to ANZECC/ARMCANZ [2000] and NHMRC/ARMCANZ [2011] assessment criteria. Results are summarised in Table 3, where the calculated *median* values are considered. As noted previously, sampling was biased toward elevated-sulfur and certain elemental enrichments, and the outlier data influencing higher calculated average values (e.g., for NO_3, Mn and Se) are currently being investigated further.

Table 3: Summary of static leach data relative to ANZECC/ARMCANZ [2000] and NHMRC/ARMCANZ [2011] assessment criteria.*

parameter (mg/L)	SO_4	N-NO_3	Al	As	B	Cd**	Co	Cr**	Cu**	Fe	Hg	Mn	Mo	Ni**	Pb**	Se	U	Zn**
95% aquatic ecosystem	*N/A*	*0.16*	*0.055*	*0.013*	*0.37*	*0.0002*	*N/A*	*0.001*	*0.0014*	*N/A*	*0.00006*	*1.9*	*N/A*	*0.011*	*0.0034*	*0.011*	*N/A*	*0.008*
Drinking water	*250*	*11*	*0.2*	*0.01*	*4*	*0.002*	*N/A*	*0.05*	*1*	*0.3*	*0.001*	*0.1*	*0.05*	*0.02*	*0.01*	*0.01*	*0.017*	*3*
Stock water	*1000*	*90*	*5*	*0.5*	*5*	*0.01*	*1*	*1*	*0.4*	*N/A*	*0.002*	*N/A*	*0.15*	*1*	*0.1*	*0.02*	*0.2*	*20*
ALL (14 samples)	17	0.05	0.05	0.00021	0.08	0.00001	0.00009	0.001	0.001	0.05	0.00005	0.01	0.00069	0.01	0.0002	0.0009	0.000106	0.001
HTP (4 samples)	15	0.05	0.05	0.00027	0.11	0.00001	0.00022	0.001	0.001	0.03	0.00005	0.02	0.00003	0.01	0.0003	0.0002	0.000004	0.001
TPH (5 samples)	21	0.05	0.81	0.00032	0.09	0.00001	0.00007	0.001	0.001	1.38	0.00005	0.01	0.00047	0.01	0.0001	0.0001	0.000027	0.001
TPM (13 samples)	22	0.05	0.16	0.00013	0.1	0.00001	0.00028	0.001	0.001	0.18	0.00005	0.01	0.00036	0.01	0.0002	0.0001	0.000033	0.001
TPC (5 samples)	100	0.05	0.05	0.00015	0.3	0.00001	0.0001	0.001	0.001	0.08	0.00005	0.01	0.00043	0.01	0.0001	0.0001	0.000017	0.001
TPB (11 samples)	26	0.05	0.05	0.0002	0.08	0.00001	0.00029	0.001	0.001	0.02	0.00005	0.03	0.00011	0.01	0.0002	0.0002	0.000006	0.001
NY (5 samples)	21	0.1	0.06	0.00039	0.1	0.00001	0.00021	0.001	0.001	0.03	0.00005	0.01	0.01232	0.01	0.0008	0.0001	0.00001	0.001
KN (10 samples)	507	0.1	0.49	0.00088	0.11	0.00081	0.46208	0.007	0.003	0.24	0.00005	3.03	0.00027	0.51	0.0003	0.0112	0.000125	0.024
WD (21 samples)	691	0.1	0.39	0.00034	0.05	0.00032	0.1268	0.002	0.003	0.86	0.00005	8.91	0.00005	0.37	0.0008	0.0119	0.00011	0.012
MM (3 samples)	926	0.8	0.04	0.00024	0.03	0.00046	0.01062	0.001	0.001	0.03	0.00005	10.82	0.00003	0.02	0.001	0.0129	0.000064	0.002
FOR (9 samples)	35	0.05	0.06	0.00043	0.15	0.00001	0.00039	0.001	0.001	0.02	0.00005	0.01	0.00139	0.01	0.0005	0.0003	0.000019	0.001

* the generally more conservative aquatic ecosystem criteria are considered (highlighted in orange), and exceedances (calculated median values) are highlighted in red.

** guideline values have not been adjusted for hardness.

It is important to note that since the physical and chemical conditions of the leach test will not be the same as those expected in the ‘as placed’ environment (e.g., due to solubility constraints, liquid to solid ratios, etc.), the leachate composition from these tests is not expected to be representative of that which may develop in the field. As such, the results should not be directly extrapolated to predict the actual water quality expected to seep from a waste rock dump, but are useful in providing an indication of the readily leachable elements that may be present. Furthermore, the characterisation programme had a focus on elevated-sulfur samples and certain elemental enrichments, therefore, the observation that several parameters show a greater leach potential is expected under acidic conditions.

The majority of Mesa H waste is expected to represent the TPC, TPM, ALL and HTP rock types, while basement rock including WD and MM are expected to be exposed in minimal quantities. Considering the calculated median values compiled for each rock type, the concentration of most parameters does not exceed the more conservative assessment criteria (typically the ANZECC/ARMCANZ [2000] trigger values applying to 95% protection level for slightly-moderately disturbed ecosystems). Exceptions are for concentrations of aluminum and iron; while the release of aluminum is likely to be limited by solubility controls [SRK, 2017], further work is ongoing to investigate the release of iron, as well as the release of other parameters under different conditions (e.g., multi-step leaching, saline leach solutions, and low-contact liquid to solid ratios [SRK, 2017]).

The analysis of static leach test results are provided in Appendix A.

Geochemical Analysis of Mesa J Tailings Samples

Geochemical test work was also carried out on five Mesa J tailings samples [EGi, 2014]. The samples are classified as non-acid forming and considered enriched in As, Fe and Se, and elevated in Bi, Co, Mn and Sb when compared to the average crustal abundance.

The analysis of tailings liquor show the majority of metals and metalloids are either at low concentrations or below the detection limit. Supplemental static leach tests were also undertaken using deionised water and saline solution, where results indicate relatively higher concentrations of copper and zinc in the saline extractions, which is likely due to a combination of cation exchange which increases their solubility [EGi, 2014]. Relatively lower concentrations of iron are associated with the saline extracts.

In general, the results indicate tailings, as represented by the samples provided, are unlikely to result in low pH conditions or metals leaching under oxidising conditions [EGi, 2014].

Fibrous Minerals

Fibrous minerals present a health hazard if fibres of a (defined) respirable size become airborne and are inhaled. The most common mineral associated with fibrous minerals encountered within the iron formations present in the Robe Valley area is riebeckite. Riebeckite is usually found in fresh (unweathered) BIF. The asbestiform variety of riebeckite is crocidolite, or blue asbestos. The presence of riebeckite does not necessarily pose a fibrous mineral risk but it is a precursor mineral to crocidolite, therefore, there exists a likelihood of encountering crocidolite.

If present, crocidolite seams would primarily occur within the unmineralised Marra Mamba Iron Formation that underlies the CID at Mesa H. In addition, crocidolite may also occur in BIF clasts found within overlying alluvium cover or within the basal pisolite horizon (i.e., TPB).

Crocidolite has not been intersected to-date in any drillholes within the Mesa H project area. However, the underlying Marra Mamba Iron Formation, as well as the TPB horizon in the Mesa H area, are considered to pose a potential fibre risk if exposed.

The *Rio Tinto Iron Ore (WA) Fibrous Minerals Management Plan* describes guidelines for the management of fibrous minerals encountered during mine production, however, based on current drilling and mine planning information, which indicates that basal or basement lithologies can generally be avoided during operations, *potentially hazardous* or *designated hazardous* areas are not expected within the life of mine or upon closure in these areas.

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Specialist Geologist, Mineral Waste Management

References

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Bowen, H.J.M. (1979) *Environmental Chemistry of the Elements*, Academic Press, London.

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EGi (2014) *Geochemical Assessment of Tailings from Yandi, Paraburdoo, Tom Price, Brockman 4 and Mesa J*, March 2014. Document No. 3824/1095 by Environmental Geochemistry International Pty Ltd.

NHMRC and ARMCANZ (2011). *Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strateg*y (as an update to the 2004 version of these guidelines).

O'Kane Consultants (2016). Robe Valley Geochemical Risk Assessment. April 2016. Document No. 896/02-02.

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RTIO (2017b) *Section 38 Referral – Supporting Information Mesa H Proposal*. June 2017. RTIO-HSE-0310732.

RTIO (2016) *AMD Risk Assessment Summary for the Robe Valley*. October 2016. Report by L Terrusi. RTIO-PDE-0061933.

RTIO (2016b) *Rio Tinto Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* (RTIO-HSE-0040347)

RTIO (2016c) *Rio Tinto Ire Ore (WA) Spontaneous Combustion and ARD (SCARD) Management Plan for Operations (formerly known as the Black Shale Management Plan)* (RTIO-HSE-0010872)

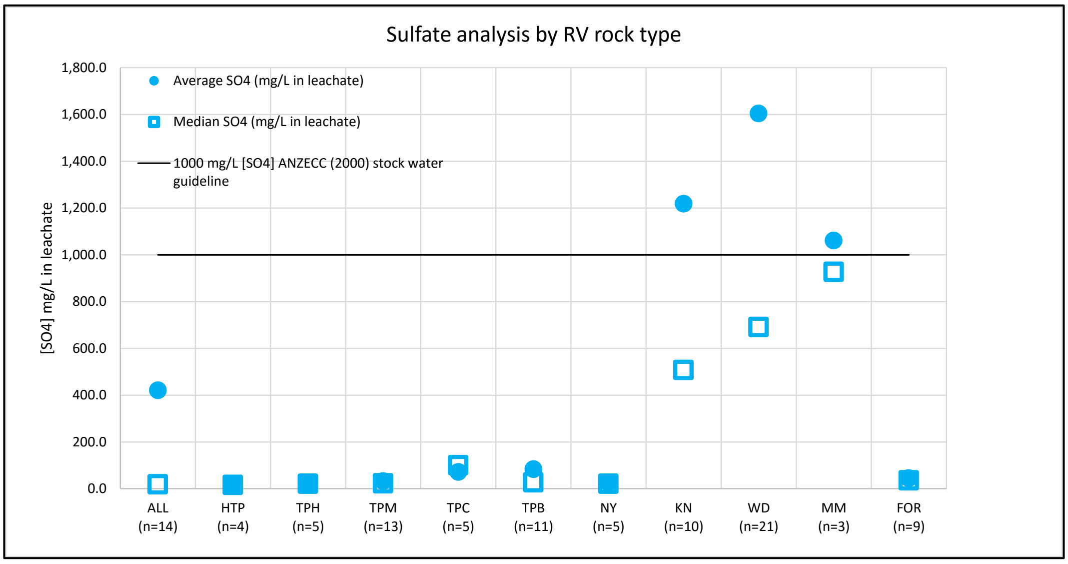
RTIO (2016d*) Rio Tinto Iron Ore (WA) Fibrous Minerals Management Plan* (RTIO-PDE-0062061)

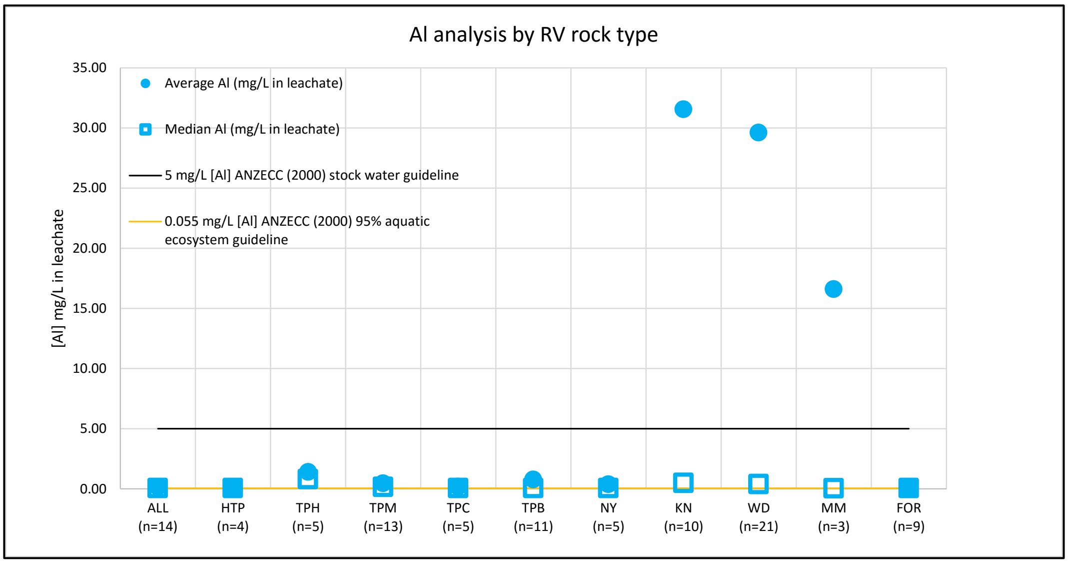
SRK (2017). *Robe Valley Geochemical Characterisation – Forms of Acidity and Supplemental Leach Testing*. August 2017. Document No. RTS140.

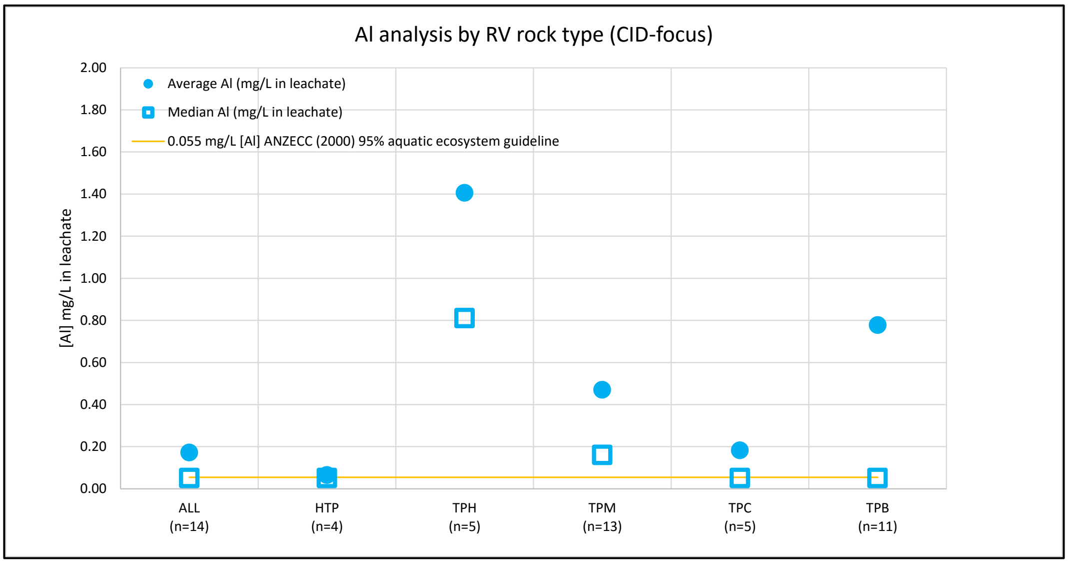
US EPA 2005, *Guidance for Developing Ecological Soil Screening Levels*, November 2003 - Revised February 2005, US Environmental Protection Agency, Washington, DC

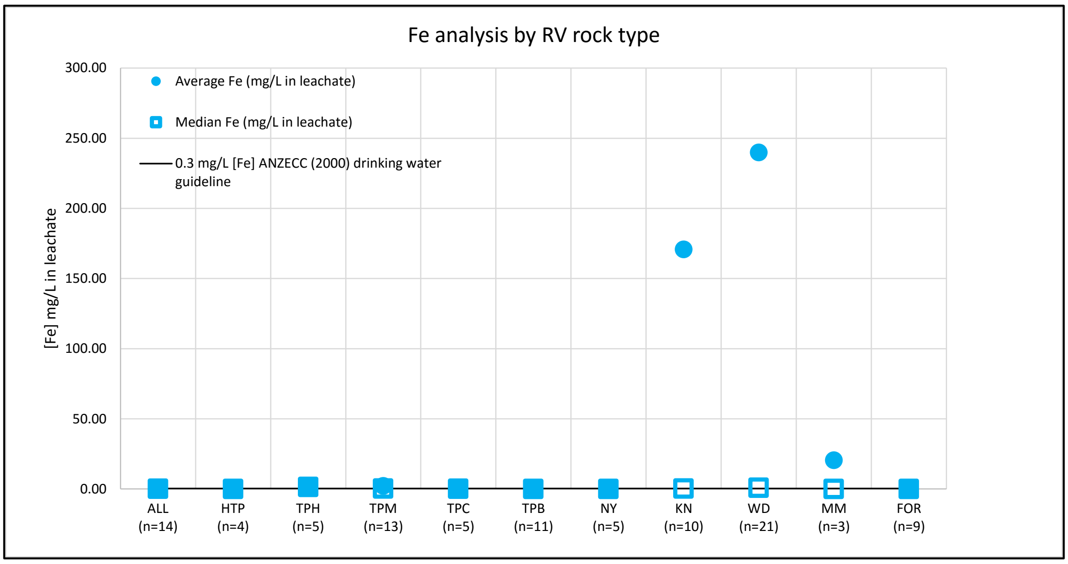
US EPA 2010, *Ecological Soil Screening Levels*, US Environmental Protection Agency, Washington DC: available at www.epa.gov/ecotox/ecossl

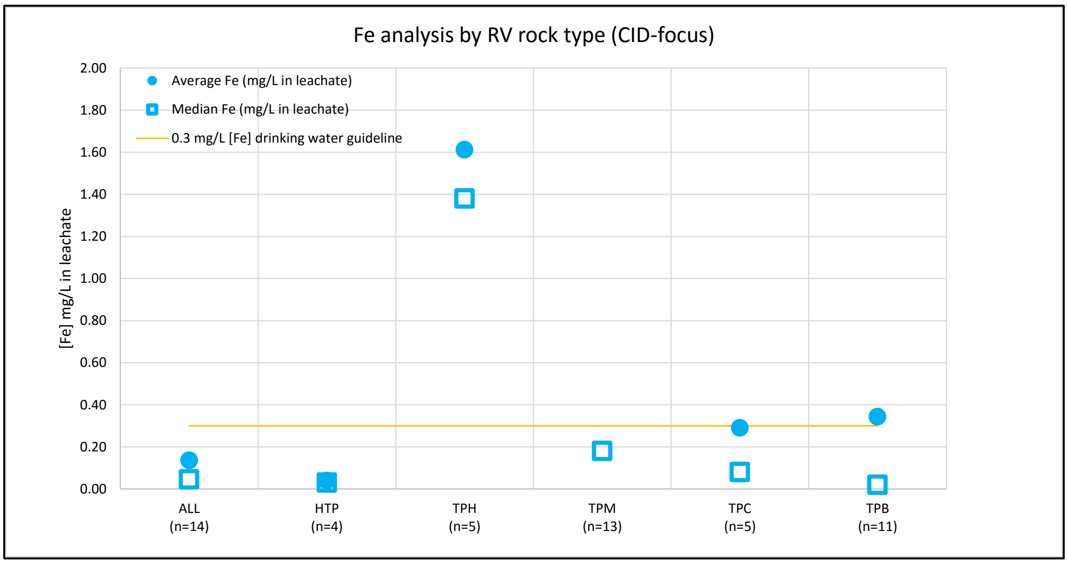
Appendix A – Static Leach Test Results – Analysis of Select Parameters

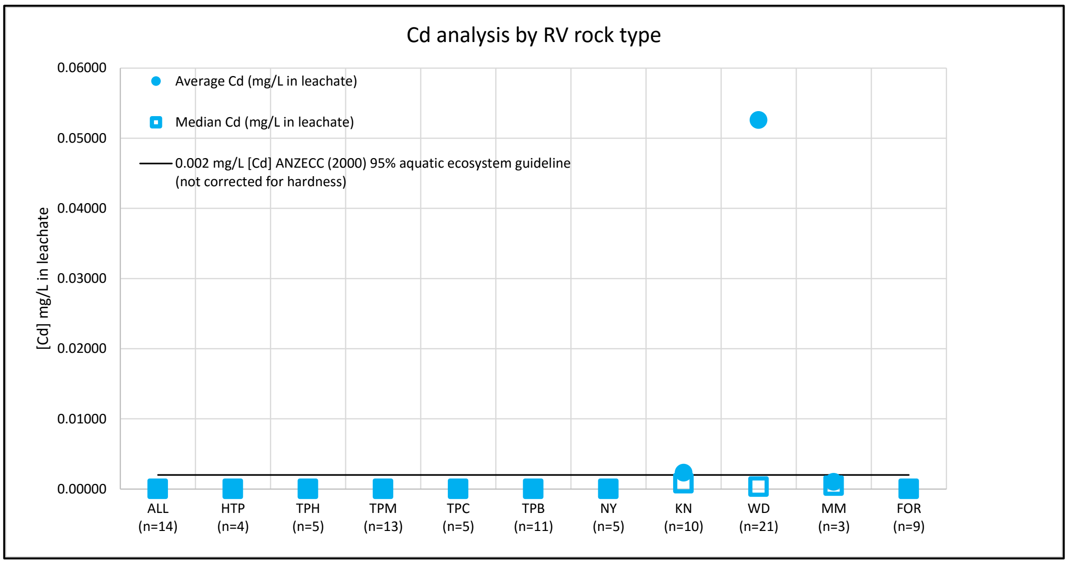


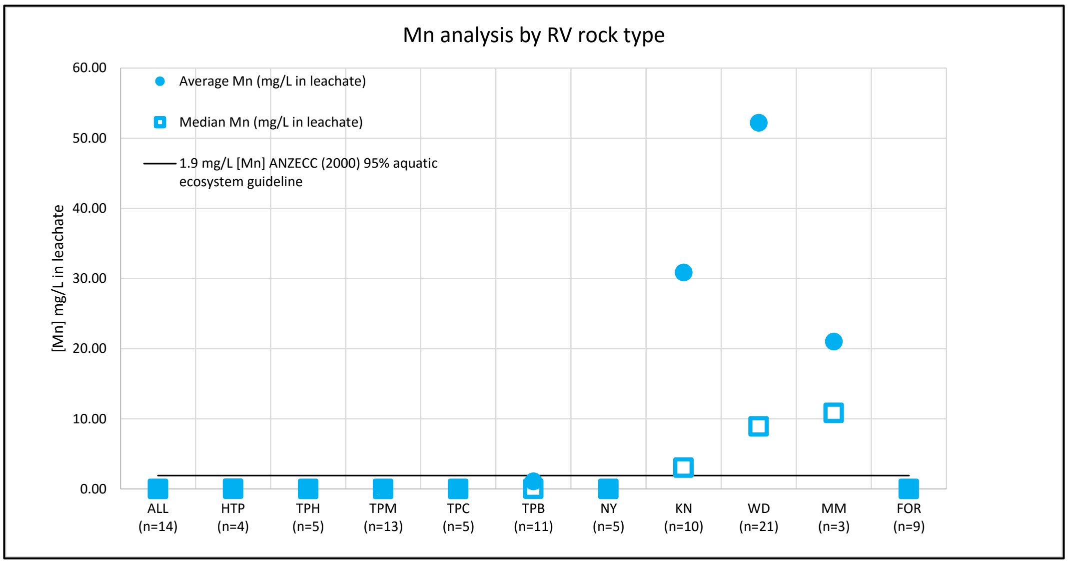


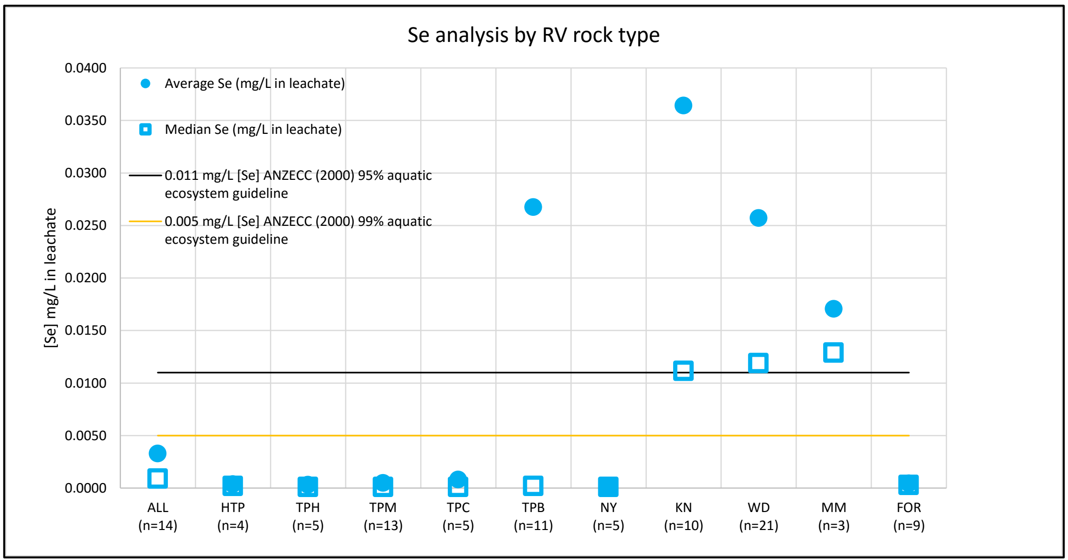


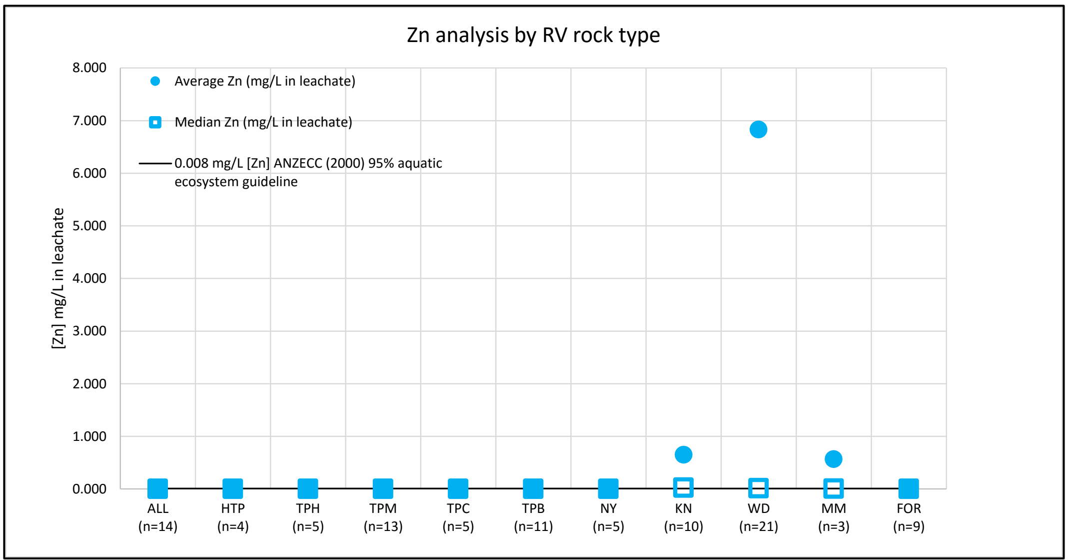

Fe analysis by RV rock type
Average Fe (mg/L in leachate)
Median Fe (mg/L in leachate)
0.3 mg/L [Fe] ANZECC (2000) drinking water guideline
[Fe] mg/L in leachate
300.00
250.00
200.00
150.00
100.00
50.00
0.00
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)


Fe analysis by RV rock type (CID-focus)
Average Fe (mg/L in leachate)
Median Fe (mg/L in leachate)
0.3 mg/L [Fe] drinking water guideline
[Fe] mg/L in leachate
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)


Cd analysis by RV rock type
Average Cd (mg/L in leachate)
Median Cd (mg/L in leachate)
0.002 mg/L [Cd] ANZECC (2000) 95% aquatic ecosystem guideline (not corrected for hardness)
[Cd] mg/L in leachate
0.06000
0.05000
0.04000
0.03000
0.02000
0.01000
0.00000
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)


Mn analysis by RV rock type
Average Mn (mg/L in leachate)
Median Mn (mg/L in leachate)
1.9 mg/L [Mn] ANZECC (2000) 95% aquatic ecosystem guideline
[Mn] mg/L in leachate
60.00
50.00
40.00
30.00
20.00
10.00
0.00
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)


Se analysis by RV rock type
Average Se (mg/L in leachate)
Median Se (mg/L in leachate)
0.011 mg/L [Se] ANZECC (2000) 95% aquatic ecosystem guideline
0.005 mg/L [Se] ANZECC (2000) 99% aquatic ecosystem guideline
[Se] mg/L in leachate
0.0400
0.0350
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)


Zn analysis by RV rock type
Average Zn (mg/L in leachate)
Median Zn (mg/L in leachate)
0.008 mg/L [Zn] ANZECC (2000) 95% aquatic ecosystem guideline
[Zn] mg/L in leachate
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)