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GAMSBERG ZINC MINING PROJECT
WASTE CLASSIFICATION ASSESSMENT

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Knight Piésold
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ABBREVIATIONS

ABA	Acid-Base Accounting
AMD	Acid mine drainage
AP	Acid generation processes
GAI	Geochemical abundance index
LC	Leachable Concentrations
LCT	Leachable Concentration Threshold
mg/kg	milligrams per kilogram
mg/l	milligrams per litre
NNP	Net neutralisation potential
NP	Acid-neutralizing processes
NPAG	Non-acid generating
NPR	Neutralising Potential Ratio
PAG	Potentially acid generating
SANAS	South African National Accreditation System
TC	Total Concentrations
TCT	Total Concentrations Threshold
WCMR	Waste Classification and Management Regulations
XRD	X-Ray Diffraction

1. INTRODUCTION AND SCOPE OF REPORT

1.1 INTRODUCTION

Black Mountain Mining (Pty) Ltd (BMM), which is a subsidiary of Vedanta Zinc International, owns and operates Gamsberg Zinc Mine (Gamsberg). Gamsberg is located approximately 30 km from BBM in the Northern Cape province of South Africa. Zinc deposits in Gamsberg were discovered in 1971 and Gamsberg Zinc Mine has been owned by Vedanta since 2011, to form part of the Black Mountain Mining Complex. The mine has open pit operations and currently produces 400,000 tonnes of ore per month with a planned expansion to double production. This will necessitate an expansion of the tailings storage facility (TSF).

BMM has appointed Knight Piésold (Pty) Ltd (KP) to conduct a Waste Classification of the tailings that will be generated in the processing of the zinc ore deposits, as part of the expansion of the Gamsberg TSF. The current TSF at Gamsberg was constructed prior to 2013 before the legislation to classify tailings as waste according to GNR 634 had been promulgated. Therefore, no waste classification has previously been done on the Gamsberg Zinc tailings.

This report covers the Waste Classification of representative tailings material at the current cyclone TSF at the Gamsberg Mine. The tailings samples were collected from various locations on the TSF from both the underflow (U/F) and overflow (O/F) streams. The Gamsberg TSF is a cyclone TSF, so each tails feed is split centrifugally on the TSF to finer and coarser stream. The O/F is the finer stream with the U/F as the coarser stream.

1.2 BACKGROUND

Gamsberg Mine is located in the lower Orange River water management area and falls within the D28C quaternary catchment in an arid climate with mean annual rainfall < 100 mm/year.

The ore body at Gamsberg has been split into 3 ore types namely, a pyrite rich ore (py), a pyrrhotite rich ore (Po) and magnetite rich (Mo). The three different ores are mined simultaneously resulting in a blend of tailings processed during the mining operations and deposited in the TSF.

Since the construction of the Gamsberg TSF, several boreholes have been drilled upgradient and downgradient of the TSF for monitoring purposes. A quarterly groundwater monitoring program has been implemented by GHT consultants. The current monitoring results indicate that the Gamsberg TSF is leaking towards the North-western corner based on an increase in water level that has been observed in the borehole at the NW corner. There is an increase in the concentration of dissolved salts (particularly as Cl and SO4) in the boreholes located to the northwest of the TSF. GHT consultants recommended ongoing monitoring and that an in depth hydrogeological investigation be conducted around the TSF area.

Previous geochemical static testing has been conducted for the waste streams at Gamsberg in 2013, by Environmental Resource Management (ERM). The report showed that the the hanging wall and foot wall waste rocks are predominantly non-acid generating, but the tailings is overall acid generating. Each tailings type and a composite sample considered representative of the ratio of blended tailings was subjected to static and kinetic testing. The tailings produced from processing of the pyrite and pyrrhotite ore are classified as acid generating whereas the magnetite rich ore tailings was non-acid generating. The study confirmed that the tailings are expected to generate acid rock drainage (ARD) within a short period of deposition, due to the high sulphide and low neutralisation content of the tailings.

ERM recommended that various TSF management protocols be put in place for the Gamsberg TSF including:

- Short deposition cycles to reduce drying out and oxidation of the tailings,
- Cladding TSF side slopes concurrently with deposition,
- Engineered controls to capture and contain TSF drainage and,
- Liming of the tailings to acceptable pH values prior to tailings deposition.

The ERM 2013 report did not include a waste classification as GNR 634 had not be promulgated at the date of the release of the report. The aqua regia digestion showed that the Gamsberg tailings are enriched in metals and heavy metals: Fe, Al, Mn, Pb, As, Cu and Ni all exceeding 100 mg/kg classifying the tailings as high risk.

As part of the expansion of the TSF which will be towards the north, a waste classification assessment of the tailings material was undertaken by KP, as input to the liner requirements and in line with regulations. This report details the findings of the assessment and recommendations.

1.3 SCOPE OF THE REPORT

The scope of the work undertaken is as follows:

- Collect representative samples for geochemical analysis of the tailings;
- Submit samples to a SANAS (South African National Accreditation System) accredited laboratory in accordance with the Waste Classification and Management Regulations (WCMR), Government Notice 634 (23 August 2013), GNR 632 (24 July 2015) and the Mineral and Petroleum Resources Development Act (Act 28 of 2002) (MPRDA);
- Interpretation of the laboratory results;
- Classify the waste in terms of the WMCR GNR 634 and GNR 632
- Prepare a report documenting the findings of the classification assessment and
- Recommended liner requirements in terms of geochemical tailings assessment.

2.0 CHEMICAL CLASSIFICATION OF TAILINGS

Waste management in South Africa is currently governed by the following legislations but is not limited to:

- The South African Constitution (Act 108 of 1996);
- The National Environmental Act (Act 107 of 1998);
- National Environmental Management: Waste Act (Act 59 of 2008) (NEM:WA);
- Hazardous Substances Act (Act 5 of 1973); and
- National Water Act (Act 36 of 1998)

According to the Waste Classification and Management Regulations (GNR 634) and the National Environmental Management: Waste Act NEM:WA (Act 59 of 2008), all waste generated must be classified in accordance with SANS 10234 within 180 days of generation. The waste is categorised into two classes based on the risk it poses namely; general waste and hazardous waste. The Act defines general and hazardous waste as follows:

- General waste – waste that does not pose an immediate hazard or threat to health or to the environment
- Hazardous waste – waste that contains organic or inorganic elements or compounds which may, owing to the inherent physical, chemical, or toxicological characteristics of the waste, have detrimental impacts on health and the environment.

The following regulations and National Norms & Standards in Government Gazette No 36784 were published to standardise and improve waste management in South Africa:

- Waste Management and Classification Regulations 2013 (GN R634);
- National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R635); and
- National Norms & Standards for the Disposal of Waste to Landfill (GN R636).

These regulations and standards specify hazardous wastes and chemical constituents in a substance or mixture otherwise intended for waste disposal that determines the disposal endpoint (Landfill Class), and current or future restricted or prohibited wastes or prohibited disposal activities.

The more recent GNR 632 dated 24 July 2015, provides additional guidance with respect to the planning, and management of residue stockpiles and deposits from a prospecting, mining, exploration or production operation. Some of the waste that is produced in mining is legally referred to as residue deposits (Section 1 of the MDPRA) i.e. tailings. The waste must be characterised including a description of the physical characteristics, chemical constituents and mineral content, and previously discarded waste can be repurposed as a valuable by-product of the extractive or mining process.

In 2018, the Chamber of Mines proposed the consequential removal of all references to residue stockpiles and residue deposits from the ambit of NEM:WA and be promulgated in terms of the NEMA which would exclude the requirement to classify tailings in terms of the Waste Classification (GNR 634). This nevertheless requires the chemical characterisation that must include:

1. The toxicity
2. The propensity to oxidize and decompose
3. The propensity to undergo spontaneous combustion

4. The pH and chemical composition of the water separated from the solids
5. The stability and reactivity and the rate thereof
6. Acid generating and neutralising potential and
7. The concentration of the volatile organic compounds.

2.1 PHASE 1: STATIC GEOCHEMICAL TESTS

Static geochemical tests provide a snap shot of the geochemical characteristics of the sampled material at a single point in time.

Acid-Base Accounting (ABA) used in the assessment of mine waste materials for acid-generating potential. The ABA program included static geochemical tests for the following parameters:

- pH (saturated paste)
- Electrical conductivity
- Total sulphur
- Acid neutralising capacity (ANC) using the Sobek Method

From the total sulphur and ANC results the Net Neutralising potential and Net Acid producing potential are calculated.

The samples were subjected to Net Acid Generation (NAG) followed by multi-element testing on both the solid and soluble fractions for:

- Total metals/metalloids
- Total cations
- Soluble metals/metalloids
- Major cations
- Major anions
- Total alkalinity and acidity

Due to the mineralogic nature of the tailings, it is unlikely to contain putrescible or volatile organic compounds and therefore distilled water leach tests are considered appropriate as only rainfall will percolate through the TSF.

Kinetic testing was not undertaken in this phase but is typically used to simulate the long term weathering of the tailings materials under field conditions. Based on results from Phase 1 testing, kinetic testing is recommended.

3.0 METHODOLOGY

3.1 SAMPLE PROGRAM

A total of 5 samples were collected from the Gamsberg TSF, representative of the various feed tails on the current TSF. The sample locations are shown below in Figure 3-1.

The samples were collected by Knight Piésold and analysed by Waterlab, an accredited laboratory for geochemical testing. The samples were labelled Sample 1, 2, 3, 4, and 5 but the full sample description is shown below in Table 3-1. The dry samples were collected on exposed surface after scraping away the top salt layer and these samples represent older tailings which have dried out compared with the wet samples collected at the spit and overflow pipe as fresh tailings from the plant.

The sample details are shown in Table 3-1 below and the full description for each sample is as follows:

- Sample 1: U/F dry at wall (from two locations within 50m)
- Sample 2: U/F wet from spigot
- Sample 3: O/F dry from beach head representing coarser overflow (from two locations)
- Sample 4: O/F dry from close to pond (from two locations within 50m)
- Sample 5: O/F wet from overflow pipe representing finer overflow

Table 3-1 Labelling of Samples

Sample ID	Sample Description	Latitude	Longitude	Laboratory ID
1	U/F Dry	-29.194312004°	18.953046032°	Sample 175229
2	U/F Wet	-29.194313237°	18.952974473°	Sample 175230
3	O/F Dry (beach head)	-29.194293076°	18.953055734°	Sample 175231
4	O/F Dry (Pond)	-29.193519176°	18.951597135°	Sample 175232
5	O/F Wet	-29.194780414°	18.940041395°	Sample 175233
5	Duplicate	-29.194780414°	18.940041395°	Sample 175233 D

The geochemical test work was carried out by Waterlab (Pty) Ltd, a SANAS (South African National Accreditation System) accredited laboratory, and included the following:

Table 3-2 Summary of Phase 1 Analyses

Type of Test	Specification
Mineralogy	Quantitative XRD
Acid Base Accounting	Modified Sobek NP, Paste pH, Total sulphur sulphate sulphide, neutralisation potential
Short Term Leach	Synthetic leaching procedure (SPLP) 1:20 solid: SLP extraction Aqua regia digestion with extract analysis and ICP scan
NAG Test	Single addition NAG Test with peroxide leach
Waste classification	Distilled water leach for mono-disposal

Figure 3-1: Gamsberg Tailings sample locations

4.0 ANALYTICAL RESULTS

4.1 MINERALOGICAL COMPOSITION

The results of the X-Ray Diffraction (XRD) analysis are presented in Table 4-1 below and shown graphically in

Figure 4-1. These results show that all the samples from the Gamsberg TSF are dominated by pyrite and quartz with small amounts of pyrrhotite, chlorite and biotite.

There is no significant difference in mineralogic composition between the dry and the wet tailings samples except that there is higher concentration of pyrite in the dry samples. None of the samples contain calcite but the presence of silicate minerals (quartz and chlorite) provides low buffering capacity. Jarosite has mainly been removed with higher concentrations in the overflow samples compared with the underflow. Iron rich minerals include magnetite, actinolite and rutile and iron sulphate rozenite occurs in the dry underflow samples.

Table 4-1 Results of XRD Analysis

Mineral Amount Weight (%)	Sample 1 - U/F Dry	Sample 2 - U/F Wet	Sample 3 - O/F Dry (beach head)	Sample 4 - O/F Dry (Pond)	Sample 5 - O/F Wet
Quartz	32.24	35.4	41.89	41.95	39.79
Pyrite	57.79	50.85	42.44	45.79	34.89
Pyrrhotite	0	2.92	0	2.86	1.44
Chlorite	3.22	3.91	11.84	3.73	11.71
Biotite	3.18	3.22	1.9	2.25	8.64
Jarosite	0	0	1.63	0.48	1.01
Rutile	0	0.34	0.29	0.27	0.64
Actinolite	0	1.79	0	2.67	1.89
Magnetite	0.76	1.57	0	0	0
Rozenite	2.22	0	0	0	0
Haycockite	0.59	0	0	0	0

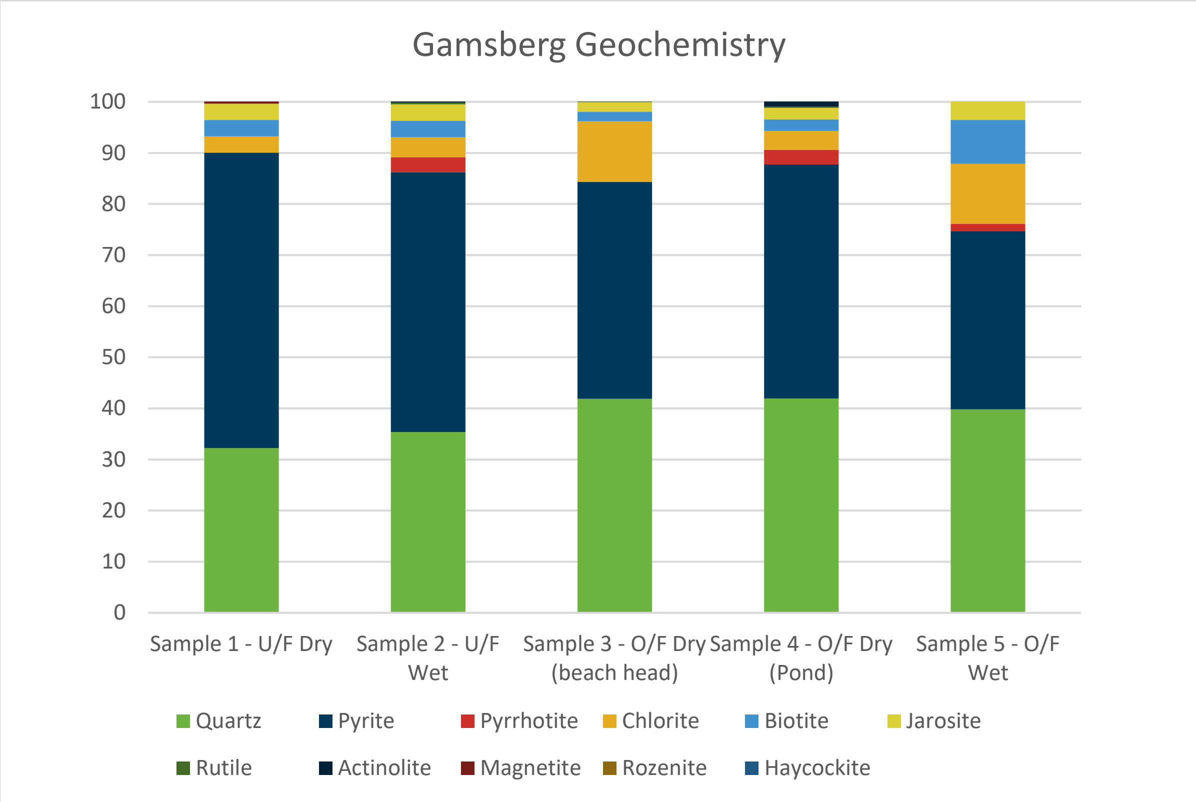

Figure 4-1 Mineral Composition of Gamsberg samples

4.2 ACID-BASE ACCOUNTING

The ABA results including Sulphur Speciation, Carbon Speciation and Acid Potential (AP) are provided in Table 4-2 below. The following observations are noted:

- The paste pH values for all the samples range from sub-acidic (5.0) to acidic (3.6).. The wet samples have pH with values ranging from 4.7 to 5.0. The older dry samples have been exposed to more oxidation than the wet samples with pH values of 3.6 and 3.7. Samples with a pH below 5.5 are classified as potentially acid generating (MEND manual, 2009).
- The sulphur speciation results are shown in Figure 4-3, all the TSF samples plot below the regression line which indicates that the sulphur is present mostly as sulphide and not sulphate. The sulphur-sulphide content for all five TSF samples are above >0.3% (average concentration: 24.3%) and are considered to be potentially acid generating (Price, 1997).
- The TSF samples contain very low carbon (<1%), this is expected as no carbonate minerals were present in the XRD analysis and confirms no risk for spontaneous combustion. Most of the carbon in the samples is present as organic carbon as seen in Figure 4-2 (assumed to be from flocculants added in the tailings process).
- The AP vs NP graph is plotted in Figure 4-5. The samples show that AP>NP indicating that the samples are acid generating and have a low buffering capacity.
- The neutralizing potential ratio (NPR) is provided in Table 4-2. The samples are considered PAG if the NPR<1 and non-PAG if NPR>2. All the samples have an NPR of less than 1 and are therefore considered to be PAG.
- The Maximum Acid Potential (MPA) has been plotted against the Acid Neutralising Capacity (ANC) as shown below in Figure 4-4. In addition, the pilot tailings from the geochemical tests

done in 2013 have been included (Whyte, 2013). The graph shows that all the dry and wet tailings samples plot in the increased risk field, with an ANC:MPA ratio of less than 1.

- Similarly the pyrite and pyrrhotite rich tailings samples plot in this increased risk field, with the magnetite rich tailings plotting in the low risk field (ANC:MPA ratio >2).
- The ERM 2013 finals tailings sample (Pilot) represents a composite sample of a mixture of the Magnetite rich, pyrite rich and pyrrhotite rich ores that would be mined in equivalent ratios. Figure 4-4 shows the current tailings samples at the Gamsberg TSF plot close to the predicted final tailings, confirming that the mining ratio is as predicted in the 2013 geochemical results but is overall acid generating.

Table 4-2 ABA Analysis for Gamsberg Samples

Sample Number	Paste pH	AP	NP	NNP	NPR (NP:AP)	Sulphide S (%)	Total Sulphur (%)
Sample 1	3.7	1 034	-27	-1 062	0.026	30.8	33.1
Sample 2	5.0	991	-0.603	-991	0.001	30.0	31.7
Sample 3	3.6	700	-19	-719	0.027	20.6	22.4
Sample 4	4.9	841	-0.603	-841	0.001	25.8	26.9
Sample 5	4.7	656	-2.12	-658	0.003	19.2	21.0
Sample 5 D	4.7	659	-1.87	-661	0.003	19.3	21.1

4.3 NET ACID GENERATION

Net acid generation (NAG) is used to assess acid generation potential and element moblisation due to sulphide oxidation reactions and mineral dissolution. The NAG pH of <4.5 and the net acid generation is > 1 kg/tonne for all samples supporting that the tailings is acid generating.

Table 4-3 NAG Results

Net Acid Generation	Sample Identification: pH 4.5					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 5
Sample Number	175229	175230	175231	175232	175233	175233 D
NAG pH: (H_2O_2)	1,9	1,9	2,0	1,9	2,0	1,9
NAG (kg H_2SO_4 / t)	86	72	61	78	60	61

Net Acid Generation	Sample Identification: pH 7.0					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 5
Sample Number	175229	175230	175231	175232	175233	175233 D
NAG pH: (H_2O_2)	4,5	4,5	4,5	4,5	4,5	4,5
NAG (kg H_2SO_4 / t)	38	41	36	37	36	37

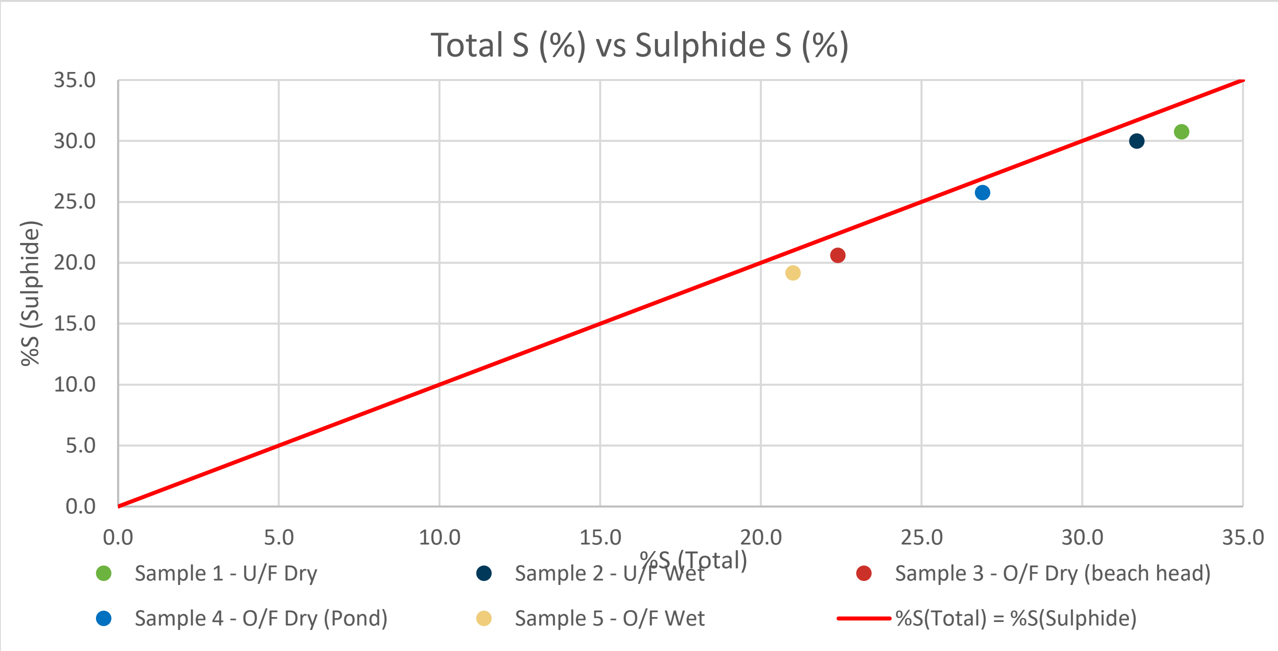

Figure 4-3: Total Sulphur (S%) Vs Sulphur-Sulphide (S%)

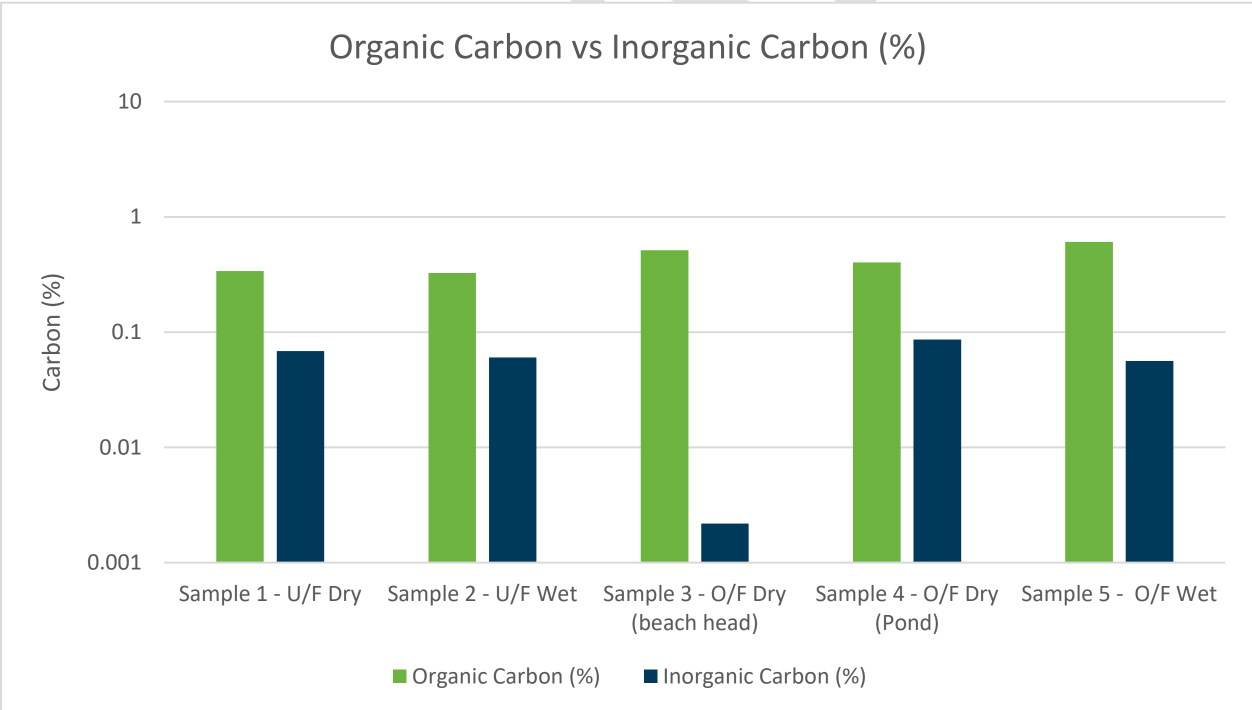

Figure 4-2: Organic Carbon (%) vs Inorganic Carbon (%)

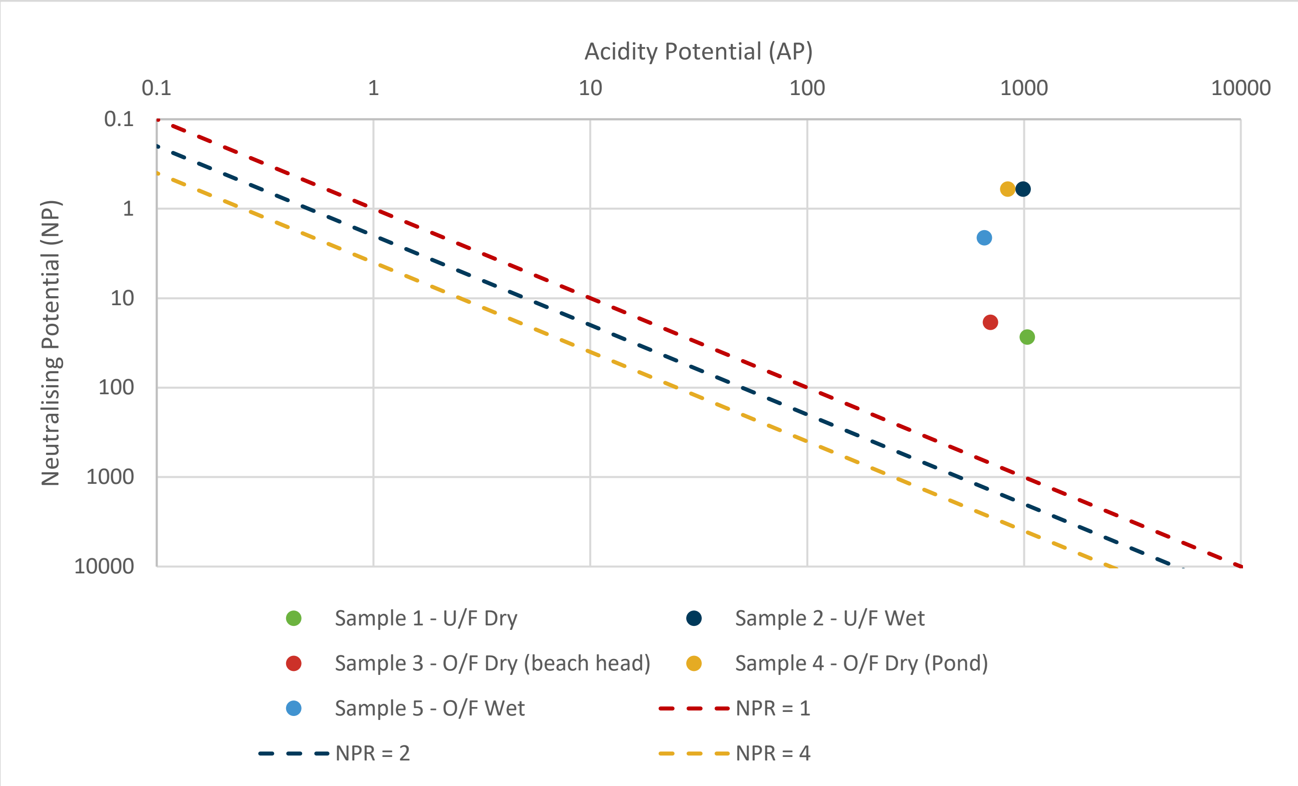

Figure 4-5: Acid Potential vs Neutralisation Potential of Gamsberg TSF samples

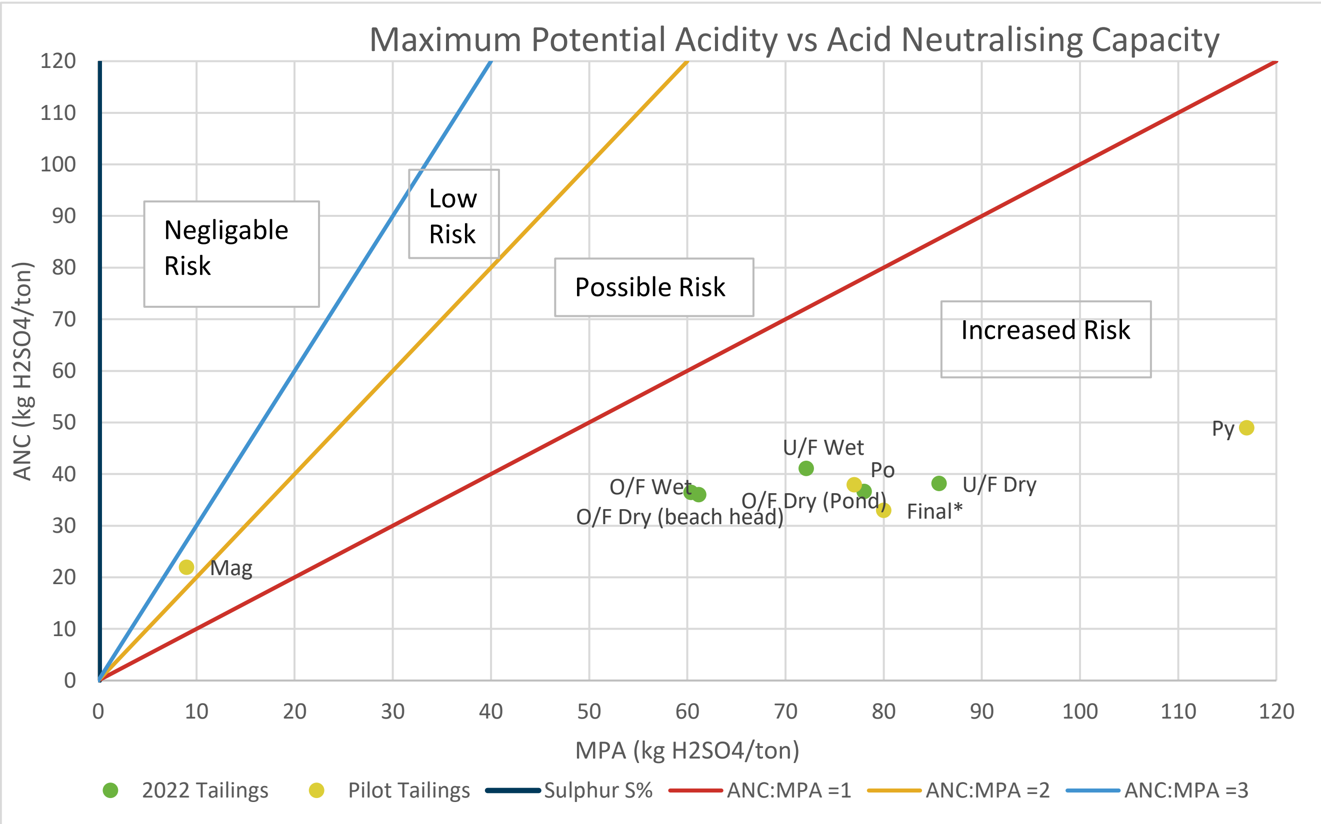

Figure 4-4: MPA vs ANC for the 2022 tailings samples and pilot samples (2013)

4.4 AMD CLASSIFICATION

An evaluation of the acid generation potential and neutralization potential was conducted using the (USEPA, 1994), (MEND manual, 2009) and (Price, 1997) criteria as detailed in Table 4-4 below. If the majority of the parameters indicate non-PAG, the rock is classified as not acid-generating. If the majority of the parameters indicate PAG, the rock is classified as acid generating or potentially acid generating (PAG).

Table 4-4 AMD Classification (USEPA 1994; Price 2005; Fey 2003, MEND 2009)

Parameter	Potentially Acid Generating	Uncertain	Non-Acid Generating	Reference
Paste pH	<5.5	-	>5.5	(MEND manual, 2009)
NNP	<-20	-20 to 20	>20	(Price, 1997)
NPR	<1	1 to 2	>2	(Price, 1997)
S%	>0.3%		<0.3%	(USEPA, 1994)
NAG KgH_2SO_4/t	>0.1		<0.1	(Price, 1997)
NAG pH	<4.5		>4.5	(MEND manual, 2009)

The summary of the AMD classification for all the samples is shown in Table 4-5 and the samples have been colour coded. The following observations were noted:

- All of the TSF samples show a paste pH ranging from 3.6 to 5.0 and are therefore classified to be potentially acid generating (PAG). The NAG pH value of the samples ranges between 1.9 - 2.0, which is less than <4.5 confirming that these samples are potentially acid generating.
- The NAG Kg H_2SO_4/t values are >0.1 for all of the TSF samples, indicating that these samples are potentially acid generating.
- The NNP values of the TSF samples is < -20, indicates the low buffering capacity of the tailings, and these samples are classified as potentially acid generating
- The sulphur-sulphide (S%), for all of the samples is acid generating, as the samples have an NPR ratio of <1 and S% of >0.3 indicating the samples are acid generating.
- The AMD classification (Table 4-5) shows that all samples classify as acid generating.

Table 4-5 AMD Classification of Gamsberg Samples

Sample Number	Paste pH	NAG pH	NAG (kg H_2SO_4/t)	Sulphide S (%)	NNP	NPR (NP:AP)	AMD Classification
Sample 1	3.7	1.9	86	30.8	-1 062	0.026	Acid Generating
Sample 2	5.0	1.9	72	30.0	-991	0.001	Acid Generating
Sample 3	3.6	2.0	61	20.6	-719	0.027	Acid Generating
Sample 4	4.9	1.9	78	25.8	-841	0.001	Acid Generating
Sample 5	4.7	2.0	60	19.2	-658	0.003	Acid Generating

4.5 MULTI-ELEMENT RESULTS

4.5.1 SPLP

As required for the classification of the waste samples in terms of GNR 635, the Gamsberg TSF samples, were subjected to the Australian Standard Leaching Procedure (ASLP) to predict the leachate concentration (LC) under slightly acidic conditions. A 1:20 solid to liquid ratio (distilled water) was used to extract soluble constituents and provide a qualitative indication of seepage quality that could leach from the tailings materials. The results of the LC are shown in Table 4-8 and the following is noted:

- The pH of the SPLP leach extract was acidic for all samples with the dry samples having lower pH than the wet samples
- The total dissolved solids(TDS) are highest for the dry samples from the underflow and overflow due to the very high sulphate concentrations up to 2200 mg/L.
- Zn, Cd, Cu and Mn are elevated in the dry samples from the underflow and overflow due to the low pH and mobilisation of heavy metals.
- It is likely that following deposition of the wet tailings, the material dries out and under the oxidising conditions, the oxidation of pyrite results in the lowering of the pH, release of sulphates and mobilisation of heavy metals.

4.5.2 TOTAL ACID DIGESTION

Aqua regia digestion is undertaken using a combination of HNO3 and HF to partially digest the waste sample and the solution is analysed by ICP scan and scaled up as the total concentration (TC) in mg/kg. The following points are noted:

- Mn, Pb and Zn are at the highest total concentrations (> 1000 mg/kg) in the tailings material as shown in the table below.
- Other metals include As, Co, Cu and Cd at lower concentrations < 1000 mg/kg)
- Fluoride is at high concentrations in the dry underflow and overflow samples, the reason for which requires further research.
- Hg, CrVI and Cyanide are not present in the tailings material.
- The Cd that is mobilised from relatively lower amounts in the total concentration shows that the low pH must be sufficiently buffered to reduce leaching of toxic metals. This will require either additional liming or testing of other materials as a pre-treatment step (Green Precipitate Treatment).
- The high iron minerals in the magnetite rich tailings may provide ferric iron required in addition to the liming process to remove the cations (Cd2+) from the tailings.
- The groundwater may provide additional buffering capacity to precipitate out the heavy metals at higher pH once the leachate reaches the groundwater but this needs to be tested under laboratory conditions.

Table 4-6 Total and Leachate Concentration Results

Parameter	Sample 1 - U/F Dry		Sample 2 - U/F Wet		Sample 3 - O/F Dry (beach head)		Sample 4 - O/F Dry (Pond)		Sample 5 - O/F Wet		Leachable Concentrations Thresholds				Total Concentrations Thresholds		
	LC (mg/l)	TC (mg/kg)	LC (mg/l)	TC (mg/kg)	LC (mg/l)	TC (mg/kg)	LC (mg/l)	TC (mg/kg)	LC (mg/l)	TC (mg/kg)	LCT 0 (mg/l)	LCT 1 (mg/l)	LCT 2 (mg/l)	LCT 3 (mg/l)	TCT 0 (mg/kg)	TCT 1 (mg/kg)	TCT 2 (mg/kg)
As, Arsenic	0.006	516	0.001	562	0.017	341	0.004	490	0.002	356	0.01	0.5	1	4	5.8	500	2 000
B, Boron	<0.025	<10	<0.025	<10	<0.025	<10	<0.025	<10	<0.025	<10	0.5	25	50	200	150	15 000	6 000
Ba, Barium	<0.025	90	0.025	114	<0.025	134	0.031	179	0.057	180	0.7	35	70	280	62.5	6 250	25 000
Cd, Cadmium	2.97	49	0.004	40	1.29	31	0.035	14	0.020	35	0.003	0.15	0.3	1.2	7.5	260	1 040
Co, Cobalt	0.232	74	<0.025	73	0.110	52	<0.025	76	<0.025	47	0.5	25	50	200	50	5 000	20 000
Cr_{Tot}, Chromium Total	0.067	84	<0.025	127	0.041	167	<0.025	162	<0.025	194	0.1	5	10	40	46 000	800 000	N/A
Cr 6+, Chromium (VI)	<0.010	<2	<0.010	<2	<0.010	<2	<0.010	<2	<0.010	<2	0.05	2.5	5	20	6.5	500	2 000
Cu, Copper	2.58	77	<0.010	37	10	359	0.140	103	0.030	159	2.0	100	200	800	16	19 500	78 000
Hg, Mercury	<0.001	<0.400	<0.001	<0.400	<0.001	<0.400	<0.001	<0.400	<0.001	<0.400	0.006	0.3	0.6	2.4	0.93	160	640
Mn, Manganese	RTF	4 400	1.31	6 000	76	4 800	22	10 000	4.04	6000	0.5	25	50	200	1 000	25 000	100 000
Mo, Molybdenum	<0.025	<10	<0.025	<10	<0.025	<10	<0.025	<10	<0.025	<10	0.07	3.5	7	28	40	1 000	4 000
Ni, Nickel	0.568	26	<0.025	37	0.351	25	0.029	34	<0.025	18	0.07	3.5	7	28	91	10 600	42 400
Pb, Lead	0.614	2 036	0.023	1 612	2.86	1 932	0.814	2 940	0.304	1624	0.01	0.5	1	4	20	1 900	7 600
Sb, Antimony	<0.001	7.2	<0.001	8	<0.001	6.4	<0.001	10	<0.001	6.80	0.02	1.0	2	8	10	75	300
Se, Selenium	<0.001	<0.400	<0.001	<0.400	<0.001	<0.400	<0.001	<0.400	<0.001	<0.400	0.01	0.5	1	4	10	50	200
V, Vanadium	<0.025	<10	<0.025	<10	<0.025	<10	<0.025	<10	<0.025	<10	0.2	10	20	80	150	2 680	10 720
Zn, Zinc	100	21 200	1.99	18 000	103	16 000	26	8 400	10	18 000	5.0	250	500	2 000	240	160 000	640 000
pH	3.7		6.3		4.1		5.5		5.8								
Chloride as Cl	<2		4		7		17		21		300	15 000	30 000	120 000	N/A	N/A	N/A
Sulphate as SO4	2 244		34		1 345		322		127		250	12 500	25 000	100 000	N/A	N/A	N/A
Nitrate as N	<0.1		<0.1		1.1		1.5		0.3		11	550	1 100	4 400	N/A	N/A	N/A
Fluoride as F	0.4	1 771	0.2	3.46	0.3	1 252	0.2	<0.5	0.2	17.87	1.5	75	150	600	100	10 000	40 000
Total Cyanide as CN	<0.07	<1.55	<0.07	<1.55	<0.07	<1.55	<0.07	<1.55	<0.07	<1.55	0.07	3.5	7	28	14	10 500	42 000

4.6 WASTE ASSESSMENT

The GN R635 specifies the National Norms and Standards for the Assessment of Waste for Landfill Disposal. The process includes identifying the chemical substances present in the waste through comparison of the Total Concentrations (TC) and Leachable Concentrations (LC) compared to Total Concentration Threshold (TCT) and Leachable Concentration Threshold (LCT) limits

The threshold levels for the TCT (TCT0, TCT1, TCT2) and LCT (LCT0, LCT1, LCT2, and LCT3) are provided which, in combination, determine the Risk Profile and corresponding waste types as set out in Table 4-7 below.

Table 4-7 Waste Type Classification

Waste Type	Criteria
Type 4	LC ≤ LCT0; and TC ≤ TCT0
Type 3	LCT0 < LC ≤ LCT1; and TC ≤ TCT1
Type 2	LCT1 < LC ≤ LCT2; and TC ≤ TCT1
Type 1	LCT2 < LC ≤ LCT3; or TCT1 < TC ≤ TCT2
Type 0	LC > LCT3; or TC > TCT2

The waste type (Type 0 to 4) described above is aligned to four landfill Classes detailed in the GN 636 National Norms & Standards for Disposal of Waste to Landfill. These landfill Classes (Class A, B, C and D) correspond to Waste Types 0 to 4 as set out in Table 4-8 below.

Table 4-8 Waste Disposal Requirements

Waste Type	Waste Risk Level	Landfill Class
Type 4	Inert Waste	Class D Landfill
Type 3	Low Risk	Class C Landfill
Type 2	Moderate Risk	Class B Landfill
Type 1	High Risk	Class A Landfill
Type 0	Very High Risk	Prohibited from Disposal

The summary of the results for total and leachate concentrations, along with applicable threshold limits used for the classification of the samples is shown in Table 4-6.

- The Leachable Concentrations (LC) of the TSF samples, for most of the parameters fall below the LCT0 threshold limits, however some samples show LC exceeding these limits.
- The dry tailings samples (Sample 1,3,and 4) exceed the LCT0 limits but not the LCT1 limits for the parameters: As, Cu, Mn, Ni, Zn and SO_4.
- The LCT2 limits are exceeded for Mn and Pb and the LCT3 limit is exceeded for Cd in the U/F dry and O/F dry samples 1 and 3.
- The wet tailings samples (Sample 2 and 5) exceed the LCT0 limits but not the LCT1 limits for the parameters Cd, Mn, Pb and Zn.
- Based on Cd exceeding the LCT03 limit (which is low due to the toxicity of cadmium), for the dry samples, the dry tailings would be classified as Type 0 waste. Cd is mobile and soluble as Cd^{2+} from pH0-6 under oxidising conditions (in tailings dam) but is stable as otavite at pH> 6 which means that liming the tailings at pH> 7 should immobilise the cadmium.

- The two dry samples had pH <5 and the wet samples at the spigot were only marginally higher (<6) indicating that the tailings were not sufficiently neutralised prior to deposition.
- The drying out of the tailings is resulting in the oxidation of pyrites, acid generation and mobilisation of heavy metals. The recommendation to maintain short deposition cycles and wet tailings to prevent ingress of air does not appear to be implemented.
- In terms of GNR632, the tailings are considered as residue deposits rather than waste and exempt from the waste classification. However, the tailings are considered hazardous or high risk due to the low pH and mobilisation of heavy metals and therefore mitigation measures to limit the impacts are required.
- Additional kinetic geochemical testing is recommended for the tailings to mitigate the impacts:
    - Column leach testing of fresh (wet tailings material) in different blend ratios with higher magnetite tailings if this could be sourced from other/older existing operations.
    - Column testing of fresh (wet tailings material) with higher buffering capacity and using the background groundwater to determine the neutralisation potential of the groundwater to precipitate heavy metals if there is leachate generated from the TSF.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the ABA analysis and Waste classification for the Gamsberg TSF samples, the following conclusions are drawn:

- The dry tailings and wet tailings are very similar in mineral composition. The mineralogy of the TSF samples is dominated by quartz and sulphur bearing minerals (pyrite, pyrrhotite and haycockite)
- Any leachate from these samples is expected to have an acidic pH due to the presence of high sulphur and sulphate minerals in the tailings.
- Most of the carbon in the samples is present as organic carbon and in small amounts <1%. This is due no carbonate minerals found in the TSF samples with only silicate minerals (quartz and chlorite) that will provide limited buffering capacity.
- The ABA analysis and AMD classification of the Gamsberg TSF samples confirms that all the samples will be acid generating.
- All of the TSF samples had sulphur-sulphide concentrations above 0.3% and an NPR ratio of <1 indicating that these samples are acid generating.
- The distilled leach testing indicates that the leachate generated from the tailings will have a low pH with high sulphate concentrations and heavy metal concentrations (As, Cd, Cu, Pb, Mn and Zn).
- Based on the norms and standards as specified in section 6 of NEM:WA (2008) Waste Classification, the samples are classified as follows;
  - The Sample 2 (U/F wet), sample 4 (O/F dry-pond) and sample 5 (O/F wet) fall within the LCT2 < LC ≤ LCT3; or TCT1 < TC ≤ TCT2, resulting in a Type 1 waste, that will require disposal at a Class A landfill .
  - The samples 1 (U/F dry) and sample 3 (O/F dry-beach head) both exceed LCT3 (LC > LCT3), resulting in a Type 0 waste due to elevated cadmium.
- The dry tailings samples classify as a type 0 waste due to the Cd in the leachate at low pH, but the wet tailings classify as a type 1 waste requiring a Class A liner. This confirms the ERM geochemical model of the dry tailings being oxidised and acid generating and therefore requiring short deposition cycles to prevent the tailings from drying out.
- In terms of the GNR 632 (NEMA), the tailings are hazardous due to mobilisation of heavy metals.
- As per the ERM recommendations the pH of the tailings material must be around 7 prior to being disposed of in the TSF.
- The current data for the Gamsberg tailings indicates that a Class A liner will be required for the new TSF but recommendations to prevent the tailings from drying out and oxidising the pyrites must be implemented or the resultant long term exposure to the elements will result in Type 0 waste.

5.2 RECOMMENDATIONS

- Kinetic testing is recommended for the tailings to clarify the following:
  - Column leach testing (humidity cell) of wet tailings combined with higher proportion of magnetite tailings, (or other ferric iron) followed by higher liming to raise the pH to at least 7 prior to deposition.

    - Trickle down testing of deeper old tailings material (below phreatic surface) to determine if once submerged by subsequent deposition cycles, the tailings will generate less ARD and therefore less mobilisation of heavy metals.
    - Column leach testing of tailings with actual groundwater to determine the buffering capacity of the groundwater and precipitation of heavy metal cations once leachate reaches the groundwater table.
- In accordance with the GNR 632, KP recommends that a detailed hydrogeological investigation is undertaken which includes the following: (as adapted from GNR 632)
    a. Geohydrological properties of the strata within the zone that could potentially be affected by the quality of seepage
    b. Define vulnerability and existing or potential use of groundwater resources within the zone that could be potentially affected by the residue facility and,
    c. Determine the potential rate of seepage from the facility and quality of the seepage using groundwater contaminant transport model.

6.0 REFERENCES

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7.0 CERTIFICATION

This report was prepared and reviewed by the undersigned.

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APPENDIX A GEOCHEMICAL CERTIFICATES