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GAMSBERG ZINC MINING PROJECT
WASTE CLASSIFICATION ASSESSEMENT

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EXECUTIVE SUMMARY

Black mountain Mining (Pty) Ltd (BMM), a subsidiary of Vendata 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. BMM 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, and provide input to the liner requirements in line with the regulations. This report covers the Waste Classification of the 2nd round of tailing's material (phase 2) taken at the current cyclone TSF at the Gamsberg Mine and the pilot tailings for the TSF expansion.

Following the initial geochemical assessment, a total of 8 additional samples were collected from the Gamsberg TSF for the 2nd round of static testing. These samples are representative of the various feed tails, RWD and the test slurry for the TSF expansion at Gamsberg Mine. The static geochemical test work was carried out by Waterlab (Pty) Ltd, a SANAS (South African National Accreditation System) accredited laboratory.

Based on the ABA analysis and Waste Classification for the 2023 Gamsberg TSF samples (phase 2 static testing), the following conclusions are noted, the leachate from the samples is expected to have an acidic pH due to the presence of high sulphur and sulphate minerals in the tailings. There is limited carbonate minerals, only silicate minerals (quartz and chlorite) that will provide limited buffering capacity.

The ABA analysis and AMD classification for the 2023 Gamsberg TSF samples confirms that all the samples will be acid generating, including the pilot tailings for the TSF expansion. The distilled leach testing (SPLP) indicates that the leachate generated from the tailings will have a low pH (3.7-5.6) with high sulphate concentrations and elevated heavy metal concentrations (As, Cd, Cu, Pb, Mn and Zn) which is a concern.

Based on the norms and standards as specified in section 6 of NEM:WA (2008) Waste Classification, the 2023 TSF samples are classified as follows;

1. The samples taken from the TSF wall, beach head, beach pond, TSF O/F, TSF U/F and Silt trap sediment 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 .
2. While the RWD sample falls within LCT1 < LC ≤ LCT2; and TC ≤ TCT1 resulting in a type 2 waste, which requires a Class B landfill. The pilot tailings for the TSF expansion falls within LCT0 < LC ≤ LCT1; and TC ≤ TCT1, resulting in a type 3 waste which requires a Class C landfill.

Unlike the 2022 samples, none of the 2023 TSF samples have classified as a type 0 waste, although the 2023 samples are similar in that the leachate from the samples is acidic, with elevated heavy metals. As identified in the 2022 study, the arid environment in this region poses a major risk to the tailings as they dry out and oxidise, they become acid generating. The Gamsberg tailings still poses a risk to the environment, with both the ABA and AMD assessment classifying the Gamsberg TSF samples and the pilot tailings as acid generating. In terms of the GNR 632 (NEMA), the tailings are hazardous due to mobilisation of heavy metals at a low pH which is feasible for the Gamsberg TSF samples.

Following the 2023 static testing of the 2nd round of TSF samples, KP recommends that a 2nd phase of kinetic testing is conducted on the Gamsberg 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 les 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.

- As per the ERM recommendations the pH of the tailings material must be around 7 prior to being disposed of in the Gamsberg TSF. Short deposition cycles should also be followed on the TSF to help prevent the tailings from drying out.

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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

1.0 INTRODUCTION

Black mountain Mining (Pty) Ltd (BMM), a subsidiary of Vendata 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 in owned by Vendata 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. On the premises, a processing plant is present, and the life of mine is estimated at 30+ years. Gamsberg is located in the lower Orange River water management area and falls within the D28C quaternary catchment.

BMM 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 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. Following the initial waste classification (phase 1) conducted in 2022 by KP, additional samples for static geochemical testing and analysis was recommended. As part of the expansion of the TSF which will be towards the north, a second waste classification assessment of the tailing's material was undertaken by KP, and provide input to the liner requirements in line with the regulations.

This report covers the Waste Classification of the 2nd round of tailing's material (phase 2) taken at the current cyclone TSF at the Gamsberg Mine and the pilot tailings for the TSF expansion. The tailings samples were collected from various locations on the TSF including the both the underflow (U/F) and overflow (O/F) streams. This report details the findings of the assessment and recommendations.

1.1 SCOPE OF REPORT

The scope of the work undertaken for the 2nd round of samples is as follows:

- Collect representative samples for geochemical analysis of the current and future 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 (14 July 2015) and the Mineral and Petroleum Resources Development Act (Act 28 of 2002) (MPRDA);
- Interpretation of laboratory results
- Classify the current and future tailings material in terms of WMCR GNR 634 and GNR 632
- Prepare a report for the phase 2 samples documenting the findings of the classification and
- Recommend the liner requirements in terms of geochemical tailings assessment.

2.0 GEOCHEMICAL 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 STATIC GEOCHEMICAL TESTS

The 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) is commonly used in the assessment of mine waste materials to determine the 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

Following the initial geochemical assessment, a total of 8 additional samples were collected from the Gamsberg TSF for the 2nd round of static testing. These samples are representative of the various feed tails, RWD and the test slurry for the TSF expansion at Gamsberg Mine. The sample locations are shown below in Figure 3-1. The samples (KPGM-S01, S02, S04, S08) are representative of dry tailings, while the samples (KPGM-S05, S07) are representative of wet tailings.

The samples were collected by KP and sent to Waterlab, an accredited laboratory for geochemical testing. The sample details are shown below in Table 3-1, and the full description for each sample is as follows:

- KPGM-S01: TSF Wall
- KPGM-S02: TSF Beachhead
- KPGM-S03: RWD Evaporates
- KPGM-S04: TSF Overflow
- KPGM-S05: Beach Pond
- KPGM-SO6: Silt Trap precipitate/sediments
- KPGM-SO7: TSF underflow
- KPGM-SO8: TSF Test work

Table 3-1: Full sample description for 2023 samples

Sample ID	Sample Description	Latitude	Longitude
KPGM-S01	TSF Wall	-29.189	18.946
KPGM-S02	TSF Beach head	-29.190	18.946
KPGM-S03	RWD Evaporates	-29.199	18.947
KPGM-S04	TSF Overflow (O/F)	-29.188	18.948
KPGM-S05	Beach Pond	-29.192	18.946
KPGM-S06	Silt Trap precipitates/sediments	-29.195	18.945
KPGM-S07	TSF Underflow (U/F)	-29.188	18.948
KPGM-S08	TSF Pilot sample (TSF expansion)	-	-
KPGM-S08-D	TSF Pilot sample Duplicate	-	-

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 2 Static Analysis

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

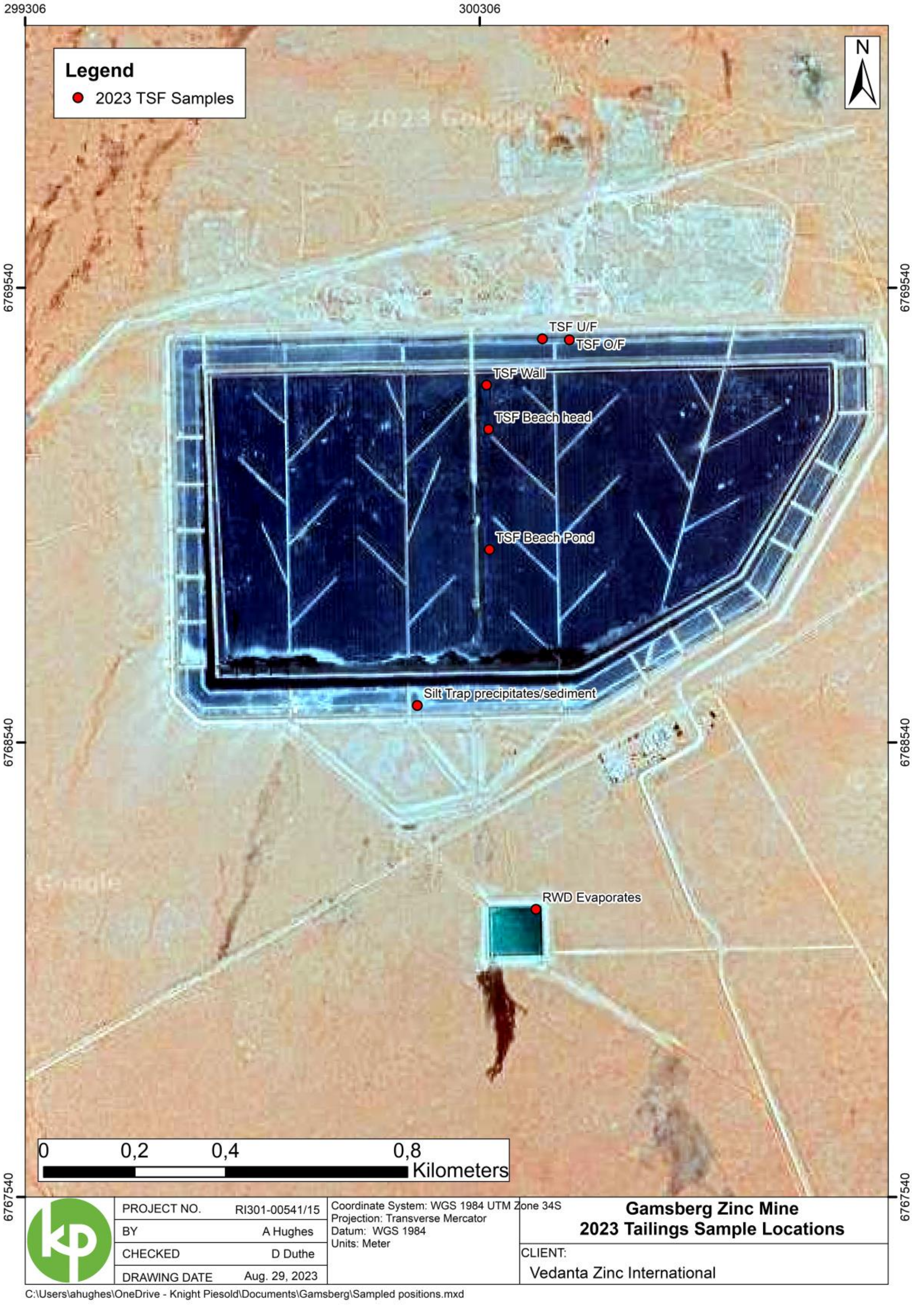

Figure 3-1: 2023 Gamsberg TSF sample locations

4.0 ANALYTICAL RESULTS

4.1 MINERALOGICAL COMPOSITION

The results of the X-Ray diffraction (XRD) analysis are shown in **Error! Reference source not found.** below and shown graphically in **Error! Reference source not found.**. These results show that all the samples from the Gamsberg TSF are dominated by Quartz and Pyrite, while the RWD and silt trap precipitate samples (KPGM-S03 & S06) are dominated by gypsum.

Similarly, to the previous samples (2022), there is little difference in mineralogic composition between the dry and wet tailings (pyrrhotite, biotite and chloride). The pilot tailings for the TSF expansion also show a similar composition; however, this sample does not contain kaolinite. In contrast the RWD and silt trap samples are dominated by gypsum (>95%)with small amounts of pyrite (<2%). None of the samples contain carbonate minerals but the presence of silicate minerals (Chlorite, Quartz and Kaolinite) indicates that the samples can provide some buffering capacity.

Table 4-1: Results of XRD Analysis

Mineral Amount Weight (%)	KPG M-S01	KPG M-S02	KPG M-S03	KPG M-S04	KPG M-S05	KPG M-S06	KPG M-S07 U	KPG M-S08 T
Quartz	32.88	48.37	1.15	48.82	46.08	1.84	42.69	45.64
Gypsum	0	0	96.8	0.99	1.13	96.38	0	0
Pyrite	50.47	43.37	1.11	22.88	33.74	1.77	28.7	32.92
Pyrrhotite	6.63	3.48	0	4.65	1.96	0	7.85	6.85
Chlorite	4.31	0	0	9.8	10.38	0	10.27	7.92
Kaolinite	2.03	2.06	0	2.66	2.18	0	1.26	0
Biotite	3.19	2.72	0	9.83	4	0	8.14	6.67
Rutile	0	0	0	0.37	0.52	0	0.33	0
Hematite	0	0	0.94	0	0	0	0.75	0

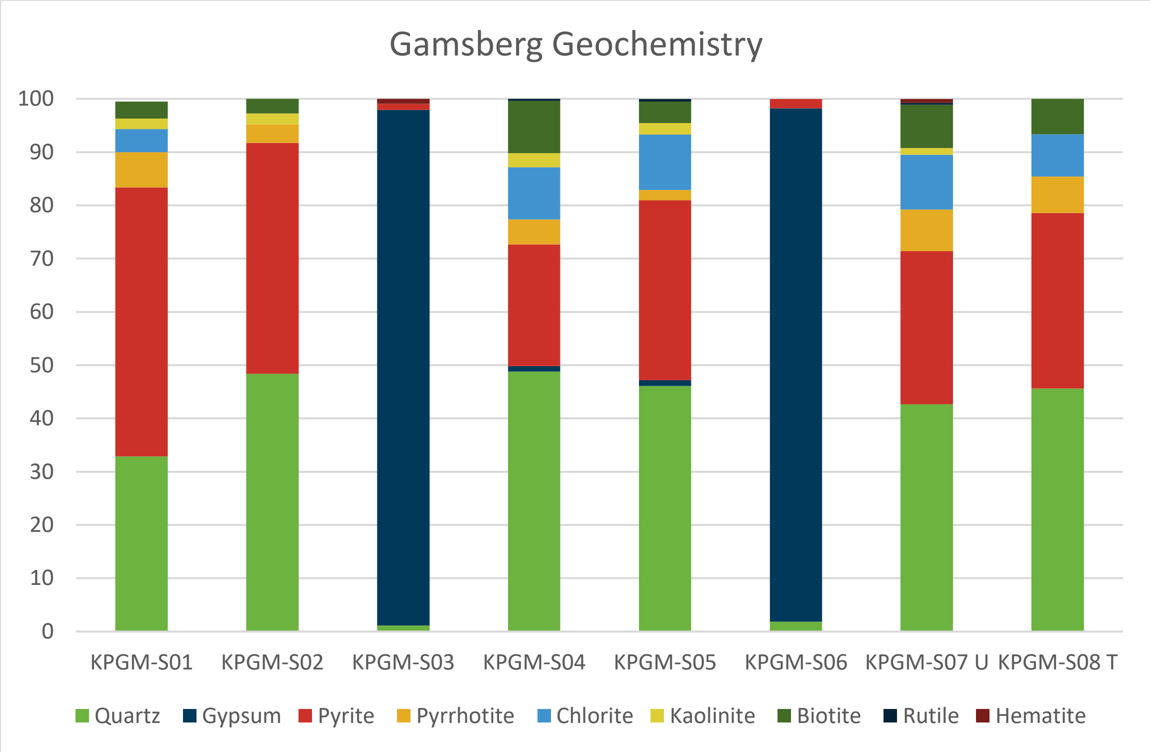

Figure 4-1: Mineral Composition of Gamsberg 2023 samples

4.2 ACID BASE ACCOUNTING

The ABA results including the Sulphur speciation, Carbon speciation and Acid Potential (AP) are provided in **Error! Reference source not found.** and discussed in more details below.

- The paste pH for all the samples ranges from sub acidic (4.3) to neutral (7.1). The tailings samples all show acidic pH values, similar to the previous results (report 2022) the dry tailings (KPGM-S01, S02, S04, S08) show the lowest pH values <5, while the wet tailings (KPGM-S05, S07) ranges from 5 - 7.1. The samples with a paste pH below 5.5 are classified as potentially acid generating (Mend manual, 2009)
- The sulphur speciation of the 2023 tailings samples are shown in **Error! Reference source not found.**, all of the samples plot on or below the regression line which indicates that the sulphur is present mostly as sulphide and not as sulphate. The sulphur-sulphide content of the TSF samples are all above 0.3 % (average concentration 45 %) and are thus considered to be potentially acid generating (ref).
- The carbon speciation for all the samples is shown in **Error! Reference source not found.**, most of the carbon for the samples is present as organic carbon. As the carbon amount for all the samples is small (<1%), which is expected as no-carbonate minerals were present in the XRD analysis, the potential for combustion from these tailings samples is low.
- The AP vs NP for all the TSF sample taken in 2023 show that the AP > NP, indicating that the samples are acid generating and have a low buffering capacity. All the NP values for the samples are negative, which indicates that these samples have a low buffering capacity.
- The neutralising potential ratio (NPR) is provided in **Error! Reference source not found.** below. A sample is considered PAG is the NPR<1 and non-PAG if NPR>2. All the samples taken in 2023 show an NPR of less than 1 and are therefore considered to be PAG. Furthermore, the NPR vs the paste pH of the samples has been plotted in **Error! Reference**

source not found., all of the samples plot in the Acid generating field with a paste pH of <5.5 and NPR of <1. However, the sample from the beach pond (KPGM-S05), plots in the Potentially Acid Generating Field, with a paste pH of >5.5 and NPR <1.

- The Maximum Acid Potential (MPA) has been plotted against the Acid Neutralising Capacity (ANC) as shown in **Error! Reference source not found.**. All of the samples plot in the increased risk field, with an MPA:ANC ratio of less than 1. However, the sample from the TSF Overflow (KPGM-S04) plots in the Possible Risk field, with an MPA:ANC ration of less than 2 but greater than 1.
- As observed in the phase 1 testing, the 2023 samples show that the current tailings plot close to the predicted final tailings, confirming that mining ratio is as predicted in the 2013 geochemical results but these samples are overall acid generating. The pilot tailings for the TSF expansion also plots close to the pilot tailings from 2013, which indicates that the ratios of the magnetite, pyrrhotite and pyrite rich tailings will be similar for the expansion work.

Table 4-2: ABA Analysis for Gamsberg 2023 samples

Sample Number	Paste pH	AP	NP	NNP	NPR	Total Sulphur (%)	Sulphide S (%)
KPGM-S01	4.3	1961	-4.00	-1965	0.002	63	61.5
KPGM-S02	4.6	1280	-2.25	-1282	0.002	41	36.4
KPGM-S04	4.7	849	-3.25	-852	0.004	27	24.1
KPGM-S05	7.1	1308	-3.75	-1312	0.003	42	39.0
KPGM-S07 U	5.0	1628	-1.50	-1630	0.001	52	49.3
KPGM-S08 T	4.7	1685	-3.75	-1689	0.002	54	52.8
KPGM-S08 T	4.7	1674	-4.00	-1678	0.002	54	52.4

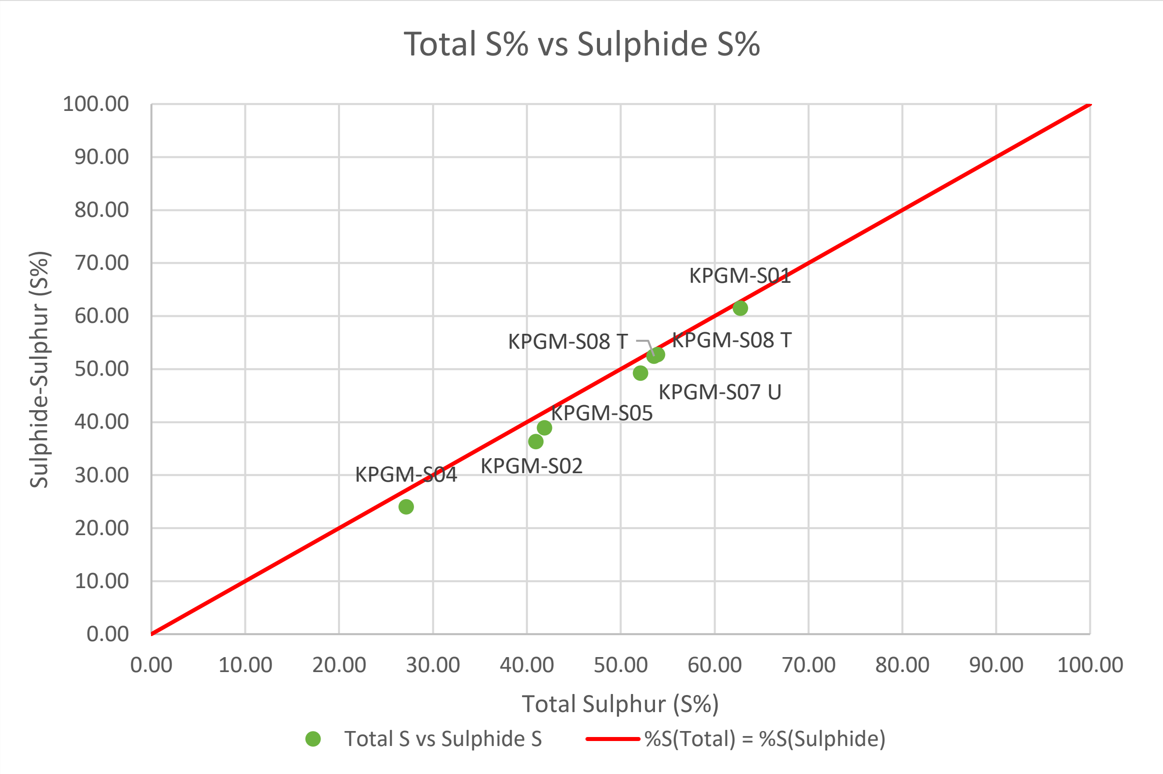

Figure 4-2: Total Sulphur (S%) vs Sulphur-Sulphide (S%)

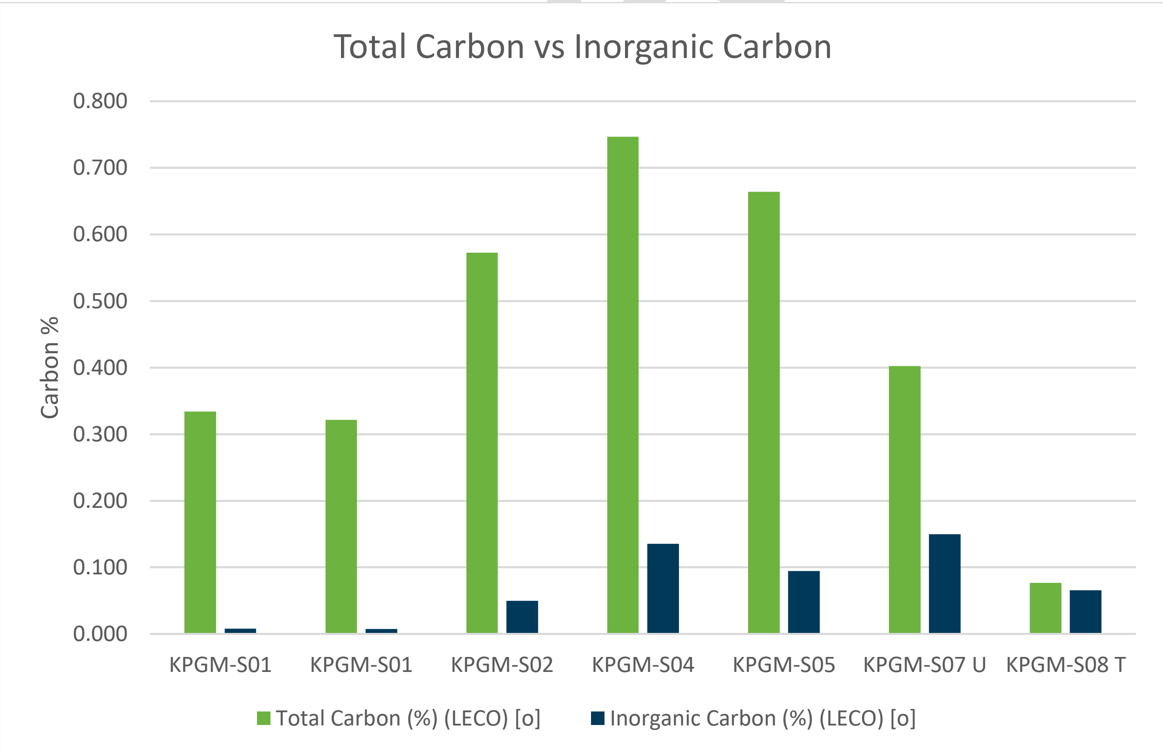

Figure 4-3: Organic Carbon (%) vs Inorganic Carbon (%)

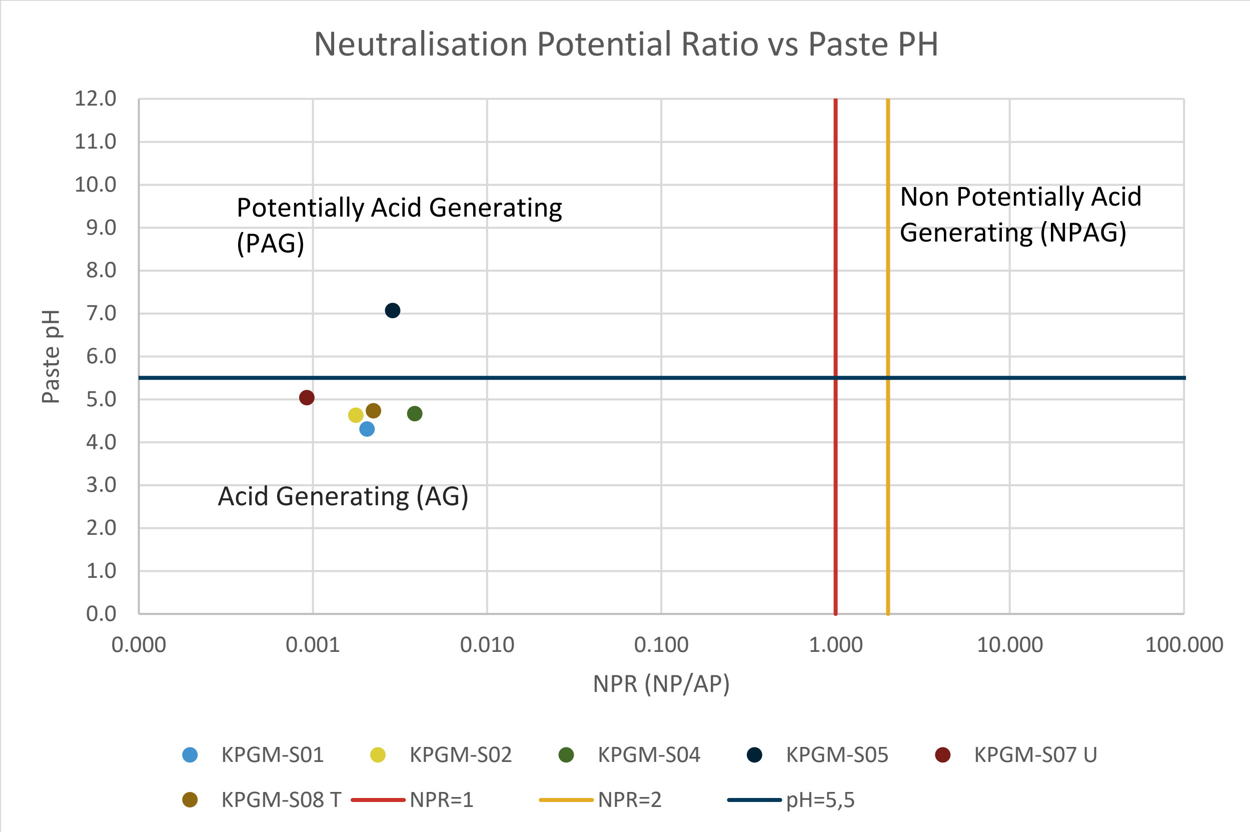

Figure 4-4: Neutralising Potential Ratio (NPR) vs Paste pH for 2023 samples

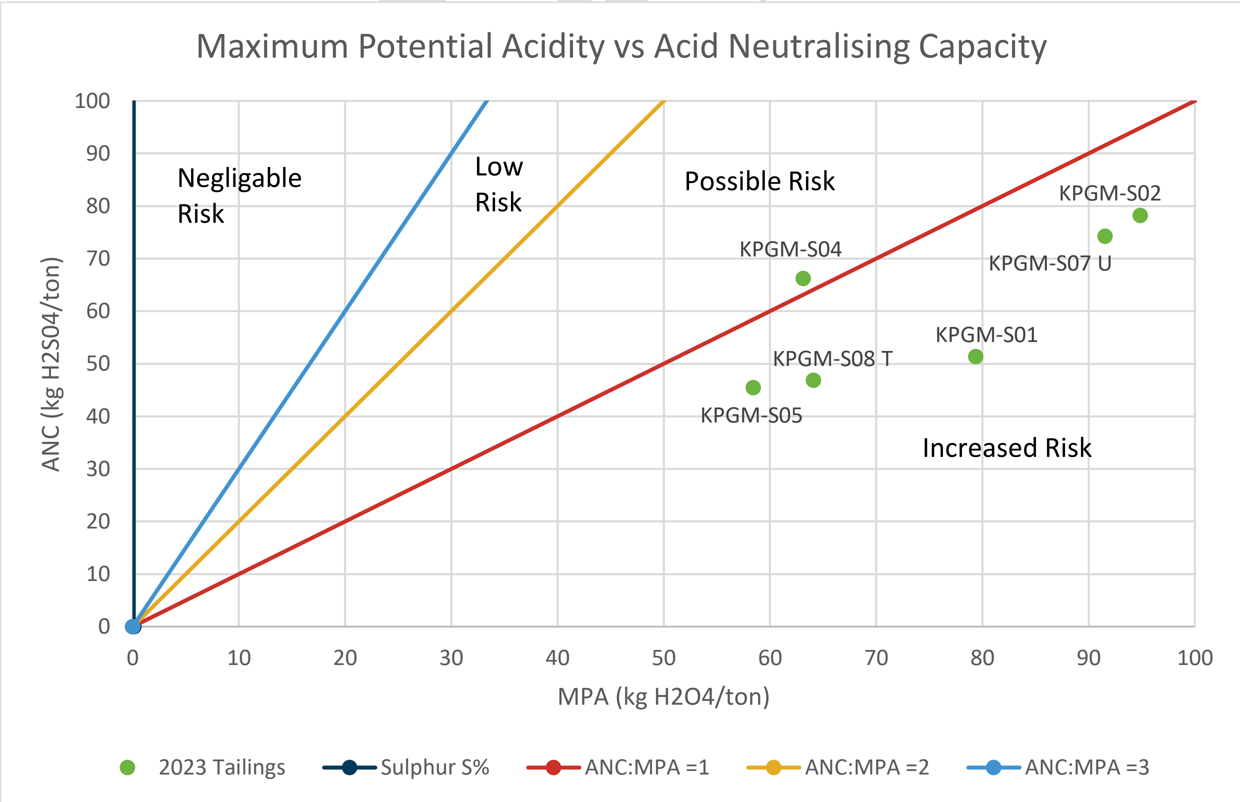

Figure 4-5: Acid Potential vs Neutralising Capacity of 2023 Gamsberg samples

4.3 NET ACID GENERATION

Net acid generation (NAG) is used to assess acid generation potential and element mobilisation due to sulphide oxidation reactions and mineral dissolution. The NAG pH is <4.5 and the net acid generation is > 1 kg/tonne for all the 2023 samples supporting that the current tailings and pilot tailings for the expansion is acid generating. The same was observed for the 2022 samples.

Table 4-3: NAG results for 2023 Gamsberg samples

Net Acid Generation	Sample Identification: pH 4.5						
Sample Number	KPGM-S01	KPGM-S02	KPGM-S04	KPGM-S05	KPGM-S07 U	KPGM-S08 T	KPGM-S08 T
NAG pH: (H_2O_2)	1.8	2.1	2.3	1.9	2.1	1.9	2.0
Titration with NaOH	79	48	32	58	46.7	64	63
Final pH: (H_2O_2)	2	5	5	2	4.5	2	2
NAG (kg H_2SO_4 / t)	79	95	63	58	92	64	63
Net Acid Generation	Sample Identification: pH 7.0						
Sample Number	KPGM-S01	KPGM-S02	KPGM-S04	KPGM-S05	KPGM-S07 U	KPGM-S08 T	KPGM-S08 T
NAG pH: (H_2O_2)	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Titration with NaOH	51	40	34	45	37.9	47	46
Final pH: (H_2O_2)	5	7	7	4	7.0	4	4
NAG (kg H_2SO_4 / t)	51	78	66	45	74	47	46

4.4 AMD CLASSIFICATION

An evaluation of acid generating potential and neutralisation potential was conducted using the refs, criteria as detailed in **Error! Reference source not found.** 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, then 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 **Error! Reference source not found.** and the samples have been colour coded as per table x above. The following observations for the Gamsberg TSF samples were noted:

- The samples from the TSF show a paste pH ranging from sub acidic (4.31) to neutral (7.01), apart from KPGM-S05, all of the samples fall below 5.5 Which indicates that these samples are PAG. While the NAG pH values for all the samples ranges from 1.80 to 2.88, which is less than 4.5 indicating that these samples are PAG.
- The NAG values are >0.1 for all of the TSF samples, indicating that these samples are PAG.
- The NNP values for all the samples is < -20, indicating a low buffering capacity of the tailings and these samples are classified as PAG.
- The NPR is plotted versus sulphur-sulphide (S%) in fig x and shows all of the samples except KPGM-S05, plot in the acid generating field. While KPGM-S065 plots in the potentially acid generating field. The high sulphur-sulphide content for all of the samples (>0.3) indicates the indicates the potential for acid generation.
- The AMD classification (**Error! Reference source not found.**) shows that all the 2023 samples from Gamsberg classify as acid generating.

Table 4-5: AMD Classification of 2023 Gamsberg Samples

Sample ID	Paste pH	NNP	NPR (NP : AP)	Sulphide S (%)	NAG (kg H_2SO_4 / t)	NAG pH	AMD Classification
KPGM-S01	4.3	-1964.5	0	61.5	79.4	1.8	Acid Generating
KPGM-S02	4.6	-1282.4	0	36.4	94.9	2.1	Acid Generating
KPGM-S04	4.7	-852	0	24.1	63.1	2.3	Acid Generating
KPGM-S05	7.1	-1311.8	0	39.0	58.4	1.9	Acid Generating
KPGM-S07 U	5	-1629.8	0	49.3	91.5	2.1	Acid Generating
KPGM-S08 T	4.7	-1688.7	0	52.8	64.1	1.9	Acid Generating
KPGM-S08 T	4.7	-1677.5	0	52.4	62.7	2	Acid Generating

4.5 MUTLI-ELEMENT RESULTS

4.5.1 SPLP

As required in GNR 635, in terms of waste classification, the 2023 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 tailing's materials. The results of the LC are shown in **Error! Reference source not found.** and the following is noted:

- The pH of the SPLP leach extract was acidic for all the TSF samples with values ranging from 3.7 – 5.6. The silt trap showed the lowest pH, while the dry tailings (KPGM-S01, S02, S04, S08) show lower pH than the wet tailings (KPGM-S05, S07), this was also observed with the 2022 samples (2022 report).
- The Total Dissolved Solids (TDS) is highest for the silt trap sample (KPGM-S06) while the overflow (O/F), underflow (U/F) and the dry tailings (KPGM-S01, S02, S04, S08) also show high TDS due to the very high sulphate concentrations (up to 1500 mg/l).
- The 2023 tailings samples show elevated concentrations for Cu, Cd, Mn and Pb due to the low pH present and mobilisation of heavy metals. The overflow and underflow tailings show lower heavy metal concentrations (Pb, Cd) when compared to the dry tailings (KPGM-S01, S02, S04, S08). This same observation was noted with the 2022 samples (report), where the dry samples show the highest heavy metals concentrations.
- The dry arid conditions at Gamsberg mine, causes the wet tailings to dry under oxidising condition, and as the TSF samples contain pyrite, the oxidation of pyrite results in lowering the pH, release of sulphates and mobilisation of heavy metals. Both the 2022 and 2023 samples show that the dry tailings material have a low pH and elevated sulphate and heavy metal concentrations particularly Cd, Pb Cu and As.

4.5.2 TOTAL ACID DIGESTION

The aqua regia digestion is undertaken using a combination of HNO_3 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:

- The metals Mn, Pb and Zn show the highest total concentration (> 1000 mg/kg) for all the 2023 tailings samples, as shown in **Error! Reference source not found.** below.
- While other heavy metals such as As and Cu show elevated concentrations (> 500 mg/kg) for all the samples.
- Unlike the 2022 samples, the total fluoride concentrations are low for all the 2023 tailings samples.
- Hg, Cr VI and Cyanide are not present in the 2023 tailings material, the same was observed for the 2022 samples.
- The total Cd and As concentrations for the 2023 samples are lower when compared to the 2022 samples. However, the low pH values associated with the 2023 tailings is a concern, as this will allow the mobilisation of heavy metals. The low Cd concentrations for the 2023 samples could be attributed to a slight change in the final tailings composition as the magnetite rich tailings from Gamsberg have a high iron mineral content which can provide ferric iron, which may remove some of the Cd^{2+} cations from the final tailings.
- Furthermore, 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	KPGM-S01		KPGM-S02		KPGM-S03		KPGM-S04		KPGM-S05		KPGM-S06		KPGM-S07 U		KPGM-S08 T		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)	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	0.007	586	0.004	340	0.001	2.80	0.003	279	0.005	369	0.017	19	0.003	344	0.004	388	0.01	0.5	1	4	5.8	500	2 000
B, Boron	0.245	70	0.383	158	0.078	97	<0.025	104	<0.025	47	<0.025	20	<0.025	<10	<0.025	81	0.5	25	50	200	150	15 000	6 000
Ba, Barium	<0.025	100.00	0.046	135.200	0.033	10.000	0.046	122.000	0.049	123.600	<0.025	<10	0.037	116.800	0.047	113	0.7	35	70	280	62.5	6 250	25 000
Cd, Cadmium	0.081	22	0.045	36	0.005	0.400	0.056	43	0.047	24	0.106	14	0.031	38	0.018	7.60	0.003	0.15	0.3	1.2	7.5	260	1 040
Co, Cobalt	<0.025	61	<0.025	30	<0.025	<10	<0.025	19	<0.025	31	<0.025	<10	<0.025	28	<0.025	45	0.5	25	50	200	50	5 000	20 000
Cr_{Tot}, Chromium Total	<0.025	142	<0.025	214	<0.025	<10	<0.025	225	<0.025	184	<0.025	<10	<0.025	154	<0.025	386	0.1	5	10	40	46 000	800 000	N/A
Cr 6+, Chromium (VI)	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200	0.05	2.5	5	20	6.5	500	2 000
Cu, Copper	0.944	132	0.014	312	0.055	6.40	0.054	455	0.155	349	3.97	741	0.015	197	0.022	99	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	<0.001	<0.400	<0.001	<0.400	<0.001	<0.400	0.006	0.3	0.6	2.4	0.93	160	640
Mn, Manganese	24	6080	14	6965	10	143	5.82	10086	7.01	5242	16	546	3.66	11512	5.44	4317	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	<0.025	<10	<0.025	<10	<0.025	<10	0.07	3.5	7	28	40	1 000	4 000
Ni, Nickel	0.086	30	0.103	36	<0.025	<10	0.103	48	0.033	25	<0.025	24	0.077	31	0.063	177	0.07	3.5	7	28	91	10 600	42 400
Pb, Lead	2.905	1070	1.63	1585	0.748	163	0.491	2421	1.502	1746	3.193	160	0.297	1911	0.271	1161	0.01	0.5	1	4	20	1 900	7 600
Sb, Antimony	<0.001	8.40	<0.001	8.80	0.001	<0.400	0.001	12	0.001	11	0.002	2.40	0.001	9.60	0.001	1.00	0.02	1.0	2	8	10	75	300
Se, Selenium	0.005	1.60	0.005	<0.400	<0.001	1.60	<0.001	<0.400	0.002	1.20	<0.001	0.800	<0.001	2.40	<0.001	4.00	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	<0.025	<10	<0.025	<10	<0.025	<10	0.2	10	20	80	150	2 680	10 720
Zn, Zinc	31	14800	28	24000	4.50	398	15	23600	14	14400	15	2567	9.70	18800	16	5600	5.0	250	500	2 000	240	160 000	640 000
pH	4.1		5.2		4.7		5.6		5.1		3.7		5.6		5.6								
Chloride as Cl	<2	647.80	<2	1731.00	15	970.40	5	1858.00	11	1384.00	15	350.90	5	2516.00	5	3432.00	300	15 000	30 000	120 000	N/A	N/A	N/A
Sulphate as SO4	149	5372.00	221	7147.00	1498	19227.00	184	7633.00	156	9895.00	1514	20291.00	109	5018.00	89	3211.00	250	12 500	25 000	100 000	N/A	N/A	N/A
Nitrate as N	<0.1	<5	<0.1	<5	0.2	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	11	550	1 100	4 400	N/A	N/A	N/A
Fluoride as F	<0.2	4.35	0.2	3.14	0.4	10.89	0.5	16.69	0.2	26.68	0.2	15.02	0.4	10.71	1.1	1.47	1.5	75	150	600	100	10 000	40 000
Total Cyanide as CN	0.10	<1.55	<0.07	<1.55	0.55	<1.55	<0.07	<1.55	<0.07	<1.55	0.09	2.20	<0.07	<1.55	<0.07	<1.55	0.07	3.5	7	28	14	10 500	42 000

4.6 WASTE ASSESSMENT

The assessment of waste must be undertaken in accordance with GN R635 National Norms and Standards for the Assessment of Waste for Landfill Disposal. The process includes identifying the chemical substances present in the waste through analysis of the Total Concentrations (TC) and Leachable Concentrations (LC) of the samples taken. These results are compared to Total Concentration Threshold (TCT) and Leachable Concentration Threshold (LCT) limits specified in GN R635 and the outcome is used to establish the type of waste and what the most suitable disposal method for it is. Various 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 **Error! Reference source not found.** 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 **Error! Reference source not found.** 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 the total and leachate concentrations, along with applicable threshold limits used for the classification of the samples is shown in **Error! Reference source not found.**. The following was noted:

- The Leachable Concentrations (LC) of the 2023 TSF samples, for majority of the parameters fall below the LCT0 threshold limits, however some samples show LC exceeding the limits.
- All the TSF samples, including the O/F and U/F samples, exceed the LCT0 but not the LCT1 limits for the parameters As, Cd, Mn, Ni, Pb, SO_4 and Zn. While the RWD sample exceeds the LCT1 limit for Pb but not the LCT2 limit.
- However, the LCT2 limits are exceeded for Pb by the TSF Wall, Beachhead, Beach pond and Silt trap samples, but all these samples are within the LCT3 limits.
- Unlike the 2022 samples, none of the Cd concentrations exceed the LCT1 limits for the 2023 TSF samples. The TSF Wall, Beachhead, O/F, Beach pond, Silt trap and U/F all classify as

Type 1 waste, whereas the RWD evaporates sample classifies as a Type 2 and the pilot tailings for the TSF expansion classifies as Type 3 waste.

- The dry samples show elevated heavy metal concentrations and lower pH values compared to the wet tailings, this is expected as the drying of the tailings is resulting in the oxidation of pyrites, acid generation and mobilisation of heavy metals. KP recommends that Gamsberg maintains 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.
- Following the results of the ABA analysis and AMD classification, KP recommends that additional kinetic geochemical testing for the Gamsberg tailings be conducted to mitigate the impacts:
    1. 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.
    2. 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

Based on the ABA analysis and Waste Classification for the 2023 Gamsberg TSF samples (phase 2 static testing), the following conclusions are drawn:

- The current tailings material and the pilot tailings for the Gamsberg TSF expansion, are similar in mineral composition, with all the 2023 TSF samples being dominated by quartz and sulphur bearing minerals (Pyrite, pyrrhotite and haycockite). Whereas the RWD sample silt trap sample are dominated by gypsum and pyrite.
- The leachate from these samples is expected to have an acidic pH due to the presence of high sulphur and sulphate minerals in the tailings.
- The carbon in the TSF 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.
- Based on the ABA analysis and AMD classification, the 2023 Gamsberg TSF samples confirms that all the samples will be acid generating. Including the pilot tailings for the TSF expansion.
- 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 (SPLP) indicates that the leachate generated from the tailings will have a low pH (3.7-5.6) with high sulphate concentrations and elevated 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;

    3. The samples taken from the TSF wall, beach head, beach pond, TSF O/F, TSF U/F and Silt trap sediment 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 .
    4. While the RWD sample falls within LCT1 < LC ≤ LCT2; and TC ≤ TCT1 resulting in a type 2 waste, which requires a Class B landfill. The pilot tailings for the TSF expansion falls within LCT0 < LC ≤ LCT1; and TC ≤ TCT1, resulting in a type 3 waste which requires a Class C landfill.

- Unlike the 2022 samples, none of the TSF samples taken in 2023 have classified as a type 0 waste, although the 2023 samples are similar in that the leachate from the samples is acidic, with elevated heavy metals. As identified in the 2022 study, the arid environment in this region poses a major risk to the tailings as they dry out and oxidise, they become acid generating. The Gamsberg tailings still poses a risk to the environment, with both the ABA and AMD assessment classifying the Gamsberg TSF samples and the pilot tailings as acid generating.
- In terms of the GNR 632 (NEMA), the tailings are hazardous due to mobilisation of heavy metals at a low pH which is feasible for the Gamsberg TSF samples.
- Based on the 2023 data for the Gamsberg tailings indicates that a Class A liner will be required for the TSF expansion. As noted in the 2022 report KP recommendations to prevent the tailings from drying out and oxidising or the resultant long term exposure to the elements will result in Type 0 waste.

5.1 RECOMMENDATIONS

- Based on the 2023 static testing of the 2nd round of TSF samples, KP recommends that a 2nd phase of kinetic testing is conducted on the Gamsberg 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 les 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)

  d. Geohydrological properties of the strata within the zone that could potentially be affected by the quality of seepage

  e. Define vulnerability and existing or potential use of groundwater resources within the zone that could be potentially affected by the residue facility and,

  f. Determine the potential rate of seepage from the facility and quality of the seepage using groundwater contaminant transport model.

- As per the ERM recommendations the pH of the tailings material must be around 7 prior to being disposed of in the Gamsberg TSF. Short deposition cycles should also be followed on the TSF to help prevent the tailings from drying out.

6.0 REFERENCES

MEND manual, P. W. (2009). *Prediction Manual for drainage chemistry from sulphidic Geologic material.* British Colombia: MEND program (Natural Resources Canada).

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1. CERTIFICATION

This report was prepared and reviewed by the undersigned.

Prepared:

Preparer, Designation
Title

Reviewed:

Reviewer, P.Eng./R.P.Bio./P.Geo.
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APPENDIX B

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APPENDIX C

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Appendix B1
Sub-Appendix Title in Title Case

Appendix B2
Sub-Appendix Title in Title Case

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APPENDIX C1

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APPENDIX C2

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APPENDIX D

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