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Siyanda Ferrochrome Project

Geochemical Assessment Report

Siyanda Ferrochrome Project

SLR Project No.: 710.19057.00010

Report No.: 01

Revision No.: 01

September 2016

Siyanda Chrome Smelting Company (Pty) Ltd

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EXECUTIVE SUMMARY

A new ferrochrome smelter is proposed near Northam in Limpopo Province. As part of the Environmental Impact Assessment procedure, waste material likely to be produced from the smelter process requires geochemical characterisation. Furthermore, the development of a source term is also required as an input parameter for the groundwater numerical model.

This report details the geochemical characterisation programme undertaken and presents the source term concentrations developed through geochemical modelling.

Two (2) waste types will be generated through the ferrochrome smelting process; a slag and a baghouse dust (BHD). These will be disposed of at two separate waste facilities.

Three (3) slag samples were provided to SLR for geochemical test work. The samples were generated from a site specific pilot plant set up by MINTEK. The pilot plant consisted of a furnace operated in a batch-wise fashion with a pre-determined amount of feed material being fed into the furnace followed by a furnace tap. The samples represent samples from three (3) different taps:

- Tap 42 was generated during the smelting of the low grade chromite with 13% limestone addition and no silica.
- Tap 75 was generated during smelting of the low grade chromite with a 5% limestone addition.
- Tap 82 was generated during fluxless smelting of the low grade chromite (0% flux).

A BHD sample was obtained from Mogale Alloys. The raw material used to create the Mogale baghouse is not specific to Siyanda, although is similar in that the chrome concentrate comes (in both cases) from the Bushveld Igneous Complex. The smelter process is fully representative of the proposed Siyanda smelter. Therefore, the sample referred to in this report as “Mogale DC Baghouse” has been used as a proxy sample for the Siyanda BHD.

Samples were sent to UIS Analytical Laboratory in Centurion for various geochemical test works which included:

- Acid Base Accounting (ABA);
 - Acid Potential (AP) analysis;
 - Neutralising Potential (NP) analysis;
- Paste pH.
- Mineralogical testing by X-ray Diffraction (XRD);
- Synthetic Precipitation Leaching Procedure (SPLP) test using distilled water.

Results of the test work showed the following:

Slag

- The total sulphur content was low in all slag samples (max. of 0.13%) and they contain sufficient neutralising potential to offset the low acid potential.
- Slag samples are considered to be non-potentially acid generating (Non-PAG).
- An alkaline paste pH indicates negligible potential for the generation of short-term acidity.
- The chemical of concern¹ identified in the leachate from the modified SPLP leach test was aluminium (Al).

Baghouse Dust (BHD)

- The total sulphur content of the Mogale DC BHD sample was high (1.8%) and contains insufficient neutralising potential to offset the acid potential.
- The BHD sample is considered to be potentially acid generating (PAG).
- A neutral paste pH indicates negligible potential for the generation of short-term acidity.
- The chemicals of concern identified in the leachate were manganese (Mn), lead (Pb), zinc (Zn) and sulphate (SO₄)

The results of the geochemical characterisation programme were used to develop a source term concentration for the proposed waste storage facilities using PHREEQC geochemical modelling. The source term concentration will ultimately be used as an input parameter in the numerical groundwater model, developed as part of the groundwater impact assessment report (SLR, 2016), which will assess the potential impacts of the waste facilities on groundwater resources.

The conceptual models for the source term concentration, developed for the water at the two waste facilities are as follows:

- The BHD will be deposited as slurry some of which will be in permeable bags in a slurry facility. It is assumed that the source term concentration will be developed exclusively by under drainage which has been generated by infiltration through the stored BHD material.
- Slag will be deposited as a molten material. Clearly the source term concentration can only form once the material has cooled. It is assumed that only the top of the cooled silicified mass will crack extensively such that rainwater will infiltrate. Therefore the slag area will be assumed to be surface water dominated with the water interacting with the top of the mass. It is appreciated that upon cooling infiltration may occur through infrequent fractures but the residence time will be short and any

¹ Through a comparison of SPLP results and water quality guidelines

interaction with silicate minerals very slow. Hence the surface water system will dominate the chemistry.

The source term concentrations for **slag derived water** are:

Element (mg/L)	Final Concentration Post Equilibrating with Atmosphere
Al	3.73
Au	0.18
Ba	0.13
Ca	46
Cl	31
K	0.17
Mg	7.73
Mn	0.31
Si	5.82
Sr	0.19
Ti	0.089
Zn	0.063
pH (pH unit)	8.5
Total Alkalinity as CaCO ₃	114
SO ₄	13.12

The source term concentrations for **BHD derived water** are:

Element (mg/L)	Source Chemistry Oxidising	Source Chemistry Reducing
Au	0.019	0.019
B	0.037	0.037
Ba	0.053	0.053
Ca	38	38
Cr	0.005	0.005
Fe	13.14	13.14
K	114	114
Li	0.013	0.013
Mg	49.8	49.8
Mn	0.89	0.89
Na	96	96
Ni	0.013	0.013
Pb	0.1	0.1
Se	0.016	0.016
Si	8.32	8.32
Sr	0.52	0.52
Ti	0.075	0.075
Zn	0.059	0.059
pH (pH unit)	8.87	8.93
Total Alkalinity as CaCO ₃	9.7	9.8
Cl	216	216
SO ₄	130	130

Element (mg/L)	Source Chemistry Oxidising	Source Chemistry Reducing
NO ₃ - N	2.2	0.5
F	1.3	1.3

The results of the BHD indicate that there is unlikely to be a significant difference in the source chemistry when it becomes anaerobic.

The results are considered acceptable for the purpose of this level of assessment and there is no reason not to proceed with the project provided that the waste facility design, as determined by this assessment and any impact mitigation measures, as determined by the water specialists, are implemented.

GEOCHEMICAL ASSESSMENT REPORT

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ACRONYMS AND ABBREVIATIONS

Below a list of acronyms and abbreviations used in this report.

Acronyms / Abbreviations	Definition
AMD	Acid Mine Drainage
AP	Acid Potential
ARD	Acid Rock Drainage
Atm	Atmosphere
BPG	Best Practice Guidelines
CoCs	Chemicals of Concern
DWAF	Department of Water Affairs
Eh	Redox
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
E.N	Electro neutrality
ktpm	Thousand Tonnes per Month
NEMA	National Environmental management Act
NNP	Net Neutralising Potential
NP	Neutralising Potential
PAG	Potentially Acid Generating
SANAS	South African National Accreditation System
SPLP	Synthetic Precipitation Leaching Procedure
TSF	Tailings Storage Facility
TWQR	Target Water Quality Range
XRD	X-ray Diffraction

NATIONAL ENVIRONMENTAL MANAGEMENT ACT (NEMA) REGULATIONS (2014) APPENDIX 6: SPECIALIST REPORTING REQUIREMENTS CHECKLIST

Below is a checklist showing information required by specialists in terms of Appendix 6 of NEMA

Item	NEMA Regulations (2014): Appendix 6	Relevant Section in Report
1(a)(i)	Details of the specialist who prepared the report	Section 8, Page 26
1(a)(ii)	The expertise of that person to compile a specialist report including a curriculum vitae	Appendix A
1(b)	A declaration that the person is independent in a form as may be specified by the competent authority	Section 8, Page 26
1(c)	An indication of the scope of, and the purpose for which, the report was prepared	Section 1.4, Page 2
1(d)	The date and season of the site investigation and the relevance of the season to the outcome of the assessment	Section 2.1, Page 4
1(e)	A description of the methodology adopted in preparing the report or carrying out the specialised process	Section 2, Page 4
1(f)	The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure	Section 1.3, Page 2
1(g)	An identification of any areas to be avoided, including buffers	N/A
1(h)	A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	N/A
1(i)	A description of any assumptions made and any uncertainties or gaps in knowledge;	Section 1, Page 25
1(j)	A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment	Section 3, Page 7 Section 4, Page 14
1(k)	Any mitigation measures for inclusion in the EMPr	N/A
1(l)	Any conditions for inclusion in the environmental authorisation	Section 7, Page 25
1(m)	Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Section 7, Page 25
1(n)(i)	A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and	Section 5, Page 23
1(n)(ii)	If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan	N/A
1(o)	A description of any consultation process that was undertaken during the course of carrying out the study	N/A
1(p)	A summary and copies of any comments that were received during any consultation process	N/A
1(q)	Any other information requested by the competent authority.	N/A

GEOCHEMICAL ASSESSMENT REPORT

1 INTRODUCTION

SLR Consulting (Africa) (Pty) Limited (“SLR”) has been appointed by Siyanda Chrome Smelting Company (Pty) Limited (“SCSC”) to undertake a geochemical assessment for their proposed ferrochrome smelter.

1.1 BACKGROUND

SCSC is proposing to construct a new ferrochrome smelter on portion 3 of the Farm Grootkuil 409 KQ, located approximately 8 km north-west of Northam in the Limpopo Province.

The project will comprise two 70 megawatt (MW) direct current (DC) furnaces, a crushing and screening plant, a slag waste facility, a baghouse dust waste facility, material stockpiles and various support infrastructure and services.

Prior to the commencement of the proposed project, an Environmental Impact Assessment (EIA) is required. As part of the EIA, geochemical characterisation of the waste material likely to be produced from the operations must be undertaken to assist in understanding the potential impacts on the surrounding environment.

1.2 PROCESS OVERVIEW AND WASTE PRODUCTS

At this stage in project planning, it is expected that incoming material will be sourced from Union Section (Swartklip) mine and possibly also from other mines in future. The proposed process is presented in Figure 1-1.

Two (2) waste types will be generated through the ferrochrome process; a slag and a baghouse dust (BHD). These will be disposed of at two separate waste facilities.

- **Slag** will be disposed of in molten form to a standalone waste facility of 21.5 hectares (ha).
- **BHD** will be disposed of in slurry form on a standalone waste facility of 9.4 ha or within permeable bags in a tradition tailings storage facility (TSF) type facility.

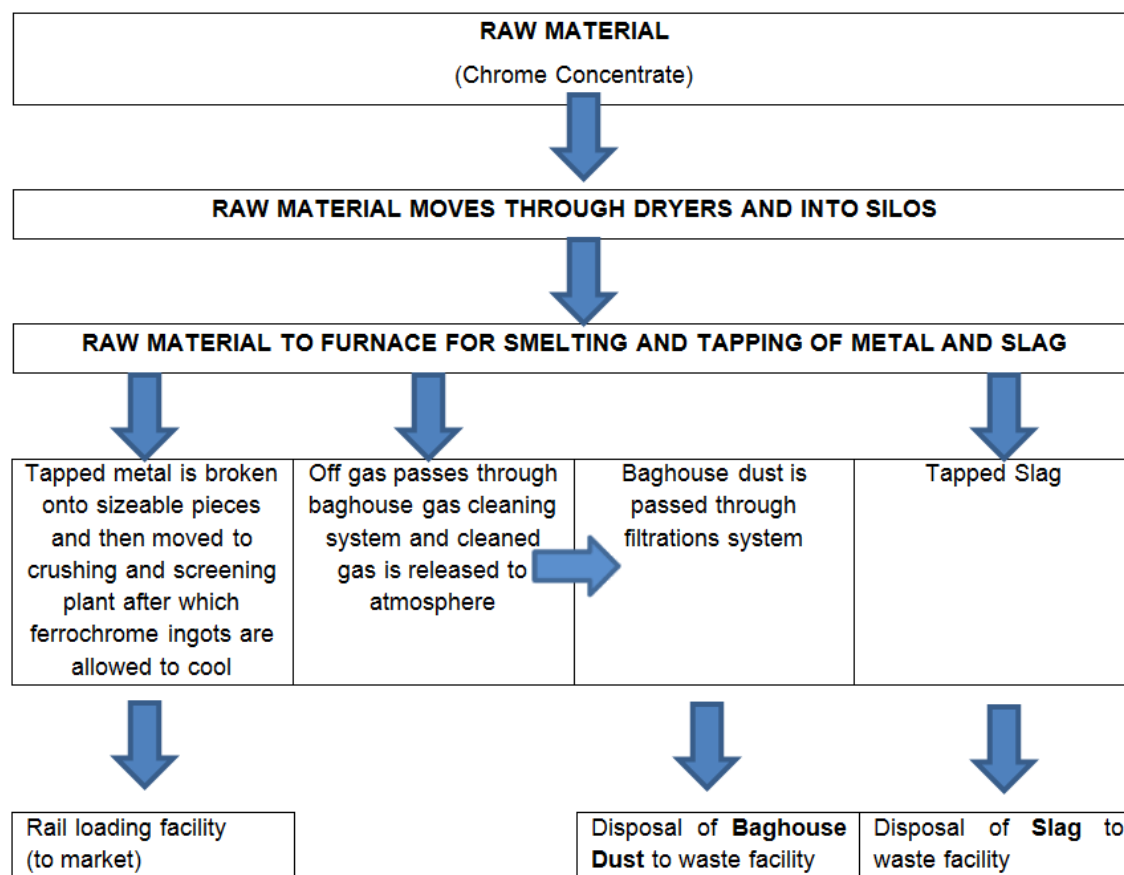


FIGURE 1-1: FLOW DIAGRAM FOR PROPOSED PROCESS

1.3 IDENTIFIED AREAS OF SENSITIVITY

The areas identified as ‘sensitive’, with regards to this geochemical assessment would be:

- Areas in proximity to the waste storage facilities.

The potential impact of the waste storage facilities on groundwater quality can be simulated in a numerical groundwater model and will be assessed in the groundwater assessment (SLR, 2016).

1.4 OBJECTIVES

The objectives of this geochemical assessment are:

- To geochemically characterise waste material from the proposed ferrochrome processing including slag material and baghouse dust.
- To develop a source term concentration for the waste material.

1.5 REPORT STRUCTURE

The report has been divided accordingly:

- Section 2 summarises the waste characterisation methodologies.
- Section 3 details the results of the geochemical test work.
- Section 4 presents the geochemical modelling and source term development
- Section 5 summarises and concludes the report.
- Section 6 presents the assumptions and limitations for the project.
- Section 7 presents recommendations for further work.

2 GEOCHEMICAL CHARACTERISATION

The following section describes the method and processes in which waste material for the proposed project was geochemically characterised.

2.1 SAMPLE GENERATION

2.1.1 SLAG

MINTEK developed a site specific pilot plant which consisted of a furnace operated in a batch-wise fashion with a pre-determined amount of feed material being fed into the furnace followed by a furnace tap. Tapping of the furnace entails opening of the slag taphole to let the slag out (this slag is collected in ladles and generally slow-cooled). The slag tap is followed by a metal tap where the metal produced is tapped out of the furnace through a dedicated taphole, into refractory-lined ladles. During February 2015, MINTEK provided SLR with three (3) slag samples as follows:

- Tap 42 was generated during the smelting of the low grade chromite with 13% limestone addition and no silica.
- Tap 75 was generated during smelting of the low grade chromite with a 5% limestone addition.
- Tap 82 was generated during fluxless smelting of the low grade chromite (0% flux).

2.1.2 BAGHOUSE DUST

A baghouse dust sample was obtained from Mogale Alloys (“Mogale”) during November 2015. The company on-site smelter is located in Krugersdorp on the West Rand.

The raw material used to create the Mogale baghouse, is not specific to Siyanda, although is similar in that both mines supplying the chrome concentrate access ore from the BIC. The smelter process however, is fully representative of the Siyanda smelter. Therefore, the sample referred to in this report as “Mogale DC Baghouse” has been used as a proxy sample for Siyanda baghouse dust. The sample however, can only be described as indicative at this stage.

2.2 LABORATORY ANALYSIS

All samples were sent to UIS Analytical Laboratory (“UIS”) in Centurion, South Africa. UIS is a SANAS (South African National Accreditation System) accredited laboratory according to ISO/IEC 17025:2005 standards.

The following laboratory tests were undertaken on samples:

- Acid Base Accounting (ABA):
 - Acid Potential (AP) analysis; and
 - Neutralising Potential (NP) analysis.
- Paste pH.
- Mineralogical testing by X-ray Diffraction (XRD).
- Synthetic Precipitation Leaching Procedure (SPLP) test using distilled water.

The tests are described in further detail in the following sections.

2.2.1 ACID BASE ACCOUNTING

2.2.1.1 Acid Potential and Neutralising Potential

Acid–Base Accounting (ABA) is an internationally accepted analytical procedure that was developed to screen the acid-producing and acid-neutralizing potential of rocks.

The Acid Generating Potential (AP) is due to the oxidation of sulphide minerals in a sample and is calculated as the total sulphide sulphur content in % multiplied by 31.25.

The Acid Neutralising Potential (NP) is a measure of the total acid a material is capable of neutralising and is predominantly a result of neutralising bases, mostly carbonates and exchangeable alkali and alkali earth cations.

AP and NP are both reported as Kg CaCO₃/Tonne.

2.2.1.2 Net Neutralising Potential (NNP)

The Net Neutralisation Potential (NNP) is calculated by subtracting the Acid Generating Potential (AP) from the Acid Neutralising Potential (NP):

$$\mathbf{NNP = NP - AP}$$

Results are reported in kg of calcium carbonate per tonne of overburden (or parts per thousand). For a sample:

- Negative NNP indicates potential to generate acid; and
- Positive NNP indicates excess acid-neutralising potential.

2.2.1.3 Neutralising Potential Ratio (NPR)

The Neutralising Potential Ratio is calculated by dividing the Neutralising Potential (NP) by the acid potential (AP):

NPR = NP/AP

In the assessment:

- NPR ratios larger than 2 indicate non-potentially acid generation (Non-PAG);
- ratios between 1 and 2 are considered inconclusive / possibly acid generating; and
- NPR ratios below 1 indicate potential acid generation (PAG).

2.2.2 PASTE PH

Paste pH analysis is undertaken in conjunction with the ABA test. The test is a simple, rapid, and inexpensive screening tool that indicates the presence of readily available NP (generally from carbonate) or stored acidity and involves the placement of 'crushed' sample with distilled water at a low solid to liquid ratio (to produce a paste) and the pH measured after approximately two minutes.

The outcome of the test is governed by the surficial properties of the solid material being tested, and more particularly, the extent of soluble minerals, which may provide useful information regarding anticipated mine water quality. It represents more closely the water to solid ratio of pore waters in wastes than other analysis procedures

2.2.3 MINERALOGY

Minerals are the building blocks of materials. Mine drainage quality is generally a function of mineral present dissolution (or precipitation) during interaction of rocks with water. X-ray Diffraction (XRD) analysis identifies the main crystalline mineral phases in each sample.

2.2.4 SYNTHETIC PRECIPITATION LEACHING PROCEDURE (SPLP)

Synthetic Precipitation Leaching Procedure (SPLP) is a laboratory extraction method designed to determine the leachability of both organic and inorganic elements present in liquids, soils, and wastes under certain conditions. The solid phase is extracted over 18 hours with an extraction fluid, and liquid-to-solid ratio of 20:1. Following extraction, the liquid extract is separated from the solid phase by filtration and analysed.

3 RESULTS AND INTERPRETATION

The results of the testing are presented in the following section. Copies of laboratory reports are provided in Appendix B.

3.1 DATA VALIDATION

The accuracy of the chemical analysis can be assessed through calculating the electro neutrality for each sample. The electro neutrality (E.N) is calculated using the following equation:

$$E.N. [\%] = \frac{\sum_{cations} \left(\frac{meq}{l}\right) - \sum_{anions} \left(\frac{meq}{l}\right)}{\sum_{cations} \left(\frac{meq}{l}\right) + \sum_{anions} \left(\frac{meq}{l}\right)} * 100\% < 10\%$$

Samples with a calculated E.N value of less than 10% are considered to show an acceptable level of accuracy. Where samples have an error percentage above 10%, results are considered to show an unacceptable level of accuracy and results / interpretation of results should be considered with caution.

The E.N calculation was applied to the leach data. Two (2) of the four (4) samples showed an error percentage above 10%. Errors above 10% are often recorded for leach test results due to the highly mineralised material the test are being undertaken on. The results are considered adequate for the use of this assessment, although the error cannot be overlooked entirely.

Comparison of the results of the laboratory duplicates indicates that the methods applied show an acceptable level of reproducibility.

3.2 ABA

The ABA results for the four (4) samples are presented in Table 4.1.

3.2.1 SLAG SAMPLES

The Acid Base Accounting (ABA) results show that the total sulphur content all three (3) slag samples are reasonably low which suggests that the samples have limited potential to generate acid. In addition, the neutralising potential ratio (NPR) of all slag samples is above 2, which implies all samples have sufficient neutralising potential to offset the low acid generation potential.

The paste pH for all three (3) slag samples was alkaline and indicates that there is negligible potential for the generation of short-term acidity.

A graph showing the total sulphur content plotted against the NPR is presented as Figure 3-1 and illustrates that based on these two criteria, all samples are classified as Non-Potentially Acid Generating (Non-PAG).

3.2.2 BHD SAMPLE

The ABA results for the Mogale DC BHD sample show that the total sulphur content was relatively elevated (1.8%), indicating a significant potential to generate acid. In addition, the NPR for this sample was below 1 which suggests that the sample has insufficient neutralising potential to offset the acid potential.

Figure 3-1 shows that the Mogale DC BHD sample is classified as Potentially Acid Generating (PAG), although the paste pH was neutral and indicates that there is negligible potential for the generation of short-term acidity.

It is noted that the acid potential calculations have been based on total sulphur. Some of the sulphur in a sample may be present in non-acid producing sulphates or native sulphur. If a significant part of the total sulphur occurs as sulphate sulphur instead of potentially acid generating sulphide sulphur, the overall risk of acid generation is reduced. These results, based on total sulphur concentrations are therefore conservative. If necessary additional testing of the actual waste sample for the presence of sulphide sulphur can be undertaken once these samples are available.

TABLE 3-1: ACID BASE ACCOUNTING RESULTS FOR SIYANDA WASTE SAMPLES

Sample ID	Paste pH	AP (kg/t)	NP (Kg/t)	NNP (NP-AP)	NPR (NP : AP)	Total Sulphur (%)	Classification
<i>Criteria</i>	<i>>5.5 (Non-PAG)</i>	-	-	<i>NNP>0 (Non-PAG)</i>	<i>>2 (Non-PAG) 1-2 (Inconclusive) <1 (PAG)</i>	-	-
SLAG Tap 42	11.4	4.06	57	53	14	0.13	Non-PAG
SLAG Tap 75	10.6	3.44	19	15	5.39	0.11	Non-PAG
SLAG Tap 82	10.1	4.06	12	7.48	2.84	0.13	Non-PAG
Mogale DC Baghouse Dust	7.2	56	8.2	-48	0.146	1.8	PAG

Note: PAG refers to Potentially Acid Generating

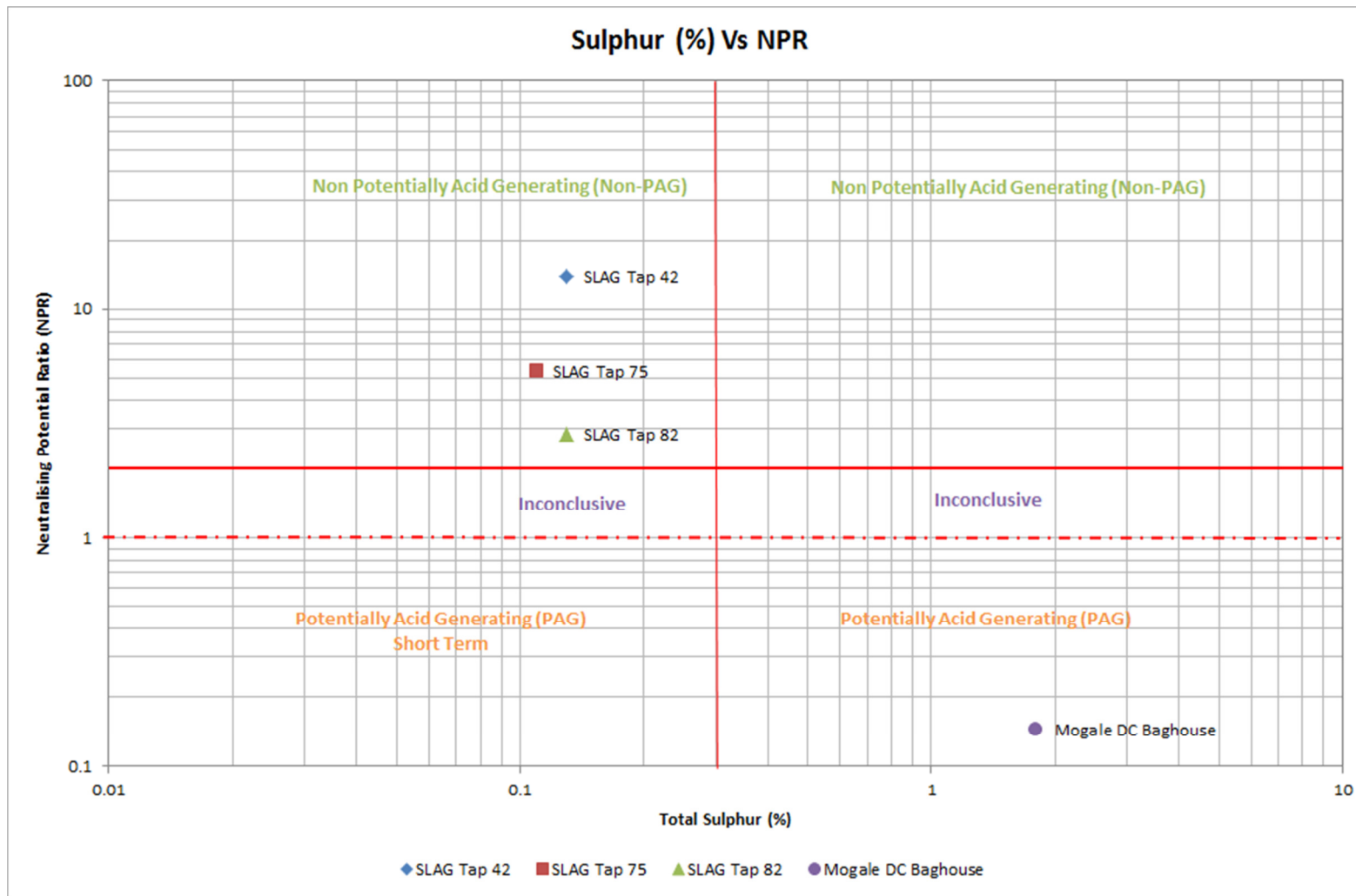


FIGURE 3-1: SULPHUR CONTENT VERSUS NEUTRALIZING POTENTIAL RATIO FOR SIYANDA SAMPLES

3.3 MINERALOGY

The three (3) slag samples and the Mogale DC BHD sample were submitted for mineralogical analysis. The crystalline mineralogy of the slag samples is detailed in Table 3-2 and presented graphically in Figure 3-2.

The key minerals of each of the three (3) slag samples are:

- Spinel: a magnesium / aluminium mineral found as a metamorphic mineral, and also as a primary mineral in rare mafic igneous rocks; in these igneous rocks, the magmas are relatively deficient in alkalis relative to aluminium, and aluminium oxide may form as the mineral corundum or may combine with magnesia to form spinel.
- Forsterite: magnesium rich mineral associated with igneous and metamorphic rocks.
- Diopside: pyroxene mineral found in ultramafic igneous rocks.
- Akermanite-Gehlenite: soro-silicates associated with extreme temperature and typically found in glassy blast furnace slag.

TABLE 3-2: MINERAL COMPOSITION (%) OF THE SIYANDA SLAG SAMPLES

Mineral	Formula	SLAG Tap 42	SLAG Tap 75	SLAG Tap 82
Spinel	$MgAl_2O_4$	33.06	57.16	59.3
Forsterite	Mg_2SiO_4	24.14	35.58	38.61
Diopside	$MgCaSi_2O_6$	28.64	7.26	2.09
Akermanite-Gehlenite	$Ca_2Mg(Si_2O_7)$ to $Ca_2Al(AlSiO_7)$	14.16	-	-

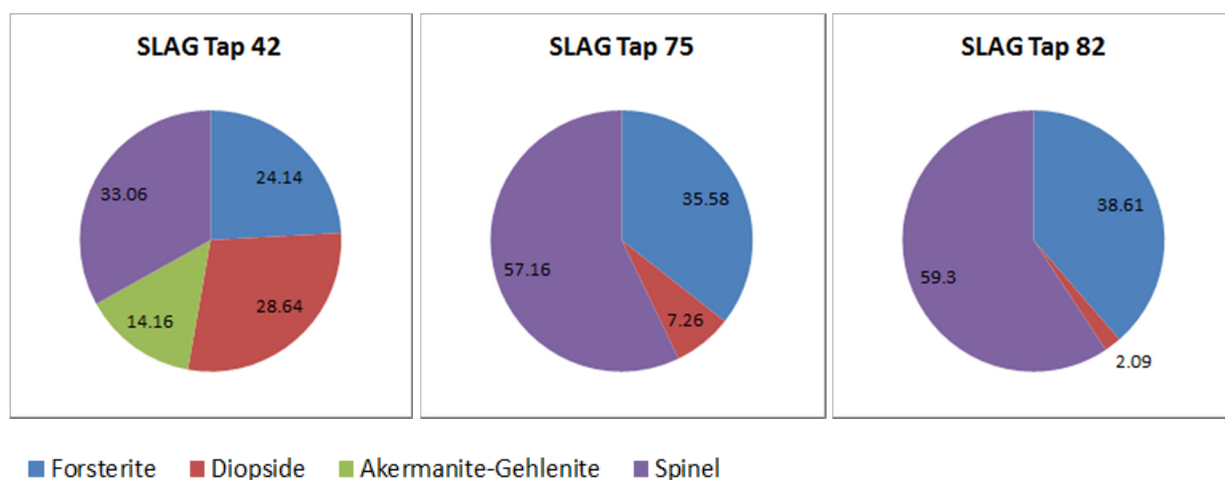


FIGURE 3-2: MINERAL COMPOSITION (%) OF THE SIYANDA SLAG SAMPLES

The crystalline mineralogy of the Mogale DC BHD sample is detailed in Table 3-3 and presented graphically in Figure 3-3.

The key minerals of the Mogale DC BHD Sample:

- Chromite: iron chromium oxide mineral.
- Zincite: zinc oxide mineral. Synthetic zincite crystals are available as a by-product of zinc smelting. Can be due to iron and manganese dopants², and associated with willemite and franklinite.
- Forsterite: magnesium rich mineral associated with igneous and metamorphic rocks.

TABLE 3-3: MINERAL COMPOSITION (%) OF THE MOGALE DC BAGHOUSE DUST SAMPLE

Mineral	Formula	Mogale DC Baghouse Dust
Chromite	FeCr_2O_4	37.35
Zincite	ZnO	26.8
Forsterite	Mg_2SiO_4	22.86
Willemite	Zn_2SiO_4	6.32
Gordaite	$\text{NaZn}_4(\text{SO}_4)(\text{OH})_6\text{Cl}\cdot 6\text{H}_2\text{O}$	3.46
Wurtzite	$(\text{Zn,Fe})\text{S}$	3.21

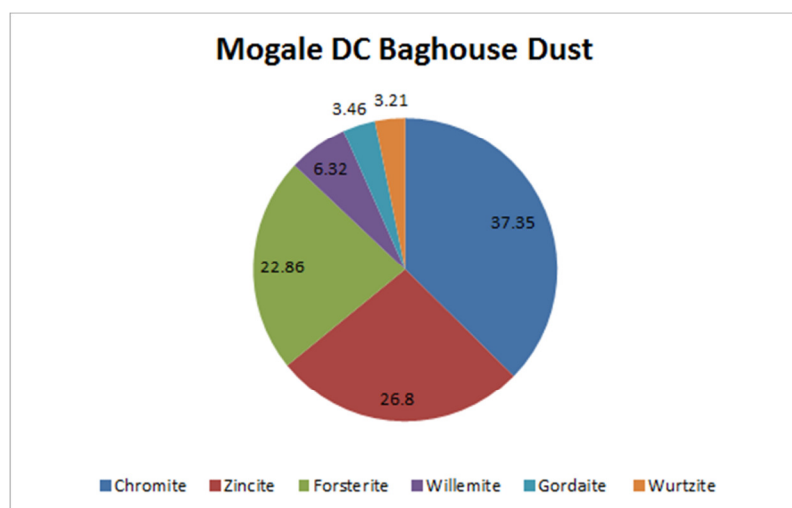


FIGURE 3-3: MINERAL COMPOSITION (%) OF THE MOGALE DC BAGHOUSE DUST SAMPLE

The BHD sample does contain a sulphide mineral (wurtzite) as indicated by the results of the ABA testing. This is similar to sphalerite with an iron content that is variable but can be up to 8%. Acid generation usually occurs when the metal to sulphur ratio is less than one (e.g. FeS_2), and does not occur when the metal sulphur ratio is equal to one (e.g. ZnS). If the iron content is low in the wurtzite then it is less likely it will form acidic drainage. Therefore it is recommended that once the waste stream is identified and additional sampling and analysis is undertaken, the sulphide and iron content is assessed.

² A trace impurity element that is inserted into a substance (in very low concentrations) to alter the electrical or optical properties of the substance

3.4 METAL LEACHING POTENTIAL

All four (4) samples were submitted to the laboratory for SPLP leach tests. The results are presented in Table 3-4.

The final pH of the leachates of two samples (Slag Tap 42 and Slag Tap 75) was higher than the initial pH 7, which indicates the presence of leachable alkalinity in the samples. The pH of the leachate of the Slag Tap 82 sample and the Mogale DC BHD sample was pH 6.2 and pH 6.5 respectively.

3.5 PRELIMINARY RISK ASSESSMENT

Leach test results are not an indicator of drainage quality, as the conditions of the test, especially the liquid-to-solid ratio, do not represent actual field conditions. Therefore, leachate concentrations are not representative of seepage or run-off that could emanate from site. However, the results may indicate chemicals of concern (CoCs) in drainage from the waste facilities.

As a preliminary screening to identify potential CoCs, the leachates were compared to the following relevant water quality standards:

- South African National Standard (SANS) 241: 2015 Limits for Drinking Water.
- Department of Water Affairs and Forestry (DWA) (2009) Target Water Quality Range for Livestock Watering.

Note that the application of drinking water guidelines does not suggest that leachates and drainage from processing activities will be used for drinking purposes.

Results for all four (4) samples, as presented in Table 3-4 show:

- The concentrations of the majority of elements are low in all samples, with many below the laboratory detection limit.
- Higher concentrations of elements are generally recorded in the Mogale DC Baghouse dust sample.
- Aluminium (Al) is identified as a CoC in one (1) slag sample (Slag Tap 42).
- Manganese (Mn), lead (Pb), zinc (Zn) and sulphate (SO₄) are identified as CoCs in the Mogale DC BHD sample. This is consistent with the mineralogy of the sample.

TABLE 3-4: SPLP LEACH TEST RESULTS FOR THE SIYANDA SAMPLES

Element (mg/L)	DWAF TWQR (2009)	SANS 241 (2015)				Siyanda Samples			
	Livestock Watering	Operational	Aesthetic	Acute Heath	Chronic Health	SLAG Tap 42	SLAG Tap 75	SLAG Tap 82	Mogale DC BHD
Ag						<0.010	<0.010	<0.010	<0.010
Al	0-5	0.3				0.71	0.14	<0.010	<0.010
As	0-1				0.01	<0.010	<0.010	<0.010	<0.02
Au						0.034	<0.010	<0.010	0.019
B	0-5				2.4	<0.010	<0.010	<0.010	0.037
Ba					0.7	0.025	<0.010	<0.010	0.053
Be						<0.010	<0.010	<0.010	<0.010
Bi						<0.010	<0.010	<0.010	<0.010
Ca	0-1000					8.80	1.06	0.010	38.00
Cd	0-0.01				0.003	<0.010	<0.010	<0.010	<0.010
Co	0-1				0.5	<0.010	<0.010	<0.010	<0.010
Cr					0.05	<0.010	<0.010	<0.010	<0.010
Cr VI	0-1					<0.010	<0.010	<0.010	<0.010
Cu	0-0.5				2	<0.010	<0.010	<0.010	<0.010
Fe	0-10		0.3		2	<0.010	<0.010	<0.010	<0.025
Hg					0.006	<0.001	<0.001	<0.001	<0.001
K						0.033	<0.010	<0.010	114
Li						<0.010	<0.010	<0.010	0.013
Mg	0-500					1.49	0.79	0.084	36.00
Mn	0-10		0.1		0.4	<0.010	0.059	<0.010	0.89
Mo	0-0.01					<0.010	<0.010	<0.010	<0.010
Na	0-2000		200			<0.010	<0.010	<0.010	96.00
Ni	0-0.1				0.07	<0.010	<0.010	<0.010	0.013
P						<0.010	<0.010	0.010	<0.010
Pb	0-0.1				0.01	<0.010	<0.010	<0.010	0.10
Sb					0.02	<0.010	<0.010	<0.010	<0.010
Se	0-50				0.04	<0.010	<0.010	<0.010	0.016
Si						2.38	0.63	0.097	<0.2
Sn						<0.010	<0.010	<0.010	<0.010
Sr						0.036	<0.010	<0.010	0.52
Ti						0.017	<0.010	<0.010	0.075
U					0.03	<0.010	<0.010	<0.010	<0.010
V	0-1				0.2	<0.010	<0.010	<0.010	<0.010
W						<0.010	<0.010	<0.010	<0.010
Zn	0-20		5			<0.010	<0.010	0.012	32.00
pH (pH unit)		5 - 9.7				7.6	7.2	6.3	6.5
EC (mS/m)			170			6.00	1.40	0.40	161
TDS			1200			26.00	<10	<10	1002
Total Alkalinity as CaCO ₃						24.00	8.00	<5	<5
Cl	0-1500		300			6.00	<5	<5	219.0
SO ₄	0-1000		250	500		<5	<5	<5	389
NO ₃ -N	0-100			11		<0.2	<0.2	<0.2	0.50
F	0-2				1.5	<0.2	<0.2	<0.2	1.30
Total CN				0.2		<0.01	0.010	<0.01	<0.01

Note: Highlighted cells indicate water quality limit exceeded

4 SOURCE TERM CONCENTRATION ESTIMATION

4.1 INTRODUCTION

A 'source term' is the mass of contaminant per unit time. It is required to assess the potential impact of contaminated seepage on groundwater quality. The source term is the product of seepage concentration and the seepage rate through the contaminant source.

The results of the geochemical characterisation programme were used to develop a source term concentration for the proposed waste storage facilities (slag and baghouse) using geochemical modelling. The source term is required to inform the groundwater numerical model.

The source term concentration development is generally consistent with South African best practice, as described in Best Practice Guidelines (BPG) G4 (DWAf, 2006). The approach includes development of a conceptual model, use of laboratory results, and equilibrium geochemical modelling.

4.2 MODELLING CODE

The PHREEQC modelling software (Parkhurst and Appelo, 1999) was selected as it is used globally for the study of geochemical reactions. In addition, the newer version of the software (2.12 onwards) incorporates the Pitzer database which enables modelling of high ionic strength solutions. Furthermore the "lnl.dat" thermodynamic database has been selected because it contains the largest range of minerals which include those identified in the slag and BHD samples.

4.3 CONCEPTUAL MODEL

The conceptual model for the source term developed for the water at the two facilities is slightly different depending on the storage area:

- The Baghouse Dust (BHD) will be deposited as slurry some of which will be within permeable bags in a slurry facility. It is assumed that the source term will be developed exclusively by under drainage which has been generated by infiltration through the stored BHD material.
- Slag will be deposited as a molten material. Clearly the source term can only form once the material has cooled. It is assumed that only the top of the cooled silicified mass will crack extensively such that rainwater will infiltrate. Therefore the slag area will be assumed to be surface water dominated with the water interacting with the top of the mass. It is appreciated that upon cooling infiltration may occur through infrequent fractures but the residence time will be short and any interaction with silicate minerals very slow. Hence the surface water system will dominate the chemistry.

Given the two scenarios, there are a number of geochemical procedures which need to be applied to the modelling as discussed in the following sections.

4.3.1 BAG HOUSE DUST STORAGE AREA

The geochemical model has been developed to estimate BHD drainage (pore water) and it is assumed that runoff will not dominate at the location. Where material is placed in permeable bags, the source term will be a function of the infiltrating water reacting with the BHD minerals and producing pore waters which will seep. Where the material is deposited as a slurry then the seeping water will be as a direct consequence of the water: mineral interaction in the mixture. These have been accommodated in the modelling as far as possible. It is assumed that if the material is a slurry, then no other additives are introduced other than rain water and the BHD.

In terms of the geochemical modelling to generate drainage chemistry, the following is undertaken:

- The mineralogy of the BHD is reviewed to establish the equilibration potential of the minerals and what should be incorporated in the model. This requires consideration of the likely equilibration kinetics involved as such data is not included in the PHREEQ modelling of equilibration (unless specific laboratory kinetic test data is available). Care is therefore required to make sure the mineral assemblage is representative.
- The initial solution used in the modelling is taken from the SPLP extraction. At this stage the 20:1 extract is used, if the field environment appears to be different once the design is formalised, this can be changed if required.
- The solution is then equilibrated with the selected mineral assemblage and allows minerals that are likely to form or dissolve under the in-situ conditions to precipitate.
- Because there is likely to be at least two redox environments in the BHD waste facility, once equilibrated with the minerals, the water is equilibrated in the presence of atmospheric oxygen at $pO_2 = 10^{-0.7}$ atm to simulate atmospheric conditions and $pO_2 = 10^{-1.7}$ atm to simulate conditions reducing conditions at depth.

4.3.2 SLAG STORAGE AREA

A geochemical model has been developed to estimate the water chemistry that is generated from the slag storage. The following has been undertaken:

- The initial solution used in the modelling is taken from the SPLP extraction.
- The SPLP extraction is established at a 20:1 ratio and therefore the components in the extract will need to be concentrated such that it aligns with the likely water rock ratio in the storage areas.
- Given that this is a runoff dominated model the solution is unlikely to equilibrate with the selected mineral assemblage.
- Simulate atmospheric conditions and $pO_2 = 10^{-1.7}$ atm and $pCO_2 = 10^{-2.5}$ are used to equilibrate the resulting water runoff.

4.4 DATA REQUIREMENTS

Any geochemical model is only useful for predicting geochemical reactions if the data used has a reliable provenance and is representative of the modelling scenario. The geochemical testing information for the BHD was undertaken on a proxy sample (which gives a good indication of the expected waste characteristics) and includes chemical analysis of leach analysis (L:S 20:1), acid extraction, acid base accounting and petrology of the slag and the BHD. This is considered suitable to undertake an assessment of the likely source water chemistry at each of the sites.

4.4.1 WATER / MATERIAL INTERACTION CHEMISTRY

The results of the SPLP testing are shown below. This has been taken from the summary presented in Table 4-1. Several components were not detected in the laboratory analysis and as these are mostly trace metals.

TABLE 4-1: RESULTS OF SPLP EXTRACTION

Element (mg/L)	SLAG Tap 42	SLAG Tap 75	SLAG Tap 82	Mogale DC Baghouse
Ag	<0.01	<0.01	<0.01	<0.01
Al	0.71	0.14	<0.010	<0.01
As	<0.01	<0.01	<0.01	<0.01
Au	0.034	<0.010	<0.010	0.019
B	<0.010	<0.010	<0.010	0.037
Ba	0.025	<0.010	<0.010	0.053
Be	<0.01	<0.01	<0.01	<0.01
Bi	<0.01	<0.01	<0.01	<0.01
Ca	8.80	1.06	0.010	38.00
Cd	<0.01	<0.01	<0.01	<0.01
Co	<0.01	<0.01	<0.01	<0.01
Cr	<0.010	<0.010	<0.010	<0.01
Cu	<0.010	<0.010	<0.010	<0.01
Fe	<0.010	<0.010	<0.010	<0.01
Hg	<0.01	<0.01	<0.01	<0.01
K	0.033	<0.010	<0.010	114
Li	<0.010	<0.010	<0.010	0.013
Mg	1.49	0.79	0.084	36.00
Mn	<0.010	0.059	<0.010	0.89
Mo	<0.01	<0.01	<0.01	<0.01
Na	<0.010	<0.010	<0.010	96.00
Ni	<0.010	<0.010	<0.010	0.013
P	<0.010	<0.010	0.010	<0.01
Pb	<0.010	<0.010	<0.010	0.10
Sb	<0.01	<0.01	<0.01	<0.01
Se	<0.010	<0.010	<0.010	0.016
Si	2.38	0.63	0.097	<0.01
Sn	<0.01	<0.01	<0.01	<0.01
Sr	0.036	<0.010	<0.010	0.52

Element (mg/L)	SLAG Tap 42	SLAG Tap 75	SLAG Tap 82	Mogale DC Baghouse
Ti	0.017	<0.010	<0.010	0.075
U	<0.01	<0.01	<0.01	<0.01
V	<0.01	<0.01	<0.01	<0.01
W	<0.01	<0.01	<0.01	<0.01
Zn	<0.010	<0.010	0.012	32.00
pH (pH unit)	7.6	7.2	6.3	6.5
Total Alkalinity as CaCO ₃	24.00	8.00	<5	5
Cl	6.00	<5	<5	219
SO ₄	<5	<5	<5	389
NO ₃ ⁻ N	<0.2	<0.2	<0.2	0.50
F	<0.2	<0.2	<0.2	1.30

The non-detected concentrations have not been included in the modelling. The exception is where an equilibrating mineral has a geochemistry which contains the trace metal and therefore could alter the chemistry in the source water.

4.4.2 MINERALOGY

The mineralogy of the slag samples is not considered in the assessment because the surface water dominated system will not have time to equilibrate with the mineral assemblage, even if there is infiltration through fractures, the kinetics of silicate equilibration will be too slow to impact the chemistry of the water.

In terms of the BHD mineralogy, this will be used in the geochemical model to equilibrate the SPLP extract. When modelling the equilibration of the SPLP fluid, the PHREEQC model brings the selected phases (minerals) into contact with an SPLP solution chemistry; each phase will dissolve or precipitate to achieve equilibrium or will dissolve completely. Pure phases include minerals with fixed composition and gases with fixed partial pressures. It is therefore important to include minerals which are more likely to dissolve and precipitate in the time frames relevant to the project.

Given the slow to very slow kinetics of some silicate mineral precipitation/dissolution (at the temperatures and pressures being dealt with at this site), it is most likely that equilibration will also be slow and favour the more reactive minerals. In terms of dissolution of silicates the Goldich Dissolution Series (Goldich, 1938) is a way of predicting the relative stability or weathering rate of various minerals on the Earth's surface. Those minerals that formed at higher temperatures and pressures at depth are less stable on the surface than minerals that form at lower temperatures and pressures. A typical example of the series is presented in Figure 4-1 below.

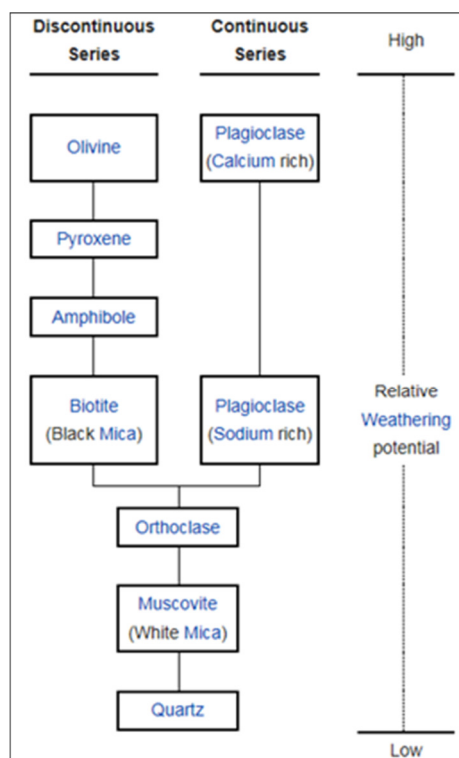


FIGURE 4-1: GOLDRICH'S WEATHERING SERIES

This in part explains the chemical composition of the SPLP leach testing which is affected by the ability of the mineral assemblage to dissolve, albeit in a relatively short duration test when equilibrium is unlikely to have been reached.

The oxides present in the BHD mineralogy require additional research to assess their stability. This has shown that the minerals wurtzite³, zincite⁴ and chromite⁵ can all weather, hence using them as equilibrium phases in the model is reasonable. In addition at this stage the PHREEQ database does not include minerals willemite and gordaite. Given these are only proxy samples at this stage, should these minerals be present in the waste steam deposited at the site, the thermodynamic data for the minerals will be researched and included for future modelling

On this basis the minerals presented in Table 4-2 will be equilibrated with the SPLP leachate when modelling the geochemical evolution of the BHD derived source term.

³ <https://kar.kent.ac.uk/49981>

⁴ <http://www.canmin.org/content/46/5/1235.abstract>

⁵ http://www.minsocam.org/ammin/AM53/AM53_1543.pdf

TABLE 4-2: MINERALOGY USED IN THE BAGHOUSE DUST MODELLING

Formation	Petrology	Phase equilibrated	Reasoning
Bag House Dust	Chromite, zincite, forsterite, willemite, gordaite and wurtzite.	Chromite, zincite, forsterite, and wurtzite.	Likely to be the most reactive mineral present.

4.5 GEOCHEMICAL MODELLING

A number of geochemical simulations were performed with the available data. A summary of the approach used in PHREEQC is shown in Table 4-3 below.

TABLE 4-3: CONCEPTUAL MODEL DEVELOPMENT FOR SLAG SAMPLES

Geochemical Simulation	Description	Relevant PHREEQC subroutine
1	Using SPLP chemistry remove water from the system to concentrate the leachate in accordance with the site layout and rainfall.	EVAPORATION
2	Calculate speciation of new solution (post concentration)	SOLUTION
3	Adjust to reflect atmospheric conditions with $pO_2 = 10^{-0.678}$ and $pCO_2 = 10^{-3.5}$	EQUILIBRIUM_PHASE

It is understood that the slag storage area will incorporate deposition of the mass in a molten/liquid form. Therefore it has been assumed that the water will only interact after the rock has cooled and a small proportion of the surface becomes cracked and can be infiltrated by rainwater.

In terms of the runoff chemistry from the area, the liquid: solid ratio will require adjustment to make the SPLP extract (which uses a 20:1 L/S ratio) consistent with that likely to be prevalent in the slag area. In terms of developing the correct L/S ratio, the following (Table 4-4) has been undertaken for each of the waste storage areas.

TABLE 4-4: CALCULATION OF ADJUSTED L/S RATION FOR SLAG STORAGE AREA

Site	Storage Area	Assumed Surface Area	Assumed interaction Depth	Annual Rainfall	Liquid/Solid Ratio	Adjustment Needed to Solution
SLAG	215,000m ²	322,500m ²	0.15m	571mm	3.8	5.25

The SPLP test gives an indication of the water composition that will equilibrate with the BHD mineralogy through the storage area and collected in the basal drainage (Table 4-5).

TABLE 4-5: CONCEPTUAL MODEL DEVELOPMENT FOR BAGHOUSE DUST SAMPLES

Geochemical Simulation	Description	Relevant PHREEQC subroutine
1	Calculate speciation and saturation indices for the SPLP leachate results	SOLUTION
2	Equilibrate with minerals identified in the mineral assemblage of the BHD.	EQUILIBRIUM_PHASE
3	Adjust to reflect oxidising and reducing conditions	EQUILIBRIUM_PHASE

Redox information is not included in the SPLP test, but it is assumed to be oxidised given the nature of the test. PHREEQC uses input data as pE and a default of +4 is used in the modelling. The relationship between Eh and pE is shown below.

$$pE = \frac{Eh \cdot F}{2.303 \cdot R \cdot T}$$

Where:

Eh = Redox (mV)

F = Faraday Constant (cal/V)

R = Gas Constant (cal/degree)

T = Temperature (Kelvin)

4.5.1 SLAG STORAGE SOURCE CHEMISTRY

The results of the PHREEQC modelling to predict the water chemistry associated with the slag storage area are presented below.

4.5.1.1 Adjusting L/S to Site Conditions

Water can be removed by two methods in PHREEQC:

- The first method involves water being specified as an irreversible reactant with a negative reaction coefficient; or
- In the second water ("H₂O") can be specified as the alternative reaction, where by water is removed from the aqueous phase to attain a specified saturation index for a pure phase.

The second method has been used in this assessment whereby the model simulates concentration of the slag SPLP extract by approximately 5.25 fold, by removing 80 percent of the water⁶.

In 1kg of water there are 55.5 mol and hence to concentrate the solution it is necessary to remove approximately 44 mol of water (i.e. 55.5 x 0.8). In a subsequent simulation, a solution is generated that has the same concentrations as the evaporated solution, but has a total of mass of water of

⁶ Calculated as follows: 55.5/5.25 = 10.57mol and therefore (10.57 – 55.5)/55.5 = -0.8 or 80% reduction

approximately 1 kg. The resulting water chemistry is then equilibrated with atmospheric oxygen and carbon dioxide.

The results of this simulation are shown in Table 4-6 below. This has excluded all non-detects in the SPLP test.

TABLE 4-6: SOURCE CONCENTRATIONS FOR SLAG DERIVED WATER

Element (mg/L)	SLAG Sample SPLP Selected	Concentrating Sample by adjusting L/S	Final Concentration Post Equilibrating with Atmosphere
Al	0.71	3.73	3.73
Au	0.034	0.18	0.18
Ba	0.025	0.13	0.13
Ca	8.8	46	46
Cl	6	31	31
K	0.033	0.17	0.17
Mg	1.49	7.73	7.73
Mn	0.059	0.31	0.31
Si	2.38	5.82	5.82
Sr	0.036	0.19	0.19
Ti	0.017	0.089	0.089
Zn	0.012	0.063	0.063
pH (pH unit)	7.5	7.685	8.5
Total Alkalinity as CaCO ₃	24	126	114
SO ₄	2.5	13.12	13.12

4.5.2 BHD STORAGE SOURCE CHEMISTRY

The composition of the source water from the BHD storage area has used the SPLP extract and the results of the XRD analysis to generate the predicted water chemistry based on equilibration of the extract with the identified mineralogy. At this stage of the assessment it is assumed that the BHD will be stored/delivered at an L/S ratio similar to the SPLP Extract (20:1 L/S ratio). The changes caused by the equilibration with the mineralogy are presented below in Table 4-7 **Error! Reference source not found.**

TABLE 4-7: PHASE CHANGES DUE TO EQUILIBRATION

Phase	Formula	Concentration Change (moles)	Mineral Concentration Change (mg/l)
Chromite	FeCr ₂ O ₄	4.813 x 10 ⁻⁸	0.011
Forsterite	Mg ₂ SiO ₄	-2.971 x 10 ⁻⁴	-41.6
Wurstitite	(Zn,Fe)S	-2.522 x 10 ⁻⁴	-38.3
Zincite	ZnO	4.889 x 10 ⁻⁴	39.6

The model has excluded most of the non-detected trace metals. The only metals to be included are those which are present in the minerals with which the SPLP extract is being equilibrated (i.e. Fe, Cr, Mg, Si and Zn).

TABLE 4-8: SOURCE CONCENTRATIONS FOR BHD DERIVED WATER

Element (mg/L)	Mogale DC Baghouse SPLP	Source Chemistry Oxidising	Source Chemistry Reducing
Au	0.019	0.019	0.019
B	0.037	0.037	0.037
Ba	0.053	0.053	0.053
Ca	38.00	38	38
Cr	0.005	0.005	0.005
Fe	0.005	13.14	13.14
K	114	114	114
Li	0.013	0.013	0.013
Mg	36.00	49.8	49.8
Mn	0.89	0.89	0.89
Na	96.00	96	96
Ni	0.013	0.013	0.013
Pb	0.10	0.1	0.1
Se	0.016	0.016	0.016
Si	0.005	8.32	8.32
Sr	0.52	0.52	0.52
Ti	0.075	0.075	0.075
Zn	32.00	0.059	0.059
pH (pH unit)	6.5	8.87	8.93
Total Alkalinity as CaCO ₃	5	9.7	9.8
Cl	219	216	216
SO ₄	389	130	130
NO ₃ - N	0.50	2.2	0.5
F	1.30	1.3	1.3

The results indicate that there is unlikely to be a significant difference in the source chemistry when it becomes anaerobic. In reality it would be expected that, if sulphate reducing conditions are present (due to organic matter content), the sulphate content in the water may reduce due to form insoluble metal sulphides including iron and zinc with time. In the oxidising water (such as that associated with tailings ponds) it is considered likely that iron oxyhydroxide will precipitate. The modelling does suggest that the wurtzite will not alter the pH during any equilibration phase with the BHD water. It will be important to understand the availability of sulphide in the samples (by kinetic NAG testing) actually deposited in the waste dump because PHREEQ does not have a kinetic subroutine for the oxidation of wurtzite.

5 SUMMARY AND CONCLUSIONS

The geochemical assessment undertaken and presented in this report has characterised samples of waste material likely to be produced through the processing at the proposed Siyanda ferrochrome Project. The waste includes slag and baghouse dust. The following conclusions are of significance with respect to the assessment:

Slag

Three (3) samples of slag were produced in a pilot plant set up by MINTEK. The results show:

- The total sulphur content was low in all slag samples (max. of 0.13%) and they contain sufficient neutralising potential to offset the low acid potential.
- Slag samples are considered to be non-potentially acid generating (Non-PAG).
- An alkaline paste pH indicates negligible potential for the generation of short-term acidity.
- The source term concentrations for slag derived water, based on geochemical modelling is presented in Table 5-1 below:

TABLE 5-1: SOURCE CONCENTRATIONS FOR SLAG DERIVED WATER

Element (mg/L)	Final Concentration Post Equilibrating with Atmosphere
Al	3.73
Au	0.18
Ba	0.13
Ca	46
Cl	31
K	0.17
Mg	7.73
Mn	0.31
Si	5.82
Sr	0.19
Ti	0.089
Zn	0.063
pH (pH unit)	8.5
Total Alkalinity as CaCO ₃	114
SO ₄	13.12

Note: The geochemical model excluded most of the non-detected trace metals. The only metals to be included are those which are present in the minerals with which the SPLP extract is being equilibrated

Baghouse Dust

A sample of baghouse dust (BHD) was collected from the Mogale DC smelter.

- The total sulphur content of the BHD sample was high (1.8%) and contains insufficient neutralising potential to offset the acid potential.
- The BHD sample is considered to be potentially acid generating (PAG).

- A neutral paste pH indicates negligible potential for the generation of short-term acidity.
- The source term concentration for BHD derived water is presented in Table 5-2.
- The results indicate that there is unlikely to be a significant difference in the source chemistry when it becomes anaerobic.

TABLE 5-2: SOURCE CONCENTRATIONS FOR BHD DERIVED WATER

Element (mg/L)	Source Chemistry Oxidising	Source Chemistry Reducing
Au	0.019	0.019
B	0.037	0.037
Ba	0.053	0.053
Ca	38	38
Cr	0.005	0.005
Fe	13.14	13.14
K	114	114
Li	0.013	0.013
Mg	49.8	49.8
Mn	0.89	0.89
Na	96	96
Ni	0.013	0.013
Pb	0.1	0.1
Se	0.016	0.016
Si	8.32	8.32
Sr	0.52	0.52
Ti	0.075	0.075
Zn	0.059	0.059
pH (pH unit)	8.87	8.93
Total Alkalinity as CaCO ₃	9.7	9.8
Cl	216	216
SO ₄	130	130
NO ₃ - N	2.2	0.5
F	1.3	1.3

The source term will be used as an input parameter in the numerical groundwater model, developed as part of the groundwater impact assessment report (SLR, 2016), which will assess the potential impacts of the waste facilities on groundwater resources.

The results are considered acceptable for the purpose of this level of assessment and there is no reason not to proceed with the project provided that the waste facility design and any impact mitigation measures, as determined by the waste design and water specialists, are implemented.

6 ASSUMPTIONS AND LIMITATIONS

The following assumptions and limitations are applicable to this geochemical assessment:

- Slag samples from the project specific pilot plant are assumed to represent the actual slag.
- Baghouse dust sample (from similar smelter operation) tested as part of this assessment is considered to be a proxy sample which gives a good indication of the expected waste characteristics.

7 RECOMMENDATIONS

Based on the assessment undertaken, the following recommendations are made:

- Baseline water monitoring should be undertaken to establish the characteristics (levels and quality) of water prior to the smelter becoming operational. Water monitoring should be continued throughout the life of the smelter and results compared to baseline conditions to assess the potential changes in groundwater characteristics over time. Monitoring should include, but not be limited to, elements identified in the source term.

8 DECLARATION OF INDEPENDENCE

I, *Jenny Ellerton* hereby declare that *SLR Consulting (Africa) (Pty) Limited*, an independent consulting firm, has no interest or personal gains in this project whatsoever, except receiving fair payment for rendering an independent professional service.

Consultant name: Jenny Ellerton

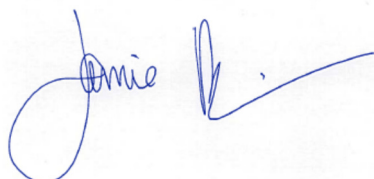


Signature:

Date: September 2016


I, *Jamie Robinson* hereby declare that *SLR Consulting (UK)*, an independent consulting firm, has no interest or personal gains in this project whatsoever, except receiving fair payment for rendering an independent professional service.

Consultant name: Jamie Robinson



Signature:

Date: September 2016



**Jenny Ellerton and Jamie
Robinson
(Report Authors)**

**Caitlin Hird
(Project Manager)**

**Jamie Robinson
(Project Reviewer)**

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Department of Water Affairs and Forestry (DWAf) (2006) *Impact Prediction. Best Practice Guidelines for Water Resource Protection in the South African Mining Industry, Guideline G4*. Department of Water Affairs and Forestry, August 2006.

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APPENDIX A: CURRICULUM VITAE OF PROJECT TEAM

QUALIFICATIONS

- MSc Geochemistry, Leeds University, 1989.
- BSc (Hons) Earth Sciences, Oxford Polytechnic, 1987.

BACKGROUND

- Jamie has over 28 years' experience as an Service Line Director, project Director, Project manager and Technical Director. He has been responsible for the management of a technical group with an annual turnover of £3M and comprising 65 staff. Jamie started the Research and Innovation group which obtained substantial financial investment from Major Companies (e.g National Grid, BP, Exxon) and enabled the team to flourish and grow in a recession.
- Jamie is an environmental geochemist and hydrochemist in assessing mine water treatment options. This has included the construction of passive treatment systems for coal and metal mine drainage in the UK and USA. Jamie designed the original Wheal Jane Treatment system in the early 1990's. Jamie is experienced in the prediction and geochemical evolution of mine water within acid pit lakes using models such as PHREEQC.
- This work has led to over twenty publications in the scientific community. Jamie has lectured in Australia and UK and is an examiner for the Specialist in Land Condition (SiLC) qualification and a scrutineer for the Royal Geological Society.

PROFESSIONAL REGISTRATIONS

- Chartered Geologist: United Kingdom (1000918) 1996
- Specialist in Land Condition, 2002
- Qualified Person: Definition of Waste (2011)

- External Examiner for Strathclyde University (2011)

FIELDS OF SPECIAL COMPETENCE

- Geochemistry
- Hydrochemistry
- Acid Mine Drainage Prediction
- Wetland Treatment System
- Human Health risk Assessment
- Contaminated Land Management
- Ecological Risk Assessment
- Groundwater Risk Assessment

EXPERIENCE

MINE WATER AND COAL SEAM GAS GEOCHEMISTRY

- 2016, South Africa, Technical Director. Jamie undertook geochemical modelling to develop a source term for a groundwater model associated with two sites used for the disposal of spent materials associated with the chrome smelter.
- 2016, UK, Coal Authority, Technical Director. Jamie undertook a review of the acidic mine water emanating from the Wheal Jane Mine in Cornwall. The project included examining the use of various active treatment options for the mine water which included the use of innovative techniques to reduce the high metal loads.
- 2016, UK, Coal Authority, Technical Director. Jamie undertook the feasibility design for the passive treatment of acidic mine drainage at two former lead – zinc mines in England. The study included examining the use of biochemical reactors and aerobic wetlands.

- 2016, UK, Coal Authority, Technical Director. Jamie won a position on the Coal Authority's Technical Panel regarding the treatment of metalliferous mine water. The three year term commission involves providing high level treatability advice regarding the treatment of mine water in the UK.
- 2015, Confidential, Ireland, Technical Director. Jamie undertook the analysis of tailings material to demonstrate they were not hazardous. Assessment tools included geochemical modelling and use of sequential extraction analysis.
- 2015, Confidential, Ireland, Technical Director Acid Mine Drainage Study, Belcarrig Quarry, Ireland. Jamie undertook a high level assessment of acidic water ponding at the base of a rhyolite quarry in Ireland. The study involved estimating the amount of treatment required using passive and active technologies. This included preliminary cost estimates for each of the techniques and selection of a preferred option
- 2015, Wolf Minerals, UK, Technical Director. Drakelands Tungsten Mine, Devon. Jamie is the Qualified Person associated with the materials management regarding the development of the mine. The Materials Management Plan review included technical assessment of the risk assessments associated with human health (arsenic) and controlled waters.
- 2013, Santos, Australia, Principal Geochemist. Geochemical modelling of brine, process water and permeate from CSG activities. A project was undertaken to ascertain the potential reactivity of the various water types upon their injection into basal formation waters in Queensland. The project used geochemical modelling to predict changes in chemistry associated with equilibration between the injected water and the aquifer mineralogy coupled with mixing with the formation water.
- 2013, Santos, Australia, Principal Geochemist. Geochemical Modelling of Brine Disposal. Jamie undertook a geochemical modelling study relating to the disposal of brine into a coastal environment. The study required preparing mixing models for the brines which were sourced from a number of locations – and then predicting clogging and scaling of the infrastructure.
- 2013, Santos, Australia, Principal Geochemist. Brine Injection Study, N Australia. Jamie undertook a geochemical assessment associated with the injection of brine into basement aquifer material. The study including developing an equilibrated model to predict the clogging of the aquifer after mixing between the brine and the natural groundwater
- 2013, OzMinerals, Australia, Principal Geochemist. Kanmantoo Mine, S Australia. Jamie undertook a geochemical investigation of blue/green water emerging from springs within an operating mine. The study included use of GWB, Visual MInteq and PHREEQ.
- 2013, Atlas Minerals, Australia, Principal Geochemist. Atlas McPhee Pit Lake Chemistry Prediction. Designed and modelled the geochemical and hydrochemical evolution of a pit lake associated with the extraction of iron ore in the Pilberra Region of Australia. The study used PHREEQ and included coordination with groundwater modelling and Leap Frog simulation of the mine evolution. Results were compared to water quality action values to ascertain the potential risk from the mining to the downstream environment.
- 2013, DMITER, Australia, Principal Geochemist. Brukunga Mine, Onsite Screening Services. A system was developed using a portable XRF and laboratory testing to enable the total sulfur and associated acid production tests to be established for a proposed remediation cell. The study set

criteria for the total S such that the rocks could be selected for use in the cell.

- 2013, OzMinerals, Australia, Principal Geochemist. Carrapateena Mine, kinetic testing of tailings material. Prediction of acid rock drainage from the tailings associated with a new mine in South .Australia. The study scheduled the testing and provided interpretation of the results to enable a mitigation plan to be developed. In addition cores of country rock sample were analysed using a portable XRF to understand the total S distribution and develop the acid rock drainage management plan for the site.
- 2013, Australia, Principal Geochemist. Technology Award to investigate Treatment of Acid Mine Drainage. Jamie and his team won an R&D award to investigate the use of biosolids for the treatment of Acid Mine Drainage associated with legacy sites in Darwin for Crocodile Gold. The biosolids were obtained from a sewage farm and provided a use other than landfilling.
- 2012, DMITRE, Australia, Principal Geochemist. Brukunga Mine Remediation Study. Jamie is the geochemist who is examining the mine closure remediation plan from a surface water contamination perspective. The study involves a number of areas which feed into the assessment of residual risk posed by the proposed remediation.
- 2011, Newcrest, Australia, Principal Geochemist. Wafi Golpu Acid Mine Drainage Study, Newcrest. Jamie was the geochemist who reviewed the available data for the proposed gold mine and generated estimated lime treatment rates for the acidic mine and rock drainage. The site is in the mountainous area of Papua New Guinea in a region known to be seismically active.
- 2011, OzMinerals, Australia, Principal Geochemist. Cerrapatena Mine, Acid Rock Drainage review. Jamie was the SKM geochemistry team reviewed the ARD potential for a future mine site. This included reviewing the sulfur chemistry and proposing kinetic testing for more accurate prediction of ARD at the site. Discussions with DMITRE led to an agreed proposal for the future assessment of the ARD at the site. Long term kinetic testing is now scheduled and forming part of the document for the retention lease.
- 2000, Waste Management, USA, Senior Geochemist. Blue Ridge Wetland, Irvine, Kentucky. Jamie designed a wetland treatment system to treat mine water under drainage emanating from a landfill site in the US. The study used settlement and reed beds to mitigate the drainage as approved by the USEPA officer.
- 2002, Environment Agency, UK, Senior Geochemist. Welsh Metal Mine Study. Jamie was the geochemist who examined the potential for various treatment options at remote sites in Wales. The study included examining the use of wetland technology for ancient mines which had particular issues regarding lead and zinc.
- 1994, ZCCM, Zambia, Geochemist. Musakashi Tailings Dam, Zambia. Jamie undertook treatability trials to establish if high sulphate waters form a tailings dam could be treated using passive wetland systems. This included a period of time on site in the Copper Belt to supervise the study.
- 2000, the Coal Authority, UK, Senior Geochemist. Reed Bed Design at former Cuthill Colliery, Scotland: When the Cuthill Colliery closed, the mine flooded and iron contaminated water began to emanate from a former mine shaft. The Coal Authority commissioned the design of a passive treatment system to mitigate the observed contamination of the local river. Jamie was the geochemist involved in calculating the size of the reed beds and settling tanks for the treatment of iron contaminated water.

- 2000, the Coal Authority, UK, Senior Geochemist. The Coal Authority, Taff Merthyr, South Wales: Responsibilities included providing the specification for the construction of a 4-hectare Wet land treatment system. The work involved the geochemical design of the system which was required to remove high iron loads to protect the local ecosystem. In addition downstream of the mine a new water recreational area required protecting from the mine water. In addition the work involved the selection of reeds, substrate and overseeing planting, with onsite attendance associated with dealing with contractor disputes over reed and substrate types.
 - 2000, the Coal Authority, UK, Senior Geochemist The Coal Authority, Lindsay, South Wales: Responsibilities included providing the geochemical specification for the construction of a 2-hectare wetland treatment system. This work involved the designing the settlement ponds for the removal of high iron loads from the mine water. Site activities required advising on the selection of reeds, substrate and overseeing planting.
 - 2000, the Coal Authority, UK, Senior Geochemist The Coal Authority, Morlais, South Wales: The Environment Agency's 'most polluting' discharge required treatment using passive wetlands/reed beds. The work involved geochemical design of the system which required a large settlement pond upstream of a reed bed system. The net alkaline mine water was due to the historic filling of the new shaft with limestone. However determination in the water quality meant modelling of the anticipated and long term quality was required.
 - 2000, the Coal Authority, UK, Senior Geochemist The Coal Authority, Dunvant and Taff Merthyr: For this study, Jamie undertook a review of mine water treatability and produced budget costing for wetland treatment.
 - 1999, the Coal Authority, UK, Senior Geochemist Laboratory of the Government Chemist: This project concerned the Treatment of Soil and Water Programme. Jamie was the expert independent referee for the research proposals submitted to the Programme. The proposals concerned the use of wetlands for treatment of acid mine drainage and wastewater.
 - 2000, the Coal Authority, UK, Senior Geochemist The Coal Authority: This project involved the assessment of the treatability of mine drainage from abandoned coal mines in Wales. Jamie compared active treatment with a wetland treatment system, producing a detailed wetland design.
 - 1996, Waste Management, USA, Senior Geochemist Algal Mat Research Project. Jamie designed and supervised the use of algal mats for the treatment of metals emanating from a former waste tip in Louisville, Kentucky.
 - 1994, National Rivers Authority, UK, Geochemist. Wheal Jane Mine, Minewater Treatability. Jamie was the geochemist who designed and tested the original pilot scheme for the treatment acidic water emanating from the Nangiles Adit in Falmouth. The study examined the use of aerobic, anaerobic and active treatment systems.
- EXPERT WITNESS**
- Jamie provided expert testimony regarding the death of a child during the floods in southern England. The assertion was that a client's landfill was responsible for causing the generation and migration of hydrogen cyanide gas into the adjoining property.
- LAND QUALITY INVESTIGATION, RISK ASSESSMENT AND REMEDIATION**
- 2016, UK, Ballylumford Power Station. Jamie undertook an ecological risk

assessment to determine if the presence of vanadium in the drainage from an old landfill passed a risk to the estuarine environment. The study used an SSD analysis in association with the vanadium and involved an H1 water quality assessment.

- 2016, UK Melton Ross Landfill risk assessment. Jamie provided a quantitative risk assessment to address the risk to a chalk aquifer from mecoprop. The assessment was reviewed and accepted by the Environment Agency.
- 2016, UK Rontec Petrol Stations. Jamie undertook a review of the available information regarding three petrol station sites. In particular the assessment was used to address a way forward for the client such that no further action from a contamination perspective would be required.
- 2016, UK La Chouet Quarry, Guernsey. Jamie undertook a preliminary investigation of a quarry used to store oil waste from the Torre Canyon spill. The project involved assessing the likely financial impact regarding the contamination on the prospective quarrying in the area. The study included examining the risk from unexploded ordnance.
- 2016, UK, Former Gasworks, Inverness, Scotland. Jamie undertook a review of information regarding a former gasworks site in Inverness with a view to forming an opinion as to the risk posed by the contamination on the surrounding groundwater. The information was used to secure a land purchase agreement.
- 2015, Australia, Review of Ecological and human health risk assessment. Jamie undertook a detailed review of recent reports regarding ecological and human health risks for a site in Sydney. The project required appreciation of current Australia guidance

such that the proposed remediation works would be accepted by the State Auditor.

- 2014, UK Selenium and Sulphate Ecological Risk Assessment. The disposal of London Clay required consideration of the risk posed by naturally occurring selenium and sulphate. The Environment Agency require confirmation that this would not pose a risk to freshwater receptors when the clay is used to create wetlands for wading birds. Jamie undertook a bioaccumulation and geochemical assessment which demonstrated the risk would not be an issue associated with the proposed project.
- 2015, Ireland, Waste Acceptance Criteria Assessment, Blackhall, Ireland. Jamie prepared a groundwater risk assessment using the EA RTM spreadsheets to calculate acceptance criteria for an inert landfill site in Ireland. The project met the EPA's requirements and also provided a pragmatic approach to assessing the site.
- 2015, UK Waste Acceptance Criteria Assessment, Fassaroe, Ireland. Jamie undertook unsaturated zone transport modelling to calculate criteria for an inert landfill site. The study included meeting the EPA's requirements and producing a useable document for the site.
- 2014, UK, Jamie prepared a groundwater risk assessment to calculate soil action values to be used for soil lining a reservoir. The assessment needed to be protective of surface water receptors for substances which might leach from the London Clay used in the lining.
- 2014, UK, Qualified Person, Kilnwood Vale, Surrey. Jamie reviewed all relevant information regarding the proposed reclamation of Kilnwood Vale for a proposed residential development by Crest Strategic projects. The role of QP involved signing a

- declaration for the Environment Agency to approve the Material Management Plan.
- 2014, UK Qualified Person Nickolls Quarry Kent. Jamie reviewed all relevant information regarding the proposed reclamation of Nickolls Quarry in Kent. The role of QP involved signing a declaration for the Environment Agency to approve the Material Management Plan.
 - 2014, Australia, Jamie undertook the human health and groundwater risk assessment to derive remediation action values for the site. The study included an innovative approach to assessing cyanide contamination including on site testing of cyanide speciation changes associated with free standing water.
 - 2014, Australia Abandoned Railway Lines Study, Adelaide. Jamie was the Project Director and technical advisor for assessing the risk posed to grazing animals near abandoned railway tracks. The study used XRF technology to delineate arsenic (and other metals/metalloids) with scheduling of bioaccessibility testing (UK) and grass analysis to calculate the theoretical dose to cattle, sheep and horses
 - 2013, Australia Jamie was the geochemist responsible for the conceptual design of a wetland for the treatment of landfill leachate at the Malabar Peninsular. This sizing of system used the Tank In Series (TIS) model and the P-C*-K first order decay model to predict treatment of Nitrogen species, BOD, Total-P, heavy metals and coliforms.
 - 2013, Australia, Jamie was the technical risk assessor involved in developing RBSLs for the protection of cattle from lead ingestion. The lead existed in soil associated with an overland pipeline and required consultation with the Regional Vet.
 - 2012, Australia Undertook vapour health risk assessment for a new development due to be constructed above groundwater contaminated with chlorinated solvents. The study tested different management scenarios associated with the basement car park and surrounding residential properties.
 - 2012, Australia This project involved the remediation design of a wood preserving chemical manufacturing site. Jamie was project manager for the investigation and remediation of the site whose groundwater and soil was contaminated with a range of chlorinated organic compounds including pentachlorophenol and dieldrin. The remediation comprised specialised geotechnical works and Jamie also obtained agreement for the groundwater risk assessment with the Environment Agency.
 - 2011, UK EON Central Networks. Jamie is the director and quantitative risk assessor for the EON Emergency Response contract. Jamie is responsible for the design and application of intrusive investigation following the initial emergency clean-up.
 - 2011, UK Defence Estates Emergency Response. Jamie was the project manager for the emergency response regarding the oil spill at the Falkland Islands. Jamie organised a site presence within 3 days and established a working methodology for the validation of the clean up. Jamie also provided outline design for a surface water treatment system in the tank farm area.
 - 2010, UK, Forensics Investigation of Ammonium. Jamie is the technical assessment and project director regarding the investigation of a former landfill and gasworks to demonstrate that the ammonium contamination in the groundwater is not source from historic

activity. Jamie uses nitrogen isotopes and hydrochemical modelling to demonstrate the source of the ammonium is from natural saline intrusion, thereby saving the client significant remediation costs.

- 2009, UK Mitchell McFarlane, Atomic Weapons Facility, Cardiff. Responsible for project management of the investigation of part of the former AWE facility in Cardiff, Wales. Contaminants included explosives, beryllium, uranium and volatile organic compounds. The work included liaison with the RPA associated with radiological protection measures and producing reports to a very tight timescale.
- 2009, UK Vapour Risk Assessment. Jamie completed a number of quantitative vapour and odour risk assessments for National Grid and Exxon Mobil. This has shown that Johnson Ettinger modelling required altering to account for biodegradation such that risk evaluation was possible at sites across the UK. This work validated the observed site conditions and demonstrated that risk to residents was minimal.
- 2009, UK Slough Borough Council, Colnbrook School. Jamie designed and directed the investigation of a former gasworks which now forms part of special needs school in Slough. The investigation showed the presence of the former structures and contamination associated with the historic use. The work has included the design of a remediation scheme which allows the school to operate during half term time.
- 2009, UK Rhonda Cynon Taff, Brofiscin Quarry. Jamie was Project Director and risk assessor for the vapour and surface water in a quarry which is contaminated with old drums of PCB waste. The risk assessment

has included detailed working between the ambient air specialist within PB and the remediation teams. The 12 month monitoring of VOCs in the ambient air, boreholes and flux boxes is being assessed to decide if the site should be determined under Part 2a.

Jamie has approved the options appraisal for the site.

- 2009, UK Jamie has provided technical advice and supervised the investigation and remediation of sites through the BSF programme. This has included providing remediation design and options analyses for the construction of a school on an existing landfill site in Walker, Newcastle. Projects have been undertaken across the North East and Kent.
- 2009, Project Director of team successful in winning the redevelopment of a former gasworks into a new town park in St Helier, Jersey. The project includes combining remediation, EIA, landscape architecture and planning. Due for opening in 2011, the town park is a major project valued at over £10M.
- 2009, Uxbridge Sorting Office Investigation, Royal Mail. Jamie designed and managed the investigation of a sorting office which is built on a former gasworks in Uxbridge. The work has led to design of a detailed remediation system to protect controlled waters.
- 2009, London Borough of Tower Hamlets, Part 2a Investigation. Jamie was the project manager and risk assessor associated with the site investigation and remedial option study for housing estates in the East End of London. This involved undertaking detailed investigations to determine the risks to residents who live on a site built on a former gasworks. The risk assessment included site specific exposure analysis involving

- questionnaires for the residents, sampling of air and concrete (foundations).
- 2008, Residential Study, National Grid Property Holdings. Jamie was the risk assessor responsible for the assessment of 100 sites throughout the UK. The residential properties are located close to former gasworks sites and an assessment of the risk to the occupants was required. A detailed flow sheet and decision matrix was developed to indicate which sites required more detailed investigation and remediation. A total of 75 sites were investigated on a rolling programme of works. After risk assessment it was shown that a number of soils required remediation due to elevated levels of PAHs, heavy metals and cyanides
 - 2008, Lattice Property Holdings Limited, Long Eaton Gasworks Remediation: This project involved soil and groundwater remediation at a former gasworks in Long Eaton, Nottinghamshire. Works included excavate and disposal of contaminated soil. Groundwater remediated by the removal of free phase hydrocarbons from groundwater surface. Jamie produced risk assessments to calculate action values for soil and groundwater remediation and was the project manager for the remediation programme. The project enabled the site to be sold for retail purposes.
 - 2007, Lattice Property Holdings Limited, Southampton Gasworks Remediation: Project manager involving the remediation of contaminated ground and groundwater of a former gasworks. The design included the removal of diesel product from groundwater. Regular contact with the PB Residential Engineer ensured the project met with regulatory approval and enabled the new Southampton FC Stadium to be constructed.
 - 2006 Lattice Property Holdings Limited, Rochester Gasworks: Project manager and technical advisor for design of soil and groundwater remediation of former gasworks in Kent. The work required quantified human health and groundwater risk assessment to determine site soil action values. In addition a detailed design review of sustainable technologies was undertaken, including; bioremediation, thermal desorption, soils washing, stabilisation and natural attenuation.
 - 2006 Lattice Property Holdings Limited, Blandford and Penzance Gasworks. Jamie undertook quantified risk assessments to establish clean-up criteria for the remediation of two gasworks. Contamination includes cyanide, phenol and PAH which required assessing in terms of risk to human health and controlled waters.
 - 2005 BP Global Environmental Services Phase 1 and Phase 2 Investigations, Bangkok and Thailand: BP Global Environmental Services has a number of sites throughout the world (outside the US) which require assessing to establish potential environmental liability associated with their ownership. The project in Thailand has involved the assessment of two lubricating oil blending/manufacturing sites. Jamie was the project manager for this project and co-ordinated the site investigation team from Australia and Thailand involving a short overseas trip to audit site investigation procedures. He was also responsible for the report production, client liaison and risk assessment.
 - 2005 BP Global Environmental Services Phase 2 Investigation, Port Dickson, and Malaysia: This project involved the assessment of two lubricating oil blending/manufacturing sites in Malaysia.

Jamie was the project manager for the investigation and was responsible for coordinating a Malaysian based investigation team and providing risk assessments for the resulting investigation.

- 2005 BP Global Environmental Services, Ystad, Sweden: This project involved a site formerly owned by BP which had been remediated by a new leaseholder. The rationale behind the remediation was assessed to establish if the associated costs (which for the basis of a claim) were reasonable. Jamie produced remediation design and strategy for contaminated groundwater associated with a former fuel storage depot.
- 2005 Esso Petroleum Company Ltd.: In his position as project manager, Jamie was appointed Witness To Fact by Esso Petroleum in their successful action involving contamination of groundwater at their site in Cambridge.
- 2003 Mendip District Council, Glastonbury: Jamie undertook a site investigation of a former tannery site involving trial pitting and the drilling of boreholes equipment. As part of the works, he sampled the landfill, which contained animal carcasses for microbiological (e.g. anthrax) and organic contaminants
- 2003 Stanlow Baseline Assessment, Ellesmere Port, Stanlow, Cheshire: BP Ltd. had recently taken control of a large distribution centre. Part of the site was due to be leased to an independent oil supply company. As part of the lease agreement, BP required a baseline study to be completed the results of which form part of the lease agreement. Jamie provided the investigation design, client co-ordination, project management, technical interpretation and report authorisation for this project.

RESEARCH AND INNOVATION

- 2013, ZeroWaste, Adelaide. Jamie was the Project Director involved in the research into the onsite treatment of soil contamination. The project included the use of local university research teams and carbon budget assessment. The conclusions were that changes to the guidance, incentives and landfill price would be required to promote more onsite treatment and soil reuse.
- 2009, Jamie managed the team, including world leaders in bioaccessibility testing to investigate methods for estimating the bioaccessibility of PAH compounds. This involved an 18 month study which used a mechanical gut (usually used for pharmaceutical testing) to simulate the human gut and involved using soil which were historically contaminated with PAH compounds.
- 2010, Jamie undertook a detailed review of former gasworks for National Grid Property Holding Limited to ascertain which could have elevated ammonia in the groundwater. From this chemical analysis was undertaken to identify the sources of the ammonia using forensic style techniques. The latter included the use of stable isotopes (nitrogen and oxygen) and classical hydrochemistry investigation techniques (the use of Piper Diagrams).
- 2009, Jamie designed the system and managed the team responsible for the innovative use of a hydrophobic belt skimmer for the removal of DNAPL from

tar tanks and groundwater at former gasworks sites. The project successfully removes tar thereby significant cost savings for the client were realised.

- 2011, Jamie undertook a variety of hydro and geochemical investigations for National Grid Property to demonstrate that ammonium within the groundwater at Becton was not caused exclusively by historic groundwater contamination. The works included the use of Piper Diagrams, Bivariant Plots, Thermodynamic Modelling, and the use of Nitrogen/Oxygen Stable Isotopes. The work successfully demonstrated to the Environment Agency that there are at least 3 sources of ammonium at the site included sewage works, saline intrusion and the gasworks.
- 2009, Jamie was commissioned by National Grid Property Holdings to design and manage an ammonium treatability study in Exeter. The work involved dispatching volumes groundwater for treatability studies in Queens University, Belfast. These included the use of column experiments to assess the treatability of the ammonium in the ground water in aerobic and anaerobic conditions. The outcome of the study developed a passive reactor for groundwater treatment.
- 2010, Jamie, working for SecondSite Property, was project manager and technical advisor to a team including SecondSite involved in the use of leaching oxygen release compounds from bentonite honeycombs and the treatment

of DNAPL compounds within groundwater.

- 2008, Jamie was project manager of a study involving the use of a bioslurry reactor to treat soil and groundwater contaminated with polyaromatic hydrocarbons, phenols and BTEX compounds. The successful project included publication in CLAIRE Technology Profiles
- 2010, Jamie was the project manager and geochemical technical advisor to a team (including National Grid, Queens University Belfast, Surry University and Oxford University) involved in researching the use of an aerobic/anaerobic permeable reactive barrier for treating groundwater contamination at a former gasworks. The system was designed to treat all contaminants of concern in the groundwater and was awarded the Brownfield Best Bio-system and Most Innovative Remediation System.

PUBLICATIONS

- 2014. Use of Sewage Sludge and Crocodile Manure for Treatment of Acidic Metalliferous Mine Drainage. Presented at 31st National meeting of American Society of Mining and Reclamation. Oklahoma City, June 2014.
- 2013 Use of Biosolids for the treatment of Acid Mine Drainage. Presented at 5th International Contaminated Site Remediation Conference, Melbourne (Aug 2013)
- 2013. Use of Biosolid for the Treatment of Acidic and Metalliferous Mine Drainage. Presented at Australia Water Association Conference: Leachate, Lurgies and Leftover. Launceston, Tasmania (May 2013)

- 2012. The Protection of Cattle from Ingestion of Lead Using Risk Assessment. Australasian College of Toxicology and Risk Assessment. 5th Annual Scientific Meeting. Adelaide Oct 25th 2012.
 - 2012. Groundwater Chemistry, Lecture presented to Groundwater School and Flinders University, Adelaide, (March 2012)
 - 2011. The Use of Environmental Forensics, presented at Sustainability Live 2011, NEC Birmingham.
 - 2010. Is It Your Liability? Robinson JDF, 2010, Presented at Sustainability Live 2010, Birmingham NEC.
 - 2009. Is it your Liability? Robinson J.D.F 2009 Environmental Business Magazine.
 - 2006. In situ bioremediation of cyanide, PAHs and organic compounds using an engineered SEquenced REactive BARrier (SEREBAR) Robinson Jamie, Thomas Russell, Wallace Steve, Daly Paddy, Kalin Robert, Land Contamination & Reclamation Vol 14, No. 2, pp. 478-482 (2006)
 - 2006. Sources and Innovative Treatment of Ammonium at Former Manufactured Gas Plants, April 2006, in Land Contamination and Reclamation ed Jamie.S, Ripp, .J and Unites. D presented. International Symposium and Exhibition on the Redevelopment of Manufactured Gas Plant sites, Reading.p525.
 - 2004. Younger, P.L., Jenkins, D.A., Rees, S.B., Jarvis, A.P., Ralph, J., Johnston, D.N. Robinson, J, and Coulton, R.H., 2004, Mine waters in Wales: pollution, risk management and remediation. In Nichol, D., Bassett, M.G. and Deisler, V.K. (Editors), Urban Geology in Wales. National Museums and Galleries of Wales, Cardiff, Geological Series Number 23. 138-154
 - 1998. "Treatment of Mine Drainage", December 1998, World Coal Magazine Vol 7 No. 12 pp 38 - 40
 - 1998. "Wetland Treatment Tackles Coal Mine Drainage Pollution", March 1998, Waste and Environment Vol 6 Issue 10 pp 6 – 9
 - 1998. "Mine Drainage and Landfill Leachate Treatment", September 1998, World Water Magazine
 - 1998. "Wetland Treatment of Polluted Waters", in "Proceedings of In-Situ and On-Site Bioremediation", Battelle Conference New Orleans, 1997
 - 1996. "Paying For Past Profits", December 1996, Environmental Biotech.
 - 1995. "Prediction and Remediation of Acid Mine Damage", September 1995, Mining Environmental Management.
- AWARDS**
- SKM Technical Award, 2013, Use of Biosolids for the treatment of acid mine drainage;
 - SKM Spot Awards:
 - 2012 – Recognition for developing new subcontracting agreements for drilling and service clearance.
 - 2012 – Recognition for rolling out Health and Safety scenario training for Adelaide VESA staff.
 - 2013 – Recognition for achieving maximum scores from client for feedback regarding the use of XRF for mapping arsenic along old railway lines.
 - Global Project of the Year 2008 PB Inc.: Forensic Study of Ammonia in Groundwater.
 - Global Project of the Year 2004: SEREBAR Groundwater Treatment System, PB Inc.

- Best Biosystem and Most Innovative Treatment System. Brownfield Briefing Awards, October 2005. Project Manager and Geochemical Design.
- R&D Award: Ammonium Treatability, Jamie won an award from PB New York to investigate the treatability of ammonium in groundwater. This involved the use of nitrogen isotopes to determine the nitrification processes operating within the SEREBAR Treatment system.
- R&D Award: Natural Attenuation of Naphthalene. Jamie won an award from PB New York project concerning a study that developed a screening model to assess whether natural attenuation is a useable remediation method for contaminated groundwater at former gasworks.

PROFESSIONAL HISTORY

- 2014 – Current: Principal Geochemist at SLR.
- 2011 – 2013: Principal Geochemist at Sinclair Kinght Merz Pty Ltd, Adelaide Australia.
- 1994 – 2011: Service Line Director Environmental Engineering at Parsons Brinckerhoff Ltd (Europe, Africa, Middle East). Bristol, UK.
- 1990 – 1994: Geochemist at Knight Piesold and Partners, Ashford, Kent.
- 1987 – 1988: Mud Logging and Geochemist, Exploration Logging Ltd.

Jenny Ellerton
Senior Hydrogeologist / Geochemist



Curriculum Vitae

Qualifications

MSc	2005	Hydrogeology – University of Birmingham
BSc (Hons)	2002	Geology and Physical Geography Dual Honours - Keele University (Upper Second)
FGS	Since 2006	Fellow of the Geological Society

Key Areas of Expertise

Jenny has **10 years** of professional experience gained in both the UK and South Africa. Key areas of Jenny's expertise are summarised below

Groundwater Assessments	Groundwater Assessments – to support environmental impact assessments, water use licence applications and engineering design.
Hydrogeological Site Investigation	Supervising drilling contractors for numerous types of site investigations and undertaking aquifer tests.
Environmental Monitoring	Groundwater, surface water, leachate & gas monitoring.
Development of Conceptual Site Models	Analysis & interpretation of geological and hydrogeological information.
Acid Rock Drainage Assessments	Geochemical assessment and remediation of mine related water pollution.
Project Management	Experience in management of field based hydrogeological studies and desk based projects.

Summary of Experience and Capability

Jenny is a Senior Hydrogeologist within SLR with 10 years of geological and hydrogeological experience gained through a master's degree and environmental consultancy both in the UK and South Africa.

Jenny has undertaken projects covering all aspects of hydrogeology and specialises in the following:

- Site investigation, including the installation of groundwater and gas monitoring boreholes and the detailed logging of soil and rock samples.
- Undertaking monitoring and sampling of surface water, groundwater, landfill gas and leachate and undertaking field permeability tests and data analysis.
- Qualitative and quantitative Hydrogeological Risk Assessments.
- Groundwater assessments for Environmental Statements in support of planning applications for mineral extraction operations, landfill developments, and other industrial and commercial developments.

- Geochemical and Acid Rock Drainage (ARD) assessments to characterise the expected waste rock material associated with the mineral extraction process of various types of mining operations in accordance with best practice.
- Waste classification in terms of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (No. R. 635) and Disposal of Waste to Landfill (No. R 636).
- Soil contamination assessment to determine the level of soil contamination in terms of soil screening values as presented in National Norms and Standards for the Remediation of Contaminated land and Soil Quality.

Recent Project Experience

Key aspects of Jenny's recent project experience are summarised below.

Project	Date	Jenny's Role
Siyanda Chrome Smelter Project (South Africa)	Current	Responsible for managing and co-ordinating the groundwater and geochemical studies. Work includes geophysical investigations, drilling and pump testing, collection of samples, development of a conceptual site model and source term and a numerical groundwater model to assess the potential impact of the site on surrounding water resources.
Kudumane Manganese Project (South Africa)	Current	Responsible for co-ordinated drilling to drill boreholes within the riverbed of the Ga-mogara River and to undertake an study to understand the groundwater / surface water interaction at the site in support of the Water Use License Application.
Manica Gold Project (Mozambique)	Current	Involved in both the groundwater and geochemical assessments for the project in support of the Environmental Impact Assessment for the Project.
Lofdal REE Project (Namibia)	Current	Responsible for the selection of representative waste samples for geochemical characterisation and undertaking an assessment of the potential for acid mine drainage (AMD) and metal leaching in support of an Environmental and Social Impact Assessment (ESIA).
Panda Hill Gold Project (Tanzania)	Current	Geochemical assessment to support engineering design work and assess potential impact on groundwater. Work included geochemical modelling and development of a salt balance.
Mokala Manganese Project (South Africa)	September 2015	Waste assessment in terms of the National Norms and Standards to determine the waste type and the class of landfill (liner specification) required to dispose of mining waste.
Alfred Knight Due Diligence Project (South Africa)	August 2014	Responsible for the selection of samples, sample analysis and interpretation of results in terms of the National Norms and Standards for the Remediation of Contaminated land and Soil Quality to determine 'baseline' condition of the soil.
Hinda Phosphate Project (Congo)	September 2013	Responsible for co-ordination and undertaking the supervision of the drilling of boreholes and pumping tests. Interpretation of field data and reporting.

Publications

None to date

APPENDIX B: LABORATORY CERTIFICATES



WATERLAB

WATERLAB (PTY) LTD

Building D, The Woods,
Perseus Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
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CERTIFICATE OF ANALYSES ACID – BASE ACCOUNTING EPA-600 MODIFIED SOBEK METHOD

Date received: 2015-03-03	Report number: 50768	Date completed: 2015-03-19
Project number: 139		Order number: 0169
Client name: SLR Consulting (South Africa) (Pty) Ltd		Contact person: Jenny Ellerton
Address: PO Box 40161, Fairy Glen, 0043		Email: jellerton@slrconsulting.com
Telephone: 012 361 8118	Facsimile: 012 991 1907	Cell: 072 077 7463

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification				
	SLAG Tap 42	SLAG Tap 75	SLAG Tap 82	Baghouse Composite Sample	Baghouse Composite Sample
Sample Number	73	74	75	76	76 D
Paste pH	11.4	10.6	10.1	10.9	11
Total Sulphur (%) (LECO)	0.13	0.11	0.13	0.57	0.57
Acid Potential (AP) (kg/t)	4.06	3.44	4.06	17.81	17.81
Neutralization Potential (NP)	57	19	12	-2.43	-1.45
Nett Neutralization Potential (NNP)	53	15	7.48	-20.24	-19.26
Neutralizing Potential Ratio (NPR) (NP : AP)	14	5.39	2.84	0.14	0.08
Rock Type	III	III	III	I	I

* Negative NP values are obtained when the volume of NaOH (0.1N) titrated (pH: 8.3) is greater than the volume of HCl (1N) to reduce the pH of the sample to 2.0 – 2.5 Any negative NP values are corrected to 0.00.

Please refer to Appendix (p.2) for a Terminology of terms and guidelines for rock classification

E. Botha
Geochemistry Project Manager



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APPENDIX: TERMINOLOGY AND ROCK CLASSIFICATION

TERMINOLOGY (SYNONYMS)

- Acid Potential (AP) ; *Synonyms:* Maximum Potential Acidity (MPA)
Method: Total S (%) (Leco Analyzer) x 31.25
- Neutralization Potential (NP) ; *Synonyms:* Gross Neutralization Potential (GNP) ; *Syn:* Acid Neutralization Capacity (ANC) (The capacity of a sample to consume acid)
Method: Fizz Test; Acid-Base Titration (Sobek & Modified Sobek (Lawrence) Methods)
- Nett Neutralization Potential (NNP) ; *Synonyms:* Nett Acid Production Potential (NAPP)
Calculation: NNP = NP – AP; NAPP = ANC – MPA
- Neutralising Potential Ratio (NPR)
Calculation: NPR = NP : AP

CLASSIFICATION ACCORDING TO NETT NEUTRALISING POTENTIAL (NNP)

If NNP (NP – AP) < 0, the sample has the potential to generate acid

If NNP (NP – AP) > 0, the sample has the potential to neutralise acid produced

Any sample with NNP < 20 is potentiall acid-generating, and any sample with NNP > -20 might not generate acid (Usher *et al.*, 2003)

ROCK CLASSIFICATION

TYPE I	Potentially Acid Forming	Total S(%) > 0.25% and NP:AP ratio 1:1 or less
TYPE II	Intermediate	Total S(%) > 0.25% and NP:AP ratio 1:3 or less
TYPE III	Non-Acid Forming	Total S(%) < 0.25% and NP:AP ratio 1:3 or greater

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CLASSIFICATION ACCORDING TO NEUTRALIZING POTENTIAL RATIO (NPR)

Guidelines for screening criteria based on ABA (Price *et al.*, 1997; Usher *et al.*, 2003)

Potential for ARD	Initial NPR Screening Criteria	Comments
Likely	< 1:1	Likely AMD generating
Possibly	1:1 – 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	2:1 – 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	>4:1	No further AMD testing required unless materials are to be used as a source of alkalinity

CLASSIFICATION ACCORDING TO SULPHUR CONTENT (%S) AND NEUTRALISING POTENTIAL RATIO (NPR)

For sustainable long-term acid generation, at least 0.3% Sulphide-S is needed. Values below this can yield acidity but it is likely to be only of short-term significance. From these facts, and using the NPR values, a number of rules can be derived:

- 1) Samples with less than 0.3% Sulphide-S are regarded as having insufficient oxidisable Sulphide-S to sustain acid generation.
- 2) NPR ratios of >4:1 are considered to have enough neutralising capacity.
- 3) NPR ratios of 3:1 to 1:1 are considered inconclusive.
- 4) NPR ratios below 1:1 with Sulphide-S above 3% are potentially acid-generating. (Soregaroli & Lawrence, 1998 ; Usher *et al.*, 2003)

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REFERENCES

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SOREGAROLI, B.A. & LAWRENCE, R.W. 1998. Update on waste Characterisation Studies. Proc. Mine Design, Operations and Closure Conference. Polson, Montana.

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E. Botha
Geochemistry Project Manager

WATERLAB (PTY) LTD
CERTIFICATE OF ANALYSES
ICP-MS SCAN ANALYSIS

Date received: 2015/03/03
 Project number: 139

Date Completed: 2015/04/02
 Report number: 50768

Client name: SLR Consulting (South Africa) (Pty) Ltd
 Address: PO Box 40161, Fairy Glen, 0043

Contact person: Jenny Ellerton
 Email: jellerton@slrconsulting.com

Extract	Sample Mass (g)	Volume (ml)	Factor
Distilled Water	50	1000	20

Sample Id	Sample Number	Ag	Ag	Al	Al	As	As
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	0.706	14	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	0.143	2.86	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	0.240	4.80	<0.010	<0.200

Sample Id	Sample Number	Au	Au	B	B	Ba	Ba
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	0.034	0.682	<0.010	<0.200	0.025	0.500
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	0.050	0.991	0.046	0.914

Sample Id	Sample Number	Be	Be	Bi	Bi	Ca	Ca
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	8.80	176
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	1.06	21
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	0.010	0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	153	3060

Sample Id	Sample Number	Cd	Cd	Ce	Ce	Co	Co
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Cr	Cr	Cs	Cs	Cu	Cu
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	112	2240	0.283	5.66	<0.010	<0.200

Sample Id	Sample Number	Dy	Dy	Er	Er	Eu	Eu
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Fe	Fe	Ga	Ga	Gd	Gd
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	0.024	0.472	<0.010	<0.200

Sample Id	Sample Number	Ge	Ge	Hf	Hf	Ho	Ho
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	0.014	0.275	<0.010	<0.200

Sample Id	Sample Number	In	In	Ir	Ir	K	K
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	0.033	0.660
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	205	4100

Sample Id	Sample Number	La	La	Li	Li	Lu	Lu
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	0.032	0.642	<0.010	<0.200

Sample Id	Sample Number	Mg	Mg	Mn	Mn	Mo	Mo
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	1.49	30	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	0.788	16	0.059	1.18	<0.010	<0.200
SLAG Tap 82	75	0.084	1.68	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	2.07	41	<0.010	<0.200	0.039	0.787

Sample Id	Sample Number	Na	Na	Nb	Nb	Nd	Nd
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	330	6600	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Ni	Ni	Os	Os	P	P
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	0.010	0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	0.012	0.240

Sample Id	Sample Number	Pb	Pb	Pd	Pd	Pt	Pt
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Rb	Rb	Rh	Rh	Ru	Ru
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	1.01	20	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Sb	Sb	Sc	Sc	Se	Se
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	0.083	1.66

Sample Id	Sample Number	Si	Si	Sm	Sm	Sn	Sn
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	2.4	48	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	0.6	12.5	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	0.1	1.9	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	14.9	299	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Sr	Sr	Ta	Ta	Tb	Tb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	0.036	0.711	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	0.872	17	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Te	Te	Th	Th	Ti	Ti
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	0.017	0.338
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	0.131	2.63

Sample Id	Sample Number	Tl	Tl	Tm	Tm	U	U
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	V	V	W	W	Y	Y
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
Baghouse Composite Sample	76	0.109	2.17	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Yb	Yb	Zn	Zn	Zr	Zr
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 42	73	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 75	74	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
SLAG Tap 82	75	<0.010	<0.200	0.012	0.240	<0.010	<0.200
Baghouse Composite Sample	76	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200



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CERTIFICATE OF ANALYSES TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received:	2015/03/03	Report number:	50768	Date completed:	2015/04/02
Project number:	139	Order number:	0169		
Client name:	SLR Consulting (South Africa) (Pty) Ltd	Contact person:	Jenny Ellerton		
Address:	PO Box 40161, Fairy Glen, 0043	Email:	jellerton@slrconsulting.com		
Telephone:	012 361 8118	Cell:	072 077 7463		

Analyses	SLAG Tap 42		SLAG Tap 75		SLAG Tap 82		Baghouse Composite Sample	
	Sample Number	73	74	75	76			
TCLP / Acid Rain / Distilled Water / H ₂ O ₂	Distilled Water		Distilled Water		Distilled Water		Distilled Water	
Dry Mass Used (g)	50	50	50	50	50	50	50	
Volume Used (mℓ)	1000	1000	1000	1000	1000	1000	1000	
pH Value at 25 °C	7.6	7.2	6.3	8.8				
Electrical Conductivity in mS/m at 25 °C	6.0	1.4	0.4	284				
Inorganic Anions	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Total Dissolved Solids at 180 °C	26	520	<10	<200	<10	<200	2116	42320
Total Alkalinity as CaCO ₃	24	480	8	160	<5	<100	164	3280
Chloride as Cl	6	120	<5	<100	<5	<100	139	2780
Sulphate as SO ₄	<5	<100	<5	<100	<5	<100	926	18520
Nitrate as N	<0.2	<4.0	<0.2	<4.0	<0.2	<4.0	0.2	4.0
Fluoride as F	<0.2	<4.0	<0.2	<4.0	<0.2	<4.0	4.1	82
Total Cyanide as CN	<0.01	<0.2	0.01	0.2	<0.01	<0.02	0.01	0.2
Hexavalent Chromium as CrVI	<0.010	<0.20	<0.010	<0.20	<0.010	<0.20	190	3800
Mercury as Hg	<0.001	<0.02	<0.001	<0.02	<0.001	<0.02	<0.001	<0.02
ICP-MS Scan	See tab ICP MS DW		See tab ICP MS DW		See tab ICP MS DW		See tab ICP MS DW	
Acid Base Accounting	See attached report 50768 ABA							
X-ray Diffraction [s]	See attached report 50768 XRD							

[s]=subcontracted

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Geochemistry Project Manager



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CERTIFICATE OF ANALYSES
X-RAY DIFFRACTION

Date received: 2015-03-03
Project number: 139

Report number: 50768

Date completed: 2015-03-16
Order number: 0169

Client name: SLR Consulting (South Africa) (Pty) Ltd
Address: PO Box 40161, Fairy Glen, 0043
Telephone: 012 361 8118

Facsimile: 012 991 1907

Contact person: Jenny Ellerton
Email: jellerton@slrconsulting.com
Cell: 072 077 7463

Composition (%) [s]			
SLAG Tap 42		SLAG Tap 75	
73		74	
Mineral	Amount (weight %)	Mineral	Amount (weight %)
Forsterite	24.14	Forsterite	35.58
Diopside	28.64	Diopside	7.26
Akermanite-Gehlenite	14.16	Akermanite-Gehlenite	0
Spinel	33.06	Spinel	57.16

Composition (%) [s]			
SLAG Tap 82		Baghouse Composite Sample	
75		76	
Mineral	Amount (weight %)	Mineral	Amount (weight %)
Forsterite	38.61	Chromite	45.08
Diopside	2.09	Forsterite	54.92
Akermanite-Gehlenite	0		
Spinel	59.3		

[s] Results obtained from sub-contracted laboratory

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CERTIFICATE OF ANALYSES X-RAY DIFFRACTION

Date received: 2015-03-03
Project number: 139

Report number: 50768

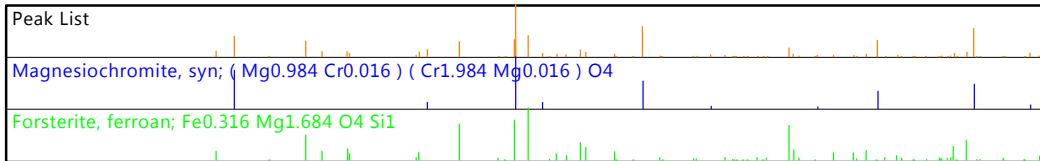
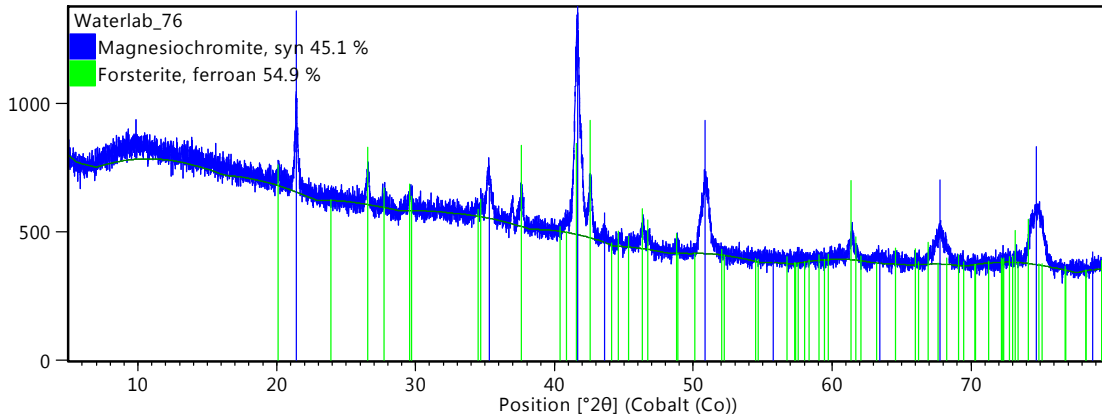
Date completed: 2015-03-16
Order number: 0169

Client name: SLR Consulting (South Africa) (Pty) Ltd
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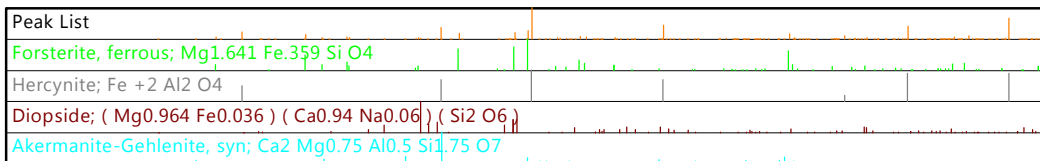
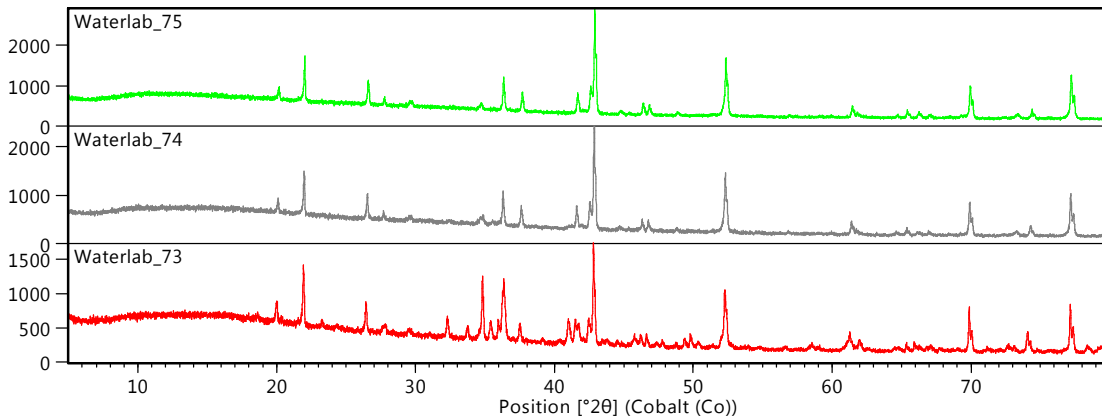
Facsimile: 012 991 1907

Contact person: Jenny Ellerton
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Counts



Counts



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CERTIFICATE OF ANALYSES **X-RAY DIFFRACTION**

Date received: 2015-03-03
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Note:

The material was prepared for XRD analysis using a backloading preparation method.

It was analysed with a PANalytical Empyrean diffractometer with PIXcel detector and fixed slits with Fe filtered Co-K α radiation. The phases were identified using X'Pert Highscore plus software.

The relative phase amounts (weight %) were estimated using the Rietveld method.

Comment:

- Due to crystallite size effects results errors may be larger than shown.
- In case the results do not correspond to results of other analytical techniques, please let me know for further fine tuning of XRD results.
- Mineral names may not reflect the actual compositions of minerals identified, but rather the mineral group.
- Amorphous phases, if present, were not taken into consideration during quantification

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CERTIFICATE OF ANALYSES
ACID – BASE ACCOUNTING
EPA-600 MODIFIED SOBEK METHOD

Date received: 2015-11-11
Project number: 139

Report number: 55841

Date completed: 2015-12-14
Order number: 0283

Client name: SLR Consulting (South Africa) (Pty) Ltd
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Contact person: Jenny Ellerton (P/O)
Email: jellerton@slrconsulting.com
Email: accountsza@slrconsulting.com
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Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification	
	Mogale DC Baghouse	Mogale DC Baghouse
Sample Number	21146	21146D
Paste pH	7.2	7.2
Total Sulphur (%) (LECO)	1.80	1.80
Acid Potential (AP) (kg/t)	56	56
Neutralization Potential (NP)	8.20	-2.41
Nett Neutralization Potential (NNP)	-48	-59
Neutralising Potential Ratio (NPR) (NP : AP)	0.146	0.043
Rock Type	I	I

* Negative NP values are obtained when the volume of NaOH (0.1N) titrated (pH: 8.3) is greater than the volume of HCl (1N) to reduce the pH of the sample to 2.0 – 2.5 Any negative NP values are corrected to 0.00.

Please refer to Appendix (p.2) for a Terminology of terms and guidelines for rock classification

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APPENDIX : TERMINOLOGY AND ROCK CLASSIFICATION

TERMINOLOGY (SYNONYMS)

- Acid Potential (AP) ; *Synonyms:* Maximum Potential Acidity (MPA)
Method: Total S(%) (Leco Analyzer) x 31.25
- Neutralization Potential (NP) ; *Synonyms:* Gross Neutralization Potential (GNP) ; *Syn:* Acid Neutralization Capacity (ANC) (The capacity of a sample to consume acid)
Method: Fizz Test ; Acid-Base Titration (Sobek & Modified Sobek (Lawrence) Methods)
- Nett Neutralization Potential (NNP) ; *Synonyms:* Nett Acid Production Potential (NAPP)
Calculation: NNP = NP – AP ; NAPP = ANC – MPA
- Neutralising Potential Ratio (NPR)
Calculation: NPR = NP : AP

CLASSIFICATION ACCORDING TO NETT NEUTRALISING POTENTIAL (NNP)

If NNP (NP – AP) < 0, the sample has the potential to generate acid
If NNP (NP – AP) > 0, the sample has the potential to neutralise acid produced

Any sample with NNP < 20 is potential acid-generating, and any sample with NNP > -20 might not generate acid (Usher *et al.*, 2003)

ROCK CLASSIFICATION

TYPE I	Potentially Acid Forming	Total S(%) > 0.25% and NP:AP ratio 1:1 or less
TYPE II	Intermediate	Total S(%) > 0.25% and NP:AP ratio 1:3 or less
TYPE III	Non-Acid Forming	Total S(%) < 0.25% and NP:AP ratio 1:3 or greater

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CLASSIFICATION ACCORDING TO NEUTRALISING POTENTIAL RATIO (NPR)

Guidelines for screening criteria based on ABA (Price *et al.*, 1997 ; Usher *et al.*, 2003)

Potential for ARD	Initial NPR Screening Criteria	Comments
Likely	< 1:1	Likely AMD generating
Possibly	1:1 – 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	2:1 – 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	>4:1	No further AMD testing required unless materials are to be used as a source of alkalinity

CLASSIFICATION ACCORDING TO SULPHUR CONTENT (%S) AND NEUTRALISING POTENTIAL RATIO (NPR)

For sustainable long-term acid generation, at least 0.3% Sulphide-S is needed. Values below this can yield acidity but it is likely to be only of short-term significance. From these facts, and using the NPR values, a number of rules can be derived:

- 1) Samples with less than 0.3% Sulphide-S are regarded as having insufficient oxidisable Sulphide-S to sustain acid generation.
- 2) NPR ratios of >4:1 are considered to have enough neutralising capacity.
- 3) NPR ratios of 3:1 to 1:1 are considered inconclusive.
- 4) NPR ratios below 1:1 with Sulphide-S above 3% are potentially acid-generating. (Soregaroli & Lawrence, 1998 ; Usher *et al.*, 2003)

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CERTIFICATE OF ANALYSES X-RAY DIFFRACTION

Date received: 2015-11-11
Project number: 139

Report number: 55841

Date completed: 2015-12-14
Order number: 0283

Client name: SLR Consulting (South Africa) (Pty) Ltd
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Contact person: Jenny Ellerton (P/O)
Email: jellerton@slrconsulting.com
Email: accountsza@slrconsulting.com
Cell: 072 077 7463

Composition (%) [s]	
Tailings 1	
10560	
Mineral	Amount (weight %)
Zincite	26.8
Chromite	37.35
Willemite	6.32
Wurtzite	3.21
Gordaite	3.46
Forsterite	22.86

[s] Results obtained from sub-contracted laboratory

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Geochemistry Project manager

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CERTIFICATE OF ANALYSES X-RAY DIFFRACTION

Date received: 2015-11-11
Project number: 139

Report number: 55841

Date completed: 2015-12-14
Order number: 0283

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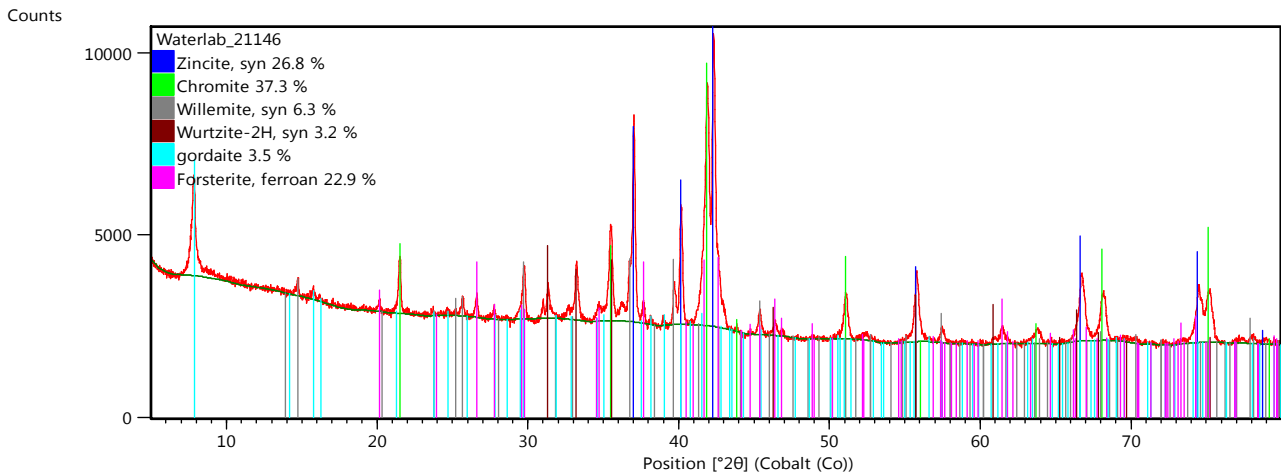
Contact person: Jenny Ellerton (P/O)
Email: jellerton@slrconsulting.com
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Cell: 072 077 7463

Note:

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Comment:

- In case the results do not correspond to results of other analytical techniques, please let me know for further fine tuning of XRD results.
- Mineral names may not reflect the actual compositions of minerals identified, but rather the mineral group.
- Due to preferred orientation effects results may not be as accurate as shown in the table.
- Amorphous phases, if present, were not taken into consideration during quantification
- Traces of additional phases may be present



Phase	Chemical Formula
Zincite, syn;	Zn O
Chromite;	Mg _{0.53} Cr _{1.32} Fe _{0.47} Al _{0.68} O ₄
Willemite, syn;	Zn ₂ (Si O ₄)
Wurtzite-2H, syn;	Zn S
gordaite;	Na Zn ₄ (S O ₄) Cl (O H) ₆ (H ₂ O) ₆
Forsterite, ferroan;	Fe _{0.2} Mg _{1.8} O ₄ Si ₁

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CERTIFICATE OF ANALYSES EXTRACTIONS AS 4439.3

Date received:	2015/11/11	Date completed:	2015/12/14
Project number:	139	Order number:	0283
Project number:	55841		
Client name:	SLR Consulting (South Africa) (Pty) Ltd	Contact person:	Jenny Ellerton (P/O)
Address:	PO Box 40161, Fairy Glen, 0043	Email:	jellerton@slrconsulting.com
Telephone:	011 467 0945	Cell:	0720777463

Analyses	Mogale DC Baghouse
Sample Number	21146
TCLP / Borax / Distilled Water	Distilled Water
Ratio*	1:20
Inorganic Anions	mg/ℓ
Total Dissolved Solids at 180°C	1002
Total Alkalinity as CaCO ₃	<5
Chloride as Cl	219
Sulphate as SO ₄	389
Nitrate as N	0.5
Fluoride as F	1.3
Total Cyanide as CN	<0.010
Hexavalent Chromium as Cr ⁶⁺	<0.010
pH	6.5
Electrical Conductivity in mS/m at 25°C	161
ICP-MS Scan	See tab ICP DW
Acid Base Accounting	See attached report 55841 ABA
X-ray Diffraction [s]	See attached report 55841 XRD

[s]=subcontracted

E. Botha
Geochemistry Project Manager



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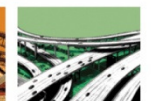
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