



DALYSHOPE ASH BACKFILL AND GEOCHEMICAL STUDY

**ANGLO OPERATIONS (PTY) LIMITED
AND
VEDANTA RESOURCES PLC**

FEBRUARY 2014

Digby Wells and Associates (South Africa) (Pty) Ltd (Subsidiary of Digby Wells & Associates (Pty) Ltd). Co. Reg. No. 2010/008577/07. Fern Isle, Section 10, 359 Pretoria Ave Randburg Private Bag X10046, Randburg, 2125, South Africa
Tel: +27 11 789 9495, Fax: +27 11 789 9498, info@digbywells.com, www.digbywells.com

Directors: A Sing*, AR Wilke, LF Koeslag, PD Tanner (British)*, AJ Reynolds (Chairman) (British)*, J Leaver*, GE Trusler (C.E.O)
*Non-Executive




DIGBY WELLS
ENVIRONMENTAL

This document has been prepared by **Digby Wells Environmental**.

Report Title: Dalyshope Ash Backfill and Geochemical Study

Project Number: ANG2137

Name	Responsibility	Signature	Date
André van Coller	Hydro-geochemist		13 February 2014
Lucas Smith	Review		15 February 2014

This report is provided solely for the purposes set out in it and may not, in whole or in part, be used for any other purpose without Digby Wells Environmental prior written consent.



TABLE OF CONTENTS

1	INTRODUCTION	1
1.1	Geochemical Study Description	2
1.2	Scope of Work	3
1.3	Deliverables	3
1.4	Methodology	4
1.4.1	<i>Data Review and Interpretations</i>	4
1.4.2	<i>Geochemical Sampling, Laboratory Tests and Interpretations</i>	4
1.4.3	<i>Conceptual Geochemical Model</i>	5
1.4.4	<i>Geochemical Modelling</i>	5
2	DESKTOP INFORMATION.....	6
2.1	Regional Geology	6
2.2	Local Geology	6
2.3	General Geochemistry	7
2.4	Basic Concepts Associated with Coal Mine Environmental Geochemistry	8
2.4.1	<i>Sulphide Mineral Oxidation and ARD Formation</i>	8
2.4.2	<i>Neutralising Mineralogy and Processes</i>	10
2.4.3	<i>Silicates and Clay Minerals</i>	11
3	CONCEPT LEVEL ARD POTENTIAL STUDY	12
4	LABORATORY TEST RESULTS AND INTERPRETATIONS	13
4.1	Sampling.....	13
4.2	Sample Identification.....	13
4.3	SANS Guidelines and Leachate Classification	14
4.4	Waste Rock Results.....	15
4.4.1	<i>Waste Rock XRF</i>	15
4.4.2	<i>Waste Rock XRD</i>	18
4.4.3	<i>Waste Rock Total Concentrations</i>	19
4.4.4	<i>Waste Rock ABA and NAG</i>	21
4.4.5	<i>Waste Rock Leachate Results</i>	23
4.5	Coal Results	24
4.5.1	<i>Coal XRF</i>	24

4.5.2	<i>Coal XRD</i>	26
4.5.3	<i>Coal Total Concentrations</i>	27
4.5.4	<i>Coal ABA and NAG</i>	29
4.5.5	<i>Coal Leachate Results</i>	30
4.6	<i>Ash Results</i>	31
4.6.1	<i>Ash XRF</i>	31
4.6.2	<i>Ash XRD</i>	32
4.6.3	<i>Ash Total Concentrations</i>	33
4.6.4	<i>Ash ABA and NAG</i>	36
4.6.5	<i>Ash Leachate Results</i>	37
4.6.6	<i>Ash Classification</i>	38
5	PIT BACKFILL GEOCHEMICAL MODELS	42
5.1	Model Setup	42
5.1.1	<i>Conceptual setup</i>	42
5.1.2	<i>Assumptions and Limitations</i>	42
5.1.3	<i>Scenario Description</i>	44
5.2	Fluid Speciation	46
5.2.1	<i>Waste Rock Speciation</i>	46
5.2.2	<i>Coal Leachate Speciation</i>	48
5.2.3	<i>Ash Leachate Speciation</i>	50
5.2.4	<i>Groundwater Speciation</i>	54
5.2.5	<i>Rain water sample</i>	57
5.3	Weathering Models	58
5.3.1	<i>Scenario W1</i>	58
5.3.2	<i>Scenario W2</i>	62
5.3.3	<i>Scenario W3</i>	65
5.3.4	<i>Scenario W4</i>	69
5.4	Mixing Reaction Models	74
5.4.1	<i>Input samples</i>	74
5.4.2	<i>Scenario M1</i>	75
5.4.3	<i>Scenario M2</i>	78
5.4.4	<i>Scenario M3</i>	83

5.4.5	<i>Scenario M4</i>	83
6	CONCLUSIONS.....	86
6.1	Final Conceptual Geochemical Models	86
6.1.1	<i>Waste Rock Dumps</i>	86
6.1.2	<i>Coal Stockpiles</i>	86
6.1.3	<i>Backfilling</i>	90
6.2	Laboratory Tests	90
6.2.1	<i>Waste rock samples</i>	90
6.2.2	<i>Coal samples</i>	92
6.2.3	<i>Ash samples</i>	93
6.2.4	<i>ARD Potential</i>	94
7	RECOMMENDATIONS.....	96
8	REFERENCES	97

LIST OF FIGURES

Figure 1: pH levels as per carbonate distribution in an aqueous system (Witthueser 2010)	11
Figure 2: Planned mining sequence	45
Figure 3: Mining benches and coal layers	45
Figure 4: Piper diagram of the waste rock leachate fluid	47
Figure 5: Stiff diagram for each waste rock leachate fluid	47
Figure 6: Piper diagram of the coal sample leachate fluid	49
Figure 7: Stiff diagram for each coal sample leachate fluid	49
Figure 8: Piper diagram of the ash leachate fluid	52
Figure 9: Stiff diagram for each ash leachate fluid	52
Figure 10: Activity vs. pH of aqueous Mn	53
Figure 11: Activity vs. pH of aqueous Ni	53
Figure 12: Activity vs. pH of aqueous B	54
Figure 13: Piper diagram of the groundwater samples	56
Figure 14: Stiff diagram for each groundwater sample	56
Figure 15: Stiff diagram of the rain water sample	58
Figure 16: Linear trend of oxygen fugacity during weathering of mine dumps	60
Figure 17: Scenario W1 pH and TDS development trend	61
Figure 18: Scenario W1 Piper diagram	61
Figure 19: Dissolution trend of selected parameters during simulation of scenario W1	62
Figure 20: Scenario W2 main aqueous species in solution	64
Figure 21: Scenario W2 mineral development during the weathering reactions	64
Figure 22: Scenario W2 secondary fluorite development	65
Figure 23: pH trend of an isolated vs atmospheric system	68
Figure 24: Scenario W3 jarosite and SO ₄ development within the system	68
Figure 25: Development of SO ₄ , Fe and K within the aqueous system	69
Figure 26: Scenario W4 fugacity trends of fO ₂ and fCO ₂	71
Figure 27: Scenario W4 pH trend	71
Figure 28: Development of the fluid with some aqueous species	72
Figure 29: Scenario W4 Piper diagram showing the water type change	72
Figure 30: Scenario M1 pH and TDS trends	76
Figure 31: Aqueous mineral development with an increase in saturation of elements	77
Figure 32: Scenario M1 development of some aqueous species	77

Figure 33: Scenario M1 ternary diagram indicating ion changes.....	78
Figure 34: Scenario M2 decrease in TDS.....	79
Figure 35: Partial fluid composition of groundwater/ash leachate mix over a 50 year period for selected species.....	80
Figure 36: Scenario M3 change in TDS.....	84
Figure 37: Scenario M3 Piper diagram	84
Figure 38: Scenario M4 change in TDS.....	85
Figure 39: Scenario M4 Mineral development during fluid mixing.....	85
Figure 40: Final conceptual geochemical WRD model.....	87
Figure 41: Final conceptual geochemical coal stockpile model.....	88
Figure 42: Final conceptual geochemical pit backfilling model.....	89

LIST OF TABLES

Table 1: Background mineralogy (Klein & Dutrow 2007; Mason 1966).....	8
Table 2: SANS 241:2005 drinking water classifications	15
Table 3: Waste rock XRF summary of major oxides	16
Table 4: Waste rock XRF summary of trace element composition.....	16
Table 5: Waste rock XRD summary of major mineral composition	19
Table 6: Waste rock total concentrations.....	20
Table 7: Waste rock ABA summary	22
Table 8: Waste rock NAG summary	22
Table 9: Coal XRF results summary of major oxides	24
Table 10: Coal XRF summary of trace element concentrations	24
Table 11: Coal XRD summary of the major mineral composition.....	27
Table 12: Coal total concentrations	27
Table 13: Coal ABA summary.....	30
Table 14: Coal NAG summary	30
Table 15: Summary of XRF results for the ash material.....	32
Table 16: Summary of XRD results for the ash material	32
Table 17: Total concentration for ash material.....	34
Table 18: ABA results for ash samples.....	36
Table 19: NAG results for ash samples	36
Table 20: Total Concentration Threshold Classification	40

Table 21: Leachable Concentration Threshold Classification.....	41
Table 22: Ash proportions	43
Table 23: Waste rock leachate fluid parameters	46
Table 24: Coal sample leachate fluid parameters	48
Table 25: Summary of the speciation parameters of the ions of concern	51
Table 26: Groundwater sample parameters	55
Table 27: Rain water sample	57
Table 28: Ash mineralogy for weathering models.....	59
Table 29: Scenario W3 mineralogy.....	66
Table 30: Scenario W4 mineralogy.....	69
Table 31: Comparison of weathering results of main ions.....	73
Table 32: Input samples.....	74
Table 33: Final fluid results from the mixing scenarios.....	81

LIST OF APPENDICES

Appendix A: Plans

Appendix B: Concept Level ARD Study

Appendix C: Laboratory Certificates

Appendix D: Leachate Classification Tables

LIST OF PLANS

Plan 1: Local geology

Plan 2: Regional geology

Plan 3: Hydrocensus boreholes

Plan 4: Drilling program

LIST OF ABBREVIATIONS

Abbreviation	Description
AATC	Anglo American Thermal Coal
ABA	Acid Base Accounting
AG	Acid Generating
AOPL	Anglo Operations (Pty) Ltd
AP	Acid Potential
ARD	Acid Rock Drainage
COI	Constituents of Interest
DEA	Department of Environmental Affairs
DMR	Department of Mineral Resources
DW	Distilled/Reagent Water
DWE	Digby Wells Environmental
EAP	Environmental Assessment Practitioner
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EMP	Environmental Management Program
EMPR	Environmental Management Program Report
IBW	Interbedding Waste Rock
ICP	Inductively Coupled Plasma Spectrometry
IPP	Independent Power Producer
K	Hydraulic Conductivity in m/d
LC	Leachable Concentration
LCT	Leachable Concentration Threshold
LDEDET	Limpopo Department of Economic Development, Environment and Tourism
LoM	Life of Mine
LoP	Life of Project
m/d	metres per day
m²/d	square metres per day
m³/d	cubic metres per day
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
Mtpa	Million tonnes per annum
NAG	Net Acid Generation
NEM:WA	National Environmental Management Waste Act
NEMA	National Environmental Management Act
NNP	Nett Neutralising Potential
non-PAG	Non-Potentially Acid Generating
NP	Neutralising Potential
NPR	Neutralising Potential Ratio

Abbreviation	Description
OBW	Overburden Waste Rock
PAG	Potentially Acid Generating
SANS	South African National Standards
SPLP	Synthetic Precipitation Leachate Procedure
T	Transmissivity in m ² /d
TC	Total Concentration
TCLP	Toxicity Characteristic Leachate Procedure
TCT	Total Concentration Threshold
TDS	Total Dissolved Solids
TSF	Tailings Storage Facilities
TSS	Total Suspended Solids
WHO	World Health Organisation
WR	Waste Rock
WRD	Waste Rock Dump
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

LIST OF CHEMICAL SYMBOLS

Chemical	Description	Chemical	Description
Ag	Silver	Mo	Molybdenum
Al	Aluminium	N	Nitrogen
As	Arsenic	Na	Sodium
Au	Gold	Nb	Niobium
B	Boron	Nd	Neodymium
Ba	Barium	Ni	Nickel
Be	Beryllium	NO₂	Nitrite
Bi	Bismuth	NO₂ as N	Nitrite as Nitrogen
Ca	Calcium	NO₃	Nitrate
Cd	Cadmium	NO₃ as N	Nitrate as Nitrogen
Ce	Cerium	O_{2(aq)}	Dissolved oxygen (aqueous)
Cl	Chloride	O_{2(g)}	Oxygen gas
Co	Cobalt	Pb	Lead
CO₂	Carbon dioxide	Pt	Platinum
CO₃	Carbonate	Rb	Rubidium
Cr	Chrome	Sb	Antimony
Cs	Caesium	Sc	Scandium
Cu	Copper	Se	Selenium
F	Fluoride	Si	Silicon
Fe	Iron	Sn	Tin
Ga	Gallium	SO₄	Sulphate
Ge	Germanium	Sr	Strontium
HCO₃	Bicarbonate	Ta	Tantalum
Hf	Hafnium	Te	Tellurium
Hg	Mercury	Th	Thorium
HO	Hydroxide	Ti	Titanium
Ho	Holmium	Tl	Thallium
Ir	Iridium	U	Uranium
K	Potassium	V	Vanadium
La	Lanthanum	W	Tungsten
Li	Lithium	Y	Yttrium
Mg	Magnesium	Zn	Zinc
Mn	Manganese	Zr	Zirconium

1 INTRODUCTION

Digby Wells Environmental (Digby Wells) has been appointed by Anglo Operations (Pty) Limited (AOPL) to be the independent Environmental Assessment Practitioner (EAP) for the proposed Dalyshope Phase 1 Coal Mine Project in the Limpopo Province.

AOPL, a business unit of Anglo American plc, is required to obtain environmental authorisation for the proposed development of the Dalyshope Phase 1 Coal Mine (the Mine). The Mine will be operated by Anglo American Thermal Coal (AATC), an operating division of AOPL, on the farms Klaarwater 231 LQ and Dalyshope 232 LQ in the Limpopo Province, approximately 60 km west of Lephalale.

AOPL holds a prospecting right in respect of the farms Dalyshope 232 LQ, Klaarwater 231 LQ, Nazarov 685 LQ, Wynberg 215 LQ, Canada 229 LQ and part of Matopi 705 LQ. The project area covers an area of 4 950.2 hectares (ha). The coordinates for the centre of the study area are 23° 32' 56.178" S and 27° 15' 10.635" E.

Currently, a business model is being developed which will consider the supply of semi-selectively mined Run of Mine (ROM) thermal coal to an Independent Power Producer (IPP), Vedanta, using opencast bench mining methods for coal extraction and a conveyor system to feed the coal into the IPP. This model is based on a 4.2 – 4.7 Mtpa (Million tonnes per annum) ROM production with a Life of Mine (LOM) of approximately 25 years. Consideration is currently being given to the possibility of constructing the Vedanta IPP on the farms Dalyshope and Klaarwater.

AATC has considered the option of constructing a wash plant to supply washed coal to Eskom should it become apparent that the IPP will not be in a position to receive coal from the proposed Dalyshope Phase 1 Coal Mine once it is operational.

Available electricity capacity in the area has already been allocated to existing users. Alternative energy supply options are therefore being investigated. Temporary power will be diesel generated until Eskom power is established after the commissioning of the IPP.

Currently, the only access to the proposed mine site is via an un-surfaced district road.

It is anticipated that the proposed mine will require approximately 1 500 m³ of water daily (730 000 m³ per annum). A feasible water source is still being investigated.

Anticipated infrastructure relating to the proposed mine will include (but is not limited to):

- Workshops;
- Temporary offices;
- Crushing stations;
- Conveyors;
- Brake test ramps;
- Pollution control facilities;
- Sewage treatment plant;

- Parking area;
- Hard park;
- Roads;
- Drainage systems;
- Bulk and potable water supply and storage infrastructure; and
- Fencing.

Applications in accordance with the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) and National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) (NEM:WA) were submitted to the Limpopo Department of Economic Development, Environment and Tourism (LDEDET) and the National Department of Environmental Affairs (DEA), respectively, for the undertaking of a EIA process and the relevant documentation will be submitted in order to obtain environmental authorisation for the proposed activities.

LDEDET will act as the decision making authority for activities under NEMA whilst DEA will act as the decision making authority for activities under NEM:WA.

As part of the application for a Mining Right on the farms Dalyshope 232 LQ, Klaarwater 231 LQ, Nazarov 685 LQ, Wynberg 215 LQ, Canada 229 LQ and part of Matopi 705 LQ, an Environmental Impact Assessment and Environmental Management Programme Report (EMPR) will be compiled for this purpose and submitted to the Department of Mineral Resources (DMR) for their approval.

1.1 Geochemical Study Description

Digby Wells is currently evaluating the feasibility of backfilling the proposed open pit at the Dalyshope project with ash materials and other waste; by undertaking geochemical laboratory analysis and detailed geochemical models. The pit backfilling evaluation forms part of the geochemical study. The study includes investigations into potential risks involved with the waste rock and coal storage facilities as well, that will be forming part of the project during the LoM.

The Dalyshope projects (mining and Vedanta IPP) are currently in EIA phase with various specialist studies and investigations initiated to determine all environmental impacts, mitigation options and their feasibility. Once mining has stopped, rehabilitation of the pit will occur through the backfilling of the void with waste rock and other available material. It has been proposed (as an option being investigated in both this geochemical assessment and the geohydrological study) to utilise ash from the Vedanta IPP as part of this backfilling material. The material used to backfill the pit needs to be chemically evaluated to determine its suitability for the proposed backfill option and that no potentially harmful leachate or ARD will occur that can be detrimental to the receiving environment or the surrounding groundwater and surface water resources.

In addition to the geochemical investigations on the proposed rehabilitation options, geochemical tests and evaluations of the waste rock and coal material that will be stored and

stock piled on site is also evaluated. The geochemical study for the project has been done in two separate stages:

- Geochemical laboratory analysis of the coal, waste rock and ash material that will be stored and utilised in the IPP and rehabilitation processes. The lab results have been analysed, evaluated and discussed to determine the potential environmental impacts; and
- Geochemical modelling of the various materials of which the ash composition will play a major chemical role to determine whether the ash backfilling is feasible from an environmental geochemical perspective.

1.2 Scope of Work

The following scope forms part of this project:

- Review and interpretations of available geological and geochemical data and reports;
- Interpretation of all geochemical laboratory results (available data and proposed sample submission results) for the coal, waste rock and ash material;
- Handling of samples and management of laboratories and their deliverables;
- Analytical groundwater flow and surface water calculations to evaluate inflow of water into the pit post closure;
- Conceptual hydro-geochemical model of the pit backfilling scenario;
- Detailed geochemical models to determine the thermodynamic process involved in the proposed backfilling scenario through simulations of fluid-waste, fluid-rock and fluid-fluid chemical interactions; and
- A specialist report detailing the risks involved, if any, with the proposed backfilling option, with summaries and recommendations.

1.3 Deliverables

The following deliverables forms part of this study:

- Geochemical laboratory results analysis and interpretations;
- Potential groundwater and surface water inflows (analytical desktop level);
- Geochemical model results and conclusions;
- Final conceptual geochemical and backfilling models; and
- Specialist report with conclusions and recommendations.

1.4 Methodology

1.4.1 Data Review and Interpretations

All available geological, geochemical, mineralogical, geohydrological and climatic data were reviewed to evaluate the current system and fed into the development of a geochemical conceptual model and scenario formulation.

1.4.2 Geochemical Sampling, Laboratory Tests and Interpretations

1.4.2.1 *Baseline conceptual study tests and data*

At the start of 2013 Golder completed a Conceptual Acid Rock Drainage (ARD) Potential Study for the Dalyshope project. ABA and NAG tests were performed on a large sample population including waste rock and coal material. These lab tests, results and reports feed into a summarised section and further interpretations in this document.

1.4.2.2 *Ash material*

Six (6) coal samples were submitted for burning and subsequent geochemical analyses were done on the ash produced from the samples. The samples consisted of individual representative samples from the lower coal layers namely the PMB, PMA, PLC, PLB and PLA. Along with these samples a composite sample of the top coal layers (PUE down to the PMC) were also submitted. The coal samples were prepared and submitted according to the following:

- These six coal samples were submitted according to the following lime dosing and burning criteria:
 - Lime dosing as per the criteria set out by Vedanta for the planned burning process expected at the power station; and
 - The coal-lime mixture was then burned for 30 minutes at 850°C with 20% excess air (or until ash was produced).
- The ash samples (6 samples) produced from the above burning were then subjected to the following laboratory tests:
 - XRD (X-Ray Diffraction) and XRF (X-Ray Florescence) analysis;
 - ABA (Acid Base Accounting) and NAG (Net Acid Generation) tests; and
 - SPLP (Synthetic Precipitation Leachate Procedure) leach tests on each sample with the leach tested for trace and major elements and metals by ICP (Inductively Coupled Plasma) spectrometry.

1.4.2.3 *Coal*

Six (6) coal samples were submitted for geochemical analyses. The samples consisted of individual representative coal samples from the lower coal layers namely the PMB, PMA, PLC, PLB and PLA. Along with these samples a composite sample of the top coal layers

(PUE down to the PMC) were also submitted. The coal samples were prepared and submitted for the following tests:

- XRD (X-Ray Diffraction) and XRF (X-Ray Florescence) analysis;
- ABA (Acid Base Accounting) and NAG (Net Acid Generation) tests; and
- DW (Distilled/Reagent water) leach tests on each sample with the leach tested for trace and major elements and metals by ICP (Inductively Coupled Plasma) spectrometry.

1.4.2.4 Waste rock

Six (6) waste rock samples were submitted for geochemical tests. The samples consisted of individual representative waste rock samples from the main waste layers to be mined along with the coal product namely the overburden (OBW1 and OBW2), inter-burdens (IBW1 and IBW2) and TRP2 and PLP1 which are the two larger layers separating the bottom coal seams. The waste samples were prepared and submitted for the following tests:

- XRD (X-Ray Diffraction) and XRF (X-Ray Florescence) analysis;
- ABA (Acid Base Accounting) and NAG (Net Acid Generation) tests; and
- DW (Distilled/Reagent water) leach tests on each sample with the leach tested for trace and major elements and metals by ICP (Inductively Coupled Plasma) spectrometry.

1.4.3 Conceptual Geochemical Model

All available geological, mineralogical and geochemical data were processed and used to develop a written description of the conceptual scenario expected during the backfilling of the Dalyshope open pit with ash and other waste. All conceptual processes, physical and chemical, will be included with geochemical model scenarios formulated from the conceptual formulation.

1.4.4 Geochemical Modelling

The following geochemical models will be completed where applicable:

- Speciation models to evaluate the chemical make-up of both surface water and groundwater in the local catchment to determine the water facies, as well as all saturate aqueous chemical species that can lead to secondary mineral formation in ideal conditions;
- Weathering and reaction models of rainwater that will be recharging the pit area and interact with both the backfill material and the local geology. All reactions and thermodynamic processes will be evaluated to determine all impacts and mechanisms that can form through the fluid-rock and fluid-waste interactions;
- Adsorption models and ion exchange will be simulated (if applicable in the evaluated environment and initial models) to determine whether any aqueous species present

in the leachate from the backfilled area will be removed from the resultant water by the underlying geology;

- Mixing models to determine and investigate the possible impact that leachate from the backfilled pit will have on the local groundwater quality; and
- All models will be simulated to best represent the planned backfilling schedule per material type.

2 DESKTOP INFORMATION

2.1 Regional Geology

The regional geology of the project area and surrounds (Plan 1) is dominated by the sedimentary sequences of the Karoo Supergroup and forms part of the Waterberg Coalfield; mainly covered by the Kalahari sands. Alluvial sedimentary formations characterises the flood plains of the Limpopo River; all along its banks through the project area.

The regional geology is made up of sandstone, shale and calcrete with alternating coal formations. The Zoetfontein Fault forms the northern boundary of this coalfield and the Eenzaamheid Fault forms the southern boundary; creating a horst structure. The Daarby fault, with a displacement of between 200 m and 400 m, roughly divides the coalfield into a shallow western area amenable to open pit mining methods as in the case of Dalyshope, and a deep north-eastern area (DWE 2011). There are a number of graben type faults running northeast to southwest which often result in alternating blocks of shallow or very deep coal. Only a few dolerite dykes are present in the south-eastern portion of the coalfield and no sill features have to date been encountered in any exploration boreholes.

2.2 Local Geology

The project area and site boundaries fall within the Ellisras basin known for its large coal deposits (Plan 2) in the Waterberg Coalfield. The local site geology is covered by quaternary sediments - Kalahari sands – with the top geological strata being the red mudstone of the Eendragtpan formation in the Ellisras basin. The upper most layers do not hold any coal seams.

The Grootegeluk formation underlying the Eendragtpan formation is the most important economic unit in the Ellisras basin with numerous thick coal seams in its 110 m thick layer along with alternating carbonaceous mudstone and shale which cyclically repeats. The coal seams and sedimentary layers of the formation formed in a tectonically stable phase of the basin history with delta abandonment allowing for peat deposits to settle and later form coal.

The Grootegeluk formation outcrops to the north and south of site along the contacts with the overlying Eendragtpan formation. The northern boundary of the project area is characterised by alluvial deposits within the flood plains of the Limpopo River. Calcrete formation is common in the area along drainage channels and small pans with high evaporation rates and low rainfall.

2.3 General Geochemistry

The mineralogy of the region is dominated by felsic minerals in the sedimentary sequences, with pyrite and other minerals associated with coal deposits. The Grootegeluk coal formation is dominated by mudstone with the depositional environment also dictating high organic matter content decreasing upward through the formation (Faure et al. 1996). The lower Grootegeluk mudstone consists mainly of kaolinite and quartz with small amounts of apatite. The upper Grootegeluk layers are rich in quartz, kaolinite, montmorillonite and smaller amounts of illite and microcline (Faure et al. 1996).

At the bottom of the Grootegeluk formation is a 2 m thick mudstone layer high in organic matter with traces of crystallised kaolinite, siderite, calcite and apatite. The lower strata of the formation have the highest quality coal associated with globular pyrite and a wide range of trace elements (Faure et al. 1996; Wagner & Tlotleng 2012). The trace element distribution in the Grootegeluk coal seams are in concentration well above the global average with exceptionally higher concentrations of mercury (Hg), cadmium (Cd), arsenic (As) and selenium (Se) associated with the formation mechanisms of the coal and associated FeS₂ (Pyrite) (Wagner & Tlotleng 2012). The wide range of trace elements and their concentrations relate to fresh water depositional environmental rather than salt water.

The upper formations of the project area are associated with calcite lenses. The major minerals of the region and their chemical formulas are listed in Table 1.

Table 1: Background mineralogy (Klein & Dutrow 2007; Mason 1966)

Mineral	Chemical formula	Comment
Quartz	SiO ₂	
Kaolinite	Al ₂ (Si ₂ O ₅)(OH) ₄	Slow dissolution rates with a release of aqueous Al-hydroxides as well as taking part in various ion exchange reactions during fluid-rock interaction and soil formation
Montmorillonite	(Na, Ca) _{0.33} (Al, Mg) ₂ (Si ₄ O ₁₀)	
Siderite	FeCO ₃	
Illite	K(Al, Mg, Fe) ₂ (Si, Al) ₄ O ₁₀ (OH) ₂	
Microcline	KAlSi ₃ O ₈	Slow weathering/dissolution rate
Apatite	Ca ₅ (PO ₄) ₃ (OH, F, Cl)	Source of PO ₄ , F and Cl aqueous species in groundwater
Pyrite	FeS ₂	AMD potential (Pyrite oxidation)
Calcite	CaCO ₃	

2.4 Basic Concepts Associated with Coal Mine Environmental Geochemistry

Coal mining and their associated activities do pose potential environmental risks with recent emphasis being placed on the geochemical impacts that may occur. Various environmental geochemical impacts can be identified through investigation of the source and waste material that will be processed and stored during the mining activities.

Coal mining in South Africa, as in the case of the Dalyshope project, is associated with certain mineralogical characteristics commonly associated with the coal formations in the Karoo Supergroup. The mineralogy and the various oxidation, solution, precipitation and kinetic reactions associated with some of the minerals lead to Acid Rock Drainage (ARD) formation and high leachability of metals from tailings storage facilities (TSF), Waste Rock Dumps (WRD) and stockpiles.

To fully understand the potential environmental geochemical risk involved with coal mining in general and more specifically the Dalyshope project and its associated mineralogy, some basic concepts and processes should be discussed. The main mineralogy that will be discussed is the XRD and XRF results of the ash, waste rock and coal geochemistry and will be the main topics.

2.4.1 Sulphide Mineral Oxidation and ARD Formation

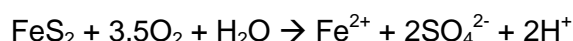
Sulphide minerals are associated with the coal deposits in the Waterberg Coalfield and in some cases the mineralogical inclusions in both the parting (waste rock) and the coal seams. The main sulphide mineral, and in most cases the only sulphide mineralogy as will be discussed section 4.3 to 4.5 of this report, is pyrite (FeS₂) and smaller inclusions of

chalcopyrite (CuFeS_2) and arsenopyrite (FeAsS). The breakdown and reactions involved with these sulphide minerals need to be fully understood in order for the mine to understand and develop a management plan for any environmental risks arising from these minerals.

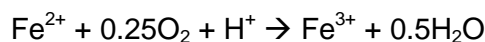
Oxidation of the sulphide minerals allows for the formation of ARD and meta-stable secondary products in various stages; each with its own characteristic reaction and processes (Dold 2005). In some cases when the material is enriched with more than one metal containing sulphide minerals, electrochemical processes and reactions can occur between the minerals when water and oxygen is added to the system. This acts as a catalyst in the same way as micro-organisms that increase the reaction rates and reactivity of the minerals. Micro-organisms is widely associated with sulphide mineral oxidation and as mentioned increases the rate of oxidation to almost 10^5 compared to normal reaction rates involving sulphides in abiotic conditions (Dold 2005). The main concern during the oxidation and reaction processes involved with sulphide minerals and the formation of ARD is the lowering of the system pH that in turn acts as a catalyst to heavy metal reactivity and mobility (Bethke 2008).

Pyrite, the most common sulphide mineral associated with coal formations and the process of ARD formation best illustrates the oxidation process and phases as follows:

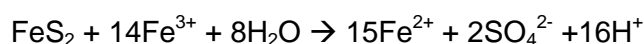
- Step 1: The oxidation of sulphur to sulphate and the release of ferrous iron;



- Step 2: The oxidation of ferrous iron to ferric iron; and



- Step 3: Hydrolysis and precipitation of ferric complexes and minerals.



The lowering of the pH of the system continuous and induces a decrease in oxidation rates of ferrous iron until ferric iron is produced and then takes over as the main catalyst to the oxidation process of pyrite. When the acid mine water (with high concentrations of ferric iron) reaches the surface or is exposed entirely to the climatic oxygenated conditions; as will be the case in mining processes and storage facilities for waste material, the system is fully oxidised. Hydrolysis then in turn allows for the precipitation of secondary minerals in which the most common minerals are goethite and jarosite. The formation of secondary minerals or salts are highly dependent on the ideal pH-Eh conditions and the availability of certain anions and cations in the surface soils.

In some cases where open systems like open pit mines are allowed to flood or in cases where waste water is captured in evaporation ponds to allow the formation of the meta-stable phases in a controlled area, the bulk of the system can be alkaline due to the hydrolysis and precipitation. However, in most cases a small layer or zone of acid water still exists and this should be managed and controlled.

The formation of secondary meta-stable minerals like goethite ($\text{Fe}(\text{OH})_3$) and other iron hydroxides produces the most acid and as soon as the pH decreases to levels below 3.5, Fe^{3+} remains in solution with $\text{Fe}(\text{OH})_3$ becoming instable. Another sulphate mineral that

forms from ARD under high evaporative conditions is gypsum. Gypsum is however highly soluble and releases metals into the system as soon as it gets into contact with water.

2.4.2 Neutralising Mineralogy and Processes

The ARD formation in most cases results in a system with a pH between 1.5 and 4. Potential buffering reactions is a major chemical ally in managing and preventing the formation of ARD. The mineralogy of both the host rock and inclusions in the coal seams of the project area, as will be discussed in the XRD results, is rich in proportional distributions of K-feldspar, calcite, siderite, quartz, muscovite, kaolinite and in the case of the ash material produced from the IPP, lime is also found in large proportions.

All these above mentioned minerals do have the potential to react with the acid water and metal leachate produced from the ARD to buffer the system towards a neutral pH range (with the exception of siderite in certain cases). The buffering reactions allows for an increase in pore-water pH.

Calcite (CaCO_3) is present in coal, waste rock and ash material and is the major buffering mineral and the most reactive in acidic conditions. The dissolution of calcite allows for the release of HCO_3^- and in more acidic conditions CO_2 . These dissolution reactions increase the carbon in the system and thus the neutralising potential of the solution increases. At a neutral pH, HCO_3^- is the dominant species and with a continuation of the buffering process as CO_3^{2-} becomes dominant the system moves into an alkaline state as shown in Figure 1. The lower the pH the higher the buffer capacity of calcite with an increase of dissolution eventually results in the precipitation of secondary calcite.

Lime (Ca(OH)_2) which is a large constituent of the ash material to be produced from the IPP and will be used as backfill is a mineral commonly used in the mining industry to depress the flotation of pyrite by increasing the systems pH to above 10 (Dold 2005). The use of the ash material is thus favourable in the case of the Dalyshope project if ARD does potentially become an environmental risk. Lime is highly soluble in water and reacts fast, but can however easily be washed away and is more favourably used in controlled or closed systems as a buffer agent.

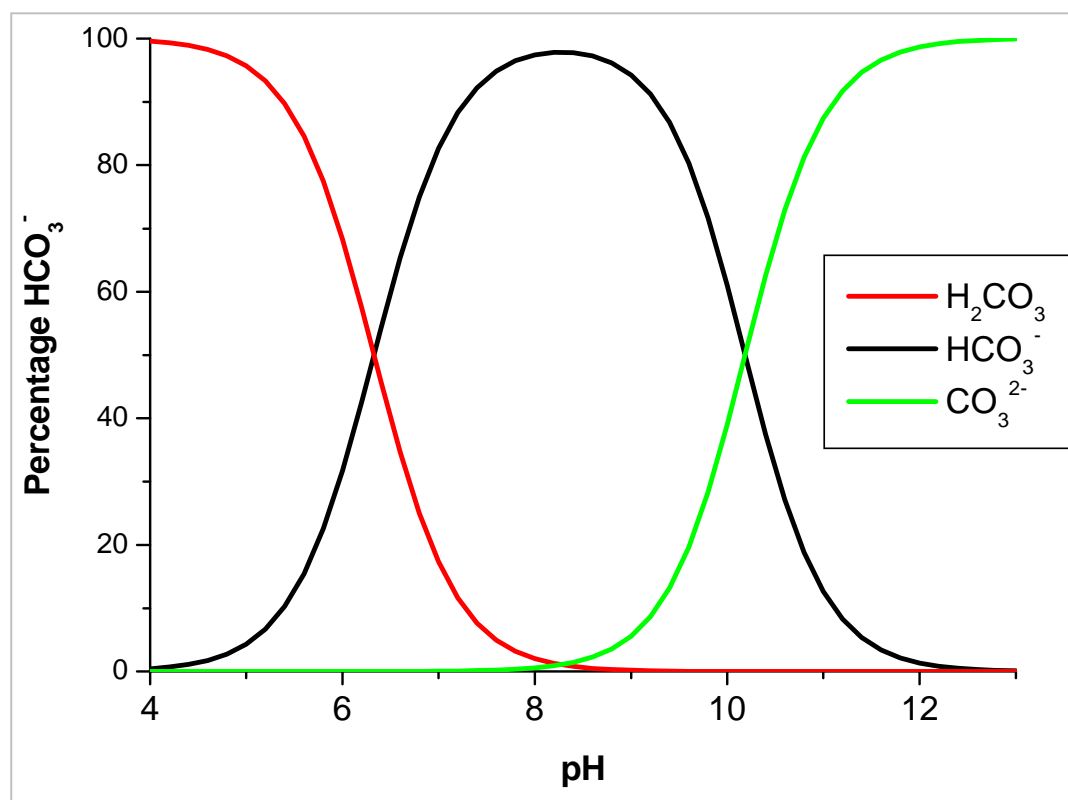


Figure 1: pH levels as per carbonate distribution in an aqueous system (Witthueser 2010)

2.4.3 Silicates and Clay Minerals

Silicate and clay minerals are associated with the mudstone and siltstone formations in which the coalfields of South Africa are formed and thus also play a major role in the environmental geochemistry of coal. As will be discussed in the lab results, the most common silicates are k-feldspar (microcline), kaolinite, muscovite and quartz with the potential formation of goethite from the sulphide oxidation and further weathering of kaolinite.

In acidic conditions alumino-silicates like feldspar consume H⁺ ions allowing a buffering of the aqueous system and contributing Ca, K, Na, Mg, Al, and Si to the system. The weathering of feldspar and other silicates are highly dependent on pH and the availability of silica, Na, K and Ca to allow for the reactions and weathering processes to take place between the minerals and the receiving environment.

The weathering of k-feldspar allows for the formation of kaolinite and as the system progresses to equilibrium, kaolinite can potentially break down to gibbsite. Although the weathering of feldspar to kaolinite consumes protons and buffers an acidic system to neutral pH ranges the further breakdown to gibbsite is not a buffering reaction and is not necessary a positive reaction to the aqueous environment. The following reactions show the above mentioned processes:

- K-feldspar weathering to form kaolinite

$$2\text{KAlSi}_3\text{O}_8 + 9\text{H}_2\text{O} + 2\text{H}^+ \rightarrow \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 + 2\text{K}^+ + 4\text{H}_4\text{SiO}_4$$
- Kaolinite weathering to form gibbsite

$$\text{AlSi}_2\text{O}_5(\text{OH})_4 + 5\text{H}_2\text{O} \rightarrow 2\text{Al}(\text{OH})_3 + 2\text{H}_4\text{SiO}_4$$

3 CONCEPT LEVEL ARD POTENTIAL STUDY

During 2013 a Concept level ARD potential study was completed by Golder Associates on behalf of Anglo Thermal Coal for the Dalyshope project. The report for this study is shown in Appendix B with the main conclusions and recommendation summarised in this EIA study.

The scope of work included a review of relevant geological information, collection of samples for acid base accounting (ABA) tests and assessment of acid rock drainage (ARD) potential of the lithological units that will be disturbed by mining (Golder 2013). The following paragraphs give the executive summary of the study as presented in the report by Golder Associates (2013).

A total of 19 composite samples, including a duplicate sample, were collected from three boreholes. All samples were submitted for ABA analysis. Upper Ecca and Middle Ecca coal had the highest sulphide-sulphur concentrations; however, the paste pH in these samples were neutral (pH = 7.2). This was attributed to the presence of calcite and siderite, which were observed in coal during sampling. Samples of parting unit PLP1 had the lowest paste pH of 5.9. These samples were characterised by low bulk neutralisation potential and carbonate NP (Golder 2013).

An assessment of the ARD potential of the sampled units was conducted based on neutralisation potential ratio (bulk NP/sulphide sulphur acid potential [SAP]), paste pH and sulphide sulphur concentration. The ARD assessment indicated that:

- Acid generating (AG) samples included:
 - Parting units PLP1 and TRP2 from borehole WB0556A (TRP2(6)).
- Potentially acid generating (PAG) samples were:
 - Parting units SD1, USF, and PUP1; and
 - Middle Ecca coal seam (ESC).
- Samples that fell in the grey zone (uncertain) included:
 - Parting units TRP2 from borehole WP0557A (TRP2-7) and PMP1;
 - Interbedding (CIB); and
 - Upper Ecca coal (UC).

These rock units are possibly acid generating if the neutralising potential is insufficiently reactive or is depleted at a rate faster than sulphides under field conditions.

- Units that were not potentially acid generating (Non-PAG) were:

- Weathered overburden (WO), fresh overburden (FO), PUP2, PLP2, TRP2 from borehole WB0555A and MS samples.

An assessment of elemental data from exploration borehole assays (AATC, November 2012) indicated that As, Bi, Cs, Hg, Mo and S are enriched in overburden, parting, interbedding and coal units from the Dalyshope Project area. These elements are potential constituents of interest (COI). An assessment of total sulphur distribution in different stratigraphic units indicated higher concentrations and wider spatial variability in total sulphur compared to parting units. Though not as significant as in coal, total sulphur varied spatially in parting units PLP1, TRP2 and PMP1. The highest concentration of total sulphur occurred within a depth of 55 m below the surface in Upper Ecca Coal plies.

The number of samples used for the concept level ARD assessment provide a good indication of the acid potential from the disturbed mine geological units. However, it does not account for the spatial variation in geochemistry of the individual lithological units. This is based on the analysis of total sulphur profiles, which indicated that sulphur is generally not uniformly distributed in parting units PUP1, PMP1, PLP1, TRP2 and coal. This implies that the ARD potential of these lithological units may vary spatially from PAG to Non-PAG across the deposit; hence a detailed geochemical assessment should be conducted across the whole area during the next phases of mine planning.

In conclusion, the concept level ARD assessment indicates a significant potential for ARD to be generated from the planned mining activities of the Dalyshope Retention mine. This ARD has the potential to affect the economic viability of the project due to the requirements for source and pathway control measures associated with mining features and the long-term mine water management liability associated with ARD. The ARD impacts can however be prevented and managed through pro-active and upfront design and planning in order to limit the long-term liability associated with ARD management at the proposed Dalyshope Retention mine operations.

4 LABORATORY TEST RESULTS AND INTERPRETATIONS

4.1 Sampling

All samples taken for waste rock, coal and ash analysis were taken by the client from the borehole locations indicated in Plan 3 and Plan 4. The representativeness of all samples were assured by the Anglo laboratories and prepared based on best practice guidelines.

Overburden samples were taken from geotechnical and percussion boreholes (Plan 4) to represent the whole weathered zone and overburden to be stripped when mining commences. Samples were taken from these boreholes due to a lack of overburden material from exploration holes and core logs. Samples were taken and stored in sealed sampling bags to minimize the potential for oxidation and contamination.

4.2 Sample Identification

Ash samples:

- Ash were produced from the following coal layers and labelled as per coal seam that served as a source:
 - Composite - ash produced from the PUE down to the PMC;
 - PLA;
 - PLB;
 - PLC;
 - PMA; and
 - PMB.

Coal samples:

- The following coal samples were submitted for testing and labelled accordingly:
 - Composite – coal from the PUE down to the PMC;
 - PLA;
 - PLB;
 - PLC;
 - PMA; and
 - PMB.

Waste rock samples:

- The following waste rock samples were submitted for testing and labelled accordingly:
 - OBW1 – Representative sample of overburden and topsoil;
 - OBW2 – Representative sample of overburden and topsoil;
 - IBW1 – Representative sample of the waste material from interbedded layers between the coal seams that will be separated;
 - IBW2 – Representative sample of the waste material from interbedded layers between the coal seams that will be separated;
 - TRP2 – Representative sample from the TRP2 separation that will from a large portion of the waste rock being dumped on site;
 - TRP2 – Representative sample from the TRP2 separation that will from a large portion of the waste rock being dumped on site; and
 - PLP1 – Representative sample from the PLP1 separation that will from a large portion of the waste rock being dumped on site.

4.3 SANS Guidelines and Leachate Classification

The results received from the leaching procedure are listed and classed against the SANS 241:2005 drinking water standards in Appendix C.

The leachate quality results were classed against the SANS 241:2005 drinking water guidelines, as well as WHO drinking water guidelines to evaluate the potential for contamination; should leachate reach and mix with local water resources. WHO guideline values were only used where the SANS guideline do not give criteria for that specific parameter. The three classes indicated in Table 2 are used to classify drinking water in South Africa.

Table 2: SANS 241:2005 drinking water classifications

Class	Recommendation
Class 1	Recommended operational limit
Class 2	Max allowable concentration for limited duration
Class 3	Not recommended for human consumption

The cation, anion and metal leach results were divided into two sets of data for analysis purposes. One set shows the chemicals that is considered to have health impacts on drinking water and in group two (mostly metals) are the chemicals considered not to have any health impacts on drinking water resources (Gorchev & Ozolins 2008).

4.4 Waste Rock Results

4.4.1 Waste Rock XRF

The XRF results in Table 3 show the major oxides and metals including sulphur that is present in the waste rock samples. These compounds will combine in the solid form to make up the various secondary minerals that will be observed in the XRD results. During the ignition of the tests there was a material loss between 6.4% and 15.53%.

The main oxides in all waste rock samples are SiO_2 , Al_2O_3 and Fe_2O_3 . These oxides along with various inclusions of MgO , MnO , K_2O , Na_2O and CaO and various smaller amounts of trace elements (Table 4) form the interbedded and overburden waste mineralogy. They combine mostly to form feldspar and clay minerals with quartz also present in high quantities. The high Al_2O_3 and SiO_2 content are typical of the sandy soils from the Kalahari formations overlying the mudstone and siltstone formations associated with the coal.

The SO_4 content is low which indicates that the system with potential high pyrite content has not yet been oxidised and weathered down to sulphate minerals. Trace elements that can potentially pose a problem and leach out are B, Ba, Mn, Mg, Ni, Rb and Sr. The leachability of the trace elements are however highly dependent on pH and the acid producing potential of the material. The XRF and mineralogy of the samples however show that the AP of the material is potentially non-acid forming; this will be confirmed by the ABA and leachate tests.

The two overburden samples (OBW1 and OBW2) have higher silica content and this material mostly represents the sandy soils of the region that has been highly weathered. The interbedded samples however show slightly lower silica content with higher percentages of Al, Fe, Ca, Mg, K and Na-oxides; indicating a lower state of weathering with fresher

material. The mineralogy to be formed from the oxide distribution will be mostly dominated by alumino-silicates and clay minerals.

Table 3: Waste rock XRF summary of major oxides

Major Oxide Concentration (wt. %)						
Oxide	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
SiO ₂	67.35	69.85	55.3	57.07	44.45	54.91
TiO ₂	0.64	0.78	1.24	1.1	2.22	1.19
Al ₂ O ₃	13.34	15.77	22.52	21.32	29.09	27.04
Fe ₂ O ₃	3.3	4.98	8.81	2.04	2.99	0.95
MnO	0.05	0.04	0.14	0.03	0.04	<0.01
MgO	0.74	0.4	0.93	0.29	0.89	<0.01
CaO	4.5	0.15	0.71	0.66	7.08	0.12
Na ₂ O	0.52	0.13	0.29	0.27	1	0.32
K ₂ O	0.96	1.41	1.96	1.3	0.61	0.55
P ₂ O ₅	0.09	0.05	0.08	0.07	0.15	0.07
Cr ₂ O ₃	<0.01	<0.01	0.03	<0.01	0.04	0.02
SO ₄	0.03	<0.01	<0.01	0.1	0.44	<0.01
LOI	8.28	6.4	7.72	15.55	10.55	14.76
Total	99.8	99.96	99.73	99.8	99.55	99.93
H ₂ O	0.47	0.71	0.26	0.39	0.22	0.39

Table 4: Waste rock XRF summary of trace element composition

Trace Element Concentration (ppm)						
Element	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
As	<5.00	3.59	<5.00	15.8	18.3	7.96
Ba	378	203	535	196	1024	258
Bi	<5.00	<1.00	<1.00	<5.00	<1.00	<5.00
Br	<1.00	<1.00	1	<1.00	1.16	<1.00
Cd	<5.00	<1.00	<1.00	<5.00	<5.00	<5.00
Ce	46.1	32.5	<5.00	15	<5.00	81.1
Cl	705	709	782	725	948	656
Co	<5.00	<5.00	52.8	<5.00	27.1	<5.00

Trace Element Concentration (ppm)						
Element	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
Cs	1.61	<1.00	<5.00	1.18	1.36	1.51
Cu	31.4	33.7	59	40.2	57.4	32.7
Ga	17.7	23.1	31.9	30	60.8	32.3
Ge	<1.00	2.09	7.47	2.6	10.8	2.82
Hf	5.83	7.4	9.17	6.78	9.3	6.19
Hg	<5.00	<5.00	<5.00	<1.00	1.2	<1.00
La	41.7	37.2	<5.00	40.7	70.2	23.5
Lu	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Mo	4.42	3.27	4.77	5.62	12.4	8.46
Nb	19	22.6	23.6	24.5	46.3	21.6
Nd	31.3	39.2	51.9	57.3	72	60.4
Ni	28.3	45.8	121	18	62.2	37.1
Pb	16.9	15.3	24.2	40.1	80	48.6
Rb	71.5	104	104	87	29.5	23.6
Sb	1.89	<5.00	5.21	<1.00	<1.00	1.56
Sc	15	11.1	14.2	11.9	12.8	9.4
Se	<1.00	<1.00	<5.00	<5.00	1.78	<1.00
Sm	9.6	8.66	5.94	10.6	15.6	14.6
Sn	4.83	4.64	10.4	2.76	3.67	3.39
Sr	108	90	140	91	1033	127
Ta	3.6	2.39	2.39	3.27	3.25	3.28
Te	12.7	3.11	3.31	3.88	30	3.85
Th	21.7	23	29	31.9	45.2	41.7
Tl	<1.00	<5.00	<1.00	<1.00	2.09	<1.00
U	4.23	5.17	6.63	6.9	14.8	5.51
V	67.1	111	182	122	254	155
W	4.17	4.94	4.59	4.87	3.06	3.13
Y	41.6	41.6	45.6	45.9	89	26.8
Yb	12.2	10.3	6.73	16.1	23.4	21.9
Zn	71.3	86.8	202	66.6	86.9	45.1
Zr	251	295	297	284	606	296

4.4.2 Waste Rock XRD

Table 5 gives the XRD mineralogy results for the waste rock samples. As per the oxide and trace element distributions that predicted the potential mineralogy within the XRD results, the main minerals are quartz, muscovite, kaolinite, microcline with calcite and pyrite. The mineralogy indicated by the XRD results is typical of the sandstone/siltstone/mudstone formations dominated by clay minerals and feldspar. Inclusions of calcite/dolomite rich in Ca and Mg are evidence for the depositional environment of the formations with high evaporation and weathering rates. The dolomite mineralogy indicated in the XRD results is a carbonate phase containing both Mg and Ca, in the depositional environment and climatic conditions associated with the project area this is most probably calcrete formations picked up by the instrumentation as dolomite minerals. However for the purpose of the study dolomite and calcrete was and will be discussed as synonymise.

The kaolinite mineralogy, as discussed in section 2.4.3, can be due to the weathering of k-feldspar with an exposure of these minerals to atmospheric conditions leading to further formation of kaolinite. The breakdown of feldspar is a pH buffering reaction, however the further weathering sequences leading to the formation of secondary gibbsite from kaolinite is not a buffering reaction.

Pyrite is present in all samples and is associated with the depositional environment in which the coal formation occurred. The presence of pyrite can potentially lead to ARD formation and thus waste rock dumps should be managed accordingly through lining or other management activities. The presence of calcite, dolomite/calcrete, microcline and the clay minerals are however allowing a higher neutralising potential and ARD can potentially be mitigated by natural processes. The potential ARD formation will be further discussed in the section on the ABA and NAG.

The mineralogy in the waste rock samples can be chemically described through the mineral formulas given below:

■ Calcite	CaCO_3
■ Dolomite (Calcrete)	$\text{CaMg}(\text{CO}_3)_2$
■ Hematite	Fe_2O_3
■ Kaolinite	$\text{Al}_2(\text{Si}_2\text{O}_5)(\text{OH})_4$
■ Microcline	KAlSi_3O_8
■ Muscovite	$\text{KAl}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH},\text{F})_2$
■ Pyrite	FeS_2
■ Quartz	SiO_2
■ Siderite	FeCO_2

The presence of siderite and hematite in the formations indicate that the original oxidation states are still stable with the main iron phase being ferrous iron (Fe(II)). Siderite can potentially act as a neutraliser under certain conditions, but with higher alkaline conditions

and pH levels being elevated the weathering reaction of siderite can lead to acid production. The dissolution of siderite produces Fe^{2+} and HCO_3^- and combined with ferrous iron oxidation under elevated pH levels gives off protons in conditions where bicarbonate is stable. More acidic environments give aqueous conditions where carbonic acid is stable; no net acid production will occur (Dold 2005).

Table 5: Waste rock XRD summary of major mineral composition

Mineral	Mineral amount per sample (weight %)					
	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
Calcite	6.58	0.07	0.31	0	2.91	0.38
Dolomite/Calcrete	0	0	0.68	0.91	0.18	0
Hematite	0.61	0.49	0.47	0.29	0.27	0.64
Kaolinite	26.79	30.53	38.43	39.93	48.29	56.14
Microcline	2.22	2.19	5.66	7.21	2.23	3.32
Muscovite	5.63	8.07	6.14	8.12	4.95	7.23
Pyrite	0.09	0.19	0.13	0.3	0.24	0.31
Quartz	58.08	58.45	44.98	32.13	40.89	31.98
Siderite	0	0	3.19	11.12	0.04	0
Total	100	100	100	100	100	100

4.4.3 Waste Rock Total Concentrations

The results for the total concentrations (TC) on the waste rock samples are given in Table 6 with comparisons against average concentrations observed in the upper continental crust throughout the world. Based on this comparison the elemental distribution of the TC for the waste rock samples are well below the continental averages for all elements.

The depositional environment associated with the coal and sedimentary formations can be the cause of these lower than normal concentrations. Although the concentrations of these elements are below average, acidic conditions can still lead to higher leachability of these elements.

Potential elements that can leach into solution from the whole rock chemistry are Fe, As, Ni, B, Ba, Mg, Mn, Ca, Na, K and Si. These elements are abundant in most Karoo formations and thus the potential seepage of these elements from the waste rock is not an abnormal occurrence.

Table 6: Waste rock total concentrations

Element	Unit	Upper continental crust average	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
Ag	mg/kg	0.05	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Al	mg/kg	80 400	0.1	19.2	22.9	1.0	0.1	1.8
As	mg/kg	1.5	0.028	0.012	0.016	0.012	0.02	0.008
Au	mg/kg	0.0018	<0.004	<0.004	0.004	0.004	<0.004	<0.004
B	mg/kg	15	0.08	0.08	0.11	0.10	0.14	0.19
Ba	mg/kg	550	1.27	0.99	0.97	0.72	0.37	0.28
Be	mg/kg	3	<0.004	0.004	<0.004	<0.004	<0.004	0.008
Bi	mg/kg	0.127	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Ca	mg/kg	30 000	51.6	19.48	32.8	39.84	164	87.2
Cd	mg/kg	0.098	0.0004	<0.0004	0.0004	0.0004	<0.0004	0.0032
Ce	mg/kg	64	<0.004	0.038	0.012	<0.004	<0.004	<0.004
Co	mg/kg	17	<0.004	<0.004	0.004	<0.004	0.040564	3.33012
Cr	mg/kg	85	<0.004	0.02	0.072	<0.004	<0.004	<0.004
Cs	mg/kg	4.8	<0.004	0.004	0.004	0.004	<0.004	0.004
Cu	mg/kg	25	<0.004	<0.004	<0.004	<0.004	<0.004	0.284
Fe	mg/kg	35 000	0.2	8.8	2.5	0.4	0.1	1.8
Ga	mg/kg	17	<0.004	0.008	0.008	<0.004	<0.004	<0.004
Ge	mg/kg	1.6	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Hf	mg/kg	5.8	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Hg	mg/kg	0.09	<0.0004	<0.0004	0.0004	0.0008	<0.0004	<0.0004
Ho	mg/kg	0.8	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Ir	mg/kg	0.00002	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
K	mg/kg	28 000	23.5	43.9	27.1	27.3	21.9	21.5
La	mg/kg	30	<0.004	<0.004	0.008	<0.004	<0.004	<0.004
Li	mg/kg	20	<0.004	0.04	<0.004	0.04	0.08	0.28
Mg	mg/kg	13 300	22.5	11.4	10.5	14.5	34.6	41.2
Mn	mg/kg	600	0.08	0.28	0.12	0.08	0.36	1.76
Mo	mg/kg	1.5	0.01	0.01	0.30	0.26	0.29	0.01

Element	Unit	Upper continental crust average	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
Na	mg/kg	28 900	48.8	24.2	162.4	165.6	29.5	27.4
Nb	mg/kg	12.5	<0.004	0.004	0.004	<0.004	<0.004	<0.004
Nd	mg/kg	26	<0.004	0.028	0.004	<0.004	<0.004	<0.004
Ni	mg/kg	50	<0.004	<0.004	<0.004	<0.004	<0.004	6.656836
Pb	mg/kg	16	<0.004	0.03	0.01	<0.004	<0.004	0.01
Rb	mg/kg	112	0.01	0.05	0.05	0.04	0.03	0.04
Sb	mg/kg	0.2	0.004	0.004	0.008	0.008	0.008	<0.004
Sc	mg/kg	13	0.032	0.074	0.038	0.004	0.008	0.02
Se	mg/kg	50	<0.004	<0.004	0.03	0.08	0.14	0.05
Si	mg/kg	308 000	37.4	81.88	44.28	8.84	14.12	26.48
Sn	mg/kg	5.5	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Sr	mg/kg	350	0.44	0.13	0.39	0.44	0.55	0.42
Ta	mg/kg	1.1	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Th	mg/kg	10.7	<0.0004	0.0044	0.0028	<0.0004	<0.0004	<0.0004
Ti	mg/kg	3 900	<0.200	0.782552	1.211156	0.0402	<0.200	<0.200
Tl	mg/kg	0.75	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
U	mg/kg	2.8	0.000	0.002	0.002	0.001	0.002	0.002
V	mg/kg	110	0.06	0.064	0.068	0.004	0.016776	<0.004
W	mg/kg	2	0.004	<0.004	0.004	<0.004	<0.004	<0.004
Y	mg/kg	22	<0.004	0.012	0.004	<0.004	<0.004	<0.004
Zn	mg/kg	71	<0.004	0.036	0.02	<0.004	<0.004	2.3
Zr	mg/kg	190	<0.004	0.028	0.016	<0.004	<0.004	<0.004

4.4.4 Waste Rock ABA and NAG

The following are the main conclusions from the waste rock ABA and NAG results for the samples taken by Digby Wells:

- The paste pH of all the waste rock samples are in a range between 7.5 and 8.1;
- The waste rock samples does have S-content higher than that of the ash material and is associated with the pyrite mineralogy associated with the layers as discussed in section 4.3.2;

- The S% of the overburden (OBW1 and OBW2) are well below 0.25% and with a high NNP and low NAG rating will not allow acid generation and is thus classified as a rock/material type III (non-acid generating);
- IBW2 shows a high tendency for acid generation with a high AP of 11.56 (kg/t) and a low NP of 5.25, leading to a low neutralising potential ratio of 0.45 and is thus classified as an acid generating rock type I. The S-content of this sample was well above the 0.25% margin;
- IBW1 and TRP 2 were classified as intermediate and a rock type II with a NPR of 1:3 or less. The S-content of these two samples were low enough, but did however not include enough minerals to allow for a high neutralising potential; and
- According to the S-content of PLP1 being 0.1% above the 0.25% margin and a close to neutral paste pH of 7.8 the sample was classified as an intermediate case. However, due to the low NAG pH of 3.2 and 4.5 for the sample and a high NAG of 3.72 and 6.47 kg H₂SO₄/t it is recommended that this sample be seen as acid generating and treated as such in any risk assessments.

Table 7: Waste rock ABA summary

Parameter	Acid Base Accounting					
	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
Paste pH	7.9	8.1	8.1	8	7.5	7.8
Total Sulphur (%) (LECO)	<0.01	0.01	0.15	0.37	0.1	0.35
Acid Potential (AP) (kg/t)	0.31	0.31	4.69	11.56	3.13	10.94
Neutralization Potential (NP)	27	-10.75	3	5.25	1.5	-12
Net Neutralization Potential (NNP)	26.69	-11.06	-1.69	-6.31	-1.63	-22.94
Neutralising Potential Ratio (NPR) (NP : AP)	86.4	34.4	0.64	0.45	0.48	1.1
Rock Type	III	III	II	I	II	II

Table 8: Waste rock NAG summary

Parameter	Net Acid Generation					
	Sample Identification: pH 4.5					
	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
NAG pH: (H ₂ O ₂)	9.4	7.5	7.9	7.6	7.9	3.2
NAG (kg H ₂ SO ₄ / t)	<0.01	<0.01	<0.01	<0.01	<0.01	3.72
	Sample Identification: pH 7					
NAG pH: (H ₂ O ₂)	9.4	7.5	7.9	7.6	7.9	4.5
NAG (kg H ₂ SO ₄ / t)	<0.01	<0.01	<0.01	<0.01	<0.01	6.47

4.4.5 Waste Rock Leachate Results

The following summary gives insight into the potential for metal leaching as per evaluations against the various guideline values:

- Results for chemicals with health significance in drinking water:
 - The two overburden samples, OBW1 and OBW2 indicated elevated leachable levels of F (1.2 mg/L in OBW1), Al (4.8 mg/L in OBW2) and Fe (2.2 mg/L in OBW2) with the leachate water from the overburden not suitable for domestic use and can potentially increase the concentrations of these elements in the receiving environment;
 - The high fluoride concentrations are associated with the clay mineralogy and small inclusions of fluorite found along with calcite in the coal formations;
 - IBW1 and TRP2 also indicated fluoride levels above the Class 1 limits;
 - Al and Fe were found above the recommended limits in IBW1 (Al = 5.7 mg/L, Fe = 0.6 mg/L) and PLP1 (Al = 0.4 mg/L, Fe = 0.4 mg/L);
 - The elevated leachable concentrations of Fe and Al is associated with the microcline, kaolinite, muscovite and pyrite mineralogy of the waste rock and the LC of both elements can increase under acidic conditions with the formation of ARD during pyrite oxidation;
 - Other elements of concern with noticeable leachable concentrations from the waste rock were Co (PLP1), Mn (PLP1), Mo (IBW1), Ni (PLP1) and Se (TRP2);
 - Although IBW1, IBW2 and TRP2 were classed as acid producing and marginal cases in the ABA results, the pH of these samples during leachate tests indicated that the mineralogy of the waste rock can potentially have enough neutralising potential. This will further be investigated and confirmed with the on-going long term kinetic tests; and
 - The pH of PLP1 indicated a level of 4.7 and slightly acidic confirming the recommendation that this sample be seen as acid generating and treated as such in any risk assessments.
- Results for chemicals that are not of health concern in drinking-water:
 - From the analysis of the waste rock samples (leachable concentrations of elements with no significant health impact) the only metals that leached in detectable concentrations were Ce, Ga, Li, Nd, Rb, Sc, Sr, Ti and high Si as would be expected from the mineralogy.
- The main elements of concern from the waste rock are F, Al, Fe, Ni, Sr, and Mn. The potential precipitation of these elements back into mineral form removing them from the aqueous environment will be confirmed with on-going long term kinetic tests.

4.5 Coal Results

4.5.1 Coal XRF

Table 9 and Table 10 shows the oxide and trace element distribution results for the coal samples sent in for analysis. A high material loss on the test ignition was observed and this is solely down to the high combustibility of the carbon content in the coal material.

The main oxides observed are SiO₂, Al₂O₃ and Fe₂O₃. These oxides mainly combine with Na₂O and K₂O to form the alumino-silicates and clay minerals associated with the Grootegeluk coal formations. Furthermore, CaO, MnO and MgO are also present in smaller percentages which are associated with the inclusion of calcite, dolomite/calcrete and fluorite. Trace element distributions that are high and potentially can leach out in significant quantities are As, Ba, Cu, Ni, Sr and U.

Table 9: Coal XRF results summary of major oxides

Major Element Concentration (weight %)[s]						
Oxide	PMB	PMA	PLC	PLB	PLA	Composite
SiO ₂	48.81	45.4	37.7	38.04	35.83	36.47
TiO ₂	0.76	0.86	1.01	1.01	1.24	1.83
Al ₂ O ₃	16.04	16.29	16.26	16.39	19.66	23.32
Fe ₂ O ₃	2.04	3.62	1.7	1.49	3.39	2.49
MnO	0.03	0.05	0.02	0.02	0.04	0.04
MgO	0.26	0.33	0.32	0.15	0.16	0.71
CaO	0.29	0.71	1.97	0.98	1.24	4.69
Na ₂ O	0.38	0.36	0.46	0.22	0.26	0.9
K ₂ O	1.02	0.77	0.52	0.52	0.6	0.53
P ₂ O ₅	0.04	0.04	0.08	0.07	0.07	0.1
Cr ₂ O ₃	<0.01	<0.01	<0.01	0.01	0.02	0.04
SO ₄	<0.01	0.01	0.13	0.05	0.14	0.19
LOI	30.32	31.39	39.63	40.87	37.16	28.36
Total	99.99	99.83	99.8	99.82	99.81	99.67
H ₂ O	0.64	0.68	1	0.89	0.79	0.97

Table 10: Coal XRF summary of trace element concentrations

Trace Element Concentration (ppm) [s]						
Element	PMB	PMA	PLC	PLB	PLA	Composite

Trace Element Concentration (ppm) [s]						
Element	PMB	PMA	PLC	PLB	PLA	Composite
As	1.85	8.9	9.4	1.04	<1.00	18
Ba	171	175	265	323	288	608
Bi	<5.00	<5.00	<5.00	<5.00	<5.00	<1.00
Br	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Cd	<5.00	<5.00	<5.00	<5.00	<5.00	<1.00
Ce	37.9	9.9	<5.00	<5.00	<5.00	<5.00
Cl	655	574	641	566	551	700
Co	<5.00	<5.00	<5.00	<5.00	<5.00	9.5
Cs	<1.00	1.29	<1.00	1.27	2.23	<5.00
Cu	27.2	31.3	37.2	30.8	34.5	49
Ga	23.3	23.9	27.2	27.3	38.2	48.6
Ge	1.25	1.56	2.21	1.62	1.28	9.7
Hf	4.3	5.79	4.99	6.1	7.3	8.9
Hg	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
La	29.2	69	34.9	3.46	47.3	70.2
Lu	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Mo	4.72	4.76	6	5.17	5.37	8.5
Nb	20.3	20.4	19.8	21.3	25.5	38.8
Nd	35.2	39.2	39.1	39.6	37.2	55.5
Ni	16.5	36	22.4	14.4	44.6	56.2
Pb	26.9	24.9	31	22.6	23.1	76
Rb	72	66.2	42.7	41.9	50.9	27.3
Sb	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Sc	8.9	7.6	9.8	9.4	9.7	15.3
Se	<5.00	<5.00	<1.00	<1.00	<1.00	<1.00
Sm	9	7.8	10.3	9.2	8.6	13.3
Sn	<1.00	<1.00	<5.00	3.68	2.18	5.1
Sr	74	74	262	255	147	840
Ta	2.71	2.26	2.18	2.23	2.02	3.52
Te	3.02	6.1	9.2	4.27	6.23	20.5
Th	28.1	24.7	22.1	24.5	35	41.7

Trace Element Concentration (ppm) [s]						
Element	PMB	PMA	PLC	PLB	PLA	Composite
Tl	<1.00	<5.00	<1.00	<1.00	<1.00	1.15
U	6.06	5.89	4.52	5.7	6.11	10.9
V	96	89	110	96	166	203
W	4.26	4.62	3.28	3.09	3.81	3.63
Y	38.3	39.3	35.7	36.8	57.3	81
Yb	13.7	10.3	15.8	13.4	11.6	19.8
Zn	40	41.7	18.1	23.1	11.9	74
Zr	221	213	245	231	301	536

The high oxide and trace element distribution in similar proportional distribution to that of the mudstone and siltstone waste rock shows the complex layering of the coal formations to be mined from the Dalyshope area. The similar compound distribution indicates the main challenge that Anglo will have with the mining process, as well as the highly contaminated coal the Vedanta IPP will have to deal with. The coal layers are regularly interbedded with sandstone, siltstone and mudstone formations evident in the oxide and mineralogical distribution to be discussed in the next section and thus high quantities of the waste rock mineralogy is to be mined and stored along with coal material. High concentrations of the compounds observed in both the coal and waste rock mineralogy can be expected to remain present in the ash produced from the coal.

4.5.2 Coal XRD

The coal XRD mineralogy results shown in Table 11 reflects the comments made in section 4.3.1 relating to the oxide and trace element distribution with the same mineralogical and geochemical observations made as in the section discussing the XRD results of the waste rock.

Although the proportional distribution is different to the waste rock mineralogy, the main constituents remain the same with high percentages of kaolinite, quartz, microcline, pyrite and muscovite; the carbon content not picked up due to a loss on ignition will change the distributions slightly. The calcite and clay mineral content is however higher than that of the waste rock with a concentrated formation event allowing higher organic and clay content along with the coal formation.

The association of siderite and pyrite can lead to acid formation and potential ARD if coal is left uncovered under atmospheric conditions. The coal material mined from the Dalyshope pit will however be stockpiled for short periods and then conveyed to the IPP for processing and burning. Although the coal layers are potentially acid forming from the pyrite inclusions (this will be confirmed through the ABA results), the short standing time can ease the management of any ARD or metal leachate produced from the coal.

Table 11: Coal XRD summary of the major mineral composition

Mineral	Mineral amount per sample (weight %)					
	PMB	PMA	PLC	PLB	PLA	Composite
Calcite	0.14	1.14	4.34	1.28	3.41	0.62
Dolomite	0	0.72	0.71	0.16	0.12	0.5
Hematite	0	0.17	0.29	0.09	0.7	0.08
Kaolinite	45.76	46.3	50.76	51.99	58.77	47.7
Microcline	6.32	4.2	7.4	4.61	4.45	7.67
Muscovite	6.17	6.47	6.06	7.19	7.95	7.28
Pyrite	0.36	1.19	0.14	0.14	0.53	0.52
Quartz	37.76	33.81	26.39	31.46	20.06	34.64
Siderite	3.5	6	3.91	3.08	4.01	0.99
Total	100	100	100	100	100	100

4.5.3 Coal Total Concentrations

The total concentration (TC) or whole rock elemental analysis for the coal samples are shown in Table 12. The elemental distribution for the coal is lower than that of the waste rock; as would be expected. Although the coal is contaminated with a lot of mineralogy associated with the interbedded waste rock material the concentrations are proportionally lower due to higher carbon content.

In the comparison with average crustal abundances of the elements it can be seen that all the coal layers tested show whole rock concentration to be well below the continental averages.

Table 12: Coal total concentrations

Element	Unit	Upper continental crust average	PMB	PMA	PLC	PLB	PLA	Composite
Ag	mg/kg	0.05	<0.004	<0.004	<0.004	0.004	<0.004	<0.004
Al	mg/kg	80400	0.59	0.17	0.80	0.14	0.04	0.56
As	mg/kg	1.5	0.012	0.016	0.036	0.004	0.012	0.032
Au	mg/kg	0.0018	0.004	0.004	<0.004	<0.004	<0.004	<0.004
B	mg/kg	15	0.6	1.0	1.0	0.7	4.1	1.1
Ba	mg/kg	550	0.26	0.62	0.49	0.43	0.22	0.33
Be	mg/kg	3	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Bi	mg/kg	0.127	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004

Element	Unit	Upper continental crust average	PMB	PMA	PLC	PLB	PLA	Compo site
Ca	mg/kg	30000	64.8	86	56.8	54.4	77.6	69.6
Cd	mg/kg	0.098	<0.0004	0.0004	0.0004	0.0004	<0.0004	0.0004
Ce	mg/kg	64	<0.004	<0.004	0.004	<0.004	<0.004	<0.004
Co	mg/kg	17	<0.004	<0.004	0.004	<0.004	<0.004	<0.004
Cr	mg/kg	85	<0.004	<0.004	0.008	<0.004	<0.004	<0.004
Cs	mg/kg	4.8	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Cu	mg/kg	25	<0.004	<0.004	0.02	<0.004	<0.004	<0.004
Fe	mg/kg	35000	0.3	0.3	0.6	0.3	0.2	0.2
Ga	mg/kg	17	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Ge	mg/kg	1.6	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Hf	mg/kg	5.8	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Hg	mg/kg	0.09	<0.0004	0.0008	<0.0004	0.0004	0.0008	0.0004
Ho	mg/kg	0.8	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Ir	mg/kg	0.00002	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
K	mg/kg	28000	35.30	31.22	22.62	19.46	23.14	38.30
La	mg/kg	30	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Li	mg/kg	20	0.04	<0.004	<0.004	<0.004	0.04	<0.004
Mg	mg/kg	13300	25.6	29.7	19.6	17.0	25.1	22.8
Mn	mg/kg	600	0.32	0.12	0.16	0.08	0.12	0.12
Mo	mg/kg	1.5	0.01	0.02	0.04	0.03	0.06	0.05
Na	mg/kg	28900	42	37	33	29	37	54
Nb	mg/kg	12.5	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Nd	mg/kg	26	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Ni	mg/kg	50	<0.004	0.049	0.015	<0.004	<0.004	<0.004
Pb	mg/kg	16	<0.004	<0.004	0.004	<0.004	<0.004	<0.004
Rb	mg/kg	112	0.04	0.03	0.03	0.02	0.03	0.03
Sb	mg/kg	0.2	0.004	0.004	0.004	0.004	0.004	0.004
Sc	mg/kg	13	0.012	0.008	0.008	0.004	0.004	0.008
Se	mg/kg	50	0.09765 6	<0.004	0.07736	0.19320 4	0.11920 4	0.06102 4

Element	Unit	Upper continental crust average	PMB	PMA	PLC	PLB	PLA	Composite
Si	mg/kg	308000	14.92	10.0	7.4	6.4	8.3	12.4
Sn	mg/kg	5.5	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Sr	mg/kg	350	0.34432	0.4	0.3	0.2	0.3	0.4
Ta	mg/kg	1.1	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Th	mg/kg	10.7	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
Ti	mg/kg	3900	0.05061 6	<0.200	<0.200	<0.200	<0.200	<0.200
Tl	mg/kg	0.75	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
U	mg/kg	2.8	0.0012	0.0028	0.0004	0.0004	0.0012	0.0020
V	mg/kg	110	0.004	0.008	0.02	0.02	0.02	0.016
W	mg/kg	2	<0.004	0.004	0.012	0.012	0.044	0.004
Y	mg/kg	22	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Zn	mg/kg	71	<0.004	0.008	0.6	0.02	<0.004	0.008
Zr	mg/kg	190	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004

4.5.4 Coal ABA and NAG

The following can be concluded from the ABA and NAG analysis of the coal samples:

- The high pyrite and siderite inclusions associated with the coal deposits of the Dalyshope area lead to high S-content in all samples;
- The coal samples from the PMB, PMA, PLA and top coal layers in the Composite sample indicate rock/material that is potentially acid generating with high S-content and low neutralising potential;
- The PLC layer has a higher calcite and clay mineral content compared to the other layers with a lower S-concentration and thus the mineralogy allows for a higher NNP that will counter any acid generation and is thus classified as a rock type III (non-acid generating); and
- Although PLB is a marginal rock type which can only be potentially acid generating with S% slightly higher than the 0.25% guideline, the NNP is low and should thus be treated as an acid generating material along with PMB, PMA, PLA and the composite coal material.

Table 13: Coal ABA summary

Parameter	Acid Base Accounting					
	PMB	PMA	PLC	PLB	PLA	Composite
Paste pH	7.7	7.6	7.8	7.8	7.9	7.8
Total Sulphur (%) (LECO)	0.26	0.72	0.23	0.27	0.47	0.65
Acid Potential (AP) (kg/t)	8.13	22.5	7.19	8.44	14.69	20.31
Neutralization Potential (NP)	-5.5	-3.75	12.75	8.75	2.5	3
Net Neutralization Potential (NNP)	-13.63	-26.25	5.56	0.31	-12.19	-17.31
Neutralising Potential Ratio (NPR) (NP:AP)	0.68	0.17	1.77	1.04	0.17	0.15
Rock Type	I	I	III	II	I	I

Table 14: Coal NAG summary

Parameter	Net Acid Generation					
	Sample Identification: pH 4.5					
	PMB	PMA	PLC	PLB	PLA	Composite
NAG pH: (H ₂ O ₂)	4.8	4.3	5.6	4.3	5.9	3.4
NAG (kg H ₂ SO ₄ / t)	<0.01	0.392	<0.01	1.37	<0.01	2.55
Parameter	Sample Identification: pH 7					
	PMB	PMA	PLC	PLB	PLA	Composite
	NAG pH: (H ₂ O ₂)	4.8	4.5	5.6	4.5	5.9
NAG (kg H ₂ SO ₄ / t)	12	10	2.35	22	0.588	14

4.5.5 Coal Leachate Results

The following summary gives insight into the potential for metal leaching as per evaluations against the various guideline values:

- Results for chemicals with health significance in drinking water:
 - fluoride concentrations are well above the recommended safe drinking water limits in the leachate concentrate in all coal samples and could be from the fluorite mineralogy associated with the calcite and mudstone layers;
 - B has leachable concentration above the recommended Class 2 limits in sample PLA (B = 1.0 mg/L);
 - Se also leached out in concentrations above the recommended drinking water limit in samples PMB, PLB and PLA; with concentrations of 0.024 mg/L, 0.048 mg/L and 0.03 mg/L respectively;

- The pH of the leachate water are all within the recommended, close to neutral range indicating that the mineralogy of the coal layers are neutralising. This will however be fully confirmed with on-going long term kinetic tests; and
- It is recommended that stockpiles be managed through storm water management and not allowing long standing time on site especially during high rainfall periods.
- Results for chemicals that are not of health concern in drinking-water:
 - The only ions leaching out in noticeable concentrations are Rb, Sc and Si;
- The only elements with high leachability from the coal material is F, B, Se, Rb and Si; and
- The potential precipitation out of solution of these elements and removal from the aqueous solution that will reach the receiving environment will however be confirmed with the on-going long term kinetic tests.

4.6 Ash Results

4.6.1 Ash XRF

The XRF results in Table 15 show the major oxides and metals including sulphur that is present in the ash samples. These compounds will combine in the solid form to make up the various secondary minerals that will be observed in the XRD results. During the ignition of the tests there was a material loss between 8.92% and 16.53%.

From the results the main oxides are SiO_2 , Al_2O_3 , Fe_2O_3 and CaO . These four compounds make up about 76% of the ash material with the rest mainly made up of carbon (C) and iron (Fe) in its elemental form. The composition of the material is typical of ash with the lime dosage and secondary formation of minerals from the burning of the carboniferous material; in combination with the pyrite, apatite, calcite and microcline mineralogy associated with the coal deposits of the Waterberg area. The high Fe and Fe_2O_3 content of the material is potentially from the pyrite associated with the coal seams; with the high CaO being from the lime dosage, as well as the calcite inclusions in the coal deposits. The Al_2O_3 , MgO and SiO_2 are from the microcline and clay mineralogy in the waste material that will contaminate some of the coal samples during the processes.

The high carbon content is directly from the coal layers burned with the S-content coming from the pyrite mineralogy associated with the coal deposits. The ash from the PMB to PLA layers have a lower S-content and this is due to these layers having a better coal quality compared to those in the top seams represented by the composite sample. The samples PMB to PLA all have S-content below 0.3% and from this can thus be concluded to be non-acid generating. However, the ash from the composite samples and lower quality coal material has an S-content of 1.08%, which is above the 0.3% guideline value and can thus be potentially acid generating.

Table 15: Summary of XRF results for the ash material

Ash sample		PMB	PMA	PLC	PLB	PLA	Composite
Unit		Weight %					
Major oxides and metals	SiO₂	39.57	33.94	33.92	35.14	26.82	31.68
	Al₂O₃	15.26	13.50	15.84	14.46	14.38	9.81
	Fe	1.13	2.31	1.75	1.01	1.38	3.02
	Fe₂O₃	1.62	3.30	2.50	1.44	1.97	4.31
	TiO₂	0.57	0.58	0.71	0.70	0.72	0.44
	CaO	15.22	16.26	10.03	9.91	22.47	21.44
	MgO	0.87	1.06	0.62	0.59	1.15	1.24
	K₂O	0.80	0.62	0.42	0.40	0.39	1.10
	MnO	0.15	0.19	0.11	0.07	0.11	0.21
	P	0.02	0.01	0.06	0.07	0.04	0.01
	Ba	0.03	0.02	0.06	0.05	0.03	0.03
	Sr	0.01	0.01	0.02	0.01	0.01	0.01
	V	0.01	0.01	0.01	0.01	0.01	0.01
	Ni	0.002	0.001	0.001	0.001	0.001	0.001
	Cr	0.01	0.01	0.01	0.01	0.01	0.01
	Zn	0.004	0.005	0.005	0.005	0.004	0.005
	C	13.50	14.50	20.60	20.10	13.80	16.70
S	0.11	0.17	0.17	0.20	0.18	1.08	
Losses	11.13	13.51	13.16	15.84	16.53	8.92	
Total	100	100	100	100	100	100	

4.6.2 Ash XRD

The main mineralogy of the ash material which is secondary minerals formed from the lime and coal burned in the IPP process can be seen in Table 16 showing the XRD results.

Table 16: Summary of XRD results for the ash material

Ash sample		PMB	PMA	PLC	PLB	PLA	Composite
Unit		%					
Mineral content	Lime	1.43	0	0	0	0	0
	Calcite	43.63	49.79	38.09	37.18	70.75	61.69
	Fluorite	0.07	0	0	0.26	0.15	0.2

Ash sample		PMB	PMA	PLC	PLB	PLA	Composite
Unit		%					
	Hematite	1.87	2.45	3.01	2.01	1.18	2.39
	Kaolinite	3.58	11.83	15.18	7.55	7.29	2.99
	Muscovite	3.02	3.41	3.56	3.36	2.29	3.09
	Quartz	46.4	32.52	40.16	49.65	18.33	29.65

The main constituents are calcite, quartz, muscovite and kaolinite and correlates with the mineralogy associated with the Grootegeluk coal formations. The calcite is from the calcite inclusions in the coals seams, as well as the lime dosage applied to the samples before burning. The quartz in the sample is most probably from the clay mineralogy and microcline in the original samples that broke down to form pure quartz. Kaolinite and muscovite are the two clay minerals that seemed to have been preserved throughout the process with these two mineral being present in the mother material.

Fluorite is present in small percentages and is a highly reactive mineral that can potentially dissolve and leach out easily with Ca and F increasing in the receiving environment. The major elemental concerns when looking at the XRD and XRF results are Fe, Mg, Mn, Ca, K and F. These elements will be present in high concentrations in the dry material and can potentially leach out under certain conditions from the minerals observed in the XRD results. However, this will be investigated in the total elemental evaluations and leachate results. The chemical formula for each mineral observed in the XRD results is listed below:

- Calcite CaCO_3
- Lime CaO
- Fluorite CaF
- Hematite FeO_2
- Kaolinite $\text{Al}_2(\text{Si}_2\text{O}_5)(\text{OH})_4$
- Muscovite $\text{KAl}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH},\text{F})_2$
- Quartz SiO_2

4.6.3 Ash Total Concentrations

The total elemental analysis for the ash material samples are shown in Table 17.

As discussed in section 2.1.5, the mineralogy of the region is dominated by felsic minerals in the sedimentary sequences, with pyrite and other minerals associated with coal deposits. The Grootegeluk coal formation is dominated by mudstone with the depositional environment also dictating high organic matter content decreasing upward through the formation (Faure *et al.*, 1996). The lower Grootegeluk mudstone consists mainly of kaolinite and quartz with small amounts of apatite. The upper Grootegeluk layers are rich in quartz, kaolinite, montmorillonite and smaller amounts of illite and microcline (Faure *et al.*, 1996).

Also mentioned by Wagner & Tlotleng (2012) the high organic matter of the coal seams and mudstone formations leads to an abundance of trace elements mostly above the crustal averages observed around the world. With this in mind the whole or total elemental analysis of the dry ash material was compared to the upper continental crust averages. This was done to see how much influence the mother material/coal has on the quality of the ash.

It can be concluded that a lot of the trace element concentrations in the ash samples are above the crustal averages due to the high metal content associated with the coal (Table 17). Although these elements are above the norm they do not necessarily indicate a potential for leaching or posing environmental problems. However, from the total element results and the comparison to average values As, B, Hg, Mg, Mn and U is of concern; as mentioned in section 2.1.5. Other elements above the crustal average are not of concern due to low dissolution rates, as well as posing no significant health risks to humans.

However, the leachate results that will be discussed in section 3.5 will give more insight into the potential environmental risks involved from the ash samples.

Table 17: Total concentration for ash material

Element	Unit	Upper continental crust average	PMB	PMA	PLC	PLB	PLA	Composite
Ag	mg/kg	0.05	0.32	0.42	0.50	0.57	0.21	0.25
Al	mg/kg	80400	80783.48	71466.38	83853.89	76548.44	76124.93	51926.95
As	mg/kg	1.5	3.31	4.96	6.55	2.11	3.36	6.22
Au	mg/kg	0.0018	0.04	0.05	0.05	0.04	0.03	0.03
B	mg/kg	15	17.30	15.18	17.35	15.74	14.88	22.87
Ba	mg/kg	550	262.00	234.00	628.00	486.00	337.00	256.00
Be	mg/kg	3	2.28	2.53	2.93	2.96	1.77	1.70
Bi	mg/kg	0.127	0.66	0.83	1.04	1.25	0.48	0.39
Ca	mg/kg	30000	108791.99	116225.88	71694.07	70836.31	160614.72	153252.32
Cd	mg/kg	0.098	0.03	0.09	0.08	0.07	0.02	0.03
Ce	mg/kg	64	69.47	65.67	97.15	85.21	41.06	50.40
Co	mg/kg	17	16.23	10.08	13.43	15.07	14.25	12.73
Cr	mg/kg	85	105.00	59.00	78.00	77.00	83.00	51.00
Cs	mg/kg	4.8	4.87	3.11	4.76	5.73	3.22	3.53
Cu	mg/kg	25	2.64	4.40	9.88	6.57	10.24	1.42
Fe	mg/kg	35000	11310.00	23110.00	17470.00	10070.00	13750.00	30160.00
Ga	mg/kg	17	15.31	7.55	19.04	14.50	15.11	7.62
Ge	mg/kg	1.6	0.41	0.86	0.31	0.27	0.70	0.12

Element	Unit	Upper continenta l crust average	PMB	PMA	PLC	PLB	PLA	Compo site
Hf	mg/kg	5.8	2.60	3.00	3.52	4.27	1.19	1.54
Hg	mg/kg	0.09	0.03	0.04	0.07	0.30	0.12	0.01
Ho	mg/kg	0.8	0.33	0.25	0.49	0.41	0.14	0.24
Ir	mg/kg	0.00002	0.04	0.01	0.04	0.02	0.03	0.03
K	mg/kg	28000	6609.63	5142.03	3519.10	3303.99	3250.83	9094.68
La	mg/kg	30	18.09	10.76	22.41	20.39	10.93	9.24
Li	mg/kg	20	22.31	13.25	39.44	46.19	51.66	16.88
Mg	mg/kg	13300	5213.25	6379.52	3754.22	3538.55	6921.69	7451.81
Mn	mg/kg	600	1175.19	1458.14	868.22	565.89	832.56	1600.00
Mo	mg/kg	1.5	1.19	1.43	2.44	2.05	2.34	2.03
Na	mg/kg	28900	730.63	685.21	764.09	724.46	443.45	800.09
Nb	mg/kg	12.5	15.85	14.86	18.03	20.23	17.87	11.73
Nd	mg/kg	26	15.89	8.86	21.88	16.41	9.48	8.37
Ni	mg/kg	50	15.14	14.11	10.53	12.06	7.55	12.98
Pb	mg/kg	16	23.91	23.79	32.22	36.69	27.05	21.49
Rb	mg/kg	112	50.74	29.14	13.43	21.06	32.22	48.53
Sb	mg/kg	0.2	0.63	0.48	0.63	0.56	0.52	0.67
Sc	mg/kg	13	32.91	2.48	31.17	11.62	23.65	23.40
Se	mg/kg	50	1.33	1.22	0.13	0.15	0.54	0.19
Si	mg/kg	308000	184992.99	158672	158578	164282	125385	148106
Sn	mg/kg	5.5	5.16	4.28	4.75	5.78	4.59	2.78
Sr	mg/kg	350	62.28	56.47	151.85	115.18	76.72	51.70
Ta	mg/kg	1.1	1.51	1.29	2.04	1.82	1.26	0.85
Th	mg/kg	10.7	12.02	8.35	24.84	24.23	1.27	3.51
Ti	mg/kg	3900	3440.72	3468.26	4225.15	4212.57	4319.16	2646.11
Tl	mg/kg	0.75	0.29	0.39	0.53	0.32	0.31	0.55
U	mg/kg	2.8	4.80	4.78	4.56	4.39	5.05	3.36
V	mg/kg	110	75.97	65.21	86.34	86.45	98.17	72.32
W	mg/kg	2	69.19	30.84	56.26	372.34	41.78	22.75
Y	mg/kg	22	22.97	15.22	31.98	28.94	5.98	15.56
Zn	mg/kg	71	44.35	45.08	47.66	45.75	43.85	53.60
Zr	mg/kg	190	87.66	101.36	140.54	156.42	43.60	58.37

4.6.4 Ash ABA and NAG

The following are the main conclusions from the ash sample NAG and ABA results:

- The paste pH values of all the ash samples are alkaline with the lowest paste pH observed in the PLC ash (8.6) with the PMB showing a high pH of 10.5;
- Ash samples PMB, PMA, PLC, PLB and PLA are produced from the higher grade coal seams and has total sulphur percentages lower than 0.25% and NPR values greater than 1:3, indicating that the samples are non-acid forming;
- The ash produced from the lower grade coal of the top seams in the composite sample however show a higher S-content of 1.11% which is higher than 0.25% and is classed as a marginal case;
- The Net Neutralising Potential (NNP) of all the samples are high and above 1 and will neutralise any acid being produced. This is also shown in the Net Acid Generation (NAG) results indicating values below 0.01 kg of H₂SO₄ per ton of material; and
- The high NNP of the samples allows for the interpretation that if any mine acid is produced in the open pit the backfilling of the pit by using the ash with high paste pH and NNP values will help in managing any AMD formation.

Table 18: ABA results for ash samples

Parameter	Unit	Sample ID					
		PMB	PMA	PLC	PLB	PLA	Composite
Paste pH	-	10.5	9.0	8.6	8.4	9.1	9.4
Total Sulphur	%	0.11	0.17	0.17	0.2	0.18	1.11
Acid Potential (AP)	kg/t	3.5	5.2	5.4	6.2	5.7	35.0
Neutralization Potential (NP)	-	130	225	88	142	137	167
Net Neutralization Potential (NNP)	-	127	220	83	136	131	132
Neutralising Potential Ratio (NPR) (NP:AP)	-	37	44	16	23	24	5
Rock Type		III	III	III	III	III	II

Table 19: NAG results for ash samples

Nett Acid Generation	Sample Identification: pH 4.5					
	PMB	PMA	PLC	PLB	PLA	Composite
NAG pH: (H₂O₂)	8.6	8.6	8.6	7.8	7.8	8.3
NAG (kg H₂SO₄ / t)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

4.6.5 Ash Leachate Results

The following summary gives insight into the potential for metal leaching as per evaluations against the various guideline values:

- Results for chemicals with health significance in drinking water:
 - From previous studies and the total elemental analysis results trace elements of concern were As, Hg, B, Mn and Se (Wagner & Tlotleng 2012). Based on the ash leachate results these parameters did not leach in significant concentrations with the exception of Mn and B. Arsenic leached out in concentrations below the recommended Class 1 guidelines, with the same conclusion for selenium, with the exception of leachate from sample PLC (Se = 0.038 mg/L). This is however still within Class 2 and not of major concern. Hg leached in minor concentrations, well below the laboratory detection limit and the drinking water guidelines;
 - pH levels range between 7.02 and 8.9 and is within the recommended Class 1 guidelines. This pH range is neutral to slightly alkaline and allows for a stable system in which heavy metals tend not to be soluble;
 - In all samples F leached in concentrations above the recommended Class 1 guidelines and all results fall within Class 3, with the exception of sample PLA that falls within the maximum allowable limit of Class 2. The source of F can be either from small trace element inclusions in the coal mineralogy or from fluorite minerals associated with the host geology and also picked up in the ash XRD results;
 - Ca in sample PMA, as well as the Composite sample leached out in concentrations within the limits of Class 2; with sample PLA leaching calcium above the recommended limits of Class 3. The source of calcium is the siderite and calcite mineralogy associated with the coal deposits, as well as lime added to the samples for burning;
 - Both F and Ca leached out in significant quantities from the ash samples. This is due to the presence of the mineral fluorite in the original coal and/or lime samples. Both these elements are also present in the mudstone and shale formations and could possibly contaminate the coal samples during the mining and burning processes;
 - Mn and Ni also leached out in high concentrations from all samples, except sample PMB:
 - Mn is an abundant mineral in the earth's crust. Although Mn commonly leaches out of most materials, they are easily precipitated out of solution once water equilibrates; or Mn gets adsorbed through ion exchange and adsorption reactions to clay minerals like smectite and kaolinite;
 - Ni is a metal ion that has a high chemical activity within the earth's crust and in aqueous environments. It is mostly found in the mineral pentlandite ((Fe, Ni)₉S₈), an iron-nickel sulphide, commonly inter-grown with pyrite and pyrrhotite. All three

these minerals are associated with coal formations and could be the source of nickel in the ash samples and their leachate product;

- The only other metal leaching in concentrations above WHO guidelines is B; however during mixing and adsorption reactions the concentrations should decrease to well below guideline values; and
- All other parameters are within the recommended guidelines and do not show any health or environmental impacts.
- Results for chemicals that are not of health concern in drinking-water:
 - From the metal leach analysis the only detectable parameters were Ag, Au, Cs, Li, Rb, Sc, Si, Sr, U and Zr;
 - All the above mentioned metals and trace elements are common elements found in the earth's crust and biosphere; and
 - None of them leached out in significant concentrations.
- The only ions of concern from the ash leachate are F, Mn, Ni and Ca;
- Ca can leach out due to the addition of lime to the coal before burning or from the siderite and calcite mineralisation associated with the formations that will be mined at Dalyshope; and
- The assay geochemistry results on the parting samples from the Dalyshope stratigraphy showed an abundance of F in the mineralisation of the region. Thus, it can be concluded that F will naturally leach out from the environment.

4.6.6 Ash Classification

Both the Leachable Concentrations (LC) and Total Concentrations (TC) of potential contaminants tested for were classed against the newest NEM:WA waste classification thresholds. All inorganic contaminants were tested for with the nature of the ash and the processes leading to its formation (burning at high temperatures under controlled conditions), fundamentally not allowing the formation of any organic materials or other contaminants like benzene that are highly combustible and would have been taken out of the process once burning was complete. The following two subsections give a full classification of the ash material.

The classification was done under mono-disposal and leachate procedures for mine sites.

4.6.6.1 Waste Classification Legislation and Guidelines

The waste classification of the ash material was undertaken according to the following legislative guidelines:

- National Environmental Management Waste Act, 2008 (ACT No. 59 of 2008). National Waste Information Regulations, 2012 (DEA 2012);

- National Environmental Management Waste Act, 2008 (ACT No. 59 of 2008). National Norms and Standards for the Assessment of Waste for Landfill Disposal (DEA 2013a);
- National Environmental Management Waste Act, 2008 (ACT No. 59 of 2008). National Norms and Standards for the Disposal of Waste to Landfill (DEA 2013b); and
- National Environmental Management Waste Act, 2008 (ACT No. 59 of 2008). National Waste Classification and Management Regulations (DEA 2013c).

It should be noted that during the Dalyshope ash backfilling study the NEMWA legislation did change and some of the tests and procedures can potentially fall under the old legislation. This will however not compromise the results with the essential steps to be followed remaining the same.

4.6.6.2 Classification

The TC and LC results were classed against the various thresholds set out by the DEA and this is shown in Table 20 and Table 21. The following conclusions and waste classification can be reached based on the results:

- One or more elements are above the LCT0, but below or equal to the LCT1 limits ($LCT0 < \text{Ash LC} \leq LCT1$);
- All elements are below or equal to the TCT1 limits ($\text{Ash TC} \leq TCT1$); and
- Per the above observations the ash/waste material can be classified as a Type 3 waste and should be disposed of at a Class C waste disposal facility.

**Table 20: Total Concentration Threshold Classification**

Element	Unit	TCT0	TCT1	TCT2	PMB	PMA	PLC	PLB	PLA	Composite
As	mg/kg	5.8	500	2000	3.31	4.96	6.55	2.11	3.36	6.22
B	mg/kg	150	15000	60000	17.30	15.18	17.35	15.74	14.88	22.87
Ba	mg/kg	62.5	6250	25000	262.00	234.00	628.00	486.00	337.00	256.00
Cd	mg/kg	7.5	260	1040	0.03	0.09	0.08	0.07	0.02	0.03
Co	mg/kg	50	5000	20000	16.23	10.08	13.43	15.07	14.25	12.73
Cr	mg/kg	46000	800000	N/A	105.00	59.00	78.00	77.00	83.00	51.00
Cu	mg/kg	16	19500	78000	2.64	4.40	9.88	6.57	10.24	1.42
Hg	mg/kg	0.93	160	640	0.03	0.04	0.07	0.30	0.12	0.01
Mn	mg/kg	1000	25000	100000	1175.19	1458.14	868.22	565.89	832.56	1600.00
Mo	mg/kg	40	1000	4000	1.19	1.43	2.44	2.05	2.34	2.03
Ni	mg/kg	91	10600	42400	15.14	14.11	10.53	12.06	7.55	12.98
Pb	mg/kg	20	1900	7600	23.91	23.79	32.22	36.69	27.05	21.49
Sb	mg/kg	10	75	300	0.63	0.48	0.63	0.56	0.52	0.67
Se	mg/kg	10	50	200	1.33	1.22	0.13	0.15	0.54	0.19
V	mg/kg	150	2680	10720	75.97	65.21	86.34	86.45	98.17	72.32
Zn	mg/kg	240	160000	640000	44.35	45.08	47.66	45.75	43.85	53.60

**Table 21: Leachable Concentration Threshold Classification**

Parameter	Unit	LCT0	LCT1	LCT2	LCT3	PMB	PMA	PLC	PLB	PLA	Composite
TDS	mg/l	1000	12500	25000	100000	278	868	584	514	998	1022
F	mg/l	1.5	75	150	600	2.7	1.9	2.8	1.7	1.3	2.5
Cl	mg/l	300	15000	30000	120000	1.2	2.6	2.0	1.6	2.9	3.0
NO ₃ as N	mg/l	11	550	1100	4400	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
SO ₄	mg/l	250	12500	25000	100000	74	147	124	104	140	338
As	mg/l	0.01	0.5	1	4	0.006	0.010	0.004	<0.001	0.003	0.001
B	mg/l	0.5	25	50	200	0.319	0.420	0.336	0.229	0.329	0.584
Ba	mg/l	0.7	35	70	280	0.175	0.232	0.277	0.372	0.349	0.160
Cd	mg/l	0.003	0.15	0.3	1.2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	mg/l	0.5	25	50	200	0.014	0.023	0.014	0.014	0.022	0.017
Cr	mg/l	0.1	5	10	40	0.001	0.001	0.001	0.001	<0.001	<0.001
Cu	mg/l	2	100	200	800	0.018	0.016	0.011	0.011	0.010	0.011
Hg	mg/l	0.006	0.3	0.6	2.4	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mn	mg/l	0.5	25	50	200	0.003	2.78	0.354	0.457	2.29	1.87
Mo*	mg/l	0.07	3.5	7	28	0.007	0.005	0.015	0.006	0.006	0.008
Ni	mg/l	0.07	3.5	7	28	<0.001	0.229	0.420	0.550	0.725	0.573
Pb	mg/l	0.01	0.5	1	4	0.002	0.002	0.002	0.002	0.002	0.002
Sb	mg/l	0.02	1	2	8	0.004	0.003	0.004	0.003	0.003	0.004
Se	mg/l	0.01	0.5	1	4	<0.001	0.018	0.038	0.017	0.001	0.020
V	mg/l	0.2	10	20	80	0.062	0.010	0.054	0.038	0.030	0.011
Zn	mg/l	5	250	500	2000	0.048	0.108	0.064	0.076	0.112	0.100

5 PIT BACKFILL GEOCHEMICAL MODELS

5.1 Model Setup

5.1.1 Conceptual setup

Based on the closure and rehabilitation plans the Dalyshope pit will be backfilled with ash from the IPP and capped with topsoil and overburden; still leaving a depression with a maximum depth of 40 m from the original surface level. The mining schedule will allow mining to start from the southeast (Figure 2) with the development of 6 main benches and two ramps. Backfilling can only start after 8 years and for conceptual purpose the assumption is made that the layers that is mined first will be burned at the IPP and then used as the first backfill material and thus the ash will be deposited in reverse vertical order from mining as indicated in Figure 3.

From baseline data the groundwater level of the local aquifers are at approximately 13.6 mbgl and in concept will rise back to levels above the backfill level creating a pond/pan once dewatering has stopped. Ash material in general has a much lower transmissivity (T) and hydraulic conductivity (K) values than the local geology and will thus form an aquitard and in some cases an aquiclude only allowing a small amount of groundwater to flow at very slow rates or none at all. Ash backfilling can lead to a 10% reduction of porosity and 50% decrease in K-value from natural conditions; with the ash hydraulic conductivity rates ranging between 5×10^{-3} m/d and 5×10^{-7} m/d. A decrease in porosity and flow rates through the aquitard allows for a slower recharge with water levels flattening out and thus sitting at higher pressure heads and ponding also occurring to form a pan or dam on top of the confining layer, in this case the area formed by the ash backfilling. Optimum moisture content from literature reviews indicates a maximum moisture content of saturated ash of 38%.

From this it can be concluded (to conceptualise the real world situation based on the available information and assumptions) that if 1 m³ rain water is allowed to recharge into the aquitard it will take a minimum of 25 years to reach the natural aquifer below the ash aquitard if horizontal flow is not taken into account. If assumed that the 38% moisture content of the ash will be kept in the ash matrix only 0.62 m³ (62%) will reach the aquifers below the aquitard.

This mixing will then occur at a ratio of 100% groundwater to 62% ash seepage. In the mixing simulations the SPLP leachate results will be used to simulate worst case scenario seepage, however weathering models will also be simulated to get a more accurate model of the ash weathering as it will occur once backfilling is complete under natural conditions.

5.1.2 Assumptions and Limitations

The geochemical modelling is currently in its initial phases and the models and scenarios will be refined as they go along with calibrations and flow data from the numerical groundwater

flow model. The current setup of models and on-going simulations is based on the following assumptions:

- It is assumed that the layers that are mined first will be burned at the IPP and then used as the first backfill material and thus the ash will be deposited in reverse vertical order from mining as indicated in Figure 3;
- Ash proportions in the final backfilled void will be similar to those observed in the proportions of original layers with the % of ash to be used in the weathering and mixing models indicated in Table 22;

Table 22: Ash proportions

ID	%
PLA	3.5%
PLB	12.9%
PLC	16.1%
PMA	11.3%
PMB	8.0%
Composite	48.2%

- A composite sample from these above percentages will be used in the modelling to have one sample to use in simulations;
- It is assumed that the 38% moisture content of the ash will be kept in the ash matrix; only 62% will reach the aquifers below the aquitard;
- It will take a minimum of 25 years for seepage to reach the natural aquifer below the ash aquitard if horizontal flow is not taken into account; and
- It was assumed that coal stockpiles will never be standing for more than 6 month before used in the IPP processes.

The geochemical modelling in this report was undertaken to evaluate chemical changes and no hydraulic parameters were used as this will form part of the mass transport and plume modelling done under the hydrogeological study. The following main limitations of the geochemical modelling should be taken note of:

- The weathering and mixing models assume that the volume of water and the mineralogy given as input is the volume to be used throughout the life of simulation and does not keep adding water/minerals to the system. The weathering of geological units is thus simulated in a slow moving system and does not take hydraulics and porosity into account as will be done in the geohydrological modelling; and
- It is highlighted that these geochemical models looks at the interaction and chemical reactions between material and fluids and no physical attributes is simulated.

5.1.3 Scenario Description

5.1.3.1 *Weathering reaction models*

- Scenario W1: The reaction of ash with rain water to assess the natural weathering reaction kinetics that will be associated with the recharge and chemical weathering of the ash backfill scenario. The weathering will take place in sequence allowing a natural increase in salts with a decrease in oxygen fugacity as depth increases;
- Scenario W2: The reaction of ash with groundwater to assess the natural weathering reaction kinetics that will be associated with the inflow of groundwater and chemical weathering of the ash backfill scenario. The weathering will take place in sequence allowing a natural increase in salts with a decrease in oxygen fugacity as depth increases;
- Scenario W3: Weathering of the coal seam mineralogy to assess the AMD potential of the coal layers during and after mining, under natural conditions; and
- Scenario W4: Weathering of the waste rock mineralogy to assess the contamination potential of the waste rock during and after mining.

5.1.3.2 *Mixing models*

- Scenario M1: Mixing of waste rock leachate with ash leachate at a 1:1 ratio to evaluate the effect of the capping of the backfilled ash with a waste rock and overburden layer;
- Scenario M2: Mixing of ash leachate at a ratio of 0.62 litre ash seepage to 1 litre of groundwater;
- Scenario M3: Mixing of waste rock leachate with groundwater to evaluate the potential effect of waste rock seepage on the groundwater quality; and
- Scenario M4: Mixing of coal leachate with groundwater to evaluate the potential effect of stockpile seepage on the groundwater quality.

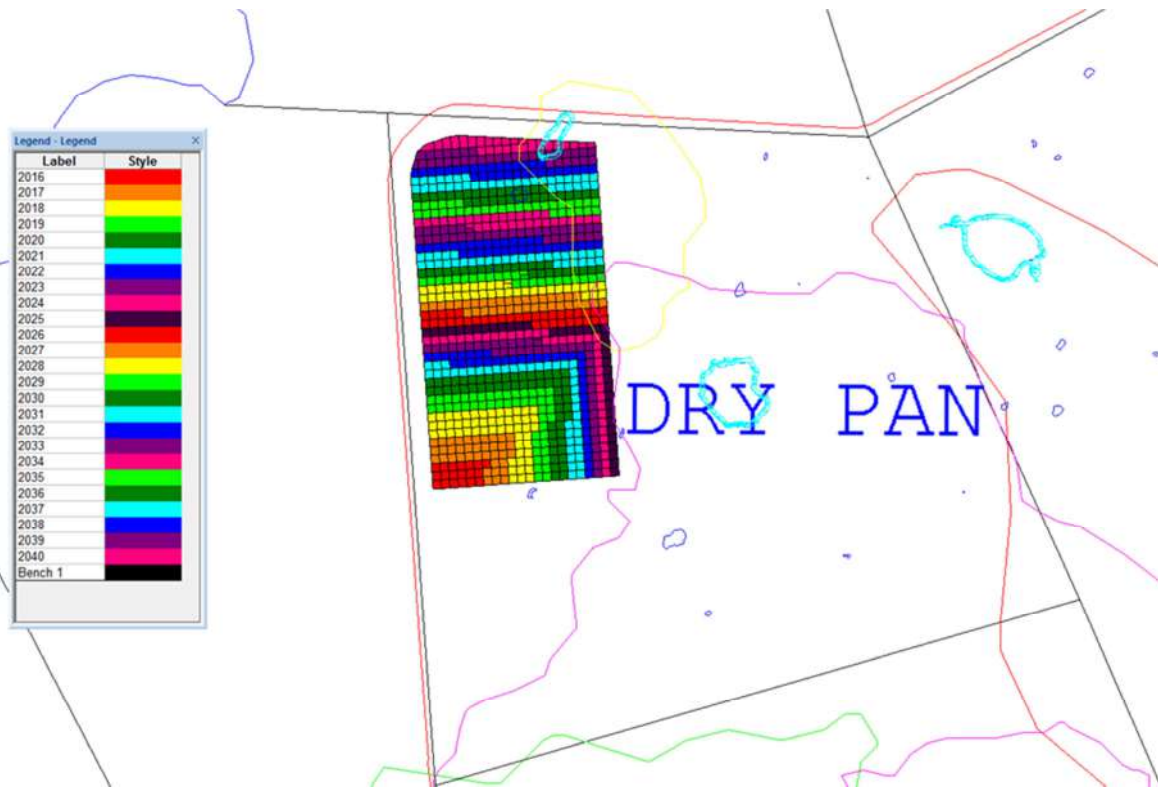


Figure 2: Planned mining sequence



DALYSHOPE PIT SIDE PROFILE (40m BENCHES)

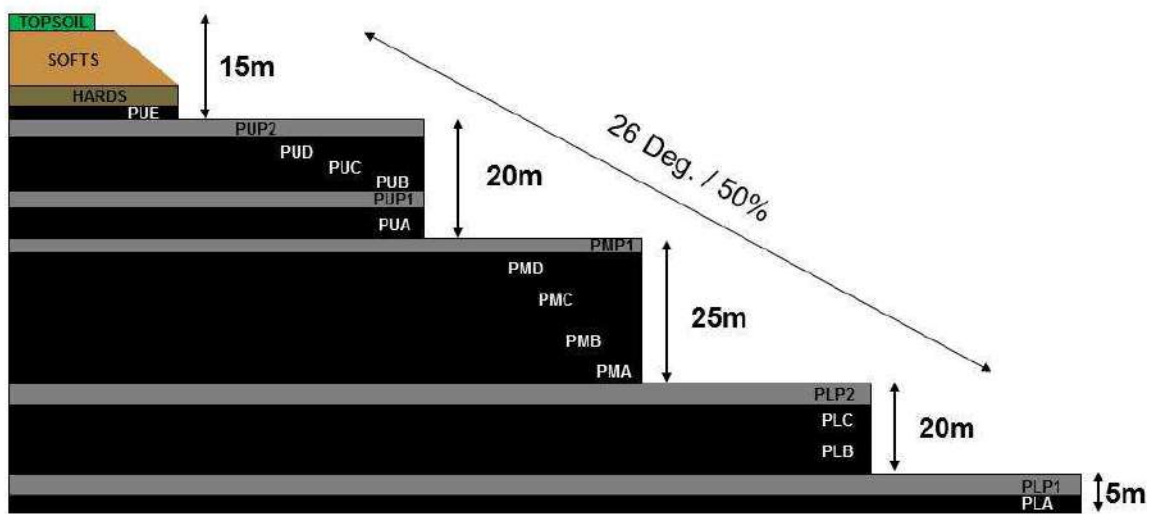


Figure 3: Mining benches and coal layers

5.2 Fluid Speciation

All fluids produced from tests and sampling runs have been speciated to allow a full understanding of the aqueous species distribution before modelling is done with the fluids.

5.2.1 Waste Rock Speciation

The waste rock samples (section 4.2.5) were submitted for static leachate tests to allow for an evaluation of the leachable concentrations from the waste rock as a worst case scenario. The resultant leachate fluid from each waste rock sample will be used in various geochemical reaction simulations and models to allow for a predictable model to be developed for the LoM and post-closure stages of the project.

The main physical parameters and calculations from the waste rock fluid speciation are given in Table 23. The fluids produced from the static tests on the waste rock samples have low TDS values; between 134 mg/L and 230.7 mg/L, with a neutral pH range for almost all samples except for PLP1 that has a potential acid generating nature. The main saturated ions with the highest activity coefficients are Ca, Na, K, HCO₃ and SO₄ and these ions gives the samples the various facies as indicated in Table 23 with the main water types being Ca/Na/K-HCO₃/SO₄.

The water types and ion distribution of the various waste rock fluids are illustrated in the Piper diagram and Stiff diagrams in Figure 4 and Figure 5. The K and Na distribution in the samples dominate the cation distributions and this is due to the high alumino-silicates and clay mineral content of the waste rock mineralogy. The development of the sulphate water is due to the oxidation and dissolution of siderite and pyrite; also included in the waste rock samples and associated with the coal formation. The high activity of some ions can lead to the secondary formation of gibbsite, gypsum, siderite, jarosite and other evaporative minerals.

The weathering of microcline and kaolinite has taken place during the leachate procedures with kaolinite and gibbsite being saturated within the system. The oxidation of pyrite has also taken place to a limited extent with high SO₄ and Fe content and low pH values in PLP1. Ca minerals are saturated in all samples with the high dissolution rate of dolomite/calcrete and calcite observed in the mineralogy leading to these super-saturated and saturated states. High F and Ca concentrations can lead to the development of fluoride in a slow moving groundwater system the farther away from the source flow occurs.

Table 23: Waste rock leachate fluid parameters

Sample ID	Unit	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
pH	-	8.2	7.7	8.3	8.3	8.1	4.7
Dissolved solids	mg/L	134	154.4	228.8	208.7	230.7	186.6
Water type	-	Ca-HCO ₃	K-HCO ₃	Na-HCO ₃	Na-HCO ₃	Ca-SO ₄	Ca-SO ₄
Charge imbalance error	%	10%	-10%	1.74%	2.90%	2.95%	0.92%

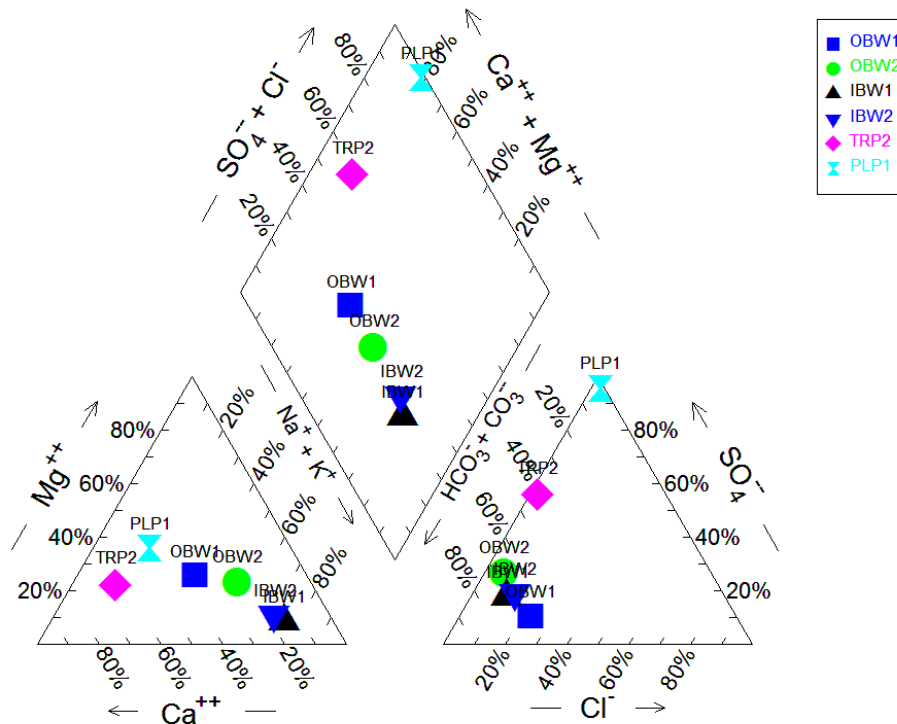


Figure 4: Piper diagram of the waste rock leachate fluid

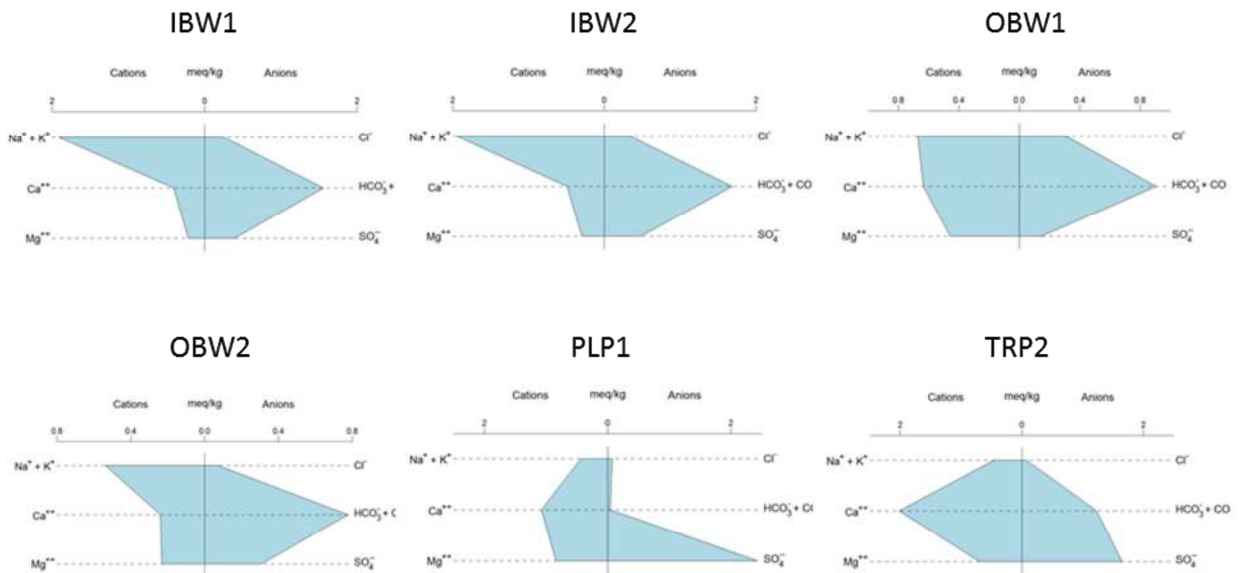


Figure 5: Stiff diagram for each waste rock leachate fluid

5.2.2 Coal Leachate Speciation

The main physical parameters and calculations from the coal fluid speciation are given in Table 24. The fluid produced from the static tests on the coal samples has lower TDS values than the waste rock samples due to the lower mineral content as can be seen with the high loss of material (mainly carbon) in the XRF results. The coal fluids show TDS values between 105.8 mg/L and 164.6 mg/L with a neutral to slightly alkaline pH range between 7.6 and 8.3. The main saturated ions with the highest activity coefficients are Ca, HCO₃ and SO₄ and these ions give the samples the various facies as indicated in Table 23; with the main water type to be produced from the coal leachate being Ca-HCO₃. The PMB sample shows a slight change in facies with a dominant SO₄ distribution allowing a Ca-SO₄ formation that could lead to the potential secondary formation of jarosite and gypsum under evaporative conditions as would be experienced by stormwater and evaporation ponds at the Dalyshope operations.

The water types and ion distribution of the various coal fluids are illustrated in the Piper diagram and Stiff diagrams in Figure 6 and Figure 7. As can be seen in the trend developed in the Piper diagram the main ion distribution in all samples remain constant with only the balance between CO₃/HCO₃ and SO₄ changing, with high sulphide mineral content being the most probable cause. The high activity of some ions can lead to the secondary formation of gibbsite, gypsum, siderite, jarosite and other evaporative minerals.

The weathering of microcline and kaolinite has taken place during the leachate procedures, with kaolinite and gibbsite being saturated within the system. The oxidation of pyrite has also taken place to a limited extent with high SO₄ and Fe content and lower pH values in PMB. The neutralising potential of calcite and other alumino-silicates is however high enough to buffer the system. Ca minerals are saturated in all samples with the high dissolution rate of dolomite/calcrete and calcite observed in the mineralogy leading to these super-saturated and saturated states. High F and Ca concentrations can lead to the development of fluoride in a slow moving groundwater system the farther away from the source flow occurs.

Table 24: Coal sample leachate fluid parameters

Sample ID	Unit	PMB	PMA	PLC	PLB	PLA	Composite
pH	-	7.6	7.8	8.3	8.2	8.2	8.2
Dissolved solids	mg/l	149.7	164.6	111.7	105.8	151.8	155.3
Water type	-	Ca-SO ₄	Ca-HCO ₃	Ca-HCO ₃	Ca-HCO ₃	Ca-HCO ₃	Ca-HCO ₃
Charge imbalance error	%	2.69%	4.93%	10.14%	7.01%	4.61%	7.08%

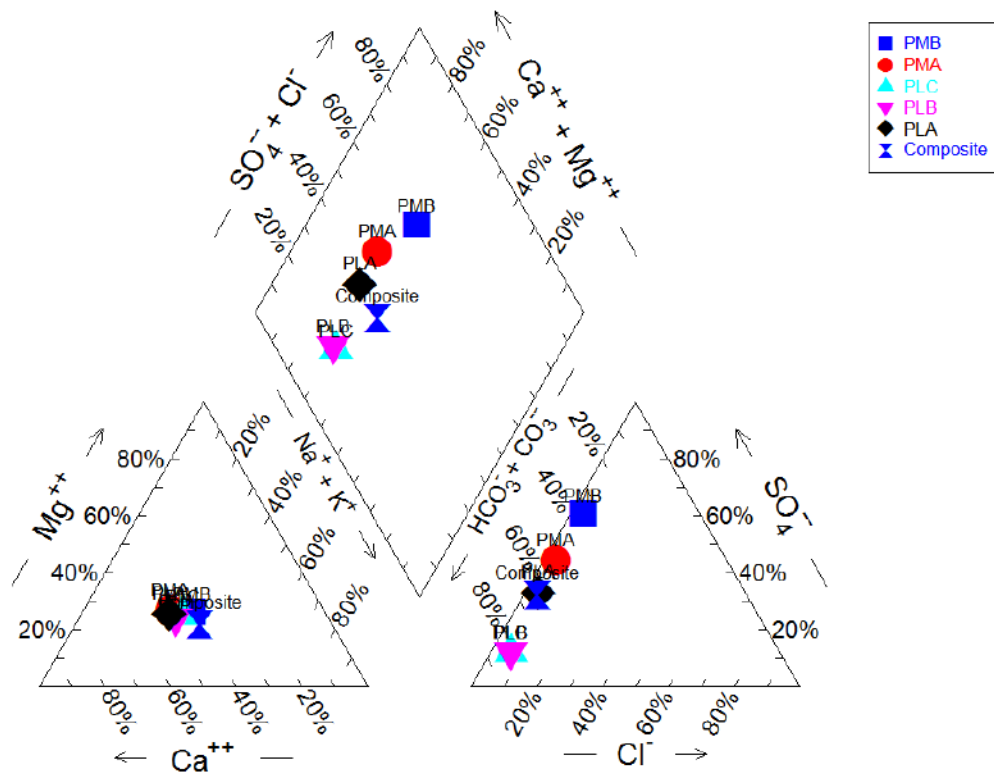


Figure 6: Piper diagram of the coal sample leachate fluid

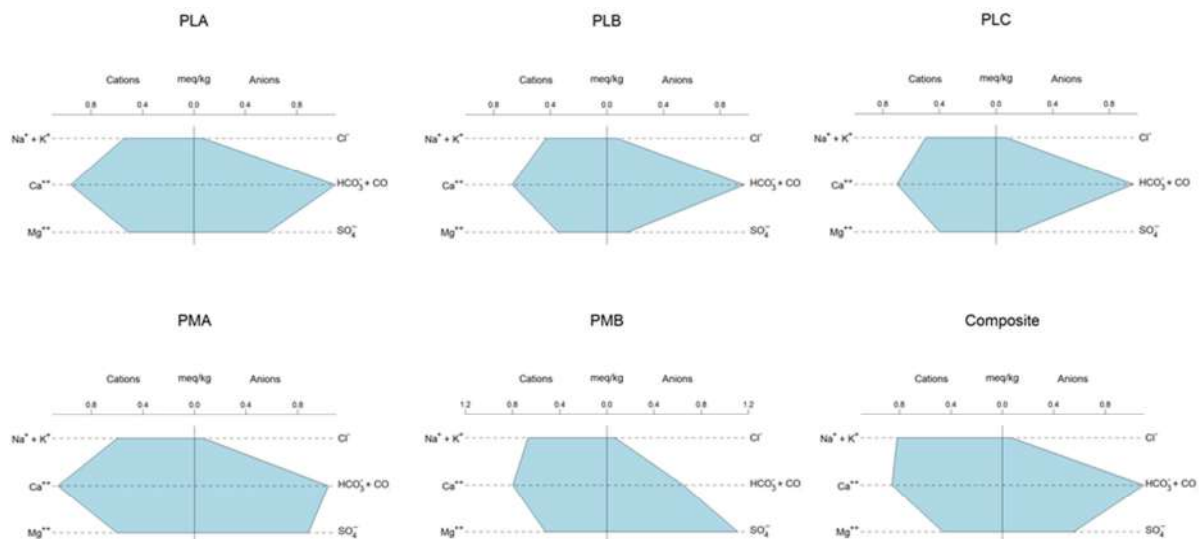


Figure 7: Stiff diagram for each coal sample leachate fluid

5.2.3 Ash Leachate Speciation

The ash leachate results show the potential of seepage from the ash that will result in water with a TDS between 278 mg/L and 1022 mg/L; with a pH ranging between 7.02 and 8.9.

The aqueous species with the highest molality in solution are HCO_3^- , Ca^{2+} , SO_4^{2-} and Mg^{2+} , with activity coefficients of 0.56 and 0.86. These ions with their high activity in the leach product allows for dissolution to occur until saturation is reached. Thereafter, the dissolution rate will decrease with an increase in precipitation of secondary minerals, containing these ions as equilibrium shifts to favour the reverse reaction (favouring the reactants). The above mentioned ions along with CO_3 are in high concentrations due to the high carbonaceous content of both the lime and coal that formed the original material before burning.

The species with the highest concentrations being HCO_3^- , Ca^{2+} , SO_4^{2-} and Mg^{2+} also shows up in the various water facies produced from the leachate as shown in the Piper diagram (Figure 8) and Stiff diagrams (Figure 9). Leachate water from sample PMA, PLC, PLB, PLA and the Composite sample has a Ca- HCO_3 (calcium-bicarbonate) water facies, with sample PMB having a slightly higher sulphate (SO_4) content resulting in a Ca- SO_4 (calcium-sulphate) water facies. The higher SO_4 content in proportional relation to the other ions can be seen in the Stiff diagram of the PMB sample compared to the other (Figure 9).

The main parameters of concern in the leachate results when compared to guideline values are Mn, Ni, Ca and F, with B only slightly above the guidelines in one sample. Table 25 gives a summary of these ion speciation parameters within the leachate solutions.

From the average activity and log activity coefficients of each species plotted against a pH range, the graphs in Figure 10, Figure 11 and Figure 12 indicate the saturated state in which the leachate water is and what a potential change in pH can cause. Ca and F were not graphed due to the fact that an increase in activity and concentration of these two species along with CO_3 will result in the reversal of reactions.

Mn is soluble at all pH levels below 10, with a pH activity range observed in the leachate samples; indicating the current aqueous state of the leach water and dissolved Mn (Figure 10). If the pH increases, the following two reactions can lead to the formation of $\text{Mn}_2(\text{OH})_3$; potentially resulting in the formation of the secondary mineral $\text{Mn}(\text{OH})_2$:

- $\text{Mn}_2(\text{OH})_3 + 3\text{H}^+ = 2\text{Mn}^{2+} + 3\text{H}_2\text{O}$
- $\text{Mn}(\text{OH})_2 + 2\text{H}^+ = \text{Mn}^{2+} + 2\text{H}_2\text{O}$

Ni, in the current aqueous system (observed in the leachate results) is soluble. However, as soon as the pH increases above 6, with a slight decrease in log activity (increase in normal activity); the pure mineral nickel oxide will precipitate out of solution through the reaction listed below (Figure 11):

- $\text{NiO} + 2\text{H}^+ = \text{Ni}^{2+} + \text{H}_2\text{O}$

Table 25: Summary of the speciation parameters of the ions of concern

Sample ID	Parameter	Molality	mg/kg in Solution	Activity coefficient	Log activity
Composite	Mn ²⁺	2.73E-05	1.50	0.59	-4.80
	Ni ²⁺	8.72E-06	0.51	0.59	-5.29
	Ca ²⁺	5.06E-03	202.60	0.59	-2.53
	F ⁻	1.18E-04	2.23	0.86	-3.99
	B(OH) ₃	9.14E-06	0.56	1.01	-5.04
PLA	Mn ²⁺	3.50E-05	1.92	0.57	-4.70
	Ni ²⁺	1.17E-05	0.69	0.57	-5.17
	Ca ²⁺	6.70E-03	268.00	0.57	-2.42
	F ⁻	6.08E-05	1.15	0.86	-4.28
	B(OH) ₃	5.22E-06	0.32	1.01	-5.28
PLB	Mn ²⁺	7.20E-06	0.40	0.65	-5.33
	Ni ²⁺	8.83E-06	0.52	0.65	-5.24
	Ca ²⁺	3.10E-03	124.20	0.65	-2.70
	F ⁻	8.25E-05	1.57	0.89	-4.13
	B(OH) ₃	3.53E-06	0.22	1.00	-5.45
PLC	Mn ²⁺	5.45E-06	0.30	0.64	-5.46
	Ni ²⁺	6.67E-06	0.39	0.64	-5.37
	Ca ²⁺	2.98E-03	119.30	0.64	-2.72
	F ⁻	1.34E-04	2.55	0.89	-3.92
	B(OH) ₃	5.10E-06	0.31	1.00	-5.29
PMA	Mn ²⁺	4.30E-05	2.36	0.59	-4.60
	Ni ²⁺	3.69E-06	0.22	0.59	-5.66
	Ca ²⁺	5.51E-03	220.60	0.59	-2.49
	F ⁻	8.90E-05	1.69	0.87	-4.11
	B(OH) ₃	6.64E-06	0.41	1.01	-5.18
PMB	Mn ²⁺	4.40E-08	0.0024	0.73	-7.50
	Ni ²⁺	7.18E-09	0.0004	0.73	-8.28
	Ca ²⁺	1.33E-03	53.34	0.73	-3.01
	F ⁻	1.32E-04	2.51	0.92	-3.92
	B(OH) ₃	3.41E-06	0.21	1.00	-5.47

Boron is a soluble metal found commonly in the aqueous species $B(OH)_3$ with the current system of the leachate samples indicated on the graph (Figure 12).

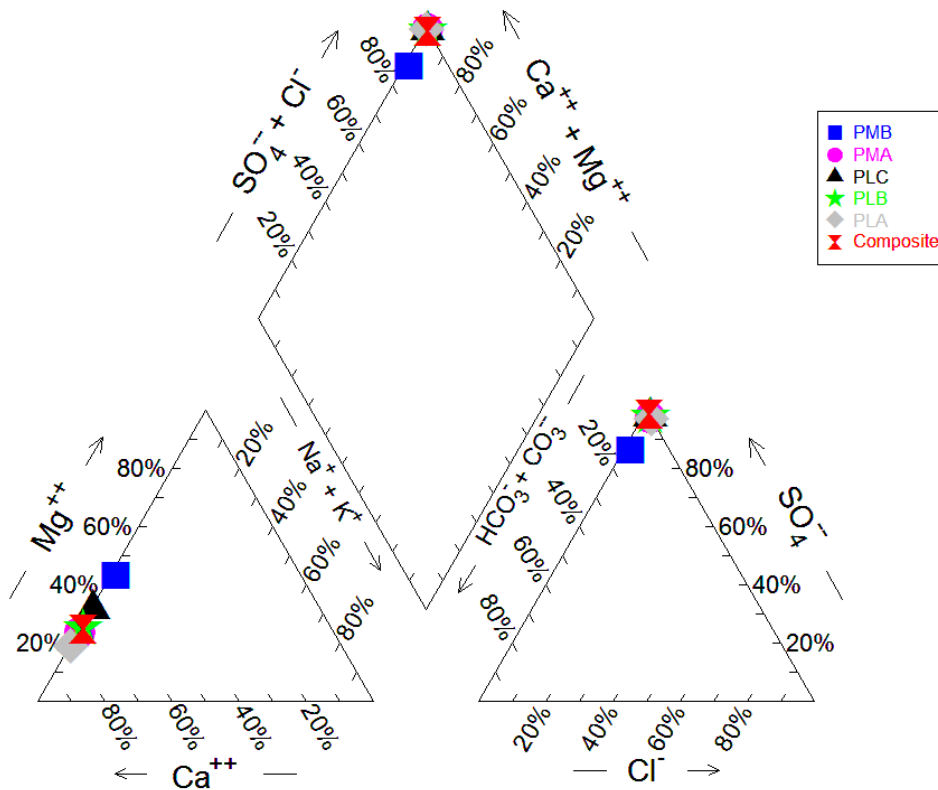


Figure 8: Piper diagram of the ash leachate fluid

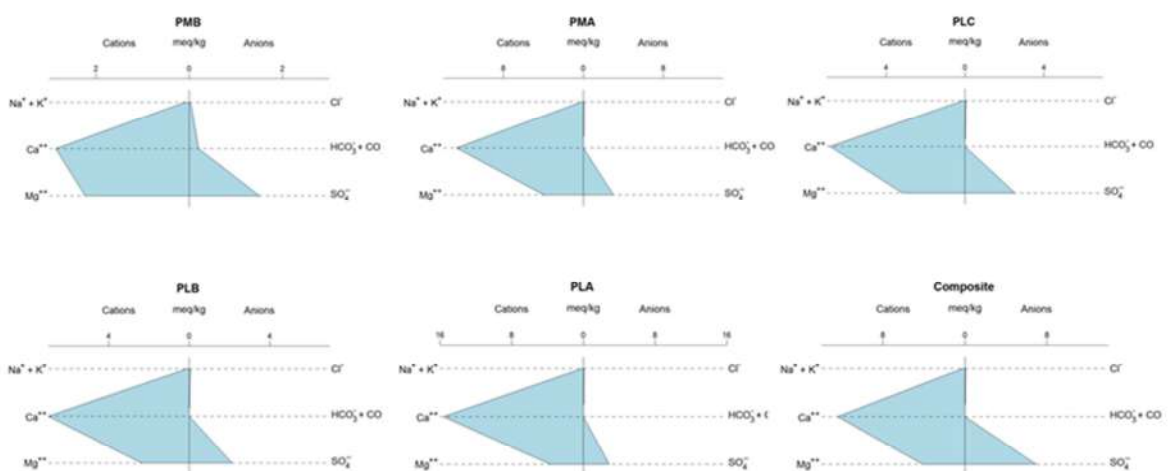


Figure 9: Stiff diagram for each ash leachate fluid

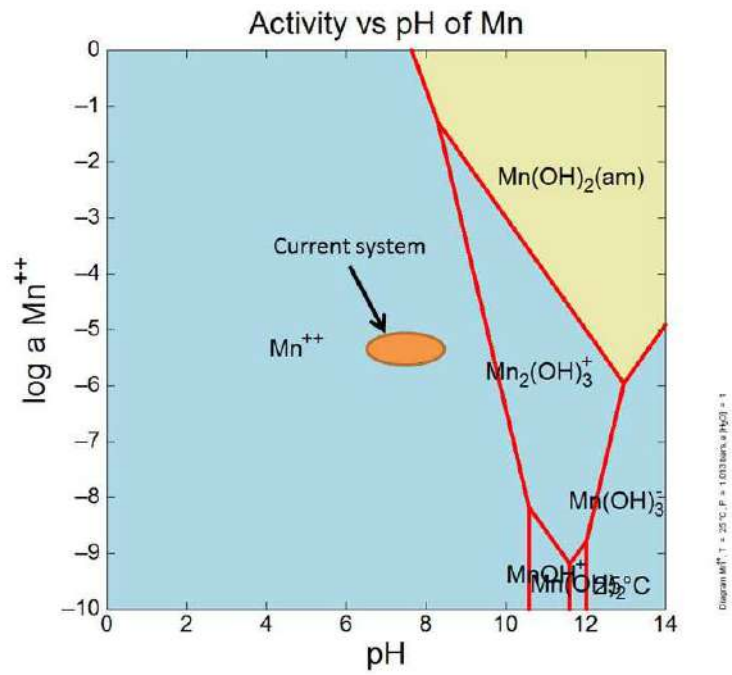


Figure 10: Activity vs. pH of aqueous Mn

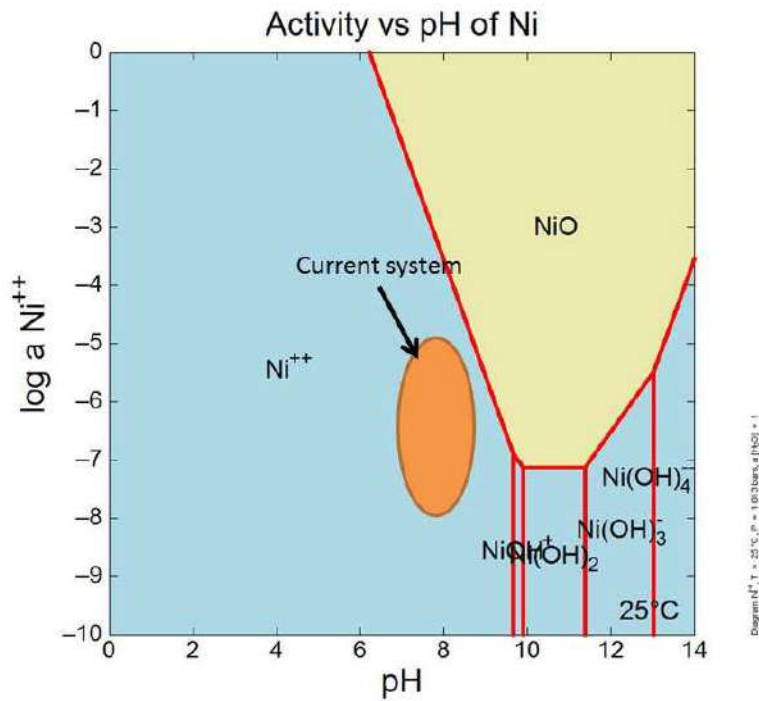


Figure 11: Activity vs. pH of aqueous Ni

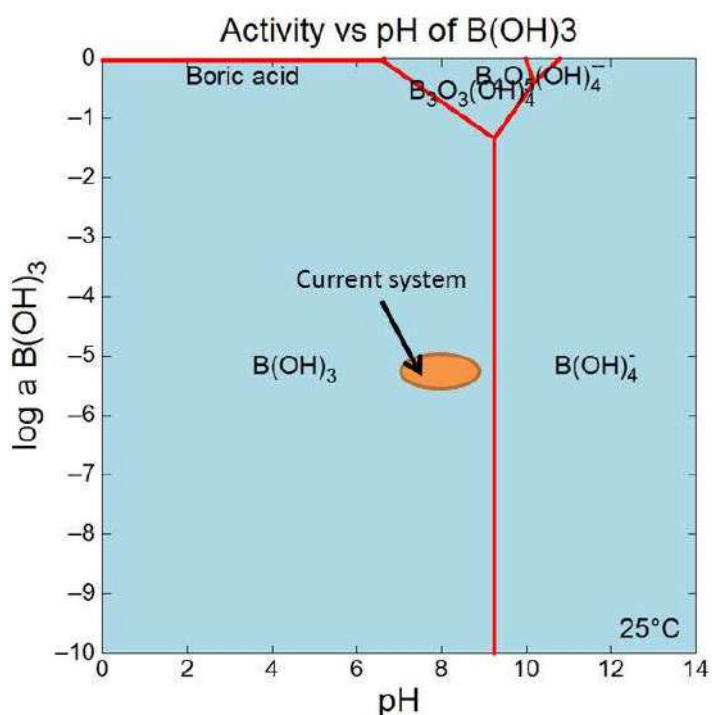


Figure 12: Activity vs. pH of aqueous B

5.2.4 Groundwater Speciation

The four (4) groundwater samples that have been chosen as input parameters into the relevant geochemical models are given in Table 26 with a mixed sample also presented. The 4 groundwater samples were chosen based on their locality to the proposed pit and will represent the main water qualities that will potentially flow towards the pit and mix with waters produced from the pit walls and backfilling material.

All 4 samples are classified as a sodium-chloride water type indicating high salt content as would be expected from the water facies in the Karoo formations. Recharge is slow with high dissolution rates of the calcite and sodium containing minerals. The Piper and Stiff diagrams in Figure 13 and Figure 14 show the ion distribution with the samples plotting almost identically on the Piper diagram.

An in depth hydrochemical description of these 4 samples is given in the geohydrological assessment report forming part of the EIA study. A mix between the 4 groundwater samples gives a similar water type and ion distribution. The mixed groundwater sample (GWM1) will be used in the geochemical model simulation to represent the groundwater that will take part in potential reactions between waste rock, coal and ash seepage water.

The pH of the groundwater ranges between 7.68 and 8.12 with TDS values between 598 mg/L and 868 mg/L. The dominant and saturated ions are Cl, Na, HCO₃ and F.

Table 26: Groundwater sample parameters

Sample ID	Unit	DBH1	DBH2	DBH3	KW4	GWM1
pH	-	7.77	7.68	8.03	8.12	7.9
TDS	mg/l	773	721	863	598	837.7
HCO ₃	mg/l	277	269	284	279	277.3
F	mg/l	0.993	1.23	1.28	1	1.126
Cl	mg/l	288	264	333	162	261.8
NO ₃	mg/l	0.0085	0.0085	0.0085	6.12	1.536
PO ₄	mg/l	0.004	0.004	0.012	0.029	0.012
SO ₄	mg/l	46.1	38.9	39.4	40.5	41.23
Al	mg/l	0.0015	0.0015	0.0015	0.0015	0.0015
Ca	mg/l	73.7	69.7	85.3	69.1	74.45
Cd	mg/l	0.001	0.001	0.001	0.001	0.001
Co	mg/l	0.001	0.001	0.001	0.001	0.001
Cr	mg/l	0.001	0.001	0.001	0.001	0.001
Cu	mg/l	0.001	0.001	0.001	0.186	0.04687
Fe	mg/l	0.0015	0.0015	0.0015	0.0015	0.0015
K	mg/l	15.9	16.2	18.7	15	16.45
Mg	mg/l	34.1	34.1	45.9	29.6	35.93
Mn	mg/l	0.0005	0.0005	0.0005	0.0005	0.0005
Na	mg/l	146	133	163	107	137.3
Ni	mg/l	0.0005	0.0005	0.0005	0.0005	0.0005
Pb	mg/l	0.002	0.002	0.002	0.002	0.002
Zn	mg/l	0.001	0.001	0.001	1.11	0.2782
NH ₄	mg/l	1.99	1.37	1.96	0.0025	1.331
Water type	-	Na-Cl	Na-Cl	Na-Cl	Na-Cl	Na-Cl
Charge imbalance error	%	-0.85%	-0.12%	2.59%	3.94%	1.10%

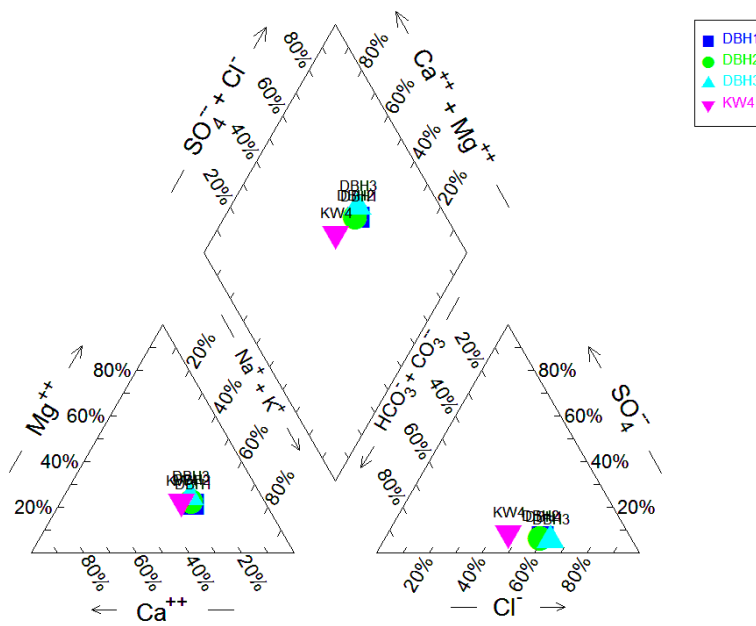


Figure 13: Piper diagram of the groundwater samples

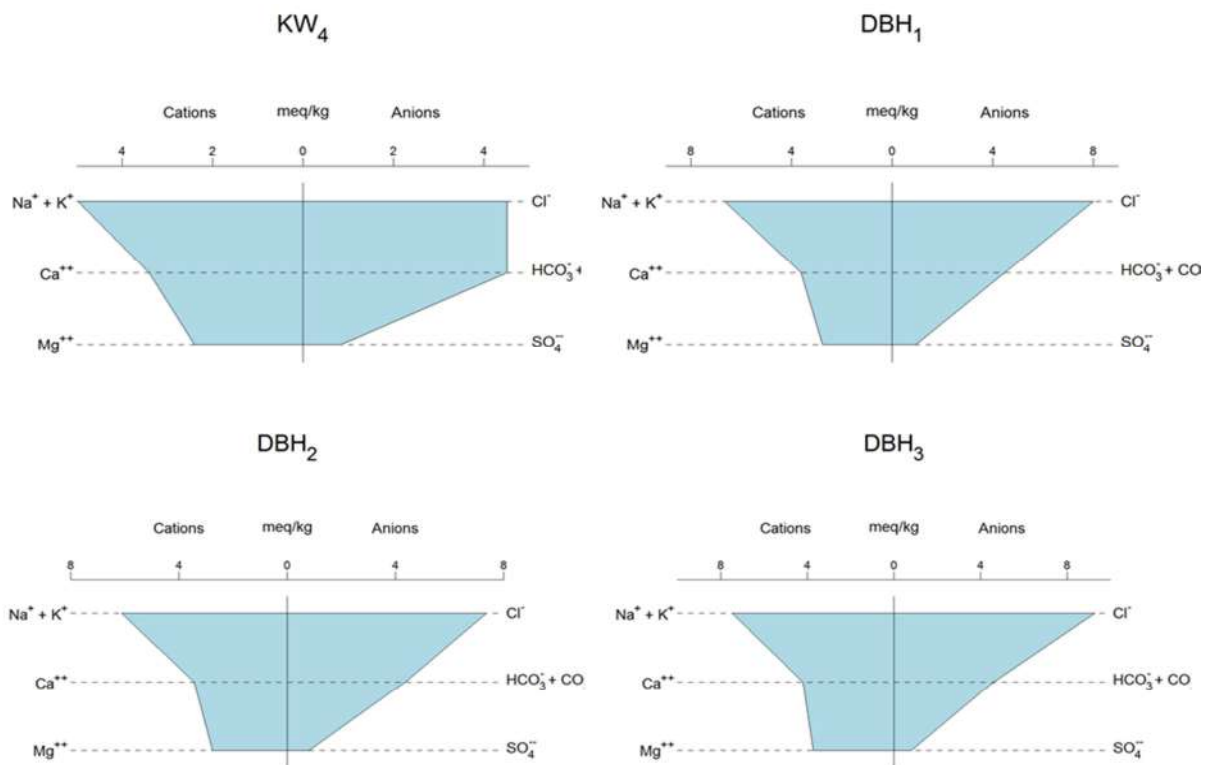


Figure 14: Stiff diagram for each groundwater sample

5.2.5 Rain water sample

Rain water is the main weathering agent along with oxygen diffusion into the various materials that will be disturbed and produced by mining and the IPP. A rainwater sample was produced to allow the simulation of the various weathering sequences and models.

The rain water sample that will be used in the simulations is shown in Table 27 with the water type indicated in Figure 15. The rainwater sample has a TDS of 20.5 mg/L with an acid rain pH of 6. It shows a Mg-Cl water type; as would be expected from rain water.

Table 27: Rain water sample

Sample ID	Unit	Rainwater
pH	-	6
HCO ₃ ⁻	mg/l	9.2
F ⁻	mg/l	0.1
Cl ⁻	mg/l	0.1
NO ₃ ⁻	mg/l	0.02
PO ₄ ⁻⁻⁻	mg/l	0.09
SO ₄ ⁻⁻	mg/l	0.1
Al ⁺⁺⁺	mg/l	0.02
Ca ⁺⁺	mg/l	1.2
Fe ⁺⁺	mg/l	0.05
K ⁺	mg/l	0.7
Mg ⁺⁺	mg/l	2
Na ⁺	mg/l	1.4
Ni ⁺⁺	mg/l	0.02
Pb ⁺⁺	mg/l	0.06
SiO ₂ (aq)	mg/l	0.1
Zn ⁺⁺	mg/l	0.25
Dissolved solids	mg/l	20.51
Charge imbalance error	%	9.71%
Water type	-	Mg-Cl

Rain water

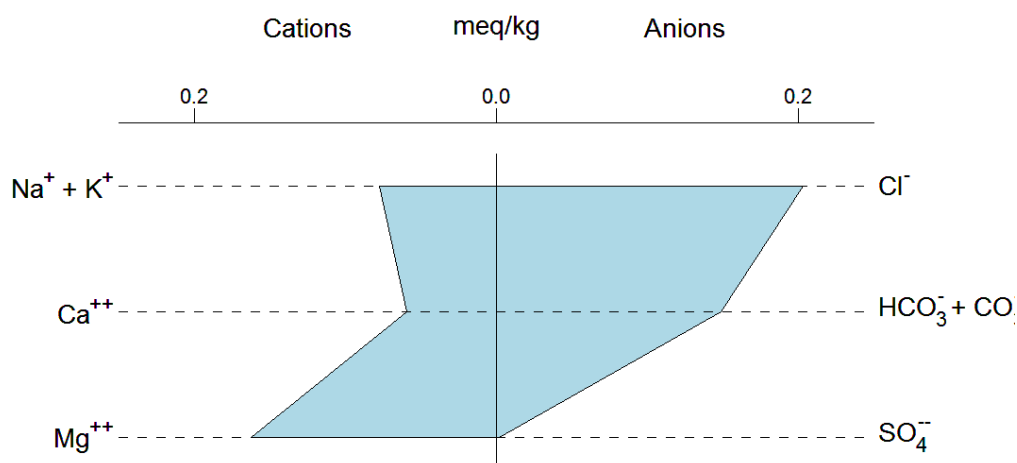


Figure 15: Stiff diagram of the rain water sample

5.3 Weathering Models

5.3.1 Scenario W1

Scenario W1 was simulated to allow a full evaluation of the seepage of rainwater through both the backfilled pit before the ash is covered with waste rock and overburden, as well as the expected process to be observed in the ash dumps that will act as storage for the ash before backfilling. The conceptual setup of the model is as follows:

- The rainwater sample (Table 27) will be allowed to equilibrate with atmospheric oxygen and then seep through the ash layers with the sequence of reaction with each layer not specific as the end weathering result will remain no matter what the layering of the ash;
- There are 6 layers of ash to be deposited within the ash dumps and backfilled pit with the first reactions taking place under fixed atmospheric fugacity of 0.21 fO₂ and then reacting with the following ash layers under a continuous decrease in oxygen;
- To simplify the weathering model an average mineralogical distribution of the ash (from XRD and XRF results) was allowed to react with a linear decrease in oxygen fugacity from a 0.21 fO₂ for the first period (backfilling will only start 8 years after project start-up) down to a fO₂ of 1x10⁻⁵⁰; and

- The pH trends and increase in salts will be observed with the final fluid compared and classed against guideline values. Simulations will run for 75 years allowing a 50 year post-closure simulation.

The above scenario description will have the same fugacity changes and weathering reactions whether backfilling is pursued or ash dumps are seen as the only waste management activity and thus represent a dual purpose.

Table 28 indicates the mineralogical distribution and kinetic reaction rates used for each mineral. For some minerals no input was given for the reaction rate and the software was allowed to use default values. Nickel sulphide, MnO and MgO was also allowed to react in small quantities as natural systems do have some metal ions that are not included in mineral compositions.

Table 28: Ash mineralogy for weathering models

Mineral/Oxide	Formula	Amount reacted	Reaction rate	Source
Lime	CaO	0.2	-	
Calcite	CaCO ₃	50.2	-	
Fluorite	CaF ₂	0.1	1x10 ⁻¹²	(Cama et al. 2010)
Hematite	Fe ₂ O ₃	2.2	-	
Kaolinite	Al ₂ (Si ₂ O ₅)(OH) ₄	8.1	1x10 ⁻¹⁷	(White & Brantley 1995)
Muscovite	KAl ₂ (Si ₃ Al)O ₁₀ (OH) ₂	3.1	1x10 ⁻¹⁷	(White & Brantley 1995)
Quartz	SiO ₂	36.1	1x10 ⁻²⁰	(Van Coller 2013)
Nickel sulphide	Ni ₃ S ₂	0.001	-	
Manganese oxide	MnO	0.1	-	
Magnesium oxide	MgO	1	-	

As rain water infiltrates the ash, whether on a discard dump or within the proposed pit as backfill, the weathering of the minerals starts out under an atmospheric oxygen fugacity (f_{O_2}) of 0.21 and decreases to values close to 0 as simulated in scenario W1 (Figure 16). A complete depleted of oxygen however never occurs due to dissolved oxygen remaining available ($O_{2(aq)}$). Although oxygen does play a major role in oxidation of sulphide minerals, in the weathering of neutralising minerals like calcite, lime and clay minerals as observed in the ash samples, the fugacity does not control the system. The dissolution of calcite occurs at such a rate that the system rapidly buffers to an alkaline pH and then equilibrates with the

very slow development of the fluid concentrations continuing thereafter (Figure 17); indicating the reaction trend through the pH and TDS development.

The above mentioned development of the fluid during the weathering of the ash allows for the water type to change from the rainwater Mg-HCO₃ towards a calcium dominated facies of Ca-HCO₃, as shown in Figure 18; illustrating the fluid development on a Piper diagram. The calcium dominated ion distribution correlates with the observations made in the leachate speciation with the final weathering fluid W1 shown in Table 31 as compared to guideline values. The concentrations observed from the simulations are lower than that given by the leachate tests due to natural conditions taken into account rather than a worst case simulation as it occurs in the laboratory. Natural mineral grain sizes and kinetic reaction rates were used in the simulations with only F (as in the case with the leachate results) and Pb dissolving to concentration higher than recommended.

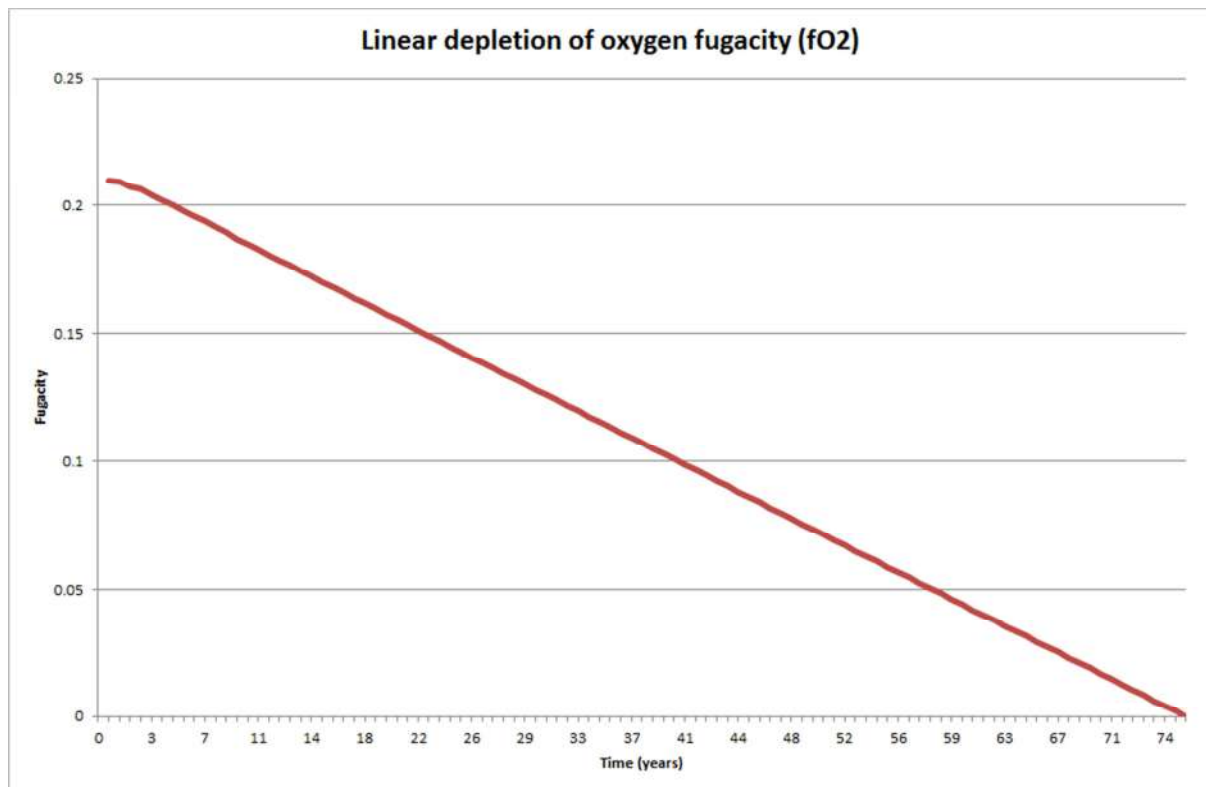


Figure 16: Linear trend of oxygen fugacity during weathering of mine dumps

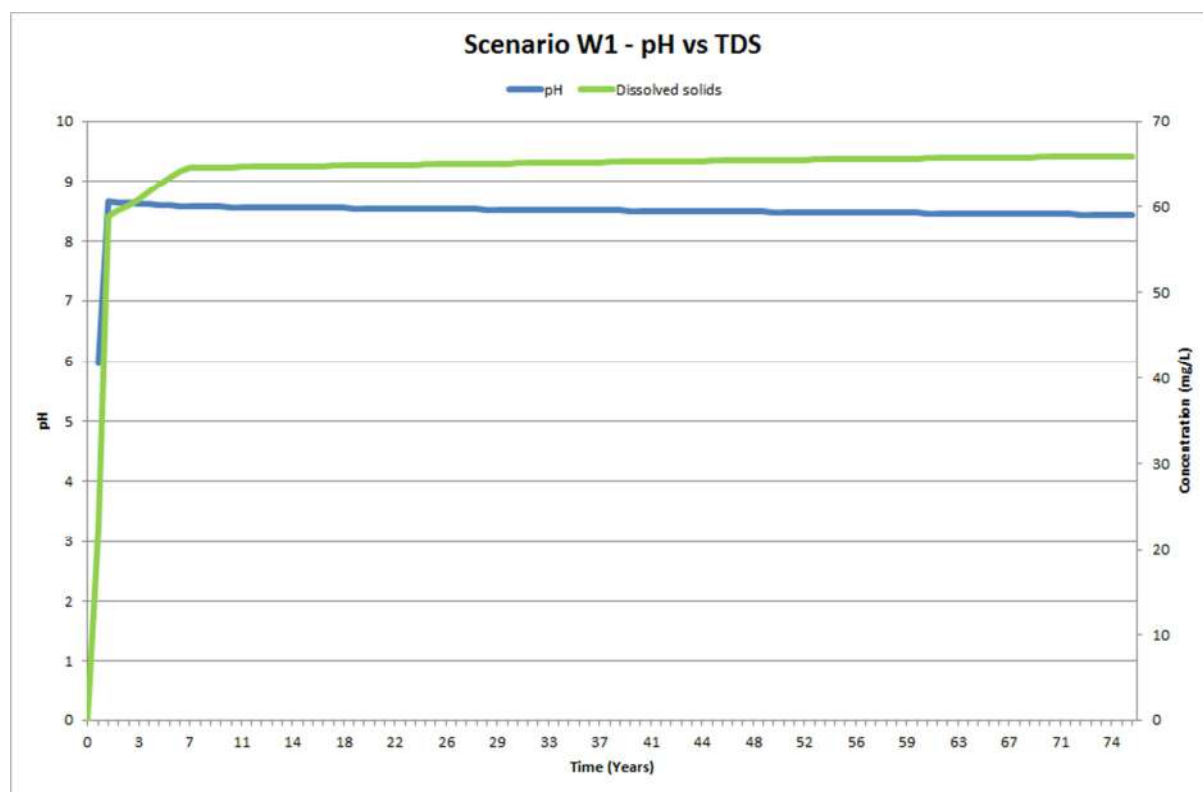


Figure 17: Scenario W1 pH and TDS development trend

Scenario W 1 Piper diagram

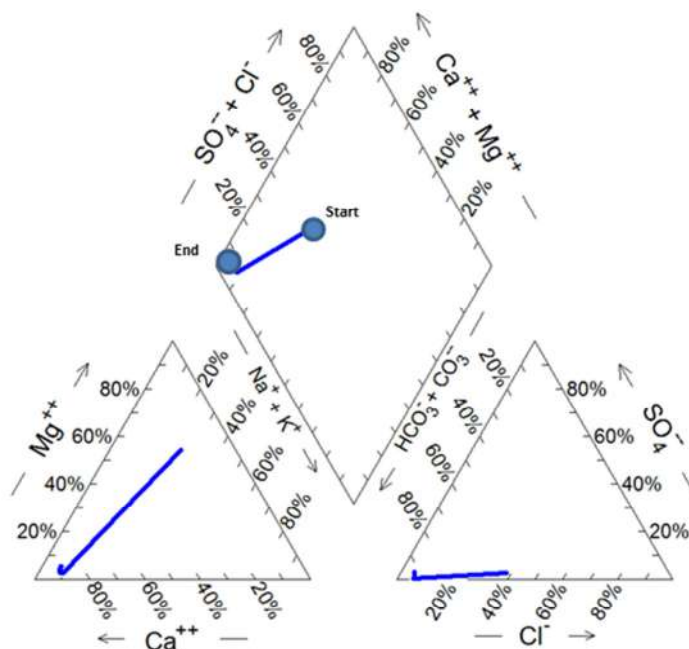


Figure 18: Scenario W1 Piper diagram

Metal and especially Ni and Al concentrations in the fluid did increase as shown in Figure 19, however it remained low enough not to raise concern. The system did equilibrate soon enough to allow a steady state to develop.

In conclusion from the ash weathering scenario it can be seen that the natural conditions and weathering of the material will result in lower salt content than observed in the laboratory tests. The only parameter of concern from the weathering reactions is fluoride.

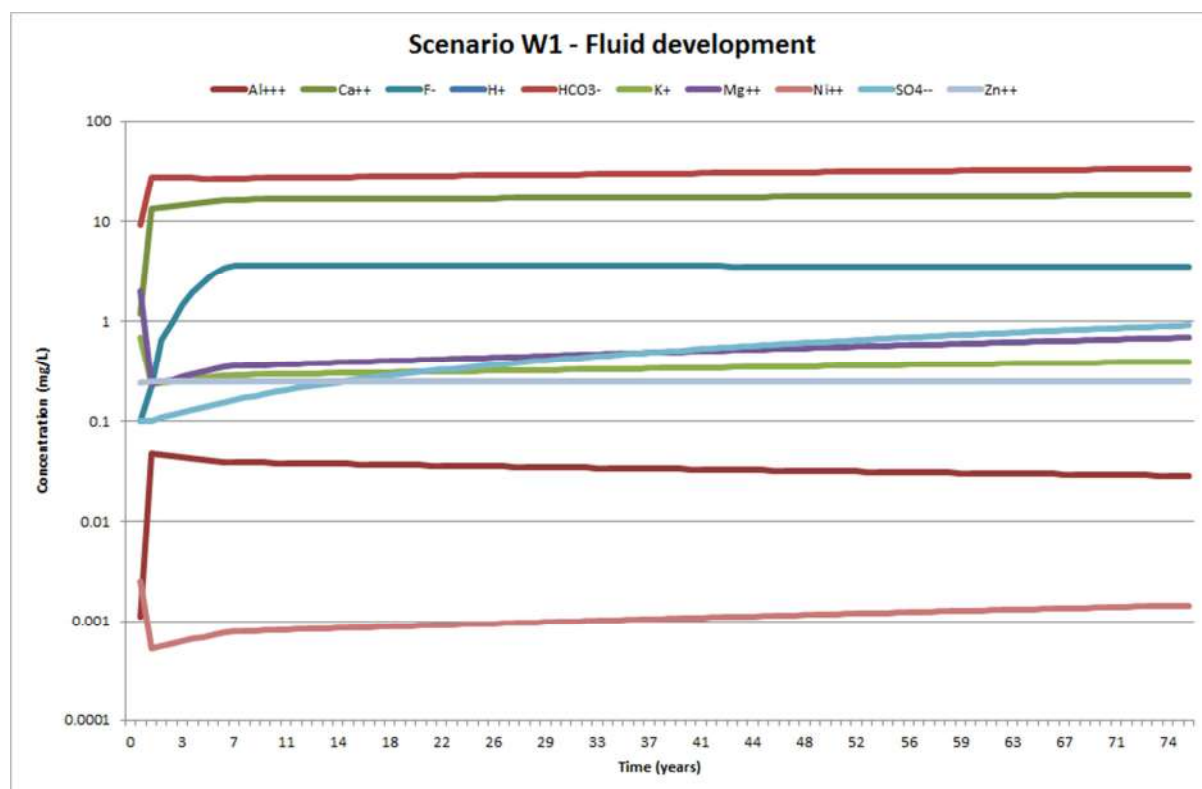


Figure 19: Dissolution trend of selected parameters during simulation of scenario W1

5.3.2 Scenario W2

Scenario W2 was simulated to evaluate the natural weathering that the ash, if used as backfilling material, will undergo through the interaction with groundwater. For this scenario the following setup was followed:

- The same ash mineralogy used in the previous scenario (W1) was allowed to react with the groundwater sample (GWM1); as discussed in section 5.2.4; and
- The groundwater as in the real world scenario is in equilibrium with atmospheric oxygen although it is not in contact with it any more. Thus the groundwater was allowed to equilibrate with fO_2 of 0.21 before it was introduced to the ash mineralogy after which the oxygen was allowed to stay at dissolve concentrations.

After equilibration with the local aquifers the groundwater flows into the pit area during the planned concurrent backfilling, as well as post-closure as dewatering has stopped. The interaction between the groundwater, with a pH of 7.9 and a Na-Cl water facies, allows various dissolution and precipitation reaction to take place with the fluid developing as

shown in Figure 20; indicating the main ions dissolving into the groundwater. Due to a lack of oxygen in the system oxidation of metal sulphide minerals are low with most of the reactions and dissolution sequences controlled by pH and buffering of the system by the neutralising minerals. The fluid evolves, in the shorter term of the word, from a Na-Cl water type (pH = 7.9, TDS = 844 mg/kg) towards a fluid with the same ion facies, but with a lower TDS of 540 mg/kg and a higher alkaline pH of 8.1 as the system has been slightly buffered by the calcite mineralogy. The higher pH is caused by the increase in dissolved CO_3 (Figure 1 section 2.4.2) allowing dissolution to continue with an initial increase in TDS, but as soon as saturation of some ions (SiO_2 , Ca, Na and F) is reached secondary formation occurs and the concentrations decrease during precipitation reactions that favours the reverse reaction paths. This process can be seen in the mineral development in the saturated fluid in Figure 21. Ca and F are the two elements that are saturated with the highest tendency to bond with each other and precipitate to form secondary fluorite. As an initial increase in all minerals is observed including pyrolusite, the system however gets super-saturated with Mn and soon pyrolusite starts precipitating and a decrease of the mineral is observed within the aqueous phase. Ca and F are two elements that are saturated in both the groundwater chemistry and the mineralogy of the ash material. In the initial reactions both F and Ca increase until F is saturated where after only Ca continues to dissolve until equilibrium is accomplished. In slow moving groundwater systems Ca and F precipitate as they move away from the source to form secondary fluorite after which F concentrations are easily depleted with Ca still dominating the system. This process can be seen in Figure 22 and the continuous dissolution of Ca is observed in the Ca dominated saturated mineralogy shown in Figure 21.

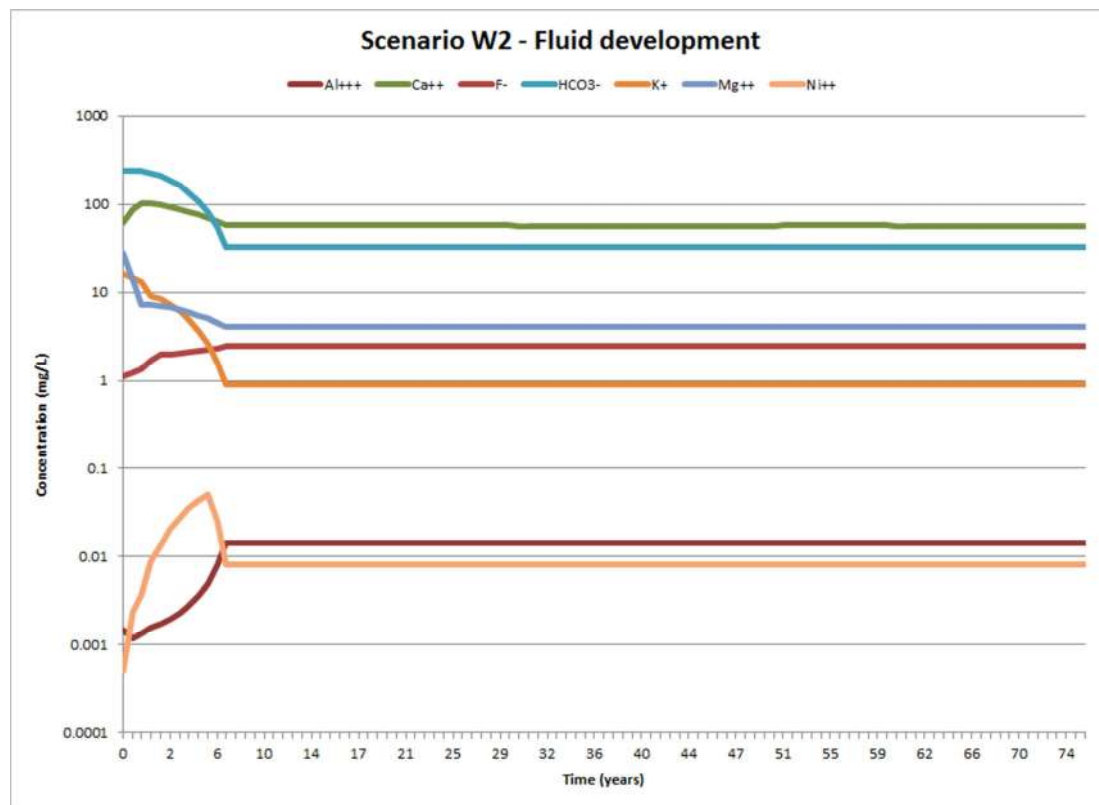


Figure 20: Scenario W2 main aqueous species in solution

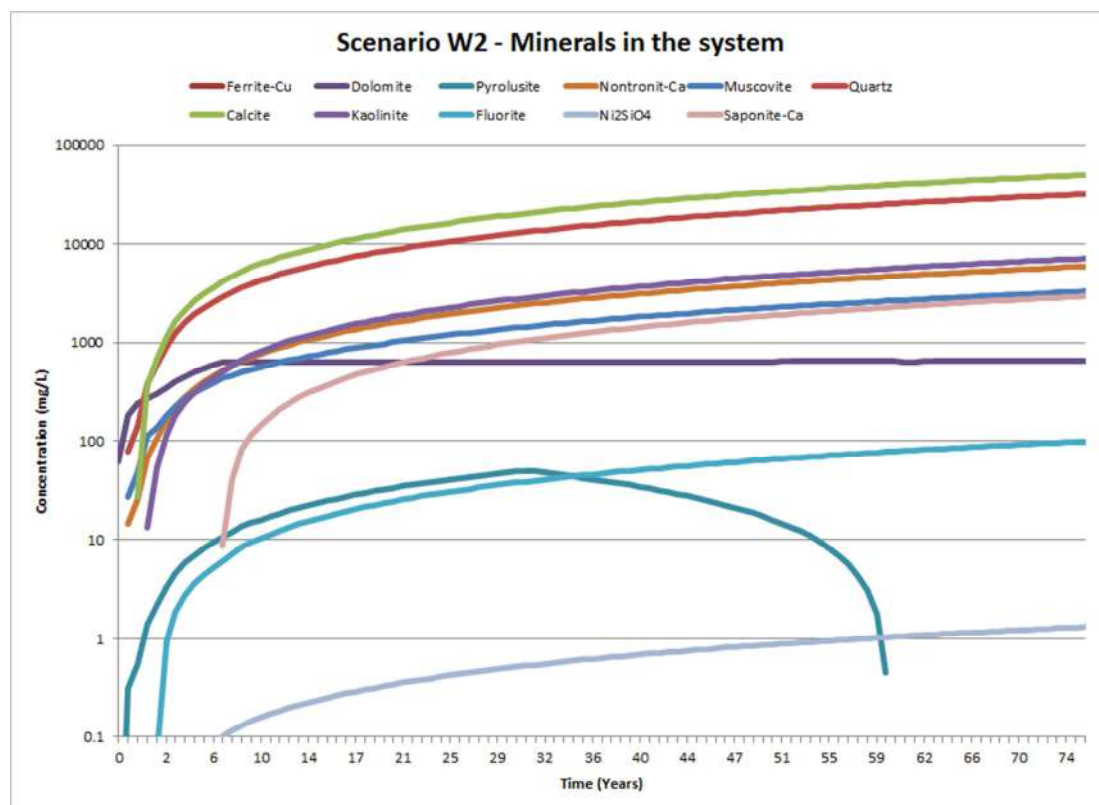


Figure 21: Scenario W2 mineral development during the weathering reactions

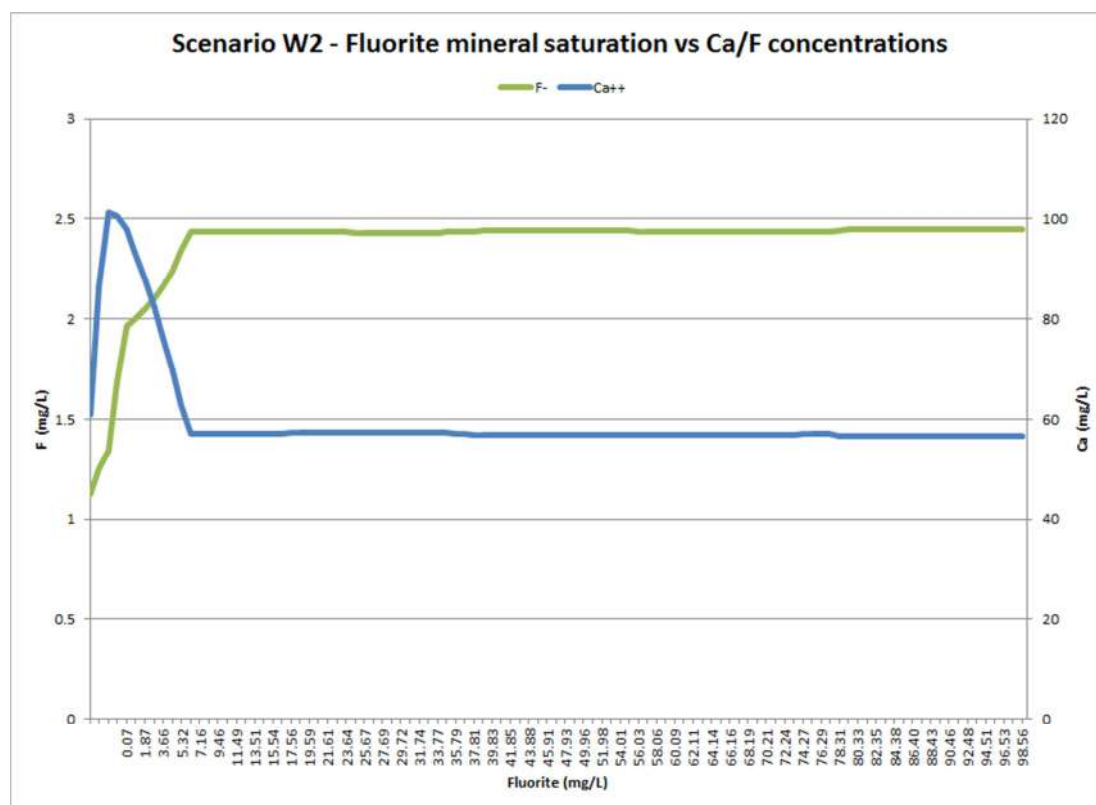


Figure 22: Scenario W2 secondary fluorite development

The comparison of the resultant fluid is once again compared to guideline values in Table 31. Fluoride, Cl and Mn are the three parameters above the recommended limits and this correlates with what is observed in the leachate results.

5.3.3 Scenario W3

Scenario W3 simulates the natural weathering of the coal seam mineralogy once exposed to the atmosphere in both the open pit and on stockpiles. These reaction simulations are done to investigate the potential development of ARD from the coal during and after operations. The following simulation setup was followed:

- It was assumed that coal stockpiles will remain above surface for no more than 6 months at a time with the IPP processes being on site allowing a short standing time;
- Due to the short standing time of the coal stockpiles and the potential exposure of coal seams being in the presence of atmospheric oxygen the reaction between rainwater was allowed to take place over a 6 month simulation at a fixed oxygen fugacity of 0.21; and
- The difference in outcome, with regards to ARD developments was also simulated and compared by allowing the same mineralogy to react in the presence of an oxygen supply that depletes naturally and then allowing the simulation to occur at constant oxygen supply where ARD development is at its most active.

The mineral compositions and reaction rates shown in Table 29 shows the data used in the W3 simulations. In the case of pure carbon as found in coal, the mineral graphite was used which is a polymorph of coal with the same mineral chemistry.

Table 29: Scenario W3 mineralogy

Mineral	Amount reacted	Reaction rate	Source
Calcite	1.8	1×10^{-17}	(White & Brantley 1995)
Dolomite/Calcrete	0.4	-	
Hematite	0.2	-	
Kaolinite	50.2	1×10^{-17}	(White & Brantley 1995)
Microcline	5.8	$1 \times 10^{-16.6}$	(Wilson 2004)
Muscovite	6.9	1×10^{-17}	(White & Brantley 1995)
Pyrite	0.5	2.7×10^{-7}	(Dold 2005)
Quartz	30.7	1×10^{-20}	(Van Coller 2013)
Siderite	3.6	-	
C	150	-	

Two 6 month (180 day) simulations were done to evaluate the potential for ARD development from stockpiles. The pH trends in both these cases are illustrated in Figure 23. When the rainwater is allowed to equilibrate with atmospheric oxygen and then proceed with the weathering reactions in the coal material, the oxygen demand for the oxidation reactions depletes the available aqueous oxygen and then equilibrates to continue with the reactions at an almost constant pH range. This is shown by the blue line in Figure 23 and illustrates the behaviour of an isolated system as is currently being experienced by the undisturbed coal seams before mining. The pH drops rapidly with the oxidation of pyrite allowing the oxygen available to the system to be used up after which the buffering capacity of the calcite and microcline mineralogy starts to buffer the pH back to a system with a 5.7 pH. However, in a second “true” simulation of the scenario expected within the stockpiling of the coal, the system is allowed to equilibrate with atmospheric oxygen fugacity and this oxygen supply is then fixed at $fO_{2(g)}$ of 0.21, with a constant supply on the surface. The constant supply of oxygen to the weathering and oxidation reactions then allows the pyrite oxidation and ARD formation to continue until the iron and sulphur supply is completely used up with a drop in pH down to 3.9. This atmospheric system is illustrated by the red line in Figure 23. The buffer capacity of the neutralising minerals in the system is no longer strong enough to counter the development of an acidic system and this indicates the development of ARD.

The rapid drop in pH shows the speed at which the oxidation reaction in the presence of sulphide minerals do proceed to develop and acidic system. In natural systems, the presence of bactericidal catalysts increase the rate of weathering and oxidation, furthering the development of ARD. In an oxygenated system the weathering of the minerals proceed

until the system is saturated with secondary minerals where after precipitation of sulphate minerals like jarosite and gypsum takes place. During the simulation of scenario W3, hematite and goethite precipitation were suppressed as these two minerals are thermodynamically stable at low temperatures and much more stable than other ferric precipitates like jarosite that usually develops in mining or ARD environments. As sulphite dissolves during the oxidation of pyrite to form aqueous SO_4 it bonds with available Fe and K hydroxides to allow the secondary formation of jarosite. As SO_4 increases the saturation of jarosite develops on the same trend and as soon as saturation allows precipitation to occur the presence of both jarosite and sulphate within the aqueous environment starts to decrease. This relationship is shown in Figure 24. Jarosite ($\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$) is a secondary mineral developing in systems with high super-saturated Fe^{3+} , K, SO_4 and various hydroxide compounds with these aqueous species. The development trend of these aqueous species in the W3 system is indicated in Figure 25.

Although not a lot of pyrite was allowed to react with the rain water, the power of oxidation reactions is however illustrated with ARD development easily taking place. The final system has an extreme TDS and salt content with almost all mineralogy being dissolved and weathered down to aqueous form. The final fluid from a six month simulation of the processes expected in the stockpiles at Dalyshope is listed and compared to guideline values in Table 31.

As would be expected from water developed by an ARD system, the salt content is high with Al, K, Ca and Pb exceeding the drinking water limits. The final sulphate and iron concentrations are low due to the precipitation of jarosite and other secondary minerals.

From the modelling scenario W3 it is recommended that stringent stormwater and seepage capturing measurements are in place on and around the site where the stockpiles will be to manage the potential ARD development and prevent possible contamination. The dry climate experienced throughout the largest part of the year in the region will however lower the probability of ARD development with the spread of pollution easily controlled.

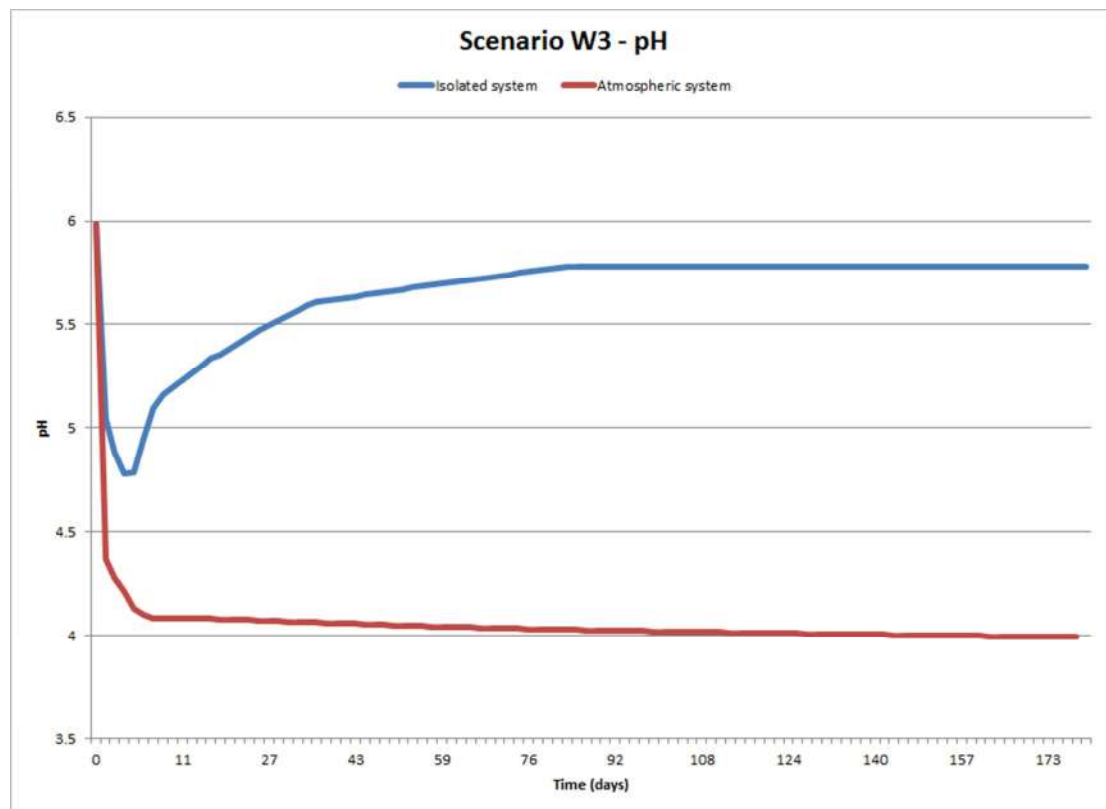


Figure 23: pH trend of an isolated vs atmospheric system

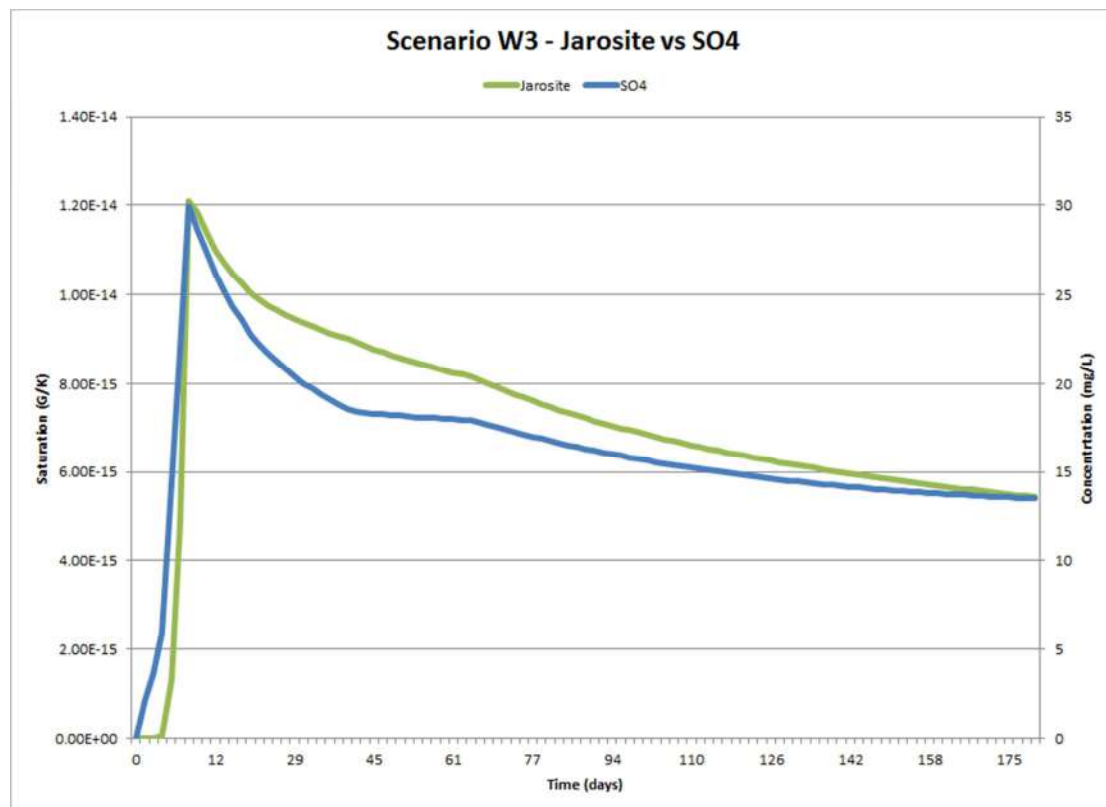


Figure 24: Scenario W3 jarosite and SO₄ development within the system

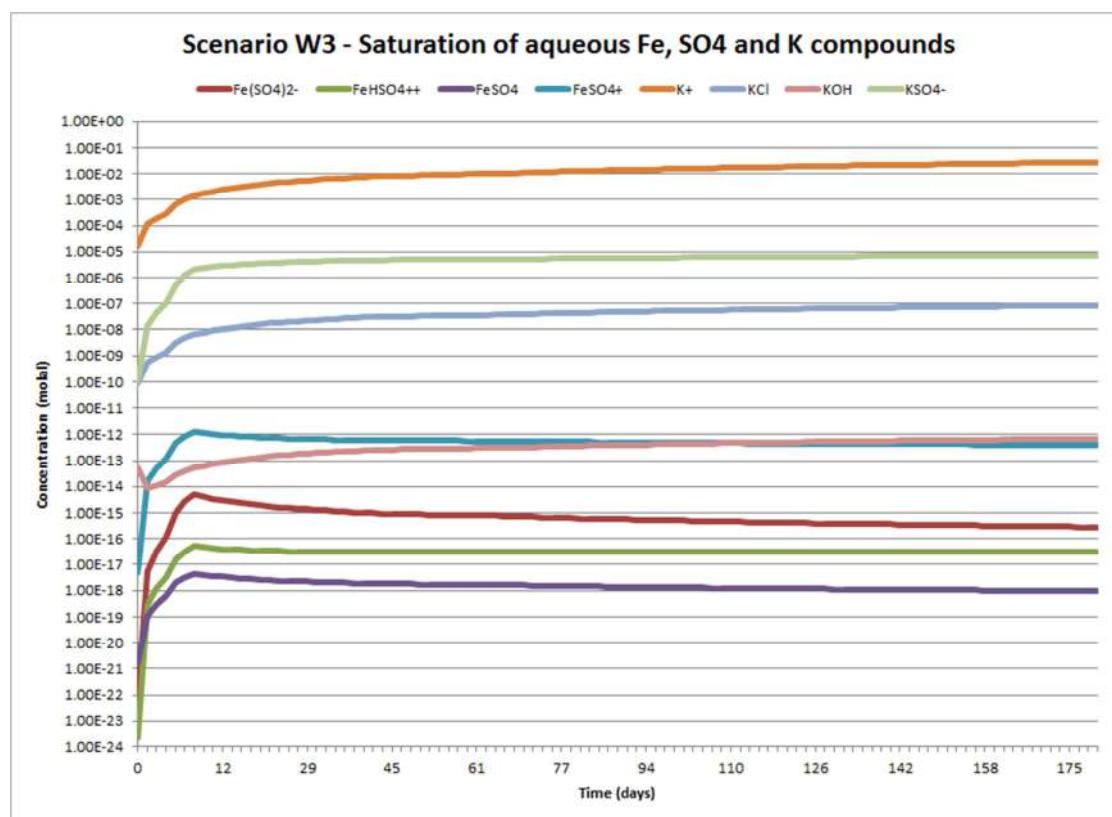


Figure 25: Development of SO₄, Fe and K within the aqueous system

5.3.4 Scenario W4

Scenario W4 simulates the natural weathering of the waste rock mineralogy once exposed to the atmosphere in both the open pit and on the waste rock dumps. These reaction simulations were done to investigate the potential development of ARD from the waste during and after operations. The following simulation setup was followed:

- The models were simulated for a period of 75 years to allow the investigation of the weathering and potential ARD development during LoM and post-closure; whether backfilling is done or not, the reaction will remain the same;
- In a conceptual model of a waste rock dump or layered backfill material, as rainwater infiltrates into the dump the oxygen availability decreases almost linearly the deeper the water enters the system or dump. This was simulated by allowing weathering to continue with a sliding oxygen fugacity from atmospheric 0.21 down to a $fO_{2(g)}$ of 1×10^{-50} ;
- Goethite and Hematite was again suppressed to allow accurate evaluations of potential ferrous mineral development from the weathering reactions at low temperature; and
- The mineral compositions and reaction rates shown in Table 30 shows the data used in the W4 simulations.

Table 30: Scenario W4 mineralogy

Mineral	Amount reacted	Reaction rate	Source
Calcite	1.7	1×10^{-17}	(White & Brantley 1995)
Dolomite	0.3	-	
Hematite	0.5	-	
Kaolinite	40.0	1×10^{-17}	(White & Brantley 1995)
Microcline	3.8	$1 \times 10^{-16.6}$	(Wilson 2004)
Muscovite	6.7	1×10^{-17}	(White & Brantley 1995)
Pyrite	0.2	2.7×10^{-7}	(Dold 2005)
Quartz	44.4	1×10^{-20}	(Van Coller 2013)
Siderite	2.4	-	

The conditions experienced in a WRD dictate a decrease in oxygen supply with an increase in carbon dioxide, the deeper water infiltrates into the dump. This is also the case when water infiltrates soils or backfilled areas; as will be the case in the pit backfilling scenario. During the simulation of scenario W4 the oxygen was manually controlled by the model inputs to allow a linear decrease in oxygen fugacity with the weathering reactions; allowing an increase in $f\text{CO}_2$ as illustrated in Figure 26.

The mineralogy of the waste rock contains mostly neutralising minerals in the form of siderite, calcite, dolomite, microcline and muscovite compared to a very small amount of pyrite. The initial buffering of the system rapidly increases the pH of the developing fluid at first and then decrease slightly as the pyrite is oxidised by the available oxygen. However, the pH is not allowed to decrease to acidic levels due to a decrease in $f\text{O}_2$ and this is illustrated in the pH graph (Figure 27).

The weathering of the waste rock with high carbonate, alumino-silicates and clay minerals allows for a development of a Ca-HCO_3 water type with a pH of 6.1. The increase in TDS (2 470 mg/L) and aqueous concentrations is illustrated in Figure 28; with the development of the water type over the reaction period shown on the Piper diagram in Figure 29. If the final water quality after a 75 year weathering period is compared to water quality guidelines (Table 31), Ca, K and Pb are elements of concern.

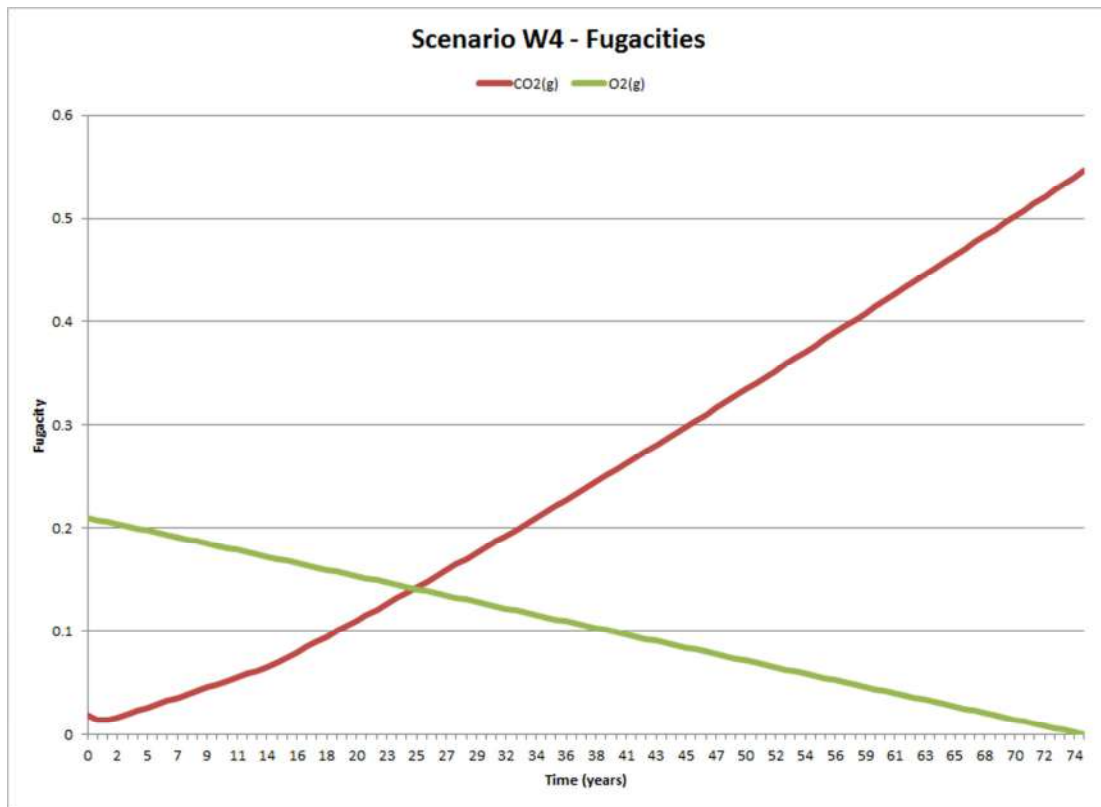


Figure 26: Scenario W4 fugacity trends of fO₂ and fCO₂

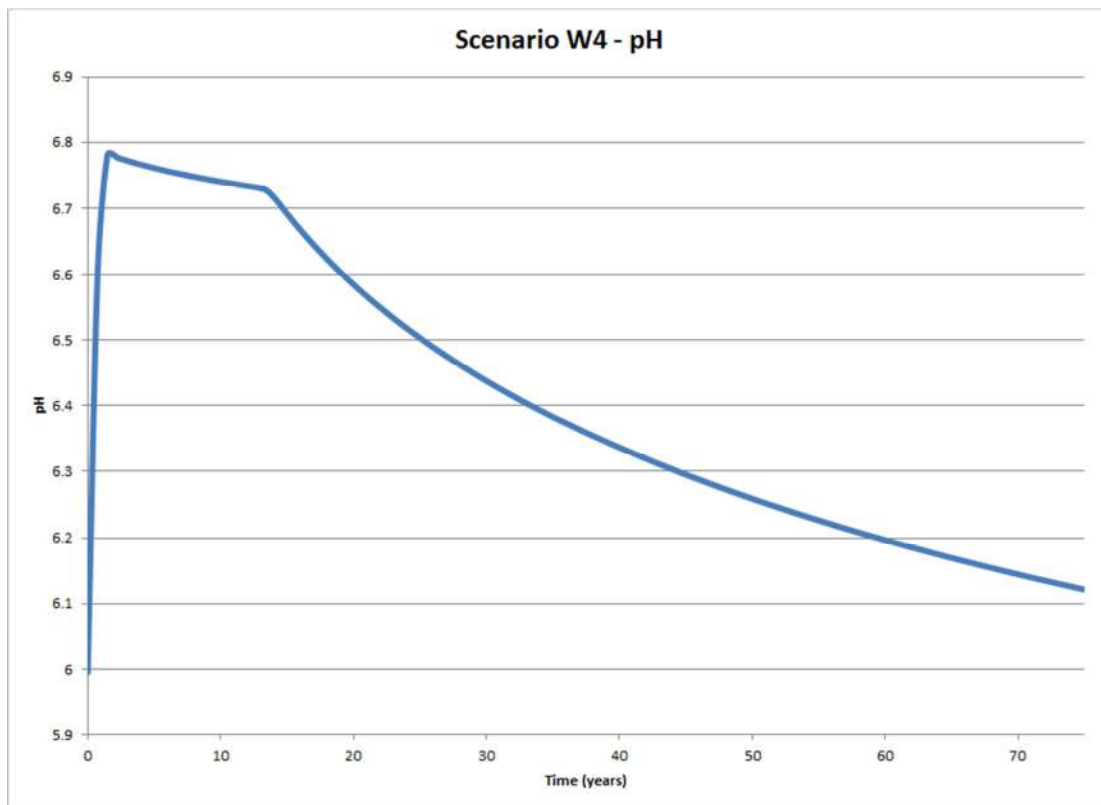


Figure 27: Scenario W4 pH trend

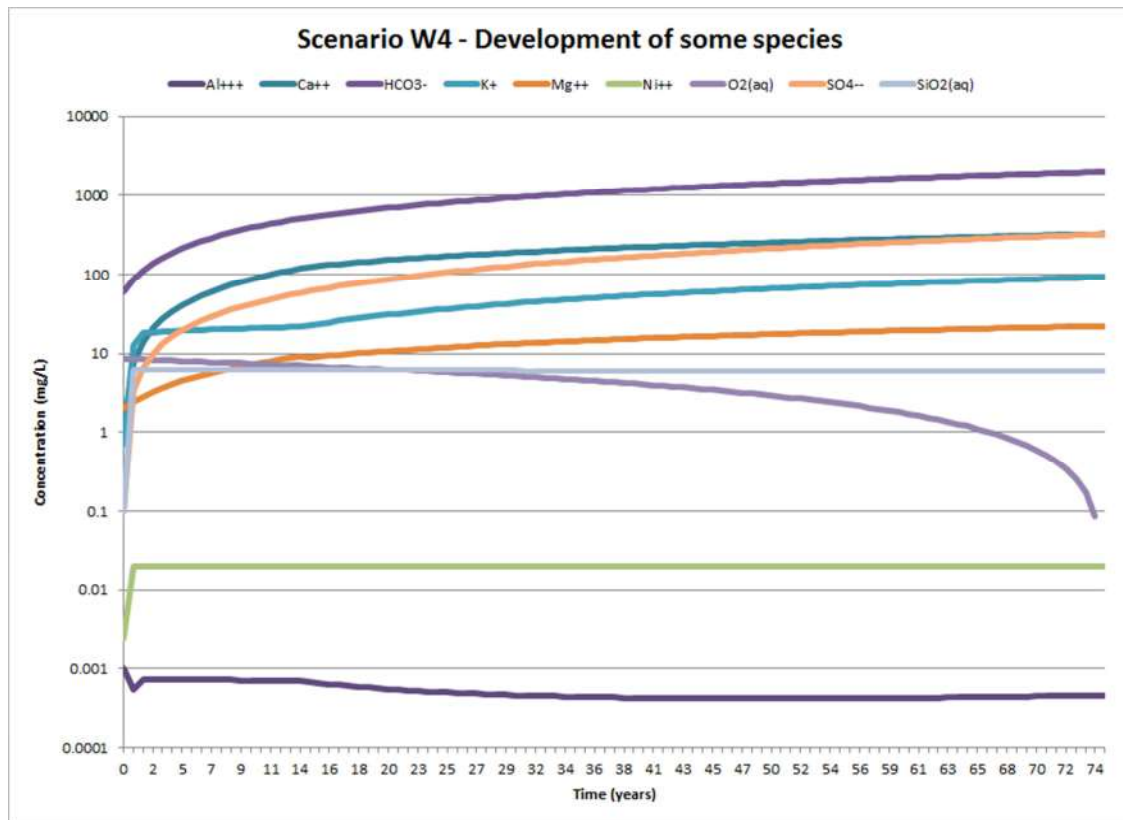


Figure 28: Development of the fluid with some aqueous species

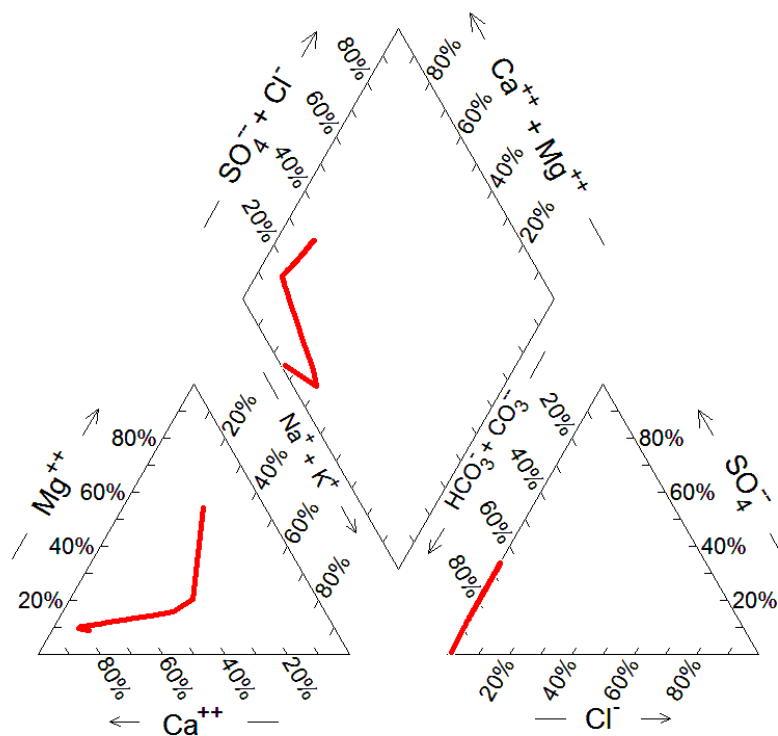


Figure 29: Scenario W4 Piper diagram showing the water type change

Table 31: Comparison of weathering results of main ions

Parameter	Unit	Class 1	Class 2	Class 3	Scenario W1	Scenario W2	Scenario W3	Scenario W4
pH	-	5 - 9.5	4 - 5 / 9.5 - 10	<4 / >10	8.4	8.1	3.99	6.1
F	mg/l	1	1.5	>1.5	3.5	2.4	0.1	0.1
Cl	mg/l	200	600	>600	1.0	261.9	6.2	0.1
NO₃ as N	mg/l	10	20	>20	0.02	1.5	0.02	0.02
SO₄	mg/l	400	600	>600	0.91	42.1	13.5	324.1
Al	mg/l	0.3	0.5	>0.5	0.03	0.01	7.1	0.0005
Ca	mg/l	150	300	>300	18.0	56.6	699.6	325.0
Fe	mg/l	0.2	2	>2	8.96E-09	9.24E-09	1.77E-05	4.96E-08
K	mg/l	50	100	>100	0.40	0.9	942.2	93.5
Mg	mg/l	70	100	>100	0.69	4.1	47.3	22.3
Mn	mg/l	0.1	1	>1	0.0002	0.7		
Na	mg/l	200	400	>400	1.4	137.3	1.2	1.4
Ni	mg/l	0.15	0.35	>0.35	0.001	0.008	0.017	0.02
Zn	mg/l	5	10	>10	0.3	0.3	0.2	0.2
SiO_{2(aq)}	mg/l	N/A	N/A	N/A	6.4	6.2	5.1	6.0

5.4 Mixing Reaction Models

5.4.1 Input samples

The samples indicated in Table 32 have served as input into the various mixing reaction models.

Table 32: Input samples

Samples		Waste rock leachate	Coal leachate sample	Ash leachate sample	Groundwater	Rainwater
Parameter	Unit	WRS	CMS	AWS	GWM	
pH		7.5	8.1	7.6	7.9	6
HCO ₃ ⁻	mg/l	63.75	60	399.4	277.3	9.2
F ⁻	mg/l	0.9833	1.8	2.351	1.126	0.1
Cl ⁻	mg/l	6.583	2.5	2.466	261.8	0.1
NO ₃ ⁻	mg/l	0.55	0.4425	0.001	1.536	0.02
SO ₄ ⁻⁻	mg/l	43.67	27.67	223.3	41.23	0.1
Al ⁺⁺⁺	mg/l	1.879	0.09581	0.03312	0.0015	0.02
AsH ₃ (aq)	mg/l	0.004	0.004853	0.002973		
B(OH) ₃	mg/l	0.1681	2.033	0.4496		
Ba ⁺⁺	mg/l	0.191	0.09791	0.2221		
Ca ⁺⁺	mg/l	16.46	17.05	207.1	74.45	1.2
Co ⁺⁺	mg/l	0.1409	5.83E-04	0.01694	5.00E-04	
Cr ⁺⁺	mg/l	0.004167	7.50E-04	6.56E-04	5.00E-04	
Cu ⁺⁺	mg/l	0.01225	0.00125	0.01197	0.04687	
Fe ⁺⁺	mg/l	0.5749	0.0761	0.01855	0.0015	0.05
K ⁺	mg/l	6.883	7.085	2.339	16.45	0.7
Li ⁺	mg/l	0.0185	0.003667	0.01898		
Mg ⁺⁺	mg/l	5.613	5.823	43.88	35.93	2
Mn ⁺⁺	mg/l	0.1117	0.03833	1.41	5.00E-04	
Na ⁺	mg/l	19.08	9.634	1.971	137.3	1.4
Ni ⁺⁺	mg/l	0.2778	0.00299	0.4661	5.00E-04	0.02
Pb ⁺⁺	mg/l	0.001913	5.83E-04	0.001953	0.002	0.06
Rb ⁺	mg/l	0.009239	0.007651	0.00274		
Se ⁻⁻	mg/l	0.01257	0.02294	0.02016		

Samples		Waste rock leachate	Coal leachate sample	Ash leachate sample	Groundwater	Rainwater
Parameter	Unit	WRS	CMS	AWS	GWM	
SiO ₂ (aq)	mg/l	18.99	5.293	26.84		0.1
Sr ⁺⁺	mg/l	0.09856	0.08029	0.278		
U ⁺⁺⁺	mg/l	3.83E-04	3.33E-04	0.005785		
V ⁺⁺⁺	mg/l	0.008949	0.003667	0.0261		
Zn ⁺⁺	mg/l	0.09993	0.02725	0.08825	0.2782	0.25
TDS	mg/l	190.5	139.8	898.9	837.7	20.51
Water type		Na-HCO ₃	Ca-HCO ₃	Ca-HCO ₃	Na-Cl	Mg-HCO ₃

5.4.2 Scenario M1

A simple mixing reaction model with no specified time period given to the reaction path was simulated under atmospheric conditions to evaluate the resultant seepage/leachate water that will develop once waste rock/overburden and ash material is backfilled into the mine void.

The following model methodology was followed:

- The mixing was allowed to take place on a ratio of 1:1 (1 litre ash seepage mixed with 1 litre waste rock seepage); and
- The fluids were equilibrated with atmospheric oxygen and allowed to react at a fixed f_{O_2} of 0.21.

The scenario was simulated to evaluate the effect that waste rock seepage and ash seepage will have on the concentrations of identified environmental risks. In the evaluation of the leachate results of both the ash and waste rock leachate the elements of potential concern was Ca, F, Mn and Ni in the ash leachate and Se, F, Al, Fe, Mn and Ni in the waste rock leachate.

In the simulation the two fluids were mixed with any potential reactions and precipitation allowed, as saturated phases of certain aqueous species increased. From Figure 30 the observed increase in TDS with a drop in pH can be seen as the reaction between the two fluids progressed. The drop in pH is induced by the increase in saturation of dolomite/calcrete in the system as seen in Figure 31. Ni₂SO₄, Co₂SO₄ and fluorite also increased with the combined fluids allowing a slight increase in the species of concern as previously mentioned and illustrated in Figure 32.

The overall fluid had a change in ionic balance with TDS increasing from 203 mg/L in the waste rock leachate solution towards 832 mg/L; with a drop in pH. The change in TDS values and the overall water type is down to an increase in bicarbonate and calcite with a decrease in K and Na as shown in the ternary diagram (Figure 33). This caused a change in water facies from Na-HCO₃ water to Ca-HCO₃ water.

The reaction between the two fluids showed a final fluid as compared to the guideline values in Table 33, with only Ca, Ni and F remaining above the recommended levels. Fluoride is still above the recommended guidelines, but did decrease slightly from the high levels experienced in the ash leachate concentrations. Overall the reaction between the buffering ash seepage and metal concentrated waste rock seepage does have a positive influence on the water chemistry and does not increase the environmental or human health risk.

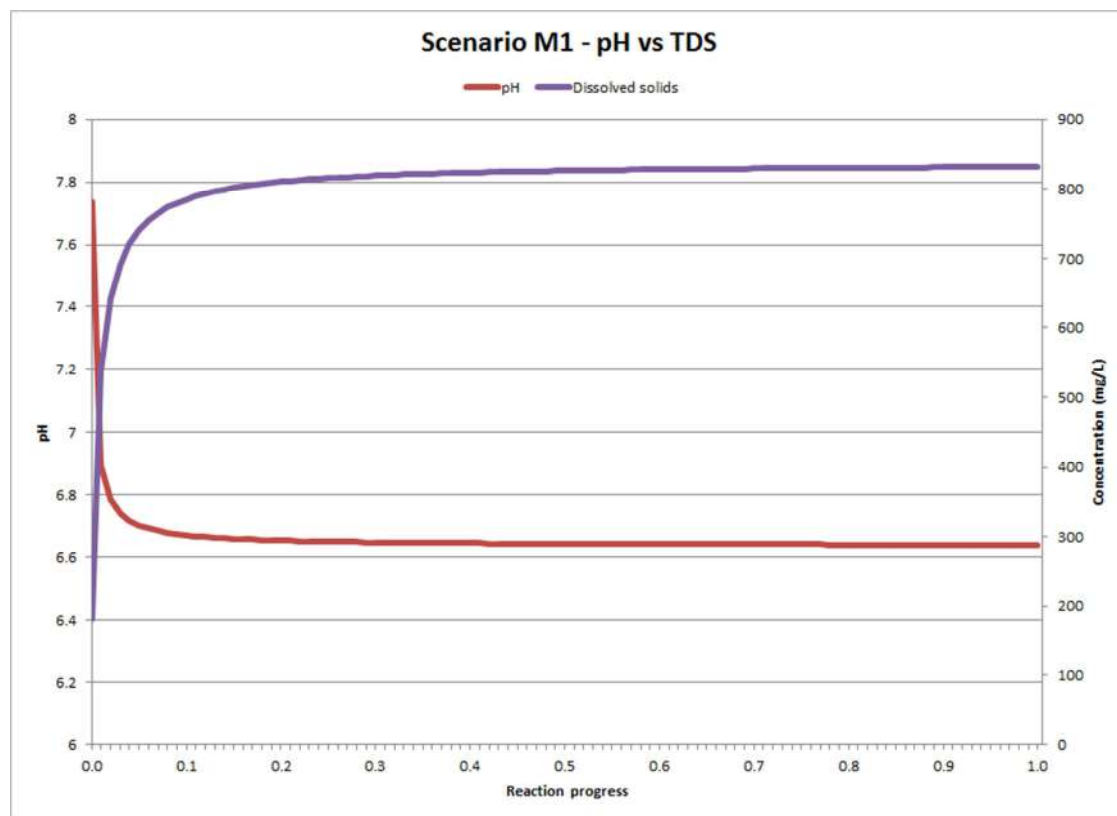


Figure 30: Scenario M1 pH and TDS trends

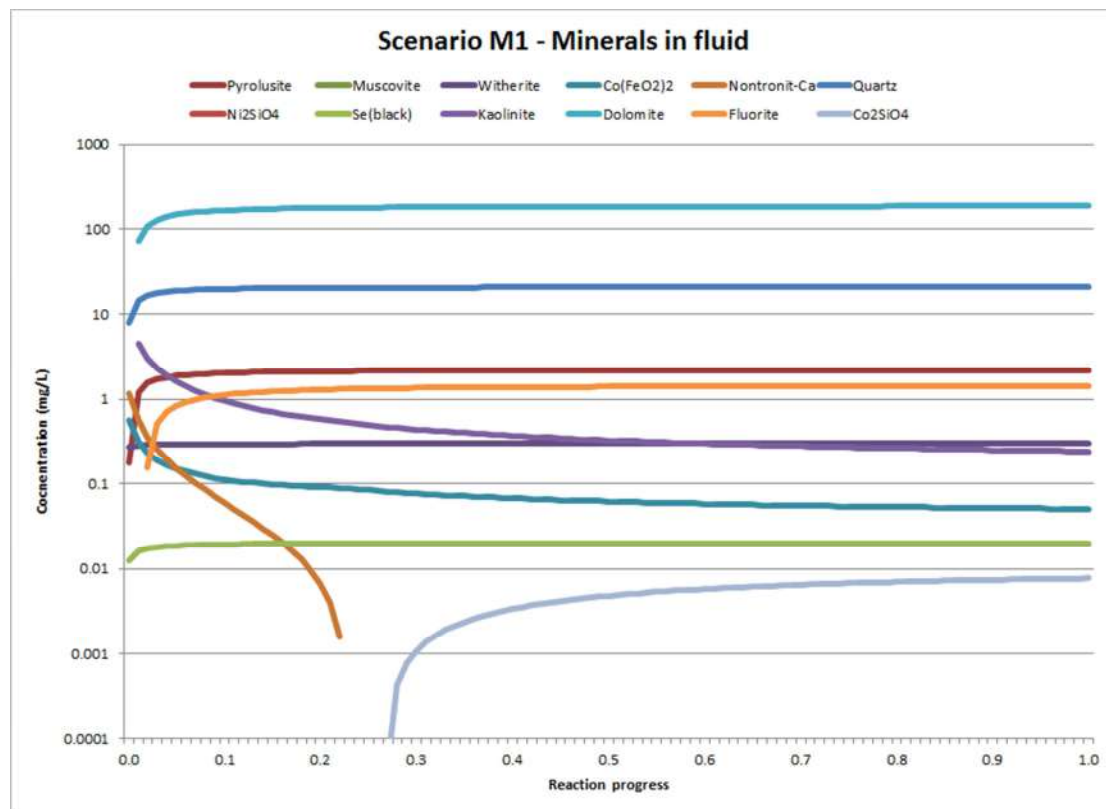


Figure 31: Aqueous mineral development with an increase in saturation of elements

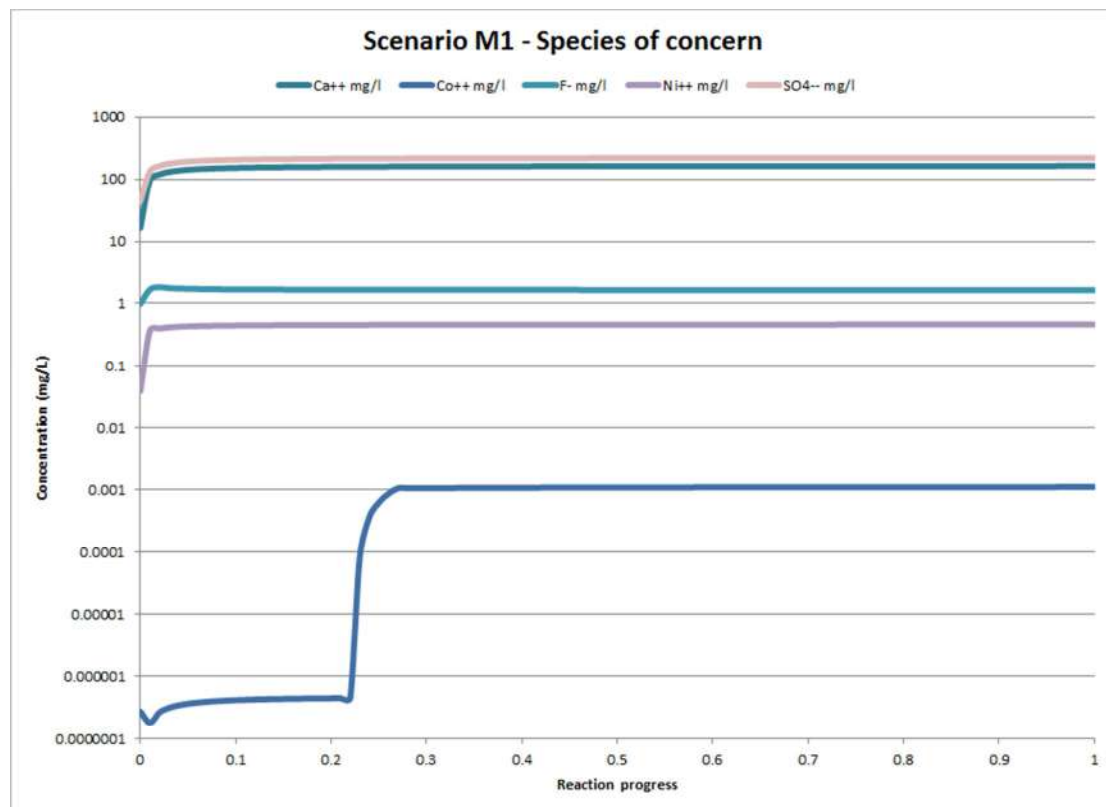


Figure 32: Scenario M1 development of some aqueous species

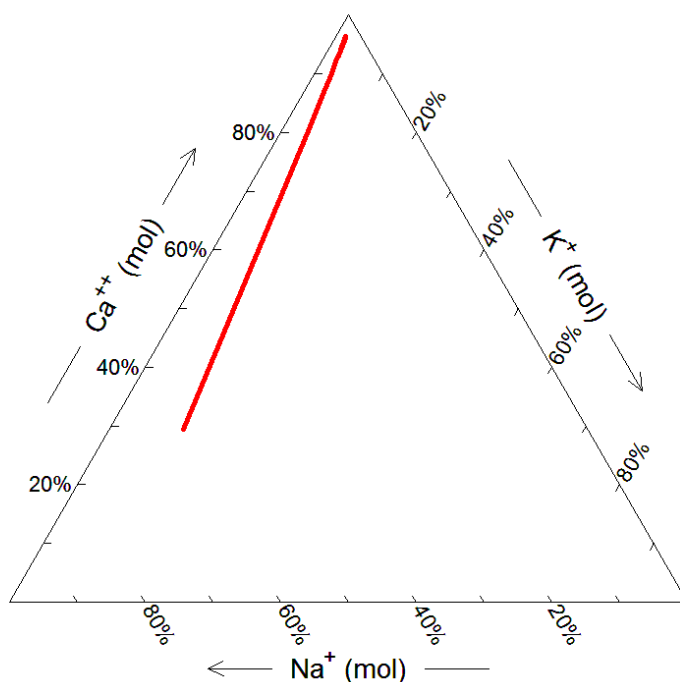


Figure 33: Scenario M1 ternary diagram indicating ion changes

5.4.3 Scenario M2

A mixing reaction model was simulated to observe what the potential reaction and dissolution effect on the leachate concentrations will be once the seepage from the ash reacts with the groundwater at the proposed Dalyshope pit. Scenario M2 was simulated by only reacting the ash leachate with the groundwater before allowing it to react with the waste rock seepage first as illustrated in Scenario M1.

The following model methodology was followed:

- A mixed leachate sample from the 6 sample results were produced based on the various proportion of ash expected as indicate in Table 32;
- The groundwater chemistry for GWM was used to simulate the groundwater quality that will mix with the seepage and is shown in Table 32;
- Leachate and groundwater samples were allowed to react at a ratio of 0.62 litre leachate for each litre of groundwater;
- The system was equilibrated with atmospheric oxygen fugacity of $fO_2 = 0.21$, after which oxygen fugacity was allowed to reduce linearly to 1×10^{-50} to simulate the accurate effect as the water reaches deeper layers with less oxygen available; and
- The mixing of the potential seepage from the ash backfill (leachate sample) with the local groundwater resources was simulated to evaluate the effect on groundwater quality and the dilution potential of the parameters of concern.

The groundwater from sample GWM has a pH of 7.9, with a Na-Cl signature. The leachate sample was allowed to mix and react with the groundwater sample for a period of 50 years at which time an equilibrated system can be observed. The TDS of both the ash seepage and the groundwater decreases to 802.8 mg/L as indicated in Figure 34. The parameters of concern are B, Mn, Ni, Ca and F. All of these elements increased the concentration of the final groundwater, but a decrease in concentrations as observed in the seepage from the ash material was shown in the resultant fluid mix. Ca, F and Ni decreased with an increase in Mn as observed in Figure 35.

Table 33 indicates the final concentrations of the aqueous species in solution M2 and is compared to the guideline values. From the original ash leachate with B, Ca, F, Mn and Ni being above recommended concentrations; fluoride, Mn and Ni remain above the guideline values with a significant decrease in Ca and B concentrations. Although there was a slight increase of these parameters from the natural groundwater concentrations, the final simulated sample showed an improvement from the leachate quality with all parameters below the maximum allowable limit for drinking water and thus on current indications the backfilling of ash is feasible if the scenario M2 does occur in which no other fluid plays a role in potential dilution.

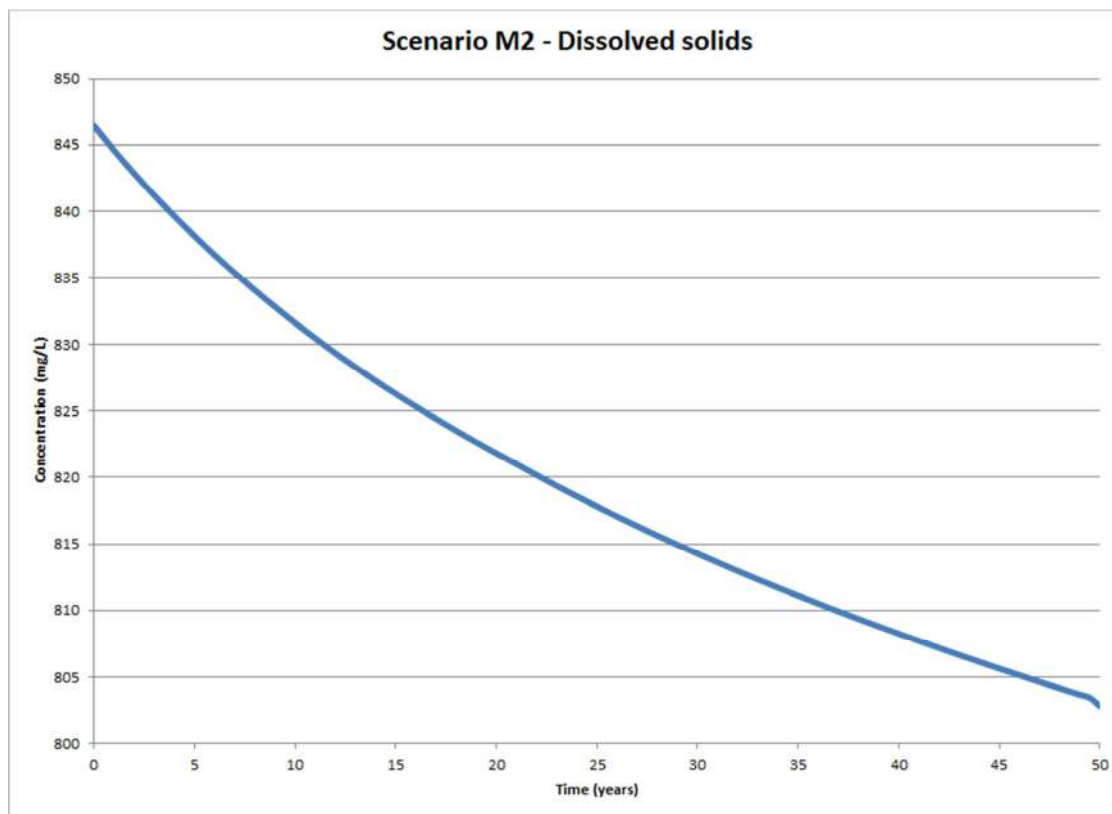


Figure 34: Scenario M2 decrease in TDS

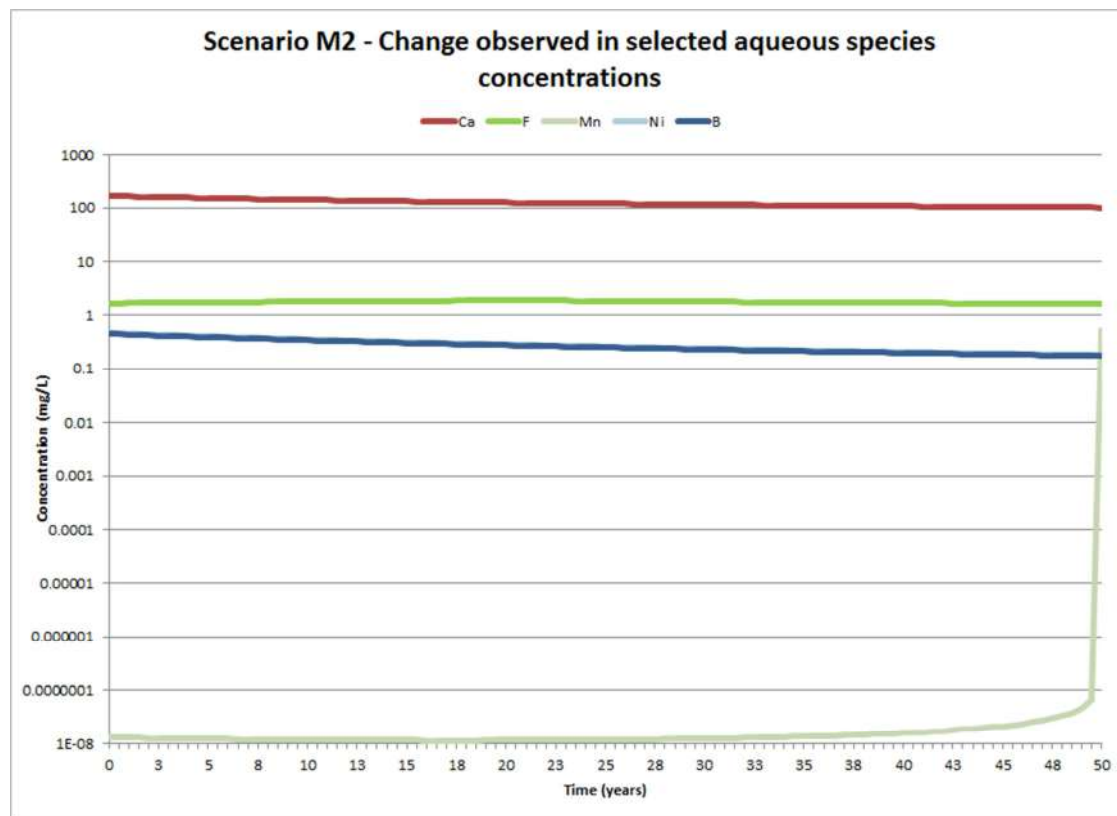


Figure 35: Partial fluid composition of groundwater/ash leachate mix over a 50 year period for selected species

**Table 33: Final fluid results from the mixing scenarios**

Parameter	Unit	Class 1 (recommended limit)	Class 2 (max allowed for limited duration)	Class 3 (not recommended for consumption)	Scenario M1	Scenario M2	Scenario M3	Scenario M4
pH	-	5 - 9.5	4 - 5 / 9.5 - 10	<4 / >10	6.6	6.8	7.2	7.2
F	mg/l	1	1.5	>1.5	1.6	1.6	1.1	1.5
Cl	mg/l	200	600	>600	2.5	162.5	134.2	132.2
SO4	mg/l	400	600	>600	221.5	110.9	42.4	34.5
Al	mg/l	0.3	0.5	>0.5	0.001	0.001	0.002	0.003
As	mg/l	0.01	0.05	>0.05	0.003	0.001	0.002	0.002
B*	mg/l	0.5			0.1	0.0	0.0	0.2
Ba*	mg/l	0.7			0.02	0.01	0.01	0.01
Ca	mg/l	150	300	>300	163.7	100.7	39.7	40.0
Co	mg/l	0.5	1	>1	0.001	0.001	0.0000001	0.00000001
Cr	mg/l	0.1	0.5	>0.5	0.001	0.001	0.002	0.001
Cu	mg/l	1	2	>2	0.01	0.03	0.03	0.02
Fe	mg/l	0.2	2	>2	4.636E-10	4.21E-10	1.51E-08	6.59E-08
K	mg/l	50	100	>100	2.4	11.0	11.2	11.8
Mg	mg/l	70	100	>100	18.8	24.1	17.3	17.4
Mn	mg/l	0.1	1	>1	1.2E-08	0.54	0.06	7.91E-10



Parameter	Unit	Class 1 (recommended limit)	Class 2 (max allowed for limited duration)	Class 3 (not recommended for consumption)	Scenario M1	Scenario M2	Scenario M3	Scenario M4
Na	mg/l	200	400	>400	2.1	85.5	78.2	73.5
Ni	mg/l	0.15	0.35	>0.35	0.46	0.18	0.14	0.002
Pb	mg/l	0.02	0.05	>0.05	0.002	0.002	0.002	0.001
Se	mg/l	0.02	0.05	>0.05	4.754E-38	5.51E-30	1.46E-29	1.65E-37
V	mg/l	0.2	0.5	>0.5	0.03	0.01	0.004	0.002
Zn	mg/l	5	10	>10	0.09	0.21	0.19	0.15
HCO ₃	mg/l	N/A	N/A	N/A	454.0	333.2	166.5	167.3
TDS	mg/l	1000	2400	>2400	832.2	802.8	492.9	486.6

5.4.4 Scenario M3

Scenario M3 was simulated using the leachate results from the waste rock and the groundwater sample GWM to evaluate the chemical impact that seepage from waste rock dumps will have on the groundwater quality. The mixture was done at a ratio of 1:1 over a period of 75 years and thus simulating the mixing from start of operation to 50 years post-closure to evaluate the impact if the backfilling option is not followed.

From Figure 36 it can be seen that the TDS value of the groundwater decreases due to saturation of dolomite and fluorite allowing the development of secondary minerals and thus salts in solution decreases. The water type did not progress and remained a Na-Cl water type with a final pH of 7.2. The Piper diagram in Figure 37 indicates the small change in salt content without changing the facies of the water. The groundwater developed under the same mineralogical constraints as experienced in the waste rock, with the only potential impact not able to be simulated through the mixing of the laboratory fluids is acid drainage from the waste rock dump.

The final fluid had an overall good water quality with only F slightly above the recommended guidelines as indicated in Table 33.

5.4.5 Scenario M4

Scenario M4 was simulated using the leachate fluid from the coal laboratory tests with the groundwater at a 1:1 ratio to evaluate the chemical impact on the groundwater quality from coal stockpile seepage. The simulation was for a LoM period of 25 years.

From Figure 38 it can be seen that the development of the water over the period allows a drop in TDS and once again this is due to a buffering of the system allowing a decrease in aqueous dolomite due to precipitation (Figure 39).

The final fluid as seen in Table 33 has an unchanged water type of Na-Cl with a good water quality with only F above the recommended guidelines. The pH of the final fluid was slightly buffered due to the saturated state of buffering minerals in both fluids; with a final pH of 7.2.

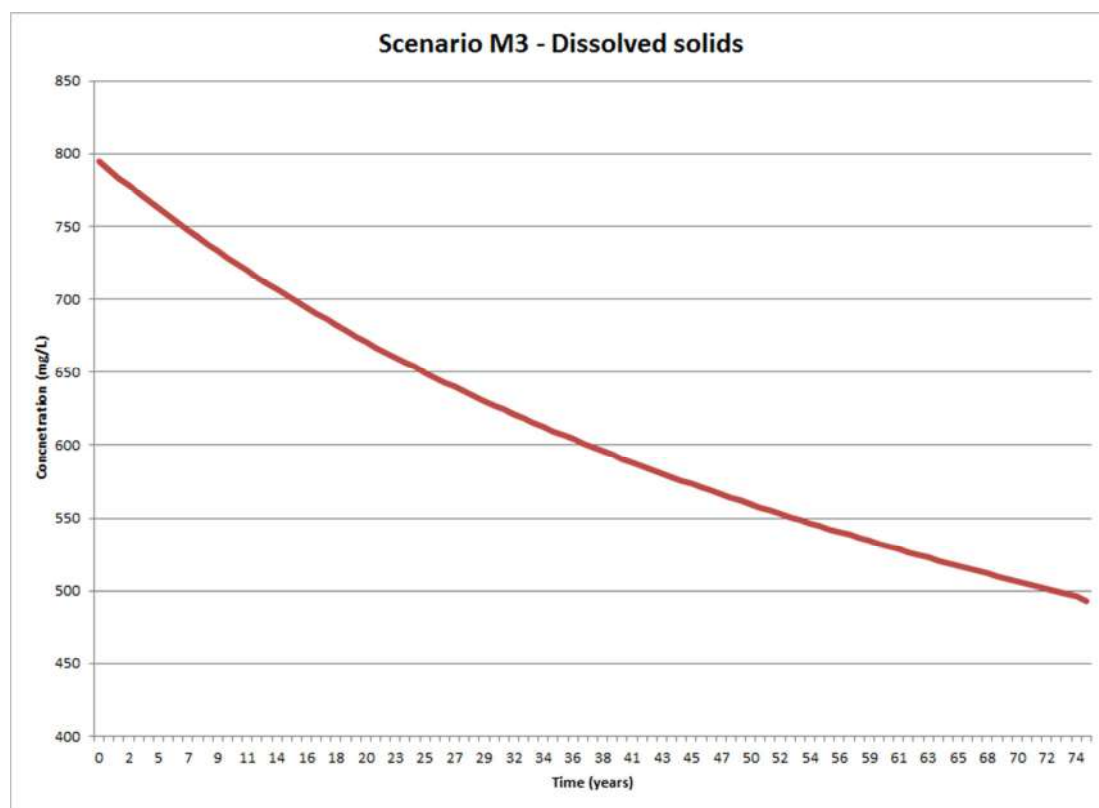


Figure 36: Scenario M3 change in TDS

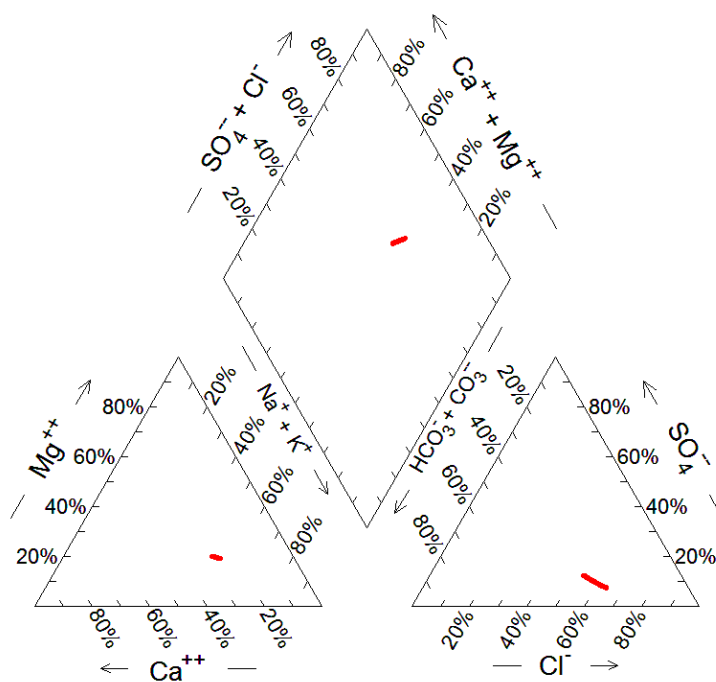


Figure 37: Scenario M3 Piper diagram

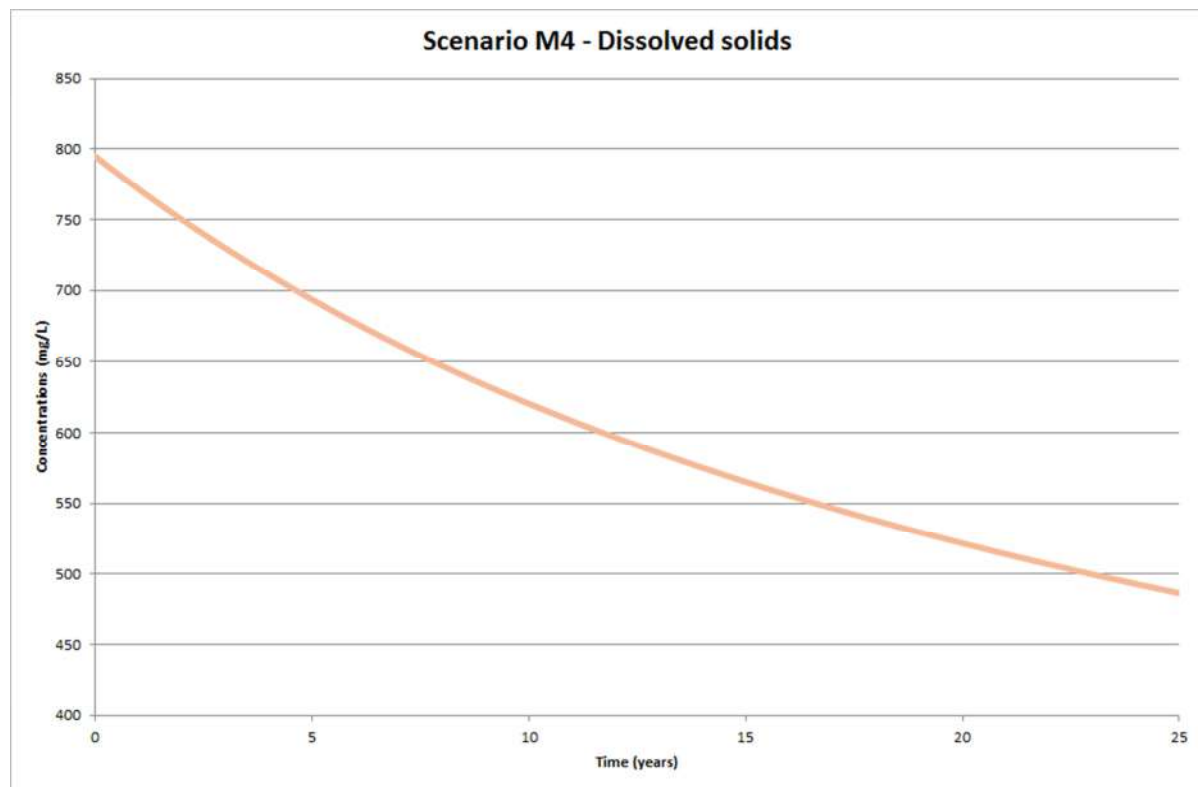


Figure 38: Scenario M4 change in TDS

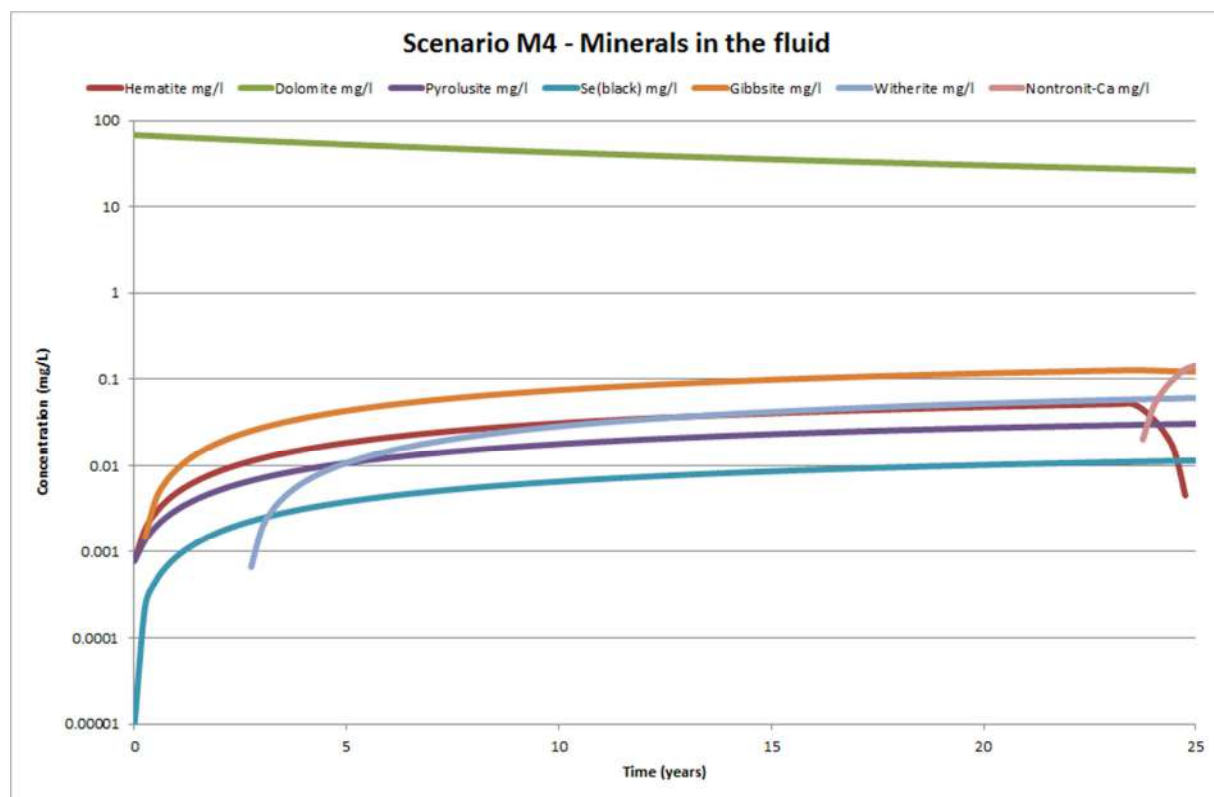


Figure 39: Scenario M4 Mineral development during fluid mixing

6 CONCLUSIONS

6.1 Final Conceptual Geochemical Models

The following section provides a summary of the outcomes per potential impact source.

6.1.1 Waste Rock Dumps

The waste rock samples showed a marginal potential for ARD with some elements leaching in concentrations above the recommended limits. The points below and the conceptual model illustrated in Figure 40 summarises the study results:

- Waste rock shows a marginal potential for ARD development, with a slight decrease in pH as oxidation reactions proceed;
- Calcite and dolomite/calcrete dissolution is however buffering reaction that neutralises the ARD potential;
- Oxygen fugacity decrease with depth in the WRD resulting in oxidation reactions and an increase in CO₂;
- Toe seepage forms through the dissolution reaction indicated in Figure 40 with the potential secondary formation of jarosite, nontronite, calcite, fluorite and talc from the WRD seepage;
- The elements of concern to monitor on surface is F, Al, Fe, Ni, Sr, and Mn;
- After contact with groundwater the seepage gets diluted with only fluoride exceeding the recommended drinking water limits; and
- It is recommended that toe seepage be captured through stormwater management and controlled in pollution control facilities.

6.1.2 Coal Stockpiles

The coal samples showed a potential for ARD with some elements leaching in concentrations exceeding the recommended limits. The points below and the conceptual model illustrated in Figure 41 summarises the study results:

- Acid formation will occur during the wet season with pyrite oxidation and very little buffering capacity;
- The elements of concern to leach from the coal stockpiles are F, B, Se and Rb, however after dilution through interaction with the groundwater only F exceeds the recommended drinking water limits;
- Jarosite, calcite and gypsum are the main secondary minerals that can form from seepage; and
- It is strongly recommended that stormwater and pollution control management be in place for the coal stockpiles.



Conceptual Geochemical WRD Model

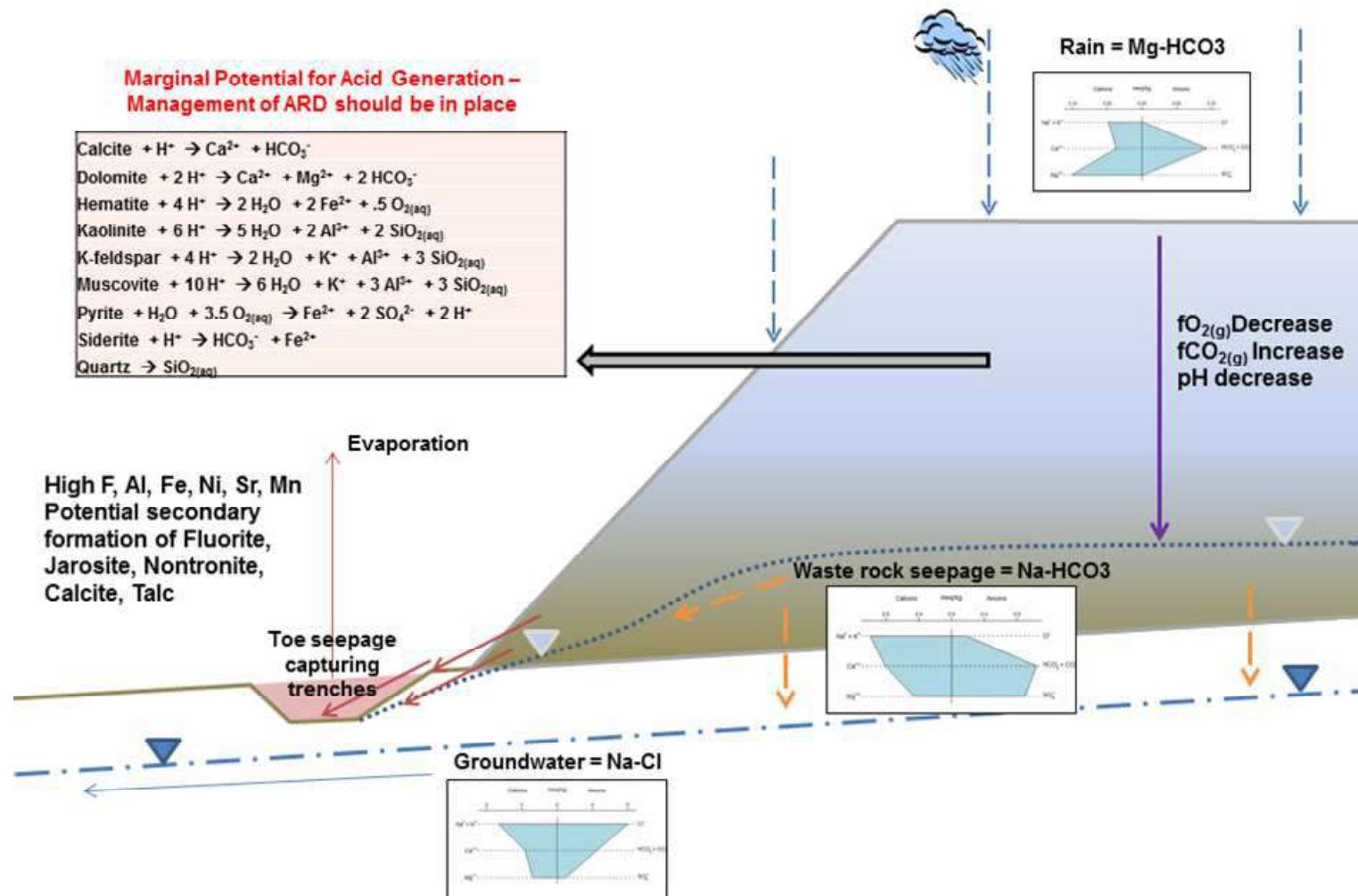


Figure 40: Final conceptual geochemical WRD model



Conceptual Geochemical Coal Stockpile Model

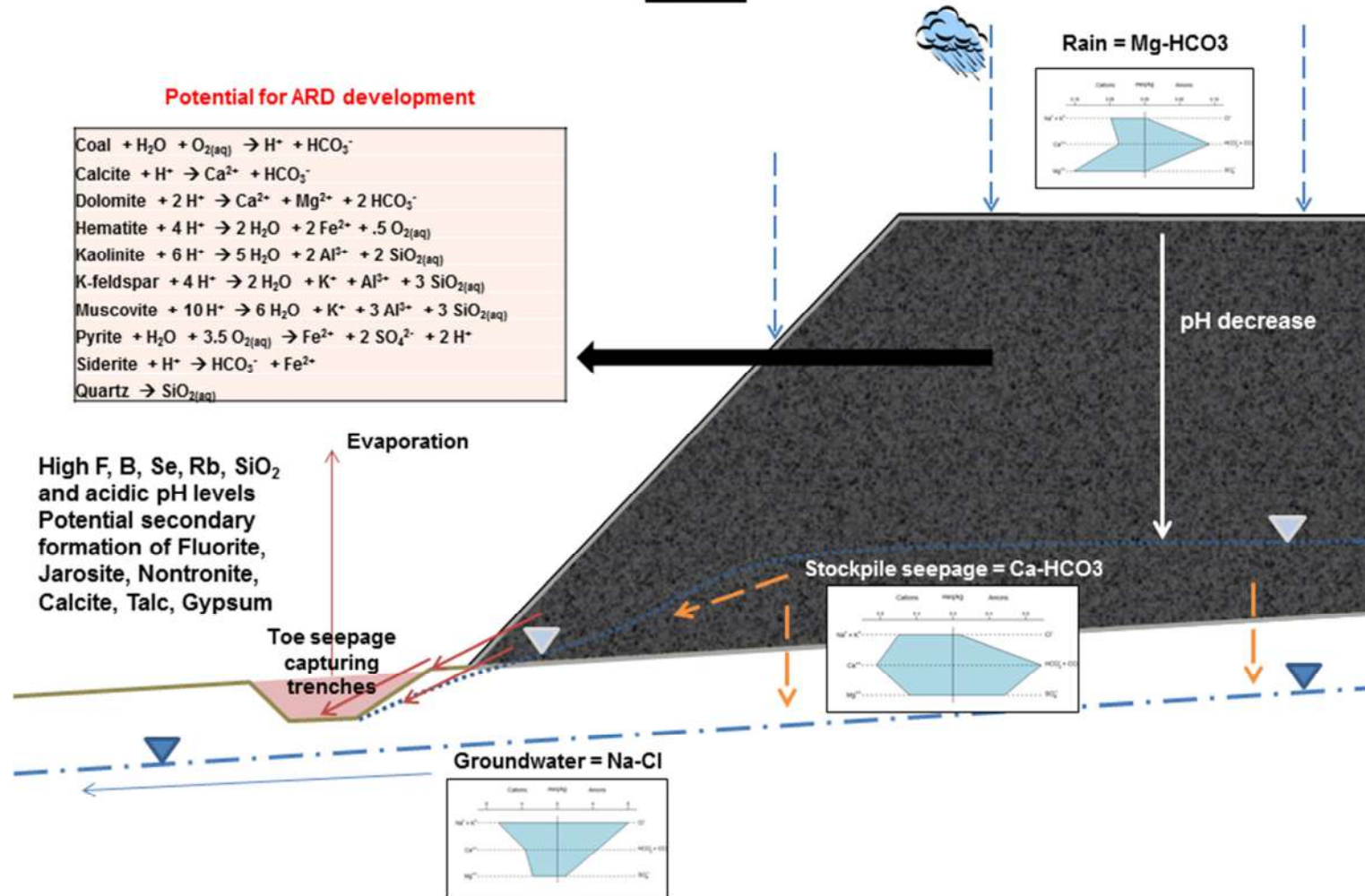


Figure 41: Final conceptual geochemical coal stockpile model



Conceptual Geochemical Pit Backfilling Model

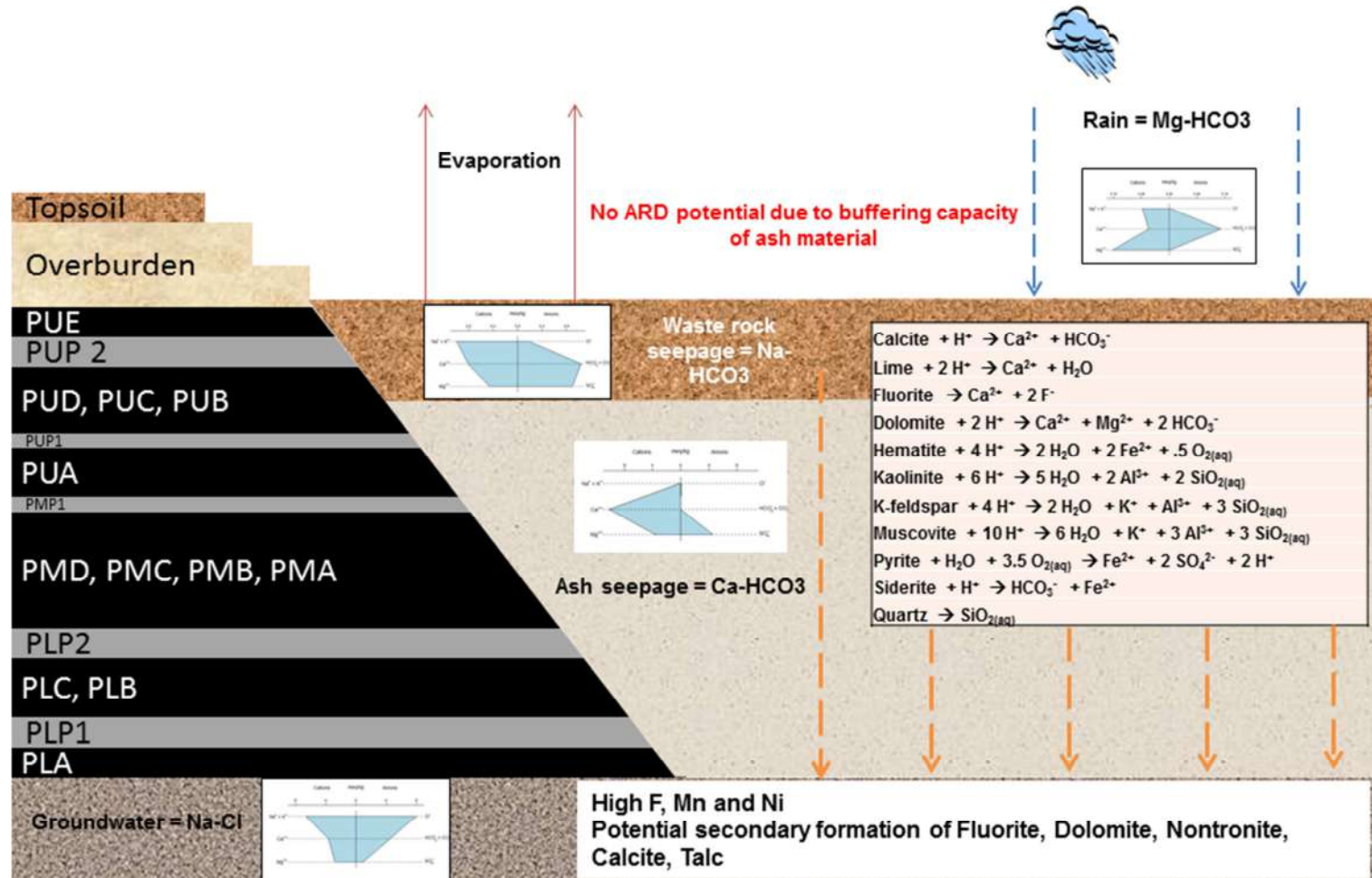


Figure 42: Final conceptual geochemical pit backfilling model

6.1.3 Backfilling

The backfilling of the pit with ash material is summarised in the points below with a final conceptual model in Figure 42:

- A mixing reaction model was simulated to observe what the potential reaction and dissolution effect on the leachate concentrations will be once the seepage from the ash reacts with the groundwater for the proposed Dalyshope pit backfilling;
- The leachate sample was allowed to mix and react with the groundwater sample for a period of 50 years at which time an equilibrated system can be observed;
- The TDS of both the ash seepage and the groundwater decreases to 802.8 mg/L as indicated in Figure 34;
- The parameters of concern are B, Mn, Ni, Ca and F. All of these elements increased the concentration of the final groundwater, but a decrease in concentrations as observed in the seepage from the ash material was shown in the resultant fluid mix;
- Although there was a slight increase of these parameters from the natural groundwater concentrations, the final simulated sample showed an improvement from the leachate quality, with all parameters below the maximum allowable limit for drinking water and thus on current indications the backfilling of ash is feasible; and
- This will be confirmed by hydrogeological modelling.

6.2 Laboratory Tests

From the geochemical laboratory tests and result interpretations the following conclusions can be reached:

6.2.1 Waste rock samples

- The main oxides in all waste rock samples are SiO_2 , Al_2O_3 and Fe_2O_3 . These oxides along with various inclusions of MgO , MnO , K_2O , Na_2O and CaO and various smaller amounts of trace elements (Table 4) form the interbedded and overburden waste rock mineralogy;
- The mineralogy in the waste rock samples can be chemically described through the mineral formulas given below:
 - Calcite CaCO_3
 - Dolomite/Calcrete $\text{CaMg}(\text{CO}_3)_2$
 - Hematite Fe_2O_3
 - Kaolinite $\text{Al}_2(\text{Si}_2\text{O}_5)(\text{OH})_4$
 - Microcline KAlSi_3O_8
 - Muscovite $\text{KAl}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH},\text{F})_2$
 - Pyrite FeS_2

- Quartz SiO_2
- Siderite FeCO_2
- Pyrite is present in all samples and is associated with the depositional environment in which the coal formation occurred. The presence of pyrite can potentially lead to ARD formation and thus waste rock dumps should be managed accordingly through lining or other management activities;
- The presence of siderite and hematite in the formations indicate that the original oxidation states are still stable with the main iron phase being ferrous iron (Fe(II));
- Siderite can potentially act as a neutraliser under certain conditions, but with higher alkaline conditions and pH levels, the weathering reaction of siderite can lead to acid production;
- The dissolution of siderite produces Fe^{2+} and HCO_3^- and combined with ferrous iron oxidation under elevated pH levels gives off protons in conditions where bicarbonate is stable. More acidic environments give aqueous conditions where carbonic acid is stable; no net acid production will occur (Dold 2005);
- The paste pH of all the waste rock samples are in a range between 7.5 and 8.1;
- The S% of the overburden (OBW1 and OBW2) are well below 0.25% and with a high NNP and low NAG rating will not allow acid generation and is thus classified as a rock/material type III (non-acid generating);
- IBW2 shows a high tendency for acid generation with a high AP of 11.56 (kg/t) and a low NP of 5.25 leading to a low neutralising potential ratio of 0.45 and is thus classified as an acid generating rock type I. The S-content of this sample was well above the 0.25% margin;
- IBW1 and TRP 2 were classified as intermediate and a rock type II with a NPR of 1:3 or less. The S-content of these two samples were low enough, but did however not include enough minerals to allow for a high neutralising potential;
- According to the S-content of PLP1 being 0.1% above the 0.25% margin and a close to neutral paste pH of 7.8, the sample was classified as an intermediate case. However, due to the low NAG pH of 3.2 and 4.5 for the sample and a high NAG of 3.72 and 6.47 kg H_2SO_4 /t it is recommended that this sample be seen as acid generating and treated as such in any risk assessments;
- The main elements of concern with leachable concentrations from the waste rock are F, Al, Fe, Ni, Sr, and Mn. The potential precipitation of these elements back into mineral form, removing them from the aqueous environment will be confirmed with on-going long term kinetic tests; and
- The pH of PLP1 indicated a level of 4.7 and slightly acidic confirming the recommendation that this sample be seen as acid generating and treated as such in any risk assessments.

6.2.2 Coal samples

- A high material loss on the XRF test ignition was observed and this is solely down to the high combustibility of the carbon content in the coal material;
- The main oxides observed are SiO_2 , Al_2O_3 and Fe_2O_3 . These oxides mainly combine with Na_2O and K_2O to form the aluminosilicates and clay minerals associated with the Grootegeluk coal formations;
- Furthermore, CaO , MnO and MgO are also present in smaller percentages which are associated with the inclusion of calcite, dolomite/calcrete and fluorite. Trace element distributions that are high and potentially can leach out in significant quantities are As, Ba, Cu, Ni, Sr and U;
- Although the proportional distribution is different to the waste rock mineralogy, the main constituents remain the same as in the waste rock samples with high percentages of kaolinite, quartz, microcline, pyrite and muscovite; the carbon content did not pick up due to a loss on ignition will change the distributions slightly;
- The high pyrite and siderite inclusions associated with the coal deposits of the Dalyshope area led to high S-content in all samples;
- The coal samples from the PMB, PMA, PLA and top coal layers in the Composite sample indicate a rock/material that is potentially acid generating with high S-content and low neutralising potential;
- The PLC layer has a higher calcite and clay mineral content than the other layers with a lower S-concentration and thus the mineralogy allows for a higher NNP and that will counter any acid generation and is thus classified as a rock type III (non-acid generating);
- Although PLB is a marginal rock type which can only be potentially acid generating with S% slightly higher than the 0.25% guideline, the NNP is low and should thus be treated as an acid generating material along with PMB, PMA, PLA and the composite coal material;
- The F concentrations are well above the recommended safe drinking water limits in the leachate concentrate in all coal samples and could be from the fluorite mineralogy associated with the calcite and mudstone layers;
- B has leachable concentration above the recommended Class 2 limits in sample PLA (B = 1.0 mg/L);
- Se also leached out in concentrations above the recommended drinking water limit in samples PMB, PLB and PLA; with concentrations of 0.024 mg/L, 0.048 mg/L and 0.03 mg/L respectively;
- The pH of the leachate water is within the recommended, close to neutral range indicating that the mineralogy of the coal layers are neutralising. This will however be fully confirmed with on-going long term kinetic tests;

- It is recommended that stockpiles be managed through stormwater management and not allowing long standing time on site especially during high rainfall periods;
- The only elements with high leachability from the coal material is F, B, Se, Rb and Si; and
- The potential precipitation out of solution of these elements and removal from the aqueous solution that will reach the receiving environment will however be confirmed with the on-going long term kinetic tests.

6.2.3 Ash samples

- From XRF results it is shown that 76% of the ash is made up of SiO_2 , Fe_2O_3 , and CaO ;
- The main mineralogy of the ash as observed in XRD results are fluorite, calcite, muscovite, kaolinite, quartz and lime with all these minerals also associated with the coal formations of the Grootegeluk formation and is thus directly descendant from the mother material involved in the burning to produce ash;
- Total elemental analysis results of the dry ash samples were classed against continental crust trace element averages with the only elements of concern from the whole ash chemistry being As, B, Mn, Mg, Hg and U. This also correlates with the observations by Wagner & Tlotleng (2012) on the regional trace element distribution observed in the region;
- The ABA and NAG results indicate that the ash is a non-acid generating material with a high NNP and low NAG that will also aid in neutralising any potential AMD;
- The low acid producing potential of the ash also shows that metal leachability will be low;
- From the elements of concern identified in all the tests, the only constituents that leached out in significant quantities and could pose a possible environmental and human health impact is F, Mn, Ni and Ca; all of which will most probably be diluted once mixed with the groundwater and surface water in the receiving environment;
- The following conclusions and waste classification can be reached based on the results:
 - One or more elements are above the LCT0, but below or equal to the LCT1 limits ($\text{LCT0} < \text{Ash LC} \leq \text{LCT1}$);
 - All elements are below or equal to the TCT1 limits ($\text{Ash TC} \leq \text{TCT1}$);
 - Per the above observations the ash/waste material can be classified as a Type 3 waste and should be disposed of at a Class C waste disposal facility;
- Based on the geochemical results of the ash material indications are that backfilling of the Anglo open pit with the ash will be feasible, this will however be further evaluated and confirmed with kinetic tests on the ash as well as geochemical models; and

- Enough data, tests, geochemical and hydrogeological models are available and has been done throughout this study to give ample background information and motivational data to allow both Vedanta and Anglo to apply for the declassification of the ash material to apply for the alternative waste management activity of backfilling the pit with the ash material.

6.2.4 ARD Potential

From the concept level ARD study done by Golder (2013), (section 3) the following conclusions can be reached on the potential for ARD formation from all disturbed material.

6.2.4.1 Waste rock - Overburden, parting and interbedding units

- The concept level study sampled all possible overburden, parting and interbedding units from the upper Eccla and middle Eccla mudstone, siltstone and sandstone layers;
- With the commencement of the EIA study the mining and processing plan of the project indicated that the upper Eccla Coal formation will be mined together with some parting and interbedding units and thus the main waste rock sequences will be that of the PLP1, TRP 2 and the weathered and unweathered overburden and separated interbedding where possible;
- The XRD results confirmed the mineralogy of the waste rock units to be enriched with microcline, kaolinite, muscovite, siderite and calcite;
- From the Golder (2013) study indications were that enough neutralizing potential in the waste rock samples were present due to the siderite and calcite mineralogy; with the paste pH of the samples indicating that the siderite weathering reactions will indeed be neutralising and not acid producing;
- The concept study indicated that the overburden was non-potential acid generating (non-PAG) with the PLP unit ranging from acid generating (AG) to potential acid generating (PAG) and the pure sandstone units of the middle Eccla and TRP2 parting being non-PAG;
- The ABA and NAG tests done by Digby Wells on the waste rock correlated with the observation made by Golder (2013), with the overburden samples being non-PAG, the interbedding samples ranging from PAG to AG and the two main parting units PLP1 and TRP2 being PAG;
- The static leachate tests done on the waste rock samples indicated that all leachate fluids produced by the waste rock had a pH range between 7.7 and 8.3 with the exception of PLP1 leaching fluid with a low pH of 4.7 confirming the PAG status given to the parting unit in the ARD evaluations;
- From the static tests SO_4 formation was also observed to be well below guideline values;

- Based on the information and data gathered on the waste rock to be produced by the Dalyshope project it can be concluded that the waste rock has sufficient neutralising potential to allow no acid generation; and

6.2.4.2 Coal – Upper Eccla and Middle Eccla coal units

- From the Golder (2013) ARD study all coal units from the upper and middle Eccla ranged from uncertain PAG to PAG;
- From the ABA and NAG tests performed on the main coal layers the PMB, PMA, PLC, PLB, and PLA from the middle Eccla indicating have the tendency for the coal to be AG to PAG;
- This was reiterated by the low NAG pH ranges of all samples being below 5;
- The composite coal sample from the upper Eccla was processed together by the IPP indicated a high AG potential;
- The XRD results indicated that there is neutralising mineralogy present in all coal samples in the form of calcite and siderite;
- The static leachate tests yielded fluids with a pH range between 7.6 and 8.3 indicating that the mineralogy does have a larger influence on the neutralising potential of the coal layers than expected over a short term;
- Leachability of metals and other element are also low except for high levels of fluoride leaching into solution from the coal layers;
- Further long term kinetic tests will confirm the potential for ARD formation and metal leachability over a longer term;
- It can be concluded that for the short anticipated period for which the coal is expected to be stockpiled that it will not have a significant environmental impact with a low ARD potential; and

6.2.4.3 Ash – Ash material produced from coal layers

- The XRD results indicated calcite, lime and clay mineral content along with quartz allowing the observation to be made from the mineralogy that the neutralising potential of the ash material will be high and can potentially have a positive impact if used as backfilling on any acid that is potentially generated by the exposed coal and parting layers and waste material;
- The ABA and NAG tests on all the ash material indicated high NNP values with alkaline paste pH ranges;
- All the ash samples were tested to be non-PAG with the exception of the composite ash sample indicating a potential for acid generation;
- However, from the static leachate tests pH values from the resulting fluid were all between 7 and 8.9, with low metal leachability except for Ni and Mn and this will be confirmed with on-going kinetic tests; and

- Based on the data at hand and the models simulated in the geochemical assessment, the ash material has no ARD potential with high neutralising potential and a minimal environmental impact and based on this assessment can be used as backfilling material.

7 RECOMMENDATIONS

Based on the preceding study results Digby Wells recommends the following:

- Monitoring of the groundwater and surface water receptors around potential pollution sources including stockpiles, waste rock dumps and ash dumps should be done on a quarterly basis;
- Based on the geochemical leachate results and the geochemical models the main parameters of concern to monitor in the water quality is Ni, F, B, Mn, Al, Fe and Ca;
- pH trends should be studied during monitoring to ensure that ARD formation is picked up early. As soon as pH levels decreases below a level of 5, management options of acid neutralisation through treatment with lime or calcite should be investigated and implemented;
- The recommendation is made that storm water management for the stockpile designs is in place during the wet season.
- ARD formation and pH trends should be monitored on and around waste rock dumps and stockpiles;
- The recommendation is made that the waste rock from the parting units PLP1 and TRP2 be managed, designed and deposited within the WRD to allow a natural geoliner to be formed by the non-PAG units of the overburden and interbedding.
- Storm water management in the vicinity of waste disposal facilities should be in place to capture potential ARD and dirty water to be diverted to pollution control dams; and
- The use of ash as backfill into the pit, based on current information and models, is feasible and will help in neutralising any potential acid generation post-closure in the area of the open pit.

8 REFERENCES

- Bethke, C.M., 2008. *Geochemical and Biogeochemical Reaction Modeling* 2nd Ed., Cambridge University Press.
- Cama, J. et al., 2010. Fluorite dissolution at acidic pH: In situ AFM and ex situ VSI experiments and Monte Carlo simulations. *Geochimica et Cosmochimica Acta*, 74(15), pp.4298–4311.
- Van Coller, A.A., 2013. *Open Pit Flooding as a Post-Closure Option: A Geochemical Approach*. University of the Free State.
- DEA, 2013a. *National Norms and Standards for the Assessment of Waste for Landfill Disposal*, Department of Environmental Affairs.
- DEA, 2013b. *National Norms and Standards for the Disposal of Waste to Landfill*,
- DEA, 2013c. *National Waste Classification and Management Regulations*, Department of Environmental Affairs.
- DEA, 2012. *National Waste Information Regulations, 2012*, Department of Environmental Affairs.
- Dold, B., 2005. Basic Concepts of Environmental Geochemistry of Sulfide Mine-Waste. *Society of Economic Geologists*.
- DWE, 2011. *Additional Hydrogeological Investigation for water resources for the proposed Boikarabelo Mining Project*,
- Faure, K., Willis, J.P. & Dreyer, J.C., 1996. The Grootegeluk Formation in the Waterberg Coalfield, South Africa: facies, palaeoenvironment and thermal history - evidence from organic and clastic matter. *International Journal of Coal Geology*, 29, pp.147–186.
- Golder, 2013. *Concept level assessment of ARD potential Dalyshope Retention Mine - Draft report*,
- Gorchev, H.G. & Ozolins, G., 2008. WHO guidelines for drinking-water quality. *WHO chronicle*, 38(3), pp.104–8.
- Klein, C. & Dutrow, B., 2007. *Manual of Mineral Science* 23rd ed., John Wiley & Sons, Inc.
- Mason, B., 1966. *Principles of Geochemistry* 3rd Edition., Washington D.C.: John Wiley & Sons, Inc.
- Wagner, N.J. & Tlotleng, M.T., 2012. Distribution of selected trace elements in density fractionated Waterberg coals from South Africa. *International Journal of Coal Geology*, 94, pp.225–237.
- White, A.F. & Brantley, S.L., 1995. *Reviews in Mineralogy* Volume 31., Washington D.C.: Mineralogical Society of America.

Wilson, M.J., 2004. Weathering of the primary rock-forming minerals : processes , products and rates. *Clay Minerals*, 39, pp.233–266.

Witthueser, K.T., 2010. Geochemistry GHR612. In *GHR612 Class notes*. Bloemfontein: Institute for Groundwater Studies.

Appendix A: Plans

Plan 1: Local geology













Plan 2: Regional geology

Plan 3: Hydrocensus boreholes







Plan 4: Drilling program

Dalyshope Geochemical Assessment Regional Geology

Legend

-  Project Area
-  Settlement
-  Fault
-  Main Road
-  Minor Road
-  Track
-  Dam Wall
-  Non-Perennial Stream
-  Perennial Stream
-  Dam / Lake
-  Non-Perennial Pan / Stream
-  Perennial Pan

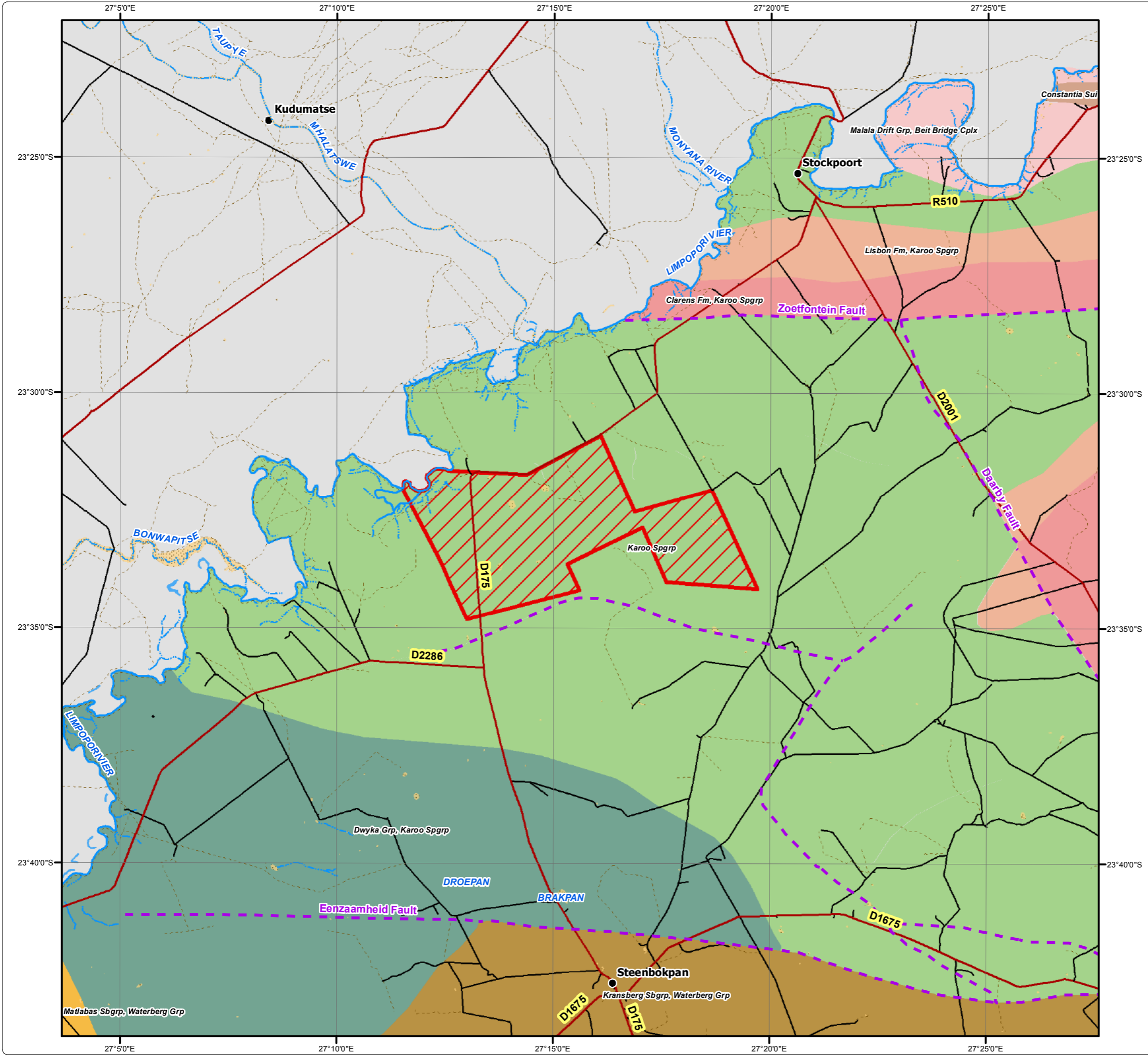
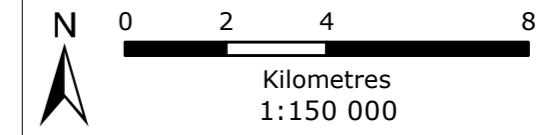
Geology

-  Clarens Fm, Karoo Spgrp
-  Constantia Sui
-  Dwyka Grp, Karoo Spgrp
-  Karoo Spgrp
-  Kransberg Sbgrp, Waterberg Grp
-  Lisbon Fm, Karoo Spgrp
-  Malala Drift Grp, Beit Bridge Cplx
-  Matlabas Sbgrp, Waterberg Grp





www.digbywells.com

Projection: Transverse Mercator Ref #: scm.ANG217.201402.015
 Datum: Hartebeesthoek 1994 Revision Number: 1
 Central Meridian: 27°E Date: 10/02/2014




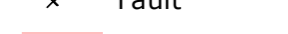
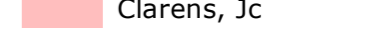
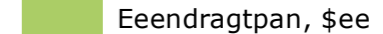


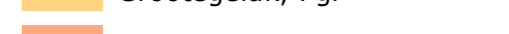
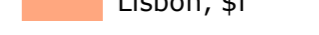
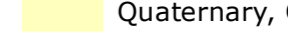



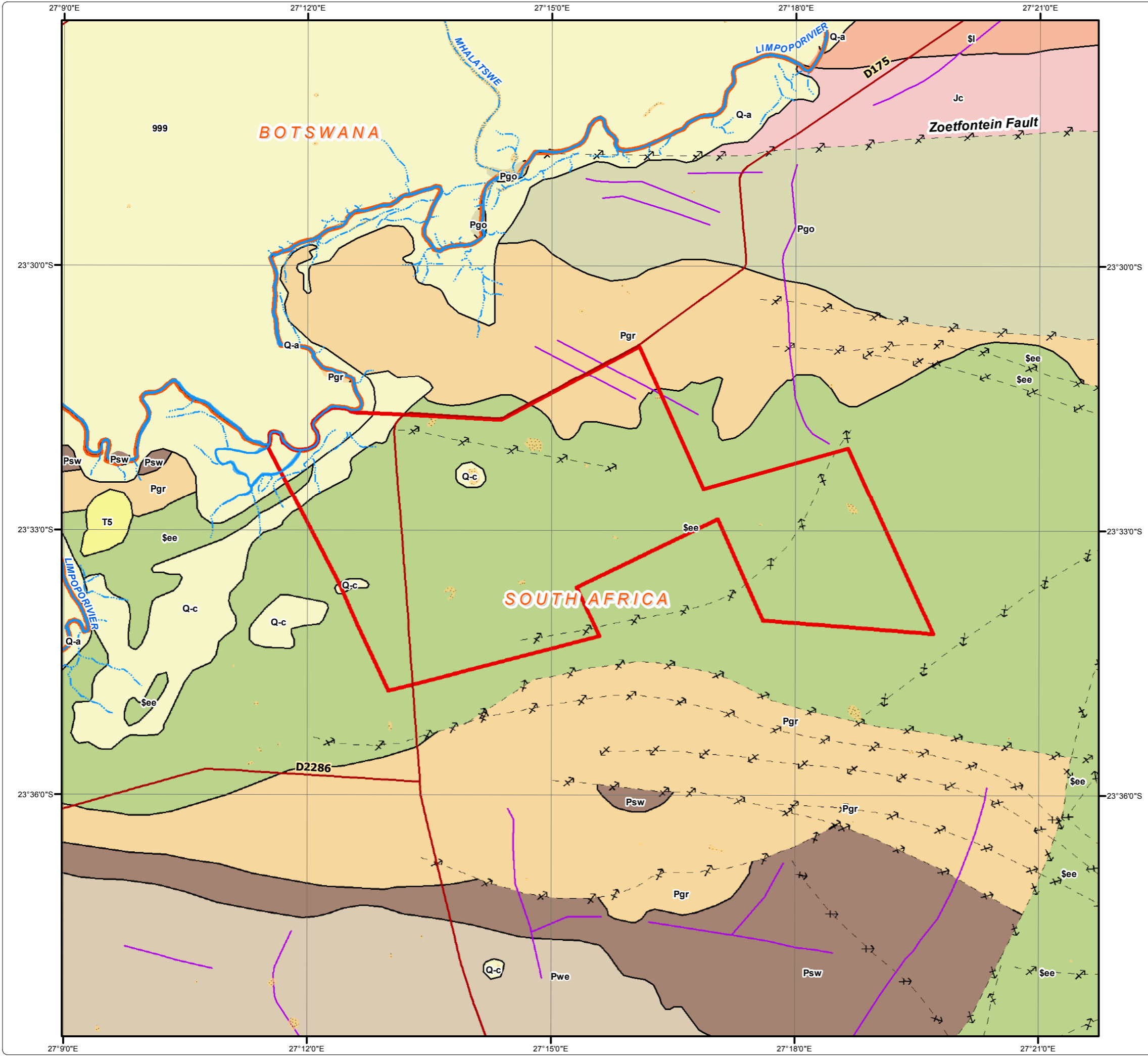
Dalyshope Geochemical Assessment Local Geology

Legend

-  Project Area
-  Main Road
-  Non-Perennial Stream
-  Perennial Stream
-  Dam / Lake
-  Non-Perennial Pan / Stream
-  Perennial Pan
-  International Boundary

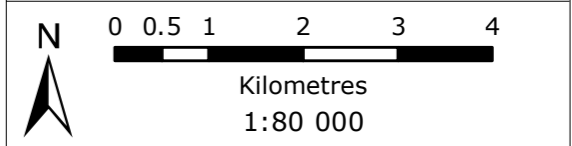
Geology

-  Lineaments
-  Geological Contact
-  Fault
-  Clarens, Jc
-  Eendragtpan, \$ee
-  Goedgedacht, Pgo
-  Grootegeluk, Pgr
-  Lisbon, \$l
-  Quaternary, Q-a / Q-c / Q40
-  Swartrant, Psw
-  Tertiary, T5
-  Wellington, Pwe




AngloAmerican
DIGBY WELLS
ENVIRONMENTAL
www.digbywells.com

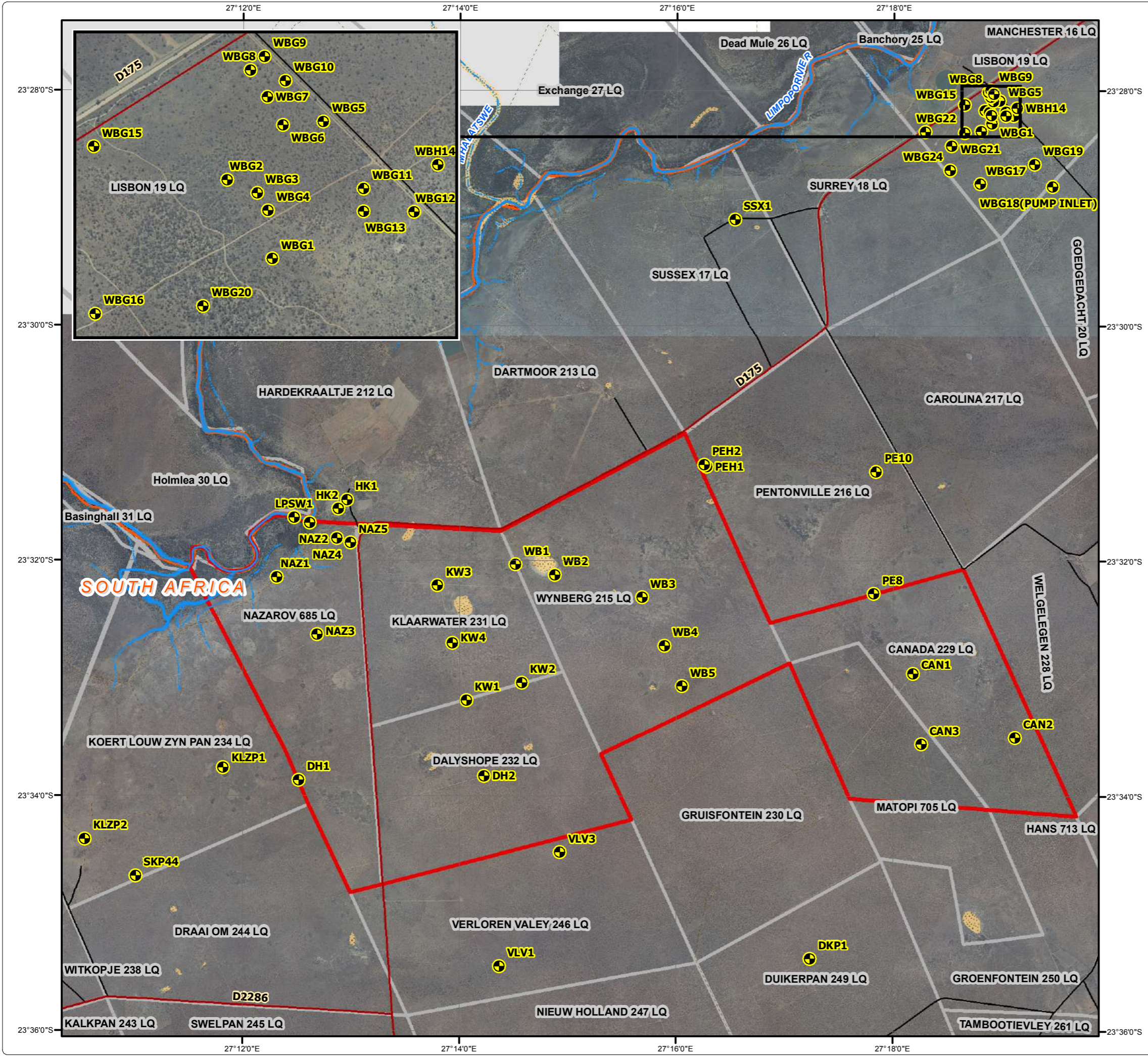
Projection: Transverse Mercator Ref #: scm.ANG2137.201402.016
Datum: Hartebeesthoek 1994 Revision Number: 1
Central Meridian: 27°E Date: 10/02/2014



Dalyshope Geochemical Assessment Hydrocensus Boreholes

Legend

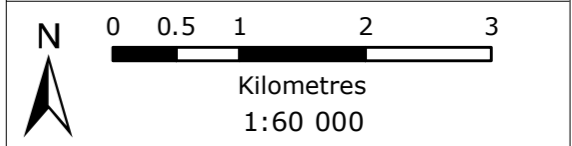
- Hydrocensus Boreholes
- Project Area
- Main Road
- Minor Road
- Track
- Non-Perennial Stream
- Perennial Stream
- Dam / Lake
- Non-Perennial Pan / Stream
- Perennial Pan
- Farm Boundary
- International Boundary





www.digbywells.com

Projection: Transverse Mercator Ref #: scc.ANG2137.201402.017
 Datum: Hartebeesthoek 1994 Revision Number: 1
 Central Meridian: 27°E Date: 10/02/2014



Dalyshope Geochemical Assessment Drilling Programme

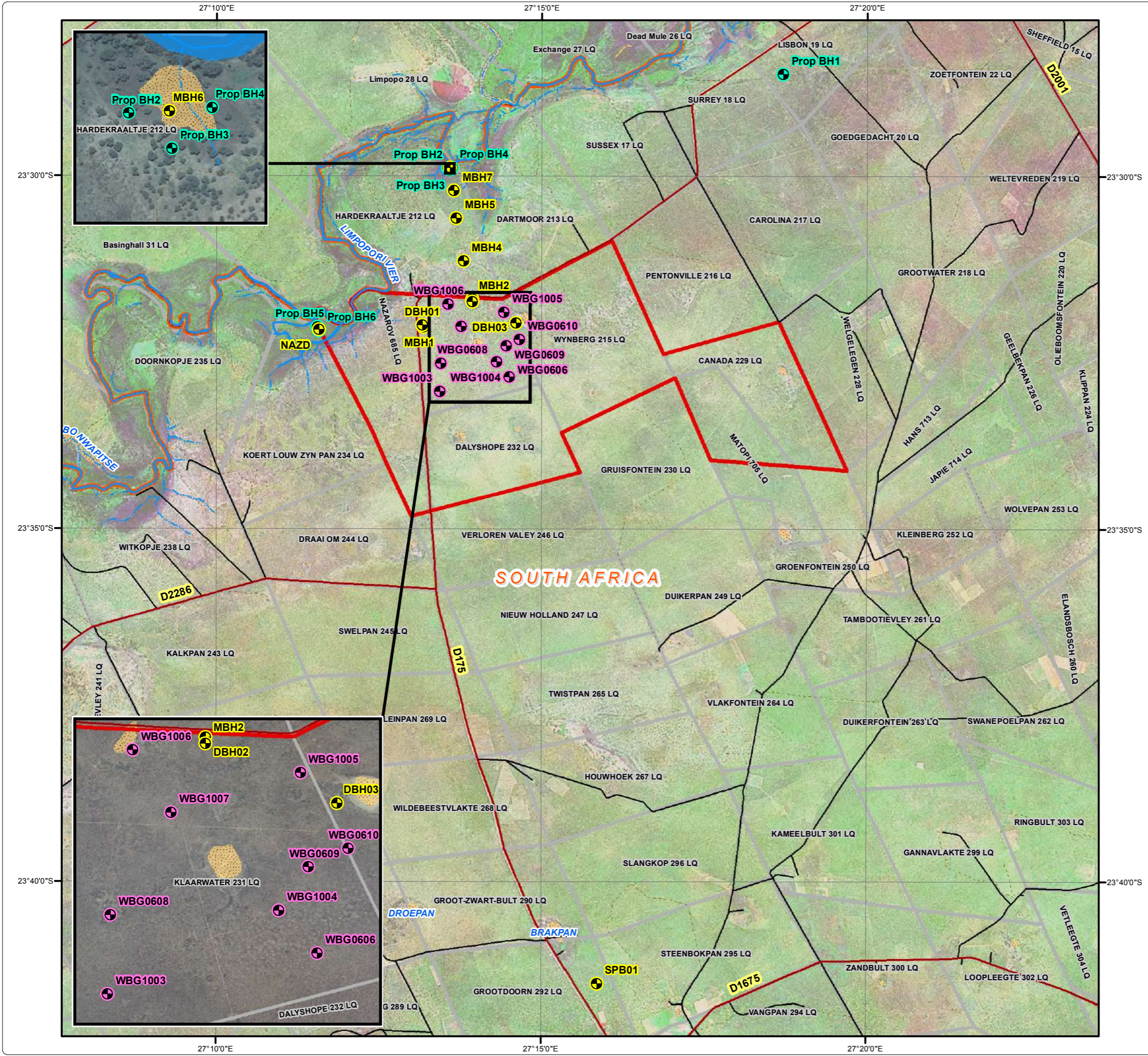
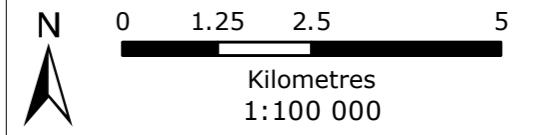
Legend

- New Boreholes
- Proposed Boreholes
- Geochem Sampling Points
- Project Area
- Settlement
- Main Road
- Minor Road
- Track
- Non-Perennial Stream
- Perennial Stream
- Dam / Lake
- Non-Perennial Pan / Stream
- Perennial Pan
- Farm Boundary
- International Boundary



www.digbywells.com

Projection: Transverse Mercator Ref #: scm.ANG2137.201402.018
 Datum: Hartebeesthoek 1994 Revision Number: 1
 Central Meridian: 27°E Date: 10/02/2014



Appendix B: Concept Level ARD Study



February 2013

ANGLO AMERICAN THERMAL COAL

Concept Level Assessment of ARD Potential Dalyshope Retention Mine - Draft Report

Submitted to:
Thermal Coal
Anglo Operations Limited
PO Box 13173
Witbank
1038



REPORT



Report Number. 12613916-11899-1

Distribution:

1 X Anglo Coal
1 X Project File
1 X Library





Executive Summary

This report presents the concept level geochemistry study conducted by Golder Associates at the proposed Dalyshope Retention Mine for Anglo American Thermal Coal. At this stage, the Dalyshope project is in the exploration phase.

The scope of work included a review of relevant geological information, collection of samples for acid base accounting (ABA) tests and assessment of acid rock drainage (ARD) potential of the lithological units that will be disturbed by mining.

The proposed mine lies in the Ellisras Coalfield. The geological succession comprises basement rocks belonging to the Bushveld Igneous Complex, Limpopo Belt and Waterberg group to the eastern, northern and southern parts, respectively. These pre-Karoo rocks are overlain by the Dwyka Group, which consists of the oldest Karoo sediments. Directly above the Dwyka is the Eccca Group, which consists of three formations namely, from bottom to top, the Wellington, Swartrand and Grootegeluk Formations. The Eccca Group is overlain by the Beaufort Group, which is in turn overlain by the Stormberg Group. Coal deposits occur in the Swartrand and Grootegeluk Formations. Three seams (up to 9 m thick) occur in the Swartrand Formation. In the Grootegeluk Formations the coal deposits consist of thick successions (up to 80 m) of multiple, thinly interbedded coal and mudstone layers, which are known as coal plies. Occurrences of pyrite in various forms are common in the coal and occasionally in the non-coal lithologies. Siderite and calcite are also prevalent as nodules, lenses and veinlets.

Except for the pits outline, no mine plans have been developed yet for the proposed Dalyshope mine. For the purposes of this concept level ARD assessment, it was assumed that coal from both the Swartrand and Grootegeluk Formations will be mined by opencast methods. Thus all the lithological units comprising overburden, interbedding, parting, coal and coal floor will be disturbed by mining.

A total of 19 composite samples, including a duplicate sample, were collected from three boreholes. All samples were submitted for ABA analysis. Upper Eccca and Middle Eccca coal had the highest sulphide sulphur concentration; however, the paste pH in these samples was neutral (pH=7.2). This was attributed to the presence of calcite and siderite, which were observed in coal during sampling. Samples of parting unit PLP1 had the lowest paste pH of 5.9. These samples were characterised by low bulk neutralisation potential and carbonate NP.

Assessment of ARD potential of the sampled units was conducted based on neutralisation potential ratio (bulkNP/sulphide sulphur acid potential [SAP]), paste pH and sulphide sulphur concentration. The ARD assessment indicated that:

- Acid generating (AG) samples included:
 - § Parting units PLP1 and TRP2 from borehole WB0556A (TRP2(6)).
- Potentially acid generating (PAG) samples were :
 - § Parting units SD1, USF, and PUP1; and
 - § Middle Eccca coal seam (ESC).
- Samples that fell in the grey zone (Uncertain) included:
 - § Parting units TRP2 from borehole WP0557A (TRP2-7) and PMP1;
 - § Interbedding (CIB); and
 - § Upper Eccca coal (UC).

These rock units are possibly acid generating if NP is insufficiently reactive or is depleted at a rate faster than sulphides under field conditions.

- Units that were not potentially acid generating (Non-PAG) were:



§ Weathered overburden (WO), fresh overburden (FO), PUP2, PLP2, TRP2 from borehole WB0555A and MS samples are not potentially acid generating (Non-PAG).

An assessment of elemental data from exploration borehole assays (AATC, November 2012) indicated that As, Bi, Cs, Hg, Mo and S are enriched in overburden, parting, interbedding and coal units from the Dalyshope Project area. These elements are potential constituents of interest (COI). An assessment of total sulphur distribution in different stratigraphic units indicated higher concentrations and wider spatial variability in total sulphur compared to parting units. Though not as significant as in coal, total sulphur varied spatially in parting units PLP1, TRP2 and PMP1. The highest concentration of total sulphur occurred within a depth of 55m below the surface in Upper Eccla Coal plies.

The number of samples used for the concept level ARD assessment provide a good indication of the acid potential from the disturbed mine geological units. However, it does not account for the spatial variation in geochemistry the individual lithological units. This is based on the analysis of total sulphur profiles, which indicated that sulphur is generally not uniformly distributed spatially in parting units PUP1, PMP1, PLP1, TRP2 and coal. This implies that the ARD potential of these lithological units may vary spatially from PAG to Non-PAG across the deposit; hence a detailed geochemical assessment should be conducted across the whole area during the next phases of mine planning.

In conclusion, the concept level ARD assessment indicates a significant potential for ARD to be generated from the planned mining activities of the Dalyshope Retention mine. This ARD has the potential to affect the economic viability of the project due to the requirements for source and pathway control measures associated with mining features and the long-term mine water management liability associated with ARD. The ARD impacts can, however, be prevented and managed through pro-active and upfront design and planning in order to limit the long-term liability associated with ARD management at the proposed Dalyshope Retention mine operations.

Further geochemical assessment of the potentially mining-disturbed rocks at the proposed Dalyshope Retention mine is required to provide a robust geochemical baseline to support mine planning and environmental assessment. Specific recommendations for further work include:

- Collection of sufficient samples to allow statistical assessment of the ARD potential and metal leaching (ML) of the lithological units that will be disturbed by mining. Based on the Global Acid Rock Drainage Guide (INAP, 2012) several hundred samples should be analysed by static testing during the Pre-feasibility phase. The acid and neutralisation potential should be incorporated into the geological block model to indicate areas of localised ARD and ML risk.
- Mineralogical analysis by XRD and short term leach tests should also be conducted to assess the mineralogical composition and ML potential of the overburden, interbedding, parting and coal across the whole mine area.
- Samples of parting units and coal that classify as PAG should be submitted for kinetic testing to assess likely long-term drainage quality taking acid generating and acid neutralising reactions into account. The GARD Guide suggests that one to two samples of each material type should be analysed by kinetic testing. Allowance should therefore be made for at least six kinetic tests.



Acronyms and Abbreviations

Acronym/Abbreviation	Description
AATC	Anglo American Thermal Coal
ABA	Acid-based accounting
AP	Acid potential
ARD	Acid Rock Drainage
CaCO ₃	Calcite
CaNP	Carbonate Neutralisation Potential
CO ₃	Carbonate
COI	Constituent of interest
GARD	Global Acid Rock Drainage Guide
ICP-AAS	Inductively Coupled Plasma–Atomic Absorption Spectroscopy
ICP	Inductively Coupled Plasma
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
mamsl	Meters above mean sea level
ML	Metal leaching
NNP	Net neutralisation potential
Non-PAG	Not Potentially acid generating
NP	Neutralisation potential
NPR	Neutralisation potential ratio
PAG	Potentially acid generating
ppm	Parts Per Million
QA/QC	Quality assurance/quality control
SAP	Sulphide Sulphur Acid Potential
SNPR	Sulphide Neutralisation Potential Ratio
SO ₄	Sulphate
TAP	Total Sulphur Acid Potential
TC	Total carbon
TNPR	Total Sulphur Neutralisation Potential Ratio
XRF	X-RAY fluorescence
wt%	Weight percent



Glossary of Terms

Term	Description
Acid-base accounting (ABA)	An analytical technique applied to mine wastes and geologic materials that is used to determine the potential acidity from sulphur analysis versus the neutralisation potential. It is used to predict the potential of that material to be acid producing or acid neutralising.
Acid generating	Refers to ore and mine wastes that contain sulphur or sulphides, which produce acid when oxidised. Acid can also be present as acid sulphates or generated by their weathering.
Acid potential (AP)	The ability of a rock or geologic material to produce acid leachates; may also be referred to as acid generation potential or AGP.
Acid rock drainage (ARD)	A low pH, metal-laden, sulphate-rich drainage that occurs during land disturbance where sulphur or metal sulphides are exposed to atmospheric conditions. It forms under natural conditions from the oxidation of sulphide minerals and where the acidity exceeds the alkalinity. Non-mining exposures, such as along highway road cuts, may produce similar drainage. Also known as acid mine drainage (AMD) when it originates from mining areas.
Composite sample	A sample made by the combination of several distinct subsamples.
Conceptual site model	A representation of a site and its environment that represents what is known or suspected about contaminant sources as well as the physical, chemical and biological processes that affect contaminant transport to potential environmental receptors.
Contaminant	Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on human and ecological receptors as well as environmental media (e.g., air, water, soil, sediment).
Kinetic Testing	A laboratory geochemical procedure to accelerate natural oxidation (weathering) reactions so that the potential of the rock to generate acid drainage can be evaluated (thus the term “kinetic”).
Metal Leaching (ML)	The release of metals from mineral phases.
Lithology	The character of a rock described in terms of its structure, colour, mineral composition, grain size, and arrangement of its visible features that in the aggregate impart individuality to the rock.
Neutral mine drainage (NMD)	A neutral to alkaline pH, metal-laden, sulphate-rich drainage that occurs during land disturbance where sulphur or metal sulphides are exposed to atmospheric conditions. It forms under natural conditions from the oxidation of sulphide minerals and where the alkalinity equals or exceeds the acidity.
Neutralisation potential (NP)	The ability of a material to neutralise acid. Neutralisation potential is comprised of more reactive minerals, such as carbonate, that provide short-term buffering and less reactive minerals such as alumino-silicates, that provide longer-term buffering.
Net Neutralisation Potential (NNP)	NNP is defined as NP - AP. The lower the NNP, the higher the potential for acid generation. Criteria (summarised by Usher et al., 2003) are as follows: <ul style="list-style-type: none">- NNP < -20 kgCaCO₃/t : Potentially acid generating;- -20 < NNP < +20 kgCaCO₃/t :Uncertainty regarding acid generation potential; and- NNP > +20 kg CaCO₃/t: Potentially acid neutralising.
Neutralisation Potential Ratio (NPR)	The NPR is defined as NP/AP. The lower the NPR, the higher the potential for acid generation. Screening Criteria by GARD (INAP, 2012) and MEND (2009) are as follows: <ul style="list-style-type: none">- NP/AP < 1 : Likely acid generating- 1 < NP/AP < 2 : Possibly acid generating- NPR > 2: Not potentially acid generating.



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

Term	Description
Neutralisation reaction	A chemical reaction in which an acid and a base or alkali (soluble base) react to produce salt and water, which do not exhibit any of the acid or base properties.
Overburden	Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful and minable materials or ores, especially those deposits that are mined from the surface by open cuts or pits.
Oxidation	A chemical process involving a reaction(s) that produces an increase in the oxidation state of elements such as iron and sulphur.
Pathway	The physical course a chemical or pollutant takes from its source to an exposed organism
pH	A measure of the acidity (pH less than 7) or alkalinity (pH greater than 7) of a solution; a pH of 7 is considered neutral. It is a measure of the hydrogen ion concentration (negative log of the hydrogen ion activity for glass electrodes) of a soil suspension or solution
Quality assurance/ quality control (QA/ QC)	A system of procedures, checks, audits, and corrective actions to ensure that all research design and performance, environmental monitoring and sampling, and other technical and reporting activities are of the quality that meets the testing objectives.
Representative sample	A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.
Saline drainage (SD)	Can be any pH but usually above pH 6. Salinity defined as TDS i.e grams of ion per kg of solvent water. The sulphate concentration of 1000 mg/l is the threshold between NMD vs. SD (GARD, 2012).
Stratigraphy	The layering or bedding of varying rock types reflecting changing environments of formation and deposition. Also, a branch of geology that concerns itself with the study of rock layers and layering (stratification).
Total Sulphur	The sum of all sulphur species of a solid material, including sulphide sulphur and sulphate sulphur.
Sulphate Sulphur	The sulphur component of a solid material that is comprised of sulphate. See also sulphide sulphur and total sulphur.
Sulphide Sulphur	The sulphur component of a solid material that is comprised of sulphide. With respect to acid base accounting, sulphide sulphur is the component that is most commonly used to calculate the acid potential. See also sulphate sulphur and total sulphur.
Static Test	A procedure for characterising the physical and or chemical properties of a sample at a point in time, such as acid base accounting. Static tests, unlike kinetic tests, do not evaluate the weathering rates of different minerals contained in geologic materials. Static tests provide a snapshot in time of the geochemical characteristics of a sample.
Waste rock	Barren or mineralized rock that has been mined but is of insufficient value to warrant treatment and is removed ahead of the metallurgical processes and disposed of on site. The term is usually used for wastes that are larger than sand-sized material and can be up to large boulders in size.
Weathering	Process whereby earthy or rocky materials are changed in colour, texture, composition, or form (with little or no transportation) by exposure to atmospheric agents.



Table of Contents

1.0 INTRODUCTION	1
2.0 OBJECTIVES	1
3.0 APPROACH AND METHODOLOGY	1
4.0 DESCRIPTION OF DALYSHOPE PROJECT	3
4.1 Project Summary	3
4.2 Climate	3
4.3 Topography and Drainage	3
4.4 Geology	3
4.4.1 Regional Geology	3
4.4.2 Geology of the Dalyshope Project Area	7
4.4.2.1 Dwyka Group	7
4.4.2.2 Eccca Group	7
4.4.2.3 Beaufort Group	12
4.4.2.4 Post Karoo Deposits	13
4.4.2.5 Faults and Igneous Intrusions	13
4.5 Geochemical Context of Site Geology	13
4.6 Assay Geochemistry	13
4.6.1 Elemental Enrichment	14
4.6.2 Total Sulphur Variability	17
4.7 Concept level mining considerations	17
5.0 SAMPLING	19
5.1 Sampling Plan	19
5.2 Sample collection and handling	21
5.2.1 Quality Assurance and Quality Control	23
6.0 ANALYTICAL METHODS	24
6.1 Acid Base Accounting	24
7.0 ANALYTICAL RESULTS AND INTERPRETATION	24
7.1 Evaluation of Sampling and Laboratory Methods Quality Assurance/Quality Control	24
7.2 Acid-Base Accounting Results	25
7.4 Assessment of sample representativeness	34
8.0 SUMMARY AND CONCLUSIONS	35
9.0 RECOMMENDATIONS	38



10.0 REFERENCES 38

TABLES

Table 1: GAI values of parting and coal samples from Dalyshope Project exploration borehole WBG0555	15
Table 2: Dalyshope Geochemical samples	22
Table 3: Quality assessment of the ABA laboratory results.....	25
Table 4: ABA analytical results and calculations	27
Table 5: Acid Generation Criteria (Price et al., 1997; MEND, 2009).....	31
Table 6: ABA Statistical summary	37

FIGURES

Figure 1: Location of Ellisras Coalfield	2
Figure 2: Waterberg Prospecting Rights and location of Dalyshope project area.....	4
Figure 3: Surface geology of the area around Dalyshope project area (adapted from Council for Geosciences (1993)).	5
Figure 4: General Stratigraphy of the Ellisras Coalfield (AATC, 2012).....	6
Figure 5: General stratigraphy of the Dalyshope project area (AATC, 2012) where the parting units are differentiated from coal plies by ending with letter P and a numerical number.	8
Figure 6: Pyrite on coal cleat (a) and bedding planes (b). The core diameter is approximately 6cm.....	9
Figure 7: Siderite nodules (brown spots) and calcite (white veins) in coal.	9
Figure 8: Siderite and pyrite in sandstone	10
Figure 9: Channel sandstone parting (PLP1)	11
Figure 10: Pyrite (pale yellow) lenses in and calcite (white) in Upper Ecca coal ply.....	12
Figure 11: Calcite and siderite in Upper Ecca coal ply	12
Figure 12: Ratios of Dalyshope parting and coal elemental concentrations against crustal average concentrations.....	16
Figure 13: Variation of Total sulphur concentration with depth.....	18
Figure 14: Plot of Total sulphur for Dalyshope exploration boreholes. Parting samples are shown as open shapes and coal seams as filled shapes.....	19
Figure 15: Location of exploration/ARD assessment boreholes and proposed open-pits at Dalyshope.....	20
Figure 16: Variations of PLP1 and TRP2 parting units in boreholes 0555A (5), 0556A (6) and 0557A (7), respectively	23
Figure 17: Paste pH versus sulphide concentration in Dalyshope coal, overburden, parting and interbedding	25
Figure 18: Sulphide sulphur versus total sulphur in Dalyshope samples.....	26
Figure 19: Sulphate sulphur versus total sulphur in Dalyshope samples	28
Figure 20: Sulphate sulphur versus sulphide sulphur in Dalyshope samples.....	29
Figure 21: Carbonate equivalent neutralisation potential (CaNP) versus Modified Sobek neutralisation potential (BulkNP).....	30
Figure 22: Acid potential versus neutralising potential graph indicating areas of likely and unlikely acid generation	32
Figure 23: Neutralisation Potential Ratio (NPR) versus Sulphide sulphur concentration in Dalyshope samples.....	33



Figure 24: Paste pH versus Sulphide Neutralisation Potential Ratio in Dalyshope samples 33

Figure 25: Plot of Total sulphur for Dalyshope exploration boreholes assay and Golder Associates ABA data for parting units. Av represents average (assay data) total sulphur concentration in the unit. 35

APPENDICES

APPENDIX A

Document Limitations

APPENDIX B

Geological logs for boreholes sampled for ARD assessment

APPENDIX C

ARD potential (ABA) results



1.0 INTRODUCTION

Anglo American Thermal Coal (AATC) appointed Golder Associates Africa (Pty) Ltd (Golder) to conduct concept level acid rock drainage (ARD) assessment of key geological units that will be disturbed by mining at the proposed Dalyshope Retention Mine. The proposed mine is located in the Ellisras/Waterberg Coalfield in the Limpopo Province of South Africa. The project area lies approximately 240 km northwest of Pretoria (Figure 1).

Mining activities associated with the mining project have the potential to impact on local surface and groundwater resources over the short, medium and long-term through the exposure, disturbance and/or deposition of geological and waste materials containing sulphide mineral assemblages. In the case of the Dalyshope Retention Mine Project, a mine plan has not been developed since the project is at a concept level. However, it is generally known what mining facilities may eventually be established on site and which may impact on the quality of surface and groundwater. This report describes the concept level assessment of acid rock drainage (ARD) potential that was conducted and summarises the collection of coal, overburden, interbedding and parting samples and interpretation of the results.

2.0 OBJECTIVES

Mining is an intrusive activity that exposes different rocks to chemically different conditions which leads to the physical and chemical alteration of the rocks. An understanding of the geochemical characteristics of each geological unit is required to determine the potential environmental risks; specifically the impact on surface water and groundwater quality posed by mines during the operational and post closure phases.

The key objective of the concept level ARD assessment was to identify the potential for acid drainage from key geological units that will be disturbed by mining. No assessment of metals leaching (ML) and prediction of mine drainage chemistry has been included and is intended for subsequent phases.

3.0 APPROACH AND METHODOLOGY

The scope of work for the concept level ARD assessment is consistent with the following guidance documents that have gained regulatory acceptance in jurisdictions around the world:

- Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials (MEND 2009).
- Global Acid Rock Drainage (GARD) Guide (INAP, 2012).

A simplified approach was followed for the concept level ARD assessment and is based on the methodology outlined in the GARD Guide:

- Step 1: Review available information and identify rock and waste units that will be exposed, disturbed or deposited by the proposed mining activities. Geochemical information was obtained from assays conducted on core samples from some of the exploration boreholes. Key aspects of the geology were reviewed and have been summarised in the subsequent sections. Inferences from the assay geochemical data are also presented.
- Step 2: Develop conceptual models of key geochemical and flow processes for each mining facility. This step has not been addressed in this report due to the concept level stage of the project.
- Step 3: Develop a sampling plan by determining the form and extent of rock and waste units that will occur in each mine component. A strategy for obtaining and testing representative samples of the geological materials and mine wastes should be developed. Twenty (18) samples were identified for the concept level ARD assessment, based on key geological units mined.

Step 4: Conduct sampling of geological materials and mine wastes. A description of the sample availability and sample from exploration cores at the proposed Dalyshope Retention Mine is presented in Section 5.2.



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

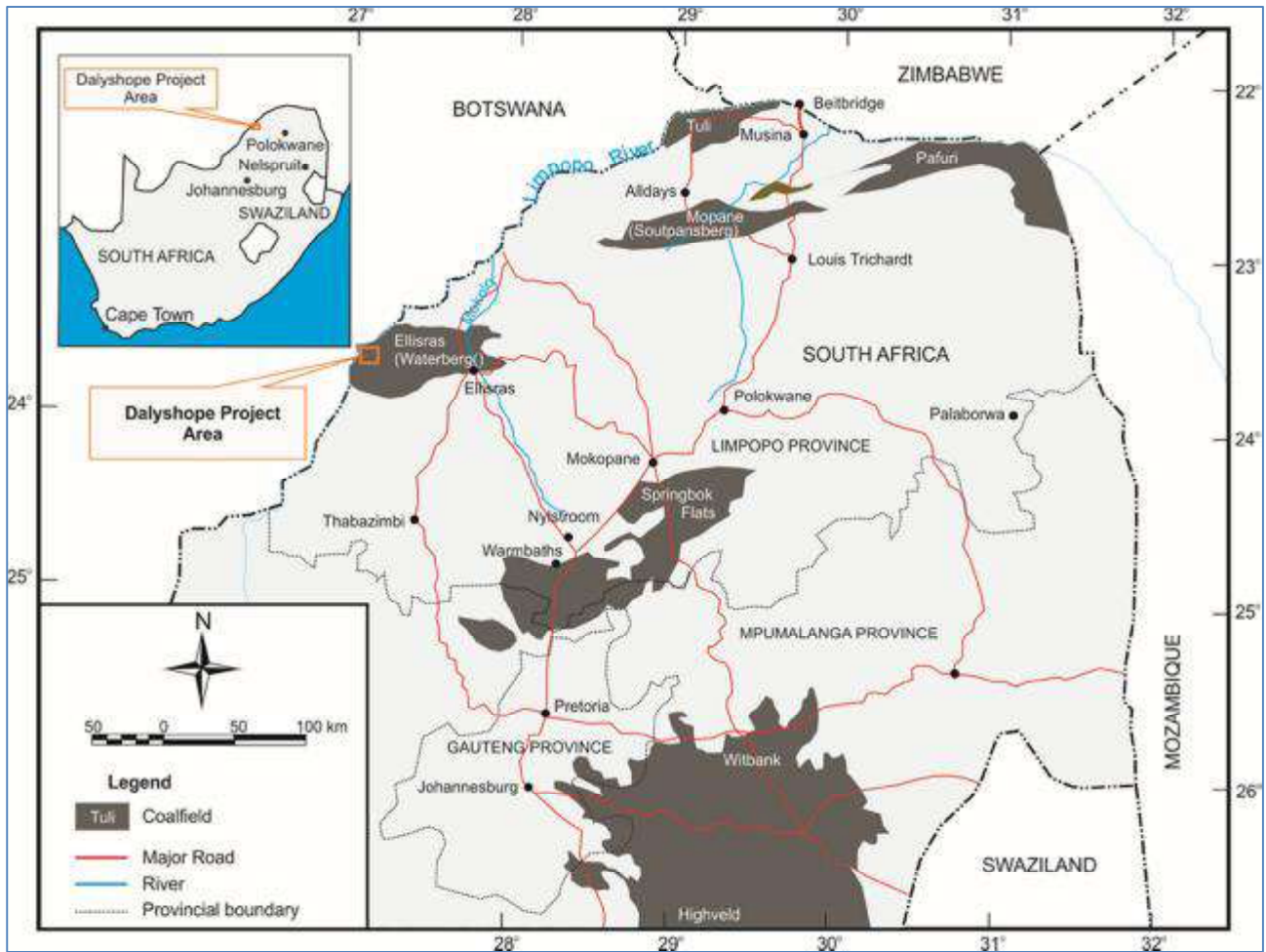


Figure 1: Location of Ellisras Coalfield

- Step 5: Conduct laboratory analysis of samples, typically including static and kinetic tests. A description of the laboratory methods used to test the samples is presented in Section 7.1. Note that only static testing, in particular, acid base accounting tests (ABA), was carried out in this concept level study.
- Step 6: Data interpretation and reporting. The analysis and interpretation of the ABA tests results is presented in Section 8.2.

Should the analytical results generated through Steps 1 to 6 indicate a potential for any of the sampled materials to generate ARD or ML under likely operational or post closure mining conditions, this may necessitate initiation of Steps 7 and 8 of the INAP (2012) methodology as a subsequent phase of the study. These steps do not form part of the scope of work described in this report but are outlined below:

- Step 7: Source-term modelling to predict time sensitive drainage chemistry for each mine facility as a function of material property, exposure mode (waste facility, mine workings, etc.), climatic variation, water balance and geochemical process.
- Step 8: Develop source and pathway control measures to prevent, minimize or mitigate water resource impacts to acceptable levels. This includes the development of performance monitoring programs during the various life cycle phases of the proposed mine.



4.0 DESCRIPTION OF DALYSHOPE PROJECT

4.1 Project Summary

Anglo American Thermal Coal (AATC) Waterberg Prospects consists of two Prospecting Rights, namely Waterberg 5 and Waterberg 7. Each of the Prospecting Rights consists of several detached properties (Figure 2). The proposed Dalyslope Retention Mine is located on farms Klaarwater 231 LQ, Dalyslope 232 LQ, Wynberg 215 LQ and Canada 229 LQ, all within Waterberg 7 prospecting rights (Figure 2). The farms lie approximately 20 km to the westnorthwest of Grootegeluk Colliery.

Ellisras basin geological structures, lithology and qualities are completely different to deposits currently mined by AATC. The only coal mining activity in the Ellisras basin is at Grootegeluk Colliery. This coal contains mostly a Power Station feedstock averaging 21.5MJ/kg, as well as a small yield of metallurgical product. The saleable product combined yield at Grootegeluk Colliery is approximately 50%. Currently, several companies are exploring the Ellisras Basin and Sasol is investigating the development of a coal to liquids plant in the area.

Because of the difference in quality of the Dalyslope Block coal in relation to the Witbank coalfield coal that AATC is currently mining, this coal is being investigated for its best uses, which may be different to the ways it is used by AATC customers in other coalfields. A geological exploration drilling programme is underway at the Dalyslope Project site.

4.2 Climate

Dalyslope Project area lies in a region that has a subtropical steppe (low-latitude hot and dry) climate. Rainfall in the region is erratic and seasonal, occurring mainly in summer (November to February). The rainfall ranges between 350 and 500 mm per year. The region has mean annual run-off of 150-397 mm. Mean annual evaporation (1800-2000 mm/a) exceeds rainfall resulting in moisture deficit in the region. Recharge is estimated at less than 1.5% of the annual rainfall (Vegter, 1995).

The area experiences warm mean annual temperatures of around 21°C. Hot summers characterise the area with daily maximum temperatures reaching 40°C. Winters are warm to very cold, with minimum daily temperatures occasionally reaching -5°C (van Rooyen and Bredenkamp, 1996).

4.3 Topography and Drainage

The Dalyslope Project area is generally flat to gently undulating with altitude ranging between 820 and 860 meters above sea level (masl). The study area lies within the Limpopo River Catchment. The main water resource close to the area is the perennial and transboundary Limpopo River, which drains in a north easterly direction to the west of the project area. A stretch of the Limpopo River forms the northwestern boundary of Klaarwater 231 LQ farm. Except for the few non-perennial pans in all the farms and streams draining the northwestern part of Klaarwater 231 LQ farm into Limpopo River, there are no other drainage lines, streams and rivers within the proposed Dalyslope Retention Mine area.

4.4 Geology

4.4.1 Regional Geology

The Dalyslope Project area lies in the Ellisras Coalfield (Figure 1). The geology and general stratigraphy of the coalfield are shown in Figure 3 and Figure 4, respectively. Various ideas have been put forward concerning the development of the Ellisras basin. Catuneanu *et al.*, (2005) consider the basin to be part of the back-bulge flexural province of the Karoo foreland system. Turner (1999) proposed a component of Gondwana rifting as a major basin control on the tectonic development of the Karoo basins. Cairncross (2001) suggested that the Ellisras basin formed due to intracratonic rifting. According to Tankard *et al.*, (2009), the long-wavelength component of Karoo subsidence resulted from lithospheric deflection due to mantle flow coupled with distal subduction. The basin development model comprises three stages: (i) crustal uplift; (ii) fault-controlled subsidence, and (iii) long period of regional subsidence during which faulting was subordinate (Tankard *et al.*, 2009).



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

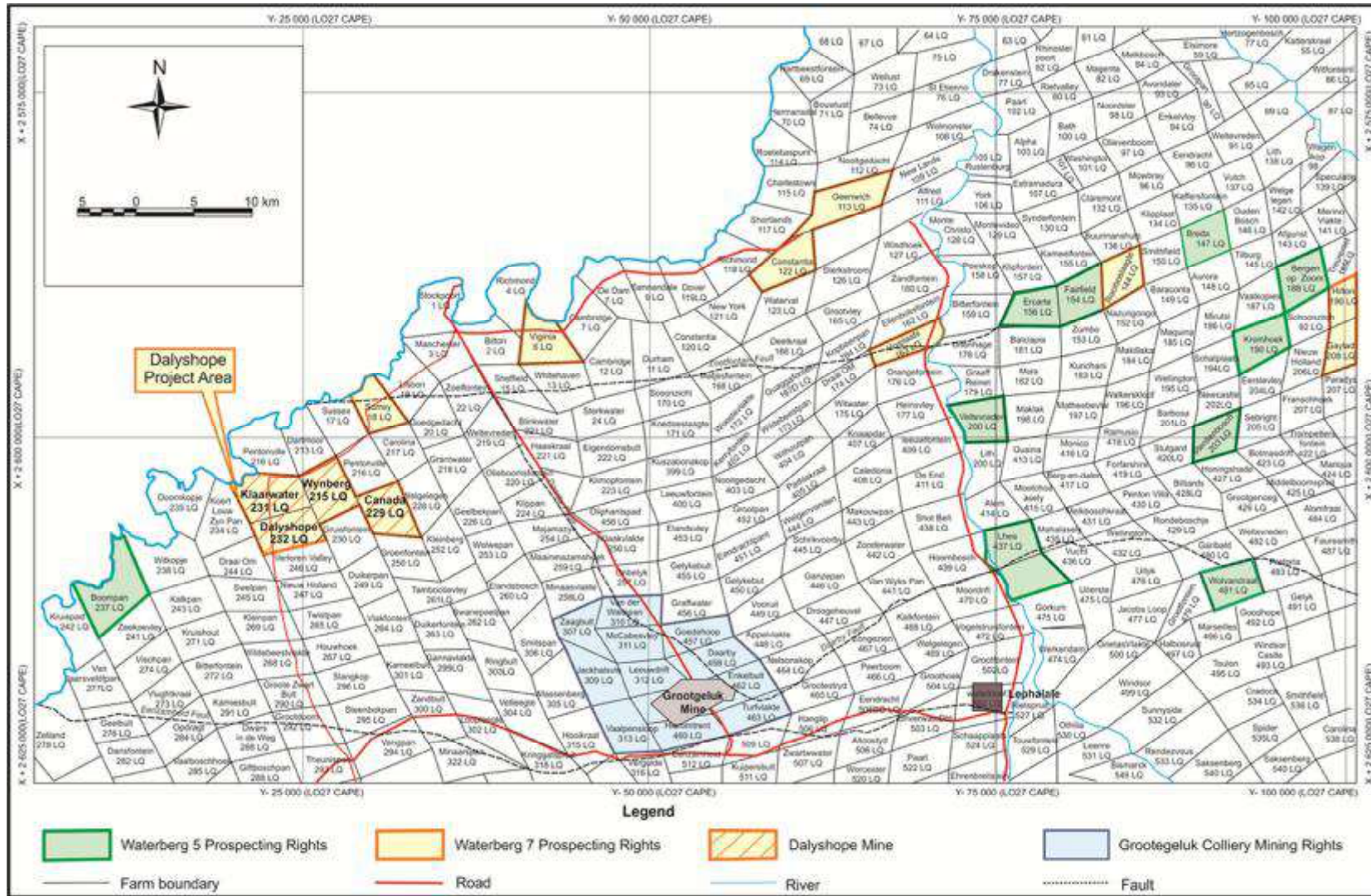


Figure 2: Waterberg Prospecting Rights and location of Dalyshope project area



Geophysical work by Fourie *et al.*, (2009) indicates that the Ellisras basin has a north-south asymmetrical profile typical of that expected in a half-graben, with a steep fault bounded side in the north and a more gently dipping sloping side in the south. The Melinda fault zone that underlies the north of the Ellisras basin is interpreted to be complexly structured with fault-bounded blocks that rotated as a result of extension (Fourie et al., 2009).

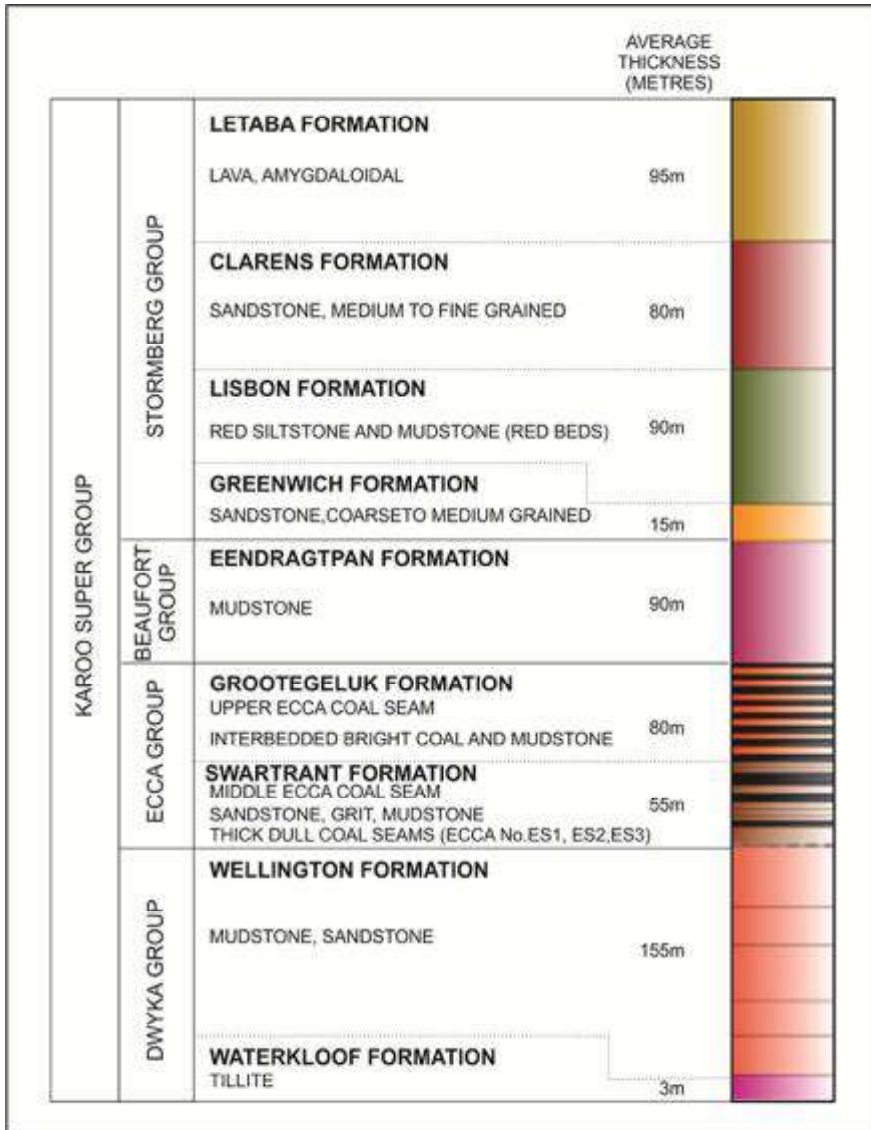


Figure 4: General Stratigraphy of the Ellisras Coalfield (AATC, 2012)

Stratigraphically, the sedimentary sequence has been broadly divided into groups and formations as established in the main Karoo Basin (Figure 4). The Karoo Supergroup sedimentary succession in the Ellisras Coalfield is underlain by:

- Limpopo Belt gneisses in the northern parts;
- Bushveld Igneous Complex granite, gabbro and norite in the eastern parts and
- Waterberg Group red beds (including quartzites and conglomerates) in the southern parts of the basin (Figure 3).

The pre-Karoo basement is overlain by the Dwyka Group, which consists of the oldest Karoo sediments. Directly above the Dwyka is the Eccca Group, which has been divided into the lower, middle and upper parts (Williamson, 1996). In the Ellisras Coalfield, the Eccca Group consists of three formations namely, the



Wellington, Swartrand and Grootegeluk Formation. These formations belong to the Lower, Middle and Upper Ecca, respectively.

The Dwyka-Ecca Group boundary is difficult to define and the transition is marked by the Wellington Formation (Figure 4). The Goedgedacht Formation is time equivalent with the sedimentary sequence represented by the Swartrand Formation, interfingers with it, and sometimes erodes into it.

The coalfield is dominated by faulting (Figure 3) in the north and southern parts. The major faults are the Zoetfontein, Eenzaamheid and Daarby fault. The former two faults have a general east-west trend and they occur on the northern and southern margins of the coalfield, respectively. The Daarby fault is characterised by a northwest-southeast trend with a major trend change as it approaches the Eenzaamheid fault to southwest-northeast (Figure 3). The Zoetfontein fault is believed to have been active during and post coal deposition, whereas the other faults are considered to be younger than the Karoo Sequence. At the point of modulation of the Daarby fault strike, there are a number of minor sympathetic fault structures that have had an effect on the attitude of the coal seams. The maximum displacement of the coal seams by the major faults is 250m. The faulting of the coalfield divides the resource into a shallow opencastable area in the central parts and a deeper underground portion in the northern and eastern parts of the basin.

4.4.2 Geology of the Dalyshope Project Area

The litho-stratigraphical subdivision commonly used by AATC is based on the work of Mr. Greg Dowling, who is a principal geologist at Anglo Coal. The general geology of the study area is presented in Figure 5 and is mainly based on the stratigraphy of the western part of the Ellisras Coalfield, west of the Daarby fault.

4.4.2.1 Dwyka Group

The base of the Karoo Supergroup in the Dalyshope project area consists of rocks of the Dwyka Group. These comprise of two cyclic sequences of diamictite, graded mudstone (varves), carbonaceous mudstone and siltstone. The varved mudstone is composed of stacks of individual units that are approximately 4cm in thickness. Each unit consists of a basal light-coloured (off-white) siltstone, which forms approximately 60-80% of the unit. Towards the top of this unit, layers consist of dark mudstone. Collectively, the varved mudstone units form a sequence up to 6m thick. The off-white laminated siltstone is often associated and inter-laminated with the varved mudstone and diamictite. The siltstone attains a maximum thickness of 10m.

The diamictite is usually very thin (less than 60cm thick), massive and matrix-supported. The matrix consists of off-white to greyish white sand and silt-sized grains with pebbles, consisting mainly of quartz, scattered throughout the unit. Towards the north the Dwyka Group is composed predominantly of diamictite with scattered large pebbles, cobbles and even boulders set in off-white to grey coarse arkosic sandstone-rich matrix.

The cyclicity indicate that during the deposition of the Dwyka Group, temperatures changed from colder to warmer, followed by another colder-warmer cycle that ended in the deposition of the overlying lower Ecca mudstones.

4.4.2.2 Ecca Group

The Lower Ecca is represented by the Wellington Formation. It consists of grey, carbonaceous mudstone and siltstone with scattered sub-angular clasts up to 5cm in diameter (Dreyer, 1991). The quartz grains or fragments are of granule size and are frequently concentrated in layers that form thin lenses in the mudstone. This mudstone-siltstone unit is crudely stratified and up to 160m thick. The mudstone-siltstone unit is overlain by a sequence consisting of alternating beds (30cm thick) of granular-sized sandstone and grey mudstone, which are in turn unconformably overlain by white, very coarse-grained sandstone. According to Beukes (1985) (as cited in MacRae, 1988), the mudstone to siltstone successions represent pro-delta successions, whilst the sandstone represents a delta front. The angular and sub-angular clasts are thought to represent debris rain deposits and indicate a glacial influence.

The Swartrand Formation, which belongs to Middle Ecca, consists of very coarse-grained sandstone, siltstone, mudstone and three coal seams. The coal seams or plies are named, from the bottom, ES1, ES2 and ES3 (Figure 5). The Swartrand Formation has an approximate thickness of 45 to 55m. The lower 20m consists of very coarse-grained sandstone with occasional cross-bedded, thin (1cm thick) siltstone and



mudstone layers (or lenses). Upward-fining sequences predominate, but upward-coarsening sequences are also present in the sandstone beds. The sandstone beds are arkosic towards their basal contacts, with rare mudstone flakes and mudstone clasts occurring at their basal contacts.

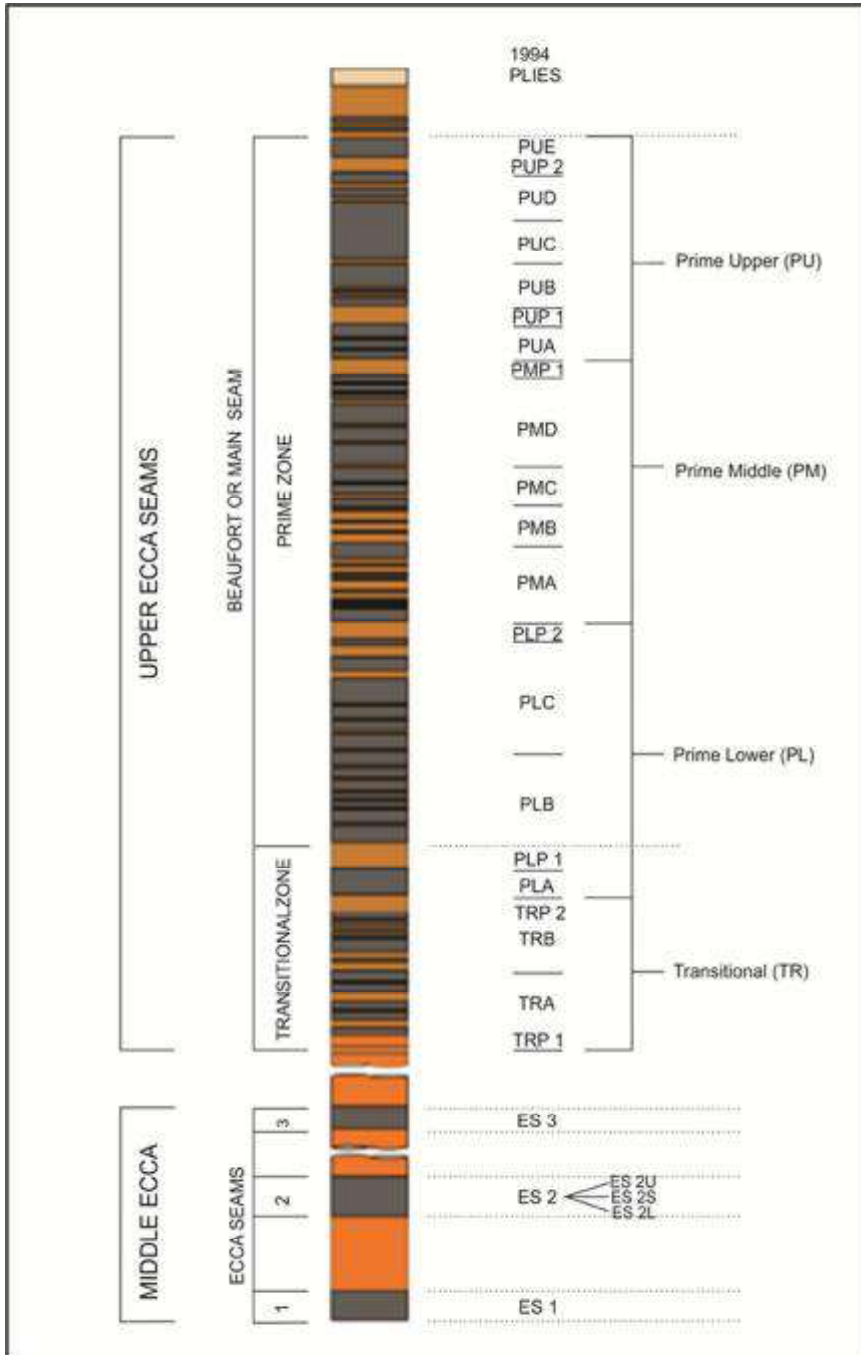


Figure 5: General stratigraphy of the Dalyshope project area (AATC, 2012) where the parting units are differentiated from coal plies by ending with letter P and a numerical number.

The ES 1 coal seam overlies the sandstone in the southern part of the area. This coal seam consists mainly of a dull, lustrous coal. A moderate amount of sulphides, mainly pyrite (FeS_2) in the form of discs and lenses, varying in size from microscopically fine up to 1 cm in diameter, occur on joints, cleats and bedding planes. Figure 6 shows examples of pyrite occurrences in ES1 that were observed in borehole core during collection of samples for environmental geochemical assessment.

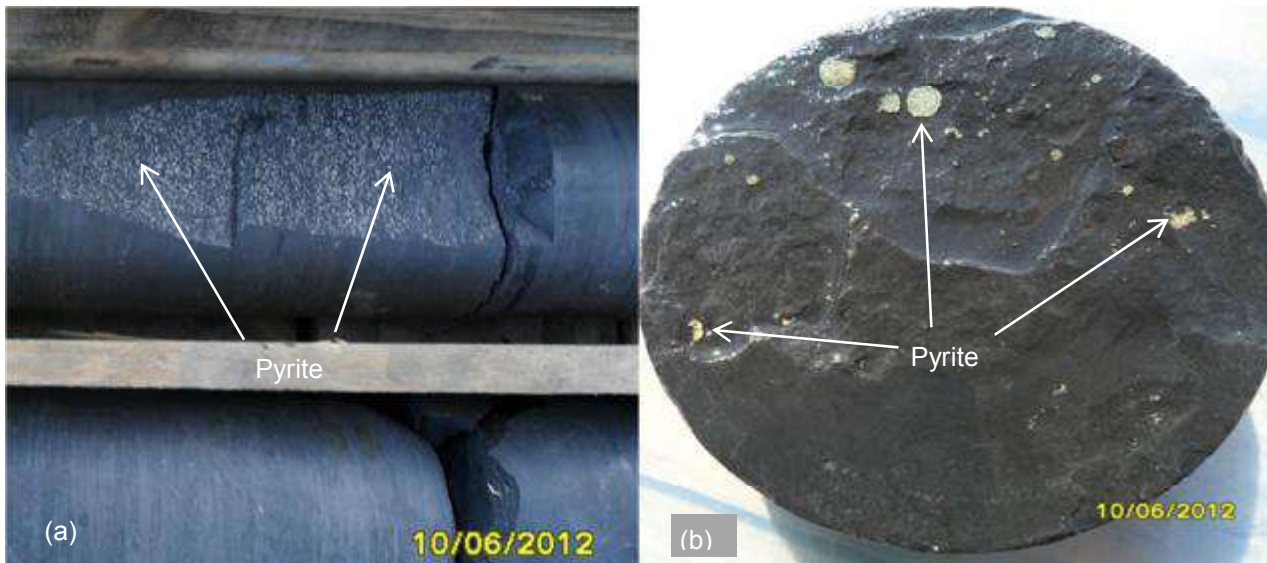


Figure 6: Pyrite on coal cleat (a) and bedding planes (b). The core diameter is approximately 6cm

Varying quantities of calcite (CaCO_3) occur mainly on joints and in cleats associated with the bright coal (Figure 7). Abundant siderite (FeCO_3) nodules, varying in size from fine (microsiderite) to approximately 3mm in diameter, occur scattered throughout the ES 1 coal seam (Figure 7).



Figure 7: Siderite nodules (brown spots) and calcite (white veins) in coal.

Due to erosion or non-deposition, the ES1 coal seam is not present in the northern parts of the area. The thickness of the ES 1 coal seam exceeds 1 m where it is fully developed. A thin (less than 0.5m thick), coarse-grained whitish-grey sandstone overlies the coal seam or channel fill sandstone where the ES 1 coal seam is not present. A sharp contact separates the sandstone unit from the overlying carbonaceous mudstone, which consists of scattered granules of quartz and granulestone lenses. Granulestone lenses are more abundant from the base and towards the middle of the unit. The unit is approximately 2.5 to 3m thick. The granular mudstone coarsens into a siltstone that coarsens into coarse-grained sandstone at the top. This coarsening-upwards sequence (2 to 4m thick) is in turn overlain by a 3.5 to 5m thick coal seam, locally known as the ES2 coal seam (Figure 5).

The ES 2 coal seam consists of three units namely, from bottom to top, a lower interbedded mudstone and coal of lower quality (ES2L), a select coal horizon consisting of dull to lustrous coal (ES2S), and an upper



unit consisting of interbedded mudstone and lower quality coal (ES2U). The zones are not always developed throughout the project area. The select bright coal unit of the ES 2 coal seam consists predominantly of bright coal with minor pyrite lenses and abundant siderite pellets.

Approximately 20 cm thick white sandstone overlies the ES 2 coal seam unconformably to the west and sharply towards east, where the mudstone unit of the ES 2 coal seam attains its maximum thickness. The lower 6 to 7m consists of white, very coarse-grained sandstone with mudstone and vitrinite intraclasts at erosional contacts, fining upwards, sometimes abruptly, into a siltstone or mudstone of up to 6m in thickness. A coal seam, locally known as the ES 3 is sporadically developed within this siltstone or mudstone unit.

The ES 3 coal usually consists of a dull, mudstone-rich coal. White, feldspar-rich, very coarse-grained sandstone overlies the ES3 coal. Upwards, the sandstone grades into siltstone or mudstone. Occasional pyrite and siderite nodules (Figure 8) are present in the sandstone unit, especially close to the contacts with coal seams. The thickness of the unit varies between 8 and 14m.

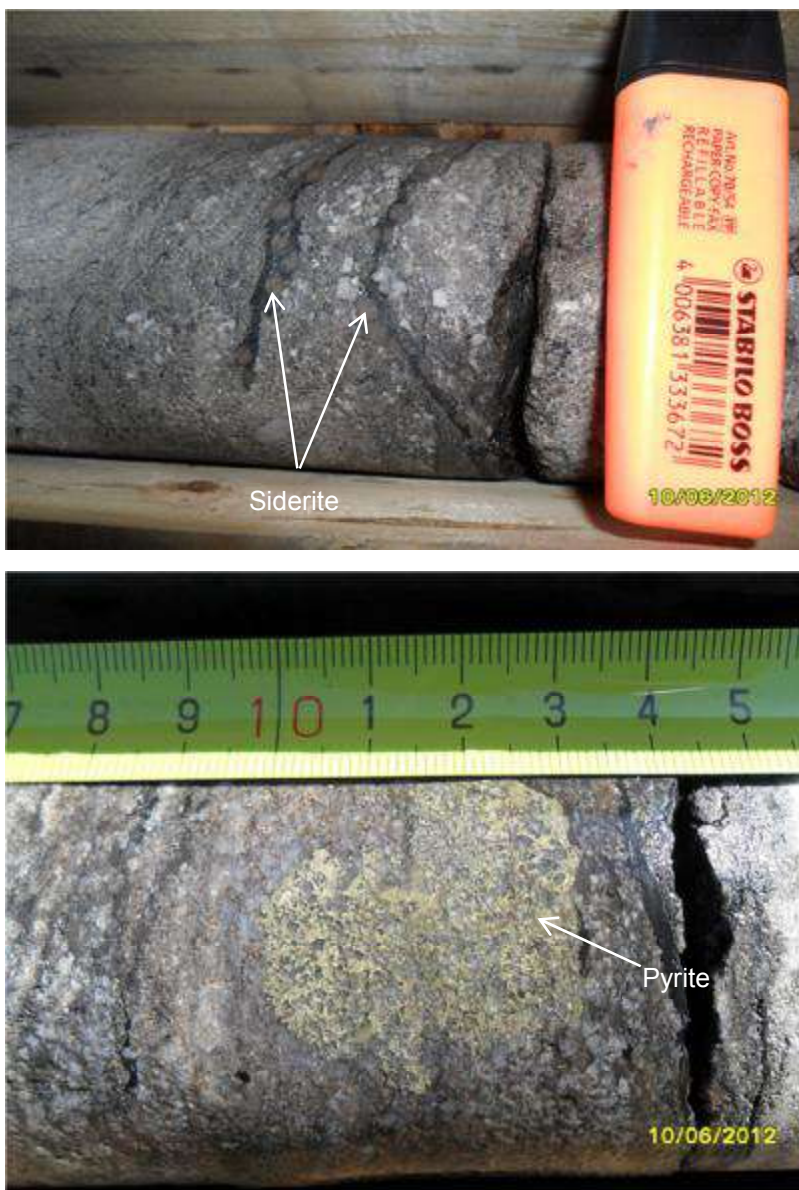


Figure 8: Siderite and pyrite in sandstone



The Swartrant Formation is thought to have been deposited in channel, splay and swamp depositional systems (Beukes, 1985 as cited in MacRae, 1988). This sandstone-dominated unit is overlain by a coal-mudstone succession of the Upper Ecca, Grootegeluk Formation.

The Upper Ecca Group consists of an 80–100m thick coal-mudstone succession. The coal-mudstone succession consists of alternating coal and mudstone layers varying in thickness from a few centimetres up to a few metres. The lower part of the Upper Ecca Group, named Transitional Zone, is approximately 25 m thick. This succession consists mainly of dull, lustrous coal bands alternating with dark grey, carbonaceous mudstone layers. In many instances, these rock units grade into one another. The top 65-70 m of the Upper Ecca is named the Prime Zone (Figure 5). This zone consists of bright coal and carbonaceous mudstone layers varying in thickness from a few centimetres to several metres. The contacts between these lithologies are usually sharp. A thin (less than 30cm thick), siltstone or silty mudstone is developed at the contact between the upper and lower portions of the succession.

The complete coal-mudstone succession has been divided into Prime Lower (PL), Prime Middle (PM) and Prime Upper (PU) Zones (Figure 5). These zones are further divided into coal plies (interbedding of coal and mudstone) [e.g. Prime Lower A (PLA), Prime Middle D (PMD), Prime Upper E (PUE) etc.]. The coal plies are separated by mainly mudstone partings [e.g. Prime Upper Parting (PUP1 and PUP2), Prime Lower Parting (PLP2) and Prime Middle Parting (PMP1) and occasionally, channel sandstone/siltstone occur in the parting units, especially in Prime Lower Parting 1 (PLP1) as shown in Figure 9. Some of the coal plies zones and partings occasionally pinch out and are therefore absent from the succession in certain places.



Figure 9: Channel sandstone parting (PLP1)

Pyrite, siderite and calcite are ubiquitous in the Upper Ecca coal plies. The pyrite occurs in various forms from veins, nodules as well as lenses; and is concentrated close to the contacts with the carbonaceous mudstone. Calcite occurs mostly on coal cleats in close association with both pyrite and siderite. This was confirmed in boreholes that were drilled for environmental geochemical characterisation (Figure 10 and Figure 11).

The Grootegeluk Formation is interpreted to have been deposited in distal, poorly drained flood basin marshes (Beukes, 1985 as cited in MacRae, 1988). However, the sub-millimetre to micron scale lamination developed in this coal is not fully explained by these types of depositional environments.

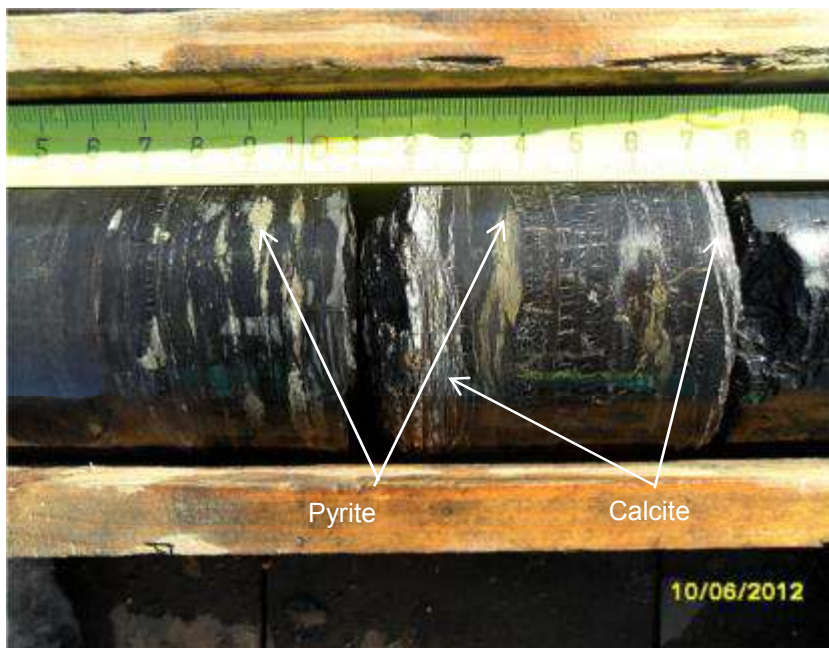


Figure 10: Pyrite (pale yellow) lenses in and calcite (white) in Upper Ecca coal ply



Figure 11: Calcite and siderite in Upper Ecca coal ply

4.4.2.3 Beaufort Group

The Eendragtpan Formation of the Beaufort group overlies the Ecca Group in the Dalyshope area. It consists of mudstone and/or variegated shale. In the southern portion of the Dalyshope Project area blue-grey massive mudstone with minor disseminated pyrite overlies the coal-mudstone succession. The overburden, approximately 30m thick, usually consists of yellow-brown clay.



4.4.2.4 Post Karoo Deposits

Sedimentary rocks younger than the Beaufort Group probably exist in the project area, but boreholes have so far not intersected these.

A calcrete layer of up to 3 m thick and Kalahari Sand overlies a weathering surface, which is up to 20 m deep. The calcrete is thought to be related to post Gondwana weathering surfaces (Van Niekerk et al., 1999), and rest on all units of the Karoo Supergroup stratigraphy, depending on erosion.

4.4.2.5 Faults and Igneous Intrusions

The Ellisras coalfield is structurally deformed, being dissected by numerous east-west and northwest-southeast trending faults (Figure 3). These have produced a series of horsts and grabens. No boreholes intersected dolerite and other mafic rocks in the Dalyshope Project area. However, basalts belonging to the Letaba Formation of the Stormberg Group, and feeder dolerites exist in the Ellisras basin.

4.5 Geochemical Context of Site Geology

The sulphide minerals e.g. pyrite, are formed as a result of deposition under reducing conditions. Consequently the minerals are stable under anoxic or reducing conditions, such as beneath the groundwater table. However, if rocks are dewatered or disturbed by mining, the sulphide minerals can oxidise to produce sulphuric acid. If there is sufficient pyrite in the disturbed rocks, the acid generation becomes significant and can result in a reduction in groundwater and surface water quality.

Carbonaceous rocks, including coal and carbonaceous mudstone are typically deposited under reducing conditions and they therefore often contain syndepositional pyrite. Pyrite is less common in sandstone and siltstone rock units (except if they contain carbonaceous material). A study by Vermeulen *et al.*, (2009) in the Ellisras Coalfield indicated the presence of sulphides, carbonates and silicate minerals in overburden and parting rock units to the west of Daaby fault, which includes the Dalyshope Project area.

Silicates, including quartz [SiO_2], kaolinite [$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$], illite [$(\text{K},\text{H}_3\text{O})(\text{Al},\text{Mg},\text{Fe})_2(\text{Si},\text{Al})_4\text{O}_{10}(\text{OH})_2 \cdot (\text{H}_2\text{O})$], smectite [$(\text{Mg},\text{Fe},\text{Al})_3(\text{Al},\text{Si})_4\text{O}_{10}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$], and chlorite [$(\text{Mg},\text{Fe},\text{Al})_6(\text{Si},\text{Al})_4\text{O}_{10}(\text{OH})_8$], were the most abundant and ubiquitous minerals in the area. These silicates are classified as intermediate (chlorite) to slow weathering, except for quartz, which is inert (Bowell *et al.*, 2000). Carbonates, in particular calcite [CaCO_3], ankerite [$\text{Ca}(\text{Fe},\text{Mg},\text{Mn})(\text{CO}_3)_2$] and siderite [FeCO_3] were also common. In terms of weathering rates, calcite is dissolving whilst ankerite and siderite are fast weathering. The study indicated that pyrite [FeS_2] was less common in overburden and parting rock units. The dissolving carbonates and slow weathering silicates can neutralise acid produced by pyrite oxidation. Siderite and to a lesser extent ankerite have limited neutralisation capacity under aerobic conditions due to the oxidation and hydrolysis of Fe producing equivalent acidity to that consumed by carbonates (Bowell *et al.*, 2000; MEND, 2009).

Exploration drilling in the Dalyshope Project area confirmed the presence of pyrite in coal, especially close to contacts with overburden and parting rock units. This implies that carbonaceous mudstone could also contain pyrite. Pyrite was also noted occasionally in sandstone (Figure 8). The pyrite occurred in various forms from fine grains to lenses and nodules (Figure 6 and Figure 10). The fine grained forms of pyrite are known to be very reactive. Thus, once the coal, overburden and parting are broken by mining, the acid potential of the rocks may be realised. This suggests a risk of ARD/ML generation in the project area. It should, however, be noted that the presence of calcite on cleat in close association with pyrite suggests a high neutralisation potential. Consequently, the net drainage quality from the proposed mine and waste facilities will depend on the balance between the acid generating minerals (pyrite) and neutralising minerals (carbonates and silicates).

A preliminary indication of the coal, overburden and parting acid potential is provided by the characteristics of the material that was sampled during the current study (Section 7.2).

4.6 Assay Geochemistry

Assay of five mudstone/carbonaceous mudstone (parting) and 22 coal samples from exploration borehole WBG0555 was provided by AATC (November 2012) for selected elemental concentrations. These have been used to assess the extent of elemental enrichment. Total sulphur assay data was also provided by



AATC (November 2012) for parting and coal from five exploration boreholes, namely WBG 0259, WBD0513, WBG0517 and WBG0555 (Figure 15). This data was used to assess variability in total sulphur concentration with depth and spatially across the sampled area.

4.6.1 Elemental Enrichment

The elemental enrichment was assessed with the aid of the geochemical abundance index (GAI), which compares the measured concentration of a particular element with the estimated median crustal abundance (INAP, 2012) using the following equation:

$$GAI = \log_2 [Cn / 1.5 \times Bn]$$

where Cn is the concentration of the element in the sample and Bn is the crustal abundance of that element. The GAI is expressed in integer increments from 0 through to 6, where:

- GAI=0 represents <3 times average crustal abundance;
- GAI=1 represents 3 to 6 times average crustal abundance;
- GAI=2 represents 6 to 12 times average crustal abundance;
- GAI=3 represents 12 to 24 times average crustal abundance;
- GAI=4 represents 24 to 48 times average crustal abundance;
- GAI=5 represents 48 to 96 times average crustal abundance; and
- GAI=6 represents more than 96 times average crustal abundance.

Average crustal abundances after Fortescue (1992) and Price *et.al.*, (1997) were used to develop the GAI of the parting and coal samples from Borehole WB0555 in the Dalyshope Project area (Table 1). Generally, a GAI of 3 or above is considered significant (INAP, 2012).

The following inferences can be made from Table 1:

- The GAI values of elements in parting and coal samples varied between GAI=0 and 6 indicating concentration ranges from less than or similar to average crustal abundances to approximately a 100-fold;
- The following elements were enriched in the parting units, with significant enrichments ($GAI \geq 3$) shown in bold:
 - § PUP2: B, Bi, Cd, Cs, Hg and **S**
 - § PUP1: As, B, **Bi**, Cs, F, **Hg** and S
 - § PMPI: As, B, **Bi**, F and S
 - § PLP2: As, B, **Bi**, Cs and S and
 - § PLP1: Al, As, B, **Bi**, Cd, and **S**

The rest of the enriched elements in the parting units had $GAI \leq 2$ indicating 3 to 12 times the average crustal abundance.

- Upper Eccla Coal was significantly enriched in As, Bi, Cs, Hg, Mo and S, with $GAI \geq 3$ and $GAI=6$ for S in 94% and 17% of the samples, respectively. Other enriched elements ($0 < GAI < 3$) in Upper Eccla Coal included B, Be, Cd, Ge, and P.



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

Table 1: GAI values of parting and coal samples from Dalyshope Project exploration borehole WBG0555

Sample ID	Seam ID	Material type	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr	Cs	Cu	F	Fe	Ga	Ge	Hg	K	La	Mg	Mn	Mo	P	S	Si	Ti	
0555AA	PUP2	Parting	0	0	0	1	0	0	2	0	1	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	
0555W	PUP1	Parting	0	0	1	2	0	0	3	0	0	0	0	1	0	1	0	0	0	3	0	0	0	0	0	0	0	2	0	0
0555U	PMP1	Parting	0	0	1	1	0	0	3	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	1	0	0	
0555N	PLP2	Parting	0	0	1	1	0	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
0555J	PLP1	Parting	0	1	1	1	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	
0555AB	PUE	Coal	0	0	5	2	0	0	2	0	1	0	0	3	0	0	0	0	2	3	0	0	0	0	3	2	6	0	0	
0555Z	PUD	Coal	0	0	1	2	0	0	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	4	0	0	
0555Y	PUC	Coal	0	0	0	2	0	0	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	
0555X	PUB	Coal	0	0	2	2	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	
0555V	PUA	Coal	0	0	3	2	0	0	2	0	0	0	0	3	0	0	0	0	0	2	0	0	0	0	1	0	6	0	0	
0555T	PMD	Coal	0	0	1	1	0	0	3	0	1	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	4	0	0	
0555R	PMC	Coal	0	0	1	1	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	
0555Q	PMB	Coal	0	0	1	1	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4	0	0	
0555P	PMA	Coal	0	0	1	1	0	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	
0555O	PMA	Coal	0	0	1	1	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	
0555M	PLC	Coal	0	0	2	1	0	0	3	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	3	0	0	
0555L	PLC	Coal	0	0	1	1	0	0	3	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4	0	0	
0555K	PLB	Coal	0	0	1	1	0	0	3	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	5	0	0	
0555I	PLA	Coal	0	0	0	1	0	0	4	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	3	0	0	
0555H	PLA	Coal	0	0	1	1	0	0	3	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	1	2	4	0	0	
0555G	TRB	Coal	0	0	0	1	0	0	4	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	
0555F	TRA	Coal	0	0	2	1	0	1	3	0	1	0	0	1	0	0	0	0	1	3	0	0	0	0	1	0	6	0	0	
0555E	ES3	Coal	0	0	0	1	0	1	3	0	1	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	
0555D	ES3	Coal	0	0	0	1	0	0	3	0	1	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	4	0	0	
0555C	ES2	Coal	0	0	0	1	0	0	3	0	1	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	3	0	0	
0555B	ES2	Coal	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	6	0	0	
0555A	ES1	Coal	0	0	0	0	0	0	2	0	1	0	0	5	0	0	0	0	2	4	0	0	0	0	0	0	4	0	0	

Bold values indicate significant enrichments



❖ Middle Eccla Coal was significantly enriched in Bi, Cs, Hg and S, with GAI=6 for S in ES2 seam. Though not significant, the coal was also enriched in B, Be, Cd, Ge and Mo with concentrations between 3 and 12 times the average crustal abundance.

The elemental concentrations have also been shown as a ratio against the average crustal concentration (Smith and Huyck, 1999) in Figure 12.

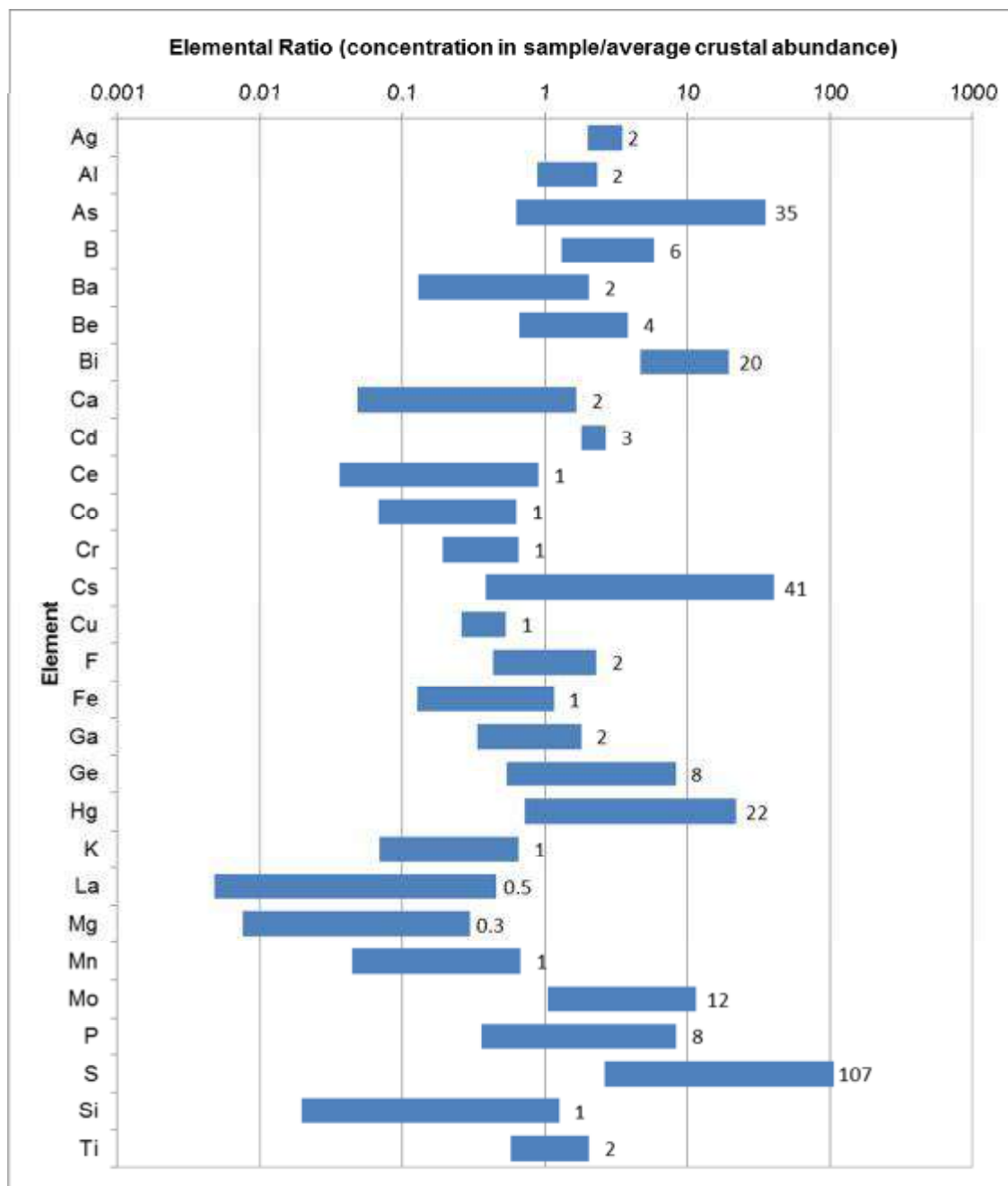


Figure 12: Ratios of Dalyshope parting and coal elemental concentrations against crustal average concentrations

Elements that exceed the crustal average by more than 10 times are: As, Bi, Cs, Hg, Mo and S. These elements are potential constituents of interest (COI) as they are environmentally significant elements. Mineralogical analysis is required to assess potential sources of the elements. Leaching tests are also required to assess mobility of these elements from mine wastes during and after mining.

All the other elements tested were present in concentrations similar to, or less than, the crustal average.



4.6.2 Total Sulphur Variability

Vertical (depth) profiles of total sulphur concentrations were plotted using four AATC exploration boreholes assay data. The data for boreholes WBG0513, WBG0517, WBG0555 and WBG0259 was plotted to assess the variation of total sulphur concentration with depth (Figure 13) and in similar lithological units between boreholes (Figure 14), respectively. The following inferences are made from Figure 13:

- Both Middle and Upper Eccla coal has a higher and wider range of Total sulphur concentration (0.13-4.07%) compared to all parting units, which have concentrations varying between 0.07% and 1.03%.
- In general, relatively high concentrations of Total sulphur occur within a depth of 55 meters from the surface in all the boreholes.
- Though the highest concentration values of Total sulphur were recorded for Upper Eccla Coal in all the boreholes, there is no marked difference in Total sulphur distribution patterns between Middle and Upper Eccla Coal.
- Except for borehole WBG0259, the concentrations of Total sulphur do not vary significantly with depth.

The following inferences are made from Figure 14:

- Very high Total sulphur concentrations (>2.5%) were recorded in Upper Eccla coal plies PUE, PUA, PMB, TRA and Middle Eccla coal seams ES2 and ES1, respectively.
- Total sulphur concentration in selected coal plies and parting units showed low variation between the four boreholes suggesting minimal spatial variation in Total sulphur distribution in the sampled area. Exceptions were:
 - § Upper Eccla coal plies: PMB (0.13-3.4%) and PLB (0.22-2.3%)
 - § Middle Eccla coal seams: ES1 (0.95-3.47%) ES2 (0.19-3.21) and
 - § Parting unit: PMP1 (0.09%-1.03%).
- Figure 13 and Figure 14 indicates that despite the similar vertical profile trends amongst the four boreholes, small shifts in depth (start and end depths) occur for selected geological strata (mainly in the Upper Eccla Group compared to Middle Eccla Group) due to the palaeotopography.

4.7 Concept level mining considerations

It is understood that the proposed Dalyshope mine will be an open-pit. The mine will consist of four pits (Figure 15) and mining will be done in phases by truck and shovel operations, with the first phase taking place in Pit 2. Except for the proposed pit areas (Figure 15), no detailed mine plans for the proposed mine facilities have been developed yet for the Dalyshope Project. It is also not yet known how mine and processing waste materials will be handled.

The following assumptions guided the development of the preliminary sampling plan

- Both the Middle Eccla and Upper Eccla coal seams will be extracted by open-pit operations. Hence the whole sequence will be exposed on the pit wall surfaces;
- The overburden and parting rock units will constitute waste rock material;
- Coal fines and discard, including the thin interbedding mudstone units will be produced during coal processing.



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

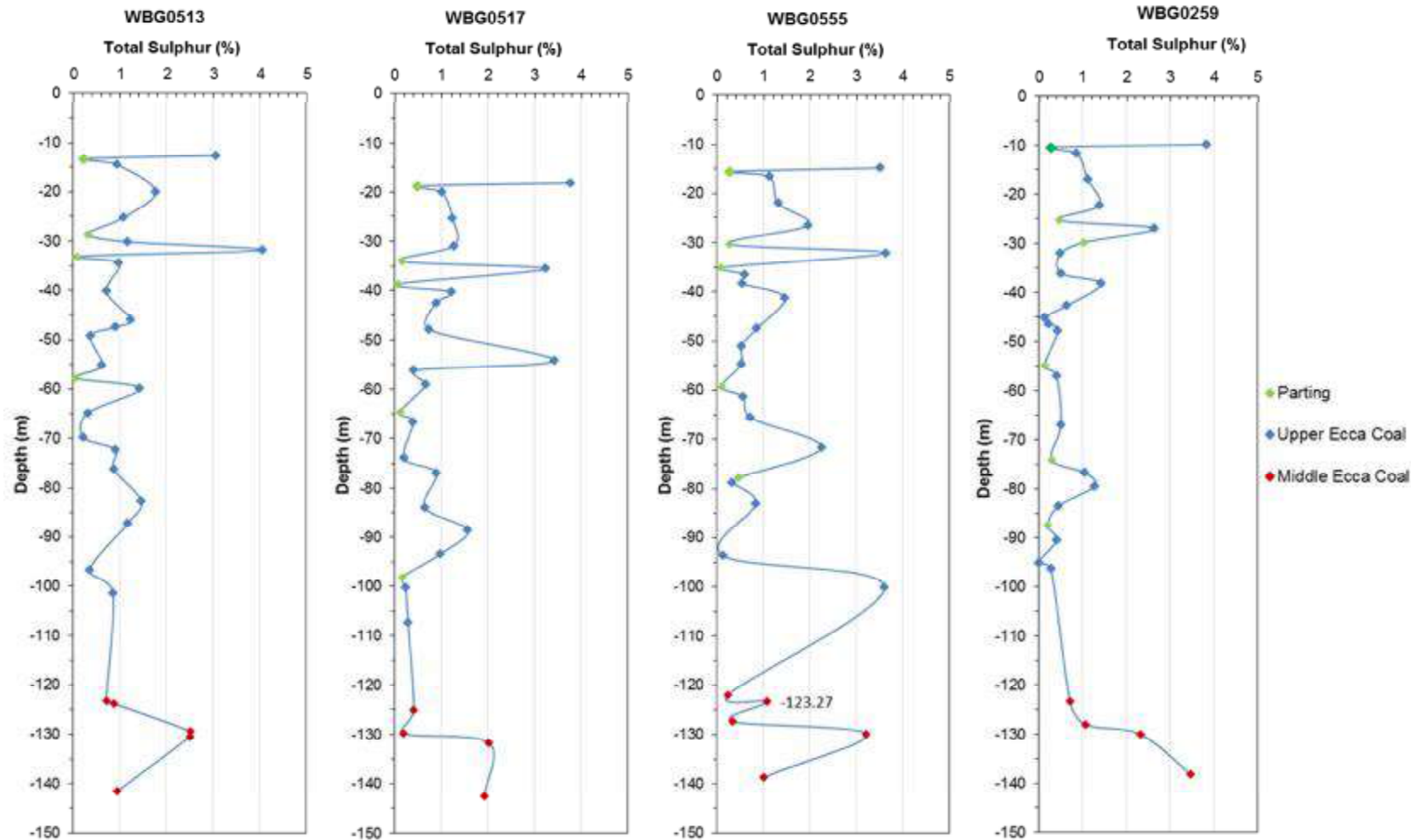


Figure 13: Variation of Total sulphur concentration with depth

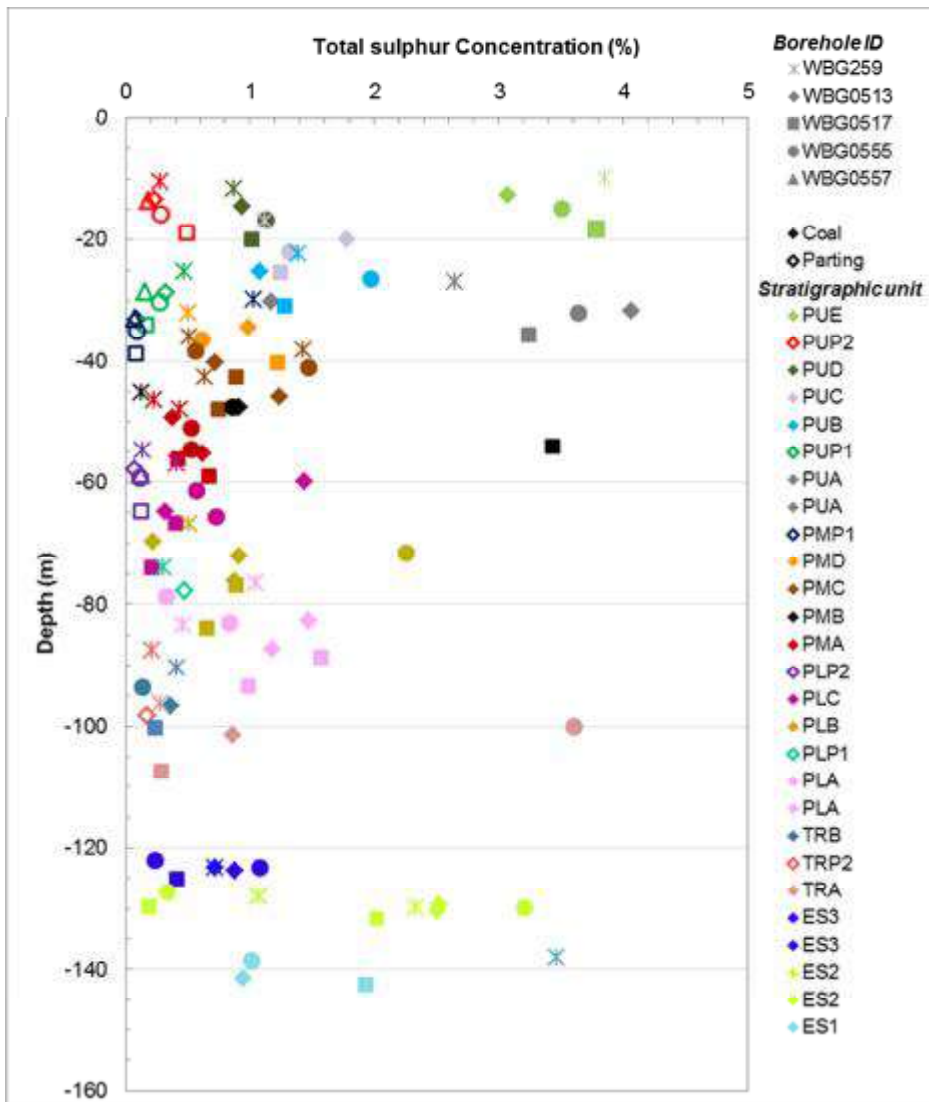


Figure 14: Plot of Total sulphur for Dalyshope exploration boreholes. Parting samples are shown as open shapes and coal seams as filled shapes.

5.0 SAMPLING

5.1 Sampling Plan

No acid rock drainage (ARD) potential characteristics were available prior to this assessment for Dalyshope Mine, beyond the indication from the study by Vermuelen et. al., (2009) that ARD could be expected from overburden, parting and coal discard.

Mine planning is currently between the exploration and pre-feasibility stages. Therefore, this concept level ARD assessment focussed on identifying the general ARD characteristics of the potentially mining-disturbed units to give guidance for representative sampling that is intended to be conducted in the pre-feasibility and feasibility stages.

According to the GARD Guide, at the exploration stage, 3 to 5 samples per key material type (INAP, 2012) is recommended. The key guiding principle for sampling is that the sample set should be sufficient to achieve compositional and spatial representativeness of the sampled units

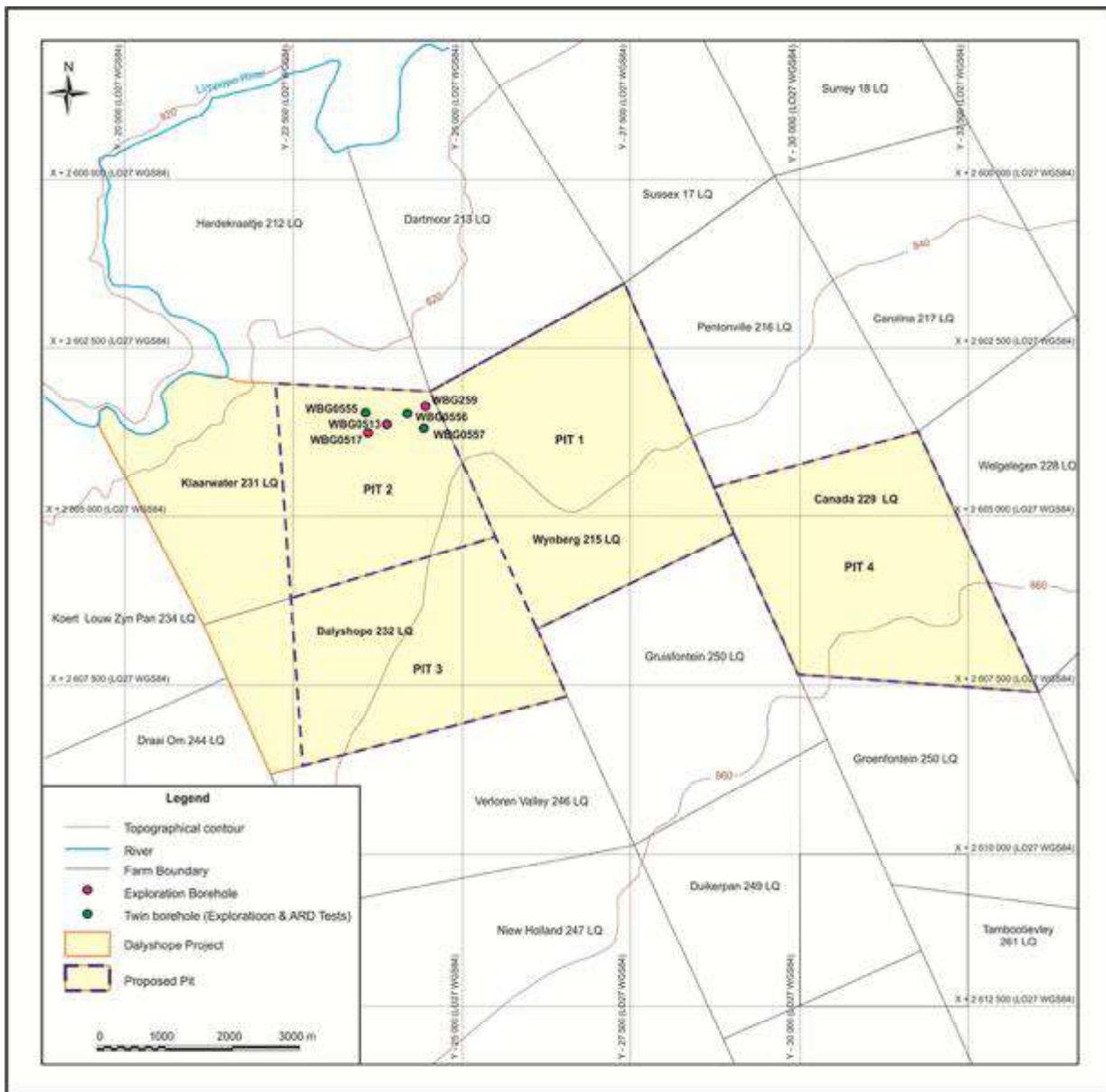


Figure 15: Location of exploration/ARD assessment boreholes and proposed open-pits at Dalyslope

Practical considerations regarding the sampling strategy are as follows:

- Sufficient samples should be collected and analysed to determine the statistical distributions of relevant geochemical parameters;
- Sampling is an iterative process that, based on the statistical variance and required confidence level, can have multiple phases;
- The number of samples and sample size is determined by the available sample material which is directly determined by the mining phase; and
- The selection of an appropriate number of samples should be guided by site specific information and use of statistical guidance. Guidelines based on the stage of mine planning are presented in the Global Acid Rock Drainage (GARD) Guide (INAP, 2012). Such guidelines can be used as a starting point after which statistical methods can be used to determine statistical variance and confidence limits.

Three boreholes (WBG0555, WBG0556 and WBG0557) with complete stratigraphic profile were made available for geochemical sampling by AATC. These boreholes were drilled next to exploration boreholes



(twin holes) to ensure that samples for resource evaluation were not compromised since the whole coal unit is required for coal assaying and coal samples were also needed for the ARD assessment. All the boreholes were located in the proposed Pit 2 area (Figure 15).

5.2 Sample collection and handling

A site visit by a Golder geochemist was conducted from 13 to 15 June 2012 during which the samples identified in the sampling plan were collected for ARD assessment. The borehole core had been clearly labelled, sealed in polythene bags and stored under cover. The samples were relatively unexposed to oxidising conditions and moisture, which could affect the environmental geochemical analysis.

The whole sequence comprising overburden, interbedding, parting and coal units from the Beaufort Group to the base of Middle Eccla Group coal seams (Figure 5) was identified for sample collection (Table 2).

A total of 41 composite samples were collected from the three boreholes. Since provision had been made for only 20 samples, including duplicates, it was necessary to composite further the samples. The compositing of lithologically similar units (stratigraphic zones) from all three boreholes was done in the field. The following methodology was followed during sample collection to obtain discrete and composite samples:

- i Collection of composite samples in each borehole- This was carried out by combining sub-samples from a distinct stratigraphic unit or lithologically similar rock units from a borehole after MEND (1994) guidelines:
 - § Discrete sub-samples, approximately 20 cm long, were collected from the top and bottom contacts as well as in the middle of the stratigraphic unit for each parting unit in the Upper Eccla sequence. The parting units were generally less than one and half meters long.
 - § Weathered and fresh overburden in the Upper Eccla and Middle Eccla Parting units were generally more than one and half meters long. Discrete sub-samples were collected at a meter interval and at the top and bottom contacts and were combined into a composite sample for each lithological unit.
 - § Upper Eccla coal and interbedding sub-samples were collected randomly across the whole sequence from PUE to TRA. These were combined into a composite sample of interbedding and coal, respectively from each borehole.
 - § Middle Eccla coal sub-samples from ES1, ES2 and ES3 were combined into a composite sample from the each borehole.

An understanding of the spatial variability of rock units across the project area was based on observations by AATC geologists during exploration drilling core logging. Compositing was done for stratigraphic units that were observed to be consistently similar in all the three boreholes by combining composite samples from each borehole. The other units, specifically Prime Lower Parting (PLP1) and Transitional Parting 2 (TRP2), which varied from one borehole to another due to presence or absence of channel sandstone, siltstone or both (Figure 16, Table 2 and Appendix B), were not composited further, i.e. across boreholes. These two stratigraphic units are known to vary while the other units are observed to be generally similar across the project area (Dube and Wakerman, pers.com).

The samples were placed in clean PVC bags and were tightly sealed. A total of 19 samples were sent to UIS (Pretoria) and SGS (Johannesburg) laboratories for crushing and ABA analysis, respectively. The samples included 12 composite, six discrete samples (Table 2) and a duplicate.

It should be noted that compositing limited the assessment of spatial variability in acid potential risk potential for physically similar rock units. However, the samples were considered sufficient to provide an indicative ARD potential risk at a conceptual level. Additional sampling of the various lithological units from more boreholes covering the whole proposed mine area will be required to establish spatial variability and the variation in geochemistry on a statistical basis.



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

Table 2: Dalyshope Geochemical samples

* Composite sample ID	Sub-sample ID	Borehole ID	Depth		Stratigraphic Unit/Code	Rock type
			From	To		
DHWO-C	WO(5)	WBG0555A	0.84	11.37	Weathered Overburden	Mudstone
	WO(6)	WBG0556A	1.7	5.85		
	WO(7)	WBG0557A	0.35	8.5		
DHFO-C	FO(5)	WBG0555A	11.37	14.87	Fresh Overburden (FO)	Mudstone, carbonaceous towards bottom contact
	FO(6)	WBG0556A	5.85	11.69		
	FO(7)	WBG0557A	8.5	12.8		
DHPUP2-C	PUP2(5)	WBG0555A	15.63	16.68	PUP2	Mudstone
	PUP2(7)	WBG0557A	13.51	14.55		
DHPUP1-C	PUP1(5)	WBG0555A	30.27	32.06	PUP1	Mudstone banded and carbonaceous
	PUP1(6)	WBG0556A	22.10	23.49		
	PUP1(7)	WBG0557A	28.54	29.90		
DHPMP1-C	PMP1(5)	WBG0555A	35.03	36.43	PMP1	Mudstone
	PMP1(6)	WBG0556A	26.73	28.40		
	PMP1(7)	WBG0557A	32.85	34.70		
DHPLP2-C	PLP2(5)	WBG0555A	59.25	61.30	PLP2	Carbonaceous mudstone
	PLP2(6)	WBG0556A	51.10	53.13		
	PLP2(7)	WBG0557A	58.67	60.80		
DHPLP1(5)		WBG0555A	77.68	78.74	PLP1	Banded Mudstone
DHPLP1(6)		WBG0556A	71.88	77.20		Banded Mudstone/Siltstone
DHPLP1(7)		WBG0557A	80.40	83.43		Mudstone/Siltstone/Sandstone
DHTRP2(5)		WBG0555A	90.80	93.66	TRP2	Carbonaceous Mudstone/Siltstone
DHTRP2(6)		WBG0556A	85.70	91.95		Mudstone/Siltstone/Variegated Sandstone
DHTRP2(7)		WBG0557A	91.60	96.20		Banded Sandstone/Siltstone
DHUSF-C	TRP1(5)	WBG0555A	101.00	101.32	Upper Eccca Coal Floor (USF)]	Siltstone
	TRP1(6)	WBG0556A	97.50	97.79		Siltstone/Sandstone
	TRP1(7)	WBG0557A	102.36	104.24		Siltstone/Sandstone
DHUC-C	UEC(5)	WBG0555A	14.98	101.25	Upper Eccca Coal (UC)	Coal
	UEC(6)	WBG0556A	12.68	97.25		Coal
	UEC(7)	WBG0557A	12.74	102.29		Coal
DHICM-C	CIB(5)	WBG0555A	14.98	101.25	Upper Eccca Coal Interbedding (CIB)	Carbonaceous Mudstone
	CIB(6)	WBG0556A	12.68	97.25		
	CIB(7)	WBG0557A	12.74	102.29		
DHMS-C	MS(5)	WBG0555A	102.09	121.55	Parting above ES3 (MS)	Sandstone/Siltstone
	MS(6)	WBG0556A	97.57	122.64		
	MS(7)	WBG0557A	105.54	126.44		
DHSD-C	SD(5)	WBG0555A	138.34	140.97	Middle Eccca Coal Floor (SD1)	Sandstone
	SD(6)	WBG0556A	137.00	143.52		Sandstone
	SD(7)	WBG0557A	139.44	143.52		Sandstone
DHESC-C	ES1, ES2 and ES3	WBG0555A	122.13	139.54	Middle Eccca Coal (ESC)	Coal
		WBG0556A	122.64	139.62		
		WBG0557A	126.44	142.35		

*C = composite sample resulting from combining sub-samples from all three boreholes; (5) = WBG0555, (6) = WBG0556, (7) = WBG0557

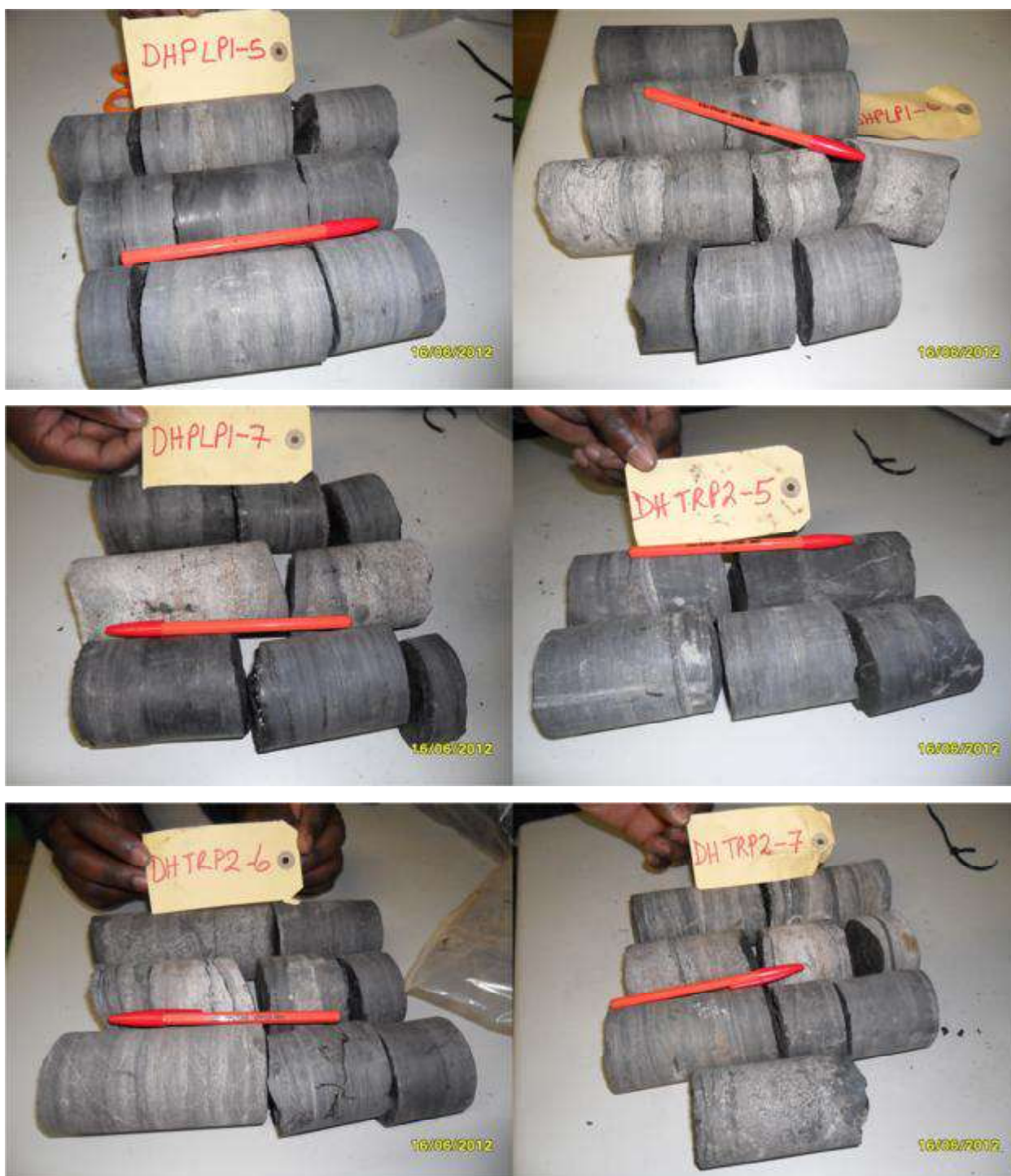


Figure 16: Variations of PLP1 and TRP2 parting units in boreholes 0555A (5), 0556A (6) and 0557A (7), respectively

5.2.1 Quality Assurance and Quality Control

The following measures were implemented during sample collection and handling to improve quality assurance and quality control:

- The geological samples were collected with assistance from the AATC exploration geologist to ensure consistency in the sampling and naming of the various stratigraphic units.



- One duplicate sample was submitted to the lab for quality assurance / quality control purposes, representing approximately 6% of the total sample complement. The sample was obtained after pulverisation.

By following these methods it is assumed that observed variation in the analytical results for the set of duplicate samples will relate primarily to analytical error rather than to sampling error or bias.

6.0 ANALYTICAL METHODS

This concept level study allowed for only acid base accounting testing of selected lithological units from Dalyshope project. It should be emphasised that more static testing, including mineralogical analysis, short term leach and net acid generation (NAG) tests respectively, are required in the subsequent phases of mine planning. This is necessary to assess metal leaching potential from the pit(s) and proposed waste storage facilities. Additionally, kinetic testing will be required if any of the geological materials that classify as Potentially Acid Generating (PAG) or Uncertain acid generating characteristics.

6.1 Acid Base Accounting

Acid base accounting (ABA) tests were conducted to predict the samples' acid neutralising potential (NP) and acid generation potential (AP). ABA analysis included determination of the following:

- Paste pH in a mixture of distilled water and pulverised sample;
- Modified Sobek (Lawrence and Wang 1996) neutralization potential (NP) by acid digestion and base titration;
- Total carbon (TC) and carbonate (CO₃) concentrations by LECO analyser; and
- Acid potential (AP) by sulphur determination (total sulphur-S (T); sulphide sulphur-S(S-2); and sulphate sulphur-S (SO₄).

SGS South Africa calculated the sulphide sulphur concentration by difference of sulphate and total sulphur concentration as determined by LECO. Sulphide sulphur, elemental sulphur and organic sulphur fractions in the sample are converted to SO₂ by pyrolysis (roasting the sample at high temperature). The remaining sulphur after pyrolysis is assumed to be sulphate sulphur. This method results in overestimation of sulphide sulphur in samples containing organic sulphur in significant quantities (e.g coal and carbonaceous units) as this sulphur specie will also be oxidised by the roasting process. Hence the organic sulphur concentration will be incorporated in the sulphide sulphur fraction.

7.0 ANALYTICAL RESULTS AND INTERPRETATION

7.1 Evaluation of Sampling and Laboratory Methods Quality Assurance/Quality Control

The results of the laboratory testing done on the samples are presented in this section. The quality of the analytical data was evaluated by assessing the relative percent difference (RPD) of the duplicate sample pair according to the following equation:

$$RPD\% = \frac{X1-X2}{X_{ave}} \times 100$$

Where:

X1 = concentration observed in the first sample;

X2 = concentration observed in duplicate sample; and

X_{ave} = average concentration = $\frac{X1+X2}{2}$

The RPDs of standard ABA parameters, sulphur and carbon species are presented in Table 3.



Table 3: Quality assessment of the ABA laboratory results

Sample ID	Paste pH	Total Sulphur	Sulphide Sulphur	Sulphate	Total Carbon	Carbonate	NP
Units	s.u	%S	%S	%SO ₄	%C	%CO ₃	kg CaCO ₃ /t
DHSD1-C	6.4	0.68	0.53	0.47	1.73	0.21	7.8
*DHSD2-C	6.2	0.72	0.54	0.56	1.87	0.21	8.3
RPD (%)	3.2	-5.7	-1.9	-17.5	-7.8	0	-6.2

*Duplicate sample

Table 3 shows that the RPDs of all parameters were within ± 30%, which is considered an acceptable limit for solid matrix samples (USEPA, 1994). Thus the quality of the laboratory results is satisfactory.

7.2 Acid-Base Accounting Results

Acid Base Accounting (ABA) analysis indicates the relative proportions of acid generating and acid neutralising components of a sample. The ABA test indicates the potential for a system to generate acidity and does not take into account mineral reaction kinetics. The ABA laboratory results (overburden, interbedding, parting and coal) including sulphur and carbon speciation, acid potential (AP) and Modified Sobek titratable neutralisation potential (BulkNP) are provided in Table 4 and Appendix C.

The paste pH of the overburden, interbedding and parting samples were found to be acidic to alkaline (5.9 to 8.1). Acidic to slightly acidic pH values were recorded (Figure 17 for parting units PLP1 and TRP2 as well as Middle Eccla coal floor (ESC). All the other lithological units had neutral to alkaline pH with the highest pH being recorded for weathered overburden (WO) sample. Both Middle Eccla (ESC) and Upper Eccla (UC) coal samples had neutral pH (7.2). There was generally negative correlation of paste pH and sulphide concentration in parting, overburden and interbedding, with low pH values being associated with high sulphide values. There was no correlation of paste pH and sulphide concentration in the coal samples (Figure 17) suggesting pH control by NP or dominance of organic sulphur form.

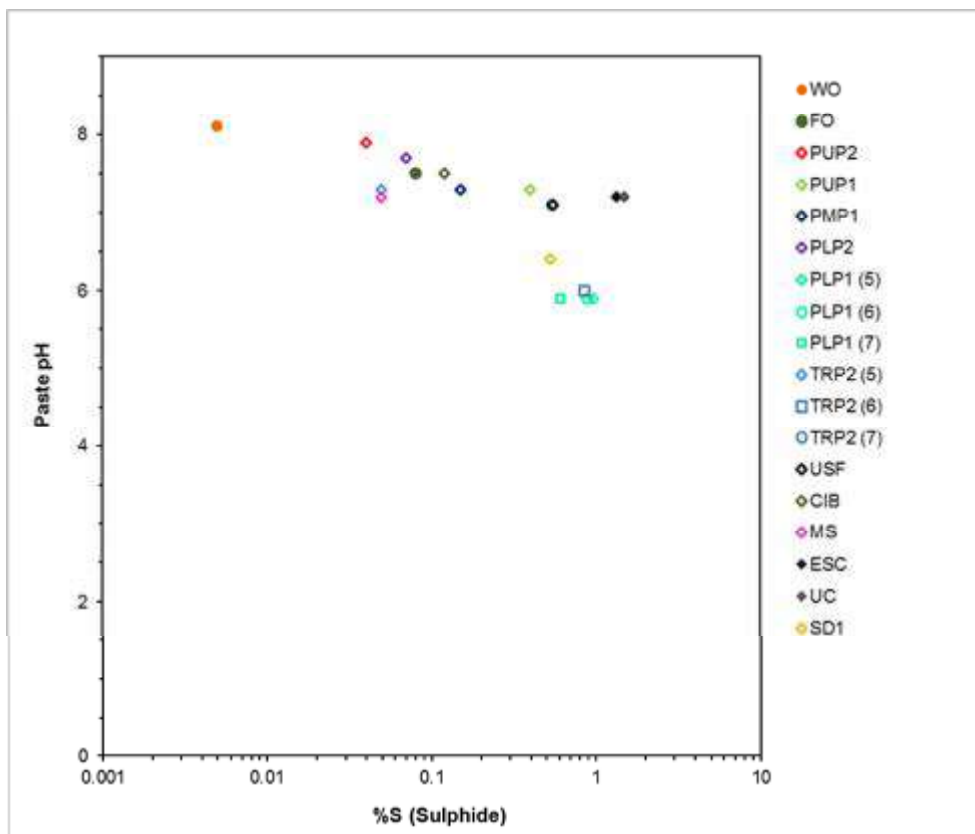


Figure 17: Paste pH versus sulphide concentration in Dalyshope coal, overburden, parting and interbedding



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

Near neutral to alkaline paste pH recorded for 72% of the overburden, interbedding, parting and coal samples indicate that there are generally sufficient reactive neutralisation minerals to buffer acidity generated by the initial oxidation of sulphides. The remaining samples were found to have acidic paste pH and had insufficient neutralisation minerals present. Mineralogy analysis is required to confirm the neutralising minerals present the overburden, interbedding, parting and coal samples. Although observations of carbonates, in particular siderite and calcite, were noted in the overburden, parting and coal during sampling (Figure 8 and Figure 11) and are known to buffer acidity in the 5.5-11 and 6-11.2 pH ranges, respectively (Sverdrup, 1990; Bowell et. al, 2000). Though ankerite was not observed during sampling, it could also be present in coal, overburden and parting rock units at Dalyshope as it occurs in the Waterberg Coalfield (Vermeulen et. al., 2009).

Total sulphur concentration was 0.02% and 0.13% in weathered and fresh overburden composite samples, respectively. The concentrations varied between 0.09% and 1.0% in parting units. The mean concentration in the parting was 0.51%. The lowest total sulphur was recorded in weathered mudstone (WO) and the highest was recorded in banded mudstone (PLP1 from borehole WB0555A, PLP1-5). Total sulphur concentration in the Middle Ecca (ESC) and Upper Ecca (UC) coal was 1.6% and 2.2%, respectively.

Table 4 indicates that the reactive sulphur concentration (% sulphide sulphur) ranged from 0.05% to 0.97% in overburden, interbedding and parting samples. The mean concentrations were 0.43% and 0.44% in overburden and parting, respectively. The lowest (<0.1%, set at half detection limit or 0.05%) and highest sulphide concentration were recorded in lithological units with lowest and highest total sulphur concentrations, respectively. Relatively high sulphide concentrations of 1.4% and 1.5% were recorded in ESC and UC coal samples, respectively. Sulphate sulphur concentrations varied between 0.013% and 0.16% in overburden and parting. The mean concentrations were of 0.035% and 0.069% in overburden and parting, respectively. The sulphate sulphur concentration was 0.25% and 0.67% in ESC and UC coal samples, respectively.

Scatterplots indicating relationships between the different sulphur species are presented in (Figure 18), (Figure 19) and (Figure 21).

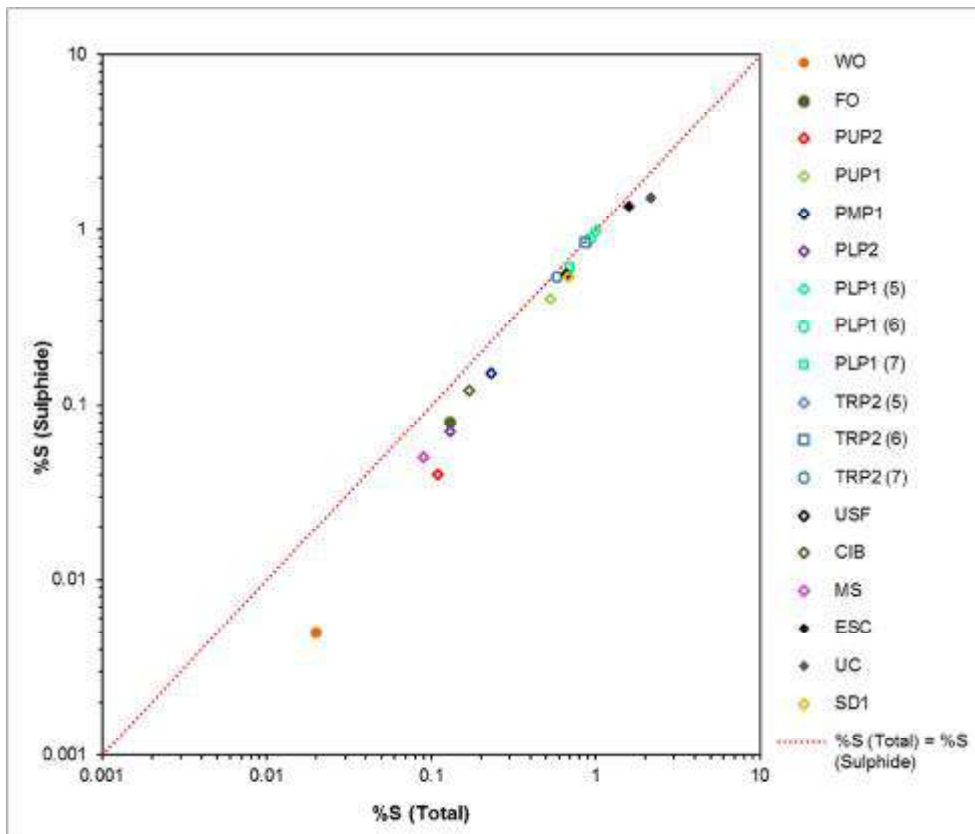


Figure 18: Sulphide sulphur versus total sulphur in Dalyshope samples

DALYSHOPE MINE ARD POTENTIAL ASSESSMENT DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

Table 4: ABA analytical results and calculations

Stratigraphic Zone	Material Type	Rock Type	Sample ID	Paste pH	Total sulphur	Sulphide	Sulphate		Total carbon	Carbonate	¹ BulkNP	² CaNP	³ TAP	⁴ SAP	⁵ SNNP	⁶ TNNP	⁷ SNPR	⁸ TNPR	Classification (Based on SNPR)
				s.u	%S	%S	%SO ₄	%S	%C	%CO ₃	⁹ kg/t				no units				
Upper Ecca	Overburden	Mudstone (weathered)	DHWO-C	8.1	0.02	0.005	0.04	0.013	1.2	4.0	93	66	0.63	0.16	93	92	595	149	Non-PAG
		Mudstone	DHFO-C	7.5	0.13	0.08	0.17	0.057	1.2	1.1	27	17	4.1	2.5	25	23	11	6.6	Non-PAG
	Parting	Mudstone	DHPUP2-C	7.9	0.11	0.04	0.22	0.073	2.6	0.94	35	16	3.4	1.3	33	31	28	10	Non-PAG
		Mudstone (banded and carbonaceous)	DHPUP1-C	7.3	0.53	0.4	0.37	0.12	8.6	0.35	8.8	5.8	17	13	-3.7	-7.8	0.70	0.53	PAG
		Mudstone	DHPMP1-C	7.3	0.23	0.15	0.25	0.083	3.9	0.11	5.1	1.8	7.2	4.7	0.41	-2.1	1.1	0.71	Uncertain
		Carbonaceous mudstone	DHPLP2-C	7.7	0.13	0.07	0.18	0.06	12	1.2	21	19	4.1	2.2	19	17	9.8	5.3	Non-PAG
		Mudstone (banded)	DHPLP1-5	5.9	1.0	0.97	0.1	0.033	5.5	0.30	2.7	5.0	31	30	-28	-29	0.089	0.086	PAG
		Mudstone/siltstone	DHPLP1-6	5.9	0.93	0.89	0.13	0.043	3.6	0.21	1.0	3.5	29	28	-27	-28	0.036	0.034	PAG
		Mudstone/siltstone/sandstone	DHPLP1-7	5.9	0.69	0.61	0.24	0.080	7.2	0.28	2.0	4.7	22	19	-17	-20	0.10	0.093	PAG
		Carbonaceous mudstone/siltstone	DHTRP2-5	7.3	0.09	0.05	0.1	0.033	3.1	0.94	12	16	2.8	1.6	11	9.6	7.9	4.4	Non-PAG
		Mudstone/siltstone/variegated sandstone	DHTRP2-6	6.0	0.87	0.85	0.07	0.023	3.7	0.16	-0.20	2.7	27	27	-27	-27	0.0094	0.0092	PAG
		Banded sandstone/siltstone	DHTRP2-7	7.1	0.58	0.54	0.12	0.040	3.1	0.40	21	6.7	18	17	4.5	3.3	1.3	1.2	Uncertain
		Siltstone/sandstone	DHUSF-C	7.1	0.66	0.55	0.34	0.11	4.0	0.28	7.0	4.7	21	17	-10	-14	0.41	0.34	PAG
		Interbedding	Carbonaceous mudstone	DHICM-C	7.5	0.17	0.12	0.13	0.043	11	0.37	7.1	6.2	5.3	3.8	3.4	1.8	1.9	1.3
Coal	Coal	DHUC-C	7.2	2.17	1.5	2.01	0.67	44	2.2	58	36	68	47	11	-10	1.2	0.85	Uncertain	
Middle Ecca	Parting	Sandstone/siltstone	DHMS-C	7.2	0.09	0.05	0.11	0.037	0.61	0.22	9.3	3.7	2.8	1.6	7.7	6.5	6.0	3.3	Non-PAG
		Sandstone	DHSD1-C	6.4	0.68	0.53	0.47	0.16	1.7	0.21	7.8	3.5	21	17	-8.8	-13	0.47	0.37	PAG
		Sandstone	*DHSD2-C	6.2	0.72	0.54	0.56	0.19	1.9	0.21	8.3	3.5	22.5	17	-8.6	-14	0.49	0.37	PAG
	Coal	Coal (ES1-3)	DHESC-C	7.2	1.6	1.4	0.75	0.25	49	0.97	24	16	50	42	-18	-26	0.57	0.48	PAG

Notes:

¹The NP measured by Modified Sobek method is indicated by the BulkNP value. NP measured is used for the NPR calculation.

²Carbonate NP (CaNP) is based on the Leco carbonate percentage.

³Total acid potential (TAP) = acid potential based on the total sulphur content.

⁴Sulphide acid potential (SAP) = acid potential based on sulphide sulphur.

⁵The Sulphide Net Neutralising Potential Ratio (SNNP) = is the difference between BulkNP and SAP.

⁶Total Net Neutralising Potential Ratio (TNNP) = is the difference between BulkNP and TAP

⁷The Sulphide Neutralising Potential Ratio (SNPR) = Ratio of SAP and BulkNP.

⁸Total Neutralising Potential Ratio (TNPR) = Ratio of TAP and BulkNP

⁹kg/t is kg CaCO₃ equivalent/tonne



The following inferences are made from Figure 18:

- The samples plot into two broad distinct clusters characterised by total sulphur concentrations above and below 0.3% respectively.
- There is generally poor to moderate correlation between total sulphur and sulphide sulphur in samples that have Total sulphur concentrations below 0.3%.
- Sulphide sulphur was significantly lower than total sulphur concentration in the weathered overburden (WO) indicating leaching effects.

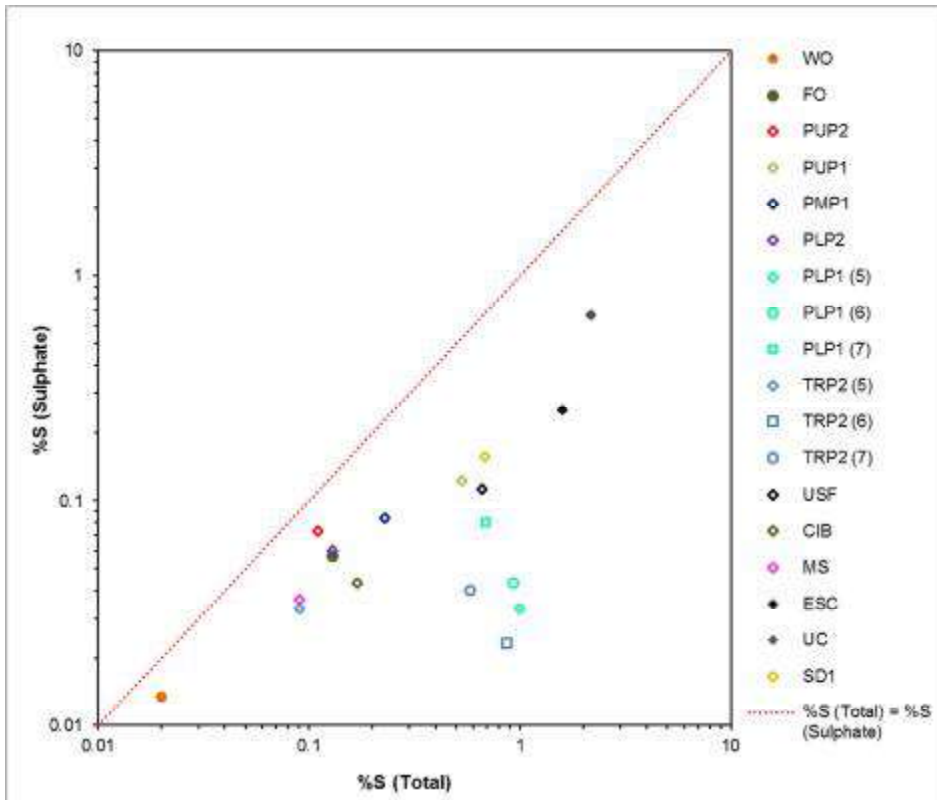


Figure 19: Sulphate sulphur versus total sulphur in Dalyshope samples

- Sulphide sulphur was approximately equal to total sulphur in 69% of the parting units including PLP1, TRP2, UCF, PUP1 and SD1.
- Sulphide sulphur was the dominant sulphur specie in both Upper Eccla (UC) and Middle Eccla (ESC) coal samples.

The samples with sulphide sulphur concentration that was significantly lower than total sulphur shows presence of other forms of sulphur, including sulphate and organic sulphur. Sulphate sulphur was significantly below total sulphur in most samples (Figure 19) indicating that sulphate sulphur is generally minor sulphur specie in the overburden, parting, interbedding and coal samples. Samples with total sulphur concentration less than 0.3% indicated a better positive correlation between total sulphur and sulphate sulphur compared to samples with more than 0.3% total sulphur.

The following observations are made from Figure 20:

- Weathered overburden (WO) and parting unit PUP2 had sulphate sulphur concentration exceeding sulphide sulphur. This indicates complete oxidation of sulphide minerals and/or presence of primary sulphate minerals.



- There is generally a good relationship between sulphide sulphur and sulphate sulphur in fresh overburden (FO) and 38% of parting units, including PUP2, PLP2, MS, PMP1 and TRP2 from one borehole. This suggests that the sulphate is likely to be from sulphide oxidation during sample collection and transportation of samples. These samples are characterised by low concentration of both sulphide sulphur and sulphate sulphur.
- Sulphide sulphur was significantly higher than sulphate sulphur in 62% of the parting units, interbedding and both coal samples.

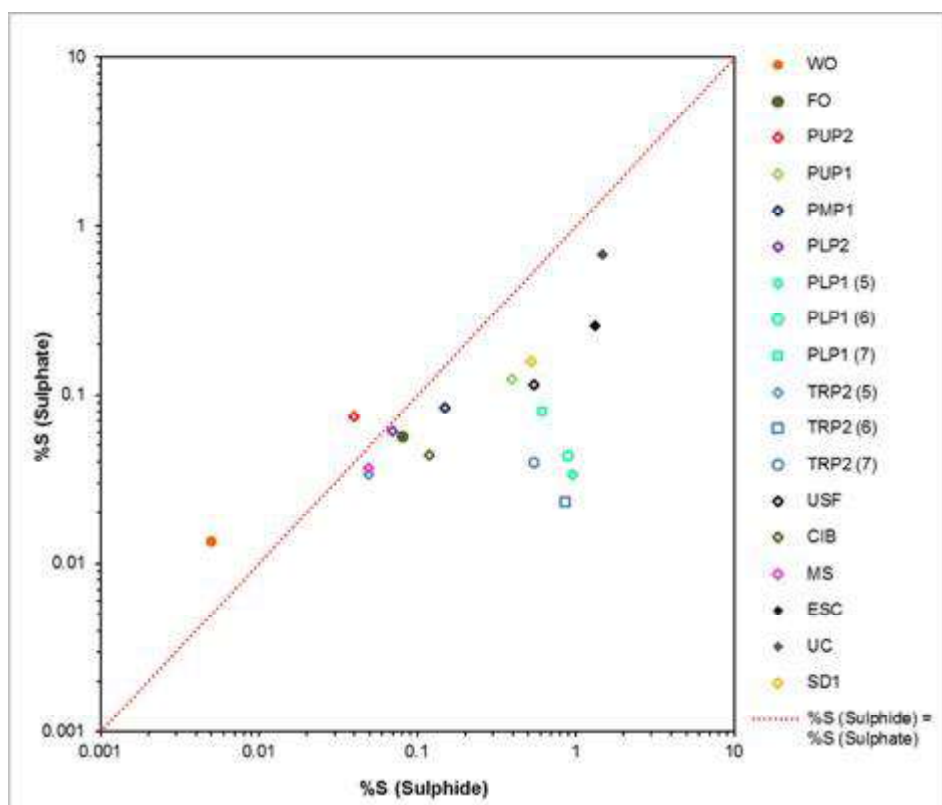


Figure 20: Sulphate sulphur versus sulphide sulphur in Dalyshope samples

The generally poor relationship between sulphide sulphur and sulphate sulphur suggests presence of primary minerals in the samples. The use of total sulphur in estimating AP of the overburden, interbedding, parting and coal from Dalyshope is overly conservative as it includes all sulphur species. For this reason, sulphide sulphur concentration was used in estimating AP in this study. It should however be emphasised that the estimated AP is also conservative, since the laboratory analytical method (pyrolysis) incorporates organic sulphur fraction into the sulphide sulphur portion (Section 6.1).

The carbonate concentration of the overburden, interbedding and parting lithological units were found to range from 0.11 to 4.0% with the highest concentration being recorded in the overburden samples (Table 4). Middle Ecca and Upper Ecca coal had carbonate concentrations of 0.97 and 2.2%, respectively. The high carbonate concentration is expected since siderite and calcite were abundant in borehole core at Dalyshope.

Two types of neutralizing potential (NP), all expressed in units of kg CaCO₃ equivalent/tonne (kg/t), were assessed for the Dalyshope samples. These include:

- Modified Sobek “bulk neutralization potential” (BulkNP) based on 24 hours-long acid digestion to determine how much acid was neutralized in the short term (Lawrence and Wang, 1996 technique) and
- Carbonate-equivalent neutralization potential (CaNP) calculated from measured solid-phase levels of inorganic carbonate (Carbonate as %CO₃).



Short term BulkNP was 93 and 27 kg/t in weathered and fresh overburden, respectively. Interbedding had BulkNP equivalent to 7.1 kg/t. Average BulkNP was 10 kg/t and ranged between -0.20 and 35 kg/t in parting samples. The negative NP value recorded for TRP2 from borehole WB0556A (TRP2-6) is indicative of acid that was released from Fe and or Mn hydroxides during laboratory testing. The BulkNP was 24 and 58 kg/t in Lower Ecca and Upper Ecca coal, respectively (Table 4).

Carbonate-equivalent neutralization potential (CaNP) was 6.2 kg/t and ranged from 17 to 66 kg/t and in interbedding and overburden, respectively. In parting samples, CaNP varied between 1.8 and 19kg/t. The average CaNP was 7.1 kg/t in parting. The CaNP was 36 and 16 kg/t in Upper Ecca and Lower Ecca coal, respectively (Table 4).

A scatter plot (Figure 21) shows that CaNP was higher than BulkNP in parting units PLP1 and TRP2 from boreholes WBG0555A and WBG0556A. This indicates that siderite (FeCO_3) represented a significant proportion of total carbonates in these samples. It should however be noted that under oxidising field conditions siderite have limited neutralising capacity as ferrous iron in these minerals are an extra source of acidity due to the strong hydrolysis of the ferrous iron in solution (Bowell et.al., 2000; MEND, 2009).

The CaNP and BulkNP are nearly equal in 28% of the samples, indicating that calcite is the main source of NP in parting units PLP2 and TRP2 from borehole WB0555A and interbedding (CIB). The NP in remainder of parting, overburden, Upper Ecca coal and Lower Ecca coal samples is attributed to mainly aluminosilicates. It should be noted that the aluminosilicates that are known to occur in the Waterberg Basin (Vermeulen, et. al., 2009) buffers acid in the 2.4-4.1, except for chlorite, which buffers pH in the 4.8-7.3 pH range.

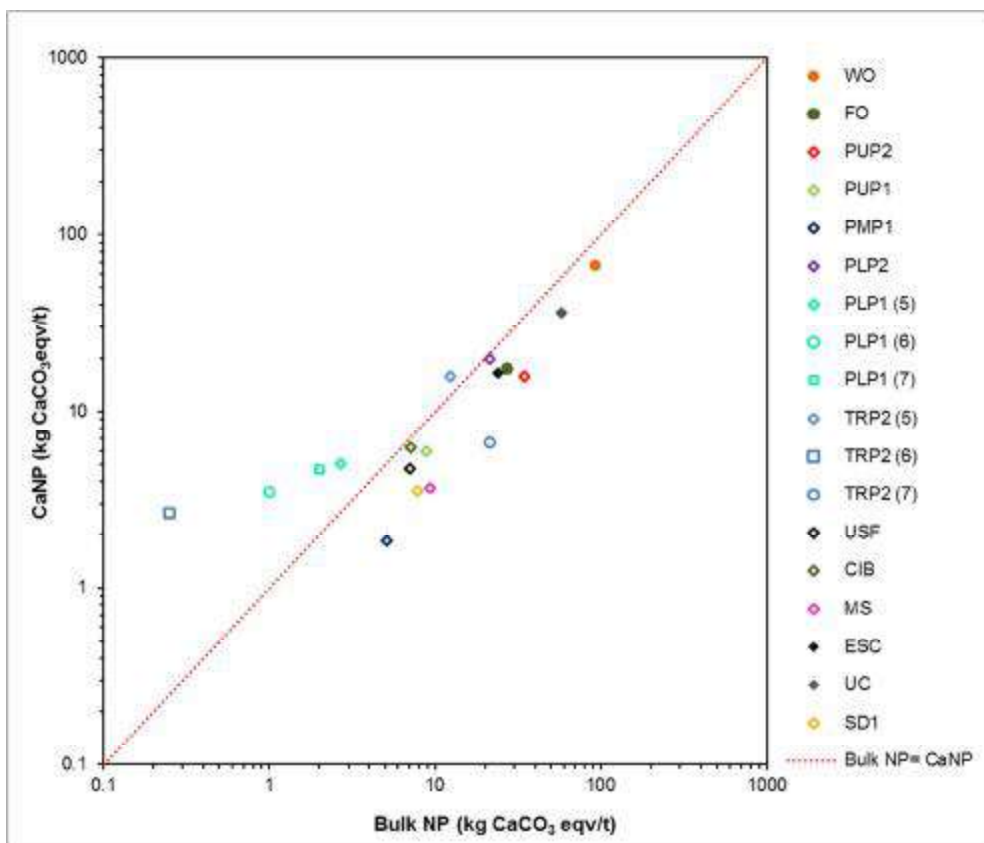


Figure 21: Carbonate equivalent neutralisation potential (CaNP) versus Modified Sobek neutralisation potential (BulkNP)

7.3 ARD Assessment

The screening criteria used in this study to assess the acid generation potential of the overburden, interbedding, parting and coal from Dalyshope is based on guidelines from Price *et al.*, (1997), Morin and Hutt (2007) and MEND (2009). These criteria are summarised in Table 5 and are graphically presented in Figure 22, Figure 23 and Figure 24. The Neutralisation Potential Ratio (NPR) is the ratio of Total Acid Potential (TAP) or Sulphide Acid Potential (SAP) and NP. In this study, SAP was used to calculate NPR for



reasons cited in section 7.2. The BulkNP was used in the NPR calculation since it accounts for the more reactive carbonate minerals as well as the less reactive silicate minerals.

Acid potential (SAP) and Bulk NP values for each sample were plotted on a graph (Figure 22). The lines corresponding to NPR values of 1:1, 2:1 and 4:1 are superimposed on this figure to classify samples according to their acid generation and neutralization potentials.

Table 5: Acid Generation Criteria (Price et al., 1997; MEND, 2009)

Guidelines from Price et al. (1997)			
Sulphide sulphur	NPR (Bulk NP /SAP)	Potential for ARD	Comment
<0.3%	----	None	No further ARD testing required provided there are no other metal leaching concerns. <i>Exceptions:</i> host rock with no basic minerals, sulphide minerals that are weakly acid soluble.
>0.3%	<1	Likely	Likely to be ARD generating.
	1-2	Possibly	Possibly ARD generating if NP is insufficiently reactive or is depleted at a rate faster than that of sulphides.
	2-4	Low	Not potentially ARD generating unless significant preferential exposure of sulphides occur along fractures or extremely reactive sulphides are present together with insufficiently reactive NP.
	>4	None	No further ARD testing required unless materials are to be used as a source of alkalinity.
Guidelines from Morin and Hutt (2007) and MEND (2009)			
Paste pH	NPR	Potential for ARD	Comment
<6	< 1 <1	Acid generating (AG)	Net acid generating, and already acidic.
>6		Potentially acid generating (PAG)	Potentially acid generating unless sulphide minerals are non-reactive. Thus samples are net acid generating, but not yet acidic.
<6 and >6	1 ≤ NPR ≤ 2	Uncertain	Possibly acid generating if NP is insufficiently reactive or is depleted at a rate faster than sulphides.
>6	>2	Not potentially acid generating (Non-PAG)	Not expected to generate acidity i.e samples are net acid neutralizing.
<6		Theoretically not possible	

The following inferences were made from (Figure 22), which is based on Price *et al.*, (1997) criterion:

- ! About 44% of the samples were likely to acid generating (NPR<1). They included:

 - § Parting units PLP, PUP1, TRP2 from borehole WB0556A (TRP2-6), UCF and SD1; and
 - § Middle Ecca coal (ESC).
- ! Units that are possibly acid generating (1<NPR<2) constitute approximately 22% of the samples and included:

 - § Parting units PMP1 and TRP2 from borehole WB0557A;



§ Upper Ecca coal (UC); and

§ Interbedding (CIB).

; Units with no potential for acid generation represent approximately 34% of all the samples. They were:

§ Overburden, both weathered (WO) and fresh (FO); and

§ Parting units PUP2, PLP2, MS and TRP2 from borehole 0557A (TRP2-7).

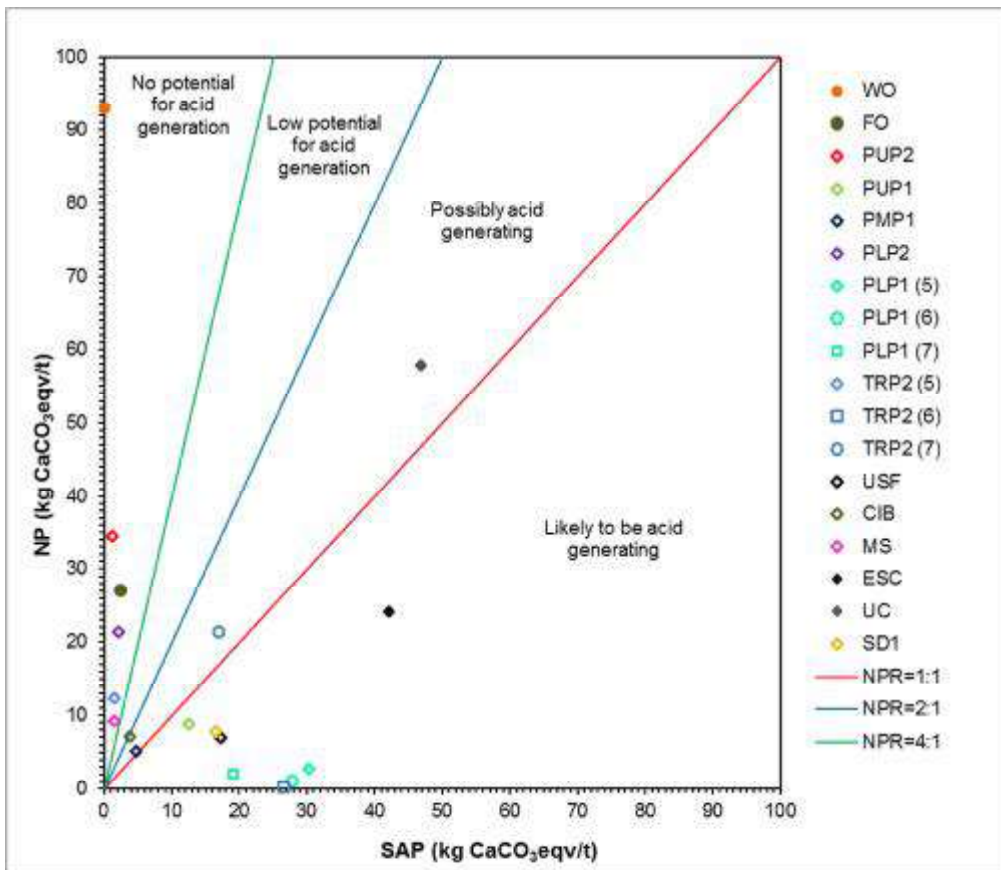


Figure 22: Acid potential versus neutralising potential graph indicating areas of likely and unlikely acid generation

If the concentration of Sulphide sulphur is considered in the screening criterion, Interbedding and parting unit PMP1, which classified as possibly acid generating in Figure 22, classify as having no potential of acid generation (Figure 23). The rest of the units remained in the same class as in Figure 22.

Figure 24 represents classification of overburden, interbedding and parting samples based on the Morin and Hutt (2007) and MEND (2009) criteria.

The following inferences can be made from Figure 24:

; Acid generating (AG) samples included:

§ Parting units PLP1 and TRP2 from borehole WB0556A (TRP2-6).

; Potentially acid generating (PAG) samples were :

§ Parting units SD1, USF, and PUP1; and

§ Middle Ecca coal seam (ESC).

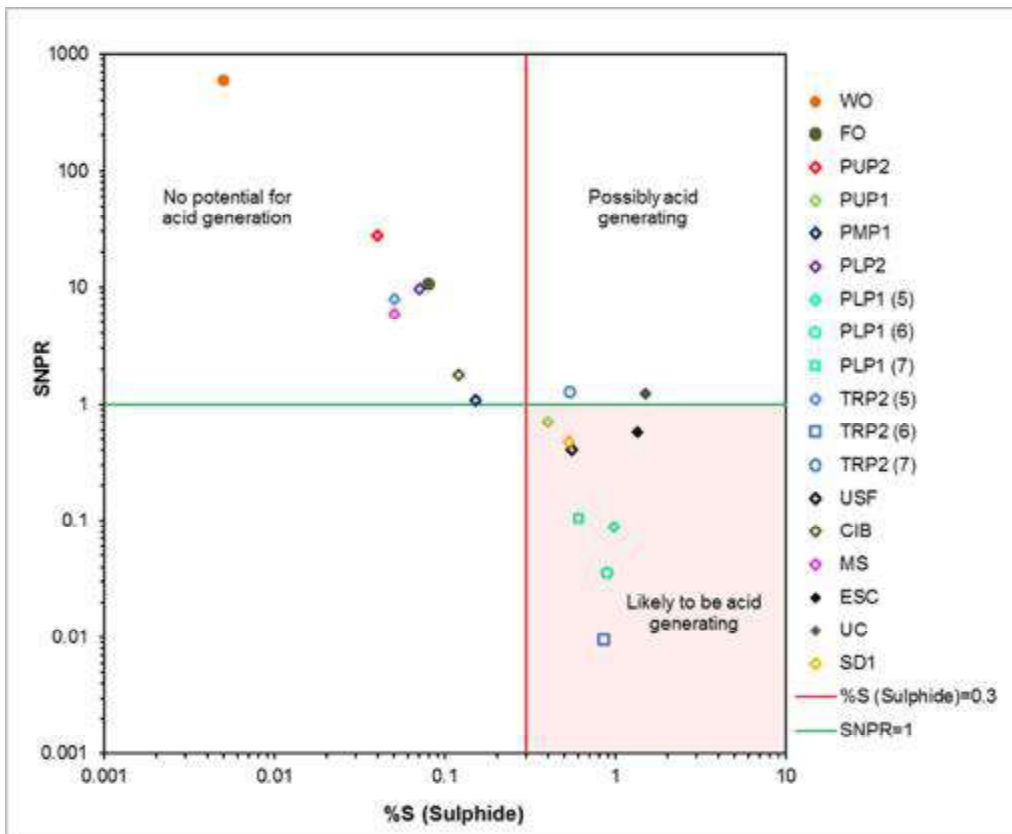


Figure 23: Neutralisation Potential Ratio (NPR) versus Sulphide sulphur concentration in Dalyshope samples

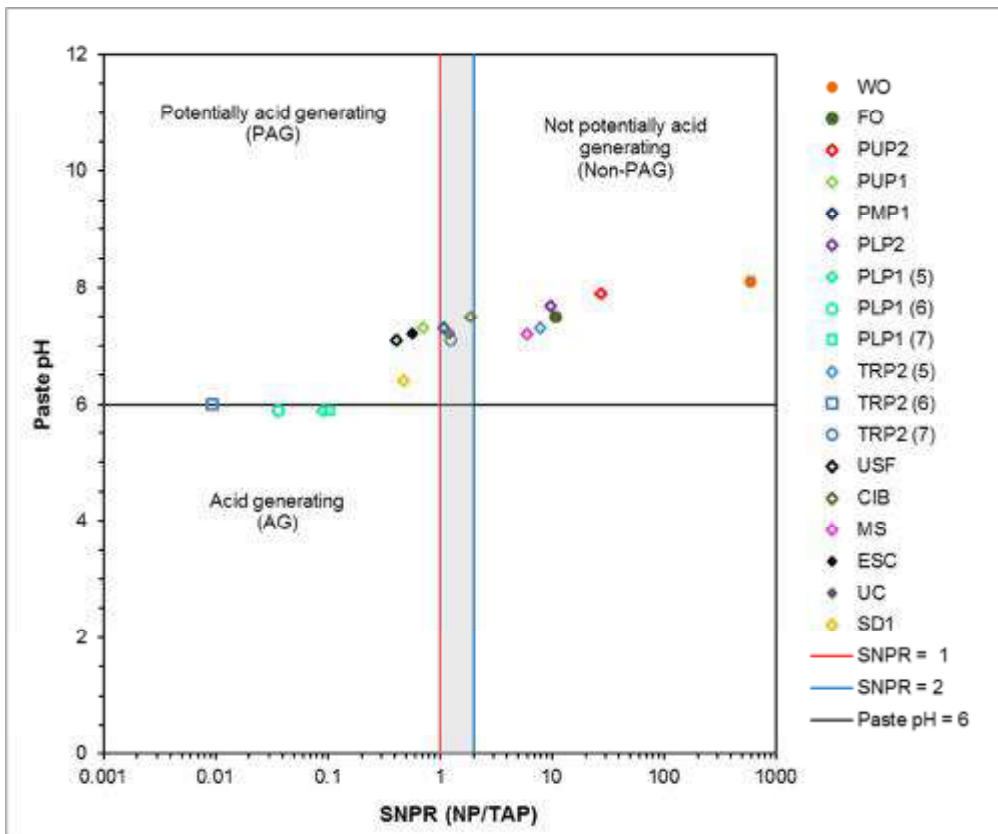


Figure 24: Paste pH versus Sulphide Neutralisation Potential Ratio in Dalyshope samples



- i Samples that fell in the grey zone (Uncertain) included:
 - § Parting units TRP2 from borehole WP0557A (TRP2-7) and PMP1;
 - § Interbedding (CIB); and
 - § Upper Ecca coal (UC).

These rock units are possibly acid generating if NP is insufficiently reactive or is depleted at a rate faster than sulphides under field conditions.

- i Units that were not potentially acid generating (Non-PAG) were:
 - § Weathered overburden (WO), FO, PUP2, PLP2, TRP2 from borehole WB0555A and MS samples are not potentially acid generating (Non-PAG).

7.4 Assessment of sample representativeness

The total sulphur concentration (GAA data) was plotted on the same graph with AATC exploration boreholes' assay data (Figure 25). This was done to assess the variation of Total sulphur with depth and spatially in overburden and parting units, and to compare GAA geochemistry and AATC assay data and assess the effects of compositing samples from different boreholes on the geochemical results.

The following inferences can be made from Figure 25:

- i The weathered overburden (WO) had the lowest total sulphur concentration. This is attributed to depletion of sulphides, sulphates and organic sulphur through weathering and leaching processes.
- i Total sulphur concentration did not vary much between boreholes for parting units PUP2 and PLP2 suggesting that these units are generally homogeneous across the sampled area as indicated by AATC exploration geologists.
- i Partings: PLP1, PMP1 and TRP2 indicated large variations in total sulphur concentrations between boreholes. This is attributed to occasional occurrence of channel sandstone in the PLP1 and TRP2 parting units. An analysis of exploration boreholes WBG0555, WBG0556 and WBG0557 log sheets (Appendix B) indicated that the grey massive mudstone unit constituting parting PMP1 is occasionally carbonaceous.
- i Total sulphur concentration varied moderately in parting unit PUP1 and indicates that sulphides are not uniformly distributed across the sampled area within this parting unit as indicated by presence of pyrite in core from only one of the boreholes in Appendix B. Thus, total sulphur concentration is related to spatial variation in lithological composition of the parting unit.
- i Compositing samples (GAA data) yielded total sulphur concentrations that were within or slightly outside concentration ranges in individual borehole samples (AATC Assay data) of parting units PUP2, PUP1, PMP1 and PLP2 parting units.
- i Total sulphur concentration values of GAA composite samples were approximately equivalent to average AATC assay data concentration values in parting units PMP1 and PLP2. Total sulphur concentration in GAA composite samples were less than and greater than average AATC assay data concentrations in parting units PUP2 and PUP1, respectively. Thus, composite samples were representative of total sulphur concentration in selected parting units and underestimated and overestimated the concentrations in units.

The variation in total sulphur in boreholes at similar stratigraphic positions suggests local lateral variations in mineralogy and geochemistry of the lithological units. This is attributed to nature of sediments/material and the depositional environments. Coal was deposited from plant remains in swamp and distal poorly drained marshes under reducing conditions. This results in formation of syndepositional pyrite and accumulation of organically bound sulphur. The parting units were deposits of clastic sediments in poorly drained basin marshes with occasional fluvial systems (oxidising conditions) resulting in carbonaceous mudstones to non-carbonaceous channel sandstone/siltstone units. This affects occurrence of sulphur bearing substances and minerals in the different lithological units.

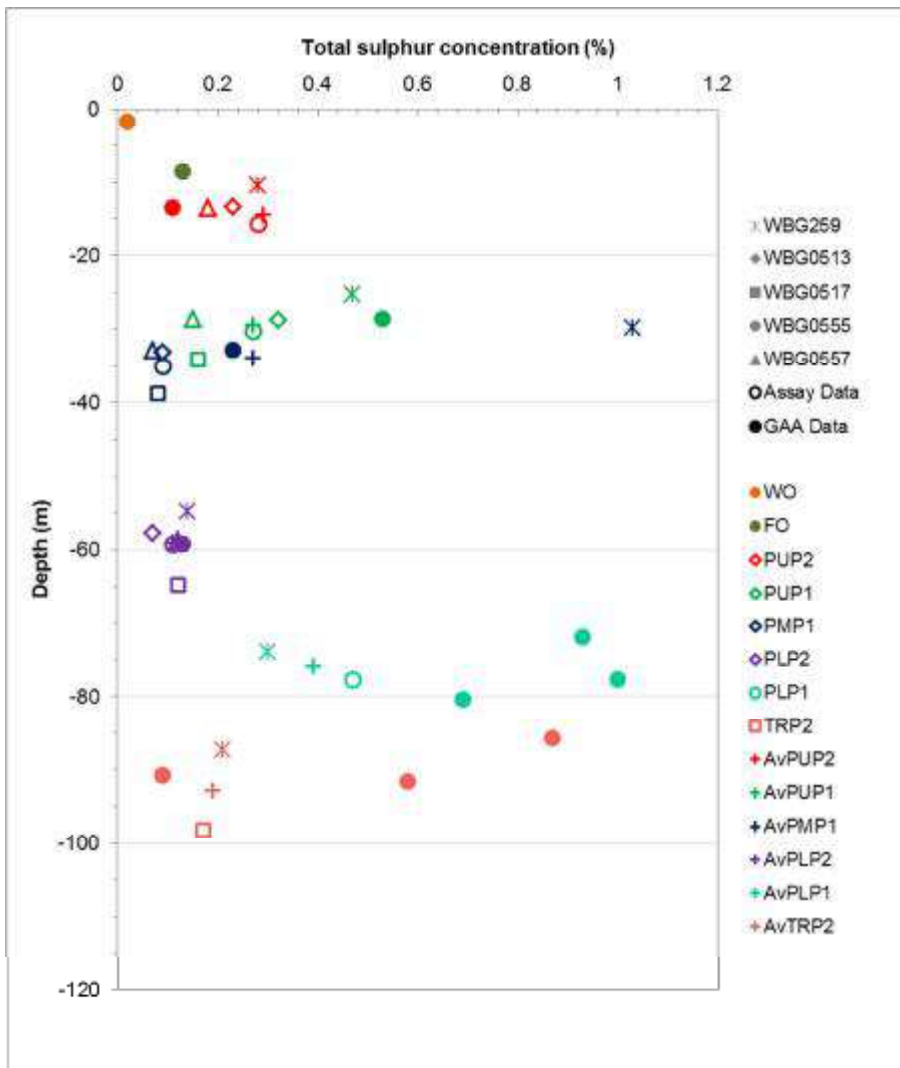


Figure 25: Plot of Total sulphur for Dalyshope exploration boreholes assay and Golder Associates ABA data for parting units. Av represents average (assay data) total sulphur concentration in the unit.

8.0 SUMMARY AND CONCLUSIONS

A concept level ARD assessment has been conducted for the proposed Dalyshope Retention mine to assess the acid generation potential of lithological units that would be disturbed during mining. The assessment included ABA analysis of 12 composites of three boreholes and six composite samples from three boreholes drilled in one of the proposed open pits, Pit 2. Distribution of total sulphur in the project area was also assessed based on AATC assay data from exploration borehole. A statistical summary of the laboratory results and calculations is presented in Table 6. The following inferences were made from the ABA results:

- i Overburden
 - § Both weathered and unweathered overburden is Non-PAG.
- i Parting
 - § Parting units PLP1, PUP1 and the Upper Ecca coal floor (USF) and ES1 coal seam floor (ESF) are AG to PAG.
 - § PMP1 classifies as uncertain acid potential.
 - § The three siltstone/sandstone samples from TRP2 parting unit was found to vary from being AG, to uncertain and non-PAG.



§ Parting units PUP2, PLP2 and the main sandstone (MS) unit above coal seam ES 3 are Non-PAG.

i Interbedding

§ Interbedding classifies as uncertain acid potential.

i Coal

§ Upper Ecca coal (UC) classifies as uncertain acid potential.

The composite of Middle Ecca coal seams ES1, ES2 and ES3 is PAG.

The number of samples used for the concept level ARD assessment provide a good indication of the acid potential from the disturbed mine geological units. However, it does not account for the spatial variation in geochemistry the individual lithological units. This is based on the analysis of total sulphur profiles, which indicated that sulphur is generally not uniformly distributed spatially in parting units PUP1, PMP1, PLP1, TRP2 and coal. This implies that the ARD potential of these lithological units may vary spatially from PAG to Non-PAG across the deposit; hence a detailed geochemical assessment should be conducted across the whole area during the next phases of mine planning.

In conclusion, the concept level ARD assessment indicates a significant potential for ARD to be generated from the planned mining activities of the Dalyshope Retention mine. This ARD has the potential to affect the economic viability of the project due to the requirements for source and pathway control measures associated with mining features and the long-term mine water management liability associated with ARD. The ARD impacts can, however, be prevented and managed through pro-active and upfront design and planning in order to limit the long-term liability associated with ARD management at the proposed Dalyshope Retention mine operations.



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

Table 6: ABA Statistical summary

Material Type	Statistical Parameter	Paste pH	Total sulphur	Sulphide	Sulphate	Total carbon	Carbonate	¹ TAP	² SAP	³ NP	⁴ CaNP	⁵ SNNP	⁶ TNNP	⁷ SNPR	⁸ TNPR
		s.u	%S			%C	%CO ₃	⁹ kg/t						no units	
Overburden	N	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Minimum	7.5	0.020	0.005	0.013	1.2	1.1	0.63	0.16	27	17	25	23	11	6.6
	Mean	7.8	0.075	0.043	0.035	1.2	2.5	2.3	1.3	60	42	59	58	303	78
	Maximum	8.1	0.13	0.080	0.057	1.2	4.0	4.1	2.5	93	66	93	92	595	149
Parting	Valid N	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Minimum	5.9	0.090	0.040	0.023	0.61	0.11	2.8	1.3	-0.20	1.8	-28	-29	0.0094	0.0092
	5th Percentile	5.9	0.090	0.040	0.023	0.61	0.11	2.8	1.3	-0.20	1.8	-28	-29	0.0094	0.0092
	Mean	6.8	0.51	0.44	0.069	4.6	0.43	16	14	10	7.1	-3.5	-5.6	4.3	2.0
	95th Percentile	7.9	1.0	0.97	0.16	12	1.2	31	30	35	19	33	31	28	10
	Maximum	7.9	1.0	0.97	0.16	12	1.2	31	30	35	19	33	31	28	10
Interbedding	N	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Measured value	7.5	0.17	0.12	0.043	11	0.37	5.3	3.8	7.1	6.2	3.4	1.8	1.9	1.3
Coal	N	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Minimum	7.2	1.6	1.4	0.25	44	0.97	50	42	24	16	-18	-26	0.57	0.48
	Mean	7.2	1.9	1.4	0.46	47	1.6	59	45	41	26	-3.6	-18	0.90	0.67
	Maximum	7.2	2.2	1.5	0.67	49	2.2	68	47	58	36	11	-10	1.2	0.85

Notes:

¹ Total acid potential (TAP) = acid potential based on the total sulphur content.

² Sulphide acid potential (SAP) = acid potential based on sulphide sulphur.

³ The NP measured by Modified Sobek method is indicated by the BulkNP value. NP measured is used for the NPR calculation.

⁴ Carbonate NP (CaNP) is based on the Leco carbonate percentage.

⁵ The Sulphide Net Neutralising Potential Ratio (SNNP) = is the difference between BulkNP and SAP.

⁶ Total Net Neutralising Potential Ratio (TNNP) = is the difference between BulkNP and TAP

⁷ The Sulphide Neutralising Potential Ratio (SNPR) = Ratio of SAP and BulkNP.

⁸ Total Neutralising Potential Ratio (TNPR) = Ratio of TAP and BulkNP

⁹ kg/t is kg CaCO₃ equivalent/tonne



9.0 RECOMMENDATIONS

Further geochemical assessment of the potentially mining-disturbed rocks at the proposed Dalyshope Retention mine is required to provide a robust geochemical baseline to support mine planning and environmental assessment. Specific recommendations for further work include:

- i Collection of sufficient samples to allow statistical assessment of the ARD potential and metal leaching (ML) of the lithological units that will be disturbed by mining. Based on the Global Acid Rock Drainage Guide (INAP, 2012) several hundred samples should be analysed by static testing during the Pre-feasibility phase. The acid and neutralisation potential should be incorporated into the geological block model to indicate areas of localised ARD and ML risk.
- i Mineralogical analysis by XRD and short term leach tests should also be conducted to assess the mineralogical composition and ML potential of the overburden, interbedding, parting and coal across the whole mine area.
- i Samples of parting units and coal that classify as PAG should be submitted for kinetic testing to assess likely long-term drainage quality taking acid generating and acid neutralising reactions into account. The GARD Guide suggests that one to two samples of each material type should be analysed by kinetic testing. Allowance should therefore be made for at least six kinetic tests.

10.0 REFERENCES

- Beukes N.J., 1985. Sedimentologie van die Ellisras steenkoolveld. Finale verslag. WNNR, KWP, NGP: Steekoolgeologieprojek. (Report to the CSIR Coal Geology Project).
- Bowell R.J., Rees S.B., and Parshley J.V. 2000. Geochemical predictions of metal leaching and acid generation: Geologic controls and baseline assessment. In Cluer J.K., Price J.G., Struhsacker E.M., Hardyman R.F., and Morris C.L., eds., *Geology and ore deposits 2000: The Great Basin and beyond: Geological Society of Nevada Symposium Proceedings, Reno/Sparks*. May 2000, p. 799-823.
- Catuneanu O., Wopfner H., Eriksson P.G., Cairncross B., Rubidge B.S., Smith R.M.H. and Hancox P.J. 2005. The Karoo basins of south-central Africa. *Journal of African Earth Sciences*, volume 43, pages 211-154.
- Cairncross B., 2001. An overview of the Permian (Karoo) coal deposits of southern Africa. *Journal of African Earth Sciences*, volume 33, pages 529-562.
- Council for geosciences. 1993. 1:250 000 scale geological map of Ellisras. Sheet number 2326, second edition.
- Dreyer J C. 1991. Waterberg Coalfield: Geology, resources, mining and products. (Abstr. Conference on South Africa's Coal Resources. Geol. Soc. S. Afr., Witbank, pages 6-9.
- Fortescue J. A. C., 1992. Landscape geochemistry- retrospect and prospect – 1990. *Applied Geochemistry*, volume 7, Pages 1-53.
- Fourie C.J.S., Henry G and Marè L.P., 2009. The structure of the Karoo-age Ellisras Basin in Limpopo Province, South Africa in the light of new airborne geophysical data: A preliminary report. 11th SAGA Biennial Technical Meeting and Exhibition Swaziland, 16-18 September 2009, pages 27-32.
- MacRae C.S., 1988. Palynostratigraphic correlation between the lower Karoo Sequence and the Waterberg Pafuri coal-bearing basins and the Hammanskraal plant macrofossil locality, Republic of South Africa. *Memoir/Memorie 75. Geological Survey*.
- MEND. 1994. Handbook for waste rock sampling techniques. Mine Environment Neutral Drainage Program (MEND) report 4.5.1-2.
- MEND. 2009. Prediction Manual for Drainage Chemistry from Sulphidic Geological Materials. Mine Environment Neutral Drainage Program (MEND) Report 1.20.1.



DALYSHOPE MINE ARD POTENTIAL ASSESSMENT

Morin K. A. and Hutt N. M., 2007. Morrison Project - Prediction of Metal Leaching and Acid Rock Drainage, Phase 1. Prepared for Rescan Environmental Services Ltd, British Columbia, Canada.

Price W.A., Morin K. and Hutt N. 1997. Guidelines for prediction of acid rock drainage and metal leaching for mines in British Columbia: Part II. Recommended procedures for static and kinetic tests. In Proceedings of the Fourth International Conference on Acid Rock Drainage. Vancouver, B.C. Canada, volume1, pages 15–30.

Smith K.S., and Huyck H.L.O., 1999. An overview of the abundance, relative mobility, bioavailability, and human toxicity of metals. In: Plumlee G.S., and Logsdon, M.J. (eds.). 1999. The Environmental geochemistry of mineral deposits - Part A: Processes, techniques, and health issues. Society of Economic Geologists, Reviews in Economic Geology, volume 6A, pages 29-70.

Tankard A., Welsink H., Aukes P., Newton R. and Stettler E., 2009. Tectonic evolution of the Cape and Karoo basin of South Africa. Marine and Petroleum Geology, volume 26 (2009), pages 1379-1412.

The International Network for Acid Prevention. (INAP) 2012. Global Acid Rock Drainage (GARD) Guide. www.gardguide.com.

Turner B.R., 1999. Tectonostratigraphical development of the Upper Karoo foreland: orogenic unloading versus thermally-induced Gondwana rifting. Journal of African Earth Sciences, volume 28, 215-238.

USEPA. 1994. Assessment and Remediation of contaminated sediments (ARCS) Guidance Document. Chicago, Ill.: Great Lakes National Program Office (EPA 905-B94-00).

van Rooyen N. and Bredekamp, G. 1996. Sweet Bushveld. In: Low, A.B. & Robelo, A.G. (eds) Vegetation of South Africa, Lesotho and Swaziland. Department of Environmental Affairs and Tourism, Pretoria, South Africa

Vegter J.R., 1995. An explanation of a set of national groundwater maps. Water Research Commission (WRC) report No TT 74/95

Vermeulen P. D., Bester M., Cruywagen L. M. and van Tonder G. J. 2009. Scoping level assessment of how water quality and quantity will be affected by mining method and mining of the shallow Waterberg Coal Reserves West of the Daarby fault. Water Research Commission (WRC) report no. K5/1830//3.

Williamson I.T., 1996. The geology of the area around Mmamabula and Dibete: Including an account of the greater Mmamabula Coalfield. District Memoir 6. Geological Survey, Botswana, 239pp.

GOLDER ASSOCIATES AFRICA (PTY) LTD.

Klupankwa

Keretia Lupankwa
Geochemist

Koovila Naicker
Senior Geochemist

KL/KN/sm

Reg. No. 2002/007104/07

Directors: SAP Brown, L Greyling, RGM Heath, FR Sutherland

Golder, Golder Associates and the GA globe design are trademarks of Golder Associates Corporation.

https://afpws.golder.com/sites/12613916ardassessmentforretentionmine/rfp/12613916-11899-1_dalyshope_ard_report_19022013.docx



APPENDIX A

Document Limitations



DOCUMENT LIMITATIONS

This Document has been provided by Golder Associates Africa Pty Ltd (“Golder”) subject to the following limitations:

- i) This Document has been prepared for the particular purpose outlined in Golder’s proposal and no responsibility is accepted for the use of this Document, in whole or in part, in other contexts or for any other purpose.
- ii) The scope and the period of Golder’s Services are as described in Golder’s proposal, and are subject to restrictions and limitations. Golder did not perform a complete assessment of all possible conditions or circumstances that may exist at the site referenced in the Document. If a service is not expressly indicated, do not assume it has been provided. If a matter is not addressed, do not assume that any determination has been made by Golder in regards to it.
- iii) Conditions may exist which were undetectable given the limited nature of the enquiry Golder was retained to undertake with respect to the site. Variations in conditions may occur between investigatory locations, and there may be special conditions pertaining to the site which have not been revealed by the investigation and which have not therefore been taken into account in the Document. Accordingly, additional studies and actions may be required.
- iv) In addition, it is recognised that the passage of time affects the information and assessment provided in this Document. Golder’s opinions are based upon information that existed at the time of the production of the Document. It is understood that the Services provided allowed Golder to form no more than an opinion of the actual conditions of the site at the time the site was visited and cannot be used to assess the effect of any subsequent changes in the quality of the site, or its surroundings, or any laws or regulations.
- v) Any assessments made in this Document are based on the conditions indicated from published sources and the investigation described. No warranty is included, either express or implied, that the actual conditions will conform exactly to the assessments contained in this Document.
- vi) Where data supplied by the client or other external sources, including previous site investigation data, have been used, it has been assumed that the information is correct unless otherwise stated. No responsibility is accepted by Golder for incomplete or inaccurate data supplied by others.
- vii) The Client acknowledges that Golder may have retained sub-consultants affiliated with Golder to provide Services for the benefit of Golder. Golder will be fully responsible to the Client for the Services and work done by all of its sub-consultants and subcontractors. The Client agrees that it will only assert claims against and seek to recover losses, damages or other liabilities from Golder and not Golder’s affiliated companies. To the maximum extent allowed by law, the Client acknowledges and agrees it will not have any legal recourse, and waives any expense, loss, claim, demand, or cause of action, against Golder’s affiliated companies, and their employees, officers and directors.
- viii) This Document is provided for sole use by the Client and is confidential to it and its professional advisers. No responsibility whatsoever for the contents of this Document will be accepted to any person other than the Client. Any use which a third party makes of this Document, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. Golder accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this Document.

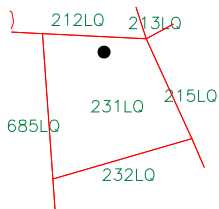
GOLDER ASSOCIATES AFRICA (PTY) LTD



APPENDIX B

Geological logs for boreholes sampled for ARD assessment

LOCALITY PLAN



ANGLO COAL GEOLOGICAL SERVICES
ANGLO COAL DIVISION
a member of the Anglo American plc group

PROJECT **WATERBERG PROJECT**
FARM **231LQ**
DISTRICT **LEPH**
PROVINCE **Lo Cape System**
TOPO SHEET **2327CA**

SHEET No. 4 of 8

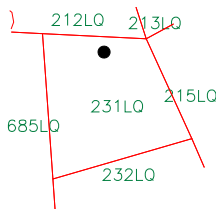
BOREHOLE No. **WBG0555**

COORDINATES CAPE Y
2603169.00
SURFACE ELEVATION
829.82
DRILLER
Earth Resources
DATE COMMENCED
13032012
DIAMETER OF CORE
064 mm.
LOGGED BY
SAMPLED BY
F/S ANALYSIS BY
COAL ANALYSIS BY
SPECIAL ANALYSIS BY
Logsheet generated
APPROVED BY

-23591.00
2613916.00
11899.00
COORDINATES WGS X
-23567.00
2603464.00
DATE COMPLETED
15032012
CASING LEFT IN HOLE
m
HEAD OF GEOLOGY
D.R.W Dingemans

INTERVAL SECTION				Samples		ANALYSIS DATA																					
DEPTH	SECTION	WIDTH	DESCRIPTION	Number	(Width)	RD	YIELD %		MOISTURE %		ASH %		VOLATILE %		Fixed Carb %		C.V.MJ/kg		SULPHUR %		SW.No	ROGA	AFT C (RED)			H.I.	A.I.
							FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML			FRAC	CUML	FRAC		
35.03		0.27	COAL, bright, 40-60% bright, calcite on cleats, sideritic	0555U (0.03)	0.03	RAW			0.55	25.0	0.0	100.0	RD=2.32	Width=1.40	Core Recovery=100%								1500	1500	1500	65	367
36.43		1.40	CARBONACEOUS MUDSTONE, medium, grey, massive	0555U (1.40)	1.40	RAW		100.0		1.2		88.6	8.0		2.2	0.68	0.09										
37.40		0.97	60% COAL, bright, 40-60% bright, calcite on cleats, sideritic, 40% CARBONACEOUS MUDSTONE, dark, grey, interbedded	0555T (1.87)	1.87	RAW		100.0		1.4		70.5	14.1		14.0	6.11	0.61						1500	1500	1500	58	746
38.30		0.35	COAL, bright, 40-60% bright, calcite on cleats	0555S (0.35)	0.35	RAW		100.0		1.6		62.7	17.5		18.2	8.90	0.56						1500	1500	1500	54	932
41.17		0.47	70% COAL, bright, 40-60% bright, calcite on cleats, sideritic, 30% CARBONACEOUS MUDSTONE, dark, grey, interbedded	0555R (0.47)	0.47	RAW		100.0		2.0		49.0	21.5		27.5	14.45	1.47						1470	1500	1500	57	692
47.50		0.27	CARBONACEOUS MUDSTONE, dark, grey, massive	0555Q (0.27)	0.27	RAW		100.0		1.4		68.3	15.7		14.6	6.51	0.86						1500	1500	1500	56	918
50.95		0.22	COAL, bright, 40-60% bright, calcite on cleats, sideritic	0555P (0.22)	0.22	RAW		100.0		1.4		64.9	17.1		16.6	7.99	0.53						1500	1500	1500	55	672
53.00		0.53	COAL, bright, 40-60% bright, sideritic, muddy	0555P (3.68)	3.68	RAW		100.0		1.5		62.0	18.2		18.4	9.09	0.53						1500	1500	1500	55	
54.87		0.15	CARBONACEOUS MUDSTONE, dark, grey, massive	0555O (0.37)	0.37	RAW		100.0		1.5		62.0	18.2		18.4	9.09	0.53						1500	1500	1500	55	

LOCALITY PLAN



ANGLO COAL GEOLOGICAL SERVICES
ANGLO COAL DIVISION
a member of the Anglo American plc group

PROJECT **WATERBERG PROJECT**
FARM **231LQ**
DISTRICT **LEPH**
PROVINCE **Lo Cape System**
TOPO SHEET **2327CA**

SHEET No. 8 of 8

BOREHOLE No. **WBG0555**

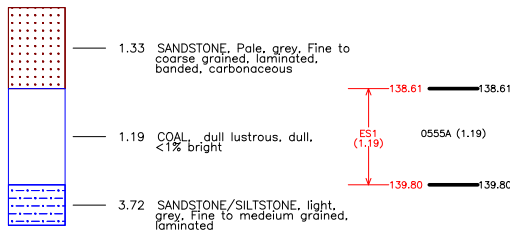
COORDINATES CAPE Y
COORDINATES CAPE X
SURFACE ELEVATION
DRILLER
DATE COMMENCED
DIAMETER OF CORE
LOGGED BY
SAMPLED BY
F/S ANALYSIS BY
SPECIAL ANALYSIS BY
Logsheet generated
APPROVED BY

-23598.00
2603169.00
829.82
Earth Resources
13032012
064 mm.
30/Aug/12
.....
HEAD OF GEOLOGY

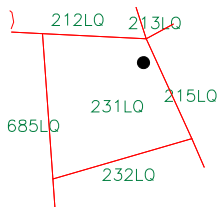
2613916
11899
WCS Y
COORDINATES WCS X
DATE COMPLETED
CASING LEFT IN HOLE
DATE
DATE
DATE
DATE
DATE

-23567.00
2603464.00
15032012
m
D.R.W Dingemans

INTERVAL SECTION				Samples		ANALYSIS DATA																						
DEPTH	SECTION	WIDTH	DESCRIPTION	Number	(Width)	RD	YIELD %		MOISTURE %		ASH %		VOLATILE %		Fixed Carb %		C.V.MJ/kg		SULPHUR %		SW.No	ROGA	AFT C (RED)			H.I.	A.I.	
							FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	CUML	CUML	DEF	HEM	FLOW	CUML	CUML	
138.61			1.33 SANDSTONE, Pale, grey, Fine to coarse grained, laminated, banded, carbonaceous																									
			1.19 COAL, dull lustrous, dull, <1% bright	0555A (1.19)		RAW	100.0		2.5		20.1		21.1		56.2		24.81		1.01			1500	1500	1500	54			
139.80			3.72 SANDSTONE/SILTSTONE, light, grey, Fine to medium grained, laminated																									
143.52																												



LOCALITY PLAN



ANGLO COAL GEOLOGICAL SERVICES
ANGLO COAL DIVISION
a member of the Anglo American plc group

PROJECT **WATERBERG PROJECT**
FARM **231LQ**
DISTRICT **LEPH**
PROVINCE **Lo Cape System**
TOPO SHEET **2327CA**

SHEET No. 3 of 7

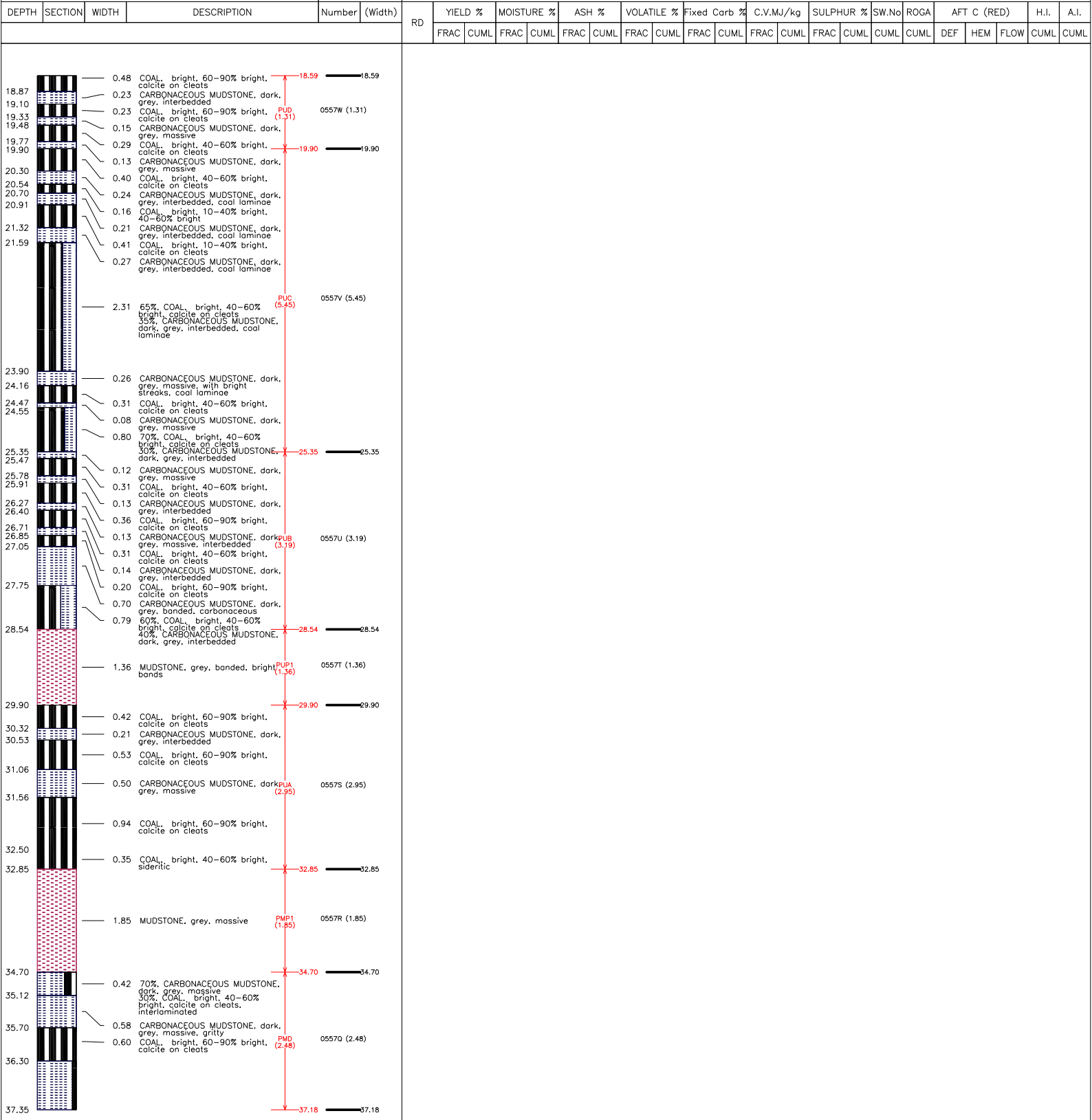
BOREHOLE No. WBG0557

COORDINATES CAPE Y
COORDINATES CAPE X
SURFACE ELEVATION
DRILLER
DATE COMMENCED
DIAMETER OF CORE
LOGGED BY
SAMPLED BY
F/S ANALYSIS BY
COAL ANALYSIS BY
SPECIAL ANALYSIS BY
Logsheet generated
APPROVED BY

-24461.00
2603400.00
830.73
Earth Resources
12032012
084 mm.
28/Aug/12
.....
HEAD OF GEOLOGY
D.R.W Dingemans

2613916.00
2603895.00
-24430.00
2603895.00
15032012
m
DATE COMPLETED
CASING LEFT IN HOLE
DATE
DATE
DATE
DATE
DATE
DATE
DATE

INTERVAL SECTION				Samples		ANALYSIS DATA																					
DEPTH	SECTION	WIDTH	DESCRIPTION	Number	(Width)	RD	YIELD %		MOISTURE %		ASH %		VOLATILE %		Fixed Carb %		C.V.MJ/kg		SULPHUR %		SW.No	ROGA	AFT C (RED)			H.I.	A.I.
							FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	FRAC	CUML	CUML	CUML	DEF





APPENDIX C

ARD potential (ABA) results



TEST REPORT

CLIENT DETAILS

Contact Keretia Lupankwa
Client Golder Associates Africa (Pty) Ltd
Address P.O Box 6001
Halfway House
1685

Telephone 011 254 4896
Facsimile 011 315 0317
Email klupankwa@golder.ac.za
Project (Not specified)
Order Number 12613916
Samples 19
Sample matrix SOIL

LABORATORY DETAILS

Laboratory SGS South Africa (Pty) Limited
Address 259 Kent Avenue
Fermdale, 2194
Telephone +27 (0)11 781 5689

Laboratory Manager Joanne O'Sullivan
SGS Reference JB12-02797 R0
Report Number 000002915
Date Received 2012/07/12 03:20:24PM
Date Reported 2012/07/27 12:55:04PM

COMMENTS

The document is issued in accordance with SANAS's accreditation requirements.
Accredited for compliance with ISO/IEC 17025. SANAS accredited laboratory T0107.



Analysis of sulphur and carbon species completed by SGS Analytical Services Booyens.

PAG: Potentially acid generating, based on interpretation of ABA data alone.

PAN: Potentially acid neutralising, based on interpretation of ABA data alone.

U: Uncertain with respect to potential acid generation or neutralisation, based on interpretation of ABA data alone.

The Modified ABA test method merely provides an indication of the potential for acid generation. Whether or not acidic drainage will result depends on the mineralogy, the availability of each acid generating and neutralising mineral present, the physical characteristics of the material and the environmental setting.

SIGNATORIES

Sarah Newton
Technical Consultant/Technical Signatory

Joanne O'Sullivan
Laboratory Manager

Report number: 000002915
 Client reference: 12613916

Sample Number Sample Name	JB12-02797.001 DHFO-C	JB12-02797.002 DHPLP1-5	JB12-02797.003 DHPLP1-6	JB12-02797.004 DHTRP2-6	JB12-02797.005 DHTRP2-7		
Parameter	Units	LOR					
Paste pH and conductivity and 10% pH in soil Method: ME-AN-024							
Paste pH	-	1	7.5	5.9	5.9	7.3	7.1

Neutralising Potential (NP) Method: ME-AN-025

Fizz Rating	-	-	1	1	1	1	1
Sample Weight	g	-	2.00	2.00	2.00	2.00	2.00
Normality of standardised HCl	N	-	0.100	0.100	0.100	0.100	0.100
Volume of HCl added	ml	-	33.8	20.0	20.0	20.0	20.0
Normality of standardised NaOH	N	-	0.097	0.097	0.097	0.097	0.097
Titre of NaOH	ml	-	23.7	19.5	20.2	15.5	11.8
NP as kg CaCO ₃ /T	kg CaCO ₃ /T	-1	27.0	2.7	1.0	12.4	21.4

SUB_Sulphur and carbon species by LECO Method: SUB

Total sulphur as S ^A	%	0.01	0.13	1.00	0.93	0.09	0.69
Sulphide as S ^A	%	0.01	0.08	0.97	0.89	0.05	0.54
Sulphate as SO ₄ ^A	%	0.03	0.17	0.10	0.13	0.10	0.12
Total carbon as C ^A	%	0.01	1.21	5.53	3.57	3.07	3.11
Carbonate as CO ₃ ^A	%	0.05	1.05	0.30	0.21	0.94	0.40

Calculation of acid/base balances Method: ME-AN-025

Acid potential*	kg CaCO ₃ /T	0.31	2.5	30	29	1.6	17
Net neutralising potential*	kg CaCO ₃ /T	-100	24.5	-27.6	-26.8	10.9	4.5
NP/AP ratio*	-	-1	10.81	0.09	0.04	7.94	1.27
Classification*	-	-	PAN	PAG	PAG	PAN	U

Sample Number Sample Name	JB12-02797.006 DHTRP2-6	JB12-02797.007 DHPLP1-7	JB12-02797.008 DHPUP1-C	JB12-02797.009 DHPUP2-C	JB12-02797.010 DHWOC		
Parameter	Units	LOR					
Paste pH and conductivity and 10% pH in soil Method: ME-AN-024							
Paste pH	-	1	6.0	5.9	7.3	7.9	8.1

Neutralising Potential (NP) Method: ME-AN-025

Fizz Rating	-	-	1	1	1	2	4
Sample Weight	g	-	2.00	2.00	2.00	2.00	2.00
Normality of standardised HCl	N	-	0.100	0.100	0.100	0.100	0.100
Volume of HCl added	ml	-	20.0	20.0	20.0	48.9	68.8
Normality of standardised NaOH	N	-	0.097	0.097	0.097	0.097	0.097
Titre of NaOH	ml	-	20.7	19.8	17.0	36.2	32.6
NP as kg CaCO ₃ /T	kg CaCO ₃ /T	-1	-0.2	2.0	8.8	34.5	92.9

SUB_Sulphur and carbon species by LECO Method: SUB

Total sulphur as S ^A	%	0.01	0.87	0.89	0.53	0.11	0.02
Sulphide as S ^A	%	0.01	0.85	0.61	0.40	0.04	<0.01
Sulphate as SO ₄ ^A	%	0.03	0.07	0.24	0.37	0.22	0.04
Total carbon as C ^A	%	0.01	3.70	7.19	8.58	2.59	1.21
Carbonate as CO ₃ ^A	%	0.05	0.15	0.28	0.35	0.94	3.99

Report number: 0000002915
 Client reference: 12613916

Sample Number Sample Name	JB12-02797.006 DHTRP2-6	JB12-02797.007 DHPLP1-7	JB12-02797.008 DHPUP1-C	JB12-02797.009 DHPUP2-C	JB12-02797.010 DHW0-C
------------------------------	----------------------------	----------------------------	----------------------------	----------------------------	--------------------------

Parameter Units LOR

Calculation of acid/base balances Method: ME-AN-025

Parameter	Units	LOR	JB12-02797.006	JB12-02797.007	JB12-02797.008	JB12-02797.009	JB12-02797.010
Acid potential*	kg CaCO ₃ /T	0.31	27	19	13	1.3	<0.31
Net neutralising potential*	kg CaCO ₃ /T	-100	-26.8	-17.1	-3.7	33.2	92.6
NP AP ratio*	-	-1	-0.01	0.10	0.70	27.57	300.43
Classification*	-	-	PAG	PAG	PAG	PAN	PAN

Sample Number Sample Name	JB12-02797.011 DHUSF-C	JB12-02797.012 DHICM-C	JB12-02797.013 DHPMP1-C	JB12-02797.014 DHPLP2-C	JB12-02797.015 DHSD1-C
------------------------------	---------------------------	---------------------------	----------------------------	----------------------------	---------------------------

Parameter Units LOR

Paste pH and conductivity and 10% pH in soil Method: ME-AN-024

Parameter	Units	LOR	JB12-02797.011	JB12-02797.012	JB12-02797.013	JB12-02797.014	JB12-02797.015
Paste pH	-	1	7.1	7.5	7.3	7.7	6.4

Neutralising Potential (NP) Method: ME-AN-025

Parameter	Units	LOR	JB12-02797.011	JB12-02797.012	JB12-02797.013	JB12-02797.014	JB12-02797.015
Fizz Rating	-	-	1	1	1	1	1
Sample Weight	g	-	2.00	2.00	2.00	2.00	2.00
Normality of standardised HCl	N	-	0.100	0.100	0.100	0.100	0.100
Volume of HCl added	ml	-	32.1	20.0	20.0	20.0	32.7
Normality of standardised NaOH	N	-	0.097	0.097	0.097	0.097	0.097
Titre of NaOH	ml	-	30.2	17.7	18.5	11.8	30.5
NP as kg CaCO ₃ /T	kg CaCO ₃ /T	-1	7.0	7.1	5.1	21.4	7.8

SUB_Sulphur and carbon species by LECO Method: SUB

Parameter	Units	LOR	JB12-02797.011	JB12-02797.012	JB12-02797.013	JB12-02797.014	JB12-02797.015
Total sulphur as S [^]	%	0.01	0.66	0.17	0.23	0.13	0.68
Sulphide as S [^]	%	0.01	0.55	0.12	0.15	0.07	0.53
Sulphate as SO ₄ [^]	%	0.03	0.34	0.13	0.25	0.18	0.47
Total carbon as C [^]	%	0.01	4.01	10.60	3.85	12.00	1.73
Carbonate as CO ₃ [^]	%	0.05	0.28	0.37	0.11	1.17	0.21

Calculation of acid/base balances Method: ME-AN-025

Parameter	Units	LOR	JB12-02797.011	JB12-02797.012	JB12-02797.013	JB12-02797.014	JB12-02797.015
Acid potential*	kg CaCO ₃ /T	0.31	17	3.9	4.7	2.2	17
Net neutralising potential*	kg CaCO ₃ /T	-100	-10.2	3.3	0.5	19.2	-8.8
NP AP ratio*	-	-1	0.41	1.89	1.10	9.78	0.47
Classification*	-	-	PAG	U	U	PAN	PAG

Sample Number Sample Name	JB12-02797.016 DHMS-C	JB12-02797.017 DHSD2-C	JB12-02797.018 DHESC-C	JB12-02797.019 DHUC-C
------------------------------	--------------------------	---------------------------	---------------------------	--------------------------

Parameter Units LOR

Paste pH and conductivity and 10% pH in soil Method: ME-AN-024

Parameter	Units	LOR	JB12-02797.016	JB12-02797.017	JB12-02797.018	JB12-02797.019
Paste pH	-	1	7.2	6.2	7.2	7.2

Neutralising Potential (NP) Method: ME-AN-025

Parameter	Units	LOR	JB12-02797.016	JB12-02797.017	JB12-02797.018	JB12-02797.019
Fizz Rating	-	-	1	1	1	1
Sample Weight	g	-	2.00	2.00	2.00	2.00
Normality of standardised HCl	N	-	0.100	0.100	0.100	0.100
Volume of HCl added	ml	-	20.0	36.3	30.5	39.7
Normality of standardised NaOH	N	-	0.097	0.097	0.097	0.097
Titre of NaOH	ml	-	16.8	34.0	21.5	17.1
NP as kg CaCO ₃ /T	kg CaCO ₃ /T	-1	9.3	8.3	24.1	57.8



ANALYTICAL REPORT

JB12-02797 R0

Report number: 000002915

Client reference: 12613916

Sample Number	JB12-02797.016	JB12-02797.017	JB12-02797.018	JB12-02797.019
Sample Name	DHMS-C	DHSD-C	DHESC-C	DHUC-C

Parameter

Units

LOR

SUB_Sulphur and carbon species by LECO Method: SUB

Parameter	Units	LOR	JB12-02797.016	JB12-02797.017	JB12-02797.018	JB12-02797.019
Total sulphur as S [^]	%	0.01	0.09	0.72	1.60	2.17
Sulphide as S [^]	%	0.01	0.05	0.54	1.35	1.50
Sulphate as SO ₄ [^]	%	0.03	0.11	0.56	0.75	2.01
Total carbon as C [^]	%	0.01	0.61	1.87	49.10	44.30
Carbonate as CO ₃ [^]	%	0.05	0.22	0.21	0.97	2.15

Calculation of acid/base balances Method: ME-AN-025

Parameter	Units	LOR	JB12-02797.016	JB12-02797.017	JB12-02797.018	JB12-02797.019
Acid potential*	kg CaCO ₃ /T	0.31	1.6	17	42	47
Net neutralising potential*	kg CaCO ₃ /T	-100	7.7	-8.6	-18.1	10.9
NP:AP ratio*	-	-1	5.93	0.49	0.57	1.23
Classification*	-	-	PAN	PAG	PAG	U

METHOD METHODOLOGY SUMMARY

ME-AN-024	Paste pH/EC is determined by mixing a portion of sample with water at a low liquid to solid ratio and measuring the pH/EC of the resulting paste. Based on MEND 1.20.1. 10% pH/EC is determined by mixing a portion of sample with water at a liquid to solid ratio of 10:1 for a given period of time and measuring the pH/EC of the supernatant.
ME-AN-025	The acid production (AP) is calculated by assuming that all the sulphide sulphur present converts to sulphuric acid (sulphate) at a production of four moles of hydrogen ion per mole of pyrite oxidised. AP = acid potential = sulphide x 31.25. Where sulphide is reported as below the MDL, 0.099 is used for the calculation.
ME-AN-025	The acid/base balances (net NP, NP/AP ratio) are calculated and used to classify the sample as either having a potential to generate acidity, a potential for acid neutralisation or, if the results fall within a certain range, uncertainty with respect to net acid generation potential. Net NP = NP – AP PAG: Potentially acid generating, based on interpretation of ABA data alone. PAN: Potentially acid neutralising, based on interpretation of ABA data alone. U: Uncertain with respect to potential acid generation or neutralisation, based on interpretation of ABA data alone. Based on MEND 1.20.1.

FOOTNOTES

IS	Insufficient sample for analysis.	QFH	QC result is above the upper tolerance
LNR	Sample listed, but not received.	QFL	QC result is below the lower tolerance
*	This analysis is not covered by the scope of accreditation.	-	The sample was not analysed for this analyte
^	Performed by outside laboratory.		
LOR	Limit of Reporting		
↑↓	Raised or Lowered Limit of Reporting		

Samples analysed as received. Unless otherwise indicated, samples were received in containers fit for purpose.
 Solid samples expressed on a dry weight basis.

This document is issued by the Company under its General Conditions of Service accessible at http://www.sgs.com/terms_and_conditions.htm. Attention is drawn to the limitation of liability, indemnification and jurisdiction issues defined therein.
WARNING: The sample(s) to which the findings recorded herein (the "Findings") relate was(were) draw and / or provided by the Client or by a third party acting at the Client's direction. The Findings constitute no warranty of the sample's representativity of all goods and strictly relate to the sample(s). The Company accepts no liability with regard to the origin or source from which the sample(s) is/are said to be extracted.
 Any unauthorized alteration, forgery or falsification of the content or appearance of this document is unlawful and offenders may be prosecuted to the fullest extent of the law.

SGS Environmental Services Randburg is accredited by SANAS and conforms to the requirements of ISO/IEC 17025 for specific test or calibrations as indicated on the scope of accreditation to be found at <http://sanas.co.za>.



At Golder Associates we strive to be the most respected global company providing consulting, design, and construction services in earth, environment, and related areas of energy. Employee owned since our formation in 1960, our focus, unique culture and operating environment offer opportunities and the freedom to excel, which attracts the leading specialists in our fields. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees who operate from offices located throughout Africa, Asia, Australasia, Europe, North America, and South America.

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Africa (Pty) Ltd.
PO Box 6001
Halfway House, 1685
Thandanani Park
Matuka Close
Halfway Gardens
Midrand
South Africa
T: [+27] (11) 254 4800



Appendix C: Laboratory Certificates

WASTE ROCK and COAL SAMPLES



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES X-RAY FLUORESCENCE

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Major Elements	Major Element Concentration (wt %)[s]					
	PMB	PMA	PLC	PLB	PLA	Composite
	18729	18730	18731	18732	18733	18734
SiO ₂	48.81	45.4	37.7	38.04	35.83	36.47
TiO ₂	0.76	0.86	1.01	1.01	1.24	1.83
Al ₂ O ₃	16.04	16.29	16.26	16.39	19.66	23.32
Fe ₂ O ₃	2.04	3.62	1.7	1.49	3.39	2.49
MnO	0.03	0.05	0.02	0.02	0.04	0.04
MgO	0.26	0.33	0.32	0.15	0.16	0.71
CaO	0.29	0.71	1.97	0.98	1.24	4.69
Na ₂ O	0.38	0.36	0.46	0.22	0.26	0.9
K ₂ O	1.02	0.77	0.52	0.52	0.6	0.53
P ₂ O ₅	0.04	0.04	0.08	0.07	0.07	0.1
Cr ₂ O ₃	<0.01	<0.01	<0.01	0.01	0.02	0.04
SO ₃	<0.01	0.01	0.13	0.05	0.14	0.19
LOI	30.32	31.39	39.63	40.87	37.16	28.36
Total	99.99	99.83	99.8	99.82	99.81	99.67
H ₂ O-	0.64	0.68	1	0.89	0.79	0.97

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd.** Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd.** Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd.**



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES X-RAY FLUORESCENCE

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Major Elements	Major Element Concentration (wt %)[s]					
	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
	18735	18736	18737	18738	18739	18740
SiO ₂	67.35	69.85	55.3	57.07	44.45	54.91
TiO ₂	0.64	0.78	1.24	1.1	2.22	1.19
Al ₂ O ₃	13.34	15.77	22.52	21.32	29.09	27.04
Fe ₂ O ₃	3.3	4.98	8.81	2.04	2.99	0.95
MnO	0.05	0.04	0.14	0.03	0.04	<0.01
MgO	0.74	0.4	0.93	0.29	0.89	<0.01
CaO	4.5	0.15	0.71	0.66	7.08	0.12
Na ₂ O	0.52	0.13	0.29	0.27	1	0.32
K ₂ O	0.96	1.41	1.96	1.3	0.61	0.55
P ₂ O ₅	0.09	0.05	0.08	0.07	0.15	0.07
Cr ₂ O ₃	<0.01	<0.01	0.03	<0.01	0.04	0.02
SO ₃	0.03	<0.01	<0.01	0.1	0.44	<0.01
LOI	8.28	6.4	7.72	15.55	10.55	14.76
Total	99.8	99.96	99.73	99.8	99.55	99.93
H ₂ O-	0.47	0.71	0.26	0.39	0.22	0.39

[s] =Results obtained from sub-contracted laboratory

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd**. Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd**. Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd**.



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES X-RAY FLUORESCENCE

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Trace Elements	Trace Element Concentration (ppm) [s]					
	PMB	PMA	PLC	PLB	PLA	Composite
	18729	18730	18731	18732	18733	18734
As	1.85	8.9	9.4	1.04	<1.00	18
Ba	171	175	265	323	288	608
Bi	<5.00	<5.00	<5.00	<5.00	<5.00	<1.00
Br	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Cd	<5.00	<5.00	<5.00	<5.00	<5.00	<1.00
Ce	37.9	9.9	<5.00	<5.00	<5.00	<5.00
Cl	655	574	641	566	551	700
Co	<5.00	<5.00	<5.00	<5.00	<5.00	9.5
Cs	<1.00	1.29	<1.00	1.27	2.23	<5.00
Cu	27.2	31.3	37.2	30.8	34.5	49
Ga	23.3	23.9	27.2	27.3	38.2	48.6
Ge	1.25	1.56	2.21	1.62	1.28	9.7
Hf	4.3	5.79	4.99	6.1	7.3	8.9
Hg	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
La	29.2	69	34.9	3.46	47.3	70.2
Lu	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Mo	4.72	4.76	6	5.17	5.37	8.5
Nb	20.3	20.4	19.8	21.3	25.5	38.8
Nd	35.2	39.2	39.1	39.6	37.2	55.5
Ni	16.5	36	22.4	14.4	44.6	56.2
Pb	26.9	24.9	31	22.6	23.1	76
Rb	72	66.2	42.7	41.9	50.9	27.3
Sb	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Sc	8.9	7.6	9.8	9.4	9.7	15.3
Se	<5.00	<5.00	<1.00	<1.00	<1.00	<1.00
Sm	9	7.8	10.3	9.2	8.6	13.3
Sn	<1.00	<1.00	<5.00	3.68	2.18	5.1
Sr	74	74	262	255	147	840
Ta	2.71	2.26	2.18	2.23	2.02	3.52
Te	3.02	6.1	9.2	4.27	6.23	20.5
Th	28.1	24.7	22.1	24.5	35	41.7
Tl	<1.00	<5.00	<1.00	<1.00	<1.00	1.15

Results continued on next page

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd.** Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd.** Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd.**



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES X-RAY FLUORESCENCE

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Trace Elements	Trace Element Concentration (ppm) [s]					
	PMB	PMA	PLC	PLB	PLA	Composite
	18729	18730	18731	18732	18733	18734
U	6.06	5.89	4.52	5.7	6.11	10.9
V	96	89	110	96	166	203
W	4.26	4.62	3.28	3.09	3.81	3.63
Y	38.3	39.3	35.7	36.8	57.3	81
Yb	13.7	10.3	15.8	13.4	11.6	19.8
Zn	40	41.7	18.1	23.1	11.9	74
Zr	221	213	245	231	301	536

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd**. Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd**. Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd**.



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES X-RAY FLUORESCENCE

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Trace Elements	Trace Element Concentration (ppm) [s]					
	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
	18735	18736	18737	18738	18739	18740
As	<5.00	3.59	<5.00	15.8	18.3	7.96
Ba	378	203	535	196	1024	258
Bi	<5.00	<1.00	<1.00	<5.00	<1.00	<5.00
Br	<1.00	<1.00	1	<1.00	1.16	<1.00
Cd	<5.00	<1.00	<1.00	<5.00	<5.00	<5.00
Ce	46.1	32.5	<5.00	15	<5.00	81.1
Cl	705	709	782	725	948	656
Co	<5.00	<5.00	52.8	<5.00	27.1	<5.00
Cs	1.61	<1.00	<5.00	1.18	1.36	1.51
Cu	31.4	33.7	59	40.2	57.4	32.7
Ga	17.7	23.1	31.9	30	60.8	32.3
Ge	<1.00	2.09	7.47	2.6	10.8	2.82
Hf	5.83	7.4	9.17	6.78	9.3	6.19
Hg	<5.00	<5.00	<5.00	<1.00	1.2	<1.00
La	41.7	37.2	<5.00	40.7	70.2	23.5
Lu	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Mo	4.42	3.27	4.77	5.62	12.4	8.46
Nb	19	22.6	23.6	24.5	46.3	21.6
Nd	31.3	39.2	51.9	57.3	72	60.4
Ni	28.3	45.8	121	18	62.2	37.1
Pb	16.9	15.3	24.2	40.1	80	48.6
Rb	71.5	104	104	87	29.5	23.6
Sb	1.89	<5.00	5.21	<1.00	<1.00	1.56
Sc	15	11.1	14.2	11.9	12.8	9.4
Se	<1.00	<1.00	<5.00	<5.00	1.78	<1.00
Sm	9.6	8.66	5.94	10.6	15.6	14.6
Sn	4.83	4.64	10.4	2.76	3.67	3.39
Sr	108	90	140	91	1033	127
Ta	3.6	2.39	2.39	3.27	3.25	3.28
Te	12.7	3.11	3.31	3.88	30	3.85
Th	21.7	23	29	31.9	45.2	41.7
Tl	<1.00	<5.00	<1.00	<1.00	2.09	<1.00

Results continued on next page

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd**. Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd**. Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd**.



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES X-RAY FLUORESCENCE

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Trace Elements	Trace Element Concentration (ppm) [s]					
	OBW1	OBW2	IBW1	IBW2	TRP2	PLP1
	18735	18736	18737	18738	18739	18740
U	4.23	5.17	6.63	6.9	14.8	5.51
V	67.1	111	182	122	254	155
W	4.17	4.94	4.59	4.87	3.06	3.13
Y	41.6	41.6	45.6	45.9	89	26.8
Yb	12.2	10.3	6.73	16.1	23.4	21.9
Zn	71.3	86.8	202	66.6	86.9	45.1
Zr	251	295	297	284	606	296

[s] =Results obtained from sub-contracted laboratory

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd**. Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd**. Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd**.



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES
X-RAY DIFFRACTION

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Composition (%) [s]								
PMB			PMA			PLC		
18729			18730			18731		
Mineral	Amount (weight %)	Error	Mineral	Amount (weight %)	Error	Mineral	Amount (weight %)	Error
Calcite	0.14	0.1	Calcite	1.14	0.23	Calcite	4.34	0.36
Dolomite	0	0	Dolomite	0.72	0.3	Dolomite	0.71	0.3
Hematite	0	0	Hematite	0.17	0.11	Hematite	0.29	0.24
Kaolinite	45.76	0.72	Kaolinite	46.3	0.75	Kaolinite	50.76	0.9
Microcline	6.32	0.69	Microcline	4.2	0.45	Microcline	7.4	0.81
Muscovite	6.17	0.48	Muscovite	6.47	0.48	Muscovite	6.06	0.54
Pyrite	0.36	0.17	Pyrite	1.19	0.21	Pyrite	0.14	0.15
Quartz	37.76	0.75	Quartz	33.81	0.75	Quartz	26.39	0.84
Siderite	3.5	0.33	Siderite	6	0.42	Siderite	3.91	0.51

Composition (%) [s]								
PLB			PLA			Composite		
18732			18733			18734		
Mineral	Amount (weight %)	Error	Mineral	Amount (weight %)	Error	Mineral	Amount (weight %)	Error
Calcite	1.28	0.3	Calcite	3.41	0.48	Calcite	0.62	0.26
Dolomite	0.16	0.21	Dolomite	0.12	0.18	Dolomite	0.5	0.24
Hematite	0.09	0.14	Hematite	0.7	0.29	Hematite	0.08	0.11
Kaolinite	51.99	0.9	Kaolinite	58.77	1.08	Kaolinite	47.7	0.78
Microcline	4.61	0.51	Microcline	4.45	0.84	Microcline	7.67	0.75
Muscovite	7.19	0.6	Muscovite	7.95	0.63	Muscovite	7.28	0.54
Pyrite	0.14	0.17	Pyrite	0.53	0.27	Pyrite	0.52	0.17
Quartz	31.46	0.87	Quartz	20.06	0.84	Quartz	34.64	0.84
Siderite	3.08	0.45	Siderite	4.01	0.48	Siderite	0.99	0.21

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd**. Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd**. Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd**.



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES
X-RAY DIFFRACTION

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Composition (%) [s]								
OBW1			OBW2			IBW1		
18735			18736			18737		
Mineral	Amount (weight %)	Error	Mineral	Amount (weight %)	Error	Mineral	Amount (weight %)	Error
Calcite	6.58	0.42	Calcite	0.07	0.17	Calcite	0.31	0.23
Dolomite	0	0	Dolomite	0	0	Dolomite	0.68	0.36
Hematite	0.61	0.18	Hematite	0.49	0.26	Hematite	0.47	0.23
Kaolinite	26.79	0.6	Kaolinite	30.53	0.66	Kaolinite	38.43	0.78
Microcline	2.22	0.63	Microcline	2.19	0.63	Microcline	5.66	0.45
Muscovite	5.63	0.42	Muscovite	8.07	0.45	Muscovite	6.14	0.51
Pyrite	0.09	0.13	Pyrite	0.19	0.18	Pyrite	0.13	0.1
Quartz	58.08	0.81	Quartz	58.45	0.81	Quartz	44.98	0.84
Siderite	0	0	Siderite	0	0	Siderite	3.19	0.45

Composition (%) [s]								
IBW2			TRP2			PLP1		
18738			18739			18740		
Mineral	Amount (weight %)	Error	Mineral	Amount (weight %)	Error	Mineral	Amount (weight %)	Error
Calcite	0	0	Calcite	2.91	0.3	Calcite	0.38	0.42
Dolomite	0.91	0.33	Dolomite	0.18	0.14	Dolomite	0	0
Hematite	0.29	0.23	Hematite	0.27	0.22	Hematite	0.64	0.29
Kaolinite	39.93	0.81	Kaolinite	48.29	0.81	Kaolinite	56.14	1.14
Microcline	7.21	0.87	Microcline	2.23	0.87	Microcline	3.32	1.14
Muscovite	8.12	0.48	Muscovite	4.95	0.48	Muscovite	7.23	0.63
Pyrite	0.3	0.17	Pyrite	0.24	0.22	Pyrite	0.31	0.26
Quartz	32.13	0.72	Quartz	40.89	0.75	Quartz	31.98	0.9
Siderite	11.12	0.51	Siderite	0.04	0.11	Siderite	0	0

[s] Results obtained from sub-contracted laboratory



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES X-RAY DIFFRACTION

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-22
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

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. Errors are on the 3 sigma level in the column to the right of the amount (in weight per cent).

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 (i.e "Muscovite" would represent the mineral group "Mica")
- Errors reported for phases occurring in minor amounts are sometimes larger than that of the quantity reported, indicating the possible absence of those phases.
- Due to preferred orientation effects results may not be as accurate as shown in the table and the clay minerals might be slightly overestimated.

Amorphous phases, if present, were not taken into account in the quantification.

Ideal Mineral compositions:

Calcite	CaCO ₃
Dolomite	CaMg(CO ₃) ₂
Kaolinite	Al ₂ Si ₂ O ₅ (OH) ₄
Microcline	KAlSi ₃ O ₈
Muscovite	KAl ₃ Si ₃ O ₁₀ (OH) ₂
Pyrite	FeS ₂
Quartz	SiO ₂
Hematite	Fe ₂ O ₃
Siderite	FeCO ₃



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-23
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification				
	PMB	PMA	PLC	PLB	PLA
Sample Number	18729	18730	18731	18732	18733
Paste pH	7.7	7.6	7.8	7.8	7.9
Total Sulphur (%) (LECO)	0.26	0.72	0.23	0.27	0.47
Acid Potential (AP) (kg/t)	8.13	22.50	7.19	8.44	14.69
Neutralization Potential (NP)	-5.50	-3.75	12.75	8.75	2.50
Nett Neutralization Potential (NNP)	-13.63	-26.25	5.56	0.31	-12.19
Neutralising Potential Ratio (NPR) (NP : AP)	0.68	0.17	1.77	1.04	0.17
Rock Type	I	I	III	II	I

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification				
	Composite	OBW1	OBW2	IBW1	IBW1
Sample Number	18734	18735	18736	18737	18737D
Paste pH	7.8	7.9	8.1	8.1	8.0
Total Sulphur (%) (LECO)	0.65	<0.01	0.01	0.15	0.12
Acid Potential (AP) (kg/t)	20.31	0.31	0.31	4.69	3.75
Neutralization Potential (NP)	3.00	27.00	-10.75	3.00	2.50
Nett Neutralization Potential (NNP)	-17.31	26.69	-11.06	-1.69	-1.25
Neutralising Potential Ratio (NPR) (NP : AP)	0.15	86.40	34.40	0.64	0.67
Rock Type	I	III	III	II	II

E. Botha
Geochemistry Project Manager



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-23
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification		
	IBW2	TRP2	PLP1
Sample Number	18738	18739	18740
Paste pH	8.0	7.5	7.8
Total Sulphur (%) (LECO)	0.37	0.10	0.35
Acid Potential (AP) (kg/t)	11.56	3.13	10.94
Neutralization Potential (NP)	5.25	1.50	-12.00
Nett Neutralization Potential (NNP)	-6.31	-1.63	-22.94
Neutralising Potential Ratio (NPR) (NP : AP)	0.45	0.48	1.10
Rock Type	I	II	II

* 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



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-23
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

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

E. Botha
Geochemistry Project Manager



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-23
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

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)

E. Botha
Geochemistry Project Manager



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-23
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

REFERENCES

LAWRENCE, R.W. & WANG, Y. 1997. **Determination of Neutralization Potential in the Prediction of Acid Rock Drainage.** Proc. 4th International Conference on Acid Rock Drainage. Vancouver. BC. pp. 449 – 464.

PRICE, W.A., MORIN, K. & HUTT, N. 1997. **Guidelines for the prediction of Acid Rock Drainage and Metal leaching for mines in British Columbia** : Part 11. Recommended procedures for static and kinetic testing. In: Proceedings of the Fourth International Conference on Acid Rock Drainage. Vol 1. May 31 – June 6. Vancouver, BC., pp. 15 – 30.

SOBEK, A.A., SCHULLER, W.A., FREEMAN, J.R. & SMITH, R.M. 1978. **Field and laboratory methods applicable to overburdens and mine soils.** EPA-600/2-78-054. USEPA. Cincinnati. Ohio.

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

USHER, B.H., CRUYWAGEN, L-M., DE NECKER, E. & HODGSON, F.D.I. 2003. **Acid-Base : Accounting, Techniques and Evaluation (ABATE): Recommended Methods for Conducting and Interpreting Analytical Geochemical Assessments at Opencast Collieries in South Africa.** Water Research Commission Report No 1055/2/03. Pretoria.

ENVIRONMENT AUSTRALIA. 1997. **Managing Sulphidic Mine Wastes and Acid Drainage.**

E. Botha
Geochemistry Project Manager



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES NETT ACID GENERATION

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-23
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Nett Acid Generation	Sample Identification: pH 4.5				
	PMB	PMA	PLC	PLB	PLA
Sample Number	18729	18730	18731	18732	18733
NAG pH: (H ₂ O ₂)	4.8	4.3	5.6	4.3	5.9
NAG (kg H ₂ SO ₄ / t)	<0.01	0.392	<0.01	1.37	<0.01

Nett Acid Generation	Sample Identification: pH 7				
	PMB	PMA	PLC	PLB	PLA
Sample Number	18729	18730	18731	18732	18733
NAG pH: (H ₂ O ₂)	4.8	4.5	5.6	4.5	5.9
NAG (kg H ₂ SO ₄ / t)	12	10	2.35	22	0.588

Nett Acid Generation	Sample Identification: pH 4.5				
	Composite	OBW1	OBW2	IBW1	IBW1
Sample Number	18734	18735	18736	18737	18737D
NAG pH: (H ₂ O ₂)	3.4	9.4	7.5	7.9	7.8
NAG (kg H ₂ SO ₄ / t)	2.55	<0.01	<0.01	<0.01	<0.01

Nett Acid Generation	Sample Identification: pH 7				
	Composite	OBW1	OBW2	IBW1	IBW1
Sample Number	18734	18735	18736	18737	18737D
NAG pH: (H ₂ O ₂)	4.6	9.4	7.5	7.9	7.8
NAG (kg H ₂ SO ₄ / t)	14	<0.01	<0.01	<0.01	<0.01

E. Botha
Geochemistry Project Manager



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES NETT ACID GENERATION

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-23
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Nett Acid Generation	Sample Identification: pH 4.5			
	IBW2	TRP2	PLP1	PLP1
Sample Number	18738	18739	18740	18740D
NAG pH: (H ₂ O ₂)	7.6	7.9	3.2	3.1
NAG (kg H ₂ SO ₄ / t)	<0.01	<0.01	3.72	3.92

Nett Acid Generation	Sample Identification: pH 7			
	IBW2	TRP2	PLP1	PLP1
Sample Number	18738	18739	18740	18740D
NAG pH: (H ₂ O ₂)	7.6	7.9	4.5	4.6
NAG (kg H ₂ SO ₄ / t)	<0.01	<0.01	6.47	6.27

E. Botha
Geochemistry Project Manager



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-30
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Analyses	Sample Identification			
	PMB		PMA	
Sample number	18729		18730	
TCLP / Acid Rain / Distilled Water / H ₂ O ₂	Distilled Water		Distilled Water	
Dry Mass Used (g)	250		250	
Volume Used (mℓ)	1000		1000	
pH Value at 25°C	7.6		7.8	
Electrical Conductivity in mS/m at 25°C	21.5		22.4	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as CaCO ₃	40	160	64	256
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO ₄	54	216	43	172
Nitrate as N	<0.2	<0.8	<0.2	<0.8
Fluoride as F	1.7	6.8	1.8	7.2
Phosphorus as P	<0.025	<0.100	<0.025	<0.100
ICP-MS Quant [s]	See attached report 42099		See attached report 42099	

[s] Subcontracted

Analyses	Sample Identification	
	ANG 2137	
Sample number	18729-18740	
Acid Base Accounting	See attached report 42099 ABA	
Net Acid Generation	See attached report 42099 NAG	
X-ray Diffraction [s]	See attached report 42099 XRD	
X-ray Fluorescence [s]	See attached report 42099 XRF	

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd**. Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd**. Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd**.



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-30
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Analyses	Sample Identification			
	PLC		PLB	
Sample number	18731		18732	
TCLP / Acid Rain / Distilled Water / H ₂ O ₂	Distilled Water		Distilled Water	
Dry Mass Used (g)	250		250	
Volume Used (mℓ)	1000		1000	
pH Value at 25°C	8.3		8.2	
Electrical Conductivity in mS/m at 25°C	15.9		13.9	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as CaCO ₃	60	240	60	240
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO ₄	7	28	7	28
Nitrate as N	<0.2	<0.8	<0.2	<0.8
Fluoride as F	2.1	8.4	1.3	5.2
Phosphorus as P	<0.025	<0.100	<0.025	<0.100
ICP-MS Quant [s]	See attached report 42099		See attached report 42099	

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd.** Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd.** Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd.**



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-30
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Analyses	Sample Identification			
	PLA		Composite	
Sample number	18733		18734	
TCLP / Acid Rain / Distilled Water / H ₂ O ₂	Distilled Water		Distilled Water	
Dry Mass Used (g)	250		250	
Volume Used (mℓ)	1000		1000	
pH Value at 25°C	8.2		8.2	
Electrical Conductivity in mS/m at 25°C	19.7		21.5	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as CaCO ₃	68	272	68	272
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO ₄	28	112	27	108
Nitrate as N	<0.2	<0.8	<0.2	<0.8
Fluoride as F	1.5	6.0	2.4	9.6
Phosphorus as P	<0.025	<0.100	<0.025	<0.100
ICP-MS Quant [s]	See attached report 42099		See attached report 42099	

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd.** Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd.** Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd.**



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-30
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Analyses	Sample Identification			
	OBW1		OBW2	
Sample number	18735		18736	
TCLP / Acid Rain / Distilled Water / H ₂ O ₂	Distilled Water		Distilled Water	
Dry Mass Used (g)	250		250	
Volume Used (mℓ)	1000		1000	
pH Value at 25°C	8.2		7.7	
Electrical Conductivity in mS/m at 25°C	17.6		9.5	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as CaCO ₃	56	224	48	192
Chloride as Cl	11	44	<5	<20
Sulphate as SO ₄	7	28	15	60
Nitrate as N	0.3	1.2	<0.2	<0.8
Fluoride as F	1.2	4.8	0.7	2.8
Phosphorus as P	<0.025	<0.100	<0.025	<0.100
ICP-MS Quant [s]	See attached report 42099		See attached report 42099	

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd**. Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd**. Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd**.



WATERLAB

WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-30
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Analyses	Sample Identification			
	IBW1		IBW2	
Sample number	18737		18738	
TCLP / Acid Rain / Distilled Water / H ₂ O ₂	Distilled Water		Distilled Water	
Dry Mass Used (g)	250		250	
Volume Used (mℓ)	1000		1000	
pH Value at 25°C	8.3		8.3	
Electrical Conductivity in mS/m at 25°C	25.9		28.6	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as CaCO ₃	96	384	104	416
Chloride as Cl	9	36	12	48
Sulphate as SO ₄	19	76	23	92
Nitrate as N	<0.2	<0.8	<0.2	0.8
Fluoride as F	0.9	3.6	1.5	6.0
Phosphorus as P	<0.025	<0.100	<0.025	<0.100
ICP-MS Quant [s]	See attached report 42099		See attached report 42099	

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd.** Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd.** Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd.**



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-09-23
Project number: 1000

Report number: 42099

Date completed: 2013-10-30
Order number: ANG2137

Client name: Digby Wells Environmental
Address: Private Bag X10046, Randberg, 2125, South Africa
Facsimile: 011 789 9498

Contact person: Andre Van Coller
Email: andre.van.coller@digbywells.com
Cell: 076 076 9443

Analyses	Sample Identification			
	TRP2		PLP1	
Sample number	18739		18740	
TCLP / Acid Rain / Distilled Water / H ₂ O ₂	Distilled Water		Distilled Water	
Dry Mass Used (g)	250		250	
Volume Used (mℓ)	1000		1000	
pH Value at 25°C	8.1		4.7	
Electrical Conductivity in mS/m at 25°C	31.9		27.9	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as CaCO ₃	76	304	<5	<20
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO ₄	80	320	118	472
Nitrate as N	<0.2	<0.8	<0.2	<0.8
Fluoride as F	1.3	5.2	0.3	1.2
Phosphorus as P	<0.025	<0.100	<0.025	<0.100
ICP-MS Quant [s]	See attached report 42099		See attached report 42099	

[s] Subcontracted

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd.** Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd.** Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd.**

WATERLAB (PTY) LTD
CERTIFICATE OF ANALYSES
ICP-MS QUANTITATIVE ANALYSIS [s]

Date received: 23/09/2013
 Project number: 1000

Date Completed: 30/10/2013
 Report number: 42099

Client name: Digby Wells Environmental
 Address: Private Bag X10046, Randberg, 2125, South Africa
 Telephone: Telephone: 011 789 9495

Contact person: Andre Van Coller
 Email: andre.van.coller@digbywells.com
 Cell: [076 076 9443](tel:0760769443)

Extract	Sample Dry Mass (g)	Volume (ml)	Factor
Distilled Water	250	1000	4

[s]= Results obtained form subcontracted laboratory

Sample Id	Sample Number	Ag	Ag	Al	Al	As	As
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMB	18729	<0.001	<0.004	0.148	0.590	0.003	0.012
PMA	18730	<0.001	<0.004	0.043	0.173	0.004	0.016
PLC	18731	<0.001	<0.004	0.200	0.800	0.009	0.036
PLB	18732	0.001	0.004	0.036	0.143	0.001	0.004
PLA	18733	<0.001	<0.004	0.010	0.038	0.003	0.012
Composite	18734	<0.001	<0.004	0.139	0.555	0.008	0.032
OBW1	18735	<0.001	<0.004	0.031	0.122	0.007	0.028
OBW2	18736	<0.001	<0.004	4.80	19	0.003	0.012
IBW1	18737	<0.001	<0.004	5.73	23	0.004	0.016
IBW2	18738	<0.001	<0.004	0.248	0.993	0.003	0.012
TRP2	18739	<0.001	<0.004	0.021	0.085	0.005	0.020
PLP1	18740	<0.001	<0.004	0.443	1.77	0.002	0.008

Sample Id	Sample Number	Au	Au	B	B	Ba	Ba
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMB	18729	0.001	0.004	0.157	0.626	0.064	0.257
PMA	18730	0.001	0.004	0.249	0.997	0.154	0.617
PLC	18731	<0.001	<0.004	0.245	0.982	0.123	0.491
PLB	18732	<0.001	<0.004	0.172	0.689	0.108	0.432
PLA	18733	<0.001	<0.004	1.04	4.14	0.055	0.221
Composite	18734	<0.001	<0.004	0.273	1.09	0.083	0.332
OBW1	18735	<0.001	<0.004	0.021	0.084	0.318	1.270
OBW2	18736	<0.001	<0.004	0.020	0.081	0.247	0.986
IBW1	18737	0.001	0.004	0.026	0.106	0.241	0.966
IBW2	18738	0.001	0.004	0.025	0.099	0.180	0.719
TRP2	18739	<0.001	<0.004	0.036	0.143	0.091	0.365
PLP1	18740	<0.001	<0.004	0.048	0.193	0.070	0.279

Sample Id	Sample Number	Be	Be	Bi	Bi	Ca	Ca
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.01	<0.04
PMB	18729	<0.001	<0.004	<0.001	<0.004	16.2	65
PMA	18730	<0.001	<0.004	<0.001	<0.004	21.5	86
PLC	18731	<0.001	<0.004	<0.001	<0.004	14.2	57
PLB	18732	<0.001	<0.004	<0.001	<0.004	13.6	54
PLA	18733	<0.001	<0.004	<0.001	<0.004	19.4	78
Composite	18734	<0.001	<0.004	<0.001	<0.004	17.4	70
OBW1	18735	<0.001	<0.004	<0.001	<0.004	12.9	52
OBW2	18736	0.001	0.004	<0.001	<0.004	4.87	19
IBW1	18737	<0.001	<0.004	<0.001	<0.004	8.2	33
IBW2	18738	<0.001	<0.004	<0.001	<0.004	9.96	40
TRP2	18739	<0.001	<0.004	<0.001	<0.004	41	164
PLP1	18740	0.002	0.008	<0.001	<0.004	21.8	87

Sample Id	Sample Number	Cd	Cd	Ce	Ce	Co	Co
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.0001	<0.0004	<0.001	<0.004	<0.001	<0.004
PMB	18729	<0.0001	<0.0004	<0.001	<0.004	<0.001	<0.004
PMA	18730	0.0001	0.0004	<0.001	<0.004	<0.001	<0.004
PLC	18731	0.0001	0.0004	0.001	0.004	0.001	0.004
PLB	18732	0.0001	0.0004	<0.001	<0.004	<0.001	<0.004
PLA	18733	<0.0001	<0.0004	<0.001	<0.004	<0.001	<0.004
Composite	18734	0.0001	0.0004	<0.001	<0.004	<0.001	<0.004
OBW1	18735	0.0001	0.0004	<0.001	<0.004	<0.001	<0.004
OBW2	18736	<0.0001	<0.0004	0.010	0.038	<0.001	<0.004
IBW1	18737	0.0001	0.0004	0.003	0.012	0.001	0.004
IBW2	18738	0.0001	0.0004	<0.001	<0.004	<0.001	<0.004
TRP2	18739	<0.0001	<0.0004	<0.001	<0.004	0.010	0.041
PLP1	18740	0.0008	0.0032	<0.001	<0.004	0.833	3.33

Sample Id	Sample Number	Cr	Cr	Cs	Cs	Cu	Cu
-----------	---------------	----	----	----	----	----	----

		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMB	18729	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMA	18730	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PLC	18731	0.002	0.008	<0.001	<0.004	0.005	0.020
PLB	18732	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PLA	18733	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
Composite	18734	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
OBW1	18735	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
OBW2	18736	0.005	0.020	0.001	0.004	<0.001	<0.004
IBW1	18737	0.018	0.072	0.001	0.004	<0.001	<0.004
IBW2	18738	<0.001	<0.004	0.001	0.004	<0.001	<0.004
TRP2	18739	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PLP1	18740	<0.001	<0.004	0.001	0.004	0.071	0.284

Sample Id	Sample Number	Fe	Fe	Ga	Ga	Ge	Ge
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.01	<0.04	<0.001	<0.004	<0.001	<0.004
PMB	18729	0.067	0.267	<0.001	<0.004	<0.001	<0.004
PMA	18730	0.065	0.258	<0.001	<0.004	<0.001	<0.004
PLC	18731	0.150	0.600	<0.001	<0.004	<0.001	<0.004
PLB	18732	0.072	0.287	<0.001	<0.004	<0.001	<0.004
PLA	18733	0.049	0.197	<0.001	<0.004	<0.001	<0.004
Composite	18734	0.054	0.217	<0.001	<0.004	<0.001	<0.004
OBW1	18735	0.043	0.174	<0.001	<0.004	<0.001	<0.004
OBW2	18736	2.190	8.76	0.002	0.008	<0.001	<0.004
IBW1	18737	0.636	2.54	0.002	0.008	<0.001	<0.004
IBW2	18738	0.105	0.422	<0.001	<0.004	<0.001	<0.004
TRP2	18739	0.027	0.109	<0.001	<0.004	<0.001	<0.004
PLP1	18740	0.448	1.79	<0.001	<0.004	<0.001	<0.004

Sample Id	Sample Number	Hf	Hf	Hg	Hg	Ho	Ho
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.0001	<0.0004	<0.001	<0.004
PMB	18729	<0.001	<0.004	<0.0001	<0.0004	<0.001	<0.004
PMA	18730	<0.001	<0.004	0.0002	0.0008	<0.001	<0.004
PLC	18731	<0.001	<0.004	<0.0001	<0.0004	<0.001	<0.004
PLB	18732	<0.001	<0.004	0.0001	0.0004	<0.001	<0.004
PLA	18733	<0.001	<0.004	0.0002	0.0008	<0.001	<0.004
Composite	18734	<0.001	<0.004	0.0001	0.0004	<0.001	<0.004
OBW1	18735	<0.001	<0.004	<0.0001	<0.0004	<0.001	<0.004
OBW2	18736	<0.001	<0.004	<0.0001	<0.0004	<0.001	<0.004
IBW1	18737	<0.001	<0.004	0.0001	0.0004	<0.001	<0.004
IBW2	18738	<0.001	<0.004	0.0002	0.0008	<0.001	<0.004
TRP2	18739	<0.001	<0.004	<0.0001	<0.0004	<0.001	<0.004
PLP1	18740	<0.001	<0.004	<0.0001	<0.0004	<0.001	<0.004

Sample Id	Sample Number	Ir	Ir	K	K	La	La
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.01	<0.04	<0.001	<0.004
PMB	18729	<0.001	<0.004	8.83	35	<0.001	<0.004
PMA	18730	<0.001	<0.004	7.81	31	<0.001	<0.004
PLC	18731	<0.001	<0.004	5.66	23	<0.001	<0.004
PLB	18732	<0.001	<0.004	4.87	19	<0.001	<0.004
PLA	18733	<0.001	<0.004	5.79	23	<0.001	<0.004
Composite	18734	<0.001	<0.004	9.58	38	<0.001	<0.004
OBW1	18735	<0.001	<0.004	5.87	23	<0.001	<0.004
OBW2	18736	<0.001	<0.004	10.99	44	<0.001	<0.004
IBW1	18737	<0.001	<0.004	6.77	27	0.002	0.008
IBW2	18738	<0.001	<0.004	6.82	27	<0.001	<0.004
TRP2	18739	<0.001	<0.004	5.49	22	<0.001	<0.004
PLP1	18740	<0.001	<0.004	5.39	22	<0.001	<0.004

Sample Id	Sample Number	Li	Li	Mg	Mg	Mn	Mn
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.01	<0.04	<0.001	<0.004
PMB	18729	0.010	0.040	6.41	26	0.080	0.320
PMA	18730	<0.001	<0.004	7.42	30	0.030	0.120
PLC	18731	<0.001	<0.004	4.91	20	0.040	0.160
PLB	18732	<0.001	<0.004	4.24	17	0.020	0.080
PLA	18733	0.010	0.040	6.27	25	0.030	0.120
Composite	18734	<0.001	<0.004	5.69	23	0.030	0.120
OBW1	18735	<0.001	<0.004	5.62	22	0.020	0.080
OBW2	18736	0.010	0.040	2.86	11	0.070	0.280
IBW1	18737	<0.001	<0.004	2.63	11	0.030	0.120
IBW2	18738	0.010	0.040	3.62	14	0.020	0.080
TRP2	18739	0.020	0.080	8.65	35	0.090	0.360
PLP1	18740	0.070	0.280	10.3	41	0.440	1.76

Sample Id	Sample Number	Mo	Mo	Na	Na	Nb	Nb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMB	18729	0.004	0.015	10.4	42	<0.001	<0.004
PMA	18730	0.005	0.022	9.4	37	<0.001	<0.004
PLC	18731	0.011	0.045	8.2	33	<0.001	<0.004
PLB	18732	0.007	0.027	7.1	29	<0.001	<0.004
PLA	18733	0.015	0.059	9.2	37	<0.001	<0.004
Composite	18734	0.013	0.051	13.4	54	<0.001	<0.004
OBW1	18735	0.001	0.006	12.2	49	<0.001	<0.004
OBW2	18736	0.002	0.006	6.1	24	0.001	0.004
IBW1	18737	0.076	0.304	40.6	162	0.001	0.004
IBW2	18738	0.065	0.262	41.4	166	<0.001	<0.004
TRP2	18739	0.073	0.292	7.4	29	<0.001	<0.004
PLP1	18740	0.002	0.010	6.9	27	<0.001	<0.004

Sample Id	Sample Number	Nd	Nd	Ni	Ni	Pb	Pb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMB	18729	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMA	18730	<0.001	<0.004	0.012	0.049	<0.001	<0.004
PLC	18731	<0.001	<0.004	0.004	0.015	0.001	0.004
PLB	18732	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PLA	18733	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
Composite	18734	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
OBW1	18735	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
OBW2	18736	0.007	0.028	<0.001	<0.004	0.006	0.025
IBW1	18737	0.001	0.004	<0.001	<0.004	0.002	0.008
IBW2	18738	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
TRP2	18739	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PLP1	18740	<0.001	<0.004	1.66	6.66	0.002	0.007

Sample Id	Sample Number	Pt	Pt	Rb	Rb	Sb	Sb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004

Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMB	18729	<0.001	<0.004	0.009	0.036	0.001	0.004
PMA	18730	<0.001	<0.004	0.008	0.033	0.001	0.004
PLC	18731	<0.001	<0.004	0.007	0.027	0.001	0.004
PLB	18732	<0.001	<0.004	0.006	0.024	0.001	0.004
PLA	18733	<0.001	<0.004	0.008	0.031	0.001	0.004
Composite	18734	<0.001	<0.004	0.008	0.033	0.001	0.004
OBW1	18735	<0.001	<0.004	0.003	0.011	0.001	0.004
OBW2	18736	<0.001	<0.004	0.013	0.051	0.001	0.004
IBW1	18737	<0.001	<0.004	0.012	0.050	0.002	0.008
IBW2	18738	<0.001	<0.004	0.010	0.041	0.002	0.008
TRP2	18739	<0.001	<0.004	0.007	0.030	0.002	0.008
PLP1	18740	<0.001	<0.004	0.010	0.040	<0.001	<0.004

Sample Id	Sample Number	Sc	Sc	Se	Se	Si	Si
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.05	<0.200
PMB	18729	0.003	0.012	0.024	0.098	3.73	14.9
PMA	18730	0.002	0.008	<0.001	<0.004	2.49	10.0
PLC	18731	0.002	0.008	0.019	0.077	1.85	7.4
PLB	18732	0.001	0.004	0.048	0.193	1.6	6.4
PLA	18733	0.001	0.004	0.030	0.119	2.08	8.3
Composite	18734	0.002	0.008	0.015	0.061	3.09	12.4
OBW1	18735	0.008	0.032	<0.001	<0.004	9.35	37.4
OBW2	18736	0.018	0.074	<0.001	<0.004	20.47	81.9
IBW1	18737	0.010	0.038	0.008	0.033	11.07	44.3
IBW2	18738	0.001	0.004	0.019	0.076	2.21	8.8
TRP2	18739	0.002	0.008	0.034	0.136	3.53	14.1
PLP1	18740	0.005	0.020	0.013	0.052	6.62	26.5

Sample Id	Sample Number	Sn	Sn	Sr	Sr	Ta	Ta
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMB	18729	<0.001	<0.004	0.086	0.344	<0.001	<0.004
PMA	18730	<0.001	<0.004	0.093	0.371	<0.001	<0.004
PLC	18731	<0.001	<0.004	0.071	0.284	<0.001	<0.004
PLB	18732	<0.001	<0.004	0.050	0.201	<0.001	<0.004
PLA	18733	<0.001	<0.004	0.082	0.328	<0.001	<0.004
Composite	18734	<0.001	<0.004	0.100	0.400	<0.001	<0.004
OBW1	18735	<0.001	<0.004	0.110	0.441	<0.001	<0.004
OBW2	18736	<0.001	<0.004	0.032	0.127	<0.001	<0.004
IBW1	18737	<0.001	<0.004	0.097	0.388	<0.001	<0.004
IBW2	18738	<0.001	<0.004	0.109	0.437	<0.001	<0.004
TRP2	18739	<0.001	<0.004	0.137	0.549	<0.001	<0.004
PLP1	18740	<0.001	<0.004	0.106	0.423	<0.001	<0.004

Sample Id	Sample Number	Te	Te	Th	Th	Ti	Ti
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200
PMB	18729	<0.001	<0.004	<0.0001	<0.0004	0.013	0.051
PMA	18730	<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200
PLC	18731	<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200
PLB	18732	<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200
PLA	18733	<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200
Composite	18734	<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200
OBW1	18735	<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200
OBW2	18736	<0.001	<0.004	0.0011	0.004	0.196	0.783
IBW1	18737	<0.001	<0.004	0.0007	0.003	0.303	1.21
IBW2	18738	<0.001	<0.004	<0.0001	<0.0004	0.010	0.040
TRP2	18739	<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200
PLP1	18740	<0.001	<0.004	<0.0001	<0.0004	<0.05	<0.200

Sample Id	Sample Number	Tl	Tl	U	U	V	V
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.0001	<0.0004	<0.001	<0.004
PMB	18729	<0.001	<0.004	0.0003	0.0012	0.001	0.004
PMA	18730	<0.001	<0.004	0.0007	0.0028	0.002	0.008
PLC	18731	<0.001	<0.004	0.0001	0.0004	0.005	0.020
PLB	18732	<0.001	<0.004	0.0001	0.0004	0.005	0.020
PLA	18733	<0.001	<0.004	0.0003	0.0012	0.005	0.020
Composite	18734	<0.001	<0.004	0.0005	0.0020	0.004	0.016
OBW1	18735	<0.001	<0.004	0.0001	0.0004	0.015	0.060
OBW2	18736	<0.001	<0.004	0.0004	0.0016	0.016	0.064
IBW1	18737	<0.001	<0.004	0.0005	0.0020	0.017	0.068
IBW2	18738	<0.001	<0.004	0.0002	0.0008	0.001	0.004
TRP2	18739	<0.001	<0.004	0.0006	0.0024	0.004	0.017
PLP1	18740	<0.001	<0.004	0.0005	0.0020	<0.001	<0.004

Sample Id	Sample Number	W	W	Y	Y	Zn	Zn
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PMB	18729	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004

PMA	18730	0.001	0.004	<0.001	<0.004	0.002	0.008
PLC	18731	0.003	0.012	<0.001	<0.004	0.154	0.614
PLB	18732	0.003	0.012	<0.001	<0.004	0.005	0.020
PLA	18733	0.011	0.044	<0.001	<0.004	<0.001	<0.004
Composite	18734	0.001	0.004	<0.001	<0.004	0.002	0.008
OBW1	18735	0.001	0.004	<0.001	<0.004	<0.001	<0.004
OBW2	18736	<0.001	<0.004	0.003	0.012	0.009	0.036
IBW1	18737	0.001	0.004	0.001	0.004	0.005	0.020
IBW2	18738	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
TRP2	18739	<0.001	<0.004	<0.001	<0.004	<0.001	<0.004
PLP1	18740	<0.001	<0.004	<0.001	<0.004	0.584	2.34

Sample Id	Sample Number	Zr	Zr
		mg/l	mg/kg
Det Limit		<0.001	<0.004
PMB	18729	<0.001	<0.004
PMA	18730	<0.001	<0.004
PLC	18731	<0.001	<0.004
PLB	18732	<0.001	<0.004
PLA	18733	<0.001	<0.004
Composite	18734	<0.001	<0.004
OBW1	18735	<0.001	<0.004
OBW2	18736	0.007	0.028
IBW1	18737	0.004	0.016
IBW2	18738	<0.001	<0.004
TRP2	18739	<0.001	<0.004
PLP1	18740	<0.001	<0.004

ASH SAMPLES

CLIENT: Japie Oberholzer - UIS
DATE: 16 September 2013
SAMPLES: 6 Sample (8168-354784-9)
ANALYSIS: Qualitative and quantitative XRD

The samples were prepared for XRD analysis using a back loading preparation method.

They were 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. Errors are on the 3 sigma level in the column to the right of the amount (in weight per cent).

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.
- Errors reported for phases occurring in minor amounts are sometimes larger than that of the quantity reported, indicating the possible absence of those phases.
- Mineral names may not reflect the actual compositions of minerals identified, but rather the mineral group.
- Due to preferred orientation as well as crystallite size effects, results may not be as accurate as shown.
- Some organic carbon may be present

If you have any further queries, kindly contact me.

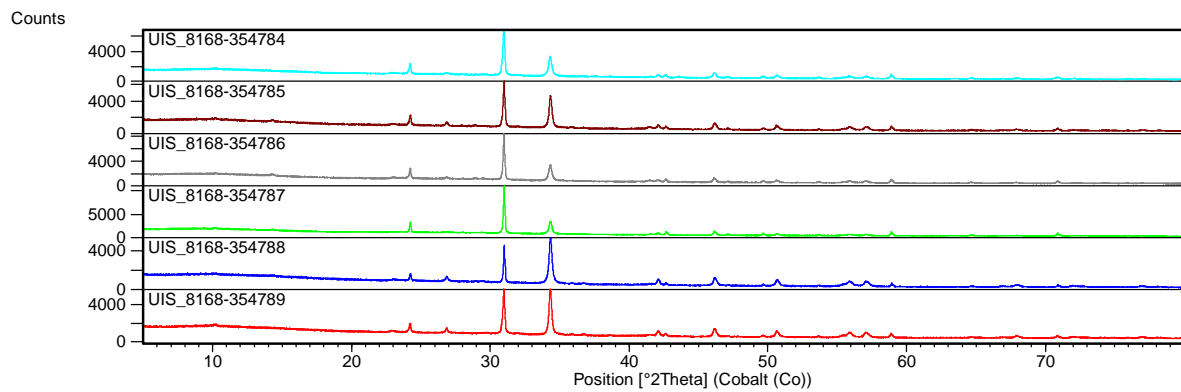


Dr. Sabine Verryn (Pr.Sci.Nat)

Samples will be stored for 3 months after which they will be discarded.

PMB			PMA			PLC		
Lime	1.43	0.27	Lime	0	0	Lime	0	0
Calcite	43.63	0.87	Calcite	49.79	0.87	Calcite	38.09	0.9
Fluorite	0.07	0.09	Fluorite	0	0	Fluorite	0	0
Hematite	1.87	0.3	Hematite	2.45	0.33	Hematite	3.01	0.36
Kaolinite	3.58	0.75	Kaolinite	11.83	0.87	Kaolinite	15.18	1.29
Muscovite	3.02	0.66	Muscovite	3.41	0.6	Muscovite	3.56	0.75
Quartz	46.4	0.99	Quartz	32.52	0.93	Quartz	40.16	1.08

PLB			PLA			Composite		
Lime	0	0	Lime	0	0	Lime	0	0
Calcite	37.18	0.81	Calcite	70.75	1.08	Calcite	61.69	0.99
Fluorite	0.26	0.17	Fluorite	0.15	0.16	Fluorite	0.2	0.15
Hematite	2.01	0.3	Hematite	1.18	0.29	Hematite	2.39	0.3
Kaolinite	7.55	0.93	Kaolinite	7.29	0.84	Kaolinite	2.99	0.72
Muscovite	3.36	0.66	Muscovite	2.29	0.63	Muscovite	3.09	0.6
Quartz	49.65	0.9	Quartz	18.33	0.78	Quartz	29.65	0.9



Phase <th>Chemical Formula </th>	Chemical Formula
Quartz low	O ₂ Si ₁
Calcite	C ₁ Ca ₁ O ₃
Fluorite	Ca ₁ F ₂
Muscovite	3T; H ₂ Al ₃ K ₁ O ₁₂ Si ₃
Kaolinite	2M; H ₄ Al ₂ O ₉ Si ₂
Hematite	Fe ₂ O ₃
Lime	Ca ₁ O ₁



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-06
Project number: 184

Report number: 41834

Date completed: 2013-10-17
Order number: 8168

Client name: UIS Analytical
Address: P.O. Box 8286, Centurion, 0046
Tel: 012 665 4291

Facsimile: 012 -665 – 4294

Contact person: Japie Oberholzer
Email: japieo@uis-as.co.za
Cell: 072 488 1001

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification			
	PMB	PMA	PLC	PLB
Sample Number	17241	17242	17243	17244
Paste pH	10.5	9.0	8.6	8.4
Total Sulphur (%) (LECO)	0.11	0.17	0.17	0.20
Acid Potential (AP) (kg/t)	3.47	5.16	5.44	6.16
Neutralization Potential (NP)	130	225	88	142
Nett Neutralization Potential (NNP)	127	220	83	136
Neutralising Potential Ratio (NPR) (NP : AP)	37	44	16	23
Rock Type	III	III	III	III

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification		
	PLA	Composite	Composite
Sample Number	17245	17246	17246D
Paste pH	9.1	9.1	9.4
Total Sulphur (%) (LECO)	0.18	1.08	1.11
Acid Potential (AP) (kg/t)	5.72	34	35
Neutralization Potential (NP)	137	159	167
Nett Neutralization Potential (NNP)	131	125	132
Neutralising Potential Ratio (NPR) (NP : AP)	24	4.70	4.81
Rock Type	III	II	II

* 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



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-06
Project number: 184

Report number: 41834

Date completed: 2013-10-17
Order number: 8168

Client name: UIS Analytical
Address: P.O. Box 8286, Centurion, 0046
Tel: 012 665 4291

Facsimile: 012 -665 – 4294

Contact person: Japie Oberholzer
Email: japieo@uis-as.co.za
Cell: 072 488 1001

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

CLASSIFICATION ACCORDING TO NEUTRALISING POTENTIAL RATIO (NPR)

E. Botha
Geochemistry Project Manager



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-06
Project number: 184

Report number: 41834

Date completed: 2013-10-17
Order number: 8168

Client name: UIS Analytical
Address: P.O. Box 8286, Centurion, 0046
Tel: 012 665 4291

Facsimile: 012 -665 – 4294

Contact person: Japie Oberholzer
Email: japieo@uis-as.co.za
Cell: 072 488 1001

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)

REFERENCES

LAWRENCE, R.W. & WANG, Y. 1997. **Determination of Neutralization Potential in the Prediction of Acid Rock Drainage.** Proc. 4th International Conference on Acid Rock Drainage. Vancouver. BC. pp. 449 – 464.

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd.** Any further use of the above information is not the responsibility or liability of **WATERLAB (Pty) Ltd.** Except for the full report, parts of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd.**



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

Date received: 2013-09-06
Project number: 184

Report number: 41834

Date completed: 2013-10-17
Order number: 8168

Client name: UIS Analytical
Address: P.O. Box 8286, Centurion, 0046
Tel: 012 665 4291

Facsimile: 012 -665 – 4294

Contact person: Japie Oberholzer
Email: japieo@uis-as.co.za
Cell: 072 488 1001

PRICE, W.A., MORIN, K. & HUTT, N. 1997. **Guidelines for the prediction of Acid Rock Drainage and Metal leaching for mines in British Columbia** : Part 11. Recommended procedures for static and kinetic testing. In: Proceedings of the Fourth International Conference on Acid Rock Drainage. Vol 1. May 31 – June 6. Vancouver, BC., pp. 15 – 30.

SOBEK, A.A., SCHULLER, W.A., FREEMAN, J.R. & SMITH, R.M. 1978. **Field and laboratory methods applicable to overburdens and minesoils**. EPA-600/2-78-054. USEPA. Cincinnati. Ohio.

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

USHER, B.H., CRUYWAGEN, L-M., DE NECKER, E. & HODGSON, F.D.I. 2003. **Acid-Base : Accounting, Techniques and Evaluation (ABATE): Recommended Methods for Conducting and Interpreting Analytical Geochemical Assessments at Opencast Collieries in South Africa**. Water Research Commission Report No 1055/2/03. Pretoria.

ENVIRONMENT AUSTRALIA. 1997. **Managing Sulphidic Mine Wastes and Acid Drainage**.

E. Botha
Geochemistry Project Manager



WATERLAB (PTY) LTD

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

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

CERTIFICATE OF ANALYSES NETT ACID GENERATION

Date received: 2013-09-06
Project number: 184

Report number: 41834

Date completed: 2013-10-17
Order number: 8168

Client name: UIS Analytical
Address: P.O. Box 8286, Centurion, 0046
Tel: 012 665 4291

Facsimile: 012 -665 – 4294

Contact person: Japie Oberholzer
Email: japieo@uis-as.co.za
Cell: 072 488 1001

Nett Acid Generation	Sample Identification: pH 4.5						
	PMB	PMA	PLC	PLB	PLA	Composite	Composite
Sample Number	17241	17242	17243	17244	17245	17246	17246D
NAG pH: (H ₂ O ₂)	8.6	8.6	8.6	7.8	7.8	8.3	8.3
NAG (kg H ₂ SO ₄ / t)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Nett Acid Generation	Sample Identification: pH 7						
	PMB	PMA	PLC	PLB	PLA	Composite	Composite
Sample Number	17241	17242	17243	17244	17245	17246	17246D
NAG pH: (H ₂ O ₂)	8.6	8.6	8.6	7.8	7.8	8.3	8.3
NAG (kg H ₂ SO ₄ / t)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

E. Botha
Geochemistry Project Manager

The information contained in this report is relevant only to the sample/samples supplied to WATERLAB (Pty) Ltd. Any further use of the above information is not the responsibility or liability of WATERLAB (Pty) Ltd. Except for the full report, parts of this report may not be reproduced without written approval of WATERLAB (Pty) Ltd.

ANALYTICAL REPORT: Coal Mix Samples

No unauthorised copies may be made of this report.

To: Digby Wells & Associates (Pty) Ltd	Date of Request: 06/08/13	UIS Analytical Services Analytical Chemistry Laboratories 4, 6
Attention: Andre van Coller		
ORDER REF: ANG2137		
Tel: +27 11 789 9495		Fax: (012) 665 4294
Cell: +27 11 789 9495		

Certificate of analysis: 8168

Lims ID	Sample ID	Note: all results in parts per million (ppm) unless specified otherwise																											
		Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Fe	Ga	Ge	Hf	Hg	Ho	Ir	K	La	Li	Mg	Mn	Mo
	SPLP LEACH	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
354784	PMB	0.001	0.062	0.006	0.001	0.319	0.175	<0.001	<0.001	58.2	<0.001	<0.001	0.014	0.001	0.001	0.018	<0.01	<0.001	<0.001	0.000	<0.0001	<0.001	<0.001	1.35	<0.001	0.016	27.5	0.003	0.007
354785	PMA	0.001	0.033	0.010	0.001	0.420	0.232	<0.001	<0.001	258	<0.001	<0.001	0.023	0.001	0.001	0.016	0.044	<0.001	<0.001	0.000	<0.0001	<0.001	<0.001	1.97	<0.001	0.021	48.6	2.78	0.005
354786	PLC	0.001	0.045	0.004	0.001	0.336	0.277	<0.001	<0.001	139	<0.001	<0.001	0.014	0.001	0.001	0.011	<0.01	<0.001	<0.001	0.000	<0.0001	<0.001	<0.001	1.19	<0.001	0.011	39.3	0.354	0.015
354787	PLB	0.001	0.025	< 0.001	0.001	0.229	0.372	<0.001	<0.001	142	<0.001	<0.001	0.014	0.001	0.001	0.011	<0.01	<0.001	0.001	0.000	<0.0001	<0.001	<0.001	1.59	<0.001	0.021	29.4	0.457	0.006
354788	PLA	0.001	0.085	0.003	<0.001	0.329	0.349	<0.001	<0.001	317	<0.001	0.001	0.022	<0.001	0.001	0.010	0.025	<0.001	0.001	0.000	<0.0001	<0.001	<0.001	2.13	0.001	0.053	45.2	2.29	0.006
354789	Composite	0.001	0.023	0.001	0.001	0.584	0.160	<0.001	<0.001	252	<0.001	<0.001	0.017	<0.001	0.001	0.011	0.023	<0.001	<0.001	0.000	<0.0001	<0.001	<0.001	3.19	<0.001	0.019	50.8	1.87	0.008
		pH	pH Temp	TDS	TDS by Sum	Susp. Sol.	P Alk.	M Alk.	F	Cl	NO2	Br	NO3	NO3 as N	PO4	SO4	Conduct	Sum of Cat	Sum of Ani	Ion Balance	NH4								
	SPLP LEACH	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
354784	PMB	8.85	24.6	278	265	NA	10	93	2.7	1.2	<0.2	<0.2	<0.2	<0.2	<0.2	74	27	5.3	6.34	-8.94	NA								
354785	PMA	7.11	25.1	868	855	NA	0.0	609.2	1.9	2.6	<0.2	<0.2	<0.2	<0.2	<0.2	147	117	17.2	15.35	5.56	NA								
354786	PLC	7.85	25.3	584	543	NA	0.0	342.2	2.8	2.0	<0.2	<0.2	<0.2	<0.2	<0.2	124	72	10.3	10.53	-0.90	NA								
354787	PLB	7.67	25.4	514	493	NA	0.0	316.3	1.7	1.6	<0.2	<0.2	<0.2	<0.2	<0.2	104	70	9.7	9.13	2.99	NA								
354788	PLA	7.02	25.3	998	1035	NA	0.0	834.2	1.3	2.9	<0.2	<0.2	<0.2	<0.2	<0.2	140	140	19.8	18.69	2.96	NA								
354789	Composite	7.39	25.5	1022	925	NA	0	413	2.5	3.0	<0.2	<0.2	<0.2	<0.2	<0.2	338	114	17.1	15.91	3.64	NA								
		Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Fe	Ga	Ge	Hf	Hg	Ho	Ir	K	La	Li	Mg	Mn	Mo
	Total Trace elements	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
354784	PMB	0.316	80783	3.31	0.038	17.3	262	2.28	0.659	108792	0.027	69.5	16.2	105.0	4.87	2.64	11310	15.3	0.414	2.60	0.03	0.334	0.038	6610	18.1	22.3	5213	1175	1.19
354785	PMA	0.422	71466	4.96	0.046	15.2	234	2.53	0.832	116226	0.091	65.7	10.1	59.0	3.11	4.40	23110	7.55	0.858	3.00	0.04	0.251	0.013	5142	10.8	13.2	6380	1458	1.43
354786	PLC	0.498	83854	6.55	0.049	17.3	628	2.93	1.04	71694	0.079	97.1	13.4	78.0	4.76	9.9	17470	19.0	0.314	3.52	0.07	0.488	0.045	3519	22.4	39.4	3754	868	2.44
354787	PLB	0.573	76548	2.11	0.041	15.7	486	2.96	1.25	70836	0.071	85.2	15.1	77.0	5.73	6.6	10070	14.5	0.271	4.27	0.3	0.413	0.022	3304	20.4	46.2	3539	566	2.05
354788	PLA	0.208	76125	3.36	0.031	14.9	337	1.77	0.484	160615	0.020	41.1	14.3	83.0	3.22	10.2	13750	15.1	0.699	1.19	0.12	0.142	0.034	3251	10.9	51.7	6922	833	2.34
354789	Composite	0.246	51927	6.22	0.030	22.9	256	1.70	0.394	153252	0.035	50.4	12.7	51.0	3.53	1.42	30160	7.62	0.124	1.54	0.01	0.236	0.030	9095	9.24	16.9	7452	1600	2.03
		SiO2	Al2O3	Fe	Fe2O3	TiO2	CaO	MgO	K2O	MnO	P	Ba	Sr	V	Ni	Cr	Cu	Zn	C	S									
	XRF - Major Oxides	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%
354784	PMB	39.6	15.3	1.13	1.62	0.575	15.2	0.865	0.80	0.152	0.015	0.026	0.006	0.008	0.002	0.011	<0.001	0.004	13.5	0.11									
354785	PMA	33.9	13.5	2.31	3.30	0.579	16.3	1.059	0.62	0.188	0.013	0.023	0.006	0.007	0.001	0.006	<0.001	0.005	14.5	0.17									
354786	PLC	33.9	15.8	1.75	2.50	0.706	10.0	0.623	0.424	0.112	0.064	0.063	0.015	0.009	0.001	0.008	0.001	0.005	20.6	0.17									
354787	PLB	35.1	14.5	1.01	1.44	0.704	9.91	0.587	0.398	0.073	0.067	0.049	0.012	0.009	0.001	0.008	0.001	0.005	20.1	0.20									
354788	PLA	26.8	14.4	1.38	1.97	0.721	22.5	1.149	0.391	0.107	0.042	0.034	0.008	0.010	0.001	0.008	0.001	0.004	13.8	0.18									
354789	Composite	31.7	9.81	3.02	4.31	0.442	21.4	1.237	1.095	0.206	0.015	0.026	0.005	0.007	0.001	0.005	<0.001	0.005	16.7	1.08									

Date:	02.10.2013	Chemical elements:	Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, Ge, Hg, Ho, Ir, K, La, Li, Mg, Mn, Mo, Na, Nb, Nd, Ni, Pb, Pt, Rb, Sb, Sc, Se, Si, Sn, Sr, Ta, Te, Th, Ti, U, V, W, Y, Zn, Zr
Analysed by:	Walter Masoga	Instrument:	ICP-OES, ICP-MS
Date:	02.10.2013	Date:	02.10.2013
Authorised:	JJ Oberholzer		

To: **Digby Wells & Associates**
 Attention: **Andre van Coller**
ORDER REF: ANG2137

Tel: +27 11 789 9495
 Cell: +27 11 789 9495

Lims ID	Sample ID	Na	Nb	Nd	Ni	Pb	Pt	Rb	Sb	Sc	Se	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
	SPLP LEACH																								
354784	PMB	1.21	<0.001	<0.001	<0.001	0.002	<0.001	0.001	0.004	0.024	<0.001	43.2	<0.001	0.069	<0.001	<0.001	<0.001	<0.05	<0.001	0.003	0.062	0.003	<0.001	0.048	<0.001
354785	PMA	1.61	<0.001	<0.001	0.229	0.002	<0.001	0.002	0.003	0.016	0.018	27.6	<0.001	0.154	<0.001	0.001	<0.001	<0.05	<0.001	0.006	0.010	<0.001	<0.001	0.108	0.002
354786	PLC	1.21	<0.001	<0.001	0.420	0.002	<0.001	0.001	0.004	0.016	0.038	28.6	<0.001	0.434	<0.001	<0.001	<0.001	<0.05	<0.001	0.006	0.054	0.001	<0.001	0.064	0.001
354787	PLB	1.33	<0.001	<0.001	0.550	0.002	<0.001	0.002	0.003	0.012	0.017	21.8	<0.001	0.469	<0.001	<0.001	<0.001	<0.05	<0.001	0.006	0.038	0.001	<0.001	0.076	0.001
354788	PLA	1.53	<0.001	0.001	0.725	0.002	<0.001	0.003	0.003	0.014	0.000	24.2	<0.001	0.288	<0.001	<0.001	<0.001	<0.05	<0.001	0.008	0.030	0.000	0.001	0.112	0.003
354789	Composite	2.64	<0.001	<0.001	0.573	0.002	<0.001	0.004	0.004	0.014	0.020	24.9	<0.001	0.238	<0.001	<0.001	<0.001	<0.05	<0.001	0.006	0.011	0.001	<0.001	0.100	0.002

Lims ID	Sample ID	Na	Nb	Nd	Ni	Pb	Pt	Rb	Sb	Sc	Se	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	SPLP LEACH																								
354784	PMB																								
354785	PMA																								
354786	PLC																								
354787	PLB																								
354788	PLA																								
354789	Composite																								

Lims ID	Sample ID	Na	Nb	Nd	Ni	Pb	Pt	Rb	Sb	Sc	Se	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Total Trace elements																								
354784	PMB	731	15.8	15.9	15.1	23.9	0.020	50.7	0.630	32.9	1.33	184993	5.16	62.3	1.51	5.15	12.02	3441	0.293	4.80	76.0	69.2	22.97	44.3	87.7
354785	PMA	685	14.9	8.86	14.1	23.8	0.027	29.1	0.481	2.48	1.22	158672	4.28	56.5	1.29	1.35	8.35	3468	0.385	4.78	65.2	30.8	15.22	45.1	101
354786	PLC	764	18.0	21.9	10.5	32.2	0.021	13.4	0.625	31.2	0.133	158579	4.75	152	2.04	5.65	24.84	4225	0.526	4.56	86.3	56.3	32.0	47.7	141
354787	PLB	724	20.2	16.4	12.1	36.7	0.034	21.1	0.564	11.6	0.153	164282	5.78	115	1.82	2.91	24.23	4213	0.324	4.39	86.5	372	28.9	45.7	156
354788	PLA	443	17.9	9.48	7.55	27.0	0.013	32.2	0.517	23.7	0.54	125386	4.59	76.7	1.26	5.66	1.269	4319	0.314	5.05	98.2	41.8	5.98	43.8	43.6
354789	Composite	800	11.7	8.37	13.0	21.5	0.011	48.5	0.669	23.4	0.185	148107	2.78	51.7	0.846	5.97	3.51	2646	0.553	3.36	72.3	22.8	15.56	53.6	58.4

Lims ID	Sample ID	Na	Nb	Nd	Ni	Pb	Pt	Rb	Sb	Sc	Se	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	XRF – Major Oxides																								
354784	PMB																								
354785	PMA																								
354786	PLC																								
354787	PLB																								
354788	PLA																								
354789	Composite																								

Date: 02.10.2013
 Analysed by: Walter Masoga

Appendix D: Leachate Classification Tables

WASTE ROCK SAMPLES

Results for chemicals that are of health significance in drinking-water																														
Parameter Unit	pH	Total Alk mg/l CaCO3	F mg/l	Cl mg/l	NO3 as N mg/l	SO4 mg/l	EC mS/m	Al mg/l	As mg/l	B* mg/l	Ba* mg/l	Ca mg/l	Cd mg/l	Co mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Hg mg/l	K mg/l	Mg mg/l	Mn mg/l	Mo* mg/l	Na mg/l	Ni mg/l	Pb mg/l	Sb mg/l	Se mg/l	V mg/l	Zn mg/l	U* mg/l
Class 1 (recommended limit)	5 - 9.5	N/A	1	200	10	400	150	0.3	0.01			150	0.005	0.5	0.1	1	0.2	0.001	50	70	0.1		200	0.15	0.02	0.01	0.02	0.2	5	
Class 2 (max allowed for limited duration)	4 - 5 / 9.5 - 10	N/A	1.5	600	20	600	370	0.5	0.05			300	0.010	1	0.5	2	2	0.005	100	100	1		400	0.35	0.05	0.05	0.05	0.5	10	
Class 3 (not recommended for consumption)	<4 / >10	N/A	>1.5	>600	>20	>600	>370	>0.5	>0.05	0.5	0.7	>300	>0.01	>1	>0.5	>2	>2	>0.005	>100	>100	>1	0.07	>400	>0.35	>0.05	>0.05	>0.05	>0.5	>10	0.015
OBW1	8.2	56	1.2	11	0.3	7	17.6	0.03	0.007	0.02	0.32	12.9	0.0001	<0.001	<0.001	<0.001	0.04	<0.0001	5.9	5.62	0.02	0.001	12.2	<0.001	<0.001	0.001	<0.001	0.015	<0.001	0.0001
OBW2	7.7	48	0.7	<5	<0.2	15	9.5	4.8	0.003	0.02	0.25	4.9	<0.0001	<0.001	0.005	<0.001	2.2	<0.0001	11.0	2.86	0.07	0.002	6.1	<0.001	0.006	0.001	<0.001	0.016	0.009	0.0004
IBW1	8.3	96	0.9	9	<0.2	19	25.9	5.7	0.004	0.03	0.24	8.2	0.0001	0.001	0.018	<0.001	0.6	0.0001	6.8	2.63	0.03	0.08	40.6	<0.001	0.002	0.002	0.01	0.017	0.005	0.0005
IBW2	8.3	104	1.5	12	<0.2	23	28.6	0.2	0.003	0.02	0.18	10.0	0.0001	<0.001	<0.001	<0.001	0.1	0.0002	6.8	3.62	0.02	0.07	41.4	<0.001	<0.001	0.002	0.02	0.001	<0.001	0.0002
TRP2	8.1	76	1.3	<5	<0.2	80	31.9	0.02	0.005	0.04	0.09	41.0	<0.0001	0.01	<0.001	<0.001	0.03	<0.0001	5.5	8.65	0.09	0.07	7.4	<0.001	<0.001	0.002	0.03	0.004	<0.001	0.0006
PLP1	4.7	<5	0.3	<5	<0.2	118	27.9	0.4	0.002	0.05	0.07	21.8	0.0008	0.83	<0.001	0.071	0.4	<0.0001	5.4	10.3	0.44	0.002	6.9	1.7	0.002	<0.001	0.01	<0.001	0.6	0.0005

Results for chemicals that are not of health significance in drinking-water																													
Parameter	Ag	Au	Be	Bi	Ce	Cs	Ga	Ge	Hf	Ho	Ir	La	Li	Nb	Nd	Pt	Rb	Sc	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	W	Y	Zr
Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
OBW 1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.01	9.35	<0.001	0.110289	<0.001	<0.001	<0.0001	<0.05	<0.001	0.001	<0.001	<0.001
OBW 2	<0.001	<0.001	0.001	<0.001	0.009542	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	0.001	0.007	<0.001	0.01	0.02	20.47	<0.001	0.03168	<0.001	<0.001	0.0011	0.195638	<0.001	<0.001	0.003	0.007
IBW 1	<0.001	0.001	<0.001	<0.001	0.003	0.001	0.002	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.001	0.001	<0.001	0.01	0.01	11.07	<0.001	0.097013	<0.001	<0.001	0.0007	0.302789	<0.001	0.001	0.001	0.004
IBW 2	<0.001	0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	0.01	0.00	2.21	<0.001	0.109358	<0.001	<0.001	<0.0001	0.01005	<0.001	<0.001	<0.001	<0.001
TRP 2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.02	<0.001	<0.001	<0.001	0.01	0.00	3.53	<0.001	0.137357	<0.001	<0.001	<0.0001	<0.05	<0.001	<0.001	<0.001	<0.001
PLP 1	<0.001	<0.001	0.002	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.07	<0.001	<0.001	<0.001	0.01	0.01	6.62	<0.001	0.105657	<0.001	<0.001	<0.0001	<0.05	<0.001	<0.001	<0.001	<0.001

COAL SAMPLES

Results for chemicals that are of health significance in drinking-water																															
Parameter Unit	pH	Total Alk mg/l CaCO3	F mg/l	Cl mg/l	NO3 as N mg/l	SO4 mg/l	EC mS/m	Al mg/l	As mg/l	B* mg/l	Ba* mg/l	Ca mg/l	Cd mg/l	Co mg/l	Cr mg/l	Cu mg/l	Fe mg/l	Hg mg/l	K mg/l	Mg mg/l	Mn mg/l	Mo* mg/l	Na mg/l	Ni mg/l	Pb mg/l	Sb mg/l	Se mg/l	V mg/l	Zn mg/l	U* mg/l	
Class 1 (recommended limit)	5 - 9.5	N/A	1	200	10	400	150	0.3	0.01			150	0.005	0.5	0.1	1	0.2	0.001	50	70	0.1		200	0.15	0.02	0.01	0.02	0.2	5		
Class 2 (max allowed for limited duration)	4 - 5 / 9.5 - 10	N/A	1.5	600	20	600	370	0.5	0.05			300	0.010	1	0.5	2	2	0.005	100	100	1		400	0.35	0.05	0.05	0.05	0.5	10		
Class 3 (not recommended for consumption)	<4 / >10	N/A	>1.5	>600	>20	>600	>370	>0.5	>0.05	0.5	0.7	>300	>0.1	>1	>0.5	>2	>2	>0.005	>100	>100	>1	0.07	>400	>0.35	>0.05	>0.05	>0.05	>0.5	>10	0.015	
PMB	7.6	40	1.7	<5	<0.2	54	21.5	0.148	0.003	0.2	0.1	16.2	<0.0001	<0.001	<0.001	<0.001	0.1	<0.0001	8.8	6.41	0.08	0.004	10.4	<0.001	<0.001	0.001	0.024	0.001	<0.001	0.0003	
PMA	7.8	64	1.8	<5	<0.2	43	22.4	0.043	0.004	0.2	0.2	21.5	0.0001	<0.001	<0.001	<0.001	0.1	0.0002	7.8	7.42	0.03	0.005	9.4	0.012	<0.001	0.001	<0.001	0.002	0.002	0.0007	
PLC	8.3	60	2.1	<5	<0.2	7	15.3	0.009	0.009	0.2	0.1	14.2	0.0001	0.001	0.002	<0.001	0.2	<0.0001	5.7	4.91	0.04	0.011	8.2	0.004	0.001	<0.001	0.001	0.019	0.005	0.154	0.0001
PLB	8.2	60	1.3	<5	<0.2	7	13.5	0.036	0.001	0.2	0.1	13.6	0.0001	<0.001	<0.001	<0.001	0.1	0.0001	4.9	4.24	0.02	0.007	7.1	<0.001	<0.001	0.001	0.048	0.005	0.005	0.0001	
PLA	8.2	68	1.5	<5	<0.2	28	19.7	0.010	0.003	1.0	0.1	19.4	<0.0001	<0.001	<0.001	<0.001	0.05	0.0002	5.8	6.27	0.03	0.015	9.2	<0.001	<0.001	0.001	0.030	0.005	<0.001	0.0003	
Composite	8.2	68	2.4	<5	<0.2	27	21.5	0.139	0.008	0.3	0.1	17.4	0.0001	<0.001	<0.001	<0.001	0.1	0.0001	9.6	5.69	0.03	0.013	13.4	<0.001	<0.001	0.001	0.015	0.004	0.002	0.0005	

Results for chemicals that are not of health significance in drinking-water																													
Parameter	Ag	Au	Be	Bi	Ce	Cs	Ga	Ge	Hf	Ho	Ir	La	Li	Nb	Nd	Pt	Rb	Sc	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	W	Y	Zr
Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
PMB	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	0.008876	0.003	3.73	<0.001	0.08608	<0.001	<0.001	<0.0001	0.012654	<0.001	<0.001	<0.001	<0.001
PMA	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008172	0.002	2.49	<0.001	0.092694	<0.001	<0.001	<0.0001	<0.05	<0.001	0.001051	<0.001	<0.001
PLC	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006697	0.002	1.85	<0.001	0.070878	<0.001	<0.001	<0.0001	<0.05	<0.001	0.003	<0.001	<0.001
PLB	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006011	0.001	1.6	<0.001	0.050305	<0.001	<0.001	<0.0001	<0.05	<0.001	0.003	<0.001	<0.001
PLA	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	0.007831	0.001	2.08	<0.001	0.081879	<0.001	<0.001	<0.0001	<0.05	<0.001	0.011	<0.001	<0.001
Composite	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008316	0.002	3.09	<0.001	0.099932	<0.001	<0.001	<0.0001	<0.05	<0.001	0.001	<0.001	<0.001

ASH SAMPLES

Results for chemicals that are of health significance in drinking-water																																			
Parameter	pH	TDS	CO3 Alk	HCO3 Alk	Total Alk	F	Cl	NO2*	NO3*	NO3 as N	PO4	SO4	EC	Al	As	B*	Ba*	Ca	Cd	Co	Cr	Cu	Fe	Hg	K	Mg	Mn	Mo*	Na	Ni	Pb	Sb	Se	V	Zn
Unit	-	mg/l	mg/l CaCO3	mg/l CaCO3	mg/l CaCO3	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Class 1 (recommended limit)	5 - 9.5	1000	N/A	N/A	N/A	1	200			10		400	150	0.3	0.01			150	0.0050	0.5	0.1	1	0.2	0.001	50	70	0.1		200	0.15	0.02	0.01	0.02	0.2	5
Class 2 (max allowed for limited duration)	4 - 5 / 9.5 - 10	2400	N/A	N/A	N/A	1.5	600			20		600	370	0.5	0.05			300	0.0100	1	0.5	2	2	0.005	100	100	1		400	0.35	0.05	0.05	0.05	0.5	10
Class 3 (not recommended for consumption)	<4 / >10	>2400	N/A	N/A	N/A	>1.5	>600	3	50	>20		>600	>370	>0.5	>0.05	0.5	0.7	>300	>0.01	>1	>0.5	>2	>2	>0.005	>100	>100	>1	0.07	>400	>0.35	>0.05	>0.05	>0.05	>0.5	>10
PMB	8.9	278	10	83	93	2.7	1.2	<0.2	<0.2	<0.2	<0.2	74	27	0.062	0.006	0.319	0.175	58.2	<0.001	0.014	0.001	0.018	<0.01	<0.0001	1.35	27.5	0.003	0.007	1.21	<0.001	0.002	0.004	<0.001	0.062	0.048
PMA	7.11	868	0.0	609	609.2	1.9	2.6	<0.2	<0.2	<0.2	<0.2	147	117	0.033	0.010	0.420	0.232	258	<0.001	0.023	0.001	0.016	0.044	<0.0001	1.97	48.6	2.78	0.005	1.61	0.229	0.002	0.003	0.018	0.010	0.108
PLC	7.85	584	0.0	342	342.2	2.8	2.0	<0.2	<0.2	<0.2	<0.2	124	72	0.045	0.004	0.336	0.277	139	<0.001	0.014	0.001	0.011	<0.01	<0.0001	1.19	39.3	0.354	0.015	1.21	0.420	0.002	0.004	0.038	0.054	0.064
PLB	7.67	514	0.0	316	316.3	1.7	1.6	<0.2	<0.2	<0.2	<0.2	104	70	0.025	<0.001	0.229	0.372	142	<0.001	0.014	0.001	0.011	<0.01	<0.0001	1.59	29.4	0.457	0.006	1.33	0.550	0.002	0.003	0.017	0.038	0.076
PLA	7.02	998	0.0	834	834.2	1.3	2.9	<0.2	<0.2	<0.2	<0.2	140	140	0.085	0.003	0.329	0.349	317	<0.001	0.022	<0.001	0.010	0.025	<0.0001	2.13	45.2	2.29	0.006	1.53	0.725	0.002	0.003	0.000	0.030	0.112
Composite	7.39	1022	0	413	413	2.5	3.0	<0.2	<0.2	<0.2	<0.2	338	114	0.023	0.001	0.584	0.160	252	<0.001	0.017	<0.001	0.011	0.023	<0.0001	3.19	50.8	1.87	0.008	2.64	0.573	0.002	0.004	0.020	0.011	0.100

* Chemicals where WHO (2008) drinking water standards were used

Results for chemicals that are not of health significance in drinking-water																															
Parameter	Ag	Au	Be	Bi	Br	Ce	Cs	Ga	Ge	Hf	Ho	Ir	La	Li	Nb	Nd	Pt	Rb	Sc	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	U	W	Y	Zr
Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
PMB	0.001	0.001	<0.001	<0.001	<0.2	<0.001	0.001	<0.001	<0.001	0.000	<0.001	<0.001	<0.001	0.016	<0.001	<0.001	<0.001	0.001	0.024	43.2	<0.001	0.069	<0.001	<0.001	<0.001	<0.05	<0.001	0.003	0.003	<0.001	<0.001
PMA	0.001	0.001	<0.001	<0.001	<0.2	<0.001	0.001	<0.001	<0.001	0.000	<0.001	<0.001	<0.001	0.021	<0.001	<0.001	<0.001	0.002	0.016	27.6	<0.001	0.154	<0.001	0.001	<0.001	<0.05	<0.001	0.006	<0.001	<0.001	0.002
PLC	0.001	0.001	<0.001	<0.001	<0.2	<0.001	0.001	<0.001	<0.001	0.000	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	0.001	0.016	28.6	<0.001	0.434	<0.001	<0.001	<0.001	<0.05	<0.001	0.006	0.001	<0.001	0.001
PLB	0.001	0.001	<0.001	<0.001	<0.2	<0.001	0.001	<0.001	0.001	0.000	<0.001	<0.001	<0.001	0.021	<0.001	<0.001	<0.001	0.002	0.012	21.8	<0.001	0.469	<0.001	<0.001	<0.001	<0.05	<0.001	0.006	0.001	<0.001	0.001
PLA	0.001	<0.001	<0.001	<0.001	<0.2	0.001	0.001	<0.001	0.001	0.000	<0.001	<0.001	0.001	0.053	<0.001	0.001	<0.001	0.003	0.014	24.2	<0.001	0.288	<0.001	<0.001	<0.001	<0.05	<0.001	0.008	0.000	0.001	0.003
Composite	0.001	0.001	<0.001	<0.001	<0.2	<0.001	0.001	<0.001	<0.001	0.000	<0.001	<0.001	<0.001	0.019	<0.001	<0.001	<0.001	0.004	0.014	24.9	<0.001	0.238	<0.001	<0.001	<0.001	<0.05	<0.001	0.006	0.001	<0.001	0.002