ENVIRONMENTAL GEOCHEMISTRY OF THE WATERBERG COALFIELDS

by

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DECLARATION

I, Lore-Mari Deysel, declare that the Doctoral Degree research that I herewith submit for the Doctoral Degree (Geohydrology) qualification at the University of the Free State is my independent work and that I have not previously submitted it for a qualification at another institution of higher education.

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Lore-Mari Deysel

Student number: 1984614733

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In memory

Of those who we loved dearly

and motivated eagerly

to complete this project,

but passed away before the finale.

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List of abbreviations

ABA	Acid-Base Accounting
ADF	Ash Disposal Facility
AP	Acid Potential
AMD	Acid Mine Drainage
ANC	Acid Neutralising Capacity
ARD	Acid Rock Drainage
ASTM	American Standard Test Method
bbl	barrel
CBM	Coal Bed Methane
CCW	Coal Combustion Waste
CCB	Coal Combustion by-Product
CCR	Coal Combustion Residue
CTL	Coal to Liquid
CV	Calorific Value (Potential for coal energy production in kilocalories/kg)
DEAT	Department of Environmental Affairs and Tourism
DMR	Department of Mineral Resources
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity (mS/m)
EIA	Environmental Impact Assessment
EMP	Environmental Management Programmes
EPA	Environmental Protection Agency
Eskom	Electricity Supply Commission of South Africa
FS	Full Succession
GWh	Gigawatt hour
GDP	Gross Domestic product
GG2	Grootegeluk Mine washing plant No.2
GCM	Grootegeluk Coal Mine
GW	Giga Watt
H_2S	Hydrogen sulphide
HAP	Hazardous Air Pollutants
HCT	Humidity Cell Test
HiPRO	High- recovery precipitations reverse osmosis

ICP-OES	Inductively coupled plasma – optical emission spectroscopy
IGS	Institute for Groundwater Studies
IOR	intrinsic Oxidation Rate
ITB	Interburden
kWh	kilowatt hour
LE	Lower Ecca
ME	Middle Ecca
mg/L	milligram per Liter
Mt	Megatonne
Mtce	Megatonne coal equivalent
Mtpa	Megatonne per annum
MWh	Megawatt hour
Mt	Million tonne
MW	Mega Watt
MWe	Mega Watt electric
MWMP	Meteoric Water Mobility Procedure
MKB	Main Karoo Basin
Mtpa	Million tonne per year
MW	Mega Watt
MPA	Maximum Potential Acidity
N	Normal
NAG	Net Acid Generation
NAPP	Net Acid Producing Potential
NEMA	National Environmental Management Act
NEMAQA	National Environmental Management: Air Quality Act (2004)
NNP	Net Neutralising Potential
NO	Nitrous oxide
NO_2	Nitrogen dioxide
NOx	Nitrogen Oxides (A generic term for mono nitrogen oxides produced by combustion. NOx can react with other compounds in the atmosphere in air to produce smog and can cause lung disease and asthma. In addition NOx can contribute to acid rainfall).
NP	Neutralising Potential
NPR	Neutralisation Potential Ratio
OVB	Overburden
PEA	Preliminary Economic Assessment

PM	Particulate Matter
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10 µm
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 µm
ppm	parts per million (mg/L)
RO	Reverse Osmosis
ROM	Run of Mine
SABS	South African Bureau of Standards
SAPP	Southern Africa Power Pool
SI	Saturation Index
SO_2	Sulphur Dioxide
SOx	Sulphur Oxides (A generic term for mono sulphur oxides produced by combustion of substances containing sulphur compounds. SOx can contribute to acid rainfall).
SPLP	Synthetic Precipitation Leaching Procedure
TCLP	Toxicity Characteristic Leaching Procedure
TCOA	Transvaal Coal Owners Association
TDS	Total Dissolved Salts
tph	tonne per hour
TSP	Total Suspended Particulate
UE	Upper Ecca
USGS	United States Geological Survey
WMA	Water Management Area
WCA	World Coal Association
WP	Weathered in Parts

1 INTRODUCTION

1.1 Preface

Worldwide, there is a continued increase in environmental awareness such as the reduction of natural resources and their impact on the environment. An increase in the world population, results in more pressure on governments and countries to supply in the populations basic needs. A major need is energy. In South Africa, coal is the main contributor to fulfil the energy and electricity demand. Mining of coal in South Africa is thus unavoidable to supply in this demand especially with the infrastructure that is already available at this moment in time and also for the near future. The nature of the impact of mining includes concerns over land and water resource use, pollutant emissions, waste generation and public health and safety.

1.2 Objectives

Coal mining will continue extensively in the future to fulfil in the demand for energy needs, especially for the production of electricity. There is currently only one existing mine in the Waterberg Coalfield, but the establishment of new mines in this area will materialise in the next 2-10 years. The newly build Medupi power station close to the Grootegeluk mine will demand more coal from the area.

Mining disturbes the ore and waste rock from their original in situ conditions and are transported to other components. Within these other components, the rock is exposed to new, geochemically different conditions that lead to new reactions such as accelerated physical and chemical weathering. This can have effects on the drainage chemistry. In general, coal mining generates proportionally less waste rock and tailings than metal mining (Bell *et al*., 1992), because the target material is visually obvious and often occurs as discrete, easily mined strata. On the other hand, because annual tonnages in coal mining are typically much greater than metal mining, equivalent tonnages of wastes are produced.

This thesis outlines the research conducted on new exploration geological samples collected in the Waterberg Coalfield to determine the geological units most likely at risk to produce AMD upon oxidation as well as the environmental geochemical risk due to elments that can be leached from the exposed rock and mine products. Coal samples were only collected from the Sasol cores. In the other samples, the coal was removed by the company for coal analyses. With mining, the coal will go to the beneficiation or coal processing plant. Static Acid Base accounting, leaching and kinetic tests (humidity cell test) were used to determine the risk. The effect of the different mining waste products at the Exxaro's Grootegeluk mine in the Waterberg area was also tested. The risk of leachate from natural sources containing a base potential to counteract the acid leachate produced, are also compared to determine the risk to the environment**.** Air is also polluted due to the mining and power station activities. Although it is discussed in the work, no particular analyses were done on air pollution. The chemical elments that are present in the coal products will play an importan role in the composition of the pollutants in the air. No tests/analyses were done in this study on the organic consituents that are also produced due to the spontaneous combustion although the products/contaminants are mentioned. The area where the study for this thesis was done is indicated on the map in the following Figure 1.

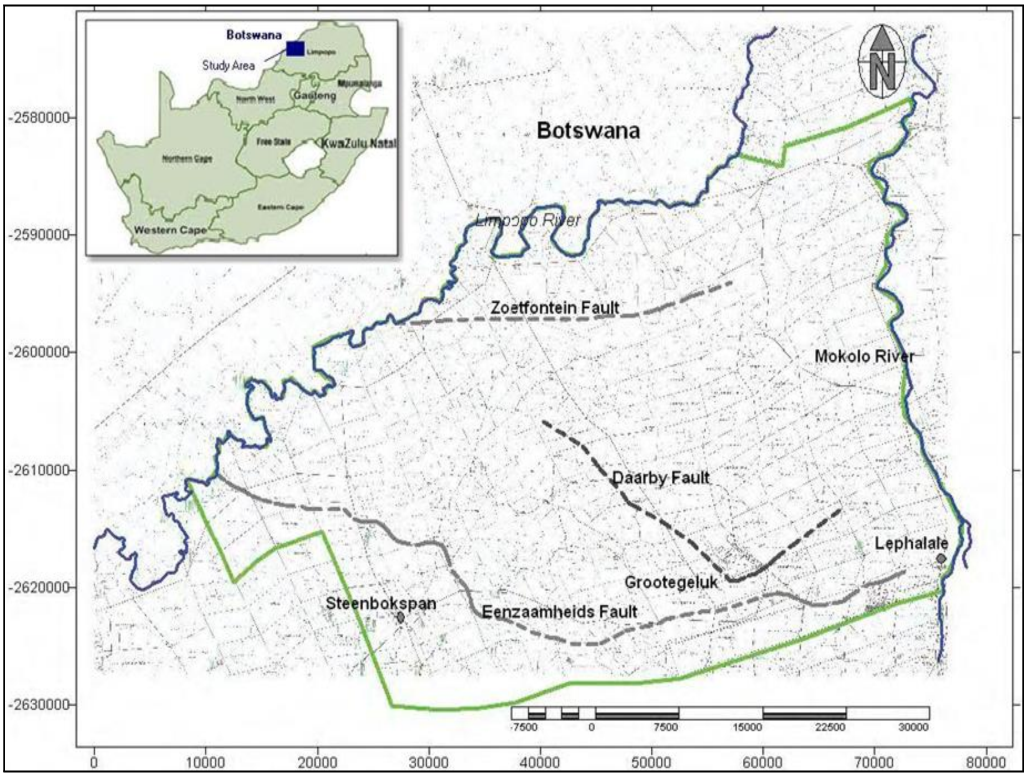


Figure 1: Location of the Waterberg coalfield with the Grootegeluk mine.

Coal plays a vital role in South Africa’s energy-economy. New coal mines will start mining operations to foresee in the demand of power stations and therefore meet the local electricity and energy need. The impact of these mining activities on the environment is realised and the best pro-active way must be followed to minimise any negative environmental effects. This can only be done if all relevant information is available and understood by environmentalists and engineers.

1.3 General background coal energy

Coal is the major fuel used for generating electricity around the world. In 2013 coal was used to generate over 40% of the world's electricity (World Coal Association, 2015). Coal is an important mining product in South Africa since it contributes to 87% of the country’s electricity production (Inside mining, 2014a).

Table 1: Sources of electricity production in South Africa (Inside mining, 2014a).

Installed Capacity	**MWe**	**%**
Coal-fired	41632	86.78
Nuclear	1931	4.03
Hydroelectric and pumped storage	2000	4.17
Gas turbines	2409	5.02
Total	47972	100.00

Projects planned for future extension of electricity production leans by 71% towards coal fired power stations (Table 2). Continuous mining of coal in South Africa is thus necessary to supply in the growing energy demands.

Table 2: Future projects for electricity production in South Africa (Inside mining, 2014a).

Future projects	**MWe**	**%**
Coal-fired	9600	70.94
Pumped storage	2832	20.93
Wind farm	1100	8.13
Total	13532	100

According to the World Coal Association (WCA) the total world coal production reached a record level of 7822.8 Mt in 2013, increasing by 0.4% from 2012. Approximately 15% (over 1.2 billion ton) of worldwide coal production is currently used by the steel industry and roughly 70% of total global steel production is dependent on coal (WCA, 2015).

Since 2003, South Africa’s coal production has remained fairly stagnant at levels of around 240million tons a year, posting only small increases. This stagnation has been attributed to depleted coal mines in the Witbank, Ermelo and Highveld coalfields, in the Mpumalanga Province, as well as operational and technological constraints that coal miners have been facing (Creamer Media’s Mining Weekly, 2010). South Africa is a significant participant in the global coal markets, but has moved down from being the fourth largest coal producer in 2001 and sixth in 2008 to number seven in 2013. This was due to a higher production by other countries (Table 3). Yet, South Africa’s coal industry is noteworthy in a number of respects: it is a relatively low cost producer (along with Indonesia and Colombia), has the world’s largest coal export terminal (91 Mtpa) in Richards Bay, and is positioned conveniently between the Atlantic and Pacific coal markets. It is also a potential swing producer, able to export competitively to either Europe or the East (Eberhard 2011). The top ten coal producers in the world for 2013 are listed in Table 3.

Table 3: Top ten coal producers in 2013 (WCA, 2015).

Country	**Million ton (2013)**
PR China	3 561 Mt
USA	904 Mt
India	613 Mt
Indonesia	489 Mt
Australia	459 Mt
Russia	347 Mt
South Africa	256 Mt
Germany	191 Mt
Poland	143 Mt
Kazakhstan	120 Mt

The five largest coal users - China, the USA, India, Russia and Japan - account for 76% of total global coal use (WCA, 2015). The World Resources Institute has identified 1200 coal plants in planning across 59 countries with a total of 1400 GW. Africa accounts for 13% of the world's population, but only 5% of the global energy consumption. The mining sector in Africa is demanding 30% of the power in Africa and 42% in South Africa. South Africa plans to increase its renewable energy footprint to 6000 MW by 2020 and to add a total of 9.6 GW of new capacity by 2030 (Inside mining May, 2014e). South Africa operates the world's only commercial coal to liquid (CTL) (synfuels) plants (Eberhard 2011) which is operated by Sasol. Most of the coal mined by Sasol is used in this CTL process.

Global patterns of coal consumption have changed dramatically in recent years, as rapid economic growth in Asia has increased the demand in that region. Whereas China constituted only 17% of primary coal demand in 1980, its share rose to 43% by 2008 and it has now emerged as the dominant consumer of coal internationally. Over the period 2000 – 2008 China's coal demand increased by 1120Mtce and accounted for three quarters of the total increase in coal demand over this period (IEA, 2010a). In 2013 China was the top coal importer in the world with 327Mt (Table 4). South Africa is a hard-coal exporter as the best coal is exported, while the poorer quality is burned in power stations specifically designed to handle the lower calorific value and higher ash contents (Inside Mining, 2014f).

Table 4: Top coal exporters and importers in 2013 (WCA, 2015).

Exporter	**Total *of which***	**Steam**	**Coking**
Indonesia	426Mt	423Mt	3Mt
Australia	336Mt	182Mt	154Mt
Russia	141Mt	118Mt	22Mt

Importer	**Total *of which***	**Steam**	**Coking**
PR China	327Mt	250Mt	77Mt
Japan	196Mt	142Mt	54Mt
India	180Mt	142Mt	38Mt

Exporter	Total *of which*	Steam	Coking
USA	107Mt	47Mt	60Mt
Colombia	74Mt	73Mt	1Mt
South Africa	72Mt	72Mt	0Mt
Canada	37Mt	4Mt	33Mt

Importer	Total *of which*	Steam	Coking
South Korea	126Mt	95Mt	31Mt
Chinese Taipei	68Mt	61Mt	7Mt
Germany	51Mt	43Mt	8Mt
UK	50Mt	44Mt	6Mt

There are currently 13 power stations in South Africa of which three were previously mothballed and later brought back. This was as a result of thehigher electricity demand (Kotze 2015, Power Plants around the World, 2015). Matimba, one of the 13 power stations, is located in the Waterberg Coalfield, Limpopo Province as well as the Medupi Power Station (currently under construction); the others are all within the Mpumalanga Province. Power plants are usually build near coal reserves and in South Africa these plants are mostly located within moderately to severely strained water management areas (Kotze 2015).

Both power stations in the Waterberg area will be using the direct-dry cooling technology which drastically reduces water use compared to the wet recirculation cooling technology (Kotze 2015). The two main technologies that have been used globally for coal combustion are pulverised fuel and fluidised bed technologies. All of Eskom's current coal fired power plants, as well as the soon to be completed Medupi and the future Kusile power plants, are pulverised fuel plants (Value Chain Overview, 2010).

From local and international experience, it is known that coal mining has a pronounced impact on surface and groundwater quality. This fact plus the continuous mining of coal to supply in energy demands will put pressure on future mining companies to limit the environmental impact (Morin and Hutt, 2001). This can only be done once the risk of the waste from the run of mine (ROM) is realised so that it can be utilised/stored in the best way and therefore limit the risk to the environment. This can be conducted by carefully pre-planned projects, implementing pollution control measures, monitoring the effects of mining and rehabilitating mined areas.

South Africa is one of the top countries with a dependence on mining for its economic growth and development. Acid and neutral mine drainage however are a threat to the environment polluting water and soil. AMD can contain high levels of heavy metals and sulphates and can thus cause water to be toxic due to soluble heavy metals. Not only does it endanger plant and animal life, but it can cause sicknesses in humans like organ failure, mental conditions, birth defects, and cancer. Even eating produce that has been irrigated by this kind of toxic water as well as farm animals that have drunk from contaminated water supply can be dangerous (Bird *et al,* 2008, Fuge *et al*, 1991, Helgen and Davis, 2000, Planet Earth Herald, 2015 & World Coal Association, 2015).

One rapidly growing refinement is the incorporation of environmental maintenance into the economics and engineering of mining. This is a reasonable consequence of increasing environmental awareness and the increasing intensity and cumulative extent of mining. This intense industrial activity around the world must be accompanied by environmental protection or restoration (Morin and Hutt, 2001).

1.4 Thesis Structure

The thesis is structured as follows:

- Chapter 1 –Introduction.
- Chapter 2 - Deals with the importance of coal and coal mining to supply in the ever growing demand of energy and environmental issues.
- Chapter 3 - Provides a general description of the area.
- Chapter 4 – Describes the position of the geological samples in the study area and the collection of the samples.
- Chapter 5- Describes the methodologies used in the investigation.
- Chapter 6 – Geological results are discussed (XRD, XRF).
- Chapter 7 – Static ABA results are discussed.
- Chapter 8 – Kinetic results are discussed.
- Chapter 9 – Leach results are discussed.
- Chapter 10 – Environmental impact.
- Chapter 11 -Overall conclusions.

NOTE: Throughout this thesis, acidic leachate produced due to mining will be referred to as Acid Mine Drainage (AMD). Acid Rock Drainage (ARD) will refer to situations where leachate is acidic from rocks or geological formations due to natural circumstances where there was no human interference.

2 COAL

2.1 Introduction

To understand the risk of coal mining can have on the environment (human, water, geological and animals), the background of what coal is, is important.

Coal is a combustible, sedimentary, organic rock, which is mainly composed of carbon, hydrogenand oxygen. It is formed from vegetation that has been consolidated between other rock strata and altered by the combined effects of pressure and heat over millions of years while forming coal seams. The energy we receive from coal today comes from the energy that plants absorbed from the sun, millions of years ago. All living plants store solar energy through a process known as photosynthesis. When plants die, this energy is usually released as the plants decay. Under conditions favourable for coal formation, the decaying process is interrupted, preventing the release of the stored solar energy. The energy is locked into the coal (WCA, 2015).

Coal formation began during the Carboniferous Period, known as the first coal age, which spanned 360 million to 290 million years ago. The build-up of silt and other sediments, together with movements in the earth's crust, known as tectonic movements, buried swamps and peat bogs, often, to great depths. With burial, the plant material was subjected to high temperatures and pressures. This caused physical and chemical changes in the vegetation, transforming it into peat and then into coal. These processes took place in the absense of oxygen and coal remains in a chemically reduced form (WCA, 2015).

The degree of change undergone by a coal as it matures from peat to lignite (stage one – lowest rank of coal) to anthracite (stage four – highest rank of coal) is known as coalification. Coalification has an important bearing on coal's physical and chemical properties and is referred to as the 'rank' of the coal. Ranking is determined by the degree of transformation of the original plant material to carbon. The ranks of coals, from those with the least carbon to those with the most carbon, are lignite, sub-bituminous, bituminous and anthracite. In addition to carbon, coals contain hydrogen, oxygen, nitrogen and varying amounts of sulphur. High-rank coals are high in carbon and therefore heat value, but low in hydrogen and oxygen (Figure 2). Low-rank coals are low in carbon but high in hydrogen and oxygen content (KCE, 2015 and WCA, 2015).

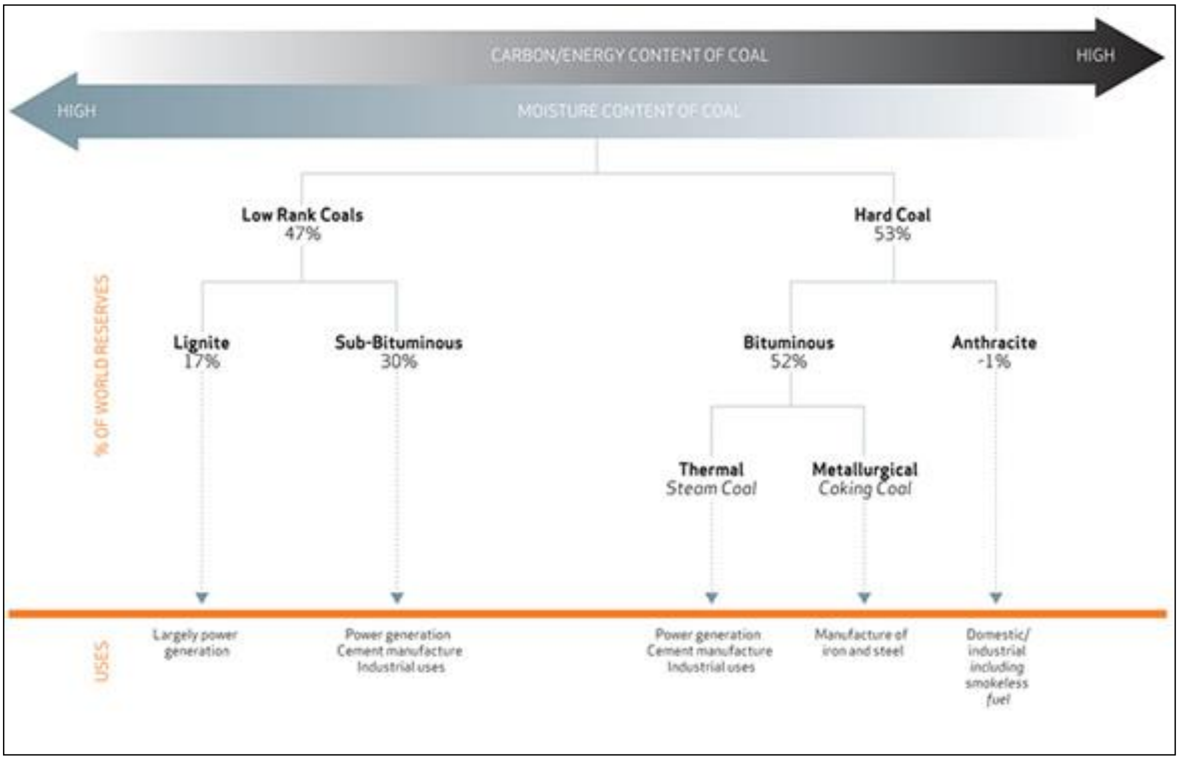


Figure 2: Coalification indicating the ranking of coal (WCA, 2015).

2.1.1 Types of coal

The peat is initially converted into lignite or 'brown coal' - these are coal-types with low organic maturity. In comparison to other coals, lignite is quite soft and its colour can range from dark black to various shades of brown. Over many more millions of years, the continuing effects of temperature and pressure produces further change in the lignite, progressively increasing its organic maturity and transforming it into the range known as 'sub-bituminous' coals. Further chemical and physical changes occur until these coals become harder and blacker, forming the 'bituminous' or 'hard coals'. Under the right conditions, the progressive increase in the organic maturity can continue, finally forming anthracite.

In addition to carbon, coals contain hydrogen, oxygen, nitrogen and varying amounts of sulphur. High-rank coals are high in carbon and therefore heat value, but low in hydrogen and oxygen. Low-rank coals are low in carbon but high in hydrogen and oxygen content (WCA, 2015). For example, sulphur content may range from low (less than 1%), through medium (1 to 3%), to high (greater than 3%), and ash yields may range from a low of about 3% to a high of 49% (if ash yields are 50% or greater on a dry basis, the substance is no longer called coal) or 65% for a composite coal seam (i.e. an ash content less than 65 % on a dry basis) (SANS 10320:2004; USGS, 2005). In the simplest terms, most coal types can be characterized by the ash content (grade) or the heat (energy) content (SANS 10320:2004).

An examination of the microscopically visible organic constituents of the coal (coal macerals) forms an important part of coal petrology. Macerals are constituent grains in coal, which are relatively homogenous and analogous to mineral forms in the study of rocks. Three groups of macerals are commonly identified (Petrakis and Grady, 1980).

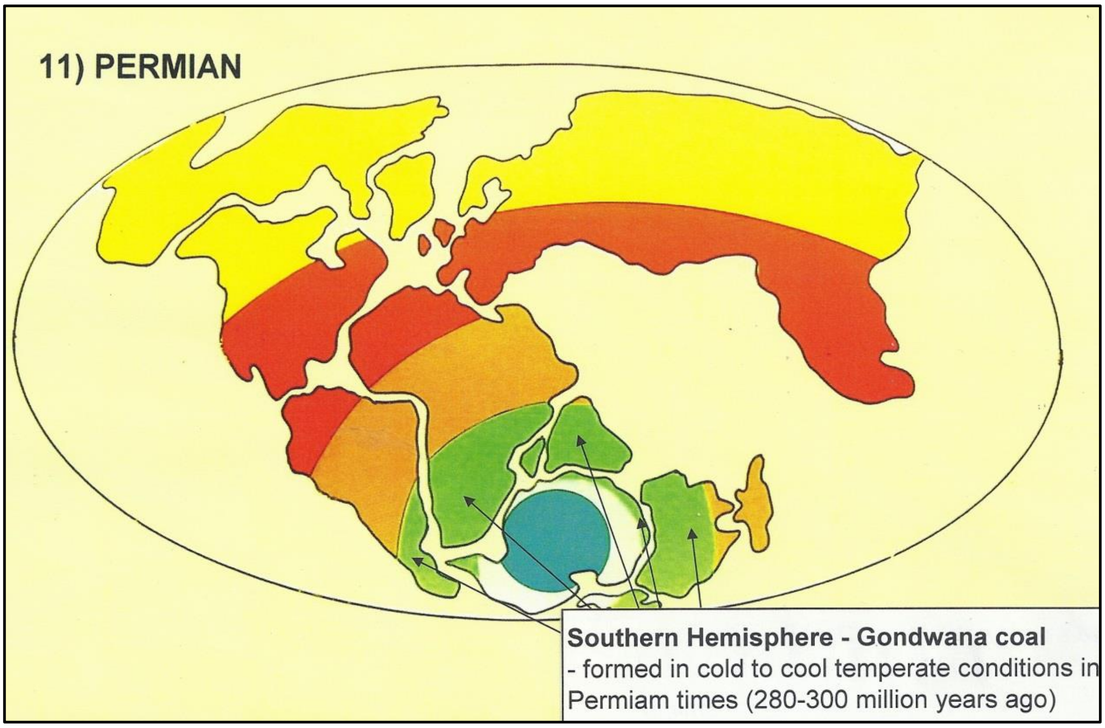
Liptinite: (derived from pollen and resins) - Originates from the remains of spores, resins, algae and plant cuticles. Liptinite macerals display a relatively low reflectance of light. Liptinite macerals are less present in coals of higher rank.

Inertinite: (derived from plant tissues) (unreactive) - Named after their limited reactivity on coking, the materials that formed these macerals were subject to early oxidation during coal formation and have the highest levels of reflectance. Inertinite macerals are relatively abundant in South African coals.

Vitrinite: (derived from humus) (reactive) - These macerals originate from wood and bark, and show greater reflectance than liptinite. The reflectance of its vitrinite macerals is held to be among the most generally applicable measures of a coal's rank.

The most modern classification systems use "mean vitrinite random reflectance" as the prime indicator of rank to classify lignites, sub-bituminous coals, bituminous coals and anthracites (low-rank, medium rank and high-rank coals, respectively). In the ISO draft standard for classification of coals, "mean random vitrinite reflectance" is used to delineate the medium and high-rank boundaries and the higher category of coal. Bed moisture (ash-free basis) is the prime rank parameter for the two lowermost rank subdivisions of coal. In order to classify further within the rank divisions stated, it is recommended the guidelines of the ISO draft for classification of coal (ISO/DIS 11760) be followed. Information to date indicates that South African coal resources are predominantly bituminous in rank, followed by some anthracitic coals and negligible lignites (SANS 10320:2004).

In a comparison of coals in a global context, Southern African coals and those from other Gondwana provinces (India, Australia, and South America) have been found to be characteristically rich in minerals, relatively difficult to beneficiate, and highly variable in rank (maturity) and organic-matter composition. This is illustrated on the map in Figure 3.



11) PERMIAN

Southern Hemisphere - Gondwana coal
- formed in cold to cool temperate conditions in
Permiam times (280-300 million years ago)

Figure 3: Gondwana coal (Falcon and Ham, 1988).

These characteristics provide the major differences between the Carboniferous coals of the northern hemisphere (ie the Laurasian region) and those found in the southern hemisphere (the Gondwana region) (Falcon and Ham, 1988).

2.1.2 Why is coal so complex?

Coal is complex because of the wide variety of factors that determine the quality of coal. These factors include:

(1) The plants, plant remains, and other organisms (such as bacteria) in the peat swamp;

(2) Biological and chemical processes and the degree of preservation of the plant matter;

(3) The geometry and location of the swamp;

(4) The mineral matter that accumulated with the plant material, or was introduced at some later stage; and

(5) Coalification.

Coal constituents: The chemical make-up of coal is variable across all coal classifications and is largely dependent on the origin of the organic material and geological conditions. The chemical, physical or petrographic characteristics of coal are an integral consideration in the trade and end-use (utilisation) of the coal product, whether it is raw coal or beneficiated coal. The most important considerations are:

Fixed carbon: The fixed carbon content of coal provides the energy and metallurgical reluctant ability for which coal is valued. The higher the fixed carbon, the higher the calorific value. Carbon increases with increasing coal rank.

Total carbon: Total carbon is the amount of fixed carbon plus any carbon present as volatile constituents (e.g. carbon monoxide, methane, hydrocarbons, etc.). Total carbon is always greater than fixed carbon and calorific value increases with increasing total carbon.

Ash: Ash is the total of non-combustible minerals contained within the coal. The presence of ash reduces its calorific value and presents handling problems. Ash originates from several sources, including the minerals contained in the original plant matter, mineral matter laid down with the plant matter, or minerals infiltrated into the peat.

Hydrogen: Hydrogen in coal is associated with thevolatile matter. In metallurgical coals the greater the H_2content, the greater the yield of NH_3 in the coke ovengas which is then used in fertiliser production. Hydrogencontent generally increases the calorific value of coal, butis not related to coal rank, with hydrogen content rangingfrom 4.5% to 6.5% from peats to bituminous coal.

Moisture: High moisture content in coal is associatedwith a lower calorific value.

Sulphur: Sulphur can occur in coal in three forms: sulphide minerals (such as pyrite), organic sulphur andsulphate minerals. While sulphides increase the calorificvalue of the coal, the presence of sulphur is undesirablein the use of coal as a fuel. The oxidation products ofsulphur can result in corrosion of equipment and theirrelease leads to local air pollution and acidificationeffects. Sulphur is also undesirable in metallurgicalapplications, causing cracking when the steel is forged or rolled at elevated temperatures. Sulphur content is notrelated to coal rank.

Oxygen: The oxygen content of coal reduces its calorificvalue. The lower the oxygen content, the better the rank.

Nitrogen: Appears in coals at between 1 and 3%. The presence of inert nitrogen reduces the calorific value of the coal, but does not relate to coal rank.

Phosphorus: Phosphorus is a coal constituent that is problematic in metallurgical applications of coal as it reduces the ductility of steel, causing cracking at low temperatures (Value chain, 2011 according to Anon, 2008).

South African coals are generally relatively low in sulphur content and high in ash content, requiring washing(beneficiation) to remove these undesirable constituents for export (World Energy Council, 2007). During beneficiation, only the pyritic sulphur can be reduced significantly. The most common chemical analyses undertaken and properties of coal include: proximate analysis, heat value, sulphur compounds, ultimate or elemental analysis, ash constituent analysis and trace element/minor constituent analysis. The physical properties of the coal are also important parameters to consider as they determine the behaviour of coal products during combustion, and conversion.

2.2 Coal in South Africa

Coal mining in South Africa plays a significant role in the country’s economy as it is responsible for nearly three quarters of Eskom’s fuel supply. The industry is also responsible for supplying the coal-to-liquids (CTL) industry, developed by the South African fuel company, SASOL, who produces around 35% of the country's liquid fuel (Coal mining in SA, 2015).

The discovery of coal in the Kwazulu-Natal, Mpumalanga and Eastern Cape provinces was first documented between 1838 and 1859. The first commercial exploitation of coal on a reasonable scale took place in 1870 in the now dormant Molteno Coal field of the Eastern Cape (Snyman, 1998). Mining in South Africa dates back to 1867 and mining from the 1880's to 1910 gave South Africa its current shape (Munnik, 2010). A diamond found in the Orange River initiated mining in South Africa. Not long after, gold was discovered and took center stage. This led to an even bigger gold discovery at the rocky hills of the Witwatersrand in Gauteng (Department of Energy, RSA 2015). A series of cartels initially controlled the industry, including the Transvaal Coal Owners Association (TCOA), which was formed in 1908 (Eberhard, 2011). Coal mining played a supportive role as provider of energy to the growing gold mining industry and many collieries were historically and still today, owned by gold mining companies (Munnik, 2010).

Coal is found in several areas throughout South Africa, and is associated with post-glacial conditions of the early Permian period (approximately – 260 Ma, Figure 4). Coal seams are found to be virtually horizontal throughout the main Karoo basin. Most of the coal formed in the stable tectonic conditions along with sedimentation of sandstones and shales of the Ecca Formation of the Karoo Supergroup (Snyman, 1998).They have been affected by numerous igneous intrusions which have produced a great variation in rank (Schmidt, 2008).The distribution of Permian Karoo strata is relatively widespread in Southern Africa, but the distribution of coal within these strata is far less common. Therefore, not all potential Early Permian Karoo lithologies contain coal (Cairncross, 2001). On the legend Ellisras refers to the Waterberg coalfield. Ellisras (Lephalale) is the main town in the area where the Waterberg coalfield is situated.

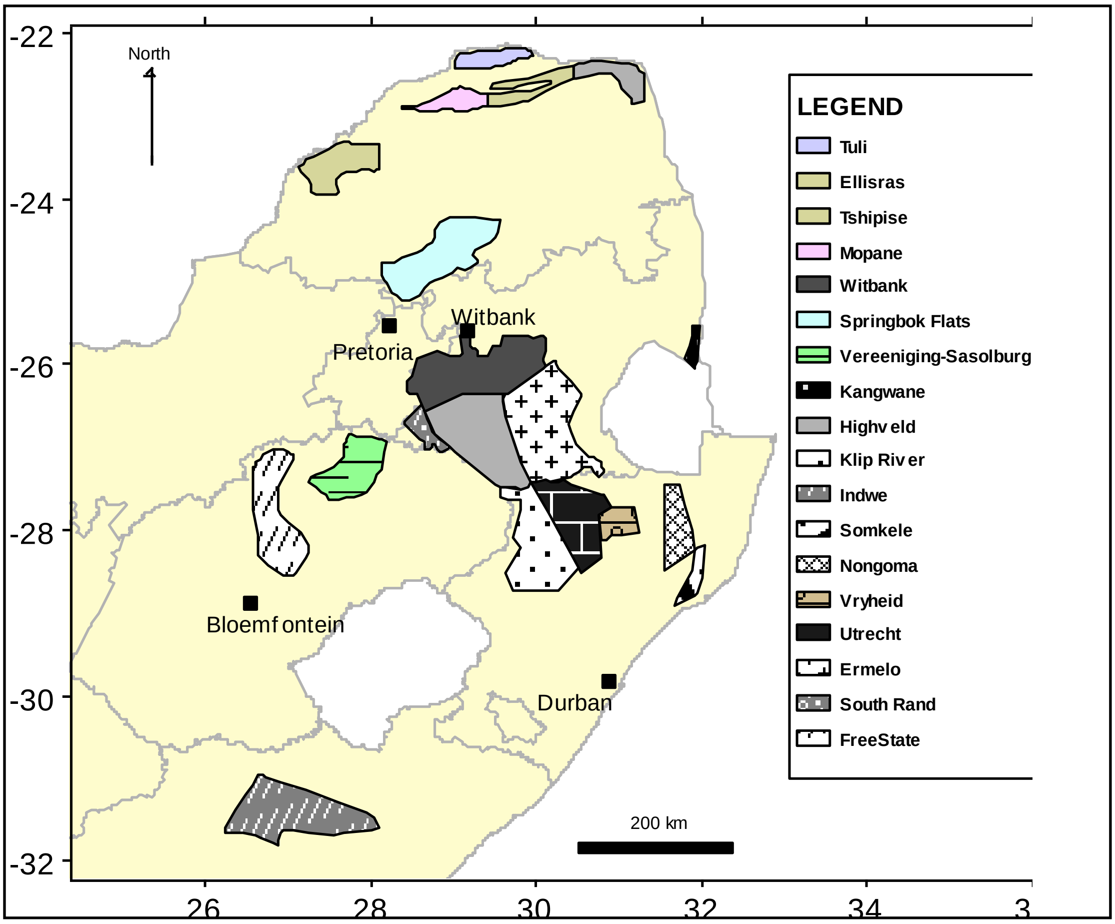


Figure 4: Coalfields of South Africa (after Snyman, 1998).

There are 19 official coalfields in South Africa (Jeffrey, 2005a). The Venda-Pafuri Coalfield in the Eastern Soutpansberg is not indicated in Figure 4 and is to the east of the Tshipise Coalfield.

There are two basic coal deposit types, which are representative of South African coal deposits, i.e. multiple seam and thick interbedded seam deposit types. **Multiple seam coal deposit type** is characterized by a discrete number of coal seams, typically between 0,5m and 7,0m in thickness, separated by inter-burden units of thickness generally significantly exceeding the thickness of the individual coal seams. The coal seams in the Witbank coalfield and Highveld coalfield in South Africa are characteristic of this coal deposit type. **Thick interbedded seam deposit type** thick coal deposit type, characterized by a succession of multiple, thinly interbedded coal and noncoal layers with a total thickness of typically between 40m and 70m. The coal deposits of the Grootgeluk formation in the Waterberg coalfield in South Africa are typical of this type (SANS 10320:2004).

The mining method used is largely determined by the financial aspect, and is based on the geological suitability of the reserve. By international standards, South Africa's coal deposits are relatively shallow with thick seams, which make them easier and, usually, cheaper to mine (Department of Energy, RSA 2015). A quarter of South Africa's bituminous coal is between 15-50 m below the surface and much of the remainder between 50-200m below (Eberhard, 2011).

In South Africa, coal production consists of about 53% open cast mines (surface mining), 40% bord-and-pillar, 4% stoping and 3% longwall (underground mining) (Creamer Media, 2010; Eberhard, 2011; Coal mines in South Africa, 2015). Advances in surface mining technology have allowed the amount of coal produced by one miner in an hour to triple since 1978 (EIA, 2015b). The majority of South Africa's coal mining operations are grouped in the Mpumalanga Province (Creamer Media, 2010; Coal mines in South Africa, 2015).

Nonetheless, new coal mines will have to be developed as existing mines exhaust their reserves (especially in the Witbank Coalfield) and because Eskom and independent power producers (IPP) (and perhaps Sasol) expand their production. Existing and abandoned coal mines in South Africa are indicated on the map in Figure 5. The Waterberg coalfield is also indicated as Ellisras on this map. The name of Ellisras has also been changed to Lephalale.

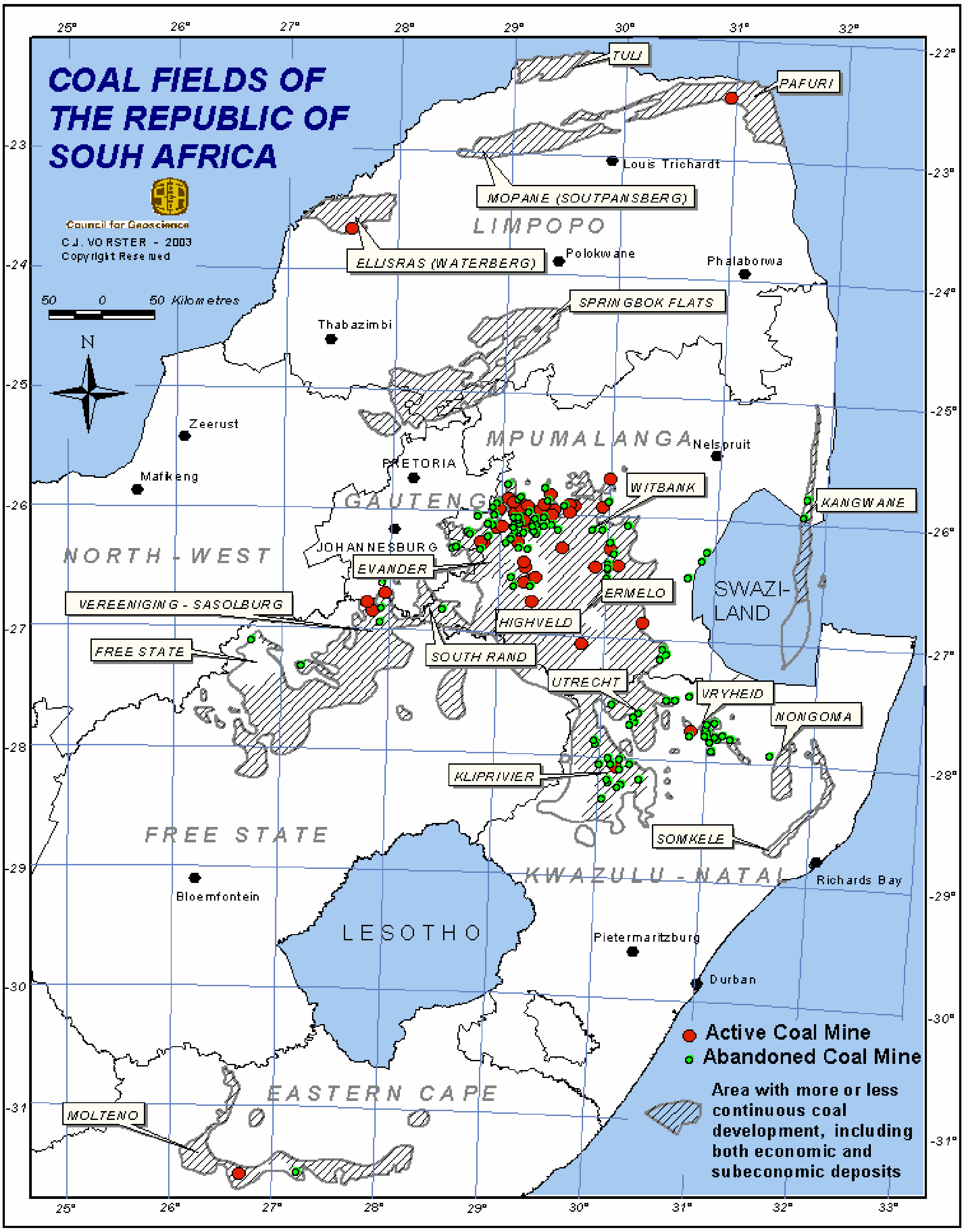


Figure 5: Coalfields with active and abandoned mines in South Africa (Vorster, 2003).

31% of all coal mines in South Africa can be found in the central Highveld while Witbank and Ermelo feature 30% and 13, 8% respectively. Coal mines in South Africa can also be found in: Waterberg, Sasolburg, South Rand, Utrecht, Kliprivier and the Soutpansberg (Africa Mining IQ, 2015).

Sulphur contents are generally between 0.6-0.7% in coal. Thermal coals used for domestic power and synfuel production have much lower calorific and higher ash values and are supplied mostly from screened ROM (although about a third of the coal supply for electricity production derives from the middlings fraction of coal washing (Eberhard, 2011). Sulphur in coal can be in the form of of: Pyritic sulphur, sulphate sulphur, organic sulphur or free sulphur. In the beneficiation process of the coal, parts of the sulphur end up in the discards which have the potential to leach because of the exposure to oxidation environmental conditions. These products eventually leach from the waste/discard dumps ending up in soil, surface water or aquifers. The sulphur sitting in the coal going to the power station will contribute to the SO_2 emissions. Eskom's coal-fired power stations use conventional pulverised coal technology, with average thermal efficiencies of 33%. Coal quality is poor with average calorific values of 4500kcal/kg (19MJ/kg), of which 29.5% is ash and 0.8% sulphur. Coal quality has been deteriorating in recent years as a result of coal suppliers reserving higher grades for more lucrative export markets. Electrostatic precipitators are employed to reduce particulate emissions but none of the power stations have flue-gas desulphurisation. Eskom currently emits 225Mt of CO_2 per annum (Eberhard, 2011).

Over 80% of South Africa's saleable coal is produced by five prominent coal mining companies, namely: BHP Billiton's Energy Coal South Africa (BECSA), Anglo American Thermal Coal, Xstrata Coal, Exxaro Resource and Sasol Mining. Of these major coal mining companies, BHP Billiton is one of Eskom's biggest suppliers, and one of the largest suppliers to the seaborne energy coal market. Anglo American's coal business owns and operates nine mines, and is currently working on several projects aimed at boosting output to 90 million tons per annum. Of the top five coal mining companies, Xstrata Coal is South Africa's third largest coal exporter (Africa Mining IQ 2015 & Overview of the South African Coal Value Chain, 2011).

2.3 Coal in the Waterberg

The Waterberg coal reserves represent the only large area with proven coal resources still remaining in South Africa. These resources have been targeted for large-scale mining in the foreseeable future, subject to infrastructure and water constraints (Eberhard, 2011). The Waterberg Coalfield has large reserves of high ash and low-calorific value coal (Jeffrey, 2005a). Other coalfields in the Limpopo Province are also being explored, with a focus on coking coal. Production in this area is expected to double in the next 5 years. The Waterberg produces mainly washed steam coals as well as small quantities of coking and metallurgical coals (Eberhard, 2011).

Grootegeluk Mine is the only major opencast coal mine in the area and has been active since 1980 (Figure 6). This mine falls within the district of Lephalale. Two of four tenements held under a mining right that the Department of Mineral Rights (DMR) granted Sekoko Coal, will almost double the coal production from 2.1 billion ton to 3.9, and is planned to start mining within the next 2 years. The coal will also be mined by way of the opencast method (terrace mining). Once mining starts, waste material will be dumped outside the pit footprint (Inside mining, 2014b).

Figure 6: Opencast mine in the study area courtesy of the Grootegeluk mine (Vermeulen et al 2009).

The Grootegeluk Open Pit Mine is located to the south of the Daarby Fault (Figure 7). The type of mining performed at this mine requires blasting and mechanical excavation on individual benches (truck and shovel). The mined pit is currently at zone 3, located about 100-120m below surface. The Grootegeluk Mine has the largest coal washing facility in the world where 8000 tonnes per hour run-of-mine coal are upgraded. Clean coal production at Grootegeluk Mine is 18.8 million tons per year (Exxaro, 2015) of which most of the coal product (14.8 Mt) is power station coal, 1.5 Mtpa metallurgical coal and 2.5 Mtpa semi-soft coaking coal (Exxaro, 2015).

The raw coal is of high ash content and large coal beneficiation plants are needed to meet the production targets. This is the main reason why since 1980, six plants have been erected at Grootegeluk Mine to produce higher quantity coal. The position of the Grootegeluk Mine and the processing plant situated just to the right of the Daarby Fault on the deep coal area can be seen in the aerial photograph.

Figure 7: The Grootegeluk pit (blue), processing plant (right insert), discard dumps (D2-D6) and slime dams (Sd1, 2 and 5) (Google map & Mac Donald 2015).

Grootegeluk is currently supplying the Matimba Power Station which was commissioned in 1991. Once the Medupi (4788MW) Power Station is completed, it will also receive coal from the surrounding active mines in the Waterberg coalfield. Medupi will be the largest dry-cooled coal-fired power station in the world (Power Technology, 2012). As per Eskom's request, the top coal zone is to be kept separate from the bottom coal zone. The coal-quality data indicates that a full wash will be required for the top zone while a partial wash will suffice from the bottom zone (Inside mining, 2014b).

The Grootegeluk Medupi Expansion Project (GMEP) has been provided with a spreader to supply coal to the Medupi Power Station. This expansion project is one of the largest in Southern Africa and upon completion, Grootgeluk will be the largest coal operation in the world, producing some 35Mtpa of power station-, coking- and steam coal. The spreader with an overall reach of 100m and a spreading capacity of 6000tph is the largest of its type in Southern Africa (Inside mining, 2014d).

In the Waterberg Coalfield ash contents can vary, but are high and can range up to 65%. Export grade coals generally require washing so that their ash content does not exceed 15%. Heating values of exported coals of around 6200kcal/kg (26MJ/kg) were common, but average values are declining and some export coals are now around 5900kcal/kg (24.7MJ/kg) (Eberhard, 2011). Semi-soft coking coal is present in an upper 60m thick sequence of intercalated mudstone and coal bands (Grootegeluk Formation) and steam coal is found in a lower 55m thick portion of discrete seams (Vryheid Formation). This high ash coal requires washing before being supplied to Eskom's power plants (typically 60% down to 35% ash). To receive different quality coals, washing would be required for exports. Mining utilises the open pit truck and shovel method with bench heights ranging from 4 to 20m. The Grootegeluk Mine (originally established by the state to supply product to Iscor's steel plants) has the world's largest coal beneficiation complex where 7600 tons per hour of ROM coal is upgraded in six different plants. The yield of blend coking coal from the upper mining benches is only at about 10%, while the yield of middlings steam coal is around 40%.

Lephalale is defined by the Limpopo Growth and Development Strategy as a coal mining and petrochemical cluster. The local economy is dominated by the Grootegeluk coal mine and the Matimba Power Station. The Local Economic Development Strategy of Lephalale Municipality's Vision for 2015 is:

- to increase coal production to more tha 100 million tonnes per annum
- have a petrochemical industry established for 160 000 barrels per day
- double the population from 120 000 to 240 000 (EIA, 2015a)

2.4 Mining and Processing

Grootegeluk Mine commenced in 1980 to produce a blend of coking coal for steelworkers' coke ovens (Kumba Resources, 2012). Thermal coal was produced as a co-product in the washing plant (GG1) and is stored and used at Matimba Power Station. GG2 (second washing plant) was specially constructed to produce power station thermal coal. This was done in order to enhance and retrieve the full tonnage of thermal coal for the Matimba Power Station. The raw coal consists of finely inter-bedded layers of sandstone and shale and thus needs to be crushed in order to liberate the coal. The various mined benches for the specific purposes are illustrated in Figure 8.

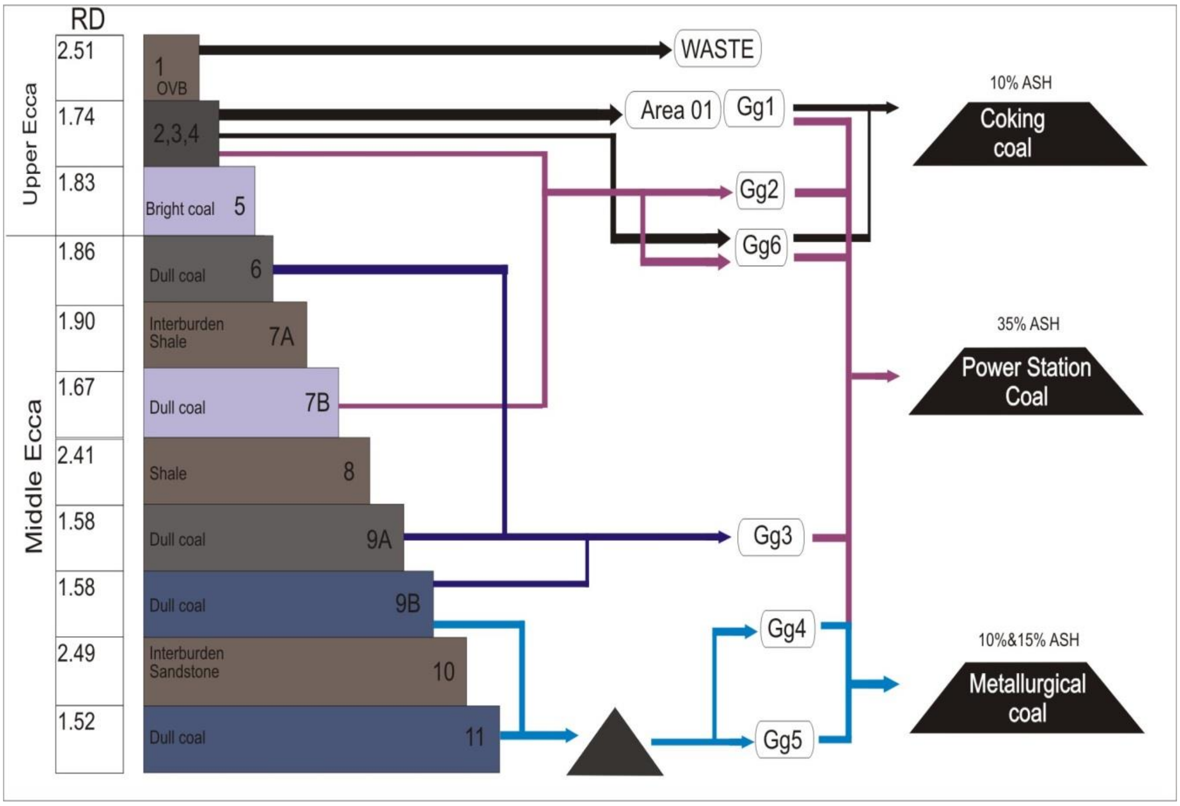


Figure 8: Simplified material flow diagram. The coal bearing Upper and Middle Ecca are processed in the various processing plants. Each mined bench consists of a specific quality coal liberated based on the specific use of the coal (Modified from Roux, 2011; Dreyer 1999).

Various mining spoils or mining waste is produced during different processes of the mining operation. The three main types of waste produced by the Grootegeluk Colliery include overburden (that needs to be stripped to reach the coal layers during open cast mining), interburden (consists of material between coal layers that are not viable to mine) and coal discards from beneficiation plants. Due to their high carbon content, the plant discards have a high propensity towards spontaneous combustion. The inter-burden material is prone to spontaneous combustion because of its carbonaceous nature. The major problem associated with such a large quantity of waste is the safe storage and disposal in such a way that will prevent the occurrence of spontaneous combustion.

The discard materials that need to be handled are mixtures of discards from various plants and waste from benches both with unknown properties. The lack of detailed knowledge on material properties complicates the design of a “safe” heap.

2.5 Coal Mineralogy

The most common minerals in coal (i.e. illite clay, pyrite, quartz, and calcite) are made up of these common elements (in rough order of decreasing abundance): oxygen, aluminium, silicon, iron, sulphur, and calcium. These minerals (Table 5) and other less common minerals usually contain the bulk of the trace elements present in coal. Minerals in coal commonly occur as single crystals or clusters of crystals. These minerals are intermixed with organic matter or fill void spaces in the coal. The sizes of mineral grains range from submicroscopic to a few centimetres.

Table 5: *Major minerals found in coal and their elemental compositions (USGS 2005).*

Major Mineral Constituents (In general order of abundance)	
Mineral name	**Chemical composition**
Quartz	SiO_2
Clay Minerals:	
Kaolinite	$Al_2Si_2O_5(OH)_4$
Illite	$KAl_4(AlSi_7O_{20})\ (OH)_4$
Montmorillonite	$(1/2\ Ca,Na)_{0.7}\ (Al,Mg,Fe)_4\ [(Si,Al)_4\ O_{10}\ ]_2\ (OH)_4.\ nH_2O$
Chlorite	$(Mg,Al,Fe)_{12}[(Si,Al)_8\ O_{20}]\ (OH)_{16}$
Pyrite	FeS_2
Calcite	$CaCO_3$
Siderite	$FeCO_3$

Although a lot is known about the minerals in coal, much remains to be learned about their occurrence, abundance, origin, and composition. For example, the type of clay mineral in a coal, whether montmorillonite or illite, determines how a coal will react when burned. Montmorillonite may or may not break down (dissociate) into its constituent parts when coal is burned; if it does dissociate, upon cooling, it can recombine with other elements or minerals to form mineral deposits on the inside surfaces of furnaces and boilers. This process (called "slagging" or "fouling") produces barriers to heat exchange in the affected equipment, which can substantially reduce its efficiency and require costly repairs (USGS, 2005).

Illite, with its simpler composition, does however not cause such problems under normal furnace operating conditions. Where these two clay minerals and others occur, their relative abundances, relationships to other minerals and exact compositions are subjects for continued research in coal quality (USGS, 2005). The elements found in coal are colour highlighted according to abundance in Figure 9.

The elements with green bars were studied by the Environmental Protection Agency (EPA) as potentially hazardous air pollutants (HAPs). Thirteen of the original elements with a green bar were cleared when the EPA found that there was no compelling evidence that they cause human health problems. Two elements from the original fifteen, mercury (Hg) and arsenic (As), indicated by a green bar across the centres of their boxes, are still under study. Mercury is studied as a HAP while arsenic as a potential pollutant in groundwater that flows through fly-ash and coal-mine spoil piles. Subsequently, in December 2000, the EPA found that mercury emissions from coal-fired power plants require regulation; the EPA have proposed regulations in 2003 and final rules were issued in 2004 (USGS, 2005).

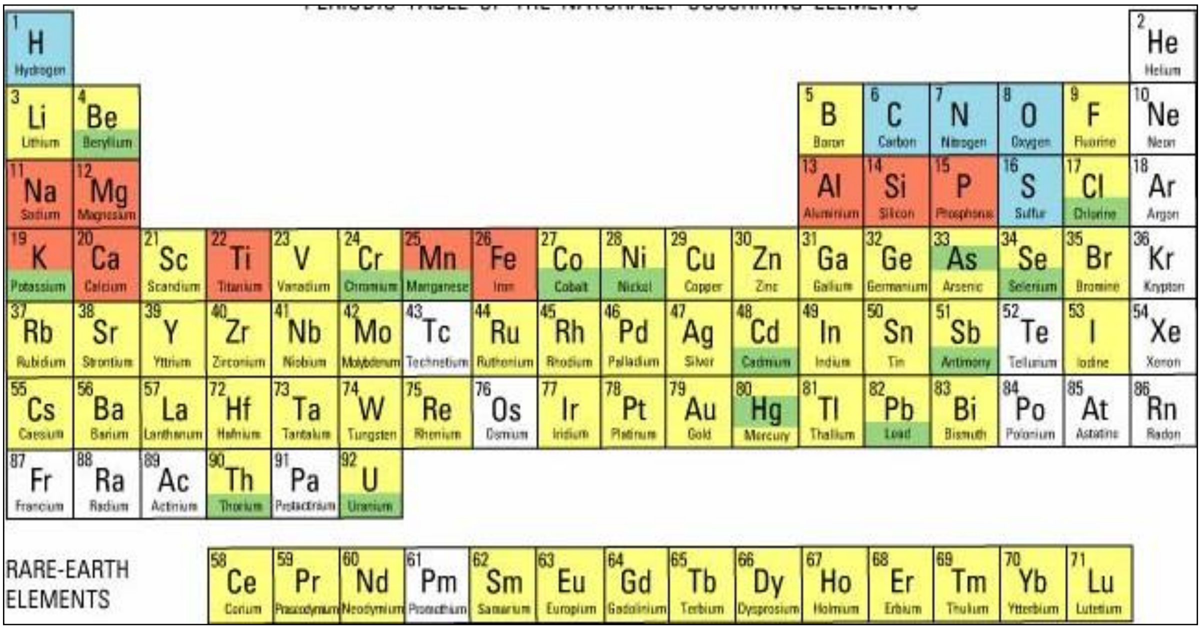


*Figure 9: Periodic table of the elements. The 76 elements found in coal are highlighted by colours with regard to their general abundance in coal, as follows: *blue, major elements (generally greater than 1.0% in abundance); red, minor elements (generally greater than or equal to 0.01%); and yellow, trace elements (generally less than 0.001%)(USGS 2005).*

The environmental issues of coal are discussed in a following section.

2.6 Ash and Discard Production

When coal is burned, most of the mineral matter and trace elements generally form ash; however, some minerals break down into gaseous compounds which go out the furnace's flue. Pyrite, for example, breaks down into the individual elements iron and sulphur. Each element then combines with oxygen to become, iron oxide and SO_xrespectively. Iron oxide, a heavy solid, becomes part of the ash and SO_x, after which a gas, is emitted as part of the flue gas. Some trace elements also dissociate from their organic or mineral hosts when coal is burned and follow separate paths. Most of these become part of the ash, but a few of the more volatile elements, such as mercury and selenium, may be emitted in the flue gas (USGS, 2005). Of coal consumed by Eskom in 2010, 36 Mt ash were produced from 122.7 Mt coal (Value Chain, 2010). Two types of fly ash are produced by coal combustion in large power plants. Class F is generally low in lime (CaO), usually under 15%, and contains a greater combination of silica, alumina and iron (greater than 70%) than Class C fly ash. Class C fly ash normally comes from coals which may produce an ash with higher lime (CaO) content — generally more than 15% often as high as 30%.

Elevated CaO may give Class C unique self-hardening characteristics (Headwater resources, 2015).

The mineral content of coal determines what kind of ash will be produced when it is burned. The fusion temperature (melting point) of the ash dictates the design of furnaces and boilers. In general, if the fusion temperature is relatively low, the molten ash is collected at the bottom of the furnace as bottom ash, requiring one design; however, if the fusion temperature is relatively high, the part of the ash that doesn't melt easily, called "fly ash," is blown through the furnace or boiler with the flue gas. It is thereafter collected in giant filter bags, or electrostatic precipitators, at the bottom of the flue stack, requiring a different design. Coals that are relatively rich in iron-bearing minerals (such as pyrite or siderite) have low fusion temperatures while coals relatively rich in aluminium-bearing minerals (such as kaolinite or illite) tend to have high fusion temperatures. If an electric generating or heating plant is designed to burn one type of coal, it must continue to be supplied with a similar coal or undergo an extensive and costly redesign in order to adapt to a different type of coal. Similarly, furnaces designed to use coal that produces high amounts of heat will suffer severe losses in efficiency if they must accept coal that burns with substantially less heat (USGS, 2005).

Coal preparation can be considered to occur in two distinct stages: screening (stage 1) and washing (stage 2). In the screening stage, large foreign objects are first removed (scalping), after which the ROM coal is crushed to reduce overall top size. This is followed by screening to separate the coal into various size fractions, -either for direct sale or for further processing by washing. Coal washing, also known as coal beneficiation, is conducted to reduce the content of ash forming minerals, thus meeting product specifications that cannot be achieved by screening alone. Coal is typically washed using density separation techniques, due to the differences in density of the inorganic, ash-forming minerals and the valuable carbon in the coal. A major portion of coal beneficiation in South Africa is done to separate the coal into distinct products, a high value export product and a lower value middlings product for local consumption. Coal cleaning reduces the ash content of coal by over 50% resulting in less waste, lower sulphur dioxide (SO_2) emissions and improved thermal efficiencies which lead to lower CO_2 emissions. The waste containing the ash-forming minerals is commonly termed discard (WCA, 2015 & Value Chain, 2010).

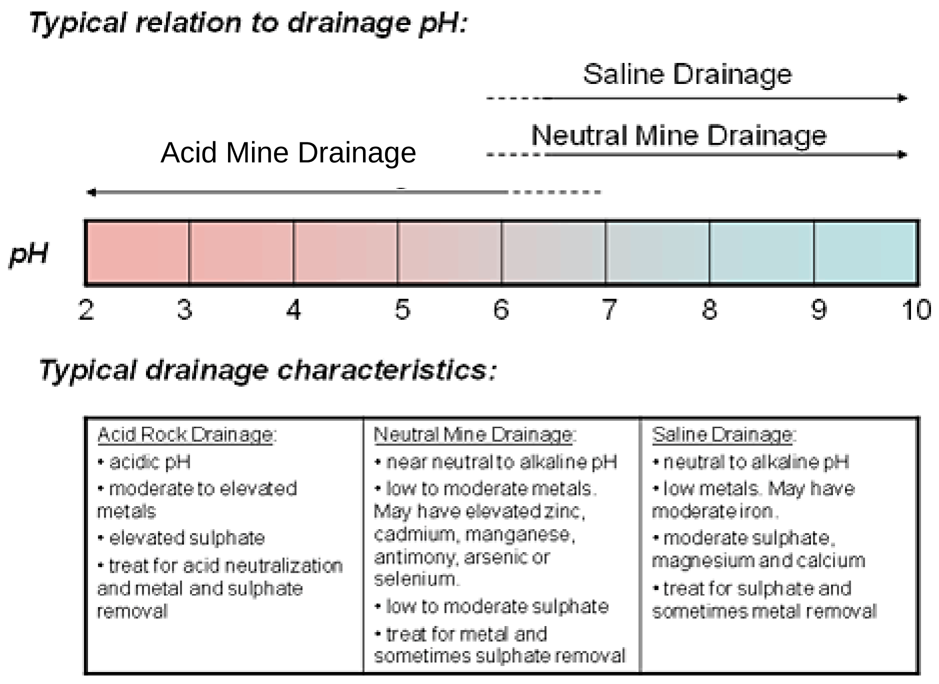
A further by-product of coal washing or beneficiation is large quantities of discard or “duff” coal. This presents both an environmental challenge as well as a potential resource for power production using fluidised bed combustors. Although, as Lloyd (2000) notes, the coal is referred to as discard for a reason: it is of poor quality (high ash and sulphur) and volatiles diminish as stockpiles age.

2.7 Environmental

2.7.1 Water quality

The largest water quality problem associated with coal mining is unquestionably acid mine drainage (AMD). Acid mine drainage consists of three interrelated problems: first, the pyrite in the rock gives rise to water with a low pH. Secondly, this acidic water in turn mobilises heavy metals from the environment, in the mine and discard facilities. Thirdly, the treatment of the water with calcium to raise the pH, makes the water more saline, a problem that requires expensive and energy intensive reverse osmosis or similar processes. It is very difficult, if not impossible, to avoid acid mine drainage. Once broken up, rock is open to oxygen, which reacts with the pyrite in both the coal and the surrounding rocks. Once water flows over this, acid mine drainage follows.

However, there can be other types of drainage from the mining area (Figure 10) – those with pH's of above 6, namely Neutral Mine Drainage (NMD) and Saline Drainage (SD) (INAP, 2009) as also referred to as the GARD Guide.



Acid Rock Drainage:	Neutral Mine Drainage:	Saline Drainage:
• acidic pH • moderate to elevated metals • elevated sulphate • treat for acid neutralization and metal and sulphate removal	• near neutral to alkaline pH • low to moderate metals. May have elevated zinc, cadmium, manganese, antimony, arsenic or selenium. • low to moderate sulphate • treat for metal and sometimes sulphate removal	• neutral to alkaline pH • low metals. May have moderate iron. • moderate sulphate, magnesium and calcium • treat for sulphate and sometimes metal removal

Figure 10: Types of mine drainage produced by sulphide oxidation (INAP, 2009).

Elements dissolved from the mining process (mine, ash, discards) can enter surface water bodies or can leach to the aquifers below and/or adjacent to these mining activities.

The spreading of elements throughout the different geological units and the exposure to now oxidising conditions other than the inert conditions before mining will play a role in the composition of the leachate from the different facilities at the mining and power facilities.

2.7.2 Air pollution from coal mining and coal use

Air contaminants released by coal-fired power stations primarily include particulates, sulphur dioxide (SO_2), nitrogen oxides (NOx) primarily as nitric oxide (NO) with smaller quantities of nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O), and trace amounts of mercury. Mining operations are typically likely to generate fugitive dust emissions ($PM_{2.5}$, PM_{10} and TSP) with small amounts of NOx, CO, SO_2, methane and CO_2 being released during blasting operations (Golder, 2011). Power generation is the main contributing source to SO_2 and NO_2 emissions in the District, contributing to 95% and 93% respectively (Walton and Ngcukana, 2009).

Prevailing winds are predominately from the north-east throughout the year and reduces the probability of pollution sources situated south of the project by affecting the project's ambient air quality (Golder, 2011 and Walton and Ngcukana, 2009). Spontaneous combustion of coal discard heaps releases toxic compounds including carbon monoxide, carbon dioxide, methane, benzenes, toluene's and xylenes, as well as sulphur, sulphur compounds, arsenic, mercury and lead. Research identified these coal fire gas minerals as having "the potential to affect the health of mine workers and communities living near the coalfields (DEAT, 2006 and Walton and Ngcukana, 2009). The high carbon content of the Waterberg discards promotes spontaneous combustion (Jeffrey, 2005).

The Mpumalanga Province has been declared as an air quality priority area due the coal mining and power stations. This province currently has amongst the worst air quality in the world which is largely due to coal mining activities, uncontrollable underground fires and power-stations burning coal. Good quality coal is exported, leaving the lesser quality to be burned by South African coalfired power stations, and adding to South Africa's carbon footprint and dirty emissions. Mpumalanga has long been seen as an area of bad air quality and in the winter months, a temperature inversion layer traps pollutants in the lower atmosphere (Munnik, 2010).

The most recent and by far the most comprehensive study of air pollution in Mpumalanga notes that elevated pollutants are SO_2, particulates (PM_{10} and $PM_{2.5}$), NOxes, O_3, benzene and H_2S. The study "anticipates" that thresholds for SO_2, PM_{10}, NO_2, O_3 and benzene are exceeded. Power generation, fuel combustion by industries and institutions, domestic fuel burning and vehicles emissions contribute to these, while significant sources of benzene include vehicle emissions, domestic coal burning and releases from the petro-chemical complex at Secunda (Munnik, 2010). SO_2 concentrations in the Waterberg area were found to infrequently exceed short term air quality limits atseveral monitoring stations. Given that short-term limits are exceeded due to the operations of the existing power station (Matimba) it is likely that the addition of Medupi power station will increase the frequency of exceedance downwind of the power stations. However, the Environmental Authorisation authorizing the Medupi power station was issued with the condition that Medupi power station and the Matimba power station should be fitted with SO_X abatement technology, should monitoring in populated areas indicate non-compliance with South African ambient air quality standards, in order to ensure compliance with these standards. Predicted PM_{10} concentrations were within the South African daily and annual limits but exceeded the more stringent South African National Standards (SANS) and European Union limit values in the vicinity (within 4 km) of the existing ash dump (EIA, 2009).

The new legislation requires significant emission sources to be identified, quantified and addressed, ambient air quality targets to be set, therefore providing access to information and public consultation (NEMAQA, 2004). The sources of air pollution in the study area are: (EIA, 2015a)

- Mining operations (Grootegeluk Colliery) – mainly fugitive dust emissions
- Matimba Power Station – main source of SO_2 emissions
- Matimba ADF – particulate matter
- Medupi Power Station
- Veld fires
- Domestic fuel burning at the surrounding township
- Agriculture
- Vehicle emisions

With the future expansion of coal mining and power stations in the area, air pollution will be higher than present. The main pollutant of concern that may pose a health risk to surrounding receptors is particulate matter (EIA, 2015a). With the discovery of palladium deposits in the northern Waterberg, mining of this resource will place more pressure on the protection of natural resources. Based on the preliminary economic assessment (PEA), first production is planned for 2018 (Inside mining, 2014c). Hazardous air pollutants between the Waterberg, Mpumalanga areas and the US and Global averages are summarised in Table 6 . Some of the concentrations are higher than the global average.

Table 6: *Hazardous Air Pollutants, volatility and class distribution*.

Concentration (ppm or mg/kg)	**U**	**V**	**Th**	**As**	**Cd**	**Pb**	**Se**	**Cl**	**F**	**Hg**
Waterberg upper Ecca (Bergh et al, 2014)	**4.7**	**96**	**9.3**	**11**	**0.2**	**76**	**1.3**	**50**	**302**	**0.37**
Waterberg Grootegeluk **(Wagner et al, 2012)**	**3.9**	**97**	**6.1**	**10.9**	**0.2**	**41**	**1.2**			**1.10**
Waterberg (Grootegeluk) (Faure et al, 1996)	**8.0**	**85**	**38**	**6.0**		**89**	**2.0**			
Witbank 4 Seam (Bergh et al, 2008)	**2.6**	**39**	**8.9**	**5.5**	0.3	**15**	0.8	27	**297**	**0.29**
Highveld 4 Seam (Wagner et al, 2005)		33		3.1	0.4	7	1.0			0.2
Witbank 2 Seam (Cairncross et al, 1990)	4.0	27	15	4.6	0.6	10	0.9			0.12
USA mean (Finkelman, USGS Resources)	2.1	22	3.2	24	0.4	11	2.8	614	98	0.17
Global Average Zhang et al 2004*, Yudovich, 2009	1.2	25	3.1	5.0	0.6	25	3.0	380*	88*	0.12
Volatility	least volatile							most volatile		
Class	Class I			Class II				Class III		
Distribution	equally distributed between bottom ash & fly ash			Enriched in fly ash, depleted in bottom ash				Volatilised & emitted fully in vapour phase, not enriched in fly ash		

Trace elements emitted from coal-burning power plants have been shown to cause severe health problems. A summary of health risks in different areas are summarised in Table 7.

Table 7: *Health risks, source and elements due to coal and combustion products.*

Country/area	**Source**	**Element/Product**	**Health risk**	**Reference**
China	Domestic coal	Mercury	humans	Zhou & Liu 1985
China	Mining Slag	Thallium	humans animals	Zhou & Liu 1985
China	Combustion Ash	Selenium	selenosis	Zheng, 1992
China & Czechoslovakia	Coal combustion	Arsenic	hearing loss & arsenonis	Bencko & Symon, 1977 - Finkelman et al 1999
Worldwide	Coal dust	Coal dust and silica	respiratory problems - all breathing organisms	Chamber of Mines, 2007 & Du Toit, 2010
Mpumalanga & **Waterberg**	Coal combustion	Coal dust - particulate matter, SO2	respiratory tract diseases	EIA, 2009 - Munnik, 2010 Terblanche et al, 1994 -
United states	Coal combustion	Mercury	humans animals	Finkelman et al 1999
Worldwide	Coal dust	Coal dust and silica	respiratory problems - all breathing organisms	Chamber of Mines, 2007 & Du Toit, 2010

Subsequently, an awareness of potential financial liabilities for remediation and third party liability have evolved and has increasingly been debated by organs of state, business leaders and industries themselves.

The application of lessons from other mining areas is appropriate for discussion here. The fact that new extraction options such as *in-situ* coal gasification are considered in addition to more traditional mining options brings additional uncertainties to the fore. Although several factors, in addition to the effect on water resources, should be considered when selecting a mining method, the long-term effect on water quality calls for a careful consideration of alternatives. It is desirable that both developers and regulators be aware of the long-term liabilities and costs associated with different mining methods. The Waterberg coal resources are situated in a relatively dry area and in view of the low rainfall and limited surface water resources, the necessary level of safeguard measures to ensure the quantity and quality of existing water resources is unclear. As a result of the area being unique in its setting and local conditions for a South African coal field, experience from other areas cannot necessarily be extrapolated directly.

There are essentially two broad approaches to reducing emissions from coal:

1. Using coal in a more efficient way e.g. by increasing combustion efficiency in power, or by using Underground Coal Gasification (UCG) to gas for synthesis or power generation.

2. Capturing and storing emissions from processes that use coal with Carbon Capture & Storage (CCS). A survey of world practice leaves an impression that countries are looking

more towards CCS than to combustion efficiency to decarbonise their economies in the future (Overview of the South African Coal Value Chain, 2011).

There are other proposed methods to use coal i.e. CBM and UCG. The methods are shortly summarised but no results from the Waterberg CBM pilot plant regarding environmental geochemistry are discussed in this study.

2.7.2.1 Coalbed methane (CBM)

CBM is produced by extracting the water in the coal seam, which reduces the water pressure (hydrostatic pressure) and enables the gas to be released (desorbed) from the coal. It then migrates through the coal seam to the gas well after which it rises to the surface.

The gas extraction process is further enhanced by hydraulic stimulation known as "fraccing". Fraccing involves the fracturing of the coal seam at pre-determined intervals. Fractures are then opened up by high pressure injections of a fine-grained inert sand suspended in a fraccing fluid. The fraccing fluid is then pumped out of the well and gas production begins once the hydrostatic pressure has reached the correct level. The fraccing fluid may require treatment and can be re-used on site or disposed of. The water management approach varies from site to site (WCA, 2015).

South African coal deposits are considered to have generally low methane gas content and low permeability, which casts doubt on the viability of coalbed methane extraction (Creedy *et al*., 2001, UNFCCC, 2000). The CBM resource in South Africa has been estimated at 0.14 –0.28 trillion m^3 (Global Methane Initiative, 2010).

2.7.2.2 Underground coal gasification (UCG)

Underground coal gasification (UCG) is a technology first proposed in the 1800's, whereby coal is ignited underground with a controlled flow of oxidant gas (such as air, enriched air, oxygen/steam or carbon dioxide/oxygen mixtures) and water. This converts the coal into synthetic gas (syngas) comprising hydrogen, carbon monoxide, methane and carbon dioxide, in proportions dependant on the exact conditions (Ergo Exergy, 2010; Eskom, 2009a). Syngas can be used directly as a fuel, fired with other fuels such as natural gas or coal, can powergas turbines for electricity generation (most efficiently using IGCC technology) or be used as a chemical feedstock for the production of synthetic natural gas, liquid fuels or chemicals by the same processes currently applied by Sasol (which currently gasifies coal for this purpose, but does this aboveground after mining the coal intact) (Eskom, 2009a; PWC, 2008). The ash remaining after gasification is left below the surface. The technique therefore enables the high efficiency extraction of energy and chemical value from the coal without the need for conventional mining operations, stockpiling, reclaiming and transportation nor the generation of mining wastes from overburden, discard and ash. Furthermore, the much-reduced underground infrastructure and elimination of below ground personnel make UCG applicable to many deposits, whichwould otherwise be unsafe, un-mineable or sub-economic (Eskom, 2009a; PWC, 2008). The shorter coal value chain from resource-in-the-ground to end-product enables UCG to produce lower cost energy than with conventional mining. Due to the absence of personnel below the surface, this type of operation also has advantages in terms of safety.

3 STUDY AREA

3.1 Location of the Area

The study area is located within the Limpopo Province of South Africa (Figure 11). The Limpopo Province is the northern most province in the country and borders with Botswana, Zimbabwe and Mozambique. The Waterberg Coalfield is an extensive deposit of coal in the Ellisras Basin. Coal was found in the Ellisras Basin in 1920, but for many years little was done to explore the resource since at the time it was considered to be too remote to justify development (Fourie *et al.,* 2006; Oberholster, 2010). Only after World War II, prospection continued and the Grootegeluk Mine was established in 1980. This mine is still operational today. The Waterberg Coalfield is about 85 kilometres from east to west and about 40 kilometres from north to south (Firestone Energy, 2009). The coalfield continues into the Botswana Coalfield which is called the Mmamabula Coalfield, and also hosts coal of economic significance (Mgojo, 2012). The Waterberg Coalfield lies within the Limpopo Water Management area.

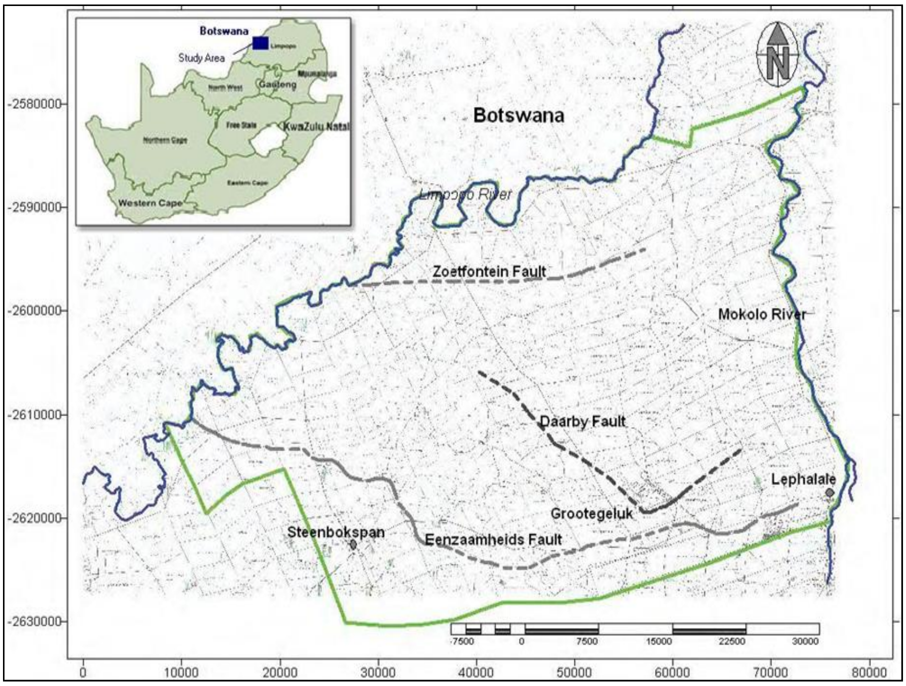


Figure 11: Map of South Africa showing the position of the Waterberg area in the Limpopo Province.

The study area is located between the towns of Ellisras (Lephalale) to the east and Steenbokpan to the west. It stretches up all the way to the Limpopo River forming the border with Botswana to the north.

3.2 Climate

The area is in a semi-arid rainfall region that is characterised by cool, dry winters (May to August) and warm, wet summers (October to March) with April and September being transition months.

The mean annual temperature ranges between 16°C in the south, to more than 22°C in the north. The maximum temperature is reached in January while the minimum temperatures are on average recorded in July. The average maximum ranges from 33 °C in January to 23.4 °C in June. The average daily minimum ranges from 20.4 °C in January to 6.7 °C in June.

The study area has a very dry winter with summer rainfall and the rainfall is very low and concentrated between October and March. The mean annual rainfall for the area is 435 mm (Figure 12 and Figure 13) and the mean annual evaporation ranges from 1800– 2000 mm.

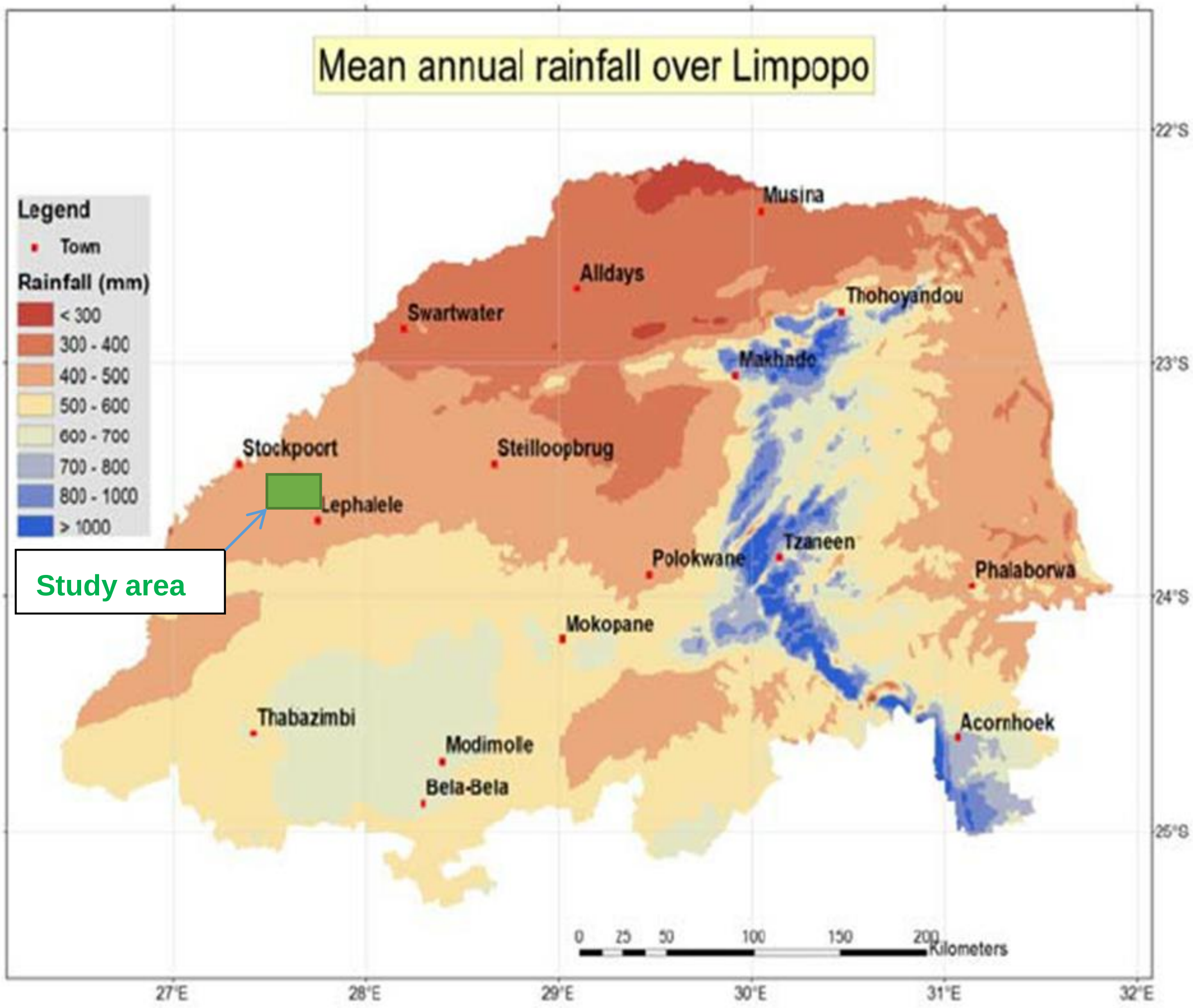


Figure 12: Mean annual rainfall in the study area (regional) (https://www.researchgate).

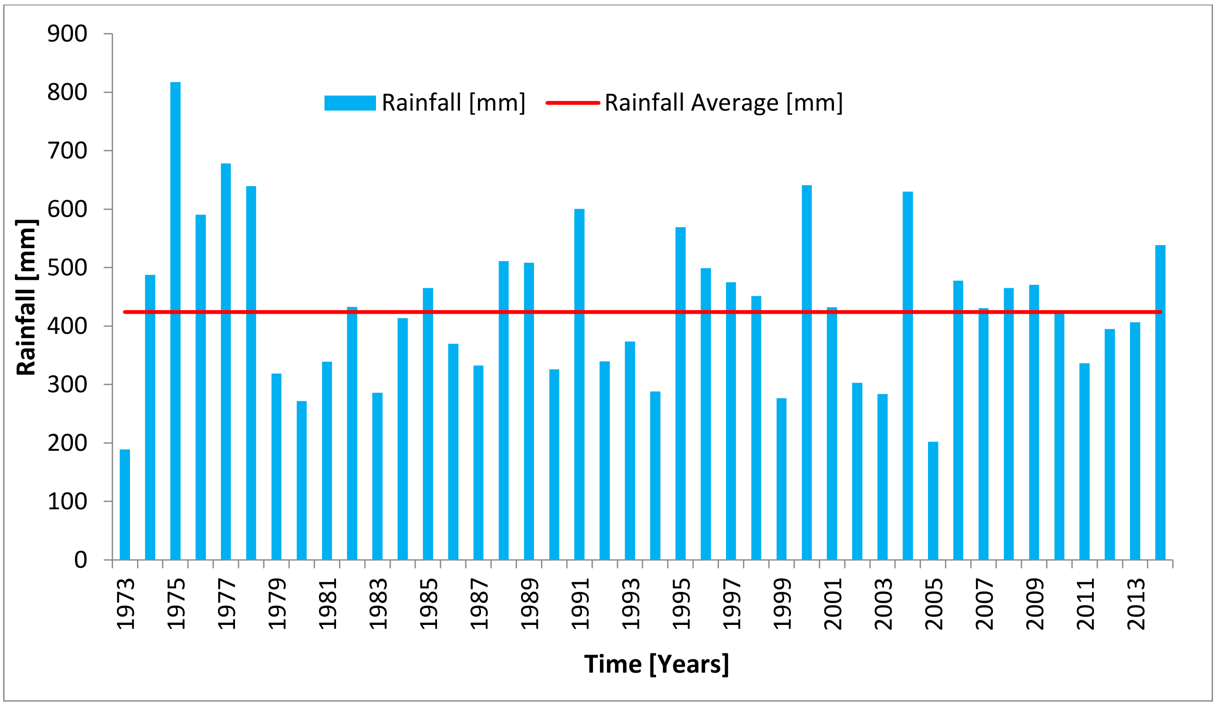


Figure 13: Mean annual precipitation (435mm) in the Waterberg Coalfield from 1973 – 2014 (L Roux, 2015).

The annual groundwater recharge potential is regarded as low. Based on the studies conducted in the area (Vegter, 1995; DWAF, 1996 Groundwater harvest potential Map, GCS, 2006), the estimated average groundwater recharge is 1.43% of the annual precipitation. This equates to a range of 4.3 - 6.2 mm recharge per annum and lies within the mean annual recharge range estimated by Vegter (1995) for the area of between 1 – 10 mm per annum (Groundwater Resources of the Republic of South Africa, Sheet 2, 1995). Prevailing winds are predominately from a north-east direction throughout the year (Golder, 2011).

3.3 Geological Setting

The coal-bearing rocks belong to the Karoo Supergroup and were deposited between 260 and 190Ma ago. They formed as a large graben structure bounded by the following basin edge faults:

- Older basin rocks (the Zoetfontein Fault) that belong to the Limpopo mobile belt in the north.
- With the Waterberg (quartzitic sandstones, conglomerates and grits) Group (Eenzaamheid and Ellisras Faults) in the south.
- As well as post Karoo faults (Daarby Fault) that disrupts coal seams.

These geological settings are indicated in Figure 14.

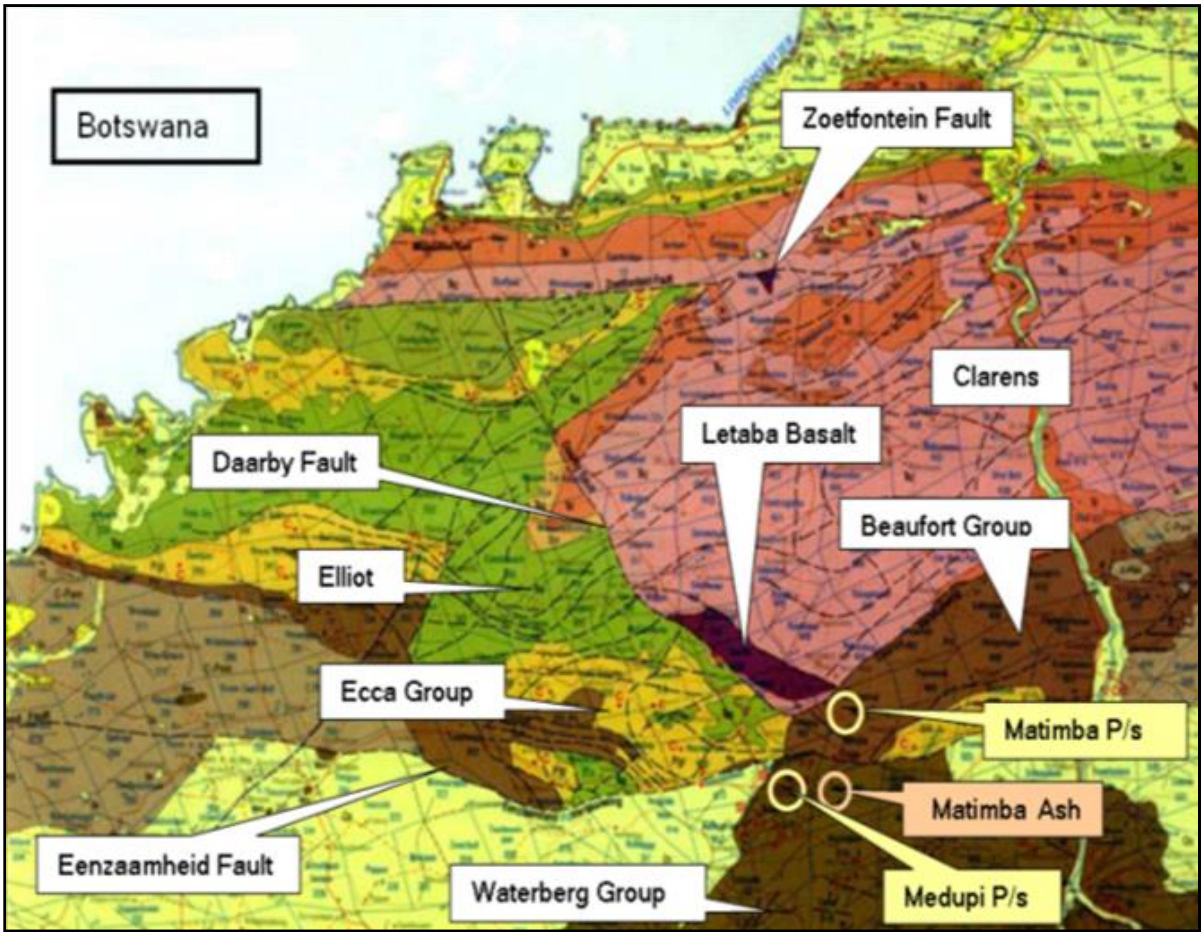


Figure 14: Geological map of the Waterberg coal fields (Vermeulen, 2006).

The formation of the basin was controlled by structures that were formed and reactivated over time (Daarby Fault) and formed the basis for the block faulting that occurs throughout the basin. The geological structures are discussed in detail with figures in this document in “Geology of the Waterberg Coalfield”.

3.4 Stratigraphy

The area covered constitutes mainly of the following geological terrains:

- The Limpopo Mobile Belt, a highly metamorphosed gneiss which is 2700Ma (Kramer *et al.*, 2006).
- The Ellisras Basin which consist of the Waterberg Group (Barker *et al.*, 2006) and the Karoo Supergroup (Johnson *et al.*, 2006) and contains the coal. Most of the basin is in the Grootegeluk Formation (110m thick in the south).
- Recent cover is from the weathering of gneiss of the Limpopo Mobile Belt and the Karoo rock in the north; but from Waterberg sandstones in the south.

- Intrusive rocks of which the most important of these rocks are those that cut through the coal-bearing rocks and disrupt the seams. They occur less frequently in the Ellisras Basin (Johnson *et al.*, 2006).

3.5 Geology of the Waterberg Coalfield

There are two main coal-bearing Formations in the Waterberg; The upper Grootegeluk Formation (previously the Volksrust Formation) which ranges in depth from 60 to 110 m in the south and the lower Vryheid Formation (Figure 15), a more carbonaceous and interbedded sequence, at approximately 55 m in thickness (Jeffrey, 2005). The lower and upper delta-plains, back-barriers and fluvial environments, are generally associated with peat formation, and have laterally extensive coal seams preferentially accumulating in fluvial environments. The coals from the Karoo Basin are generally, inertinite-rich with high ash content. However, it has been found by Johnson *et al*., (2006) that there is an increase in vitrinite content and a decrease in ash content within seams moving from west to east across the coalfields of South Africa. Rapid subsidence coincides with high sedimentation rates which resulted in coals that are "thin, laterally impresistent, vitrinite rich and shaly". According to Snyman (1998), a generally accepted setting for the formation of peat in the Ellisras (Lephalale) area is a floodplain setting with meandering rivers. The repeated flooding together with the creation of crevasses, contributed to the rapid alteration of mudstone and coal in the Grootegeluk Formation. The Grootegeluk Formation which is present in the study area is the predominant formation from which coal is mined.

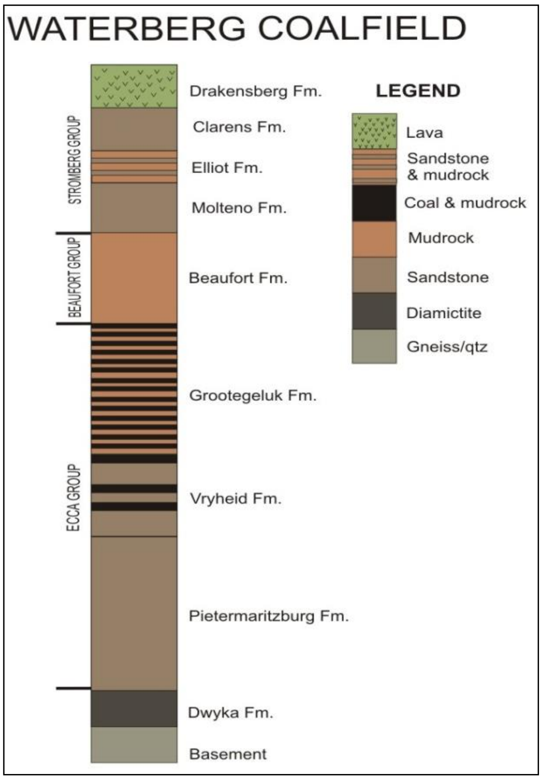


Figure 15: The stratigraphic units of the Dwyka, Ecca and Beaufort Groups in the Waterberg Basin (Modified from Faure et al., 1996).

The coalfield is composed of areas with full successions of coal where all the coal bearing strata of the Grootegeluk Formation is present. The Grootegeluk Formation is partly weathered away (i.e. not all the coal bearing strata is present and weathering can be present at different stratigraphic levels in the formation). Other parts consist of all the coal strata of the Grootegeluk Formation (Upper Ecca) but were absent due to weathering and only the Vryheid (previously Volksrust) Formation (Middle Ecca) is present. The distribution of the full succession, middle Ecca and weathered areas are indicated on the map in Figure 16.

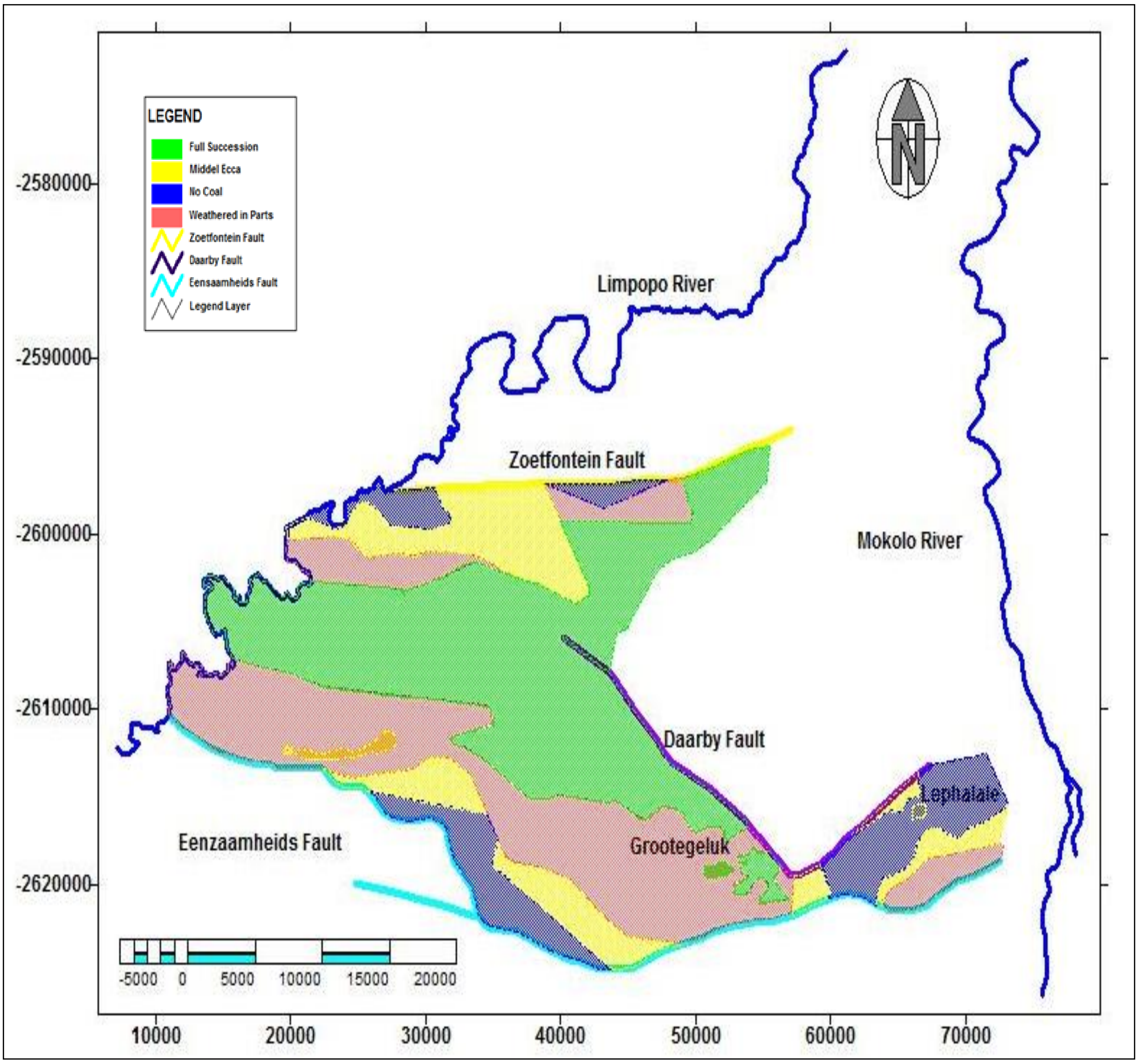


Figure 16: The weathered zones and major faults in the study area (Vermeulen et al, 2009).

The Ecca Group comprises of a lower arenaceous portion and a more argillaceous upper portion with numerous coal seams. At the time of deposition, a fluvial deltaic environment that covered a large part of South Africa existed. At Grootegeluk, the Ecca group is divided into Upper, Middle and Lower Ecca. The Upper and Middle Ecca are currently mined with coal layers divided into 11 zones (Figure 18) with a total thickness of 111 m. The Upper and Middle Ecca are separated by an interbed of finely laminated carbonaceous shale to coaly shale of 2.6 m in thickness.

In general, there appears to be an upwards decrease of coal to mudstone ratio present within certain zones. The Grootegeluk Formation (mudstone, carbonaceous shale, coal) has a distinctive upper coal unit with well-developed thick coal layers alternating with well-developed mudstone layers. Towards the bottom of the succession both coal and mudstone layers alternate more frequently and are thinner.

Originally the Ecca Group coals of the Waterberg Basin were divided into zones 1, 2, 3, 4A, 4, 5A, 5B, 5C, 6A, 6B, 6C and 7 numbered from the bottom up (De Jager, 1976). The Grootegeluk Coal Mine (GCM) has currently changed the division into eleven coal zones which are now in existence. According to De Jager (1976) zones 1, 2, 3, 4A and 4 of the Vryheid Formation consist of predominantly dull coal seams. The coal from these zones are suitable for power generation as a raw coal that does not have to be beneficiated and thus very little plant discards will be produced. Zones 5-11 assigned to the overlaying Grootegeluk Formation have intercalated bright coal and a mud layer (Figure 15). The complex layering of the coal with the mudstone and sanstones of a full succession at the Grootegeluk mine can be seen in the following figure (Figure 17).

Figure 17: Exploration core in the full succession indication the complexity of the layering of the coal.

The Waterberg Coalfield is thus divided into 11 coal-bearing zone coal seams (Figure 18). Benches 1-5 from the upper zone (Grootegeluk Formation) and 6-11 (poor quality coal) is found in the lower zone (Vryheid Formation). The benches from the Grootegeluk Formation typically contain bright coals at the base and grade upwards into shale. The GCM (Grootegeluk Coal Mine) (at present the only operating coal mine in the Waterberg

Coalfield) benches 2, 3 and 4 yield a coking coal on beneficiation. Bench 5 produces a thermal grade coal (high phosphorus) and benches 6-11 are dull coals, highly interbedded with mudstone and carbonaceous mudstone. The presence of fine mudstone intercalations in the Waterberg Coalfield causes higher beneficiation of the coals (Jeffrey, 2005).

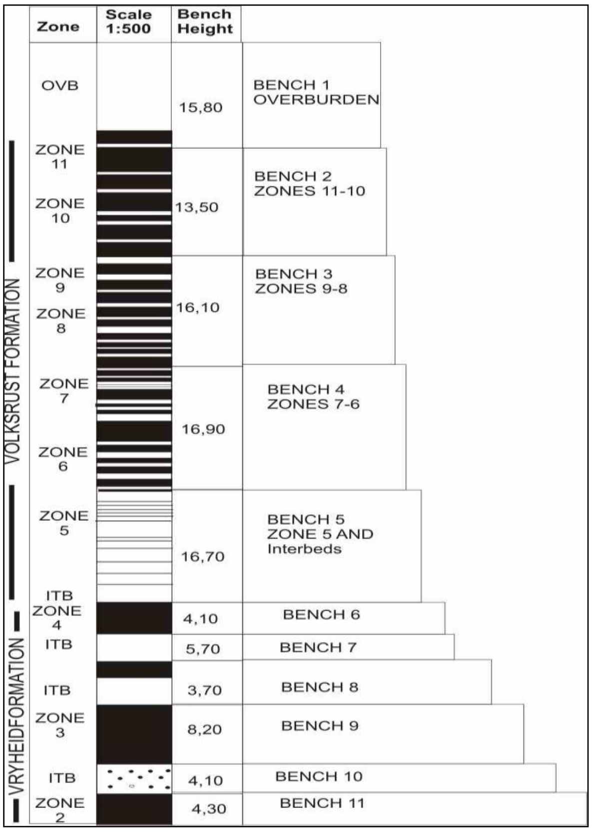


Figure 18: Stratigraphic column with the lithological units for the Grootegeluk Formation in the Waterberg Coalfield. OVB- overburden and ITB- interburden (Dreyer, 1999).

3.6 Structural geology

The Waterberg Coalfield is bounded by the Eenzaamheid and Zoetfontein Faults on the southern and northern margins, and extend approximately 80 km east-west and 40 km north-south. The post-Karoo Daarby Fault, with a displacement of 200 to 400 m, divides the coalfield into a shallower western area and a deeper north-eastern area. Smaller faults that are mostly unmapped subdivide the coalfield into blocks (Jeffrey, 2005). Due to the presence of the Daarby Fault, the coal seams are located at deeper depths to the east and north/east. The coal seams in the west are shallower and can be extracted by opencast mining. Vermeulen *et al*., (2011) describes the three main categories identified by Dreyer (1999) according to the weathered geology (Figure 19).

The categories are illustrated in the following figure. The full successions of coal are indicated where all the coal bearing strata of the Grootegeluk Formation is present. The Grootegeluk Formation is partly weathered away, i.e. not all the coal bearing strata is present and weathering can be present at different stratigraphic levels in the Grootegeluk

Formation. The coal strata of the Grootegeluk Formation are absent due to weathering and the Volksrust Formation (Middle Ecca) is therefore all that can be observed (Figure 19).

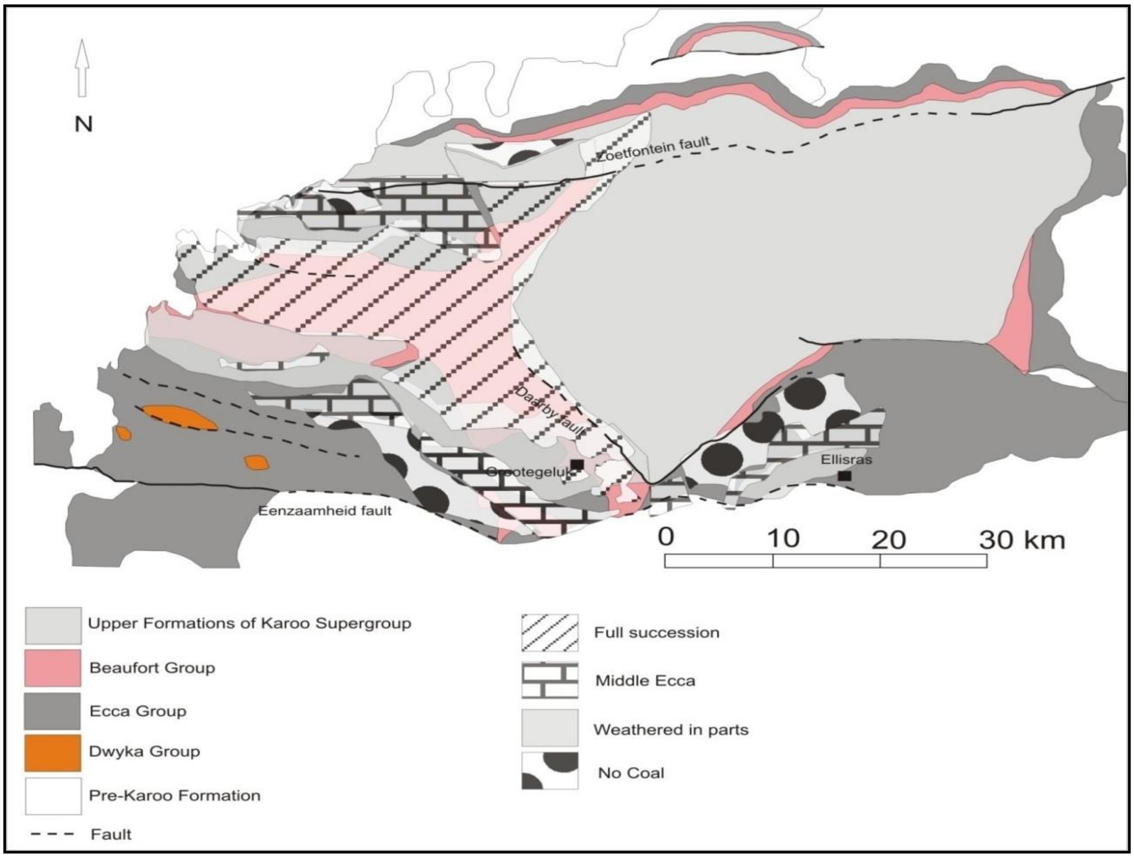


Figure 19: A generalised geological map of the Waterberg Basin. Coal is open-cast mined at the GCM which is approximately 25km west of Ellisras (Modified from Snyman, 1998 and Bester, 2009).

The Daarby Fault with its north east then north west trend is a combination of two faults that have the same throw and throw directions. The Daarby Fault has a downthrow of 360m to the north and dips at an angle of between 50° and 60°. The fault brings the upthrown Beaufort and Ecca Groups in the south into contact with downthrown Letaba, Clarens and Red Bed Formations in the north (Johnstone, 1989). The Eenzaamheid Fault is located south of the Daarby Fault with a 250m throw to the north at a near vertical angle. The upthrown Waterberg Group on the southern side is in contact with the downthrown Beaufort and Ecca Groups on the northern side of the fault.

In between the Daarby and Eenzaamheid Faults there are associated smaller faults present (Figure 20). The associated faults have varying strikes, throws and throw directions. The most important geohydrologicalaspect of the faulting is the increase in rock permeablility for both the Beaufort and Ecca Groups.

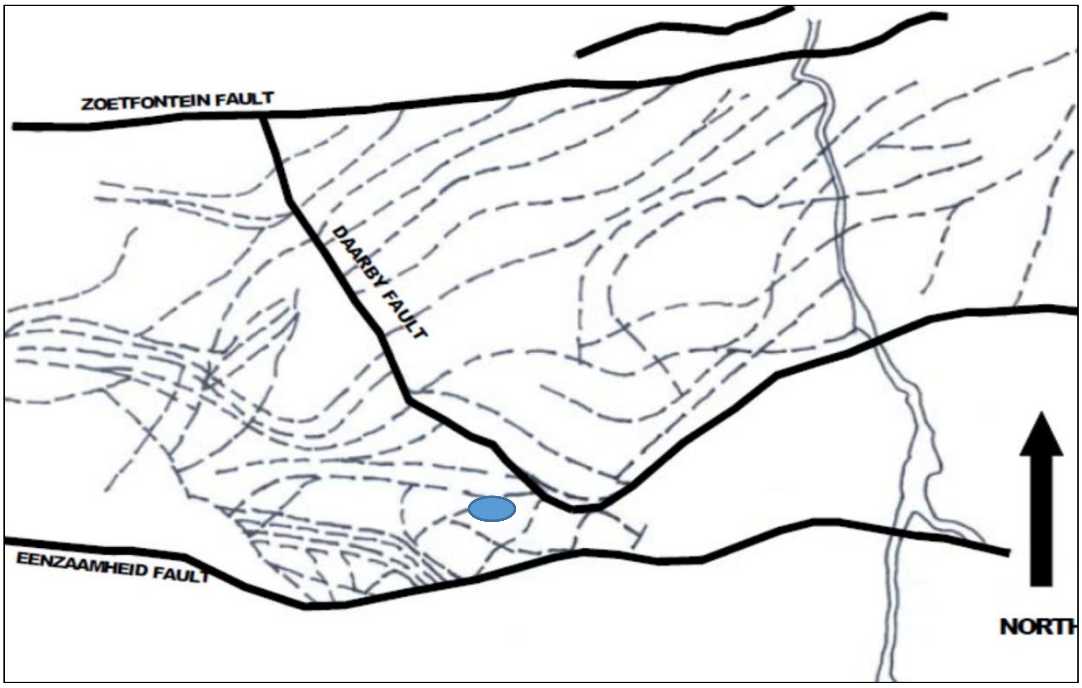


Figure 20: Structural geology of the major **------** *faults; Daarby, Eenzaamheid and Zoetfontein and minor - - - faulting (after Roux, 2004).*

3.7 Water Use and Management

Water quality in South African coalmines is an important consideration for the long-term management of mining impacts (Hodgson *et al.*, 2001). Aspects of water management and protection in South Africa have changed considerably in the last few years, with the promulgation of laws like the New National Water Act (Act No 36, 1998) which focuses on sustainability and equality. These principles take into account:

- The basic human needs of present and future generations.
- The need to protect water resources;
- The need to share water resources with other countries;
- The need to promote social and economic development through the use of water; and
- The need to establish suitable institutions in order to achieve the purpose of the Act.

As part of the impact of these laws aspects such as waste discharge costs and the polluter pays principle have become important focuses of water management on the South African collieries (Postma and Schwab, 2002).

The Matimba Power Station which was commissioned in 1991 and situated at the Grootegeluk Coal Mine, is air cooled for use in arid areas where water is limited. The water consumption of the different cooling technologies used by Eskom, are summarised in

Table 8 (Value Chain, 2010). This indicates the 13-16 x lower volume of water used by Matimba vs water cooled power stations.

Table 8: Specific freshwater requirements for cooling technologies at power stations (Value Chain, 2010).

Type of power station	**Specific water consumption (litre /kWh sent out)**
Wet cooled coal-fired	1.9 - 2.1
Dry cooled coal-fired	0.12 - 0.16
Nuclear	0.05

Previous hydrocensuses conducted show that groundwater in the area is mainly used for domestic supply, limited watering of gardens and for livestock and game watering and that sufficient quantities cannot be pumped for crop irrigation purposes since the borehole yields from the regional aquifers are relatively low. Groundwater at Grootegeluk Coal Mine is abstracted through dewatering boreholes and used in the beneficiation plants, for dust suppression on haul roads and within the open pit mine. The majority of the area surrounding Grootegeluk Coal Mine is utilised for cattle and game farming. No crop cultivation (either dry land or irrigation) occurs due to the sandy soils and relatively low rainfall. The surrounding landowners are heavily reliant on groundwater (boreholes) since surface water is only available for a short period after rainfall events (Exxaro Coal, 2014).

Groundwater flow near the Grootegeluk Mine indicates that the mine is influencing the surrounding aquifers. The addition of new open pit mines is understood to alter the flow direction of groundwater. During the creation of the open pits, the topography is changed and directly affects the groundwater flow (Figure 21) (Bester, 2009).

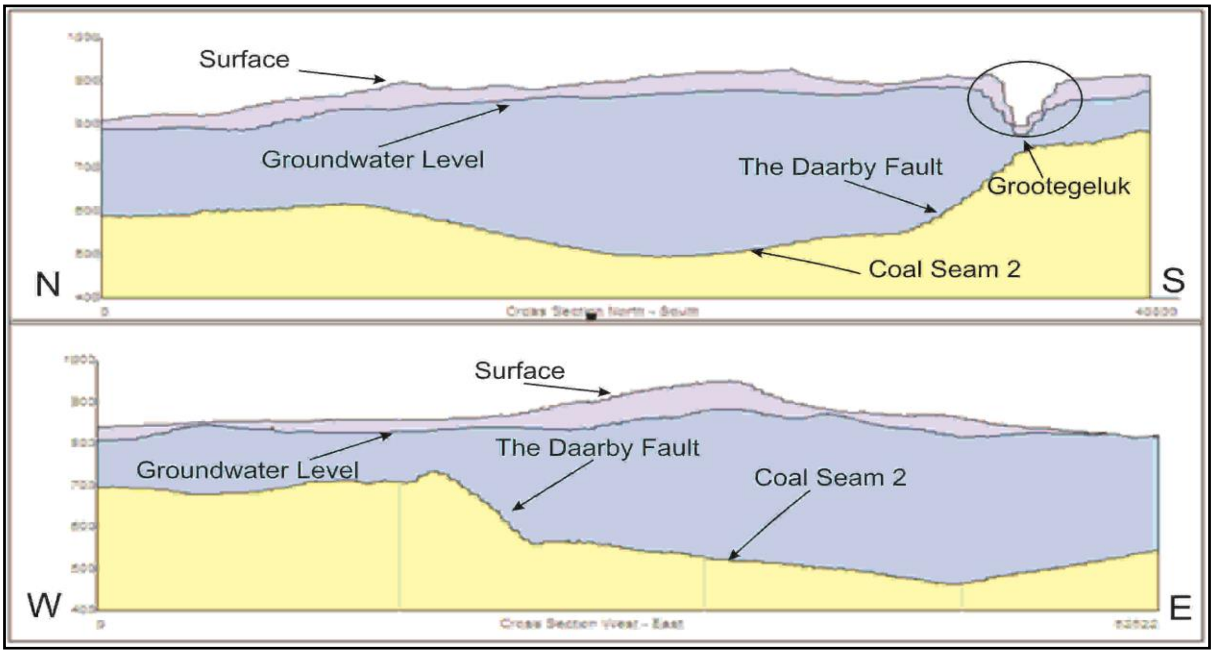


Figure 21: North/south and west/east cross-sections of the study area.

Water levels south of the Daarby Fault surrounding the open pit show a steady decline in regional piezometric levels. This decline is due to the continual dewatering of the open pit and the decline from an 890 mamsl before mining operations, to 840 mamsl at the then open pit (Johnstone, 1989; Golder, 2013). Pre-mining groundwater flow directions were towards the Mokolo and Limpopo Rivers as they are the primary receptors in the area (ERM, 2012). Further declines in groundwater levels around the pit can be expected. The newly created depression will divert water into the pit and in extreme situations reverse the groundwater flow (Vermeulen et al, 2009) (Figure 22). Water flowing towards the pit can be seen in the flow vectors at the present mine pit. This same scenario with the groundwater elevation and flow direction towards to pit was reported in the Environmental Resource Management report (2012).

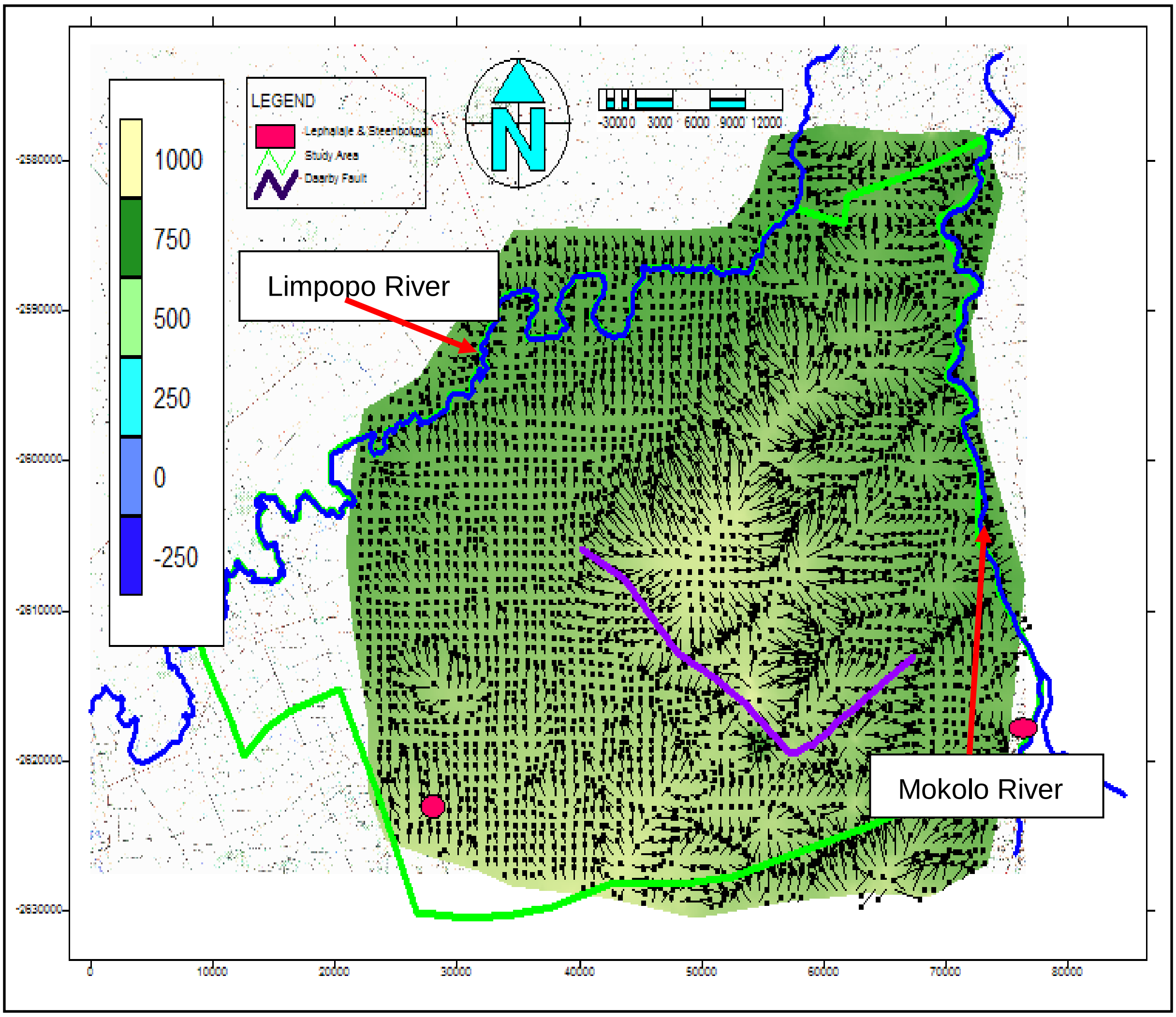


Figure 22: Topographic contour map of the study area showing flow vectors and the Daarby fault (Vermeulen et al, 2009).

Conversely, water levels north of the Daarby Fault show a steady increase in the regional piezometric level of one or two meters per year. This increase is only after the summer rainfall events, but there appears to be a continuous recharge throughout the year which could indicate that recharge could be from other sources. Johnstone (1989) estimated the amount of process water and water from the open pit (introduced to the area north of the Daarby Fault) at approximately 2000 m^3 per day. The waste dump has permeabilities that are 100 times that of the adjacent soils of the dumps.

The major contrast between the water levels north and south of the Daarby Fault suggests two aquifer units on each side, with little if any hydraulic connection between the two. The different water levels on opposite sides of the fault again indicate the impermeability of the fault.

3.8 Effect of Mining on Surface and Groundwater

The area has no dominant surface water features that are permanent in the Waterberg Coalfield. The surface water can only be seen in rainy seasons, as it appears as water pools. Changes in the surface water have been noted in the pit bottom sump as well as the seepage from the exposed faces of the sump (Roux, 2011). The challenge of contamination is more prominent in the wet seasons, when the exposed faces of the pit and its oxidation products are washed. The oxidation products have contributed mainly to the increase in total dissolved salts, electrical conductivity and the sulphate concentration which contributes to the acidification of the water.

The impact of the mines will only be felt “down-stream” towards the town of Steenbokpan and only on the western side of the Daarby Fault. The areas east of the fault will be unaffected by the mines with regards to surface runoff. Due to the location of the pits in the elevated areas, an increased influx of water into the pits during periods of high precipitation will occur. In an exaggerated three-dimensional (3D) view of the contour map, some changes in elevation can be seen, although none of these are extreme (Figure 23). When compared to the rest of the study are, towards the south lies a very deep area which indicates the open pit at the Grootegeluk Mine. The open pit has an impact on the surface of the study area and the addition of more open pits in the area will increase the impact. In order for the pit(s) to have a large enough impact on the topography to change the flow directions of surface runoff, there would need to be many pits of great size present in close proximity to one another. The elevation of the Grootegeluk Coal Mine varies from 900 – 922m above sea level. The area is generally flat and featureless, with the exception of Nelsonskop (922m) to the east of the mine. The Waterberg mountain range is located 100km to the south, which has an elevation of 3600m above sea level. Mining activities at Grootegeluk Coal Mine have influenced the topography of the area in terms of the following created surface features (Golder Associates, 2013; Exxaro Coal, 2014):

- The open pit, which is approximately 120m deep and 852ha in extent and advancing at a rate of 80m to 100m per year;
- The various discard dumps, which cover approximately 1 000ha at heights varying between 40m and 80m;
- Run of mine (ROM) stockpiles;
- Infrastructure such as the plant, offices, and workshops which are as high as approximately 50m and occupy approximately 10ha; and
- The existing slimes dams 1 and 2 which cover approximately 100ha with a height of about 45m.
- In addition to this, there is the fly ash dump of the power station.

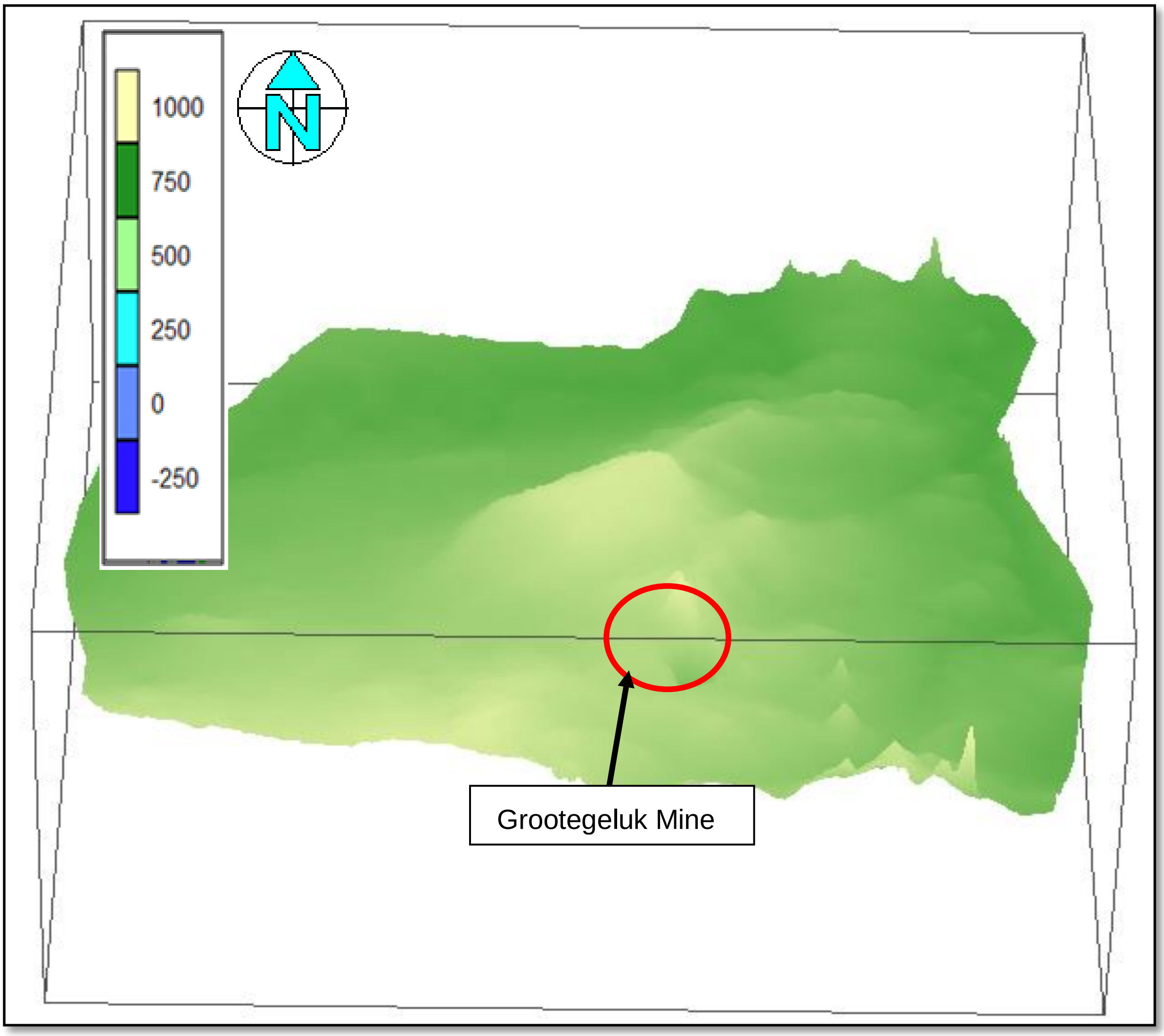


Figure 23: Exaggerated 3D view of the study area topography (Vermeulen et al, 2009).

It is not known how many additional mines are planned for the study area, but in all likelihood it is doubtful that there will be such a large number of pits that they will change the surface topography to such a dramatic extent that they will alter the flow direction of surface runoff.

A contour map of the depth of the water levels combined with a map of the surface topography (green map) of the area is displayed in Figure 24. This indicates that the water levels mirror the topography.

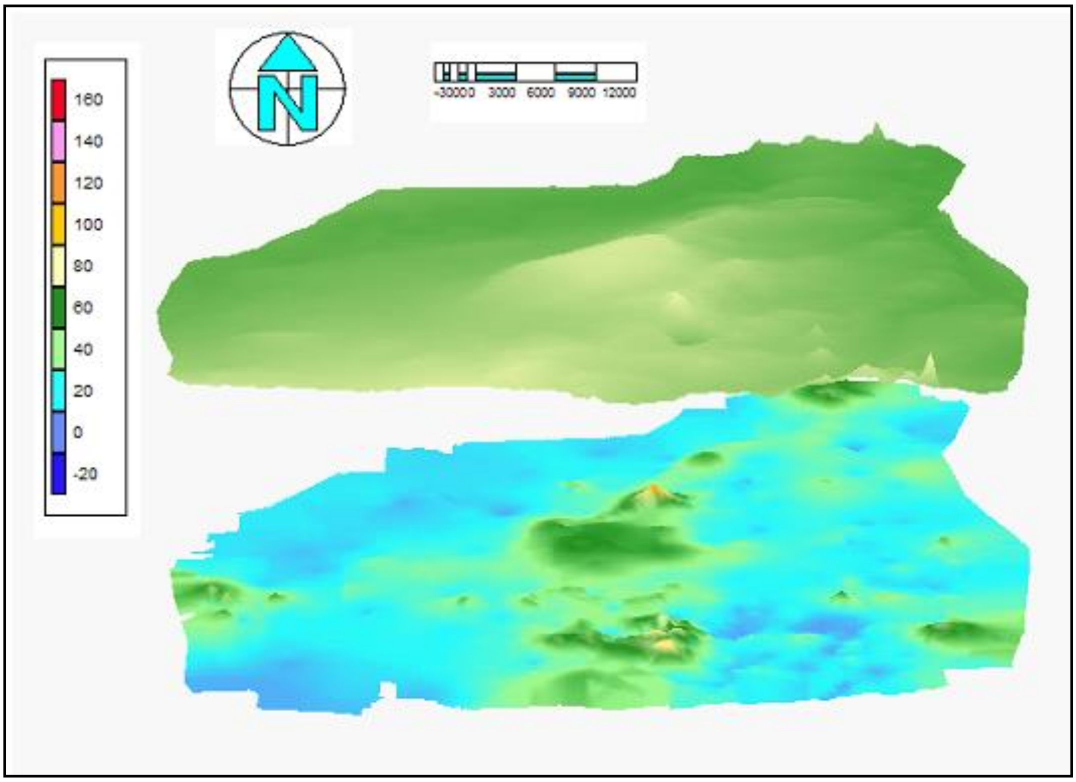


Figure 24: Topography and water level contour maps (Vermeulen et al, 2009).

The areas off higher elevation serve as recharge zones for the lower lying areas of the study area. Excavation of large open pits in the study area will have an influence on the flow of groundwater in the area west of the Daarby Fault. The area outlined in red (Figure 25) indicates the location of the Grootegeluk Mine. Bearing in mind that the image is exaggerated, groundwater will flow in the direction of the pit (Figure 22) as indicated by the flow vectors.

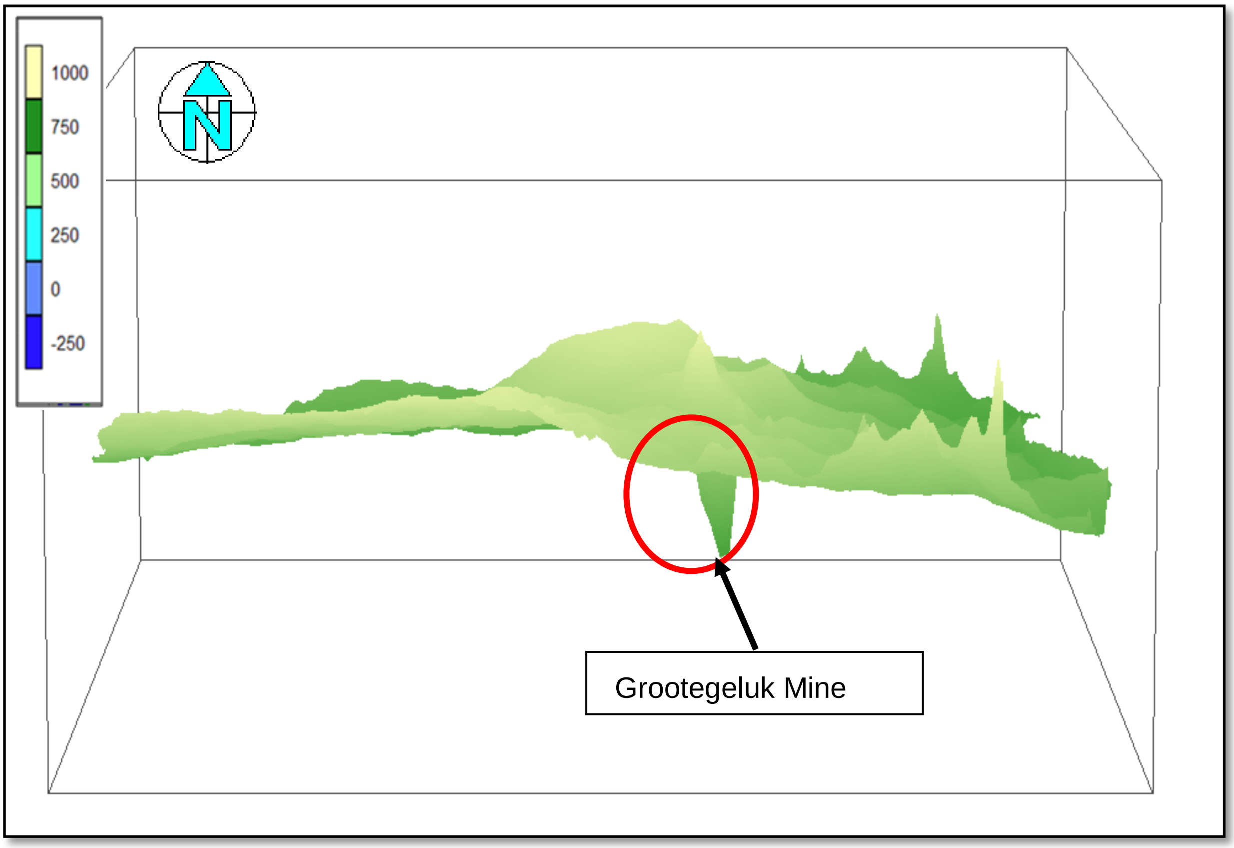


Figure 25: Exaggerated 3D view of the study area topography (side view) (Vermeulen et al, 2009).

Figure 25 indicates that the surface water would move towards the Grootegeluk pit from the north-west and away from the pit in the south-east. The pre-mining groundwater flow directions were towards the Mokolo and Limpopo Rivers as they are the primary receptors in the project area. Due to mine dewatering that started around 1980, groundwater flow is currently mainly towards the Grootegeluk Coal Mine open pit in the area around the pit west and south of the Daarby Fault (Golder, 2012).

The slope analysis in the mining area is less than 8% (Figure 26). The Mokolo River is approximately 810 m above sea level, while the mine is approximately 900m above mean sea level. This results in an almost negligible gradient of 90:21000 m or 0.0043% and thus there is no defined flow of water and runoff from the area is slow. Surface water is found only after a rainfall event, and due to the relative flat topography and sandy soil cover, most of the rainwater seeps into the groundwater aquifer. Small shallow pans or depressions occur in the veld where runoff may temporarily collect (Exxaro, 2014). No natural drainage channels occur on the mine area, except for Sandloopspruit which is located approximately 1 km north of the mine's slimes dams. Due to the flat topography, highly permeable sands and the absence of any surface water drainage courses, the mine has no direct impact on the surface hydrology of the Mogol Catchment (Golder Associates, 2013).

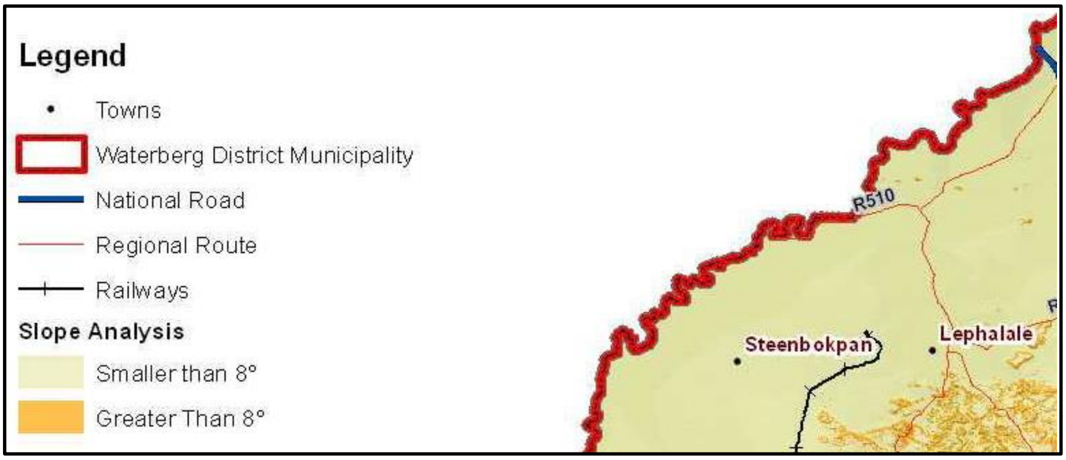


Figure 26: Slope analysis (Status quo report 2010).

In conclusion, because of the flat topography and the low rainfall, there will be little inflow of runoff into the pit(s).

Surface water contamination occurs as the result of overflow, spillage or excess water which is due to process problems or natural events that channel from the plant area via the storm water drainage system to the slimes handling facility. The type of contamination that will therefore occur in the surface water bodies will be similar to that of groundwater, with the exception of hydrocarbon contamination that will occur as the result of oil spillages from the mining fleet.

The aquifers in the geological formations are summarised in the following table, indicating low yielding values (EIA, 2006).

Table 9: Geological formations in the region and aquifer yields at boreholes (EIA, 2006).

Formation/Group	Description
Clarens Formation	Argillaceous and arenaceous rocks
	Intergranular and fractured aquifers
	Borehole yields 0.1 - 0.5 l/s
Ecca Group (Grootegeluk)	Upper and middle Ecca
	Fractured aquifers
	Borehole yields 0.5 – 2.0 l/s
Ecca Group (Swartrant)	Lower Ecca
	Intergranular and fractured aquifers
	Borehole yields 0.5 – 2.0 l/s
Dwyka Group	Predominantly arenaceous rocks
	Fractured aquifers
	Borehole yields 0.5 – 2.0 l/s
Waterberg Group	Predominantly arenaceous rocks
	Fractured aquifers
	Borehole yields 0.5 – 2.0 l/s

3.9 Water Quality

Most of the Grootegeluk Mine’s infrastructure is situated north of the Daarby Fault. The mining operation has caused a raise in water levels of the water in the aquifers on the north eastern side of the Daarby Fault and changed the groundwater chemistry in this compartment (aquifers). The water dams, washing areas, slimes dams and storm water dams were unlined which caused the seepage to move to the aquifers. This contributed greatly to the change in the water chemistry and water level. Elevated concentrations of cations and anions occur mostly in the vicinity of the Waste Dumps, Tailings Storage Facilities and the Matimba Ash dump. Pyrite is one of the most important sulphides found in waste rock of mines as well as Grootegeluk. Oxidation of pyrite (FeS_2) leads to the formation of sulphuric acid (H_2SO_4) dissolving heavy metals because of the lower pH, and leads to higher sulphate levels and total dissolved solids.

Deteriorating conditions were observed at most of the sampling points over the past 10 years. The sulphate (SO_4) concentrations are most indicative of the impact mining related activities as well as power station related activities had on the groundwater environment since mining activities started in the Grootegeluk area in 1980 (Bester, 2009; Golder, 2013).

The areas towards the south east around the Grootegeluk mine indicate elevated EC levels (Figure 27) and in some of the boreholes elevated sulphate values. These elevated values are associated with the activities at the mine (Vermeulen *et al*, 2009).

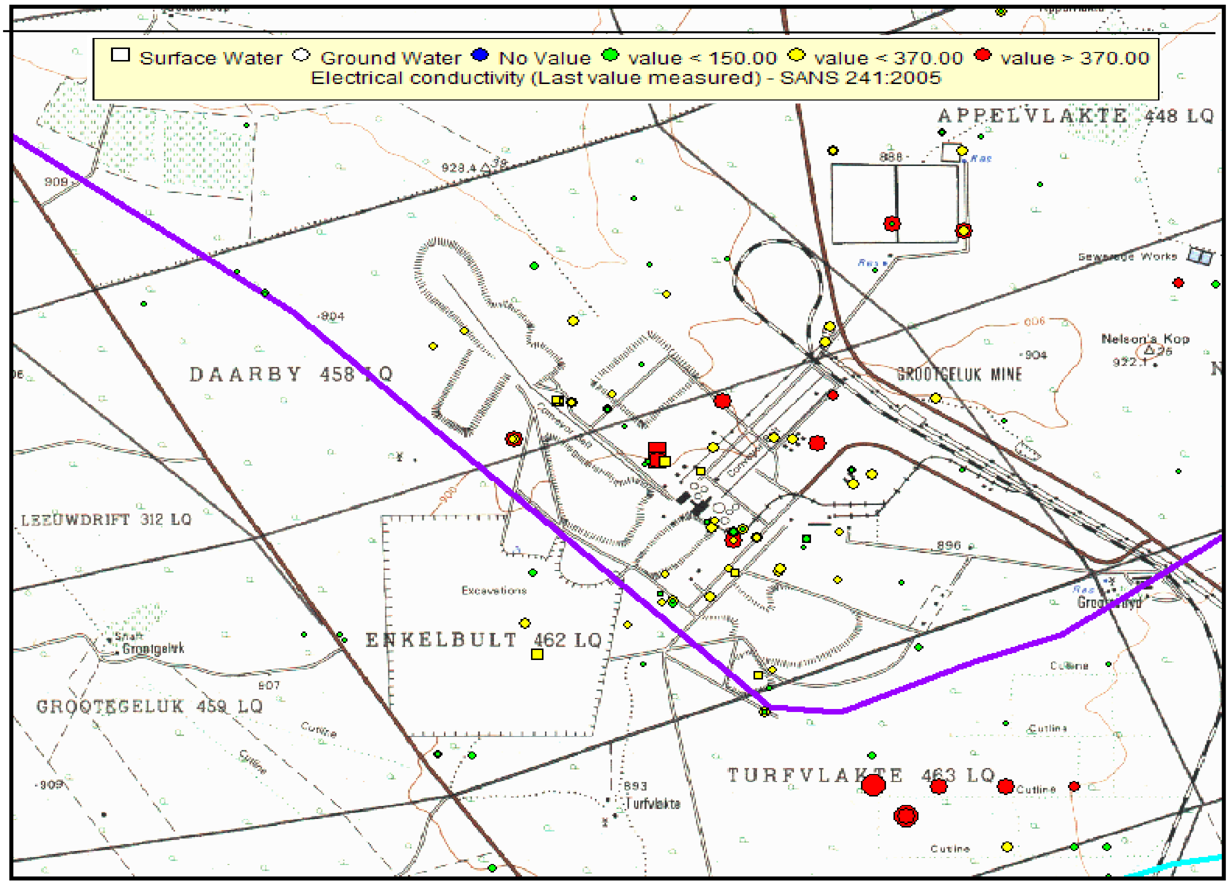


Figure 27: Size distribution for EC values of boreholes and evaporation ponds at the Grootegeluk mine (Vermeulen et al, 2009).

In the mining compartment, the water level is lowered (Bester, 2009; Golder, 2013) due to abstraction. The infrastructure layout is indicated in the following map in

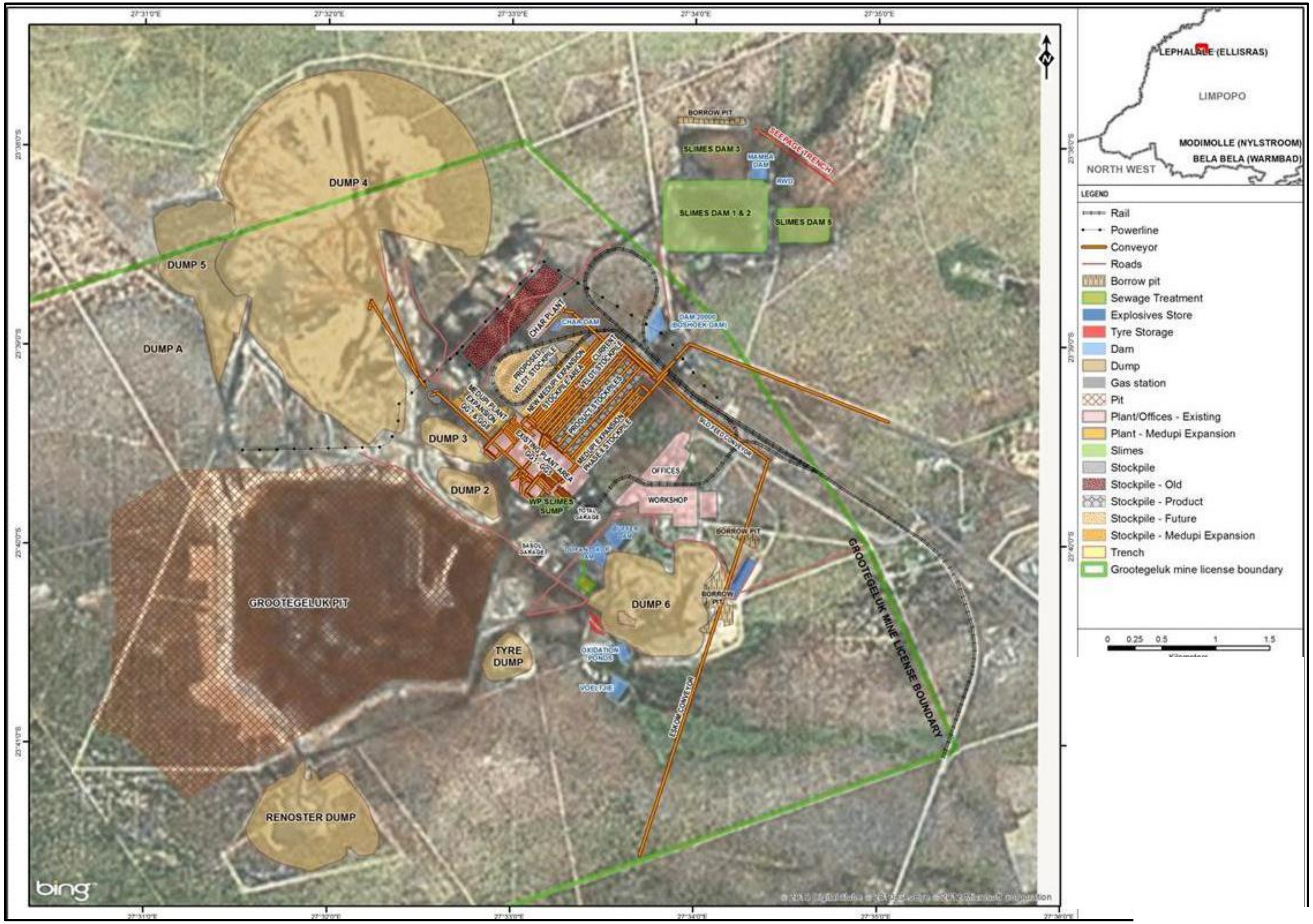


Figure 28: Infrastructure layout at the Grootegeluk Coal Mine (Golder, EMPR, 2013).

The areas/footprints and products at the mining site are summarised in Table 10. The volumes of coal mine products stored on the area with deep coal to the north of the Daarby fault are enormous and thus the influences on the natural water levels on this northern side of the Daarby fault.

Table 10: Facilities at the Grootegeluk mine site (Golder, 2012).

Facility	**area (ha)**	**height (m)**	**product**
Coal processing plant & 6 beneficiation plants	120		buildings
Dump 1 & 2	78.6	41.3	Overburden
Dump 3			Over & interburden
Dump 4 & 5	709	82.0	coarse coal discards
Dump 6	88	34.6	Interburden
Renoster dump A	84	22.0	Overburden
Renoster dump B	5	9.0	Overburden
Kidney Stockpile	Temp storage of coarse discards for dump 4&5		
Tyre Dump	15.6	12.7	coal, overburden, slimes.
GG1 - GG6 Stockpiles	60		coal products
GG7 & GG8	71.4		coal products
Veldt stockpiles	max 100 000 tonne		coal products for market demand
Slimes Dams 1&2	61.4	37.4	slimes
Slimes 3	30.2	5.8	Reclamation
Slimes 5	14.5	3.1	Reclamation
Facility	**area m2**	**depth m**	**capacity m3**
Mamba dam	21800	5.1	73000
Bosbok dam	32120	6.0	110000
Oliphantskop dam	31600	2.5	79000
Water Pollution Slimes sump	no values		
In-Pit Storage	no values - will vary as mine progress		
Voeltjie Dam - clean water	22900	2.2	50380
Storm water dam	42000	1.2	50520
Concrete dam	255	0.7	1782
Char Plant	6800	2	12828
Sewage treatment new			182 500/annum
Sewage treatment old			62 000/annum

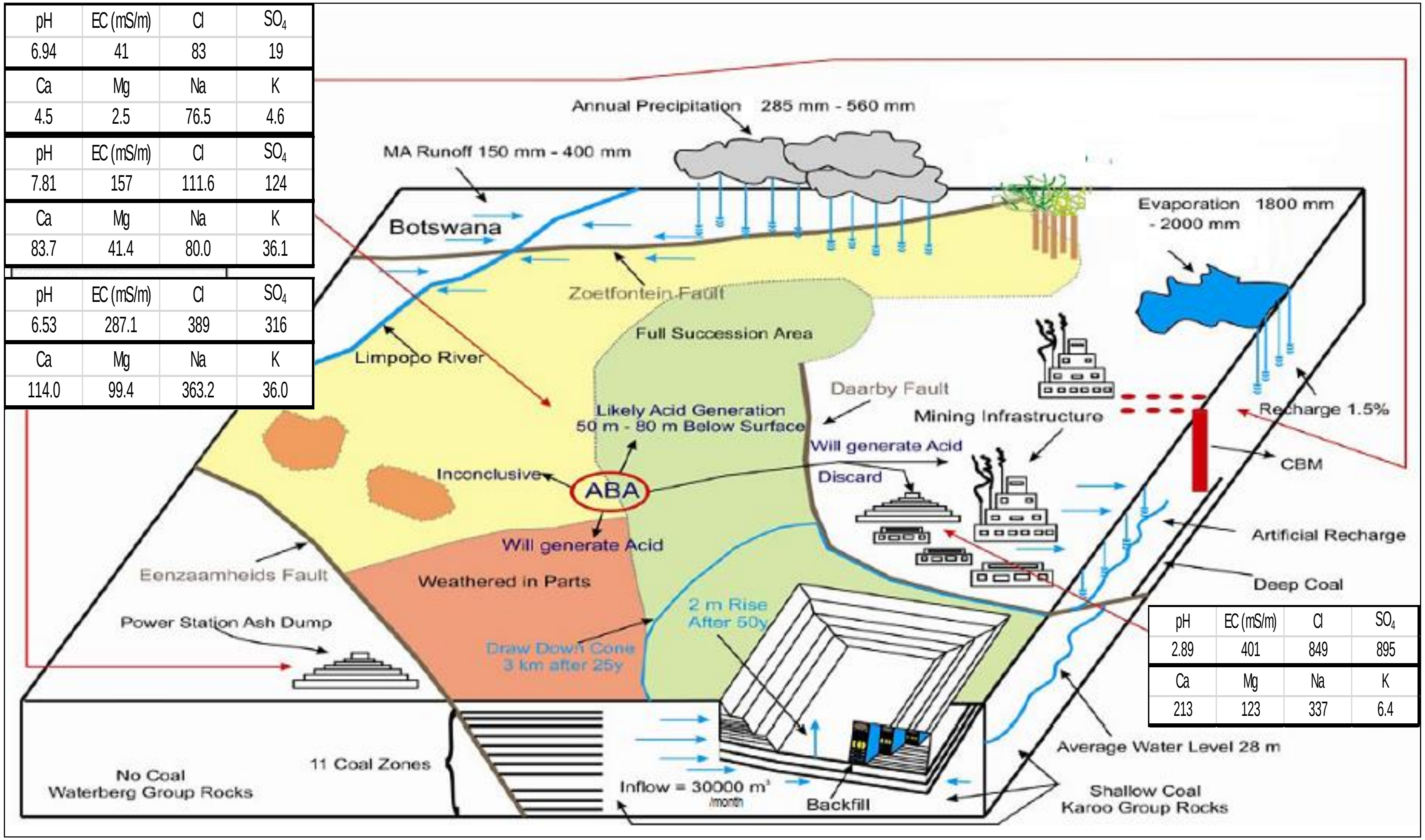
A comparison between the groundwater entering the open pit and the groundwater from the Beaufort/Ecca aquifer shows high total dissolved solids (particularly sulphate, magnesium and calcium). The impermeable Daarby Fault results in most of the groundwater that enters the pit to originate from the Beaufort/Ecca sediments. The high values of calcium, magnesium and sulphate salts are presumed to be mobilised by percolating rain water that dissolves salts from joints and fractures. Along with the lowering of the water levels, the previously saturated Ecca sediments are exposed to oxygen which increases the precipitation of salts along fractures and bedding planes. Rain water migrates to the groundwater through these fractures, resulting in the dissolution of salts and an increase in the total dissolved solid content of the groundwater as well as being the cause for the difference in water quality (Vermeulen *et al,* 2009).

The Matimba Fly Ash Dump is situated on the Zwartwater farm. This area has higher EC values than the surrounding study area and the major difference is attributed to the following reasons (Bester**,** 2009):

- The boreholes south of the Eenzaamheid Fault marks the transition from Karoo rocks north of the fault, into Waterberg Group rocks south of the fault.
- The Waterberg Group sandstones generally have a lower salt content than the Karoo Group (Dreyer, 2014). Accordingly it is possible that the salts from the rocks have leached into the groundwater, resulting in the higher EC values of the Karoo (Figure 29).

Anthropogenic causes can be attributed to the farm location (fly-ash dump for the Matimba Power Station) and the possibility of salts leaching from dumps into the farm boreholes. The boreholes are hosted within the Waterberg Group rocks in the shallow aquifer. The salts will enter the upper weathered aquifer during periods of high recharge and move through the unweathered aquifer. The boreholes drilled into the Waterberg Group have higher EC values and is thought to be affected by the position of the boreholes that have been drilled into a dyke. When compared to the boreholes drilled into the Karoo rocks, a major contributor to this change is the location which is situated close to the ash dump and is contaminated by the leachate that is moving downward from the dump.

There are some boreholes in the Karoo rocks that have a high EC. This does not specifically have to do with contamination, but with the depth of the borehole which has been noted at 420m and situated south of the Daarby Fault, far from mine infrastructure. The water quality of the study area and the surrounding area is summarised in Figure 29.



pH	EC (mS/m)	Cl	SO_4
6.94	41	83	19

Ca	Mg	Na	K
4.5	2.5	76.5	4.6

pH	EC (mS/m)	Cl	SO_4
7.81	157	111.6	124

Ca	Mg	Na	K
83.7	41.4	80.0	36.1

pH	EC (mS/m)	Cl	SO_4
6.53	287.1	389	316

Ca	Mg	Na	K
114.0	99.4	363.2	36.0

pH	EC (mS/m)	Cl	SO_4
2.89	401	849	895

Ca	Mg	Na	K
213	123	337	6.4

Figure 29: *Summary of the water quality in the study and surrounding area (Modified from Bester, 2009).*

3.10 Geohydrology

The groundwater potential of the formations is limited due to the low permeability, storage and transmissivity. The Eenzaamheid Fault forms the southern boundary within the study area. This boundary separates the area into two distinct geological units, the Karoo Supergroup to the north of the fault, and the Mokolian Supergroup to the south of the fault. The Environmental Impact Assessment Report that was done in the Lephalale area (EIA, 2006) reported no artesian boreholes or large-scale groundwater abstraction, even along numerous faults in this area. In the Grootegeluk mining area, as in the largest portion of South Africa, only secondary, fractured rock aquifers occur (Golder, 2012).

Geological structures normally enhance the groundwater potential by increasing the permeability and transmissivity of the host rock. The fractured fault zones (eg. Eenzaamheid Fault) within the study area are possible areas of increased groundwater potential. However, based on observations made during his study, Bester (2009) believes the Eenzaamheid and Daarby Faults are impermeable and the variation in water levels seen at the drilled boreholes supports the impermeable nature of the faults. Bester (2009) also assumes that the three main faults in the study area (Eenzaamheid, Daarby and Zoetfontein Faults) serve as no flow boundaries, with deeper water levels on the western side of the Daarby Fault compared to the eastern side. The faults themselves, do however act as zones with higher transmissivity.

There are two distinct types of aquifers found in the groundwater system of the geological formations of the Waterberg Coalfields. The two aquifers in the area are associated with an upper weathered (sandy) material groundwater system and an underlying competent and fractured rock material groundwater system.

The annual rainfall that eventually reaches the groundwater table is about 1-2% and the calculated evaporation (1800-2000mm/a) is higher than the average rainfall in the area (285-560 mm/a). This seasonal variation is also reproduced in the borehole yields and the influence is so strong, that for the rainy season the yields can be around 1-3 l/s, but decrease remarkably during the dry seasons. In some areas the upper aquifer will be completely dry during the dry season.

The water levels of the Lower and Middle Ecca are higher than in the Upper Ecca which suggests confined aquifer conditions (Roux, 2004). The general depth to groundwater level ranges between 20 and 40mbgl. Normally the groundwater level contours reflect the topographical contours at a moderate gradient. This however differs in the areas where there is large scale of external impacts on the groundwater environment during the lowering of the groundwater level through mine dewatering, and where the geology and aquifer interactions are not excessively complex.

A cone of depression has formed around the mining pit due to in-pit abstraction of water to keep the pit dry. The modelled cone extends for approximately 8.0 km in a westerly direction from the exposed pit faces (Synergistics, 2006), but according to Roux (2004), it is estimated that the zone of influence of the cone of depression is restricted to 3.5 km. In the area to the north east of the Daarby fault, it is estimated that the average pre-mining groundwater table was approximately 20 to 30m below surface (Synergistics, 2006). Artificial recharge beause of seepage has caused groundwater levels to increase from approximately 30 m below the surface to one or two metres below the surface. Groundwater mounding has occurred because of this seepage from unlined water storage dams, slimes dams, water spills in and around the processing complex, as well as from stormwater ponding around the mining waste and process discard facilities. The natural flow direction of groundwater from this area is in a south-easterly direction, which has further promoted the migration of the mounding to the south. Based on existing groundwater modelling, the areas of groundwater depression (south) and mounding (north) are indicated in Figure 1Figure 30 (Environmental Scoping Report, 2014).

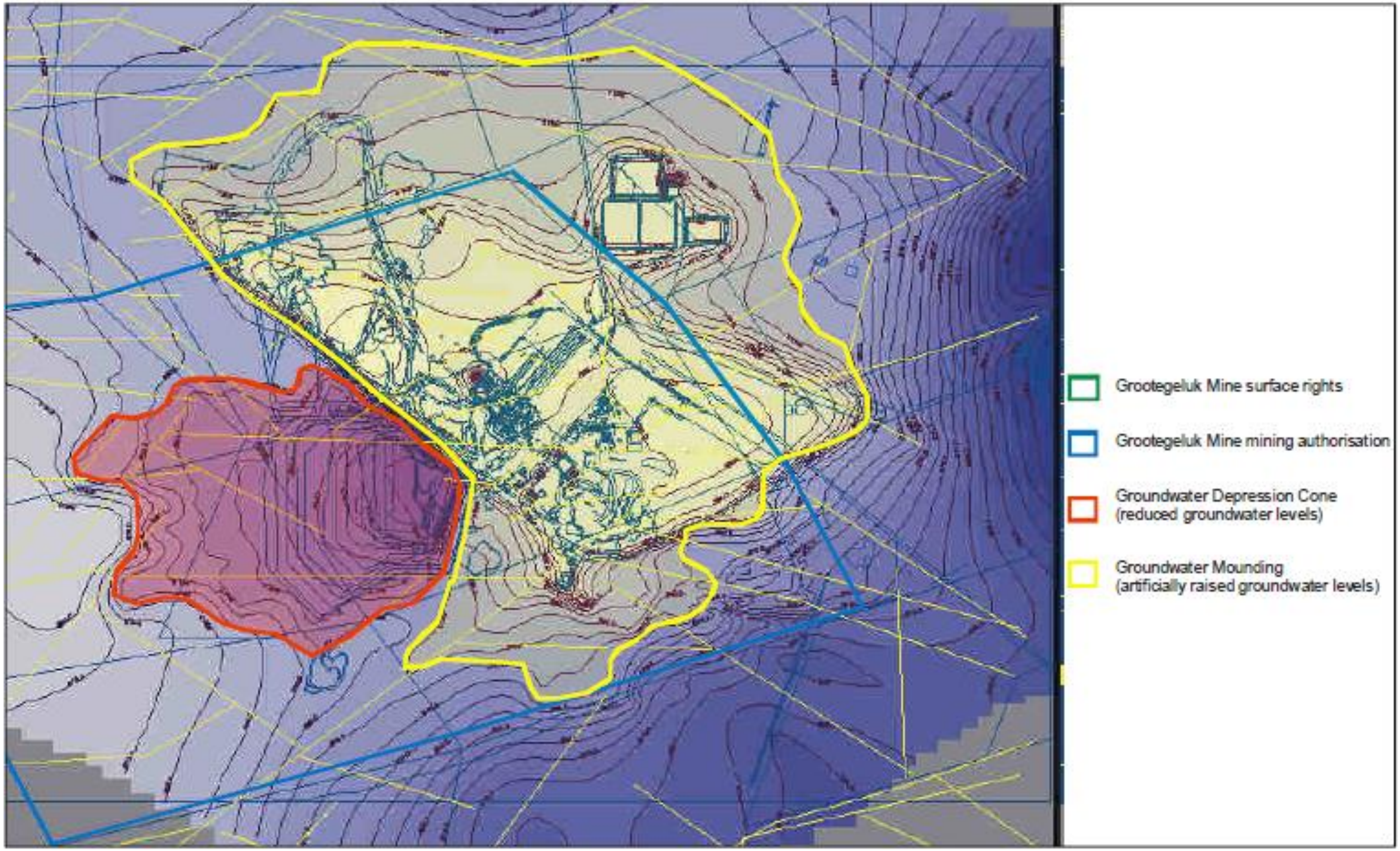


Figure 30: Predicted groundwater levels around Grootegeluk Coal Mine (Environmental Scoping Report, 2014).

3.11 Environmental contamination

Contaminants (biological, physical, chemical or radiological) are substances (normally absent in the environment) which, in sufficient concentration, can adversely affect living organisms through water, air, soil and/or food. Some contaminants may be harmful if consumed/inhaled at certain levels (EPA, 2015). In this study air and water contamination will be discussed.

At the coal mined in the Waterberg coalfield, the source of the environmental contamination starts with the mining of the coal product. Overburden is removed to expose the coal. The coal is then transported to the coal processing and beneficiation plants where the different types of coal are separated – power plant, coking or metallurgical coal. These coal products are stored at different stock piles and are moved within a certain time from these storing facilities. Inbetween the coal layers are the interburden layers which have to be removed to obtain the coal product. The pit walls are now also exposed to oxidation. At the coal processing and benefeciation plant where the coal is washed, discard coal (non-usable) is a product from this washing process. The overburden, interburden and discards are stored in dumps. The water used to wash the coal, contains fines/slurry and this product is pumped to slimes dams. Once the mine footprint is large enough, backfilling of the dump products takes place into the pit area. In this mining process up to the coal product, all of the disturbed geological formations are now exposed to oxidation (oxygen and water). The influence from the abovementioned facilities will be to the underlying rock formations leading to the aquifers influencing the groundwater. Dust from the mining activities will influence the quality of the air. At the power plant, the coal is used to generate electricity and fly ash is a by-product stored nearby the power plant. The fly ash is concentrated with metals. Leacing from the fly ash dump will influence the underlying aquifers, the very arid climate The combustion of the coal gives off organics and particulate matter that are exposed into the air.

The matter (metals, organics) captured in the original source before mining, will influence to what extend the environmental impact or source for environmental impact will be. Case studies and research indicate that there are environmental (air, soil and water) impacts at existing and closed mining facilities. Environmental management at mines has changed (bettered) with time to limit these impacts. (example: lining of waste facilities, better treatment options of effluent, better air filters, better consctruction of dumps to limit spontanious combustion).

Oxidation of the over-, interburden and coal products, can lead to mine drainage (acidic to neutral). The extend will depend on the ratio of acid:neutralising products in the original products to be excavated to obtain the coal. This study was to determine the risk of the future to be mined areas towards AMD and the release of leachable products (metals) and thus the environmental geochemical risk from the different areas to be mined.

3.12 Sample Collection

Four companies (Sekoko, Sasol, Resgen and Exxaro) had recently drilled exploration boreholes. These exploration boreholes were drilled to obtain information on the quality of the different coal layers and for their future mining in the Waterberg coalfield. Geological samples were collected from these cores for the use in ABA analysis to determine whether the rocks found in the different layers in the study area will generate acid upon oxidation and also to determine the water and acid leachable elements/metals in all the samples. ABA analysis also predicted the base potential that different rock types have; this potential counters the acid generation. In total, 828 samples were collected from different lithological units within the coal-bearing Ecca Formation. The various samples cover a wide range in the study area, including the different respective depths of weathering (Middle Ecca, full succession coal and weathered in parts). The areas belonging to the different mining companies as well as the position of the boreholes are indicated in (Figure 31).

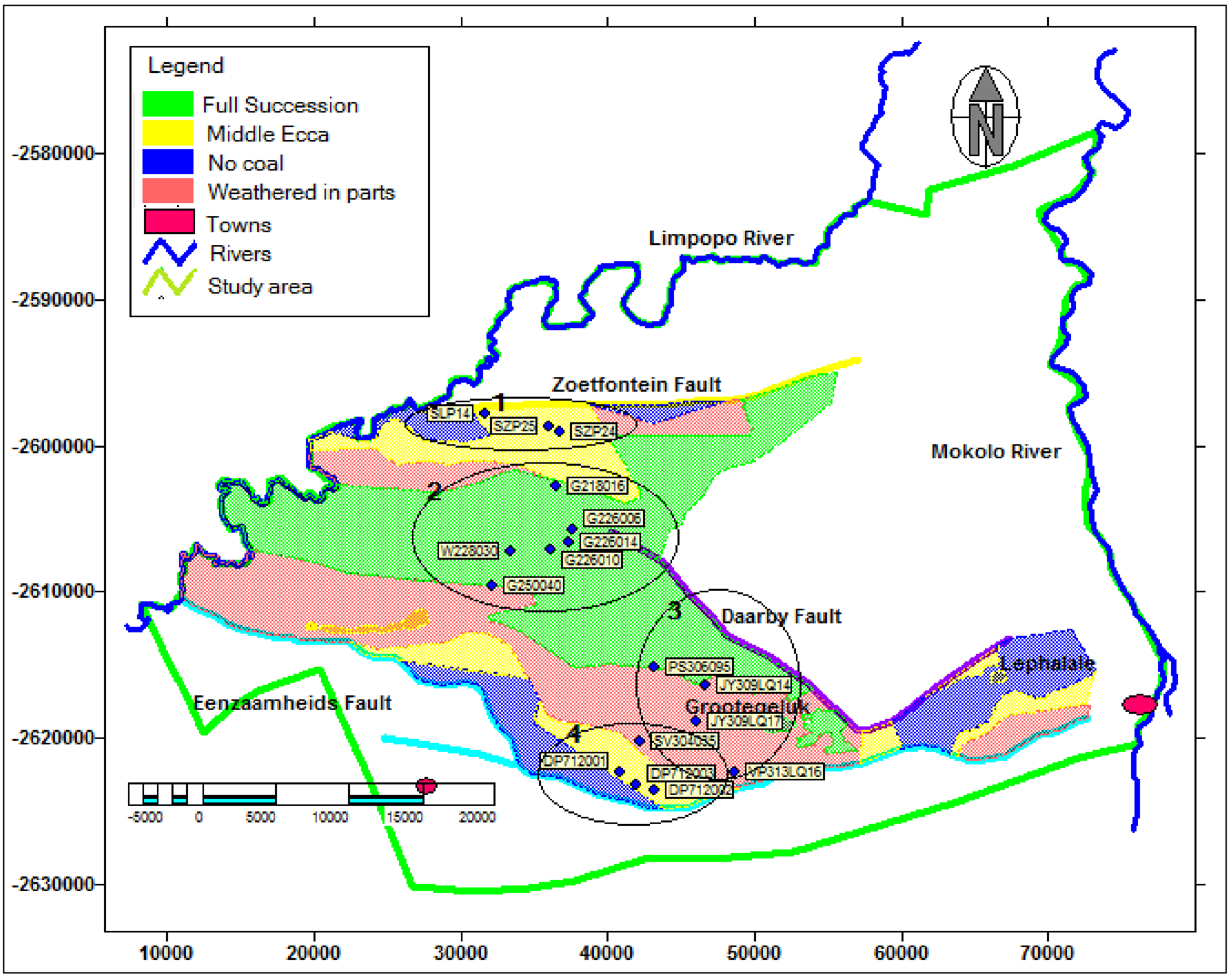


Figure 31: Location of companies in the study are where samples were collected: 1 – Resgen, 2 – Sasol, 3 – Grootgeluk, 4 - Sekoko.

The study area was further divided into three main categories according to weathered geology (Figure 31). They are:

- Areas that contain the full succession of geology
- Areas that have been weathered down to the middle Ecca
- Areas that have been **weathered in parts**.

There is a significant variation in the level to which the geology has been eroded and thus also the depth of the coal which varies greatly in the study area. From the information gathered, it is clear that there are large volumes of coal that can be economically extracted from the Waterberg Coalfield.

Kinetic tests were done on 63 of the samples – in some cases to get answers on some of the static results falling in the 20kg/tonne unsure region outcome of having neither an acid or neutralising outcome after static aba testing.

3.12.1 Borehole samples

An example of core collected from the various companies is shown in Figure 32. Sekoko and Sasol provided borehole material with different diameters that was pulverized for analytical purposes. Borehole core (6 cm diameter) from Sekoko was handpicked from the remaining interburden that was left over after the coal seams had been removed. The borehole core (12 cm diameter) from Sasol was complete with the coal seams still in place. Pulverised samples from Resgen were then further pulverised for laboratory use. The chip samples from Exarro's Grootegeluk Coal Mine (GCM) consisted of overburden in one meter intervals in the respected areas. The extent of boreholes from Sekoko ranged from 0m to 146.75 m in depth. Sasol has the deepest borehole range of 0 to 196.4 m in depth, while the overburden material from Grootegeluk covers the top few meters at the sample positions.

Figure 32: Core sample from exploration borehole near the GCM, with large pyrite hosted within the coal.

Figure 33 portrays the distribution of the samples over the study area, as well as the respective successions the samples are located within. Based on the levels of weathering, the area is divided into three general areas. All the borehole samples collected were already drilled by the mining companies and no borehole was drilled particularly for this study.

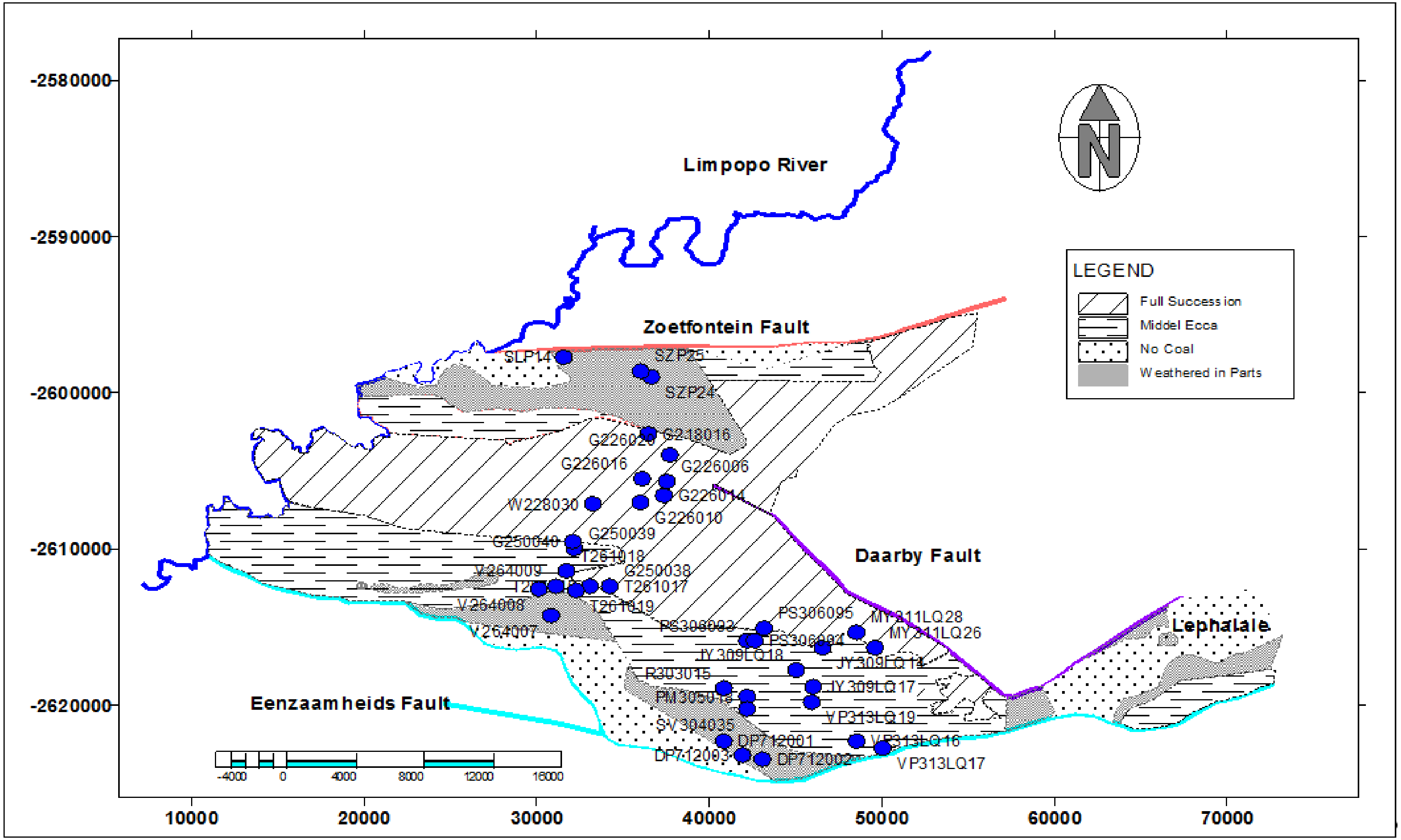


Figure 33: The three major faults with the weathered zones (Bester 2009) and the boreholes samples (blue).

3.12.2 Ash samples

The Matimba Power Station disposes of ash produced during the power generation process on surface fly ash dumps to the south of this station. Fly ash is conveyed from the power station to the ash dump site. The ash is dumped on heaps by a speader, which allows the disposed ash to be placed at specific sites. Dust is controlled by sprinklers that keep the ash heaps wet, and suppresses the formation of dust. Fly ash was collected from the conveyor belt (A) and the dump (B) on the 27th of November 2013 (Figure 34).

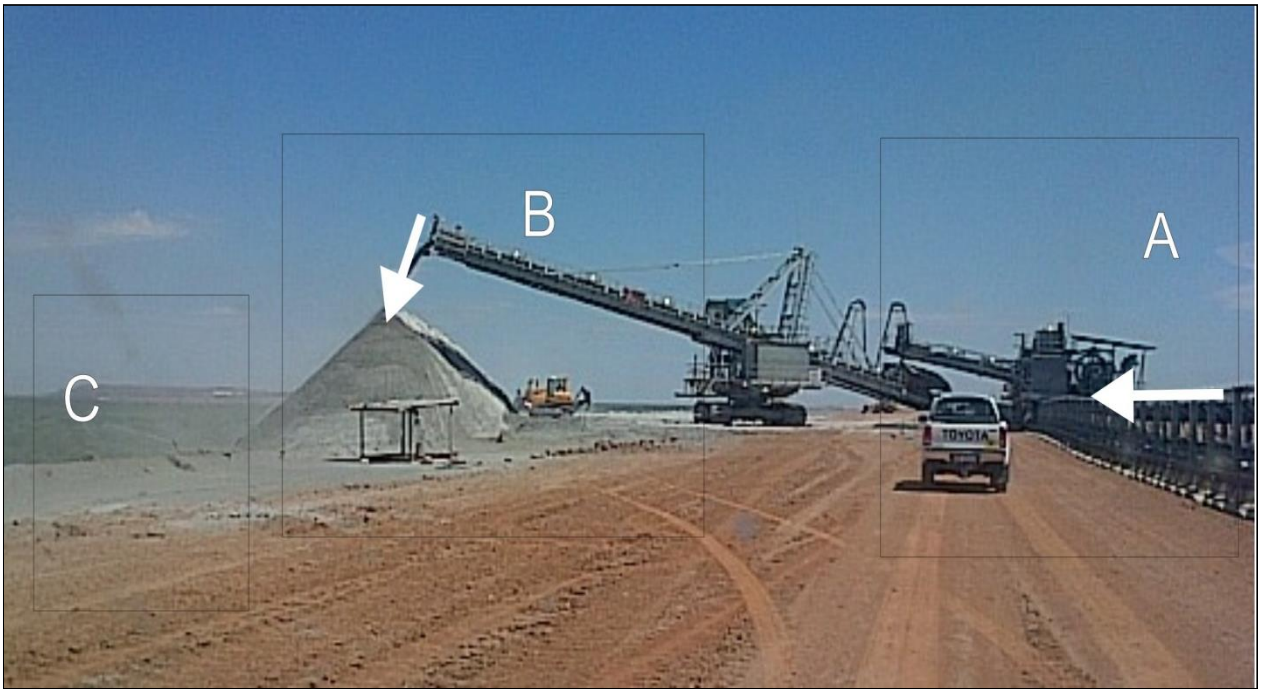


Figure 34: The fresh ash dump, A) the conveyor belt feeds ash to the dump, B) the ash spreader deposits the ash at the specific points of the dump, C) sprinklers along the edge of the heaps suppresses dust originating from the ash dump.

3.12.3 Composite samples

The ROM coal from GCM in the Upper Ecca contains a large amount of intercalated shale (55-65% ash content), and must be beneficiated to produce coal products. The intercalated shale and mudstone produce a typical coal yield of ±50% with the remainder classified as plant discard. The mining and beneficiation process therefore leads to a substantial amount of material that can potentially produce AMD.

The beneficiation process of the coal is product specific and was subjected to the gravity separation which is either single or double wash. The double wash plant produces a low ash coal (±10% ash) which is used as blend coking coal and middling products (±35% ash) in power generation. These products operate at a relative density of 1.80g/cc. In contrast, a single wash plant produces only power station coal and operates at a higher relative density of 1.90g/cc. The newer plants at Grootegeluk operate at relative densities of ±2.10g/cc during beneficiation.

The composite samples received from Exxaro Mine consisted of processing plant discard from the Grootegeluk Mine. The composites ranged over the different densities at which the coal is separated as well from the various zones, depending on which succession the material was originally mined from.

A complete list of samples, received and analysed by the Institute for Groundwater studies from the various companies (Sasol, Exxaro, Resgen and Sekoko), are summarised in Table 41 (Appendix). The table includes the number of samples and the succession to which the boreholes were sampled. Based on the depths of weathering, the samples are grouped into different categories and thereafter discussed.

4 ACID-BASE ACCOUNTING (ABA) TESTS AND ANALYSIS

In order to assess the various acid and base producing potentials of the material sampled from various sections in the study area, ABA tests were performed. These tests consist of two parts, static and kinetic tests. The static test provides a rough indication of the acid generation potentials of the various lithological units. The kinetic test is done over a period of 20 weeks and helps to establish which of the samples are prone to produce acid by exposing it to water and oxygen and to establish the rate of constituent leaching.

4.1 Introduction to Static ABA

Acid base accounting analyses (ABA) are a first-order classification procedure only, during which the acid-neutralising and acid-generating potential of rock samples are determined and the difference, also known as the net neutralising potential (NNP), can be calculated. Different methods of conducting ABA test work will lead to different sets of sample data for evaluation. The method only indicates the overall balance of acidification potential (AP) and neutralisation potential (NP) and is in its most basic form, merely a screening process. Accordingly, it provides no information on the rate (kinetic rate) at which acid generation or neutralisation will take place and due to its limitations, ABA procedures are known as Static Procedures (Brady *et a*l, 1994, Cruywagen, 1999, GARD Guide, 2009, Usher *et al.,* 2002, Ziemkewicz and Meek, 1994). A given potential of a rock or coal sample to generate or neutralise acid is determined by its mineralogical composition. It is not only the quantitative mineralogical composition, but also includes individual mineral grain size, shape, texture, and spatial relationship with other grains in the rock (GARD Guide 2009 & Usher *et al.,* 2002).

ABA can only yield a "worst case scenario" value for potential acid production and a "worst case", "most likely case", or "best case" value for potential neutralisation (Usher *et al.,* 2002). The neutralisation potential is a measurement of the sum of the total carbonates, alkaline earth’s and bases available to neutralise acidity and therefore represents the most favourable condition.

The values resulting from these calculations, expressed as calcium carbonate equivalent, are compared in order to compute a net acid-producing or neutralising potential. Material exhibiting a net acid production potential of 5 tons/1000 tons of overburden material or more as calcium carbonate equivalent, is classed as toxic or potentially toxic (Sobek *et al*, 1978, Hunter, 1997b). Studies have shown that “the application of the Acid-Base accounting methods to overburden handling and placement throughout the USA and

Canada has generally been effective in eliminating or reducing adverse water quality impacts".

4.1.1 The primary advantages of ABA

- Short turn-around time for sample processing.
- Low cost.
- Relatively simple analytical procedures.
- Relatively simple interpretation of results (Hunter, 1997b, Evangelou and Zhang, 1995).

4.1.2 The primary disadvantages of ABA

- The method only predicts a maximum potential acidity and a maximum neutralisation capability, assuming complete acid/base consumption. The actual acid production and neutralisation release rates cannot be predicted in this manner, nor can the completeness of the reaction be assessed (Mills, 1998c).
- ABA assumes that all the acid production from a rock can be attributable to iron disulphide minerals (predominantly pyrite) (Usher *et al.,* 2002).

4.1.3 Prediction methods

It is believed that an accurate form of prediction offers the most cost-effective means of reducing the potential impact of AMD. These impacts that are being measured on the environment and in the mining sector as the costs associated with AMD can be prevented by allowing advanced planning for prevention and control (GARD Guide, 2009 & Usher *et al.,* 2002).

The objective of a prediction programme is to reduce uncertainty to a level at which potential risk and liability can be identified and effective extraction, waste handling and where necessary, mitigation and monitoring strategies, can be selected.

The scope of a prediction programme will depend on site-specific conditions and factors. Some programmes may comprise of a few simple tests, in a relatively short period of time and with a modest budget. Others can involve extensive testing and analyses lasting several months to more than two years and with much higher costs.

The approach can include some or all of the following:

- Initial assessment and site reconnaissance.
- Sampling.

- Chemical, mineralogical and physical analyses.
- Short-term leaching tests.
- Geochemical static tests (ABA).
- Geochemical kinetic tests.
- Mathematical models.

With sufficient data the potentially higher accuracy of models and predictions can minimise the impact of acid generation in the mines (GARD Guide, 2009 & Usher *et al.,* 2002). The IGS most commonly uses the static peroxide method for ABA and is explained in more detail in the next section and it is also the method used for evalutation of the samples in this study.

4.1.4 Static methods (Acid-Base Accounting)

Static methods are some of the more common tests generally used for ABA calculations. These are screening methods which determines the difference between the acid-generating capability and the acid-neutralising potential of a particular sample or set of samples. Paste pH = Initial pH's and the final pH = NAG pH. Listed in Table 11 are the most common procedures in static ABA testing.

Table 11: Most commonly used static ABA methods (Usher et al., 2002).

Paste pH	Static Net Acid Generation (NAG) procedure
Peroxide methods	BC Research Initial test
Sulphur content	BC Research Confirmation Test
Calculated NP	Sobek Neutralisation Potential method
Carbonate NP determination	Modified Acid-Base accounting procedures for neutralising potential
Lapakko neutralisation potential test procedure	COASTECH modified biological oxidation test
Net Carbonate Value (NCV) for Acid-Base accounting	

4.1.5 Peroxide methods

To determine the acid potential in ABA calculations, several tests using hydrogen peroxide as an oxidant for sulphide minerals exist. In the NAG process, the acid potential is determined using a titration. The NAG pH solution is similar to that obtained in the method used at the IGS. The difference with the IGS method is that 30% peroxide is added in increments and that the supernatant is analysed by ICP-OES. The S value obtained is then used to calculate the AP. The method used for this study was the method as developed at the IGS to determine the AP, and calculations will be done expressing the final results as Net Neutralising Potential (NNP).The NNP test provides an accurate quantitative assessment of acid-generating potential under controlled laboratory conditions. A comprehensive summary of the different methods and a comparison of ABA data were completed at the IGS (Cruywagen, 1999).

It is important to note that there are two ways to express ABA results. The NNP method expressed as $CaCO_3$ is mostly used in North America, South Africa and most of the rest of the world. The other way, NAPP (Net acid producing potential) way, expressed as H_2SO_4, is mostly used in Australia, New Zealand and SE Asia (GARD Guide, 2009 & Stewart *et al*., 2006). The corresponding terminologies in the different expression of ABA results are summarised in Table 12.

Table 12: Table comparing different terminologies in ABA determinations.

NNP - American/Rest of world	**NAPP – Australian/Asian**
NNP - Net Neutralising Potential	NAPP - Net Acid Producing Potential
Paste pH - Initial pH	Paste pH - Initial pH
NP - Neutralising Potential = Base Potential	ANC - Acid Neutralising Capacity
AP - Acid potential (peroxide and S via ICP)	MPA - Maximum Potential Acidity
NNP = NP-AP	NAPP = MPA - ANC
NNP expressed as kg/tonne $CaCO_3$	NAPP expressed as kg/tonne H_2SO_4
Final pH peroxide - determine AP (S by ICP-OES)	NAG - Net acid generation (S by titration)
NPR (Neutralising Potential Ratio) = ratio NP:AP	PAF – Potentially acid forming NAF – Non acid forming

Plotting the results for the above mentioned, will give the following graphs that are almost mirror images to each other. The blue box in Figure 35 indicates where samples with a base potential will plot and those in the red box on the left, acid potential samples.

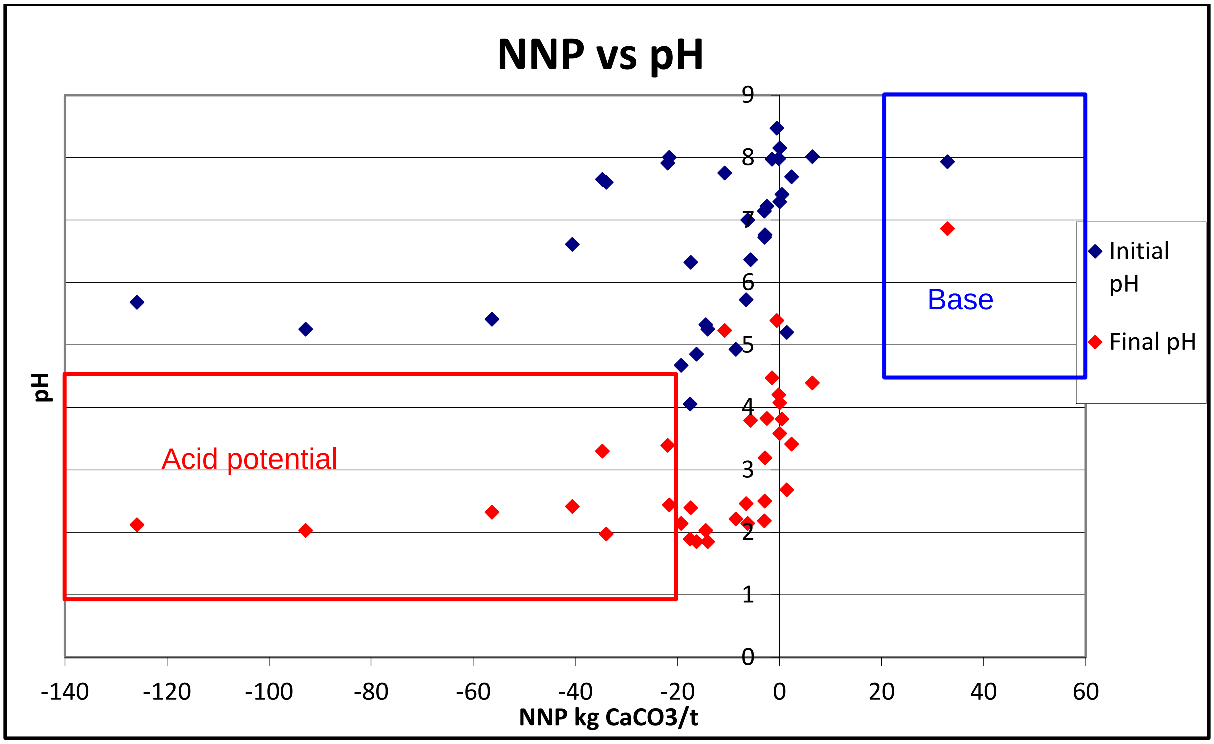


Figure 35: Static ABA expressed the NNP way as $CaCO_3$ kg/tonne.

Using the NAPP graph for expressing results, samples to the bottom right of the 20 kg NAPP line in the red box, represents the samples with an acid potential (Figure 36) also known as PAF (potentially acid forming). The NAG pH values and NAPP are the values to plot within the boxes. The samples plotting in the blue box are those with a base potential and also known as the NAF (Non Acid Forming) samples.

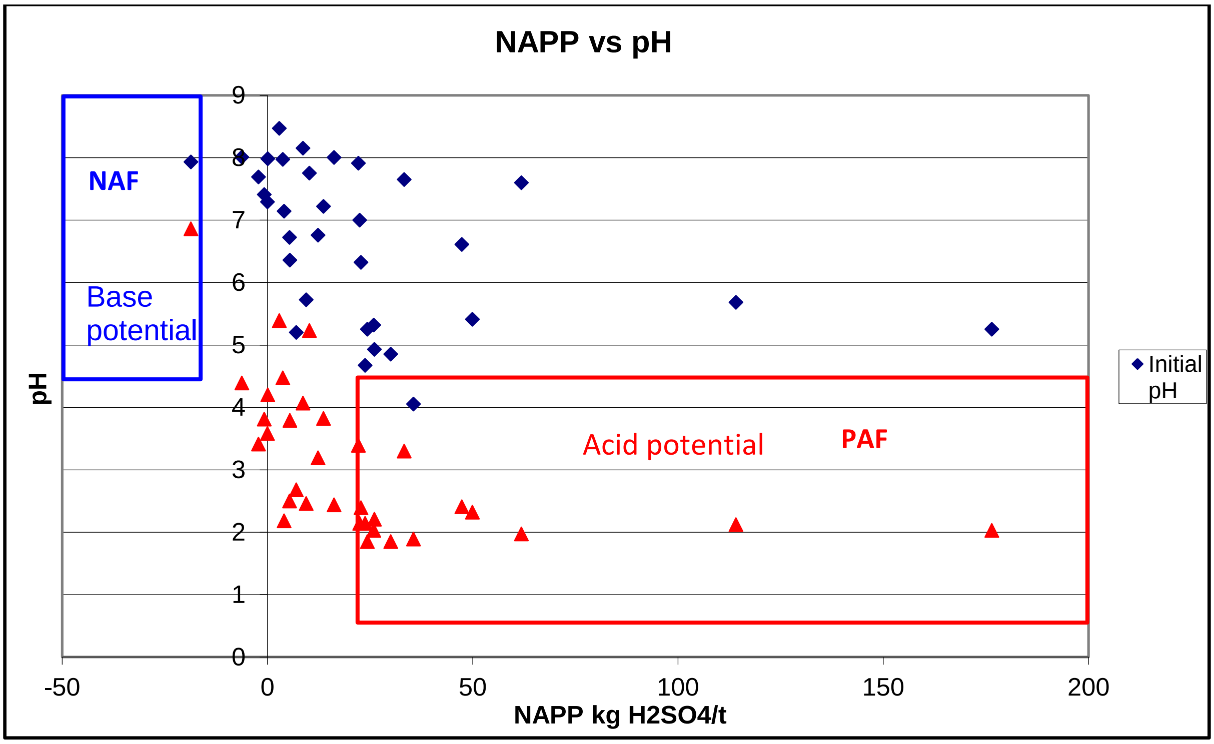


Figure 36: Static ABA expressed the NAPP way as H_2SO_4 kg/tonne.

In the case of NNP, a positive $CaCO_3$ kg/tonne of example 80, indicates a sample with a positive NNP and will therefore not turn acidic upon oxidation, while in the NAPP case, a positive H_2SO_4 kg/tonne value of 80 indicates a sample turning acidic upon oxidation. The acid producing samples are classified as PAF – Potentially acid forming according to the H_2SO_4 way of expressing results and samples with a neutral NAPP, NAF – Non-acid Forming (Amira, 2002 and Stewart *et al.*, 2006)).

Current work indicates that NNP test results correlate well with ABA, particularly when the net neutralisation potential values are relatively low and negative, which is the range in which greater certainty is required (Usher *et al.,* 2002). The test relies on the ability of hydrogen peroxide to oxidise sulphides, such as pyrite, in a sample of mining waste to produce sulphuric acid.

The acid produced is simultaneously neutralised by carbonates and/or other acid-consuming minerals in the sample. At the end of the reaction, the final pH of slurry provides a qualitative indication of acid-generating potential. Titration of the slurry to determine its acid content allows the calculation of the net acid produced by the peroxide digestion, and a quantitative assessment of the acid-generating potential.

The pH recorded at the end of the H_2O_2 digestion (final pH) step prior to titration, can provide a qualitative indication of the acid-generating potential.

Table 13: Interpretation of final NAG (AP) test pH (Lapakko and Lawrence, 1993).

Final pH in NAG Test (Final pH):	**Acid-Generating Potential:**
> 5.5	Non-acid-generating
3.5 to 5.5	Low risk acid-generating
<3.5	High risk acid-generating

Since the pH values are dependent on the specific site lithology and mineralogy, precaution should be exercised when interpreting NAP data in this way. Calibration with other tests and analyses is therefore recommended if the test is to be used in this way. Caution should also be exercised when interpreting NAG test results for coal reject samples and other materials that may contain high levels of organic material (such as potentially acid sulphate soils, dredge sediments and other lake or marine sediments).

After the Neutralisation Potential (NP) and Acid Generation Potential (AP) are determined, the difference between the two has to be determined by using the two methods of combination:

- The difference in value between NP and AP, or Net Neutralisation Potential (NNP = NP-AP), and when the NNP of a sample is negative, it indicates that the sample is likely to be a source of acid.
- An area of uncertainty exists were the NNP is -20 to 20 kg/t $CaCO_3$ (Figure 37) which requires further tests to be conducted.

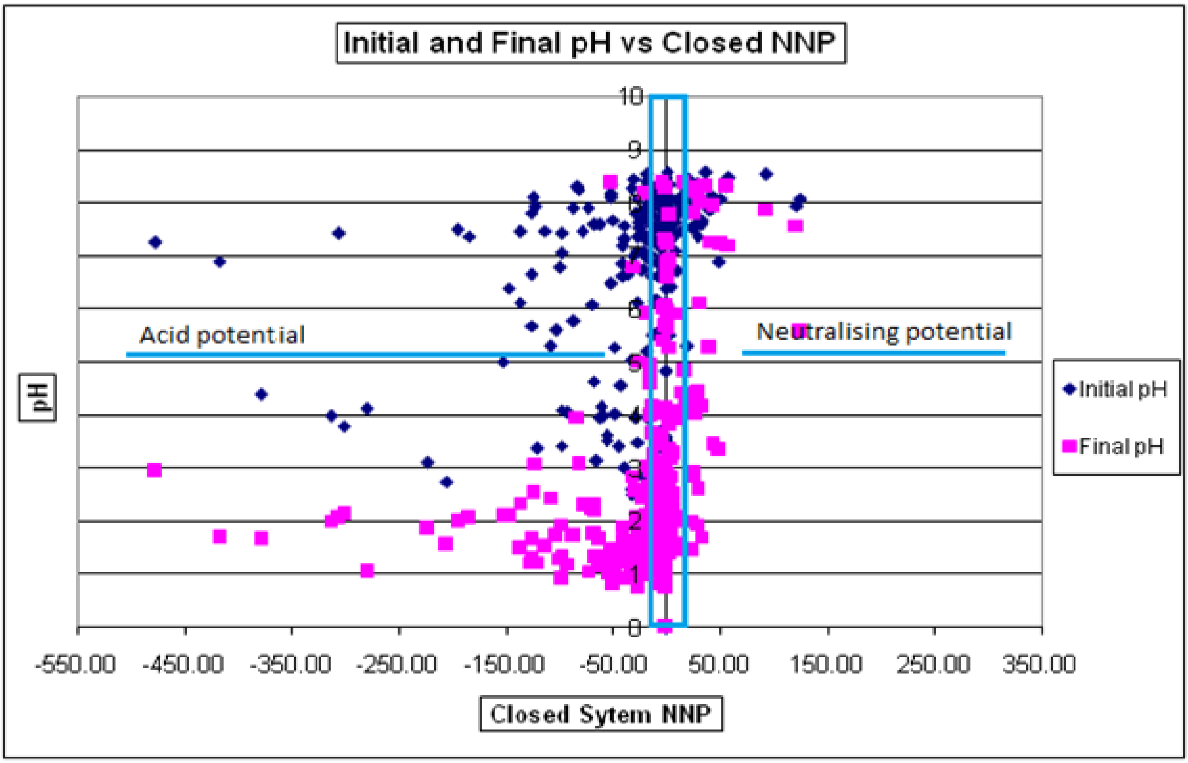


Figure 37: Closed Net Neutralising Potential indicating the area of uncertainty with values from ±20kg/tonne NNP.

All organic material must be completely oxidised, otherwise acid NAG (AP) results could be unrelated to sulphides. Several aliquots of H_2O_2 reagent may be added to the sample to break down organic acidity. Samples with a positive NAPP (negative NNP) value, high sulphur content and high ANC (NP) must be evaluated carefully (Usher *et al.,* 2002).

It is important to differentiate between so called "**open**" and "**closed**" systems. The carbonate system is predominant in controlling the buffering intensity and neutralising capacity of natural waters, and represents a complex system involving the transfer of carbon among three phases: solid, liquid and gas. When $CO_{2(g)}$ is brought into contact with water, it will dissolve and form carbonic acid (H_2CO_3) until an equilibrium state is reached. Depending on the pH of the solution, the carbonic acid will tend to dissociate to hydrogen, bicarbonate (HCO_3) and carbonate (CO_3^{2-}) ions.

In an Open System:

$FeS_2 + 2CaCO_3 + 3{,}75O_2 + 1.5H_2O \Leftrightarrow Fe(OH)_3 + 2SO_4^{2-} + 2Ca^{2+} + 2CO_2$ (carbon dioxide exsolves into the atmosphere)

Acidity produced from 1 mole of FeS_2 (64 g sulphur) is neutralised by 2 moles of $CaCO_3$ (200 g) or 1 g sulphur: 3.125 g $CaCO_3$ (Brady *et al.,* 1994).

In a Closed System

$FeS_2 + 2CaCO_3 + 3,75O_2 + 3,5H_2O \Leftrightarrow Fe(OH)_3 + 2SO_4^{2-} + 2Ca^{2+} + 2H_2CO_3$ (carbon dioxide dissolve in water).

H_2CO_3 reacts with carbonate in the following reaction:

$H_2CO_3 + CaCO_3 \Leftrightarrow Ca^{2+} + 2HCO_3^-$

A second reaction depicting the maximum calcium carbonate requirements for acid neutralisation in a closed system may therefore be written as:

$FeS_2 + 4CaCO_3 + 3,75O_2 + 3,5H_2O \Leftrightarrow Fe(OH)_3 + 2SO_4^{2-} + 4Ca^{2+} + 4HCO_3^-$ (Lloyd and Heathcote (1985), Cravotta *et al.* (1990).

In this reaction, 1 mole of FeS_2 is neutralised by 4 moles of $CaCO_3$ which results in a mass ratio of 1 g pyrite: 6.25 g calcite. The application of the correct conceptual model is therefore of great importance in the interpretation of the results.

4.2 Sulphide Minerals with Acid Potential

Pyrite (cubic crystal structure) and marcasite (orthorhombic crystal structure) (both with formula FeS_2) are the dominant sulphide minerals that are found in the coal samples as well as the sedimentary rocks within the deposits (Pope *et al*., 2010). Pyrite is the most abundant sulphide mineral found in the Waterberg Coal.

Pyrite oxidation is as follows

$4FeS_2 (s) + 15 O_2 + 14 H_2O = 8H_2SO_4^- + Fe(OH)_3 (s)$(yellowboy)

These minerals are ferrous sulphide while chalcopyrite and arsenopyrite can be added to the list. Other sulphide minerals with an acid potential are named below and might occur but were not identified by XRD in this study:

Chalcopyrite (acid generating with ferric iron as oxidant)

$4CuFeS_2 + 17O_2 + 10H_2O = 4Cu^{2+} + 4Fe (OH)_3(s) + 8SO_4^{2-} + 8H^+$

Arsenopyrite (slower than pyrite oxidation, used both oxygen and ferric iron as oxidant)

$4FeAsS + 14O_2 + 16H_2O = 4Fe (OH)_3(s) + 4SO_4^{2-} + 4H_2AsO_4^- + 12H^+$

Other sulphide minerals exists which are non-ferrous within the deposits and are not limited to sulphide minerals such as enargite, which releases acid, or Galena (PbS) and sphalerite (ZnS) which do not release acid. These reactions can however produce elevated dissolved trace element concentrations or precipitation of trace elements that are rich in secondary minerals (Pope *et al.,* 2010).

Enargite (slower than pyrite oxidation – oxygen and ferric iron as oxidant)

$4Cu_3AsS_4 + 43O_2 + 6H_2O = 12CuO(s) + 16SO_4^{2-} + 4H_2AsO_4^- + 4H^+$

Galena may also be oxidised by Fe^{3+} under acidic conditions.

$PbS + 8Fe^{3+} + 4H_2O = 8H^+ + SO_4^{2-} + Pb^{2+} + 8Fe^{2+}$

The oxidation reaction of **sphalerite** by assuming that all the sulfur is oxidised to sulphate (Blowes *et al*., 2004).

$ZnS + 2O_2 = Zn^{+2} + SO_4^{-2}$

4.3 Minerals with an Acid Neutralising Potential

The acidity of the mine is influenced by the neutralisation potential of the wastes which will determine the acidic or neutral outcome according to the free availability of the base potential (GARD Guide, 2009 & White *et al*, 1999). Calcium and magnesium carbonates which include minerals such as calcite, magnetite, dolomite and ankerite (White *et al*., 1999) have been stated through literature as the better option for neutralisation. Various minerals are available in the lithology that act as a source of neutralisation such as (1) calcium and magnesium–bearing carbonates; (2) calcium, magnesium and aluminium oxides and hydroxides; (3) soluble, non-resistant silicate minerals, and (4) phosphates.

4.3.1 Source of neutralisation by using carbonate minerals

The most significant pH buffering reactions in mine settings are the dissolution of carbonate minerals, aluminum hydroxide, ferric oxyhydroxide and aluminosilicate minerals. Neutralisation potential from rocks disturbed by mining is primarily provided by carbonate minerals such as aragonite, calcite ($CaCO_3$), dolomite ($CaMg\ (CO_3)_2$), magnesite ($MgCO_3$) and rhodochrosite ($MnCO_3$) through which open system carbonate dissolution and high solubility of cations are released. Siderite ($FeCO_3$), a common carbonate mineral, has no net neutralising effect because its dissolution is followed by Fe^{2+} oxidation and subsequent hydrolysis of Fe^{3+} (Skousen *et al.*, 1997; Weber *et al.,* 2005; Haney *et al*., 2006). Carbonate minerals can be rich in trace elements such as Cu, Zn, Cd and neutralisation reactions can therefore also release these trace elements. Calcite is the most reactive mineral depleted, followed by dolomite-ankerite and siderite (Blowes *et al*., 2004).

Calcite

$\mathbf{CaCO_3} + 2H^+ = Ca^{2+} + H_2O + CO_2$

Dolomite

$\mathbf{CaMg\ (CO_3)_2} + 2H_2SO_4 = CaSO_4 + MgSO_4 + 2CO_2 + 2H_2O$

Siderite

$\mathbf{FeCO_3} + 2H^+ = Fe^{2+} + CO_2 + H_2O$

$Fe^{2+} + 1/4\ O_2 + H^+ = Fe^{3+}\ ½H2O$

$Fe^{3+} + 3H_2O = ¼\ FeOH_3 + 3H^+$

In some cases the concentration of the buffering minerals exceeds that of the sulphide minerals, and carbonate minerals undergo rapid dissolution which allows for neutralisation.

4.3.2 Source of neutralisation by hydroxide minerals

Dissolution of the hydroxide minerals takes place after the carbonate minerals are depleted. According to Blowes *et al.,* (2004) the increase in aluminum is associated with depletion of the carbonate mineral which suggests that aluminum hydroxide (gibbsite) will be the first hydroxide mineral to dissolve. The dissolution of these mineral functions acts as a buffer of the pH of 4-4.5 and as soon as the mineral gets depleted, the pH continues to drop (2.5-3.5) until equilibrium with an iron-oxyhydroxide (ferrihydrite or goethite) has been reached.

4.3.3 Source of neutralisation by using aluminosilicate minerals

By being a form of neutralisation, dissolution of aluminosilicate influences the mine drainage chemistry. Pope *et al.,* (2010) stated that, "the dissolution of the minerals is a contribution of dissolved components as well as the formation of secondary minerals that can store and release acidity."

$NaAlSi_3O_8 + 4H^+ + 4H_2O = 3H_4SiO_4 + Na^+ Al^{3+}$

$KFe_3(SO_4)_2(OH)_6 + 3 H_2O = K^+ + Fe(OH)_3 + 2SO_4^{-2} + 3H^+$

Aluminosilicate minerals can influence the drainage chemistry of the mine by acid neutralisation, contribution of dissolved components (Pope *et al*., 2010) as well as the formation of secondary minerals that can store and release acidity.

Kwong (1993) suggested that the minerals are divided into different groups regarding the reaction rate (Table 14). In nature, the neutralisation of AMD results in a difference in rock appearance (oxidised and different in texture and colour from the host rock) and/or additions to bottom sediments or sediment particle surfaces (including rocks and boulders in watercourse beds) The neutralising minerals present in the Waterberg geological layers are **highlighted** in Table 14.

Table 14: Relative Mineral Reactivity at pH5 (from Sverdrup (1990) & Kwong, (1993)).

Mineral group	Typical minerals	Relative activity at pH5
Dissolving	**Calcite**, aragonite, **dolomite**, magnesite, brucite.	1
Fast weathering	Anorthite, nepheline, olivine, garnet, jadeite, leucite, spodumene, diopside, wollastonite	0.6
Intermediate weathering	Epidote, zoisite, enstatite, hypersthene, augite, hedenbergite, hornblende, glaucophane, tremolite, actinolite, gnthophyllite, serpentine, chrysotile, talc, chlorite, biotite.	0.4
eatheriSlow wng	Albite, oligoclase, labradorite, montmorrillonite, vermiculite, gibbsite, **kaolinite**.	0.02
Very slow weathering	**K-feldspars**, **muscovite**.	0.01
Inert	**Quartz**, rutile, zircon.	0.004

Minerals are also formed as a result of AMD processes, some of which are rare and highly priced by mineral collectors (e.g. boleite), others that are used for jewellery (e.g. malachite) and the restwhich form mineral deposits (e.g. chalcocite).

4.4 Secondary Minerals

Secondary minerals predominantly form because of precipitation of constituents derived from oxidation reactions. These minerals are usually found in acidic drainage as a product of primary minerals; this is due to the highly reactive nature of the acidic waters that dissolves the secondary minerals (Alpers and Nordstrom, 1999). Secondary minerals are able to store acid and release metals when the minerals are dissolved (Plumlee, 1999). In cases where the secondary minerals are insoluble, most of the major contaminants in the acidic waters could be brought to a halt which will be a great source of attenuation and of a detoxifying mechanism (Alpers and Nordstrom, 1999). On the contrary, if the secondary minerals are soluble they have the ability to slow down the mobility of the toxic metals. The same amount of attention that is given to the effect of pyrite oxidation and water chemistry in interpreting chemical processes in a mining environment should be placed on the secondary minerals in an environment where acidic water is present.

The formation of the secondary minerals depends on the following factors; the type of sulphide reacting, host lithology, pH and bacteria present or absent and time. The dissolution and the formation of the secondary minerals will have an effect on the composition of water that is in connection with the sulphidic waste. Soluble sulphate minerals found in dry and semi-dry environments can store acidity and metals during dry periods and then release them during wet periods. This can result in extreme seasonal variations in metal concentrations and therefore affect the aquatic environment. Secondary minerals are also known to have an influence on the activity of the trace elements such as Cu and Zn (Plumlee, 1999). Secondary minerals are described in the following categories (Nordstrom and Alpers, 1999):

- Metal oxides, hydroxides and hydroxyl sulphates;
- Soluble sulphates;
- Less-soluble sulphates;
- Carbonates; and
- Secondary sulphates.

Soluble sulphates of magnesium and aluminium are commonly associated with AMD. During oxidation of pyrite the dissolution of dolomite reduces the acidity. Calcium and magnesium are released and can form gypsum (Blowes *et al*., 2004). The oxidation of iron sulphides leads to the formation of goethite. Hematite and ilmenite are also common products during oxidation.The precipitation of hydroxides or related chemicals is dependent on the aqueous concentration of a metal, the pH and the reduction/oxidation (redox) potential of the solution as well as the concentrations of other ions. The chemistry of real AMD systems is extremely complex.

4.5 Kinetic Tests

Laboratory kinetic testing methods are used to validate and interpret static test methods, and predict long-term weathering rates and the potential of mine wastes and geologic materials to release discharges that my have impacts on the environment. The term kinetic is used to describe a group of test work procedures wherein the acid generation (metal solubilisation and transport) characteristics of a sample are measured with respect to time. ABA methods are referred to as static because measurements are made over a short and fixed period of time (GARD Guide, 2009). Humidity cell test (HCT) was the kinetic tests done in this study. Both acid generation and metal leaching can be evaluated through kinetic testing. The results from kinetic testing are frequently used in combination with data from static test, mineralogical analyses and geochemical modeling to evaluate geochemical controls on leachate composition and conduct water quality prediction under a range of conditions. In the event of the ABA not being able to predict with certainty if the sample would become acidic (or not), kinetic tests are usually done. Due the time and space and cost running humidty cells, only 68 humidity cells were set up for this study. It consisted of different samples: some that were inconclusive during ABA analyses, some that had clear acid or base static outcomes and mixtures of the composites from beneficiation plants with different lithological units. This was done to assess possible ratios to optimise the current handling of waste material during and after mining operations.

The humidity cells were set up according to the ASTM method (ASTM D5733, 2013) and the methods used for each process during the determination of the potential acidity are summarised in Figure 38.

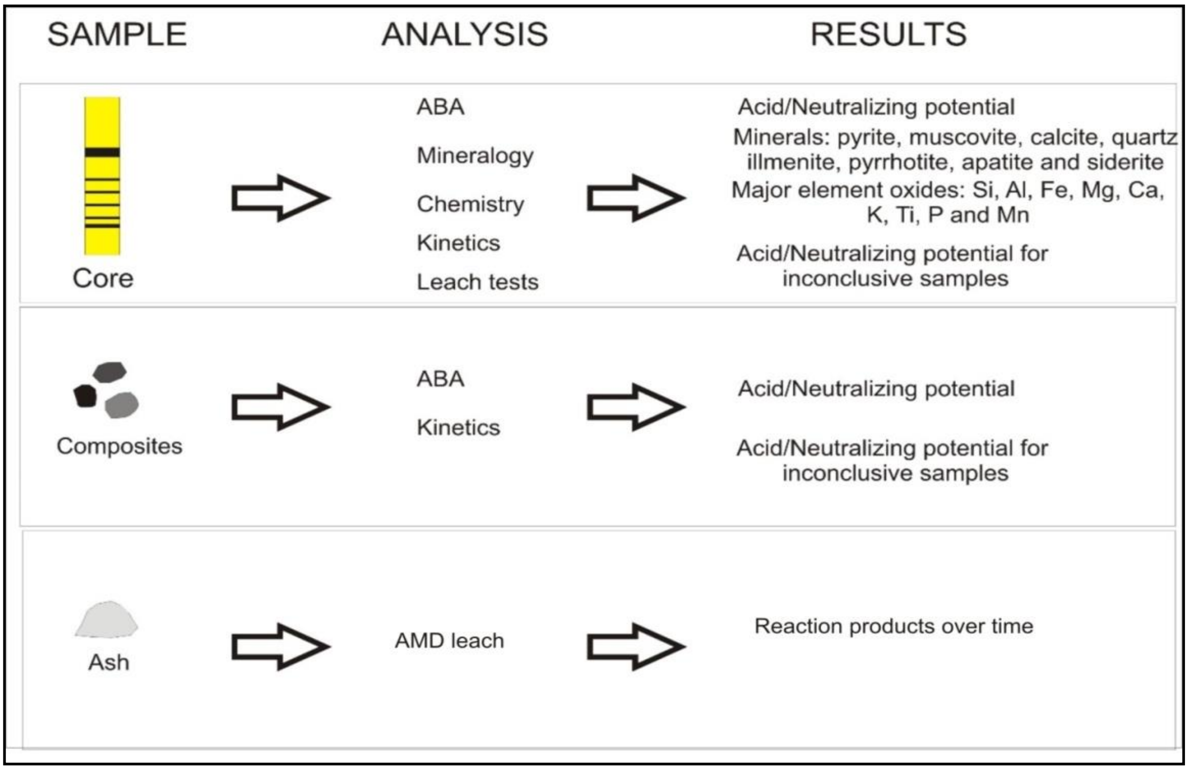


Figure 38: A flow chart of the methods used to determine the samples potential to produce acid.

4.5.1 Humicidy cell tests

HCTs are primarily intended to generate information on weathering rates of primary minerals (e.g., sulphides); information that can be used to estimate the potential for future net-acid conditions. Dissolution rates of readily soluble primary and secondary minerals present at the onset of testing (e.g., gypsum, hydrothermal jarosites) can also be derived from HCT results. In combination with geochemical modeling, HCT leachate results can be, and are frequently, used to make inferences with respect to drainage chemistry, but due to a lack of equilibration with primary and secondary minerals during HCT operation, such an evaluation has to be conducted with cautionHumidity cell test work was performed on material in which the potential for acid generation was uncertain, and was done in an attempt to define acid generation characteristics. Procedures for humidity cells are described below and they are one of the most commonly used methods of determining kinetic AMD characteristics of drill core, waste and other rock samples and tailings.

The main advantages of kinetic tests are:

- Test methods are designed to simulate field conditions. If pyrite oxidation rates and mechanisms can be better understood, it is possible that AMD can be stopped at the source so that complications downstream from mine sites will be eliminated (Jerz and Rimstidt, 2000).
- Reaction rates (kinetics) can be evaluated. Researchers such as Stromberg and Banwart (1999) have shown a good correlation between oxygen consumption and sulphate production in laboratory columns.
- Well-characterised test materials can be utilised.
- Leaching of overburden constituents other than acidity and alkalinity can be evaluated (Hunter, 1997).

The primary disadvantages associated with leaching tests are:

- Test time is lengthy; a typical minimum run time is 20 weeks.
- Analysis is expensive.
- The long-term predictable capability of leaching tests is still uncertain.
- Data interpretation requires a more sophisticated review than the Acid-Base Accounting method (Hunter, 1997).
- The most popular kinetic test currently conducted is the humidity cell (ASTM D5744-13) test (Figure 39).

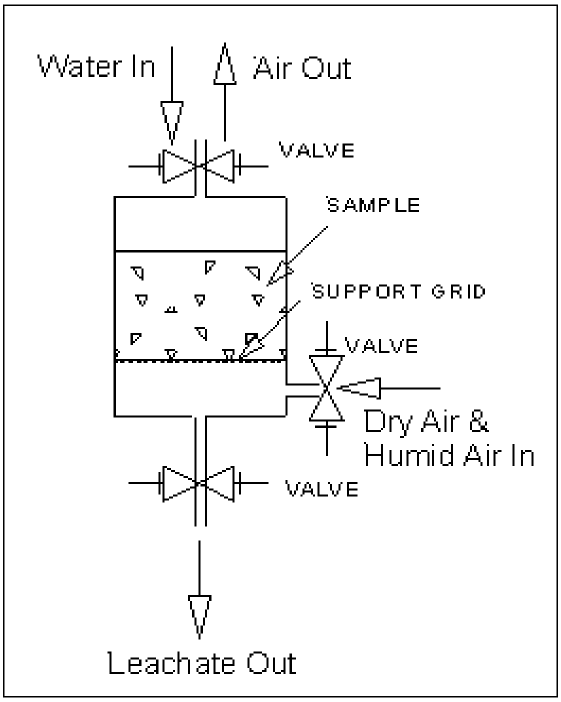


Figure 39: Generic schematic diagram of a humidity cell (Mills, 1998).

The trend in humidity cell testing is time-consuming and ranges from the ASTM suggested 20 week period, to more than 2 years. The procedure is designed to mimic the conditions expected to occur in rehabilitated spoil or existing waste conditions. Samples are subjected to alternating water leaching and exposed to moist air. It has been indicated that fine-grained pyrite with a large surface area is much more reactive and more likely to produce acidity than coarse-grained pyritic material. It is suggested that Acid-Base Accounting should be used as an initial screening test for overburden samples. Leaching tests will more accurately predict drainage quality (Hunter, 1997).

One of the major weaknesses of kinetic test interpretation is the lack of long-term data. Although tests are now generally run for significantly longer periods than in the recent past, the usual test duration of months or even 1 – 2 years, does not simulate the behaviour of a waste component in time frames often measured in years or tens of years. Assumptions have therefore been made that the stability of concentrations and rates observed after a reasonable length of time of testing can be extrapolated into the future (Lawrence and Day, 1997).

Kinetic tests are carried out to determine the weathering characteristics of a sample as a function of time. For proposed new and existing mines specific objectives for both the short-and long-term can include:

- Validation of static test results and classification.
- Determination of the rate of sulphide oxidation/acid generation.
- Determination of the rate of neutralisation depletion.
- Determination of the availability of NP.
- Time to the onset of AMD.
- Evaluation and selection of AMD control methods.
- Prediction of water quality.

Figure 40: An IGS humidity cell (left) and an array of cells set up at the IGS (right).

For an existing mine where AMD might already be a problem, some or all of the above objectives also apply. In addition, it may be necessary to add the following objectives to facilitate the selection of mitigation methods and for the development of a closure plan:

- Evaluation of the extent of oxidation.
- Evaluation of the extent of neutralisation.
- Evaluation of stored reaction products within wastes (Dagenais and Poling, 1997; Lawrence and Day, 1997).

Kinetic tests typically involve subjecting a sample of the waste material to periodic leaching and analysis of the drainage. The most reliable test would be the one that replicates the actual field conditions exactly. In practice this is not possible; not only because of the time factor, but also because it is impossible to simulate the physical, chemical, biological, meteorological and other factors associated with an actual dump, tailing impoundment or other mine component. With respect to the time factor, the difficult choice in designing, performing and interpreting a kinetic test is either to have a test which attempts to approximate actual field conditions, in which case the test will usually be of too short in duration, or to provide accelerated conditions, in which case the test might be unrealistic. In the former case, kinetic tests can often fail to demonstrate the onset of AMD or reach any steady state with respect to oxidation rates, neutralisation rates or water quality (Lawrence and Day, 1997). HCTs represent a standardized test under fully oxygenated conditions with periodic flushing of reaction products (GARD Guide, 2009 & Price, 2009).

Humidity cells provide the rates of reaction and they define a concept of intrinsic oxidation rate to describe a system’s reaction kinetics. The intrinsic oxidation rate (IOR) is the rate of oxidation of material in a system (column, stockpile and dump) under the particular conditions pertaining to that point. The IOR is a function of many variables such as oxygen concentration, sulphide sulphur concentration, temperature, pH, pyrite morphology and microbial ecology and is also time dependent. Since it is currently impossible to predict the IOR function by measuring individual material characteristics, the only other approach is to measure the oxidation rate itself, either of samples in the laboratory or in the field. Laboratory measurements can be designed to provide the functional dependence of the IOR on any of the variables that are judged to be important (Comarmond and Jeffrey, 2000). This is essentially what kinetic tests hope to achieve.

Oxidation rates of sulphidic mine wastes measured at a range of scale sizes have been collected from a number of sources. The results suggest that well-designed laboratory columns under controlled conditions, provide comparable information to that obtained on oxidation rates from field test piles (Comarmond and Jeffrey, 2000). The rates of pyrite oxidation by oxygen in moist air are comparable to the rates of pyrite oxidation by ferric iron in solution (Jerz and Rimstidt, 2000), so that an idea of the order of magnitude of oxidation can be found for an already acidified system that is submerged.

The key objectives of laboratory kinetic tests are (a) long-term stable reaction rates under kinetic conditions and (b) depletion times for acid-generating, acid-neutralising, and metal-leaching minerals. Therefore, interpretations of the tests focus on calculating.

4.6 Leach Tests

Leaching is the process by which inorganic, organic contaminants or radionuclides are released from the solid phase into the water phase under the influence of mineral dissolution, desorption and complexation processes. It can be affected by chemical aspects namely pH, redox, dissolved organic matter and (micro) biological activity. The physical aspects influencing the leaching relate to the manner of contact between the liquid and the solid material. Chemical aspects can also include precipitation or sorption processes, whereby dissolved constituents return to the solid phase (Baun et al, 2003).

The process itself is universal, as any material (ash, discard and mining waste rock) exposed to contact with water will leach components from its surface or its interior depending on the porosity of the material considered. Chemical forms in which the metal/trace element is associated will not only determine the metal’s behaviour but also the mobility and bioavailability within the environment.

Regulatory agencies, industries and the public need a tool for quantitative prediction of leachate composition to properly assess the risks and benefits of a particular Coal Combustion By-products (CCB) application for mine reclamation. There are different leaching methods available that is being used by contract laboratories for the mining industry and consulting companies. Currently applied laboratory extraction procedures yield imprecise estimates of field leachate composition and field studies alone do not provide the causal relationships for the observed behaviour. Also, since TCLP and SPLP use standard leaching solutions, they do not predict interactions between the solid waste and components of a specific mine water.Whether the results are representable to field conditions are doubtful, since even today either SPLP (resulting in non-toxic effluent) or total metal digestion (too severe to mimic environmental conditions) are used.

Results obtained with the TCLP on a limited number of fly and bottom ash samples showed that the range of concentrations of specified constituents was well below regulatory limits (Muraka *et al*. 1993). The applicability of extraction of mining wastes (discard/ash/slimes/tailings/waste-rock) by the acid rain methods (TCLP and SPLP) which contain very low acidity cannot be applicable to mining conditions where AMD are generated. These residues are therefore classified as non-hazardous wastes and can be disposed of on land, without the risk of contaminating groundwaters to the extent of exceeding drinkingwater standards.These applications in the mining environment on waste are not eagerly expected to give real AMD leachate results (Parbhakar-Fox, A 2014, ALS Environmental, 2001, Yan *et al*, 2000). Mining waste samples that were sent to laboratories by Parbhakar-Fox were subjected to water, peroxide and the SPLP method.

Available metal leaching tests at SGS as the published methods they use from which a customer and choose, includes: EPA 1312 Synthetic Precipitation Leaching Procedure (SPLP), EPA 1311 Toxicity Characteristic Leaching Procedure (TCLP), Shake flask or short-term leach (de-ionized water), Meteoric Water Mobility Procedure (MWMP), ASTM D3987 (method for shake extraction of solid waste with water), EN 12457 (European test protocol), MA100-Lix.Com.1.1 (Quebec), Sequential leach extraction (Tessier *et al*., 1979) and Project-specific leach tests. A method is described by Ziemkewics (2006a &b) where mine water of the area is used to leach the waste product until all buffering potential are removed. This can only be done if AMD for that particular mine site is available. The shake flask experiment is simple and inexpensive to set up and is a typically shorter duration test than the humidity cell, column or lysimeter (Steel *et al,* 2009). Variations in experimental methodologies used with examples have been described by Filipek *et al*. (1991) and Gleisner and Herbert (2002). Total concentrations of a sample can be obtained by Aqua Regia (HCl + HNO_3) and microwave extraction – this is mostly used in Europe, except in Scandinavia where they would rather use a HNO_3 extraction that is weaker than Aqua Regia (Hutter, 2012). The latter digestions are to obtain a full elemental analysis. These conditions are however not related to field conditions. Table 15 is a summary of different leaching methods documented and which are used by laboratories in the industry.

Table 15: Summary of different extraction methods to determine leachate composition.

Method	**Extraction fluid**	**Applicability to mining environment with AMD and CCB's**	**ratio (liquid;solid)**
TCLP	buffered acetic acid	No - valuates metal mobility in a sanitary landfill	20:1
SPLP	slightly acidic water (pH 4.2 or 5) (acid rain)	No - evaluate the fate and transport of metals in an engineered land disposal facility	20:1
Shake flask/short term leach	de-ionized water	see note	different ratios
MWMP	Type II reagent grade water. Sample in a column	see note	1:1
EN 12457 (European test protocol			10:1
DIN ISO 19730:2008 revised 2012	1mol NH_4NO_3	mobility in soil	?

Method	Extraction fluid	Applicability to mining environment with AMD and CCB's	ratio (liquid;solid)
ASTM D3987 (method for shake extraction of solid waste with water)	distilled water	see note	4:1
Modified D3987	pH of distilled water adjusted to pH5.5 by carbonic acid	? Will depend on the final pH.	4:1
MA100-Lix.Com.1.1 (Quebec)	SPLP TCLP and water extraction	No	20:1
Sequential leach extraction	$MgCl_2$, KNO_3,NaOAc, KF, EDTA,H2O2, NH_4OAc, NH_2OH, HCL, HF	No	unknown
Mine water leaching procedure	mine water of the area	several additions until pH drops to that of the mine water - all buffering potential are removed	n/a
BC special waste extraction procedure (SWEP)	0.5 N Acetic acid or 0.1 N Hydrochloric acid	No - not amd associated media	3:1
ASTM 4793 (2009) - Standard Test Method for Sequential Batch extraction of waste with water	water extractions	see note	n/a
Project-specific leach test	no information on this - client should be able to select leaching fluid	will depend on selection of client	?
Acid digestion	Acid and heated	too extreme - not environmental in mining with amd	10:1
Note: All water extractions - give an indication of elements that will go into solution on first contact with precipitation. Final pH of extraction solution to be measured.			

Fly ash can be mixed with lime exhibiting self-cementing properties and can be used to cap surfaces, line pavements and isolate acidic materials in the backfill to prevent AMD formation. In addition, highly alkaline CCBs are used to directly neutralise acidic materials. CCBs are used as structural fills in mining and are also used to control acid mine drainage, subsidence and for soil reclamation (Butalia and Wolfe, 2000). Several case studies have been conducted on the direct neutralisation of AMD using highly alkaline CCBs (Ashby 2001, EPRI 2001). Placement of CCBs in coal mines raises the prospect of reactions with geochemically aggressive, acidic groundwater in the mine. The CCBs are generally alkaline and are often seen as valuable amendments for groundwater improvement. However, the weathering behaviour of CCBs will change with exhaustion of their alkalinity and regulatory agencies need to know the potential to leach toxic elements overextended time periods. Any other mining product which can be subjected to AMD should be subjected to a proper leaching test to evaluate the risk to the environment.

At the IGS a leach extraction method was developed to predict the leaching behaviour of CCBs and all other samples excavated in the mining process. All samples in this study were subjected to the leaching test as described hereafter with H_2SO_4. A dilute sulphuric acid solution (±0.1 N) that mimics AMD is added to a known mass of the sample to be tested. The pH of the sample mixture is measured after 24 hours of reaction time. Should the pH of the sample not be below pH 2.50, drops of concentrated sulphuric acid are carefully added to lower the pH to just below 2.50 - the medium should not become overly acidic. The reason for this is to ensure that the medium with the sample is in the low (acid) pH range as if exposed to acidic AMD. This is also done to test the environmental leaching possibilities of a sample. A sample with a base potential may not release any toxic metals in its neutral pH range and this will cause a false range of concentrations of specified constituents that will be below regulatory limits and the hazardous potential of the waste will be overlooked. It is important to test this in samples with a positive NNP (example fly ash/overburden). Predicting the effect of a particular ash on a given coal mine’s drainage quality is of particular importance.

The geochemical reactions of dissolution/precipitation/adsorption/desorption, and oxidation/reduction are recognised as controlling the mobilisation of various constituents from solid residues (Ainsworth and Rai, 1987 abd Roy and Griffin, 1982).

Sulphuric acid contains characteristics that are closest to AMD. It is thus used in the leaching of elements since it best represents that of AMD, other than HNO_3 or HCl. While certain salts will precipitate in the presence of H_2SO_4 it can stay in solution with the other acids. Using concentrated acids and heat to extract elements is not close to field conditions and is the reason why the mixtures are not heated. This is of particular importance to determine the elements that can leach from example fly ash or neutralising samples used in backfilling, and mixing of discards at coal mines. Extraction methods using the TCLP or SPLP method are not “harsh” enough since the sample mixture in the case of samples with a base potential does not turn acidic. An AMD mixture was obtained from the humidity cells of samples from this Waterberg study. The acidity of this AMD and the other reaction mixtures used was tested to indicate the strength/capacity of the acid. A Ratio of 10:1 extract solution is used in this method while for the TCLP and SPLP, the ratio is 20:1 liquid:solid ratio.

Table 16: Acidity values of different leaching media.

Sample	**SPLP**	**IGS Acid Leach (±0.1N H_2SO_4)**	**Waterberg AMD Mixture**
Determinant	**Value**	**Value**	**Value**
Acidity as $CaCO_3$ mg/L	20	3 600	14 000

Acidity is only one of the aspects to be considered when assessing the potential for acid generation. It is important to note that a solution with a pH of 2 might not have a high acidic value. Other factors that provide important information in terms of possible impacts include the quantity and nature of elements released by water solubilisation, oxidation and an acidic environment.

Coal mines associated with Acid Mine Drainage (AMD) usually have lithologies that include high concentrations of sulphate, aluminium, manganese and iron. Additional elements include calcium, potassium, magnesium and sodium. The major contributors to the acidic drainage are ferrous and ferric Iron (Fe^{+2}; Fe^{+3}), aluminium and manganese as well as free hydrogen ions. The element abundance in AMD derived from different minerals like zinc and cadmium result from the dissolution of sphalerite. Calcium and sulphate are derived from secondary gypsum dissolution and the weathering of calcite and pyrite (Nordstrom and McCleskey, 2006).

A detailed chemical analysis was done on all the samples subjected to the static ABA tests. Elements included: Al, Ba, Ca, Cd, Co, Cu, Cr, Fe, K, Mg, Mn, Na, Ni, Pb, S, Sb, Sr and Zn. The leachate characteristics of the rock and coal samples mimic conditions in an initial pH, after oxidation had taken place in an acidic environment.

4.7 Geology, XRD, XRF

4.7.1 Whole rock analysis

The rock/coal sample potential to generate or neutralise acid is determined by the mineralogical composition of the sample analysed. This is determined by using the X-ray fraction (XRF) instrument. XRF is used to determine the chemical composition of a rock/coal sample which can analyse several elements from beryllium, to uranium. The instrument is equipped with a sample changer which has several duplex detectors that allows enhancement for transition metals. The instrument consists of two detectors namely: the scintillation and the duplex. The scintillation detector is used to enhance heavy element sensitivity. The duplex detector is used to enhance sensitivity as well as to analyse a wider range of transition metals (PANanalytical, 2013). XRF was used to identify the oxides of the major elements of the selected samples from different areas, including SiO_2, Al_2O_3, CaO, K_2O, Na_2O, Fe_2O_3, MnO, MgO, TiO_2, BaO and P_2O_5.

4.7.2 Mineralogical identification

Mineralogical analysis of the rock or coal sample is done by using an X-ray diffraction (XRD) machine. X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a quantitative crystalline material (Dutrow and Clark, 2013). The analysed material is finely grounded and homogenised after which an average bulk composition is determined. The primary and secondary minerals from the samples are identified by using this analysis.

Based on the static ABA results, X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses were done. XRF is a semi-quantitative whole rock analyses mainly used to identify the chemical compositions of major and trace elements from selected samples. XRD is a quantitative method that identifies the minerals present within the samples. Sample preparation requires material to be crushed, milled and made into fusion disks and pellets. The major elements are determined as oxides in wt%.

5 XRD AND XRF RESULTS

The information acquired from geochemical and mineralogical tests on mine waste materials can assist with predicting the level of environmental risk and potential impacts (Robertson *et al*, 2015).

In total, only 50 samples were subjected to XRD and XRF analyses. The analyses determined the mineral and elemental chemistry. The most abundant trace metals were (high – low) Ba, Zr, Sr, Cr, V, Cu and Zn. The trace metals in the lowest concentrations were (lowest – higher) Br, Cd, Tl, Ag and Nb. A full list of the results can be seen in Table 43, Table 44 and Table 45.

The samples with a neutralising capacity mainly contained minerals calcite and ankerite/dolomite. This is due to the carbonate content within the mineral chemistry. Pyrite (Table 45) is the dominant mineral in the acidifying samples. The mineral chemistry of pyrite contains iron and sulphide elements that under favourable conditions contribute to the production of acidic waters.

There is a difference in the mineral distribution of the three successions over the various lithologies. The different minerals found in the mudstones are shown in Table 17.

Table 17: The mineral distribution in the mudstones of the different successions.

Minerals	Full succession	Partly weathered	Middle Ecca
Quartz	■	■	■
Kaolinite	■	■	■
Siderite	■		
Calcite	■	■	
Muscovite	■	■	■
Rutile	■	■	■
Pyrite	■	■	
Marcasite	■		
Hematite	■		
Apatite		■	
Pyrrothite		■	
Feldspar			■

The mudstones have both neutralising and acid generating potentials which are associated with their mineral chemistry. The mineral chemistry of the sandstones from the three successions appears to be relatively similar with minor exceptions for hematite, ilmenite and feldspar (Table 18).

Table 18: The mineral distributions found in sandstones of the different successions.

Minerals	**Full succession**	**Partly weathered**	**Middle Ecca**
Quartz	■	■	■
Kaolinite	■	■	■
Siderite	■	■	■
Muscovite	■	■	■
Rutile	■	■	■
Pyrite	■	■	■
Hematite		■	
Ilmenite			■
Feldspar			■

The fact that XRD and XRF were only done on 50 selected samples and not for each and every sample that ABA was done on, limits one on a full detailed comparison between all the samples. Carbonates are expected in the sandstones but on the samples analysed, it was only an accessory minteral in the form of calcite.

On average, the samples acidifying and those with a base potential contain on average similar concentrations of SiO_2. Those acidifying contained 65.7% and those with a base potential 67.8% SiO_2. The values for the samples with a positive NNP, the CaO (2.17%) and MgO (1.10%) versus the samples with a negative NNP (acid potential) were CaO (1.2%) and MgO (0.57%). The samples with an overall base potential contain more CaO and MgO. These values and averages are summarised in *Table 19* with the NNP for an open system for comparison.

XRF analyses were carried out to evaluate the chemical compositions of various lithological units in the study area. The detailed XRF values are in Table 43.

The XRF analyses indicated the major constituents as being SiO_2 and Al_2O_3. This is expected for sedimentary rocks (sandstones, mudstones, siltstones) with mineralisation of quartz, muscovite, feldspar and clay. Fe_2O_3 is found in concentrations between 0.5-17.9%. The values with Fe_2O_3 higher than 10% (marked in yellow) corresponds to the presence of siderite, pyrite and The difference in the Fe_2O_3 concentration is a reflection of the concentration of pyrite and siderite within the analysed material.

The trace analyses (Table 44) that were done on the samples gave an indication of the potential problems that could leach from the material when used for different purposes.

Table 19: Average ABA and XRF values with XRD results (majors)

Sample	initial pH	final pH	NNP (open)	lithology	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Quartz	Kaolinite	Siderite	Calcite	Ankerite/ Dolomite	Pyrite
WGB4A	7.90	1.07	-372.45	ss/coal/mudstone	57.30	36.08	2.01	0.45	0.44	X	XXX		x	x	
WVB4E	7.38	2.06	-70.69		66.97	28.59	1.99	0.13	0.06	XXX	XX				
WGH171	5.78	1.72	-44.06	mudstone	63.20	28.32	2.98	0.25	0.34	XX	XXX				xx
WTB1A	5.28	1.20	-35.52	coal/ss	64.44	30.67	1.43	0.19	0.08	XXX	XX				x
WGC8	7.60	2.31	-29.07	mudstone/coal	44.15	14.69	28.94	8.17	1.47	XX	X	XX	X	xx	xx
WVC3	2.62	1.15	-23.17	coal/ss	68.75	26.32	2.10	0.21	0.36	XX	XX				
WGH169	7.20	1.91	-19.82	ss	94.92	1.26	0.94	0.09	0.15	XXX	xx				
WTB2	7.99	2.63	-15.51	coal/siltstone	78.94	16.71	0.71	0.20	0.13	X	XXX	XX			xx
WRA2B	2.76	1.76	-12.77	coal	63.62	31.75	1.62	0.13	0.54	XXX	XX				x
WGH170	6.77	1.76	-10.12	ss	76.54	20.10	0.90	0.04	0.01	XX	XX				
W13A	8.25	3.07	-9.58	mudstone/coal	67.27	15.87	9.29	3.00	1.62	XX	XX	xx	x	xx	
WGH160	7.00	2.56	-8.72	mudstone	56.83	37.87	0.63	0.17	0.67	X	XXX				
RB51	7.49	2.46	-8.51	mudstone	56.33	20.50	17.92	1.86	1.41	XX	XX	X	xx	x	X
WGB9A	8.36	1.72	-7.46	mudstone/coal	65.38	18.36	10.98	1.27	0.84						
WGB9A	8.36	1.72	-7.46	mudstone/coal	65.78	18.41	10.98	1.26	0.85	XX	XX	X	x	x	x
WTC4A	7.30	2.00	-6.54	coal/mudstone	65.02	30.49	1.00	0.16	0.37	XXX	XX				x
WTB4	7.48	1.52	-5.52	coal/mudstone	28.65	17.24	39.81	10.63	1.74	X	XX		XX	xx	XX
RB18	8.07	3.62	-4.62	shale	65.50	30.93	1.00	0.10	0.07	XX	XX				x
RB24	7.35	3.54	-3.25	mudstone	63.78	33.14	0.72	0.08	0.00	XX	XXX				
RB11	7.37	4.26	-3.21	ss	71.02	24.57	2.32	0.11	0.00	XXX	XX				xx
W1B	8.13	5.42	-2.12	mudstone	79.41	11.56	1.38	0.25	0.59	XXX	XX				
RC10	5.55	2.20	-2.07	ss	79.77	15.65	0.71	0.19	0.04	XXX	X			x	

Sample	initial pH	final pH	NNP (open)	lithology	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Quartz	Kaolinite	Siderite	Calcite	Ankerite/ Dolomite	Pyrite
WGH195	7.22	2.62	-2.01	ss	67.97	28.32	0.52	0.06	0.58	XX	XXX				
WGH192	7.11	2.43	-1.28	siltstone	70.41	22.26	4.14	0.28	1.13	XXX	XX	xx		x	x
WGH182	6.39	2.97	-0.34	mudstone	60.08	34.80	1.15	0.09	0.94	XX	XXX	xx			
WGH172	6.80	3.10	-0.07	mudstone	61.22	34.89	0.72	0.08	0.00	XX	XXX				
W19A	8.06	4.98	-0.07	mudstone/coal	71.63	17.99	4.40	2.63	0.88	XX	XX	xx	xx	x	x
Average	6.95	2.51	-26.15		**65.74**	**23.97**	**5.60**	**1.19**	**0.57**						
RB19	7.04	3.69	1.21	shale	67.97	24.91	4.94	0.14	0.07	XXX	XX	xx			
WGH181	6.80	3.84	4.73	mudstone	51.45	33.36	11.75	0.20	0.11	X	XXX	X			
RB29	7.00	5.95	5.78	ss	77.95	18.92	1.01	0.46	0.15	XXX	XX	x	x	x	
WVC4A	3.39	3.08	16.75	ss/mudstone	58.02	33.31	0.48	2.37	1.10	XX	XX				
RB38	7.60	3.37	23.04	ss	66.75	29.08	0.96	0.11	0.01	XX	XXX	x			
WGB8E	8.13	4.44	29.58	mudstone	49.80	16.33	24.49	6.10	1.86	X	XX	XX	X	xx	
WGC10B	7.53	4.41	32.31	mudstone/coal	68.12	20.94	5.40	1.43	1.12	XXX	XX		x	x	x
W15A	8.30	8.01	36.83	mudstone/coal	71.34	17.41	6.13	2.16	2.80	XX	XX	xx	xx	xx	
WGH165	7.86	5.93	46.87	siltstone	81.41	9.66	1.63	3.01	1.23	XXX	X		x	x	x
W16A	8.53	7.88	50.83	mudstone/coal	67.61	17.49	7.65	2.49	2.84	XX	XX	xx	xx	xx	
RC2	8.48	2.54	57.83	ss	83.66	7.75	2.08	4.42	0.14	XXX	X	x	xx		x
W10B	8.39	8.26	86.95	mudstone	67.38	15.68	7.12	5.08	2.20	XX	XX	xx	xx	xx	x
WGH193	8.08	5.57	128.31	siltstone	70.48	22.11	4.18	0.28	0.67	XXX	XX		x	x	xx
Average	7.47	5.15	40.08		**67.84**	**20.53**	**5.99**	**2.17**	**1.10**						

6 ABA RESULTS

Static Acid Base Accounting was performed on samples to provide results for the Acid Potential (AP) and the Neutralising Potential (NP) of the various samples. From the results, a summary of the closed NNP, NPR (Neutralisation Potential Ratio) and the S% were given which better explains NP-AP of the coal/rock samples. The results show that acid-neutralising potential exists for the analysed samples of different lithologies and successions. The ABACUS programme was used to draw the plots to better represent the results.

The straight line for the NPR versus the % Sulphide-S is seen in the majority of the figures. This phenomena is due to a zero base potential value for those samples. NPR is calculated by dividing the acid neutralisation potential by the acid generation potential (NP/AP).

The circles in the map indicate the 4 different areas in which the samples originates. Mining currently only exsist at the Grootegeluk.

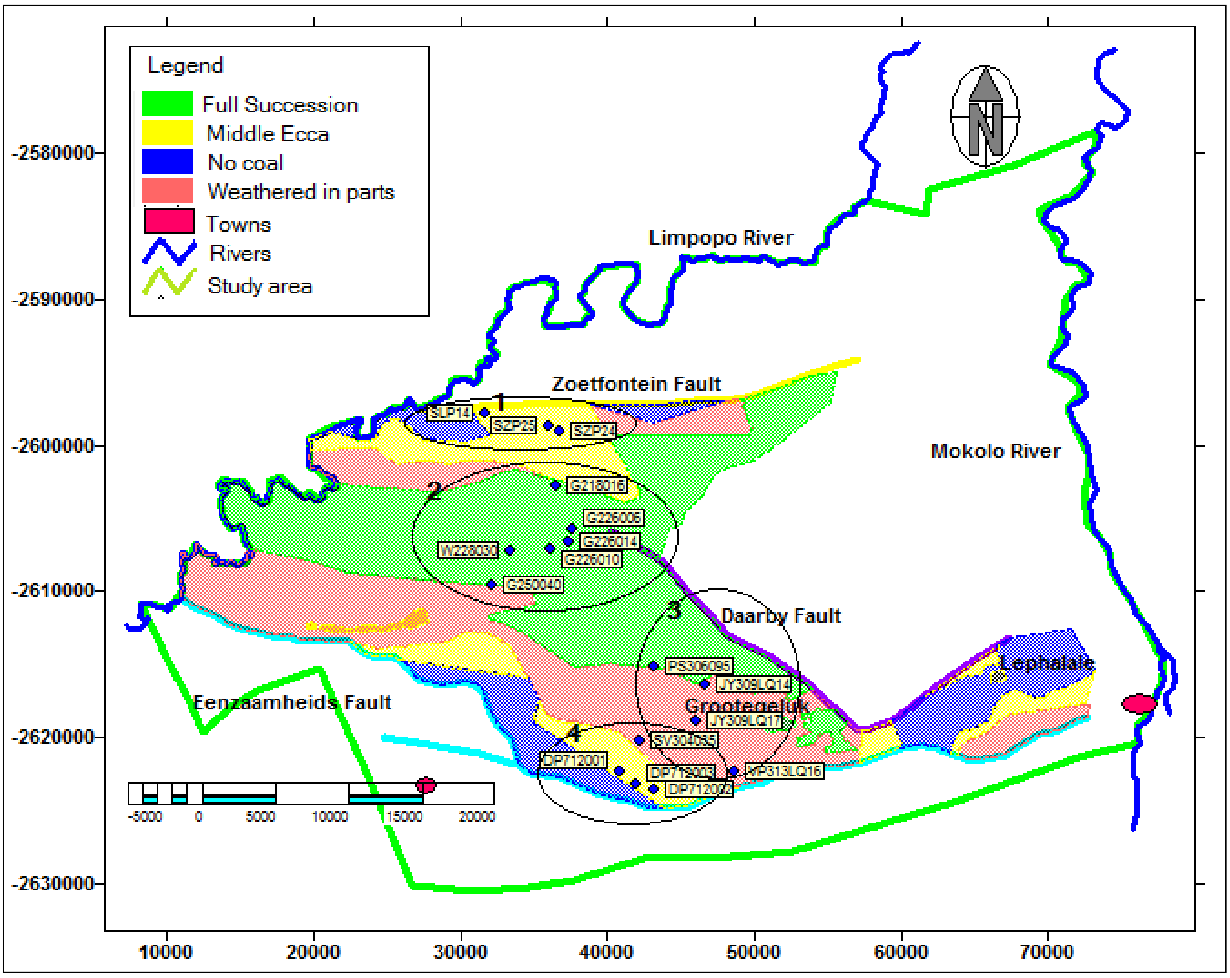


Figure 41: Location of companies in the study are where samples were collected: 1 – Resgen, 2 – Sasol, 3 – Grootgeluk, 4 - Sekoko.

6.1 Sasol

Samples from this area (area 2, Figure 41**)** were taken from the Full succession and consist of rocks from the coal, interburden and overburden samples. Overburden samples consist of mudstone while interburden materials have coal, sandstone and shale samples. Static ABA tests were performed on 231 individual samples from Sasol. Sasol samples were located in the Full succession from the overburden, interburden and coal samples.

6.1.1 Initial and final pH

The initial and final pH results are summarised in detail in Table 46 (Appendix). The majority of the results indicate a high risk for acid generation, with the final pH of 69.7% samples below 3.5 upon complete oxidation. The minimum, maximum and mean of the initial and final pH results and pH percentage distribution of the Sasol samples are shown in Table 20.

Table 20: Statistics from the initial and final pH results of the Sasol samples.

Parameter	Initial pH	Final pH
Minimum	2.50	0.77
Maximum	8.59	8.38
Mean	6.93	3.11

Final pH	percentage
>5.5	16.45
3.5 - 5.5	13.85
<3.5	69.70

From the static tests done on the samples received from the Sasol mining area, it is clear that for the majority of samples, the results indicate values that are within the ±20kg/tonne NNP (Figure 42). The Sasol samples also contained coal, whereas for the other regions the coal was removed by the mining companies.

The static test results (pH vs NNP) are plotted and indicated in Figure 42. The statistics from this graph are summarised in (Table 21) with the majority of samples falling in the area (-20 - +20 kg/tonne NNP) of uncertain outcome. Samples in this uncertain zone of ABA results needs futher testing such as kinetic tests to give clearer answers on the outcome of the samples in the ±20 NNP area.

Table 21: Percentage Open and Closed NNP distribution of the Sasol samples.

NNP outcome	closed	open
nnp > 20 - BP samples	9.5	13.9
uncertain - within ±20	43.1	53.7
< -20 nnp - AP samples	47.4	32.5

The Sasol samples also contained coal, whereas for the other regions the coal was removed beforehand by the mining companies.

The ABA analyses (Figure 42) showed that the coal samples from the full, middle and partly weathered successions, along with mixtures of mudstone and coal, have the potential to generate acid. The sandstone samples have a higher acid generating potential. Mudstone from the partly weathered areas showed an excess neutralising potential.

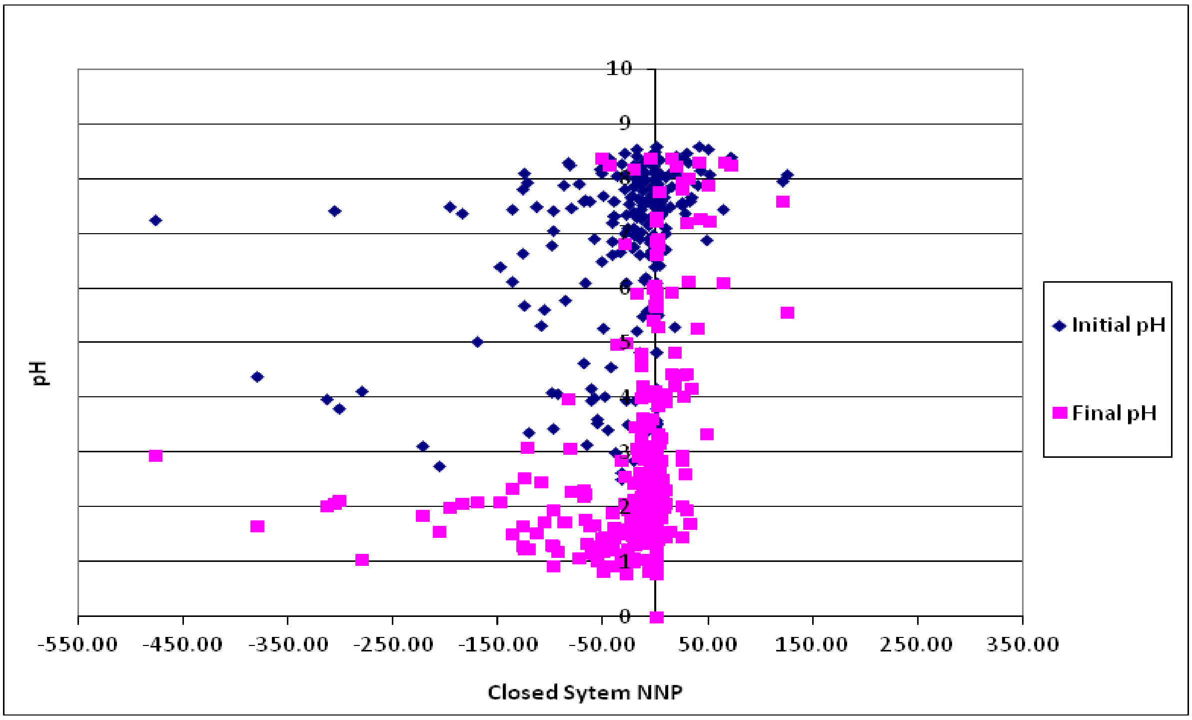


Figure 42: Closed NNP plotted versus initial and final pH for Sasol.

6.1.2 Summary: Sasol ABA

The NPR of the samples is indicated in Figure 43 and Figure 44. Samples in Figure 43 indicate that some of the samples plot above the blue (NPR=4) line of possible acidification and represents the samples with a neutralising potential. Samples plotting below the red (NPR=1) line are those with an acid potential. The majority of the samples have a ratio of between 1:1 to 4:1 NPR. For a sample to produce and sustain acidity for a significant period, 0.3% Sulphide-S is needed in the absense of any NP. Samples that are plotted in Figure 44 with a NPR less than 4 and more than 1 (between the red and green lines) are the samples that have an uncertain outcome. 32.5% of the samples pose a high risk of acid generation from the interburden and coal samples. 53.7% has a low acid generating risk for the interburden samples. The deeper Vryheid Formation (Middle Ecca) consists of most samples that are acid generators, while the higher Grootegeluk Formation contains more carbonaceous material.

The straight line on the graphs is obtained in ABACUS where the base potential values are close to zero.

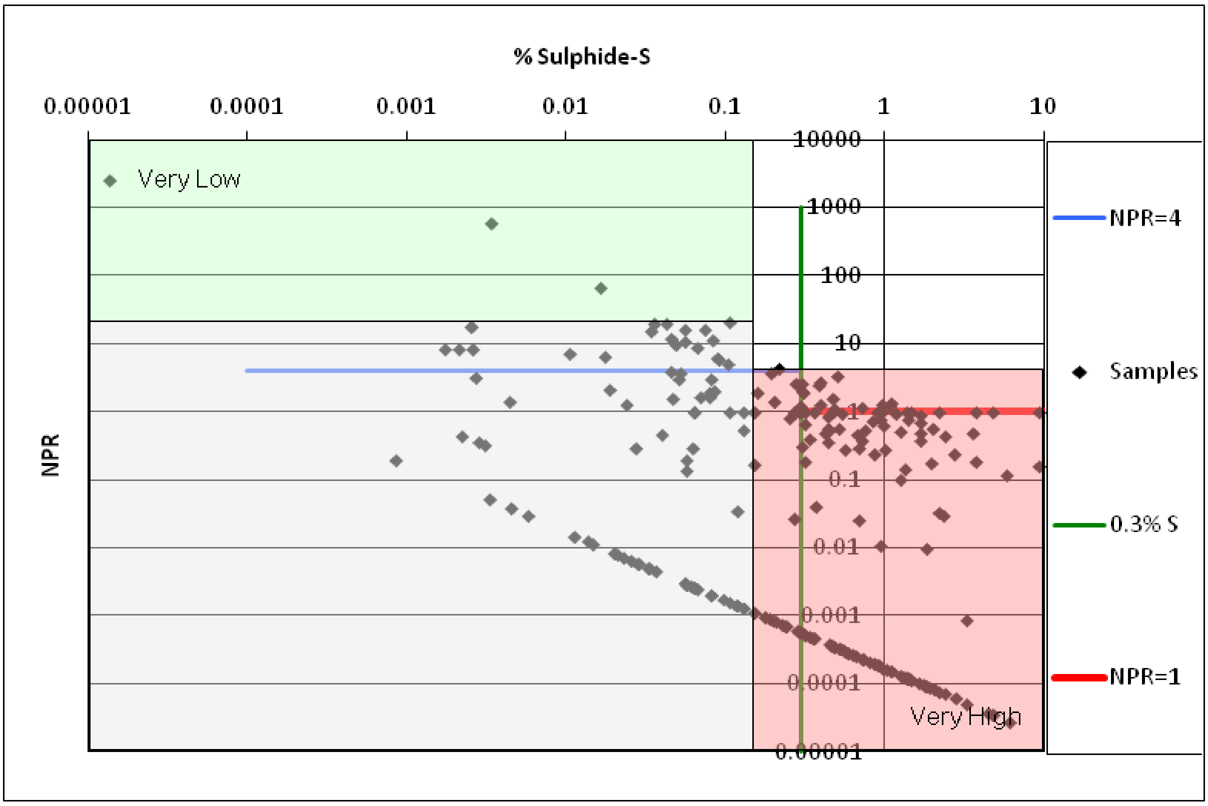


Figure 43: NPR versus % Sulphide-S for the Sasol samples.

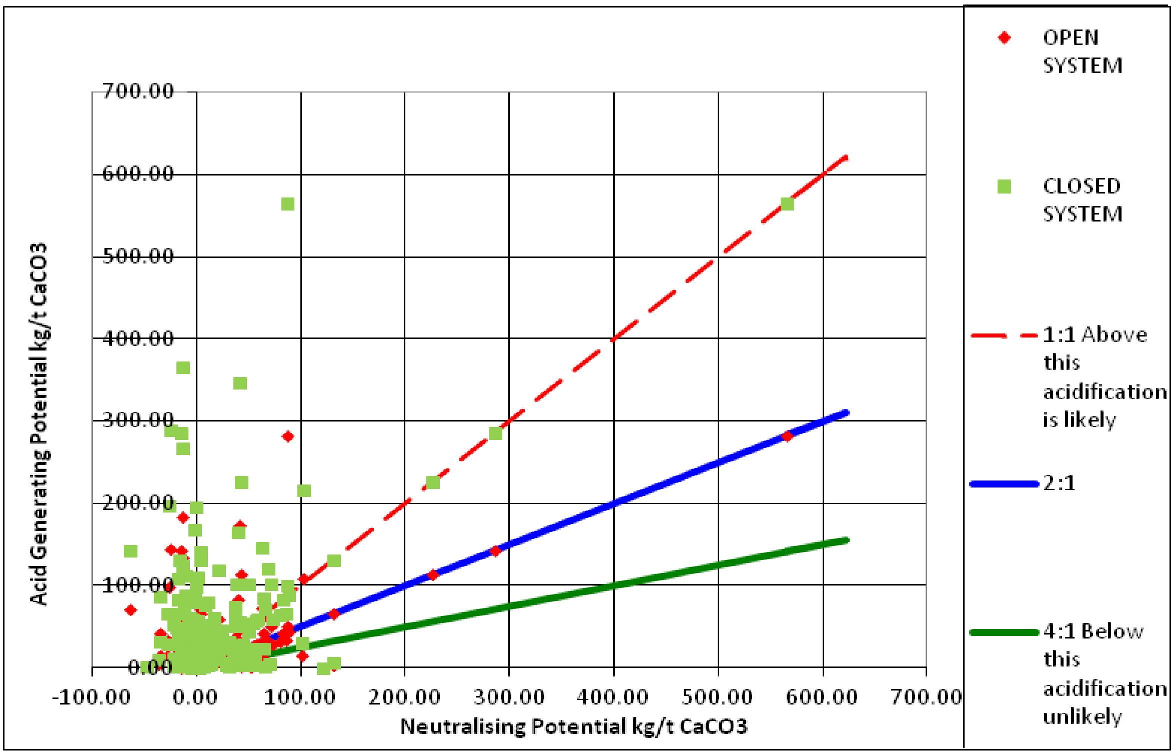


Figure 44: NP versus AP (NPR) for the Sasol samples.

6.2 Resgen

A total of 148 samples from Resgen (zone 1, Figure 41) were collected and analysed from the farms Zoetfontein and Lisbon, and a detailed table of the results can be seen in Table 48. Resgen samples were collected from the Middle Ecca and taken from various depths between 1 to 72 m. The sample material included interburden.

6.2.1 Initial and Final pH

Samples with a medium to high risk of acid generation occur in almost equal proportions. Over 7.4% of the Resgen samples have an excess of acid potential which classifies the samples as having a higher risk for acid generation. Approximately 8.7% of the samples have a higher potential to neutralise acid. The remaining 83% have an inconclusive outcome which has to be verified with other tests. The minimum, maximum and mean of the initial and final pH results are shown in Table 22 with the final pH of 45.3% samples below 3.5 upon complete oxidation. The final pH of the samples varies mostly according to depth; samples that were taken from shallow depths between 1 to 25 m have a final pH of above 5.5. The few samples at depths of 14 to 25 m have pH values of below 3.5. Samples that were taken at greater depths of between 31 to 72 m have a higher risk of acid generation. The higher risk of acid is associated with the abundance of sandstone found at greater depths in the Vryheid Formation, containing more of the mineral pyrite.

Table 22: Statistics from the initial and final (oxidised) pH results of the Resgen samples.

Parameter	**Initial pH**	**Final pH**
Minimum	3.32	1.32
Maximum	9.03	8.56
Mean	7.08	4.10

Final pH	**percentage**
>5.5	24.3
3.5 - 5.5	30.4
<3.5	45.3

The NNP for both closed and open systems is summarised in detailed in Table 48. (Appendix). The negative values indicate acid production while positive values indicate the samples with an acid neutralising (base) potential. The NNP (for a closed system) and the initial and final pH results are plotted in (Figure 45), indicating that there is a wide distribution of acid and base potential (Table 49) (Appendix). The closed and open NNP for most of the samples (83.8%) ranges between (-20 to 20 kg/tons CaCO3) which requires further tests to be carried out as the results are uncertain. The percentage of samples plotting in the different NNP areas are summarised in Table 23.

Table 23: Percentage NNP distribution of the Resgen samples.

NNP outcome	Closed (%)	Open (%)
NNP > 20 - NP samples	8.8	11.4
uncertain - within ±20	83.8	81.9
< -20 NNP - AP samples	7.4	6.7

8.8 – 11.4% of the samples have an excess of neutralising potential in a closed and open system. 7.4 – 6.7% have a closed and open NNP (>-20kg/tons CaCO3) and are classified as samples that contain enough sulphide minerals to produce acid.

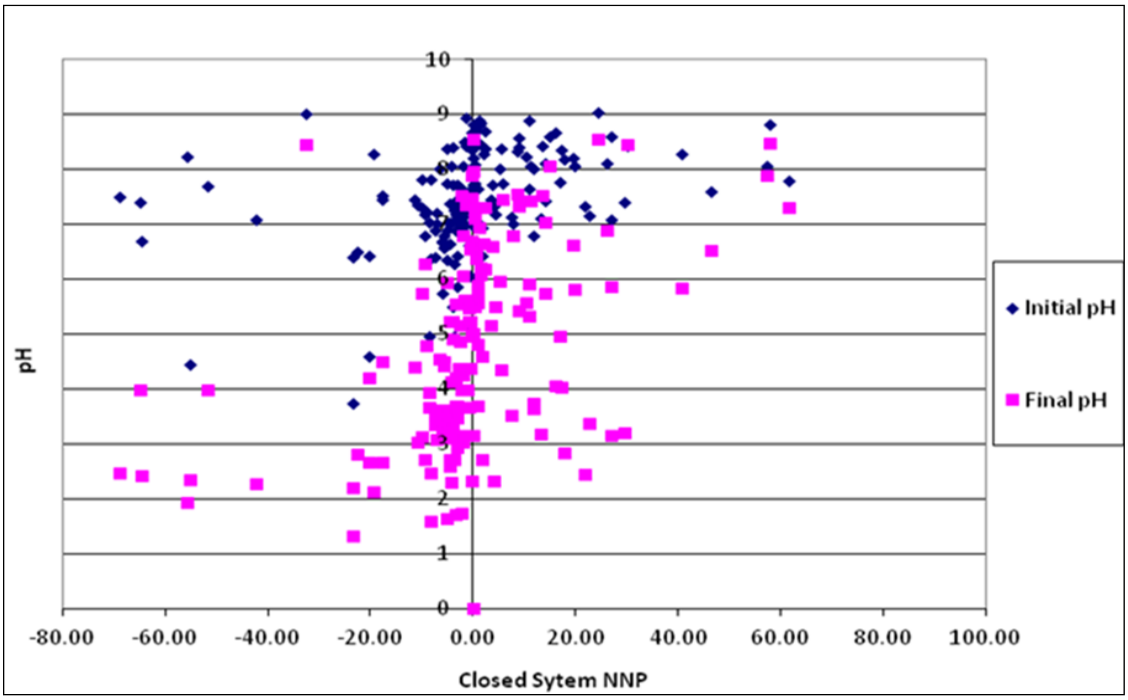


Figure 45: NNP versus initial and final pH for Resgen samples.

The percentage sulphur (% Sulphide-S) determined in the samples are plotted against the Neutralising Potential Ratio (NPR) and presented in Table 49 (Appendix). Figure 46 indicates a low risk of acid production with a high base potential, when compared to samples from Sasol. The NP vs. AP (NPR) for both closed and open systems is illustrated in Figure 47. The majority of the samples exhibit an NPR ratio between 4:1 and 1:1. This classifies the samples as uncertain to become acidic. A few samples have a ratio of <1:1 indicating the likelihood of acid production.

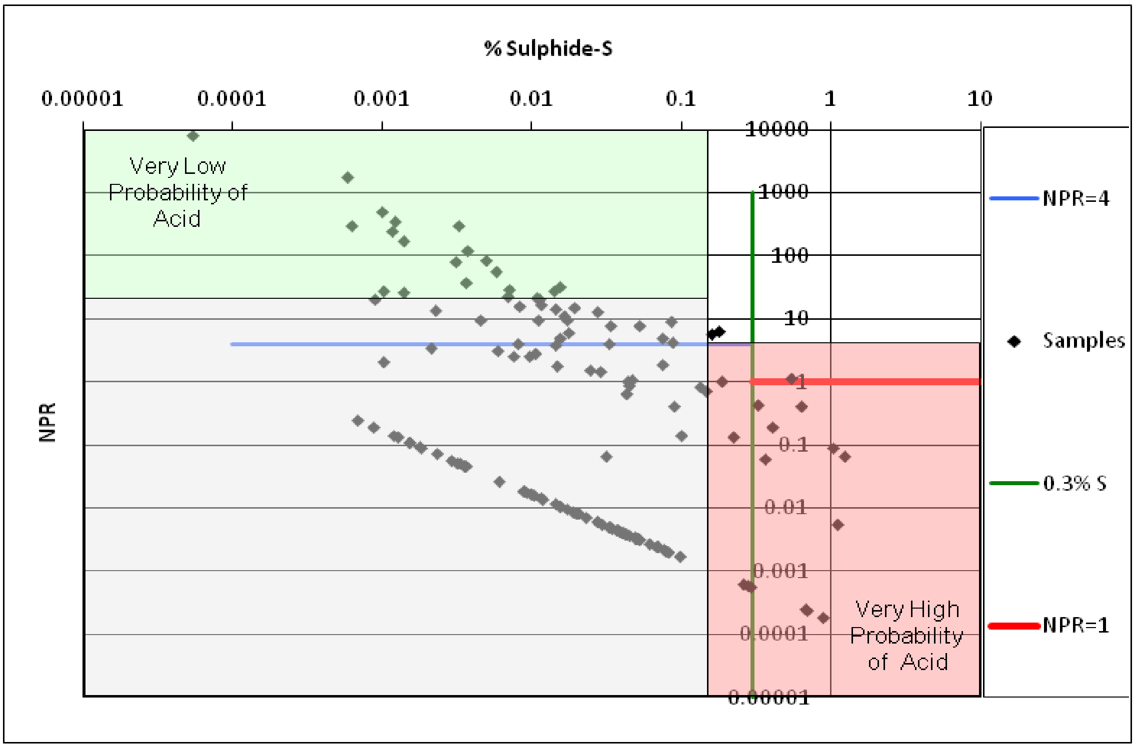


Figure 46: NPR versus %S for the Resgen samples.

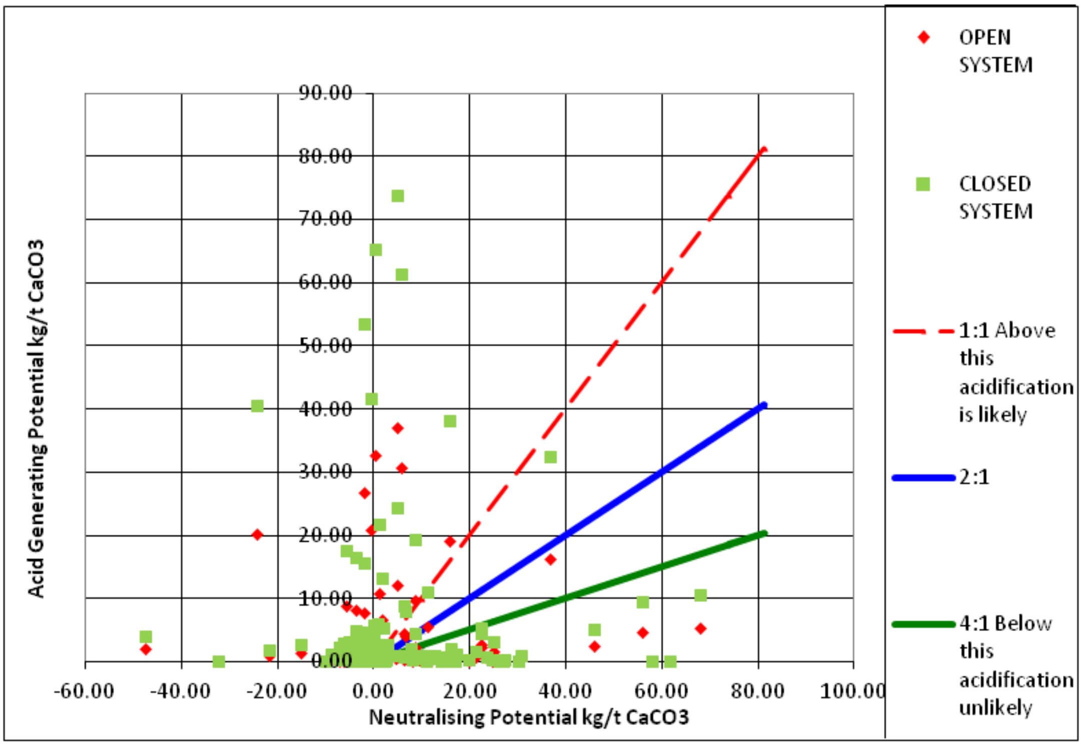


Figure 47: NPR (NP versus AP) for the Resgen samples.

The ABA results indicated that the calcrete, mudstone and shale samples from Resgen had both a neutralising and acid generating potential. The sandstone samples showed inconclusive data which categorises the material as either having an acid or neutralising potential. Mixtures of shale with mudstone and sandstone showed the potential to produce acid. The negative NP values are obtained for samples which are already acidic from the field.

6.3 Grootegeluk

Static ABA tests were performed on 292 Grootegeluk (area 3, Figure 41) overburden samples taken from different boreholes. Overburden samples from Grootegeluk were collected from the three different geological regions, based on weathering of the Ecca. The initial and final pH results are shown as a detailed table in Table 50 (Appendix).

6.3.1 Initial and Final pH of the samples

The majority of the samples have a low risk of acid generation, with only 5.4% samples with a final pH below 3.5. This information and the minimum, maximum and mean of the initial and final pH results from the Grootegeluk samples are shown in Table 24.

Table 24: Statistics of the initial and final pH results from the Grootegeluk samples.

Parameter	**Initial pH**	**Final pH**
Minimum	4.69	1.79
Maximum	9.42	8.73
Mean	7.4	5.67

Final pH	**percentage**
>5.5	51.4
3.5 - 5.5	43.2
<3.5	5.4

Only 5.4% of the samples show a high acid risk. 84.9% of the Grootegeluk samples are in the -20 - +20 NNP grey area (Table 25). The remaining 15% have a base potential and can be considered to counteract AMD.

Table 25: NNP statistics of the Grootegeluk samples for Closed and Open systems.

NNP outcome	**Closed (%)**	**Open (%)**
NNP > 20 - NP samples	15.1	14.7
uncertain - within ±20	82.9	84.3
< -20 NNP - AP samples	3.0	1.0

The detailed NNP for both closed and open systems is shown as a detailed table in Table 50 (Appendix). Over 82 - 84% of the results show a NNP range of -20 to 20 kg/tons $CaCO_3$ which indicates the inconclusive nature of the samples. Other samples have a NNP value (21 to 310 kg/tons CaCO3) that shows that the samples have an access in neutralising potential (Figure 48). Minerals with a neutralisation potential in the Waterberg Coalfield from the Karoo Supergroup have been identified as calcite and dolomite/ankerite.

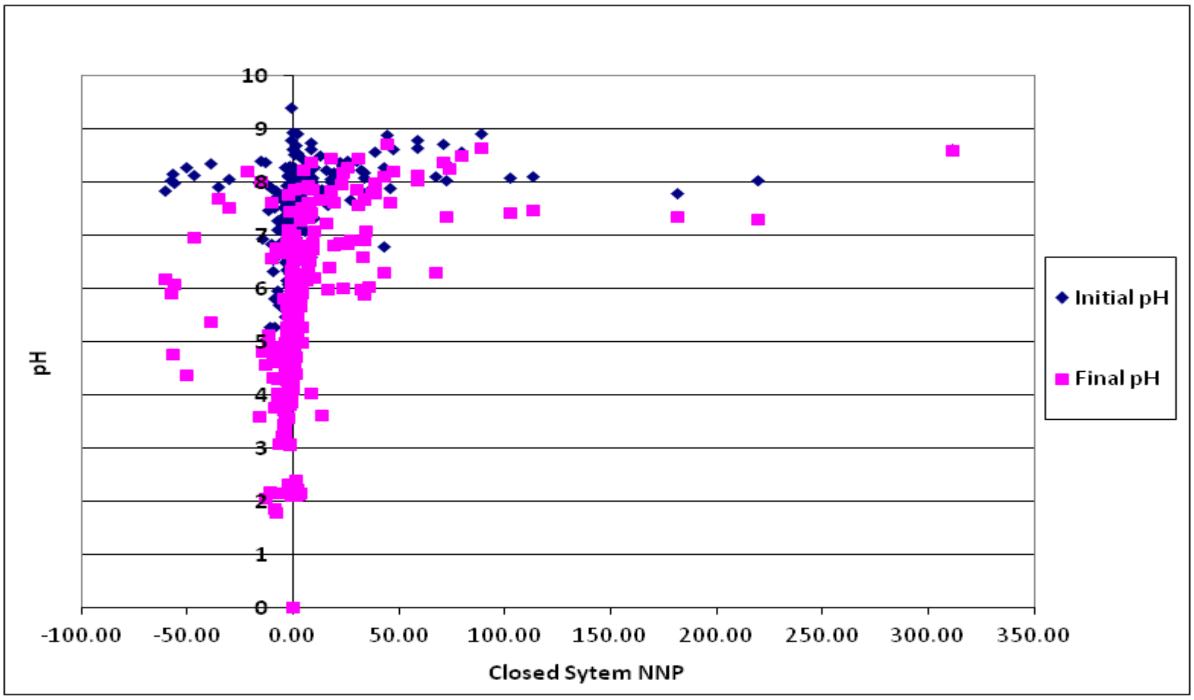


Figure 48: NNP versus initial and final pH for Grootegeluk.

Figure 49 indicates that the majority of the samples have less than 0.3% Sulphide –S. The NPR for both closed and open systems is shown in Figure 50. The majority of the samples exhibit an AP-NP ratio of greater than 4:1; which indicates the unlikelihood for the samples to become acidic (negative NNP). A few samples with a ratio of less than 1:1 highlight the likelihood of samples to generate acid. The overburden samples from Grootegeluk consist of more neutralising than acid producing minerals and the NPR results of the Grootegeluk samples are tabled in detail in Table 51. The overburden samples from Grootegeluk indicated the highest base potentials.

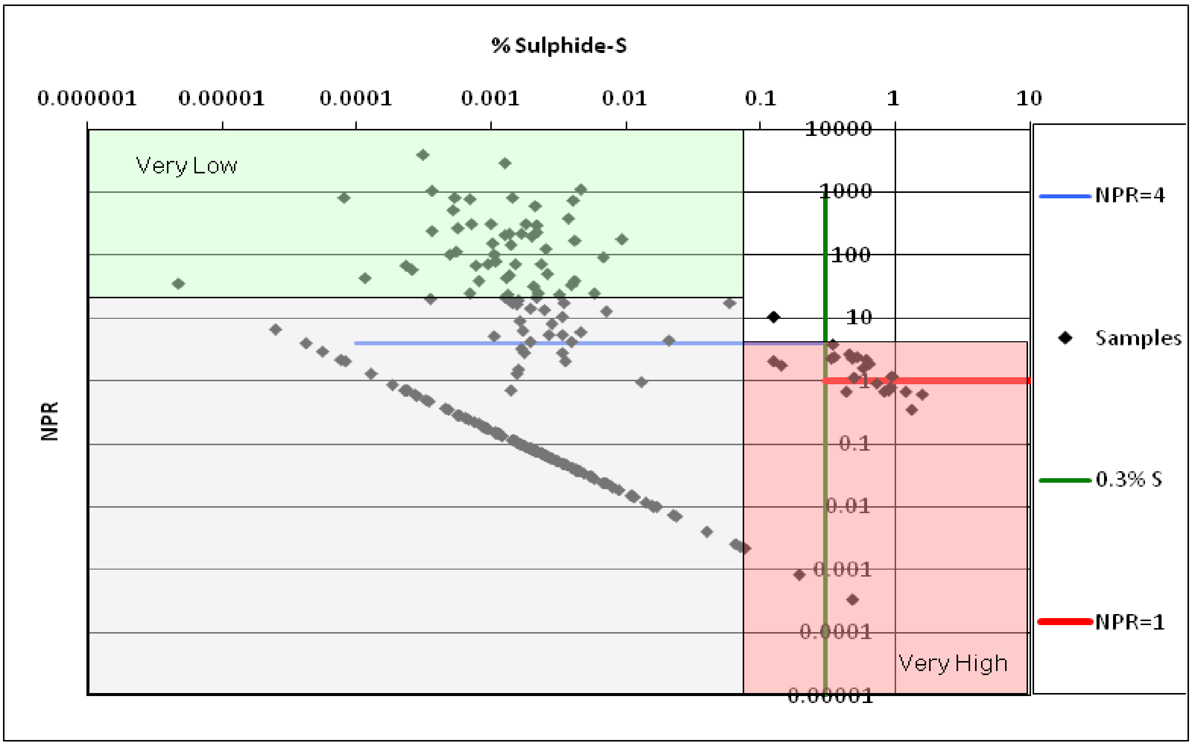


Figure 49: NPR versus %S for Grootegeluk.

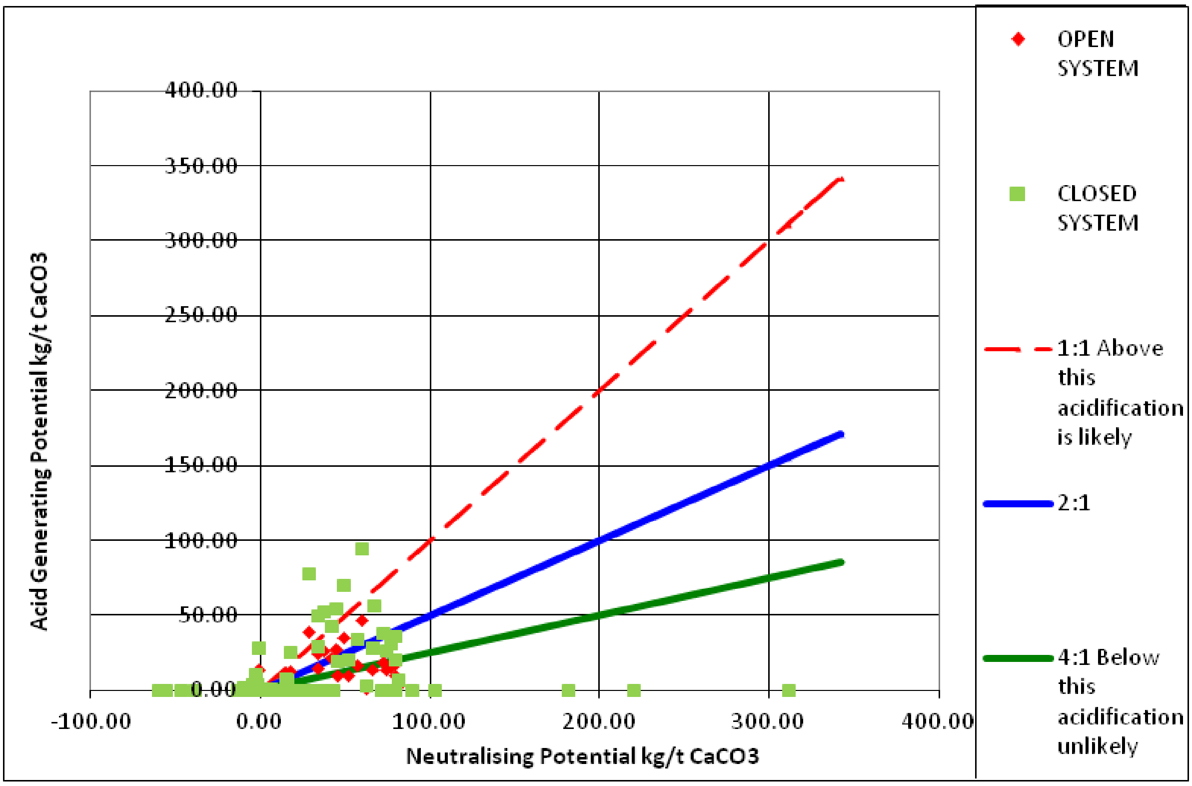


Figure 50: NPR (AP versus NP) for Grootegeluk.

The ABA analyses of clay, shale and sandstone samples from the partly weathered and full successions indicated neutralising potential. On the other hand, shale samples from the Full succession have strong base producing potential. All the samples taken close to the coal layers have a strong acid generating potential.

6.4 Sekoko

The samples collected from Sekoko comprise overburden and interburden selected from drilling cores taken from the Middle Ecca. Static ABA tests were performed on 41 individual samples from Sekoko. The initial and final pH results are shown as a detailed table in Table 52.Sampling was done at various depths of between 23 m and 141 m and from the areas which are partly weathered at 27 to 61 m.

6.4.1 Initial and Final pH

The majority of the samples (90%) have an initial pH of above 6. The minimum, maximum and mean of the initial and final pH results of the Sekoko samples are shown in Table 26. The lowest final pH value of the samples is at 1.44. Over 55.8% of the Sekoko samples have an excess of acid potential and are classified as having a high acid generating risk, while about 2.3% of the samples have a higher base potential. The remaining samples are inconclusive and require further testing.

Table 26: Statistics of the initial and final pH results of the Sekoko samples.

Parameter	Initial pH	Final pH
Minimum	3.04	1.44
Maximum	7.46	6.83
Mean	6.26	2.47

Final pH	percentage
>5.5	9.3
3.5 - 5.5	34.9
<3.5	55.8

Only 11.6% of the samples show a high acid riskwith 86% in the -20 - +20 NNP grey area (Table 27). The remaining 2.3 % have a base potential and can be considered to counteract AMD

Table 27: NNP statistics of the Sekoko samples for Closed and Open systems.

NNP outcome	Closed (%)	Open (%)
NNP > 20 - NP samples	0	2.3
uncertain - within ±20	86	86.1
< -20 NNP - AP samples	14	11.6

The NNP for both closed and open systems is shown as a detailed table in Table 53. The NNP (for a closed system) as well as the initial and final pH results indicate that a few samples have a limited neutralising potential (Figure 51).

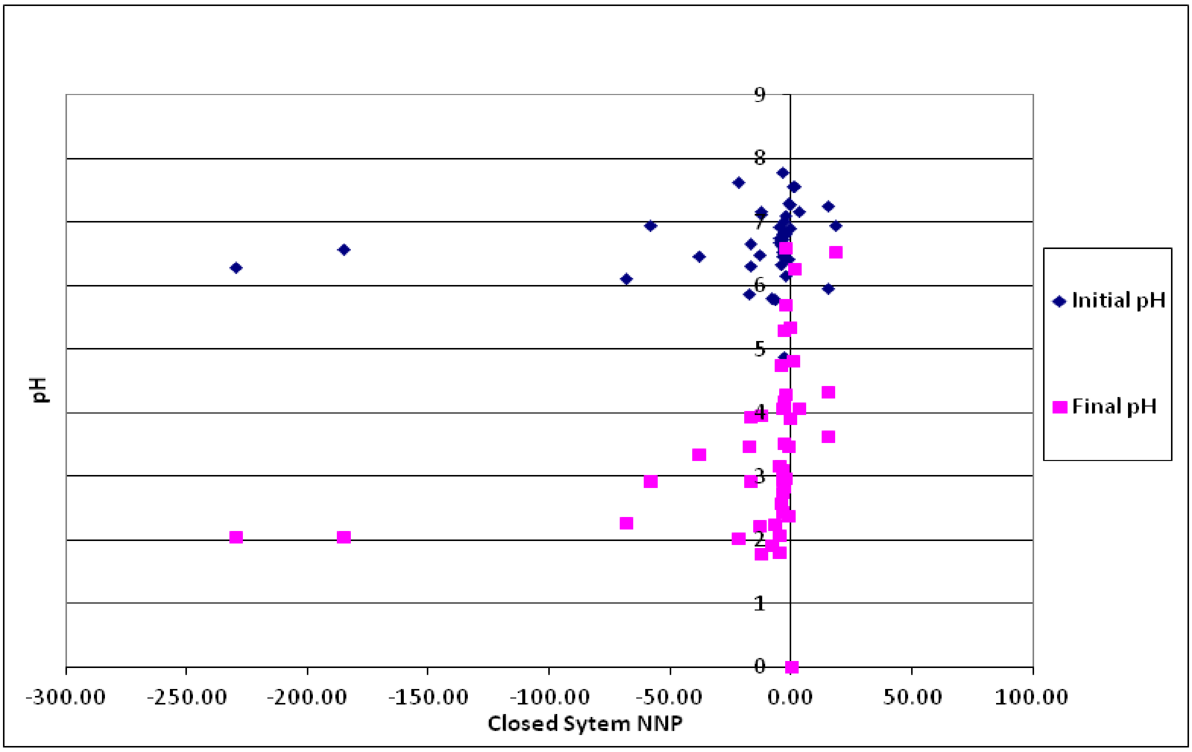


Figure 51: NNP versus initial and final pH for Sekoko.

Figure 53 shows the ratio of AP vs. NP for the open and closed system where most of the samples plot with a NPR smaller than 1:1. The samples have the likelihood of turning acidic upon oxidation. A few samples have Sulphide –S values of less than 0.3%. The Sekoko samples taken from the Middle Ecca consisted of medium to coarse grained sandstone and in most cases contained pyrite mineral. The % Sulphide-S against the NPR (Figure 53) indicated a limited quantity of samples that have a high acid producing risk. The NPR (Figure 52) indicates the limited base potential of some of the samples. The ABA results for sandstone and mudstone samples indicated an acid producing potential.

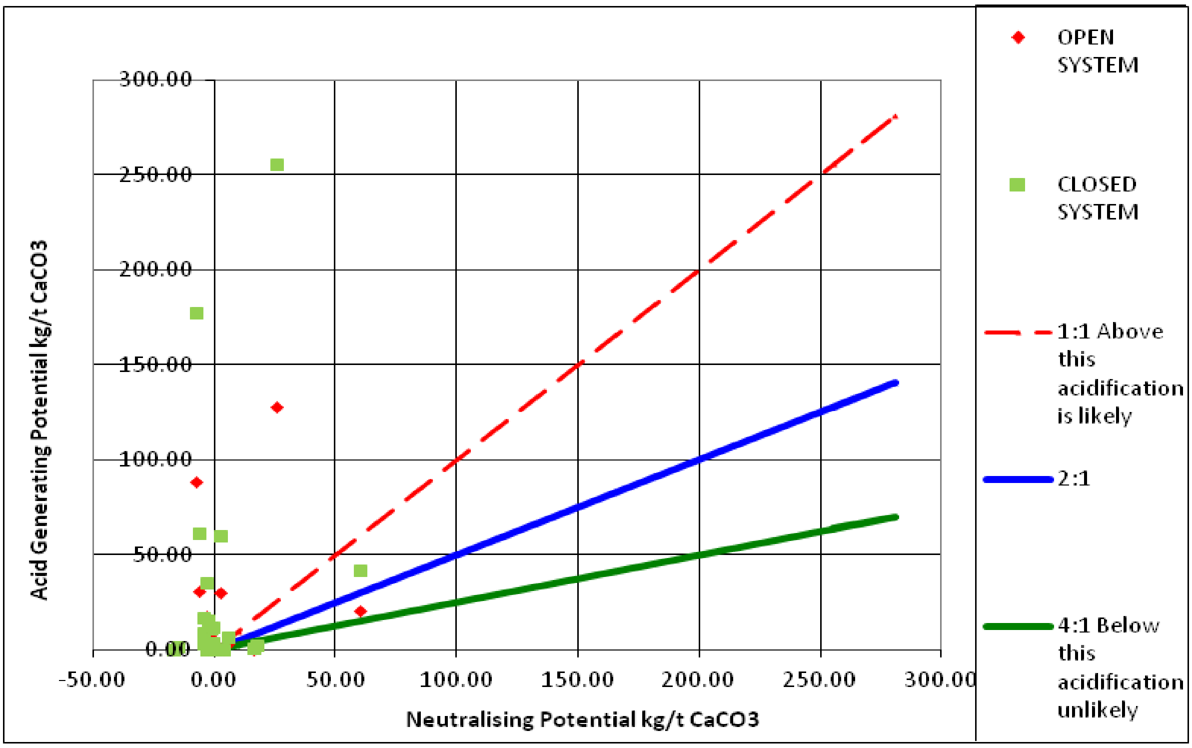


Figure 52: NPR for Sekoko.

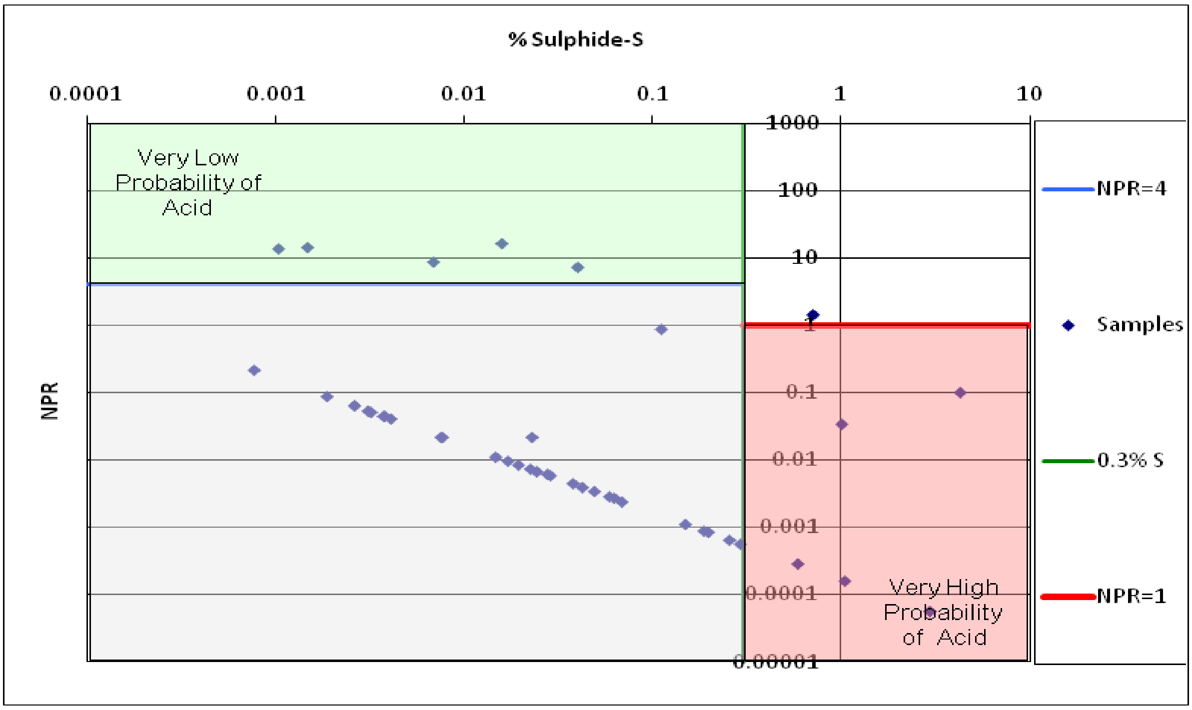


Figure 53: NPR versus % S for Sekoko.

6.5 Composite Samples

Static ABA tests were performed on 119 composite/discard samples taken from different fractions of the processing plant discard. The fractions consist of float and sink densities and ranges between D1.80-S2.20 and D2.10-S2.20. The samples were from different zones 1 to 10. Table 55 and Table 55 give an indication of SO_4 values after complete oxidation. Zones 1, 2, 3 and 4 from the Middle Ecca have the highest average of SO_4 which is a phenomenon that was noted throughout the analysis in other areas of the study. The acid potential results are summarised in Table 56.

6.5.1 Initial and Final pH

The initial and final pH results indicate that all the samples have a very high risk for acid generation. Approximately 92% of the samples have a high acid risk potential while the remaining 6% have a medium risk to generate acid. The minimum, maximum and mean of the initial and the final pH results from the Composite samples are shown inTable 28. Samples with higher densities D2.10-S2.20 appear to have lower final pH values than lower density D1.90-S2.20 samples.

Table 28: Statistics of the initial and final pH results from the Composite samples.

Parameter	Initial pH	Final pH
Minimum	3.04	1.44
Maximum	7.46	6.83
Mean	6.26	2.47

Final pH	percentage
>5.5	1.68
3.5 - 5.5	5.88
<3.5	92.44

Only 5.88% of the samples are in the -20 - +20 NNP grey area (Table 29) and 1.68% have a base potential.

Table 29: NNP statistics of the Composite samples for Closed and Open systems.

NNP outcome	Closed (%)	Open (%)
NNP > 20 - NP samples	0.84	0.84
uncertain - within ±20	11.76	29.41
< -20 NNP - AP samples	87.4	69.75

The NNP for both closed and open systems indicates that negative values indicate acid mine production while positive values will indicate samples with acid neutralising (base) potential. The NNP (for a closed system) and the initial and final pH results are plotted in a graph, indicating the high acid generating potential of the samples in Figure 54.

The percentage sulphur (% Sulphide-S) determined in the samples is plotted against the Neutralising Potential Ratio (NPR) (Figure 55). The graph shown in Figure 55 indicates that the majority of the samples have an acid generating potential with very high sulphur content.

The NPR is additionally indicated in a plot of NPR (NP/AP) graph (Figure 56). All the samples submitted for ABA analyses have high acid generating potentials.

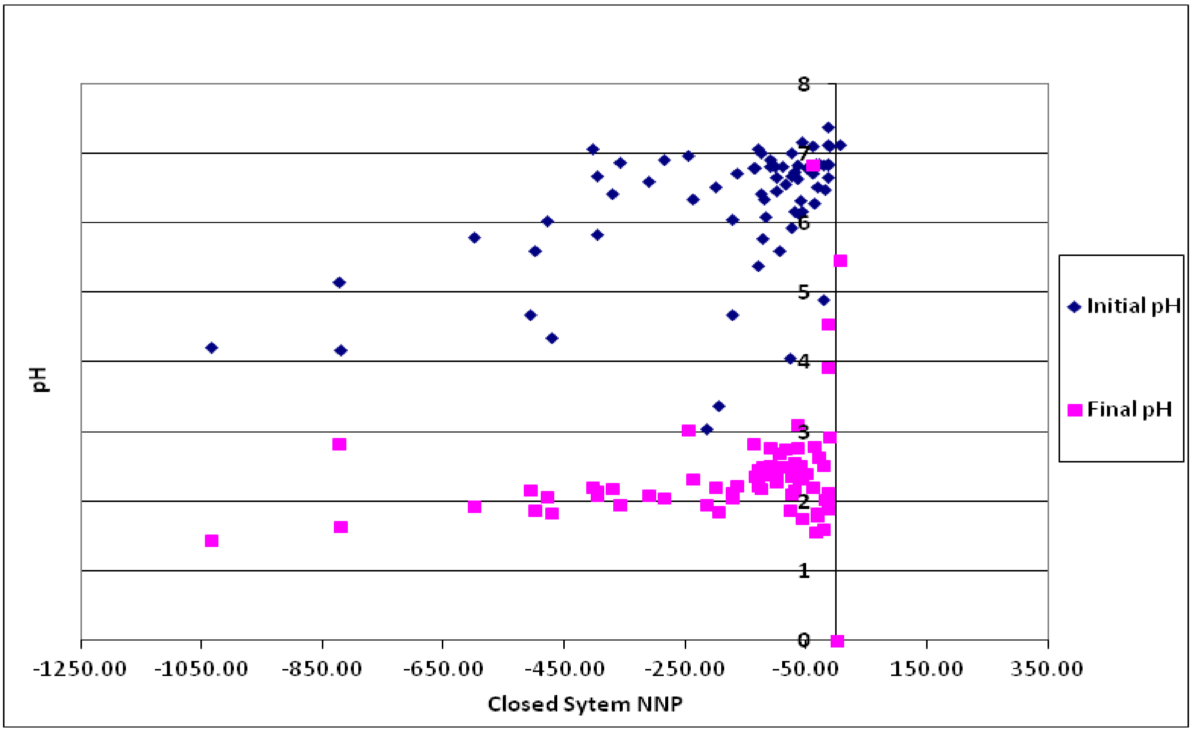


Figure 54: NNP versus initial and final pH for Composite samples.

The percentage sulphur (% Sulphide-S) determined in the samples is plotted against the Neutralising Potential Ratio (NPR) (Figure 55). The graph shown in Figure 55indicates that the majority of the samples have an acid generating potential with very high sulphur content.

The NPR is additionally indicated in a plot of NPR (NP/AP) graph (Figure 56). All the samples submitted for ABA analyses have high acid generating potentials.

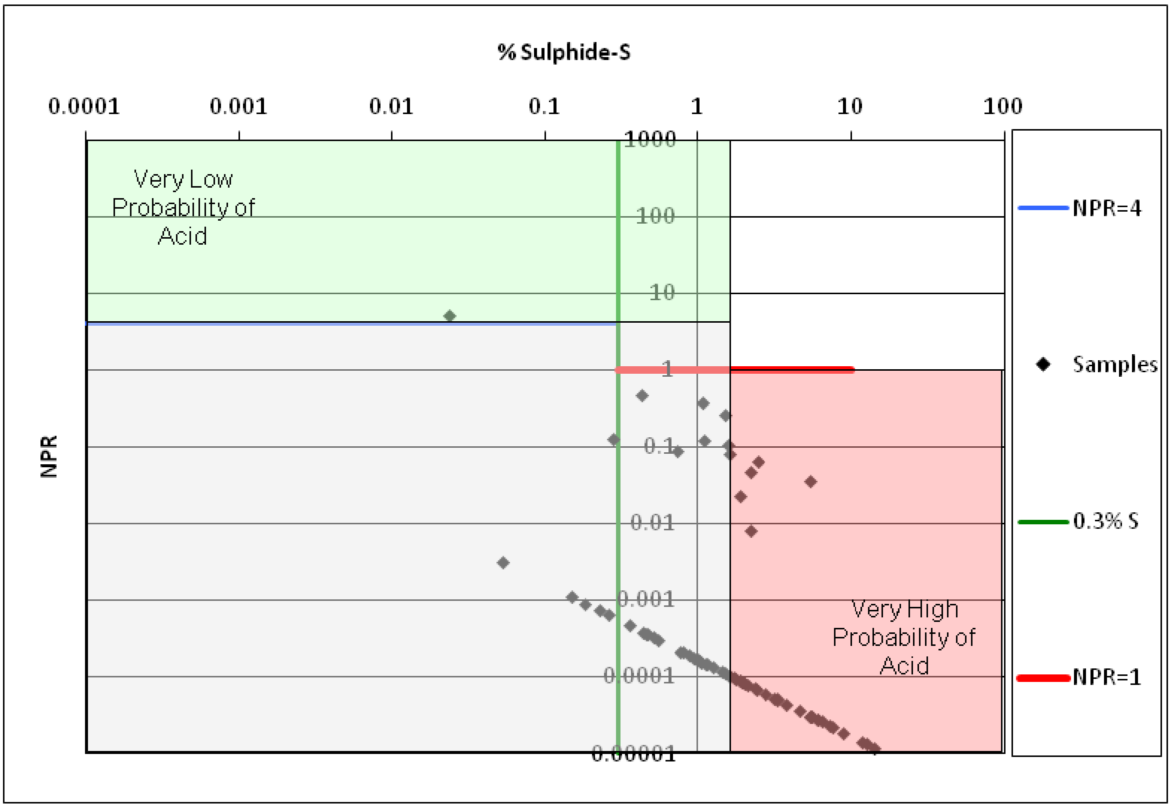


Figure 55: NPR versus %S for Composite samples.

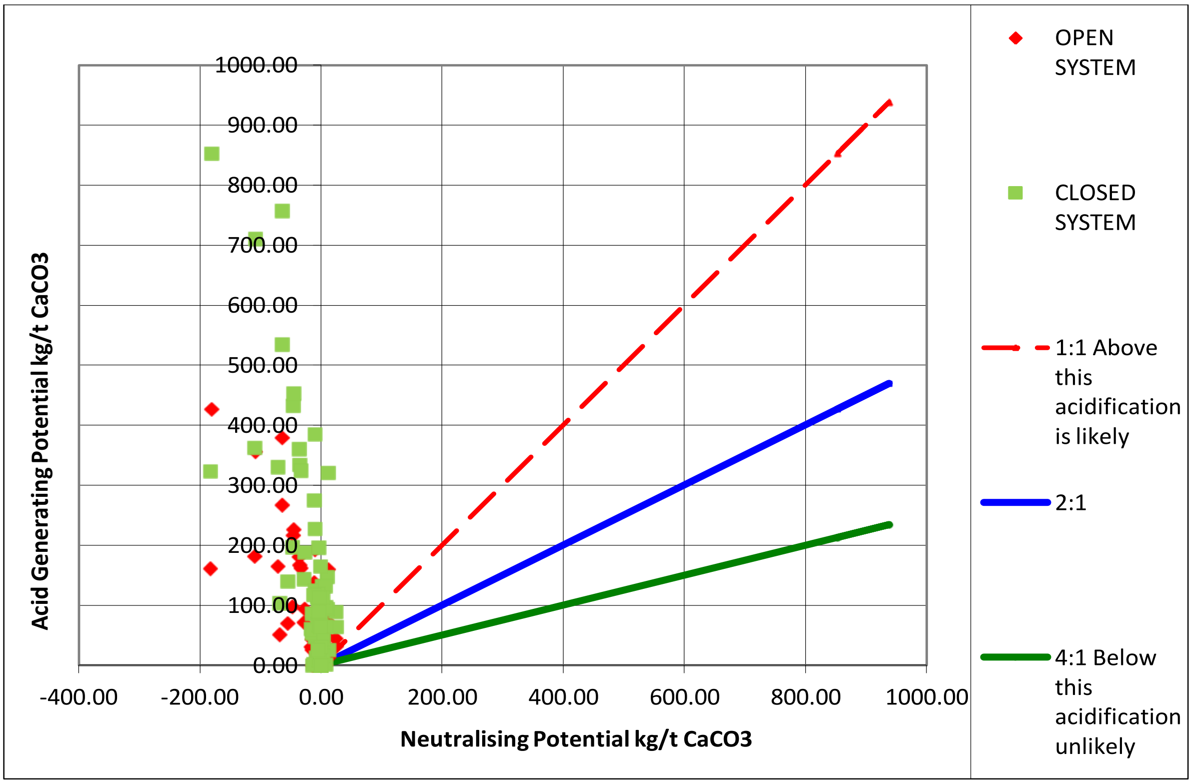


Figure 56: NPR (AP versus NP) for Composite samples.

The average NNP of the discards from the different zones are plotted in Figure 57.

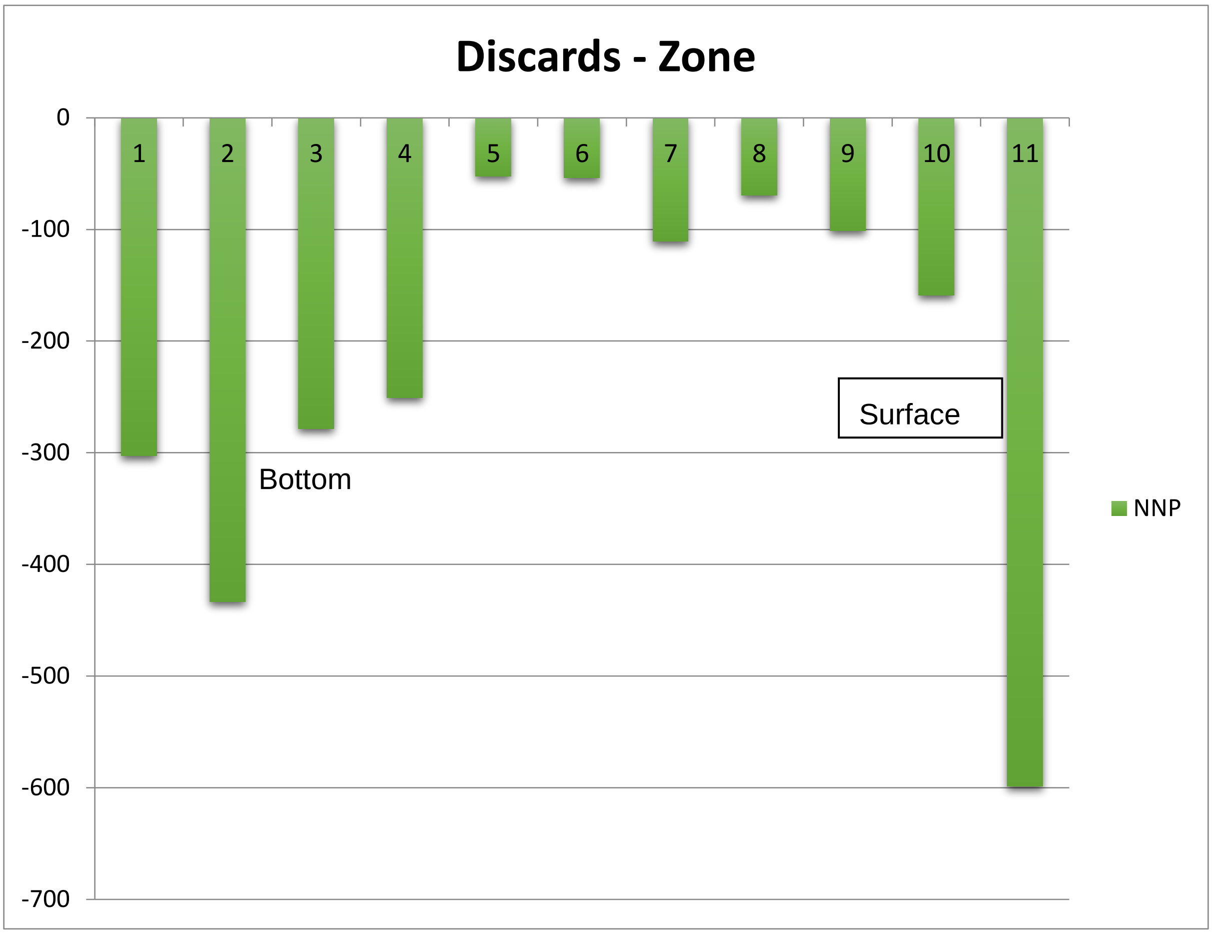


Figure 57: Average NNP values of the discards in the different zones.

The discard from the deeper coal zones (1-4) contain a higher acid potential. Unfortunately, only one sample from zone 11 (top coal layer) was received. This specific value might be an outlier since it is expected that higher acid potential samples are in the deeper zones.

6.5.2 Comparison

The majority of the samples from Sasol are classified as having a NPR of less than 1, implying that the samples have a high potential for acid generation. The difference in NPR is noticed with the Resgen samples of which the NPR is > 4 and therefore classifies the samples as having a low probability of acid generation. The Resgen samples also have a low sulphide percentage (less than 0.3) which is too low to sustain acid generation. The Sekoko samples show a different trend in this regard as some samples indicate a high probability of acid generation, while others indicate a low probability of acid generation. Samples from Grootegeluk have a NPR of > 4, which classifies the samples as having a low probability of acid generation. The composite samples that predominantly consist of processing plant discard have a NPR of less than 1, indicative of a high potential to produce acid.

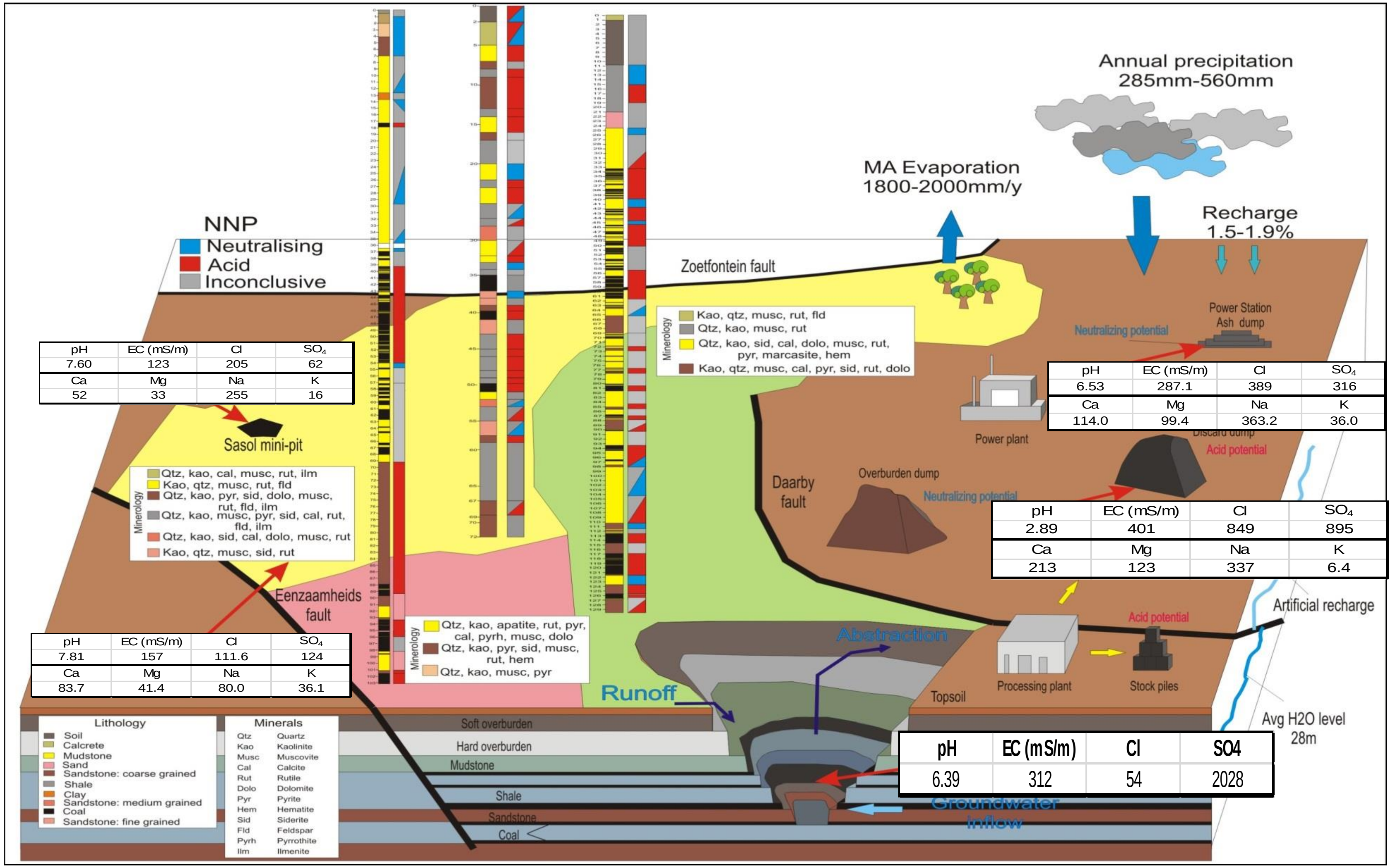
The ABA highlighted the lithological units that are prone to turn acidic or that have a neutralising potential. A summary of the geological logs, the minerals within the units as well as their acid and neutralising potential, are indicated in Figure 58. The different potentials are discussed according to the classification of Bester (2009) and Dreyer (1999), into partly weathered, Middle Ecca and Full successions. The sampled intervals are shown as geological borehole logs where tests have been conducted (adjacent to the log), specifying the result of the test and the sample name.

The partly weathered successions' geological units have a dominant NP above the coal units. The geology included calcrete, mudstone, shale and sandstone. These units typically consist of quartz, kaolinite, muscovite, calcite, dolomite and rutile (Figure 58). The units that showed an acidic nature were the coal samples as well as the sandstone found underneath the coal layers. In the sandstone samples the quartz, kaolinite, pyrite, muscovite, ilmenite and rutile minerals were positively identified (Figure 58).

The geological units of the analysed Middle Ecca successions revealed more acid producing sections than that of the partly weathered successions. The geological units that were prone to become acidic were shale, mudstone and both coarse and medium grained sandstone. The units predominantly contain quartz, kaolinite, pyrite, muscovite, rutile, ilmenite and feldspar (Figure 58). The fine grained sandstone, calcrete and soil all indicated a neutralising potential. The main minerals identified within these geological units were quartz, kaolinite, muscovite, siderite, calcite, dolomite and rutile.

The dominant geological units in the full successions that have an acid producing potential were the sandstone and the coal units. These units consist of quartz, kaolinite, muscovite, pyrite, siderite and rutile (Figure 58). The mudstone and shale units all showed a neutralising potential, and the minerals identified within these units included quartz, kaolinite, muscovite, pyrite, hematite, marcasite and calcite (Figure 58).

The static ABA tests are divided into boreholes from different geological areas, namely the Full succession, partly weathered and weathered down to the Middle Ecca. The sampled intervals are shown as geological borehole logs where tests have been conducted and it is indicated adjacent to the log, specifying the result of the test and the sample name (Figure 131 to Figure 135) (Appendix). The samples subjected to testing from the full geological succession are summarised in Figure 131 and Figure 132. The partly weathered geological succession are summarised in Figure 133 and Figure 134, and the Middle Ecca geological succession in Figure 135.



pH	EC (mS/m)	Cl	SO_4
7.60	123	205	62
Ca	Mg	Na	K
52	33	255	16

pH	EC (mS/m)	Cl	SO_4
6.53	287.1	389	316
Ca	Mg	Na	K
114.0	99.4	363.2	36.0

pH	EC (mS/m)	Cl	SO_4
2.89	401	849	895
Ca	Mg	Na	K
213	123	337	6.4

pH	EC (mS/m)	Cl	SO_4
7.81	157	111.6	124
Ca	Mg	Na	K
83.7	41.4	80.0	36.1

pH	EC (mS/m)	Cl	SO4
6.39	312	54	2028

Figure 58: Summary of the acid and neutralising potential of the various contributing factors over the extent of the study area. The water qualities are indicated for the mined pit, inactive mini-pit andpower station. Overburden and discard dump sites (modified after Mac Donald, 2015).

7 KINETIC TEST RESULTS

Kinetic tests determine the weathering characteristics of a sample as a function of time. Kinetic tests typically involve subjecting a sample of the waste material to periodic leaching and analysis of the drainage. Humidity cells tests were done for this study. The leaching tests predict the drainage quality of the samples more accurately.

Where the potential of acid generation is uncertain, kinetic test work is performed in an attempt to define acid generation characteristics. The term kinetic is used to describe a group of test work procedures wherein the acid generation (and metal solubilisation and transport) characteristics of a sample are measured with respect to time.

Samples for kinetic testing were selected based on the results of the static ABA tests. The kinetic tests are intended to mimic the physicochemical processes of weathering found at mining sites, usually at an accelerated rate. These tests require more time and are considerably more expensive than static tests (US EPA, 1994). The samples were chosen to be representative of the lithologies present in the study area. The leachate was analysed for pH, conductivity, sulphate, acidity and alkalinity and the analyses was used to confirm the AMD risk associated with a range of ABA values linked to the specific lithologies. Based on the static and kinetic ABA data, a useful handling plan for the material from the mining and processing area can be developed.

A total of 68 samples were tested to determine their acid generating potential. The samples consisted of overburden, interburden and composite plant discards. Table 57 (Appendix) includes a detailed table of the samples selected for kinetic ABA tests. Test were done over a 20 -21 week period. Note that in the time graphs it is indicated as each consecutive day.

7.1 Full Succession Samples

The first parameter to consider in these samples is pH, since this will provide an indication of the onset of acidification (Figure 59 and Figure 60). Some of the cells from this area had initial pH values that were already acidic. Of interest too is the fact that these cells are cells with excess acid potential (AP) over neutralising potential (NP). From an acid generation point of view these results tie in well. The other pH values were initially neutral and remained neutral throughout the testing, while a few samples went from neutral too acidic over the testing period.

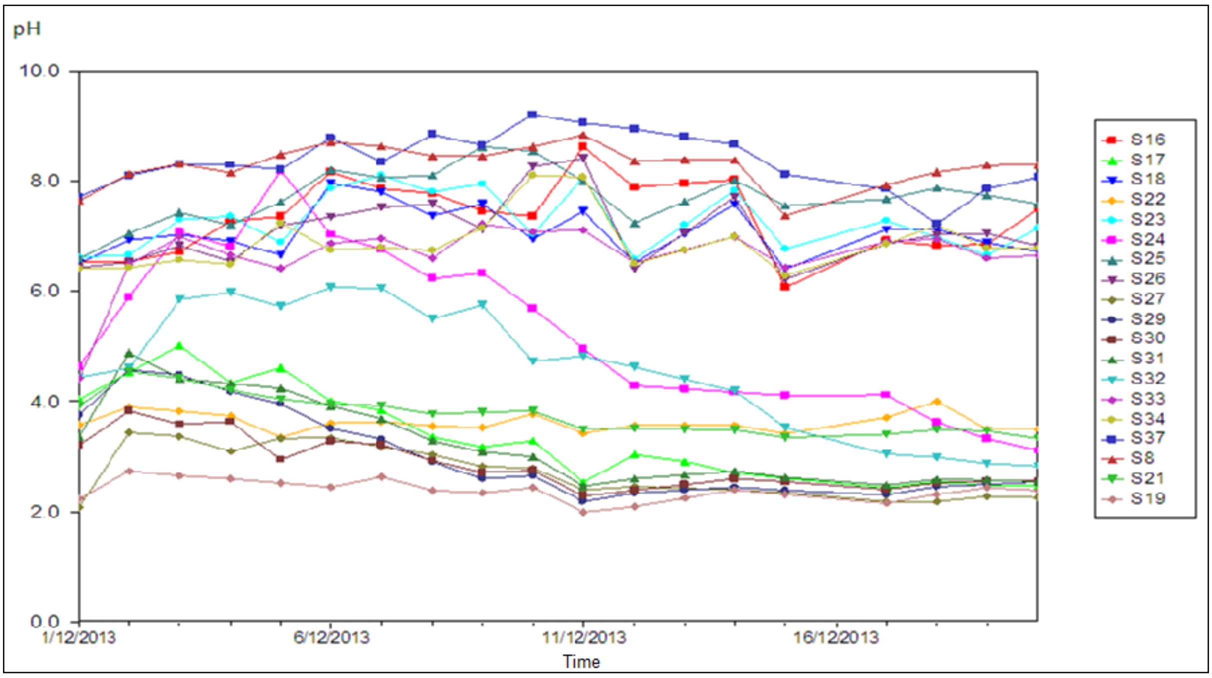


Figure 59: pH values from the humidity cells for the Full succession 1 samples.

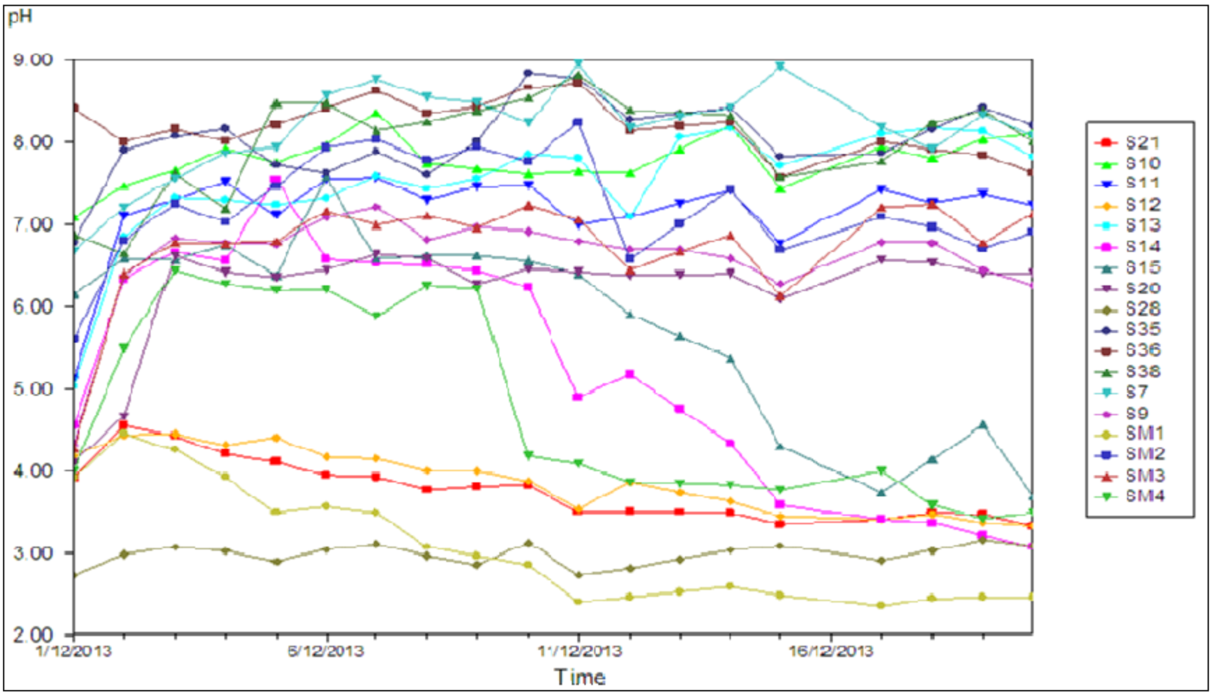


Figure 60: pH values from the humidity cells for the Full succession 2 samples.

Sulphate is the next important parameter to consider (Figure 61). Inspection of the sulphate values shows a sharp decline in values of some samples over the first few weeks as oxidised products are flushed out. This suggests that the sulphide oxidations that occurred prior-kinetic testing, were flushed out. The high SO_4 values at the beginning of the test work suggest that some oxidation occurred in the samples prior to initiation of the kinetic cell test, supported by the low pH value. The drop in pH over time with the production of sulphate is clearly illustrated in Figure 62 for sample S24. In this sample, the pH dropped with the sulphate production versus GM4, and the pH stayed neutral for the duration of the test.It was also very low and decreased in sulphate production.

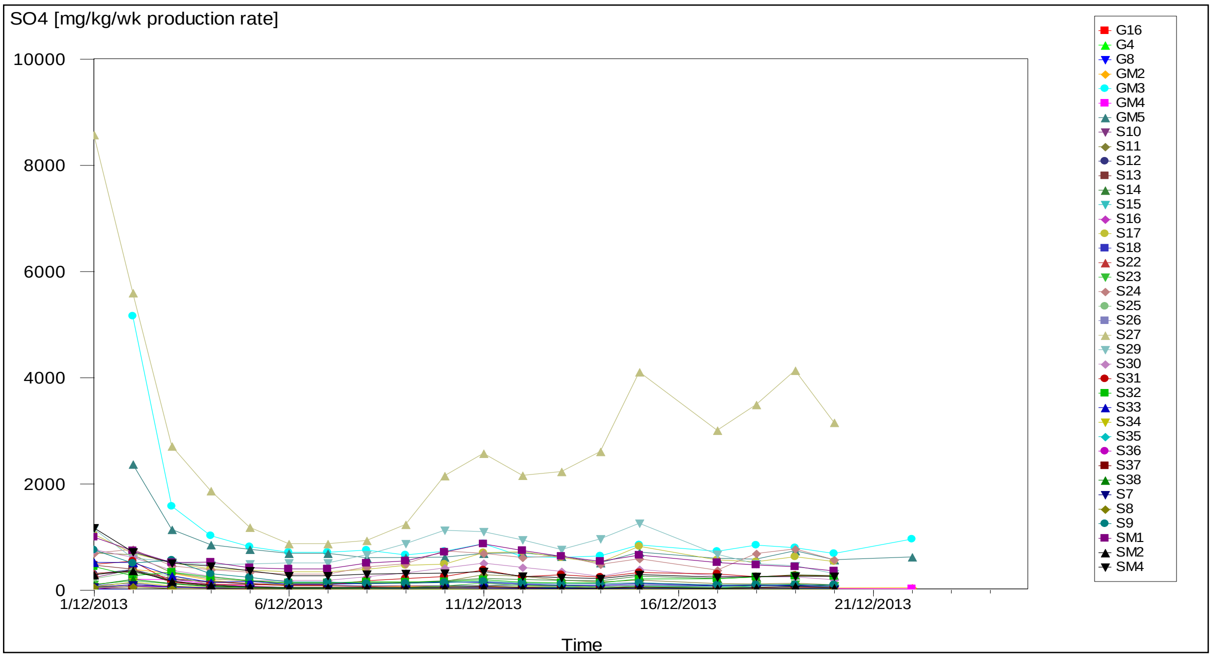


Figure 61: Humidity cell sulphate results for the Full succession samples.

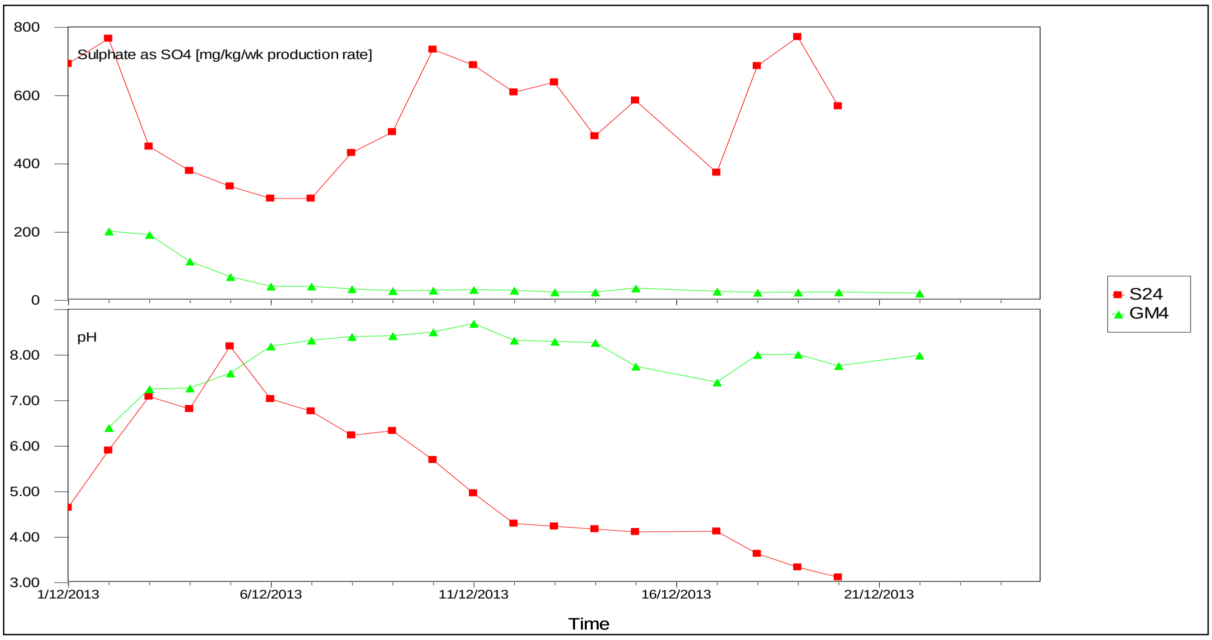


Figure 62: pH and sulphate results for a Full succession sample.

The cumulative mass of sulphate produced clearly indicatesthe samples acidifying (Figure 63 and Figure 64). The cumulative plot shows how the production flattens over the course of the testing and this is typically what is expected at the mines when they fill up as well, due to initial oxidation on the outside surface of the material. The gradient of the curve provides an indication of the relative rates of sulphide production.

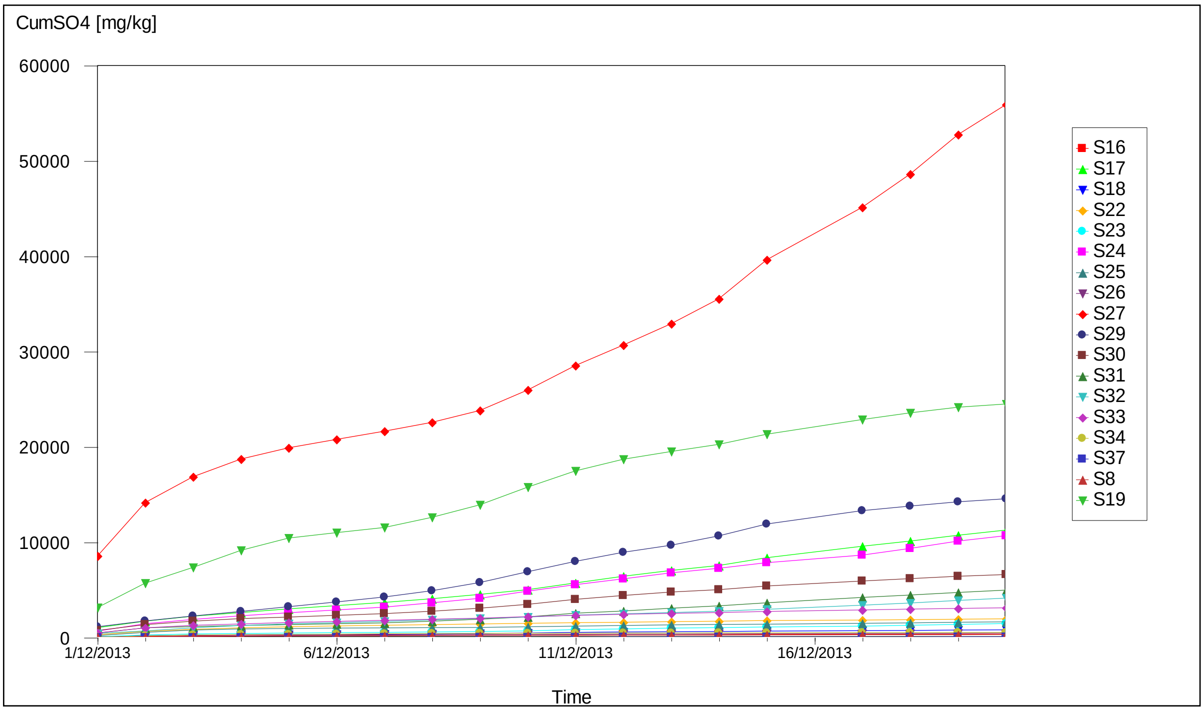


Figure 63: Cumulative sulphate production for Full succession 1 samples.

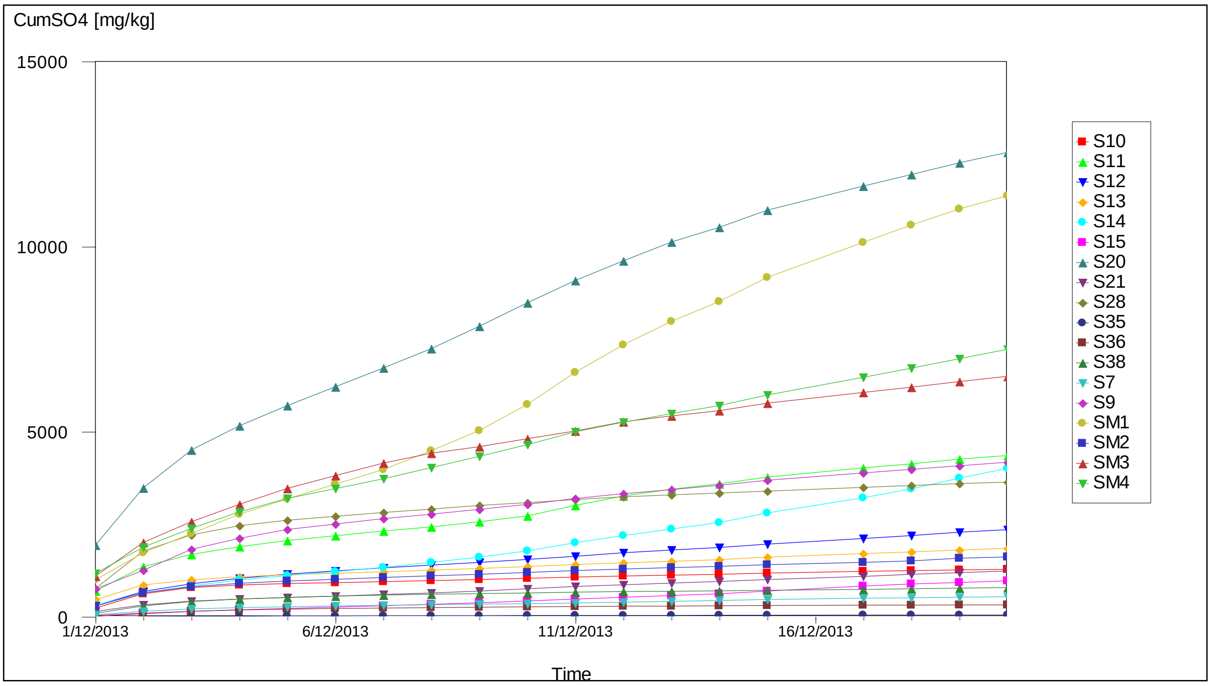


Figure 64: Cumulative sulphate production for Full succession 2 samples.

The graphs for sulphate and iron indicated that the liberation of the two elements coincide, which is associated with the oxidation of pyrite (Figure 65).

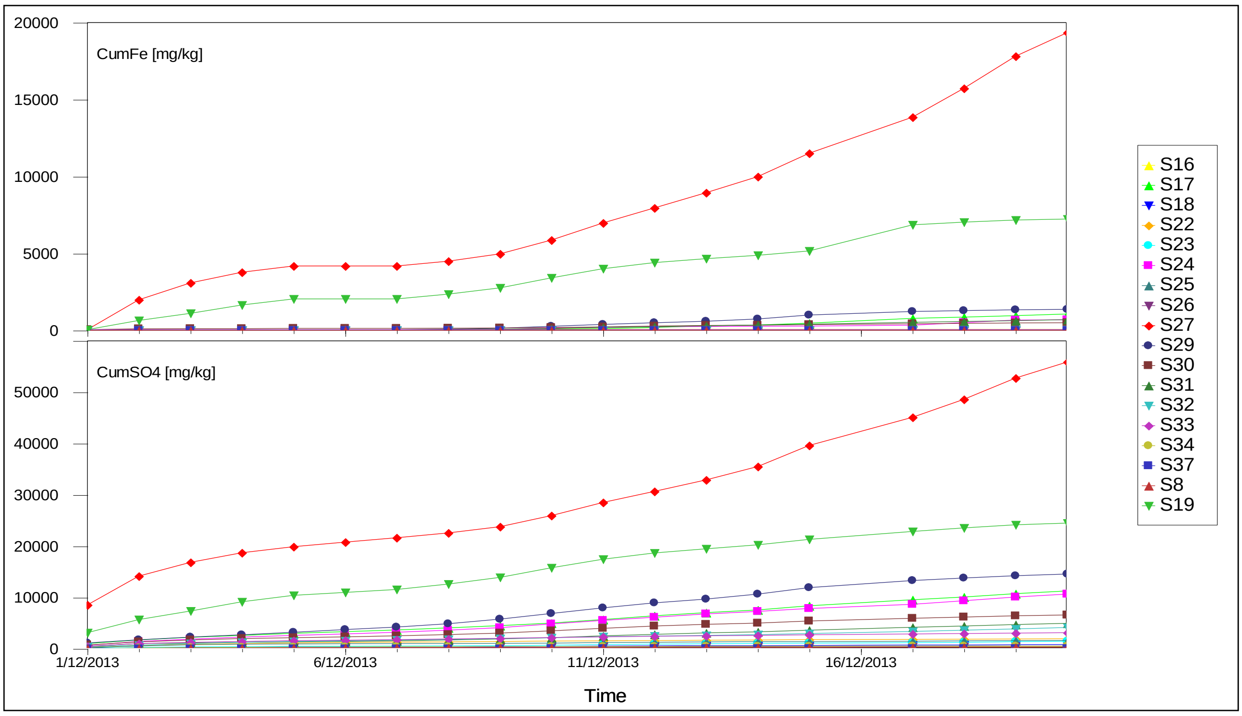


Figure 65: Sulphate and iron production for samples from the Full succession.

By using the trilinear Durov diagram (Figure 66), the nature of each humidity cell's leachate and the evolution thereof can be visualised effectively. The distinct grouping of each cell is evident, as is the fact that the electrical conductivity (EC) is driven by the relative sulphate/calcium/magnesium enrichment with respect to bicarbonate, and also to a lesser degree by the sodium being leached.

The results for the humidity cells indicate the migration of the chemical composition within each cell. Over time, the elements are leached from the system and show the migration pattern observed in Figure 66. Not all the Full succession samples are plotted, but similar graphs are obtained for the rest of the samples.

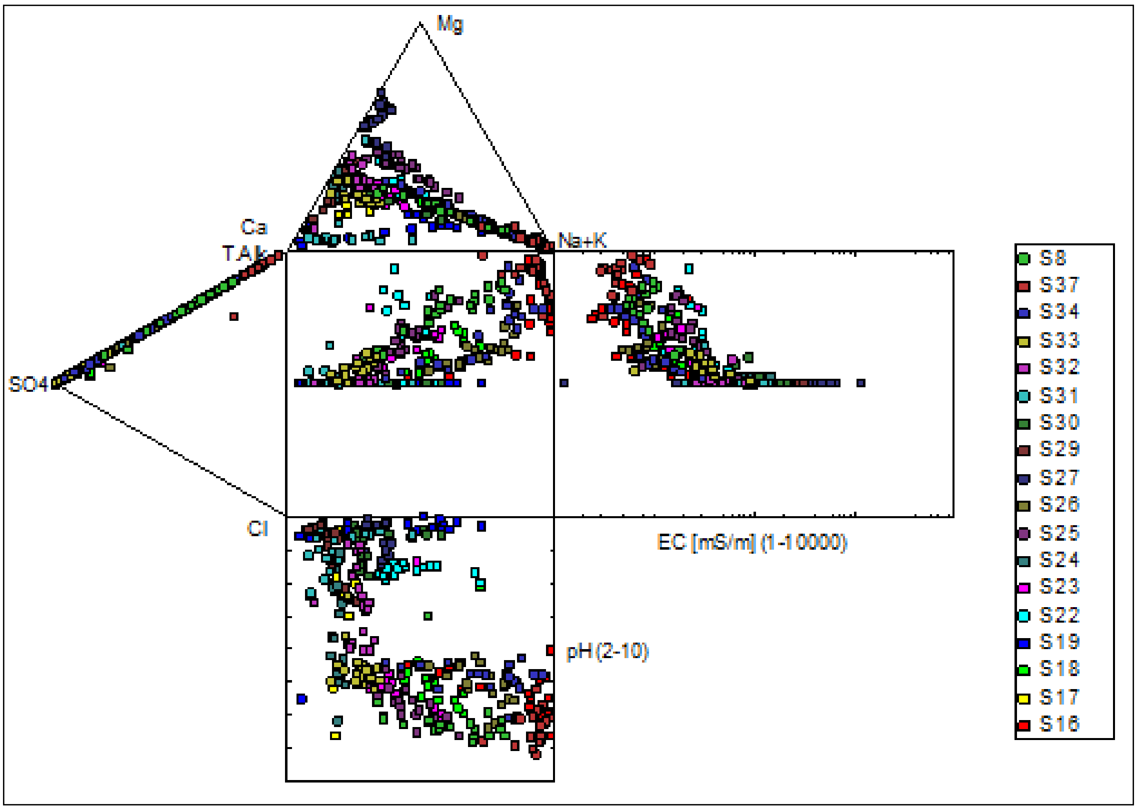


Figure 66: Durov diagram indicating chemical composition migration for some Full succession samples.

The leaching of calcium from the humidity cells are illustrated in Figure 67. The liberation of the calcium will coincide with the depletion of the neutralising potential of the samples (Figure 67). The NP decrease as calcium is leached from the sample, lowering the buffering capacity the sample would have.

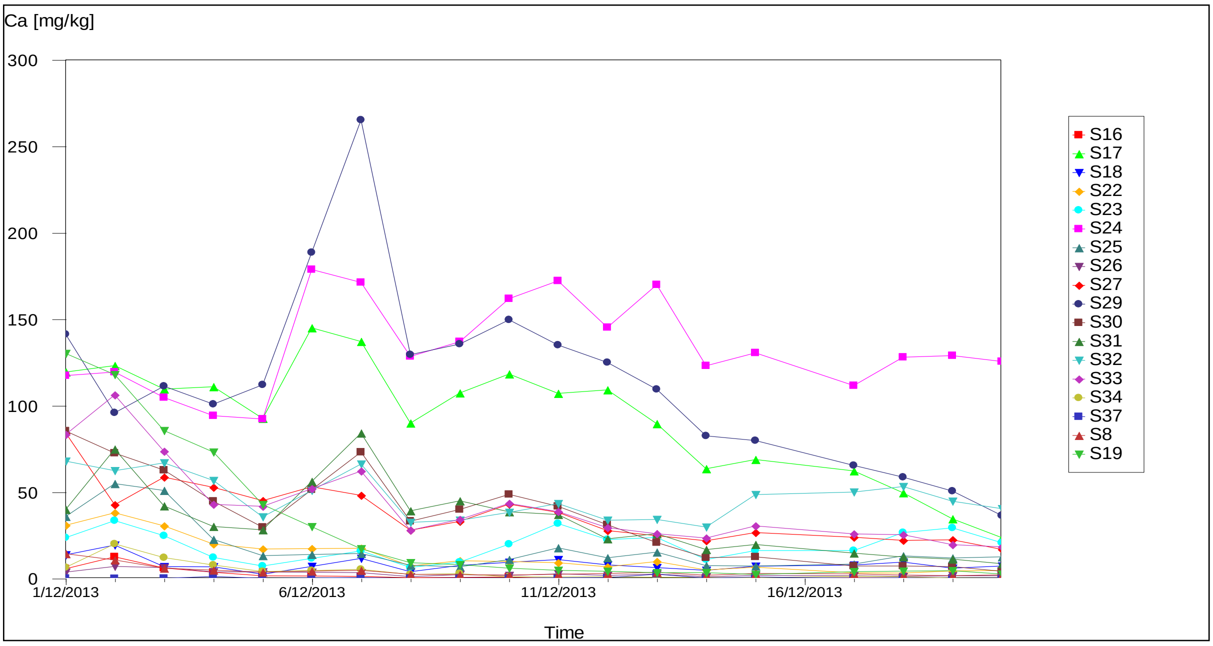


Figure 67: Leaching of calcium from the Full succession cells.

The cumulative salt load liberated from the cells over the time is plotted in Figure 68. Iron and sulphate are the major contributors to the total dissolved solids (TDS) for the high valued samples which are mainly due to the oxidation process. The TDS will be liberated into the environment, causing higher salt values in streams and groundwater.

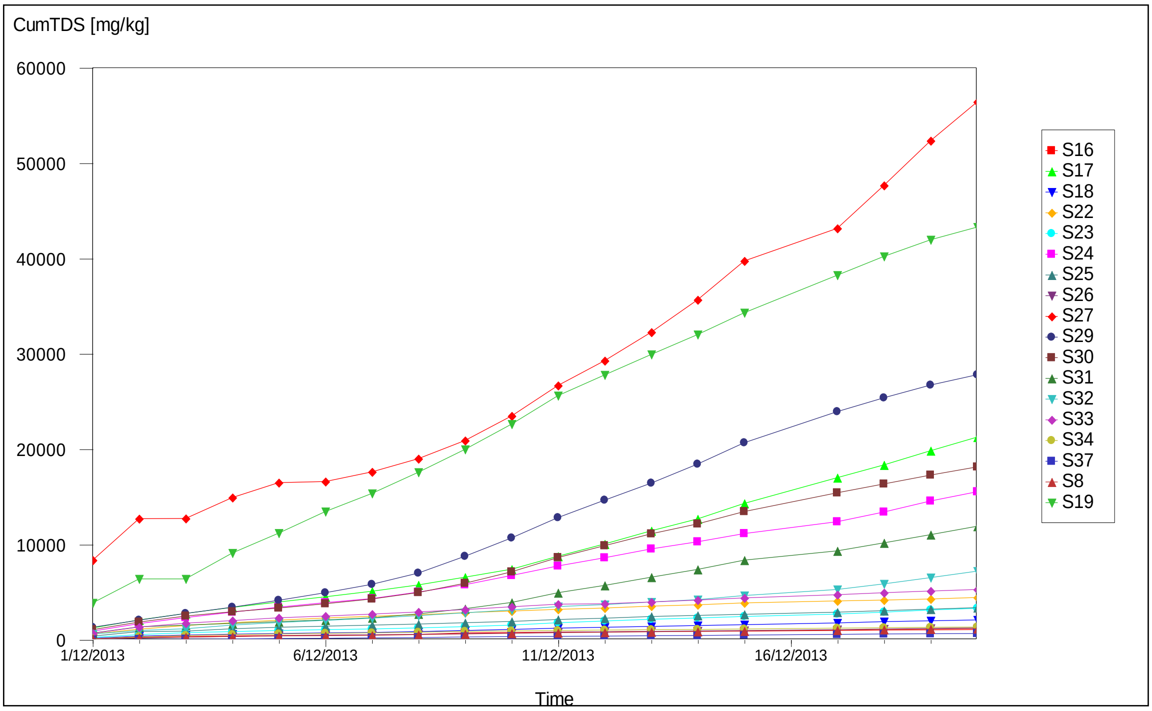


Figure 68: Cumulative TDS (Full succession cells).

7.2 Partly Weathered Samples

All the partly weathered succession samples retained their initial pH values at the start of the kinetic testing, with small variations. No samples with a neutral starting pH changed to acidic (Figure 69) over the time of testing (20 and some up to 21 weeks). Note – not all humidty cells started at week one and these cells indicate as if it were run much longer. These samples would be ideal to use as their chemical characteristics doesn’t change over time.

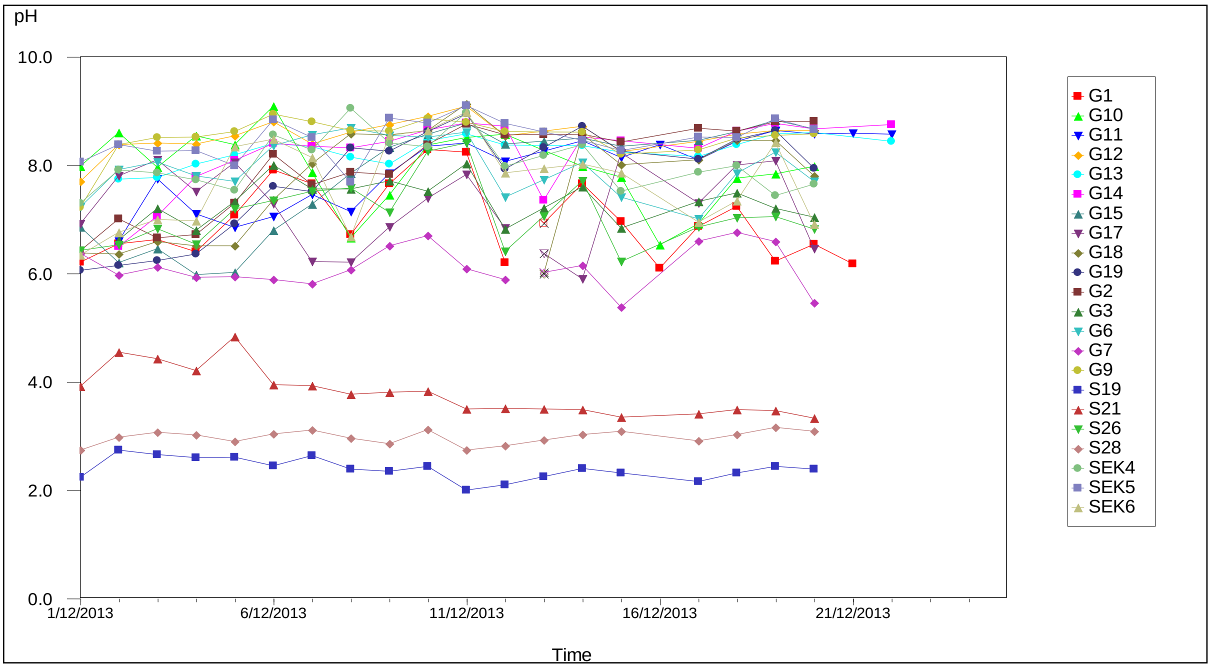


Figure 69: pH values over time for the partly weathered samples.

The liberated sulphate values are plotted in Figure 69. The sample with the lowest pH (S19), released the highest sulphate values. There appears to be two liberations for the sulphate within the sample. The first liberation of the sulphate can be from oxidation products already present, due to oxidation of the sample prior to the test. The second liberation is most likely as a result of the fresh oxidation of sulphide species in the sample. The pH and sulphate values for the acidic samples are plotted in Figure 70.

The cumulative sulphate value plot indicates how the production flattens over the course of testing (Figure 72). This is however not true for all of the samples as the cumulative plot shows an increase in sulphate over time. At this low acidic pH it is assumed that the process would be self-sustaining and would continue to produce sulphate.

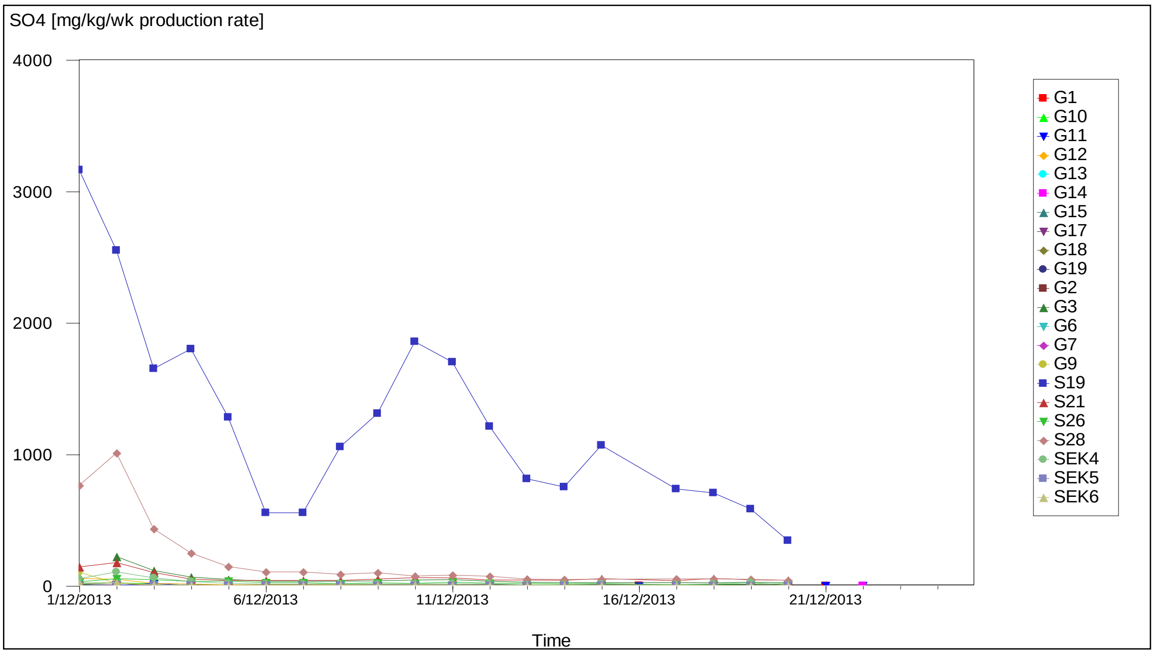


Figure 70: Sulphate values for the partly weathered samples.

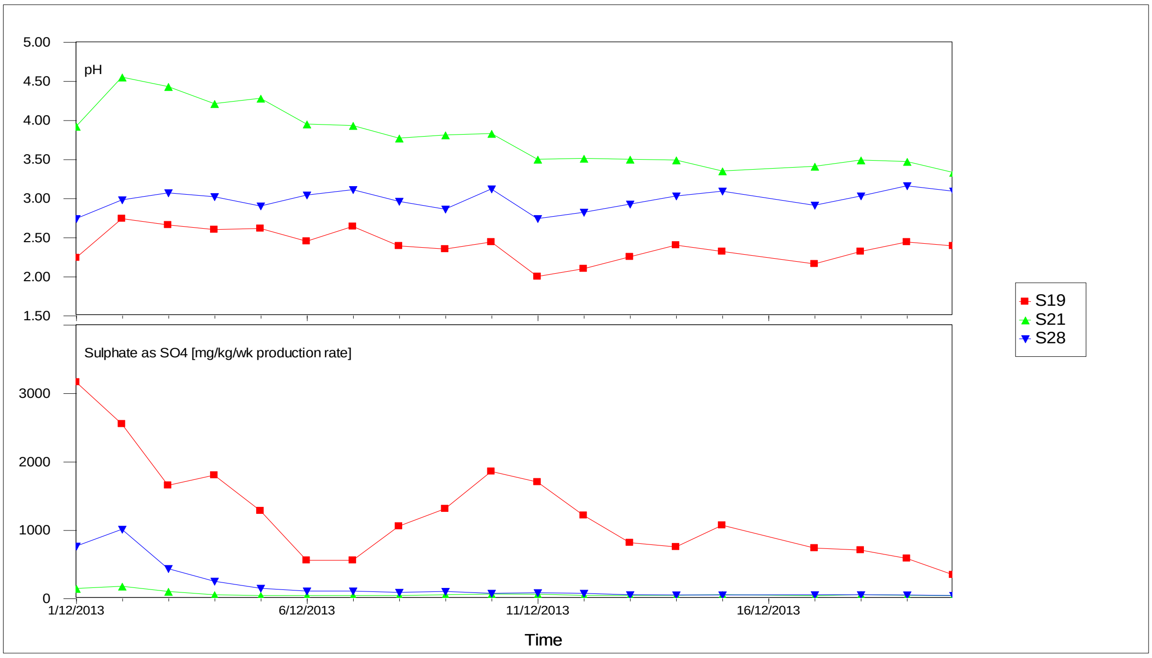


Figure 71: *pH and sulphate values for the partly weathered samples*.

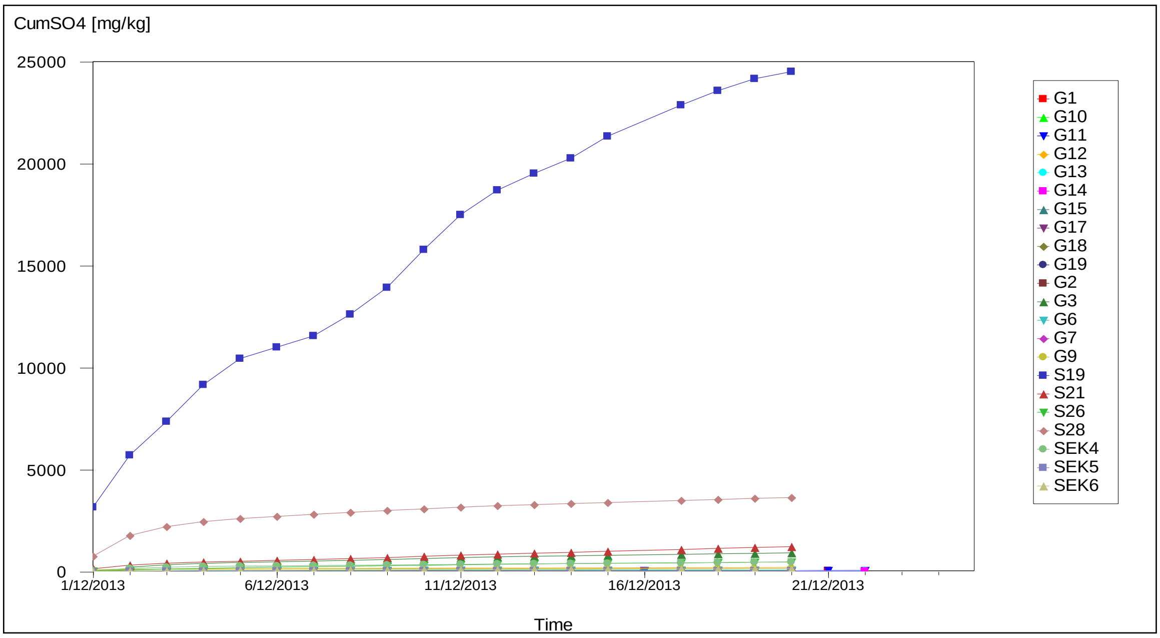


Figure 72: Cumulative sulphate values for the partly weathered samples.

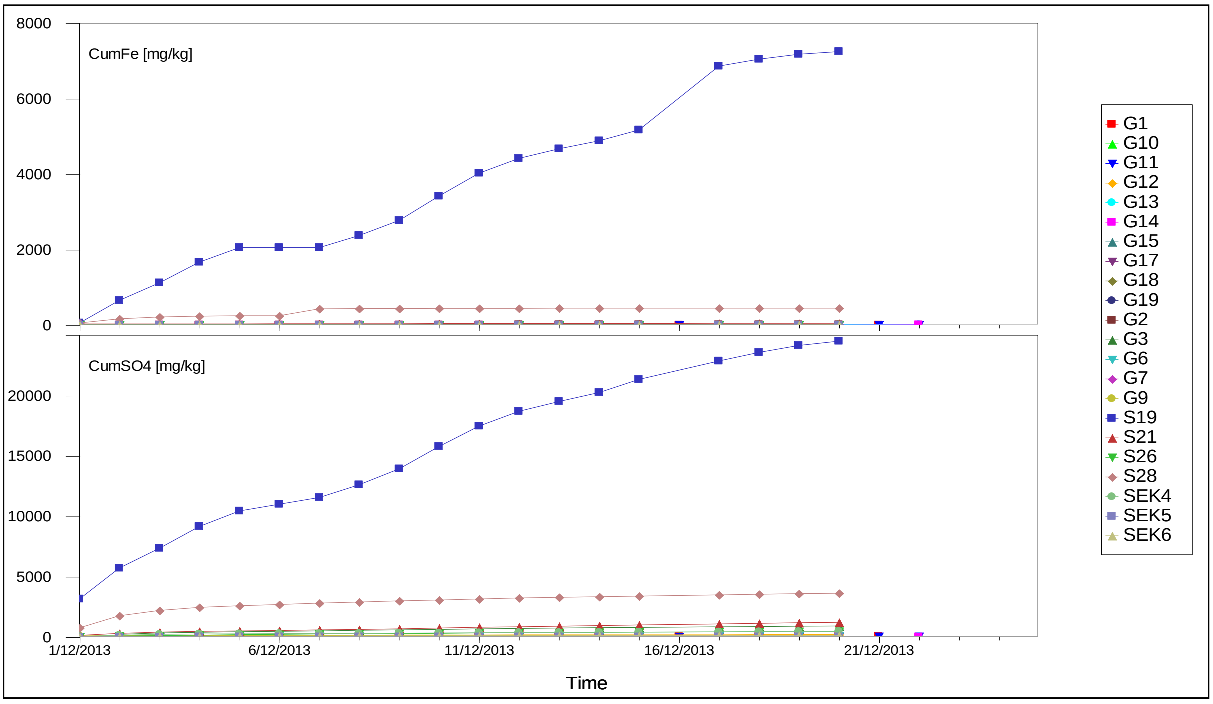


Figure 73: Cumulative sulphate and iron values for the partly weathered samples.

By using the Durov diagram (Figure 74), the nature of each humidity cell's leachate and the evolution thereof can be visualised. The distinct grouping of each cell is evident, as is the fact that the electrical conductivity (EC) is driven by the relative sulphate/calcium/magnesium enrichment with respect to bicarbonate and also to a lesser degree the sodium being leached.

The cumulative salt load liberated from the cells over the time is plotted in Figure 75. Iron and sulphate are the major contributors to the total dissolved solids (TDS) in the samples with the high values, which are mainly due to the oxidation process. The elements that are dissolved are liberated into the environment and this increases the amount of dissolved solids (salt) that end up in the groundwater and streams. The total liberation of salts from the exposed rock or sample is clearly seen over time. The results from the kinetic testing in this case are in line with that of the static ABA.

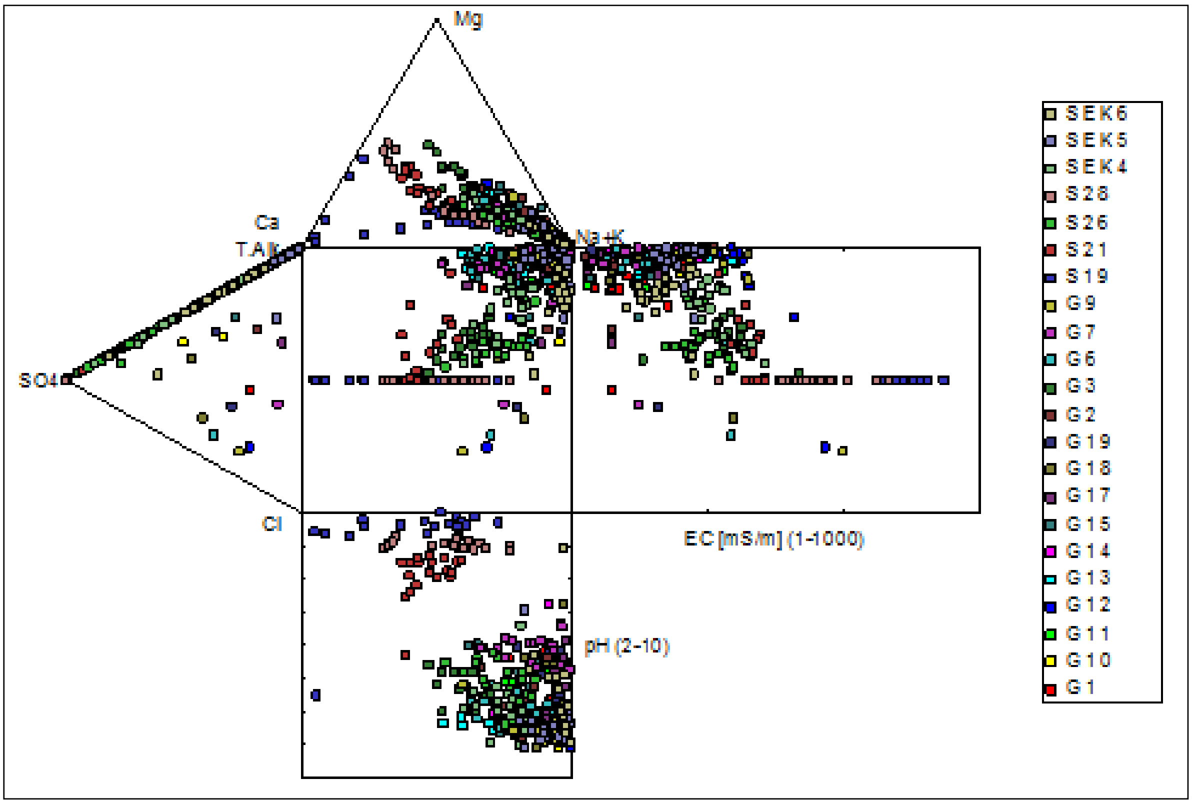


Figure 74: Durov diagram (partly weathered).

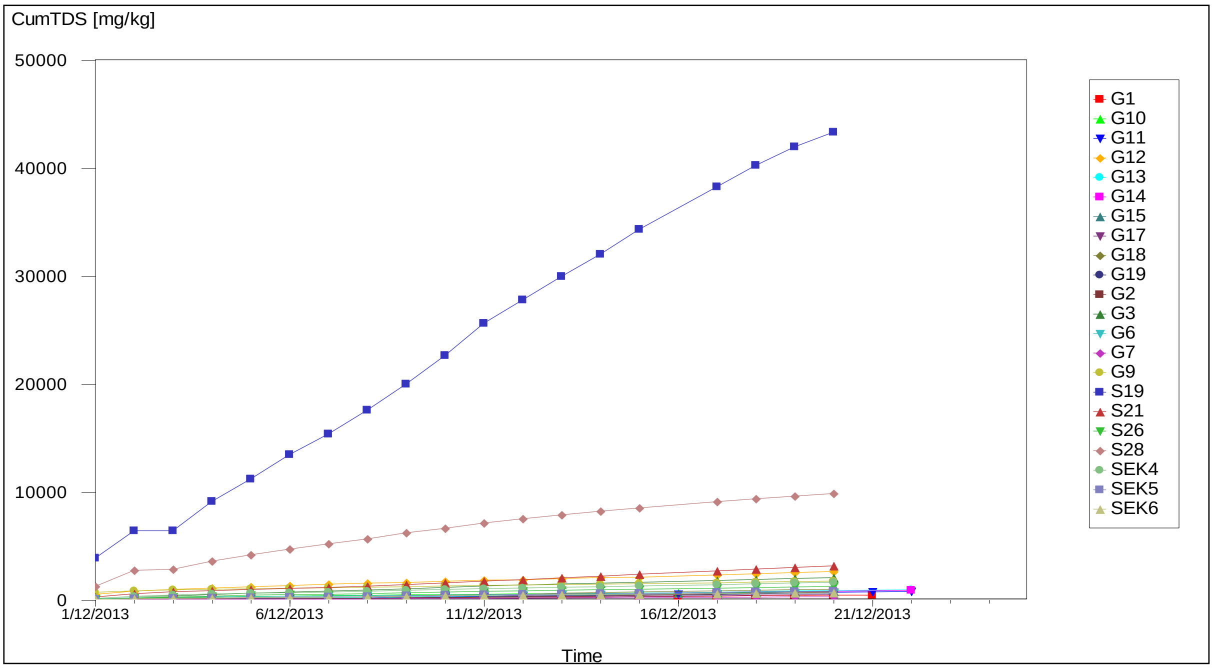


Figure 75: Cumulative TDS values for the partly weathered samples.

7.3 Middle Ecca

Only a few samples were selected from the Middle Ecca. The pH and sulphate values of the Middle Ecca are provided in Figure 76 and these two parameters will provide an indication of the onset of acidification.

The pH results from the Middle Ecca samples remained approximately neutral and increased slightly over the 20 week testing time. The high sulphate values at the beginning of the tests are those that go into solution and are not mainly due to oxidation because the pH of the samples stayed neutral (Figure 76).

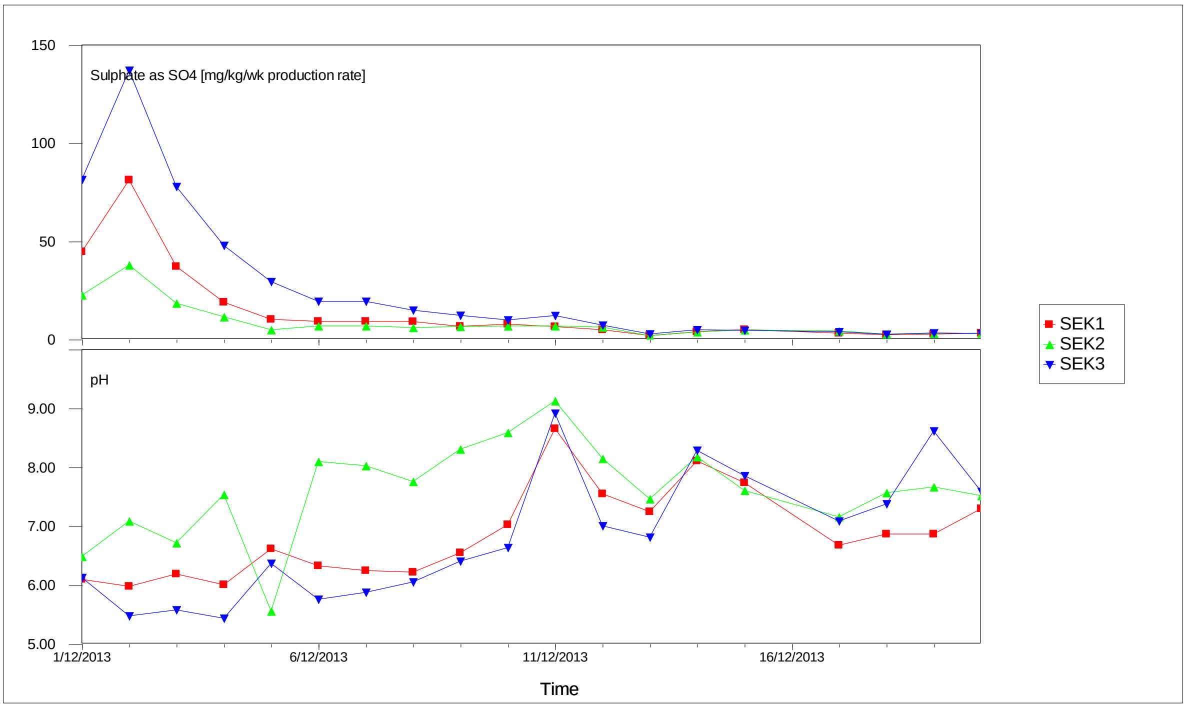


Figure 76: Sulphate and pH values over time for the Middle Ecca samples.

The kinetic results obtained in the time frame of this experiment coincides with the results obtained with the static ABA. This occurred even though the acidic pH values of the final static pH results were not obtained over the time of the experiment, confirming the contribution of surface area to the reaction rate (Figure 76). The total salts liberated by the Middle Ecca Formations are much lower than those of other succession samples tested. The oxidation of iron and sulphate better explains the elevations in TDS for Figure 77, and this trend over time is typical for pyrite.

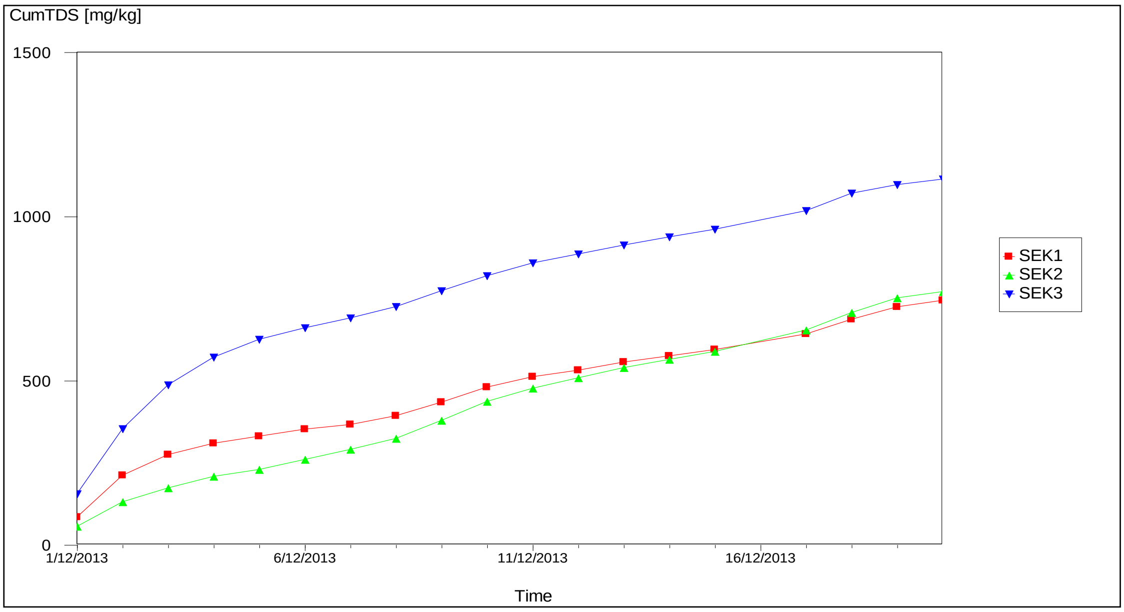


Figure 77: Cumulative TDS values over time for the Middle Ecca samples.

7.4 Combination of Samples

Eleven kinetic cells were run with a combination of samples selected from the static ABA results. All samples were combined in a ratio of 1:1, while one sample (sample SM2) was comprised of 25% of each of the contributing sample. The combined samples' pH, calcium and sulphate values are shown in Figure 78.

The result showed a slight increase in calcium over time, and also explains the decrease of sulphate as the calcium probably acts as a buffer within the samples. The pH of the majority of the samples stays at relatively neutral values with two exceptions; SM1 and SM4. The slight increase in pH is due to the liberation of calcium and this is seen in sample SM4 where the pH increased when calcium was released and as soon as the calcium was removed, the pH decreased to the initial acidic value.

The iron and sulphate graphs, clearly indicate that acidification of the samples are in most cases linked to pyrite oxidation (Figure 79).

The cumulative TDS for the combined kinetic cells are plotted in Figure 80. There is an increase in TDS over time, which indicates that the samples have a high salt load. These salts can be released if exposed to rain and the rain would leach salt from the material over time.

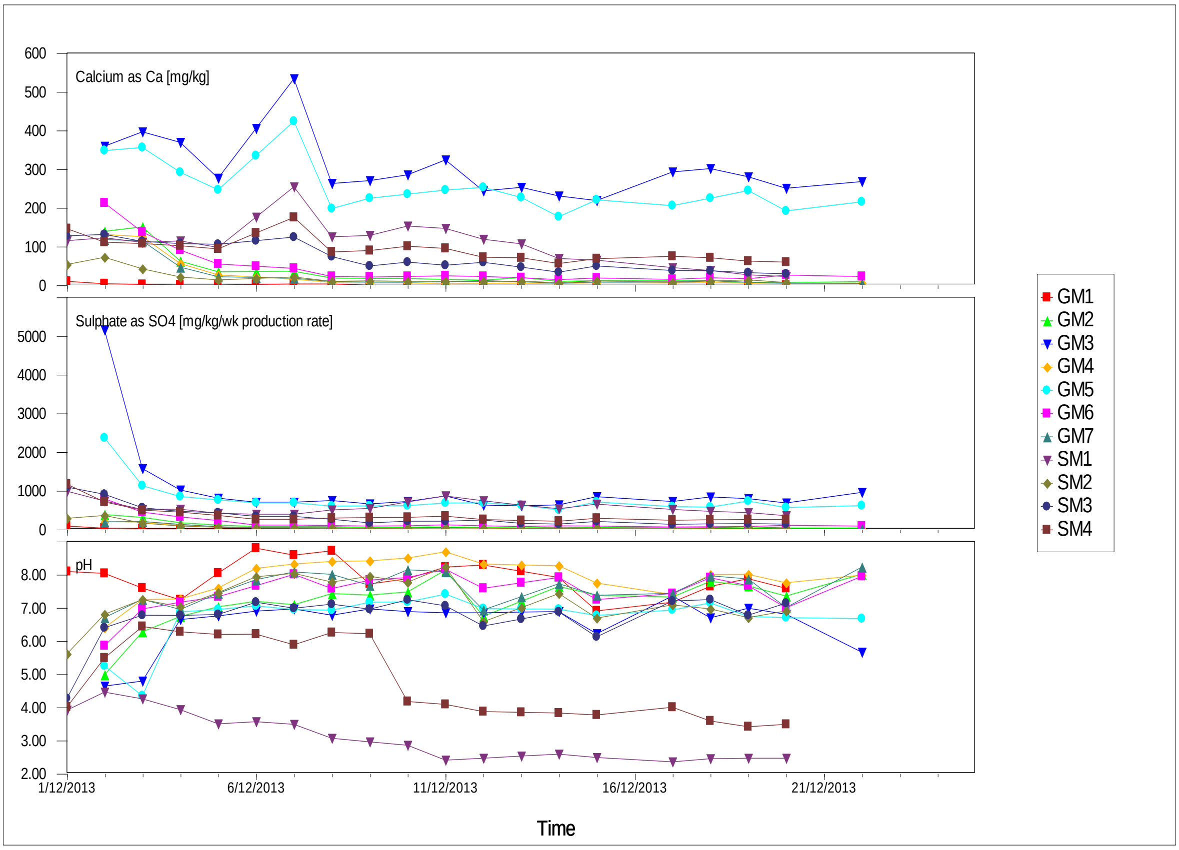


Figure 78: pH, calcium and sulphate values for the combined/mixtures cells.

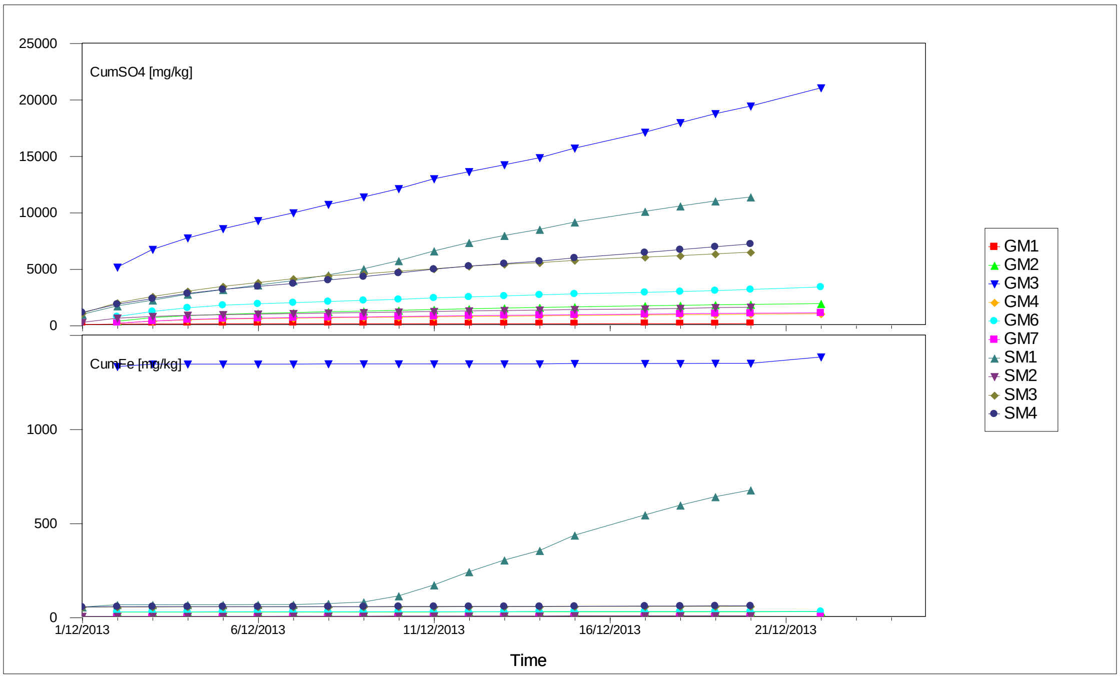


Figure 79: Iron and sulphate values for the combined cells.

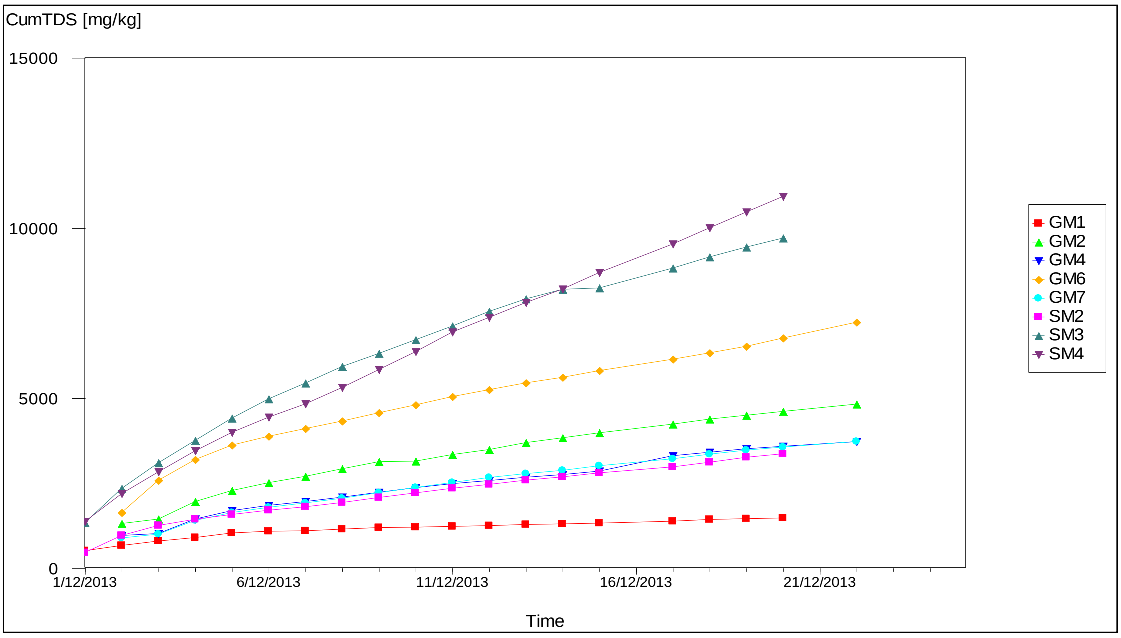


Figure 80: Cumulative TDS values for the combined cells.

The remaining percentage sulphur for all the humidity cells (except the combination cells) are shown in Figure 81, Figure 82 and Figure 83. The remaining sulphur plot indicates that even if the humidity cells have a low acid potential, they still contain a high percentage of the original sulphur in the humidity cells after leaching. The remaining sulphur in the humidity cells with a high acid potential show that up to 25% of the sulphur has been leached from these cells over 20 weeks of kinetic testing.

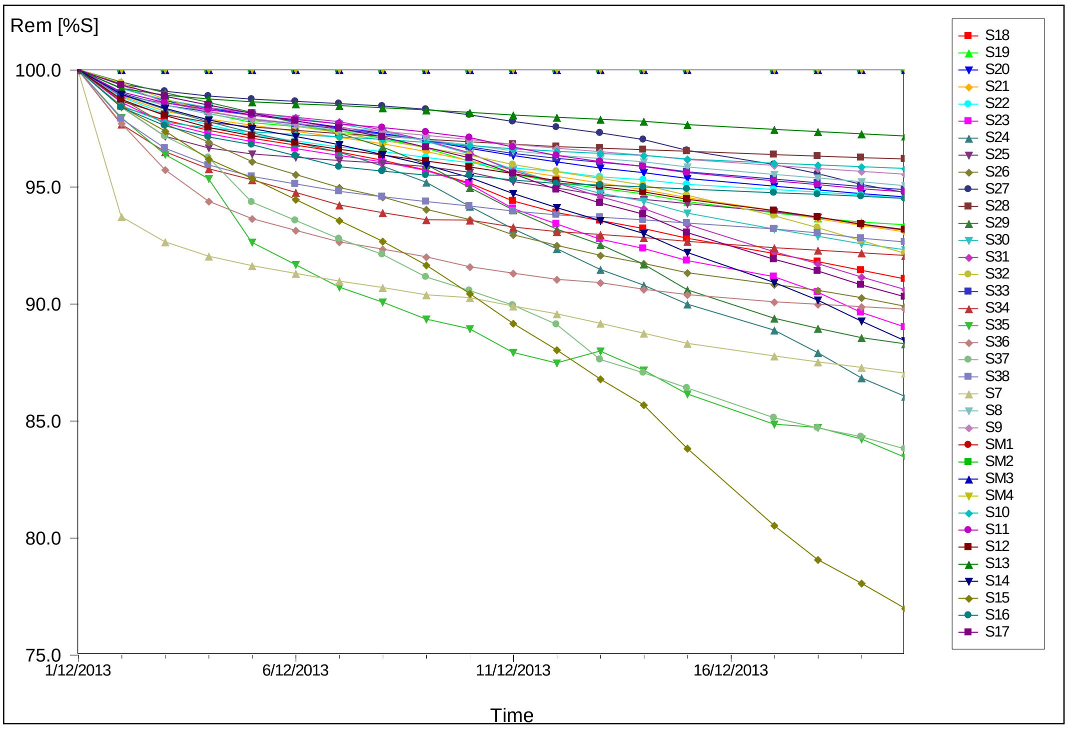


Figure 81: Remaining % S for the Full succession.

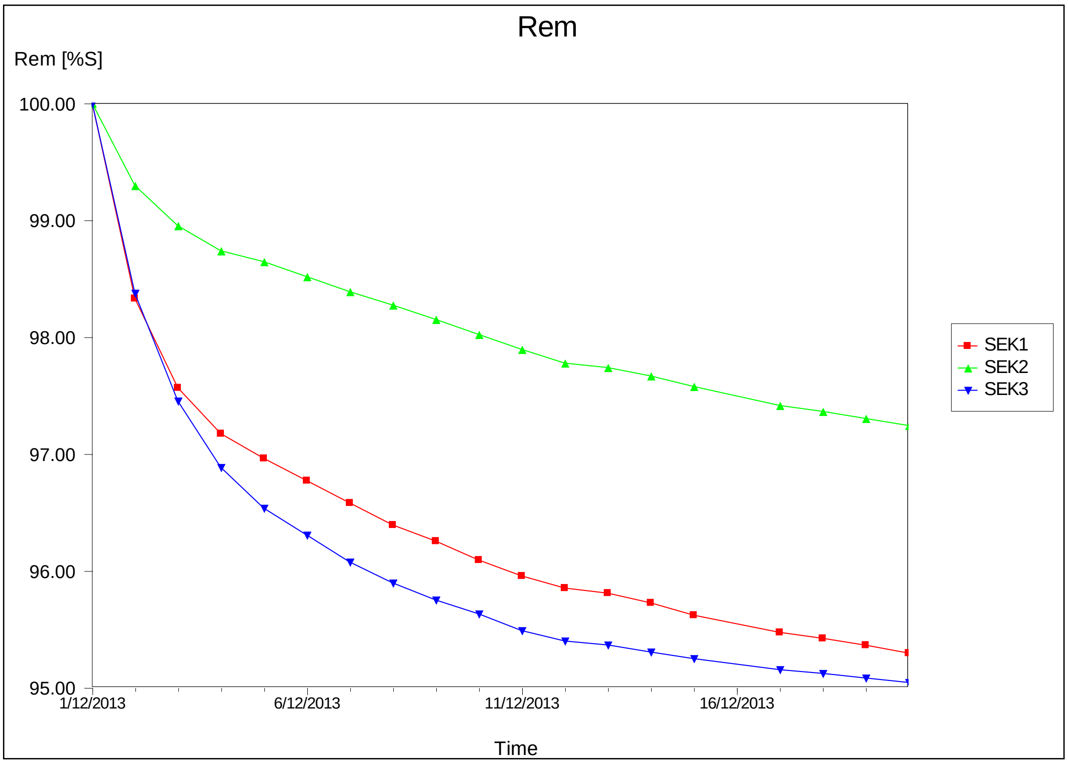


Figure 82: Remaining % S for the Middle Ecca succession.

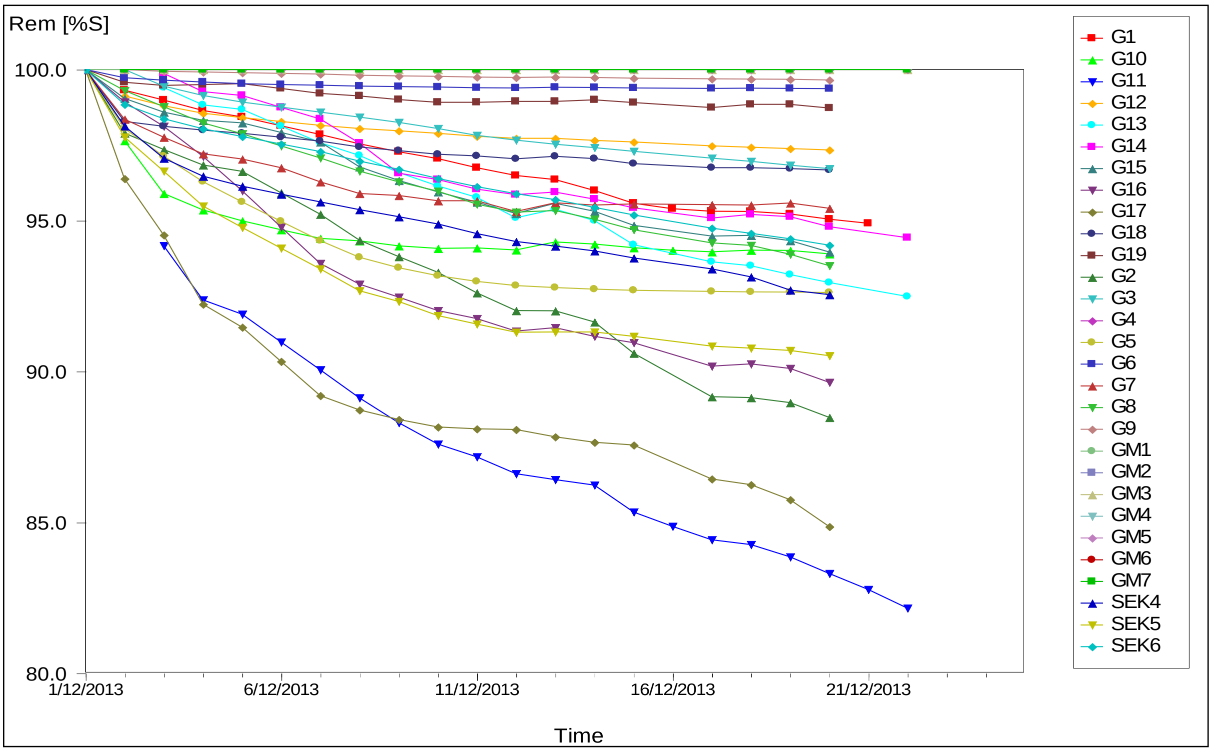


Figure 83: Remaining % S for the partly weathered successions.

The remaining percentage NP measured as alkalinity for the cells correlates with the pH of the samples. The alkalinity in Figure 84 indicates that with a decrease in pH (<4.5), there is little or no alkalinity left in the sample.

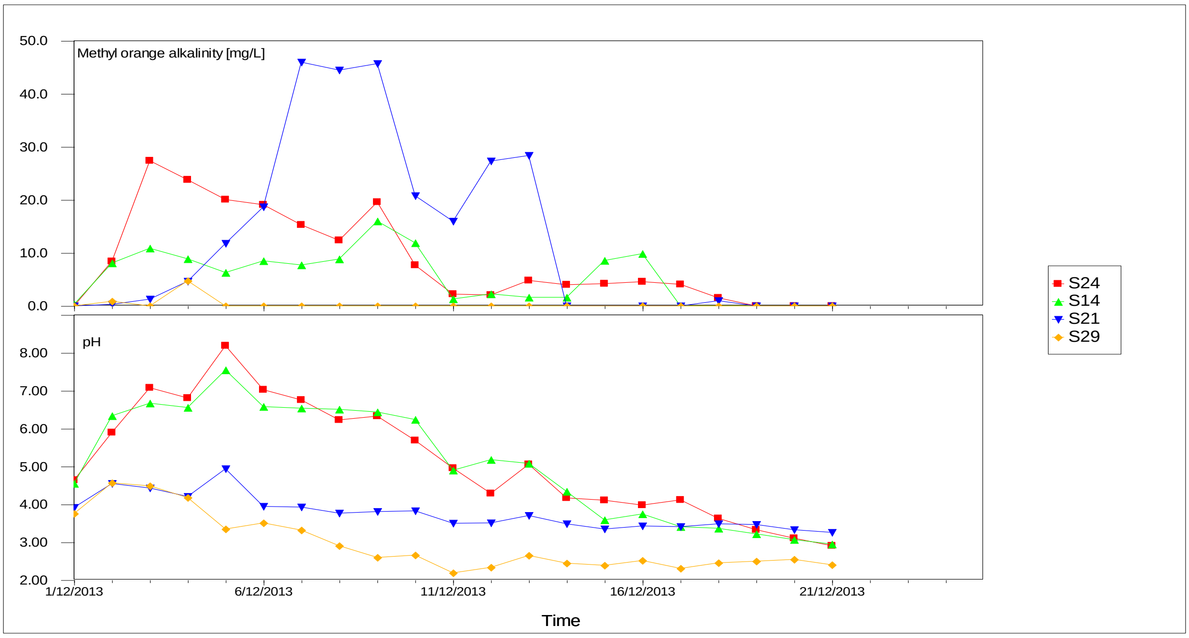


Figure 84: pH and alkalinity relationship.

In most cases the kinetic data confirmed what was obtained with the static ABA tests. However, only in some cases the kinetic cell results (after 20 weeks) did not completely correlate with the static ABA results which was due to a time constrain (many authors recommend kinetic/humidity cells to run for longer than 20 weeks). The total salt (expressed as TDS) released from exposed rock into the environment can be seen from the cumulative TDS values plotted over time. The exact onset of when ARD will start, and exactly how long it will take, cannot be predicted. It is important to study the geological units, mainly interburden and plant discards that can produce ARD and also to ensure that the samples are handled accordingly with the goal in mind to minimise the ARD and the effect on the environment.

7.5 Overall Summary

7.5.1 Overburden

The ABA analyses indicated a dominantly neutralising potential for overburden samples as well as an acidic potential for the shale units on top of the coal. The samples that did not show a clear distinction were subjected to further kinetic tests. The samples that were analysed over a 20 week period indicated non-acid producing potentials and some with neutralising potentials.

The pH provides an indication of the onset of acidification (Figure 85). The initial pH values from the overburden samples were neutral at the offset and remained neutral throughout the testing. The sulphate values show a decline over the first week as the oxidised products are removed from the system (Figure 86) which suggests that the sulphide oxidation occurred prior to kinetic testing. Figure 87 indicates the sulphate concentrations when the high values are removed to show the range of the overburden samples.

The cumulative mass of sulphate produced indicated that the overburden samples do not continue to produce sulphate, but rather reaches a constant rate where sulphide is produced (Figure 88). The cumulative plot shows how this flattens over the course of the testing time to provide a better spread of production rates.

During the kinetic tests, the results for calcium and alkalinity were relatively high (Figure 89). The relatively low calcium values indicate that carbonates are immediately available and demonstrate the balance between the released alkalinity and the acidity generated. If the balance between the alkalinity and the acidity stays positive, the system will not acidify.

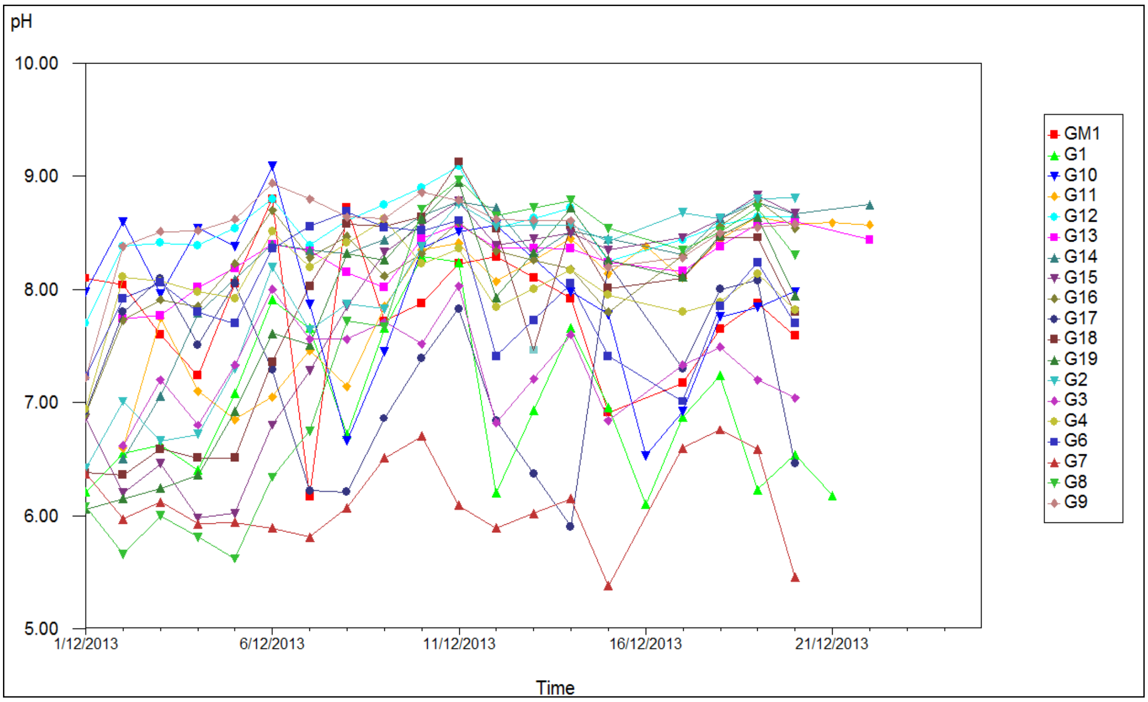


Figure 85: The pH values of the humidity cells for overburden material.

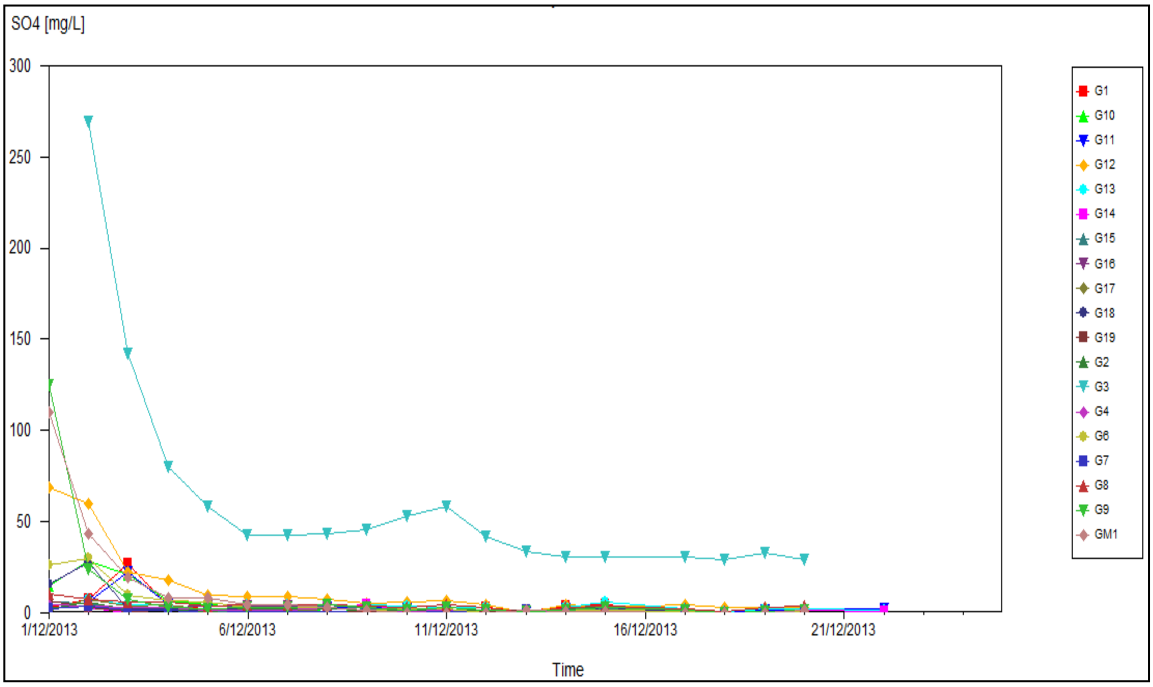


Figure 86: The sulphate values of the humidity cells for overburden material.

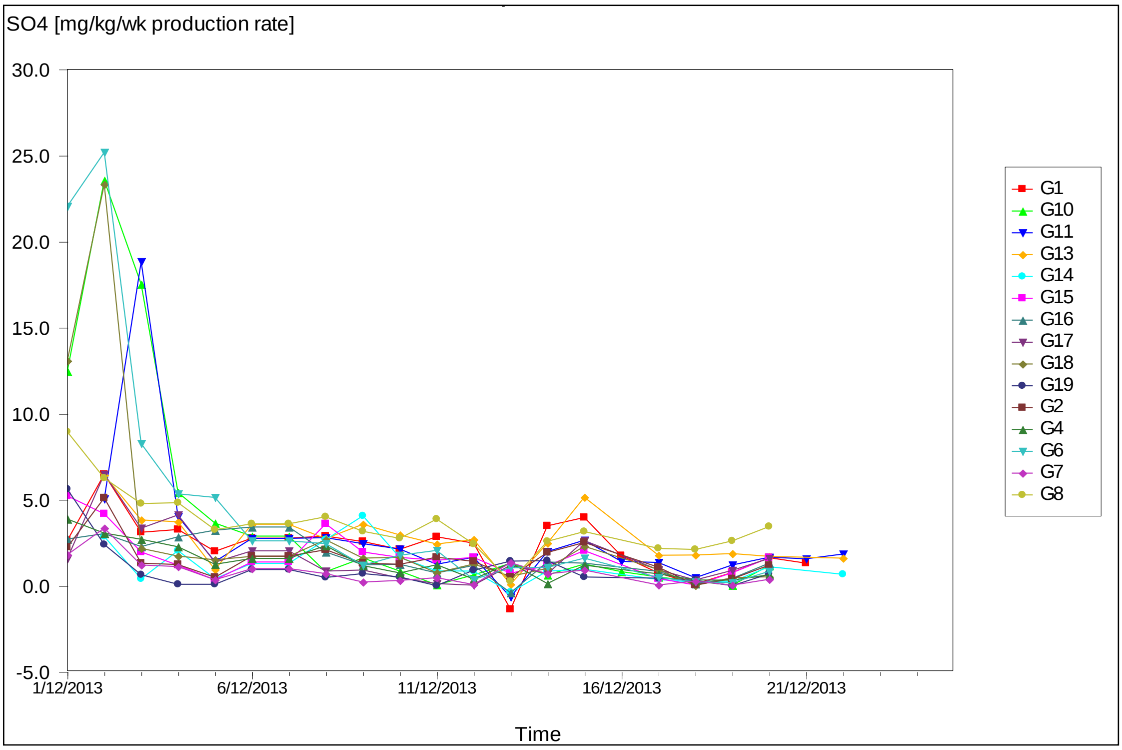


Figure 87: The enlarged sulphate values of the humidity cells for overburden material.

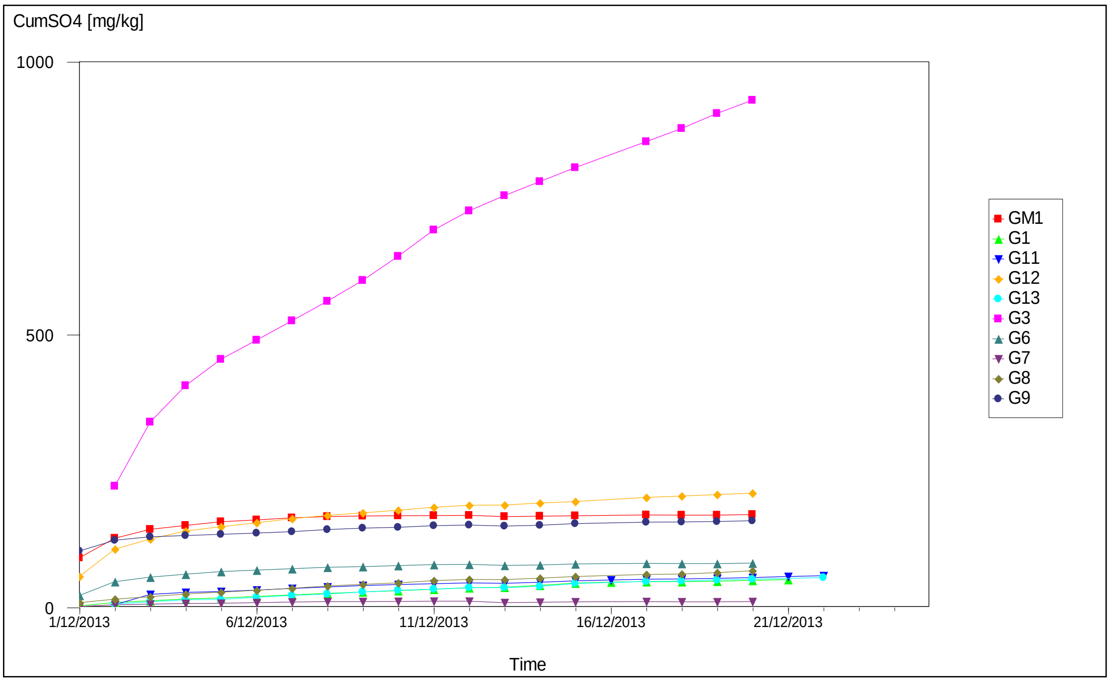


Figure 88: Cumulative sulphate production (mg/kg) of humidity cells for overburden material.

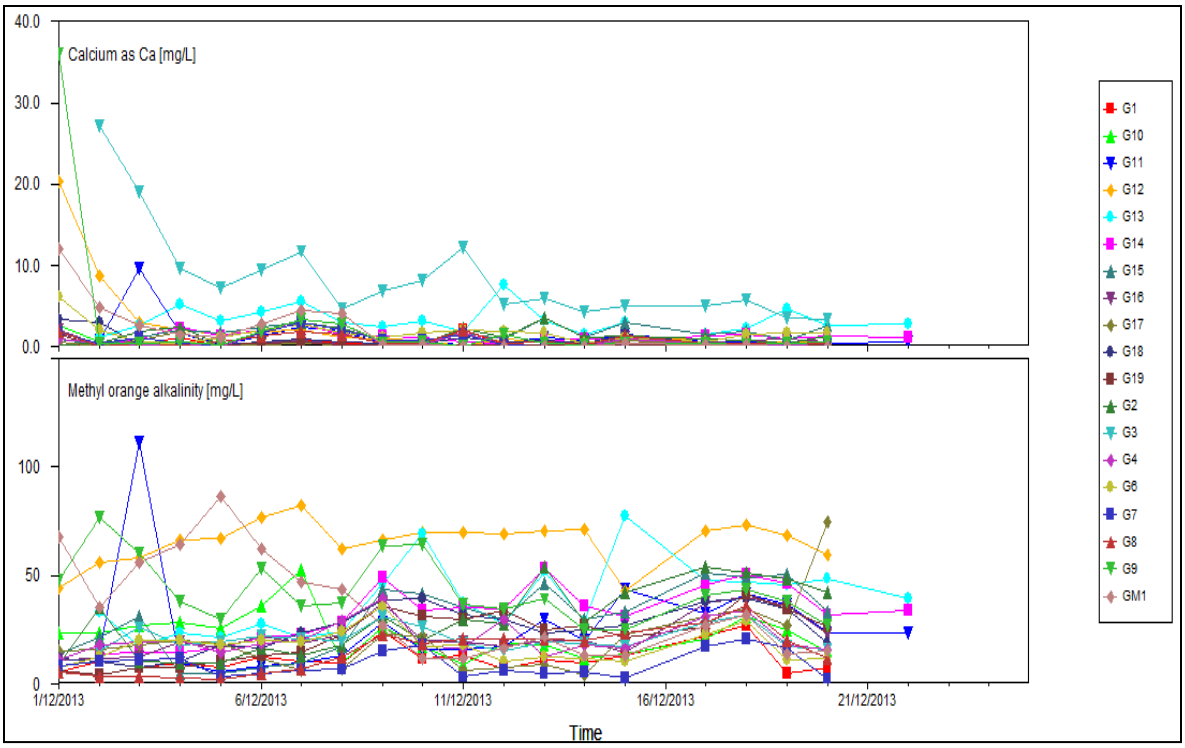


Figure 89: The Ca and alkalinity values of humidity cells for overburden material.

7.5.2 Interburden

The ABA analyses showed that the analysed interburden samples contained both acidic and neutralising potentials. Interburden and mixtures of acidic and neutralising interburden was selected to run kinetic tests on. The purpose hereof was to show the extent to which acid producing interburden, mixed with a neutralising component, could reduce the acidic nature of the samples.

Mudstone, shale and calcrete layers indicated a neutralising potential, while sandstone had a relatively high acid generating potential. The initial pH values of the interburden samples were both acidic and neutral. The acidic pH values stayed acidic, whilst some of the neutral pH values remained neutral and others became acidic (Figure 90). The kinetic samples S14, S15, S24, S32 and SM2 consisted of mudstone, sandstone and siltstone (Table 30).

Table 30: The kinetic tests that became acidic from initially neutral pH values.

Kinetic sample	**Sample name**	**Lithology**
S14	WGH 170	Sandstone
S15	WGH 192	Sandstone
S24	WGD2 (A)	Sandstone/coal
S32	WGB4 (B)	Mudstone/sandstone
SM2	WGG2+WGG4(D)+WGG4(F) +WGG6(A)	Mudstone and sandstone

The sulphate values indicate a slight decline over the first few weeks of testing, with a gradual increase for the remainder of the test. The slight increase is due to the oxidised products being flushed from the system (Figure 91). The gradual increase of the interburden samples suggests sulphide oxidation occurred during kinetic testing.

The cumulative mass of sulphate produced showed that the interburden samples continue to produce sulphate and did not appear to reach a constant rate of sulphate production (Figure 92). The cumulative plot demonstrates the increase in relative rates of sulphate production over the course of the testing time. With prolonged exposure the system would acidify as sulphate is released into the system.

Calcium and alkalinity results showed high calcium values, with relatively low alkalinity for the interburden material (Figure 93). The high calcium values indicate the availability of carbonates whereas in this case, the carbonates are not immediately available.

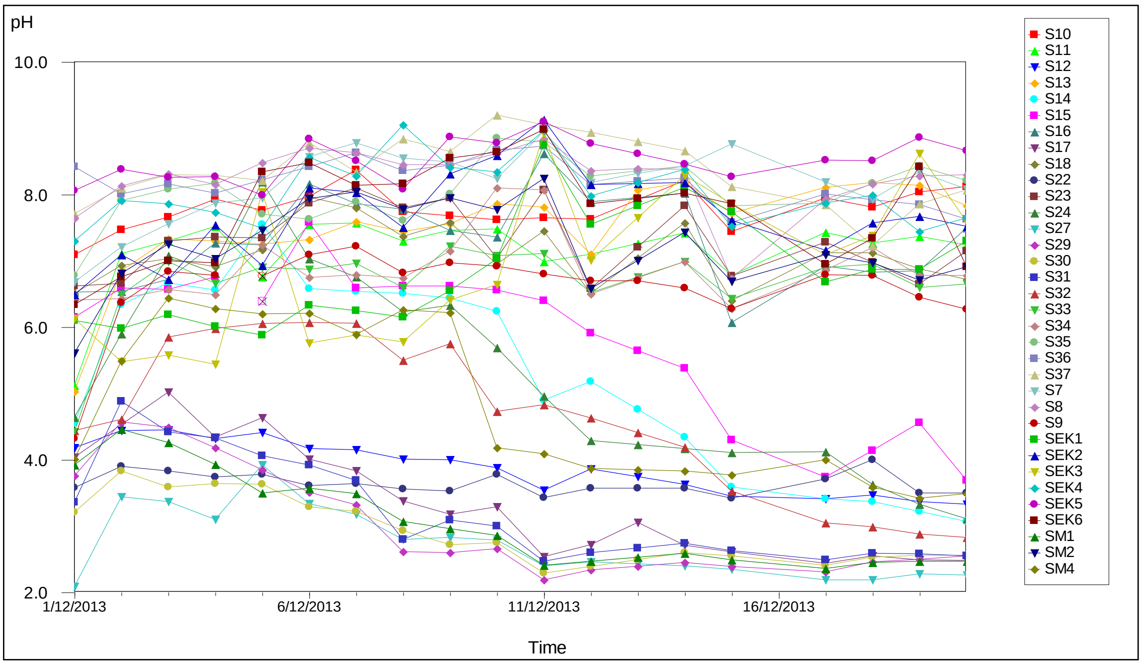


Figure 90: The pH values of the humidity cells for interburden material.

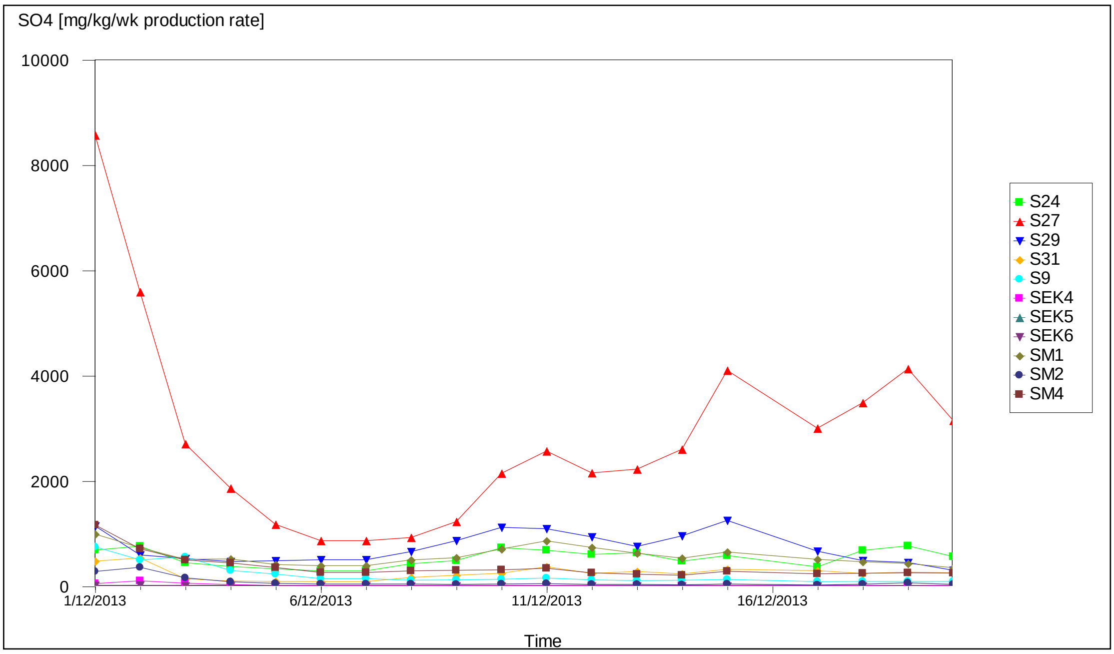


Figure 91: The sulphate values of the humidity cells for interburden material.

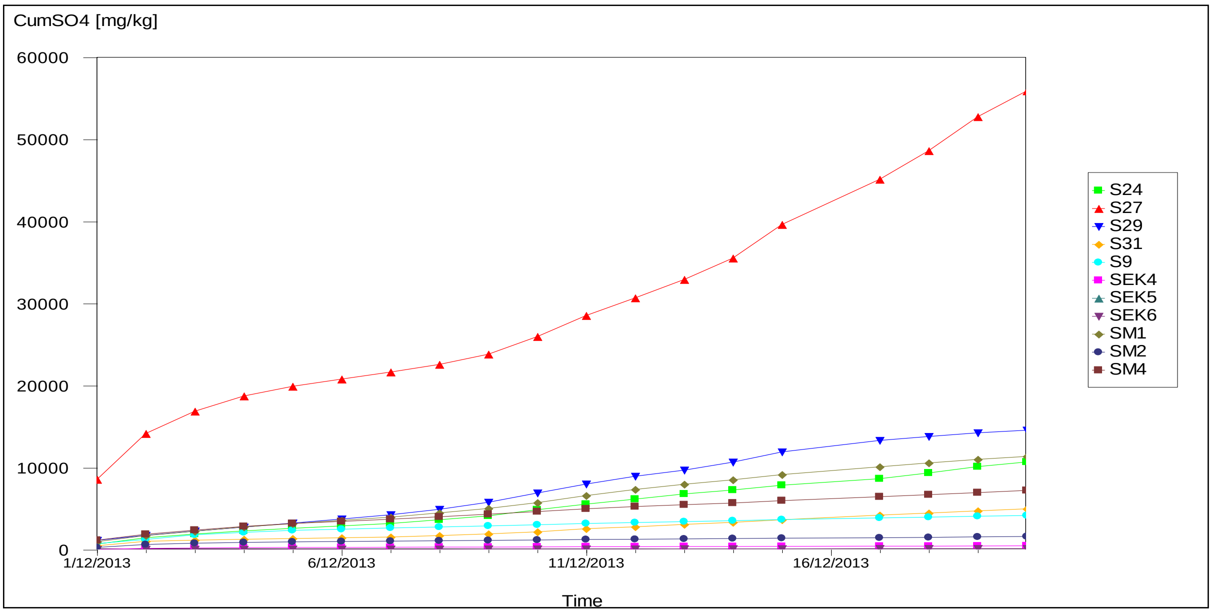


Figure 92: Cumulative sulphate production (mg/kg) of humidity cells for interburden material.

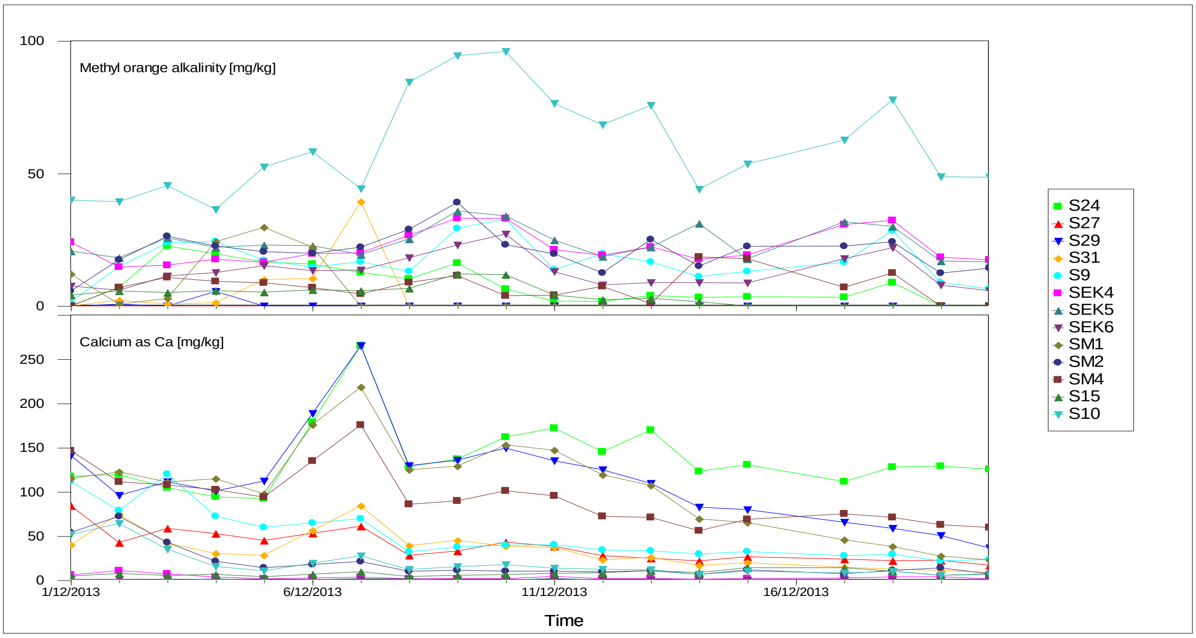


Figure 93: The calcium and alkalinity values of humidity cells for interburden material.

7.5.3 Plant and discards/composites

The plant discards consist of unwanted material that remains after coal separation, also known as composite samples. The different density composite samples were analysed and indicated that they all have a high acid production potential.

7.5.4 Mixed overburden, interburden and discards

The overburden and interburden have already been mentioned as neutralising and acidic, respectively. A combination (predetermined mixture ratio) of overburden, interburden and composites can potentially reduce the risk of acid generation within the pit. Kinetic tests on mixtures of overburden, interburden and composite material showed that the acidic nature of the samples were reduced. In the event that the buffer potential of the mixed overburden and interburden fail to reduce the acid generation and the exposure to oxygen in the presence of water, the acid generating process will be accelerated. All the samples were mixed in a 50:50% ratio, except for sample SM2 which consisted of 25% of each sample. The ABA results of the samples that were mixed are summarised in (*Table 31*). A combination of a sample with a positive NNP was combined with samples with a negative NNP (acid producer).

The initial pH values of the samples were acidic but after testing was completed, the samples became neutral due to the overall effect of mixing overburden, interburden and composite material (Figure 94). The decrease in pH for samples GM3 shows the limited buffer capacity this mixture would have, initially increasing the pH and after the buffer capacity is not adequate enough, decreasing the pH.

Table 31: Summary of the ABA results of samples used for the mixed HCT.

Kinetic name	sample combination	sample	initial pH	final pH	NNP (open)	sample	initial pH	final pH	NNP (open)
Gm1	JB27+VA3	**JB27**	7.1	4.73	-3.08	**VA3**	8.59	8.50	79.1
Gm2	MB3+CZONE9B	**MB3**	8.11	7.48	113.04	**CZONE9B**	6.12	2.32	-33.544
Gm3	MB1+CZONE1A	**MB1**	7.8	7.37	181.38	**CZONE1A**	5.19	1.57	-438.197
Gm4	MB3+CZONE6B	**MB3**	8.11	7.48	113.04	**CZONE6B**	6.54	2.12	-11.758
Gm5	MB2+CZONE2A	**MB2**	8.04	7.32	219.53	**CZONE2A**	6.54	1.88	-273.675
Gm6	VA47+PZONE10A	**VA47**	8.32	8.27	77.45	**PZONE10A**	6.68	2.36	-37.890
Gm7	VA43+PZONE6B	**VA43**	8.8	8.04	60.22	**PZONE6B**	6.54	2.12	-11.758
Sm1	WGA3 (A)+WGA4	**WGA3 (A)**	7.95	7.58	114.5	**WGA4**	6.4	2.09	-82.38
Sm2	WGG2+ WGG4(D)+ WGG4(F)+ WGG6(A)	**WGG2**	7.52	3.99	-5.75	**WGG4 (F)**	7.99	6.13	-4.41
		WGG4 (D)	8.01	4.43	-1.25	**WGG6 (A)**	8.08	7.23	23.12
Sm3	WRA4(A)+WRA5(B)	**WRA4 (A)**	6.99	2.72	-24.8	**WRA5 (B)**	7.59	4.68	33.78
Sm4	WGA3(A)+WGB10	**WGA3 (A)**	7.95	7.58	114.5	**WGB10**	8.1	1.24	-34.74

The slight sulphate decline in samples GM2-GM7 at the initiation of kinetic testing suggests that the oxidised products were leached from the system (Figure 95). The cumulative mass of sulphate produced indicates that the overburden, interburden and composite samples all continued to produce sulphate over the course of the test (Figure 96). The gradient of the curve provides an indication of the relative sulphate production rates, showing that the initial high sulphate production continues to increase over time.

Calcium and alkalinity results showed that there were relatively low amounts of alkalinity released into the surroundings (Figure 97). Although the carbonates are not immediately released, the balance between the acid generated and the released alkalinity stays positive. If the balance is influenced negatively acid would start generating from these materials and infiltrate to the bottom of the pit and eventually into the groundwater system.

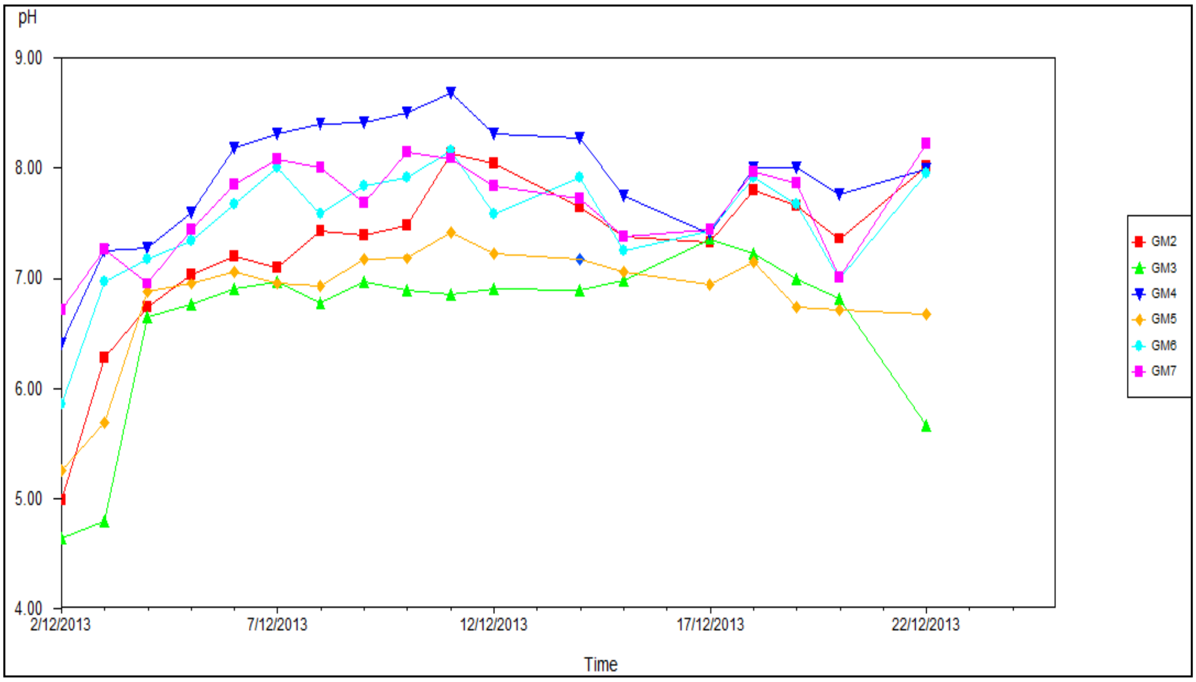


Figure 94: The pH values of the humidity cells for overburden, interburden and composite material.

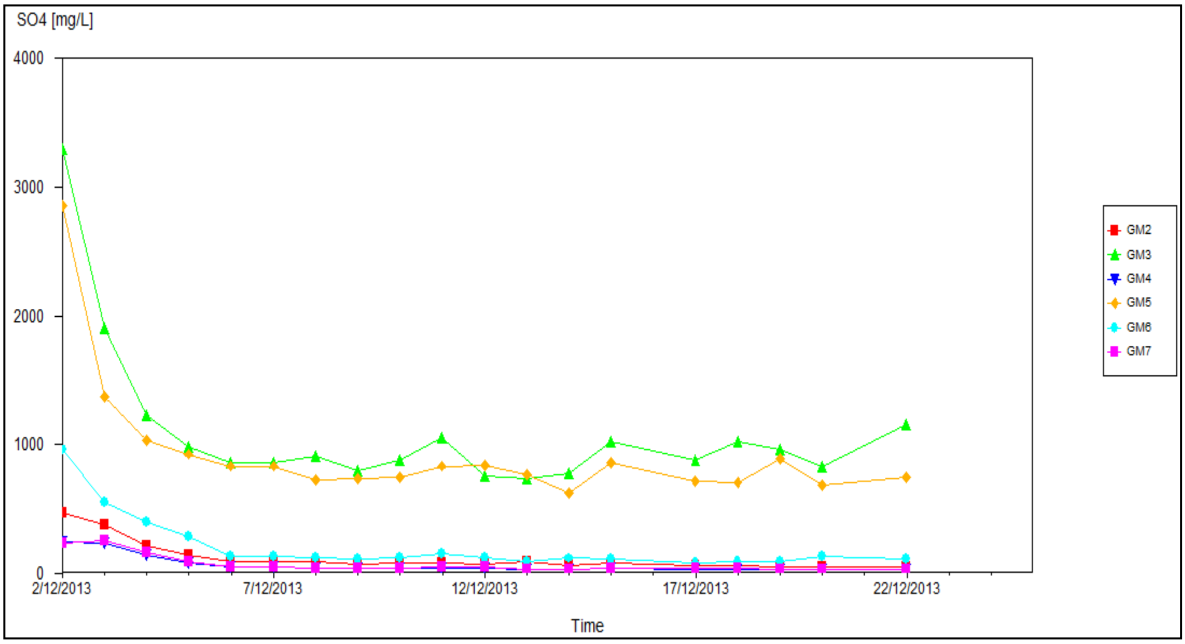


Figure 95: The sulphate values of the humidity cells for overburden, interburden and composite material.

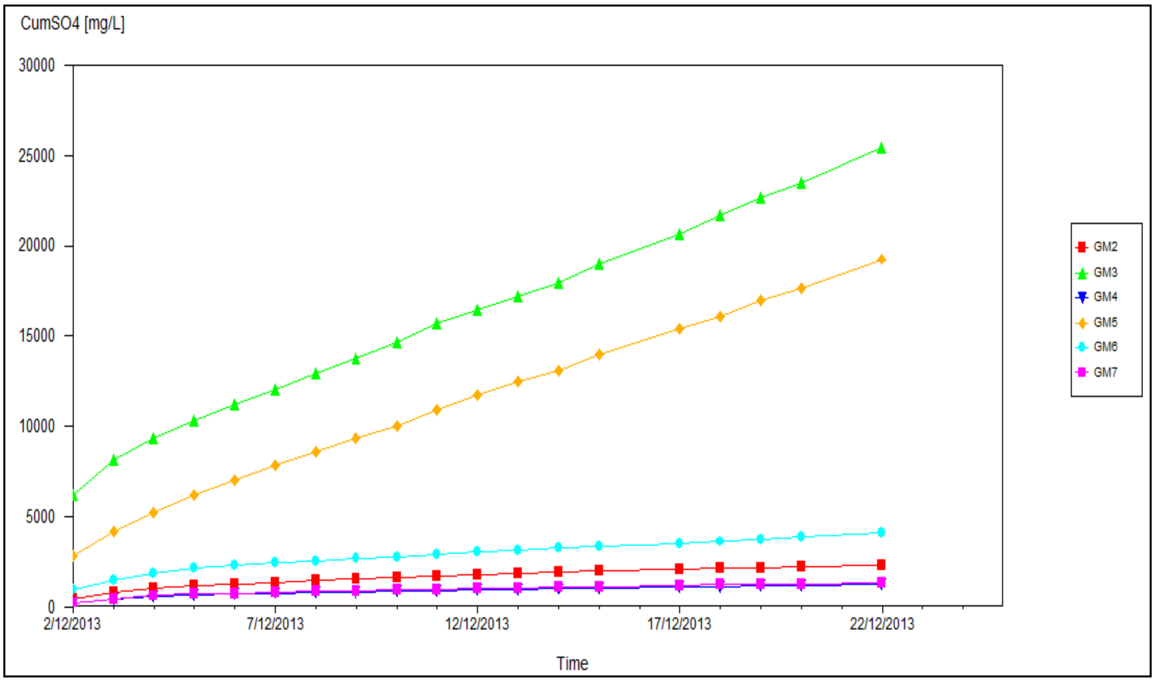


Figure 96: Cumulative sulphate production (mg/kg) of humidity cells for overburden, interburden and composite material.

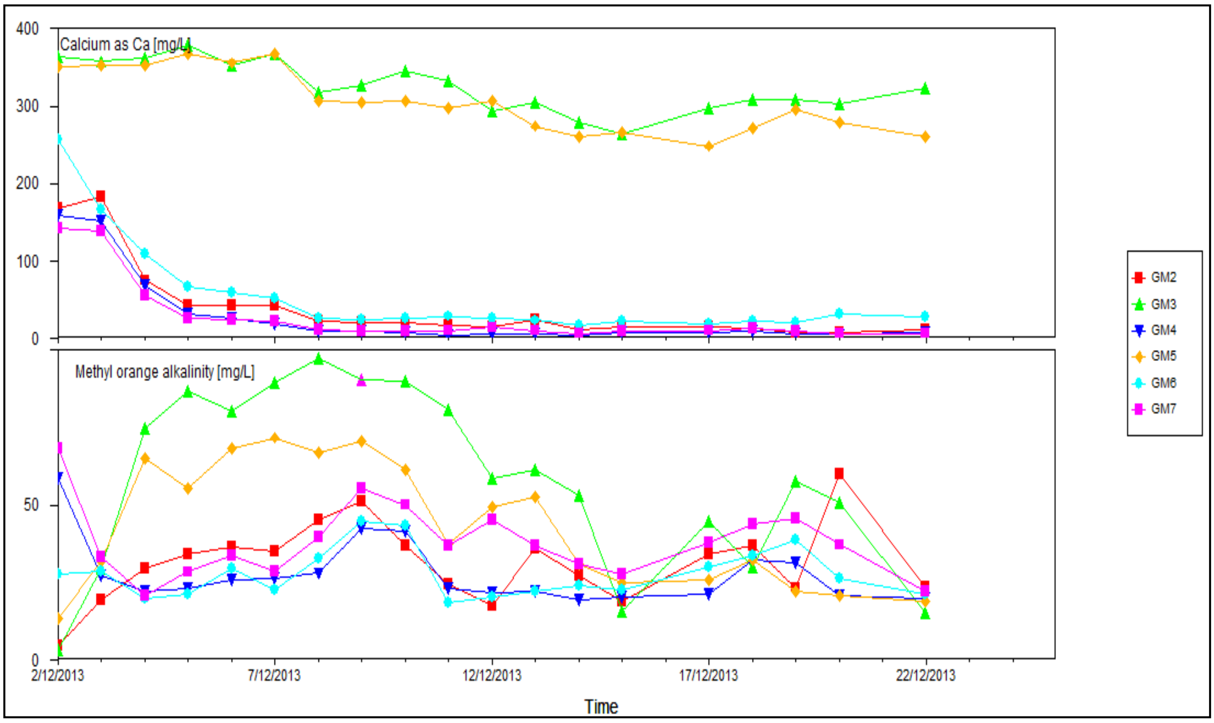


Figure 97: The calcium and alkalinity values of humidity cells for overburden, interburden and composite material.

Two samples were combined (50% each), one with an ABA positive NNP and one with a negative NNP (acid producer) and a kinetic cell were run for this combination (Figure 98). In addition, these samples (S33 and S29) were individually analysed. The result of the combination (SM4) cell indicated that for the period of testing the base potential was leached, and the mixed/combined sample leachate became acidic.

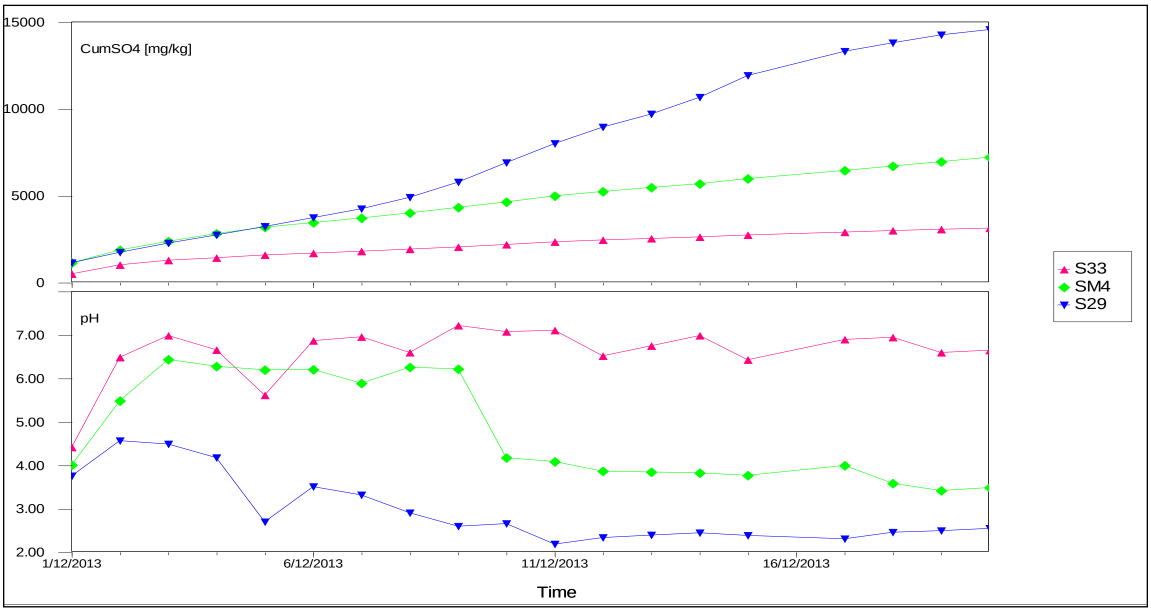


Figure 98: Cumulative sulphate production and pH for the combination humidity cells.

Only one other HCT, SM1, turned out to produce AMD over the short test period of 20-21 weeks which corresponds to the final ABA NNP sum.

Table 32: Summary of the net ABA and HCT outcome after 20-21 weeks.

Kinetic name	sample combination	sample	NNP (open) (A)	sample	NNP (open) (B)	NNP sum of combined ABA (open) (column A and B)	HCT outcome after 20-21 week period
Gm1	JB27+VA3	**JB27**	-3.08	**VA3**	79.1	76.02	neutral-alkaline
Gm2	MB3+CZONE9B	**MB3**	113.04	**CZONE9B**	-33.544	79.496	neutral-alkaline
Gm3	MB1+CZONE1A	**MB1**	181.38	**CZONE1A**	-438.197	-256.817	neutral-alkaline
Gm4	MB3+CZONE6B	**MB3**	113.04	**CZONE6B**	-11.758	101.282	neutral-alkaline
Gm5	MB2+CZONE2A	**MB2**	219.53	**CZONE2A**	-273.675	-54.145	neutral-alkaline
Gm6	VA47+PZONE10A	**VA47**	77.45	**PZONE10A**	-37.89	39.56	neutral-alkaline
Gm7	VA43+PZONE6B	**VA43**	60.22	**PZONE6B**	-11.758	48.462	neutral-alkaline
Sm1	WGA3 (A)+WGA4	**WGA3 (A)**	114.5	**WGA4**	-82.38	32.12	acidic
Sm2	WGG2+ WGG4(D)+ WGG4(F)+ WGG6(A)	**WGG2**	-5.75	**WGG4 (F)**	-4.41	11.71	neutral-alkaline
		WGG4 (D)	-1.25	**WGG6 (A)**	23.12		
Sm3	WRA4(A)+WRA5(B)	**WRA4 (A)**	-24.8	**WRA5 (B)**	33.78	8.98	neutral-alkaline
Sm4	WGA3(A)+WGB10	**WGA3 (A)**	114.5	**WGB10**	-34.74	79.76	acidic

Evaluating the ABA values as in Table 31 and the HCT outcome summarised in Table 32, it is clear that the base potential reactions are exceeding that of the acid production for the samples where an acidic HCT outcome is expected – samples GM3 and GM5.

From the abovementioned results it is therefore suggested that the 20-21 week are too short to determine the final outcome for these HCT. Open system NNP values are used since the HCT are aerated.

7.6 Geochemical modelling

A number of hydrogeochemical processes can occur as the HTC evolves through various stages towards a particular hydrochemical type and quality. A good understanding of such hydrogeochemical processes is very important for investigating the characteristics of the HTC leachate. Typical hydrogeochemical processes that can occur during AMD include: acid neutralisation/buffering, chemical precipitation, attenuation or dissolution of metals (Blowes and Ptacek, 1994). The product of pyrite oxidation is not a pure ferric hydroxide but a mixture of phases with variable stoichiometry, including goethite (moderately crystalline), ferrihydrate (poorly crystalline), schwertmannite and jarosite (well crystalline) (Bigham and Nordstrom, 2000).

PHREEQC hydrogeochemical model was populated with data from different humidity cells and the saturation indexes (SI) over the 20-21 weeks were calculated. Zero SI indicates solubility equilibrium of the solution composition with respect to the mineral phase. Negative SI indicates undersaturation while positive values reflect supersaturation hydrogeochemical conditions. Undersaturation implies that the mineral phase can dissolve in the solution while the opposite is true for supersaturation.

The major differences between a HTC sample with a neutral-alkaline leachate (Figure 99) and an acid leachate (Figure 100) are visible from these graphs. The complexes that mostly form for the cells with low pH are sulphate related due to the oxidation of sulphide minerals. In cells with alkaline pH’s leachate products from mainly dolomite and calcite saturation is expected.

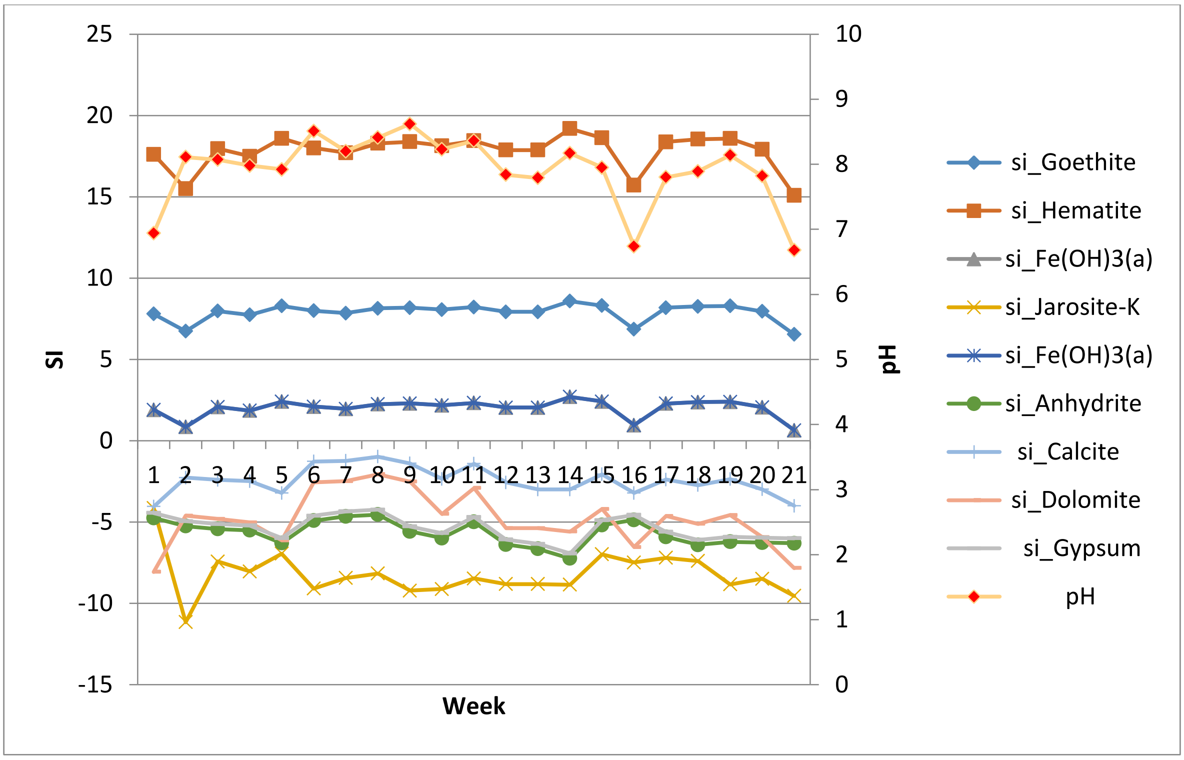


Figure 99: Saturation indices of selected minerals from a neutral humidity cell G4.

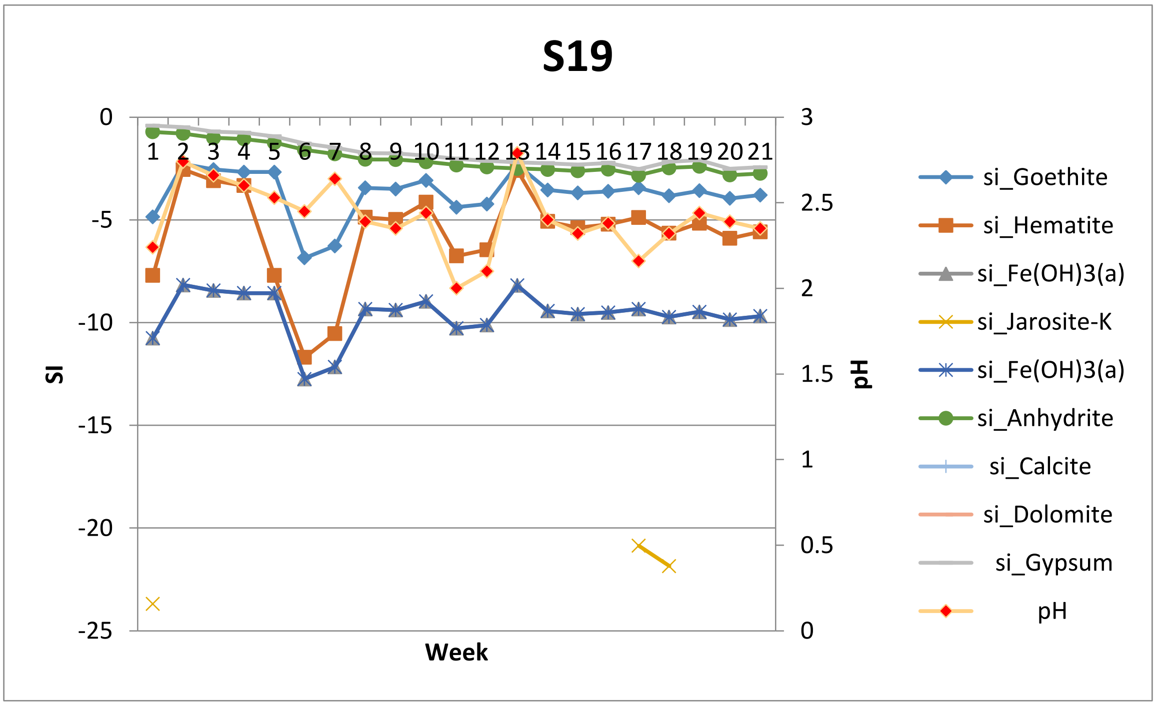


Figure 100: Saturation indices of selected minerals from an acid humidity cell S19.

No saturation for dolomite, calcite or gypsum was obtained in the acidic humidity cell (Figure 100) as these products were already leached and/or not present in the sample.

The saturation indices of dolomite, calcite, jarosite, goethite, hematite and $Fe(OH)_3$ are very much pH dependent versus the other SI complexes. The SI values for humidity cell SM4 (mixed sample) (Figure 101) which started at pH 4.01, reached pH 6.2 for 7 weeks and then dropped to 3.39 at the end of week 21 show similar results to those discussed above.

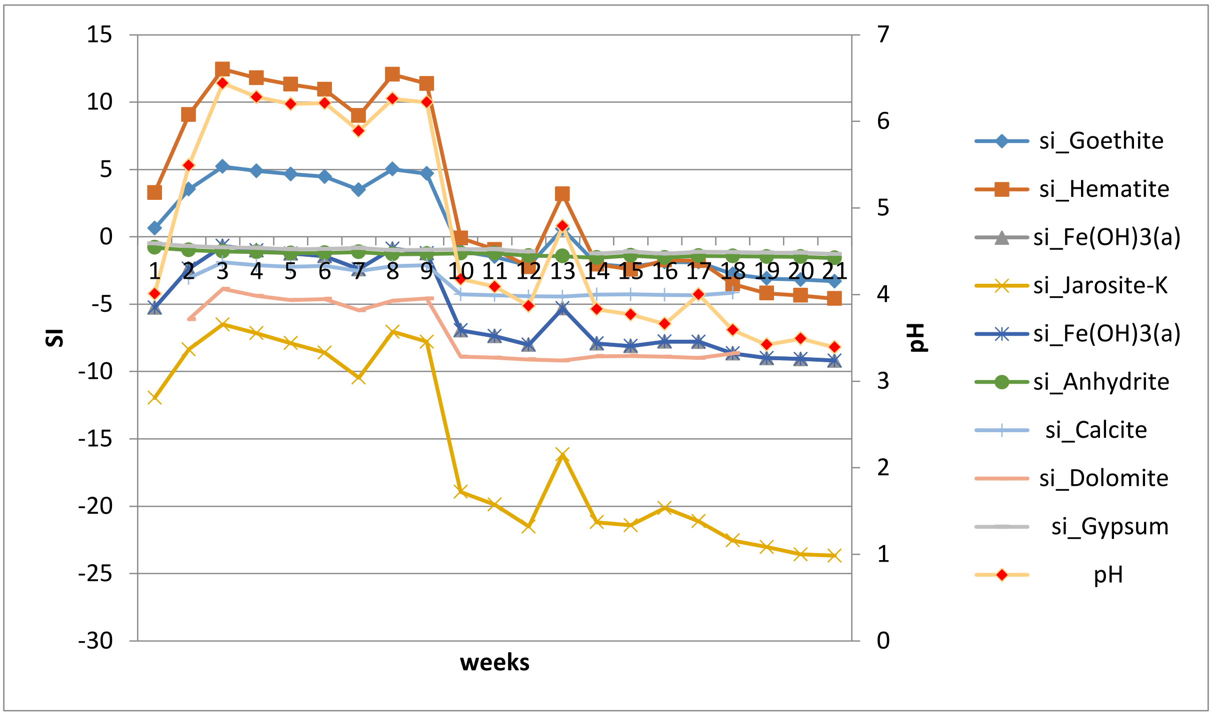


Figure 101: Saturation indices of selected minerals in humidity cell SM4 (plot A).

Splitting of the results into the products expected because of sulphide oxidation (Figure 102) and the product that are expected to be produced in an alkaline environment (Figure 103) indicates the trend as discussed for the previous samples. Gypsum is not pH dependent in this sample according to Figure 101 and Figure 103.

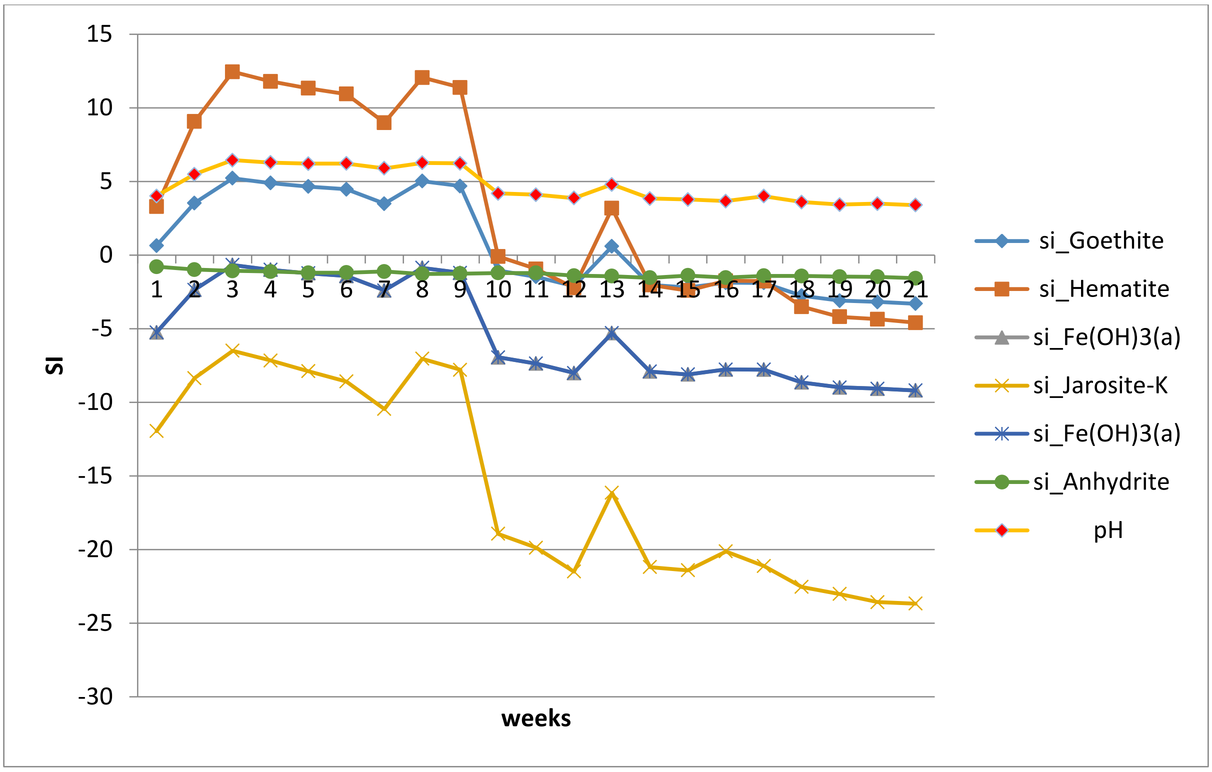


Figure 102: Saturation indices of selected minerals in humidity cell SM4 (plot B).

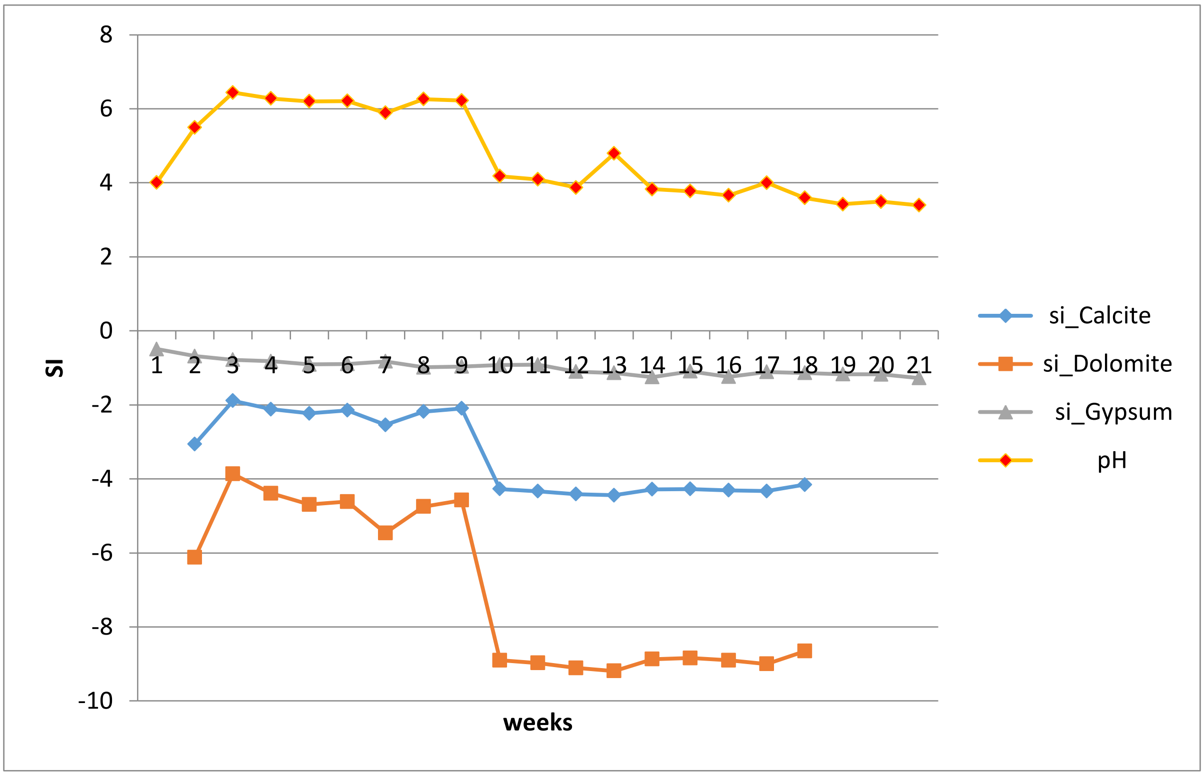


Figure 103: Saturation indices of selected minerals in humidity cell SM4 (plot C).

During the oxidation of pyrite, it is expected that ferric hydroxide is the main product. However as indicated by Bigham and Nordstrom (2000), the product of pyrite oxidation is not a pure ferric hydroxide but a mixture of phases with variable stoichiometry, such as goethite (moderately crystalline), ferrihydrate (poorly crystalline), schwertmannite and jarosite (well crystalline). The presence of these phases in the leachate is therefore an indication that acid mine drainage is being generated

Similar graphs were obtained with the HCT results of the other cells. The data are summarised in Table 58. Values of -999 are omitted in graphs.

The 20-21 week humidity cell testing time is too short and longer times are suggested to evaluate the results.

8 LEACH RESULTS

Leaching is the process by which elements are released from the solid phase into the water phase, under the influence of changes in the direct environment of the mining products (ash – waste). Fly Ash usually contains high neutralising potentials. It is therefore co-mixed or used as lining to samples that are prone to acidify. As discussed in section 4.5, there are different leaching procedures. The problem with these discussed methods are that they are not aggressive enough to liberate elements/metals from the product (Ash/overburden/CCB's) tested, since the final pH after leaching is still neutral to alkaline (TCLP, SPLP, water). The digestion of samples with concentrated acids and heating liberate all the elements available and it is not close to environmental conditions.

8.1 Ash and Acid

The liberation of elements at different pH's and the use of dilute acid on fly ash samples will be used to demonstrate the solubility of the elements.Fly ash from a coal fired power station was leached using different acids (HCl, HNO_3 and H_2SO_4) to different pH's.

The solubility of different elements vs pH and with different 0.1 N acids is indicated in the following graphs. One of the reasons sulphuric acid is favoured is that it is closer to AMD than any other extraction mixture. On each of the graphs the initial value of the element in a water sample is also indicated as a green dot. The influence of the experiments contribution to the concentration of the element can thus be assessed in this way. The high aluminium values can also be noted - the concentrations in the leachate is close to that of the major cations like magnesium, iron and calcium.

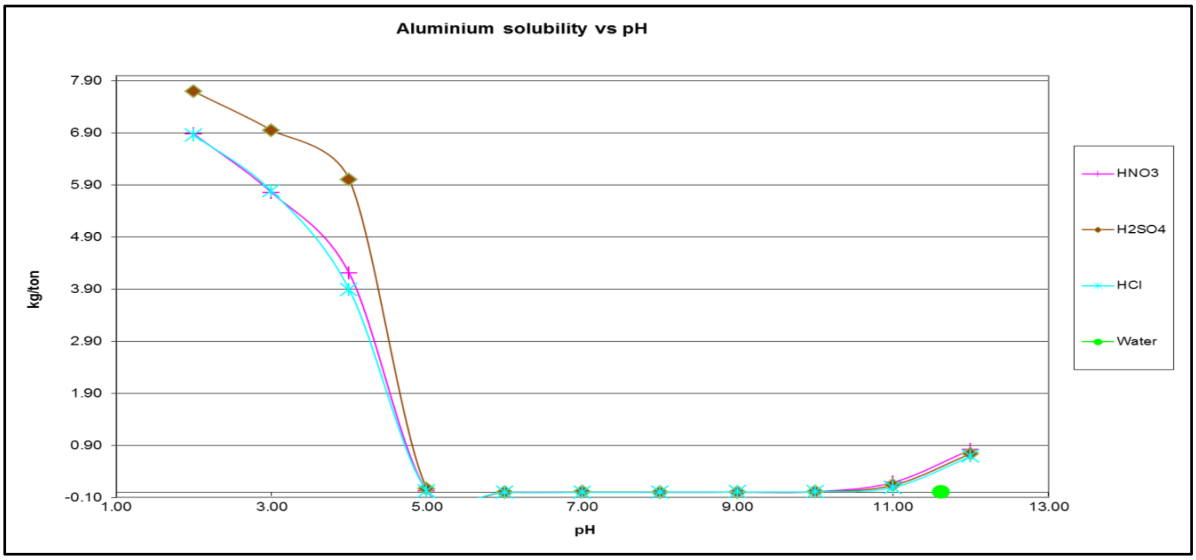


Figure 104: Aluminium solubility in fly ash vs pH.

Where fly ash is used to neutralise AMD from discards and waste rocks that are mixed, the high aluminium values are of concern. It is important to calculate the correct neutralising potential of the ash in the determination of the volume of ash to be used with the AMD. An excess NP must be present to ensure the non-acidification of the ash.

A few graphs of some elements are plotted to show the pH effect.

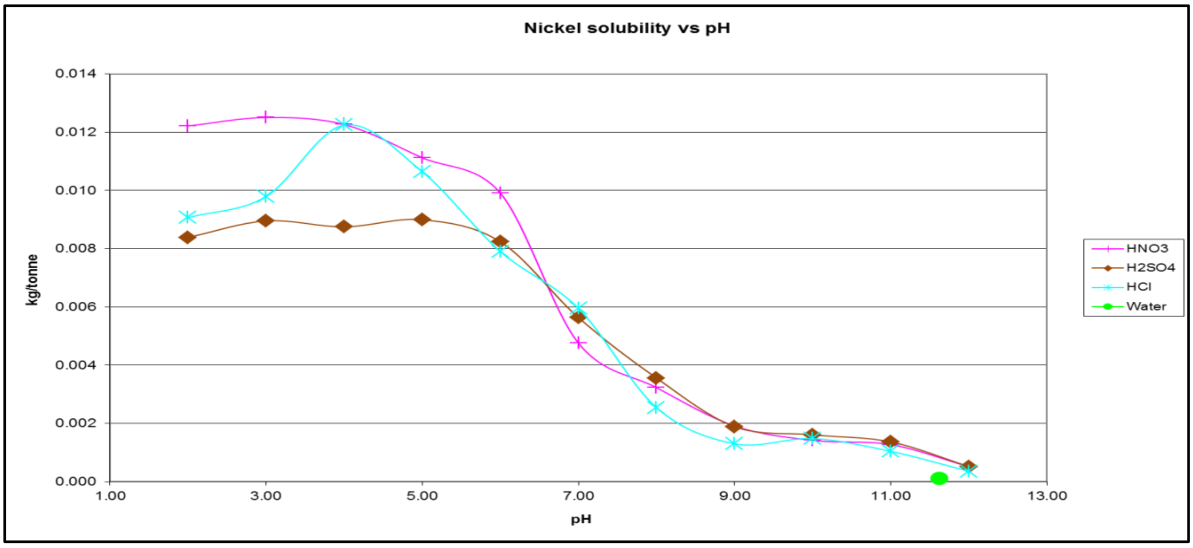


Figure 105: Nickel solubility in fly ash vs pH.

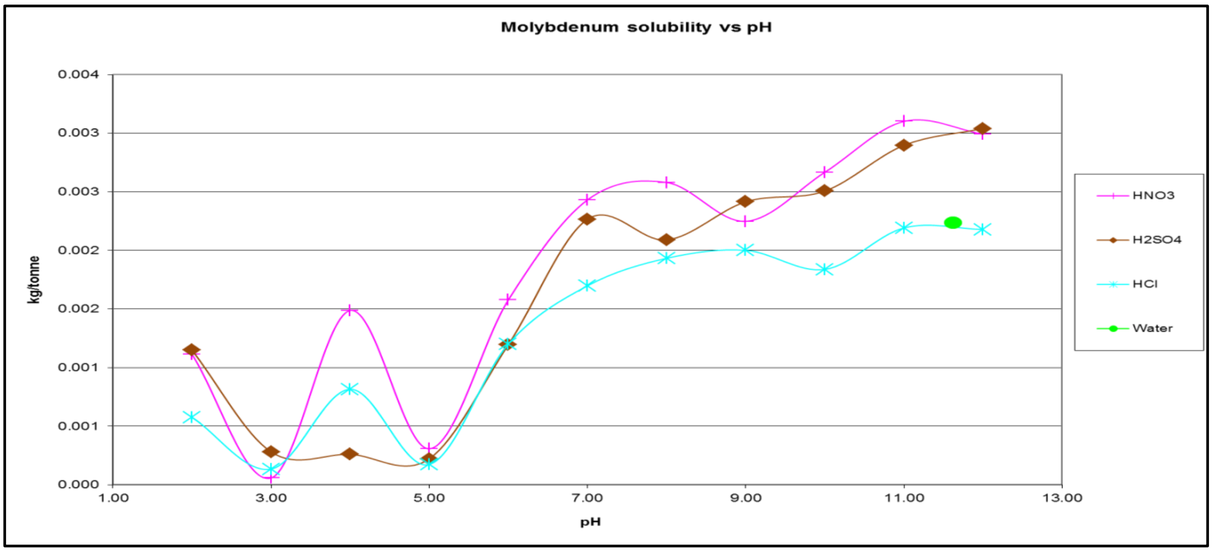


Figure 106: Molybdenum solubility in fly ash vs pH.

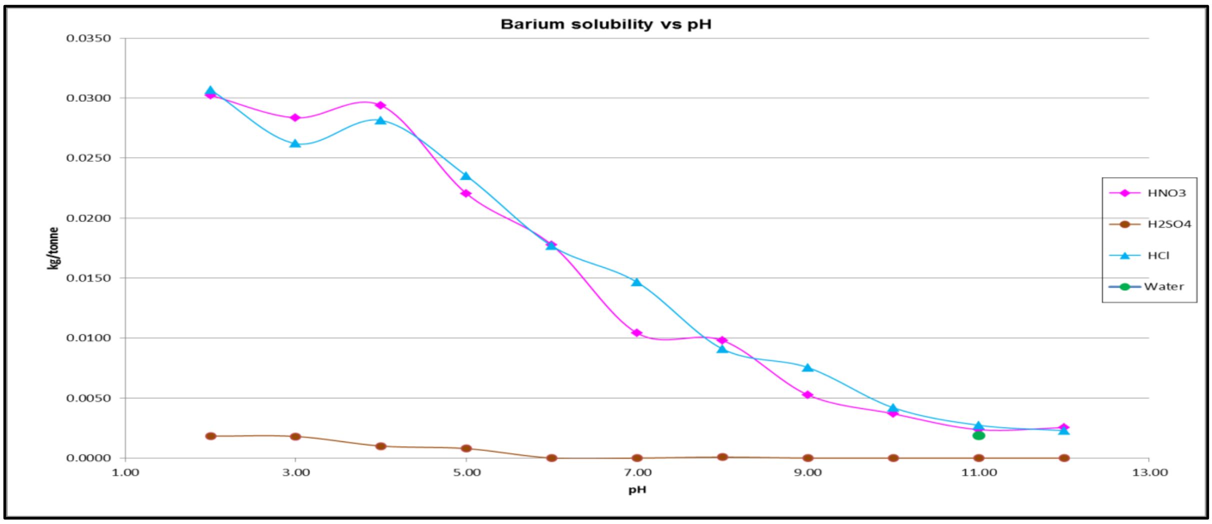


Figure 107: Barium solubility in fly ash vs pH.

The solubility of the elements that was tested in this experiment is summarised in Table 59 (Appendix). The nickel solubility is in line with other metal at a low pH – at low pH high solubility of metals. The behaviour of the molybdenum with very low solubility at low pH but higher at neutral pH have also been noted by other authors (Izquierdo and Quierol, 2012). This behaviour of molybdenum at neutral pH's causes it to be more difficult to remove since at neutral pH's, most of the metals precipitate and can be removed from the environment (stream/dam). Strontium and potassium values were not as pH dependant as the other elements/metals tested. Barium solubility in the presence of the H_2SO_4 is very low due to the precipitation of $BaSO_4$. $BaCO_3$ is also used in AMD treatment which leads to lower final TDS values (versus $CaCO_3$) of the effluent. This is as a result of the precipitation of the $BaSO_4$, while the carbonate is used to buffer/neutralise the leachate (Castillo, 2015 and Rotting, 2008).

There is not that much of a difference between the solubility of the metals/elements tested amongst the different acids, except in the case of barium.

8.2 Ash and AMD

Ash in general has a high neutralising potential (Abbott *et al*, 2001, Seoane and Leiros, 2001, Stewart *et el*, 1997, Vadapalli *et al*, 2008 and Xenidis *et al*, 2002). The analysed ash samples from the Matimba Power Station had pH values that ranged from between 9.30 and 10.91. The neutralising potential of the ash samples were between 0.124kg/tons and 0.208kg/tons. If ash however becomes acidic it can mobilise heavy metals into the natural system and can become harmful.

Four interburden samples acidified during kinetic testing (S17, S19, S27 and S29) and the leachate from these samples were mixed and analysed. The pH of this AMD mixture was

2.41 and the acidity 14 000 $CaCO_3$ ppm. This mixture was used to test the effect on the pH of the fly ash and different Ash:AMD ratios. 100ml of the AMD mixture was added to 5g, 10g, 20g and 50gof the fresh ash samples. The results are summarised inTable 33.

Table 33: The different time intervals for leachate and ash mixtures.

Time (hours)	**Ratio (l:s)**	**AMD pH**	**1**	**24**	**48**
Mass (g)		**Initial pH**	**Final pH**	**Final pH**	**Final pH**
5	20:1	2.41	3.01	2.98	3.36
10	10:1	2.41	4.06	4.08	3.92
20	5:1	2.41	4.84	5.35	4.87
50	2:1	2.41	6.19	6.47	7.99

The ratios of AMD mixture:ash is plotted in Figure 108. The ratio of acidic water to ash is very important as the ash has a limited alkalinity. Only with a ratio of less than 5 liquid : 1 solid will there be enough neutralising capacity in the ash to counteract the acid. At a ratio of 2:1 (50g sample) the pH of the AMD mixture was higher than 6.

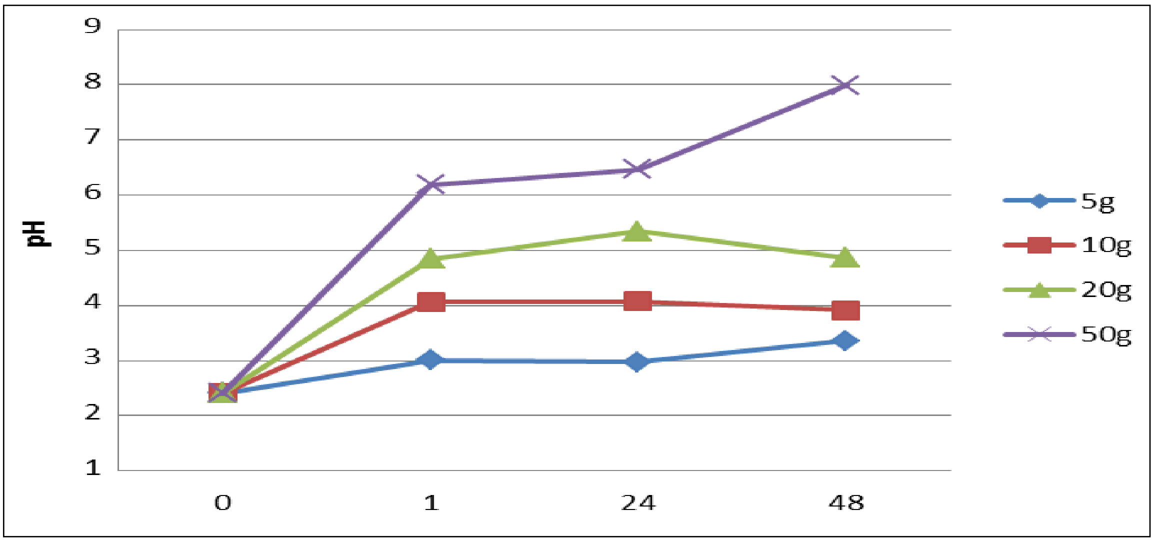


Figure 108: pH values for the AMD mixture and ash over time.

These ratios will be important to determine the safe handling of spoils with Ash.

8.3 Water, Peroxide, SPLP and Acid Leach

All samples are exposed to different leaching procedures during the static ABA method. Water is used to obtain the paste pH, after which the pH is measured.The supernatant is then filtered and the elements determined by ICP-OES. The same materialised for the NAP or final pH where peroxide is use. The IGS standard leach (Cruywagen, 1999) with diluted H_2SO_4 is also conducted on all the samples received. The pH of the final mixture is monitored and acidified until the pH is below 2.50, after which the supernatant is removed for analysis. The pH of the acid leach is monitored to be below pH 2.5 so that elements/metals that might go into solution under AMD conditions can be analysed. SPLP analysis was done on a few samples as a regulator to show that it is equal to the water leach and not that useful to the mining industry (Table 34).

The following graph (Figure 109) indicates the solubility of different elements/metals from the overburden samples which in general tested to have mostly net neutralising potentials (Grootegeluk samples).

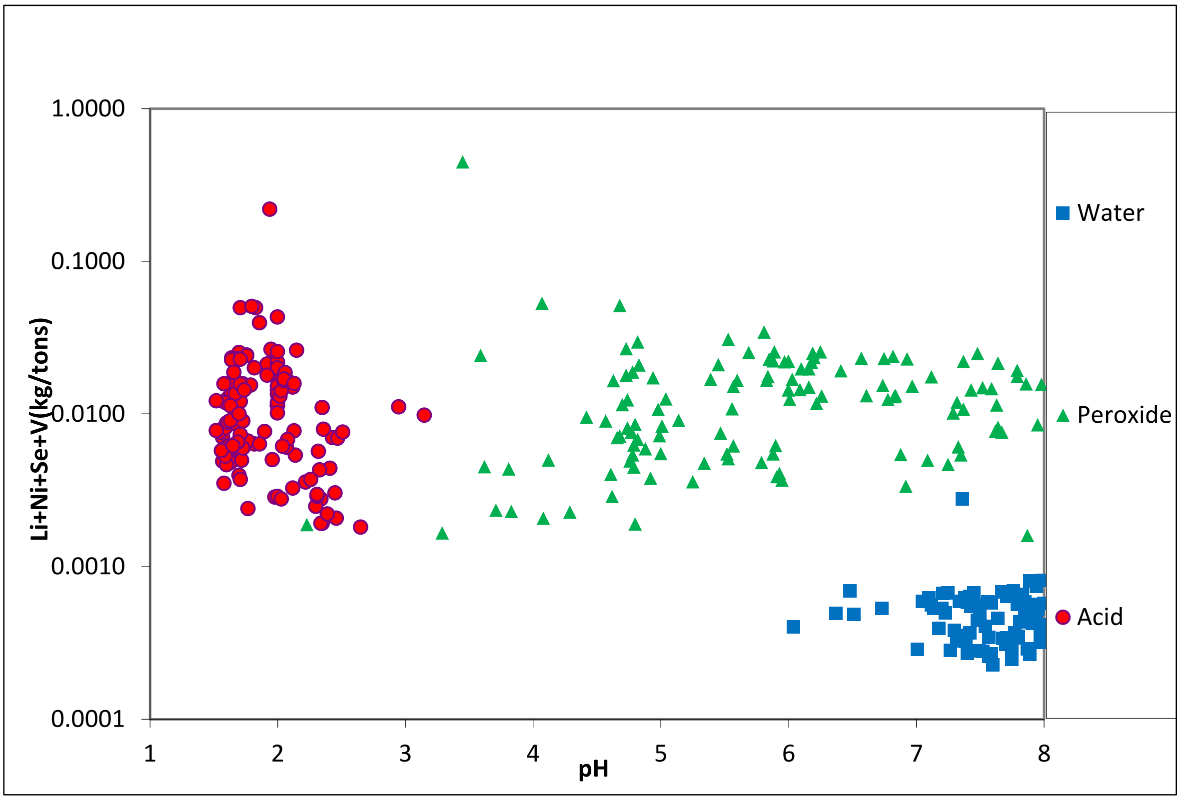


Figure 109: Metals/elements in solution at different pH's in different media for overburden samples.

The concentration of the trace metals are 10 – 1000x higher in samples that are acidified. With peroxide oxidation, an acidic pH is not always obtained. The results of the tested Resgen samples indicate this more clearly (Figure 110).

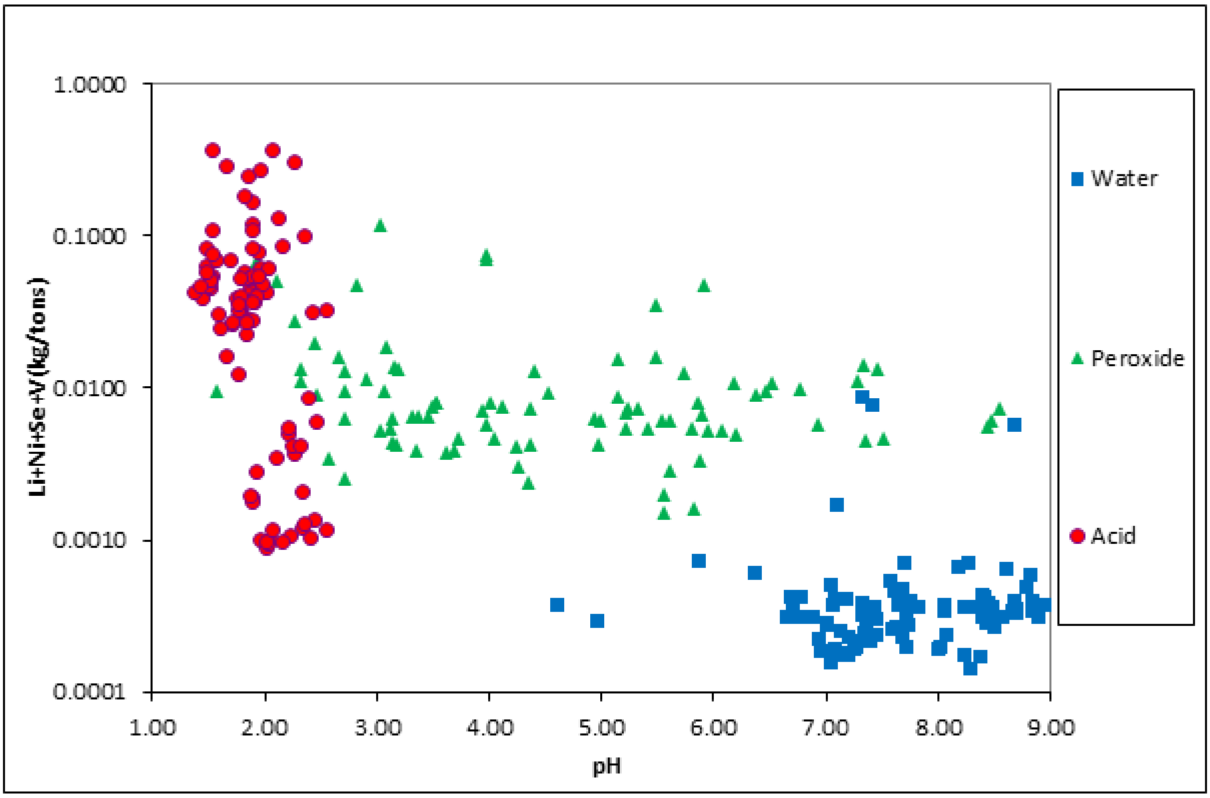


Figure 110: Total trace metal concentration in solution at different pH media for the Resgen samples.

Sulphate and iron show an increase in concentration associated with the presence of the sulphide mineral pyrite for the composite sample. The aluminium goes into solution with the drop in pH (Figure 111).

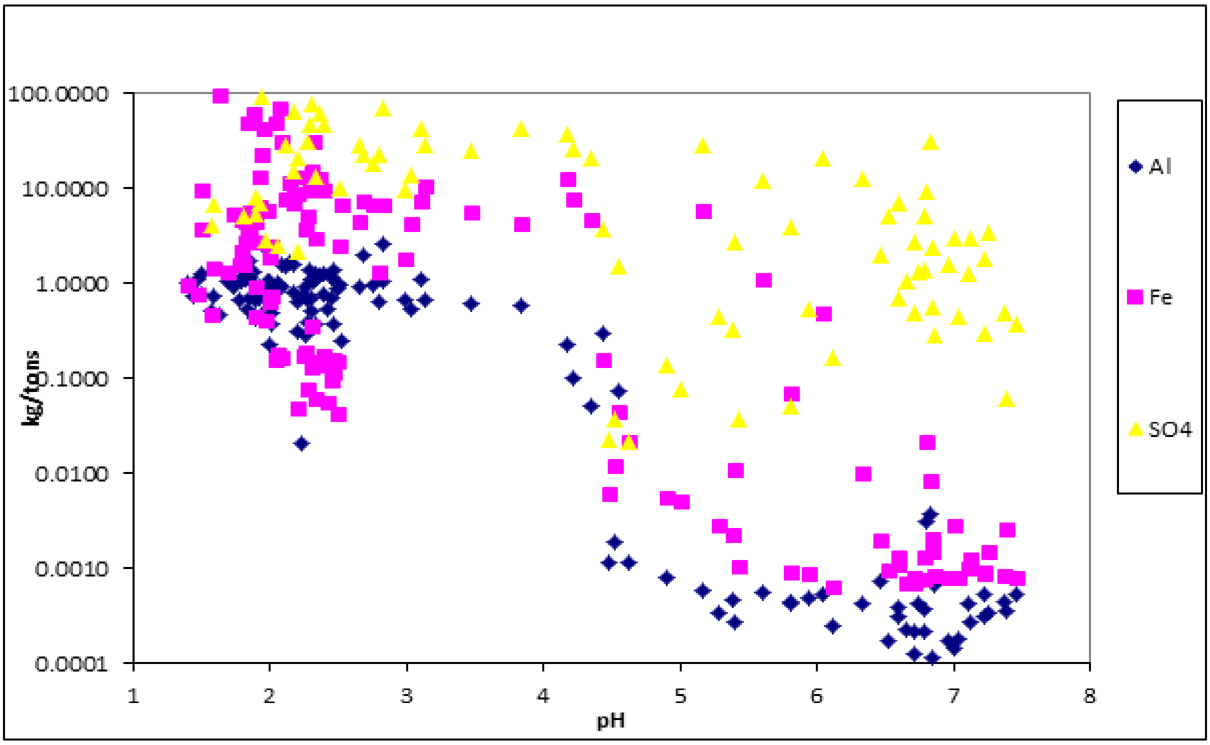


Figure 111: Release of Al, Fe and SO4 as a function of pH for the Composite samples.

There is no distinct pattern in the acid leachable trace metals from the Composite samples in the different zones. These results are plotted in the following graph (Figure 112).

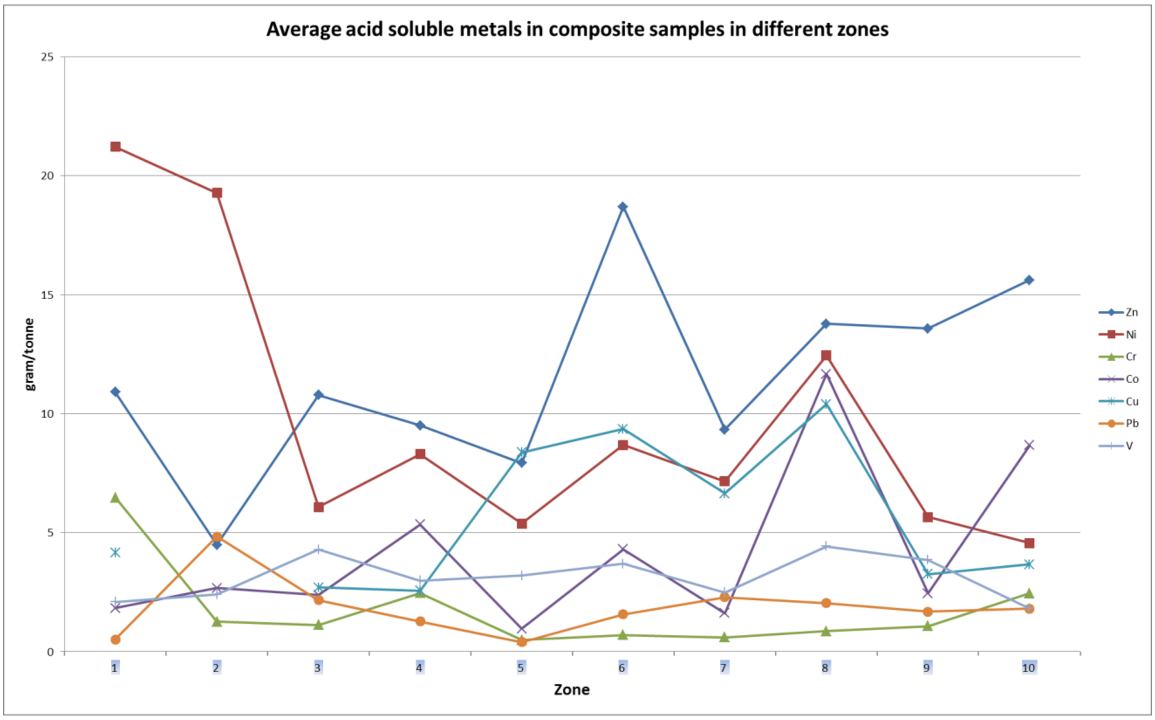


Figure 112: Acid soluble trace metals in the different composites from different zones.

After the SPLP tests were completed, the pH's of the mixtures were similar to the pH's of the paste pH testsin which case deionized water was used. The elements that are leached with the SPLP test are similar to the water leach test. Results of ash samples from the Waterberg and Mpumalanga area were subjected to these tests and are included in Table 34. These results indicate that the water leach tests that were done provide similar results to that of the SPLP tests.

Table 34: Trace elements (gram/tonne) leached with water and SPLP in ash samples.

Leach media	Sample	pH	Ba	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	B	Li
SPLP	Fresh Ash Mpum	8.58	0.681	0.003	3.683	0.136	0.717	0.147	0.023	0.039	3.744	0.000	57.18	3.041
SPLP	Old Ash Mpum	8.42	0.477	0.002	1.301	0.130	0.594	0.239	0.016	0.038	2.994	0.000	33.84	1.430
SPLP	Ash 1 Wberg	8.82	0.600	0.000	0.510	0.000	0.560	0.080	0.000	0.000	1.230	0.040	18.69	1.350
SPLP	Ash 2 Wberg	8.58	0.790	0.000	0.160	0.000	0.810	0.110	0.000	0.000	1.170	0.040	25.92	0.430
SPLP	Old Ash Wberg	8.42	0.640	0.000	0.080	0.090	0.370	0.130	0.060	0.000	1.550	0.060	109.74	0.700
Water	Fresh Ash Mpum	8.85	1.532	0.000	4.277	0.073	0.662	0.254	0.004	0.042	2.250	0.151	37.97	3.527
Water	Old Ash Mpum	8.52	0.170	0.023	1.926	0.164	0.529	0.819	0.000	0.031	1.040	0.040	28.09	0.987
Water	Ash 1 Wberg	8.45	0.550	0.000	0.670	0.000	0.880	0.090	0.000	0.000	1.030	0.040	18.62	1.970

Leach media	Sample	pH	Ba	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	B	Li
Water	Ash 2 Wberg	8.36	0.780	0.000	0.170	0.000	0.940	0.050	0.000	0.000	0.910	0.050	20.29	0.400
Water	Old Ash Wberg	8.35	0.530	0.000	0.090	0.110	0.440	0.090	0.040	0.000	1.780	0.100	95.54	0.620

An AMD mixture was also used as a medium to leach the ash samples. These results, together with the leach results obtained with a diluted H_2SO_4 solution (IGS leach), is presented in table 25. The AMD mixture had a very high Fe concentration whichinfluenced the results.

Table 35: Trace elements (gram/tonne) leached with AMD and acid in ash samples.

Leach media	Sample	pH	Ba	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	B	Li
AMD	Fresh Ash Mpum	2.07	0.55	6.84	4.81	5.79	0	57	5.6	0.475	2.57	5.54	70.91	5.09
AMD	Old Ash Mpum	2.09	0.53	0.09	3.50	4.29	0	82	0.7	0.000	1.00	2.45	100.75	5.45
AMD	Ash 1 Wberg	No sample												
AMD	Ash 2 Wberg	2.28	0.98	3.98	10.33	9.12	0	113	16.0	0.000	36.64	7.47	94.21	6.96
AMD	Old Ash Wberg	2.38	0.47	1.39	7.55	9.43	0	96	25.6	0.000	21.81	19.75	282.96	5.22
Acid	Fresh Ash Mpum	1.64	0.01	24.26	8.53	13.78	11858	122	7.8	0.85	20.69	6.79	134.57	12.14
Acid	Old Ash Mpum	1.98	0.07	0.65	7.69	6.99	9810	130	0.4	0.75	19.48	5.97	128.60	10.39
Acid	Ash 1 Wberg	1.84	0.28	1.15	10.33	5.97	613	95	7.2	0.00	53.32	10.17	49.93	5.32
Acid	Ash 2 Wberg	1.64	0.46	1.43	13.86	5.33	550	85	6.2	0.00	48.68	10.16	55.34	5.03
Acid	Old Ash Wberg	1.98	0.71	0.64	6.60	2.79	483	24	3.3	0.00	25.58	5.58	165.67	3.32

Elements like Co and Ni are barely leached with water and SPLP, but the values obtained with AMD and the acid leach are up to 1000’s of times higher than that obtained with water or SPLP.

Aluminium is leached in high concentrations with the AMD and the acid leach is indicated in Table 36.

Table 36: Comparison of the Aluminium leached (kg/tonne) with different media.

Row Labels	**Leach media**	**Al**	**Leach media**	**Al**
Fresh Ash Mpum	AMD	4.154	SPLP	0.078
Old Ash Mpum	AMD	5.644	SPLP	0.047
Ash 1 Wberg	AMD	no sample	SPLP	0.001
Ash 2 Wberg	AMD	3.459	SPLP	0.001
Old Ash Wberg	AMD	2.438	SPLP	0.001
Fresh Ash Mpum	Acid	12.740	Water	0.090
Old Ash Mpum	Acid	12.292	Water	0.028
Ash 1 Wberg	Acid	3.759	Water	0.001
Ash 2 Wberg	Acid	3.619	Water	0.001
Old Ash Wberg	Acid	1.932	Water	0.001

Similar results were obtained for overburden samples that were tested with a positive NNP (neutralising potential). From the results, it is clear that the AMD mixture caused precipitation of the iron since the iron gave a zero value once the value of the AMD mixture was subtracted. Trace element concentrations like Co, Cr, Ni, V and Zn in the leachate are less in the old ash samples, indicating that it has been leached by precipitation from the surface where the ash samples were taken. The extraction with an AMD mixture is much more complex for AMD in the area must have started or been created with humidity cells, whereas the extraction with diluted sulphuric acid are much less complex, cheaper and the results are comparable.

The elements that leach with the SPLP method were similar to that obtained with water. The reason being that the acidity of the SPLP mixture are not strong enough (acid enough) to lower the pH of samples with neutral to alkaline pH's. This SPLP method used to evaluate the impact of samples on the environment, should be instantly replaced with the H_2SO_4 leach which mimics AMD.

9 ENVIRONMENTAL IMPACTS

Monitoring of boreholes on the mining, processing, ash dump and power stations sites happens on a continuous base to evaluate the impact, if any, of the activities on the environment.

It is important to note that the backgroundwater of the aquifers in the Karoo (Grootegeluk mine where the shallow coal are and opencast mining will proceed) differs from that of the Waterberg geology. These differences can be seen in the stiff diagrams of the chemistry. The influence of neutral and acid mine drainage is clear in the water samples of the boreholes close to the ash dump and discard facilities (Figure 113).

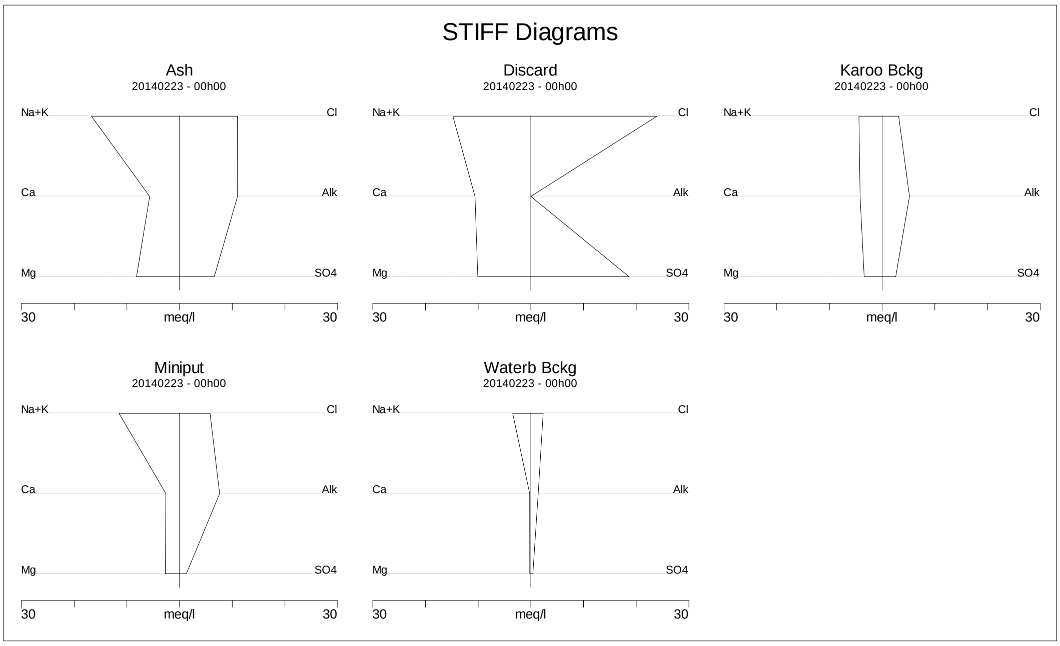


Figure 113: Stiff diagrams of the chemistry of the background waters (Karoo and Waterberg) and mining affected waters.

There are no major streams or rivers that are fed by runoff from the discard or ash dump. There are a few surface sampling points as indicated in the next map (Figure 114) and sampling points R02, R03 and R04 are in the Sandloop.

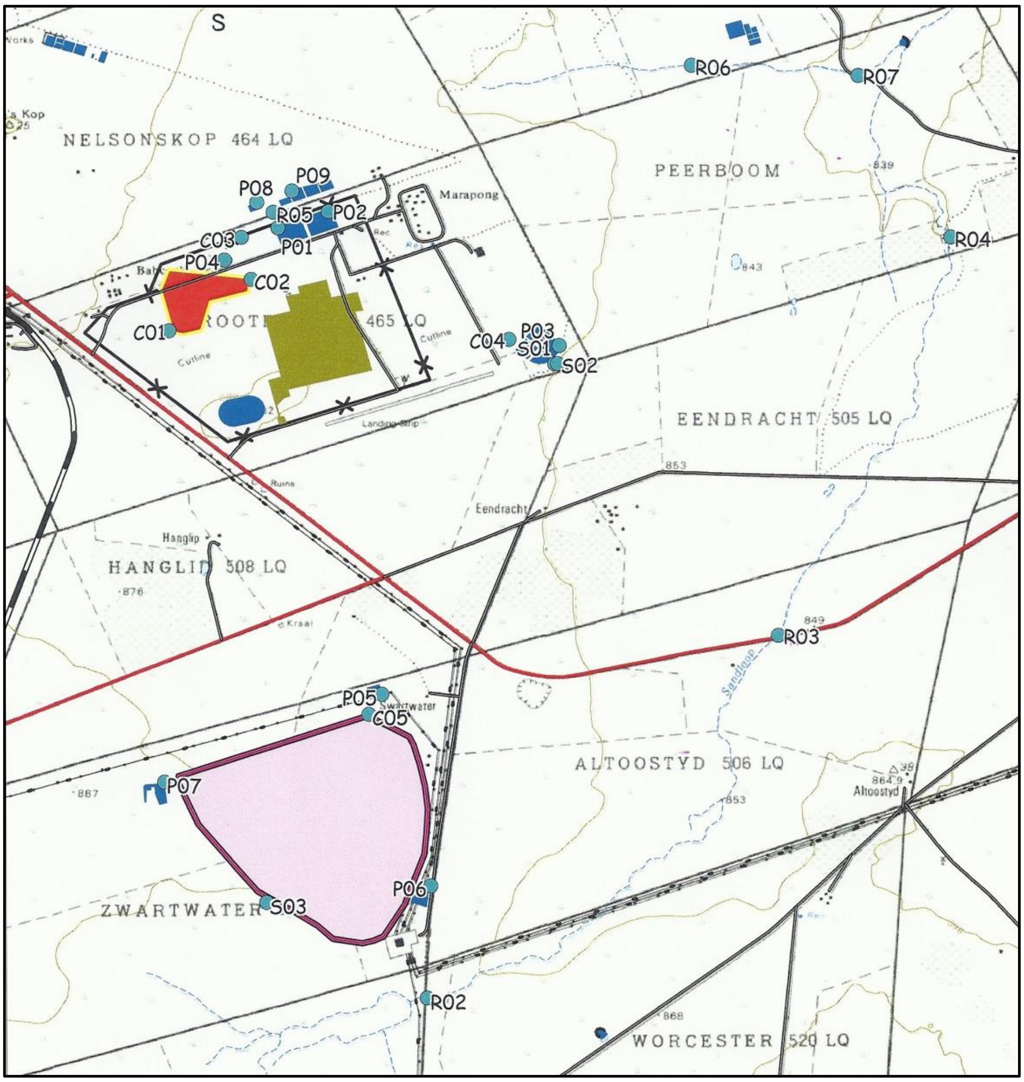


Figure 114: Surface sampling points.

The time graph of the surface sampling data is plotted in the next graph (Figure 115). The surface samples close to the ash dump has high calcium and sulphate and these points were last sampled at the beginning of 2013. Sampling point R07 which was monitored most recently, indicate no changes that can be contributed to any contamination from either the ash dump or the power station.

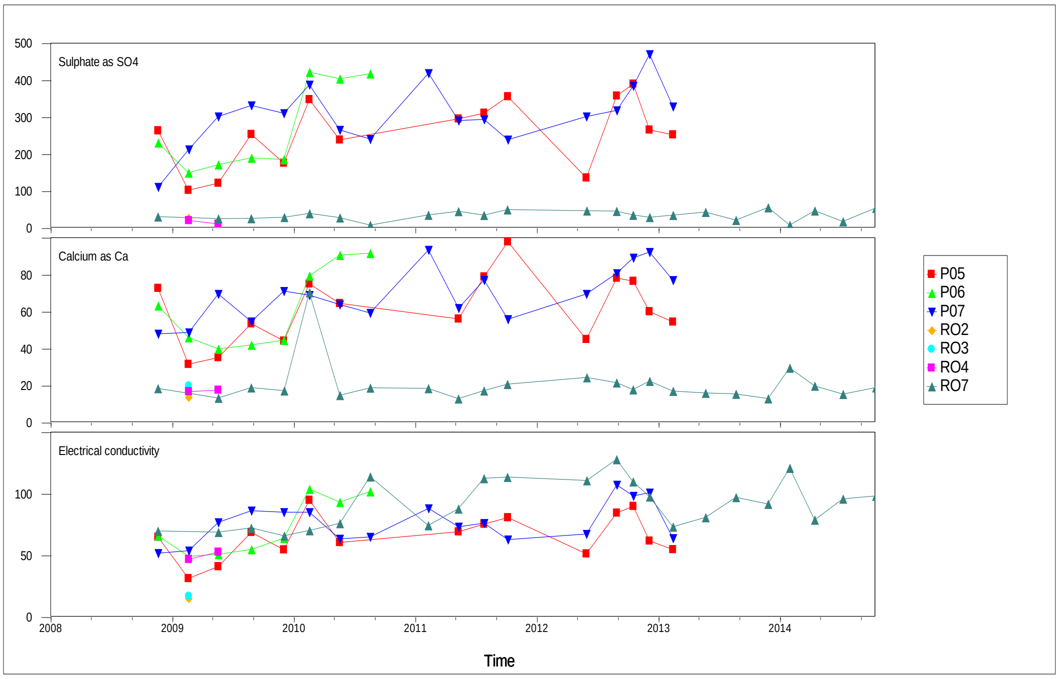


Figure 115: Time graph for EC, sulphate and calcium of surface monitoring points.

Only a few of the monitoring boreholes have acidic pH's and these boreholes are all close to facilities that are unlined. The positions of the monitoring boreholes with the low pH's on the site are indicated in the following map (Figure 116).

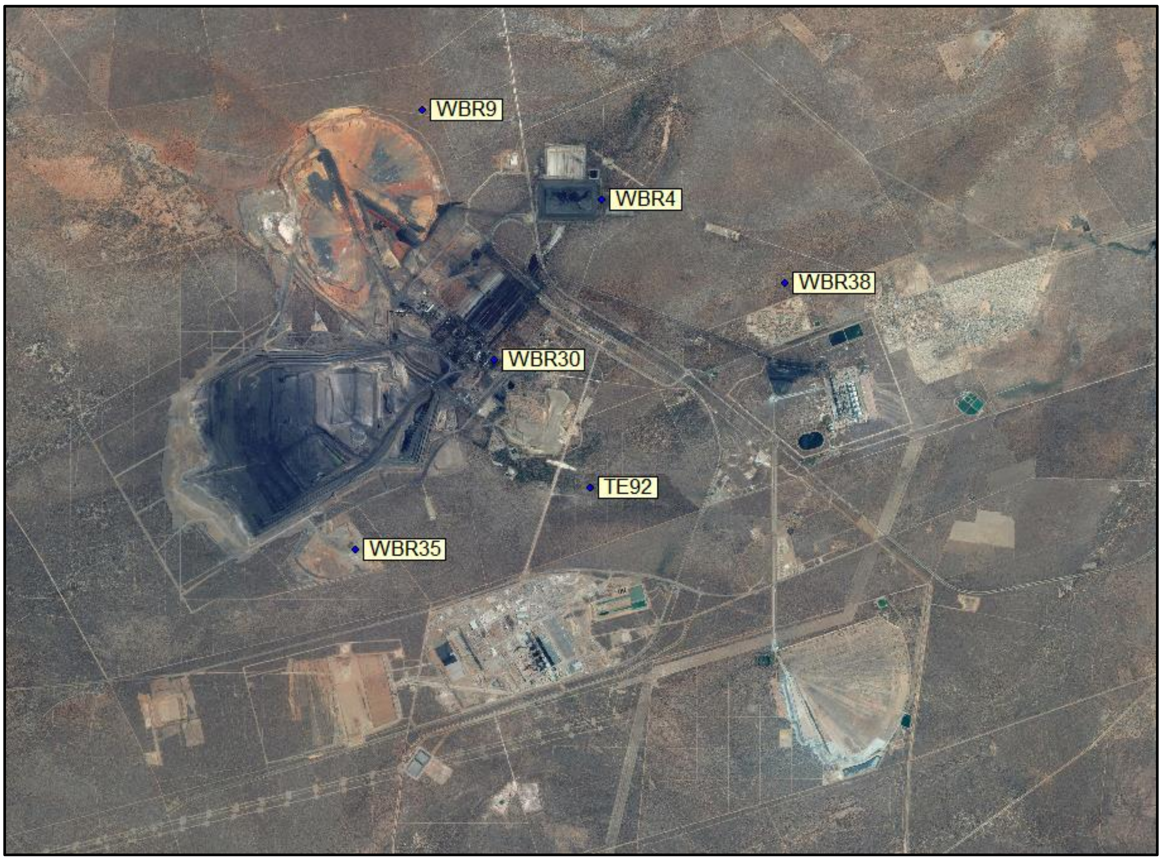


Figure 116: Position of boreholes with low pH values on the site.

The impact of oxidation on the discard dump and slimes dam of the abovementioned monitoring boreholes can be seen in the upcoming graph of pH and alkalinity. As the pH drops below 4.5, the alkalinity value (buffering capacity of the water in the aquifer) becomes zero. The error in the ion balances and the incomplete analysis of sulphate, iron and trace elements of the data retrieved unfortunately eliminates further elements to be plotted.

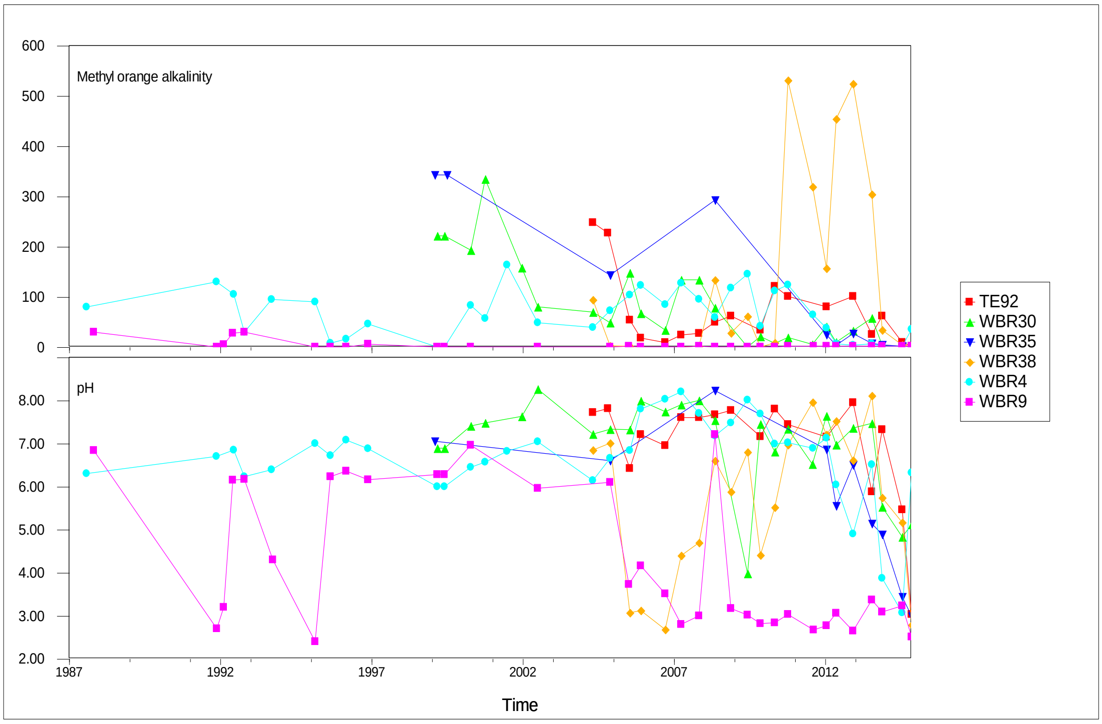


Figure 117: pH and alkalinity time graphs of monitoring boreholes.

When mining activities started in the early 1980's, the AMD threat to the environment was not realised and some of the waste/slimes facilities were not lined. The leachate turned acidic and has already affected the aquifer(s) underneath. Sample WBR9 (Figure 118) contains the only data indicating pyrite oxidation where iron is still dissolved in the aquifer.

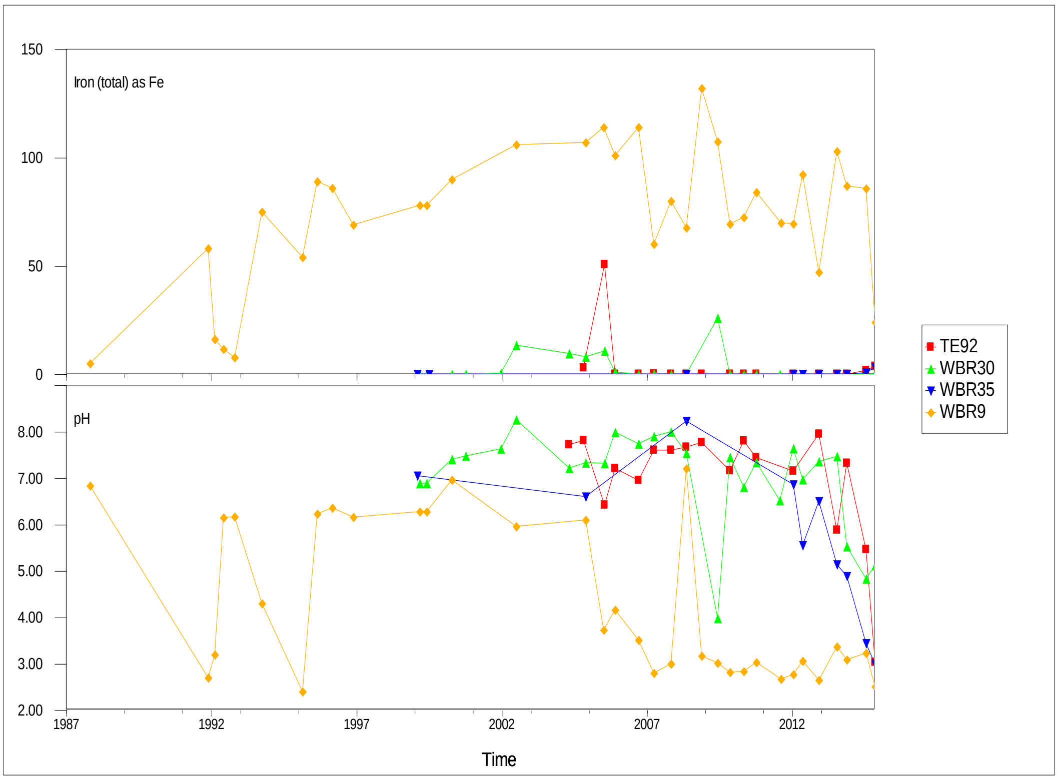


Figure 118: Time graphs of pH and iron.

The position of the monitoring boreholes at the ash dump is indicated on the map of

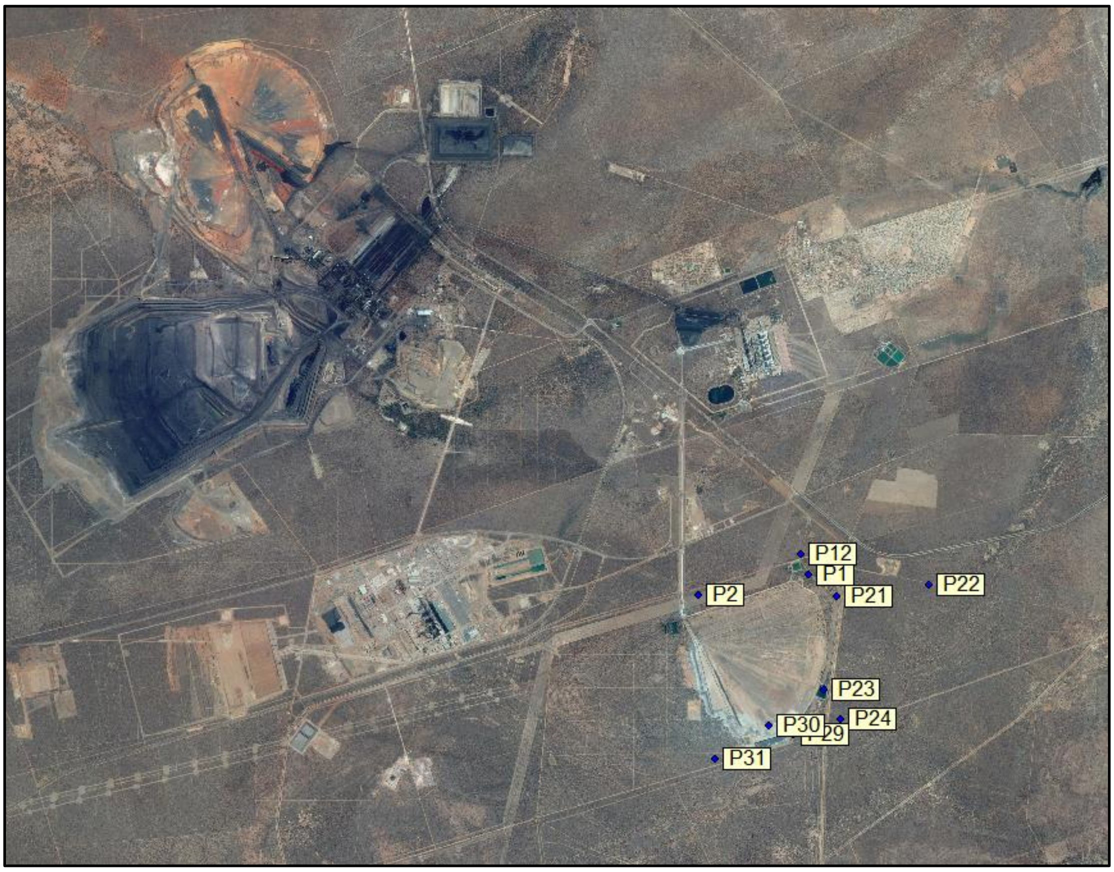


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Figure 119: Position of monitoring boreholes at the ash dump.

The chemical results of the ash dump monitoring boreholes indicate the influence of sulphate from the fly ash leaching into the aquifers and affects water quality (Figure 120 and Figure 119).

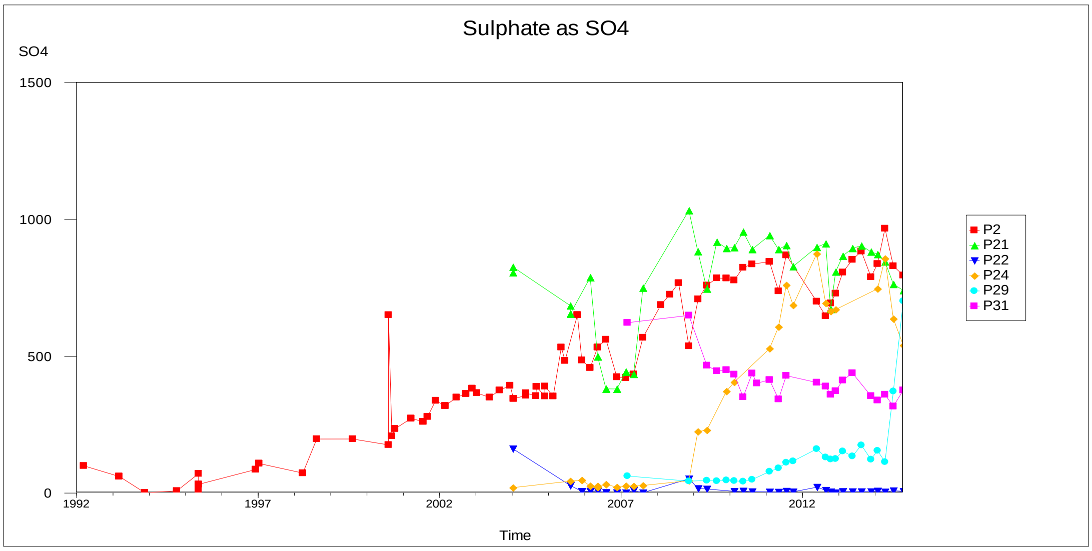

Figure 120: Time graph of sulphate values in monitoring boreholes at the ash dump.

Handling of spoils or discards by mixing it with either fly ash and/or interburden will have an impact on the end product and thus the impact on the environment.Discards are generated during mining operations when coal is extracted from intermittent rock waste. Spoils consist of mined overburden and noneconomic mineral deposits removed during mining operations. The composition of spoils vary greatly depending on the area, depth and lithology where mined. The amount and type of waste generation is a direct result of the method used during the mining process namely surface open cast, underground mining and blasting or continuous mining. Backfilling methods must in general fit in with the mine design. The type of backfill that is going to be used is also usually identified during the design stages.

There is a need to dispose large amounts of colliery waste or spoil in such a manner that the least amount of damage is done to the surrounding environment. About 80% of waste is dry or solid spoil and usually tipped on site close to the pit head. The other form of waste generated is a wet by-product during the washing of the coal. This requires a different method of disposal and in some countries they make use of lagooning. The main environmental effects of these processes include visual intrusion, loss of land, noise and dust from vehicle movement during tipping of dry waste, and potential water pollution. The various activities have an immediate visible effect on the local area but the effect can be much deeper.

Extraction, beneficiation and processing of metals and industrial mineral ores produce mining wastes. Waste can be divided into categories which include:

- Waste rock, when material is moved to gain access to ore and excludes any material that is used during reclamation.
- Tailings, usually in a slurry form, from beneficiation processes.
- Mine water, water that infiltrates mines during extraction including groundwater or precipitation.
- Processing waste, residuals after beneficiation process, such as smelting and electrolytic refining operations.

Placement of backfill is one of the tools used in managing voids created during mining processes and reduces the cost and impact of a separate waste disposal site or process (Ward *et al.*, 2006). Backfilling may be done by hydraulic or pneumatic techniques, using a variety of materials including run of mine waste rock, milled tailings, or other materials, and may include the use of cement or other modifiers to increase strength. It may also have a favourable effect on the environment by addressing water quality impacts (such as from acid drainage), reducing waste rock disposal requirements and ground fissuring, and increasing long-term strata stability as well as providing roof support.

9.1 Current backfilling method in the study area

At Grootegeluk the set objectives determine the backfilling method. These objectives include the minimal risk of spontaneous combustion, minimal cost and maximum safety conditions. The backfilling entails the compartmentalising of waste and overburden. The first-year compartments required the construction of an eastern sealing wall using sandstone from bench 10 (45m thick). After the construction of the 11m high wall, the reactive inter-burden material from benches 7A and 8 were backfilled from the north-eastern corner (Figure 121). Material placement is very important and cannot be mixed during the off-loading of spoils. The contact area is isolated by inert material from either overburden or bench 10 (sandstone) in order to lower the risk of transferring spontaneous combustion to the pit's high walls.

A total of 14 benches are present, and benches 1, 7 and 9 are sub-divided into 1A, 1B, 7B, 9A and 9B. The bottom of the eastern part of the pit is used for a water dam and is utilised as an industrial-water recycling system. The northern part of the dam (sediment dam) clarifies the water from the plant. Next to the water dam (toward the west) is a backfilling dump. The third-year compartment is progressing with the sealing layer visible in the back of the compartment's advance (Adamski, 2003). The compaction of the sealing layer is due to mining equipment travelling on the backfilled compartments.

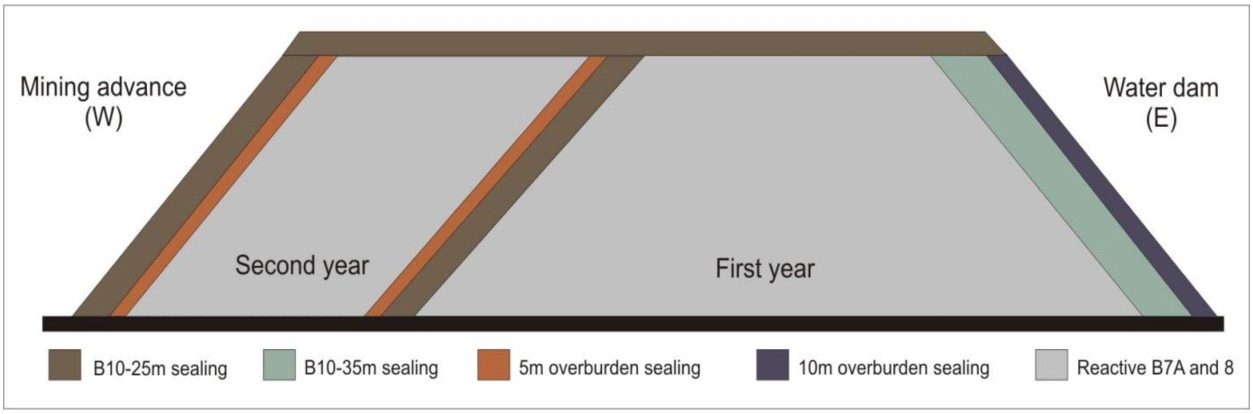

Figure 121: Backfilling advance at the Grootegeluk mine (redrawn from Adamski, 2003).

9.2 Investigated scenarios for handling of spoils

The scenarios suggested in this section focus on the benches removed during coal mining. The material removed from the GCM includes overburden, interburden and processing plant discard. The ABA and kinetic tests highlighted the lithological units that are prone to turn acidic or poses a neutralising potential. [1]

These findings helped to formulate different spoils management scenarios as the problematic units were identified. In order to have a full understanding of the various impacts the different geological units can have on the surrounding area of this study, different scenarios are discussed. The different pH ranges are indicated on the figures included for the various scenarios.

The various scenarios focus mainly on co-disposal and blending, where sulphide rich waste is blended, co-disposed or both, with alkaline material. Co-disposal requires the mixing of fine and coarse grained material, and blending entails the addition of alkaline material to such an extent to neutralize the acid potential of the discard. Alkaline material ensures that the metals are immobile permanently by converting them into soluble minerals such as sulphates, carbonates and hydroxides. The scenarios all refer to the backfilling method currently used at the Grootegeluk Colliery.

9.2.1 Scenario 1 – Interburden

The ABA analyses showed that the interburden samples analysed contained both acidic and neutralising potentials. Interburden and mixtures of acidic and neutralising interburden were selected for kinetic tests. The purpose was to determine the extent that acid producing interburden, mixed with a neutralising component, would have to reduce the acidic nature of the sample. Mudstone, shale and calcrete layers showed a neutralising potential, while sandstone had a relatively high acid generating potential.

The initial pH values for the interburden samples as mentioned are both acidic and neutral. The acidic pH values stayed acidic, whilst some of the neutral pH values remained neutral and some turned acidic. The kinetic samples S14, S15, S24, S32 and SM2 consist of mudstone, sandstone and siltstone. The sulphate values show a slight decline over the first weeks, with a gradual increase for the remainder of the test. The slight increase is due to the oxidised products leaving or being flushed from the system. Calcium and alkalinity results showed high calcium values with relatively low alkalinity for the interburden material.

Backfilling with only interburden has a high possibility of acid production that would reach the groundwater system (Figure 122). In favourable conditions (exposed to oxygen and water), the interburden would generate acid over a longer period of time. The quantity and quality of the interburden material is not suitable to use as filler alone in the pit.

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[1] Backfilling was discussed in the WRC Report No, K5/2142 – A detailed acid base accounting study of the coal-bearing Karoo formations in the Waterberg Coalfield. L Deysel was co-project leader on this project.

The removal of large quantities of coal results in less material to fill the pit with. In the event that the interburden would not be enough to fill the pit, a compacted layer of topsoil or overburden can be placed above the interburden. The overburden acts as a buffer with a neutralising potential.

The overburden cover would increase the path length for oxygen diffusion to the reactive material in the pit and the mixed interburden material. The fine grained cover layer overlaying the coarse grained interburden will have a higher degree of moisture retention I the upper part of the cover layer. This ensures a high level of pore water saturation and a lower rate of oxygen diffusion.

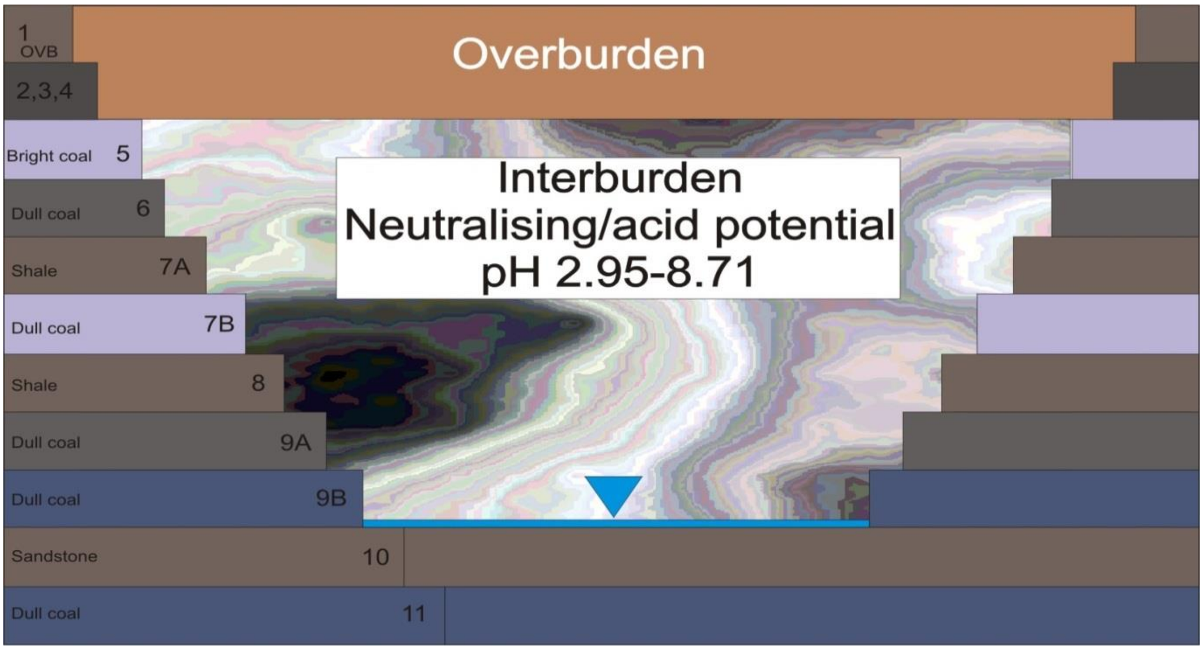

Figure 122: Schematic representation where opencast pit is filled with interburdern material.

9.2.2 Scenario 2 – Overburden

The ABA analyses showed a predominantly neutralising potential for overburden samples as well as an acidic potential for the shale units near the coal. The samples that did not show a clear distinction was further tested by kinetic testing. The samples that were analysed over the 20 weeks of testing indicated non-acid producing potentials and some samples with neutralising potentials.

The pH provides an indication on the onset of acidification. The initial pH values from the overburden samples were neutral to start with and remained neutral throughout the testing.

The sulphate values show a decline over the first weeks as the oxidised products are flushed from the system. The relatively low calcium values indicate that carbonates are immediately available and show the balance between the released alkalinity and the acidity generated. If the balance between the alkalinity and the acidity stays positive the system will not acidify.

Backfilling with overburden directly into the opencast pit would not acidify, but rather neutralise the surrounding area (Figure 123). The groundwater system would not be influenced in a negative way. In the event of heavy rain and infiltration, no acid would be produced nor be introduced into the system. The extent of the pit is unfortunately so large (100 m below surface) that the amount of overburden material available would not fill the entire pit. Overburden would be the ideal backfilling material to use because of its buffering potential.

The thick overburden layer would increase the path length for oxygen diffusion to the reactive layers within the pit that is being backfilled. The fine grained cover layer has a higher degree of moisture retention and would be easily evaporated in drier seasons. The high moisture retention also ensures a high level of pore water saturation and reduces the rate of oxygen diffusion.

The pit can be filled with water to the compacted overburden, but this will require the construction of water pipes and channels into the pit from the river and can become costly. The addition of water into the pit will only be advised if some of the exposed mined benches have a high acid generating potential. The amount of overburden available is too little to fill the entire void of the pit and in most cases the overburden material is saved for rehabilitation after mine closure.

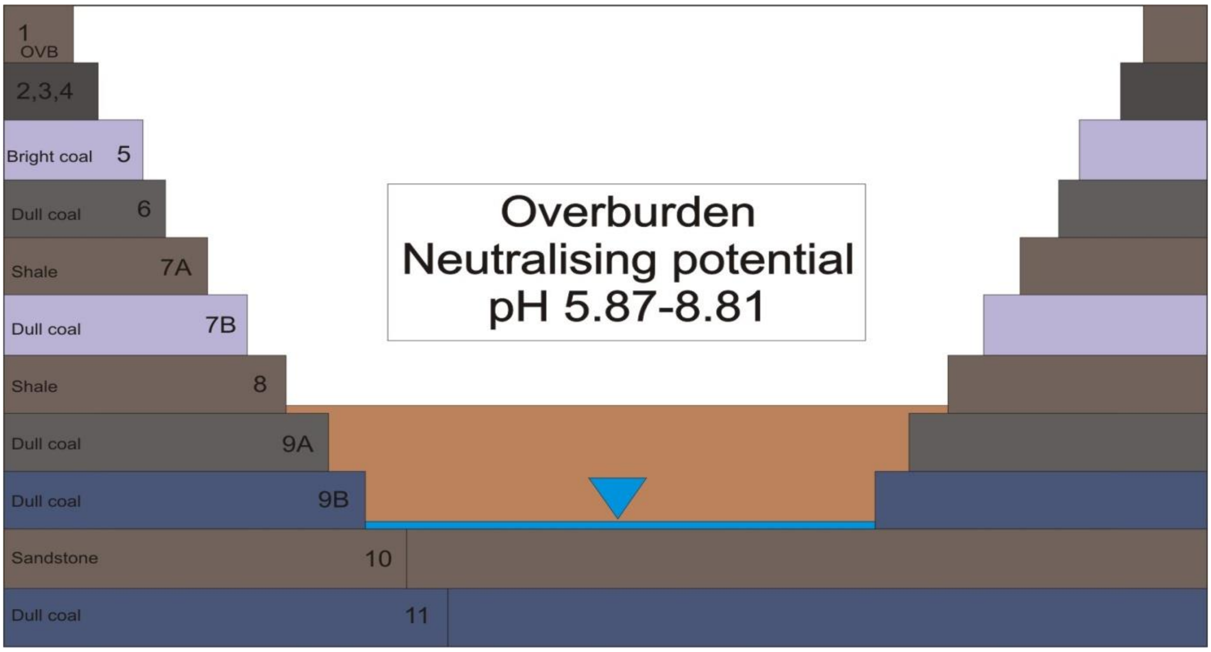

Figure 123: Schematic representation where opencast pit is filled with overburden (ovb) material.

9.2.3 Scenario 3 – Plant discards/composites

Plant discards consist of the unwanted material that remains after coal separation, also known as composite samples. The different density composite samples were analysed and indicated that they all have a high potential to produce acid.

The main risks associated with discard are the sulphide potential that leads to the generation of acid upon exposure to oxygen and moisture. There is a risk for metals to mobilise in surface or groundwater when they are liberated in acidic conditions. There can also be contaminant influx due to precipitation, creating runoff from discard storage piles.

Backfilling with composite or discard material would influence the groundwater system in a negative way, especially if the discards are exposed to favourable conditions (oxidation and water). The best way to decrease the risk would be to immediately fill the pit with water (Figure 124). The water can be piped or channelled from the river, but this can become costly. Water reduces the exposure of the composite material to the combination of oxygen and occasional water, which are the two main factors that activate acid generation. The composite material also has the potential to spontaneously combust when in contact with oxygen. The water in the pit with the discard increases the pore water saturation, reducing the rate of oxygen diffusion to the combustible material.

It should be mentioned that to channel water is costly and regarded as not feasible. Although the immediate fill using water would reduce the spontaneous combustion of waste material, it cannot be the best solution for managing discard.

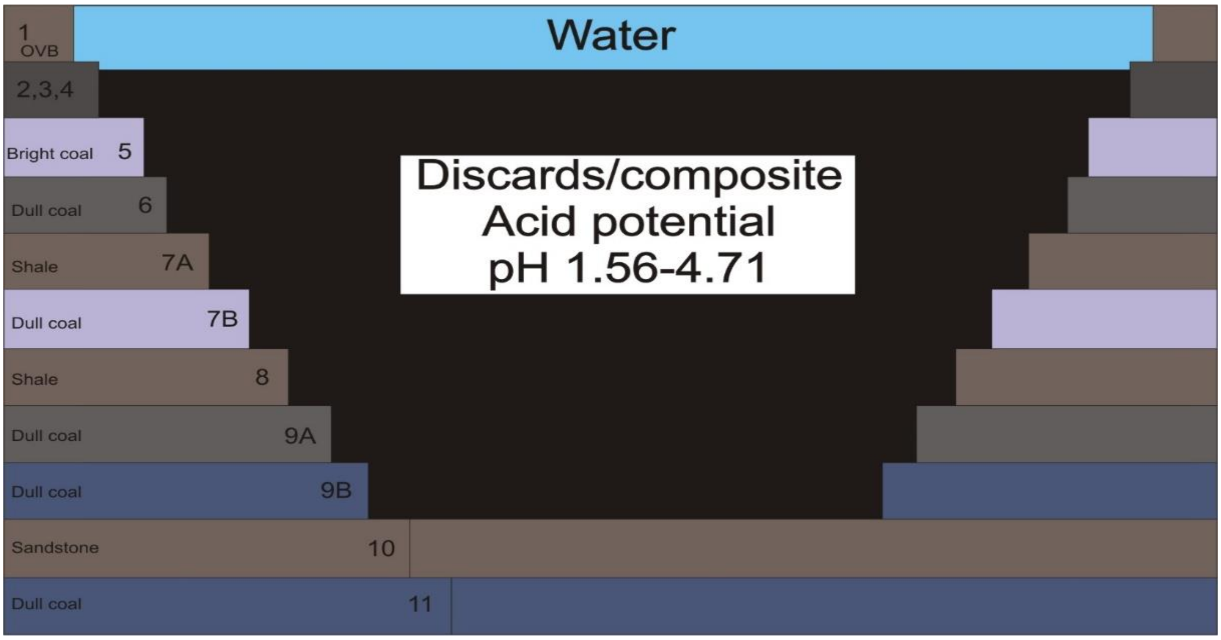

Figure 124: Schematic representation where opencast pit is filled with composite material.

9.2.4 Scenario 4 – Mixed overburden, interburden and discards/composites

The overburden and interburden have already been mentioned, as neutralising and acidic, respectively. A suitable ratio of overburden, interburden and composite material will have a positive effect on the surroundings after they are placed back into the pit. Acid generation from these materials will be neutralised in the pit in the event that they are exposed to favourable conditions. Kinetic tests on mixtures of overburden, interburden and composite material confirmed that the acidic nature of the samples could be reduced. In the event that the buffer potential of the mixed overburden and interburden failed to reduce acid generation, exposure to oxygen and water would accelerate the acid generating process.

The initial pH values of the samples were acidic and after the testing was completed, turned neutral for the overburden and interburden mixed with the composite material. The slight sulphate decline in samples GM2-GM7 at the initiation of kinetic testing, suggests the oxidised products are being flushed from the system. Calcium and alkalinity results show the relatively low values of alkalinity released into the surroundings.

As a consequence, backfilling with the correct mixture of overburden, interburden and composite material would create a balance between the highly acidic and neutralising potentials (Figure 125). If the backfill material was exposed to favourable conditions, the pH and acid production will be insignificant.

This scenario does not have enough data to propose how long the system would buffer itself. It is recommended to run the humidity cells for longer to have an estimation of the extent of the buffer capacity or neutralising potential. The most important aspects observed from the humidity cells are that blending the material does have a positive effect on the system in reducing the acid generating potential.

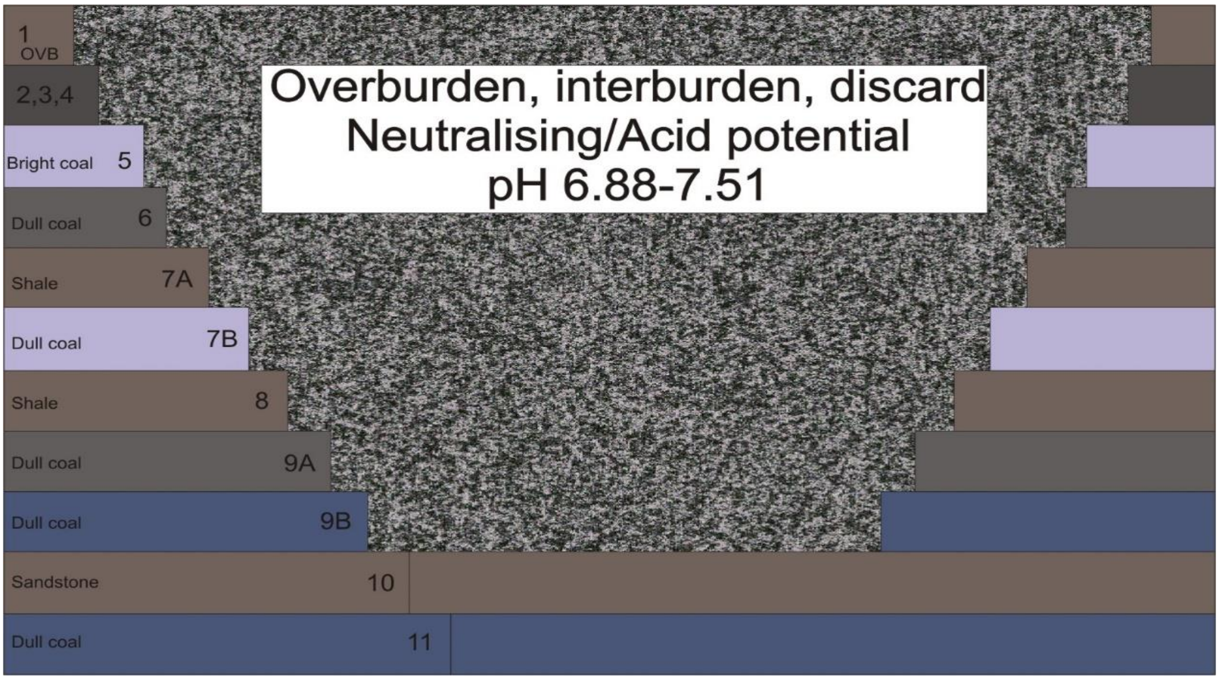

Figure 125: Schematic representation where opencast pit is filled with overburden, interburden and composite material.

9.2.5 Scenario 5 – Interburden and ash

The analysed ash samples from the Matimba Power Station had pH values that ranged between 9.30- 10.91. The alkalinity component and the addition of any acid generating material reduce the risk of acid generation. If fly ash becomes acidic it unfortunately mobilises heavy metals into the natural system and can become a risk in this regard.

Fly ash from coal-fired power stations is one of a number of materials that may be used in mine backfill (Ward *et al*., 2006); others include waste rock such as overburden, natural sands or gravels and coarse or fine reject materials from preparation plants. Flyash that comes into contact with acid mine drainage will increase the pH of the mine water. Ash can be mixed with acidic water to neutralise it, and co-disposed in an appropriate manner.

The co-disposal of interburden and ash material will result in an excess of neutralising potential. The material properties of interburden, with both an acid and neutralising potential, would not lead to acid production due to the high neutralising potential of the fly ash material. If fly ash was intermittently layered in between samples prone to produce acid, it would positively affect the surrounding area and neutralise any acidic threat to the system.

The best option would be to co-dispose fly ash and interburden into layers and cover it with a layer of compacted fly ash (*Figure 126*).

The compacted fly ash top layer will act as a seepage reducer, and in the event that water managed to seep in, it would not produce acid. The long term effect of fly ash cannot be stated with certainty other than that it has a high neutralising potential and can be co-disposed with acidic material to reduce an acid generating potential. The acid producing spoils can also be buried on-site with fly ash or other neutralising material surrounding it. For underground mines ash can be introduced as a low-permeability fill or grout within the voids, fractures, subsurface openings and to reduce the contact of acid generating rocks to water and air.

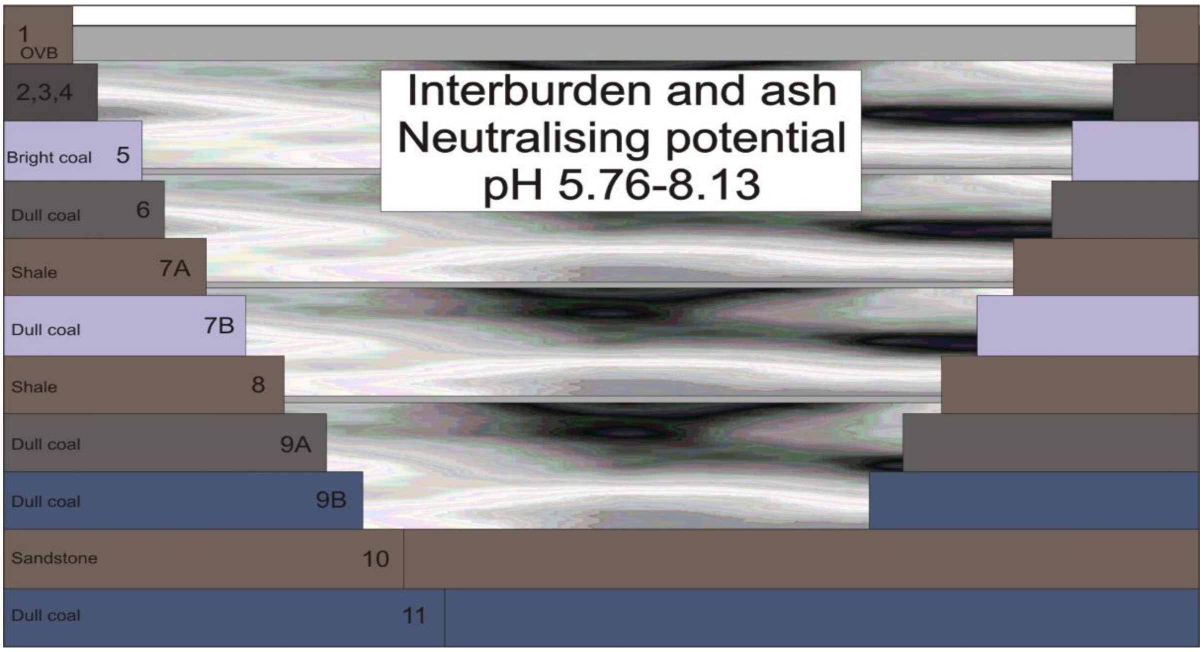

Figure 126: Schematic representation where opencast pit is filled with interburden and fly ash material.

9.3 Proposed handling of spoils

Based on the investigated scenarios, the mixture and/or layering of a combination of material would be recommended. The layered option proposed by Adamski (2003) which is the current means of backfilling at Grootegeluk Mine, has the lowest long-term environmental risk for water impact. It reduces AMD rates and leaches alkalinity into underlying acid generating discard material.

The backfilling method scenarios investigated are based on the current method applied at the Grootegeluk Colliery. From these scenarios, two types of backfilling for fly ash and different discard should be considered and possibly implemented in the mining industry. The types of systems for backfilling are discussed as two options, one in the event prior to disposal and the other as the disposal of waste in layers. Either Option 1 or 2 can be implemented depending on the economic motivation or viability of each option.

The design objectives for any backfill pit cover should include the following:

- Reduce the ingress of atmospheric oxygen to the underlying waste material to the minimum acceptable level
- Reduce entry of meteoric water to the underlying waste material to less than 5% of annual precipitation at the site
- Provide a medium for establishing a sustainable vegetation cover that is consistent with the final land use of the area.

The first two objectives can be easily achieved by incorporating a layer of fine-textured material in the cover system (MEND, 2004). The objective is to utilize the capillary barrier concept to help maintain near saturation within the fine-textured layer. This would additionally help to lower the ingress of oxygen by reducing the oxygen diffusion rate. The fine-textured layer has a low hydraulic conductivity. The low conductivity and the low capillary barrier would control the percolation to the underlying waste material. This is the ideal design that relates to the layered co-disposal for discards and ash. If ash is deemed not suitable to use an alternative would be clay. Clay, when compacted, has a saturated hydraulic conductivity of 10^{-8} cm/s (Ayres *et al*., 2012). Skousen *et al.*, (1997) analysed various fly ash material to determine the relative hydraulic conductivity of ash between 10^{-5} or 10^{-6} cm/s.

It is recommended that a small scale field test be done before and after ash is backfilled into the pit. This would give a much better idea and understanding of what can and would happen in the specific study area. Additionally geochemical modelling is recommended for further work in order to assess the amount of salt loads and chemical interaction between the various backfilled materials within the pit.

9.3.1 Blending of material prior to disposal into the pit (Option 1)

This option utilises the conveyor belt from the power plant that will discharge ash onto overland conveyors from the mine discard dump transfer station entering the pit. Mixing the fly ash and discard will occur through the transfer stations up to the stacker. Material is initially mixed with already existing equipment, therefore avoiding additional costs for building the required conveyor belts. One major factor influencing this option would be the availability of fly ash and discard.

The combination of fly ash and discard has a higher degree of water retention in the mixture than discard material alone would have. Fly ash prohibits the spontaneous combustion of discard by limiting the oxidation potentials. Fly ash also dilutes the reactive portion of the discard backfill.

9.3.2 Disposal of waste in layers (Option 2)

This option uses the power station fly ash and transfers it onto in-pit conveyors for the initial deposition of an ash layer. This initial fly ash layer would act as a wedge that can be covered with interburden material with the fly ash, and interburden acting as a seal. A layer of discard can then be placed above the already backfilled material, until enough discard is placed into the pit to start depositing fly ash above the pit water. With this option, the fly ash will be deposited above the expected pit groundwater level after recovery. The fly ash disposal rates will directly affect the volume of fly ash that will initially be deposited into the bottom of the pit as well as the thicknesses of the layers. The last ash cover can only be done if the discard has reached the height of the pit. This layer option is therefore strongly affected by the coal processing plant that will produce the discard material.

9.4 Effects of backfill material

This section proposes the different factors that could potentially affect the groundwater system, by illustrating the different water movement paths within backfilled material. There are various factors that contribute to the pit water. These include direct rainfall recharge, runoff from backfill materials, working face and active mining area, groundwater inflow from the surrounding environment and any mine water pumped to the opencast mine. These factors are shown in Figure 127.

The closure phase of mining will re-fill the pit with water to reduce the head difference between the surrounding groundwater table and in-pit water level, and thus lower the inflow rates over time. The recharge within backfill material occurs as unsaturated flow and is majorly dependant on the material properties. The hydraulic conductivity of the backfill material would be higher than the original solid material that was removed.

The water that accumulates in the opencast pit is typically hydraulically linked to the groundwater system in the surrounding environment. The regional groundwater gradients will control the groundwater system of the surrounding area.

Recharge rates through the backfilled area is expected to be relatively low. The reason for this is due to the behaviour of the backfilled material and the cover layers. The combination of the backfill and cover material acts as a store and release process for water entering into the system.

Seepage through the backfilled material will be influenced by the moisture present in the material and the different layers it intersects as it seeps into the backfill material. The layered option of the material will reduce the seepage or moisture migration as the material properties of the various layers differ.

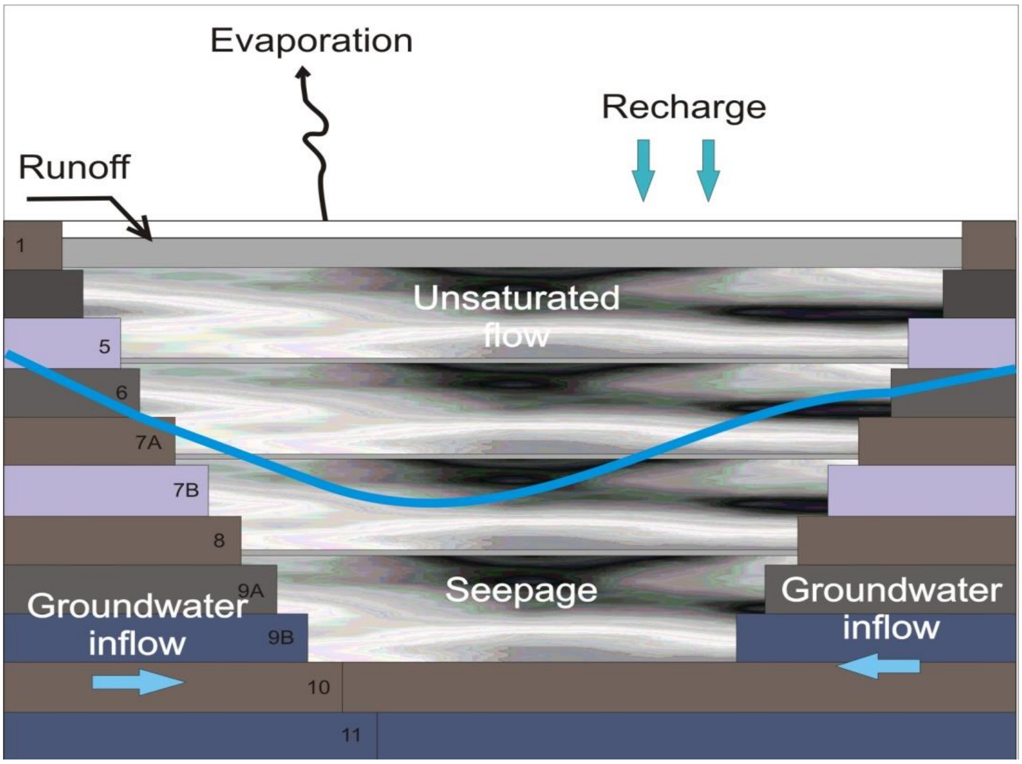

Figure 127: Schematic representation for the proposed water flow within the backfilled pit.

Salts and metals are primarily sourced from soluble salt and metal contents associated with backfill materials. The materials used as backfill; coal discard, interburden and ash all have a soluble salt fraction. This fraction will dissolve upon contact with water. The dissolved salts are flushed from the material with the first introduction to water. The materials that contain sulphide minerals will undergo oxidation, and produce AMD. The oxidation products of AMD include salinity (SO_4, Cl^-, Ca, Mg, Na, and K) and acidity (proton and metal acidity). Trace elements form part of the flushed dissolved metals and can also have a toxic impact on the water quality. The impact of AMD on water systems is strongly influenced by the buffering minerals present in the water (either acid or alkaline). Mineral precipitation occurs after the dissolved components exceed the solubility for a stable mineral. The mineral will begin to precipitate to maintain equilibrium with the solution at the solubility limit.

The time for the backfill material to acidify for a layered backfill scenario will take the longest time. This point is reached when the available NP is consumed and results in an acidic leachate from the backfill. The blending with ash would reduce the risk of AMD as it adds additional NP to the system and due to the low hydraulic conductivity present in fly ash material the water retention in ash would be increased. Fly ash “clog/block” the system reducing the infiltration rate of waster to underlying material.

The specific mining area are very complex and can have up to eleven different coal zones and as many zones of interburden. Handling the interburden, overburden and discards in a way to minimize the environmental impact will require knowledge of the behaviour of the different layers once mined. The pyrite in the sandstone layers (135-138m – Sekoko sample) (Figure 128) are an indication of the environmental risk once exposed to oxidation.

Figure 128: Pyrite in sandstone layers (135-138m depth).

Oxidation of iron sulphides are tell tale of the yellow staining on the core on the left after 3 years of exposure to natural oxidation while the sandstone on the right was not exposed to oxidation (Figure 129).

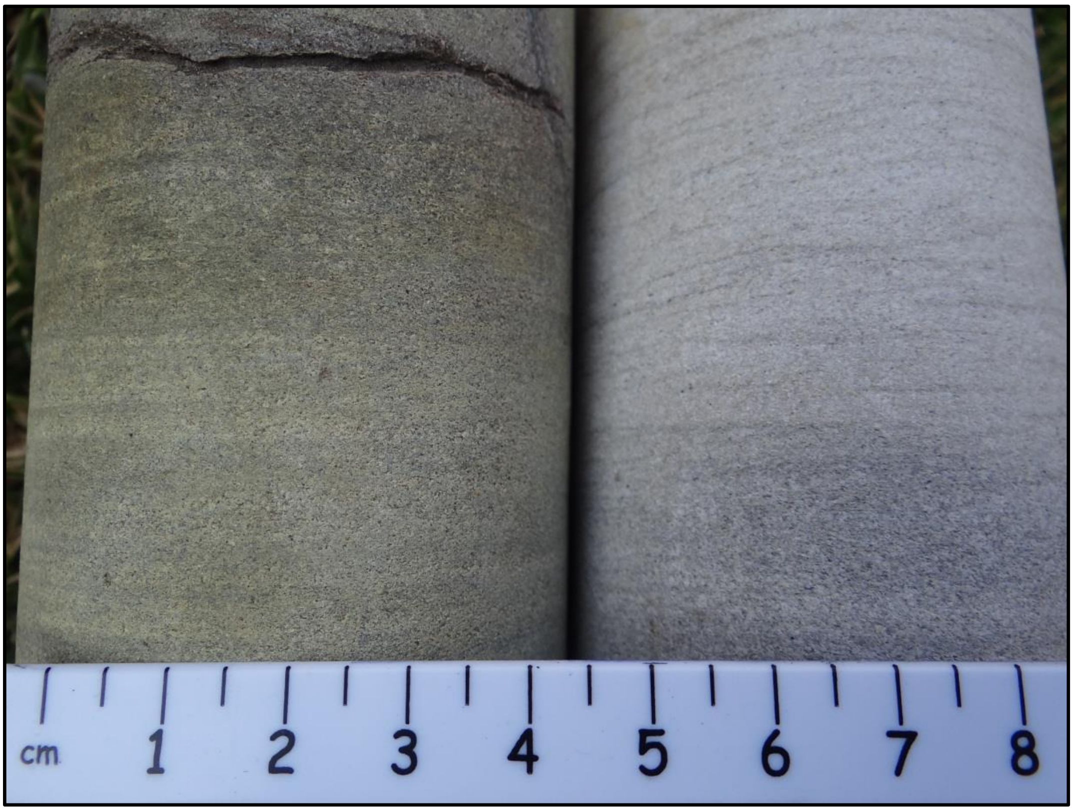

Figure 129: Sandstone indicating oxidation in the presence of iron sulphides (left) and no oxidation (right).

The overburden tested in this study, indicated an overall base potential - thus it will be able to neutralise AMD, while the interburden contained the higher potential to produce AMD. The discards contained the highest AMD potential. The risk to the environment of elements that can leach, will be best predicted by using the results obtained from the sulphuric acid leach.

10 CONCLUSION

The most important issue in economic growth and development is to obtain measures that can minimise the negative impact on the environment. With the ever increasing demand for energy, the continuous demand for coal increases andareas not previously minedtherefore expands.The by-products of coal mining and the production of electricity from the coal leave an environmental mark. To minimise this mark optimally, all the risks associated with mining should be available and understood.It is important to note that every mining site is unique and although a world-wide recipe cannot solve the problems associated with coal mines in South Africa, it can provide guidance.

Since there are still large coal deposits in the Waterberg which can be mined by opencast mining, the risk of the geological units still to be mined was assessed. Acid generation due the oxidation of mainly pyrite is a source of contamination that can impact the groundwater and to a lesser or no extend the surface water ofthe mining facilities.

The Waterberg is a very dry area and there is no constant feed of contaminated leachate into major streams or rivers. This will only happen if there is a major flood, otherwise the streams close to the facilities are not perennial and mostly dry. The evaporation in the area is also very high.The aquifers close to the ash dump are also vulnerable to elevated total dissolved solids leaching from the ash.

Another environmental risk is air pollution from mines, including that of Medupi Power Station which will commence shortly. Of note is also the liquid plant of Sasol that might start up in future once all logisticalproblems around water supply as well as road and rail infrastructure has been addressed.

In this study area, coal is present in 11 zones in the Karoo Formation. The coal is located between three main geological structures (the Eenzaamheid-, Daarby and Zoetfontein Faults). The major geological formations in the study area are the Karoo and the Waterbergand there is currently only one active coal mine, the Grootegeluk mine, which started operation in 1980. There are different grades of coal present and, the coal is washed (beneficiated) to better the quality and grade (CV) for different purposes.

Samples were collected from exploration boreholes in all three areas of the region (partly weathered, Full succession and Middle Ecca). The ABA results of the samples tested, indicated that the interburden (sandstone, shale and coal) and discards has a potential to generate acid. This included the composite samples with various densities from the processing plant. The overburden material displayed a neutralising potential. The ABA results indicated that the shale and mudstone samples both have acid and neutralising potentials and that the majority of sandstone samples beneath 60m had a distinct acid generating potential. The discards in the 4 deepest coal zones also contain a higher acid producing potential which is due to the higher pyrite concentrations. The calcium and magnesium carbonate holds the buffering capacity of the samples.

This mine has been in operation since the 1980's and has ever since had a well-planned and operated monitoring system in place. The mine was also used as a model to determine the impact new mines will have on the area and the impact is clear in some of the monitoring boreholes on the site. Unlined facilities lead to the contamination of the aquifers to a point where the pH of the water is acidic. The monitoring boreholes close to the ash dump is affected by a raise in the total dissolved solids due to calcium and sulphate leaching from the ash.

To obtain the total impact or toxicity potential of samples, it is necessary to identify the elements that are available in the different wastes that can leach into the environment. This can be determined by using kinetic tests which is time consuming and because not all the cells might turn acidic, it may not provide the true potential. The acid leach test with diluted sulphuric acid will give an indication of what can be leached in an acid mine drainage environment simulating AMD.

All the risks associated with the different geological units should be identified so that the best decision and planning of waste facilities for future extensions can be made, and so that the negative footprint on the environment can be minimised.

The environment (aquifers, rivers, streams and oceans) is vulnerable to contamination originating from mining sites. This contamination can end up in the food chain or even be directly consumed by humans. As seen from the case studies, the influences on human health are serious. No studies on human health were investigated in this study.

To enable us to evaluate the potential of samples not prone to turn acidic upon oxidation and classified as safe to counteract the acidity produced by AMD, the samples should be tested by methods more linked to the environment it will be subjected to. Harsh digestions of samples doing full elemental analyses will give unrealistic high values of the elements, and are not representative of environmental conditions. Therefore, incorporating a method using a mild H_2SO_4 solution as leaching media that mimics AMD should seriously be considered by the mining community and people working in the environment determining the risk of AMD. Currently, standard methods like the TCLP and SPLP are widely used by laboratories as a standard to determine the leachable elements. The results obtained by these methods will totally underestimate the potential of elements posing a threat to the environment. The results are then communicated to the consultant/environmentalist and "incorrect" assumptions can then be made. The important factor to determine at the end of a leach procedure is to test the final pH of the leach product with the geological specimen tested before elemental analysis commence. The geology of each region will determine the geochemical composition of the effluent due to the environmental factors.

Results obtained from 295 samples in this study on overburden, interburden and coal samples are summarised in the following table (Table 37). It is results from the water leach and that from the acidic IGS leach, mimicking AMD. The parameters are arranged from the one with the highest acid:water ratio to the lowest. In this case aluminium, manganese and copper were the parameters that were released up to 100 times more using an acidic media. Molybdenum and barium are the parameters with no elevated release in an acidic environment. The elements with the highest concentrations were iron, calcium, aluminium followed by magnesium.

Table 37: Comparison of parameters released in different media (overburden, interburden and coal).

Parameter	Average g/tonne leached water	Average g/tonne leached IGS acid leach	Ratio Acid : Water
pH	**7.04**	**1.83**	
Al	18.01	2068.95	114.9
Mn	3.20	353.41	110.5
Cu	0.18	19.14	108.9
Fe	122.89	6606.13	53.76
Cr	0.03	1.77	52.35
Zn	1.36	61.49	45.31
Mg	55.96	1589.14	28.40
V	0.33	8.06	24.66
Li	0.21	5.07	24.55
Ca	243.10	5245.01	21.58
Co	0.42	8.20	19.29
Be	0.04	0.63	16.68
Sr	1.16	18.31	15.72
Pb	0.41	5.00	12.12
Sn	0.22	2.52	11.28
K	66.98	725.34	10.83
Ni	0.87	9.26	10.66
As	0.07	0.66	8.872
Cd	0.01	0.05	3.619
Sb	0.24	0.74	3.138
Na	74.14	207.31	2.796
Se	0.25	0.55	2.209
Ba	0.40	0.33	0.8328
Mo	1.84	0.11	0.0618

The average results obtained for ash samples using the same leach media (water and acidic leach) also indicate a much higher release of elments in the acidic enivironment but with a much bigger ratio difference than that for the overburden, interburden and coal samples. Aluminium, iron, magnesium and calcium are also released in the highest concentrations in the ash.

Table 38: Comparison of parameters released in different media in ash samples.

Parameter (Ash samples)	Average g/tonne leached water - Ash	Average g/tonne leached IGS acid leach - Ash	Ratio Acid : Water (Ash samples)
pH	**8.36**	**1.82**	
Fe	0.204	9615.793	47095
Mn	0.056	224.023	3996
Co	0.003	5.680	1940
Al	13.405	11036.107	823
Sn	0.000	0.024	241
Mg	51.266	6428.261	125
Cu	0.106	11.814	111
As	0.014	1.411	102
Be	0.008	0.738	95.2
Ni	0.070	4.814	68.8
Pb	0.068	2.829	41.6
Cd	0.008	0.292	37.6
Zn	0.582	13.286	22.8
V	0.993	20.835	21.0
Se	0.086	1.618	18.9
Cr	0.953	13.537	14.2
Ca	550.252	4831.982	8.78
U	0.014	0.111	7.87
Li	4.319	29.875	6.92
K	91.494	367.833	4.02
Na	564.900	868.529	1.54
Mo	0.427	0.548	1.28
Ba	0.507	0.028	0.056
Sb	0.005	0.000	0.021

With the macro elements calcium, magnesium, sodium and potassium omitted from the tables, the average solution in gram / tonne of rock for the remaining elements compares as follows.

Table 39: Comparison of parameters released in different media in ash samples (second)

Parameter (ovb, itb and coal)	Average g/tonne leached from OVB, ITB and coal in acidic media	Parameter (Ash samples)	Average g/tonne leached from Ash in acidic media
Fe	6606	**Al**	11036
Al	2069	**Fe**	9616
Mn	353	**Mn**	224
Zn	61.5	**Li**	29.9
Cu	19.1	**V**	20.8
Sr	18.3	**Cr**	13.5
Ni	9.26	**Zn**	13.3
Co	8.20	**Cu**	11.8
V	8.06	**Co**	5.68
Li	5.07	**Ni**	4.81
Pb	5.00	**Pb**	2.83
Sn	2.52	**Se**	1.62
Cr	1.77	**As**	1.41
Sb	0.74	**Be**	0.74
As	0.66	**Mo**	0.55
Be	0.63	**Cd**	0.29
Se	0.55	**U**	0.11
Ba	0.33	**Ba**	0.03
Mo	0.11	**Sn**	0.02
Cd	0.05	**Sb**	0.00
Average gram/tonne released acidic pH	459	Average gram/tonne released acidic pH	1049
Average gram/tonne released neutral pH (water)	7.61	Average gram/tonne released neutral pH (water)	1.09

The average grams of elements released per tonne with the acidic leach media are higher for the fly ash samples than that obtained for the interburden, overburden and coal samples. Compared to the average released with the water leach it is note worthy that it is very few parameters that is noticed in a water leach. The average pH at the end of the water leach experiment was 7.04 – 8.36. pH's measured at the end of the SPLP tests gave average pH.s of 7.21 – 8.61 while the acidic leach were 1.82 – 1.83. The pH's are summarised in the next table (Table 40).

Table 40: Average final (end) pH's with different leaching media.

Sample	Water	SPLP	Acid leach
Ash	8.36	8.61	1.82
OVB ITB Coal	7.04	7.21	1.83

With pH values in the case of the SPLP experiment having neutral values, the applicability of this test for the mining industry are questioned where AMD is expected. The elements leached with the water experiment are similar to that obtained by SPLP. This case study indicates the major difference between the leaching in a media more relevant to field (AMD conditions) versus water/SPLP to determine the environemental risk of a potential base source to the environment. Leaching with water and or SPLP is also important to give the environemental risk of the sample once in contact with rain.

In the static ABA procedure, peroxide is also used and the pH's of the media ranges inbetween the water and the acidic pH of the sulphuric acid leach. Graphs of pH vs solubility indicates clearly the influence of the pH on the solubility of the elements that go into solution. pH's obtained from the peroxide varies from acidic to alkaline. This trend is indicated in the following figure (Figure 130).

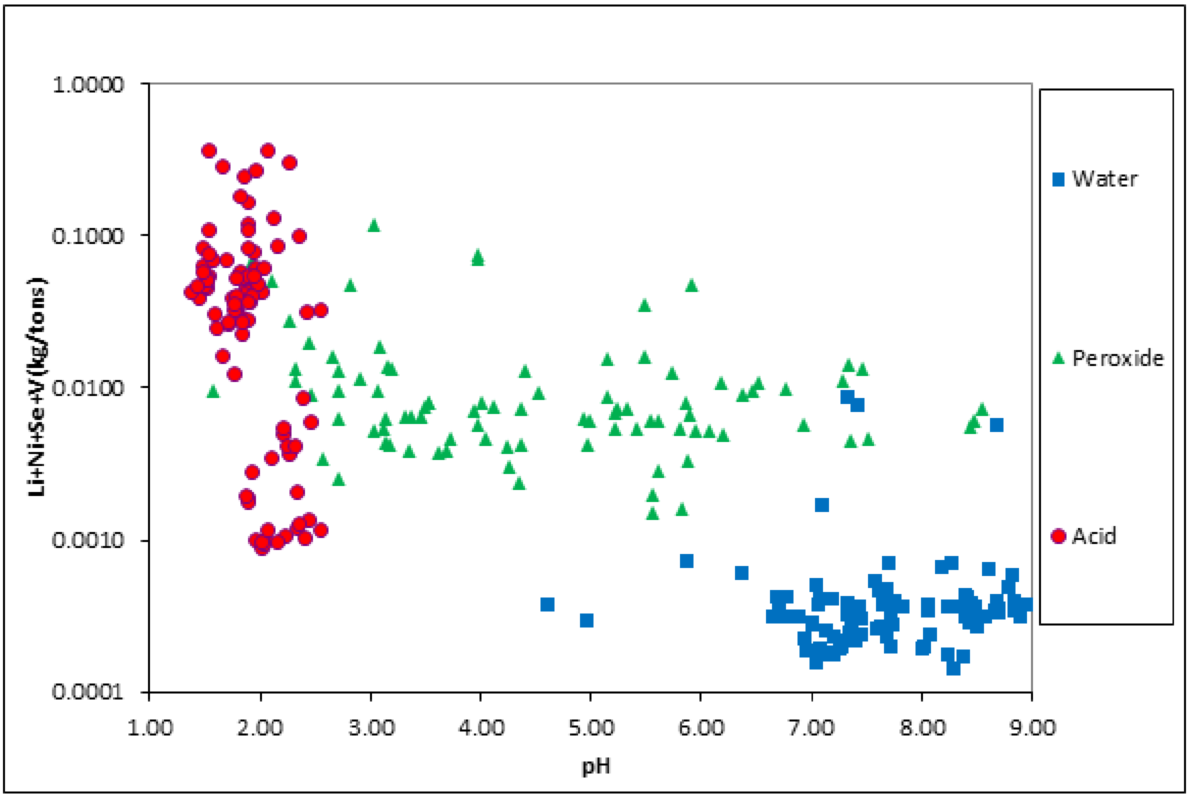

Figure 130: Total metal concentrations in solution at various pH environments.

Personal communication made with Parbhakar-Fox, (2014) brought an agreement that the methods standardly used by laboratories are totally underestimating the risk of the "dangerous" elements/metals to the environment. Total digestion of the sample will on the other hand yield unrealistic values compared to field conditions.

The question is: what can mining companies expect hydrogeochemically during mining of the different geological layers?

Of the samples tested, the sandstone and shale containing overburden contained the highest NNP values. These layers will be ideal to use as a buffer to neutralise any potential AMD that might be produced from layers with no NNP. The trace elements contained in these layers that can leach under acidic pH’s are: Co, Ni, Sr, V, Cu, Cr, Zn, Li and Lead (high to low).

The interburden samples have a variety of NNP values – from neutralisers to samples with and access to acid production. The composite (discard) samples tested indicated that these samples contained the highest AMD potential. Trace elements that leached under low pH’s are: Zn, Sr, Ni, Cu, Co, V, Li, Cr and Pb (high to low). These samples must be handled with great care to minimise oxidation and the storage facilities should be adequately prepared to minimise further contamination of the aquifers from the waste storage facilities. The deeper the samples/layers, the higher the acid producing potential once exposed when mined.

Once backfilling of the pit start, the best mixing scenario for backfilling must be selected to minimise production of AMD. Leaching of elements and toxic metals from the layers due to an acidic environment because of AMD should be well taken into account for environmental geochemical risks. The standard testing procedures determining the leach products used by testing laboratories and specified by regulatory bodies are not applicable to the AMD environment.

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12 APPENDICES

Table 41: The samples received and analysed from the different locations. *FS – Full succession, ME - Middle Ecca, WP- weathered in parts.*

Area	**Borehole**	**Renamed samples**	**Number of samples**	**Succession type**
GROOTEGELUK	JY309LQ17	JA	46	WP
	JY309LQ18	JB	20	WP
	JY309LQ14	JC	24	WP
	MY311LQ26	MA	19	FS
	MY311LQ28	MB	26	FS
	VP313LQ16	VA	38	WP
	VP313LQ17	VB	19	WP
	VP313LQ19	VC	36	WP
	VP313LQ18	VD	24	WP
RESGEN	SZP24	RA	61	ME
	SZP25	RB	68	ME
	SLP14	RC	56	ME
SASOL	G250040	WGH	47	FS
	W228030	W	38	FS
	G226006	WGA	18	FS
	G226014	WGC	15	FS
	G226010	WGB	24	FS
	G256039	WGE	3	WP
	G256038	WGF	2	FS
	V264007	WVA	9	ME
	V264008	WVB	8	WP
	V264009	WVC	8	WP
	G226010	WGG	15	FS
	G218016	WGD	17	FS
	R303015	WRA	8	
	T261019	WTA	2	ME
	T261018	WTB	5	WP
	T261016	WTC	9	WP
	T261017	WTD	7	FS
SEKOKO	DP712001	DP01	11	ME
	DP712002	DP2	7	ME
	DP712003	DP3	6	ME
	PS93	PS93	1	WP
	PS94	PS94	1	WP
	S131	S131	1	
	DM19	DM19	1	
	SV35	SV35	3	WP
	PS95	PS95	3	WP
	PM18	PM18	3	WP
COMPOSITE			119	

Table 42: Calculations for humidity cells (Morin and Hutt, 1997 & Price, 2009).

Acid generation
Acid Production Rate (mg $CaCO_3$/kg/wk) = Acidity (mg $CaCO_3$/L)* Volume Leachate Collected /Sample Weight
Sulphate Production Rate (mg/kg/wk) = Sulphate (mg/L)* Volume Leachate Collected/ Sample Weight
Remaining S $_{total}$ (% of original) = {Initial %S-[(Cumulative Sulphate Production Rate(mg/kg)*32.06/96.06/1000))]/Initial S total as %S}*100%
Remaining S $_{sulphide}$ (% of orginal) = {Initial %S $_{sulphide}$-[(Cumulative Sulphate Production Rate(mg/kg)*32.06/96.06/1000))]/Initial S $_{sulphide}$ as %S}*100%
Sulphate Production Rate by Surface Area (mg/m2/wk) = Sulphate Production Rate (mg/kg/wk) /Surface Area (m2/kg)
Molar Ratios
Carbonate Molar Ratio = [(Ca mg/L)/40.08) + (Mg(mg/L)/24.31) +(Sr(mg/L)/87.62)] /(SO_4(mg/L)/96.06)
Feldspar Molar Ratio = [(Ca (mg/L)/40.08)+ (K(mg/L)/2*39.1)+ (Na(mg/L)/22.99)] /(SO_4(mg/L)/96.06)
Acid Neutralisation and NP Consumption
Alkalinity Production Rate(mg $CaCO_3$/kg/wk) = Alkalinity (mg $CaCO_3$/L)* Volume Leachate Collected/ Sample Weight
Carbonate Ratio NP Consumption (mg $CaCO_3$/kg/wk) = Carbonate Molar Ratio *Theoretical NP Consumption (mg/kg/wk)
based on:
2 H^+ +$SO_4{}^{2-}$ +(Cax, Mg1-x)CO_3(s) = x Ca^{2+} +(1-x)Mg^{2+} + $SO_4{}^{2}$- + H_2CO_3
or 2 H^+ + $SO_4{}^{2}$- + 2(Cax, Mg1-x)CO_3(s) = 2x Ca^{2+} +(2-2x) Mg $_{2+}$ + $SO_4{}^{2}$- + 2 $HCO_3{}^-$
Feldspar Molar Ratio Total NP Consumption (mg $CaCO_3$/kg/wk) = Feldspar Molar Ratio *Theoretical NP Consumption (mg/kg/wk) based on:
2 H^+ + $SO_4{}^{2}$+ + H_2O + $CaAl_2Si_2O_8$ = Ca^{2+} + $SO_4{}^{2}$+2 Al(OH)3+2H4SIO4
2 H^+ + $SO_4{}^{2}$+ + H_2O + 2$KAlSi_2O_8$ = 2K^+ + $SO_4{}^{2}$+2 Al(OH)3+4H4SIO4
2 H^+ + $SO_4{}^{2}$+ + H_2O + 2$NaAlSi_2O_8$= 2Na^+ + $SO_4{}^{2}$+2 Al(OH)3+2H4SIO4
Theoretical NP Consumption at pH 6 (mg $CaCO_3$/kg/wk) = Sulphate Production Rate (mg/kg/wk)* 100.09/96.06
based on:
2 H^+ + $SO_4{}^{2}$+$CaCO_3$(s) = Ca^{2+} + $SO_4{}^{2}$+ H_2CO_3
Empirical Open-System NP consumption around neutral pH(mg/$CaCO_3$/kg/wk) = Theoretical NP Consumption (mg/kg/wk)+Alkalinity Production Rate (mg/kg/wk)- Acidity Production Rate(mg/kg/wk)

based on:
$2\ H^{+} + SO_4{}^{2}$- $+CaCO_3(s) = Ca^{2+} + SO_4{}^{2}+ H_2CO_3$
plus $H_2CO_3+CaCO_3(s) = Ca^{2+} + 2\ HCO_3^{-}$
minus un-neutralized acidity
Theoretical Closed System NP consumption pH 6.5 ($mg/CaCO_3/kg/wk$) = [Theoretical NP Consumption (mg/kg/wk)*2]- Acidity Production Rate (mg/kg/wk)
based on:
$2\ H^{+} +CaCO_3(s) = Ca^{2+} + 2\ HCO_3^{-}$
minus un-neutralized acidity
Remaining NP(% of original) + {[Initial NP (t CaCO4/1000 t)- Cumulative NP Depletion Rate (mg/kg)/1000)]/Initial NP (t CaCO4/1000 t)}*100%
Metal Leaching
Metal Leach Rates (mg/kg/wk) = Metal Concentration (mg/L)* Volume of Leachate Collected (L)/ Sample weight (kg)
Remaining Metal (% of original) = {Initial Metal content(mg/kg)-[(Cumulative Metal Leach Rate(mg/kg)/Initial Metal Content(mg/kg) }*100%
Notes: At the latter stages of some testing programs, analyses for sulphate, alkalinity and metals are not done on a weekly basis but may be decreased to monthly. In this circumstance, weekly values for rates can be calculated through interpolation of the proceeding and subsequent measured values.

Table 43: Major element results from XRF analysis.

	SiO2	Al2O3	Fe2O3	CaO	MgO	MnO	K2O	P2O5	TiO2	Total
WGH160	56.834	37.871	0.627	0.166	0.667	0.056	0.742	0.244	1.845	99.052
WGH165	81.414	9.663	1.634	3.01	1.229	0.174	0.003	0.176	2.192	99.495
WGH169	94.923	1.255	0.936	0.094	0.153	0.063	0	0.183	1.779	99.386
WGH170	76.536	20.098	0.901	0.042	0.014	0.056	0.152	0.12	1.541	99.46
WGH171	63.196	28.316	2.976	0.253	0.338	0.053	0.669	0.816	2.559	99.176
WGH172	61.22	34.889	0.718	0.083	0	0.055	0.41	0.127	1.779	99.281
WGH181	51.446	33.363	11.752	0.195	0.114	0.192	0.182	0.122	2.028	99.394
WGH182	60.079	34.799	1.151	0.092	0.941	0.064	0.261	0.156	2.291	99.834
WGH192	70.408	22.258	4.143	0.28	1.129	0.076	0.245	0.052	1.339	99.93
WGH193	70.478	22.111	4.183	0.279	0.666	0.077	0.242	0.05	1.345	99.431
WGH195	67.972	28.319	0.518	0.061	0.581	0.056	0.241	0.06	1.827	99.635
WGB9A	65.384	18.358	10.978	1.274	0.837	0.254	1.555	0.076	0.757	99.473
WGB4A	57.297	36.082	2.005	0.45	0.438	0.062	0.868	0.205	2.05	99.457
WGB8E	49.801	16.325	24.486	6.099	1.863	0.534	0.808	0.08	0.614	100.61
WGB9A	65.779	18.405	10.976	1.262	0.848	0.256	1.571	0.073	0.763	99.933
WGC9A	70.561	22.679	1.603	0.14	0.579	0.057	2.142	0.047	1	98.808
W1B	79.407	11.564	1.378	0.254	0.588	0.069	0.552	0.097	0.844	94.753
W10B	67.382	15.676	7.118	5.081	2.195	0.086	0.848	0.041	0.692	99.119
W13A	67.273	15.87	9.29	2.999	1.617	0.103	0.986	0.051	0.717	98.906
W15A	71.337	17.405	6.13	2.161	2.8	0.071	1.215	0.051	0.76	101.93
W16A	67.613	17.489	7.651	2.488	2.838	0.074	1.254	0.065	0.794	100.266
W19A	71.628	17.99	4.397	2.626	0.88	0.063	0.897	0.047	0.772	99.3
S4	56.235	37.607	1.487	0.723	0.449	0.055	0.548	0.113	1.69	98.907
S5	77.331	14.034	3.496	1.279	1.295	0.094	0.476	0.062	0.689	98.756
S8	72.052	23.543	1.051	0.172	0.948	0.057	0.349	0.075	1.242	99.489
S9	72.158	22.867	1.274	0.529	0.596	0.061	0.378	0.07	1.199	99.132
S47	57.302	37.278	1.599	0.713	0.203	0.056	0.589	0.11	1.714	99.564
S49	58.42	35.708	2.934	0.305	0.009	0.056	0.579	0.134	1.478	99.623
S61	91.739	5.292	0.8	0.028	0.169	0.058	0.279	0.029	0.281	98.675
S69	66.7	18.377	10.888	0.222	0.39	0.164	1.544	0.079	1.056	99.42
S71	90.914	5.647	0.745	0.104	0.647	0.058	0.738	0.032	0.275	99.16
WGC10B	68.12	20.94	5.40	1.43	1.12	0.07	1.69	0.06	0.85	99.68
WGC8	44.15	14.69	28.94	8.17	1.47	0.59	0.80	0.09	0.63	99.54
WGC9A	70.45	23.51	1.62	0.13	0.64	0.06	2.24	0.05	1.03	99.73
WRA2B	63.62	31.75	1.62	0.13	0.54	0.06	0.27	0.08	1.60	99.66
WTB1A	64.44	30.67	1.43	0.19	0.08	0.06	0.41	0.31	2.36	99.94
WTB2	78.94	16.71	0.71	0.20	0.13	0.07	1.71	0.07	1.28	99.83
WTB4	28.65	17.24	39.81	10.63	1.74	0.22	0.06	0.30	0.84	99.48
WTC4A	65.02	30.49	1.00	0.16	0.37	0.06	0.83	0.14	1.75	99.83
WVB4E	66.97	28.59	1.99	0.13	0.06	0.06	0.38	0.08	1.43	99.69
WVC3	68.75	26.32	2.10	0.21	0.36	0.06	0.29	0.08	1.64	99.80
WVC4A	58.02	33.31	0.48	2.37	1.10	0.06	0.28	2.38	1.63	99.63
RB11	71.018	24.567	2.315	0.109	-0.008	0.151	0.101	0.102	1.28	99.635
RB18	65.501	30.927	0.999	0.102	0.065	0.056	0.459	0.08	1.321	99.51
RB19	67.971	24.909	4.944	0.141	0.065	0.125	0.332	0.12	1.061	99.668
RB24	63.779	33.143	0.719	0.082	0.003	0.056	0.235	0.115	1.452	99.584
RB29	77.945	18.918	1.014	0.462	0.152	0.062	0.153	0.114	0.915	99.735
RB38	66.748	29.084	0.963	0.107	0.007	0.058	0.383	0.102	1.565	99.017
RB51	56.33	20.5	17.916	1.864	1.408	0.192	0.385	0.095	0.904	99.594
RC10	79.769	15.646	0.708	0.186	0.037	0.07	1.602	0.067	1.234	99.319
RC2	83.659	7.752	2.082	4.423	0.141	0.132	0.622	0.042	0.62	99.473
RC56	83.76	12.032	1.31	0.267	0.076	0.069	0.62	0.097	0.881	99.112

Table 44: Trace element results obtained from XRF analyses.

Sample	Sc	V	Cr	Co	Ni	Cu	Zn	Br	Rb	Sr	Y	Zr	Nb	Ag	Cd	Ba	Tl	Pb
WVC 4(A)	21	76	80	7	26	113	26	2	20	1383	95	383	18	9	4	1628	8	42
WVC 3	10	33	55	11	50	36	8	3	22	13	27	130	7	9	0	44	6	13
WVB 4E	11	34	62	10	24	21	29	3	31	17	42	132	8	8	0	61	7	14
WTC 4(A)	18	78	84	5	18	10	21	2	59	64	41	245	20	5	2	215	6	34
WTB 4	17	63	73	11	50	243	41	3	19	139	26	100	4	16	7	413	8	18
WTB 1(A)	9	57	111	18	78	60	15	4	23	109	20	156	9	7	3	201	6	22
WTA 2	5	23	26	16	39	29	3	5	11	466	18	50	-1	5	2	529	7	6
WRA 2(B)	10	92	144	11	49	73	3	4	21	24	26	145	5	5	1	29	7	14
RB38	10	73	78	12	39	15	58	1	39	69	30	956	17	10	4	268	8	25
RB29	13	70	97	6	35	120	18	2	33	57	22	294	11	9	1	538	7	22
RB24	18	118	164	6	49	76	49	1	41	57	33	377	21	8	-1	398	7	37
RB19	20	114	172	13	56	38	83	2	42	63	35	244	12	10	7	461	7	26
RB18	18	100	148	12	55	124	36	1	51	33	37	281	15	8	2	288	6	32
RB11	17	121	151	11	40	119	43	2	29	90	24	336	17	8	3	893	6	24
S5	16	93	164	11	48	46	28	2	44	40	28	206	8	9	7	747	7	19
S4	12	63	103	12	42	25	19	2	37	44	20	199	4	10	3	1557	7	12
RC10	9	84	130	13	29	17	41	2	56	109	17	706	10	14	3	474	5	22
RC2	12	44	95	13	31	101	28	2	39	64	13	324	4	8	6	897	4	11
RB56	7	52	88	9	33	65	51	3	30	136	13	393	6	10	2	482	6	14
RB51	12	73	90	26	49	52	79	3	29	63	26	152	7	11	7	205	9	14
S69	13	119	163	23	86	132	82	2	55	73	21	315	10	5	1	407	6	19
S61	4	26	42	9	18	33	16	2	25	34	9	131	2	12	2	93	5	8
S49	22	176	261	16	80	129	120	2	42	92	23	238	10	11	-1	274	6	28
S47	21	114	150	11	44	123	18	3	39	58	30	163	11	8	5	172	6	28
S9	18	73	154	7	37	16	23	5	48	32	33	254	18	12	4	393	6	31
S8	16	90	159	7	38	78	26	3	37	43	31	233	11	15	0	685	7	23
W13 A	13	111	49	8	16	99	48	1	78	107	24	186	11	13	4	251	5	20
W10 B	12	48	30	10	20	46	57	0	65	94	32	178	11	14	4	202	7	18
WGC	7	3	1	6	7	8	1	3	4	55	2	95	4	7	1	11	6	1

Sample	Sc	V	Cr	Co	Ni	Cu	Zn	Br	Rb	Sr	Y	Zr	Nb	Ag	Cd	Ba	Tl	Pb
10B		2	9			9	9		8		0					4		0
WGC 9A	9	66	51	6	10	83	40	2	118	51	27	200	16	9	1	363	7	27
WGH 171	31	338	401	13	62	145	172	2	49	476	47	414	19	9	2	1335	7	56
WGH 170	6	66	94	8	33	68	37	2	29	45	29	743	14	9	2	337	8	29
WGH 160	9	53	25	5	7	-6	14	1	15	86	45	455	16	13	0	595	6	13
WGH 165	7	54	45	6	14	41	25	2	19	63	70	1148	11	11	9	610	9	26
WGC 8	8	34	18	10	13	51	16	3	28	143	18	61	3	9	1	119	7	12
WGB 9(A)	5	30	18	9	9	11	25	3	52	57	18	76	4	8	4	172	5	10
WGB 8(C)	9	37	19	9	11	8	15	2	39	74	18	79	5	12	2	169	5	9
WGB 4(A)	16	60	69	7	31	66	5	2	44	73	79	203	14	8	-1	247	8	40
W1B	15	67	47	7	29	54	40	2	105	40	37	204	11	12	7	273	7	19
S71	4	24	40	6	14	12	14	2	36	40	7	167	1	10	1	214	6	10
W16A	11	66	44	10	14	150	44	2	87	138	35	199	13	9	5	177	6	15
W15A	11	64	41	11	16	133	33	2	80	92	30	195	12	10	3	164	7	22
WGH 160	14	95	89	6	33	92	37	2	52	128	30	207	21	8	3	398	6	46
W19A	13	69	44	12	13	90	260	1	74	81	27	211	13	11	2	142	9	24
WGH 195	5	40	106	8	28	69	87	2	28	28	10	576	20	9	4	145	6	14
WGH 193	8	8	13	5	15	-10	6	1	16	93	6	74	0	10	2	242	7	8
WGH 192	9	59	123	21	50	38	53	1	29	35	7	233	13	13	1	229	7	25
WGH 182	12	136	134	40	50	52	82	1	34	112	24	591	35	9	2	248	6	44
WGH 181	15	168	125	73	91	83	84	1	29	79	19	405	30	15	3	192	6	40

Table 45: XRD results (XXX-dominant, XX-major, X-minor, xx-accessory and x-rare).

Sample	Quartz	Kaolinite	Siderite	Calcite	Ankerite/Dolomite	Muscovite/Illite	Rutile/Anatase	Pyrite	Ilmenite	Hematite	Marcasite	Apatite	Pyrrhotite	Feldspar
WGH160	X	XXX				xx	x							
WGH165	XXX	X		x	x		x	x						
WGH169	XXX	xx					x			x				
WGH170	XX	XX				x	x							
WGH171	XX	XXX				xx	xx	xx						
WGH172	XX	XXX				xx	x							
WGH181	X	XXX	X			x	x							
WGH182	XX	XXX	xx			x	x							
WGH192	XXX	XX	xx		x	x	x	x						
WGH193	XXX	XX		x	x	x	x	xx						
WGH195	XX	XXX				xx	x							
WGB4A	X	XXX		x	x	xx	x							
WGB8E	X	XX	XX	X	xx	xx	x							
WGB9A	XX	XX	X	x	x	X	x	x						
W1B	XXX	XX				xx	x							
W10B	XX	XX	xx	xx	xx	xx	x	x						
W13A	XX	XX	xx	x	xx	xx	x				x			
W15A	XX	XX	xx	xx	xx	X	x							
W16A	XX	XX	xx	xx	xx	X	x							
W19A	XX	XX	xx	xx	x	xx	x	x						
S4	XXX	XX		xx		xx	x		x					
S5	XXX	XX		xx		xx	x		xx					
S8	XXX	XX				x	x		x					
S9	XXX	XX				xx	x							
S47	X	XXX		x		xx	x							
S49	X	XXX				xx	x	x	x					
S61	XXX	X				x								
S69	XX	X	X			xx	x							X
S71	XXX	xx			x	x								xx
WGC10B	XXX	XX		x	x	X	x	x						
WGC8	XX	X	XX	X	xx	xx		xx						
WGC9A	XXX	XX				XX	x							
WRA2B	XXX	XX				xx	x	x						
WTB1A	XXX	XX				X	xx	x						
WTB2	X	XXX	XX				x	xx						
WTB4	X	XX		XX	xx			XX						

Sample	Quartz	Kaolinite	Siderite	Calcite	Ankerite/Dolomite	Muscovite/Illite	Rutile/Anatase	Pyrite	Ilmenite	Hematite	Marcasite	Apatite	Pyrrhotite	Feldspar
WTC4A	XXX	XX				xx	x	x						
WVB4E	XXX	XX					x			x				
WVC3	XX	XX					x			x				
WVC4A	XX	XX					x					xx	x	
RB11	XXX	XX				x	x	xx						x
RB18	XX	XX				xx	x	x						x
RB19	XXX	XX	xx			xx	x							
RB24	XX	XXX				x	x							x
RB29	XXX	XX	x	x	x	x	x							
RB38	XX	XXX	x			xx	x							
RB51	XX	XX	X	xx	x	xx	x	X						
RC10	XXX	X			x	xx	x							X
RC2	XXX	X	x	xx		x	x	x						xx
RC56	XXX	X	x	x	x	xx	x							x

Table 46: Summary of the ABA results of the Sasol samples.

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
W10A	8.32	8.38	43.64	14.47	Verify with other tests	interburden	mudstone
W10B	8.39	8.26	86.95	71.86	Probably Excess Neutralising Minerals	interburden	mudstone
W11A	8.41	8.38	30.22	-5.16	Verify with other tests	interburden	mudstone/coal
W11B	8.38	8.26	-13.64	-44.19	Potential Acid Generator	interburden	mudstone/coal
W12A	8.34	8.38	-0.88	-51.48	Potential Acid Generator	interburden	mudstone/coal
W12B	8.43	8.22	52.65	19.77	Verify with other tests	interburden	mudstone/coal
W13A	8.25	3.07	-9.58	-82.38	Potential Acid Generator	interburden	mudstone/coal
W13B	8.26	8.18	21.99	-20.34	Potential Acid Generator	interburden	mudstone/coal
W14A	8.46	6.8	20.61	-30.24	Potential Acid Generator	interburden	mudstone/coal
W14B	8.11	2.54	-42.7	-124.86	Potential Acid Generator	interburden	mudstone/coal
W15A	8.3	8.01	36.83	31.04	Probably Excess Neutralising Minerals	interburden	mudstone/coal
W15B	8.35	7.76	12.1	3.2	Verify with other tests	interburden	mudstone/coal
W16A	8.53	7.88	50.83	49.16	Probably Excess Neutralising Minerals	interburden	mudstone/coal
W16B	8.34	7.8	28.4	25.67	Probably Excess Neutralising Minerals	interburden	mudstone/coal
W17A	7.58	4.09	-3.04	-7.6	Verify with other tests	interburden	coal
W17B	8.01	3.45	-11.76	-20.32	Potential Acid Generator	interburden	mudstone/coal
W18A	8.47	7.21	30.35	29	Probably Excess Neutralising Minerals	interburden	mudstone/coal
W18B	8.3	8.3	68.19	65.93	Probably Excess Neutralising Minerals	interburden	mudstone/coal
W19A	8.06	4.98	-0.07	-37.64	Potential Acid Generator	interburden	mudstone/coal
W19B	7.92	7.93	34.59	25.86	Probably Excess Neutralising Minerals	interburden	mudstone/coal
W1A	8.53	5.91	-9.78	-18.76	Verify with other tests	interburden	mudstone
W1B	8.13	5.42	-2.12	-2.29	Verify with other tests	interburden	mudstone
W2A	8.23	6.01	-2.4	-2.42	Verify with other tests	interburden	mudstone
W2B	8.1	6.85	0.74	0.82	Verify with other tests	interburden	mudstone
W3A	7.26	6.91	2.07	2.07	Verify with other tests	interburden	mudstone
W3B	8.08	6.79	1.36	1.41	Verify with other tests	interburden	mudstone
W4A	7.68	7.22	0.82	0.77	Verify with other tests	interburden	mudstone
W4B	7.9	6.89	2.65	2.58	Verify with other tests	interburden	mudstone
W5B	7.99	6.06	-0.03	-0.11	Verify with other tests	interburden	mudstone
W6A	8.39	6.6	1.24	1.16	Verify with other tests	interburden	mudstone
W6B	8.03	7.29	-0.01	-0.07	Verify with other tests	interburden	mudstone
W7A	7.25	5.69	1.1	1.13	Verify with other tests	interburden	mudstone
W7B	8.36	5.78	0.43	0.35	Verify with other tests	interburden	mudstone
W8A	8.49	5.68	-0.03	-0.13	Verify with other tests	interburden	mudstone
W8B	8.59	5.65	0.08	0.1	Verify with other tests	interburden	mudstone
W9A	8.58	8.3	52.92	41.13	Probably Excess Neutralising Minerals	interburden	mudstone
W9B	7.85	5.94	0.96	0.89	Verify with other tests	interburden	mudstone
WGA1	7.48	1.55	1.66	-5.72	Verify with other tests	interburden	ss/coal

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
WGA10	6.61	1.29	-24.85	-43.35	Potential Acid Generator	interburden	mudstone/coal
WGA10 (F)	7.41	2.28	18.96	7.52	Verify with other tests	interburden	mudstone/coal
WGA11	6.13	2.35	-66.5	-137.24	Potential Acid Generator	interburden	mudstone
WGA11 (A)	6.9	1.4	-24.22	-45.57	Potential Acid Generator	interburden	mudstone
WGA2	6.85	1.29	-3.79	-19.66	Verify with other tests	interburden	coal/mudstone
WGA2 (A)	7.69	1.63	11.12	-14.82	Verify with other tests	interburden	ss/coal
WGA3	7.78	3.64	-3.61	-12.8	Verify with other tests	interburden	mudstone/coal
WGA3 (A)	7.95	7.58	114.5	107.8	Probably Excess Neutralising Minerals	interburden	ss/coal
WGA4	6.4	2.09	-82.38	-148.01	Potential Acid Generator	interburden	mudstone/coal
WGA5	7.96	4.43	39.52	30.97	Probably Excess Neutralising Minerals	interburden	mudstone/coal
WGA5 (A)	7.32	3.13	-3.17	-3.67	Verify with other tests	interburden	mudstone/coal
WGA6	6.61	2.07	-10.07	-15.14	Verify with other tests	interburden	mudstone/coal
WGA6 (A)	7.86	1.42	-19.41	-21.23	Potential Acid Generator	interburden	mudstone/coal
WGA6 (B)	7.63	1.88	-16.88	-17.47	Verify with other tests	interburden	mudstone/coal
WGA6 (C)	8.3	3.97	-49.67	-83.05	Potential Acid Generator	interburden	mudstone/coal
WGA7	7.18	3.46	3.15	-5.96	Verify with other tests	interburden	mudstone/coal
WGA7 (C)	7.5	4.03	-0.97	-1.1	Verify with other tests	interburden	mudstone/coal
WGA8	7.66	4.16	45.25	33.59	Probably Excess Neutralising Minerals	interburden	mudstone/coal
WGA8 (A)	7.25	1.53	-5.56	-10.07	Verify with other tests	interburden	mudstone/coal
WGA9	7.33	2.02	36.94	-13.01	Verify with other tests	interburden	mudstone/coal
WGA9 (A)	7.37	2.61	7.72	-7.77	Verify with other tests	interburden	mudstone/coal
WGB10 (A)	8.28	4.8	41.63	41.44	Probably Excess Neutralising Minerals	interburden	mud/ss/coal
WGB10 (B)	8.17	1.29	8.09	-52.26	Potential Acid Generator	interburden	mudstone/coal
WGB10 (C)	8.04	1.45	5.56	2.36	Verify with other tests	interburden	ss/mudstone
WGB10 (D)	8.11	2.05	-7.54	-15.93	Verify with other tests	interburden	ss/mud/coal
WGB10 (E)	8.1	1.24	-34.74	-51.33	Potential Acid Generator	interburden	ss/mudstone
WGB3	7.82	1.28	-69.75	-126.97	Potential Acid Generator	interburden	ss
WGB4 (A)	7.9	1.07	-372.45	-723.04	Potential Acid Generator	interburden	ss/coal/mudstone
WGB4 (B)	5.69	1.24	-71.52	-125.87	Potential Acid Generator	interburden	coal/ss
WGB4 (C)	8.41	3.06	-12.2	-18.36	Verify with other tests	interburden	ss
WGB4 (D)	8	2.86	-0.57	-22.63	Potential Acid Generator	interburden	ss
WGB5 (A)	7.45	1.5	-14.14	-14.67	Verify with other tests	interburden	mud/ss/coal
WGB5 (B)	8.28	2.86	-31.28	-40.58	Potential Acid Generator	interburden	ss/coal
WGB5 (C)	7.35	5.01	-24.92	-27.87	Potential Acid Generator	interburden	ss/coal
WGB5 (D)	8.29	2.48	-13.77	-23.96	Potential Acid Generator	interburden	ss/coal
WGB7 (A)	8.12	1.54	1.68	-11.69	Verify with other tests	interburden	ss/coal
WGB7 (B)	7.94	3.09	-66.4	-122.09	Potential Acid Generator	interburden	mudstone/ss/coal
WGB7 (C)	7.55	2.04	-23.37	-25.08	Potential Acid Generator	interburden	mudstone/coal
WGB7 (D)	7.8	2.06	-22.31	-29.42	Potential Acid Generator	interburden	mud/ss/coal
WGB8 (A)	8.18	1.71	-12.12	-14.11	Verify with other tests	interburden	mudstone/coal

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
WGB8 (B)	7.89	1.73	-50.02	-87.89	Potential Acid Generator	interburden	coal
WGB8 (C)	8.08	1.05	-24.01	-27.9	Potential Acid Generator	interburden	mudstone/coal
WGB8 (D)	7.85	1.06	-19.85	-20.48	Potential Acid Generator	interburden	ss
WGB8 (E)	8.13	4.44	29.58	15.43	Verify with other tests	interburden	mudstone
WGB9 (A)	8.36	1.72	-7.46	-10.9	Verify with other tests	interburden	mudstone/coal
WGB9 (B)	7.63	2.93	-11.36	-12.33	Verify with other tests	interburden	mud/ss/coal
WGC10 (A)	6.78	1.31	-59.11	-101.29	Potential Acid Generator	interburden	mudstone/coal
WGC10 (B)	7.53	4.41	32.31	22.24	Probably Excess Neutralising Minerals	interburden	mudstone/coal
WGC11 (A)	7.4	1.78	-10.44	-20.88	Potential Acid Generator	interburden	mudstone/coal
WGC11 (B)	7.53	1.53	9.41	-4.05	Verify with other tests	interburden	mudstone/coal
WGC4 (A)	6.49	1.44	-29.15	-50.81	Potential Acid Generator	interburden	mudstone/coal
WGC4 (B)	7.58	1.43	-13.37	-39.19	Potential Acid Generator	interburden	mudstone/coal
WGC5	7.11	4.06	13.38	8.48	Verify with other tests	interburden	mudstone/coal
WGC6 (A)	7.33	1.62	-20.66	-39.51	Potential Acid Generator	interburden	mudstone/coal
WGC6 (B)	7.78	3.93	11.71	8.88	Verify with other tests	interburden	mudstone/coal
WGC7	6.9	1.77	-5.82	-15.05	Verify with other tests	interburden	mudstone/coal
WGC7 (A)	7.31	1.54	-21.21	-41.93	Potential Acid Generator	interburden	mudstone/coal
WGC8	7.6	2.31	-29.07	-69.63	Potential Acid Generator	interburden	mudstone/coal
WGC8 (A)	7.39	2.5	7.84	6.24	Verify with other tests	interburden	mudstone/coal
WGC9 (A)	7.58	1.65	0.66	-13.04	Verify with other tests	interburden	mudstone/coal
WGC9 (B)	7.26	2.2	-0.69	-13.69	Verify with other tests	interburden	mudstone/coal
WGD1	7.84	2.19	4.24	-3.49	Verify with other tests	interburden	mudstone/coal
WGD1 (A)	8.15	7.28	48.28	41.35	Probably Excess Neutralising Minerals	interburden	mudstone/coal
WGD2 (A)	7.5	1.99	-89.71	-179.58	Potential Acid Generator	interburden	ss
WGD3	7.42	2.06	-103.797	-248.71	Potential Acid Generator	interburden	ss/coal
WGD4	6.68	1.94	-3.54	-2.6	Verify with other tests	interburden	mudstone/coal
WGD4 (D)	5.21	1.34	-11.33	-18.54	Verify with other tests	interburden	mudstone/coal
WGD5	7.86	1.94	-7.64	-11.26	Verify with other tests	interburden	mudstone/coal
WGD5 (A)	7.88	4.11	14.51	-1.85	Verify with other tests	interburden	mudstone/coal
WGD6 (A)	7.67	3.62	-2.66	-3.39	Verify with other tests	interburden	mudstone/coal
WGD6 (B)	7.87	5.27	41.18	40.28	Probably Excess Neutralising Minerals	interburden	mudstone/coal
WGD6 (C)	7.51	5.29	16.43	1.02	Verify with other tests	interburden	mudstone/coal
WGD7	7.98	2.04	-7.4	-9.45	Verify with other tests	interburden	mudstone/coal
WGD7 (A)	6.9	2	-6.06	-8.32	Verify with other tests	interburden	mudstone/coal
WGD7 (B)	7.45	3.24	11.47	-13.82	Verify with other tests	interburden	mudstone/coal
WGD8 (A)	6.73	1.49	-13.14	-23.54	Potential Acid Generator	interburden	mudstone/coal
WGD8 (B)	7.58	2.86	10.42	3.69	Verify with other tests	interburden	mudstone/coal
WGD8 (C)	6.84	2.83	-4.43	-5.63	Verify with other tests	interburden	mudstone/coal
WGD9	5.03	1.51	-19.35	-32.8	Potential Acid Generator	interburden	clay ground/mudstone
WGE2	7.61	1.77	-42.83	-67.12	Potential Acid Generator	interburden	

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
WGE4 (A)	8.09	4.12	-9.94	-10.94	Verify with other tests	interburden	
WGE4 (B)	8.28	2.88	-6.21	-11.55	Verify with other tests	interburden	
WGF10	8.1	4.82	26.63	17.39	Verify with other tests	interburden	mudstone/coal
WGF7	3.96	1.07	-19.26	-28.52	Potential Acid Generator	interburden	coal/mudstone
WGG1	7.42	1.78	-38.49	-97.83	Potential Acid Generator	interburden	ss
WGG2	7.52	3.99	-5.75	-15.66	Verify with other tests	interburden	ss/mud/coal
WGG2 (A)	7.7	1.61	22.06	13.37	Verify with other tests	interburden	coal/mudstone
WGG2 (C)	7.59	2.18	-64.64	-167.62	Potential Acid Generator	interburden	coal/ss
WGG3	7.31	2.8	-18.76	-47.12	Potential Acid Generator	interburden	coal/ss
WGG4	7.16	2.03	15.63	-5.27	Verify with other tests	interburden	mudstone/coal
WGG4 (A)	5.3	1.43	30.76	29.72	Probably Excess Neutralising Minerals	interburden	mudstone/coal
WGG4 (D)	8.01	4.43	-1.25	-2.97	Verify with other tests	interburden	mudstone/ss
WGG4 (E)	6.69	1.52	33.39	31.37	Probably Excess Neutralising Minerals	interburden	mudstone/ss
WGG4 (F)	7.99	6.13	-4.41	-6.8	Verify with other tests	interburden	mudstone
WGG5 (C)	7.31	3.34	2.7	2.62	Verify with other tests	interburden	coal/mudstone
WGG5 (E)	7.93	4.02	27.19	21.8	Probably Excess Neutralising Minerals	interburden	mudstone
WGG5 (F)	7.73	3.96	5.24	-38.78	Potential Acid Generator	interburden	mudstone/coal
WGG6	7.53	3.99	50.57	45.47	Probably Excess Neutralising Minerals	interburden	mudstone/coal
WGG6 (A)	8.08	7.23	23.12	18.6	Verify with other tests	interburden	mudstone
WGG6 (B)	7.53	2.73	2.74	-2.13	Verify with other tests	interburden	carbonaceous mudstone
WGH (160)	7	2.56	-8.72	-29.2	Potential Acid Generator	interburden	mudstone
WGH (161)	6.98	2.06	-1.06	-2.77	Verify with other tests	interburden	mudstone
WGH (162)	6.61	2.48	2.88	1.46	Verify with other tests	interburden	mudstone
WGH (163)	6.09	2.23	-37.06	-67.68	Potential Acid Generator	interburden	mudstone
WGH(164)	6.66	1.61	-17.43	-34.25	Potential Acid Generator	interburden	siltstone
WGH (165)	7.86	5.93	46.87	14.51	Verify with other tests	interburden	siltstone
WGH (166)	7.91	4.59	2.14	-13.4	Verify with other tests	interburden	ss
WGH (167)	6.9	1.71	-4.91	-5.78	Verify with other tests	interburden	ss
WGH (168)	7	2.31	10.18	8.61	Verify with other tests	interburden	ss
WGH (169)	7.2	1.91	-19.82	-40.72	Potential Acid Generator	interburden	ss
WGH (170)	6.77	1.76	-10.12	-21.12	Potential Acid Generator	interburden	ss
WGH (171)	5.78	1.72	-44.06	-86	Potential Acid Generator	interburden	mudstone
WGH (172)	6.8	3.1	-0.07	-1.26	Verify with other tests	interburden	mudstone
WGH (173)	6.71	2.69	-0.77	-2.65	Verify with other tests	interburden	ss
WGH (174)	5.61	1.72	-53.97	-106.95	Potential Acid Generator	interburden	ss
WGH (175)	6.9	1.69	-278.31	-552.57	Potential Acid Generator	interburden	mudstone
WGH (176)	7.43	6.1	64.59	64.1	Probably Excess Neutralising Minerals	interburden	mudstone
WGH (177)	7.35	3.27	6.17	5.64	Verify with other tests	interburden	mudstone
WGH (178)	7.02	3.99	-13.74	-14.35	Verify with other tests	interburden	mudstone
WGH (179)	6.79	2.92	1.14	0.42	Verify with other tests	interburden	mudstone

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
WGH (180)	7.46	2.27	1.8	1.24	Verify with other tests	interburden	mudstone
WGH (181)	6.8	3.84	4.73	2.64	Verify with other tests	interburden	mudstone
WGH (182)	6.39	2.97	-0.34	-1.16	Verify with other tests	interburden	mudstone
WGH (183)	6.8	2.58	-1.88	-2.72	Verify with other tests	interburden	ss
WGH (184)	7.65	1.76	-7.68	-24.44	Potential Acid Generator	interburden	ss
WGH (185)	6.89	3.35	49.86	48.58	Probably Excess Neutralising Minerals	interburden	ss
WGH (187)	6.54	2.98	-0.44	-0.85	Verify with other tests	interburden	ss
WGH (188)	6.61	1.67	0.24	0.11	Verify with other tests	interburden	ss
WGH (189)	6.8	2.46	-1.89	-2.33	Verify with other tests	interburden	ss
WGH (190)	6.62	2.4	-3.3	-6.86	Verify with other tests	interburden	shale/ss
WGH (191)	6.41	3.17	4.08	3.77	Verify with other tests	interburden	mud/silt
WGH (192)	7.11	2.43	-1.28	-21.74	Potential Acid Generator	interburden	siltstone
WGH (193)	8.08	5.57	128.31	125.13	Probably Excess Neutralising Minerals	interburden	siltstone
WGH (194)	5.02	2.09	-86.07	-170.19	Potential Acid Generator	interburden	siltstone
WGH (195)	7.22	2.62	-2.01	-3.68	Verify with other tests	interburden	ss
WGH (196)	7.46	2.3	-41.29	-81	Potential Acid Generator	interburden	ss
WGH (197)	7.57	2.96	25.44	25.5	Probably Excess Neutralising Minerals	interburden	coal
WGH (186)	6.56	2.53	-1.31	-1.41	Verify with other tests	interburden	ss
WRA2 (B)	2.76	1.76	-12.77	-20.13	Potential Acid Generator	interburden	coal
WRA3 (B)	7.11	1.4	-29.75	-75.71	Potential Acid Generator	interburden	coal/ss
WRA4 (A)	7.74	3.72	9.36	8	Verify with other tests	interburden	mudstone/coal
WRA4 (A)	6.99	2.72	-24.8	-74.12	Potential Acid Generator	interburden	ss/coal
WRA4 (D)	7.34	3.15	7.7	5.14	Verify with other tests	interburden	mud/coal/ss
WRA4 (G)	7.65	3.7	-33.21	-65.71	Potential Acid Generator	interburden	coal
WRA5 (B)	7.59	4.68	33.78	32.09	Probably Excess Neutralising Minerals	interburden	mudstone/coal
WRA5 (F)	7.52	1.63	-12.75	-33.58	Potential Acid Generator	interburden	coal/mudstone
WTA1	3.99	1.15	-69.65	-77.03	Potential Acid Generator	interburden	coal/ss
WTA2	4.13	1.05	-147.01	-280.27	Potential Acid Generator	interburden	coal
WTB1 (A)	5.28	1.2	-35.52	-49.35	Potential Acid Generator	interburden	coal/ss
WTB1 (B)	4.06	1.2	-59.92	-92.91	Potential Acid Generator	interburden	coal
WTB2	7.99	2.63	-15.51	-15.85	Verify with other tests	interburden	coal/siltstone
WTB3	3.62	1.02	-41.68	-56.05	Potential Acid Generator	interburden	ss/mud/coal
WTB4	7.48	1.52	-5.52	-113.65	Potential Acid Generator	interburden	coal/mudstone
WTC1	3.37	1.24	-50.04	-65.64	Potential Acid Generator	interburden	coal/ss
WTC2 (A)	6.15	1.5	-77.76	-120.69	Potential Acid Generator	interburden	coal/ss
WTC2 (B)	4.64	2.2	-7.08	-10.68	Verify with other tests	interburden	coal/ss
WTC3 (A)	6.2	1.63	-30.56	-68.7	Potential Acid Generator	interburden	ss/mudstone
WTC4 (A)	7.3	2	-6.54	-8.97	Verify with other tests	interburden	coal/mudstone
WTC4 (B)	6.72	2.06	-11.15	-17.93	Verify with other tests	interburden	coal/mudstone
WTC4 (C)	3.98	2.01	-8.55	-25.83	Potential Acid Generator	interburden	coal/mudstone

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
WTC4 (D)	7.57	4.21	-169.45	-313.85	Potential Acid Generator	interburden	mudstone
WTD2	7.68	0.83	-28.67	-50.46	Potential Acid Generator	interburden	coal/mudstone
WTD2 (A)	3.12	1.86	-124.23	-222.73	Potential Acid Generator	interburden	coal
WTD3 (A)	5.31	2.45	-54.03	-109.13	Potential Acid Generator	interburden	coal
WTD3 (B)	4.4	1.65	-196.62	-379.45	Potential Acid Generator	interburden	coal
WTD4 (A)	4.55	0.92	-27.55	-43.28	Potential Acid Generator	interburden	mudstone/coal
WTD4 (B)	4.03	1.45	-47.79	-48.48	Potential Acid Generator	interburden	coal
WTD4 (C)	7.05	1.94	-49.2	-98.12	Potential Acid Generator	interburden	coal
WVA1	4.16	1.17	-34.41	-61.27	Potential Acid Generator	interburden	coal
WVA2 (A)	3.53	1.17	-27.72	-56.06	Potential Acid Generator	interburden	coal
WVA3	4.84	1.82	-7.89	-16.21	Verify with other tests	interburden	coal/mudstone
WVA4	3.42	1.21	-41.03	-45.6	Potential Acid Generator	interburden	coal/mudstone
WVA4 (A)	7.25	2.94	-198.31	-484.27	Potential Acid Generator	interburden	coal/mudstone
WVA4 (C)	3.95	1.17	-32.75	-61.93	Potential Acid Generator	interburden	coal/mudstone
WVA4 (D)	6.64	1.66	-61.34	-126.95	Potential Acid Generator	interburden	coal
WVA5	5.52	1.47	-1.09	1.45	Verify with other tests	interburden	coal/mudstone
WVA5 (A)	5.59	1.05	-5.3	-6.98	Verify with other tests	interburden	coal/mudstone
WVB2)	3.8	2.13	-158.41	-301.56	Potential Acid Generator	interburden	
WVB3	3.5	1.23	-17.47	-26.91	Potential Acid Generator	interburden	
WVB4	6.11	0.77	-17.5	-28.85	Potential Acid Generator	interburden	
WVB4 (A)	3.95	1.3	-10.82	-20.25	Potential Acid Generator	interburden	
WVB4 (B)	4.1	1.32	-57.38	-99.09	Potential Acid Generator	interburden	
WVB4 (C)	3.43	1.29	-54.27	-98.34	Potential Acid Generator	interburden	
WVB4 (E)	7.38	2.06	-70.69	-183.92	Potential Acid Generator	interburden	
WVB4 (D)	5.82	1.82	-7.68	-12.82	Verify with other tests	interburden	
WVC1	3.58	1.34	-95.5	-170.51	Potential Acid Generator	interburden	coal/ss
WVC2	2.5	0.98	-19.64	-25.44	Potential Acid Generator	interburden	coal/clay
WVC3	2.62	1.15	-23.17	-31.9	Potential Acid Generator	interburden	coal/ss
WVC3 (A)	2.85	1	-18.72	-22.11	Potential Acid Generator	interburden	ss
WVC4 (A)	3.39	3.08	16.75	21.24	Probably Excess Neutralising Minerals	interburden	ss/mudstone
WVC4 (B)	5.5	2.34	-10.68	-12.27	Verify with other tests	interburden	coal/mudstone
WVC9	3	0.92	-24.45	-38.47	Potential Acid Generator	interburden	coal/mudstone
WVC9	3	0.92	-24.45	-38.47	Potential Acid Generator	interburden	coal/mudstone

Table 47: Interpretation of NP/AP ratios for the Sasol samples.

Site Name	**Neutralising Potential Ratio(NP/AP) for Open System**	**Interpretation Open System**	**Interpretation Closed System**
WGA2	0.001	Likely Acid Generator	Likely Acid Generator
WGA11	0.060	Likely Acid Generator	Likely Acid Generator
WGA10	0.001	Likely Acid Generator	Likely Acid Generator
WGA9	1.742	Acid under certain conditions	Likely Acid Generator
WGA3	0.608	Likely Acid Generator	Likely Acid Generator
WGA7	1.290	Acid under certain conditions	Likely Acid Generator
WGA4	0.000	Likely Acid Generator	Likely Acid Generator
WGA6	0.002	Likely Acid Generator	Likely Acid Generator
WGA8	4.856	No Acid Potential	Acid under certain conditions
WGA5	5.251	No Acid Potential	Acid under certain conditions
WGA6 (C)	0.000	Likely Acid Generator	Likely Acid Generator
WGA6 (A)	0.005	Likely Acid Generator	Likely Acid Generator
WGA6 (B)	0.017	Likely Acid Generator	Likely Acid Generator
WGA3(A)	1185.088	No Acid Potential	No Acid Potential
WGA5(A)	0.013	Likely Acid Generator	Likely Acid Generator
WGB9 (B)	0.003	Likely Acid Generator	Likely Acid Generator
WGB9 (A)	0.006	Likely Acid Generator	Likely Acid Generator
WGB5 (B)	0.002	Likely Acid Generator	Likely Acid Generator
WGB5 (A)	0.000	Likely Acid Generator	Likely Acid Generator
WGB5 (D)	0.003	Likely Acid Generator	Likely Acid Generator
WGB4 (A)	0.000	Likely Acid Generator	Likely Acid Generator
WGB10 (A)	1.488	Acid under certain conditions	Likely Acid Generator
WGB7 (A)	1.126	Acid under certain conditions	Likely Acid Generator
WGB3	0.000	Likely Acid Generator	Likely Acid Generator
WGB8 (E)	3.090	Acid under certain conditions	Acid under certain conditions
WGB4 (C)	0.002	Likely Acid Generator	Likely Acid Generator
WGB7 (B)	0.000	Likely Acid Generator	Likely Acid Generator
WGB8 (D)	0.016	Likely Acid Generator	Likely Acid Generator
WGB7 (D)	0.001	Likely Acid Generator	Likely Acid Generator
WGB8 (B)	0.000	Likely Acid Generator	Likely Acid Generator
WGB7 (C)	0.006	Likely Acid Generator	Likely Acid Generator
WGB8 (A)	0.005	Likely Acid Generator	Likely Acid Generator
WGB5 (C)	0.003	Likely Acid Generator	Likely Acid Generator
WGB10 (B)	1.134	Acid under certain conditions	Likely Acid Generator
WGB8 (C)	0.003	Likely Acid Generator	Likely Acid Generator
WGB10 (E)	0.001	Likely Acid Generator	Likely Acid Generator
WGB4 (B)	0.000	Likely Acid Generator	Likely Acid Generator
WGB10 (C)	2.734	Acid under certain conditions	Acid under certain conditions

Site Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
WGB10 (D)	0.101	Likely Acid Generator	Likely Acid Generator
WGA2(A)	1.249	Acid under certain conditions	Likely Acid Generator
WGA7(C)	0.075	Likely Acid Generator	Likely Acid Generator
WGA10(F)	2.561	Acid under certain conditions	Acid under certain conditions
WGC10 (A)	0.000	Likely Acid Generator	Likely Acid Generator
WGC9 (B)	0.966	Likely Acid Generator	Likely Acid Generator
WGC9 (A)	1.058	Acid under certain conditions	Likely Acid Generator
WGC4 (A)	0.000	Likely Acid Generator	Likely Acid Generator
WGC6 (A)	0.001	Likely Acid Generator	Likely Acid Generator
WGC8	0.287	Likely Acid Generator	Likely Acid Generator
WGC7	0.360	Likely Acid Generator	Likely Acid Generator
WGC6 (B)	5.984	No Acid Potential	Acid under certain conditions
WGC11 (B)	1.724	Acid under certain conditions	Likely Acid Generator
WGC5	3.843	Acid under certain conditions	Acid under certain conditions
WGC4 (B)	0.482	Likely Acid Generator	Likely Acid Generator
WGC11 (A)	0.001	Likely Acid Generator	Likely Acid Generator
WGC7 (A)	0.001	Likely Acid Generator	Likely Acid Generator
WGC10 (B)	5.075	No Acid Potential	Acid under certain conditions
WGC8(A)	6.114	No Acid Potential	Acid under certain conditions
WGD7	0.006	Likely Acid Generator	Likely Acid Generator
WGD4	0.002	Likely Acid Generator	Likely Acid Generator
WGD8(C)	0.009	Likely Acid Generator	Likely Acid Generator
WGD5	0.009	Likely Acid Generator	Likely Acid Generator
WGD1	1.567	Acid under certain conditions	Likely Acid Generator
WGD1(A)	8.568	No Acid Potential	No Acid Potential
WGD3	0.237	Likely Acid Generator	Likely Acid Generator
WGD5(A)	1.912	Acid under certain conditions	Likely Acid Generator
WGD6(A)	0.010	Likely Acid Generator	Likely Acid Generator
WGD6(B)	39.075	No Acid Potential	No Acid Potential
WGD7(B)	1.463	Acid under certain conditions	Likely Acid Generator
WGD7(A)	0.006	Likely Acid Generator	Likely Acid Generator
WGD8(A)	0.001	Likely Acid Generator	Likely Acid Generator
WGD2(A)	0.002	Likely Acid Generator	Likely Acid Generator
WGD4(D)	0.001	Likely Acid Generator	Likely Acid Generator
WGD6(C)	2.175	Acid under certain conditions	Acid under certain conditions
WGD8(B)	2.797	Acid under certain conditions	Acid under certain conditions
WGD9	0.001	Likely Acid Generator	Likely Acid Generator
WGE4 (A)	0.010	Likely Acid Generator	Likely Acid Generator
WGE2	0.000	Likely Acid Generator	Likely Acid Generator

Site Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
WGE4 (B)	0.002	Likely Acid Generator	Likely Acid Generator
WGF10	3.883	Acid under certain conditions	Acid under certain conditions
WGF7	0.001	Likely Acid Generator	Likely Acid Generator
WVA5 (A)	0.005	Likely Acid Generator	Likely Acid Generator
WVA5	0.001	Likely Acid Generator	Likely Acid Generator
WVA3	0.052	Likely Acid Generator	Likely Acid Generator
WVA4 (A)	0.310	Likely Acid Generator	Likely Acid Generator
WVA2(A)	0.021	Likely Acid Generator	Likely Acid Generator
WVA1	0.000	Likely Acid Generator	Likely Acid Generator
WVA4	0.002	Likely Acid Generator	Likely Acid Generator
WVA4(C)	0.000	Likely Acid Generator	Likely Acid Generator
WVA4(D)	0.065	Likely Acid Generator	Likely Acid Generator
WVB4 (A)	0.001	Likely Acid Generator	Likely Acid Generator
WVB3	0.001	Likely Acid Generator	Likely Acid Generator
WVB4	0.001	Likely Acid Generator	Likely Acid Generator
WVB4 (C)	0.000	Likely Acid Generator	Likely Acid Generator
WVB4 (B)	0.000	Likely Acid Generator	Likely Acid Generator
WVB2)	0.000	Likely Acid Generator	Likely Acid Generator
WVB4 (E)	0.376	Likely Acid Generator	Likely Acid Generator
WVB4(D)	0.002	Likely Acid Generator	Likely Acid Generator
WVC2	0.001	Likely Acid Generator	Likely Acid Generator
WVC3 (A)	0.003	Likely Acid Generator	Likely Acid Generator
WVC4 (B)	0.005	Likely Acid Generator	Likely Acid Generator
WVC9	0.001	Likely Acid Generator	Likely Acid Generator
WVC3	0.001	Likely Acid Generator	Likely Acid Generator
WVC4 (A)	0.003	Likely Acid Generator	Likely Acid Generator
WVC1	0.000	Likely Acid Generator	Likely Acid Generator
W1A	0.001	Likely Acid Generator	Likely Acid Generator
W1B	0.058	Likely Acid Generator	Likely Acid Generator
W2A	0.396	Likely Acid Generator	Likely Acid Generator
W3A	5090.404	No Acid Potential	No Acid Potential
W4A	16.700	No Acid Potential	No Acid Potential
W4B	35.714	No Acid Potential	No Acid Potential
W5B	0.702	Likely Acid Generator	Likely Acid Generator
W6A	16.851	No Acid Potential	No Acid Potential
W6B	0.894	Likely Acid Generator	Likely Acid Generator
W7B	6.235	No Acid Potential	Acid under certain conditions
W8A	0.645	Likely Acid Generator	Likely Acid Generator
W9A	5.490	No Acid Potential	Acid under certain conditions

Site Name	**Neutralising Potential Ratio(NP/AP) for Open System**	**Interpretation Open System**	**Interpretation Closed System**
W9B	16.208	No Acid Potential	No Acid Potential
W10A	2.496	Acid under certain conditions	Acid under certain conditions
W10B	6.764	No Acid Potential	Acid under certain conditions
W11A	1.854	Acid under certain conditions	Likely Acid Generator
W11B	0.554	Likely Acid Generator	Likely Acid Generator
W12A	0.983	Likely Acid Generator	Likely Acid Generator
W12B	2.601	Acid under certain conditions	Acid under certain conditions
W13A	0.868	Likely Acid Generator	Likely Acid Generator
W13B	1.520	Acid under certain conditions	Likely Acid Generator
W14A	1.405	Acid under certain conditions	Likely Acid Generator
W14B	0.480	Likely Acid Generator	Likely Acid Generator
W15A	7.355	No Acid Potential	Acid under certain conditions
W15B	2.359	Acid under certain conditions	Acid under certain conditions
W16A	31.394	No Acid Potential	No Acid Potential
W16B	11.381	No Acid Potential	No Acid Potential
W17A	0.335	Likely Acid Generator	Likely Acid Generator
W17B	0.001	Likely Acid Generator	Likely Acid Generator
W18A	23.379	No Acid Potential	No Acid Potential
W18B	31.241	No Acid Potential	No Acid Potential
W19A	0.998	Likely Acid Generator	Likely Acid Generator
W19B	4.962	No Acid Potential	Acid under certain conditions
WGG2	9.935	No Acid Potential	No Acid Potential
WGG4 (A)	4.064	No Acid Potential	Acid under certain conditions
WGG6	18.857	No Acid Potential	No Acid Potential
WGG1	0.351	Likely Acid Generator	Likely Acid Generator
WGG4(B)	0.004	Likely Acid Generator	Likely Acid Generator
WGG2 (A)	1.065	Acid under certain conditions	Likely Acid Generator
WGG3	0.721	Likely Acid Generator	Likely Acid Generator
WGG2 (C))	0.761	Likely Acid Generator	Likely Acid Generator
WGG4 (D)	30.749	No Acid Potential	No Acid Potential
WGG4 (E)	0.277	Likely Acid Generator	Likely Acid Generator
WGG4 (F)	17.559	No Acid Potential	No Acid Potential
WGG5 (C)	36.162	No Acid Potential	No Acid Potential
WGG5 (E)	12.240	No Acid Potential	No Acid Potential
WGG5 (F)	2.255	Acid under certain conditions	Acid under certain conditions
WGG6 (A)	22.267	No Acid Potential	No Acid Potential
WGG6 (B)	3.186	Acid under certain conditions	Acid under certain conditions
WRA2 (B)	0.000	Likely Acid Generator	Likely Acid Generator
WRA3 (B)	0.744	Likely Acid Generator	Likely Acid Generator

Site Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
WRA4 (A)	1.084	Acid under certain conditions	Likely Acid Generator
WRA4 (D)	4.010	No Acid Potential	Acid under certain conditions
WRA4 (G)	7.853	No Acid Potential	Acid under certain conditions
WRA4 (A)	3.755	Acid under certain conditions	Acid under certain conditions
WRA5 (B)	21.025	No Acid Potential	No Acid Potential
WRA5 (F)	0.796	Likely Acid Generator	Likely Acid Generator
WTA1	0.001	Likely Acid Generator	Likely Acid Generator
WTA2	0.000	Likely Acid Generator	Likely Acid Generator
WTB1 (A)	0.001	Likely Acid Generator	Likely Acid Generator
WTB2	0.030	Likely Acid Generator	Likely Acid Generator
WTB4	0.949	Likely Acid Generator	Likely Acid Generator
WTB1 (B)	0.000	Likely Acid Generator	Likely Acid Generator
WTB3	0.001	Likely Acid Generator	Likely Acid Generator
WTC4 (A)	0.001	Likely Acid Generator	Likely Acid Generator
WTC1	0.001	Likely Acid Generator	Likely Acid Generator
WTC4 (B)	0.505	Likely Acid Generator	Likely Acid Generator
WTC1	0.000	Likely Acid Generator	Likely Acid Generator
WTC2(A)	0.003	Likely Acid Generator	Likely Acid Generator
WTC2(B)	0.199	Likely Acid Generator	Likely Acid Generator
WTC3(A)	0.004	Likely Acid Generator	Likely Acid Generator
WTC4(C)	0.000	Likely Acid Generator	Likely Acid Generator
WTC4(D)	0.002	Likely Acid Generator	Likely Acid Generator
WTD4 (B)	0.014	Likely Acid Generator	Likely Acid Generator
WTD4 (A)	0.001	Likely Acid Generator	Likely Acid Generator
WTD2	0.000	Likely Acid Generator	Likely Acid Generator
WTD2(A)	0.000	Likely Acid Generator	Likely Acid Generator
WTD3(A)	0.019	Likely Acid Generator	Likely Acid Generator
WTD3(B)	0.000	Likely Acid Generator	Likely Acid Generator
WTD4(B)	0.000	Likely Acid Generator	Likely Acid Generator

Table 48: Summary of the ABA results of the Resgen samples.

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
RA1	7.02	3.61	-7.09	-7.19	Verify with other tests	Interburden	soil
RA10	8.06	7.43	11.20	11.23	Verify with other tests	Interburden	calcrete
RA11	7.82	5.73	-0.05	-0.11	Verify with other tests	Interburden	calcrete
RA12	6.5	2.8	-37.24	-38.27	Potential Acid Generator	Interburden	calcrete
RA14	7.65	5.73	61.54	61.52	Probably Excess Neutralising Minerlas	Interburden	calcrete
RA15	5.5	3.24	3.79	3.83	Verify with other tests	Interburden	shale
RA17	7.03	4.82	1.05	1.03	Verify with other tests	Interburden	shale
RA18	6.71	3.67	-0.35	-0.69	Verify with other tests	Interburden	mudstone
RA2	8.82	8.56	2.48	2.44	Verify with other tests	Interburden	calcrete
RA20	6.42	3.7	-2.55	-3.06	Verify with other tests	Interburden	mudstone
RA22	7.43	7.52	-1.94	-2.20	Verify with other tests	Interburden	mudstone
RA25	7.52	4.5	-1.86	-3.68	Verify with other tests	Interburden	shale/mudstone
RA25	6.28	3.15	-16.42	-17.67	Verify with other tests	Interburden	shale/mudstone
RA26	7.74	7.31	1.61	0.21	Verify with other tests	Interburden	mudstone
RA26	4.96	3.67	-6.21	-8.63	Verify with other tests	Interburden	shale/mudstone
RA28	6.6	3.62	-3.85	-5.31	Verify with other tests	Interburden	mudstone
RA29	7.75	7.45	6.87	5.88	Verify with other tests	Interburden	mudstone
RA29	7.14	6.78	-4.56	-5.82	Verify with other tests	Interburden	mudstone/shale
RA3	6.43	4.59	1.72	1.83	Verify with other tests	Interburden	calcrete
RA30	5.74	3.22	-4.62	-5.65	Verify with other tests	Interburden	mudstone/shale
RA31	6.57	4.5	6.57	4.5	Potential Acid Generator	Interburden	mudstone/shale
RA32	7.27	4.38	-0.54	-0.56	Verify with other tests	Interburden	shale
RA34	8.59	8.05	14.91	14.82	Verify with other tests	Interburden	shale
RA34	7.22	4.8	-7.64	-9.15	Verify with other tests	Interburden	shale
RA35	7.01	3.15	-3.81	-4.63	Verify with other tests	Interburden	ss
RA35	7.17	6.28	-0.5	2.37	Verify with other tests	Interburden	ss
RA36	6.9	4.2	1.06	0.79	Verify with other tests	Interburden	shale/ss
RA38	6.8	4.42	-25.54	-27.47	Potential Acid Generator	Interburden	mudstone
RA39	8.11	7.04	15.19	14.19	Verify with other tests	Interburden	shale
RA39	6.43	4.21	-20.02	-22.71	Potential Acid Generator	Interburden	shale/mudstone
RA4	8.42	8.46	-0.33	-0.36	Verify with other tests	Interburden	calcrete
RA40	8.28	6.64	2.21	2.17	Verify with other tests	Interburden	shale/mudstone
RA41	8.35	7.88	-0.31	-0.34	Verify with other tests	Interburden	mudstone
RA44	6.9	3.39	-3.21	-5.28	Verify with other tests	Interburden	shale/mudstone
RA45	6.91	1.74	-2.70	-3.26	Verify with other tests	Interburden	shale/mudstone
RA46	6.95	6.07	-1.27	-1.73	Verify with other tests	Interburden	mudstone
RA48	7	4.85	-1.41	-1.67	Verify with other tests	Interburden	mudstone
RA51	6.61	5.23	-1.10	-1.08	Verify with other tests	Interburden	ss/mudstone

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
RA52	7.03	2.29	-3.31	-4.80	Verify with other tests	Interburden	shale
RA53	7.17	1.7	66.84	65.69	Probably Excess Neutralising Minerlas	Interburden	shale
RA54	4.44	2.34	-45.24	-77.69	Potential Acid Generator	Interburden	carbonaceous shale
RA58	8.06	7.9	-16.2	-16.44	Verify with other tests	Interburden	ss
RA6	8.02	6.69	-0.10	-0.19	Verify with other tests	Interburden	calcrete
RA60	6.7	2.41	-27.21	-42.64	Potential Acid Generator	Interburden	shale/ss
RA63	8.2	6.61	19.66	19.48	Verify with other tests	Interburden	ss
RA68	8.02	3.64	11.94	11.73	Verify with other tests	Interburden	ss
RA69	6.06	6.54	-0.60	-0.60	Verify with other tests	Interburden	shale/ss
RA7	8.32	7.54	8.59	8.60	Verify with other tests	Interburden	calcrete
RA77	3.75	1.32	-9.88	-18.65	Verify with other tests	Interburden	ss
RA78	7.46	2.66	-11.24	-18.34	Verify with other tests	Interburden	ss
RA79	6.35	1.65	-3.50	-5.52	Verify with other tests	Interburden	shale/ss
RA8	8.09	7.1	0.39	0.32	Verify with other tests	Interburden	calcrete
RA82	6.41	3.55	27.87	25.52	Probably Excess Neutralising Minerlas	Interburden	ss
RA84	7.43	3.7	-7.58	-11.82	Verify with other tests	Interburden	ss
RA9	8.1	6.9	26.12	26.09	Probably Excess Neutralising Minerlas	Interburden	calcrete
Rb1	6.93	2.72	1.80	1.74	Verify with other tests	interburden	soil
RB10	7.61	5.24	-0.44	-0.54	Verify with other tests	interburden	ss
RB11	7.37	4.26	-3.21	-3.44	Verify with other tests	interburden	ss
RB12	7.71	5.23	-4.05	-16.53	Verify with other tests	interburden	ss
RB13	8.02	4.54	-6.24	-6.29	Verify with other tests	interburden	shale/ss
RB14	7.37	3.15	-3.25	-3.32	Verify with other tests	interburden	shale/mudstone
RB15	7.07	3.16	1.37	0.06	Verify with other tests	interburden	mudstone
RB16	6.96	4.38	-2.26	-2.72	Verify with other tests	interburden	ss/mudstone
RB17	7.69	5.81	20.50	19.67	Verify with other tests	interburden	ss/shale
RB18	8.07	3.62	-4.62	-4.70	Verify with other tests	interburden	shale
RB19	7.04	3.69	1.21	0.93	Verify with other tests	interburden	shale
Rb2	7.43	5.74	14.08	14.04	Verify with other tests	interburden	soil
RB20	7.27	3.94	-8.30	-8.64	Verify with other tests	interburden	shale/mudstone
RB21	7.04	3.18	13.60	13.28	Verify with other tests	interburden	mudstone
RB22	7.1	3.14	27.04	26.93	Probably Excess Neutralising Minerlas	interburden	mudstone
RB23	7.08	3.04	-1.09	-10.74	Verify with other tests	interburden	shale
RB24	7.35	3.54	-3.25	-3.56	Verify with other tests	interburden	mudstone
RB25	7.25	3.53	7.71	7.46	Verify with other tests	interburden	mudstone
RB26	7.13	3.19	30.41	30.25	Probably Excess Neutralising Minerlas	interburden	shale
RB27	7.4	5.16	4.04	3.59	Verify with other tests	interburden	shale
RB28	7.46	2.71	-4.07	-4.67	Verify with other tests	interburden	shale

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
RB29	7	5.95	5.78	5.26	Verify with other tests	interburden	ss
Rb3	9.01	8.45	-32.41	-32.46	Potential Acid Generator	interburden	calcrete
RB30	8.01	5.57	10.79	10.29	Verify with other tests	interburden	ss/mudstone
RB31	8.23	2.58	-4.34	-4.61	Verify with other tests	interburden	mudstone
RB32	6.65	2.33	1.06	-0.28	Verify with other tests	interburden	mudstone
RB33	7.63	3.1	-2.70	-4.97	Verify with other tests	interburden	mudstone
RB34	7.74	6.53	51.11	46.36	Probably Excess Neutralising Minerlas	interburden	shale
RB38	7.6	3.37	23.04	22.62	Probably Excess Neutralising Minerlas	interburden	ss
RB39	7.16	3.04	-1.69	-2.03	Verify with other tests	interburden	ss
Rb4	9.03	8.56	24.62	24.48	Probably Excess Neutralising Minerlas	interburden	calcrete
RB40	7.2	5.84	43.33	40.79	Probably Excess Neutralising Minerlas	interburden	ss
Rb41	8.28	5.49	20.48	4.24	Verify with other tests	interburden	ss
Rb42	7.68	5.16	1.83	-2.58	Verify with other tests	interburden	ss
Rb43	8.57	5.42	9.42	8.92	Verify with other tests	interburden	shale
Rb44	7.72	2.92	-0.46	-3.11	Verify with other tests	interburden	shale
Rb45	7.33	2.33	6.25	3.99	Verify with other tests	interburden	shale
Rb46	8.19	2.83	20.00	17.74	Verify with other tests	interburden	shale
Rb47	8.24	1.94	-25.04	-55.76	Potential Acid Generator	interburden	shale
Rb48	8.27	2.12	-7.36	-19.52	Verify with other tests	interburden	shale
Rb49	4.6	2.66	-11.98	-20.21	Potential Acid Generator	interburden	shale
Rb5	8.6	5.86	26.87	26.87	Probably Excess Neutralising Minerlas	interburden	calcrete
RB51	7.49	2.46	-8.51	-22.00	Potential Acid Generator	interburden	mudstone
RB52	7.33	2.45	24.38	23.78	Probably Excess Neutralising Minerlas	interburden	mudstone/ss
RB53	8.5	4.37	1.23	0.80	Verify with other tests	interburden	ss/shale
RB54	7.09	2.28	-8.82	-17.04	Verify with other tests	interburden	shale
RB55	6.37	1.58	-6.81	-8.36	Verify with other tests	interburden	shale/ss
RB56	8.38	4.36	5.94	5.61	Verify with other tests	interburden	ss
RB57	7.31	3.12	-9.49	-10.10	Verify with other tests	interburden	ss
RB58	7.21	3.08	-5.23	-5.67	Verify with other tests	interburden	ss
RB59	6.78	2.71	-7.48	-7.93	Verify with other tests	interburden	ss/shale
Rb6	7.65	5.33	11.03	11.01	Verify with other tests	interburden	mudstone
RB60	7.82	2.47	-7.62	-8.32	Verify with other tests	interburden	shale
Rb61	7.41	3.99	-32.33	-65.03	Potential Acid Generator	interburden	shale
Rb62	7.33	3.99	-1.52	-2.12	Verify with other tests	interburden	shale
Rb63	8.89	5.91	11.37	11.02	Verify with other tests	interburden	shale
Rb64	8.06	4.24	-1.64	-1.94	Verify with other tests	interburden	shale
Rb65	4.96	2.71	-2.77	-3.59	Verify with other tests	interburden	shale
Rb66	8.68	5.5	5.75	0.21	Verify with other tests	interburden	shale
Rb67	8.36	4.02	19.83	17.21	Verify with other tests	interburden	shale

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
Rb68	7.46	4.4	-4.83	-11.43	Verify with other tests	interburden	ss
Rb69	7.7	3.99	-49.64	-51.69	Potential Acid Generator	interburden	ss
Rb7	7.72	5	0.09	0.06	Verify with other tests	interburden	mudstone
Rb70	8.39	5.93	-2.14	-5.11	Verify with other tests	interburden	ss
Rb71	8.49	5.62	-0.80	-1.73	Verify with other tests	interburden	ss
Rb72	8.42	7.53	13.72	13.39	Verify with other tests	interburden	ss
Rb8	7.76	4.97	16.85	16.81	Verify with other tests	interburden	sandstone
Rb9	7.58	4.95	-0.13	-0.18	Verify with other tests	interburden	shale
RC1	4.92	1.88	-4.41	-4.56	Verify with other tests	overburden	soil
RC10	5.55	2.20	-2.07	-3.30	Verify with other tests	interburden	ss
RC11	3.46	1.92	-1.53	-3.01	Verify with other tests	interburden	ss
RC12	3.35	1.86	-6.91	-7.34	Verify with other tests	interburden	ss
RC13	7.36	2.32	2.68	-1.33	Verify with other tests	interburden	ss
RC14	5.89	1.96	0.96	0.78	Verify with other tests	interburden	ss
RC15	5.61	2.04	-1.00	-1.28	Verify with other tests	interburden	ss
RC16	4.05	2.00	16.59	16.02	Verify with other tests	interburden	ss
RC17	6.38	2.32	1.18	0.74	Verify with other tests	interburden	ss
RC18	5.56	2.22	1.52	0.79	Verify with other tests	interburden	ss
RC19	6.93	2.44	1.49	1.17	Verify with other tests	interburden	ss
RC2	8.48	2.54	57.83	57.74	Probably Excess Neutralising Minerlas	interburden	ss
RC20	6.21	2.02	1.74	1.49	Verify with other tests	interburden	ss
RC21	6.48	2.01	0.95	0.72	Verify with other tests	interburden	ss
RC22	7.34	2.06	9.18	8.97	Verify with other tests	interburden	ss
RC23	6.19	2.35	2.84	2.41	Verify with other tests	interburden	ss
RC24	7.47	2.15	-0.05	-0.11	Verify with other tests	interburden	ss
RC25	7.30	2.39	2.41	2.28	Verify with other tests	interburden	ss
RC3	6.08	2.26	1.65	1.62	Verify with other tests	interburden	ss
RC4	4.12	2.20	-2.91	-4.19	Verify with other tests	interburden	ss
RC5	6.78	2.23	7.99	7.88	Verify with other tests	interburden	ss
RC6	5.23	2.30	-4.37	-4.47	Verify with other tests	interburden	ss
RC7	3.32	2.09	-4.97	-5.98	Verify with other tests	interburden	ss
RC8	3.73	1.88	12.26	11.83	Verify with other tests	interburden	ss
RC9	3.50	2.45	-4.73	-5.93	Verify with other tests	interburden	ss

Table 49: Interpretation of the NP/AP ratios for the Resgen samples.

Site Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
S1	27.413	No Acid Potential	No Acid Potential
S2	338.974	No Acid Potential	No Acid Potential
S3	0.221	Likely Acid Generator	Likely Acid Generator
S4	168.359	No Acid Potential	No Acid Potential
S5	16622.729	No Acid Potential	No Acid Potential
S6	591.303	No Acid Potential	No Acid Potential
S7	4.099	No Acid Potential	Acid under certain conditions
S8	484.996	No Acid Potential	No Acid Potential
S9	0.221	Likely Acid Generator	Likely Acid Generator
S10	0.093	Likely Acid Generator	Likely Acid Generator
S41	2.261	Acid under certain conditions	Acid under certain conditions
S42	1.415	Acid under certain conditions	Likely Acid Generator
S43	19.517	No Acid Potential	No Acid Potential
S44	0.825	Likely Acid Generator	Likely Acid Generator
S45	3.763	Acid under certain conditions	Acid under certain conditions
S46	9.848	No Acid Potential	No Acid Potential
S47	0.185	Likely Acid Generator	Likely Acid Generator
S48	0.395	Likely Acid Generator	Likely Acid Generator
S49	0.001	Likely Acid Generator	Likely Acid Generator
S61	0.011	Likely Acid Generator	Likely Acid Generator
S62	0.017	Likely Acid Generator	Likely Acid Generator
S63	33.796	No Acid Potential	No Acid Potential
S64	0.034	Likely Acid Generator	Likely Acid Generator
S65	0.012	Likely Acid Generator	Likely Acid Generator
S66	2.038	Acid under certain conditions	Acid under certain conditions
S67	8.565	No Acid Potential	No Acid Potential
S68	0.268	Likely Acid Generator	Likely Acid Generator
S69	0.005	Likely Acid Generator	Likely Acid Generator
S70	0.281	Likely Acid Generator	Likely Acid Generator
S71	0.133	Likely Acid Generator	Likely Acid Generator
S72	41.722	No Acid Potential	No Acid Potential
RB12	0.495	Likely Acid Generator	Likely Acid Generator
RB13	0.055	Likely Acid Generator	Likely Acid Generator
RB51	0.135	Likely Acid Generator	Likely Acid Generator
RB52	16.107	No Acid Potential	No Acid Potential
RB53	1.297	Acid under certain conditions	Likely Acid Generator
RB54	0.000	Likely Acid Generator	Likely Acid Generator
RB55	0.006	Likely Acid Generator	Likely Acid Generator

Site Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
RB56	19.092	No Acid Potential	No Acid Potential
RB57	0.016	Likely Acid Generator	Likely Acid Generator
RB58	0.009	Likely Acid Generator	Likely Acid Generator
RB59	0.009	Likely Acid Generator	Likely Acid Generator
RB60	0.014	Likely Acid Generator	Likely Acid Generator
RB11	0.042	No Acid Potential	No Acid Potential
RB14	0.145	Likely Acid Generator	Likely Acid Generator
RB15	2.047	Acid under certain conditions	Acid under certain conditions
RB16	0.022	Likely Acid Generator	Likely Acid Generator
RB17	25.723	No Acid Potential	No Acid Potential
RB18	0.116	Likely Acid Generator	Likely Acid Generator
RB19	5.219	No Acid Potential	Acid under certain conditions
RB20	0.029	Likely Acid Generator	Likely Acid Generator
RB21	43.441	No Acid Potential	No Acid Potential
RB22	243.758	No Acid Potential	No Acid Potential
RB23	0.887	Likely Acid Generator	Likely Acid Generator
RB24	0.032	Likely Acid Generator	Likely Acid Generator
RB25	32.452	No Acid Potential	No Acid Potential
RB26	66.042	No Acid Potential	No Acid Potential
RB27	9.883	No Acid Potential	No Acid Potential
RB28	0.017	Likely Acid Generator	Likely Acid Generator
RB29	12.060	No Acid Potential	No Acid Potential
RB30	22.869	No Acid Potential	No Acid Potential
RB31	0.038	Likely Acid Generator	Likely Acid Generator
RB32	1.793	Acid under certain conditions	Likely Acid Generator
RB33	0.004	Likely Acid Generator	Likely Acid Generator
RB34	11.756	No Acid Potential	No Acid Potential
RB38	56.086	No Acid Potential	No Acid Potential
RB39	0.029	Likely Acid Generator	Likely Acid Generator
RB40	18.046	No Acid Potential	No Acid Potential
RC1	0.042	No Acid Potential	No Acid Potential
RC2	601.191	No Acid Potential	No Acid Potential
RC3	55.417	No Acid Potential	No Acid Potential
RC4	0.008	Likely Acid Generator	Likely Acid Generator
RC5	75.243	No Acid Potential	No Acid Potential
RC6	0.094	Likely Acid Generator	Likely Acid Generator
RC7	0.010	Likely Acid Generator	Likely Acid Generator
RC8	29.430	No Acid Potential	No Acid Potential
RC9	0.008	Likely Acid Generator	Likely Acid Generator
RC10	0.008	Likely Acid Generator	Likely Acid Generator
RC11	0.007	Likely Acid Generator	Likely Acid Generator

Site Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
RC12	0.023	Likely Acid Generator	Likely Acid Generator
RC13	1.668	Acid under certain conditions	Acid under certain conditions
RC14	6.382	No Acid Potential	Acid under certain conditions
RC15	0.036	Likely Acid Generator	Likely Acid Generator
RC16	30.050	No Acid Potential	No Acid Potential
RC17	3.680	Acid under certain conditions	Acid under certain conditions
RC18	3.087	Acid under certain conditions	Acid under certain conditions
RC19	5.747	No Acid Potential	Acid under certain conditions
RC20	8.149	No Acid Potential	No Acid Potential
RC21	5.212	No Acid Potential	Acid under certain conditions
RC22	44.992	No Acid Potential	No Acid Potential
RC23	7.608	No Acid Potential	Acid under certain conditions
RC24	0.190	Likely Acid Generator	Likely Acid Generator
RC25	18.782	No Acid Potential	No Acid Potential

Table 50: Summary of the ABA results for the Grootegeluk samples.

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
JB 21	7.56	5.53	-0.83	-0.92	Verify with other tests	ovb	clay
JB 22	8.15	4.78	32.93	32.87	Probably Excess Neutralising Minerals	ovb	clay
JB 23	7.25	4.68	-1.01	-1.08	Verify with other tests	ovb	clay
JB 24	7.76	4.83	-2.03	-2.11	Verify with other tests	ovb	clay
JB 25	7.2	4.68	-2.16	-2.25	Verify with other tests	ovb	clay
JB 26	7.89	4.82	-3.33	-3.42	Verify with other tests	ovb	clay
JB 27	7.1	4.73	-3.08	-3.17	Verify with other tests	ovb	clay
JB 28	7.83	4.74	-2.30	-2.34	Verify with other tests	ovb	shale
JB 29	7.5	4.73	-3.25	-3.32	Verify with other tests	ovb	shale
JB 30	7.79	4.66	7.81	7.74	Verify with other tests	ovb	shale
JB 31	7.43	4.63	-3.90	-3.99	Verify with other tests	ovb	shale
JB 32	7.48	4.57	-6.50	-6.53	Verify with other tests	ovb	shale
JB 33	7.36	4.07	-0.06	-0.51	Verify with other tests	ovb	shale
JB11	7.34	2.11	1.33	1.24	Verify with other tests	ovb	clay
JB12	7.36	2.14	-1.28	-1.27	Verify with other tests	ovb	clay
JB13	7.39	2.15	3.05	3.03	Verify with other tests	ovb	clay
JB15	7.38	2.13	2.51	2.52	Verify with other tests	ovb	clay
JB16	7.45	2.15	2.04	2.06	Verify with other tests	ovb	clay
JB17	7.42	5.07	-0.43	-0.35	Verify with other tests	ovb	clay
JB18	7.58	5.8	-1.26	-1.26	Verify with other tests	ovb	clay
MA10	7.89	6.82	-0.13	-0.14	Verify with other tests	ovb	soil
MA11	8.3	7.87	0.41	0.40	Verify with other tests	ovb	soil
MA12	8.04	5.34	0.30	0.27	Verify with other tests	ovb	soil
MA13	8.25	7.25	15.59	15.55	Verify with other tests	ovb	soil
MA14	8.12	7.35	4.90	4.29	Verify with other tests	ovb	shale
MA15	8.14	7.95	10.95	6.72	Verify with other tests	ovb	shale
MA16	7.91	7.64	17.15	-10.31	Verify with other tests	ovb	shale
MA18	8.11	7.29	18.41	3.59	Verify with other tests	ovb	shale
MA19	8.05	7.98	39.80	22.57	Probably Excess Neutralising Minerals	ovb	shale
MA2	7.6	6.19	0.61	0.56	Verify with other tests	ovb	soil
MA20	7.91	7.79	51.42	37.04	Probably Excess Neutralising Minerals	ovb	shale
MA21	7.91	7.64	61.44	45.91	Probably Excess Neutralising Minerals	ovb	shale
MA3	7.75	6.25	3.22	3.19	Verify with other tests	ovb	soil
MA4	7.87	5.89	-1.00	-1.01	Verify with other tests	ovb	soil
MA5	7.59	5.85	-0.17	-0.03	Verify with other tests	ovb	soil
MA6	7.75	5.57	0.40	0.44	Verify with other tests	ovb	soil
MA7	7.97	5.56	0.30	0.29	Verify with other tests	ovb	soil
MA8	7.68	5.97	1.30	1.39	Verify with other tests	ovb	soil
MA9	7.57	7.33	6.93	6.96	Verify with other tests	ovb	soil

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
MB1	7.8	7.37	181.38	184.24	Probably Excess Neutralising Minerals	ovb	ss
MB10	8.7	5.88	1.54	1.50	Verify with other tests	ovb	shale
MB11	8.14	6.97	12.96	12.93	Verify with other tests	ovb	shale
MB12	8.36	5.39	20.88	20.84	Probably Excess Neutralising Minerals	ovb	shale
MB13	7.85	6.2	-0.33	-0.35	Verify with other tests	ovb	shale
MB14	8.17	4.78	2.74	2.69	Verify with other tests	ovb	shale
MB15	8	6.1	3.75	3.73	Verify with other tests	ovb	shale
MB16	8.04	5.93	2.13	2.13	Verify with other tests	ovb	shale
MB2	8.04	7.32	219.53	232.84	Probably Excess Neutralising Minerals	ovb	shale
MB20	7.98	4.92	0.82	0.77	Verify with other tests	ovb	shale
MB22	8.09	6.92	33.14	32.87	Probably Excess Neutralising Minerals	ovb	shale
MB23	8.09	7.43	90.15	77.30	Probably Excess Neutralising Minerals	ovb	shale
MB24	7.85	6.78	3.35	-11.05	Verify with other tests	ovb	shale
MB25	8.07	7.52	-26.19	-51.02	Potential Acid Generator	ovb	shale
MB26	7.99	3.59	-4.24	-41.94	Potential Acid Generator	ovb	shale/coal
MB3	8.11	7.48	113.04	115.21	Probably Excess Neutralising Minerals	ovb	shale
MB4	7.67	6.93	26.77	26.76	Probably Excess Neutralising Minerals	ovb	shale
MB5	8.04	7.37	72.05	72.04	Probably Excess Neutralising Minerals	ovb	shale
MB6	8.09	6.75	9.36	9.33	Verify with other tests	ovb	shale
MB7	7.76	6.57	2.09	2.11	Verify with other tests	ovb	shale
MB8	8.22	6.16	6.04	6.06	Verify with other tests	ovb	shale
MB9	7.95	5.45	-0.98	-1.00	Verify with other tests	ovb	shale
VA16	8.64	5.3	0.06	0.08	Verify with other tests	ovb	shale
VA17	8.18	6.83	19.11	19.08	Verify with other tests	ovb	shale
VA19	8.51	7.67	12.56	12.52	Verify with other tests	ovb	shale
VA21	8.01	7.63	6.60	6.57	Verify with other tests	ovb	shale
VA22	8.02	6.88	9.51	9.38	Verify with other tests	ovb	shale
VA23	8.16	7.62	19.48	19.41	Verify with other tests	ovb	shale
VA24	8.2	7.67	33.49	33.43	Probably Excess Neutralising Minerals	ovb	shale
VA25	7.85	7.79	38.55	38.48	Probably Excess Neutralising Minerals	ovb	shale
VA26	8.06	7.86	17.70	17.74	Verify with other tests	ovb	shale
VA27	7.59	7.59	30.90	30.83	Probably Excess Neutralising Minerals	ovb	shale
VA28	6.74	6.74	6.58	6.54	Verify with other tests	ovb	shale
VA29	6.84	6.84	25.30	25.41	Probably Excess Neutralising Minerals	ovb	shale
VA30	6.41	6.4	16.80	16.84	Verify with other tests	ovb	shale
VA31	5.91	5.91	3.99	3.99	Verify with other tests	ovb	shale
VA32	6.09	6.09	1.52	1.47	Verify with other tests	ovb	shale
VA33	5.79	5.79	1.91	1.83	Verify with other tests	ovb	shale

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
VA34	7.09	7.09	34.06	34.12	Probably Excess Neutralising Minerals	ovb	shale
VA35	6.61	6.61	32.71	32.75	Probably Excess Neutralising Minerals	ovb	shale
VA36	6.03	6.03	35.34	35.37	Probably Excess Neutralising Minerals	ovb	shale
VA38	7.12	7.12	-2.34	-2.29	Verify with other tests	ovb	shale
VA39	6.01	6.01	23.75	23.74	Probably Excess Neutralising Minerals	ovb	shale
VA40	8.25	6	31.87	31.88	Probably Excess Neutralising Minerals	ovb	shale
VA42	8.9	8.73	44.34	44.46	Probably Excess Neutralising Minerals	ovb	shale
VA43	8.8	8.04	60.22	58.45	Probably Excess Neutralising Minerals	ovb	shale
VA44	8.11	6.31	67.15	67.19	Probably Excess Neutralising Minerals	ovb	shale
VA45	8.76	7.43	11.90	8.14	Verify with other tests	ovb	shale
VA46	8.41	8.29	35.24	25.33	Probably Excess Neutralising Minerals	ovb	shale
VA47	8.32	8.27	77.45	73.69	Probably Excess Neutralising Minerals	ovb	shale
VA48	8.66	8.13	68.70	58.52	Probably Excess Neutralising Minerals	ovb	shale
VA49	8.62	8.21	60.49	46.93	Probably Excess Neutralising Minerals	ovb	shale
VA51	7.93	7.71	11.84	-35.54	Potential Acid Generator	ovb	shale
VA52	8.21	8.22	13.55	-21.87	Potential Acid Generator	ovb	shale
VA53	8.28	8.12	60.99	43.02	Probably Excess Neutralising Minerals	ovb	shale
VA54	7.72	7.71	52.75	33.73	Probably Excess Neutralising Minerals	ovb	shale
VA55	8.25	7.98	87.23	65.89	Probably Excess Neutralising Minerals	ovb	shale
VA56	8.28	7.1	38.40	10.11	Verify with other tests	ovb	shale
VA57	8.3	4.38	-11.10	-50.28	Potential Acid Generator	ovb	shale
VA58	7.44	7.46	19.67	-2.05	Verify with other tests	ovb	shale
VB1	7.29	4.05	-7.57	-7.64	Verify with other tests	ovb	calcrete
VB10	8.8	5.39	-1.19	-1.23	Verify with other tests	ovb	shale
VB11	8.93	5.68	1.78	1.74	Verify with other tests	ovb	shale
VB12	8.94	5.33	-0.42	-0.44	Verify with other tests	ovb	shale
VB13	8.55	5.54	1.76	1.86	Verify with other tests	ovb	shale
VB14	8.53	5.8	0.47	0.37	Verify with other tests	ovb	shale
VB15	8.54	5.21	1.85	1.81	Verify with other tests	ovb	shale
VB17	8.3	5.55	-2.38	-2.41	Verify with other tests	ovb	shale
VB18	8.31	5.34	-1.31	-1.42	Verify with other tests	ovb	shale
VB19	8.23	5.17	-1.29	-1.36	Verify with other tests	ovb	shale
VB20	8.12	5.69	-1.78	-1.90	Verify with other tests	ovb	shale
VB3	7.24	7.03	-0.03	0.10	Verify with other tests	ovb	shale
VB4	7.35	6.15	-1.15	-1.17	Verify with other tests	ovb	shale
VB5	7.33	5.82	3.38	3.32	Verify with other tests	ovb	shale
VB6	7.32	5.36	1.62	1.56	Verify with other tests	ovb	shale

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
VB7	7.49	5.68	3.59	3.48	Verify with other tests	ovb	shale
VB8	7.41	5.5	0.45	0.39	Verify with other tests	ovb	shale
VB9	7.42	5.32	-0.59	-0.62	Verify with other tests	ovb	shale
VC10	8.28	5.83	-3.61	-3.61	Verify with other tests	ovb	shale
VC17	7.74	5.86	-0.65	-0.63	Verify with other tests	ovb	shale
VC3	9.42	4.29	-1.01	-1.00	Verify with other tests	ovb	shale
VC4	8.11	4.69	-2.37	-2.37	Verify with other tests	ovb	shale
VC5	8.39	4.58	-13.52	-13.54	Verify with other tests	ovb	shale
JA1	7.05	3.29	-3.45	-3.43	Verify with other tests	ovb	ss
JA10	7.59	6	16.07	15.97	Verify with other tests	ovb	clay
JA11	7.46	4.98	-0.98	-1.03	Verify with other tests	ovb	clay
JA12	8.26	5.47	-1.23	-1.23	Verify with other tests	ovb	clay
JA13	7.34	6.22	10.06	10.04	Verify with other tests	ovb	clay
JA14	7.38	4.76	-3.98	-3.99	Verify with other tests	ovb	clay
JA15	6.51	4.94	-3.31	-3.32	Verify with other tests	ovb	clay
JA16	7.4	5.04	-1.63	-1.61	Verify with other tests	ovb	clay
JA17	7.14	5.01	-1.53	-1.57	Verify with other tests	ovb	clay
JA18	6.37	5.69	-2.38	-2.37	Verify with other tests	ovb	clay
JA19	7.23	5.81	-0.63	-0.57	Verify with other tests	ovb	clay
JA2	7.18	3.45	-4.24	-4.22	Verify with other tests	ovb	ss
JA20	6.48	6.18	0.86	0.95	Verify with other tests	ovb	clay
JA21	6.89	6.56	-0.08	-0.15	Verify with other tests	ovb	clay
JA22	6.8	6.3	42.82	42.73	Probably Excess Neutralising Minerals	ovb	clay
JA23	6.9	5.62	1.77	1.87	Verify with other tests	ovb	clay
JA24	6.95	6.76	-0.20	-0.21	Verify with other tests	ovb	calcrete
JA25	6.88	6.32	-0.42	-0.39	Verify with other tests	ovb	calcrete
JA26	6.89	5.05	-1.71	-1.78	Verify with other tests	ovb	clay
JA27	7.45	5.04	-3.04	-3.12	Verify with other tests	ovb	clay
JA28	7.11	5.53	-0.72	-0.68	Verify with other tests	ovb	clay
JA3	7.54	3.71	-4.19	-4.18	Verify with other tests	ovb	ss
JA30	7.14	5.64	0.93	0.96	Verify with other tests	ovb	clay
JA31	7.17	5.35	0.50	0.52	Verify with other tests	ovb	clay
JA32	7.27	4.98	-2.78	-2.76	Verify with other tests	ovb	clay
JA33	7.27	4.96	-1.49	-1.49	Verify with other tests	ovb	clay
JA34	6.96	5.01	1.40	1.42	Verify with other tests	ovb	clay
JA35	7.28	5.09	-0.72	-0.71	Verify with other tests	ovb	clay
JA36	6.58	5.44	-1.66	-1.77	Verify with other tests	ovb	clay
JA37	6.61	5.29	4.47	4.37	Verify with other tests	ovb	clay
JA38	6.75	4.78	-1.67	-1.87	Verify with other tests	ovb	clay
JA39	7.22	5.12	-2.27	-2.27	Verify with other tests	ovb	clay
JA4	7.12	3.81	-6.77	-6.75	Verify with other tests	ovb	ss

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
JA40	6.78	4.41	-7.71	-7.71	Verify with other tests	ovb	clay
JA41	6.58	4.55	0.14	-0.02	Verify with other tests	ovb	clay
JA43	6.54	5.11	-1.87	-1.67	Verify with other tests	ovb	clay
JA44	6.38	3.98	-2.10	-1.98	Verify with other tests	ovb	clay
JA45	6.51	4.12	-2.56	-2.72	Verify with other tests	ovb	clay
JA46	6.32	3.86	-1.12	-1.22	Verify with other tests	ovb	clay
JA5	7.71	4.82	-4.65	-4.62	Verify with other tests	ovb	ferrricreet
JA6	7.21	5.83	-3.06	-3.14	Verify with other tests	ovb	ss
JA7	7.42	6.26	1.08	1.06	Verify with other tests	ovb	ss
JA8	6.73	6.16	0.98	0.97	Verify with other tests	ovb	ss
JA9	7.45	5.84	-0.51	-0.57	Verify with other tests	ovb	clay
JB14	6.93	6.12	-0.10	-0.22	Verify with other tests	ovb	clay
JB19	6.86	5.89	-21.80	-42.88	Potential Acid Generator	ovb	clay
JB20	7.01	6.19	-52.63	-56.24	Potential Acid Generator	ovb	clay
JB32	7.48	4.57	-6.50	-6.53	Verify with other tests	ovb	shale
JB33	7.36	4.07	-0.06	-0.51	Verify with other tests	ovb	shale
JC10	7.77	4.790	0.36	0.52	Verify with other tests	ovb	shale
JC11	8.14	6.73	3.07	2.72	Verify with other tests	ovb	shale
JC12	8.06	6.86	1.20	0.88	Verify with other tests	ovb	shale
JC13	7.88	6.06	0.75	0.59	Verify with other tests	ovb	shale
JC14	7.47	6.52	7.47	7.49	Verify with other tests	ovb	shale
JC15	7.88	6.81	5.13	5.09	Verify with other tests	ovb	shale
JC16	7.21	5.93	-0.72	-0.84	Verify with other tests	ovb	shale
JC17	7.34	6.43	0.07	-0.01	Verify with other tests	ovb	shale
JC18	7.19	6.71	2.06	1.96	Verify with other tests	ovb	shale
JC19	7.22	6.55	0.63	0.35	Verify with other tests	ovb	shale
JC2	7.78	2.230	-5.17	-5.20	Verify with other tests	ovb	calcrete
JC20	7.38	6.73	0.26	0.13	Verify with other tests	ovb	shale
JC3	7.88	3.620	13.24	13.22	Verify with other tests	ovb	calcrete
JC31	7.40	5.530	-2.46	-2.53	Verify with other tests	ovb	shale
JC32	7.52	4.880	-8.59	-8.58	Verify with other tests	ovb	shale
JC33	7.70	4.620	-8.77	-8.78	Verify with other tests	ovb	shale
JC34	7.49	5.140	-11.43	-11.44	Verify with other tests	ovb	shale
JC35	7.71	5.600	-1.61	-1.60	Verify with other tests	ovb	shale
JC36	7.30	4.700	-4.03	-4.04	Verify with other tests	ovb	shale
JC37	7.57	4.790	-2.87	-2.87	Verify with other tests	ovb	shale
JC38	7.38	4.420	-3.95	-3.94	Verify with other tests	ovb	shale
JC39	7.39	4.740	-2.84	-2.83	Verify with other tests	ovb	shale
JC4	7.94	3.830	-3.46	-3.46	Verify with other tests	ovb	calcrete
JC40	7.42	4.800	-2.34	-2.34	Verify with other tests	ovb	shale
JC41	7.32	4.990	3.82	3.81	Verify with other tests	ovb	shale

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
JC42	7.37	4.800	-2.54	-2.52	Verify with other tests	ovb	shale
JC43	7.33	4.770	-4.16	-4.15	Verify with other tests	ovb	shale
JC44	7.27	4.290	-3.29	-3.28	Verify with other tests	ovb	shale
JC45	7.01	4.610	0.23	0.28	Verify with other tests	ovb	shale
JC5	8.13	4.080	-2.48	-2.44	Verify with other tests	ovb	shale
JC6	7.81	5.900	33.70	33.68	Probably Excess Neutralising Minerals	ovb	shale
JC7	8.11	5.950	3.99	3.93	Verify with other tests	ovb	shale
JC8	7.94	5.000	-11.68	-11.73	Verify with other tests	ovb	shale
JC9	8.18	4.120	-0.55	-0.62	Verify with other tests	ovb	shale
VA1	7.35	4.71	-0.09	-0.18	Verify with other tests	ovb	calcrete
VA10	8.02	7.5	7.81	7.72	Verify with other tests	ovb	shale
VA11	8.43	8.47	30.72	30.60	Probably Excess Neutralising Minerals	ovb	shale
VA13	8.28	7.88	8.97	8.83	Verify with other tests	ovb	shale
VA14	8.31	8.2	23.69	23.50	Probably Excess Neutralising Minerals	ovb	shale
VA15	8.26	7.9	3.64	3.48	Verify with other tests	ovb	shale
VA18	8.39	6.88	21.62	21.51	Probably Excess Neutralising Minerals	ovb	shale
VA2	8.62	8.6	310.95	312.54	Probably Excess Neutralising Minerals	ovb	shale
VA20	7.9	6.67	2.61	2.45	Verify with other tests	ovb	shale
VA3	8.59	8.5	79.10	78.85	Probably Excess Neutralising Minerals	ovb	shale
VA4	8.72	8.38	70.94	70.89	Probably Excess Neutralising Minerals	ovb	shale
VA41	8.4	7.87	50.72	50.25	Probably Excess Neutralising Minerals	ovb	shale
VA5	8.93	8.66	89.17	89.06	Probably Excess Neutralising Minerals	ovb	shale
VA50	8.41	8.03	37.44	37.37	Probably Excess Neutralising Minerals	ovb	shale
VA6	8.59	8	38.92	38.71	Probably Excess Neutralising Minerals	ovb	shale
VA7	8.62	8.39	8.10	7.98	Verify with other tests	ovb	shale
VA8	8.43	8.23	5.28	5.06	Verify with other tests	ovb	shale
VA9	8.01	8.47	17.97	18.10	Verify with other tests	ovb	shale
VB2	6.28	3.06	-1.54	-1.54	Verify with other tests	ovb	shale
VB21	7.11	4.92	-4.12	-6.20	Verify with other tests	ovb	shale
VB22	6.94	5.29	-3.03	-3.24	Verify with other tests	ovb	shale
VB23	6.6	5	-3.30	-3.63	Verify with other tests	ovb	shale
VB24	6.8	5.09	-2.83	-2.99	Verify with other tests	ovb	shale
VB25	6.85	4.96	-3.81	-3.87	Verify with other tests	ovb	shale
VB26	6.89	5.05	-2.24	-2.29	Verify with other tests	ovb	shale
VB27	6.87	4.94	-2.99	-3.20	Verify with other tests	ovb	shale
VB28	7.01	4.63	-2.62	-2.97	Verify with other tests	ovb	shale
VB29	6.94	4.81	-9.03	-14.76	Verify with other tests	ovb	shale
VB30	6.86	4.51	-0.68	-0.54	Verify with other tests	ovb	shale

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
VB31	6.64	3.81	-1.03	-1.50	Verify with other tests	ovb	shale
VB32	6.54	3.09	-1.35	-1.76	Verify with other tests	ovb	shale
VB40	6.49	4.41	0.98	0.98	Verify with other tests	ovb	shale
VC11	6.5	4.57	-2.01	-2.07	Verify with other tests	ovb	shale
VC12	6.56	5.12	-0.69	-0.75	Verify with other tests	ovb	shale
VC13	6.47	5.34	0.07	0.03	Verify with other tests	ovb	shale
VC14	6.27	5.44	-0.85	-0.77	Verify with other tests	ovb	shale
VC15	6.61	6.28	1.55	1.52	Verify with other tests	ovb	shale
VC16	6.45	6.37	-0.93	-0.97	Verify with other tests	ovb	shale
VC18	6.53	5.05	0.02	-0.02	Verify with other tests	ovb	shale
VC19	6.64	4.97	-1.29	-1.33	Verify with other tests	ovb	shale
VC20	7.37	7.78	-2.09	-2.07	Verify with other tests	ovb	shale
VC21	7.26	7.03	-2.52	-2.54	Verify with other tests	ovb	shale
VC22	6.67	4.62	-1.82	-1.84	Verify with other tests	ovb	shale
VC23	7.33	7.06	-2.03	-2.04	Verify with other tests	ovb	shale
VC24	7.19	7	-1.60	-1.65	Verify with other tests	ovb	shale
VC25	7.23	6.72	5.48	5.47	Verify with other tests	ovb	shale
VC26	7.08	6.83	-6.11	-6.17	Verify with other tests	ovb	shale
VC27	6.88	6.67	1.32	1.32	Verify with other tests	ovb	shale
VC28	7.04	6.78	1.32	1.32	Verify with other tests	ovb	shale
VC29	6.6	4.04	8.78	8.80	Verify with other tests	ovb	shale
VC30	7.18	6.86	-3.02	-3.04	Verify with other tests	ovb	shale
VC31	7.01	7.04	-1.73	-1.71	Verify with other tests	ovb	shale
VC32	6.64	4.39	-2.37	-2.41	Verify with other tests	ovb	shale
VC33	6.82	6.41	6.85	6.86	Verify with other tests	ovb	shale
VC35	6.75	4.72	1.03	1.01	Verify with other tests	ovb	shale
VC36	6.42	4.43	-1.85	-1.86	Verify with other tests	ovb	shale
VC38	6.7	4.28	-2.06	-2.11	Verify with other tests	ovb	shale
VC39	7.20	4.21	-0.01	-0.01	Verify with other tests	ovb	shale
VC41	6.84	6.57	-10.45	-10.50	Verify with other tests	ovb	shale
VC42	6.57	4.25	-0.56	-0.60	Verify with other tests	ovb	shale
VC43	6.43	4.06	-1.73	-1.94	Verify with other tests	ovb	shale/coal
VC6	6.41	4.67	-1.50	-1.50	Verify with other tests	ovb	shale
VC8	7.85	4.72	-1.66	-1.57	Verify with other tests	ovb	shale
VD1	7.02	4.92	0.35	0.24	Verify with other tests	ovb	
VD10	5.85	4.32	-7.15	-7.29	Verify with other tests	ovb	
VD11	6.07	4.41	-1.49	-1.56	Verify with other tests	ovb	
VD12	5.8	4.2	-2.55	-2.64	Verify with other tests	ovb	
VD13	6.34	4.66	-9.21	-9.31	Verify with other tests	ovb	
VD14	5.48	3.67	-3.69	-3.76	Verify with other tests	ovb	
VD15	5.64	3.76	-3.52	-3.62	Verify with other tests	ovb	

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
VD16	5.63	3.57	-2.46	-2.53	Verify with other tests	ovb	
VD17	5.6	3.46	-4.00	-4.13	Verify with other tests	ovb	
VD18	5.28	2.18	-10.53	-11.01	Verify with other tests	ovb	
VD19	5.04	2.06	-11.69	-12.89	Verify with other tests	ovb	
VD2	7.95	7.53	4.14	4.11	Verify with other tests	ovb	
VD20	5.82	3.78	-7.85	-8.57	Verify with other tests	ovb	
VD21	5.71	3.09	-6.13	-6.46	Verify with other tests	ovb	
VD22	5.98	4.88	-6.18	-8.43	Verify with other tests	ovb	
VD23	4.69	1.79	-6.80	-8.73	Verify with other tests	ovb	
VD24	5.28	1.87	-7.20	-7.43	Verify with other tests	ovb	
VD3	8.1	5.51	1.87	1.84	Verify with other tests	ovb	
VD4	6.38	4.06	-1.19	-0.97	Verify with other tests	ovb	
VD5	6.66	4.49	-1.59	-1.64	Verify with other tests	ovb	
VD6	6.17	4.03	-2.86	-2.93	Verify with other tests	ovb	
VD7	6.08	4.21	-2.17	-2.25	Verify with other tests	ovb	
VD8	5.66	3.95	-2.73	-2.85	Verify with other tests	ovb	
VD9	6.05	4.43	-1.30	-1.43	Verify with other tests	ovb	

Table 51: Interpretation of the NA/AP ratios for the Grootegeluk samples.

Sample Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
JA 1		No Acid Potential	No Acid Potential
JA 2		No Acid Potential	No Acid Potential
JA 3		No Acid Potential	No Acid Potential
JA 4		No Acid Potential	No Acid Potential
JA 5		No Acid Potential	No Acid Potential
JA 6	0.1	Likely Acid Generator	Likely Acid Generator
JA 7	40.6	No Acid Potential	No Acid Potential
JA 8	97.5	No Acid Potential	No Acid Potential
JA 9	0.2	Likely Acid Generator	Likely Acid Generator
JA 10	164.2	No Acid Potential	No Acid Potential
JA 11	0.2	Likely Acid Generator	Likely Acid Generator
JA 12	14.6	No Acid Potential	No Acid Potential
JA 13	458.3	No Acid Potential	No Acid Potential
JA 14	0.6	Likely Acid Generator	Likely Acid Generator
JA 15	1.1	Acid under certain conditions	Likely Acid Generator
JA 16		No Acid Potential	No Acid Potential
JA 17	0.3	Likely Acid Generator	Likely Acid Generator
JA 18		No Acid Potential	No Acid Potential
JA 19		No Acid Potential	No Acid Potential
JA 20		No Acid Potential	No Acid Potential
JA 27	0.1	Likely Acid Generator	Likely Acid Generator
JB 21	0.1	Likely Acid Generator	Likely Acid Generator
JB 22	500.4	No Acid Potential	No Acid Potential
JB 23	0.1	Likely Acid Generator	Likely Acid Generator
JB 24	0.1	Likely Acid Generator	Likely Acid Generator
JB 25	0.1	Likely Acid Generator	Likely Acid Generator
JB 26	0.1	Likely Acid Generator	Likely Acid Generator
JB 27	0.1	Likely Acid Generator	Likely Acid Generator
JB 28	0.2	Likely Acid Generator	Likely Acid Generator
JB 29	0.1	Likely Acid Generator	Likely Acid Generator
JB 30	103.8	No Acid Potential	No Acid Potential
JB 31	0.1	Likely Acid Generator	Likely Acid Generator
JB 32	0.4	Likely Acid Generator	Likely Acid Generator
JB 33	0.9	Likely Acid Generator	Likely Acid Generator
JB32	0.4	Likely Acid Generator	Likely Acid Generator
JB33	0.9	Likely Acid Generator	Likely Acid Generator
JC2	0.3	Likely Acid Generator	Likely Acid Generator
JC3	629.7	No Acid Potential	No Acid Potential
JC4	1.4	Acid under certain conditions	Likely Acid Generator

Sample Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
JC5		No Acid Potential	No Acid Potential
JC6	1625.8	No Acid Potential	No Acid Potential
JC7	65.9	No Acid Potential	No Acid Potential
JC8	0.2	Likely Acid Generator	Likely Acid Generator
JC9	0.1	Likely Acid Generator	Likely Acid Generator
JC10		No Acid Potential	No Acid Potential
JC31	0.2	Likely Acid Generator	Likely Acid Generator
JC32		No Acid Potential	No Acid Potential
JC33	1.2	Acid under certain conditions	Likely Acid Generator
JC34	2.6	Acid under certain conditions	Acid under certain conditions
JC35		No Acid Potential	No Acid Potential
JC36	1.2	Acid under certain conditions	Likely Acid Generator
JC37		No Acid Potential	No Acid Potential
JC38		No Acid Potential	No Acid Potential
JC39		No Acid Potential	No Acid Potential
JC40	13.6	No Acid Potential	No Acid Potential
JC41	232.8	No Acid Potential	No Acid Potential
JC42		No Acid Potential	No Acid Potential
JC43		No Acid Potential	No Acid Potential
JC44		No Acid Potential	No Acid Potential
JC45		No Acid Potential	No Acid Potential
MA11	40.4	No Acid Potential	No Acid Potential
MA12	10.5	No Acid Potential	No Acid Potential
MA13	414.1	No Acid Potential	No Acid Potential
MA14	9.0	No Acid Potential	No Acid Potential
MA15	3.6	Acid under certain conditions	Acid under certain conditions
MA16	1.6	Acid under certain conditions	Likely Acid Generator
MA18	2.2	Acid under certain conditions	Acid under certain conditions
MA19	3.3	Acid under certain conditions	Acid under certain conditions
MA20	4.6	No Acid Potential	Acid under certain conditions
MA21	5.0	No Acid Potential	Acid under certain conditions
MB1	1506.6	No Acid Potential	No Acid Potential
MB2	5858.2	No Acid Potential	No Acid Potential
MB3		No Acid Potential	No Acid Potential
MB4	1666.7	No Acid Potential	No Acid Potential
MB5	7890.1	No Acid Potential	No Acid Potential
MB6	311.8	No Acid Potential	No Acid Potential
MB7		No Acid Potential	No Acid Potential
MB8		No Acid Potential	No Acid Potential
MB9	0.4	Likely Acid Generator	Likely Acid Generator
MB10	34.2	No Acid Potential	No Acid Potential

Sample Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
MB11	471.8	No Acid Potential	No Acid Potential
MB12	605.4	No Acid Potential	No Acid Potential
MB13	0.4	Likely Acid Generator	Likely Acid Generator
MB14	56.0	No Acid Potential	No Acid Potential
MB15	140.3	No Acid Potential	No Acid Potential
MB16	934.9	No Acid Potential	No Acid Potential
MB20	17.9	No Acid Potential	No Acid Potential
MB22	120.8	No Acid Potential	No Acid Potential
MB23	8.0	No Acid Potential	No Acid Potential
MB24	1.2	Acid under certain conditions	Likely Acid Generator
MB25	0.0	Likely Acid Generator	Likely Acid Generator
MB26	0.9	Likely Acid Generator	Likely Acid Generator
MA2	13.0	No Acid Potential	No Acid Potential
MA3	141.6	No Acid Potential	No Acid Potential
MA4	1.0	Likely Acid Generator	Likely Acid Generator
MA5		No Acid Potential	No Acid Potential
MA6		No Acid Potential	No Acid Potential
MA7	87.3	No Acid Potential	No Acid Potential
MA8		No Acid Potential	No Acid Potential
MA9		No Acid Potential	No Acid Potential
MA10	1.0	Acid under certain conditions	Likely Acid Generator
VA17	647.5	No Acid Potential	No Acid Potential
VA21	212.5	No Acid Potential	No Acid Potential
VA22	78.4	No Acid Potential	No Acid Potential
VA23	258.0	No Acid Potential	No Acid Potential
VA24	623.1	No Acid Potential	No Acid Potential
VA25	597.3	No Acid Potential	No Acid Potential
VA26		No Acid Potential	No Acid Potential
VA27	478.7	No Acid Potential	No Acid Potential
VA28	147.0	No Acid Potential	No Acid Potential
VA29		No Acid Potential	No Acid Potential
VA30		No Acid Potential	No Acid Potential
VA31	1674.5	No Acid Potential	No Acid Potential
VA32	36.2	No Acid Potential	No Acid Potential
VA33	26.9	No Acid Potential	No Acid Potential
VA34		No Acid Potential	No Acid Potential
VA35		No Acid Potential	No Acid Potential
VA36		No Acid Potential	No Acid Potential
VA38		No Acid Potential	No Acid Potential
VA39	2195.9	No Acid Potential	No Acid Potential
VA40		No Acid Potential	No Acid Potential

Sample Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
VA44		No Acid Potential	No Acid Potential
VA46	4.6	No Acid Potential	Acid under certain conditions
VA48	7.8	No Acid Potential	Acid under certain conditions
VA52	1.4	Acid under certain conditions	Likely Acid Generator
VA53	4.4	No Acid Potential	Acid under certain conditions
VA54	3.8	Acid under certain conditions	Acid under certain conditions
VA56	2.4	Acid under certain conditions	Acid under certain conditions
VA57	0.7	Likely Acid Generator	Likely Acid Generator
VC3		No Acid Potential	No Acid Potential
VC4	4.1	No Acid Potential	Acid under certain conditions
VC5	0.5	Likely Acid Generator	Likely Acid Generator
VC8		No Acid Potential	No Acid Potential
VC10	1.4	Acid under certain conditions	Likely Acid Generator
VC17		No Acid Potential	No Acid Potential
JA23		No Acid Potential	No Acid Potential
JA28		No Acid Potential	No Acid Potential
JA30		No Acid Potential	No Acid Potential
JA31		No Acid Potential	No Acid Potential
JA32		No Acid Potential	No Acid Potential
JA33		No Acid Potential	No Acid Potential
JA34		No Acid Potential	No Acid Potential
JA35		No Acid Potential	No Acid Potential
JA39		No Acid Potential	No Acid Potential
JA40		No Acid Potential	No Acid Potential
JB11	16.6	No Acid Potential	No Acid Potential
JB12		No Acid Potential	No Acid Potential
JB13	205.7	No Acid Potential	No Acid Potential
JB15		No Acid Potential	No Acid Potential
JB16		No Acid Potential	No Acid Potential
JB17		No Acid Potential	No Acid Potential
JB18	8.0	No Acid Potential	No Acid Potential
VA16		No Acid Potential	No Acid Potential
VA19	300.6	No Acid Potential	No Acid Potential
VA42		No Acid Potential	No Acid Potential
VA43	35.1	No Acid Potential	No Acid Potential
VA45	4.2	No Acid Potential	Acid under certain conditions
VA47	21.6	No Acid Potential	No Acid Potential
VA49	5.5	No Acid Potential	Acid under certain conditions
VA51	1.2	Acid under certain conditions	Likely Acid Generator
VA58	1.9	Acid under certain conditions	Likely Acid Generator
VB1	0.1	Likely Acid Generator	Likely Acid Generator

Sample Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
VB3		No Acid Potential	No Acid Potential
VB4	0.7	Likely Acid Generator	Likely Acid Generator
VB5	51.5	No Acid Potential	No Acid Potential
VB6	28.9	No Acid Potential	No Acid Potential
VB7	35.4	No Acid Potential	No Acid Potential
VB8	8.8	No Acid Potential	No Acid Potential
VB9	0.4	Likely Acid Generator	Likely Acid Generator
VB10	0.2	Likely Acid Generator	Likely Acid Generator
VB11	38.7	No Acid Potential	No Acid Potential
VB12	0.4	Likely Acid Generator	Likely Acid Generator
VB13		No Acid Potential	No Acid Potential
VB14	5.7	No Acid Potential	Acid under certain conditions
VB15	47.8	No Acid Potential	No Acid Potential
VB17	0.3	Likely Acid Generator	Likely Acid Generator
VB18	0.1	Likely Acid Generator	Likely Acid Generator
VB19	0.2	Likely Acid Generator	Likely Acid Generator
VB20	0.1	Likely Acid Generator	Likely Acid Generator
VA1	0.1	Likely Acid Generator	Likely Acid Generator
VA2	2587.0	No Acid Potential	No Acid Potential
VA3	320.2	No Acid Potential	No Acid Potential
VA9		No Acid Potential	No Acid Potential
VA10	93.3	No Acid Potential	No Acid Potential
VA11	259.3	No Acid Potential	No Acid Potential
VA13	62.1	No Acid Potential	No Acid Potential
VA14	125.1	No Acid Potential	No Acid Potential
VA15	23.1	No Acid Potential	No Acid Potential
VA18	208.2	No Acid Potential	No Acid Potential
VA20	17.9	No Acid Potential	No Acid Potential
VA41	110.7	No Acid Potential	No Acid Potential
VA50	581.4	No Acid Potential	No Acid Potential
JA17	0.0	Likely Acid Generator	Likely Acid Generator
JA21	0.1	Likely Acid Generator	Likely Acid Generator
JA22	515.6	No Acid Potential	No Acid Potential
JA24	0.7	Likely Acid Generator	Likely Acid Generator
JA25		No Acid Potential	No Acid Potential
JA26	0.2	Likely Acid Generator	Likely Acid Generator
JA36	0.1	Likely Acid Generator	Likely Acid Generator
JA37	48.3	No Acid Potential	No Acid Potential
JA38	0.0	Likely Acid Generator	Likely Acid Generator
JA41	1.9	Acid under certain conditions	Likely Acid Generator
JA43		No Acid Potential	No Acid Potential

Sample Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
JA44		No Acid Potential	No Acid Potential
JA45	0.1	Likely Acid Generator	Likely Acid Generator
JA46	0.1	Likely Acid Generator	Likely Acid Generator
JC11	9.8	No Acid Potential	No Acid Potential
JC12	4.7	No Acid Potential	Acid under certain conditions
JC13	5.9	No Acid Potential	Acid under certain conditions
JC14		No Acid Potential	No Acid Potential
JC15	152.2	No Acid Potential	No Acid Potential
JC16	0.1	Likely Acid Generator	Likely Acid Generator
JC17	1.9	Acid under certain conditions	Likely Acid Generator
JC18	21.7	No Acid Potential	No Acid Potential
JC19	3.3	Acid under certain conditions	Acid under certain conditions
JC20	3.0	Acid under certain conditions	Acid under certain conditions
JB14	0.2	Likely Acid Generator	Likely Acid Generator
JB19	0.0	Likely Acid Generator	Likely Acid Generator
JB20	0.0	Likely Acid Generator	Likely Acid Generator
VF7	0.1	Likely Acid Generator	Likely Acid Generator
VE37	0.1	Likely Acid Generator	Likely Acid Generator
MC1	0.2	Likely Acid Generator	Likely Acid Generator
VC29		No Acid Potential	No Acid Potential
VD1	4.3	No Acid Potential	Acid under certain conditions
VD2	148.2	No Acid Potential	No Acid Potential
VD3	78.4	No Acid Potential	No Acid Potential
VD4		No Acid Potential	No Acid Potential
VD5	0.2	Likely Acid Generator	Likely Acid Generator
VD6	0.1	Likely Acid Generator	Likely Acid Generator
VD7	0.1	Likely Acid Generator	Likely Acid Generator
VD8	0.1	Likely Acid Generator	Likely Acid Generator
VD9	0.1	Likely Acid Generator	Likely Acid Generator
VD10	0.1	Likely Acid Generator	Likely Acid Generator
VD11	0.1	Likely Acid Generator	Likely Acid Generator
VD12	0.1	Likely Acid Generator	Likely Acid Generator
VD13	0.1	Likely Acid Generator	Likely Acid Generator
VD14	0.2	Likely Acid Generator	Likely Acid Generator
VD15	0.1	Likely Acid Generator	Likely Acid Generator
VD16	0.2	Likely Acid Generator	Likely Acid Generator
VD17	0.1	Likely Acid Generator	Likely Acid Generator
VD18	0.0	Likely Acid Generator	Likely Acid Generator
VD19	0.0	Likely Acid Generator	Likely Acid Generator
VD20	0.0	Likely Acid Generator	Likely Acid Generator
VD21	0.0	Likely Acid Generator	Likely Acid Generator

Sample Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
VD23	0.0	Likely Acid Generator	Likely Acid Generator
VD24	0.0	Likely Acid Generator	Likely Acid Generator
VC6	70.4	No Acid Potential	No Acid Potential
VC11	0.2	Likely Acid Generator	Likely Acid Generator
VC12	0.2	Likely Acid Generator	Likely Acid Generator
VC13	2.6	Acid under certain conditions	Acid under certain conditions
VC14		No Acid Potential	No Acid Potential
VC15	42.7	No Acid Potential	No Acid Potential
VC16	0.3	Likely Acid Generator	Likely Acid Generator
VC18	1.5	Acid under certain conditions	Likely Acid Generator
VC19	0.3	Likely Acid Generator	Likely Acid Generator
VC22	0.2	Likely Acid Generator	Likely Acid Generator
VC32	0.3	Likely Acid Generator	Likely Acid Generator
VC35	51.0	No Acid Potential	No Acid Potential
VC36	0.6	Likely Acid Generator	Likely Acid Generator
VC38	0.2	Likely Acid Generator	Likely Acid Generator
VC42	0.2	Likely Acid Generator	Likely Acid Generator
VC43	0.0	Likely Acid Generator	Likely Acid Generator
VB2	1.5	Acid under certain conditions	Likely Acid Generator
VB31	0.0	Likely Acid Generator	Likely Acid Generator
VB32	0.0	Likely Acid Generator	Likely Acid Generator
VB40	141.9	No Acid Potential	No Acid Potential
VC39	1.8	Acid under certain conditions	Likely Acid Generator

Table 52: ABA results for the Sekoko samples.

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
DP01 (10)	6.94	2.08	-4.18	-4.99	Verify with other tests	interburden	
DP01 (3)	6.42	3.49	-0.82	-1.05	Verify with other tests	interburden	
DP01 (4)	6.17	2.97	-1.6	-2.18	Verify with other tests	interburden	
DP01 (5)	5.88	3.48	-10.18	-17.81	Verify with other tests	interburden	
DP01 (6)	4.88	3.52	-2.68	-3.36	Verify with other tests	interburden	
DP2 (1)	6.81	5.3	-2.97	-3.09	Verify with other tests	interburden	
DP2 (5)	6.75	3.17	-3.72	-4.97	Verify with other tests	interburden	
DP2 (6)	6.11	2.28	-37.58	-68.48	Potential Acid Generator	interburden	
DP22 (1)	6.32	3.94	-16.94	-17.06	Verify with other tests	interburden	
DP3 (3)	6.82	2.95	-3.42	-3.47	Verify with other tests	interburden	
DP713 (3)	6.84	2.84	-2.78	-3	Verify with other tests	interburden	
PM18 (3)	5.78	2.24	16.09	14.9	Verify with other tests	interburden	siltstone/sandstone
PS94 (1)	7.31	2.39	-0.65	-1.32	Verify with other tests	interburden	carbonaceous mudstone
PS95 (1)	7.58	6.28	1.22	1.17	Verify with other tests	interburden	mudstone
PS95 (2)	6.95	6.54	39.29	18.29	Verify with other tests	interburden	mudstone
SV35 (1)	6.57	2.05	-96.35	-185	Potential Acid Generator	interburden	ss
SV35 (3)	7.79	2.76	-2.44	-3.57	Verify with other tests	interburden	ss
005 (1)	7.01	4.19	-3.25	-3.13	Verify with other tests	interburden	
5A (2)	7.27	4.33	15.49	15.02	Verify with other tests	interburden	
DP01 (1)	7.12	1.79	-7.06	-12.57	Verify with other tests	interburden	
DP01 (11)	6.64	4.75	-3.65	-4.09	Verify with other tests	interburden	
DP01 (2)	7.64	2.04	-13.29	-21.95	Potential Acid Generator	interburden	
DP01 (7)	6.68	1.81	-2.82	-4.87	Verify with other tests	interburden	
DP01 (8)	7.28	5.35	2.48	-0.8	Verify with other tests	interburden	
DP01 (9)	6.54	2.44	-2.85	-3.57	Verify with other tests	interburden	
DP2 (2)	6.83	5.71	-2.19	-2.29	Verify with other tests	interburden	
DP2 (3)	6.5	2.23	-8.79	-13.27	Verify with other tests	interburden	
DP2 (4)	6.59	4.09	-2.93	-3.01	Verify with other tests	interburden	
DP3 (1)	7.17	3.97	-6.6	-12.42	Verify with other tests	interburden	
DP3 (2)	6.45	4.3	-2.06	-2.17	Verify with other tests	interburden	
DP3 (5)	6.48	3.35	-20.8	-38.43	Potential Acid Generator	interburden	
DP3 (6)	7.18	4.07	3.37	3.16	Verify with other tests	interburden	
DP3(4)	6.67	2.93	-15.85	-16.69	Verify with other tests	interburden	
DP712 (1)	6.47	3.1	-3.45	-3.95	Verify with other tests	interburden	
DP713 (1)	6.74	4.07	-3.38	-3.41	Verify with other tests	interburden	
DP713 (2)	7.11	6.6	-2.24	-2.32	Verify with other tests	interburden	
PM18 (1)	6.92	3.92	-0.61	-0.7	Verify with other tests	interburden	ss
PM18 (2)	6.34	2.58	-2.62	-4.07	Verify with other tests	interburden	sideritic rock

sample	initial pH	final pH	NNP (open)	NNP (Closed)	interpretation	zone	lithology
PS93 (1)	7.56	4.83	0.81	0.78	Verify with other tests	interburden	mudstone
PS95 (3)	6.29	2.06	-101.96	-229.6	Potential Acid Generator	interburden	mudstone
S131 (1)	5.82	1.93	-6.59	-8.36	Verify with other tests	interburden	
SV35 (2)	6.95	2.94	-28.02	-58.1	Potential Acid Generator	interburden	ss

Table 53: Interpretation of the NP/AP ratios for the Sekoko samples.

Sample Name	Neutralising Potential Ratio(NP/AP) for Open System	Interpretation Open System	Interpretation Closed System
DP3(4)	0.008	Likely Acid Generator	Likely Acid Generator
SV35 (3)	0.015	Likely Acid Generator	Likely Acid Generator
PS95 (2)	2.871	Acid under certain conditions	Acid under certain conditions
DP01 (3)	0.045	Likely Acid Generator	Likely Acid Generator
DP713 (1)	0.436	Likely Acid Generator	Likely Acid Generator
DP01 (2)	0.001	Likely Acid Generator	Likely Acid Generator
SV35 (1)	0.00	Likely Acid Generator	Likely Acid Generator
DP01 (10)	0.012	Likely Acid Generator	Likely Acid Generator
DP01 (7)	0.005	Likely Acid Generator	Likely Acid Generator
DP01 (6)	0.015	Likely Acid Generator	Likely Acid Generator
PM18 (3)	14.495	No Acid Potential	No Acid Potential
DP2 (2)	0.108	Likely Acid Generator	Likely Acid Generator
DP713 (3)	0.044	Likely Acid Generator	Likely Acid Generator
DP01 (8)	1.755	Acid under certain conditions	Likely Acid Generator
DP2 (6)	0.00	Likely Acid Generator	Likely Acid Generator
DP2 (5)	0.008	Likely Acid Generator	Likely Acid Generator
DP22 (1)	0.089	Likely Acid Generator	Likely Acid Generator
DP3 (3)	0.181	Likely Acid Generator	Likely Acid Generator
5A (2)	33.862	No Acid Potential	No Acid Potential
DP01 (1)	0.002	Likely Acid Generator	Likely Acid Generator
DP01 (9)	0.014	Likely Acid Generator	Likely Acid Generator
PS95 (3)	0.201	Likely Acid Generator	Likely Acid Generator
SV35 (2)	0.069	Likely Acid Generator	Likely Acid Generator
DP01 (11)	0.023	Likely Acid Generator	Likely Acid Generator
DP2 (3)	0.002	Likely Acid Generator	Likely Acid Generator
DP2 (4)	0.128	Likely Acid Generator	Likely Acid Generator
DP01 (4)	0.017	Likely Acid Generator	Likely Acid Generator
DP01 (5)	0.001	Likely Acid Generator	Likely Acid Generator
PM18 (1)	0.104	Likely Acid Generator	Likely Acid Generator
DP3 (5)	0.001	Likely Acid Generator	Likely Acid Generator
DP712 (1)	0.02	Likely Acid Generator	Likely Acid Generator
DP3 (2)	0.09	Likely Acid Generator	Likely Acid Generator
S131 (1)	0.006	Likely Acid Generator	Likely Acid Generator
DP3 (1)	0.002	Likely Acid Generator	Likely Acid Generator
PM18 (2)	0.007	Likely Acid Generator	Likely Acid Generator
DP3 (6)	17.61	No Acid Potential	No Acid Potential
DP713 (2)	0.129	Likely Acid Generator	Likely Acid Generator
005 (1)	0.022	Likely Acid Generator	Likely Acid Generator
DM19 (1)	0.005	Likely Acid Generator	Likely Acid Generator
DP2 (1)	0.083	Likely Acid Generator	Likely Acid Generator
PS93 (1)	27.181	No Acid Potential	No Acid Potential
PS94 (1)	0.044	Likely Acid Generator	Likely Acid Generator
PS95 (1)	28.952	No Acid Potential	No Acid Potential

Table 54: The percentage sulphur in the Upper Ecca samples.

Borehole sample	**Density**	**RD 1.80-2.20**	**RD 1.9-2.20**	**RD 2.1-2.20**
	Zones	**%S**		
MY	MY11		9.2	
	MY10			1.67
	MY8		1.96	
	MY6		1.2	
	MY5			0.74
	MY5		0.5	
CZONE	CZONE10A			4.46
	CZONE9A		0.91	
	CZONE9B			0.95
	CZONE8A		0.48	
	CZONE8B			0.79
	CZONE7A		0.59	
	CZONE7B			8.21
	CZONE6A		0.39	
	CZONE6B			0.34
	CZONE5A			1.15
	CZONE5AA		0.74	
PZONE	PZONE10A		1.25	
	PZ10A		5.16	
	PZ10B			7.34
	PZONE9A		1.7	
	PZONE9B			2.38
	PZ9A		0.43	
	PZ9B			5.25
	PZONE8A		0.55	
	PZONE8B			0.87
	PZ8A		0.32	
	PZ8B			0.75
	PZONE7A		0.32	
	PZONE7B			0.43
	PZ7A		1.44	
	PZ7B			0.86
	PZONE6A		0.26	
	PZONE6B			0.19
	PZ6A		1.54	
	PZ6B			0.96

Borehole sample	**Density**	**RD 1.80-2.20**	**RD 1.9-2.20**	**RD 2.1-2.20**
	Zones	**%S**		
MY	MY11		9.2	
	PZONE5A		0.79	
	PZONE5B			0.78
	PZ5A		1.45	
	PZ5B			0.71
JYZONE	JYZ9A		2.44	
	JYZ9B			1.07
	JYZ8A		0.21	
	JYZ8B			0.93
	JYZ7A		1.53	
	JYZ7B			1.98
	JYZ6A		0.17	
	JYZ6B			0.72
	JYZ5A		0.23	
	JYZ5B			0.58
ZTZONE	ZTZONE10A		1.41	
	ZTZONE10B			1.14
	ZTZ10		1.42	
	ZT9		0.34	
	ZT9A			0.27
	ZTZ9		0.13	
	ZTZ8		0.13	
	ZTZ8B			0.08
	ZTZ7		2.63	
	ZTZ7			1.09
	ZTZONE7		0.41	
	ZTZ7		2.55	
	ZTZ7A			0.07
	ZTZ6A		0.09	
	ZTZ6B			0.17
	ZTZ6		1.32	
	ZTZ6			1.02
	ZTZ5B			0.51
	ZTZ5		1.48	
	ZTZ5A			1.54
SNZONE	SN10		1.09	
	SN9			1.84

Borehole sample	**Density**	**RD 1.80-2.20**	**RD 1.9-2.20**	**RD 2.1-2.20**
	Zones	**%S**		
MY	MY11		9.2	
	SN9		1.82	
	SN6		1.8	
	SN6(B)			1.7
	SN5		0.84	
	SN8			1.78
	SN7		0.42	

Table 55: The percentage sulphur in the Middle Ecca Composite samples.

Borehole sample	Density	RD 1.80-2.20	RD 1.9-2.20	RD 2.1-2.20
	Zones	%S		
CZONE	CZONE4AA	3.06		
	CZONE3A	7.37		
	CZONE2A	7.97		
	CZONE1A			0.73
PZONE	PZONE4AA			1.14
	PZONE4A			8.02
	PZ4			12.55
	PZ4A			2.13
	PZ3	3.9		
	PZONE3A	2.51		
	PZONE2A	3.25		
	PZ2	7.3		
	PZONE1B	5.17		
	PZ1	3.32		
JYZONE	JYZ4B			0.91
	JYZ4AB			0.3
	JYZ2A	5.73		
	JYZ1A	1.07		
ZTZONE	ZTZONE4			5.44
	ZTZ4AA			0.05
	ZTZ3A	6.23		
	ZTZ2A	12.13		
	ZTZ2		6.22	
	ZTZ1A	13.94		
	ZTZONE1A	0.02		
	ZTZ1A		3.15	
	ZTZ1B		1.13	
	ZTZONE1B	2.11		
SNZONE	SN4A			5.2
	SN4			5.44
	SN3	5.98		
	SN2	5.81		
	SN1B	0.5		
	SN1B		0.48	
MYZONE	MY4			6.2
	MY4A			1.93

Borehole sample	**Density**	**RD 1.80-2.20**	**RD 1.9-2.20**	**RD 2.1-2.20**
	Zones	**%S**		
CZONE	CZONE4AA	3.06		
	MY1		11.8	
	MY1B	0.14		
	MY1B	1.03		

Table 56: Acid potential of composite samples.

Density	Sample name	Zones	Acid potential
D1.80 S2,20	CZONE1A	1	267.8
D1.80 S2.20	PZONE1B	1	166.6
D1.80 S2.20	ZTZONE1A	1	0.7
D1.80 S2.20	ZTZONE1B	1	64.5
D1.80 S2,20	JYZ1A	1	33.5
D1.80 S2.20	PZ1	1	103.9
D1.80 S2.20	ZTZ1A	1	435.5
D1.90-S220	ZTZ1A	1	98.3
D1.90-S2.20	ZTZ1B	1	35.2
D1.90-S2.20	MY1	1	368.8
D1.80-S2.20	MY1B	1	4.5
D1.80-S2.20	SN1B	1	15.7
D1.80-S2.20	MY1B	1	32.1
D1.90-S2.20	SN1B	1	14.9
D1.80 S2.20	CZONE2A	2	230.4
D1.80 S2.20	PZONE2A	2	101.4
D1.80 S2.20	JYZ2A	2	179.0
D1.80 S2.20	PZ2	2	228.2
D1.80 S2.20	ZTZ2A	2	379.2
D1.90-S2.20	ZTZ2	2	194.2
D1.80-S2.20	SN2	2	181.7
D1.80 S2.20	PZ3	3	122.0
D1.80 S2.20	PZONE3A	3	78.4
D1.80 S2.20	CZONE3A	3	95.6
D1.80 S2.20	ZTZ3A	3	194.7
D1.80-S2.20	SN3	3	186.9
D2.10 S2.20	PZ4	4	392.3
D2.10 S2.20	PZ4A	4	66.6
D2.10 S2.20	PZONE4AA	4	35.5
D2.10 S2.20	CZONE4AA	4	22.8
D2.10 S2.20	ZTZONE4	4	170.0
D2.10 S2.20	JYZ4B	4	28.5
D2.10 S2.20	JYZ4AB	4	9.4
D2.10 S2.20	PZONE4A	4	250.7
D2.10 S2.20	ZTZ4AA	4	1.6
D2.10-S2.20	MY4	4	193.8
D2.10-S2.20	NS4A	4	162.4
D2.10-S2.20	MY4A	4	60.3
D2.10-S2.20	SN4	4	170.1
D1.90 S2.20	PZONE5A	5	24.6

Density	Sample name	Zones	Acid potential
D2.10 S2.20	PZONE5B	5	24.4
D2.10 S2.20	CZONE5A	5	35.8
D1.90 S2.20	CZONE5AA	5	23.2
D1.90 -S2.20	JYZ5A	5	7.1
D2.10 32.20	JYZ5B	5	18.2
D1.90 S2.20	PZ5A	5	45.3
D2.10 S2.20	PZ5B	5	22.3
D2.10 S2.20	ZTZ5B	5	15.9
D1.90-S2.20	ZTZ5	5	46.2
D2.10 S2.20	ZTZ5A	5	48.1
D2.10-S2.20	MY5	5	23.2
D1.90-S2.20	SN5	5	26.3
D1.90-S2.20	MY5	5	15.6
D1.90 -S2.20	CZONE6A	6	12.1
D2.10 S2.20	CZONE6B	6	10.6
D1.90 S2.20	PZONE6A	6	8.2
D2.10 S2.20	PZONE6B	6	5.9
D1.90 -S2.20	JYZ6A	6	5.3
D2.10 32.20	JYZ6B	6	22.6
D1.90 S2.20	PZ6A	6	48.2
D2.10 S2.20	PZ6B	6	30.1
D1.90 S2.20	ZTZ6A	6	2.8
D2.10 S2.20	ZTZ6B	6	5.2
D1.90-S2.20	SN6	6	56.2
D1.90-S2.20	ZTZ6	6	41.3
D1.90-S2.20	MY6	6	37.6
D2.10-S2.20	SN6(B)	6	53.2
D2.10-S2.20	ZTZ6	6	31.9
D1.90-S2.20	SN7	7	13.3
D1.90-S2.20	ZTZ7	7	82.2
D2.10-S2.20	ZTZ7	7	34.1
D1.90 S2.20	CZONE7A	7	18.4
D2.10 S2.20	CZONE7B	7	256.7
D1.90 S2.20	PZONE7A	7	9.9
D2.10 S2.20	PZONE7B	7	13.5
D1.80 S2.20	ZTZONE7BA	7	12.7
D1.90 S2.20	JYZ7A	7	47.7
D2.10 S2.20	JYZ7B	7	61.7
D1.90 S2.20	PZ7A	7	45.1
D2.10 S2.20	PZ7B	7	26.8
D1.90 S2.20	ZTZ7	7	79.8
D2.10 S2.20	ZTZ7A	7	2.2

Density	Sample name	Zones	Acid potential
D1.90 S2.20	PZONE8A	8	17.1
D1.90 S2.20	CZONE8A	8	15.0
D2.10 S2.20	CZONE8B	8	24.6
D2.10 S2.20	PZONE8B	8	27.2
D1.90 S2.20	JYZ8A	8	6.7
D2.10 S2.20	JYZ8B	8	29.1
D1.90 S2.20	PZ8A	8	9.9
D2.10 S2.20	PZ8B	8	23.5
D1.90 S2.20	ZTZ8	8	4.1
D2.10 S2.20	ZTZ8B	8	2.5
D2.10 S2.20	SN8	8	55.6
D190-S2.20	MY8	8	61.2
D1.90 S2.20	CZONE9A	9	28.6
D2.10 S2.20	CZONE9B	9	29.7
D1.90 S2.20	PZONE9A	9	53.0
D2.10 S2.20	PZONE9B	9	74.5
D1.90 S2.20	JYZ9A	9	76.2
D2.10 S2.20	JYZ9B	9	33.5
D1.90 S2.20	PZ9A	9	13.3
D2.10 S2.20	PZ9B	9	164.2
D1.90 S2.20	ZT9	9	10.8
D2.10 S2.20	ZT9A	9	8.3
D1.90 S2.20	ZTZ9	9	4.1
D2.10 S2.20	SN9	9	57.4
D1.90-S2.20	SN9	9	56.8
D2.10 S2.20	PZONE10B	10	54.3
D1.90 S2.20	ZTZONE10A	10	44.0
D2.10 S2.20	ZTZONE10B	10	35.6
D2.10 S2.20	CZONE10A	10	139.3
D1.90 S2.20	PZONE10A	10	39.1
D1.90 S2.20	PZ10A	10	161.1
D2.10 S2.20	PZ10B	10	229.2
D1.90-S2.20	ZTZ10	10	44.4
D2.10-S2.20	MY10	10	52.3
D1.90-S2.20	SN10	10	34.2
D1.90-S2.20	MY11	11	287.4

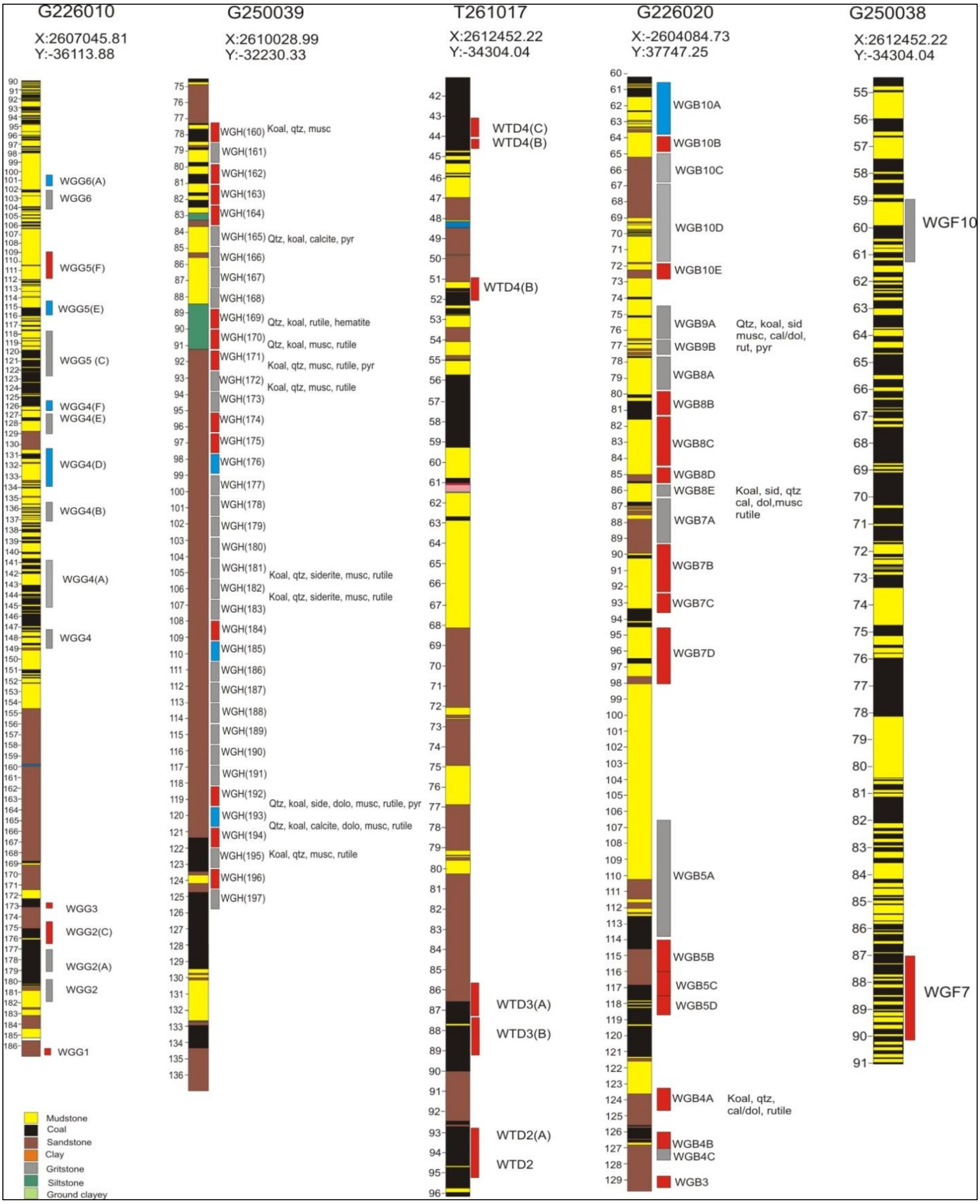

Figure 131: Full successions for Sasol. The sampled intervals are indicated directly next to the borehole profiles with the acid generating potentials, red - acid, blue - neutralising and grey-inconclusive results. Minerals found within the samples are also indicated where applicable.

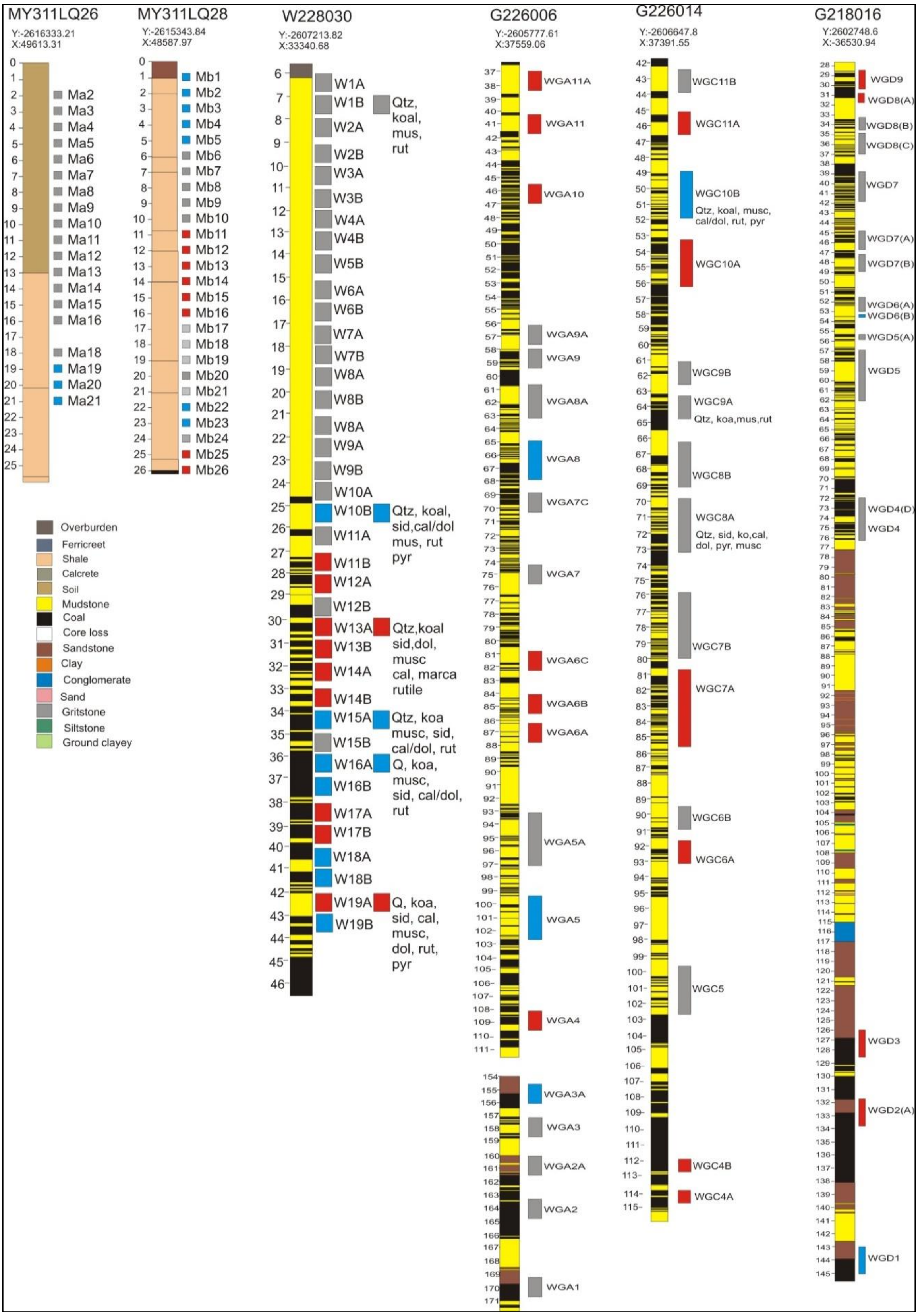

Figure 132: Full successions for Sasol and Exxaro.The sampled intervals are indicated directly next to the borehole profiles with the acid generating potentials, red - acid, blue - neutralising and grey - inconclusive results. Minerals found within the samples are also indicated where applicable.

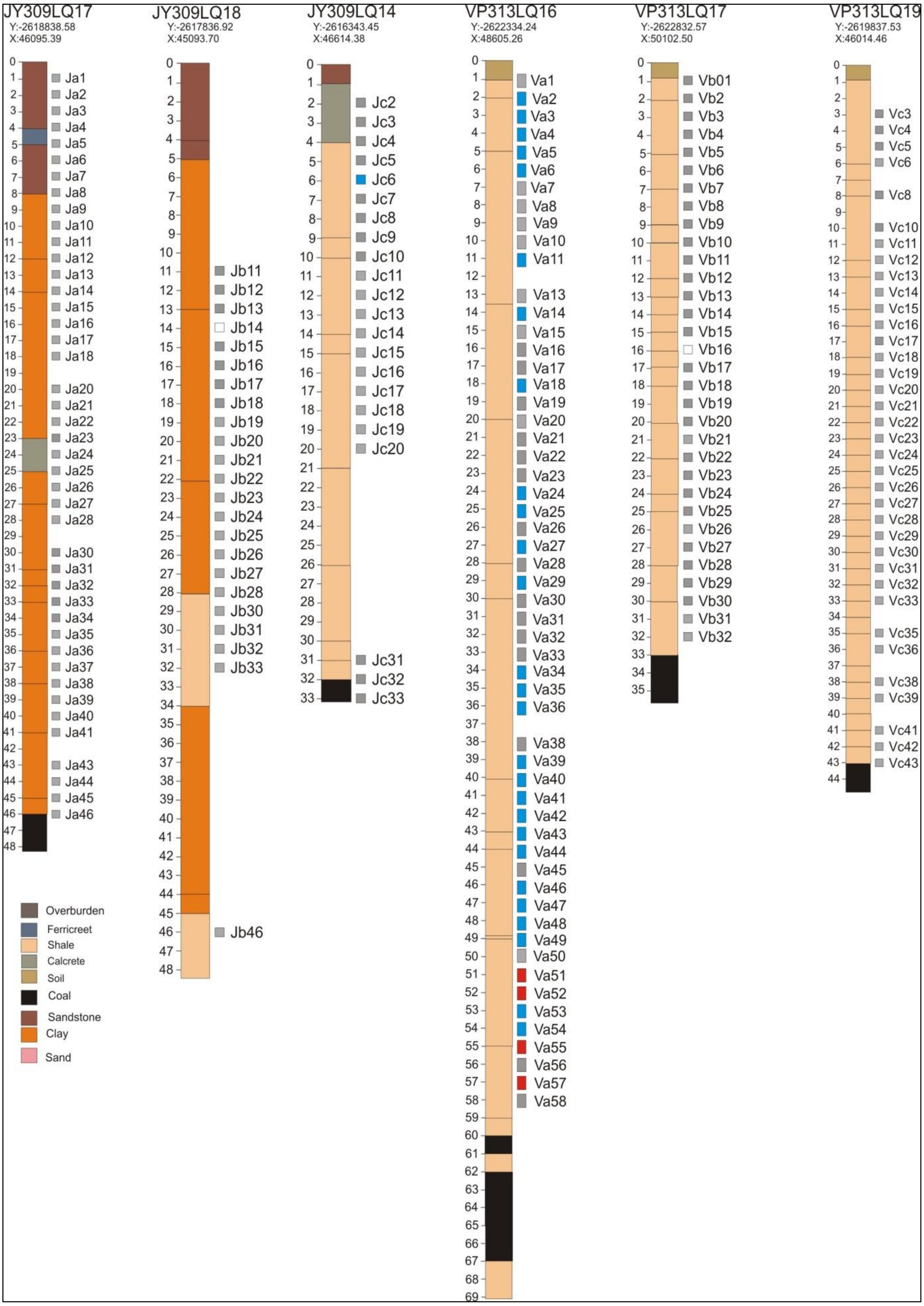

*Figure 133: Partly weathered successions for Exxaro.*The sampled intervals are indicated directly next to the borehole profiles with the acid generating potentials, red - acid, blue - neutralising and grey - inconclusive results. Minerals found within the samples are also indicated where applicable.

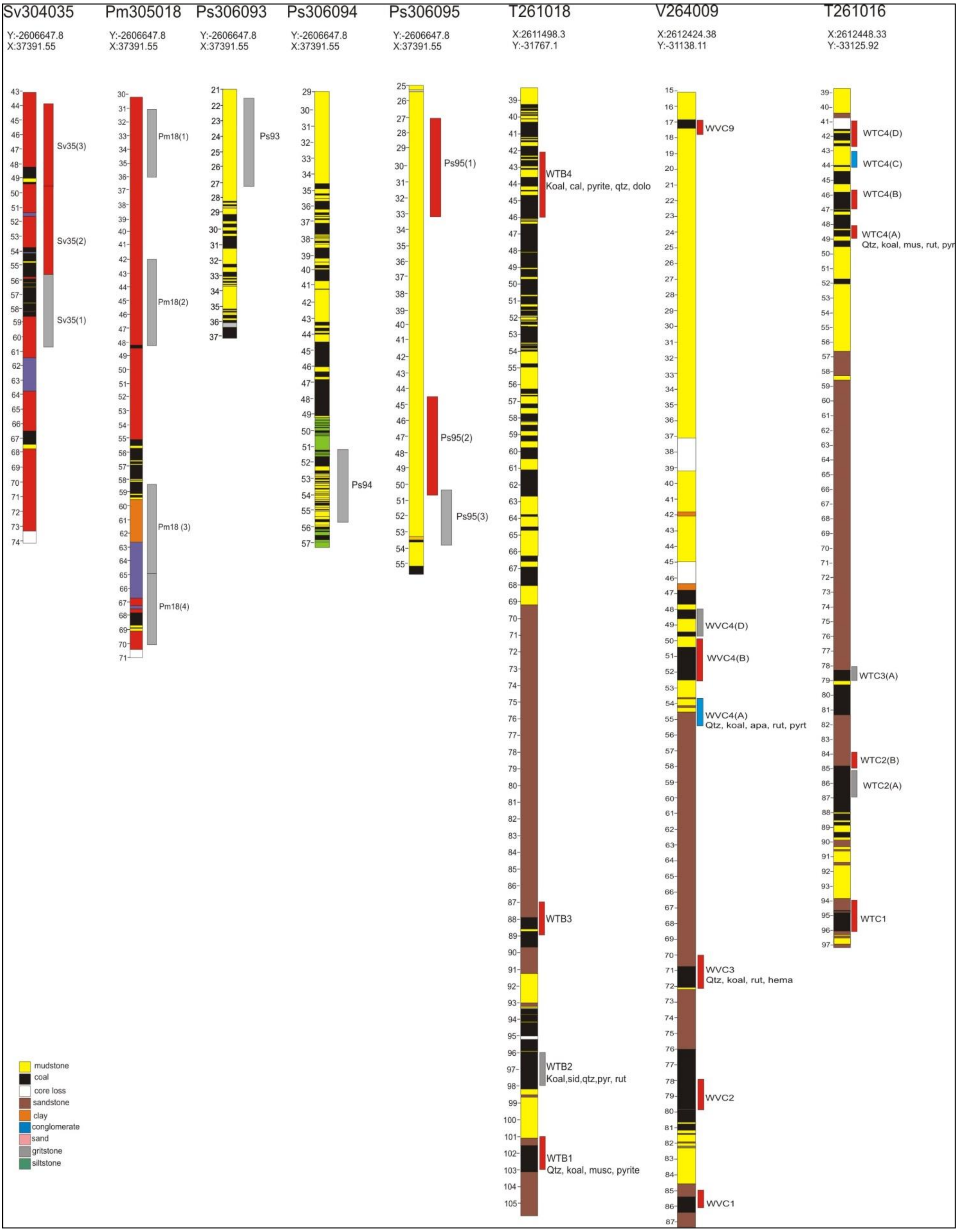

Figure 134: Partly weathered successions for Sasol and Sekoko. The sampled intervals are indicated directly next to the borehole profiles with the acid generating potentials, red - acid, blue - neutralising and grey - inconclusive results. Minerals found within the samples are also indicated where applicable.

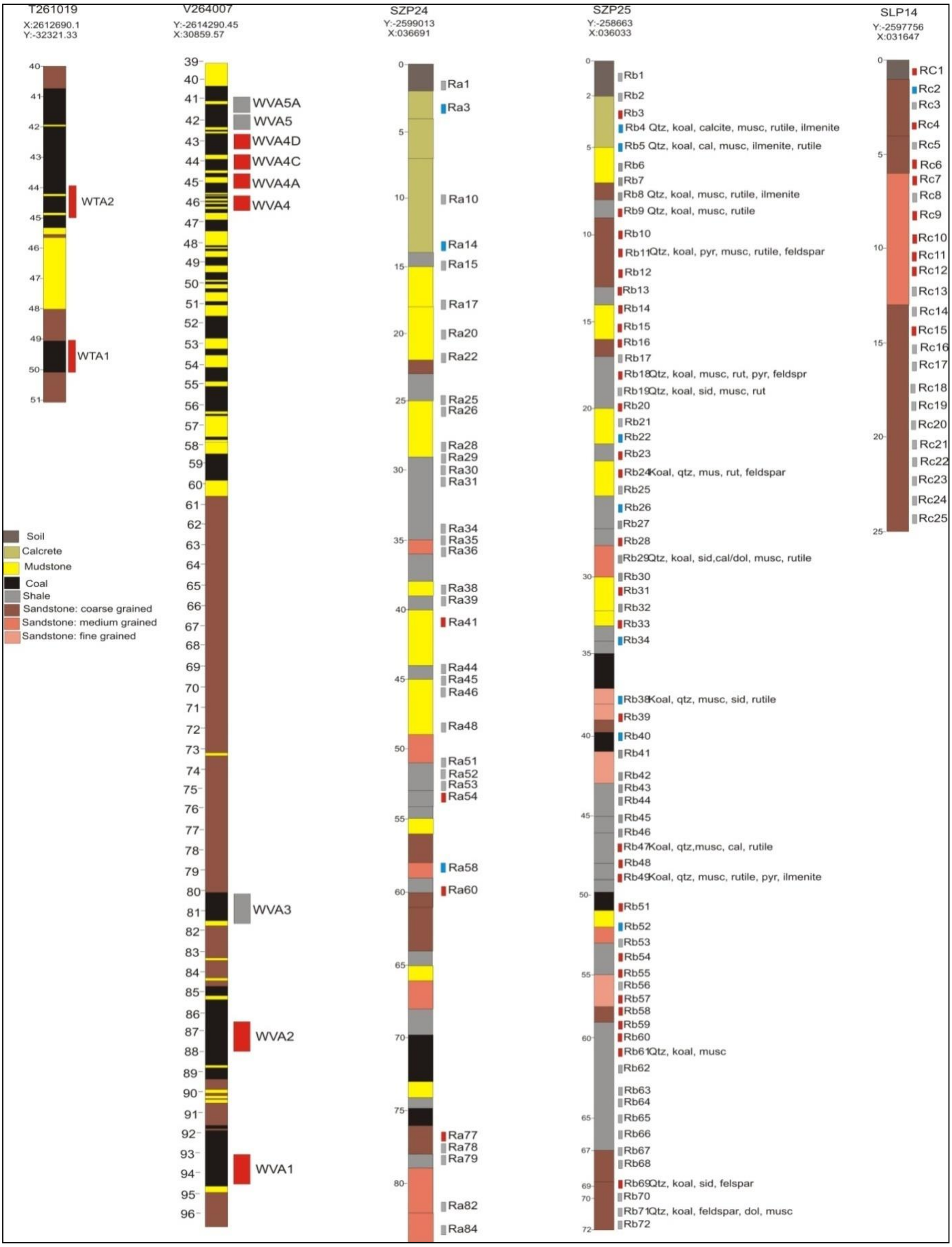

Figure 135: Weathered down to middle Ecca successions for Sasol and Resgen.The sampled intervals are indicated directly next to the borehole profiles with the acid generating potentials, red - acid, blue - neutralising and grey - inconclusive results. Minerals found within the samples are also indicated where applicable.

Table 57: The samples and combination of samples selected for kinetic testing.

sample	Kinetic name	initial pH	final pH	NNP (open)	NNP (Closed)	Succession	lithology
WGC6 (B)	S7	7.78	3.93	11.71	8.88	Full succession	mudstone/coal
WGH (165)	S8	7.86	5.93	46.87	14.51	Full succession	siltstone
WGB10 (E)	S9	8.1	1.24	-34.74	-51.33	Full succession	ss/mudstone
WGB10 (D)	S10	8.11	2.05	-7.54	-15.93	Full succession	ss/mud/coal
WGG2 (C)	S11	7.59	2.18	-64.64	-167.62	Full succession	coal/ss
WGG4 (D)	S12	8.01	4.43	-1.25	-2.97	Full succession	mudstone/ss
WGA1	S13	7.48	1.55	1.66	-5.72	Full succession	ss/coal
WGH (192)	S14	7.11	2.43	-1.28	-21.74	Full succession	siltstone
WGH (170)	S15	6.77	1.76	-10.12	-21.12	Full succession	ss
WGH (172)	S16	6.8	3.1	-0.07	-1.26	Full succession	mudstone
WGA4	S17	6.4	2.09	-82.38	-148.01	Full succession	mudstone/coal
WGC11 (B)	S18	7.53	1.53	9.41	-4.05	Full succession	mudstone/coal
WVC1	S19	3.58	1.34	-95.5	-170.51	Full succession	coal/ss
WRA4 (A)	S20	6.99	2.72	-24.8	-74.12	Full succession	ss/coal
WTC2 (B)	S21	4.64	2.2	-7.08	-10.68	Full succession	coal/ss
WGG4 (F)	S22	7.99	6.13	-4.41	-6.8	Full succession	mudstone
WGG6 (A)	S23	8.08	7.23	23.12	18.6	Full succession	mudstone
WGD2 (A)	S24	7.5	1.99	-89.71	-179.58	Full succession	ss
WRA5 (B)	S25	7.59	4.68	33.78	32.09	Full succession	mudstone/coal
WVB4 (C)	S26	3.43	1.29	-54.27	-98.34	Full succession	
WTD4 (C)	S27	7.05	1.94	-49.2	-98.12	Full succession	coal
WVC4 (B)	S28	5.5	2.34	-10.68	-12.27	Full succession	coal/mudstone
WGA3 (A)	S29	7.95	7.58	114.5	107.8	Full succession	ss/coal
WGD9	S30	5.03	1.51	-19.35	-32.8	Full succession	clay ground/mudstone
WGH (195)	S31	7.22	2.62	-2.01	-3.68	Full succession	ss
WGB4 (B)	S32	5.69	1.24	-71.52	-125.87	Full succession	coal/ss
WGB10 (C)	S33	8.04	1.45	5.56	2.36	Full succession	ss/mudstone
WGH (181)	S34	6.8	3.84	4.73	2.64	Full succession	mudstone
W1B	S35	8.13	5.42	-2.12	-2.29	Full succession	mudstone
W16B	S36	8.34	7.8	28.4	25.67	Full succession	mudstone/coal
W1A	S37	8.53	5.91	-9.78	-18.76	Full succession	mudstone

sample	Kinetic name	initial pH	final pH	NNP (open)	NNP (Closed)	Succession	lithology
W16A	S38	8.53	7.88	50.83	49.16	Full succession	mudstone/coal
DP01 (10)	SEK 1	6.94	2.08	-4.18	-4.99	Middle Ecca	
DP3 (6)	SEK 2	7.18	4.07	3.37	3.16	Middle Ecca	
DP01 (4)	SEK 3	6.17	2.97	-1.6	-2.18	Middle Ecca	
PS95 (2)	SEK 4	6.95	6.54	39.29	18.29	Partly weathered	mudstone
PS93 (1)	SEK 5	7.56	4.83	0.81	0.78	Partly weathered	mudstone
PM18 (3)	SEK 6	5.78	2.24	16.09	14.9	Partly weathered	siltstone/sandstone
VB4	G1	7.35	6.15	-1.15	-1.17	Partly weathered	shale
VA33	G2	5.79	5.79	1.91	1.83	Partly weathered	shale
JB15	G3	7.38	2.13	2.51	2.52	Partly weathered	clay
MB24	G4	7.85	6.78	3.35	-11.05	Partly weathered	shale
VD4	G5	6.38	4.06	-1.19	-0.97	Partly weathered	
VB15	G6	8.54	5.21	1.85	1.81	Partly weathered	shale
VC15	G7	6.61	6.28	1.55	1.52	Partly weathered	shale
MA5	G8	7.59	5.85	-0.17	-0.03	Partly weathered	soil
VA15	G9	8.26	7.9	3.64	3.48	Partly weathered	shale
JC11	G10	8.14	6.73	3.07	2.72	Partly weathered	shale
JA36	G11	6.58	5.44	-1.66	-1.77	Partly weathered	clay
VA2	G12	8.62	8.6	310.95	310.8	Partly weathered	shale
JA18	G13	6.37	5.69	-2.38	-2.37	Partly weathered	clay
VC32	G14	6.64	4.39	-2.37	-2.41	Partly weathered	shale
JA28	G15	7.11	5.53	-0.72	-0.68	Partly weathered	clay
MB10	G16	8.7	5.88	1.54	1.5	Partly weathered	shale
JC31	G17	7.4	5.53	-2.46	-2.53	Partly weathered	shale
JA5	G18	7.71	4.82	-4.65	-4.62	Partly weathered	ferrricreet
VC3	G19	9.42	4.29	-1.01	-1	Partly weathered	shale
JB27+VA3	Gm1	8.52	8.4	64.79	64.75	Partly weathered	
MB3+CZONE9B	Gm2	7.73	7.6	17.51	1.76	Partly weathered	
MB1+CZONE1A	Gm3	6.08	2.04	-122.90	-353.41	Partly weathered	
MB3+CZONE6B	Gm4	7.82	6.93	33.03	29.19	Partly weathered	
MB2+CZONE2A	Gm5	7.13	2.49	64.11	-36.91	Partly weathered	
VA47+PZONE10A	Gm6	7.47	3.07	-29.31	-114.04	Partly weathered	
VA43+PZONE6B	Gm7	7.78	7.31	11.02	-5.79	Partly weathered	

sample	Kinetic name	initial pH	final pH	NNP (open)	NNP (Closed)	Succession	lithology
WGA3 (A)+WGA4	Sm1	7.4	4.57	26.96	-8.70	Full succession	
WGG2+WGG4(D)+ WGG4(F)+WGG6(A)	Sm2	7.65	4.76	23.67	2.18	Full succession	
WRA4(A)+WRA5(B)	Sm3	7.3	4.44	-5.56	-36.67	Full succession	
WGA3(A)+WGB10	Sm4	8.03	6.9	100.83	87.67	Full succession	

Table 58: Saturation indices for humidity cells.

Sample - G3 (week)	Goethite	Hematite	Fe(OH)3(a)	Jarosite-K	Fe(OH)3(a)	Anhydrite	Calcite	Dolomite	Gypsum	pH
1	-999	-999	-999	-999	-999	-1.906	-2.211	-4.152	-1.602	6.62
2	7.327	16.663	1.436	-2.876	1.436	-2.245	-1.484	-2.706	-1.942	7.20
3	6.716	15.440	0.825	-4.016	0.825	-2.691	-2.276	-4.305	-2.388	6.80
4	7.605	17.218	1.714	-3.257	1.714	-2.922	-1.825	-3.407	-2.618	7.33
5	7.643	17.294	1.752	-5.308	1.752	-2.942	-0.987	-1.804	-2.639	8.00
6	8.489	18.987	2.598	-1.366	2.598	-2.861	-1.481	-2.848	-2.558	7.56
7	7.792	17.592	1.901	-3.712	1.901	-3.192	-1.743	-3.347	-2.889	7.56
8	7.893	17.794	2.002	-3.750	2.002	-3.028	-1.267	-2.441	-2.725	7.71
9	8.165	18.337	2.274	-2.262	2.274	-2.908	-1.479	-2.790	-2.605	7.52
10	7.916	17.840	2.025	-4.563	2.025	-2.706	-0.923	-1.862	-2.403	8.03
11	6.731	15.469	0.840	-4.844	0.840	-3.159	-2.551	-4.965	-2.855	6.82
12	6.731	15.469	1.230	-4.844	0.840	-3.204	-4.399	-8.679	-2.901	4.79
13	8.384	18.776	2.493	-2.423	2.493	-3.347	-2.106	-4.061	-3.044	7.60
14	6.868	15.745	0.977	-4.866	0.977	-3.291	-2.476	-4.770	-2.988	6.84
15	7.121	16.250	1.230	-4.504	1.230	-3.434	-2.408	-4.619	-3.131	6.92
16	7.677	17.363	1.786	-3.774	1.786	-3.302	-1.788	-3.509	-2.999	7.33
17	7.727	17.461	1.835	-4.278	1.835	-3.285	-1.539	-2.984	-2.981	7.49
18	7.654	17.316	1.763	-3.592	1.763	-3.407	-2.336	-4.607	-3.104	7.20
19	7.339	16.687	1.448	-4.221	1.448	-3.482	-2.513	-4.938	-3.179	7.04
20	6.404	14.817	0.513	-5.898	0.513	-3.423	-2.757	-5.370	-3.119	6.68
GM6	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	5.971	13.950	0.080	-1.588	0.080	-0.770	-1.941	-3.908	-0.467	5.86
2	6.668	15.343	0.776	-3.420	0.776	-1.047	-0.911	-1.904	-0.744	6.97
3	7.166	16.341	1.275	-2.787	1.275	-1.267	-0.997	-2.128	-0.963	7.17
4	7.883	17.774	1.992	-1.494	1.992	-1.535	-0.969	-2.087	-1.231	7.34
5	7.724	17.455	1.833	-3.484	1.833	-1.830	-0.488	-1.131	-1.527	7.67
6	7.567	17.142	1.676	-4.889	1.676	-1.872	-0.328	-0.834	-1.569	8.01
7	7.639	17.285	1.748	-3.710	1.748	-2.136	-0.838	-1.862	-1.833	7.58
8	7.868	17.744	1.977	-3.801	1.977	-2.198	-0.478	-1.129	-1.894	7.84
9	7.768	17.544	1.877	-4.361	1.877	-2.159	-0.387	-0.909	-1.856	7.92
10	7.886	17.780	1.995	-4.542	1.995	-2.036	-0.507	-1.196	-1.733	8.16
11	7.797	17.603	1.906	-3.432	1.906	-2.139	-1.029	-2.220	-1.836	7.59
12	7.963	17.934	2.072	-3.659	2.072	-2.266	-0.850	-1.884	-1.963	7.79
13	8.173	18.355	2.282	-3.305	2.282	-2.304	-0.809	-1.771	-2.000	7.92
14	7.661	17.330	1.770	-2.892	1.770	-2.231	-1.399	-2.927	-1.928	7.25
15	8.055	18.117	2.164	-3.326	2.164	-2.374	-1.038	-2.202	-2.071	7.71
16	7.654	17.316	1.763	-3.665	1.763	-2.445	-1.161	-2.505	-2.142	7.43
17	7.844	17.695	1.953	-4.489	1.953	-2.310	-0.557	-1.280	-2.007	7.91
18	7.835	17.677	1.944	-3.741	1.944	-2.357	-0.797	-1.683	-2.054	7.67
19	6.814	15.636	0.923	-4.551	0.923	-2.050	-1.450	-3.006	-1.747	7.00
20	7.157	16.322	1.266	-3.426	1.266	-1.963	-1.514	-3.129	-1.660	7.03
21	7.669	17.345	1.778	-4.892	1.778	-2.157	-0.652	-1.445	-1.853	7.95
GM3	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	3.654	9.317	-2.238	-3.547	-2.238	-0.259	-4.088	-8.129	0.043	4.64
2	2.342	6.692	-3.550	-8.957	-3.550	-0.392	-3.646	-7.317	-0.090	4.79
3	-999	-999	-999	-999	-999	-0.489	-0.433	-1.258	-0.186	6.65
4	-999	-999	-999	-999	-999	-0.620	-0.434	-1.463	-0.317	6.76
5	-999	-999	-999	-999	-999	-0.557	-0.155	-1.011	-0.254	6.90
6	-999	-999	-999	-999	-999	-0.494	0.067	-0.638	-0.191	6.97
7	-999	-999	-999	-999	-999	-0.664	0.084	-0.601	-0.361	6.78
8	-999	-999	-999	-999	-999	-0.680	-0.135	-1.065	-0.377	6.97
9	-999	-999	-999	-999	-999	-0.639	-0.255	-1.224	-0.336	6.89
10	-999	-999	-999	-999	-999	-0.552	-0.316	-1.294	-0.249	6.85
11	-999	-999	-999	-999	-999	-0.725	-0.528	-1.758	-0.422	6.85

12	-999	-999	-999	-999	-999	-0.724	-2.537	-5.790	-0.422	4.79
13	-999	-999	-999	-999	-999	-0.735	-0.552	-1.848	-0.432	6.89
14	5.779	13.566	-0.112	-3.941	-0.112	-0.693	-1.802	-3.942	-0.390	6.22
15	-999	-999	-999	-999	-999	-0.733	-0.584	-1.711	-0.430	6.86
16	-999	-999	-999	-999	-999	-0.627	-0.077	-0.907	-0.324	7.36
17	6.900	15.809	1.009	-2.072	1.009	-0.581	-0.919	-2.459	-0.278	6.70
18	-999	-999	-999	-999	-999	-0.627	-0.381	-1.418	-0.324	6.99
19	-999	-999	-999	-999	-999	-0.688	-0.623	-1.994	-0.385	6.81
20	-999	-999	-999	-999	-999	-0.702	-0.270	-1.353	-0.399	7.11
21	5.395	12.799	-0.496	-3.261	-0.496	-0.595	-2.334	-5.173	-0.291	5.66
s24	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	2.597	7.203	-3.294	-8.813	-3.294	-0.973	-999.000	-999.000	-0.670	4.64
2	-999	-999	-999	-999	-999	-0.932	-2.661	-5.461	-0.629	5.90
3	-999	-999	-999	-999	-999	-1.119	-0.934	-2.057	-0.816	7.08
4	-999	-999	-999	-999	-999	-1.196	-1.272	-2.802	-0.892	6.81
5	-999	-999	-999	-999	-999	-1.235	0.012	-0.303	-0.932	8.19
6	8.218	18.444	2.327	0.098	2.327	-1.092	-1.094	-2.500	-0.788	7.03
7	-999	-999	-999	-999	-999	-1.007	-1.107	-2.514	-0.704	6.76
8	6.298	14.604	0.407	-3.130	0.407	-1.050	-2.041	-4.460	-0.747	6.23
9	6.480	14.969	0.589	-2.512	0.589	-1.004	-1.714	-3.681	-0.700	6.33
10	5.997	14.001	0.106	-1.941	0.106	-0.862	-2.765	-5.815	-0.559	5.69
11	3.292	8.592	-2.599	-8.085	-2.599	-0.849	-3.893	-7.959	-0.545	4.96
12	1.592	5.192	-4.299	-11.249	-4.299	-0.944	-4.312	-8.835	-0.641	4.29
13	2.276	6.561	-3.615	-10.500	-3.615	-0.873	-3.709	-7.554	-0.570	4.39
14	0.665	3.338	-5.227	-13.785	-5.227	-1.046	-4.271	-8.792	-0.743	4.17
15	0.583	3.175	-5.308	-13.713	-5.308	-0.977	-4.292	-8.782	-0.674	4.11
16	0.281	2.570	-5.611	-14.436	-5.611	-1.151	-4.166	-8.596	-0.849	3.98
17	0.807	3.622	-5.085	-13.217	-5.085	-1.154	-4.320	-9.015	-0.852	4.12
18	0.028	2.068	-5.867	-13.905	-5.867	-0.989	-4.012	-8.376	-0.694	3.63
19	-0.858	0.293	-6.749	-15.908	-6.749	-0.968	-999.000	-999.000	-0.665	3.33
20	-2.423	-2.837	-8.314	-20.098	-8.314	-1.018	-999.000	-999.000	-0.715	3.11
21	-2.101	-2.193	-7.992	-18.437	-7.992	-1.015	-999.000	-999.000	-0.712	2.91
S19	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	-4.856	-7.704	-10.747	-23.691	-10.747	-0.716	-999	-999	-0.413	2.24
2	-2.276	-2.543	-8.167	-999	-8.167	-0.797	-999	-999	-0.495	2.74
3	-2.549	-3.090	-8.440	-999	-8.440	-1.002	-999	-999	-0.699	2.66
4	-2.669	-3.330	-8.560	-999	-8.560	-1.063	-999	-999	-0.760	2.60
5	11.275	24.558	5.384	-999	5.384	-1.240	-999	-999	-0.937	7.53
6	-6.851	-11.694	-12.742	-999	-12.742	-1.590	-999	-999	-1.287	2.45
7	-6.268	-10.529	-12.160	-999	-12.160	-1.795	-999	-999	-1.492	2.64
8	-3.442	-4.876	-9.333	-999	-9.333	-2.053	-999	-999	-1.750	2.39
9	-3.495	-4.983	-9.387	-999	-9.387	-2.067	-999	-999	-1.764	2.35
10	-3.075	-4.142	-8.967	-999	-8.967	-2.172	-999	-999	-1.869	2.44
11	-4.385	-6.761	-10.276	-999	-10.276	-2.327	-999	-999	-2.024	2.00
12	-4.231	-6.454	-10.123	-999	-10.123	-2.429	-999	-999	-2.126	2.10
13	-2.302	-2.596	-8.193	-999	-8.193	-2.500	-999	-999	-2.197	2.79
14	-3.543	-5.079	-9.434	-999	-9.434	-2.544	-999	-999	-2.241	2.40
15	-3.695	-5.381	-9.586	-999	-9.586	-2.616	-999	-999	-2.313	2.32
16	-3.614	-5.220	-9.505	-999	-9.505	-2.531	-999	-999	-2.228	2.38
17	-3.444	-4.880	-9.335	-20.858	-9.335	-2.823	-999	-999	-2.521	2.16
18	-3.830	-5.653	-9.721	-21.852	-9.721	-2.470	-999	-999	-2.167	2.32
19	-3.586	-5.163	-9.477	-999	-9.477	-2.401	-999	-999	-2.098	2.44
20	-3.955	-5.903	-9.846	-999	-9.846	-2.822	-999	-999	-2.518	2.39
21	-3.796	-5.583	-9.687	-999	-9.687	-2.740	-999	-999	-2.437	2.35
SM1	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	0.386	2.780	-5.505	-12.618	-5.505	-0.910	-999	-999	-0.607	3.92
2	1.356	4.719	-4.536	-11.707	-4.536	-0.940	-999	-999	-0.637	4.46

3	-1.262	-0.516	-7.153	-19.286	-7.153	-1.059	-999	-999	-0.756	4.26
4	-1.797	-1.585	-7.688	-19.935	-7.688	-1.045	-999	-999	-0.742	3.93
5	-2.972	-3.935	-8.863	-22.453	-8.863	-1.160	-999	-999	-0.857	3.50
6	-2.551	-3.093	-8.442	-21.366	-8.442	-0.992	-999	-999	-0.689	3.57
7	-3.820	-5.633	-9.712	-24.909	-9.712	-0.897	-999	-999	-0.594	3.49
8	-3.123	-4.238	-9.014	-21.479	-9.014	-1.036	-999	-999	-0.733	3.07
9	-3.191	-4.373	-9.082	-21.329	-9.082	-1.012	-999	-999	-0.709	2.96
10	-2.971	-3.934	-8.862	-20.295	-8.862	-0.903	-999	-999	-0.600	2.86
11	-4.081	-6.154	-9.972	-22.420	-9.972	-0.916	-999	-999	-0.613	2.41
12	-3.798	-5.588	-9.689	-22.073	-9.689	-1.029	-999	-999	-0.726	2.47
13	-3.479	-4.950	-9.370	-21.492	-9.370	-1.085	-999	-999	-0.782	2.59
14	-3.538	-5.067	-9.429	-21.789	-9.429	-1.286	-999	-999	-0.983	2.59
15	-3.662	-5.316	-9.553	-21.890	-9.553	-1.285	-999	-999	-0.981	2.49
16	-3.506	-5.003	-9.397	-21.818	-9.397	-1.539	-999	-999	-1.236	2.60
17	-4.144	-6.279	-10.035	-23.154	-10.035	-1.512	-999	-999	-1.209	2.36
18	-3.930	-5.852	-9.821	-22.822	-9.821	-1.588	-999	-999	-1.285	2.45
19	-3.929	-5.850	-9.820	-22.836	-9.820	-1.736	-999	-999	-1.433	2.47
20	-3.995	-5.982	-9.886	-23.187	-9.886	-1.857	-999	-999	-1.554	2.47
21	-3.958	-5.907	-9.849	-23.779	-9.849	-2.148	-999	-999	-1.844	2.58

SM4	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	0.635	3.279	-5.256	-11.952	-5.256	-0.795	-999.000	-999.000	-0.492	4.01
2	3.527	9.062	-2.364	-8.355	-2.364	-0.987	-3.062	-6.123	-0.684	5.49
3	5.217	12.442	-0.674	-6.505	-0.674	-1.084	-1.888	-3.867	-0.780	6.44
4	4.893	11.794	-0.998	-7.163	-0.998	-1.126	-2.115	-4.391	-0.823	6.28
5	4.654	11.317	-1.237	-7.896	-1.237	-1.211	-2.228	-4.695	-0.908	6.20
6	4.461	10.930	-1.430	-8.588	-1.430	-1.199	-2.146	-4.613	-0.895	6.21
7	3.490	8.988	-2.401	-10.456	-2.401	-1.127	-2.542	-5.461	-0.824	5.89
8	5.020	12.047	-0.871	-7.045	-0.871	-1.289	-2.181	-4.750	-0.986	6.26
9	4.685	11.378	-1.206	-7.789	-1.206	-1.266	-2.097	-4.577	-0.962	6.22
10	-1.052	-0.095	-6.943	-18.935	-6.943	-1.225	-4.273	-8.902	-0.922	4.18
11	-1.477	-0.946	-7.368	-19.885	-7.368	-1.220	-4.336	-8.975	-0.918	4.09
12	-2.122	-2.235	-8.014	-21.504	-8.014	-1.403	-4.410	-9.108	-1.101	3.87
13	0.583	3.173	-5.309	-16.154	-5.309	-1.438	-4.441	-9.190	-1.135	4.79
14	-2.024	-2.038	-7.916	-21.192	-7.916	-1.550	-4.281	-8.871	-1.249	3.83
15	-2.213	-2.417	-8.106	-21.409	-8.106	-1.392	-4.274	-8.839	-1.092	3.77
16	-1.879	-1.747	-7.773	-20.133	-7.773	-1.538	-4.308	-8.900	-1.241	3.66
17	-1.891	-1.774	-7.783	-21.116	-7.783	-1.411	-4.329	-8.999	-1.109	4.00
18	-2.762	-3.512	-8.658	-22.545	-8.658	-1.430	-4.157	-8.655	-1.136	3.59
19	-3.101	-4.193	-8.992	-23.024	-8.992	-1.473	-999	-999	-1.169	3.42
20	-3.183	-4.358	-9.074	-23.571	-9.074	-1.479	-999	-999	-1.176	3.49
21	-3.302	-4.596	-9.193	-23.667	-9.193	-1.579	-999	-999	-1.276	3.39

SM3	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	1.419	4.846	-4.473	-10.853	-4.473	-0.862	-4.328	-8.556	-0.559	4.27
2	4.004	10.017	-1.887	-9.790	-1.887	-0.889	-1.753	-3.358	-0.586	6.40
3	6.240	14.488	0.349	-4.702	0.349	-1.050	-1.086	-2.150	-0.747	6.78
4	6.213	14.434	0.322	-4.921	0.322	-1.106	-1.046	-2.185	-0.803	6.77
5	6.307	14.622	0.416	-4.841	0.416	-1.126	-1.087	-2.354	-0.823	6.80
6	7.264	16.536	1.373	-3.179	1.373	-1.175	-0.688	-1.578	-0.872	7.17
7	6.733	15.473	0.842	-4.158	0.842	-1.155	-0.640	-1.504	-0.852	6.99
8	7.044	16.097	1.153	-3.942	1.153	-1.393	-0.543	-1.327	-1.089	7.11
9	7.046	16.101	1.155	-3.813	1.155	-1.669	-0.905	-2.005	-1.366	6.96
10	7.242	16.492	1.351	-3.883	1.351	-1.533	-0.805	-1.747	-1.230	7.24
11	7.586	17.180	1.695	-2.372	1.695	-1.594	-1.063	-2.206	-1.291	7.06
12	5.646	13.301	-0.245	-6.321	-0.245	-1.499	-1.848	-3.745	-1.196	6.45
13	0.923	3.854	-4.969	-15.851	-4.969	-1.743	-3.103	-6.242	-1.441	4.79
14	6.937	15.883	1.046	-4.166	1.046	-1.882	-1.378	-2.791	-1.578	6.88
15	5.434	12.875	-0.458	-6.187	-0.458	-1.621	-2.085	-4.189	-1.318	6.13
16	7.250	16.507	1.359	-3.561	1.359	-1.816	-1.306	-2.647	-1.513	7.01
17	7.439	16.886	1.548	-3.652	1.548	-1.849	-1.046	-2.168	-1.546	7.21

18	7.419	16.847	1.528	-3.812	1.528	-1.838	-0.901	-1.811	-1.535	7.25
19	6.589	15.186	0.698	-4.934	0.698	-1.887	-1.636	-3.256	-1.584	6.78
20	7.322	16.651	1.430	-3.952	1.430	-1.940	-1.289	-2.564	-1.636	7.14
21	6.855	15.718	0.964	-4.392	0.964	-1.919	-1.489	-2.929	-1.616	6.87
SM2	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	4.621	11.250	-1.270	-6.040	-1.270	-1.479	-3.230	-6.641	-1.176	5.61
2	-999.000	-999.000	-999.000	-999.000	-999.000	-1.301	-1.436	-3.101	-0.997	6.81
3	7.675	17.358	1.784	-2.382	1.784	-1.729	-0.952	-2.144	-1.426	7.25
4	7.044	16.097	1.153	-4.172	1.153	-2.184	-1.472	-3.163	-1.881	7.03
5	7.647	17.301	1.756	-4.075	1.756	-2.495	-1.237	-2.669	-2.192	7.46
6	7.856	17.719	1.964	-4.912	1.964	-2.492	-0.683	-1.583	-2.189	7.94
7	8.758	19.525	2.867	-2.412	2.867	-2.431	-0.874	-1.980	-2.128	8.04
8	7.779	17.566	1.888	-4.846	1.888	-2.715	-0.901	-2.031	-2.412	7.78
9	7.749	17.506	1.858	-5.496	1.858	-2.729	-0.558	-1.350	-2.426	7.95
10	7.833	17.673	1.942	-4.656	1.942	-2.697	-1.001	-2.198	-2.393	7.77
11	8.006	18.019	2.115	-5.496	2.115	-2.656	-0.621	-1.487	-2.352	8.24
12	6.210	14.429	0.319	-6.217	0.319	-2.795	-2.479	-5.169	-2.492	6.58
13	6.782	15.572	0.891	-5.154	0.891	-2.757	-1.903	-4.042	-2.454	6.79
14	8.048	18.105	2.157	-3.521	2.157	-3.006	-1.684	-3.592	-2.703	7.43
15	6.559	15.126	0.668	-5.450	0.668	-2.638	-2.028	-4.273	-2.335	6.69
16	8.002	18.011	2.111	-3.981	2.111	-3.094	-1.668	-3.553	-2.790	7.51
17	7.547	17.102	1.656	-3.974	1.656	-3.005	-1.797	-3.876	-2.701	7.09
18	7.181	16.370	1.290	-4.436	1.290	-2.699	-1.740	-3.780	-2.396	6.97
19	6.462	14.933	0.571	-5.431	0.571	-2.442	-2.216	-4.719	-2.139	6.71
20	6.825	15.659	0.934	-5.569	0.934	-2.909	-2.198	-4.683	-2.606	6.91
21	5.936	13.880	0.045	-6.635	0.045	-2.749	-2.535	-5.330	-2.446	6.48
GM7	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	7.711	17.431	1.820	-3.697	1.820	-3.208	-1.655	-3.518	-2.905	6.71
2	6.997	16.001	1.106	-4.581	1.106	-2.724	-1.545	-3.292	-2.420	7.26
3	7.211	16.430	1.320	-4.936	1.320	-3.303	-1.870	-3.969	-2.999	6.95
4	8.104	18.217	2.213	-2.075	2.213	-2.258	-1.023	-2.215	-1.954	7.44
5	8.041	18.089	2.150	-3.568	2.150	-3.014	-1.185	-2.675	-2.711	7.85
6	7.770	17.549	1.879	-3.877	1.879	-2.933	-1.472	-3.190	-2.630	8.08
7	7.746	17.499	1.855	-4.021	1.855	-2.886	-1.240	-2.815	-2.582	8.01
8	8.028	18.065	2.137	-3.720	2.137	-2.952	-0.865	-1.919	-2.649	7.68
9	8.648	19.305	2.757	-2.524	2.757	-3.224	-1.502	-3.240	-2.920	8.15
10	7.261	16.530	1.370	-3.139	1.370	-1.347	-0.554	-1.302	-1.044	8.09
11	6.705	15.418	0.814	-4.242	0.814	-1.777	-1.386	-2.942	-1.473	6.94
12	8.222	18.452	2.331	-3.911	2.331	-3.120	-1.361	-2.998	-2.817	7.51
13	8.109	18.225	2.218	-4.448	2.218	-3.078	-0.824	-1.899	-2.774	7.73
14	8.042	18.092	2.151	-4.775	2.151	-2.827	-0.560	-1.388	-2.524	7.38
15	7.754	17.516	1.863	-4.703	1.863	-2.507	-0.563	-1.311	-2.204	7.74
16	7.709	17.425	1.818	-5.649	1.818	-2.842	-0.623	-1.477	-2.539	7.44
17	7.839	17.686	1.948	-5.353	1.948	-2.801	-0.616	-1.373	-2.497	7.97
18	7.756	17.520	1.865	-5.899	1.865	-2.898	-0.456	-1.028	-2.594	7.87
19	7.679	17.365	1.788	-5.527	1.788	-2.548	-0.450	-1.111	-2.245	7.01
20	8.061	18.131	2.170	-6.094	2.170	-3.334	-0.950	-2.171	-3.031	7.16
21	-999	-999	-999	-999	-999	-1.383	-0.776	-1.703	-1.080	8.23
GM5	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	5.253	12.515	-0.638	-1.532	-0.638	-0.379	-2.940	-6.071	-0.077	5.25
1	-0.362	1.285	-6.253	-16.279	-6.253	-0.469	-3.926	-8.177	-0.166	4.35
2	6.355	14.718	0.464	-4.003	0.464	-0.606	-0.420	-1.200	-0.303	6.88
3	6.748	15.504	0.857	-3.171	0.857	-0.677	-0.475	-1.401	-0.374	6.95
4	6.921	15.850	1.030	-3.011	1.030	-0.621	-0.136	-0.833	-0.318	7.06
5	6.717	15.443	0.826	-3.260	0.826	-0.560	-0.136	-0.917	-0.257	6.95
6	6.458	14.924	0.567	-4.178	0.567	-0.801	-0.468	-1.575	-0.498	6.93
7	7.218	16.444	1.327	-2.555	1.327	-0.762	-0.159	-0.981	-0.459	7.17
8	7.048	16.105	1.157	-3.146	1.157	-0.748	-0.189	-0.985	-0.445	7.18
9	7.584	17.175	1.692	-2.190	1.692	-0.699	-0.167	-0.957	-0.396	7.42

10	6.774	15.557	0.883	-3.377	0.883	-0.691	-0.470	-1.534	-0.388	6.98
11	6.378	14.765	0.487	-4.044	0.487	-0.747	-0.662	-1.951	-0.444	6.79
12	7.021	16.050	1.130	-2.833	1.130	-0.881	-0.790	-2.224	-0.578	6.96
13	6.335	14.678	0.444	-4.089	0.444	-0.720	-1.037	-2.701	-0.417	6.77
14	6.985	15.978	1.094	-2.950	1.094	-0.818	-0.909	-2.459	-0.515	6.97
15	6.611	15.230	0.720	-3.848	0.720	-0.789	-0.856	-2.421	-0.486	6.94
16	7.107	16.221	1.216	-3.126	1.216	-0.772	-0.513	-1.720	-0.469	7.15
17	6.127	14.263	0.236	-4.640	0.236	-0.687	-1.103	-2.832	-0.384	6.74
18	5.925	13.859	0.034	-5.398	0.034	-0.825	-1.201	-3.032	-0.522	6.71
19	6.756	15.520	0.865	-3.392	0.865	-0.678	-0.736	-2.090	-0.375	6.94
20	5.997	14.001	0.106	-4.927	0.106	-0.767	-1.241	-3.083	-0.464	6.68
G5	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	5.0276	12.0632	-0.8635	-6.6799	-0.8635	-1.5992	-2.7639	-5.5963	-1.296	6.27
2	4.9788	11.9657	-0.9123	-7.5613	-0.9123	-1.1364	-1.6707	-3.453	-0.8332	6.71
3	5.4861	12.9802	-0.405	-6.2302	-0.405	-1.5597	-2.1806	-4.5223	-1.2564	6.52
4	6.0743	14.1565	0.1832	-5.1713	0.1832	-1.572	-2.0006	-4.2033	-1.2687	6.72
5	7.096	16.2001	1.205	-3.3555	1.205	-1.7003	-1.7153	-3.6438	-1.397	7.06
6	7.8897	17.7875	1.9987	-2.2495	1.9987	-1.6358	-1.3698	-3.0546	-1.3325	7.51
7	6.0711	14.1502	0.18	-5.1356	0.18	-1.5732	-1.9822	-4.3651	-1.27	6.68
8	7.3313	16.6706	1.4402	-3.4944	1.4402	-1.8039	-1.3899	-3.1669	-1.5005	7.28
9	7.8667	17.7415	1.9757	-3.3003	1.9757	-2.0949	-0.9473	-2.3126	-1.7915	7.64
10	8.0528	18.1136	2.1618	-3.7407	2.1618	-2.2932	-1.1296	-2.6485	-1.9899	7.88
11	7.8617	17.7314	1.9707	-6.3993	1.9707	-2.5961	-0.7281	-1.744	-2.2928	8.45
12	7.949	17.9061	2.058	-4.7265	2.058	-2.9582	-1.4992	-3.4485	-2.6549	7.86
13	8.4012	18.8104	2.5102	-3.7113	2.5102	-3.4308	-1.8057	-4.0679	-3.1274	7.79
14	8.5246	19.0572	2.6336	-4.6628	2.6336	-3.8319	-1.798	-4.0015	-3.5285	8.17
15	7.972	17.952	2.081	-4.6315	2.081	-3.9366	-2.3564	-4.8703	-3.6332	7.44
16	7.9489	17.9057	2.0578	-4.3452	2.0578	-4.7158	-3.3584	-6.9052	-4.4124	7.17
17	7.3782	16.7643	1.4871	-5.8307	1.4871	-4.438	-2.5582	-5.3808	-4.1346	7.16
18	8.0742	18.1565	2.1832	-4.7412	2.1832	-4.7784	-2.509	-5.208	-4.475	7.25
19	7.1093	16.2265	1.2183	-6.3668	1.2183	-5.5271	-4.35	-8.6786	-5.2237	6.77
20	6.6057	15.2195	0.7147	-7.7709	0.7147	-5.6718	-4.3915	-8.8839	-5.3684	6.70
21	5.897	13.8021	0.006	-8.9828	0.006	-5.2861	-4.1579	-8.4177	-4.9827	6.43
GM6	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	5.971	13.9502	0.0799	-1.5882	0.0799	-0.7701	-1.9409	-3.9083	-0.467	5.86
2	6.6675	15.3431	0.7764	-3.42	0.7764	-1.0468	-0.9112	-1.9039	-0.7436	6.97
3	7.1664	16.3409	1.2754	-2.7873	1.2754	-1.2666	-0.997	-2.1279	-0.9633	7.17
4	7.8831	17.7743	1.9921	-1.4937	1.9921	-1.5346	-0.9689	-2.0865	-1.2313	7.34
5	7.7237	17.4554	1.8326	-3.4835	1.8326	-1.8304	-0.4875	-1.131	-1.5271	7.67
6	7.5669	17.1419	1.6759	-4.8885	1.6759	-1.8723	-0.3275	-0.8337	-1.569	8.01
7	7.6387	17.2854	1.7477	-3.71	1.7477	-2.1361	-0.8381	-1.8619	-1.8328	7.58
8	7.8679	17.7438	1.9769	-3.8007	1.9769	-2.1975	-0.4782	-1.1291	-1.8942	7.84
9	7.7681	17.5442	1.8771	-4.3605	1.8771	-2.1593	-0.3867	-0.9088	-1.856	7.92
10	7.8859	17.7798	1.9948	-4.5417	1.9948	-2.0362	-0.5069	-1.1957	-1.7329	8.16
11	7.7973	17.6027	1.9063	-3.4315	1.9063	-2.1393	-1.0287	-2.2196	-1.8359	7.59
12	7.9628	17.9335	2.0717	-3.6588	2.0717	-2.2664	-0.8496	-1.8842	-1.9631	7.79
13	8.1733	18.3547	2.2823	-3.3054	2.2823	-2.3037	-0.8093	-1.7714	-2.0004	7.92
14	7.661	17.33	1.7699	-2.8923	1.7699	-2.231	-1.3992	-2.927	-1.9277	7.25
15	8.0545	18.117	2.1635	-3.3263	2.1635	-2.374	-1.0378	-2.2021	-2.0706	7.71
16	7.6539	17.3159	1.7629	-3.6653	1.7629	-2.4453	-1.161	-2.5052	-2.142	7.43
17	7.8435	17.695	1.9525	-4.4888	1.9525	-2.3102	-0.5568	-1.2802	-2.0068	7.91
18	7.8347	17.6773	1.9436	-3.7411	1.9436	-2.3571	-0.7973	-1.6834	-2.0537	7.67
19	6.8141	15.6361	0.923	-4.5514	0.923	-2.05	-1.4501	-3.0058	-1.7467	7.00
20	7.1568	16.3216	1.2658	-3.4262	1.2658	-1.9633	-1.5141	-3.1286	-1.66	7.03
1	7.6685	17.3451	1.7775	-4.892	1.7775	-2.1565	-0.652	-1.4449	-1.8531	7.95
GM5	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	5.2532	12.5147	-0.6382	-1.5316	-0.6382	-0.3794	-2.9402	-6.0706	-0.0767	5.25
2	-0.3618	1.2848	-6.253	-16.2787	-6.253	-0.4689	-3.9264	-8.1766	-0.1661	4.35
3	6.355	14.7182	0.4639	-4.003	0.4639	-0.6064	-0.42	-1.2003	-0.3033	6.88

4	6.748	15.5041	0.8568	-3.171	0.8568	-0.6774	-0.4749	-1.4008	-0.3743	6.95
5	6.921	15.8501	1.0298	-3.0105	1.0298	-0.6207	-0.1357	-0.8331	-0.3177	7.06
6	6.7173	15.4427	0.8261	-3.2599	0.8261	-0.5604	-0.136	-0.9166	-0.2574	6.95
7	6.4582	14.9244	0.567	-4.1779	0.567	-0.8013	-0.4675	-1.5752	-0.4981	6.93
8	7.2182	16.4444	1.327	-2.555	1.327	-0.7624	-0.1591	-0.9806	-0.4592	7.17
9	7.0482	16.1046	1.1571	-3.1462	1.1571	-0.7482	-0.1889	-0.9853	-0.445	7.18
10	7.5836	17.1753	1.6924	-2.1897	1.6924	-0.6991	-0.1669	-0.9572	-0.396	7.42
11	6.7743	15.5568	0.8832	-3.3773	0.8832	-0.6908	-0.47	-1.5339	-0.3877	6.98
12	6.3783	14.7647	0.4872	-4.0437	0.4872	-0.7472	-0.6616	-1.9507	-0.4441	6.79
13	7.0209	16.0498	1.1298	-2.8325	1.1298	-0.8813	-0.7904	-2.2235	-0.5781	6.96
14	6.3351	14.6784	0.444	-4.0891	0.444	-0.7203	-1.0366	-2.701	-0.4172	6.77
15	6.9848	15.9776	1.0937	-2.9501	1.0937	-0.8177	-0.9087	-2.459	-0.5145	6.97
16	6.6107	15.2295	0.7196	-3.8482	0.7196	-0.7892	-0.8563	-2.421	-0.486	6.94
17	7.1066	16.2214	1.2155	-3.1258	1.2155	-0.7721	-0.5134	-1.7199	-0.4689	7.15
18	6.1274	14.263	0.2363	-4.6403	0.2363	-0.6866	-1.1028	-2.8318	-0.3835	6.74
19	5.9254	13.8588	0.0343	-5.3984	0.0343	-0.825	-1.2013	-3.0321	-0.5218	6.71
20	6.7559	15.52	0.8648	-3.3921	0.8648	-0.6781	-0.7355	-2.0901	-0.3749	6.94
1	5.9966	14.0012	0.1055	-4.9274	0.1055	-0.7673	-1.2413	-3.0826	-0.4641	6.68
GM4	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	6.0027	14.0135	0.1116	-4.4156	0.1116	-1.3408	-1.1139	-2.3703	-1.0376	6.40
2	7.4228	16.8537	1.5318	-2.8641	1.5318	-1.3574	-0.6078	-1.4143	-1.0542	7.25
3	7.3451	16.6983	1.4541	-3.5645	1.4541	-1.7718	-0.9512	-2.118	-1.4685	7.27
4	8.1779	18.3638	2.2869	-2.4505	2.2869	-2.2047	-0.878	-1.9837	-1.9014	7.60
5	7.7525	17.5131	1.8615	-5.8392	1.8615	-2.4961	-0.3185	-0.91	-2.1928	8.19
6	7.529	17.066	1.6379	-6.8061	1.6379	-2.609	-0.3163	-1.0025	-2.3057	8.32
7	7.7377	17.4833	1.8466	-6.8935	1.8466	-2.9411	-0.4771	-1.3199	-2.6377	8.40
8	7.9806	17.9692	2.0896	-6.2422	2.0896	-3.019	-0.289	-0.9493	-2.7157	8.42
9	7.8073	17.6227	1.9163	-7.0609	1.9163	-3.0696	-0.284	-0.9379	-2.7663	8.50
10	7.8206	17.6493	1.9296	-7.6338	1.9296	-3.274	-0.6088	-1.6221	-2.9706	8.69
11	7.8772	17.7624	1.9862	-6.4581	1.9862	-3.1591	-0.8323	-2.1064	-2.8558	8.32
12	7.8815	17.7709	1.9904	-7.9564	1.9904	-3.2044	-0.3882	-1.2705	-2.901	8.79
13	8.2493	18.5066	2.3583	-5.3285	2.3583	-3.3283	-1.1244	-2.6508	-3.025	8.27
14	7.9997	18.0074	2.1087	-4.175	2.1087	-2.9325	-1.2795	-2.9352	-2.6292	7.75
15	8.1146	18.2372	2.2236	-4.7636	2.2236	-3.1253	-1.1924	-2.7447	-2.8219	7.95
16	7.5846	17.1772	1.6936	-4.5827	1.6936	-3.102	-1.6489	-3.7315	-2.7987	7.40
17	7.7902	17.5884	1.8992	-5.9441	1.8992	-3.0798	-0.7883	-2.0199	-2.7764	8.00
18	7.8956	17.7992	2.0046	-5.5945	2.0046	-3.2054	-0.942	-2.2381	-2.902	8.01
19	7.6705	17.349	1.7795	-5.6652	1.7795	-3.2854	-1.4427	-3.2732	-2.982	7.76
20	7.8596	17.7273	1.9686	-4.4478	1.9686	-3.347	-1.7052	-3.752	-3.0436	7.51
1	7.7297	17.4674	1.8387	-6.1731	1.8387	-3.2211	-1.1291	-2.6206	-2.9178	7.99
GM3	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	3.6539	9.3165	-2.2378	-3.5469	-2.2378	-0.2585	-4.0884	-8.1285	0.0434	4.64
2	2.3416	6.6916	-3.5496	-8.9567	-3.5496	-0.3923	-3.6463	-7.3174	-0.0895	4.79
3	-999	-999	-999	-999	-999	-0.4892	-0.4329	-1.2581	-0.1862	6.65
4	-999	-999	-999	-999	-999	-0.6201	-0.4342	-1.4625	-0.317	6.76
5	-999	-999	-999	-999	-999	-0.5574	-0.1546	-1.0106	-0.2544	6.90
6	-999	-999	-999	-999	-999	-0.4943	0.0671	-0.6379	-0.1913	6.97
7	-999	-999	-999	-999	-999	-0.6642	0.0836	-0.6011	-0.3612	6.78
8	-999	-999	-999	-999	-999	-0.68	-0.1346	-1.0652	-0.3769	6.97
9	-999	-999	-999	-999	-999	-0.6389	-0.2552	-1.2236	-0.3358	6.89
10	-999	-999	-999	-999	-999	-0.5516	-0.3157	-1.2935	-0.2485	6.85
11	-999	-999	-999	-999	-999	-0.725	-0.5281	-1.7575	-0.4218	6.85
12	-999	-999	-999	-999	-999	-0.7241	-2.537	-5.79	-0.4215	4.79
13	-999	-999	-999	-999	-999	-0.7347	-0.5516	-1.8482	-0.4315	6.89
14	5.779	13.5662	-0.1121	-3.9412	-0.1121	-0.6926	-1.8018	-3.9419	-0.3895	6.22
15	-999	-999	-999	-999	-999	-0.7327	-0.5835	-1.7109	-0.4296	6.86
16	-999	-999	-999	-999	-999	-0.627	-0.0773	-0.9072	-0.3239	7.36
17	6.9004	15.8089	1.0092	-2.072	1.0092	-0.5808	-0.9188	-2.4587	-0.2778	6.70
18	-999	-999	-999	-999	-999	-0.627	-0.3814	-1.4176	-0.3239	6.99
19	-999	-999	-999	-999	-999	-0.6884	-0.623	-1.9941	-0.3853	6.81

20	-999	-999	-999	-999	-999	-0.7018	-0.2702	-1.3534	-0.3986	7.11
1	5.3953	12.7988	-0.4958	-3.2606	-0.4958	-0.5945	-2.3338	-5.173	-0.2914	5.66
GM2	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	3.4006	8.8093	-2.4905	-7.1784	-2.4905	-1.1345	-3.6409	-7.254	-0.8314	4.98
2	4.7733	11.5548	-1.1177	-7.2954	-1.1177	-1.1548	-1.6948	-3.4507	-0.8516	6.28
3	6.1833	14.3746	0.2922	-4.9286	0.2922	-1.5923	-1.3489	-2.7665	-1.289	6.74
4	6.9803	15.9687	1.0893	-3.8317	1.0893	-1.933	-1.1972	-2.4371	-1.6297	7.03
5	7.3302	16.6684	1.4392	-3.543	1.4392	-2.0865	-0.9719	-1.9811	-1.7832	7.20
6	7.1442	16.2964	1.2531	-3.7287	1.2531	-2.0846	-1.0832	-2.2058	-1.7813	7.10
7	7.5992	17.2063	1.7081	-3.5857	1.7081	-2.3178	-0.9074	-1.8596	-2.0144	7.43
8	7.5691	17.1461	1.678	-3.7145	1.678	-2.4326	-0.9186	-1.8672	-2.1292	7.39
9	7.6334	17.2748	1.7424	-3.8137	1.7424	-2.3829	-0.9722	-1.9465	-2.0796	7.48
10	7.7355	17.479	1.8445	-5.5255	1.8445	-2.4281	-0.5589	-1.1725	-2.1247	8.14
11	6.6024	15.2129	0.7114	-4.9165	0.7114	-2.5197	-2.1315	-4.31	-2.2163	6.75
12	0.4295	2.8672	-5.4617	-17.3354	-5.4617	-2.3178	-3.6018	-7.2155	-2.0148	4.79
13	8.0047	18.0174	2.1137	-3.6531	2.1137	-2.7163	-1.1185	-2.2366	-2.413	7.65
14	7.8689	17.7459	1.9779	-3.0351	1.9779	-2.5305	-1.4975	-3.0075	-2.2271	7.38
15	7.7977	17.6033	1.9066	-3.3915	1.9066	-2.8378	-1.8012	-3.6008	-2.5344	7.30
16	7.5206	17.0492	1.6296	-4.0741	1.6296	-2.6238	-1.2394	-2.5276	-2.3205	7.33
17	7.7292	17.4665	1.8382	-4.9798	1.8382	-2.6964	-0.81	-1.63	-2.3931	7.80
18	7.7067	17.4215	1.8157	-4.7771	1.8157	-2.9245	-1.3458	-2.6615	-2.6212	7.66
19	7.5124	17.0328	1.6213	-4.6836	1.6213	-3.005	-0.6781	-1.2928	-2.7017	7.36
20	6.6809	15.3697	0.7898	-5.6752	0.7898	-2.989	-2.173	-4.27	-2.6856	6.88
GM1	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	7.6176	17.2433	1.7266	-4.6254	1.7266	-2.5761	-0.3814	-0.1753	-2.2728	8.10
2	-999	-999	-999	-999	-999	-3.2113	-1.0284	-1.847	-2.9079	8.04
3	7.7604	17.5287	1.8693	-4.3405	1.8693	-3.777	-1.4902	-2.6816	-3.4737	7.60
4	7.4983	17.0047	1.6073	-4.8046	1.6073	-4.3753	-2.0381	-3.7641	-4.0719	7.24
5	8.3556	18.7191	2.4645	-4.6559	2.4645	-4.527	-1.2435	-2.1261	-4.2237	8.05
6	7.7063	17.4206	1.8153	-9.4883	1.8153	-4.4179	-0.2753	-0.4132	-4.1145	8.80
7	5.086	12.1801	-0.805	-9.5503	-0.805	-4.1911	-2.7743	-5.5029	-3.8877	6.17
8	7.6	17.208	1.709	-10.1625	1.709	-4.4149	-0.3114	-0.5905	-4.1116	8.72
9	7.7702	17.5484	1.8792	-7.7381	1.8792	-5.8297	-2.6084	-4.9782	-5.5263	7.72
10	7.6568	17.3215	1.7658	-9.7258	1.7658	-6.3838	-2.949	-5.6815	-6.0804	7.88
11	7.8635	17.7351	1.9725	-10.0206	1.9725	-6.8965	-3.1233	-999	-6.5931	8.23
12	7.927	17.862	2.036	-9.985	2.036	-6.4899	-2.4566	-4.8748	-6.1865	8.29
13	0.8523	3.7127	-5.0388	-19.9035	-5.0388	-6.5319	-6.1984	-12.5419	-6.2288	4.79
14	8.3719	18.7517	2.4809	-6.9185	2.4809	-6.1622	-3.2741	-6.4288	-5.8588	7.92
15	7.0448	16.0977	1.1538	-7.5945	1.1538	-5.6572	-3.4942	-6.8038	-5.3538	6.91
16	8.002	18.0121	2.111	-6.6496	2.111	-5.821	-3.097	-6.013	-5.5176	7.63
17	7.2922	16.5925	1.4012	-8.5679	1.4012	-6.4267	-3.1372	-6.0851	-6.1233	7.17
18	7.9208	17.8496	2.0298	-7.2091	2.0298	-6.022	-2.7197	-5.1964	-5.7186	7.65
19	8.0493	18.1067	2.1583	-9.513	2.1583	-7.0482	-3.0709	-5.8181	-6.7448	7.88
20	7.6574	17.3228	1.7664	-7.732	1.7664	-6.0468	-3.2496	-6.4033	-5.7434	7.59
1	6.0059	14.0198	0.1149	-11.6855	0.1149	-7.0085	-4.3272	-8.4162	-6.7051	6.55
SM1	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	0.3859	2.78	-5.5052	-12.6176	-5.5052	-0.9099	-999	-999	-0.6068	3.92
2	1.3556	4.7194	-4.5355	-11.7068	-4.5355	-0.9399	-999	-999	-0.6367	4.46
3	-1.262	-0.516	-7.1531	-19.2856	-7.1531	-1.0589	-999	-999	-0.7556	4.26
4	-1.7966	-1.5852	-7.6877	-19.9345	-7.6877	-1.0447	-999	-999	-0.7415	3.93
5	-2.9717	-3.9354	-8.8628	-22.4525	-8.8628	-1.1599	-999	-999	-0.8567	3.50
6	-2.5506	-3.093	-8.4416	-21.3657	-8.4416	-0.9924	-999	-999	-0.6892	3.57
7	-3.8203	-5.6326	-9.7115	-24.9086	-9.7115	-0.8969	-999	-999	-0.5937	3.49
8	-3.1231	-4.2381	-9.0142	-21.4793	-9.0142	-1.0358	-999	-999	-0.7326	3.07
9	-3.1905	-4.373	-9.0816	-21.3289	-9.0816	-1.0123	-999	-999	-0.7091	2.96
10	-2.9711	-3.9341	-8.8622	-20.2946	-8.8622	-0.9029	-999	-999	-0.5998	2.86
11	-4.0811	-6.1541	-9.9723	-22.42	-9.9723	-0.9158	-999	-999	-0.6127	2.41
12	-3.7979	-5.5876	-9.689	-22.0734	-9.689	-1.0293	-999	-999	-0.7261	2.47
13	-3.4792	-4.9503	-9.3703	-21.4921	-9.3703	-1.085	-999	-999	-0.7818	2.59

14	-3.5377	-5.0674	-9.4288	-21.789	-9.4288	-1.2861	-999	-999	-0.9829	2.59
15	-3.662	-5.316	-9.5532	-21.8897	-9.5532	-1.2845	-999	-999	-0.9813	2.49
16	-3.5057	-5.0034	-9.3968	-21.8184	-9.3968	-1.5392	-999	-999	-1.236	2.60
17	-4.1435	-6.279	-10.0346	-23.1543	-10.0346	-1.5123	-999	-999	-1.2091	2.36
18	-3.9302	-5.8524	-9.8213	-22.8221	-9.8213	-1.5884	-999	-999	-1.2852	2.45
19	-3.9288	-5.8495	-9.8199	-22.8356	-9.8199	-1.736	-999	-999	-1.4327	2.47
20	-3.9948	-5.9816	-9.8859	-23.1874	-9.8859	-1.8567	-999	-999	-1.5535	2.47
21	-3.9575	-5.9069	-9.8485	-23.7787	-9.8485	-2.1476	-999	-999	-1.8443	2.58
S32	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	1.6504	5.3089	-4.2407	-11.3438	-4.2407	-1.2983	-999	-999	-0.9951	4.44
2	1.6481	5.3043	-4.2429	-999	-4.2429	-1.4225	-4.5643	-9.9806	-1.1193	4.61
3	-999	-999	-999	-999	-999	-1.3663	-3.1253	-6.2676	-1.063	5.85
4	-999	-999	-999	-999	-999	-1.5167	-2.9297	-5.9395	-1.2134	5.98
5	-999	-999	-999	-999	-999	-1.7815	-999	-999	-1.4781	3.81
6	-999	-999	-999	-999	-999	-1.751	-2.8346	-5.8046	-1.4477	6.07
7	5.4496	12.9072	-0.4415	-5.7278	-0.4415	-1.6734	-3.5868	-7.3428	-1.37	6.06
8	-999	-999	-999	-999	-999	-1.8501	-3.8014	-7.784	-1.5467	5.50
9	-999	-999	-999	-999	-999	-1.8485	-3.3247	-6.8168	-1.5452	5.75
10	-999	-999	-999	-999	-999	-1.7856	-4.6813	-9.5482	-1.4823	4.73
11	-999	-999	-999	-999	-999	-1.6829	-4.5955	-9.3227	-1.3796	4.83
12	-999	-999	-999	-999	-999	-1.8494	-4.7699	-9.675	-1.5461	4.63
13	-999	-999	-999	-999	-999	-1.8805	-4.6901	-9.5142	-1.5771	4.79
14	-999	-999	-999	-999	-999	-1.923	-999	-999	-1.6197	4.19
15	-2.4088	-2.8096	-8.2999	-21.6142	-8.2999	-1.6235	-999	-999	-1.3202	3.53
16	-2.5544	-3.1008	-8.4455	-21.6153	-8.4455	-1.6661	-999	-999	-1.3628	3.38
17	-3.3724	-4.7367	-9.2634	-23.0969	-9.2634	-1.6254	-999	-999	-1.3221	3.05
18	-3.3447	-4.6813	-9.2357	-22.7385	-9.2357	-1.5699	-999	-999	-1.2666	2.99
19	-3.4256	-4.8432	-9.3167	-22.6018	-9.3167	-1.6247	-999	-999	-1.3214	2.88
20	-3.6204	-5.2327	-9.5114	-23.3455	-9.5114	-1.6655	-999	-999	-1.3622	2.83
1	-3.7569	-5.5058	-9.648	-23.8636	-9.648	-1.7847	-999	-999	-1.4814	2.82
S31	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	-1.1859	-0.3637	-7.0769	-17.1305	-7.0769	-1.4962	-999	-999	-1.1929	3.36
2	1.8258	5.6598	-4.0652	-12.1082	-4.0652	-1.2076	-4.1338	-8.1496	-0.9044	4.88
3	0.7712	3.5505	-5.1199	-15.2288	-5.1199	-1.7474	-4.7471	-10.5697	-1.4441	4.42
4	0.3526	2.7133	-5.5385	-999	-5.5385	-1.9879	-4.7968	-10.5148	-1.6847	4.33
5	-3.4123	-4.8063	-9.3136	-999	-9.3136	-2.0681	-4.9448	-11.0847	-1.7854	3.19
6	-999	-999	-999	-999	-999	-1.8105	-4.3176	-9.6531	-1.5086	3.92
7	-1.1477	-0.2838	-7.0425	-999	-7.0425	-1.7096	-3.9252	-8.9168	-1.4136	3.69
8	-2.262	-2.516	-8.1531	-999	-8.1531	-1.7545	-999	-999	-1.4512	3.29
9	-2.552	-3.096	-8.4431	-999	-8.4431	-1.6513	-999	-999	-1.348	3.09
10	-2.3341	-2.6601	-8.2251	-999	-8.2251	-1.6763	-999	-999	-1.373	3.00
11	-3.6708	-5.3336	-9.5619	-999	-9.5619	-1.6519	-999	-999	-1.3487	2.47
12	-3.4847	-4.9614	-9.3758	-999	-9.3758	-1.926	-999	-999	-1.6227	2.60
13	3.2175	8.443	-2.6735	-999	-2.6735	-1.7852	-999	-999	-1.4819	4.79
14	-3.0317	-4.0554	-8.9228	-999	-8.9228	-2.0545	-999	-999	-1.7512	2.74
15	-3.2882	-4.5683	-9.1792	-999	-9.1792	-1.9074	-999	-999	-1.6041	2.63
16	-3.0555	-4.103	-8.9466	-999	-8.9466	-2.1283	-999	-999	-1.825	2.71
17	-3.6569	-5.3058	-9.548	-22.3638	-9.548	-2.0798	-999	-999	-1.7765	2.49
18	-3.4481	-4.8882	-9.3392	-22.1382	-9.3392	-2.1916	-999	-999	-1.8883	2.59
19	-3.4608	-4.9135	-9.3518	-999	-9.3518	-2.1898	-999	-999	-1.8865	2.58
20	-3.5064	-5.0048	-9.3975	-999	-9.3975	-2.3584	-999	-999	-2.0551	2.55
1	-3.4381	-4.8681	-9.3291	-999	-9.3291	-2.3626	-999	-999	-2.0593	2.58
S30	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	-1.7056	-1.403	-7.5967	-17.0017	-7.5967	-1.0857	-999	-999	-0.7825	3.21
2	0.1994	2.4088	-5.6938	-13.5409	-5.6938	-1.199	-4.1353	-8.4371	-0.8998	3.83
3	-1.2245	-0.4309	-7.1257	-17.6497	-7.1257	-1.3766	-3.9422	-8.0442	-1.0936	3.59
4	-1.3	-0.5871	-7.1958	-18.2569	-7.1958	-1.5972	-4.2578	-8.6429	-1.3034	3.64
5	-1.8997	-1.7914	-7.7908	-19.7778	-7.7908	-1.8585	-999	-999	-1.5552	3.46
6	-999	-999	-999	-999	-999	-1.655	-999	-999	-1.3517	3.29

7	-2.6348	-3.2616	-8.5259	-21.0135	-8.5259	-1.5707	-999	-999	-1.2674	3.22
8	-3.1813	-4.3546	-9.0724	-21.8162	-9.0724	-1.7358	-999	-999	-1.4325	2.93
9	-3.5773	-5.1466	-9.4684	-22.1309	-9.4684	-1.6206	-999	-999	-1.3174	2.72
10	-3.2744	-4.5408	-9.1655	-21.2724	-9.1655	-1.4762	-999	-999	-1.1729	2.75
11	-4.4786	-6.949	-10.3697	-23.7035	-10.3697	-1.5615	-999	-999	-1.2583	2.29
12	-4.1591	-6.3101	-10.0502	-23.4244	-10.0502	-1.7108	-999	-999	-1.4076	2.39
13	3.0069	8.0218	-2.8842	-9.0066	-2.8842	-1.8267	-999	-999	-1.5234	4.79
14	-3.7462	-5.4843	-9.6372	-23.0327	-9.6372	-2.1754	-999	-999	-1.8721	2.60
15	-3.7146	-5.4211	-9.6057	-22.5111	-9.6057	-2.0794	-999	-999	-1.7761	2.55
16	-3.6575	-5.3069	-9.5485	-22.8181	-9.5485	-2.2683	-999	-999	-1.965	2.62
17	-4.2873	-6.5664	-10.1783	-24.1349	-10.1783	-2.4214	-999	-999	-2.1182	2.41
18	-3.8939	-5.7797	-9.785	-23.3351	-9.785	-2.426	-999	-999	-2.1227	2.53
19	-3.8606	-5.7131	-9.7516	-23.3038	-9.7516	-2.4671	-999	-999	-2.1638	2.56
20	-3.976	-5.944	-9.8671	-23.8032	-9.8671	-2.7251	-999	-999	-2.4219	2.56
1	-3.8401	-5.6722	-9.7312	-23.7458	-9.7312	-2.779	-999	-999	-2.4756	2.63
s24	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	2.5972	7.2025	-3.2939	-8.8134	-3.2939	-0.9731	-999	-999	-0.6699	4.64
2	-999	-999	-999	-999	-999	-0.9319	-2.6607	-5.4612	-0.6287	5.90
3	-999	-999	-999	-999	-999	-1.1189	-0.9343	-2.0574	-0.8157	7.08
4	-999	-999	-999	-999	-999	-1.1955	-1.2724	-2.8022	-0.8923	6.81
5	-999	-999	-999	-999	-999	-1.2351	0.0122	-0.3026	-0.9318	8.19
6	8.2178	18.4437	2.3267	0.0978	2.3267	-1.0915	-1.094	-2.4998	-0.7883	7.03
7	-999	-999	-999	-999	-999	-1.0073	-1.1069	-2.514	-0.7042	6.76
8	6.2978	14.6037	0.4067	-3.13	0.4067	-1.0504	-2.0412	-4.4595	-0.7471	6.23
9	6.4804	14.9688	0.5893	-2.5115	0.5893	-1.0036	-1.7139	-3.6809	-0.7004	6.33
10	5.9966	14.0013	0.1055	-1.9414	0.1055	-0.8621	-2.7652	-5.8154	-0.559	5.69
11	3.2918	8.5917	-2.5993	-8.0845	-2.5993	-0.8485	-3.8925	-7.9592	-0.5454	4.96
12	1.592	5.1922	-4.2992	-11.2492	-4.2992	-0.944	-4.3124	-8.8351	-0.641	4.29
13	2.2764	6.5609	-3.6148	-10.4998	-3.6148	-0.8727	-3.7094	-7.5541	-0.5696	4.39
14	0.6647	3.3376	-5.2266	-13.7848	-5.2266	-1.0463	-4.2706	-8.7915	-0.7434	4.17
15	0.5833	3.1749	-5.308	-13.7129	-5.308	-0.9766	-4.2915	-8.7824	-0.6739	4.11
16	0.2805	2.5697	-5.6111	-14.4363	-5.6111	-1.1509	-4.1664	-8.5956	-0.8489	3.98
17	0.8066	3.6215	-5.0846	-13.2167	-5.0846	-1.1543	-4.3201	-9.0146	-0.8515	4.12
18	0.0279	2.0679	-5.8673	-13.905	-5.8673	-0.9891	-4.0117	-8.3758	-0.694	3.63
19	-0.8576	0.293	-6.7487	-15.9084	-6.7487	-0.9678	-999	-999	-0.6647	3.33
20	-2.4227	-2.8372	-8.3138	-20.0979	-8.3138	-1.018	-999	-999	-0.7149	3.11
1	-2.1005	-2.1929	-7.9916	-18.4367	-7.9916	-1.0148	-999	-999	-0.7117	2.91
s20	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	0.838	3.6842	-5.0533	-11.9871	-5.0533	-0.6807	-999	-999	-0.3778	4.11
2	-999	-999	-999	-999	-999	-0.7247	-4.1832	-7.9927	-0.4218	4.67
3	-999	-999	-999	-999	-999	-0.8229	-1.5573	-2.8589	-0.5198	6.62
4	-999	-999	-999	-999	-999	-0.9679	-1.751	-3.4218	-0.6648	6.42
5	5.4795	12.9672	-0.4115	-5.6444	-0.4115	-1.0702	-2.0209	-4.0239	-0.767	6.20
6	8.5825	19.1731	2.6913	2.8663	2.6913	-0.9939	-1.6997	-3.4828	-0.6908	6.45
7	9.3666	20.7414	3.4754	4.7963	3.4754	-0.924	-1.5776	-3.2874	-0.621	6.64
8	-999	-999	-999	-999	-999	-1.0177	-1.4286	-3.0088	-0.7145	6.59
9	6.0058	14.0198	0.1147	-3.96	0.1147	-0.9214	-1.8488	-3.8466	-0.6182	6.28
10	6.2264	14.4609	0.3353	-3.8397	0.3353	-0.9429	-1.2659	-2.4893	-0.6398	6.46
11	-999	-999	-999	-999	-999	-0.9391	-1.2495	-2.5326	-0.6359	6.42
12	-999	-999	-999	-999	-999	-0.9706	-1.3444	-2.8304	-0.6674	6.38
13	-999	-999	-999	-999	-999	-0.9402	-2.7123	-5.645	-0.6375	4.79
14	-999	-999	-999	-999	-999	-1.1216	-1.3646	-2.9577	-0.8183	6.40
15	-999	-999	-999	-999	-999	-1.044	-1.8092	-3.7967	-0.7408	6.09
16	-999	-999	-999	-999	-999	-1.2331	-1.5456	-3.2252	-0.9299	6.35
17	-999	-999	-999	-999	-999	-1.2914	-1.236	-2.6534	-0.9881	6.57
18	-999	-999	-999	-999	-999	-1.2696	-1.1987	-2.5326	-0.9664	6.54
19	-999	-999	-999	-999	-999	-1.3483	-1.535	-3.1647	-1.0451	6.41
20	-999	-999	-999	-999	-999	-1.3752	-1.5136	-3.1153	-1.0719	6.41
1	-999	-999	-999	-999	-999	-1.4091	-1.4397	-2.9231	-1.1058	6.52
S19	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**

				K						
1	-4.8561	-7.7037	-10.7474	-23.6912	-10.7474	-0.7158	-999	-999	-0.4132	2.24
2	-2.2757	-2.5431	-8.167	-999	-8.167	-0.7972	-999	-999	-0.4945	2.74
3	-2.5489	-3.0896	-8.4401	-999	-8.4401	-1.0018	-999	-999	-0.6988	2.66
4	-2.6692	-3.3301	-8.5604	-999	-8.5604	-1.063	-999	-999	-0.7601	2.60
5	11.275	24.5582	5.3838	-999	5.3838	-1.24	-999	-999	-0.937	7.53
6	-6.8511	-11.694	-12.7421	-999	-12.7421	-1.5899	-999	-999	-1.2867	2.45
7	-6.2684	-10.5287	-12.1595	-999	-12.1595	-1.7952	-999	-999	-1.4919	2.64
8	-3.4422	-4.8763	-9.3334	-999	-9.3334	-2.0526	-999	-999	-1.7496	2.39
9	-3.4954	-4.9825	-9.3866	-999	-9.3866	-2.0669	-999	-999	-1.7639	2.35
10	-3.0752	-4.1421	-8.9665	-999	-8.9665	-2.1716	-999	-999	-1.8688	2.44
11	-4.3847	-6.761	-10.276	-999	-10.276	-2.3266	-999	-999	-2.0238	2.00
12	-4.2313	-6.4544	-10.1225	-999	-10.1225	-2.4287	-999	-999	-2.1258	2.10
13	-2.3018	-2.5955	-8.1929	-999	-8.1929	-2.4997	-999	-999	-2.1966	2.79
14	-3.5433	-5.0785	-9.4344	-999	-9.4344	-2.5437	-999	-999	-2.2406	2.40
15	-3.6946	-5.381	-9.5857	-999	-9.5857	-2.6155	-999	-999	-2.3125	2.32
16	-3.6139	-5.2196	-9.505	-999	-9.505	-2.5314	-999	-999	-2.2282	2.38
17	-3.444	-4.8797	-9.3353	-20.8584	-9.3353	-2.8233	-999	-999	-2.5206	2.16
18	-3.8303	-5.6525	-9.7214	-21.8516	-9.7214	-2.4702	-999	-999	-2.1671	2.32
19	-3.5856	-5.1631	-9.4767	-999	-9.4767	-2.4007	-999	-999	-2.0975	2.44
20	-3.9554	-5.9026	-9.8464	-999	-9.8464	-2.8216	-999	-999	-2.5183	2.39
1	-3.7955	-5.583	-9.6867	-999	-9.6867	-2.7404	-999	-999	-2.4372	2.35

s17	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	0.7303	3.4687	-5.1608	-11.8788	-5.1608	-0.8798	-999	-999	-0.5766	4.04
2	0.7435	3.495	-5.1476	-13.7999	-5.1476	-0.9503	-999	-999	-0.6471	4.53
3	-999	-999	-999	-999	-999	-1.0715	-3.8532	-7.827	-0.7683	5.02
4	-999	-999	-999	-999	-999	-1.1367	-999	-999	-0.8335	4.34
5	-999	-999	-999	-999	-999	-1.2041	-1.5897	-3.4592	-0.9009	7.18
6	-999	-999	-999	-999	-999	-1.0935	-999	-999	-0.7903	4.01
7	-999	-999	-999	-999	-999	-1.0124	-999	-999	-0.7092	3.84
8	-2.0861	-2.1642	-7.9772	-19.3151	-7.9772	-1.2098	-999	-999	-0.9066	3.36
9	-2.7043	-3.4004	-8.5953	-20.5452	-8.5953	-1.1093	-999	-999	-0.8061	3.18
10	-2.1457	-2.2833	-8.0368	-19.2914	-8.0368	-1.0702	-999	-999	-0.767	3.29
11	-3.7144	-5.4208	-9.6056	-21.7154	-9.6056	-1.0715	-999	-999	-0.7684	2.54
12	-0.4008	1.2065	-6.2919	-15.0721	-6.2919	-1.015	-999	-999	-0.7118	3.62
13	3.3341	8.6762	-2.557	-7.4846	-2.557	-1.1357	-4.6045	-9.527	-0.8325	4.79
14	-3.1265	-4.2449	-9.0176	-20.7773	-9.0176	-1.331	-999	-999	-1.0278	2.71
15	-3.1588	-4.3094	-9.0499	-20.5768	-9.0499	-1.2071	-999	-999	-0.904	2.61
16	-3.0473	-4.0865	-8.9384	-20.5718	-8.9384	-1.2729	-999	-999	-0.9697	2.67
17	-3.3709	-4.7337	-9.262	-21.104	-9.262	-1.4017	-999	-999	-1.0986	2.44
18	-3.4348	-4.8616	-9.3259	-21.5178	-9.3259	-1.4387	-999	-999	-1.1355	2.55
19	-3.5699	-5.1317	-9.461	-21.625	-9.461	-1.5543	-999	-999	-1.2512	2.49
20	-3.5468	-5.0855	-9.4379	-21.6329	-9.4379	-1.749	-999	-999	-1.4458	2.48
1	-3.4948	-4.9815	-9.3859	-21.4814	-9.3859	-1.8283	-999	-999	-1.5252	2.47

s14	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	2.4316	6.8712	-3.4595	-9.4836	-3.4595	-1.5444	-999	-999	-1.2411	4.55
2	-999	-999	-999	-999	-999	-1.4042	-2.3998	-4.8665	-1.1009	6.34
3	-999	-999	-999	-999	-999	-1.7251	-2.0406	-4.1233	-1.4218	6.67
4	-999	-999	-999	-999	-999	-1.8357	-2.2863	-4.64	-1.5324	6.56
5	-999	-999	-999	-999	-999	-2.0809	-1.6123	-3.2815	-1.7776	7.55
6	-999	-999	-999	-999	-999	-1.8812	-2.1396	-4.4204	-1.5778	6.58
7	-999	-999	-999	-999	-999	-1.76	-2.0756	-4.3139	-1.4567	6.54
8	-999	-999	-999	-999	-999	-1.9398	-2.3885	-4.9354	-1.6365	6.51
9	-999	-999	-999	-999	-999	-1.8566	-2.1277	-4.4325	-1.5533	6.44
10	-999	-999	-999	-999	-999	-1.7071	-2.3645	-4.9001	-1.4038	6.24
11	1.6937	5.3954	-4.1974	-13.3605	-4.1974	-1.5663	-4.4822	-9.1204	-1.263	4.90
12	2.5452	7.0985	-3.3458	-12.034	-3.3458	-1.6493	-4.1105	-8.3253	-1.3459	5.18
13	1.3814	4.7708	-4.5097	-14.421	-4.5097	-1.6684	-4.3916	-8.8939	-1.3651	4.79
14	0.339	2.6861	-5.552	-16.1946	-5.552	-1.7535	-999	-999	-1.4501	4.34
15	-1.5527	-1.0973	-7.4437	-19.3577	-7.4437	-1.5113	-999	-999	-1.208	3.59

16	-1.143	-0.2779	-7.034	-18.8006	-7.034	-1.6542	-999	-999	-1.3509	3.75
17	-2.0742	-2.1404	-7.9653	-20.5601	-7.9653	-1.5699	-999	-999	-1.2666	3.41
18	-2.0608	-2.1137	-7.9519	-20.2979	-7.9519	-1.5437	-999	-999	-1.2404	3.37
19	-2.2939	-2.5798	-8.185	-20.4362	-8.185	-1.5382	-999	-999	-1.2349	3.22
20	-2.6099	-3.2118	-8.501	-20.9786	-8.501	-1.5666	-999	-999	-1.2634	3.07
21	-2.7201	-3.4321	-8.6111	-20.915	-8.6111	-1.5647	-999	-999	-1.2614	2.95
s10	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	-999	-999	-999	-999	-999	-1.5725	-0.8883	-1.7851	-1.2692	7.09
2	-999	-999	-999	-999	-999	-1.3516	-0.482	-0.9109	-1.0483	7.47
3	-999	-999	-999	-999	-999	-1.8183	-0.4059	-0.7233	-1.515	7.66
4	-999	-999	-999	-999	-999	-2.457	-0.4916	-0.8429	-2.1536	7.93
5	-999	-999	-999	-999	-999	-2.7851	-0.6433	-1.1034	-2.4818	7.76
6	-999	-999	-999	-999	-999	-2.7442	-0.1581	-0.1556	-2.4408	7.97
7	-999	-999	-999	-999	-999	-2.6301	0.2425	0.6362	-2.3268	8.37
8	-999	-999	-999	-999	-999	-2.9066	-0.3943	-0.6646	-2.6033	7.74
9	-999	-999	-999	-999	-999	-2.7723	-0.3425	-0.5156	-2.469	7.68
10	-999	-999	-999	-999	-999	-2.7215	-0.3332	-0.467	-2.4182	7.62
11	-999	-999	-999	-999	-999	-2.7579	-0.4847	-0.7413	-2.4546	7.65
12	-999	-999	-999	-999	-999	-2.8957	-0.5901	-0.9318	-2.5924	7.63
13	-999	-999	-999	-999	-999	-3.0092	-0.4292	-0.579	-2.7058	7.78
14	-999	-999	-999	-999	-999	-3.1861	-0.4615	-0.635	-2.8828	8.21
15	-999	-999	-999	-999	-999	-2.8599	-0.9808	-1.6561	-2.5566	7.44
16	-999	-999	-999	-999	-999	-3.1321	-0.6414	-0.9375	-2.8287	7.97
17	-999	-999	-999	-999	-999	-3.1629	-0.4741	-0.6474	-2.8596	7.95
18	-999	-999	-999	-999	-999	-3.1433	-0.4511	-0.5552	-2.84	7.81
19	-999	-999	-999	-999	-999	-3.3152	-0.6636	-0.9811	-3.0118	8.04
20	-999	-999	-999	-999	-999	-3.2911	-0.5002	-0.6537	-2.9877	8.12
1	-999	-999	-999	-999	-999	-3.3267	-0.7013	-0.9984	-3.0234	7.98
SM3	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	1.4187	4.8456	-4.4726	-10.8528	-4.4726	-0.8618	-4.3275	-8.5558	-0.5589	4.27
2	4.0044	10.017	-1.8867	-9.7901	-1.8867	-0.8886	-1.7527	-3.3575	-0.5855	6.40
3	6.2402	14.4884	0.3491	-4.702	0.3491	-1.0501	-1.0856	-2.1504	-0.7469	6.78
4	6.213	14.434	0.3219	-4.9214	0.3219	-1.1064	-1.0463	-2.1849	-0.8032	6.77
5	6.3072	14.6224	0.4161	-4.8411	0.4161	-1.1264	-1.0869	-2.3544	-0.8231	6.80
6	7.264	16.5361	1.373	-3.1786	1.373	-1.1754	-0.6882	-1.578	-0.8722	7.17
7	6.7326	15.4734	0.8416	-4.1584	0.8416	-1.1549	-0.64	-1.5041	-0.8517	6.99
8	7.0443	16.0966	1.1532	-3.9424	1.1532	-1.3925	-0.5425	-1.3271	-1.0893	7.11
9	7.0463	16.1007	1.1553	-3.8134	1.1553	-1.669	-0.9053	-2.0051	-1.3658	6.96
10	7.2422	16.4924	1.3511	-3.8831	1.3511	-1.5329	-0.8054	-1.7472	-1.2296	7.24
11	7.5858	17.1796	1.6947	-2.3717	1.6947	-1.5942	-1.0631	-2.2062	-1.291	7.06
12	5.6463	13.3007	-0.2447	-6.3206	-0.2447	-1.4989	-1.8481	-3.7448	-1.1956	6.45
13	0.9228	3.854	-4.9685	-15.8512	-4.9685	-1.7433	-3.1034	-6.2422	-1.4406	4.79
14	6.9373	15.8826	1.0463	-4.1659	1.0463	-1.8816	-1.3782	-2.791	-1.5783	6.88
15	5.4335	12.8751	-0.4575	-6.1869	-0.4575	-1.621	-2.0848	-4.1886	-1.3177	6.13
16	7.2495	16.5071	1.3585	-3.5612	1.3585	-1.8162	-1.3057	-2.6474	-1.5129	7.01
17	7.4391	16.8861	1.548	-3.6523	1.548	-1.8492	-1.0461	-2.1681	-1.5459	7.21
18	7.4192	16.8465	1.5282	-3.8117	1.5282	-1.8383	-0.9007	-1.8113	-1.535	7.25
19	6.5892	15.1864	0.6981	-4.9344	0.6981	-1.8872	-1.6359	-3.2563	-1.5839	6.78
20	7.3215	16.651	1.4304	-3.9521	1.4304	-1.9397	-1.2886	-2.5636	-1.6363	7.14
21	6.8552	15.7184	0.9642	-4.3923	0.9642	-1.9192	-1.489	-2.9285	-1.6159	6.87
SM2	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	4.6209	11.2499	-1.2702	-6.0402	-1.2702	-1.4791	-3.23	-6.6405	-1.1758	5.61
2	-999	-999	-999	-999	-999	-1.3005	-1.4356	-3.1012	-0.9972	6.81
3	7.6749	17.3578	1.7839	-2.3822	1.7839	-1.7294	-0.952	-2.1437	-1.4261	7.25
4	7.0444	16.0968	1.1533	-4.1715	1.1533	-2.1843	-1.4724	-3.1633	-1.881	7.03
5	7.6466	17.3012	1.7556	-4.0748	1.7556	-2.4952	-1.2371	-2.6686	-2.1918	7.46
6	7.8555	17.7189	1.9644	-4.9124	1.9644	-2.4924	-0.6833	-1.5828	-2.189	7.94
7	8.7583	19.5247	2.8673	-2.4122	2.8673	-2.4313	-0.8736	-1.9797	-2.128	8.04
8	7.779	17.5661	1.888	-4.846	1.888	-2.715	-0.9006	-2.0314	-2.4116	7.78

9	7.749	17.5059	1.8579	-5.4964	1.8579	-2.7293	-0.5579	-1.3502	-2.426	7.95
10	7.8326	17.6732	1.9416	-4.6562	1.9416	-2.6965	-1.0009	-2.1978	-2.3932	7.77
11	8.0056	18.0193	2.1146	-5.4959	2.1146	-2.6556	-0.6208	-1.4865	-2.3522	8.24
12	6.2104	14.4288	0.3194	-6.2165	0.3194	-2.7949	-2.4792	-5.1692	-2.4916	6.58
13	6.782	15.5721	0.891	-5.1536	0.891	-2.757	-1.9032	-4.0423	-2.4536	6.79
14	8.0483	18.1047	2.1573	-3.5209	2.1573	-3.0061	-1.6836	-3.5919	-2.7028	7.43
15	6.5588	15.1256	0.6678	-5.4499	0.6678	-2.6382	-2.0278	-4.2725	-2.3349	6.69
16	8.0016	18.0113	2.1106	-3.9814	2.1106	-3.0936	-1.6676	-3.5525	-2.7902	7.51
17	7.5468	17.1016	1.6558	-3.9744	1.6558	-3.0047	-1.7966	-3.8764	-2.7014	7.09
18	7.1807	16.3695	1.2897	-4.4357	1.2897	-2.699	-1.7396	-3.7799	-2.3956	6.97
19	6.4622	14.9325	0.5712	-5.4314	0.5712	-2.442	-2.2162	-4.7191	-2.1386	6.71
20	6.8254	15.6589	0.9344	-5.5692	0.9344	-2.9091	-2.1981	-4.6827	-2.6058	6.91
21	5.9357	13.8795	0.0447	-6.6345	0.0447	-2.7494	-2.5351	-5.3297	-2.4461	6.48
GM7	**Goethite**	**Hematite**	**Fe(OH)3(a)**	**Jarosite-K**	**Fe(OH)3(a)**	**Anhydrite**	**Calcite**	**Dolomite**	**Gypsum**	**pH**
1	7.7114	17.4308	1.8204	-3.6966	1.8204	-3.2082	-1.6549	-3.5176	-2.9049	6.71
2	6.9966	16.0013	1.1056	-4.5814	1.1056	-2.7238	-1.545	-3.292	-2.4204	7.26
3	7.2108	16.4295	1.3197	-4.9358	1.3197	-3.3025	-1.8699	-3.9692	-2.9991	6.95
4	8.1043	18.2166	2.2133	-2.0747	2.2133	-2.2576	-1.0228	-2.2153	-1.9542	7.44
5	8.0407	18.0894	2.1497	-3.5683	2.1497	-3.0138	-1.1853	-2.6749	-2.7105	7.85
6	7.7703	17.5486	1.8793	-3.8769	1.8793	-2.9331	-1.4719	-3.1899	-2.6297	8.08
7	7.7456	17.4992	1.8546	-4.0207	1.8546	-2.8856	-1.2397	-2.8151	-2.5823	8.01
8	8.0283	18.0646	2.1373	-3.7199	2.1373	-2.952	-0.8652	-1.9192	-2.6487	7.68
9	8.6482	19.3045	2.7572	-2.524	2.7572	-3.2238	-1.5024	-3.2403	-2.9204	8.15
10	7.2611	16.5303	1.3701	-3.1385	1.3701	-1.3472	-0.554	-1.3023	-1.0439	8.09
11	6.705	15.4179	0.8139	-4.2419	0.8139	-1.7766	-1.3856	-2.9424	-1.4733	6.94
12	8.2218	18.4517	2.3308	-3.911	2.3308	-3.1202	-1.3609	-2.9981	-2.8168	7.51
13	8.1085	18.225	2.2175	-4.4476	2.2175	-3.0776	-0.8235	-1.8991	-2.7742	7.73
14	8.0419	18.0918	2.1509	-4.7754	2.1509	-2.827	-0.5599	-1.3881	-2.5236	7.38
15	7.7539	17.5158	1.8628	-4.7029	1.8628	-2.5068	-0.5628	-1.3113	-2.2035	7.74
16	7.7085	17.425	1.8175	-5.6487	1.8175	-2.8424	-0.6228	-1.4765	-2.539	7.44
17	7.8392	17.6863	1.9481	-5.3528	1.9481	-2.8007	-0.6156	-1.3726	-2.4973	7.97
18	7.756	17.5201	1.865	-5.8991	1.865	-2.8976	-0.4556	-1.028	-2.5942	7.87
19	7.6786	17.3652	1.7875	-5.5274	1.7875	-2.5481	-0.4501	-1.1114	-2.2448	7.01
20	8.0613	18.1306	2.1703	-6.0944	2.1703	-3.3344	-0.9501	-2.1712	-3.031	7.16
21	-999	-999	-999	-999	-999	-1.3834	-0.7759	-1.7028	-1.0801	8.23

Table 59: Solubility of elements in Fly Ash at different pH's with different acids (gram/tonne).

Conditions	As	Ba	Be	Cd	Cr	Co	Cu	Li	Mn	Mo	Ni	Se	V	Zn	Al	Fe	Ca
pH12 H_2SO_4	0.438	0.000	0.000	0.000	0.434	0.000	0.372	27.274	0.170	3.040	0.521	0.971	19.996	0.816	740.5	2.4	7054
pH11 H_2SO_4	0.791	0.000	0.001	0.000	0.351	0.012	0.467	29.159	0.700	2.896	1.366	0.861	14.502	0.716	133.1	0.9	12866
pH10 H_2SO_4	0.432	0.000	0.003	0.000	0.302	0.040	0.410	27.990	2.330	2.506	1.609	0.867	5.932	1.647	11.2	1.3	15997
pH9 H_2SO4	0.306	0.000	0.000	0.000	0.241	0.089	0.367	29.485	23.400	2.415	1.890	0.844	3.631	0.879	3	0.7	17801
pH8 H_2SO4	0.097	0.076	0.003	0.003	0.143	0.433	0.256	26.474	81.270	2.089	3.556	0.629	1.252	1.284	3.6	1	17807
pH7 H_2SO4	0.000	0.000	0.006	0.031	0.138	0.915	0.366	24.171	103.180	2.265	5.635	0.703	1.545	2.357	6	2.5	17107
pH6 H_2SO4	0.000	0.000	0.027	0.075	0.076	1.646	0.592	25.117	110.490	1.197	8.238	0.633	0.384	6.314	1.4	1.3	18586
pH5 H_2SO_4	0.000	0.788	0.530	0.142	0.248	1.657	3.592	23.194	115.150	0.222	8.995	0.443	0.173	8.192	64.7	47	18928
pH4 H_2SO_4	0.000	1.004	1.404	0.198	6.932	1.510	6.730	21.581	119.660	0.260	8.750	0.666	0.240	8.103	6001	243.2	20330
pH3 H_2SO_4	0.000	1.801	1.520	0.219	28.729	1.429	8.035	18.662	110.400	0.281	8.956	0.845	2.853	8.337	6949	1736.2	19714
pH2 H_2SO_4	3.123	1.825	1.134	0.269	28.765	1.516	8.820	17.026	103.480	1.149	8.388	1.178	43.711	7.770	7692	3150.2	20685
pH12 HNO_3	0.081	2.535	0.012	0.030	0.599	0.000	0.470	27.261	0.080	2.991	0.514	1.243	19.216	0.643	818.1	0.5	8663
pH11 HNO_3	0.539	2.369	0.003	0.000	0.606	0.016	0.597	27.615	0.950	3.100	1.273	1.104	17.688	1.263	188.6	0.9	13853
pH10 HNO_3	0.513	3.694	0.017	0.008	0.112	0.017	0.400	26.877	1.570	2.667	1.419	0.916	8.736	1.277	12.3	0.5	15933
pH9 HNO_3	0.383	5.265	0.000	0.000	0.100	0.054	0.467	17.445	12.600	2.248	1.913	0.755	4.734	1.120	4.9	2.8	15462
pH8 HNO_3	0.074	9.800	0.018	0.012	0.059	0.317	0.418	18.401	71.050	2.579	3.230	0.894	2.748	1.324	1.6	0.5	16336
pH7 HNO_3	0.000	10.415	0.004	0.025	0.091	0.733	0.282	20.464	107.720	2.431	4.757	1.037	2.645	1.690	1.6	0.6	16865
pH6 HNO_3	0.000	17.759	0.021	0.117	0.125	1.789	0.548	21.131	135.920	1.578	9.908	0.753	0.893	6.719	1.6	1.4	18166
pH5 HNO_3	0.000	22.044	0.316	0.133	0.139	1.879	2.564	18.883	133.530	0.307	11.123	0.736	0.424	10.010	19.2	66.7	16746
pH4 HNO_3	2.248	29.388	1.545	0.305	20.616	1.961	8.772	17.869	141.600	1.487	12.264	1.286	29.494	12.696	4201	1476.3	18245
pH3 HNO_3	0.000	28.365	1.772	0.260	27.497	1.708	10.231	15.949	126.520	0.058	12.505	1.221	0.600	14.931	5753	382.1	18279
pH2 HNO_3	1.741	30.237	1.440	0.298	37.128	1.818	10.987	17.211	129.130	1.114	12.217	1.600	49.986	12.358	6877	2652	19624
pH12 HCl	0.168	2.286	0.051	0.008	0.462	0.002	0.316	21.346	0.190	2.178	0.356	1.139	13.828	1.753	687.2	1.3	8338
pH11 HCl	0.257	2.735	0.004	0.004	0.361	0.028	0.326	23.079	0.830	2.192	1.044	0.658	9.078	1.225	90.7	1	10172
pH10 HCl	0.179	4.197	0.000	0.012	0.100	0.027	0.343	21.743	1.280	1.838	1.482	0.706	5.152	0.872	12.2	0.5	15181
pH9 HCl	0.099	7.544	0.000	0.032	0.115	0.093	0.233	23.297	17.910	2.000	1.302	1.013	3.430	0.931	5.1	0.6	18081
pH8 HCl	0.076	9.092	0.000	0.036	0.084	0.243	0.320	21.063	55.370	1.932	2.542	0.926	2.629	0.784	1.3	0.5	17703
pH7 HCl	0.000	14.652	0.000	0.066	0.052	1.042	0.331	19.303	98.530	1.698	5.949	0.765	1.233	1.428	0.7	0.7	18405
pH6 HCl	0.000	17.682	0.015	0.099	0.076	1.445	0.333	19.777	116.150	1.202	7.903	0.682	0.873	4.157	0.8	1.1	18373
pH5 HCl	0.000	23.520	0.341	0.132	0.098	1.587	2.535	19.415	124.890	0.174	10.642	0.518	0.321	8.130	21	67.5	18845
pH4 HCl	0.871	28.151	1.503	0.226	11.629	1.593	8.326	19.838	123.230	0.816	12.245	0.936	16.116	9.313	3886	977.1	20744
pH3 HCl	0.000	26.208	1.596	0.209	22.957	1.445	7.036	15.972	111.970	0.134	9.792	0.907	0.383	8.735	5782	369.4	18714
pH2 HCl	0.586	30.696	1.378	0.246	28.350	1.659	8.542	14.030	105.340	0.577	9.067	1.279	39.999	7.989	6858	2495.1	19581
pH11.62 H_2O	0.016	1.855	0.017	0.002	9.585	0	0.028	8.345	0.004	2.2	0.077	0.525	1.906	0.018	1.1	0	1116

13 SUMMARY

The **Waterberg Coalfields** represent the last area in South Africa which contain large quantities of coal resources. The most important issue with economic growth and development is to take measures to minimise the impact on the environment. With the ever increasing demand for energy, the **demand for continuous mining of coal increases** and thus expands into areas not previously mined. The **by-products** of coal mining and the production of electricity from the coal leaves an **environmental footprint**. For this footprint to be minimised, all the risks associated with mining should be available and understood.

Since there are still large coal deposits in the Waterberg which can be mined by opencast mining, the risk of the **geological** units still to be mined was assessed. **Acid generation** due the **oxidation** of mainly **pyrite** is a source of **contamination** that can impact the groundwater and to a lesser or no extend the surface water from the mining facilities.

Another environmental risk is air pollution from mines, includingthat of Medupi Power Station which will commence shortly. It is a very dry area and thus the aquifers must be protected as far as possible.

In this study area,coal is mined by the **opencast** method from the Karoo formation There currently only one active coal mine in the study area, namely the Grootegeluk mine which started operation in 1980.

Samples were collected from exploration boreholes in all three areas in the region (partly weathered, Full succession and Middle Ecca). **Acid-Base Accounting** was done on all 800+ samples and it indicated that the interburden and discards contained the highest AMD potential while the overburden had the highest buffering capacity.

The impact is clear on some of the monitoring boreholes on the site. Unlined facilities lead to the contamination of the aquifers to a point where the pH of the water is acidic. The monitoring boreholes close to the ash dump is affected by a raise in the total dissolved solids due to calcium and sulphate leaching from the ash.

To get the total impact or toxicity potential of samples, it is necessary to identify the **elements** that are available in the different wastes that can **leach** into the environment.

All the risks associated with the different geological units should be known so that the best decision and planning of waste facilities for future extensions can be made, and so that the negative footprint on the environment can be minimised.

14 OPSOMMING

Die Steenkoolvelde in die Waterberge verteenwoordig die laaste gebied in Suid-Afrika waar groot hoeveelhede steenkool nog beskibaar is. Die grootste probleem met ekonomiese groei en ontwikkeling is om maatreëls in plek te kry wat die negatiewe impak op die omgewing sal minimaliseer. Met die toenemende behoeftena energie is daar 'n deurlopende behoefte na die ontginning van steenkool asook die uitbreiding daarvan na voorheen ongemynde gebiede.

Die byprodukte wat ontstaan a.g.v. die myn van steenkool en die opwek van elektrisiteit met behulp van steenkool, laat 'n negatiewe impak op die omgewing. Indien al die risiko's wat verband hou met mynbou bekend is en verstaan word, kan dit die effek wat dit op die omgewing het, minimaliseer.

Aangesien daar nog steeds groot steenkoolneerslae in die Waterberg is wat ontgin kan word, is die risiko van die ongemynde geologiese eenhede in hierdie studie ondersoek.

Suur produksie vind plaas a.g.v. oksidasie deur hoofsaaklik piriet. Hierdie is 'n bron van grondwater besoedelik by myn fasiliteite. Met die ontstaan van meer myne het lugbesoedeling ook toegeneemen die nuwe Medupi Kragstasie sal ook risiko vir die omgewing inhou. Die steenkoolvelde is in 'n baie droë streek geleë en die akwifere moet daarom soveel moontlik beskerm word van besoedeling.

Die steenkool is in die Karoo formasies geleë en word deur middel van die oopgroef myn metode gemyn. Grootgeluk is tans die enigste aktiewe steenkoolmyn in die area en het sy ontstaan in 1980 gehad.

Monsters is vekry vanaf eksplorasie boorgate in al drie areas (gedeeltelik verweer, vol suksessie en die middel Ecca). Gevolglik is Suur Basis Berekeninge gedoen op die 800 monsters wat daarop gewys het dat die tussenlae (interburden) en weggooi (discards) monsters die hoogste suur potensiaal (AMD) bevat. Die boonste lae (overburden) bevat die hoogste buffer kapasiteit.

Die invloed van die aktiwiteite is sigbaar in van die moniterings boorgate. Die ongevoerde fasiliteite het gelei tot die besoedeling van sommige akwifere tot by 'n punt waar dit suur geword het. Die moniterings boorgate by die ashoop word beinvloed deurdat die totale opgeloste stowwe in die grondwater verhoog het a.g.v. kalsium en sulfaat wat van die ashoop af ingesyfer het.

Om die totale potensiaal van die toksisiteit van die monsters te bepaal is dit noodsaaklik om die elemente wat beskikbaar is en in die omgewing kan uitloog, te bepaal.

Indien al die risiko's van die verskillende geologiese eenhede bekend is, kan die beste besluite en beplanning gedoen word om die negatiewe impak op die omgewing tot die minimum te beperk