QUANTITATIVE EVALUATION OF MINERALS IN COAL DEPOSITS IN THE WITBANK AND HIGHVELD COALFIELDS AND THE POTENTIAL IMPACT ON ACID MINE DRAINAGE

By

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ABSTRACT

A mineralogical and geochemical study on the coal and coal-bearing successions of the Witbank and Highveld Coalfields in the Mpumalanga Province of South Africa was proposed in order to, firstly, investigate the quantitative distribution of minerals in the lithological units, and secondly, to correlate this data with the potential of the units to contribute to acid mine drainage conditions in the region.

X-ray diffraction and X-ray fluorescence techniques were used to analyse the samples from the study area. Samples from the No. 1, No. 2, No. 4 and No. 5 coal seams were collected from several mines in the Witbank Coalfield, while samples from the No. 4 and No. 5 coal seams were collected from borehole material obtained from the Highveld Coalfield. The inorganic components make up approximately 8.00 to 35.00 wt% of a coal sample. SiO_2 concentrations varied between 0.00 and 35.00 wt% of a sample, Al_2O_3 between 0.50 and 16.00 wt%, Fe_2O_3 between 0.03 and 10.00 wt%, and S between 0.15 and 8.00 wt%. Minor concentrations of CaO (0.00 to 8.00 wt%) and MgO (0.00 to 1.00 wt%) were present. P_2O_5 occurred in concentrations of 0.00 to 3.50 wt% and K_2O was in the order of 0.00 to 1.30 wt%. Na_2O values were the lowest varying between 0.00 and 0.45 wt%. The only difference in chemistry between Witbank and Highveld coals was a slight increase in Na_2O (0.00 to 0.51 wt%) in the Highveld coals.

These results were confirmed by the XRD investigations. The mineral components in the XRD patterns were semi-quantitatively evaluated in terms of dominant (>40% of the mineral fraction), major (10-40%), minor (2-10%), accessory (1-2%) and rare (<1%) constituents. The mineral fraction in the coals was dominated by quartz and kaolinite, with major to minor and trace amounts of calcite, dolomite and pyrite, as well as accessory phosphates phases.

XRF and XRD results for the coal-bearing units were also in good agreement. Higher K_2O and Na_2O concentrations were obtained in the sandstones in comparison to the siltstone and carbonaceous shale samples, and were supported by the presence of feldspars and clays such as illite in XRD interpretations. A normative program designed for Australian coals and sedimentary rocks, called Sednorm, was used to calculate normative mineralogical compositions from the geochemical results. Good correlations were obtained for comparisons made between the chemical composition, mineralogical interpretations and normative results for the coal and sediment samples.

Acid-base accounting was used to investigate the potential of the coal and coal-bearing units to produce acid mine drainage conditions. The acid and neutralising potentials are largely dependant on the abundance and availability of minerals such as pyrite and calcite respectively. According to the screening criteria proposed by Usher *et al.* (2001), averages for Neutralising Potential Ratio (NPR) suggest that all the coal and coal-bearing units, excluding the unit between No. 1 and No. 2 coal seams, are potentially acid generating. The latter lithological unit is considered to be inconclusive. The average Net Neutralising Potential (NNP) values suggest that the No. 5 coal seam, No. 4 Upper coal seam, and between No. 4 and No. 2 coal seams are potentially acid generating. This is a result of the weathering of carbonates in these lithological units. The other units could become either acidic or neutral.

In theory it is possible to calculate the AP from the analysed S by multiplying the S value by 31.25. Assuming that all sulphide-S is available for oxidation, then the total S analysed could be used to predict the AP for samples on which no acid-base determinations has been carried out. Similarly, the excellent correlation between the NP and CaO, and between the NP and combined CaO and MgO, confirms that these chemical components are largely responsible for NP values. It is then also possible to predict the NP by using the CaO and MgO concentrations for samples for which no AP or NP data is available.

The application of ABA in this study offered a major contribution to understanding the complexities governing water-rock interactions. Results provided a preview of situations that might arise regarding groundwater quality in a certain area, but also offers ample time to decide on appropriate prevention or remediation programs. The potential for these lithological units to contribute to the deterioration of groundwater is evident.

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ABBREVIATIONS AND ACRONYMS

ABA	Acid-base Accounting
AMD	Acid Mine Drainage
AP	Acid Potential
BOC	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
g/kg	Grams per Kilogram
LOI	Loss on Ignition
LTA	Low-temperature Ashing
mg/L	Milligram per Litre
mol s^{-1}	Moles per Second
mS/m	Millisiemens per meter
MΩ	Megaohm
NAG	Net Acid Generating Test
NNP	Net Neutralising Potential
NP	Neutralising Potential
NPR	Neutralising Potential Ratio
Ω	Ohm
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

CHAPTER 1

INTRODUCTION

1.1 Overview

The combustion of organic material in coal by power stations is probably one of the main activities by which the coal mining and manufacturing industry produces pollutants. These pollutants affect different areas in our environment. Underground and opencast mining activities take place together with excessive use of water. After being extracted the coal is then processed to form synthetic fuels, gases, and numerous by-products which prove to make human existence simpler.

Yet the sacrifice we make in order to reach this stage of supremacy over what is at our disposal, is not always justifiable. If one considers the repercussions of activities such as mining, the deleterious effects are wide-spread.

The mining of coal exposes this resource to ideal conditions for unfavourable reactions to take place. Acid mine drainage (AMD) conditions are primarily caused by the oxidation of the sulphide minerals. However, in coal mines, the minerals pyrite (FeS_2) and marcasite (FeS_2) are largely responsible for an AMD problem. The use of water during coal mining provides a suitable medium and supplies sufficient oxygen for pyrite oxidation to occur. The rate of oxidation is dependant on temperature, pH, oxygen concentration, chemical composition of the pore water and microbial population (Azzie, 1999). Waters affected by these reactions are often strongly acidic, and often accumulate in underground workings and aquifers.

However, attaining these conditions is more complex than just the oxidation of sulphide minerals. Various reactions between many other mineral phases give rise to a complex combination of constituents with numerous adverse effects on the surrounding environment. It is this interaction between minerals and the immediate environment, especially the surrounding groundwater, which creates the real problem associated with coal mining.

In order to specify the cause and find a solution to this problem it is necessary to investigate, firstly, exactly what is being dealt with in terms of the nature of coal (i.e. minerals, macerals, fixed carbon, moisture, etc.) and secondly, attempt to quantify the extent to which interaction has taken place or could take place between the coal and the environment.

Thus, the objective of this study is to provide a basic mineralogical database for coals in the Witbank and Highveld coal fields, and to investigate the potential of these rocks to produce acidic or alkaline conditions. The investigation aims at constructing a practical representation of the distribution of minerals. Thus, predicting future AMD occurrences might be possible.

Although most of the mines in the region has been active for the last century (Snyman, 1998; Smith and Whittaker, 1986a), only recently has the problem of acid mine drainage been addressed. Certain areas in the Witbank and Highveld coal fields are characterised by lush, green surfaces covering previously exploited underground operations, which could and often do collapse at any instance, while voids in these workings often contain acidic water.

However, most mining companies today have made a concerted effort to ensure that similar situations do not arise in future once mining has ceased. Therefore, to be able to proceed with mining and rehabilitation in such way to ensure that the same scenario does not occur, the results from an investigation such as this would be exceptionally useful.

1.2 Location of the study area

The Witbank coal field is situated east of Johannesburg. The southern boundary of the coal field is considered to extend from approximately 5 km south of Delmas Colliery in an east-northeast direction to about 5 km south of South Witbank Colliery. From this point eastwards, for about 60 km, a natural boundary is formed by a series of inliers of Rooiberg Group felsite, known as the Smithfield ridge.

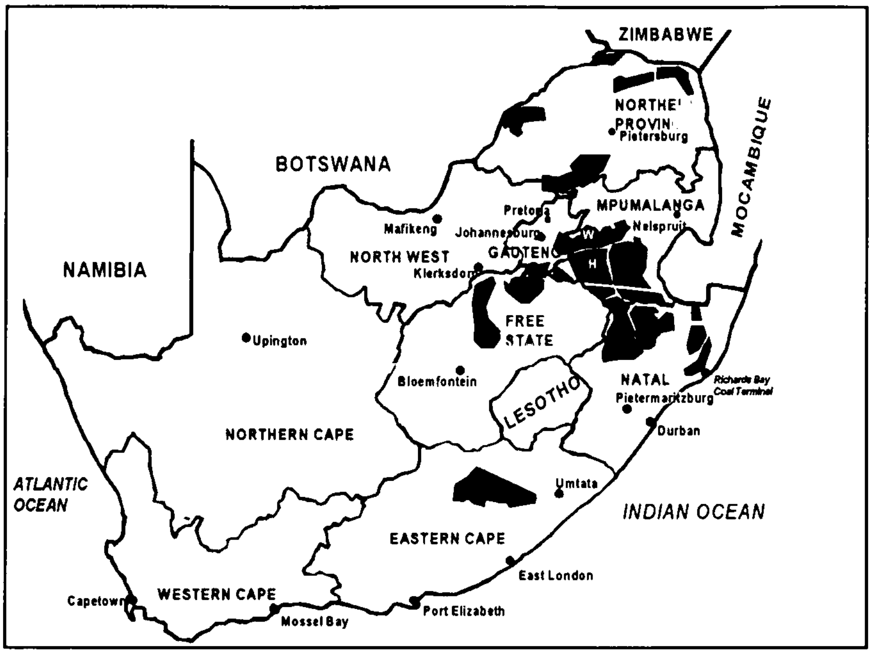


Figure 1.1 – The distribution of the coal fields in the five relevant provinces (H – Highveld coalfield, W – Witbank coalfield)

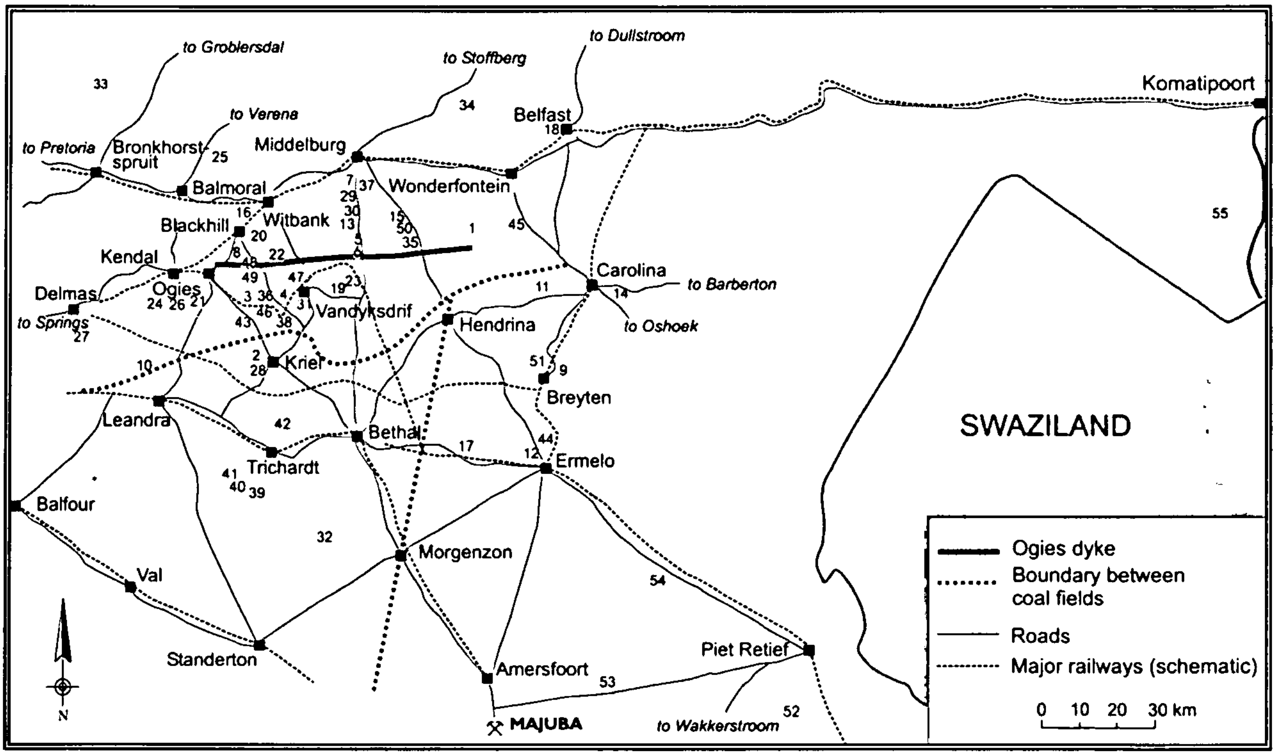


Figure 1.2 – Collieries in Mpumalanga as well as southern boundary between Witbank and Highveld coal fields, and eastern boundary of Highveld coal field (after Snyman, 1998)

The Highveld Coalfield is situated south of the Witbank Coalfield. Its eastern boundary is formed by a straight line through Hendrina, Davel and Morgenzon (Snyman, 1998) (Figure 1.1 and Figure 1.2).

1.3 Geology and tectonic setting

After the Pan-African tectonothermal event which brought about the assembly of Gondwana, the southern edge of this super-continent experienced a prolonged period of sedimentation. The Cape Supergroup was deposited from the Ordovician to the upper Devonian as beach, deltaic and shallow marine clastic sediments on a broad, relatively stable platform. The Cape Fold Belt was part of the more extensive Pan Gondwanian Mobile Belt generated through compression, collision and terrain accretion along the southern margin of Gondwana. The associated foreland basin fragmented as a result of Gondwana break-up, and is preserved today in South America (Parana Basin), southern Africa (Karoo Basin), Antarctica (Beacon Basin) and Australia (Bowen Basin) (Catuneanu *et al., 1998*).

The Karoo Basin is a retroarc foreland basin developed in the front of the Cape Fold Belt, in relationship to the Late Palaeozoic-Early Mesozoic subduction episode of the palaeo-Pacific plate underneath the Gondwana plate. The maximum megasequence of the Karoo sedimentary succession exceeds 6km and reflects changing environments from glacial to deep marine, deltaic, fluvial and aeolian (Catuneanu *et al.,* 1998).

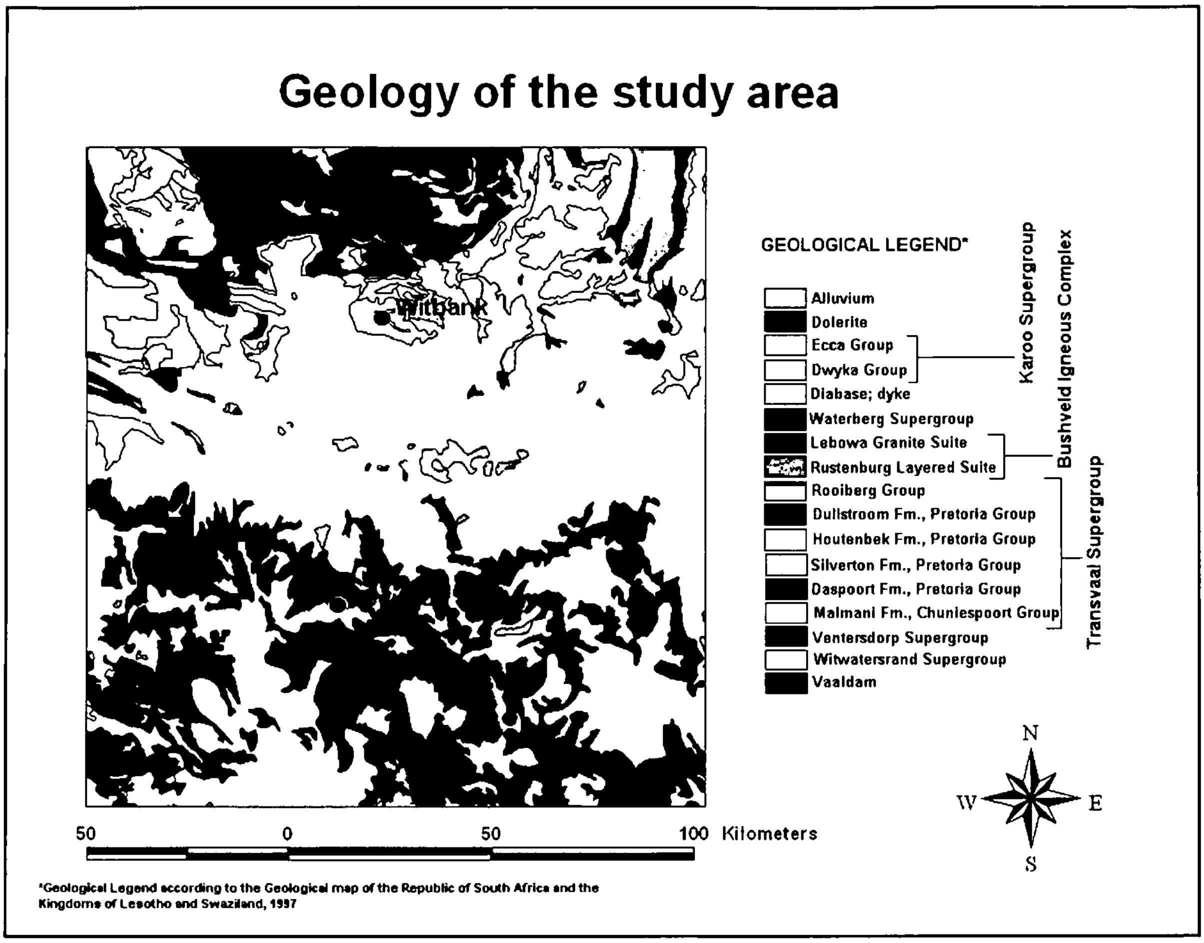
A period of glacial sedimentation during the Permian-Carboniferous marks the beginning of numerous phases giving rise to the formation of the Karoo Supergroup in which most of the coal deposits of southern Africa are deposited (Thomas *et al.,* 1993). Diamictites and associated fluvio-glacial sediments of the Dwyka Group were deposited by both grounded and floating ice (Catuneanu *et al.,* 1998). After glaciation a shallow sea remained, fed by large volumes of meltwater (Smith *et al.,* 1993). Black clays and muds accumulated on the submerged platform under cold climatic conditions to form the Lower Ecca Group, while deltas prograded and eventually combined to form broad alluvial plains constituting the Upper Ecca Group.

The distribution and the thickness of the lower seams are controlled mainly by glacial, pre-Karoo valleys and pre-Karoo topographic highs, while the upper seams were controlled by the basinward extent of delta progradation and by pre-Karoo topographical highs around the basin margin (Smith and Whittaker, 1986a).

Towards the end of the Upper Permian (Figure 1.3) the deposits of the Beaufort Group formed on semi-arid alluvial plains mainly as a result of floodplain aggradation. With increased aridification debris fans prograded into the central parts of the basin (Molteno Formation) and these fans were later drained by meandering belts (Elliot Formation). The periodic floods together with aeolian sand dune deposits were preserved as the Clarens Formation which marks the end of Karoo sedimentation. The wide range of structural and sedimentary settings, together with various ages, climates, and plant communities are the reasons for the difference in organic and inorganic material and the degree of maturity or rank of the coals of the region (Falcon, 1986). This will be discussed in further detail in the next section.

SUPERGROUP	AGE (Ma)		GROUP	FORMATION
KAROO	140	Jurassic	Drakensberg	Drakensberg
	195			Clarens
	225	Triassic		Elliot
	230	Upper Permian	Beaufort	Adelaide Subgroup
		Middle Permian	Ecca	Volksrust
				Vryheid
	260			Pietermaritzburg
	300	Lower Permian	Dwyka	

Figure 1.3 – Lithostratigraphic nomenclature for the Karoo Supergroup (after Azzie, 2002)


Geology of the study area

*Geological Legend according to the Geological map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland, 1997

Figure 1.4 – Geological map of the study area

The regional geology of the study area is illustrated in Figure 1.4. The area is characterised by numerous post-Karoo age dolerite sills and dykes, while rocks of the Vryheid Formation of the Ecca Group covers most of the surface area. Five separate bituminous coal seams are preserved in the Vryheid Formation (Cairncross, 2001), and were deposited under cool, wet climatic conditions. To the north the Transvaal Supergroup and the Ventersdorp Supergroup can be observed, as well as several tillite and diamictite of the Dwyka Group outcrops (Figure 1.4).

1.3.1 The Witbank Coalfield

The Witbank coalfield, also previously known as the Springs-Witbank Coalfield, is currently the most important coalfield in the country, and extends over a distance of some 180km from Brakpan and Springs areas in the west, to Belfast in the east and about 40km in a north-south direction. The mines in this coalfield are situated primarily within the Olifants River Catchment (Figure 1.5) (Smith and Whittaker, 1986b).

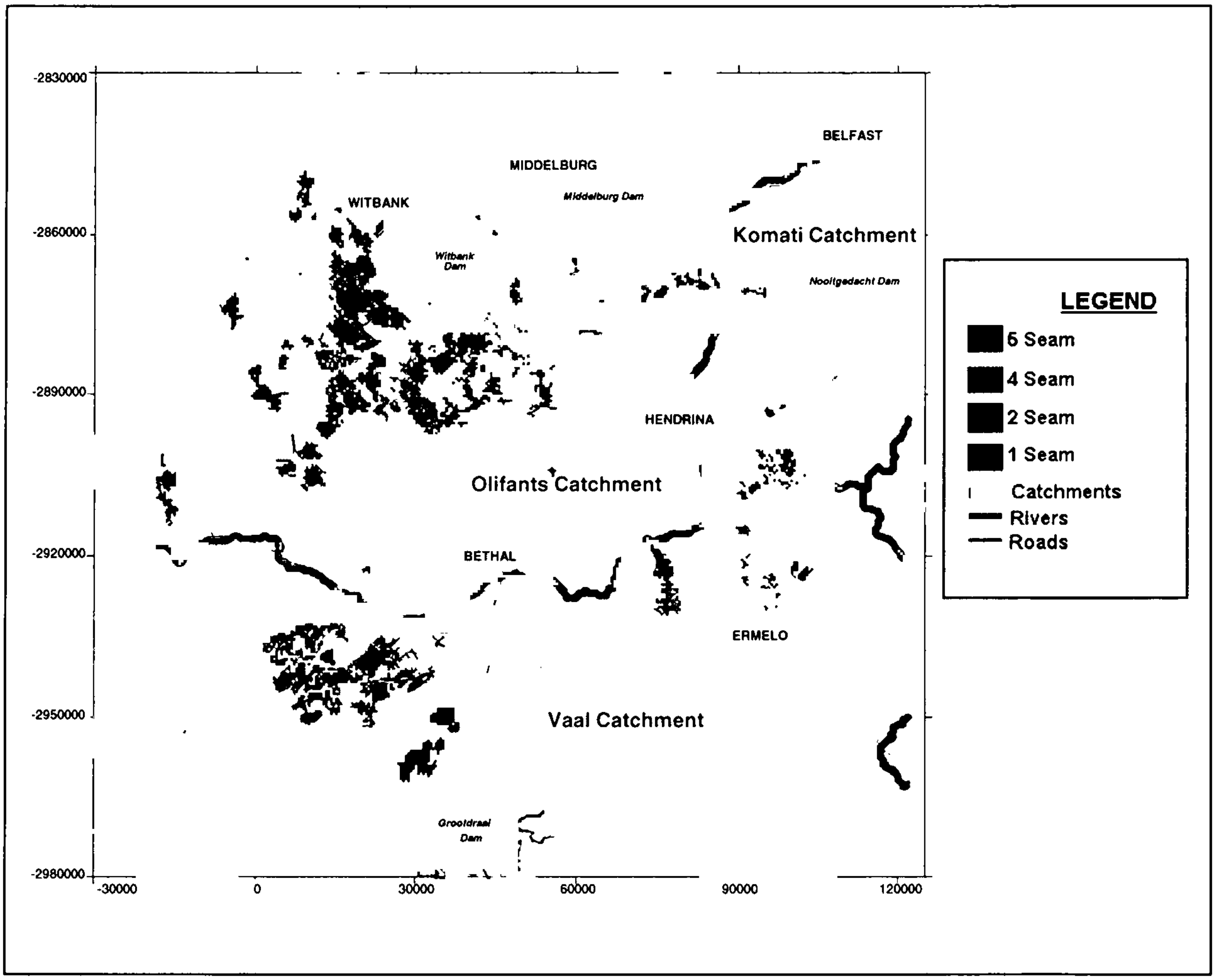


Figure 1.5 – Locality map of some opencast and underground mines in the Witbank and Highveld Coalfields

1.3.1.1 Origin and stratigraphy

The strata of the Vryheid Formation and the Dwyka Group of the Karoo Supergroup in the study area consist primarily of sandstone, carbonaceous shale, siltstone, minor conglomerate and several coal seams (Cairncross, 2001). Stratigraphic columns from different parts of the coalfield are illustrated in Figure 1.6. This wide range of sedimentary and structural settings within which the coal seams were deposited, combined with the range in age, climate and plant communities give rise to the numerous differences in terms of organic and inorganic matter and the degree of maturity of the coal seams (Falcon, 1986).

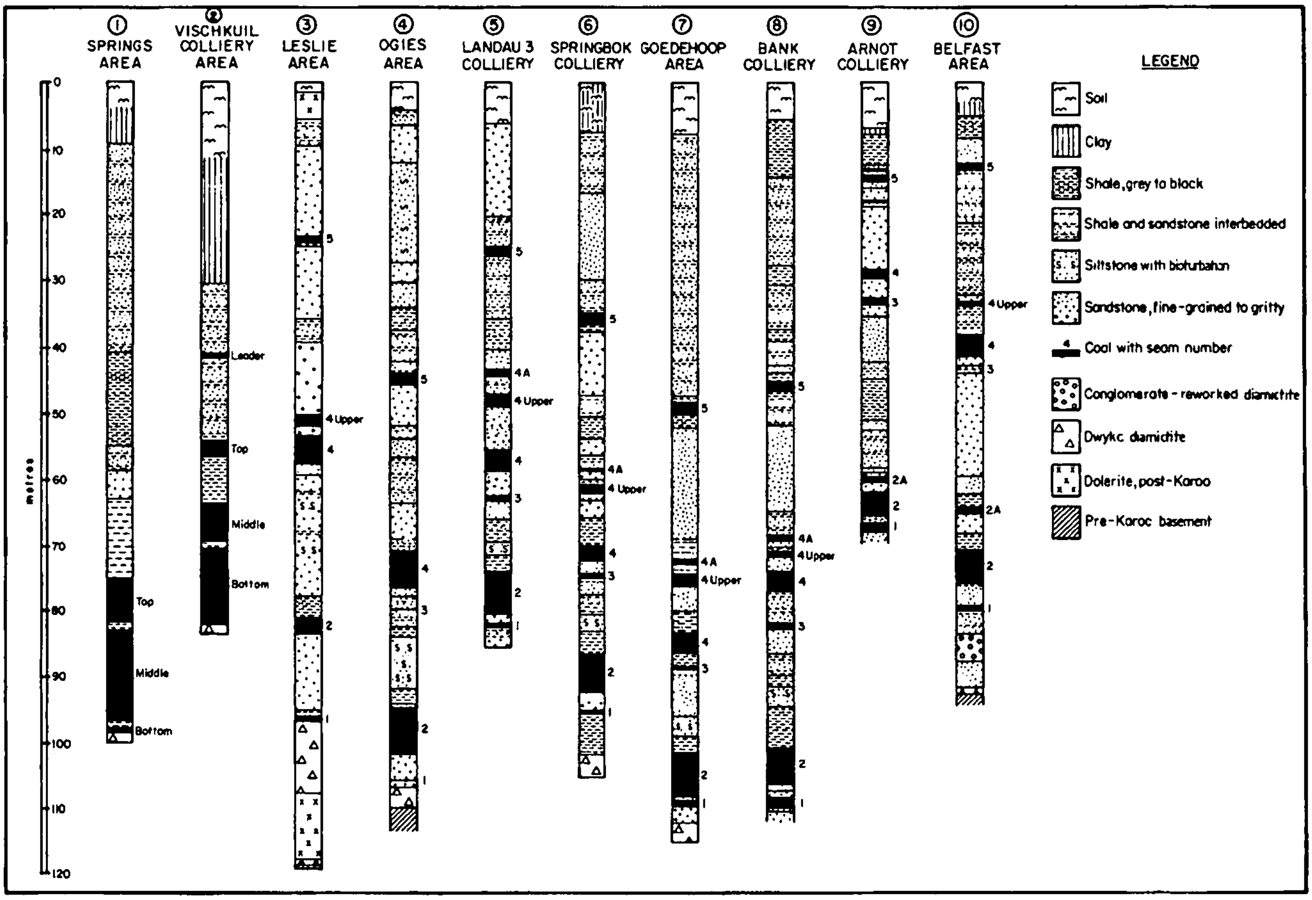


Figure 1.6 – Stratigraphic columns for different parts of the Witbank Coalfield (Smith and Whittaker, 1986b)

The sediments of the Vryheid Formation of the Ecca Group of the Karoo Supergroup were deposited on an undulating floor which influenced the distribution and thickness of the sedimentary successions as well as the quality of coal seams. Although post-

Karoo erosion has removed substantial volumes of sediments a maximum of 180m of Karoo Supergroup strata has been preserved. Several major glacial valleys are preserved in the area in which Dwyka Group sediments are the thickest. Numerous ridges, mainly of pre-Karoo igneous rocks are present of which the Smithfield Ridge forms the southern boundary of the coalfield. Five coal seams are contained within a 70m succession and parting thickness between the seams is constant across the field (Smith and Whittaker, 1986b).

1.3.1.2 Description of coal seams

Four of the five seams in the coalfield are developed over a strike length of approximately 180km. The No. 2 seam is economically the most important, but Nos. 5, 4 and 1 seams are mined in areas where locally the coal quality is high and the thickness is suitable for mining purposes. The least economically important seam, No. 1 seam, is better developed in the northern and eastern part of the field where it is approximately 1.5 to 2m thick. It consists mainly of lustrous to dull coal with local shale and sandstone parting and a competent sandstone or grit roof, especially in the Arnot area (Snyman, 1998).

The No. 2 seam constitutes approximately 69% of the resources of the Highveld Coalfield. An average natural thickness of 6.5m is found in the central part and increases to about 8.5m in the south-west where the upper part is shaly and not economic. In the east it is about 3m thick. A consistent sandstone parting separates the seams into a No. 2 and No.2 Upper seam. Mining conditions are generally favourable where sandstone constitutes the roof. There are areas where shale is present in the roof (Smith and Whittaker, 1986b). The No. 3 coal seam is discontinuous throughout the coalfield and not of economic importance.

In addition to the No. 4 seam (or 4 Lower), this coal zone generally contains a No. 4 Upper and a No. 4A seams (Figure 1.6) both of which are too thin to be economically exploitable. The main No. 4 seam consists of dull to dull lustrous coal with a natural thickness varying between 2.5m in the central part of the field to 6.5m elsewhere. The roof of the No. 4 Lower seam comprises shale which presents poor stability conditions. The No. 5 seam, which is approximately 1.8m thick in most areas, consists mainly of bright coal with thin shale partings and a weak laminated sandstone roof. The seam has been eroded and it's distribution is controlled mainly by present-day topography (Snyman, 1998).

1.3.1.3 Structure

The distribution of the seams is controlled by the pre-Karoo topography, but the seams are mainly flat and dip only slightly in a southerly direction. Steeper dips are encountered in the lower seams while seams Nos. 4 and 5 have a rather regular disposition. The No. 4 seam is also greatly influenced by the erosional effects of the overlying sandstone. The strata of the Karoo are generally undeformed with abundant small faults (Smith and Whittaker, 1986b).

Dolerite dykes and sills affected most of the areas of the coalfield. Large sections of the coal seams have been devolatilised and are rendered useless for mining purposes. North, north-east and east trends are noticed in the case of the dykes while the most prominent dyke, the Ogies Dyke strikes west-east for approximately 100km. To the north of the Ogies Dyke smaller dykes are less common than in the south and vary considerably in thickness from 0.5m to 1m in the north to 5m thick in the south (Smith and Whittaker, 1986b).

The extent to which areas of coal seams in the immediate vicinity of such intrusions are burnt or devolatilised depends not only on the thickness of the intrusion, but the temperature, period of molten flow and attitude of the intrusion, and the intrusions are classified into porphyritic and non-porphyritic groups. The amount of displacement caused by dolerite sills is equivalent to the thickness of the sill. However, the associated devolatilisation presents a more serious problem to mining and coal resources estimation (Smith and Whittaker, 1986b).

1.3.2 The Highveld Coalfield

The Highveld Coalfield covers an area of approximately 7000km^2 and extends over a distance of some 95km from Nigel and Greylingstad in the west to Davel in the east, and 90km in a north-south direction (Jordaan, 1986). As seen from the distribution of mines in Figure 1.5, the coalfield is situated in Vaal River Catchment area.

1.3.2.1 Origin and stratigraphy

Similar to the sedimentation in the Witbank coalfield, the rocks of the Karoo Supergroup in the Highveld coalfield were deposited on undulating pre-Karoo surfaces. However, post-Karoo erosion removed large volumes of coal along the northern margin of the field. Glacial diamictite, siltstone and mudstone deposits are overlain by clastic sediments and coal measures. The sediments were deposited in fluvio-deltaic environments while the coal accumulated as peat in swamps and marshes (Jordaan, 1986).

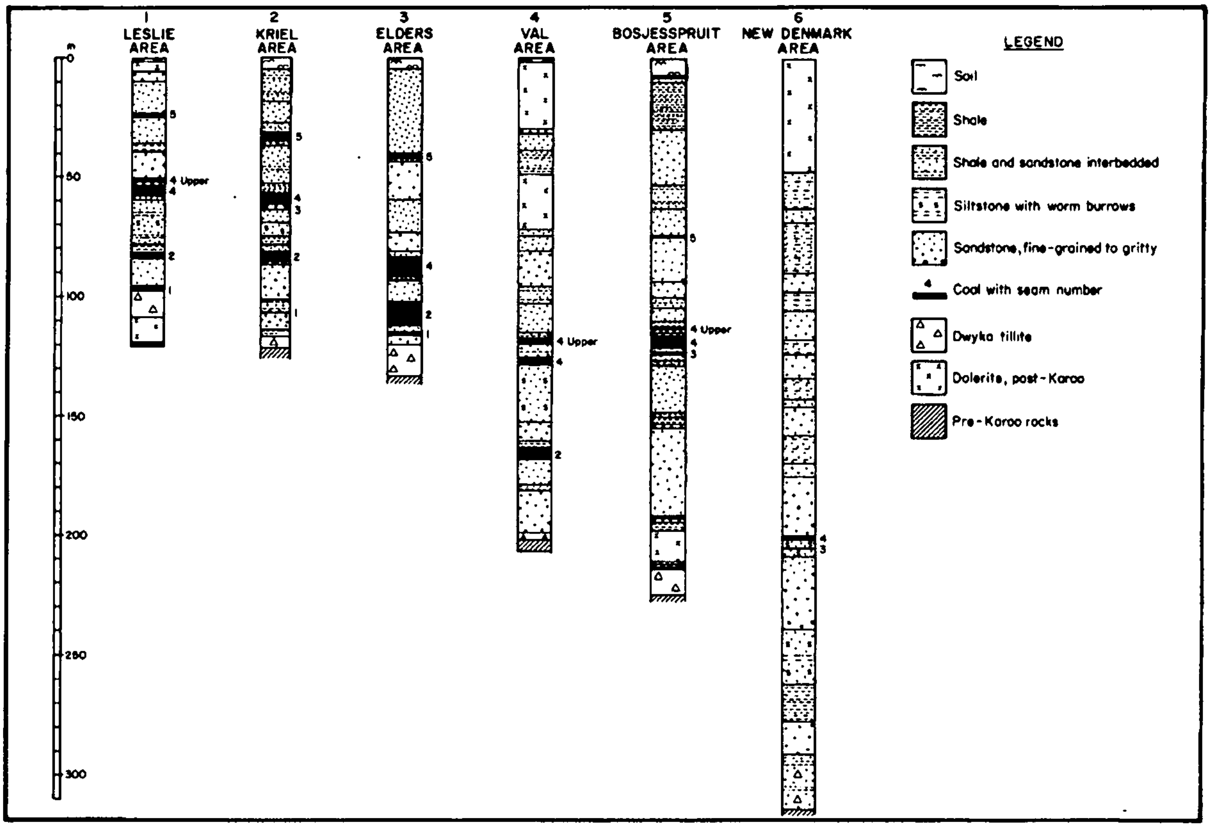


Figure 1.7 - Stratigraphic columns for different parts of the Highveld Coalfield (Jordaan, 1986)

Three phases of sedimentation took place, the first delta-dominated phase giving rise to upward coarsening cycles of dark grey, micaceous siltstone, fine-grained sandstone with abundant carbonaceous material, and coarse-grained sandstone, while widespread bioturbation is found in these rocks. The fluvially dominated coal-bearing horizon is about 75m thick in which five coal seams have been recognized in the northern and western parts, but the lower two seams are absent in the southern and eastern parts. Above Nos. 4 and 5 coal seams glauconitic sandstones are indicative of marine transgression periods. Micaceous shale, siltstone and sandstone of the upper deltaic succession overlie the coal measure (Jordaan, 1986).

1.3.2.2 Description of coal seams

As seen from Figure 1.7, there are five seams developed in the coalfield, namely, Nos. 1, 2, 3, 4 and 5. The No. 4 seam is further subdivided into Nos. 4 Upper, 4A and 4 coal seams. Nos. 2, 4, 4 Upper and 5 seams are economically important. The Nos. 1, 3 and 4A coal seams are thin and discontinuous. The thickness of No. 2 coal seam varies from 1.5 to 4m, but can reach 8m in the west and north-east. Irregularly distributed shale partings are present in the seam, and due to the variability of the coal, only the upper 2 to 3m, or the basal 2 to 3m forms the mineable horizon. It consists of bituminous coal with roof rocks ranging from fine-grained sandstone, intercalated sandstone, siltstone and shale (Jordaan, 1986).

The No. 4 seam consists mainly of dull coal with shale intercalations in the upper part of the seam. It's thickness varies from 1 to 12m but averages 4m (Snyman, 1998). The roof is variable and consists of grit, coarse- to fine-grained sandstone, intercalated sandstone and siltstone or shale, while the generally competent floor consists of sandstone and siltstone. The No.4 Upper seam comprises low grade bituminous coal and can only be mined where the in-seam parting is thick enough to provide competent roof conditions. It is characterised by a strong, coarse-grained sandstone floor and a weak interlaminated sandstone and siltstone roof (Jordaan, 1986).

The No. 5 coal seam consists mainly of bright coal. It is present across the majority of the coalfield but only reaches a mineable thickness in the northern and western parts (Snyman, 1998). The natural thickness varies between 1 and 2m. The roof of the No. 5 seam comprises a fine-grained sandstone and siltstone (Jordaan, 1986).

1.3.2.3 Structure

The seams are generally flat, but the intrusion of dolerite sills caused significant displacement in the strata. Dolerite dykes and sills, which might be of the same age as the Drakensberg Formation, are present mainly along north-south, north-east and north-west trends. The dykes had a destructive effect on the coal seams in most areas of the coalfield and devolatilised zones range from 1 to 30m. The sills are present over large parts of the coalfield, but considerable portions of these sills has been removed due to post-Karoo erosion. These sills are porphyritic and non-porphyritic in character (Jordaan, 1986).

1.4 Palaeo-climate and vegetation

The most important factors influencing the formation of coal in the early stages of plant accumulation and degradation are (i) tectonic control and sedimentary environments, (ii) plant communities, (iii) prevailing climatic conditions, and, (vi) conditions such as water level, Eh and pH, and salinity. This section will therefore briefly discuss the vegetation and climatic conditions present during the formation of the above-mentioned coal seams.

Cold to cool temperate conditions where present during the existence of the Permian swamps of the basins of Gondwana. The coal-bearing successions accumulated on relatively stable continental depressions in the form of different types of basins, the Karoo retroarc foreland basin being one of them. Different plant species contribute different forms of decaying humic matter which will therefore influence the product of accumulation and degradation. So too does changes in climate provide different temperatures, humidity, and rainfall which affects the rate and type of decay of the plant matter (Falcon, 1986).

Major floral and climatic changes brought about by continental drift may have effected the migration of vegetational belts, which is especially evident during Karoo sedimentation. The most significant feature with regard to climate changes during Karoo times is the early Dwyka glaciation. With this phase drawing to a close, rapid glacial advances and retreats from local ice cap centres took place, and the continent passed through numerous distinct vegetational phases starting during Late Carboniferous and Early Permian times. Climatic changes vary from Permian-Carboniferous arctic to subarctic, cold temperate to temperate, and finally into hot, arid desert conditions during Triassic times and finally during Jurassic times, ending in volcanism.

The earliest pre-Karoo floras have been described to occur during the Lower-Carboniferous age, which was followed by Dwyka glaciation. At the end of the Dwyka new plant assemblages began to flourish, and mixed *Glossopteris-Gangamopteris* flora was resident in the swamps of the Mid-Ecca Group. The Upper Ecca and Beaufort Group was characterised by Glossopteris with swampy flats and abundant reed-like horsetails. The Molteno sediments of the Upper Triassic yielded fern-like flora called Dicroidium which died out during the deposition of the semi-arid Clarens Formation towards the Late Triassic-Early Jurassic (Falcon, 1986; Smith, *et al.,* 1993).

1.5 Topography

The topography of the study area is characterised by gently undulating surfaces, as seen from the topographic map in Figure 1.8, with several local streams, larger rivers and pans shaping the landscape. Average surface elevations are around 1540mamsl, but sandstone plateaus such as those in the north reaches 1600 mamsl (Azzie, 1999).

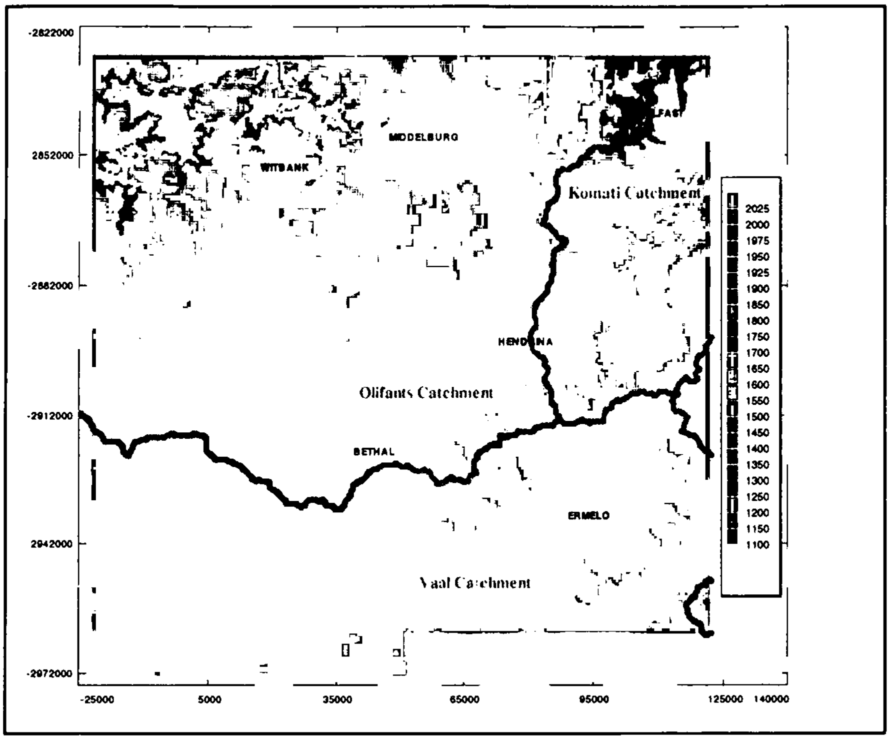


Figure 1.8 – Surface contours of the Mpumalanga Coalfields

1.6 Groundwater and drainage systems

Three catchment areas, namely the Komati Catchment, the Olifants Catchment, and the Vaal Catchment situated in the north-eastern, central and south-western parts of the coalfields serves as the main drainage systems. Surface water quality of the Loskop Dam, Witbank Dam, Middelburg Dam, Nooitgedacht Dam, the Grootdraai Dam and other smaller rivers (Figure 1.9) and streams can be obtained in Grobbelaar (2001). The Olifants River and Steenkoolspruit are the major drainage valleys in the Witbank Dam catchment, while the Klein Olifants River is the primary drainage valley in the Middelburg Dam catchment (Chelin, 2000).

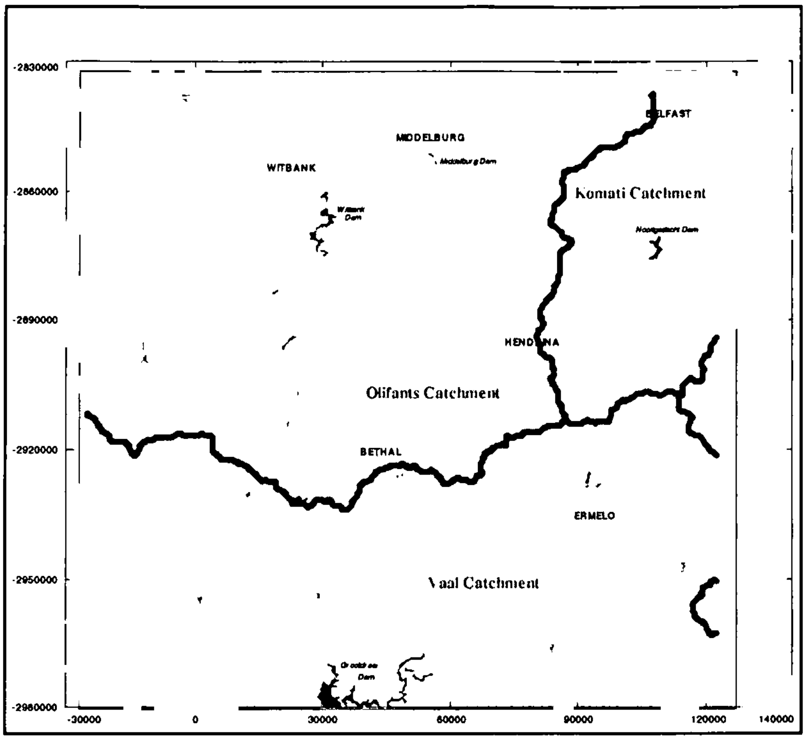


Figure 1.9 – Drainage map of the Mpumalanga Coalfields

According to Azzie (1999) and Grobbelaar (2001) two groundwater systems are present, namely, the weathered and unweathered Ecca Group\Vryheid Formation aquifers. The first lies between depths of 5 and 12m below surface and occurs at the interface of soil and bedrock. Rainfall infiltrating into the weathered rock reaches impermeable layers of sediments below the weathered zone. Groundwater flow patterns usually follow the topography. The aquifer within the weathered zone is generally low-yielded (range 100 – 2000 L/hour) because of it's insignificant thickness (Hodgson and Krantz, 1998).

The lower system occurring in the unweathered Vryheid Formation consists of sandstones, siltstones, shales and coal. Groundwater within these sediments will be contained within fractures, joints and bedding planes. The Ogies Dyke is impermeable over much of it's length and thus compartmentalizes the groundwater. The coal seams have the highest hydraulic conductivity of all lithological units in the Ecca Group (Grobbelaar, 2001).

The depth of the water table is between 1 and 8m below surface, and water levels have been recorded to be within 5 to 15m of the ground surface. Pre-Karoo aquifers are not tapped often due to their great depths and low-yielding character (Grobbelaar, 2001).

CHAPTER 2
PREVIOUS WORK

2.1 Geochemistry and mineralogy of the Ecca Group

Various factors affect the major and trace element distributions in sedimentary rocks. These would include variables such as source rock compositions, intensity of weathering, sedimentation rates, depositional environments, and diagenesis. Depending on the depositional history and the above-mentioned factors, different mineral assemblages are observed in different lithologies.

The Ecca Group becomes more shaly in a southerly direction and is composed almost entirely of shale south of a line through Bloemfontein and Harding. The Vryheid Formation can be divided into several cycles of sedimentation in which a succession of depositional environments can be recognized (Van Vuuren and Cole, 1979). Coarse, fluviodeltaic sandstones make up the proximal facies of this gently subsiding shelf platform, and wedges out into siltstone and mudstone facies (Pietermaritzburg and Volksrust Formations) in the south (Snyman, 1998). The formation is composed mainly of coarse-grained arkose, conglomerate, micaceous siltstone, carbonaceous shale, coal seams and thin layers of limestone (Stratten, 1986).

Although numerous references are available with regard to the structural, environmental and depositional conditions of the Karoo Basin, limited literature is available on the mineralogy and geochemistry of these sediments. Furthermore, increasing interest in the latter fields has not been prominent. The section of this study concerning the chemical investigation of the coal-bearing successions in the Karoo Supergroup is therefore a generous contribution to the knowledge on the topic.

Previous work in this regard involved a brief petrological study on the coal-bearing strata of the Ecca sediments by Bühmann and Bühmann (1988) as part of a research project. Coal and rock samples were collected from core drilled in the

Witbank Coalfield, Eastern Transvaal Coalfield and Vryheid Coalfield and analysed by means of X-ray diffraction in order to evaluate minerlogical variables as indicators of fluctuating palaeoenvironment conditions during the formation of the coal deposits.

Clay assemblages dominate the mineralogical components of samples amongst the coals, and are even more abundant amongst the sediments in most cases. These assemblages display variations from kaolinite-free to kaolinite-dominated with subordinate mica and chlorite as well as minor traces of illite\smectite interstratification in the Witbank Coalfield. A similar distribution pattern is displayed in the Eastern Transvaal Coalfield, however, chlorite dominance in certain sections of the sequence is commonly associated with the carbonate minerals, and the illite\smectite interstratification contains up to 80% illite in some cases. The clay fraction in the Vryheid Coalfield is dominated by chlorite and mica with a low amount of illite\smectite interstratification (Bühmann and Bühmann, 1988).

The relationship between clay and non-clay fractions was examined in terms of the presence and absence of kaolinite. K-feldspar is more abundant in kaolinite dominant samples while plagioclase proportions are higher in kaolinite-free samples. Siderite is more prevalent in kaolinitic samples. Apatite is associated with 2:1 layer silicates which are indicative of marine environments while crandallite is restricted to kaolinite dominant samples.

There is no direct association between pyrite and any clay minerals; however the presence of pyrite does suggest marine influence or a reducing environment. Mica and chlorite are both regarded as detrital components which were formed under conditions of low chemical weathering resulting in the absence of kaolinite where a marine water environment was present. The presence of freshwater aids the transformation of illite, chlorite and smectite to kaolinite (Bühmann and Bühmann, 1988). As shown by Bühmann and Bühmann the use of prevailing mineral assemblages could serve as a dependable indicator as to what depositional conditions were.

Another study that provides reasonable information on the mineralogy and geochemistry of the Karoo sediments was conducted by Azzie (2002) using both XRF and XRD techniques. It was found that the sediments consist predominantly of the two oxides SiO_2 and Al_2O_3. The sandstones (including the glauconitic layers) have between 41 and 87 wt% SiO_2, while the shales and siltstones have between 27 and 61 wt% SiO_2. Al_2O_3 was highest in the siltstones and shales (9 – 23 wt%) followed by the sandstones (5 – 24 wt%). Fe_2O_3, CaO, MgO, Na_2O and K_2O are present in smaller concentrations than SiO_2 and Al_2O_3, while P_2O_5, MnO and Cl were barely present in any of the rocks. From XRD interpretations Azzie deduced that kaolinite and quartz are the main mineral constituents in all rock samples, while feldspars occur in major to minor proportions. Illite and siderite were present in major to minor amounts while pyrite, calcite and dolomite were present in minor to trace proportions in the shales and siltstones.

A comparison of available data on the Karoo coal-bearing successions with other coal-bearing successions in Australia and U. S. A. show that the sandstones, shales and siltstones in the Karoo Supergroup are reasonably similar in composition to those in other countries, despite differences in age and depositional environment. Documented information on the geochemistry of coal-bearing strata is published by Nicholls (1968), and Styan and Bustin (1984), and includes a range of varying conditions under which coal-bearing strata have been deposited. However, extensive mineralogical information on the Karoo strata is still necessary and substantial information could be provided in this study.

2.2 Review of mineral matter in coal

Extensive research studies and projects have been conducted on coal universally, and even more so on the complexity of it's constituents. Such detailed studies on the mineralogy and geochemistry of coal have been carried out in abundance in countries such as Australia, Canada, India, Pakistan and USA, amongst others. However, the same is not true for the numerous deposits located in South Africa. On very few occasions has coal mineralogy and geochemistry been investigated in further detail by well known researchers in the field. Thus, aspects characterising coal minerals in other deposits of different age, depositional environment and source areas has relevance to understanding minerals in South African coal deposits. Although much is gained from petrographical or chemical studies of the organic constituents, the mineral matter in coal also provides information on the depositional conditions and geological history of the coal-bearing sequences and individual coal beds (Ward, 2002).

The composition of can could be divided into organic constituents, inorganic constituents, and fluid constituents in the organic and inorganic matter. Non-crystalline organic matter consists of lithotypes and macerals, and amorphous phases, while crystalline organic matter such as the hartite-evenkite group is also present. Crystalline or mineral inorganic matter comprises of crystals, grains and aggregates of different minerals, and, metamict and gel minerals. Volcanic and cosmic materials would form part of the amorphous or non-crystalline inorganic matter. Liquid and gas phases occur in minerals together with fluid inclusions to form the fluid constituents of coal (Vassilev and Vassileva, 1996).

The crystalline inorganic matter occurring in coal may form as a result of a range of different processes. These include input of sediment into the original peat-forming environment by epiclastic and pyroclastic processes, accumulation of skeletal particles and other biogenic components within the peat deposit, and precipitation of material in the peat swamp or in the pores of the peat bed. The minerals are often visible in hand specimen, and can frequently be observed during examination of drill-cores, outcrops or mine exposures.

Such megascopic occurrence include thick bands or lenticles of clay-rich or pyritic material, rounded pellets or nodules of mineral matter and dispersed crystals of mineral matter within the coal, as well as minerals that forms coatings on, or infillings in, cleats and other fractures. Microscopic data reveal that many of the minerals in coal occur in a very intimate association with organic constituents. Minerals may therefore also occur as isolated euhedral crystals, as broken, presumably detrital fragments, as microscopic nodules, or in some cases as sub-microscopic crystalline aggregates or framboids. Many minerals, however, occur as petrifactions, representing infillings of cell cavities in the individual coal macerals (Ward, 1986).

Various coal samples contain similar assemblages of major and minor minerals. There is, however, comprehensible distinctions concerning modes of occurrence and the genesis of these minerals. So too is the understanding of certain terms such as epigenetic and syngenetic of the utmost importance. Syngenetic minerals in this case would refer to minerals that have formed contemporaneously with, and by essentially the same processes as the enclosing sediment. Epigenetic minerals occur after the deposition of the sediment. In understanding the genesis of minerals in coal the terms detrital and authigenic are also significant. Detrital minerals results from the mechanical disintegration of the parent rock and commonly occurs as a result of syngenetic processes forming sedimentary rocks, while authigenic minerals are formed or generated in place and have not been transported. These minerals therefore commonly occur due to epigenetic processes that may take place after deposition (Bates and Jackson, 1980).

Although the amount of inorganic matter varies considerably, the major minerals in the crystalline matter of coal are normally quartz, kaolinite, illite, calcite, pyrite, plagioclase, K-feldspar, and occasionally gypsum, Fe-oxyhydroxides, sulphates, dolomite, ankerite and siderite. These minerals will be discussed with regard to their abundance and mode of occurrence in coalfields across the world and in South Africa.

2.2.1 Quartz

Quartz is the most common mineral in coal and is both detrital and authigenic in origin. It is found as pore infillings in the organic matter in coal, a mode of occurrence that clearly indicates it's authigenic origin. Epigenetic quartz is massive or is present as bipyramidal crystals (Vassilev and Vassileva, 1996). Such crystals might have a volcanic origin or could have been precipitated authigenically. Occurrences where quartz has filled the cells of plant tissues at the early stage of development have been observed; however, according to Ward (2002) the origin of this silica is uncertain. However, a large proportion of silica in modern-day peats is of biogenic origin (Ward, 1986).

The introduction of silica by hydrothermal solutions results in the quartz filling cracks, forming lenses and encrusting coal fragments. It may constitute up to half of the mineral matter in Australian coals (Ward, 1986), but makes up only 10% of the oxidation residues. This percentage may vary considerably depending on the depositional setting. Coals from the Gunnedah Basin in New South Wales, Australia contain relatively low amounts of quartz of detrital origin as observed by Ward *et al.* (1999). Similarly, Ward *et al.* (2001b) also noticed that quartz formed a major part of the mineral matter of coal seams in the Gloucester Basin with significantly elevated amounts (>40%) of this mineral in the lower seams of the basin, which in this case may represent contamination of the original peat by quartz-rich tuffaceous sediment.

Electronic low-temperature (oxygen-plasma) ashing of some reference materials from the North American Argonne Premium coal series showed that quartz made up approximately 7 to 20% of the LTA residues. However, the mineral was more abundant in ash prepared at 370°C (Ward *et al.,* 2001a). Thus, the significance of this detrital and/or authigenic mineral is apparent, despite the difference in age and depositional environment between northern hemisphere and southern hemisphere coals. Furthermore, numerous authors such as Mackowsky (1968), Bouška (1981) and Ward (1984) have observed and confirmed the presence and modes of occurrence of quartz in coal.

2.2.2 Clay minerals, feldspars and micas

Clay minerals present in coal are mainly kaolinite, subordinate illite and minor amounts of montmorillonite. In most cases, kaolinite makes up almost all the mineral matter along with quartz. It may occur in the pores and cell cavities of the coal macerals or as layers, lenses and lenticles. Authigenic kaolinite is a result of diagenetic alteration of illite, montmorillonite, feldspars, muscovite, other alumino-silicates, and pyroclastic glasses. Some clay minerals which occur as veinlets or crusts and fine films on slicken-side surfaces in coal, may have an epigenetic origin.

There are various theories concerning the origin of kaolinite as suggested by Ward (1986). Occurrences where kaolinite has been sourced from volcanic material input to the original peat deposit has been observed (Ward, 2002), however, Al_2O_3 is soluble under low pH conditions and can thus be leached from any detrital mineral material and transported to areas with higher pH where it is authigenically precipitated (Vassilev and Vassileva, 1996). This precipitation leads to the formation of various minerals such as bauxite-group minerals, depending on the precipitation conditions. The occurrence of quartz and kaolinite as the dominant mineral matter in coals is not uncommon. In some high rank coals the concentrations of illite, mica and chlorite can be higher than kaolinite probably as a result of decomposition of some pre-existing minerals (Vassilev and Vassileva, 1996).

Although more commonly associated with the non-coal strata, illite is often completely absent as a discrete mineral constituent in coal samples (Ward, 1986). Not only the partings in coal, but also the overlying and underlying shales, contain more illite than kaolinite (Mackowsky, 1968). It occurs frequently in the form of mixed-layer or interstratified clay minerals. It's low concentration may simply reflect a low proportion of detrital input to the peat swamp, or indicate that the mineral in it's pure form is susceptible to alteration (Ward, 1986). It also occurs in reasonable proportions in ash residues of North American coals as studied by Ward (2001a) and it's mainly detrital presence in coals from Bulgaria, the United States, Australia, Japan, Canada, China and South Africa has been observed by Vassilev and Vassileva (1996).

Although occurring is lesser percentages, montmorillonite and chlorite are also found in coals throughout the world, and represent one of the principle clay minerals in Australian bituminous coals, other than kaolinite. They are most likely to be of detrital origin (Ward, 1984, 1986; Vassilev and Vassileva, 1996).

Feldspars are represented by K-feldspars and plagioclases as semi-rounded grains and prismatic crystals of detrital, or even pyroclastic origin (Ward, 1986). These minerals are common in non-coal strata, or at least in the coal bearing sequences. Mica is represented by muscovite and subordinate biotite. Muscovite and biotite may both be of detrital origin while muscovite may also be as a result of diagenetic weathering of feldspars (Vassilev and Vassileva, 1996).

2.2.3 Sulphides

One of the major contributors to air and water pollution originating from coal mining operations is the group of sulphide minerals which commonly occur in coal and occasionally in coal-bearing sequences. It is therefore important to understand the mode of occurrence of sulphur in coal. The total sulphur in coal can be used as an environmental indicator of the original peat. High sulphur content is often associated with marine influence at the time of/or immediately after deposition. Higher concentrations of sulphur are usually found at interfaces that indicate a change of environment (i.e. fresh to brackish water).

There are three major forms of sulphur identified in coals, namely organic, pyritic and sulphate sulphur (Mackowsky, 1968; Bouška, 1981; Ward and Gurba, 1998). Organic sulphur is part of the plant tissue and forms as the plant grows. It is chemically bound to the carbon molecules, but it is not as well established as inorganic sulphur. Syngenetic organic sulphur is derived primarily from original plant sulphur. Reduced hydrogen sulphide can also react to form organic sulphur compounds if iron is not readily available to form pyrite. The organic sulphur in coal is mainly attached to the side chains of the organic molecules in the form of (-SH) groups. With the increase in coalification and rank, the (-SH) content of the macerals decreases due to condensation. Low-sulphur coal contains mostly syngenetic organic sulphur (Ward and Gurba, 1998).

Pyritic and sulphate sulphur forms are often referred to as inorganic sulphur. Sulphate sulphur is often formed by oxidation of the pyritic sulphur. Inorganic sulphur is introduced to the coal during and/or after peat accumulation and during coalification. Pyritic sulphur mainly occurs as pyrite and marcasite. Sulphur forms including galena, sphalerite and millerite have also been reported in some coal samples (Ward and Gurba, 1998). This type of sulphur can form syngenetically during peat formation as a result of microbial reduction of aqueous sulphate during early diagenesis. Bacterial reduction of sulphate takes place in a variety of sedimentary environments, both marine and freshwater, wherever organic matter and sulphate coexist in the absence of oxygen. Syngenetic pyrite is usually characterized by small, isolated crystallites and framboids (Vassilev and Vassileva, 1996).

Epigenetic pyrite is usually observed as large crystals, massive forms with various overgrowths encompassing the previous overgrowths or as cleat- and fracture-filling pyrite. This secondary incorporation of sulphur is determined by the availability of sulphate, the reactivity of the organic matter, the extent of sulphate reduction and the availability of iron and other metals to form mineral sulphides. Some epigenetic occurrences may represent remobilisation of organic sulphur or syngenetic sulphides within the coal, while other may be the result of factors outside the original depositional system, such as nearby igneous intrusions, or caused by post-depositional fluid movement through the coal-bearing succession. Unlike most syngenetic pyrite, post-depositional sulphides are not necessarily an indication of marine influence on the formation of the coal seam (Spiker *et al.,* 1994; Ward, 2002).

Primary sulphate is formed by equilibration of sulphate molecules with water molecules and catalyzed by sulphate reducing bacteria early in diagenesis. Secondary sulphate is formed by late stage oxidation of sulphide (i.e. during weathering) by one of the following mechanisms:

a) Utilizing O_2 as an oxidizing agent

$$S^{2-} + 2O_2 \Rightarrow SO_4^{2} \qquad (1)$$

b) Utilizing Fe^{3+} or some other oxidizing agent in the absence of oxygen

$$S^{2-} + 8Fe^{3+} + 4H_2O \Rightarrow SO_4^{2} + 8Fe^{2+} + 8H^{+} \qquad (2)$$

The sulphide oxidation via reaction (2) is generally faster than via reaction (1), and is predominant under natural conditions. Generally coals show a wide variation of primary and secondary sulphate and very few coals are dominated by one source (McCarthy *et al.* 1998).

2.2.4 Carbonates

The carbonates of calcium, iron magnesium and manganese are some of the most obvious of the incombustible constituents since they occur as the common cleat infillings of coal seams (Williamson, 1967) and are mostly authigenic minerals in coals (Vassilev and Vassileva, 1996). These minerals are of both syngenetic and epigenetic origin. Syngenetic calcite, dolomite, and ankerite occur as individual grains, lenses or infilling cell pores. The latter minerals also occur as veinlets filling cavities of cementing of fractures coal fragments, suggesting an epigenetic origin. Larger, spheroidal to regular masses of syngenetic minerals, mainly calcite but also including siderite, dolomite, pyrite and quartz, occur in some seams as coal concretions. These mineral accumulations are regarded as representing concretions formed in the peat bed, either during plant deposition or after early diagenesis. Siderite occurrences include nodules with a typically radiating crystal structure and replacements of the maceral components. An abundance of syngenetic siderite is usually thought to indicate deposition of the coal mainly under non-marine conditions (Vassilev and Vassileva, 1996).

Epigenetic carbonates, such as calcite, dolomite, ankerite, and siderite, are common cleat infilling materials in coal seams. In some cases the cleat fillings may show chemical variations such as those observed in some North American coals (Ward, 2002). Vassilev and Vassileva (1996), along with various authors, have observed the presence of other carbonates such as smithsonite, magnesite, rhodochrosite, and witherite, amongst others.

2.2.5 Phosphates

Phosphate minerals in coal exist as minor to rare constituents of the mineral matter, but are still associated with coal deposits. They are detrital and authigenic in origin. Phosphorus in coal occurs mainly as inorganic phosphates and lesser amounts of organically bound phosphorus complexes. Sources of phosphorus may be in enriched volcanic material introduced during peat accumulation or the organic matter in the peat bed (Ward, 2002).

A range of phosphate minerals can occur in coals, including apatite and the aluminophosphates of the crandallite group, which occur mainly as syngenetic cell and pore infillings, or as epigenetic cleat and fracture fillings due to the remobilisation of phosphate formed earlier within the coal seam. Crandallite-group minerals are composed of four principal elements, namely phosphorus, calcium, barium/strontium and aluminium. Crandallite occurs as 3µm size colloidal precipitates, as concretions and as porous aggregates as large as 100 µm (Rao and Walsh, 1999). Apatite occurs as prismatic crystals and occasionally in clusters. Occurrences of uranium phosphate, goyazite and vivianite, as well as the association between phosphorus and some rare earth elements have been observed (Vassilev and Vassileva, 1996).

2.2.6 Other minerals

Although the spectrum of minerals occurring in coals has been reviewed in considerable detail, subsidiary amounts of less common minerals also occur in coals. Chlorite, which in some cases would be regarded as a significant constituent, occurs as an authigenic mineral together with other chlorides such as halite. Alumino-silicate volcanic glass has also been observed as spheres, spheroids and angular particles. The accessory minerals in coal show great variety, but their low concentrations create difficulty in determining some of them (Vassilev and Vassileva, 1996).

2.3 Mineral matter in South African coal

Significant observations can be made by investigating the information on the distribution, occurrence and abundance of minerals in the coal deposits of the Karoo Supergroup which has been gathered up to date. A study by Gaigher (1980) deduced that the inorganic matter in some South African coals is dominated by clay minerals, mainly kaolinite and illite, followed by quartz and then the carbonates calcite, dolomite and siderite. Mineral matter is seen to vary over a range of 11% to 36% of a total sample. Gaigher observed that quartz contents are extremely variable. Samples taken in the centre of the Witbank No. 2 seam had the lowest quartz contents, while the Witbank No. 5 seam samples contained higher proportions of quartz (17% to 35% of mineral matter). Nearly all No. 2 seam samples contained dolomite and siderite in addition to calcite, while pyrite was present in all samples from the respective coalfields sampled in this study.

The most important constituents of mineral matter in coal, which consists of the clay mineral fraction, are analysed in more detail. Samples from the Witbank coalfield No. 2 and 4 seam contained abundant kaolinite with only traces of illite and expandable clays such as illite-smectite and montmorillonite. Regular interstratified illite-montmorillonite dominates the clay fraction of the No. 5 seam samples (Gaigher, 1980). On average, the clay mineral composition of Witbank coal falls close to the composition field for Australian coals, but with somewhat less expandable clays. In the Witbank No. 2 seam, coal from the extremities of the coalfield are of slightly lower rank, containing kaolinite values as high as 88% compared to the 61% kaolinite from the central part of the coalfield.

Similarly, Azzie (2002) found that the principle clay mineral present in coal samples from the Highveld area was kaolinite. It was not established whether mixtures of discrete montmorillonite and illite were present. Quartz was absent, or present in trace quantities in the coal units. Calcite and magnesite were dominant carbonate phases while pyrite was generally a minor constituent. Concentration of the phosphate apatite was highest in the coal samples, and very rare or absent in the sediments. Ankerite, microcline and anatase were also identified using XRD analysis.

The occurrence of aragonite in carbonate lenses in coals from the Witbank area has been noted by Van der Spuy and Willis (1991). Although, aragonite has been observed in coals from other countries (Vassilev and Vassileva, 1996), the lack of this carbonate was emphasized by Van der Spuy and Willis. However, the XRD analyses of carbonate lenses from coal mines in the Witbank area indicated that aragonite is a major mineral phase in some of these assemblages. Seeing that the individual mineral concentration in coal is less than 5%, it is difficult to identify minerals in lower concentrations. Thus, after an examination of a diffraction scan

Van der Spuy and Willis concluded that most of the strongest peaks of aragonite are obscured by, and appear as "shoulders" on either side of peaks of minerals such as quartz, kaolinite and pyrite, therefore the presence of aragonite in South African coals could be possible.

According to Gaigher (1980) the chemical analyses of coal ash from South African coals show the residue to have features of hydrolysate sediment, modified by the element collecting activities of the plants and the low Eh – pH conditions. SiO_2, MgO, Na_2O and K_2O percentages were significantly low when compared to crustal averages, probably due to their solubility under humid conditions. The enrichment in Al_2O_3 and TiO_2, with median values between 26% and 1.2% respectively, might also have been as a result of leaching and accumulation by plants. P_2O_5 has a varying concentration in coal from 0.05 to 4%.

Similar average concentrations for Al_2O_3 and TiO_2 where obtained by Azzie (2002), with significant correlation between TiO_2 and quartz (r_s=0.81) suggesting that to some degree they are complexed with the organic matter. Unlike in the Gaigher study, available analyses of sulphur and iron showed good agreement with each other (r_s=0.76) and pyrite from Azzie's mineralogical interpretations. From analyses for calcium, magnesium and the carbonate minerals it was deduced that calcite was more abundant in the coal samples than dolomite; yet both do occur in the coals, and sometimes in substantial amounts that are well within the order of 10 to 40 wt% total the mineral composition. Insufficient data was available to indicate a correlation between Na_2O, K_2O and CaO, and the feldspars in the coals.

With regard to trace elements, Gaigher was unable to establish whether there are any major variations in certain trace element concentrations between the different coal fields. However, it was noted that the coal ash seemed to be enriched in tungsten, gallium, and sometimes strontium, with respect to the earth's crust. Azzie has thus contributed considerably to knowledge on the association between major and trace elements, and various mineral constituents in coal. Good correlation between Nb and quartz (r_s=0.75), and between TiO_2 and Nb, Zr, Th, Sc, Y and Cu was observed, however, no explanation could be presented for this association.

Although no phosphate minerals were identified, a significant correlation exists between Sr and Ca, but not for Sr and calcite and dolomite. A similar scenario exists for Ba which showed weak correlations with the oxides and the minerals. Rb has a strong correlation with K_2O in coals (r_s=0.93), suggesting that Rb is related to K itself and not any particular mineral component. The only significant correlation regarding Zr was with quartz. Zr concentrations are usually higher in felsic rocks and so too in granite. It may be indicative of the influence of igneous material. Concentrations of this element do not exceed 300ppm in coals.

The very brief background regarding mineralogical research on South African coals suggests that more could be done to increase our knowledge of our coal deposits. Information gained by the objectives of this study will hopefully contribute to our understanding of the mineralogical composition of coal deposits of the Witbank and Highveld Coalfields.

CHAPTER 3

GEOCHEMISTRY AND MINERALOGY OF THE COAL AND COAL-BEARING SUCCESSIONS

3.1 Experimental analytical methods used in coal mineralogical analyses

Researchers in coal mineralogy and geochemistry have encountered continuous difficulties with analytical procedures. In order to improve the accuracy with which analytical techniques are performed, and the correctness of results, various experimental methods have come to pass. The need for such improvements in coal analyses has it's origin in the fact that mineral matter in coal constitutes only about 10-30 wt% of a sample. The excessive amounts of organic matter tend to obscure results in various ways, and the low concentrations of inorganic matter contribute to difficulties in analyses. However, not all experimental methods prove to be precise, and an expected degree of error accompanies most results. A look at such techniques would emphasize the importance of accuracy and care during analytical procedures.

The main objectives of some experiments are to separate mineral matter from organic matter in coal, and there are a few ways through which this can be done. Many researchers make use of chemical treatment in order to isolate the mineral matter. This method is more cost efficient compared to acquiring analytical instruments such as oxygen-plasma ashers which will be discussed later.

Ward (1974) addressed the problem by suggesting a chemical treatment of small amounts of coal with hot (85°C), concentrated hydrogen peroxide. Approximately 100ml of hydrogen peroxide is added to 1g of pulverised coal and the mixture is left to oxidise for a few days. The coal changes to a grey-brown or white residue when the reaction is complete. Once the process was complete, the residue was then separated in a centrifuge and dried. Drying was carried out in the laboratory to avoid dehydration and structural changes in the clay minerals. With X-ray diffraction of this residue it was possible to identify quartz and kaolinite in most cases. Phosphate minerals and calcium oxalate minerals were also observed. The technique proved to be a low-cost technique for isolating insoluble mineral matter, but it has limitations. The reactions that take place with the hydrogen peroxide, depending on the constituents of the coal, could be spontaneous and are dangerous to handle. Even though chlorides are not abundant in coals, the organic acids may attack both chlorides and carbonate where present. Kunze and Dixon (1986) proposed an almost identical technique for the removal of organic matter, and once again the same limitation concerning the susceptibility of carbonates is emphasized.

O'Shay *et al.* (1990) used hydrogen peroxide to determine the potential acidity in the pyritic overburden developed in mining areas. The oxidation of iron disulphides, such a pyrite and marcasite from mine spoils produces this acidity problem. To prevent excessive acidity problems from occurring on the spoil surface, or to correct acidity problems that may have occurred after levelling the spoil, a rapid, accurate, and reproducible potential acidity technique was required. The original and modified acidity potential methods were applied to samples from a mine spoil. Samples were pre-treated with $CaCl_2$ to remove residual acid, then oxidised with H_2O_2. Potential acidity values obtained from samples using the modified method were compared with potential acidity values from the original method. The modified method proved to be accurate and less variable in comparison to the original potential acidity method.

Chemical treatment prior to mineral matter identification in some Pakistani coals was carried out by Khan *et al.* (2002). Extractions were made separately with ammonium acetate, HCl, HNO_3 and HF+HCl solutions, as well as an acid mixture consisting of H_2O, HNO_3, HCl and HF. The extraction residues and virgin coals were ashed at 750°C. Cu, Mn, Zn, Fe, Ca, Mg, Na and K were determined using various methods. According to Khan *et al.* (2002) complete demineralization of coal requires successive treatments with various acids. Prolonged soaking followed by extraction is recommended to compensate for complex porosity and vesicular channels in coal. Lithophillic elements like Fe, Ca, Mg and K can be effectively extracted compared to chalcophillic elements like Cu and Zn with all the aforementioned extracts.

In most instances the amount of material which can be accommodated during one analysis is minute, making it difficult to accommodate larger samples. Furthermore, working with chemicals requires extreme cautiousness and procedures might take up to weeks, thus rather time consuming when working with many samples. Therefore, techniques such as normative interpretation of ash analysis data and low-temperature ashing may be a commendable alternative.

Normative interpretations are based on the chemical composition of the coal's high-temperature ash. Such techniques would assume that the various elements in the ash were originally partitioned between particular minerals, and hence represent an attempt to derive a "theoretical" mineralogy from the chemical analysis data. They are most effective if the actual minerals present are known from independent evidence, such as X-ray diffraction (Ward, 1999).

One of the most established methods of isolating mineral matter in coals without major alteration is through low-temperature oxygen-plasma ashing. This technique is described thoroughly by Gluskoter (1965). Oxygen is passed through a high-energy electromagnetic field produced by a radio-frequency oscillator. An electrodeless ring discharge takes place in the gas, and activated oxygen is produced. The activated gas is a mixture of atomic and ionic species as well as in vibrationally excited states. The activated oxygen passes over the sample which is placed in a Pyrex boat 5cm below the radio-frequency field until the organic matter is decomposed. The actual ashing temperature appears to lie between 150° and 200°C. A light-coloured dry mineral residue remains when the oxidation process is complete (Gluskoter, 1965; Ward, 1986). This technique probably represents the most reliable method for determining the percentage of total mineral matter in coal (Ward, 1999).

3.1.1 Experimental procedures followed during this study

An attempt was made to isolate the mineral matter of the coal used in this study for XRD analyses. Although chemical treatment before analysis was considered, the technique presented numerous difficulties and limitations with regard to the facilities available and the enormous amount of samples which where to be analysed.

It was therefore decided to make use of a muffle furnace to oxidise a few samples. Small amounts of material were placed in porcelain holders, and left in a muffle furnace first for 50 hours at 350°C, then for 60 hours at 250°C, and lastly for 70 hours at 150°C. According to Kruger (1981) an ashing temperature of 350°C is optimum as ashing at temperatures higher than this might give rise to changes in the mineralogical composition, while the process will take place exceptionally slower at lower temperatures.

As seen from Tables 3-1 to 3-3, the percentage weight loss decreases as the temperature is lowered, even though the heating period is increased. However, to draw a reasonable conclusion from this experiment the behaviour of the minerals in coal during ignition must be understood. As mentioned before, the assemblage encountered in the coal consists primarily of quartz, kaolinite, montmorillonite, illite and mixed-layer clays, pyrite, calcite, dolomite and siderite, and possibly feldspars, micas, phosphates and chlorides. From literature it is apparent that most of the mineral groups mentioned should not undergo transformation due to a temperature increase up to 350°C (Ribbe, 1974; Vaughan and Craig, 1978; Kruger, 1981; Reeder, 1983; Nriagu and Moore, 1984) . However, results obtained in this experiment prove that normal ashing in a muffle furnace can bring about phase changes, depending on the circumstances during the procedure and the mineral assemblage involved.

Weight loss in the initial stages would be accredited primarily to the loss of H_2O. Due to the combustion of organic matter at higher temperatures oxidation would commence. The X-ray diffraction patterns of each sample prior to and after heating and the virgin coal are illustrated in Appendix 2.

Figure A2-7 illustrates the XRD patterns of sample LU1. The pattern remains similar despite an increase in temperature, with background interference peaks more subtle and the appearance of the strongest peaks of calcite and dolomite, which are especially noticeable in the sample that has been heated to 350°C. From the percentage weight loss at 350°C it is clear that there is a reasonable amount of inorganic matter present in this sample as minor phases become detectable even though more than half of the material has been volatilised. However, as noted by Kruger (1981), it is also clear that combustion at lower temperatures has almost no effect on the sample even though the duration of combustion was lengthened, as observed in Table 3-3.

Table 3-1: Results after heating for 50 hours at 350°C (units in grams)

*Sample	**Crucible	C&S(before)	S(before)	C&S(after)	S(after)	S wt loss	% wt loss
LU1	20.10	30.10	10.00	23.80	3.70	6.30	63.00
LU24	18.60	28.50	9.90	19.40	0.80	9.10	91.92

*S – Sample; **C – Crucible

Sample LU24 was rich in organic material as observed in the percentage weight loss both at 350°C and 250°C as seen in Tables 3-1 and 3-2, respectively. The XRD patterns for this sample are illustrated in Figure A2-8. Problems with the ashing technique emerged especially with the combustion of this sample. Although a large volume of the organic material could be removed successfully, mineral phases remaining in the ash had undergone alteration at 350°C. As seen from XRD patterns, in the small amount of ash remaining, a reasonable amount of phases are present. X-ray diffraction of the coal produced an inadequate pattern in terms of the manual interpretation method applied.

The visibility of the peaks on the diffraction patterns improve as the temperature is raised, and only at 250°C are some minute peaks detected. At 350°C the major mineral phases are prominent; however, the occurrence of specific minerals in coals is not necessarily as a result of reactions that has taken place in natural systems, but could be due to reactions taking place in the furnace. Calcite is dominant throughout the experiments at all temperatures, while kaolinite, anhydrite, dolomite, and hematite only appear at 350°C. Kaolinite is also the dominant clay mineral in most coals and is therefore expected to be present; so too has dolomite been observed together with calcite in South African coals. The phases which pose a problem are anhydrite and hematite. Anhydrite is a calcium-sulphate and hematite is an iron-oxide mineral.

These phases were not observed in studies by Gaigher (1980), Azzie (2002) or Bühmann and Bühmann (1988), thus their occurrence could have an alternative origin. Pyrite and calcite which often co-exist in the same assemblage are both thought to be stable under temperatures as those used in the experiment. However, it appears that these minerals were altered during the combustion process. The oxidation of pyrite results in the formation of hematite and a loss in sulphur as SO_3. Calcite decomposes to CaO and CO_2 during combustion. Therefore, it is possible for the SO_3 from pyrite and the CaO from calcite to react to form $CaSO_4$, anhydrite. Ward *et al.* (2001a) noted similar occurrences in a study involving the low-temperature ashing and ashing in a muffle furnace. Minerals such as kaolinite and pyrite were significantly lower in the ash prepared in a muffle furnace at 370°C. The same minerals were more abundant in the low-temperature ash, confirming the alteration of constituents which could possibly take place in a muffle furnace. The oxidation of pyrite is not uncommon in the presence of oxygen, thus the formation of hematite can be explained. Furthermore, this sulphur was available to combine with the calcium from the calcite to form anhydrite.

Table 3-2: Results after heating for 60 hours at 250°C (units in grams)

Sample	Crucible	C&S(before)	S(before)	C&S(after)	S(after)	S wt loss	% wt loss
LU1	20.40	30.50	10.10	29.80	9.40	0.70	6.93
LU24	32.00	40.20	8.20	36.40	4.40	3.80	46.34

Table 3-3: Results after heating for 70 hours at 150°C (units in grams)

Sample	Crucible	C&S(before)	S(before)	C&S(after)	S(after)	S wt loss	% wt loss
LU1	20.00	30.20	10.20	29.70	9.70	0.50	4.90
LU24	22.70	26.20	3.50	26.10	3.40	0.10	2.86

After ashing a few more samples it was decided that the process has an adverse effect on the original mineralogy which is of utmost importance. Researchers in the field such as Dr. James Willis (personal communication, 2003) from the University of Cape Town, South Africa believes that unwanted transformations may take place in a furnace involving sulphur and even phosphorus. Although the formation of anhydrite and hematite could form due to natural processes as well, the experimentally induced transformation of mineral phases, which should be avoided at all costs, seems more likely.

Ashing at lower temperatures was time-consuming for the amount of samples involved and produced poor results as is evident from the experiments, while ashing at higher temperatures brought about unnecessary changes in the samples. Prof. Colin Ward from the University of New South Wales, Sydney, Australia kindly agreed to ash ten coal samples and analyse them using X-ray diffraction together with Siroquant^{TM} interactive interpretation software, as well as X-ray fluorescence. According to Ward (1999), oxidising the organic matter and isolating the minerals without major alteration can be achieved successfully with low-temperature oxygen-plasma ashing.

Figures A2-9 to A2-12 in Appendix 2 illustrates the difference in peak visibility before and after the samples were subjected to low-temperature ashing. Figure A2-9 depicts the unashed XRD pattern of sample M-20. The dominant minerals, namely, quartz, kaolinite and pyrite are visible, however, the pattern is slightly obscure due to high backgrounds which in this case are caused by the organic material in the coal. A similar pattern is obtained from the X-ray diffraction of the unashed KOR-10 sample as illustrated in Figure A2-11. Kaolinite along with minor calcite and dolomite made up the mineralogy.

The Siroquant^{TM} software allows the proportions of up to 25 different minerals in a mixture to be quantified from a conventional X-ray powder diffractometry pattern using Rietveld techniques. Rietveld (1969) developed a formula to give the intensity at any point in the scan of a single mineral, with information on how to refine relevant crystal structure and instrumental parameters by least-squares analysis of the profile. Siroquant calculates a theoretical XRD profile and fits it to the measured pattern by full-matrix least-squares refinement of the following Rietveld parameters: phase scales, line asymmetry, phase preferred orientation, phase line widths, instrument zero, the line shape parameter for each phase, and the phase unit cell dimensions. A calculated XRD pattern of each mineral could be generated from it's known crystal structure, and the sum of all calculated patterns can be fitted to the observed XRD pattern of a multi-mineral sample by least squares analysis to find the optimum individual phase scales. These are then used to determine the mineral percentages.

The parameters can be adjusted simply and interactively with the program, to replicate more closely the mineral's contribution to the measured pattern and allow for variation due to atomic substitution, layer disordering, preferred orientation, and other factors in the standard pattern used. Crystallographic and chemical data as well as reference patterns can be developed for use in Siroquant^{TM} directly from measured XRD patterns of a specific mineral, allowing minerals with poorly developed crystal structures to be incorporated in the analysis (Ward *et al.,* 2001a).

Figures A2-10 and A2-12 illustrate the X-ray diffraction patterns of samples M- 20 and KOR-10 respectively. The peaks of the patterns are noticeably distinguishable compared to those in the unashed patterns. Results from the Siroquant^{TM} interpretation shows that sample M-20 consists of 21.5% quartz, 51.5% kaolinite, 12.2% illite, 3.9% mixed layer clays and 11.0% pyrite, while sample KOR-10 consists of 0.2% quartz, 78.4% kaolinite, 4.6% illite, 1.6% pyrite, 3.7% calcite, 10.3% dolomite and 1.3% bassanite. In the latter case, the bassanite is thought to represent artefacts of the plasma ashing process, formed when organically associated Ca or Ca from calcite, and in some cases Na, combines with organic sulphur released during the oxidation of organic matter (Ward *et al.,* 2001a).

The use of LTA to isolate mineral matter is effective despite minor occurrences of artefacts such as bassanite. The oxidation of sulphides such as pyrite was also avoided, causing the original mineralogy to remain unaltered. Secondly, the detection of poorly crystalline and rare minerals such as illite and mixed-layer clays is made easier with the help of the Siroquant^{TM} software. The X-ray fluorescence data concerning these ten samples is in good agreement with the Siroquant interpretation and the interpretation technique applied at UFS.

There are numerous techniques used for determining the chemical composition of a rock sample, X-ray fluorescence being reliable for various applications. The ten samples ashed at UNSW were also analysed by UFS using standard XRF procedures in order to determine the variations in whole coal XRF analysis and fused disk XRF analysis. As proposed by Dr. Willis from UCT, whole coal XRF analyses for major and trace elements regarding coal samples are more accurate, since no unwanted changes are brought about, as is the case when heating and fusing samples. A brief explanation of the sample preparation procedures will highlight distinct differences in total chemical composition and mineral disintegration temperatures.

The standard procedure followed at UFS involves drying the samples at 110°C for 24 hours to determine the H_2O content, then heating them to 980°C to obtain the LOI. The problem with applying this method was that a percentage of carbonate minerals and other phases were not completely disintegrated. Thus, during the preparation of the fusion disk any CO_2 still left will be lost, leaving less of the ash originally weighed off to prepare the disk and resulting in lower totals. Samples were subsequently heated to 1050°C and 1080°C to ensure complete decomposition of all phases. Results for the 1050°C and 1080°C ash are found in Tables 3-4 to 3-7. This rise in temperature resulted in an increase in the LOI. Results obtained for the 1050°C and 1080°C ash are very similar, since each sample was individually calcined for 5 hours.

Table 3-4: UFS XRF data – 1050°C ash

mple	SiO_2	TiO_2	$Al2O_3$	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O-	LOI	Total
1-5	11.11	0.36	8.47	0.34	0.02	1.28	2.85	0.06	0.31	0.29	3.06	73.66	101.81
U37	12.65	0.28	6.71	0.14	0.01	0.37	1.49	0.00	0.08	0.01	1.25	79.67	102.66
U10	7.71	0.36	7.00	1.27	0.02	1.34	3.54	0.00	0.06	0.06	3.29	74.36	99.01
R10	13.19	0.56	12.03	0.40	0.02	0.77	2.18	0.01	0.11	0.06	2.49	70.43	102.25
K1	4.90	0.13	2.88	7.86	0.07	0.98	3.27	0.01	0.02	0.01	3.30	78.76	102.19
13	9.44	0.19	5.17	0.12	0.01	0.22	0.82	0.00	0.08	0.00	3.64	81.31	101.00
20	13.00	0.28	5.30	6.11	0.00	0.03	0.05	0.00	0.26	0.01	0.95	77.30	103.29
T12	16.06	0.70	7.92	0.17	0.00	0.03	0.06	0.00	0.10	0.04	3.11	74.61	102.80
2M	14.53	0.42	11.28	0.60	0.01	0.33	2.72	0.00	0.13	1.69	2.47	69.05	103.23

Table 3-5: UFS XRF data – 1050°C ash - normalised LOI and H_2O free

Sample	SiO_2	TiO_2	$Al2O_3$	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
BH1-5	44.28	1.43	33.76	1.36	0.08	5.10	11.36	0.24	1.24	1.16	100.00
DOU37	58.19	1.29	30.86	0.64	0.05	1.70	6.85	0.00	0.37	0.05	100.00
KHU10	36.10	1.69	32.77	5.95	0.09	6.27	16.57	0.00	0.28	0.28	100.00
KOR10	44.97	1.91	41.02	1.36	0.07	2.63	7.43	0.03	0.38	0.20	100.00
LK1	24.34	0.65	14.31	39.05	0.35	4.87	16.24	0.05	0.10	0.05	100.00
LU13	58.82	1.18	32.21	0.75	0.06	1.37	5.11	0.00	0.50	0.00	100.00
M20	51.92	1.12	21.17	24.40	0.00	0.12	0.20	0.00	1.04	0.04	100.00
OPT12	64.04	2.79	31.58	0.68	0.00	0.12	0.24	0.00	0.40	0.16	100.00
R2M	45.82	1.32	35.57	1.89	0.03	1.04	8.58	0.00	0.41	5.33	100.00

Table 3-6: UFS XRF data – 1080°C ash

mple	SiO_2	TiO_2	Al2O$_3$	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O-	LOI	Total
H1-5	10.06	0.32	7.61	0.29	0.01	1.17	2.59	0.06	0.29	0.26	2.75	76.05	101.46
U37	12.95	0.29	6.85	0.14	0.01	0.37	1.51	0.00	0.08	0.01	1.10	78.93	102.24
U10	8.07	0.39	7.36	1.31	0.02	1.41	3.75	0.00	0.07	0.07	3.32	74.99	100.76
R10	13.04	0.55	11.99	0.44	0.02	0.76	2.12	0.01	0.11	0.06	2.48	70.61	102.19
K1	5.12	0.13	2.97	7.79	0.07	1.02	3.38	0.01	0.01	0.01	3.09	78.82	102.42
13	10.87	0.22	6.02	0.12	0.01	0.25	0.95	0.00	0.09	0.00	3.46	80.49	102.48
20	13.38	0.28	5.46	6.29	0.00	0.03	0.05	0.00	0.27	0.01	0.90	74.66	101.33
T12	15.71	0.69	7.79	0.16	0.00	0.02	0.06	0.00	0.10	0.04	2.93	72.87	100.37
2M	12.22	0.35	9.28	0.52	0.01	0.25	2.29	0.00	0.10	1.40	2.34	72.44	101.20

The procedure followed in preparation for whole coal XRF analysis involves making a pressed powder briquette using Hoechst Wax. The method is described in Appendix 1 and results for the whole coal XRF are found in Tables 3-8 and 3-9. Sulphur was determined using powder briquettes, seeing that all or at least most sulphur is lost during the ashing process. The results are normalised to a LOI, H_2O and S-free basis to ensure consistent comparison of the data.

Table 3-7: UFS XRF data – 1080°C ash - normalised LOI and H_2O free

Sample	SiO_2	TiO_2	Al2O$_3$	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
BH1-5	44.40	1.41	33.58	1.28	0.04	5.16	11.43	0.26	1.28	1.15	100.00
DOU37	58.31	1.31	30.84	0.63	0.05	1.67	6.80	0.00	0.36	0.05	100.00
KHU10	35.95	1.74	32.78	5.84	0.09	6.28	16.70	0.00	0.31	0.31	100.00
KOR10	44.81	1.89	41.20	1.51	0.07	2.61	7.29	0.03	0.38	0.21	100.00
LK1	24.96	0.63	14.48	37.98	0.34	4.97	16.48	0.05	0.05	0.05	100.00
LU13	58.66	1.19	32.49	0.65	0.05	1.35	5.13	0.00	0.49	0.00	100.00
M20	51.92	1.09	21.19	24.41	0.00	0.12	0.19	0.00	1.05	0.04	100.00
OPT12	63.94	2.81	31.71	0.65	0.00	0.08	0.24	0.00	0.41	0.16	100.00
R2M	46.25	1.32	35.12	1.97	0.04	0.95	8.67	0.00	0.38	5.30	100.00

Table 3-8: UFS XRF data – Whole coal analyses

mple	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	S	H_2O-	LOI	Total
H1-5	6.30	0.31	4.78	0.25	0.39	2.34	0.25	0.35	0.31	0.80	3.06	82.66	101.80
U37	7.99	0.27	3.91	0.12	0.09	1.25	0.00	0.07	0.00	0.63	1.25	84.67	100.25
HU10	4.73	0.44	5.12	0.71	0.63	3.95	0.00	0.07	0.07	0.67	3.29	78.36	98.04
R10	7.48	0.55	6.63	0.28	0.34	1.93	0.02	0.11	0.07	0.38	2.49	81.43	101.71
K1	2.11	0.08	2.17	7.51	0.40	3.25	0.04	0.00	0.00	1.44	3.30	78.76	99.06
U13	4.32	0.14	2.76	0.08	0.04	0.67	0.01	0.07	0.00	0.55	3.64	87.31	99.59
20	7.59	0.21	3.19	4.68	0.00	0.00	0.00	0.23	0.01	2.89	0.95	80.30	100.05
T12	11.01	0.78	4.51	0.15	0.00	0.00	0.00	0.08	0.04	0.62	3.11	79.61	99.91
2M	7.35	0.33	5.92	0.36	0.07	1.87	0.00	0.10	1.40	0.40	2.47	78.05	98.32

Table 3-9: UFS XRF data – Whole coal analyses - normalised LOI, H_2O and S free

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
BH1-5	41.23	2.03	31.28	1.64	2.55	15.31	1.64	2.29	2.03	100.00
DOU37	58.32	1.97	28.54	0.88	0.66	9.12	0.00	0.51	0.00	100.00
KHU10	30.09	2.80	32.57	4.52	4.01	25.13	0.00	0.45	0.45	100.00
KOR10	42.96	3.16	38.08	1.61	1.95	11.09	0.11	0.63	0.40	100.00
LK1	13.56	0.51	13.95	48.26	2.57	20.89	0.26	0.00	0.00	100.00
LU13	53.43	1.73	34.13	0.99	0.49	8.29	0.07	0.87	0.00	100.00
M20	47.71	1.32	20.05	29.42	0.00	0.00	0.00	1.45	0.06	100.00
OPT12	66.45	4.71	27.22	0.91	0.00	0.00	0.00	0.48	0.24	100.00
R2M	42.24	1.90	34.02	2.07	0.40	10.75	0.00	0.57	8.05	100.00

As for some examples concerning correlations between these analyses, Figures 3.1 to 3.4 illustrates oxide correlations for Fe_2O_3, SiO_2, Al_2O_3 and CaO.

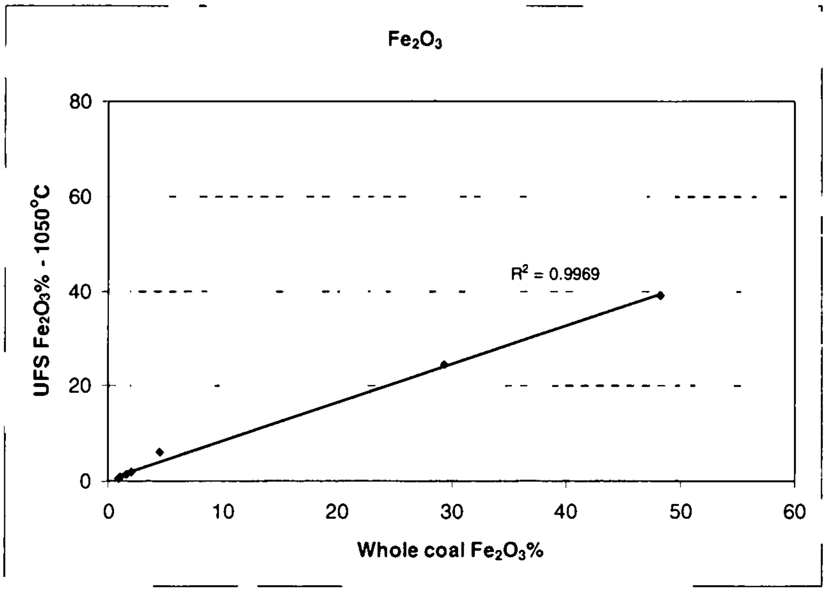


Figure 3.1 – Relationship between Whole coal Fe_2O_3% and UFS Fe_2O_3% at 1050°C

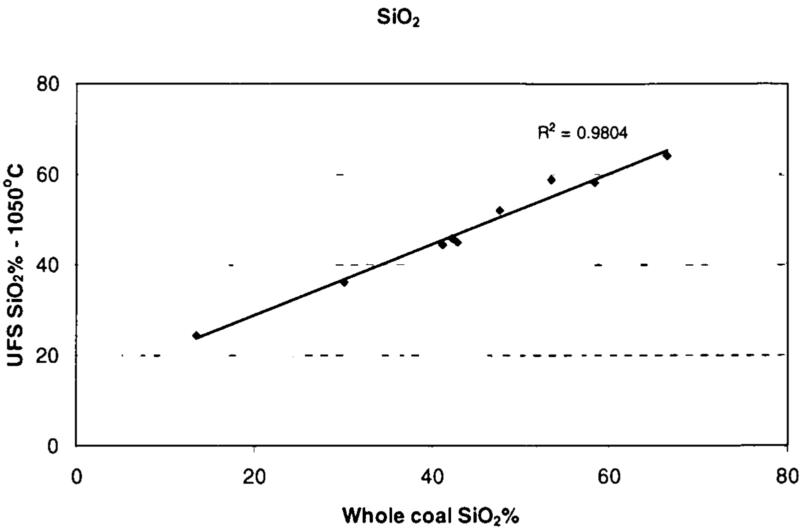


Figure 3.2 – Relationship between Whole coal SiO_2% and UFS SiO_2% at 1050°C

Good correlations were noted in comparisons between the whole coal results and the 1050°C and 1080°C ash analyses as depicted in Figures 3.1 to 3.4. Some of the correlations, albeit good correlations, still show differences between the actual concentrations of whole coal and fusion disk results.

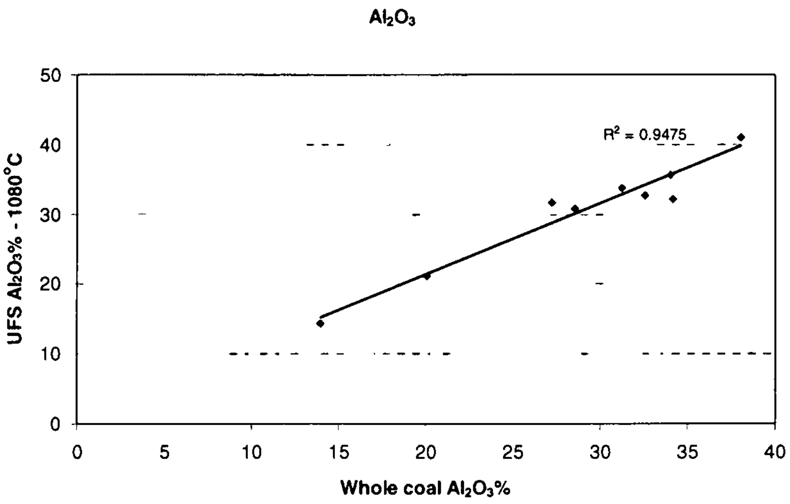


Figure 3.3 – Relationship between Whole coal Al_2O_3% and UFS Al_2O_3% at 1080°C

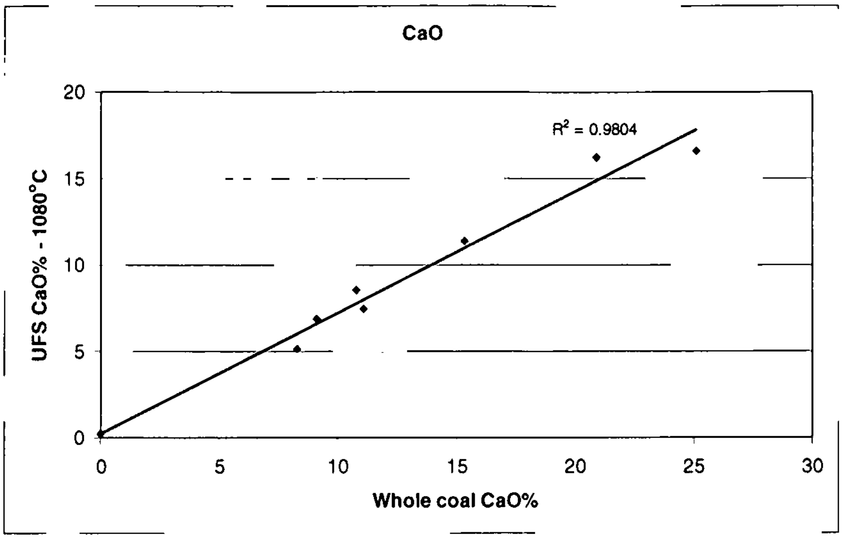


Figure 3.4 – Relationship between Whole coal CaO% and UFS CaO% at 1080°C

As observed in tables 3-4 to 3-9, whole coal oxide concentrations are higher than the fusion disk oxide concentrations for the 1050°C and 1080°C ash. A possible reason for this phenomenon is the loss of inorganic material along with the organic matter during the ashing process. For the determination of the LOI, the samples are placed in a furnace at a high temperature leading to combustion during which large quantities of carbon are released (some as soot). This results in lower concentrations in the fusion disk analyses.

If all phases are not completely decomposed at the end of the ashing process, some of the volatile constituents in the sample will be lost when the disk is fused. This affects the totals of the fusion disk analysis which should be lower than the powder briquette results. La_2O_3 is added to the fusion disks to account for mass absorption. The infinite thickness of a powder briquette is extremely important, and therefore thicker briquettes are prepared to avoid X-rays from passing through them (Appendix 1). To ascertain the effect of mass absorption, the linearity of curves were tested by analysing mixtures of samples LK 1 and LU13.

Table 3-10 contains XRF results on whole coal samples for mixtures of samples LK1 and LU13, as well as the pure end members of these samples. The proportions of these samples were mixed in a Turbula mixer for 30 minutes and subsequently analysed. The “Cal.” column represents the values that should be obtained when a proportion of one sample is mixed with a proportion of the other. The oxide name represents the values analysed for each sample, and the "Diff." column represents the difference between the calculated and the analysed values for each sample. The sample names are according to the proportion of the sample in the mixture e.g. LK75LU25 represents 75% of sample LK1 and 25% of sample LU13. Calculated values for LOI and H_2O (from the end members) were used since no LOI and H_2O was determined for these mixtures. Results for oxides that occur in low concentrations such as TiO_2, MgO, Na_2O, K_2O, P_2O_5, S and CaO were close to the calculated results. Results for SiO_2, Al_2O_3 and Fe_2O_3 differed slightly from the calculated values (Table 3-10).

Table 3-10: UFS XRF data – Whole coal analyses – Mixtures of samples LK1 and LU13

Sample	SiO_2	Cal.	Diff.	Al_2O_3	Cal.	Diff.	Fe_2O_3	Cal.	Diff.	CaO	Cal.	Diff.
LK1-100	2.11	2.11	0.00	2.17	2.17	0.00	7.51	7.51	0.00	3.25	3.25	0.00
LK75LU25	2.93	2.66	0.27	2.66	2.32	0.35	5.48	5.65	-0.17	2.74	2.61	0.14
LK50LU50	3.74	3.22	0.53	2.92	2.47	0.46	3.21	3.80	-0.59	2.08	1.96	0.12
LK25LU75	3.85	3.77	0.09	2.93	2.61	0.32	1.39	1.94	-0.55	1.37	1.32	0.06
LU13-100	4.32	4.32	0.00	2.76	2.76	0.00	0.08	0.08	0.00	0.67	0.67	0.00

Table 3-10: UFS XRF data – Whole coal analyses – Mixtures of samples LK1 and LU13 (continued)

Sample	TiO_2	Cal.	MgO	Cal.	Na_2O	Cal.	K_2O	Cal.	P_2O_5
LK1-100	0.08	0.08	0.40	0.40	0.04	0.04	0.00	0.00	0.00
LK75LU25	0.10	0.10	0.33	0.31	0.03	0.03	0.02	0.02	0.00
LK50LU50	0.11	0.11	0.24	0.22	0.02	0.03	0.03	0.04	0.00
LK25LU75	0.13	0.13	0.13	0.13	0.01	0.02	0.05	0.05	0.00
LU13-100	0.14	0.14	0.04	0.04	0.01	0.01	0.07	0.07	0.00

Table 3-10: UFS XRF data – Whole coal analyses – Mixtures of samples LK1 and LU13 (continued)

Sample	S	Cal.	H_2O-	Cal.	LOI	Cal.	Total	Cal.
LK1-100	1.44	1.44	3.3	3.3	78.76	78.76	99.06	99.06
LK75LU25	1.20	1.22	3.39	3.39	80.65	80.65	99.52	98.94
LK50LU50	0.99	1.00	3.47	3.47	82.54	82.54	99.35	98.83
LK25LU75	0.78	0.77	3.56	3.56	84.42	84.42	98.62	98.71
LU13-100	0.55	0.55	3.64	3.64	86.31	86.31	98.59	98.59

From Table 3.10 it is evident that the SiO_2 concentrations are slightly higher than the calculated concentrations, but without a trend favouring a range of compositions. The variation in differences is attributed to sampling/mixing variations rather than mass absorption effects. A similar argument applies for Al_2O_3 concentrations. Fe_2O_3

concentrations, on the other hand, are slightly lower than calculated. For the SiO_2 concentration the largest deviation also occurred in mixture LK50LU50. This was probably also due to sampling/mixing variations. It must be remembered that sampling from a low atomic substance such as coal can present deviations due to the settling of heavy component such as FeS_2.

Since the possibility of mass absorption has been taken into account by analysing mixtures of the samples mentioned above, and the ashing of coal samples could bring about changes to the chemical constituents, whole coal XRF analyses were carried out on the coal samples. Standard XRF techniques used at UFS was applied to the sediment samples together with XRD analyses on coal and sediment samples. The results are discussed in the next section.

3.2 Distribution of mineral matter in investigated samples and possible mode of occurrence

All statistical analyses were performed using the software Microsoft Excel and STATISTICA V.5. In some cases outliers were excluded to ensure accurate results. All raw datasets are tabulated in Appendix 2 and are clustered according to the mines were samples were collected.

3.2.1 Chemical composition of coal and sediment samples

3.2.1.1 The Witbank Coalfield

a. No. 1 coal seam

Coal from this seam is characterised by low total ash percentages averaging at 25%, and increasing from west to east across the field. With the exception of sample 3957 from Arnot-North Mine which was provided by other sources, oxides and trace elements are distributed evenly. The latter sample is located in the vicinity of samples collected at Arnot Mine. However, even though this section of the coal field is known to have higher ash percentages, the elevated SiO_2 percentage in sample 3957 could be the result of different sampling methods, emphasising the importance of consistency and accuracy during sampling procedures. This coal sample could have been carbonaceous shale which was mistaken for coal, or it could have been contaminated. It was therefore excluded from further calculations.

As seen from Table 3-11, oxide concentrations for the coal samples are in good agreement with brief studies carried out by previous researchers, and no unusual results were obtained. SiO_2, Al_2O_3, K_2O and TiO_2 all decrease from east to west, while Fe_2O_3 and S which are similarly distributed and more abundant in the south-eastern region due to the presence of pyrite. In this instance CaO and MgO are abundant in the southern and north-eastern regions respectively, while elevated concentrations of P_2O_5 are located in the extreme western region of the seam.

Table 3-11: The minimum, maximum and average concentrations of oxides (wt%) and trace elements (ppm) in No. 1 coal seam

Element	Min.	Max.	Ave.	Element	Min.	Max.	Ave.
SiO_2	0.00	17.01	8.58	Rb	0.00	14.7	3.42
TiO_2	0.24	0.91	0.43	Ba	12.46	231.88	109.93
Al_2O_3	2.18	8.41	5.04	Sr	26.37	175.27	92.55
Fe_2O_3	0.04	3.41	1.16	Zr	7.20	177.91	87.65
S	0.27	1.67	0.73	Nb	3.43	16.94	9.40
MnO	0.00	0.00	0.00	Y	12.89	40.94	24.51
MgO	0.00	0.25	0.09	Sc	1.07	13.45	6.39
CaO	0.00	1.57	0.57	Cr	14.37	110.22	42.58
Na_2O	0.00	0.01	0.00	Cu	4.22	46.01	14.23
K_2O	0.00	0.18	0.08	V	13.49	111.2	43.33
P_2O_5	0.00	0.44	0.06	Zn	7.28	48.38	22.58
Mn	0.00	200.01	71.89	Ni	8.30	202.47	54.19

There are no specific visible trends in the distribution of trace elements in the seam, but certain elements occur in a similar pattern. These concentrations were not significantly elevated, and considerable values could probably be as a result of the nature of the source material. The high-lying north-eastern region is characterised by high concentrations of V, Y, Cu, Ba and Mn varying between 0.00 and >200 ppm. Nb, Zr and Ni are highest at the northern and southern centres of the seam, while reasonable concentrations of Cr, Cu, Rb, Sr and Zn are located in the south-eastern region. High Sc concentrations are found in the eastern and western parts together with significant Zn. Some significant concentrations of Sr and Y are found in the north-western and south-western regions, respectively.

There are numerous occurrences of noteworthy correlation coefficients between major and trace elements. This could be because some elements were abundant in the primary environment, or because some elements occur in the same minerals. Similarly, there are many correlations which are merely coincidence due to the fact that the number of samples were insufficient, and that numerous elements occur in low concentrations in the assemblage. The significant and useful correlations could be explained either in terms of their geochemical characteristics, the source material or the depositional environment.

High correlations for a total of 17 coal samples exists between SiO_2 and, TiO_2 and Al_2O_3, and even more so between TiO_2 and Al_2O_3 ($r=0.935$). SiO_2 often makes up the bulk of the mineral assemblage and is thus well correlated with the total ash percentage. Aluminium occurs in feldspars, micas, non-kaolinite clay minerals and kaolinite. Feldspars and micas are frequently absent from the mineral assemblage, and this is apparent in the low concentrations of Na and K, suggesting that the relationship between Al_2O_3 and TiO_2 as seen in Figure 3.5, could be limited to the presence of kaolinite.

TiO_2 in coal is reported to occur in oxides, clays and complexed with organic matter (Azzie, 2002). However, no prominent correlation exists between Ti and kaolinite found in the normative interpretation. The presence of the Ti phase anatase has not been supported by XRD studies in this study, but this does not exclude the possibility of a separate Ti phase occurring. According to Ward *et al.* (1999) Al and Ti are soluble in highly acid conditions, thus the Ti could be precipitated in conjunction with the kaolinite within the structure or as a separate phase. Anatase is also common as a minor constituent in Australian coals (Ward *et al.*, 1999).

Although there is a clear absence of feldspars and micas in the coals and very low concentrations of K_2O and Na_2O, a good correlation exists between K_2O, Rb and Ba as seen in Figure 3.6. This could be expected seeing that the source material is broadly accepted to originate from the north (Cadle *et al.,* 1990) where abundant igneous rocks are present. The correlation between K and Ba could be attributed to the geochemical association between these elements. The presence of feldspars and their close relationship with Ba and Rb is therefore also explained. Concentrations of Na_2O are often below the detection limit, therefore, no accurate analyses could be performed with the Na_2O values.

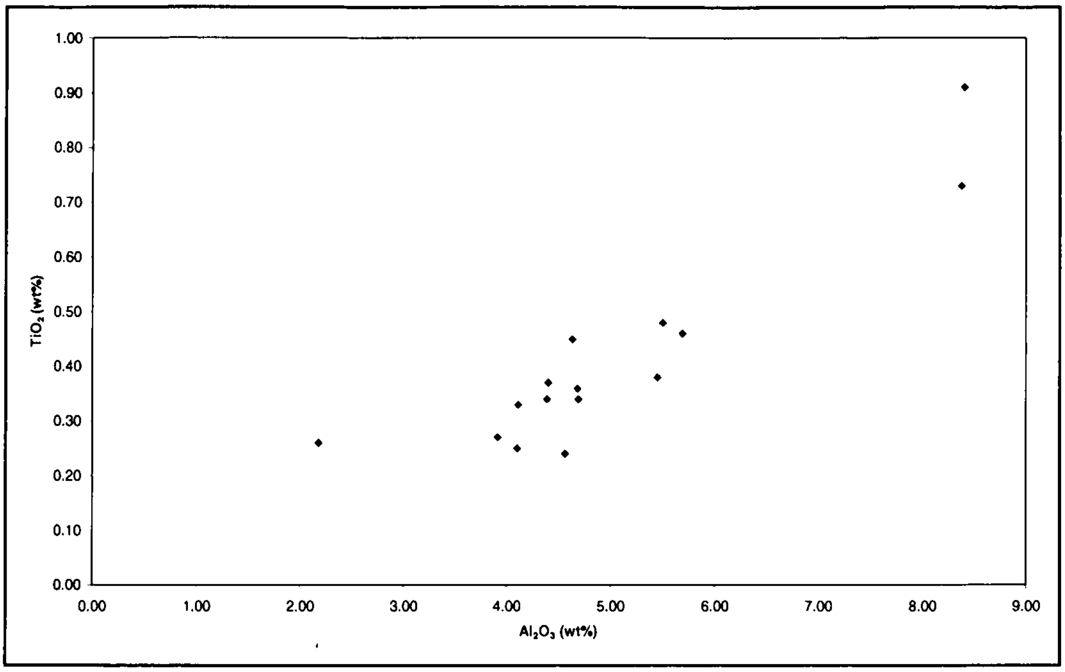


Figure 3.5 – Relationship between TiO_2 and Al_2O_3 concentrations

The expected correlation between Fe_2O_3 and S (r=0.939) is primarily due to the presence of pyrite and can be seen in Figure 3.7. The outlier in the north-eastern corner of the graph may force such an exceptional correlation, but correlations between Fe and S are very high in other coal seam sample sets. Ni also shows a good correlation with Fe_2O_3 and S, and to a lesser extent with pyrite. This is common in other seams in the field and might be due to some relationship between Ni and Fe, but insufficient data was available for this seam to draw any definite conclusions.

Apart from feldspars, carbonate minerals in coal account for almost all MgO and CaO concentrations in the form of dolomite and calcite (Gaigher, 1980).

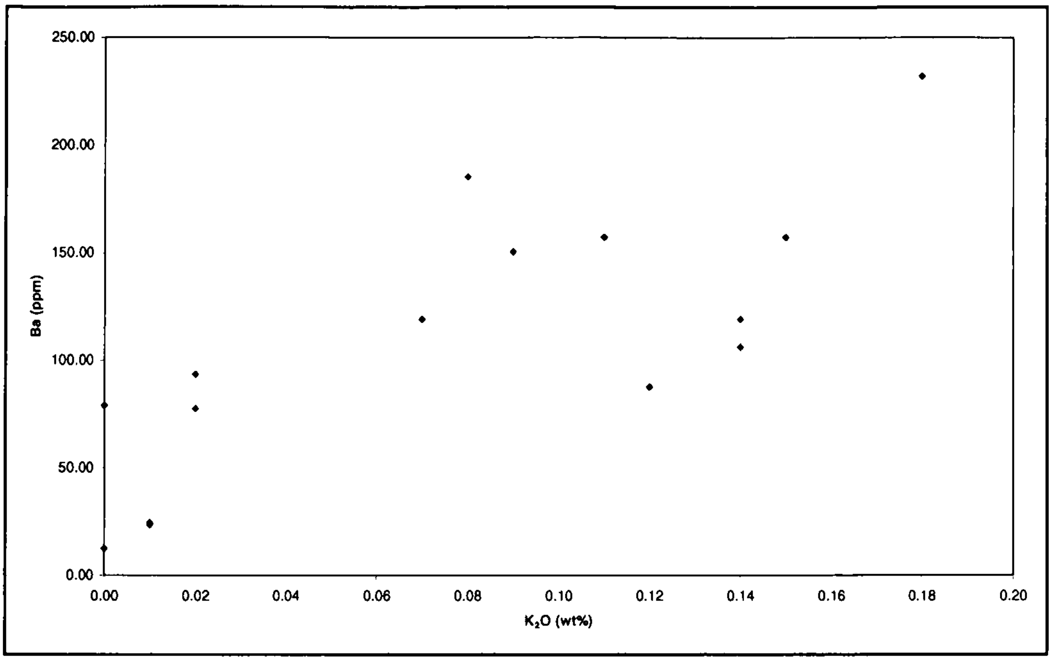


Figure 3.6 – Relationship between K_2O and Ba concentrations

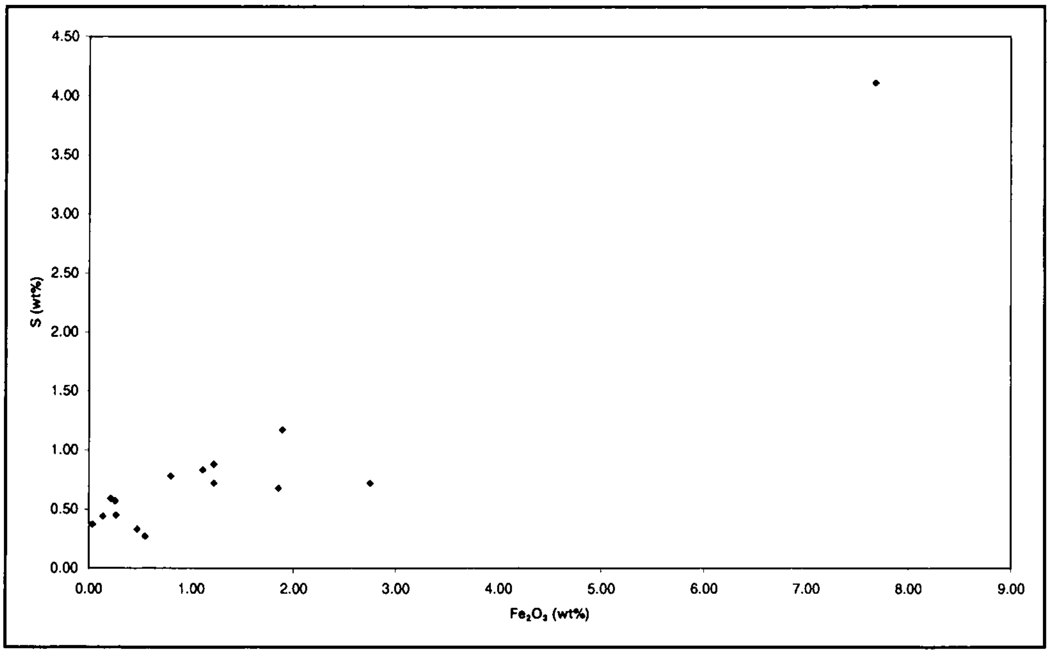


Figure 3.7 – Relationship between Fe_2O_3 and S concentrations

There are a few good yet unusual correlations observed between Cr and SiO_2 (r=0.877), TiO_2 (r=0.899), Al_2O_3 (r=0.805), Na_2O (r=0.885) and K_2O (r=0.924), between V and SiO_2 (r=0.929), TiO_2 (r=0.946), Al_2O_3 (r=0.831), Na_2O (r=0.951) and K_2O (r=0.972), and between Zr and TiO_2 (r=0.927) and Al_2O_3 (r=0.899). As noted by Azzie (2002) the occurrence of Cr, V and Zr could be a reflection of the source material, and similarly, Ward *et al.* (1999) has observed positive correlations between these elements and other oxides. However, this is an isolated incidence occurring mainly in the No. 1 seam coal. The associations of some rare earth element with phosphate minerals from the goyazite-crandallite group are also not overlooked as phosphate minerals have been observed in other sample sets used in this study. The correlation between Zr and TiO_2 is probably derived from their geochemical relationship which is prominent in other rock types as well.

Mineral and oxide distributions in the roof and floor lithologies are very different from the coal as is to be expected. These rocks consist of varying proportions of siltstone, sandstone and carbonaceous shale. Although it was difficult to draw up useful correlations due to the limited amount of samples, a brief indication of the chemical composition is provided with these analyses.

Table 3-12: The minimum, maximum and average concentrations of oxides (wt%) and trace elements (ppm) in siltstone floor rocks of No. 1 coal seam

Element	Min.	Max.	Ave.	Element	Min.	Max.	Ave.
SiO_2	34.53	61.87	46.78	Ba	115.20	251.50	197.94
TiO_2	0.83	2.15	1.51	Sr	16.30	63.50	46.60
Al_2O_3	7.33	22.32	14.10	Zr	182.60	391.40	273.33
Fe_2O_3	0.38	4.15	1.83	Nb	5.20	17.50	12.09
S	0.18	0.99	0.43	Y	7.50	31.30	20.86
MnO	0.00	0.04	0.02	Sc	12.50	27.30	21.50
MgO	0.00	0.15	0.05	Cr	187.20	341.30	276.91
CaO	0.01	0.18	0.09	Cu	3.20	64.10	29.51
Na_2O	0.02	0.15	0.07	V	194.50	403.10	303.41
K_2O	0.38	1.10	0.73	Zn	31.70	56.70	45.67
P_2O_5	0.02	0.04	0.03	Ni	18.80	382.20	133.31
Rb	0.00	33.70	12.33	Co	6.40	69.10	29.37

As expected the SiO_2 content of the sandstones of the floor rocks were the highest followed by the siltstone as shown in Table 3-12, and then shale. Abundant Al_2O_3 was observed in the only shale sample available while Fe_2O_3 and S were abundant in the siltstone floor rocks. Low concentrations of Ca and Mg is supported by the absence of carbonate in the XRD patterns of most of these rocks, while the increase in K_2O in comparison to the coal is very prominent and probably due to the presence of illite frequently occurring in the roof and floor lithologies.

Elevated concentrations of Ba, V, Cr and Zr are present in all three rock types, but this time the possibility of phosphate association is ruled out by the low P_2O_5 concentration. This occurrence might once again be due to source rock influence. An exceptionally large concentration of Ni observed in the siltstone samples, in which the Fe_2O_3 and S contents are once again the highest. Seeing that the coal and siltstone samples in which Fe_2O_3, S and Ni are well correlated are not in the same vicinity, and some samples appear to be outliers, no specific reason could be provided for this occurrence. However, the probability of Ni's association with Fe becomes unavoidable.

Table 3-13: The minimum, maximum and average concentrations of oxides (wt%) and trace elements (ppm) in sandstone roof rocks of No. 1 coal seam

Element	Min.	Max.	Ave.	Element	Min.	Max.	Ave.
SiO_2	76.66	91.25	85.39	Ba	24.60	223.10	114.31
TiO_2	0.29	1.44	0.93	Sr	20.80	208.80	77.38
Al_2O_3	3.13	7.45	4.90	Zr	181.60	662.00	435.03
Fe_2O_3	0.71	4.01	1.95	Nb	8.70	26.10	16.45
S	0.03	1.44	0.58	Y	3.60	19.50	12.03
MnO	0.00	0.07	0.03	Sc	0.00	8.60	4.04
MgO	0.00	1.63	0.43	Cr	58.40	178.00	108.69
CaO	0.00	4.71	1.26	Cu	0.00	6.30	2.56
Na_2O	0.01	0.11	0.05	V	30.40	69.30	44.15
K_2O	0.09	1.42	0.83	Zn	14.10	91.40	44.31
P_2O_5	0.02	0.03	0.02	Ni	9.20	215.90	75.15
Rb	0.00	35.50	18.61	Co	0.00	164.40	51.14

Roof rocks of the No. 1 coal seam consisted of some sandstones and one siltstone sample. The bulk mineralogy of sandstones does not always consist strictly of quartz as seen in Table 3-13. Sandstones in this case show observations of elevated Fe_2O_3 and CaO percentages. Dolomite has been detected in the sandstone and siltstone samples containing reasonable amounts of CaO and MgO. It is possible for this carbonate to exist with calcite in the same assemblage; however, from XRD patterns dolomite or ferroan dolomite for that matter is detected more often in the sediment samples than in the coals, was also noted by Azzie (2002).

K_2O concentrations are supported by the presence of feldspars and illite/smectite clays in the siltstone and sandstones. Although pyrite is mainly associated with the coal, nodules of this mineral have been observed in hand specimen in roof and floor rocks. Good correlation exists between K_2O, Rb and Ba as in the case with the coal. A high concentration of Zr is once again well correlated with TiO_2, as well as with Nb. The occurrence of Zr in coal as discrete particles has been noted by Ward *et al.* (1999). In the latter case a strong correlation between Zr and TiO_2 was observed. Significant correlations exist between Ni, Fe and S along with reasonable correlations between Sr and MgO (r=0.993) and CaO (r=0.995).

Seeing that low P concentrations are present and a negative correlation (r=-0.022) exists between P and Sr, supported by no phosphate phases in the XRD patterns, it is unlikely that Sr-phosphates might be present. Correlation between Cr, V, and Cu, and between Ni and Co are probably a result of geochemical similarities, although their modes of occurrence are variable.

b. No. 2 coal seam

A total of 138 coal samples were collected from this seam on which analyses were done. With this sample set it was possible to make conclusions from some contours graphs drawn using STATISTICA V.5.

SiO_2, TiO_2, Al_2O_3, Na_2O and K_2O concentrations are distributed along a northeast-southwest strike as seen from Figures 3.8 to 3.12. These components are primarily derived from, and are associated with the mineralogy of the source material. The association of TiO_2 and Al_2O_3 is once again evident in their distribution as well as their correlation coefficient (r=0.784).

The magnitude of this sample set also makes it possible to avoid unusual correlations based on lower concentrations and insufficient data. A noticeable and expected correlation exists between K_2O and Rb (r=0.785), between Sr and P_2O_5 (r=0.681), and between Ba and Sr (r=0.813). These relationships are due to the association of K_2O and Rb in the primary environment, and the association of Sr, Ba and P_2O_5 with Ca-aluminophosphate minerals such as crandallite and goyazite.

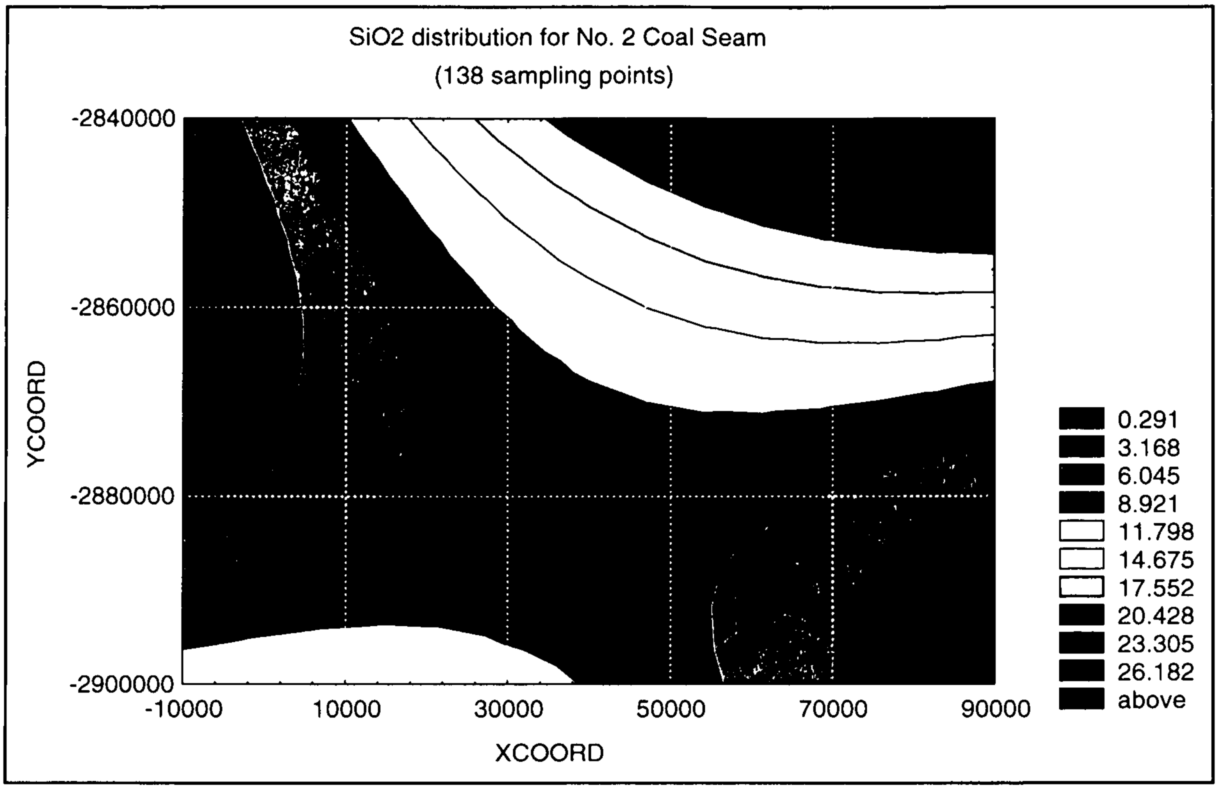


Figure 3.8 – SiO_2 distribution in the No. 2 coal seam

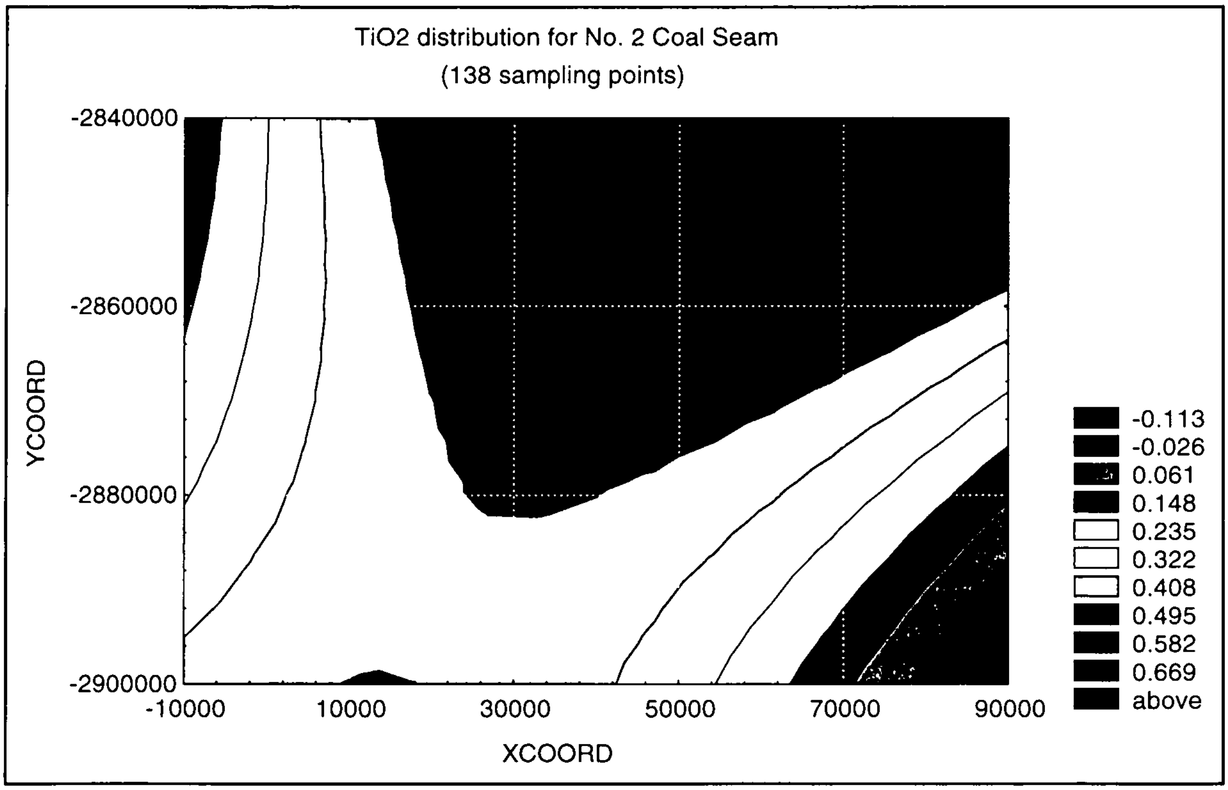


Figure 3.9 – TiO_2 distribution in the No. 2 coal seam

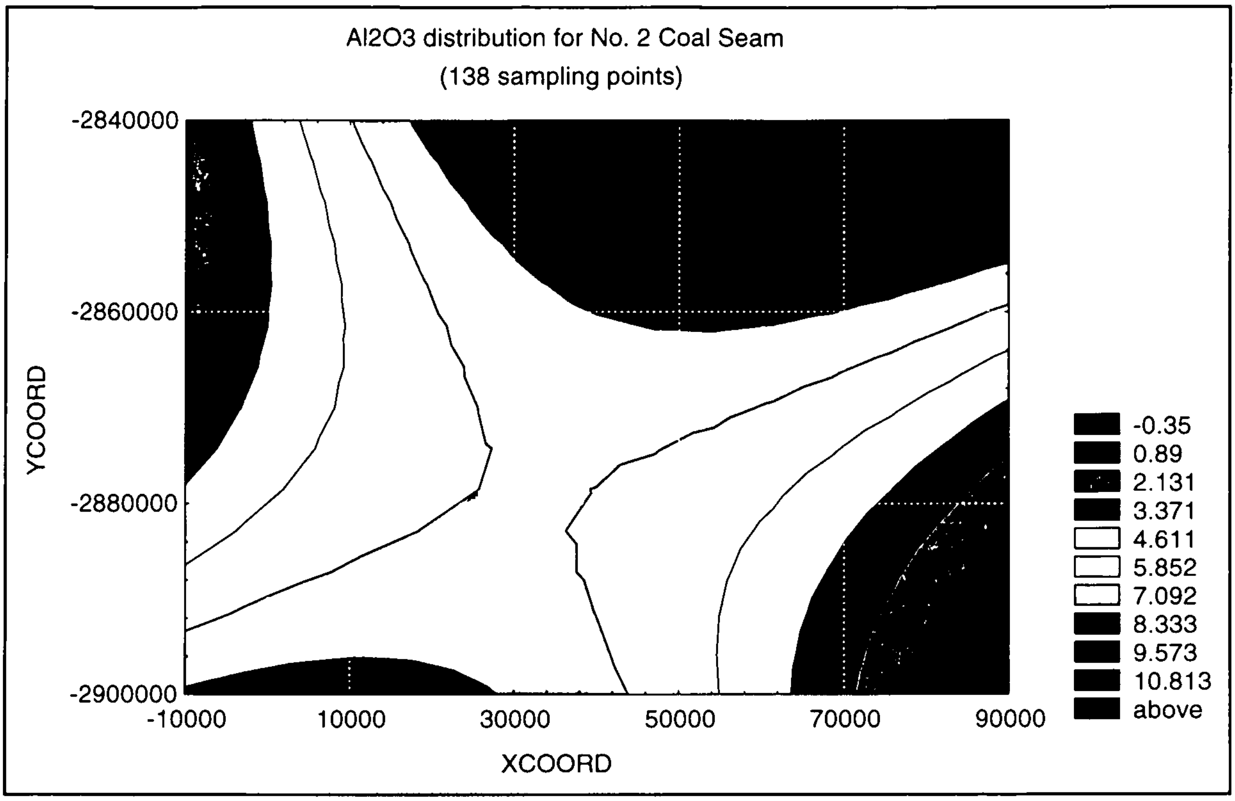


Figure 3.10 – Al_2O_3 distribution in the No. 2 coal seam

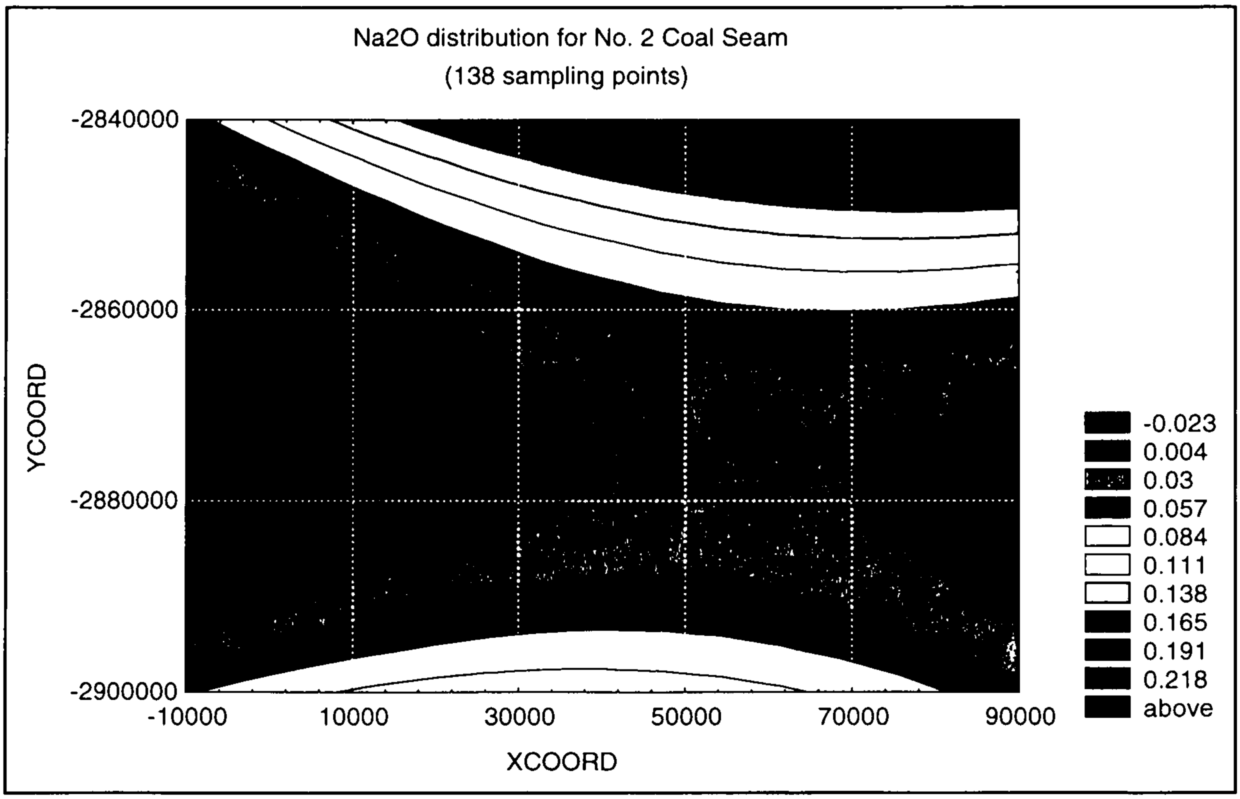


Figure 3.11 – Na_2O distribution in the No. 2 coal seam

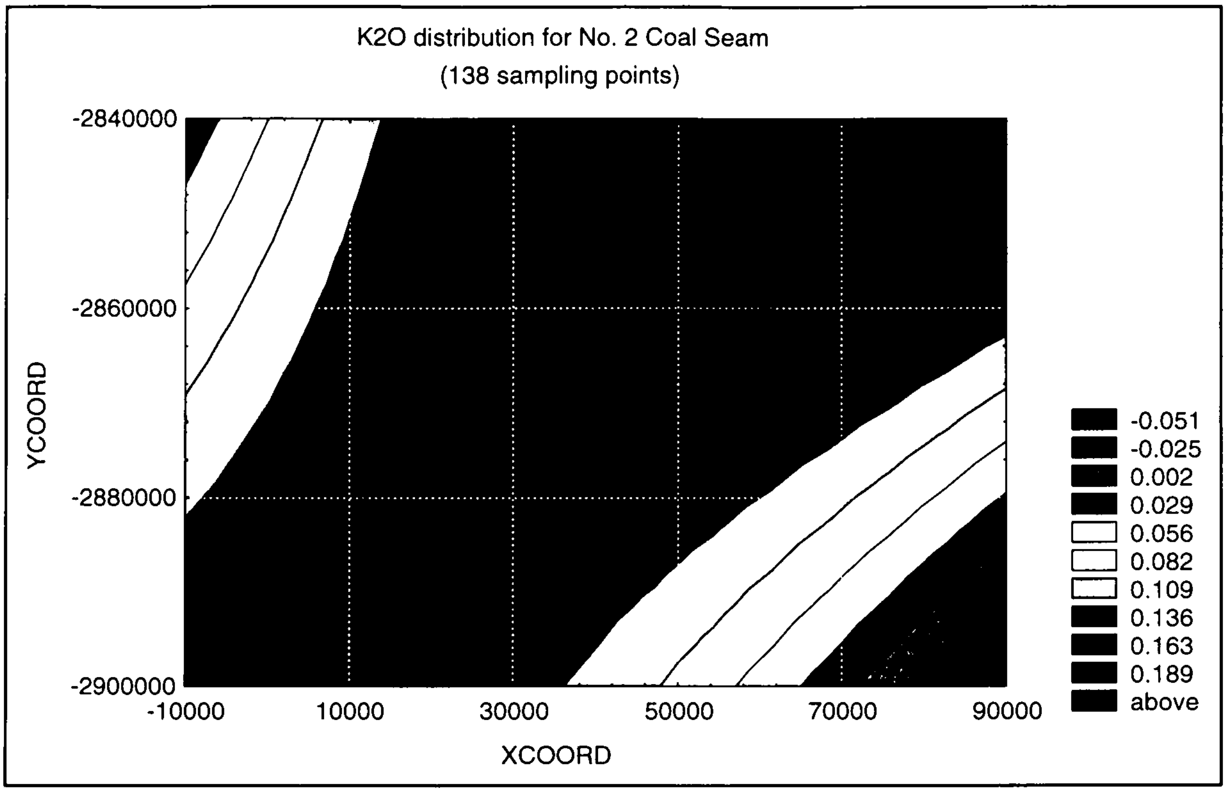


Figure 3.12 – K_2O distribution in the No. 2 coal seam

The most striking relationship in this seam is the correlation between Fe_2O_3 and S. With a correlation coefficient of 0.901it is expected that the Fe_2O_3 and S distribution would be reasonably similar. Despite the two outliers in Figure 3.15, there is still an exceptional correlation. However, the contour maps present a different situation. Figures 3.13 and 3.14 illustrate the Fe_2O_3 and S distribution respectively. There is an overlap of the highest concentrations for both elements in the north-western region of the seam, but the elevated amounts of Fe_2O_3 in the northern and southern regions are very obvious. After calculating the amount of Fe_2O_3 needed to combine with the total S (all sulphur was thus assumed to have been inorganic/pyritic sulphur), the percentage of Fe_2O_3 left was distributed in a similar pattern to that seen in Figure 3.13. Only four cases were observed in which S was left after forming pyrite. This distribution for Fe could be as a result of, firstly, the fact that Fe could be present in higher proportions in carbonates such as dolomite and siderite, and clays such as montmorillonite, both of which were present in XRD interpretations. Secondly, because the samples were not heated, the only S that could have been lost was due to oxidation in air during storage or in nature, leaving an excess of Fe. Organic sulphur is rarely present in larger concentrations than 0.6 wt% (Ward *et al.*, 1999).

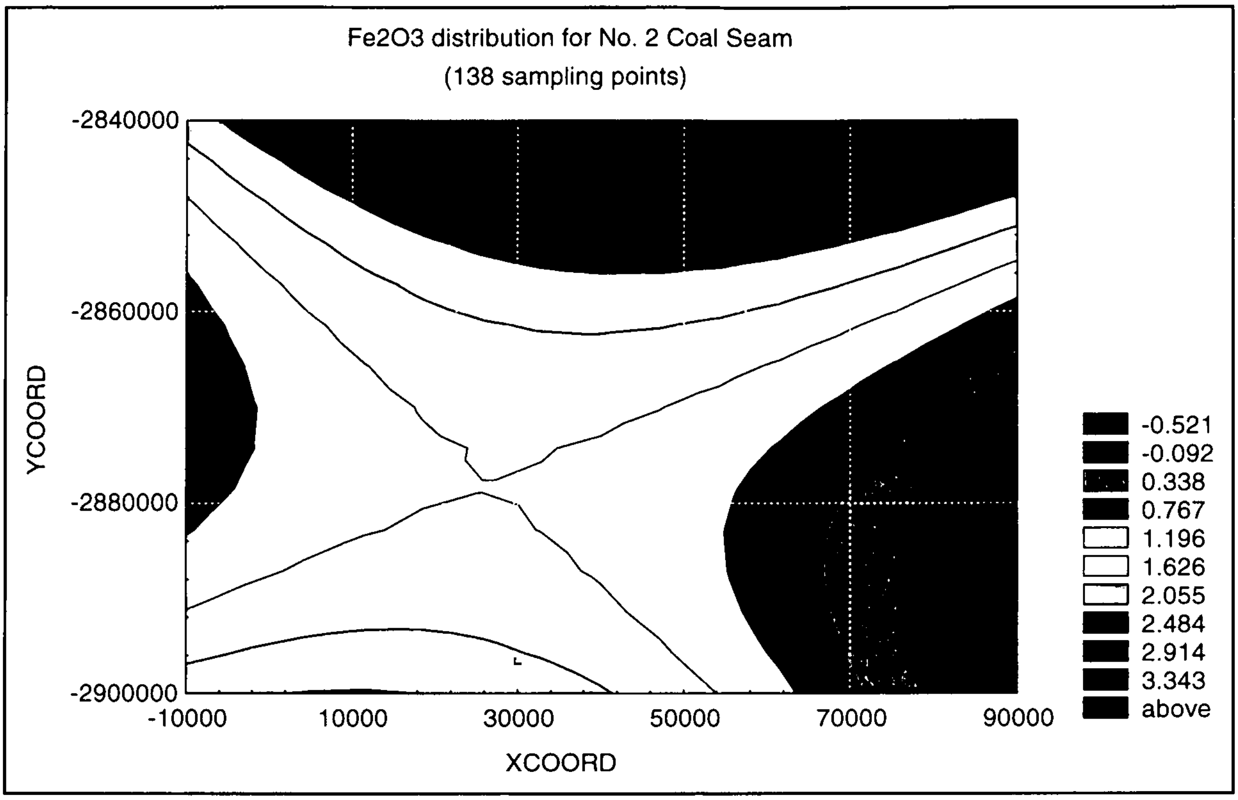


Figure 3.13 – Fe_2O_3 distribution in the No. 2 coal seam

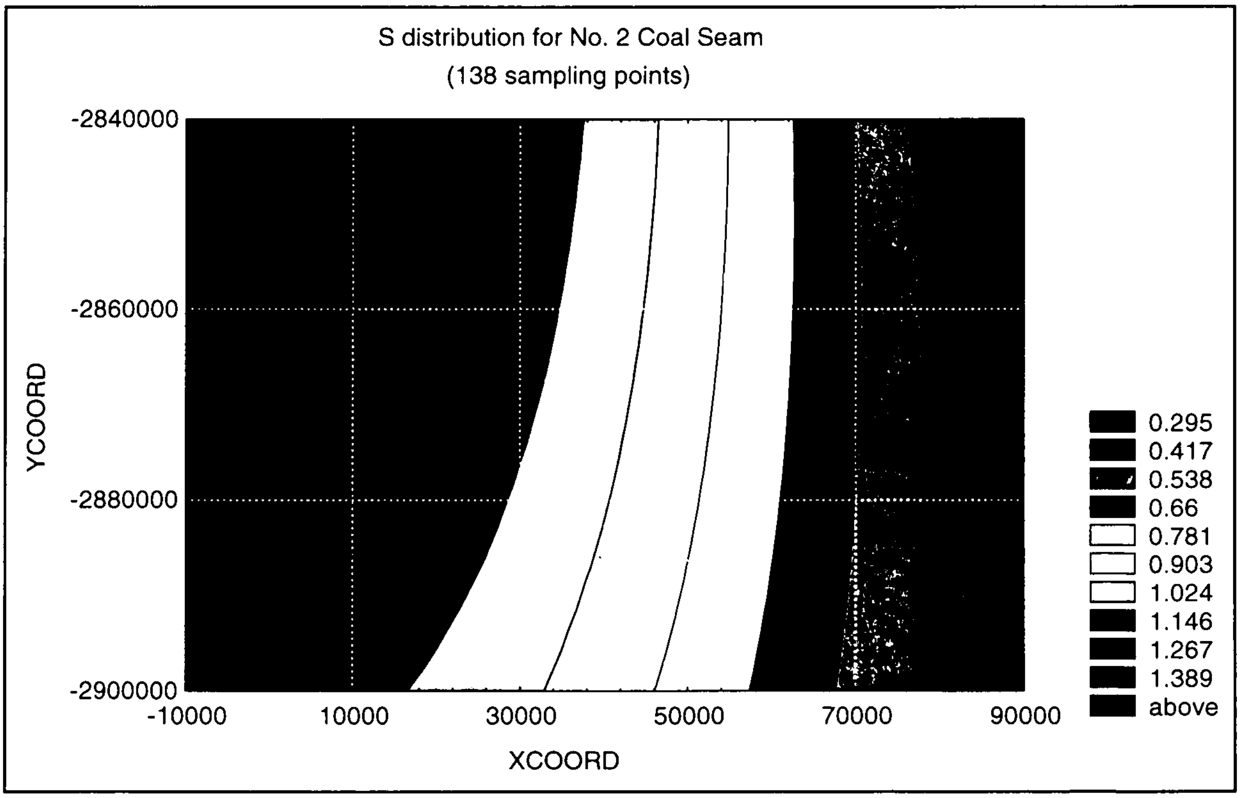


Figure 3.14 – S distribution in the No. 2 coal seam

Thus, it is more likely for this excess Fe to be captured in other mineral phases.

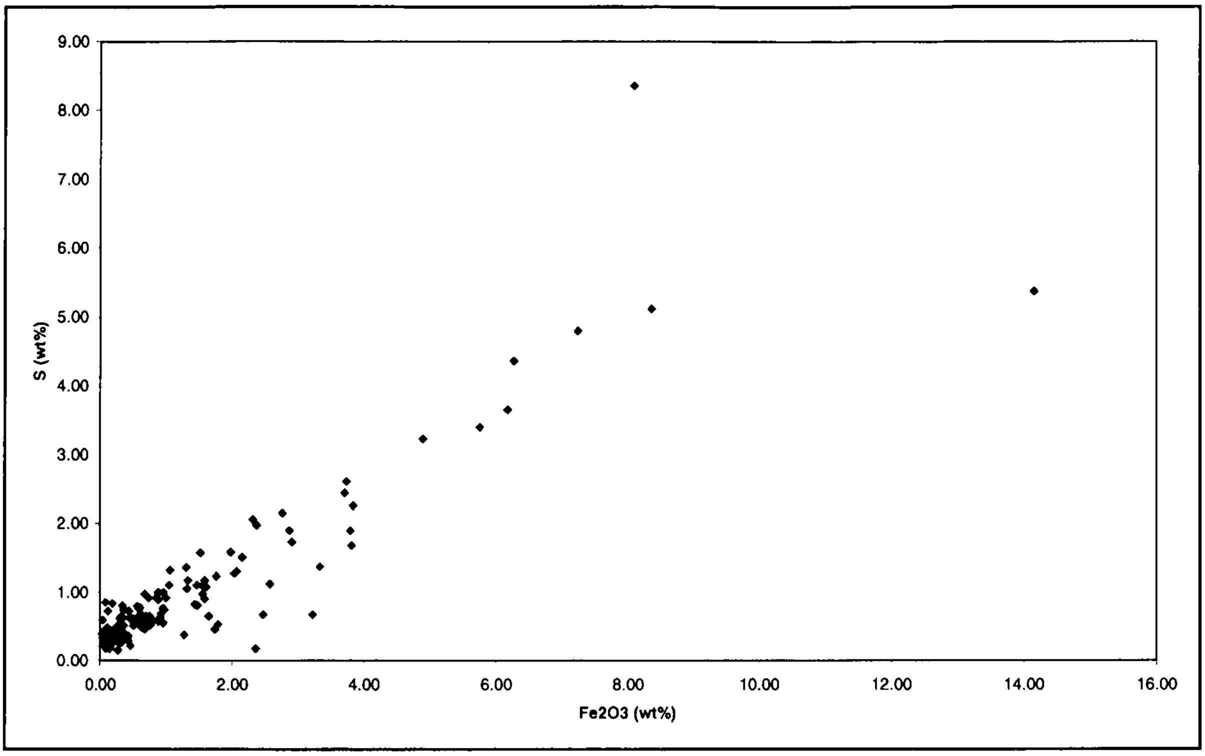


Figure 3.15 – Relationship between Fe_2O_3 and S concentrations

CaO, MgO and P_2O_5 distributions are similar to that of S. The biggest difficulty in sampling roof and floor lithologies lies in the fact that some mines leave a layer of coal at the top and bottom of the mineable horizons; the coal seams are sometimes just too thick to be able to reach roof rocks, and borehole material in which the whole seam can be sampled is not always available.

Table 3.14: The minimum, maximum and average concentrations of oxides (wt%) and trace elements (ppm) in sandstone floor rocks of No. 2 coal seam

Element	Min.	Max.	Ave.	Element	Min.	Max.	Ave.
SiO_2	43.34	84.73	66.91	Ba	55.70	367.30	195.69
TiO_2	0.38	1.73	1.00	Sr	23.90	498.40	184.42
Al_2O_3	4.42	29.00	13.92	Zr	65.10	448.70	215.93
Fe_2O_3	0.79	5.22	2.13	Nb	6.70	36.10	16.39
S	0.06	0.58	0.24	Y	1.70	57.20	18.97
MnO	0.00	0.16	0.04	Sc	2.40	38.50	13.32
MgO	0.00	6.12	1.47	Cr	40.30	764.30	268.72
CaO	0.02	8.42	2.69	Cu	0.00	96.70	23.25
Na_2O	0.00	0.20	0.07	V	13.80	1018.70	296.49
K_2O	0.30	0.96	0.60	Zn	11.30	94.30	44.00
P_2O_5	0.01	0.12	0.05	Ni	9.10	194.90	54.26
Rb	0.70	108.90	29.50	Co	0.00	83.00	18.66

The floor rocks of the No. 2 coal seam consisted mainly of sandstone, siltstone and carbonaceous shale of which too few samples were obtained to draw up any useful correlations. SiO_2 concentrations in sandstones shown in Table 3.14 are slightly lower than in those of the No.1 seam roof samples; however, Fe_2O_3, CaO, MgO, Na_2O and K_2O concentrations are similar. The elevated Fe_2O_3 would be as a result of the presence of siderite, while K_2O and Na_2O are supported by an increase in illite in the sediments, as observed in the XRD interpretations. The carbonates calcite and dolomite often occur together with siderite. In this case no definite explanation could be given for the increased V concentrations, but the Ni and Fe_2O_3 concentrations are also elevated. Al_2O_3 and K_2O concentrations in the siltstone rocks range from 10 to 24 wt % and 0.64 to 1.48 wt%, respectively. This could be accounted for by the presence of kaolinite, K-feldspars and illite. This situation is the same for the two carbonaceous shale samples, although they contain abundant TiO_2 and Fe_2O_3 in addition to Al_2O_3 and K_2O, which is evident as the XRD patterns show traces of siderite for these samples.

Carbonaceous shale roof rocks of the No.2 coal seam are similar in chemical composition to the floor shales apart from an average increase in P_2O_5 of 0.30 wt%. The corresponding Ba and Sr values for elevated P_2O_5 are as high as 1000 and 900 ppm, respectively. This elevated P_2O_5, Ba and Sr is supported by the presence of fluorapatite in XRD interpretations. Siltstone samples collected in the roof of this seam are almost identical to the floor siltstones in terms of major element oxides and trace elements.

c. No. 4 coal seam

While the SiO_2, TiO_2, Al_2O_3, Fe_2O_3 and S contents of this seam are similar to concentrations in the No.1 and No. 2 coal seams, CaO and P_2O_5 show elevations as indicated in Table 3-15. SiO_2 and Al_2O_3 (r=0.880) correlate well and are highest in the north-north eastern region of the seam, suggesting a possible change in direction of the influx of source material or a change in depositional conditions. Both Fe_2O_3 and S distributions correspond since their concentrations decrease from west to east. P_2O_5 is highest mainly in the middle of the seam, while high Ca values are found in the south-western area, decreasing towards the east.

Kaolinite is often present as the dominant silicate in some of the mineralogical assemblages. This corresponding distribution of SiO_2 and Al_2O_3 could be the result of the weathering of feldspars or to the existence of favourable conditions enabling kaolinite precipitation. The presence of kaolinite suggests an acid leaching or freshwater environment, while the chemical breakdown of feldspar occurs rather in a freshwater environment than in an alkaline or marine environment (Bühmann and Bühmann, 1987). According to Ward (2002), Al is soluble under low pH conditions, and could be leached out from detrital minerals and transported to areas with conditions suitable for kaolinite precipitation.

Thus, interaction of Al_2O_3 with any silica in solution would result in the formation of authigenic kaolinite, depending on the conditions (Ward, 2002). It is also possible that an igneous source with abundant K-feldspar provided this silica and alumina, but most of the feldspar has been weathered giving rise to more kaolinite. Thus, the distribution of SiO_2 and Al_2O_3 could be controlled by the source material but more likely by the solubility and precipitation conditions of kaolinite.

Pyrite, occurring mainly as a secondary or authigenic mineral phase, is the main reason for the distribution of Fe_2O_3 and S (r=0.926) in this manner. It is linked to marine influences during peat formation (Bühmann and Bühmann, 1987).

Calcite and dolomite are both abundant in the seam, while fluorapatite accounts for the majority of P_2O_5 and some of the CaO and Al_2O_3 concentrations. The correlation between P_2O_5 and Sr (r=0.886) implies that phosphates from the crandallite group could be present, even though only fluorapatite has been detected in XRD interpretations.

Table 3.15: The minimum, maximum and average concentrations of oxides (wt%) and trace elements (ppm) in No. 4 coal seam

Element	Min.	Max.	Ave.	Element	Min.	Max.	Ave.
SiO_2	0.00	27.63	8.69	Rb	0.00	92.85	11.64
TiO_2	0.06	2.19	0.39	Ba	73.35	2902.38	590.28
Al_2O_3	1.45	12.89	5.11	Sr	58.96	3646.04	703.26
Fe_2O_3	0.06	6.78	2.32	Zr	0.00	657.48	88.60
S	0.31	4.66	1.90	Nb	0.00	22.01	7.42
MnO	0.00	0.00	0.00	Y	3.27	50.98	18.03
MgO	0.03	0.74	0.28	Sc	0.00	37.70	7.36
CaO	0.00	4.86	2.27	Cr	0.00	1049.21	53.21
Na_2O	0.00	0.16	0.04	Cu	5.22	53.77	17.15
K_2O	0.00	0.56	0.16	V	2.66	468.68	45.92
P_2O_5	0.00	1.82	0.48	Zn	0.34	56.77	8.11
Mn	0.00	401.72	98.55	Ni	2.60	102.38	19.97

The sandstones in the roof and floor lithologies of this seam are characterised by elevated concentrations of Al_2O_3, TiO_2 and K_2O in comparison to the same rocks of the No.1 and No. 2 seams. Fe_2O_3 is also abundant in the roof sandstones; however S values are low averaging 0.31 wt%. Illite, kaolinite and K-feldspar are well defined in the XRD patterns, but siderite could not be detected easily, suggesting that Fe could be caught up in minor montmorillonite and dolomite. The trace element distributions are very similar to other sandstones with no remarkable correlations except between elements and oxides with specific geochemical relationships; while siltstone and carbonaceous shale roof and floor rocks are also very similar to those of the other seams.

No. 4 coal seam has a reasonably constant parting consisting of sandstone at Arnot, Douglas, Forzando and Optimum Mines, siltstone in the Rietspruit Mine area and carbonaceous shale at Tavistock Mine. The trace element concentrations are considerably lower and sometimes similar to those in floor and roof lithologies of the same rock type, while major element oxides are compatible as well.

d. No. 5 coal seam

Table 3-16 illustrates that the No. 5 coal seam contains SiO_2, TiO_2, Al_2O_3, Fe_2O_3 and S concentrations which are compatible to the lower seams, along with very low concentrations of CaO, MgO and P_2O_5. At the few locations where samples were available for this coal seam, the SiO_2, TiO_2, Al_2O_3 and K_2O concentrations decrease from west to east. Fe_2O_3 and S, on the other hand, are distributed evenly amongst the sample localities. Na_2O is almost negligible throughout all the coals and trace elements are not much different either. The expected correlations are present and so too correlations which arise due to insufficient cases during matrix calculations.

Table 3.16: The minimum, maximum and average concentrations of oxides (wt%) and trace elements (ppm) in No. 5 coal seam

Element	Min.	Max.	Ave.	Element	Min.	Max.	Ave.
SiO_2	5.79	29.27	13.05	Rb	0.00	65.71	19.12
TiO_2	0.07	0.47	0.19	Ba	0.00	751.48	145.56
Al_2O_3	2.17	11.15	4.79	Sr	2.85	143.39	52.07
Fe_2O_3	0.22	3.15	1.29	Zr	34.32	340.10	116.80
S	0.34	1.82	0.91	Nb	6.51	41.81	14.26
MnO	0.00	0.00	0.00	Y	0.94	29.60	11.23
MgO	0.00	0.28	0.12	Sc	0.10	11.37	3.85
CaO	0.00	0.13	0.04	Cr	0.00	107.09	15.75
Na_2O	0.00	0.02	0.00	Cu	3.73	15.09	8.51
K_2O	0.15	1.04	0.39	V	5.80	59.18	21.67
P_2O_5	0.00	0.00	0.00	Zn	0.00	9.83	3.89
Mn	0.00	7.50	2.09	Ni	0.00	12.39	2.28

Sandstones, siltstones and carbonaceous shale also make up the roof and floor rocks of the No. 5 coal seam. The only noticeable difference is that all rock types contain significant elevations in MgO which could mainly be accounted for by the presence of montmorillonite in the XRD interpretations. CaO and K_2O concentrations were considerable too averaging at 0.28 and 2.72 wt% respectively, and since almost no calcite was present, CaO and K_2O are accounted for by plagioclase feldspar in a few siltstones. Siderite appeared to be a dominant component in some of the XRD interpretations in accordance with the higher Fe_2O_3 and low S values, but some of the Fe_2O_3 forms part of the montmorillonite phase. Kaolinite, illite and K-feldspar are often found together with siderite in most roof and floor rocks

3.2.1.2 The Highveld Coalfield

a. No. 4 coal seam

Although fewer samples were obtained in this coalfield, Figure 3.16 illustrates that the concentrations of some major element oxides are similar except for the few samples analysed. However, due to insufficient data, a clear distribution could not be detected, but the data still gives an indication of what major differences exist between the two fields. All except CaO and Na_2O concentrations are very similar to not only the No.4 seam coals in the Witbank Coalfield, but also the other seams as well. The mineral components consist of quartz, major kaolinite, calcite, dolomite, pyrite, siderite and sometimes major phosphate phases. K-feldspar has also been detected on rare occasions.

Correlations between Fe_2O_3 and S (r=0.887), P_2O_5 and Sr (r=0.933), and K_2O and Rb (0.765) are due to the presence of pyrite and crandallite, and the geochemical association between K and Rb, respectively. Ba and Sr are the only trace elements showing any elevation in concentration, while the others are in good agreement with those observed in the seams of the Witbank Coalfield.

Roof and floor lithologies for this seam consist of sandstones and siltstones. Siltstones from the roof and floor rocks are characterised by high Fe_2O_3 and K_2O concentrations which is evident in the presence of siderite and K-feldspar in some of the XRD interpretations. Floor sandstones contain less SiO_2 and more Al_2O_3 than roof sandstones in which major illite and feldspars are present. The Fe_2O_3:S ratio is high suggesting that most of the Fe is probably accounted for by siderite, since montmorillonite is not a prominent phase in the assemblage. Trace element concentrations for sandstone and siltstones are similar.

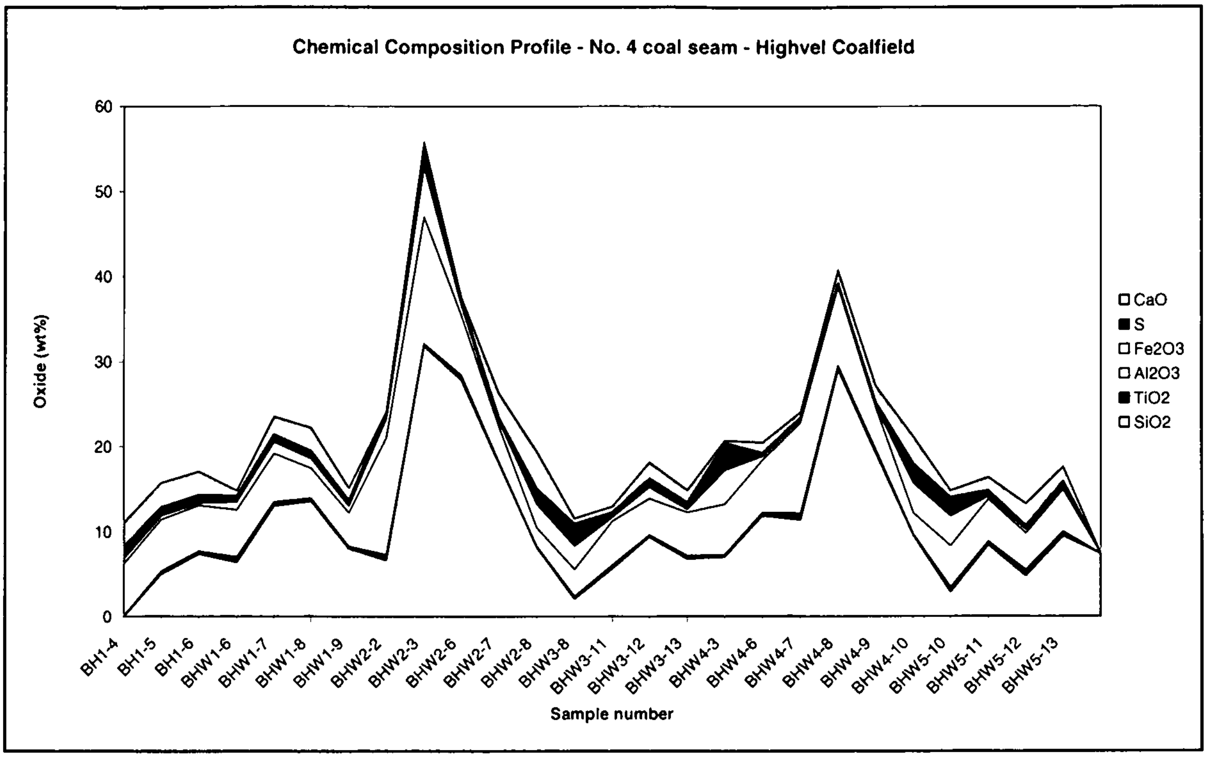


Figure 3.16 – Variations in concentration of some element oxides and sulphide in No. 4 coal seam

b. No. 5 coal seam

Unlike the No.5 seam in the Witbank Coalfield, this seam contains noticeable concentrations of SiO_2, CaO, MgO and Na2O; however illite, feldspars and the carbonates were not detected in the XRD patterns of these samples. Fe_2O_3 and S (r=0.840) has a significant correlation. A few sandstone and shale samples were collected from the roof and floor lithologies, both of which do not contain any significantly elevated concentrations of major or trace elements.

3.2.2 X-ray Diffraction Interpretation

3.2.2.1 The Witbank Coalfield

The X-ray diffraction interpretation method applied at the University of the Free State involves comparing the diffraction scan to separate peak files for minerals included in the software database. All diffraction peaks may not be completely visible, but, depending on the operator, this method could be applied with great accuracy since the interpretation relies primarily on the researcher's discretion. The occurrence of these minerals in the XRD diffraction patterns are supported by their chemical compositions as explained in the previous sections. One problem that arises in these interpretations concerns chemical components which are present in low concentrations. Phases such as illite, montmorillonite and feldspar are never abundant or rarely occur as major phases in coal, thus the low concentrations of K_2O and Na_2O are not always represented clearly in the XRD pattern. Similarly, an abundance of a specific element from XRF results does not necessarily mean that it is indicative of a specific phase. Fe is one such element which occurs in various mineral phases. It is easy to make an assumption that most of the Fe would be accounted for by sulphides in this case; however, if gaseous compounds such as SO_3 and CO_2 are unknown, assumptions as to whether the distribution of Fe would be as sulphides or carbonates should be done with great care.

Minerals detected in the XRD patterns were semi-quantitatively evaluated in terms of dominant (>40% of the mineral fraction), major (10-40%), minor (2-10%), accessory (1-2%) and rare (<1%) constituents. The interpretations will be discussed according to the phases prominent in each seam. Examples of diffraction scans with identified peaks are illustrated in Figures A2-1 to A2-6 on pages A2-87 to A2-92 in Appendix 2. All samples were analysed in accordance with specifications set out in Appendix 1. All XRD interpretations are tabulated in Appendix 2 according to sampling localities.

a. No. 1 coal seam

The mineralogical composition of coal deposits across the world consists of a dominant assemblage of quartz, kaolinite, clay minerals, sulphides, carbonates and phosphates, and some rare minerals characteristic of the depositional environment or the source material. Quartz and kaolinite commonly occur as the dominant phases in this seam. Calcite, dolomite and pyrite occur mainly as minor phases. It is rather difficult to distinguish between illite and illite/smectite interstratification using this technique since there are a few peak overlaps occurring at the major illite peak 2θ position, but this phase is not abundant in the seam. Siderite is prominent for a mineral that occurs mainly in the roof and floor lithologies, even though it was only in minor concentrations. Low concentrations of fluorapatite have been detected in samples from Kleinkopje Mine, while minor montmorillonite is observed in the Arnot Mine area. Roof and floor rocks are dominated by quartz, kaolinite and sometimes minor feldspars and clay minerals.

b. No. 2 coal seam

Kaolinite, calcite and dolomite are the dominant phases in the No. 2 seam. Dolomite is more often than not present in larger concentrations than calcite, and sometimes only one of these carbonates appear along with dominant kaolinite proportions. Pyrite and montmorillonite occur as minor phases together with the phosphates fluorapatite and crandalillte. Fluorapatite is present mainly in samples in the western region of the seam, and decreases towards the east. Crandallite was observed only in one sample from the Leeufontein Mine.

Quartz is present in most of the samples and it's concentration might vary from dominant to accessory in the coal samples, but it is clearly one of the prevalent phases in the roof and floor lithologies. K-feldspar is prominent in the sandstones, while illite is more common in the siltstones and shales. Plagioclase was found infrequently, while siderite constantly appeared in sandstone samples. Calcite and dolomite are present in the sediments, but mainly in lower concentrations. Pyrite rarely makes an appearance in sandstones, but sometimes it can be one of the major phases especially at the roof-coal interface. This precipitation could be due to a change in Eh at the interface.

In order to determine whether there were any differences in the mineralogical or geochemical nature of coal with different roof lithologies, coal underlying sandstones, siltstones and shales were analysed and compared. This might have given an indication of the environmental conditions under which the sediments were deposited, but the only definite conclusion that could be made was that the general mineralogical and chemical compositions of coal were very similar.

c. No. 4 and No. 5 coal seams

As expected, quartz concentrations seem to decrease towards the west while kaolinite is almost ubiquitous throughout the seams. Calcite, dolomite and montmorillonite still occur in minor concentrations and pyrite sometimes as a major component, while K-feldspar has been observed as an accessory constituent. Once again illite and siderite in the roof and floor rocks contain similar concentrations compared to the other seams.

3.2.2.2 The Highveld Coalfield

a. No. 4 and No. 5 coal seams

Mineral distributions in the Highveld Coalfield are similar to the coal and sediment mineralogy of the Witbank Coalfield. The main constituents, quartz, kaolinite, calcite, dolomite and minor montmorillonite, occur in the coal in varying proportions, while illite, siderite and K-feldspar are more common in the roof and floor rocks. Only one occurrence of crandallite and plagioclase feldspar was observed in samples BH1-5 and BHW3-5 respectively. In addition, pyrite concentrations are much lower in comparison to the Witbank Coalfield.

The XRD interpretation provided a useful indication as to which phases governed the mineralogy and which were enriched or depleted as a result of depositional or source material influences.

3.2.3 Normative Mineralogical Interpretation using Sednorm

The software used to determine the normative mineralogy, called SEDNORM, was designed by D. R. Cohen and C. R. Ward at the Department of Applied Geology, University of New South Wales, Australia. It calculates the mineralogy especially of sedimentary rocks based on chemical analyses. The sequence of allocating elements or oxides to the various minerals is a function of observed sedimentary mineral assemblages, mineral stabilities in surface environments and the restriction of certain elements to specific minerals e.g. (phosphorus completely contained in apatite). There is some degree of independent mineralogical data required (XRD, SEM or optical petrology) to control whether minerals such as feldspar, muscovite and montmorillonite are present and the control of compositional parameters for minerals such montmorillonite (within certain restrictions) is optional (SEDNORM – Users Manual, 1990).

The principles which have to be applied in order to derive the normative mineralogy from the oxide percentages are set out as follows:

i. Both apatite and crandallite may exist in coals, but phosphorus is assumed to be present in apatite since it is the dominant phosphate in sedimentary rocks.
ii. Any sulphur present is assumed to be consumed in pyrite or gypsum, depending on the degree of oxidation.
iii. Chlorine is allocated to halite.
iv. The distribution of potassium between K-feldspar, illite and muscovite can be fixed and any excess potassium remaining after the clays or muscovite are formed can be assigned to K-feldspar.
v. Options are available to assign calcium and magnesium to the carbonates first and then apatite and gypsum, or in the preferred order. The carbonates permitted are calcite, magnesite and siderite, and calcite is formed in preference to siderite with excess iron being assigned to hematite.
vi. The inclusion of montmorillonite is optional, and a choice is provided regarding the cation ratios in the smectite component, if it appears to be present from sources such as XRD.
vii. To compensate for minor errors in differentiating between structural and absorbed water, the water content could be increased until the Al_2O_3 and SiO_2 are exhausted. Any alumina and silica left will be assigned to gibbsite and quartz, respectively.

viii. In the event of excess chlorine being present sodium is added to the system to form halite, and similarly chlorine is added to form halite if excess sodium is present after feldspar is formed.

The program was applied successfully by Ward *et al.* (1999) in a study concerning the mineralogy of sandstones; however it's use in the determination of coal mineralogy has proved to be limited in this study. Nonetheless, correlations between the normative mineralogy and the chemical composition are fairly consistently.

3.2.3.1 Coal

Correlations are obtained between quartz and SiO_2 (r=0.767), pyrite and, Fe_2O_3 (r=0.933) and S (r=0.960), siderite and Fe_2O_3 (0.885), magnesite and CaO (r=0.819) and MgO (r=0.835), calcite and CaO (r=0.812), apatite and P_2O_5 (r=0.919), and slightly between illite-smectite and K_2O (r=0.633) since K_2O is allocated to illite-smectite and K-feldspar. Plots illustrated in Figures 3.17 to 3.25 indicate these relationships.

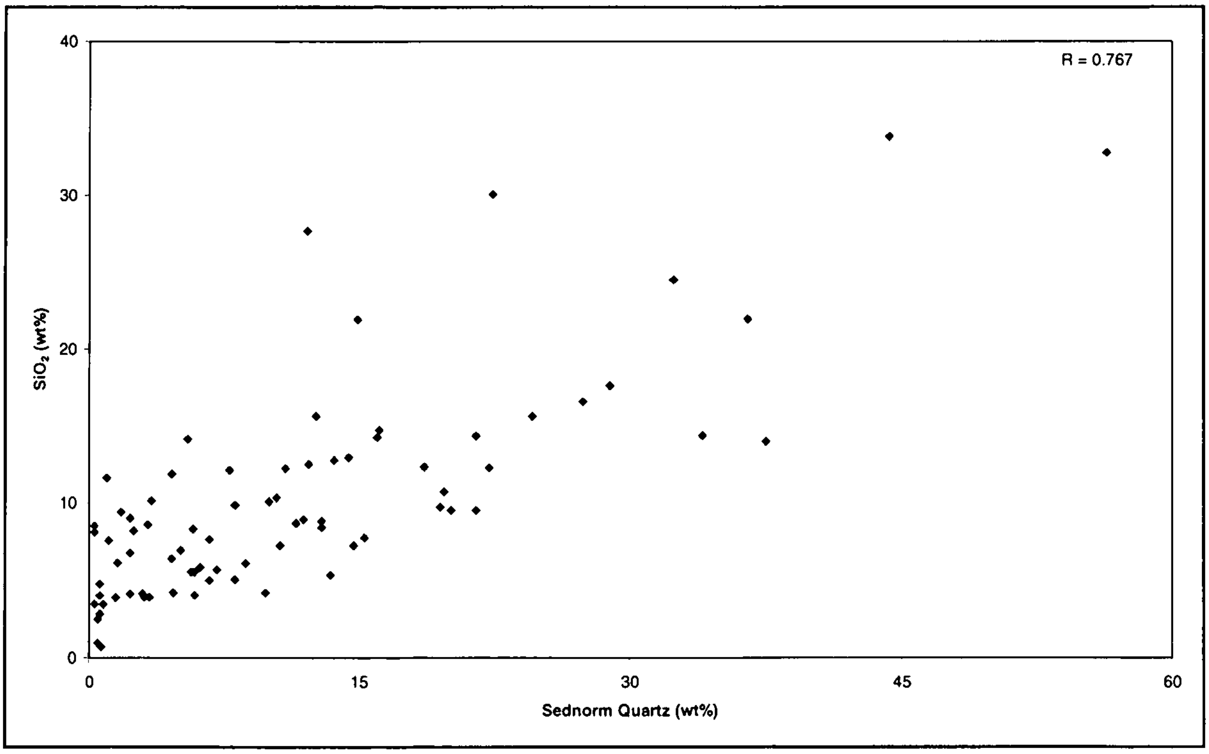


Figure 3.17 – Relationship between normative Quartz and SiO_2 percentages in coal samples

A regression analysis executed in Microsoft Excel proved that the correlation coefficients are almost identical to those obtained from the correlation matrix drawn up in STATISTICA. Since quartz is mainly a minor constituent in the coals, the normative results in Figure 3.17 corresponds exceptionally well, as SiO_2 is used firstly to form other silicate phases for which there is sufficient amounts of K, Ca, Na, Al, Mg and Fe.

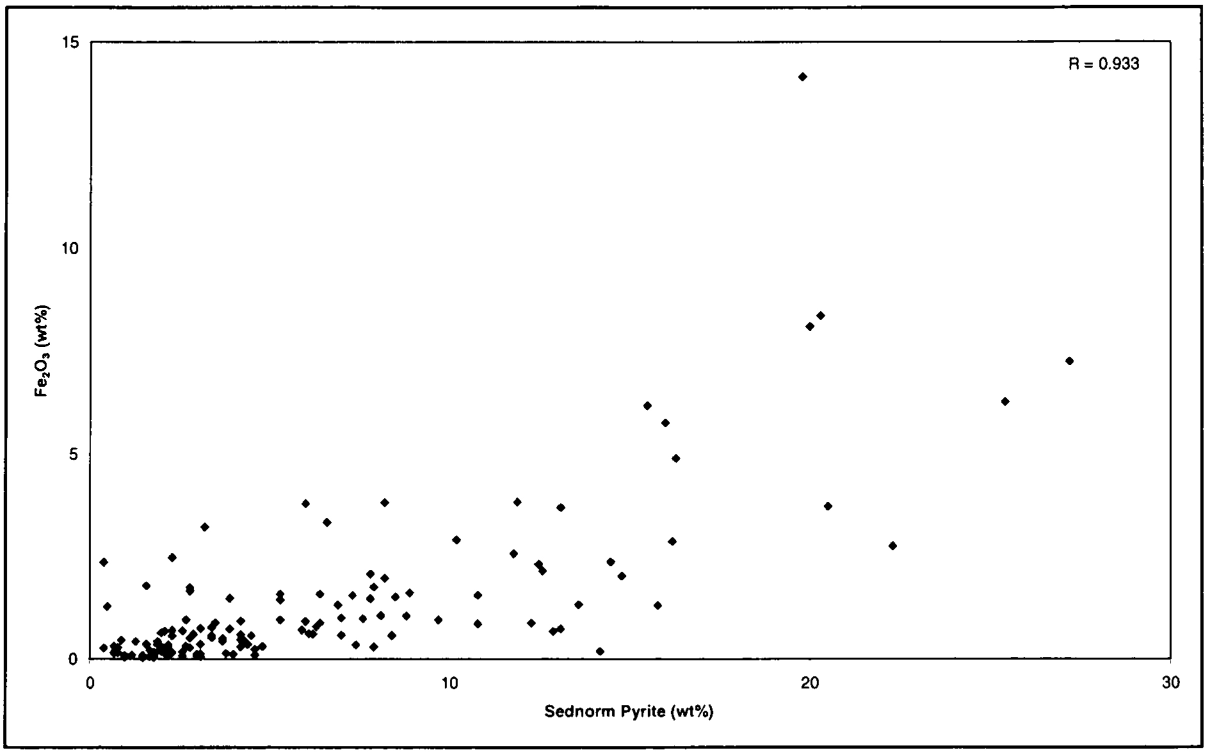


Figure 3.18 – Relationship between normative Pyrite and Fe_2O_3 percentages in coal samples

The correlation coefficient obtained for Fe_2O_3 and siderite in Figure 3.19 is slightly lower than the correlation coefficient for Fe_2O_3 and pyrite seen in Figure 3.18. This could be due to the fact that pyrite was more abundant in the coal samples than siderite. Thus, most Fe_2O_3 was available for pyrite formation until all S was used, and the remaining Fe_2O_3 was assigned to siderite.

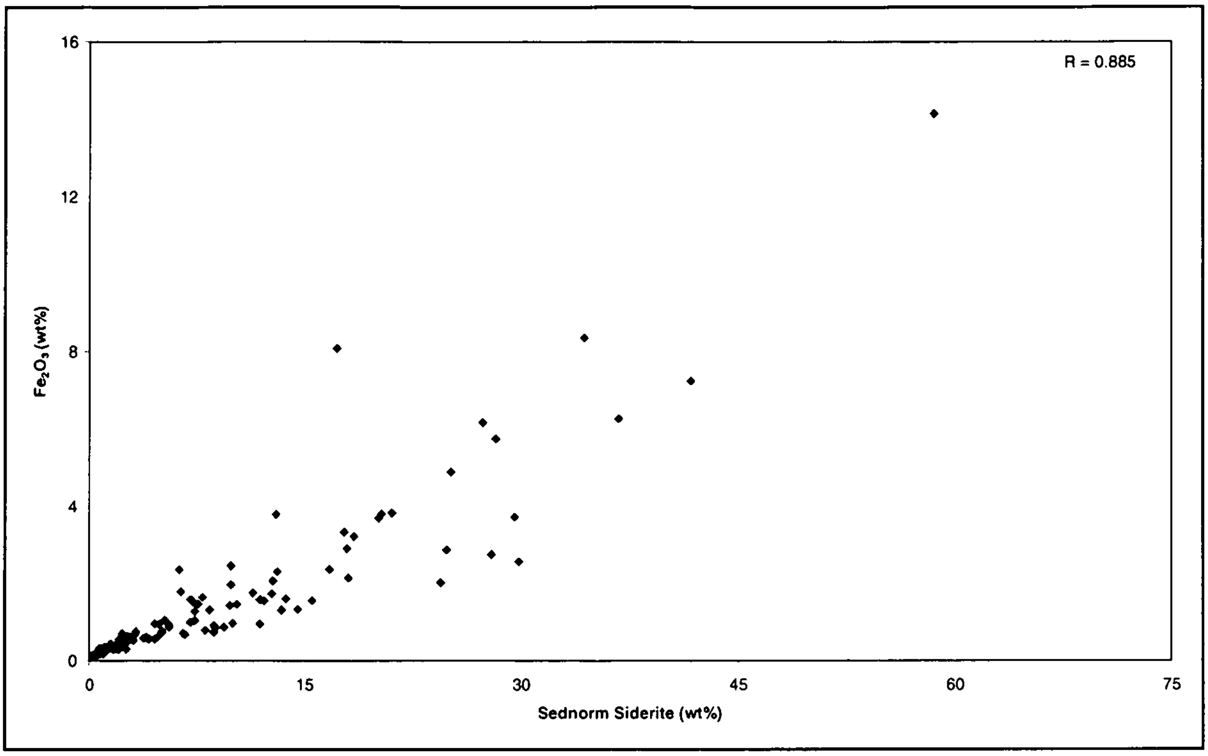


Figure 3.19 – Relationship between normative Siderite and Fe_2O_3 percentages in coal samples

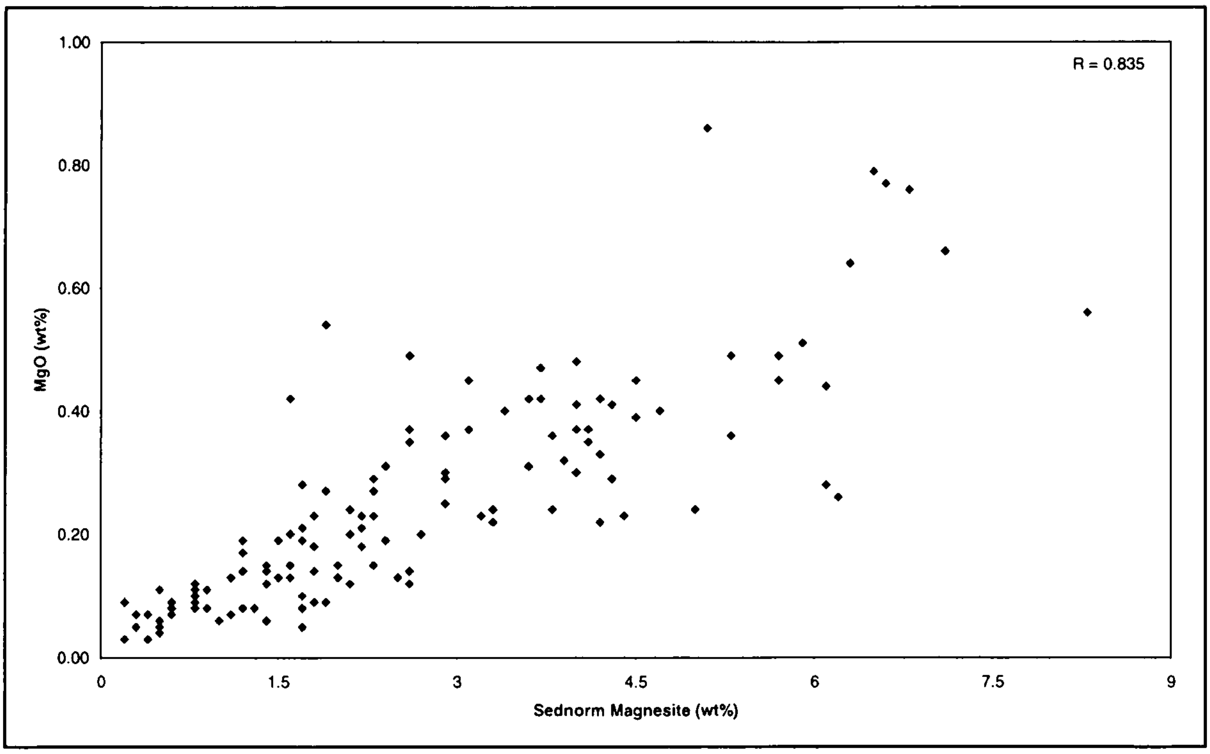


Figure 3.20 – Relationship between normative Magnesite and MgO percentages in coal samples

Remembering that the normative program was designed mainly for Australian sedimentary rocks, it accommodates magnesite as the dominant Mg-carbonate instead of dolomite which is more prominent in South African coals. Yet, the magnesite percentage in Figure 3.20 is in good agreement with the MgO of which most is supposed to be in the form of dolomite.

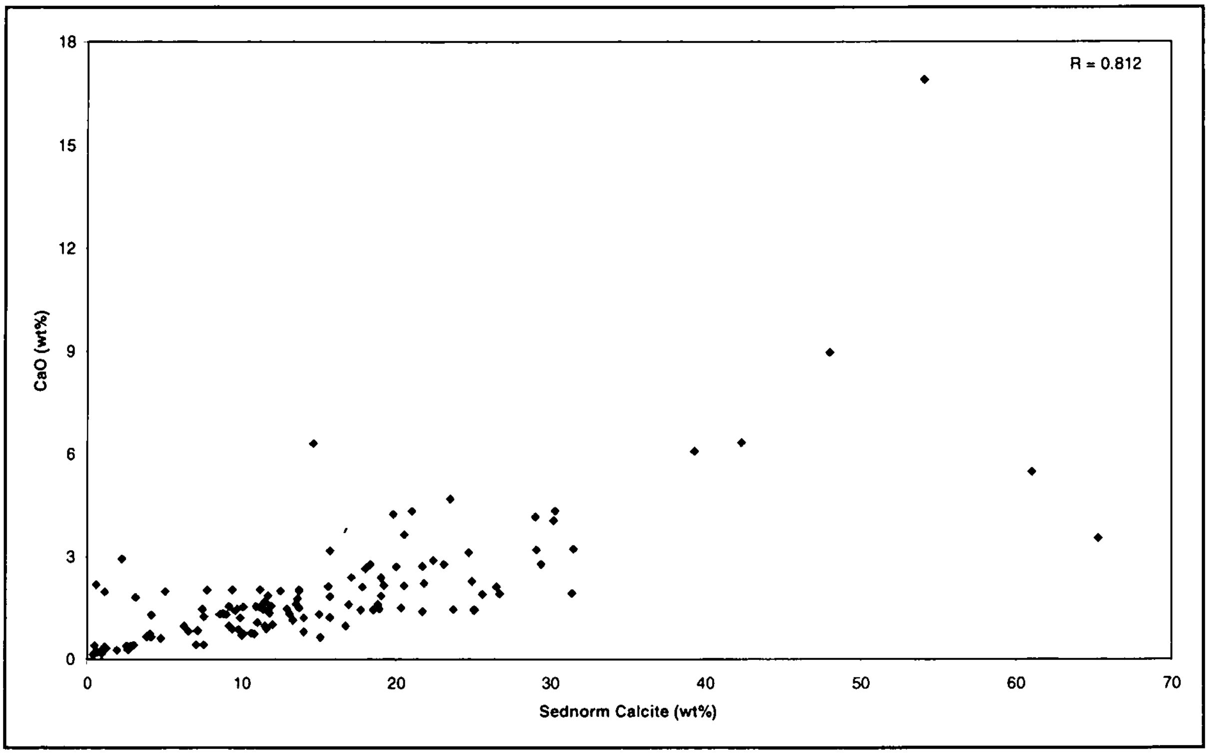


Figure 3.21 – Relationship between normative Calcite and CaO percentages in coal samples

CaO is used to form calcite before any other Ca-bearing phase confirming the high correlation coefficient of r=0.812 as seen in Figure 3.21. However, dolomite does occur as the dominant carbonate in many coal samples and the correlation between magnesite and CaO (r=0.819) is slightly higher than between calcite and CaO. Therefore, if enough MgO is present, CaO could be consumed by magnesite first. The high correlation between apatite and P_2O_5 in Figure 3.22 lies in the fact that it is the only phosphate phase allowed to consume all present phosphorus, and with the presence of sufficient CaO and lower P_2O_5, apatite could be formed until all P_2O_5 is used.

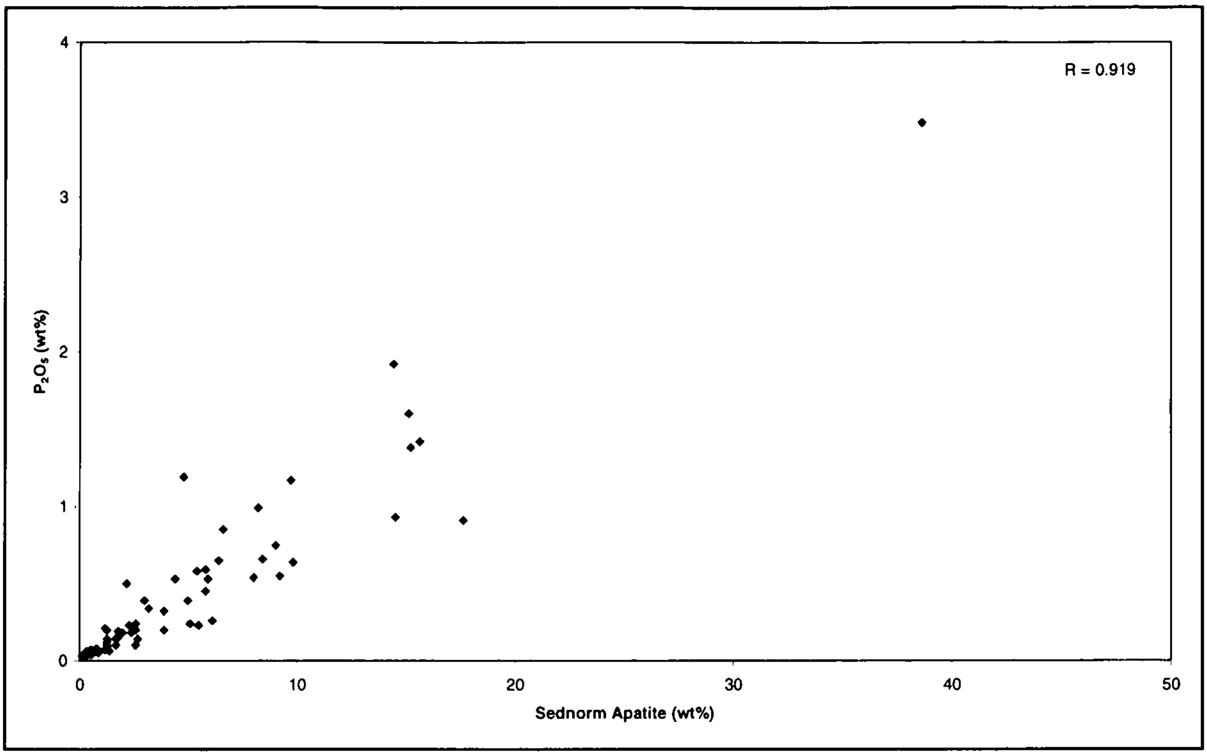


Figure 3.22 – Relationship between normative Apatite and P_2O_5 percentages in coal samples

3.2.3.2 Sediments

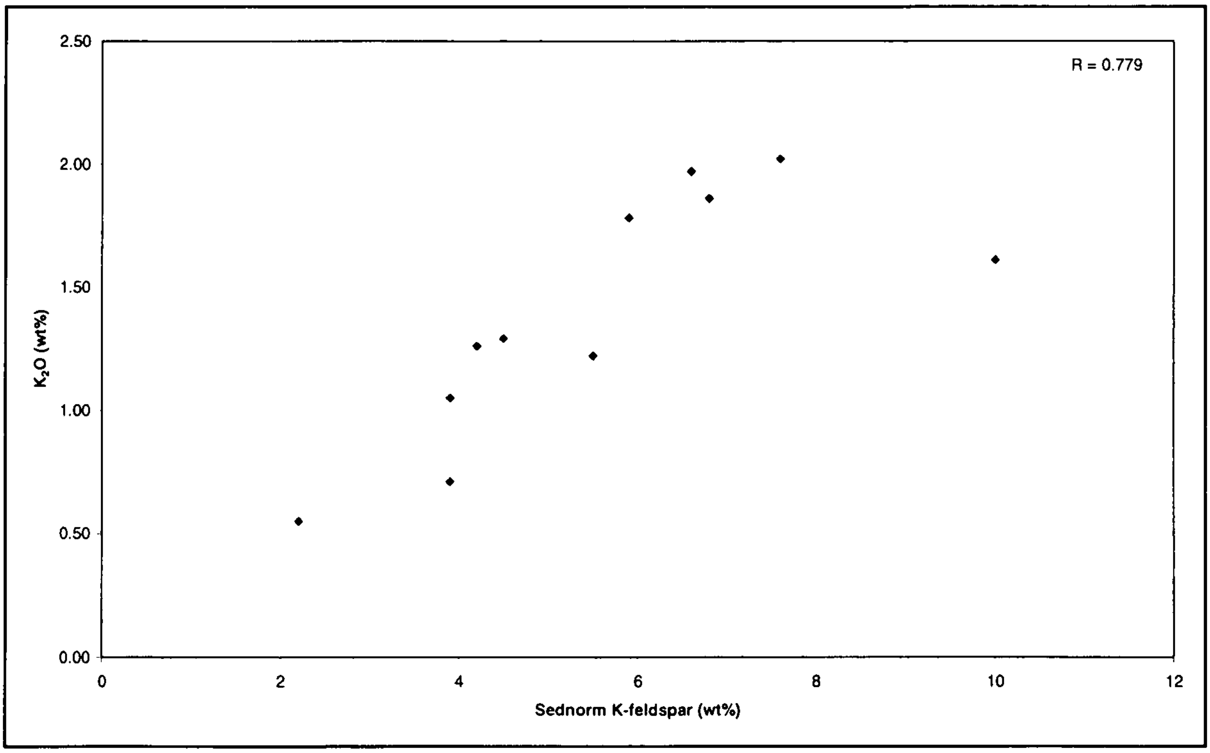


Figure 3.23 – Relationship between normative K-feldspar and K_2O percentages in sediment samples

The correlation between feldspars and their compounds is best seen in the sediments where abundant K_2O and Na_2O is present. The correlation between K-feldspar and K_2O (as seen in Figure 3.23) and Na_2O is r=0.779 and r=0.769, respectively. A good correlation between K_2O and illite-smectite (r=0.831) is also observed in Figure 3.25. The correlation between Al_2O_3 and kaolinite is also more significant in the sediments (r=0.869) than in the coals as seen in Figure 3.24. This is probably because abundant Al_2O_3 is present in the sediments due to the fact that more alumino-silicate phases are present than in the coal, and kaolinite also occur as a dominant phase in the sediments.

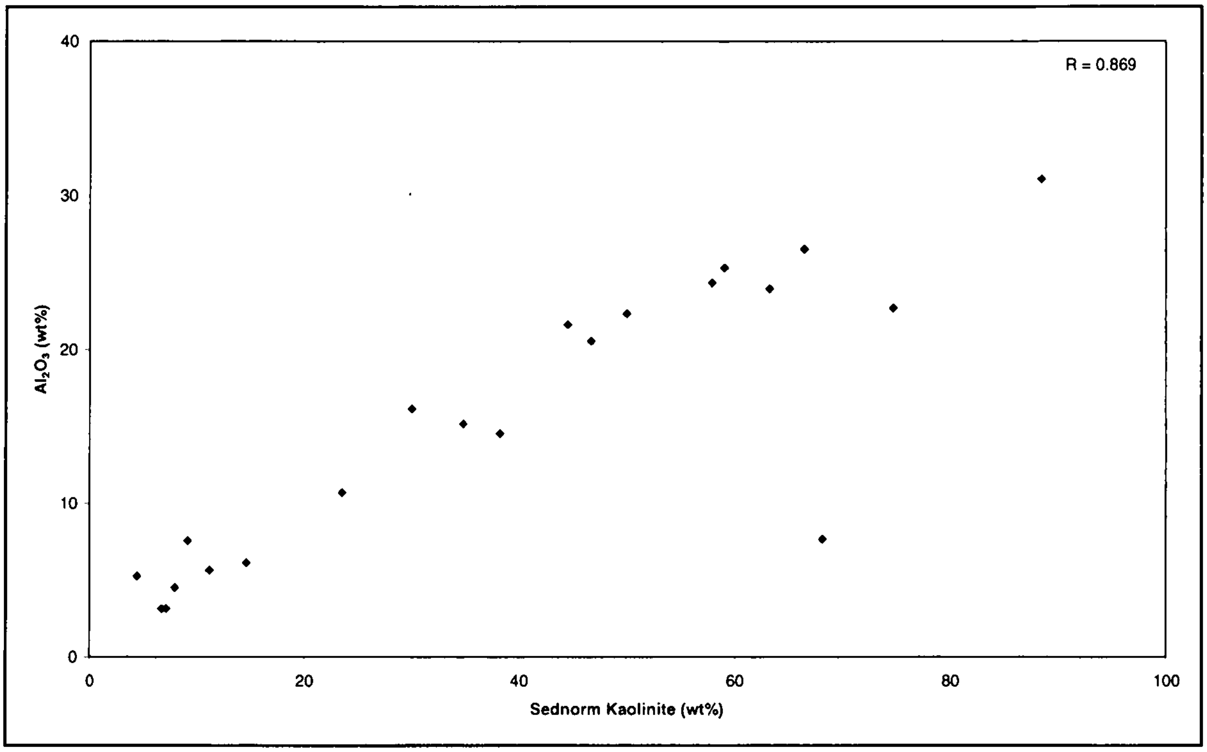


Figure 3.24 – Relationship between normative Kaolinite and Al_2O_3 percentages in sediment samples

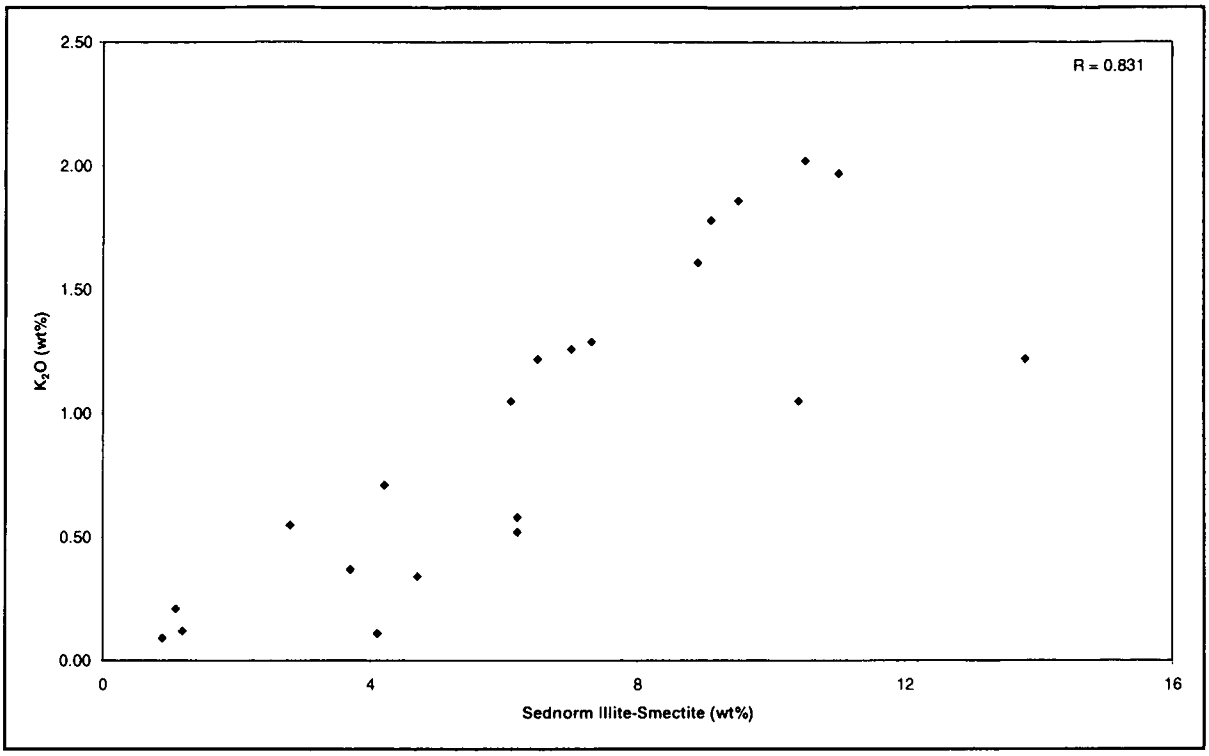


Figure 3.25 – Relationship between normative Illite-Smectite and K_2O percentages in sediment samples

The mineralogical composition of coal and coal-bearing units are similar in some instances, although some differences are observed. The ability of this mineralogy to contribute to groundwater character and the influence on ground water owing to a difference in mineralogy is the main objectives of this study, and these possible influences are discussed in the following chapters.

CHAPTER 4

GEOCHEMICAL CHARACTERIZATION AND QUALITY OF COLLIERY WATERS

4.1 Quality of colliery waters

The diversity of water use makes this compound imperative to the functional existence of all life forms. Despite its scarcity in various countries, it is still used in numerous processes and operations often resulting in the deterioration of nearby rivers, lakes or groundwater systems. A look at what groundwater systems and other water bodies in and around the mining environment are subjected to provide a brief yet informative explanation of the complexities governing water quality.

It would be incorrect to say that the chemical nature of water is influenced only by the entities with which it is in direct contact. Various mechanical factors and constraints in water movement play a significant role. Depending on the type pf ore present, the quality of water in the vicinity of ore deposits might differ considerably to water where no such geological deposits are present. Whether ore deposits are being mined, the manner in which they are mined and the rehabilitation procedures applied after mining has ceased, could result in large differences in water quality regarding such scenarios.

The coal mines in the Mpumalanga Province are situated within the Olifants River and Vaal River Catchments as seen in Figure 1.8. Rainwater in the region contains elevated sulphate concentrations, while a rise in salt concentrations is observed in the Loskop Dam. Sulphate anions dominate waters of the Loskop Dam as well as the Witbank and Middelburg Dams (Hodgson and Krantz, 1998). As mentioned in Chapter 1, the weathered and unweathered Ecca Group aquifers are the most significant since the Pre-Karoo aquifers are at great depths and have a low-yielding character in terms of water quantity. The excellent quality of water in the weathered Ecca Group aquifers can be attributed to the many years of dynamic groundwater flow through the weathered sediments. Leachable salts have been removed from the system long ago and it is only the slow decomposition of clay particles which presently releases some elements into the water. Water in the unweathered/fractured aquifer could possibly seep through the No. 2 coal seam, causing higher salt loads there than in the waters of the weathered aquifer; nevertheless acceptable concentrations of various salts ranging between 1 and 400 mg/l are still obtained (Hodgson and Krantz, 1998).

With rapid industrial development in the Mpumalanga province, several factors able to contribute to the deteriorating water quality were introduced. Power generation, municipal waste, sewage effluent, metallurgical and agricultural waste are some of the contributors to pollution, but the effects of mining activities seems to be the primary cause for concern regarding water quality, therefore it's influence will be discussed in further detail. Water monitoring systems implemented over the last few decades display some significant results regarding the quality of both surface and underground water surrounding these mines, the key process giving reason for concern being acid mine drainage (AMD).

This study was aimed at correlating the water quality in a specific area with the mineralogical composition of the coal and the roof and floor lithologies in that area. In order to illustrate the mineral distribution across such an area, it is necessary to obtain spatial data from a structured, intensive sampling programme. It is not always possible to sample even a smaller area, such as a mine, at regular intervals to gather sufficient information to compile maps. The task was more complicated due to the areal extent of the area investigated. Samples collected from the mines included in this study were often kilometres apart.

There are some other constraints that could be unfavourable during sampling procedures. Accessing all lithologies underground in one area is not always possible, resulting in the need for borehole material. It is clear from the research conducted that extensive planning and some modifications were needed to ensure that this specific objective was achieved. A decision was made to concentrate on a mineralogical study with investigations in the acid-base potential of representative samples. Acid-base accounting (ABA) was used mainly to verify the potential of the coal and sediments in the coalfield to contribute to the geochemical character of water, and is laid out in Chapter 5. A brief description of AMD, it's influence on water quality and the factors controlling water quality are provided in the next sections of this chapter.

4.1.1 Sources of acid mine drainage (AMD)

Sulphuric acid is formed by the reaction of water with iron sulphides, particularly pyrite, which is a common constituent in coal seams. It may be produced from drainage of mines from which sulphide ores are being extracted, from tailings produced in plants where the ores are processed and through groundwater emerging from abandoned mines charged with sulphuric acid and various salts of metals. Such chemical pollution also includes salts of zinc, lead, arsenic, copper and aluminium (Strahler and Strahler, 1973). The reactions of pyrite with oxygen and water found in literature (Grobbelaar, 2001; Azzie, 1999; Chelin, 2000) proceeds as follows:

Step one: The pyrite oxidizes upon contact with air and water
1) $2FeS_2 + 7\ O_2 + 2H_2O \rightarrow 4SO_4^{2-} + 2Fe^{2+} + 4H^+$

Step two: Iron oxidizes to ferric iron
2) $4Fe^{2+} + 4O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$

Step three: Precipitation occurs with ferric iron to ferric hydroxide
3) $Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$

Thus, the overall reaction can be written as:
$4FeS_2 + 15O_2 + 14H_2O \rightarrow 8H_2SO_4 + 4Fe(OH)_3$

Once acid has been formed it will either remain and accumulate in the rock by filling pores, or be removed by water. Sufficient alkaline material is needed to neutralise AMD conditions depending on the extent of distribution of the acid. The most common acid consuming or neutralising mineral is calcite ($CaCO_3$) and neutralisation occurs via the reactions:

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$$

or

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3$$

If acid generation continues long enough to exhaust the neutralising ability of $CaCO_3$, the pH will drop and create more favourable conditions for acid generation. The pH of natural waters is controlled by reactions involving an acid-base system, such as the carbonic acid system (Azzie, 1999).

Chemical equilibrium models for the study of the carbonic acid system include both an open and a closed system. An open system assumes that the water is in equilibrium with the partial pressure of CO_2 in the atmosphere. This model is used when there is ample time for atmospheric carbon dioxide to saturate a solution. For example, this chemical model can be used to study the chemistry of shallow lakes, cooling towers and geological formations. In a closed system the acid-base reactions are much faster than gas dissolution equilibrium reactions (Cruywagen, 2000). Natural systems tend to change relatively rapidly thus no equilibrium with the surrounding atmosphere is attained. The closed system is therefore commonly used in most environmental engineering and environmental science applications (Cruywagen, 2000).

When $CO_{2\,(g)}$ is brought into contact with water it will dissolve forming carbonic acid (H_2CO_3) until an equilibrium state is reached. The carbonic acid will dissociate to hydrogen, bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. In an open system the water will be in contact with a gas phase thus carbon dioxide will enter the solution and when the calcite dissolves it is referred to as "open system dissolution". If no gas phase is present, such as below the water table or tailings ponds below the surface, no carbon dioxide will be provided while the calcite dissolves. The solubility of calcite increases within an open system in comparison to a closed system. Dolomite could serve as a neutralising agent for sulphuric acid, but it is less effective than calcite (Cruywagen, 2000).

Although very brief, this overview of AMD confirms that the generation and remediation of AMD is a cause for concern regarding most coal mines, as well as other mining sectors; especially since the effects are evident in the deterioration of aquatic and terrestrial life forms surrounding these areas.

4.1.2 The effects of AMD on colliery water quality

Research on AMD has gradually intensified since the problem becomes more apparent each year, and similar situations are encountered in coal mines elsewhere. The influence of coal mining methods on water quality is described comprehensively by Hodgson and Krantz (1998).

The dissolution of sodium, potassium and chloride-bearing minerals occur simultaneously with the oxidation of pyrite in the spoils of opencast mines. Accelerated pyrite oxidation occurs together with the precipitation of ferric hydroxide. The total sulphur in coal gives little indication of the final pH of the spoil waters. Low sulphur content may still produce acid if insufficient neutralising constituents are present, and when neutralising constituents are depleted, water quality is sure to deteriorate. Water quality in shallow underground mines varies from acid to neutral to saline conditions (Hodgson and Krantz, 1998). In some cases water is not saturated with respect to sulphate due to periodic recharge, while other cases are observed where calcium sulphate dominates waters due to the carbonates in the coal. Low calcium and magnesium concentrations suggest that the base potential has been exhausted, and high metal concentrations are present due to a low pH (Hodgson and Krantz, 1998).

Water quantity in deep underground mines varies considerably depending on the mining method used, namely, bord-and-pillar, high extraction, stoping, longwall and shortwall mining. Water quality will be explained in terms of bord-and-pillar and high extraction mining. Interstitial water in bord-and-pillar mines is dominated by sodium and chloride ions, and due to the small load, high concentrations of metals are not present. On the other hand, water in stagnant pools deteriorate due to the high acid generating potential of the coal seam, which often increases once the base potential has been depleted. Natural alkalinity of water that flows into the mine or carbon dioxide from the atmosphere could suffice as a means to buffer acid. Water in high extraction mines is initially high in sodium, but later deteriorates due to pyrite oxidation and an increase in sulphate, calcium and magnesium takes place. Panel waters in such mines have high alkaline tendencies due to available carbonates (Hodgson and Krantz, 1998).

Waters from coal mines in other countries show a similar trend. Calcium sulphate type waters characterise abandoned opencast coal mines in Ohio, while magnesium concentrations are often similar to calcium concentrations, and elevated concentrations of sulphate, boron, fluoride and chloride are present (Haefner, 2002).

In a study examining sulphate transport and trends as an indicator of drainage from past and present coal mining in the Allegheny and Monongahela River Basins, U. S. A., a comprehensive description of the effects of acid mine drainage is presented. The AMD effects on various rivers and streams in the basins are evident in the deaths of numerous aquatic plants and animals (Sams and Beer, 2000). Similarly, AMD water quality at an opencast coal mine in Indiana was characterised by high acidity, high concentrations of iron, manganese and sulphate, and lack of alkalinity. Remediation processes applied here included the placement of coal ash commonly used for it's alkaline nature to improve AMD conditions (Martin *et al.*, 1990).

These are just a few of many known cases during which improper or no water monitoring programs were implemented resulting in rapid deterioration of water quality.

4.2 Factors influencing geochemical character of water

From the previous section it is evident that the quality of water is controlled mainly by the degree of water-rock or water-mineral interaction, however, specific parameters are used in determining the suitability of water for a specific purpose.

4.2.1 Electrical conductivity (EC)

Conductivity is a numerical expression of the ability of a solution to conduct an electric current, and depends on the concentration of ions, their mobility and valence, as well as temperature. Solutions of inorganic acids, bases and salts are good conductors, while solutions of organic components conduct current very poorly. The physical measurement made in a laboratory determination of conductivity is usually of resistance, measured in Ω or MΩ, and since the reciprocal for ohm is siemens according to the International System of Units, it is reported as millisiemens per meter (mS/m). There are various uses for conductivity measurements which are carried out in a laboratory such as establishing the degree of mineralisation and the variations in dissolved mineral concentration, just to mention a few. The apparatus consists of different components and the procedure is set out systematically in Franson *et al.* (1985).

4.2.2 Salinity

Salinity is defined as the total solids in water after all carbonates have been converted to oxides, all bromide and iodide have been replaced by chloride, and all organic matter has been oxidised, and is presented as grams per kilogram (g/kg). A specific method for determining salinity in a certain situation is proposed. The electrical conductivity and hydrometric methods are recommended for analyses performed along a shoreline, while the argentometric technique is more suited for laboratory or field analysis of estuarine or coastal inlet waters (Franson *et al.,* 1985).

4.2.3 pH value

It is possible to describe the acidity, neutrality or alkalinity of an aqueous solution quantitatively by using the hydrogen-ion concentration, but because these concentrations values may be very small it is often more convenient to present them in terms of pH. pH is defined as the negative of the logarithm of the molar hydrogen-ion concentration:

$$pH = - \log [H^+]$$

It is measured on a scale ranging from 1.00 to 14.00, where 1.00 represents extreme acidity, 7.00 represents neutral and 14.00 would be purely alkaline or basic. Water quality is often characterised in terms of its alkalinity or acidity as this parameter is very dependant on ion concentration (Ebbing, 1993).

4.2.4 Total suspended solids (TSS) and total dissolved solids (TDS)

Solids refer to the matter suspended or dissolved in water or wastewater. The degree to which solids are suspended and dissolved in water contributes to it's suitability for industrial and domestic use. During an analytical procedure, the "total solids" is a measure of residue left after the evaporation of a sample and includes total suspended solids (the portion of solids retained by a filter) and total dissolved solids (the portion that passes through the filter). The concentration of solids is presented as milligram per litre (mg/L). Recommended methods are also set out in Franson *et al.* (1985).

4.2.5 Metals

Most metals occurring naturally in a certain environment tend to concentrate in nearby streams, rivers and lakes, depending on their abundance, mobility and the minerals in which they occur. In areas where geological bodies containing prominent concentrations of a specific metal are situated, elevated concentrations of the metals associated with the orebody are commonly found in the surrounding environment. This is a useful indicator in determining the location of ore deposits. The exploitation of such a deposit would often result in a higher concentration of metals in the area, but mainly in the water bodies, generally having a negative effect on the water quality.

Several analytical techniques are available in determining the distribution of metals in surface and ground water. Calcium, magnesium, iron and manganese are commonly analysed in groundwater from coal mines as these ions are donated by the carbonates, sulphides and silicates present in the coals and sedimentary rocks. They also determine the suitability of water for use in mining operations. Calcium is dissolved from minerals such as calcite and gypsum, and forms soluble salts with bicarbonate, sulphate, fluoride, phosphate and chromate. The main source of magnesium is dolomite but it is associated with silicates, sulphates and chlorides. Both calcium and magnesium are responsible for water hardness, and calcium also reduces metal toxicity by hindering their absorption (Azzie, 1999).

Acidic surface drainage and some underground water sources frequently contain higher iron concentrations. Iron may occur in true solution, in a colloidal state, in inorganic or organic iron complexes, or in coarse suspended particles. It is obtained from sulphides, carbonates, oxides and hydroxides, and some silicates. The ionic state of iron present in a solution depends primarily on it's surrounding Eh and pH conditions. Different procedures are thus used for the determination of ferrous and ferric iron (Franson *et al.,* 1985). Manganese is found in solution predominantly as the manganous ion Mn^{2+}. On oxidation to the manganic ion, Mn^{4+}, manganese tends to precipitate out of solution to form a black hydrated oxide, which causes staining problems often associated with manganese-bearing waters (Azzie, 1999). On precipitation, iron and manganese contribute to the sediment deposits that pollute heat exchangers and pipelines. These metals are presented as milligrams per litre (mg/L).

4.2.6 Inorganic non-metallic constituents

Chloride, sulphate and silica are primary inorganic non-metallic constituents used to characterise water. An excessive chloride concentration gives water a typical salty taste depending on the concentration, in mg/L, and on other cations present. High chloride content may harm metallic pipes and structures, as well as growing plants. Silica is obtained from quartz and other silicate minerals, and occurs as suspended particles, in a colloidal state and as silicate ions. The silicate content of natural water ranges from 1 to 30 mg/L. For industrial uses elevated concentrations are undesirable as silica scales are difficult to remove from equipment. Mine drainage contributes large amounts of sulphate through pyrite oxidation, but also through the dissolution of minerals such as gypsum (Franson *et al.,* 1985). High concentrations of sulphate may promote degradation of concrete structures. Determination of these constituents is vital and a range of methods are available for this purpose.

4.2.7 Organic constituents

The total organic carbon (TOC), the biochemical oxygen demand (BOC) and the chemical oxygen demand (COD) are used as parameters in characterising colliery waters. Carbon compounds in water can be oxidised by biological and chemical processes, and the BOC and COD characterise these fractions, respectively. Although it does not provide the same information, TOC is a more convenient and direct expression of total organic carbon content. Organic matter promotes the formation of microbial slimes, acting as a nutrient source for bacterial growth (Azzie, 1999).

The components characterising water quality are introduced into the system by means of various reactions and processes such as redox reactions, acid-base reactions, ion exchange, dissolution-precipitation and aqueous speciation. For more information regarding these processes the reader is referred to Hodgson and Krantz (1998).

4.3 A model for the preliminary assessment of sources of pollution

Taking precautionary measures to curb deterioration in groundwater quality is always a feasible approach to prevent such a situation from developing into a crisis. Yet, negative influences on water surrounding mines are sometimes only detected once conditions have already reached detrimental levels. Since monitoring water quality has become an integral part of operating a mine, more knowledge has been gathered concerning the causes, effects and solutions associated with water problems. It is necessary to understand unfavourable reactions that are associated with specific mine wastes and by-products, and how they affect the surrounding environment. Therefore, examining the potential of any source to contribute to pollution could be cost-effective and beneficial, as time and resources spent on remediation often amounts to vast quantities.

As seen from equations above, pyrite weathering eventually results in iron oxyhydroxide precipitation resulting in a greater net acid production. However, minewater often achieves equilibrium due to forward and reverse reactions occurring at a similar pace. Minerals such as carbonates and aluminosilicates also consume acidity and helps buffer pH. According to data presented by Banwart and Malmström (2001), calcite dissolves 3 orders-of-magnitude quicker than pyrite, which in turn dissolves nearly 3 order-of magnitude quicker than aluminosilicates as observed in Figure 4.1. If these minerals are present in similar quantities, calcite will produce sufficient alkalinity to neutralise the acidity produced by the pyrite until it is depleted (Figure 4.2).

Once calcite is depleted the acidity level will be determined by the weathering rates of pyrite and the silicates. Although the discharge might remain near-neutral throughout the lifetime of the calcite, the lifetime of pyrite corresponds to the contaminating lifetime of a site (Banwart and Malmström, 2001). On the other hand, this would only be partially true since the calcite depletion rate would be largely dependent on the pyrite oxidation rate due to the required neutralisation. Secondly, once you have submergence with water the conditions will become progressively less oxic, thus the pyrite reaction rate decreases.

The mineral behaviour explained above formed the basis of a hydrochemical model for the preliminary assessment of minewater pollution proposed by Banwart and Malmström (2001). It was aimed at classifying a site in terms of the potential threat to the environment. The model estimates the contamination strength of the source, longevity and possible future changes in discharge quality. Firstly, the current mineral weathering rates are estimated by setting up an integrated mass-balance based on the water budget (including surface and groundwater flows), the associated water qualities and the yield from the present contaminant load (source strength). It is then possible to calculate the flow (mol s^{-1}) of a contaminant due to a process in a rock or ore deposit, by observing various water flows to and from the deposit and the contaminant concentration. This only applies for steady state water flow conditions i.e. once a mine has filled and the inflow from recharge and groundwater influx is being balanced by decanting and seepage.

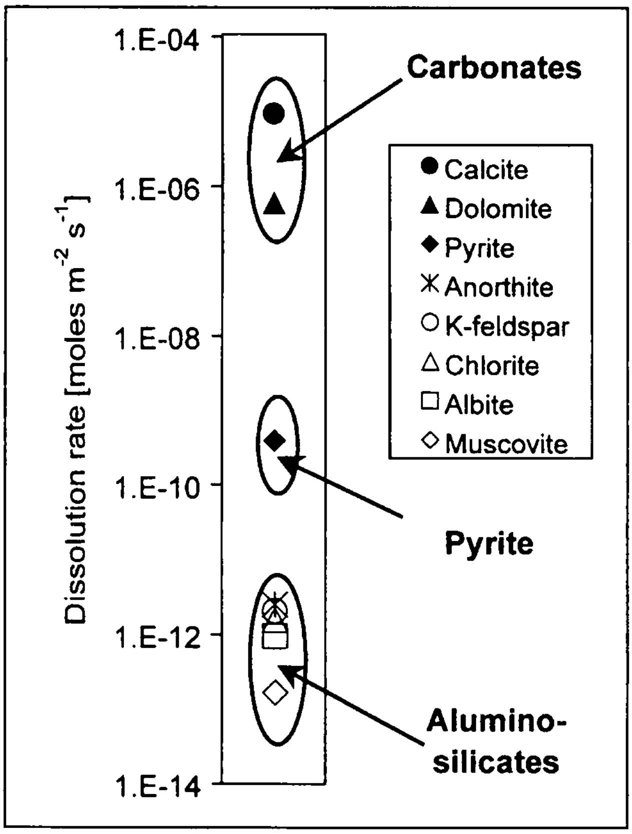


Figure 4.1 – Surface area dissolution rates for source minerals far from solubility equilibrium at oxic conditions and pH 5 and 25°C (Banwart and Malmström, 2001)

Certain reaction products also provide evidence of specific weathering processes. The flow a reaction product is related to the rate of the weathering process which is calculated in mol s^{-1}. Having obtained the weathering rate, an estimation of the duration of the weathering reaction is obtained by calculating the lifetime of the mineral in the deposit. The amount of the mineral is determined by areal extent and depth of the source as well as on the composition of the rock and ore in it. This mineral content could be estimated using chemical analysis and thin sections. Now it is possible to predict the present acidity load, the neutralising potential and the lifetime of further acid generating conditions (Banwart and Malmström, 2001).

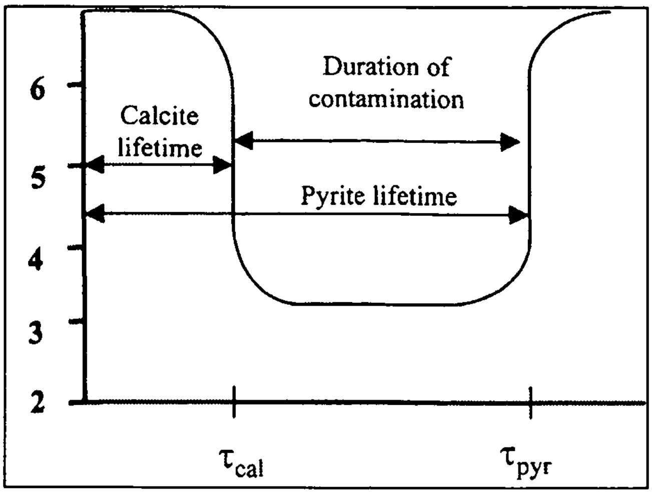


Figure 4.2 – Relationship between trends in pH with the lifetime of minerals that produce and consume acidity (Banwart and Malmström, 2001)

Some results were obtained when the model was applied to a mine rock waste deposit located in the northern part of Sweden, a flooded abandoned coal mine with deep workings in northern England and a mine tailings deposit also situated in the northern part of Sweden. For the rock waste deposit it was predicted that the acid levels would be controlled by relative rates of sulphide and silicate mineral weathering since depletion of calcite prior to pyrite was expected. Acidic conditions would also exist after depletion of calcite in the abandoned coal mine. Although the lifetimes of both pyrite and calcite/dolomite in the tailings dumps were within the order of 100 years, the estimated lifetime of chalcopyrite was in the order of thousands of years, implying the need for long-term remediation (Banwart and Malmström, 2001).

CHAPTER 5

ACID-BASE ACCOUNTING

Acid-base accounting used to predict the acid and neutralising potential of samples analysed in this study. The technique makes it possible to quantify the potential of a sample to produce acidic or alkaline conditions. A detailed explanation of the experimental procedure followed can be found in Hodgson and Krantz (1998), Cruywagen (2000) and Usher *et al.* (2001). The procedure applied to the samples in this study is briefly set out in Appendix 3 and includes the raw data.

5.1 Acid-base determinations for the Witbank and Highveld Coalfields

Acid mine drainage results from the interactions of certain sulphide minerals with oxygen, water, and bacteria. Pyrite is recognised as the major source of acidic drainage. The acid potential (AP) is a measure of the potential of a sample to generate acidity according to the following reaction:

$$FeS_2 + 3.75O_2 + 3.5H_2O = Fe(OH)_3 + 2SO_4^{2-} + 4H^+$$

The amount of calcite required to neutralise a given amount of acid mine drainage depends on the behaviour of CO_2 during neutralisation and on the pH reached. If the AMD is to be neutralised to pH 6.3 or above, then the following reaction may be written:

$$FeS_2 + 2CaCO_3 + 3.75O_2 + 1.5H_2O = Fe(OH)_3 + 2SO_4^{2-} + 2Ca^{2+} + 2CO_2$$

For each mole of pyrite that is oxidised, two moles of calcite are required for acid neutralisation. On a mass ratio basis, for each gram of sulphur present, 3.125g of calcite is required for acid neutralisation. When expressed in parts per thousand of spoil, for each 10 ppt of sulphur present, 31.25 ppt of calcite is required for acid neutralisation.

The stoichiometry in the previous equation is based on the exsolving of carbon dioxide gas out of the spoil system. In a closed system (as described in Chapter 4), carbon dioxide is not exsolved, and additional acidity from carbonic acid is generated. Cravotta *et al.* (1990) proposed that up to four moles of calcite might be needed for acid neutralisation as follows:

$$FeS_2 + 4CaCO_3 + 3.75O_2 + 3.5H_2O \rightarrow 2SO42^- + Fe(OH)_3 + 4Ca^{2+} + 4HCO_3^-$$

The stoichiometry of equation above shows that twice as much calcite would be required for acid neutralisation. On a mass basis, for each 10 ppt of sulphur present, 62.5 tons of calcite is needed for acid neutralisation in one thousand tons of spoil (Cravotta *et al.*, 1990).

Results obtained from the laboratory experimental procedure are used in calculating the AP, neutralising potential (NP) and net neutralising potential (NNP) as follows:

$$AP = \frac{SO_4\text{ (mg/L)/weight (g)}}{1000} \text{ x ml } H_2O \text{ or } H_2O_2 = \text{kg } SO_4\text{/t of sample}$$

$$AP\text{ (Open) } (CaCO_3\text{ kg/t}) = \frac{SO_4\text{ kg/t}}{48} \text{ x } 50$$

$$NP\ (CaCO_3\text{ kg/t}) = (\text{N } H_2SO_4 \text{ x ml acid}) - (\text{N NaOH x ml alkali})\text{/weight (g) x } 50$$

Thus, the NNP is determined by subtracting the acid potential from the neutralising potential.

NNP (Open) = NP – AP (Open)

In a closed system, AP (Closed) = AP (Open) x 2, and, NNP (Closed) = NP – AP (Closed) (Hodgson and Krantz, 1998).

There are various types of screening criteria used to interpret ABA results. According to Usher *et al.* (2001), an integration of Net Acid Generating Test (NAG) pH, Net Neutralising Potential (NNP), Neutralising Potential Ratio (NPR), and %S and NPR, could lead to a good classification of test results. The reader is referred to Cruywagen (2000) for a comprehensive description of the NAG procedure. The NAG pH obtained from this procedure can serve as a rough guideline as follows:

- If final pH = >5.5; the sample is non-acid generating,
- If final pH is between 3.5 and 5.5; the sample is low risk acid generating,
- If the final pH = <3.5; the sample is high risk acid generating.

When using the NNP as screening criteria, research has shown that there is a range from -20 to 20 kg/t $CaCO_3$ where a sample can become acidic or remain neutral. Thus, a sample with a NNP <20 is potentially acid generating and a sample with a NNP >20 might not generate acid (Usher *et al.*, 2001).

The NPR, or NP: AP, is the ratio between the acid and neutralising potential. It ranges from <1:1 which suggests likely AMD generation to >4:1 suggesting no potential for AMD. By combining the NPR with the sulphide percentage, another set of rules can be derived as follows:

- Samples with less than 0.3% sulphide-S are regarded as having insufficient oxidisable sulphide-S to sustain acid generation.
- NPR ratios of >4:1 are considered to have enough neutralising capability, while NPR ratios between 3:1 and 1:1 are inconclusive.
- NPR ratios of <1:1 with more than 0.3% sulphide-S are potentially acid generating (Usher *et al.*, 2001).

5.1.1 The Witbank Coalfield

Data from 64 rock and coal samples was available in this coalfield. The raw data found in Appendix 3 is organised according to lithologies ranging from below the No. 1 seam at the bottom of the dataset, to above the No. 5 seam at the top. Although the dataset is limited, averages were used to illustrate the vertical distribution of acid and neutralising potentials in the coalfield.

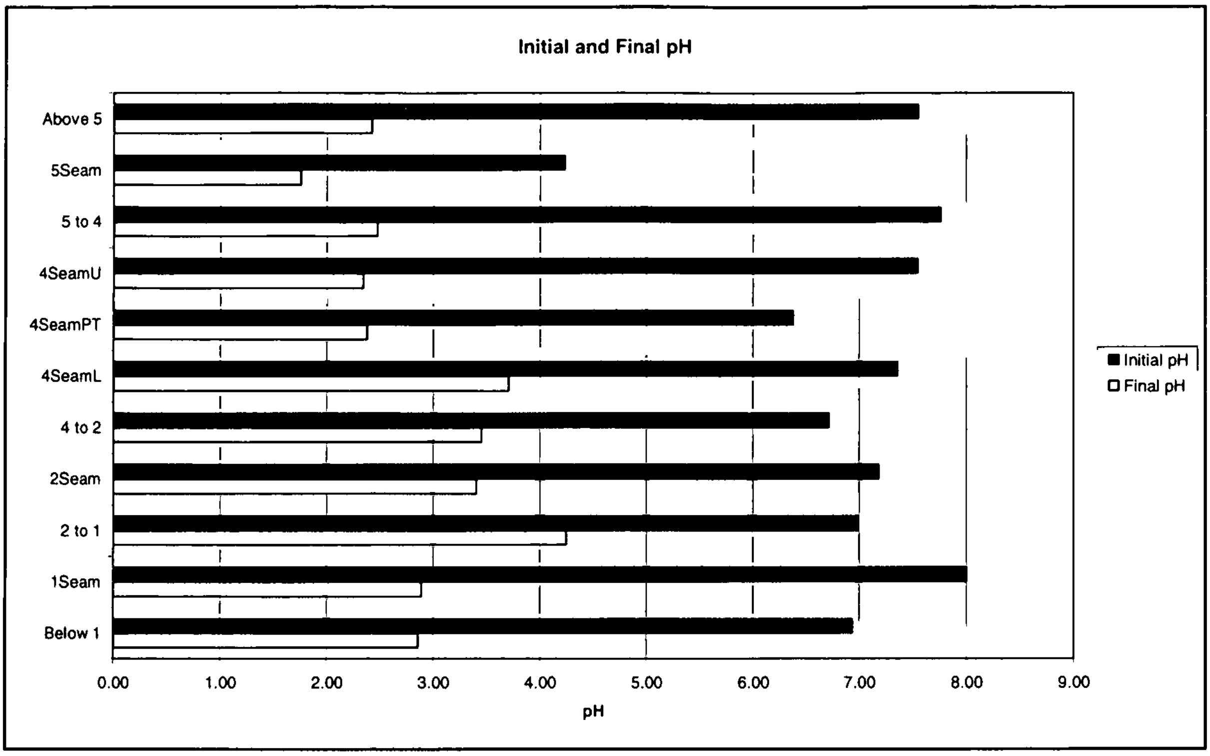


Figure 5.1 – Initial and final pH of the samples before and after complete pyrite oxidation and carbonate dissolution

From Figure 5.1 it is apparent that the natural or initial pH of both rock and coal samples are close to alkaline or at least to neutral conditions. With the exception of the No. 5 seam all of the lithological units are expected to remain at these pH conditions if no oxidation takes place. A possible reason for the initial pH of the No. 5 seam being much lower could be because it is situated closer to the water table. Any reactions that might have taken place could be due to groundwater movement through the seam dissolving most of the carbonates. The final pH of all lithologies indicates that acidic conditions would dominate if complete sulphide oxidation was to occur. No. 5 seam also has a lower final pH suggesting that total available carbonates could already be leached out leaving less sources of alkalinity to buffer the acid. It could also be that acid producing constituents were originally more abundant than acid consuming constituents.

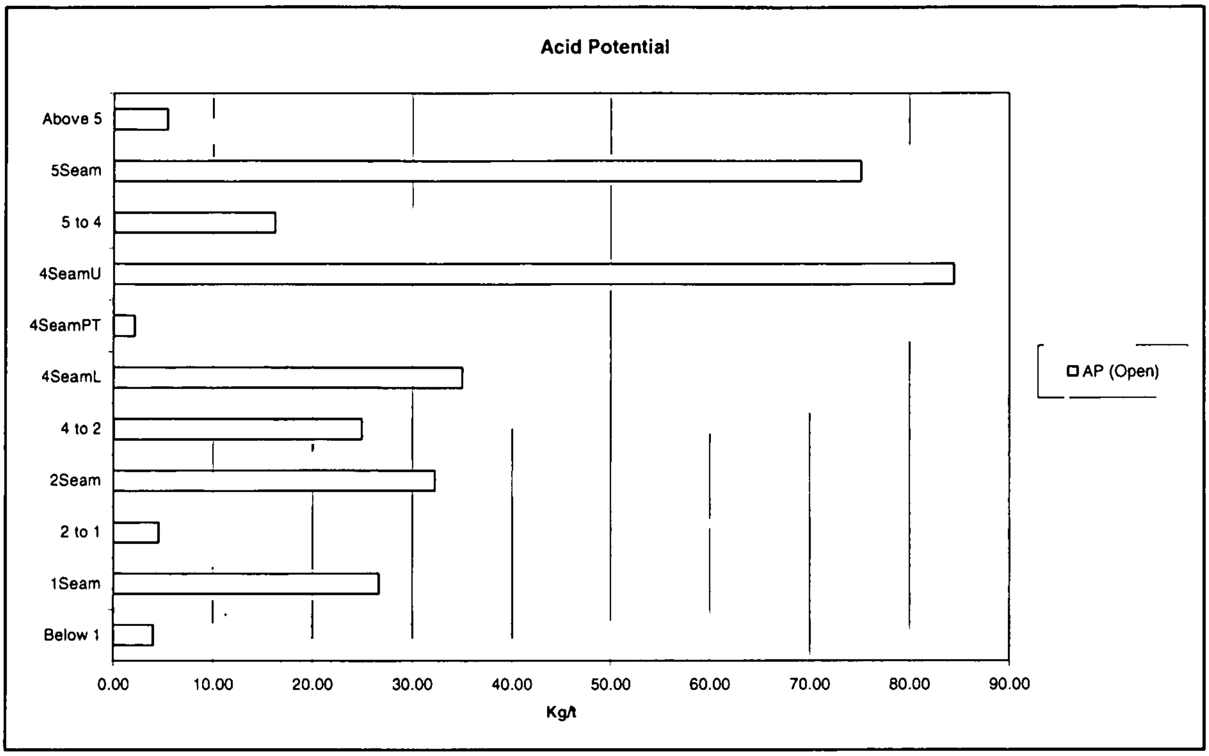


Figure 5.2 – Acid potential (for an open system) for the Witbank Coalfield

The AP in an open system is illustrated in Figure 5.2 above. Since the acid potential is determined primarily by the percentage of sulphur present it can be concluded that the rock units contain low concentrations acid producing minerals such as pyrite. This is evident in XRD interpretations, and is supported by XRF analyses and normative calculations as explained in Chapter 3. Mineralogical investigations also proved that coals contained larger quantities of pyrite, thus the AP of the coal units are higher. The acid potential for No. 5 and No. 4 Upper seams both indicate that sulphides are very abundant in the seams.

However, the No. 5 seam has a negative NP as seen in Figure 5.3, thus very few neutralising constituents are present in this seam. From interpretations in Chapter 3, the seam contained only minor quantities of calcite and dolomite, and very low CaO and MgO concentrations were obtained in XRF results, which is in good agreement with it's NP. No. 4 Upper seam on the other hand contains a larger NP and will thus have a stronger buffering ability. This is also confirmed by XRF results showing CaO concentrations averaging at 2.27 wt%.

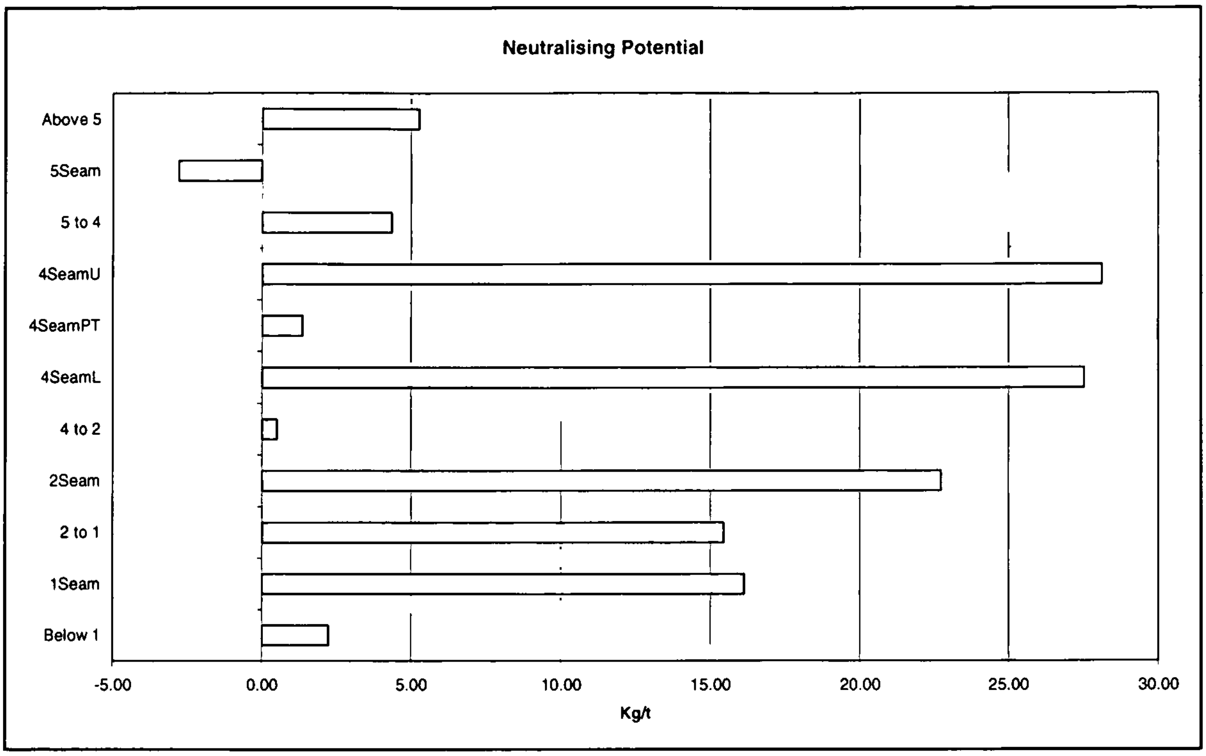


Figure 5.3 – Neutralising potential for the Witbank Coalfield

Although neutralising constituents are present in all the lithological units, Figure 5.4 clearly illustrates that the acid potential for both open and closed systems exceeds the neutralising potential by excessive quantities. Only between No. 1 and No. 2 seams would sufficient alkalinity be provided to buffer acidity. CaO and MgO concentrations are not high enough in the roof rocks of the No.1 seam and the floor rocks of No.2 seam to clarify this neutralising potential completely. The presence of feldspars and other aluminosilicates would contribute to the neutralising potential even if it occurs at a slower rate (Banwart and Malmström, 2001). However, actual acid and neutralisation release rates cannot be predicted with the technique, neither can the completeness of the reaction be assessed (Cruywagen, 2000). Thus, the pyrite reaction rate has to be very slow in order for the system to be brought back to neutral conditions by feldspars and aluminosilicates once the acidification has already occurred. Even though the neutralising potential is low, pyrite seldom occurs in this unit; therefore little neutralising potential is required.

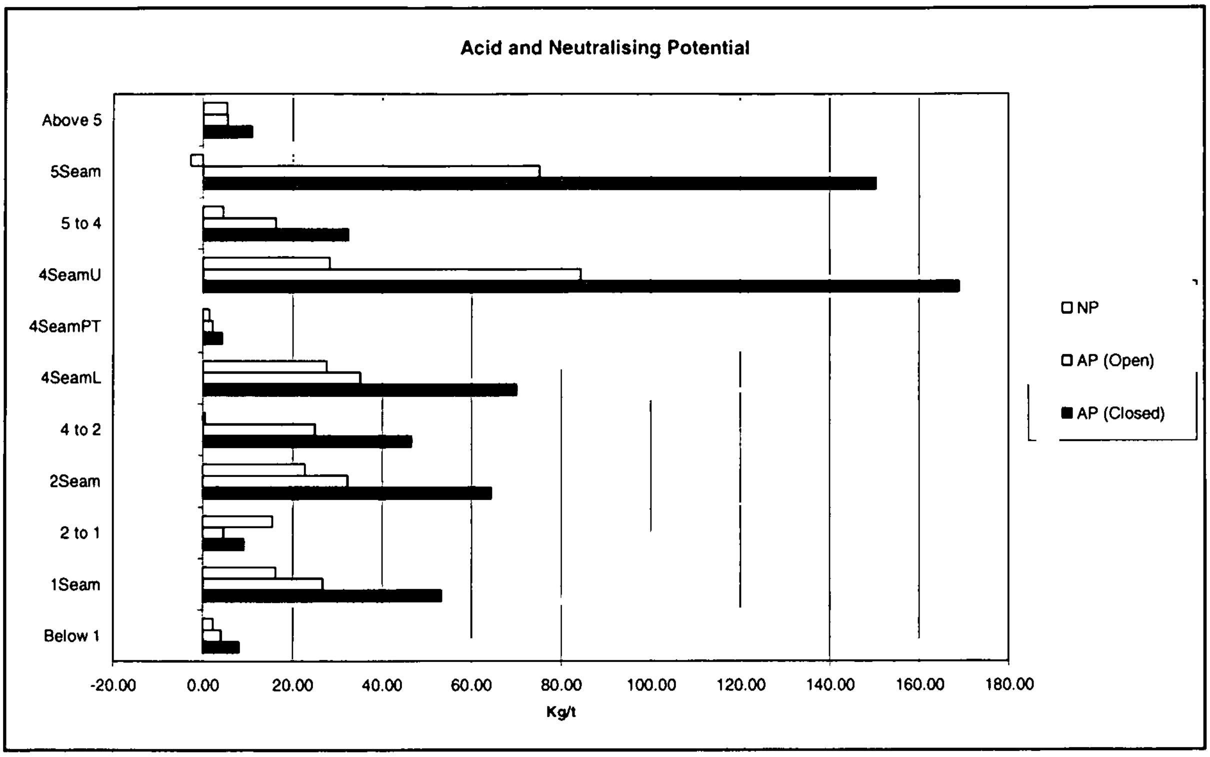


Figure 5.4 - Acid potential (for an open and closed system) and neutralising potential for the Witbank Coalfield

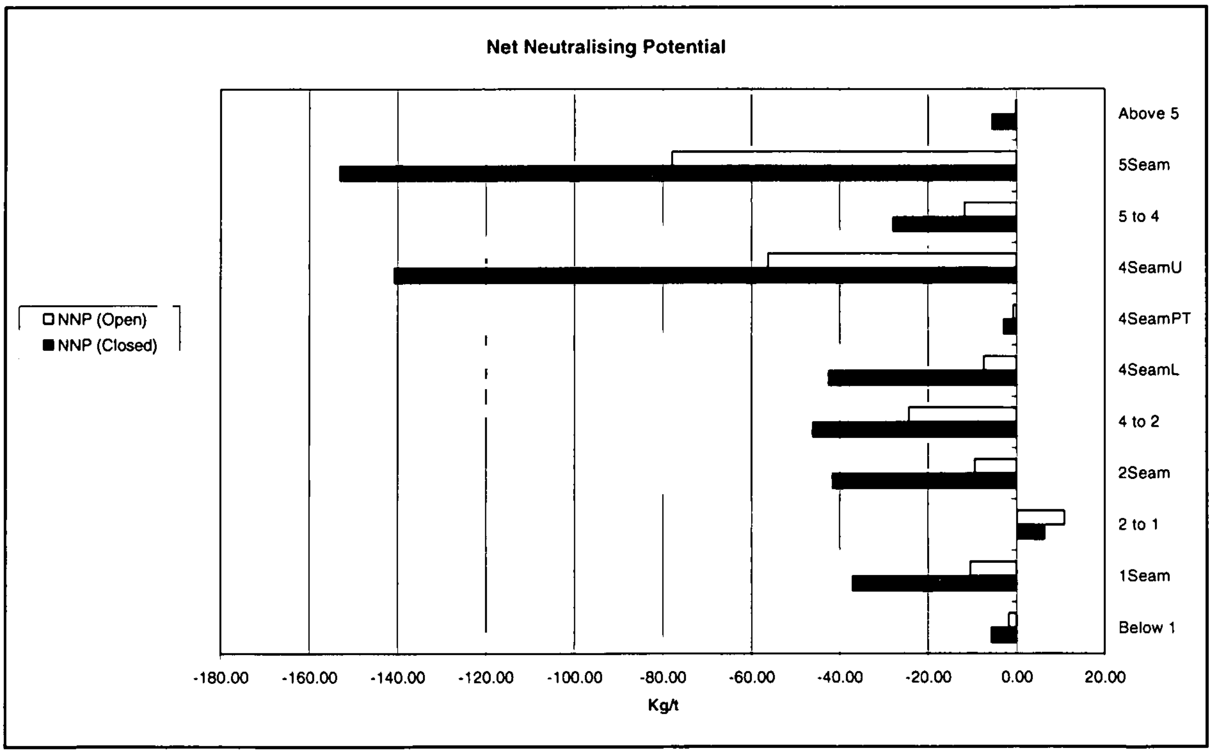


Figure 5.5 – Net neutralising potential for the Witbank Coalfield

Acid-base accounting data on these coalfields has been generated by the Institute for Groundwater Studies at the UFS and are often presented as case studies in reports such as the Water Research Commission Reports. In many cases interpretations from results predict that water quality in and surrounding the coal mines in the Witbank and Highveld coalfields will probably become acidic due to the environmental circumstances as well as rock and coal mineralogy. This investigation was a confirmation that lithological units will contribute greatly and negatively to the water quality in the area, unless remediation programs are implemented. A negative NNP is observed in Figure 5.5 for all lithological units except between the No.1 and No. 2 seams. The more negative the NNP becomes, the more $CaCO_3$ per ton of spoil will have to be added to neutralise the acidity.

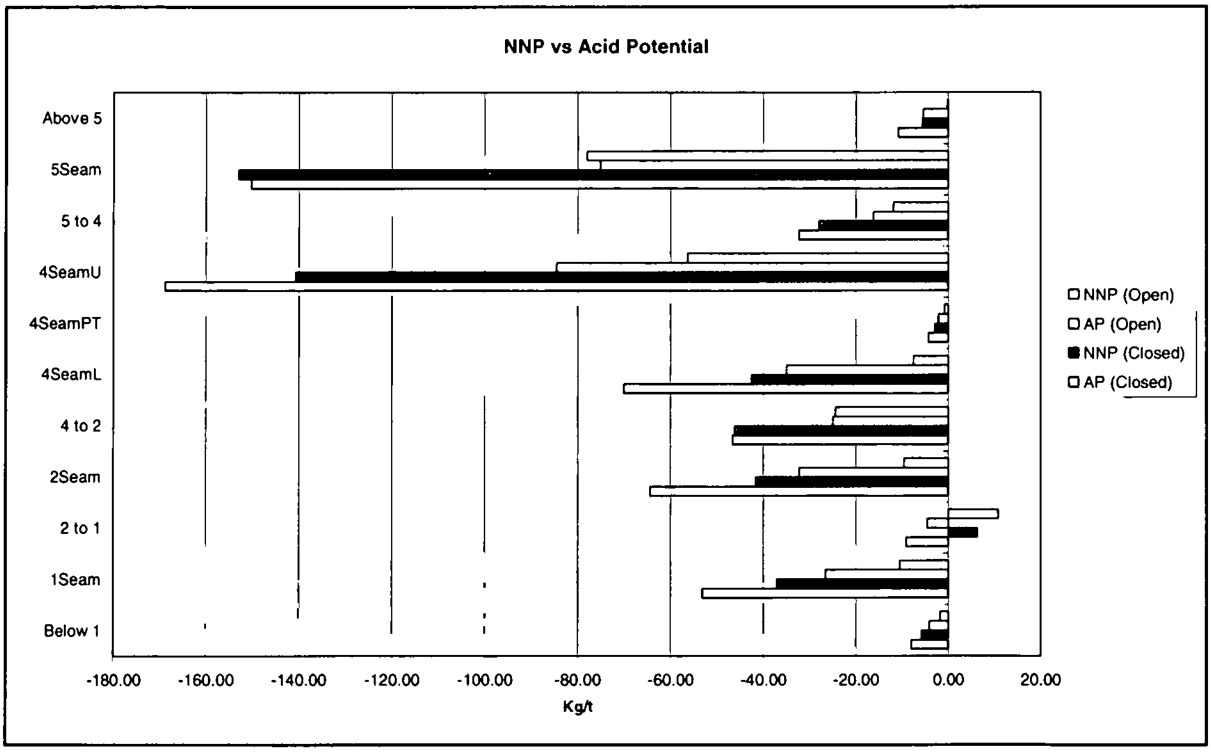


Figure 5.6 - Acid potential (for an open and closed system) and net neutralising potential (for an open and closed system) for the Witbank Coalfield

The constant decrease in the AP, NP and NNP in depth is very obvious and possibly due to a lack of circulating groundwater, therefore a lack of leaching of reactive species in the lower units. Although sulphur increased or decreased in a specific direction horizontally in a seam, no exact distribution was noted vertically for a borehole or for the dataset as a whole. Sulphur percentages were extremely variable and within ranges of 0.01 to as much as 20 wt% of a sample. A similar situation is observed for calcium. However, from the ABA results a trend in vertical distribution might exist. A multiple regression analysis performed on these samples showed that the sulphur percentage is 95% accountable for the NNP. Figure 5.6 illustrates this influence. The AP is plotted as a negative value in order for a comparison to be made. For most units the NNP is almost equivalent to or slightly less than the AP. A negative NNP indicates the inability of a sample to provide sufficient neutralising constituents to buffer the acid produced, or stated otherwise, the acid produced was present in larger quantities than the alkalinity. In this study, the negative NNP corresponds well to the AP, thus the neutralising potential was quite insufficient.

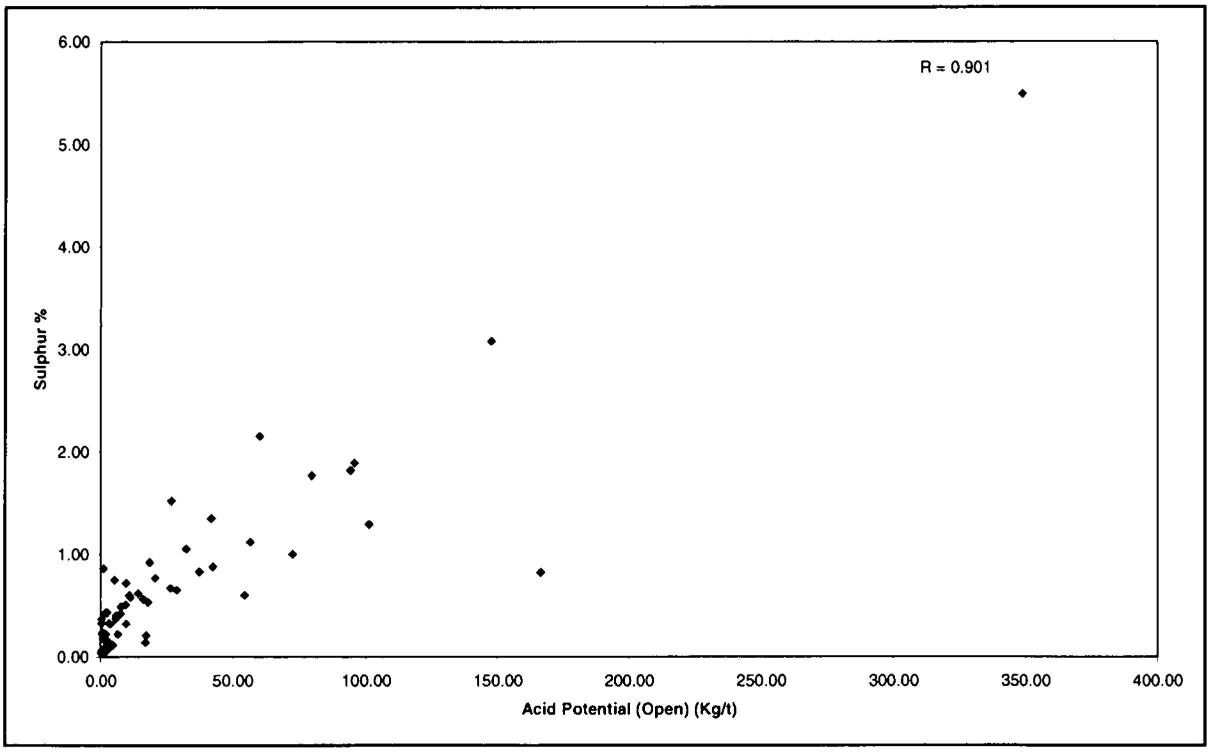


Figure 5.7 - Acid potential (for an open system) and sulphur %

Good correlations between the AP and S %, and NP and CaO % can be seen in Figures 5.7 and 5.8 respectively. The sulphur obtained from XRF analyses is in good agreement with the AP (Open) as seen in Figure 5.7 (r = 0.901). Correlations for Fe_2O_3 and AP were insignificant, possibly due to the fact that most of the Fe_2O_3 was not present as pyritic Fe_2O_3 but as $FeCO_3$ or in montmorillonite, as concluded in

Chapter 3. Neither was there any noteworthy correlation between normative pyrite and AP.

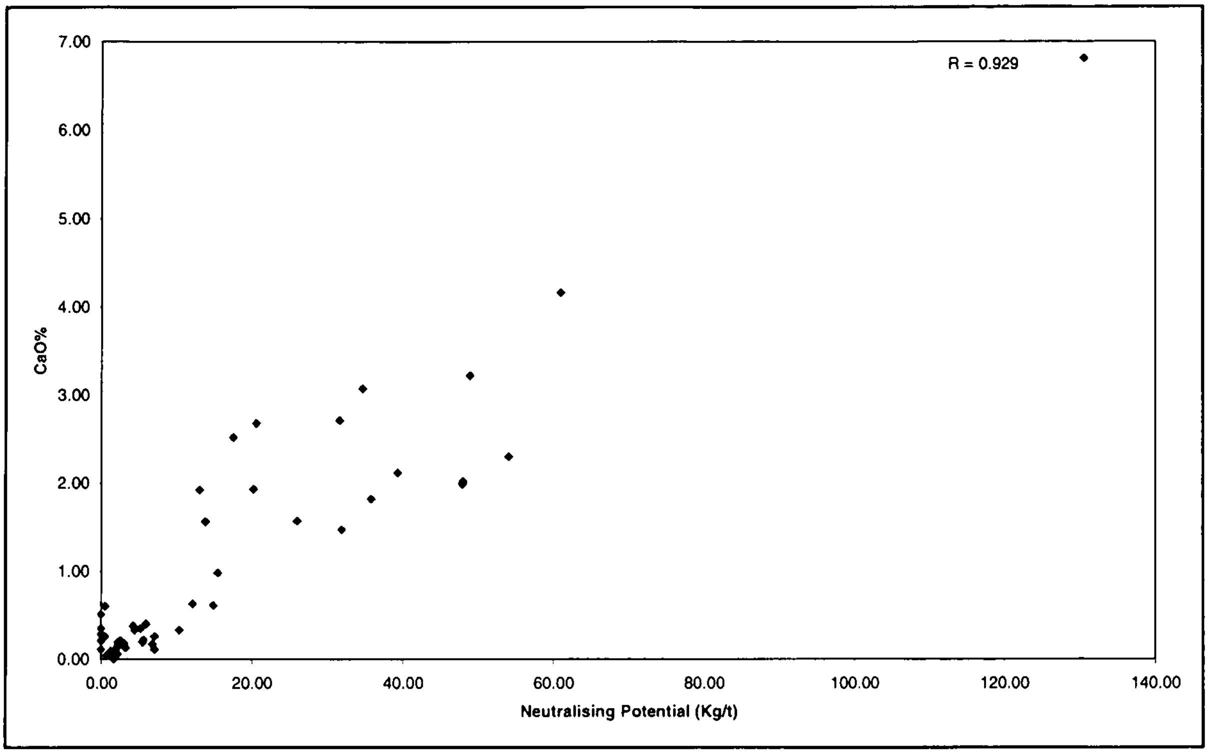


Figure 5.8 - Neutralising potential and CaO %

A significant correlation was obtained for the NP and CaO % (r = 0.929) (Figure 5.8) as well as the combined CaO and MgO % (r=0.906) and the NP. An insignificant correlation was observed between the NP and MgO% (r=0.395), and between the NP and normative calcite (r=0.634) and dolomite (r=0.612).

Table 5-1: Average NPR (NP: AP) ratio and NNP for lithological units of the Witbank Coalfield (open system)

Samples	NP:AP	NNP
Above 5	0.973	-0.15
5 Seam	-0.037	-77.97
5 to 4	0.268	-11.85
4 SeamU	0.333	-56.32
4 SeamPT	0.637	-0.78
4 SeamL	0.786	-7.50
4 to 2	0.020	-24.46
2 Seam	0.704	-9.55
2 to 1	3.355	10.84
1 Seam	0.606	-10.49
Below 1	0.553	-1.81

This could mean that the NP is more dependant on the calcite concentration than the dolomite concentration, or that calcite, and not dolomite, is the dominant reacting carbonate species available for neutralisation. According to the screening criteria proposed by Usher *et al.* (2001), averages for NPR in Table 5-1 suggest that most lithological units are potentially acid generating. The unit the No. 1 and No. 2 coal seams are considered to be inconclusive. The average NNP values in Table 5-1, however, suggest that only No. 5 coal seam, No. 4 Upper coal seam, and between No. 4 and No. 2 coal seams are potentially acid generating. The other units could become either acidic or neutral.

In a case study presented by Usher *et al.* (2001) a comparable scenario for Optimum Opencast Colliery in the Witbank Coalfield is observed. The lithological units were sampled in a similar manner to that in this study. An excess of AP over NP was present. The upper units had the lowest NP and AP. Since carbonates are more reactive than sulphides, leaching by circulating groundwater occurred in the upper units giving rise to a lower neutralisation potential. A higher NP was also observed for the unit between No. 2 and No. 4 coal seams due to the lack of carbonate leaching with depth. For a detailed explanation of the techniques applied and test conducted on this colliery the reader is referred to Usher *et al.* (2001). The case study is in agreement with the findings in this study, which includes samples from other areas of the Witbank Coalfield as well.

5.1.2 The Highveld Coalfield

Limited acid-base accounting data was available for this coalfield, yet from the data for No. 4 and No. 5 seams tabulated in Appendix 3, it seems that the same situation could be expected as in the Witbank Coalfield. The highest negative NNP values are also observed for the coal seams. Values range from approximately -156.14 to -25.66 kg/t.

Table 5-2: Average NPR (NP: AP) ratio and NNP for lithological units of the Highveld Coalfield (open system)

Samples	NP:AP	NNP
Above 5	0.004	-110.68
5 Seam	-0.012	-156.14
5 to 4	0.005	-32.29
4 Seam	0.244	-38.31
Below 4	0.006	-25.66

The average NPR ratios and NNP as seen in Table 5-2 suggest that these samples have potential to generate acid.

By observations made from this data significant predictions can be made as to the influence mineralogy might have on the surrounding groundwater. The potential for these lithological units to contribute to the deterioration of groundwater is definitely evident. This method is, however, based on ideal situations where it is assumed that complete oxidation of sulphides and dissolution of carbonates will occur. The presence of these constituents does not necessarily guarantee their availability, which is often dependant on the minerals in which certain elements are contained, as well as geochemical factors such as pH, Eh and temperature. Secondly, the method does not take rates of weathering and oxidation into account. Thus, the prediction is more relevant when ideal conditions exist.

The sulphur analysed represents total S. This would include the sulphide-S, sulphate-S and organic-S. The only sulphide detected by XRD interpretations during this study was pyrite. No sulphate phases were present in these interpretations, and it was not possible to determine the organic sulphur content with XRF techniques. The S concentration therefore accounts for the sulphide-S and the organic-S. In theory it is possible to calculate the AP from the analysed S by multiplying the S value by 31.25 from the calculations explained in section 5.1. Assuming that all sulphide-S is available for oxidation, then the total S analysed could be used to predict the AP for samples on which no acid-base determinations has been carried out. The correlation between the XRF S and the AP confirms that there is a good relationship between these components for the sample set as a whole.

Regarding the NP, the CaO analysed includes Ca from all Ca-bearing phases such as montmorillonite, dolomite, fluorapatite, crandallite, and the major Ca-phase, calcite. The excellent correlation between the NP and CaO, and between the NP and combined CaO and MgO, confirms that these chemical components are largely responsible for NP values. It is then also possible to predict the NP by using the CaO and MgO concentrations for samples for which no AP or NP data is available. The mineralogy therefore provides an alternative for determining acid and base potentials in the event that no ABA tests are available, and could be used to verify the accuracy of ABA analyses.

The application of ABA in this study offered a major contribution to understanding the complexities governing water-rock interactions. The time involved in such interactions often amounts to decades and even centuries. Nonetheless, interpretation of ABA data not only provides a preview of situations that might arise regarding groundwater quality in a certain area, but also offers ample time to decide on appropriate prevention or remediation programs.

CHAPTER 6

DISCUSSIONS AND CONCLUSIONS

XRF and XRD analyses were conducted on various coal and sediment samples from the Witbank and Highveld Coalfields with the aim to improve our understanding of the mineralogy and geochemistry of these coals and coal-bearing units. Samples were collected from the No. 1, No. 2, No. 4 and No. 5 coal seams, as well as their roof and floor lithologies.

Different preparation and analytical procedures were applied to determine the differences that exist between the available methods. Low-temperature ashing and X-ray diffraction carried out on some samples by the University of New South Wales accentuated the need and practicality of integrating other techniques with XRD. X-ray diffraction on LTA coals proved to be accurate in identifying minerals that occur as rare constituents, especially since the organic material in coal tends to obscure interpretations from raw coal XRD, but artefacts were also produced during the process.

There are numerous variables influencing the results from XRF analyses on coals. Differences were observed between whole coal and fusion disk XRF results. The calcination and fusion of coal samples introduce some difficulties concerning the loss of important constituents in coal, such as sulphur and possibly phosphorus.

Thick powder briquettes were prepared (Appendix 1) to prevent X-rays from passing through the coal briquettes. Mass absorption is accounted for in fusion disks by the addition of La_2O_3 during preparation (Spectroflux 105) and by matrix corrections. The high temperature determination of the LOI can lead to the loss of inorganic constituents resulting in errors.

The differences between whole coal results of mixed proportions of two samples are attributed to variations in sampling and mixing. The possibility of segregation of heavy minerals in samples during mixing and storage has also been considered, and was contained by careful sample handling and thorough mixing. The standard XRF preparation technique is recognised as precise and reliable, but in this case whole coal analysis was deemed more suitable.

During XRD interpretations the mineral components in coal were expressed as a percentage of the inorganic constituents. The inorganic fraction consisted primarily of dominant quartz and kaolinite, and sometimes even dominant pyrite, calcite and dolomite. The latter three were almost ubiquitous in the coals. The Ca-phosphate mineral, crandallite was detected in the western region of the Witbank and Highveld Coalfields (Chapter 3). Although only present in low concentrations, fluorapatite was detected throughout in the Witbank coals except in the extreme northeastern region. This mineral was not present in the Highveld coals.

Chemical analyses confirmed the mineralogical interpretations. The inorganic components make up approximately 8.00 to 35.00 wt% of a coal sample. SiO_2 concentrations varied between 0.00 and 35.00 wt% of a sample, Al_2O_3 between 0.50 and 16.00 wt%, Fe_2O_3 between 0.03 and 10.00 wt%, and S between 0.15 and 8.00 wt%. Samples that contained quartz as a dominant mineral in XRD patterns corresponded well with the SiO_2 concentrations in the chemical analyses. Al_2O_3 was represented mainly by kaolinite, and sometimes traces of montmorillonite and illite. Since siderite was not common in the XRD patterns of coal samples, pyrite accounted for Fe_2O_3 and S concentrations in the chemical analyses. Yet, an access of Fe_2O_3 over S was present suggesting that minor to accessory phases containing Fe_2O_3 (such as montmorillonite, siderite, hematite and goethite) might not have been detected in the XRD interpretations.

Minor concentrations of CaO (0.00 to 8.00 wt%) and MgO (0.00 to 1.00 wt%) were present. CaO was mainly accounted for by calcite and dolomite, while the presence of major dolomite concentrations in XRD interpretations explained elevated MgO values in the chemical analyses. P_2O_5, which occurred in concentrations of 0.00 to 3.50 wt%, was highest in samples containing fluorapatite and crandallite as major to minor phases. K_2O was in the order of 0.00 to 1.30 wt%, and only elevated in samples containing minor illite and feldspar concentrations. Similarly, Na_2O values were the lowest varying between 0.00 and 0.45 wt%. The only difference in chemistry between Witbank and Highveld coals was a slight increase in Na_2O (0.00 to 0.51 wt%) in the Highveld coals.

The distribution of element oxides is best observed across the No. 2 coal seam since a sufficient database was available for noting trends. As seen in Chapter 3, particular trends exist in the mineralogical distribution as well as in the oxide distribution. An integration of mineralogical interpretations and chemical analyses confirms that SiO_2, TiO_2, Al_2O_3, Na_2O and K_2O concentrations are elevated in the northeastern corner of the Witbank Coalfield, and decreases in a south-westerly direction. This corresponds with the mineralogy since samples containing dominant quartz and kaolinite are also found in the northeastern region. As mentioned in Chapter 2, these minerals could be of detrital or authigenic origin. Quartz could be provided by the influx of material from sources to the north of the coalfields, while kaolinite could have been formed due to the alteration of feldspars, or supplied as detrital material.

S decreases towards the eastern parts of the coalfield, while Fe_2O_3 is highest in the northern region. Similar to the S distribution, pyrite also is highest in the west suggesting that the Fe_2O_3 concentration is dominated by other Fe-bearing phases. CaO, MgO and P_2O_5 show similar distribution to that of S. Although such trends were not clearly discernible in other seams due to insufficient data, a comparable distribution could exist.

The coal-bearing units of the Vryheid Formation consists of sandstones, siltstones and carbonaceous shales, and in some areas, mudstones are present. There are some slight yet noteworthy variations in chemical composition of the rock types throughout the stratigraphic units.

From the XRD interpretations in Chapter 3 it was concluded that the mineralogy of the sedimentary rocks consisted of quartz and kaolinite as dominant minerals, illite and siderite as minor constituents, and calcite, dolomite and pyrite as major to accessory components. Sandstone samples display a dominating silicate chemistry combined with considerable elevations in Al_2O_3 ranging from 1.00 to 20.00 wt% of a sample. As with the coals, quartz accounted for most SiO_2 in chemical analyses, while high Al_2O_3 was represented by abundant kaolinite and illite in the XRD patterns. As expected, Al_2O_3 concentrations were higher in siltstones (10.00 to 25.00 wt%) and the highest in the shales averaging at 20.00 wt%, along with a decrease in SiO_2. Fe_2O_3 (0.50 to >4.00 wt%) and S (0.05 to >2.00 wt%) concentrations were higher in siltstone samples; however, these elements were elevated in sandstones in some instances. Correspondingly, pyrite was abundant in siltstones. Siderite confirmed major Fe_2O_3 concentrations in sandstones samples. CaO and MgO where only elevated in rock samples containing reasonable amounts of calcite and dolomite. Higher K_2O and Na_2O concentrations especially in the sandstones were evident in both coalfields and were supported by the presence of feldspars and clays such as illite in XRD interpretations.

The normative program used to calculate the mineralogy from the chemical analyses was used to compare the XRD interpretations as discussed in Chapter 3. Good correlations exist between the normative mineralogy and the chemical composition for minerals such as pyrite and S% (r=0.885), calcite and CaO% (r=0.812), kaolinite and Al_2O_3% (r=0.869), and apatite and P_2O_5% (r=0.919). It is concluded that an integration of such a program with XRF analysis and XRD interpretation methods could improve the accuracy and confidence with which results are produced.

Acid-base accounting was applied in this investigation in the prediction water quality and the implementation of proper remediation programs.

Based on the discussions in Chapter 5, ABA results for these samples show that the lithological units in the coalfields possess the ability to contribute to deterioration in ground and surface water quality in the surrounding area. The mineralogy of the coal seams and the rock units contributes to this potential to produce acid mine drainage conditions. Although it might take as much as centuries, it can be concluded that all coal seams and rock units will produce acidity and alkalinity simultaneously. Two types of screening criteria was used to determine whether acid or alkaline conditions will prevail once all acid consuming and acid producing minerals has been oxidised. From the NNP, or net neutralising potential, it can be predicted that the No. 5 coal seam, the No. 4 coal seam and the unit between No. 2

and No. 4 coal seams will be predominantly acidic. The NNP of the other units vary between -20 kg/t and 20 kg/t, therefore these stratigraphic units could become either acidic or alkaline. The unit between No. 1 and No. 2 coal seams is the only unit possessing enough neutralising potential to buffer the acid produced, but could still become acid since the NNP is less than 20 kg/t.

The NPR or NP: AP ratios, for all stratigraphic units (except between No. 1 and No. 2 coal seams) are less than 1:1 suggesting that acid conditions will dominate. The NPR ratio between No. 1 and No. 2 coal seams is at least 3:1 implying that enough buffering capacity is available to counteract the acid. The AP and NP are largely dependant on the presence of pyrite and calcite, respectively. Good correlations were obtained between the NP and CaO% (r=0.929) and the AP and S% (r=0.901); therefore it is possible to use the mineralogy to predict these factors. It should also be remembered that these predictions do not take time and weathering rates into consideration, thus such conditions will only be obtained once ideal situations are reached, as discussed in Chapter 5.

The distribution of minerals and abundance of reacting mineral species in the coalfields can also be used to predict acidification and neutralisation in a certain area. Since pyrite is highest in the western part of the coalfield, it could be expected that acid conditions are more likely to occur in this region. The availability of carbonates will provide buffering capacity, but, from Chapter 5 it is evident that insufficient carbonates are available for long term neutralisation. Clay minerals and other aluminosilicates are abundant in the northern region where less acid producing species available. These minerals, together with the carbonates, might have a greater influence on the neutralising potential in the northeastern region, since less acid producing species are available here.

The occurrence and modal distribution of mineral phases is illustrated in Chapter 3, although the mining areas included in the study were not adequate enough to obtain a representative amount of samples to justify the magnitude of the region. An extensive collection was obtained for the No. 2 coal seam as well as for the No. 4 coal seam.

Compiling regional maps showing the distribution or trends in mineralogy and an overall interpretive map in terms of acid generating potential based solely on mineralogy, was also included as one of the project objectives. This mineralogical distribution is very well illustrated for the No. 2 coal seam and clear trends are observed.

Acid-base accounting data generated from this study will assist in terms of making plausible predictions concerning the potential of the coal and rocks in the Witbank and Highveld Coalfields to contribute to acid mine drainage. This investigation has led to a better understanding of the coals and their roof and floor lithologies in the study area, and the use of this information in future applications will be a benefit, especially to the mining industry.

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APPENDIX 1

ANALYTICAL METHODS USED FOR ROCK AND COAL SAMPLES

A1.1 X-ray fluorescence Spectrometry (XRF)

A1.1.1 Sample preparation

Underground channel samples and sections from borehole core were cleaned and crushed to approximately 10mm chip size using a jaw crusher, after which 200g of the fraction was milled in a Siebtechnik carbon-steel swing mill to produce powdered rock samples of approximately 50µm particle size.

For the preparation of fusion disks for major element analyses 2g of each powdered rock sample was oven-dried at 110°C for 24 hours. After being left to cool in a dessicator the sample was weighed to determine the water content. The crucibles were then placed in a furnace at 980°C for 4 hours, and then left to cool before measuring the mass loss in order to determine the loss on ignition (LOI) of each sample.

Powder briquettes of rock samples were prepared for trace element analyses. Approximately 10g of the powdered material was mixed with six drops of Moviol which serves as a binding agent. Boric acid was used to form a protective casing, and samples were pressed at 15 tons pressure on a steel dye to form 32mm diameter briquettes.

Powder briquettes of the pulverised coal samples were prepared by combining 32g of the powder with 8g of Hoechst Wax C and mixed in a Turbula mixer for 30 minutes. The mixture was then pressed at 15 tons pressure into 40mm diameter cylindrical briquettes which were used for both major and trace element analysis of coal samples.

A1.1.2 Technique

X-ray fluorescence uses the characterisation of X-ray spectral information to determine the elemental composition of solid samples. Primary excitation of X-rays takes place in the X-ray tube. The bombardment of atoms by primary X-rays leads to the ejection of an electron in the inner shell of the atom. The removal of this electron results in the excitation of secondary X-rays and these are detected and analysed. Atoms of an element produce a characteristic set of X-ray spectral lines for the elements in the portion of the sample undergoing excitation due to the unique electron configuration of each element. Each spectral line of an element has a unique wavelength. Wavelength dispersive XRF uses the rotation through a measured angle (2θ) of a crystal of a known interplanar spacing (d) to separate the X-ray energy of different wavelengths (λ) from the sample, in accordance to Bragg equation:

$$n\lambda = 2d \, Sin \, \theta$$

where n is an integer denoting the spectral order. As the analysing crystal is rotated a detector measures the intensity of the radiation at each wavelength. The intensity is plotted against the wavelength to produce a spectrum of peaks from which the elements in the sample are determined (Azzie, 2002).

A1.1.2.1 Coal analysis

a. Calibration standards

Three South African Reference materials were used for calibration purposes to ensure the accuracy of the analyses. The major element and trace element concentrations are given in the tables below as weight % oxide and ppm respectively.

Table A1-1: Major and trace element concentrations of reference materials used for coal analyses

Element	SARM18	SARM19	SARM20
SiO_2	6.200	15.00	17.66
TiO_2	0.114	0.341	0.630
Al_2O_3	2.570	8.010	11.27
Fe_2O_3	0.290	1.750	1.170
MgO	0.110	0.200	0.430
CaO	0.180	1.390	1.870
Na_2O	0.013	0.290	0.270
K_2O	0.145	0.240	0.140
P_2O_5	0.003	0.013	0.140
S	0.560	1.490	0.510
Nb	6	10	16
Zr	67	351	180
Y	12	20	29
Sr	44	126	330
Rb	8.1	9	10
Zn	5.5	12	17
Cu	5.9	13	18
Ni	10.8	16	25
Mn	22	157	80
Cr	16	50	67
V	23	35	47
Ba	78	304	372
Sc	4.3	7.6	10

b. Major elements

The major element concentrations determined for coal samples which included Si, Ti, Al, Fe, S, Mg, Ca, Na, K and P, were determined using the coal powder briquettes. Analyses were carried out on a Philips PW 1404 wavelength dispersive X-ray fluorescence spectrometer with a Rh X-ray tube at 50kV and 50mA.

Table A1-2: Analytical conditions for determining major element concentrations for coal analyses

Element/Line	Collimator	Crystal	Detector	LWL	UPL	Counting time (s)
SiKα	C	PET	FL	26	80	100
TiKα	F	LIF(220)	FL	32	68	100
AlKα	C	PET	FL	26	80	100
FeKα	F	LIF(220)	FL	16	68	100
SKα	C	GE	FL	32	74	100
MgKα	F	PX-1	FL	36	68	100
CaK	F	LIF(220)	FL	30	76	50
NaKα	F	PX-1	FL	30	78	100
KKα	F	LIF(200)	FL	32	74	100
PKα	C	GE	FL	34	74	100

Intensities were collected using the Philips X40 software and corrections were made for background, spectral overlap and matrix corrections.

c. Trace elements

Trace element concentrations were determined using the 40mm diameter powder briquettes and analytical conditions are provided in the table A1-3. Intensities for some elements were corrected for mass absorption effects using the RhKα Compton peak. All analyses were conducted under vacuum using a Rh X-ray tube.

Table A1-3: Analytical conditions for determining trace element concentrations for coal analyses

Element/ Line	Coll.	Crystal	Detector	LWL	UPL	Counting time(s)	Background postion(s)	kV	mA
RhKα	F	LIF(220)	SC	34	75	200		80	35
NbKα	F	LIF(200)	SC	30	74	200		80	35
ZrKα	F	LIF(200)	SC	30	74	200		80	35
YKα	F	LIF(200)	SC	30	74	200	-0.86; +0.74	80	35
SrKα	F	LIF(200)	SC	30	74	200	+0.78	80	35
RbKα	F	LIF(200)	SC	30	74	200	+0.60	80	35
ZnKα	F	LIF(220)	FS	20	80	200	-1.08; +4.24	60	45
CuKα	F	LIF(220)	FS	20	80	200	+4.44	60	45
NiKα	F	LIF(220)	FS	20	80	200	+2.52	60	45
MnK	F	LIF(220)	FL	15	75	200	+1.00	50	55
CrKα	F	LIF(220)	FL	15	75	200	-4.10; +2.90	50	55
VKα	F	LIF(200)	FL	13	67	200	+3.40	50	55
BaLα	F	LIF(200)	FL	25	75	200	-5.20	50	55
ScKα	F	LIF(200)	FL	25	75	200	-2.78	50	55

A1.1.2.2 Rock analysis

a. Calibration standards

Various certified international rock standards (USGS, CCRMP, CRPG, ANRT, GIT-IWG, GSJ and MINTEK) were used for calibration purposes to ensure accurate analyses.

b. Major elements

Major element concentrations for rock samples were determined for Si, Ti, Al, Fe, S, Mn, Mg, Ca, Na, K and P using the fusion disks prepared according to the Norrish and Hutton (1969) technique on a Philips PW 1404 wavelength dispersive X-ray fluorescence spectrometer with a Rh X-ray tube at 50kV and 50mA for all elements, except at 40kV and 75mA for Na.

Table A1-4: Analytical conditions for determining major element concentrations for rock analyses

Element/Line	Collimator	Crystal	Detector	LWL	UPL	Counting time (s)
SiKα	F	PET	FL	35	75	60
TiKα	F	LIF(200)	FL	35	68	10
AlKα	C	PET	FL	30	70	60
FeKα	F	LIF(220)	FS	30	70	30
SKα	C	GE	FL	32	74	100
MnKα	F	LIF(220)	FS	35	70	80
MgKα	C	PX-1	FL	30	75	100
CaK	F	LIF(200)	FL	35	70	10
NaKα	C	PX-1	FL	30	78	140
KKα	F	LIF(200)	FL	35	70	20
PKα	C	GE	FL	30	72	60

Intensities were collected using Philips X40 software and corrections were made for background, spectral overlap as well as matrix corrections.

c. Trace elements

Trace element concentrations for rock samples were determined using 32mm diameter powder briquettes. Intensities for some elements were corrected for mass absorption effects using the RhKα Compton peak. All analyses were conducted under vacuum using a Rh X-ray tube. Analytical conditions are provided in table A1-5.

Table A1-5: Analytical conditions for determining trace element concentrations for rock analyses

lement/Line	Coll.	Crystal	Detector	LWL	UPL	Coun-ting time(s)	Background postion(s)	kV	mA
RhKα	F	LIF(200)	FS	30	75	30		50	55
NbKα	F	LIF(200)	SC	25	75	80		60	40
ZrKα	F	LIF(200)	SC	30	75	80		60	40
YKα	F	LIF(200)	SC	30	75	80		60	40
SrKα	F	LIF(200)	SC	30	70	80		60	40
RbKα	F	LIF(200)	SC	30	75	80	-0.02	60	40
ZnKα	F	LIF(200)	FS	35	65	80	+1.00	60	40
CuKα	F	LIF(200)	FS	25	70	80	+1.50	60	40
NiKα	F	LIF(200)	FS	35	65	80	-0.70; +1.00	60	40
CoKα	F	LIF(220)	FS	15	80	80		60	40
CrKα	F	LIF(220)	FS	15	70	80	-4.10; +2.90	60	40
VKα	F	LIF(220)	FS	15	70	80	-2.70	60	40
BaLα	F	LIF(200)	FL	25	75	80	-5.10	50	55
ScKα	F	LIF(200)	FS	25	75	80	-2.72	60	40

A1.2 X-ray Diffraction analysis (XRD)

A1.2.1 Sample preparation

The crushed material for each rock and coal sample obtained from the Siebtechnik carbon-steel swing mill was used for X-ray diffraction analysis. Approximately 3g was placed in a flat square holder with a cylindrical mould and pressed lightly with a clean glass slide to produce a flat analytical surface. The sample holder was then slipped into the instrument holder. All analyses where carried out with a Siemens D5000 Diffraktometer with a CuKα radiation at 30kV and 40mA. Diffraction scans of the X-ray intensity pattern against 2θ angle were viewed and interpreted using DIFFRAC-AT V.3.0 software together with the JCPDS Mineral Powder Diffraction File Data Book (1980a) and JCPDS Mineral Powder Diffraction File Search Manual (1980b).

A1.2.2 Technique

X-ray diffraction from crystalline solids occurs as a result of the interaction of X-rays with the electron charge distribution in the crystal lattice. The ordered nature of the electron charge distribution, whereby most of the electrons are distributed around atomic nuclei which are regularly arranged, means that superposition of the scattered X-ray amplitudes will give rise to regions of constructive and destructive interference. Since the λ is known, the crystal plane spacing (d) can be calculated for those angles (θ) where the reflection intensity maxima are encountered. A goniometer is used to rotate the sample through a measured angle (2θ) in the path of the incident X-ray beam and the reflected X-ray beam intensity for each angle is measured by a proportional counter. Using a powdered sample, a great number of particles are arranged in random orientation, ensuring that each crystallographic plane would lie parallel to the surface in a fair number of grains.

The diffraction peaks are individually considered to be the result of diffraction of the incident X-ray beam of wavelength λ from crystal lattice planes, having Miller indices hkl and spacing d_{hkl}. Plotting the measured intensity against the 2θ angle (or corresponding crystal d-spacing) produces a diffractogram from which the minerals in the sample can be characterised. (Wainerdi *et al.,* 1971).

APPENDIX 2

ANALYTICAL RESULTS

The following tables contains all analytical data concerning sample localities, XRF results, XRD interpretation and some plotted scans, as well as normative calculation results. Mn is analysed as a trace element for all coal samples.

Table A2-1: Coordinates for samples collected at Arnot Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
ARA1	-2864883.98	77952.94	1622.86	BASE	Basement
ARA2	-2864883.98	77952.94	1626.53	SLT	Siltstone
ARA3	-2864883.98	77952.94	1628.51	1F	Sandstone
ARA4	-2864883.98	77952.94	1629.20	1IF	Siltstone
ARA5	-2864883.98	77952.94	1629.50	1	Coal
ARA6	-2864883.98	77952.94	1630.15	1R	Sandstone
ARA7	-2864883.98	77952.94	1630.28	GRIT	Sandstone
ARA8	-2864883.98	77952.94	1630.62	2F	Siltstone
ARA9	-2864883.98	77952.94	1632.42	2	Coal
ARA10	-2864883.98	77952.94	1633.92	2	Coal
ARA11	-2864883.98	77952.94	1635.76	2R	Sandstone
ARA12	-2864883.98	77952.94	1662.64	4F	Siltstone
ARA13	-2864883.98	77952.94	1663.05	4L	Coal
ARA14	-2864883.98	77952.94	1663.24	4PT	Sandstone
ARA15	-2864883.98	77952.94	1663.26	4U	Coal
ARA16	-2864883.98	77952.94	1663.87	4R	Sandstone
ARB1	-2864947.98	77967.96	1630.91	1F	Siltstone
ARB2	-2864947.98	77967.96	1631.44	1	Coal
ARB3	-2864947.98	77967.96	1631.85	1R	Siltstone
ARB4	-2864947.98	77967.96	1632.45	2F	Siltstone
ARB5	-2864947.98	77967.96	1633.07	2L	Coal
ARB6	-2864947.98	77967.96	1634.54	2PT	Sandstone
ARB7	-2864947.98	77967.96	1637.13	2U	Coal
ARB8	-2864947.98	77967.96	1637.29	2R	Sandstone
ARB9	-2864947.98	77967.96	1662.61	4F	Siltstone
ARB10	-2864947.98	77967.96	1663.18	4L	Coal
ARB11	-2864947.98	77967.96	1663.35	4PT	Sandstone
ARB13	-2864947.98	77967.96	1664.04	4R	Sandstone
ARC1	-2866327.09	77573.22	1624.48	1F	Carb-shale
ARC2	-2866327.09	77573.22	1624.59	1	Coal
ARC3	-2866327.09	77573.22	1625.37	1R	Sandstone
ARC4	-2866327.09	77573.22	1626.88	2F	Siltstone
ARC5	-2866327.09	77573.22	1627.21	2	Coal
ARC6	-2866327.09	77573.22	1628.04	2	Coal
ARC7	-2866327.09	77573.22	1630.20	2R	Sandstone
ARD1	-2866352.86	77469.63	1624.08	1F	Siltstone

ARD2	-2866352.86	77469.63	1624.39	1	Coal
ARD3	-2866352.86	77469.63	1624.82	1R	Sandstone
ARD4	-2866352.86	77469.63	1625.74	2F	Siltstone
ARD5	-2866352.86	77469.63	1626.15	2	Coal
ARD6	-2866352.86	77469.63	1628.46	2	Coal
ARD7	-2866352.86	77469.63	1629.31	2R	Sandstone

Table A2-2: Coordinates for samples collected at Arnot-North Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
3936	-2857270.17	73329.04	1644.50	Clay	Clay
3937	-2857270.17	73329.04	1641.50	2LR	Shale
3938	-2857270.17	73329.04	1638.50	2L	Coal
3939	-2857270.17	73329.04	1629.50	2LF	Carb-shale
3940	-2857270.17	73329.04	1627.50	SST	Sandstone
3941	-2857270.17	73329.04	1621.50	SST	Sandstone
3942	-2856746.44	72331.99	1646.00	SH	Shale
3943	-2856746.44	72331.99	1640.00	SH	Carb-shale
3944	-2856746.44	72331.99	1637.00	2R	Carb-siltstone
3945	-2856746.44	72331.99	1631.00	2L	Coal
3946	-2856746.44	72331.99	1628.00	2F	Carb-siltstone
3947	-2856746.44	72331.99	1625.00	SST	Sandstone
3948	-2855373.57	72709.39	1648.50	SH	Shale
3949	-2855373.57	72709.39	1646.50	SH	Shale
3950	-2855373.57	72709.39	1645.50	2R	Carb-shale
3951	-2855373.57	72709.39	1643.50	2L	Coal
3952	-2855373.57	72709.39	1638.50	2F	Sandstone
3953	-2855373.57	72709.39	1627.50	SST	Sandstone
3954	-2854105.73	74421.50	1653.50	2R	Carb-shale
3955	-2854105.73	74421.50	1651.50	2L	Coal
3956	-2854105.73	74421.50	1649.50	2F	Sandstone
3957	-2854105.73	74421.50	1647.50	1U	Coal
3958	-2854105.73	74421.50	1645.50	1F	Sandstone
3959	-2854105.73	74421.50	1644.50	SLT	Carb-siltstone

Table A2-3: Coordinates for samples collected at Bank Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
BAN1	-2878644.35	45214.91	1522.84	2L	Coal
BAN2	-2878644.35	45214.91	1523.84	2M	Coal
BAN3	-2878644.35	45214.91	1524.84	2U	Coal
BAN4	-2879297.47	45462.95	1537.45	2L	Coal
BAN5	-2879297.47	45462.95	1538.45	2M	Coal
BAN6	-2879297.47	45462.95	1539.45	2U	Coal
BAN7	-2879454.29	46319.89	1552.53	2L	Coal
BAN8	-2879454.29	46319.89	1553.53	2M	Coal
BAN9	-2879454.29	46319.89	1554.53	2U	Coal
BAN10	-2879454.29	46319.89	1555.03	2R	Shale
BAN11	-2878162.08	50813.27	1607.58	5F	Siltstone
BAN12	-2878162.08	50813.27	1608.02	5L	Coal
BAN13	-2878162.08	50813.27	1608.58	5U	Coal

BAN14	-2878162.08	50813.27	1609.05	5R	Shale
BAN15	-2879073.68	49481.60	1603.03	5F	Siltstone
BAN16	-2879073.68	49481.60	1603.58	5L	Coal
BAN17	-2879073.68	49481.60	1604.02	5U	Coal
BAN18	-2879073.68	49481.60	1604.58	5R	Shale
BAN19	-2872869.08	50547.11	1562.23	2L	Coal
BAN20	-2872869.08	50547.11	1563.23	2M	Coal
BAN21	-2872869.08	50547.11	1564.23	2U	Coal

Table A2-4: Coordinates for samples collected at Bankfontein Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
BK1	-2880508.00	920.00	1536.00	2	Coal
BK2	-2880555.00	913.00	1535.57	2	Coal
BK3	-2880551.00	877.00	1536.25	2	Coal

Table A2-5: Coordinates for samples collected from Borehole 1

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
BH1-1	-2947146.93	15989.31	1525.88	5H	Coal
BH1-2	-2947146.93	15989.31	1525.66	5M	Coal
BH1-3	-2947146.93	15989.31	1481.96	GRT	Sandstone
BH1-4	-2947146.93	15989.31	1480.09	4L	Coal
BH1-5	-2947146.93	15989.31	1479.09	4L	Coal
BH1-6	-2947146.93	15989.31	1478.55	4L	Coal
BH1-7	-2947146.93	15989.31	1478.01	SST	Siltstone

Table A2-6: Coordinates for samples collected from Borehole wedge 1

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
BHW1-1	-2950042.50	23166.14	1468.31	SST	Sandstone
BHW1-2	-2950042.50	23166.14	1465.22	SST	Sandstone
BHW1-3	-2950042.50	23166.14	1464.83	SST	Sandstone
BHW1-4	-2950042.50	23166.14	1463.99	SST	Siltstone
BHW1-5	-2950042.50	23166.14	1463.63	4R	Siltstone
BHW1-6	-2950042.50	23166.14	1463.52	4	Coal
BHW1-7	-2950042.50	23166.14	1462.63	4	Coal
BHW1-8	-2950042.50	23166.14	1461.96	4	Coal
BHW1-9	-2950042.50	23166.14	1460.39	4	Coal
BHW1-10	-2950042.50	23166.14	1459.93	4F	Siltstone
BHW1-11	-2950042.50	23166.14	1458.44	SST	Sandstone
BHW1-12	-2950042.50	23166.14	1457.25	SST	Sandstone

Table A2-7: Coordinates for samples collected from Borehole wedge 2

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
BHW2-1	-2954192.99	17751.51	1458.76	4HR	Sandstone
BHW2-2	-2954192.99	17751.51	1458.44	4H	Coal
BHW2-3	-2954192.99	17751.51	1458.25	4H	Coal
BHW2-4	-2954192.99	17751.51	1457.82	4HF	Siltstone
BHW2-5	-2954192.99	17751.51	1447.27	4LR	Sandstone
BHW2-6	-2954192.99	17751.51	1446.26	4L	Coal

BHW2-7	-2954192.99	17751.51	1444.55	4L	Coal
BHW2-8	-2954192.99	17751.51	1444.31	4L	Coal
BHW2-9	-2954192.99	17751.51	1444.14	4LF	Siltstone

Table A2-8: Coordinates for samples collected from Borehole wedge 3

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
BHW3-1	-2933495.01	27629.99	1551.37	5R	Sandstone
BHW3-2	-2933495.01	27629.99	1551.30	5	Coal
BHW3-3	-2933495.01	27629.99	1550.52	5PT	Sandstone
BHW3-4	-2933495.01	27629.99	1550.45	5	Coal
BHW3-5	-2933495.01	27629.99	1550.18	5CSH	Carb-shale
BHW3-6	-2933495.01	27629.99	1549.52	5F	Sandstone
BHW3-7	-2933495.01	27629.99	1512.66	4HR	Sandstone
BHW3-8	-2933495.01	27629.99	1518.55	4H	Coal
BHW3-9	-2933495.01	27629.99	1512.25	4HF	Siltstone
BHW3-10	-2933495.01	27629.99	1507.88	4LR	Sandstone
BHW3-11	-2933495.01	27629.99	1507.07	4L	Coal
BHW3-12	-2933495.01	27629.99	1505.69	4L	Coal
BHW3-13	-2933495.01	27629.99	1504.71	4L	Coal
BHW3-14	-2933495.01	27629.99	1501.91	4LF	Siltstone

Table A2-9: Coordinates for samples collected from Borehole wedge 4

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
BHW4-1	-2936351.00	1032.19	1515.53	5	Coal
BHW4-2	-2936351.00	1032.19	1485.84	4HR	Sandstone
BHW4-3	-2936351.00	1032.19	1485.01	4H	Coal
BHW4-4	-2936351.00	1032.19	1484.81	4HF	Sandstone
BHW4-5	-2936351.00	1032.19	1483.93	4LR	Sandstone
BHW4-6	-2936351.00	1032.19	1483.07	4L	Coal
BHW4-7	-2936351.00	1032.19	1482.69	4L	Coal
BHW4-8	-2936351.00	1032.19	1481.65	4L	Coal
BHW4-9	-2936351.00	1032.19	1480.71	4L	Coal
BHW4-10	-2936351.00	1032.19	1480.16	4L	Coal
BHW4-11	-2936351.00	1032.19	1479.80	4LF	Sandstone

Table A2-10: Coordinates for samples collected from Borehole wedge 5

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
BHW5-1	-2935040.00	25124.98	1560.05	5R	Sandstone
BHW5-2	-2935040.00	25124.98	1558.99	5	Coal
BHW5-3	-2935040.00	25124.98	1555.65	5F	Sandstone
BHW5-4	-2935040.00	25124.98	1517.12	SST	Sandstone
BHW5-5	-2935040.00	25124.98	1514.91	SST	Sandstone
BHW5-6	-2935040.00	25124.98	1513.93	SST	Sandstone
BHW5-7	-2935040.00	25124.98	1512.78	SST	Sandstone
BHW5-8	-2935040.00	25124.98	1511.99	SST	Siltstone
BHW5-9	-2935040.00	25124.98	1511.91	4R	Sandstone
BHW5-10	-2935040.00	25124.98	1511.61	4	Coal
BHW5-11	-2935040.00	25124.98	1510.10	4	Coal

BHW5-12	-2935040.00	25124.98	1509.89	4	Coal
BHW5-13	-2935040.00	25124.98	1508.81	4	Coal
BHW5-14	-2935040.00	25124.98	1508.73	4F	Siltstone
BHW5-15	-2935040.00	25124.98	1508.03	SST	Siltstone

Table A2-11: Coordinates for samples collected at Delmas Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
DEL1	-2908320.00	-17200.00	1510.00	4R	Carb-shale
DEL2	-2908325.00	-17200.00	1510.00	4	Coal
DEL4	-2907780.00	-17700.00	1510.00	4	Coal
DEL5	-2907720.00	-17710.00	1510.00	4	Coal
DEL6	-2907760.00	-17580.00	1510.00	4F	Sandstone
DEL7	-2907340.00	-17540.00	1510.00	4	Coal
DEL8	-2907359.00	-17545.00	1510.00	4	Coal
DEL9	-2907347.00	-17540.00	1510.00	4	Coal
DEL10	-2906470.00	-16956.00	1510.00	4	Coal
DEL11	-2906464.00	-16950.00	1510.00	4	Coal
DEL12	-2906470.00	-16942.00	1510.00	4	Coal
DEL13	-2906473.00	-16950.00	1510.00	4	Coal
DEL14	-2906520.00	-16054.00	1510.00	4	Coal
DEL15	-2906527.00	-16050.00	1510.00	4	Coal
DEL16	-2905938.00	-16000.00	1510.00	4	Coal
DEL17	-2905940.00	-16007.00	1510.00	4	Coal

Table A2-12: Coordinates for samples collected at Douglas Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
DOU1	-2881667.00	30130.00	1495.65	1F	Siltstone
DOU2	-2881667.00	30130.00	1496.70	1	Coal
DOU3	-2881667.00	30130.00	1497.20	1	Coal
DOU4	-2881667.00	30130.00	1497.60	1R	Sandstone
DOU5	-2881667.00	30130.00	1499.70	2AF	Siltstone
DOU6	-2881667.00	30130.00	1500.20	2A	Coal
DOU7	-2881667.00	30130.00	1500.52	2AR	Siltstone
DOU8	-2881667.00	30130.00	1500.70	2L	Coal
DOU9	-2881667.00	30130.00	1502.70	2M	Coal
DOU10	-2881667.00	30130.00	1505.80	2U	Coal
DOU11	-2881667.00	30130.00	1506.60	2R	Siltstone
DOU12	-2881667.00	30130.00	1523.70	4LF	Siltstone
DOU13	-2881667.00	30130.00	1524.70	4LL	Coal
DOU14	-2881667.00	30130.00	1525.70	4LM	Coal
DOU15	-2881667.00	30130.00	1526.20	4L	Coal
DOU16	-2881667.00	30130.00	1526.70	4LR	Siltstone
DOU17	-2881667.00	30130.00	1555.70	5F	Sandstone
DOU18	-2881667.00	30130.00	1557.70	5	Coal
DOU19	-2881667.00	30130.00	1558.00	5R	Sandstone
DOU20	-2879326.00	28806.00	1540.60	4R	Siltstone
DOU21	-2879326.00	28806.00	1540.30	4R	Siltstone
DOU22	-2879326.00	28806.00	1539.30	4L	Coal
DOU23	-2879326.00	28806.00	1539.00	4LF	Carb-shale

DOU24	-2879326.00	28806.00	1522.97	2R	Siltstone
DOU25	-2879326.00	28806.00	1522.30	2U	Coal
DOU26	-2879326.00	28806.00	1521.30	2M	Coal
DOU27	-2879326.00	28806.00	1520.30	2M	Coal
DOU28	-2879326.00	28806.00	1519.30	2L	Coal
DOU29	-2879326.00	28806.00	1517.80	2F	Sandstone
DOU30	-2879542.98	39860.97	1548.93	4LR	Siltstone
DOU31	-2879542.98	39860.97	1548.53	4LU	Coal
DOU32	-2879542.98	39860.97	1547.53	4LM	Coal
DOU33	-2879542.98	39860.97	1546.33	4LL	Coal
DOU34	-2879542.98	39860.97	1546.03	4LF	Sandstone
DOU35	-2879542.98	39860.97	1528.63	2R	Siltstone
DOU36	-2879542.98	39860.97	1528.03	2LU	Coal
DOU37	-2879542.98	39860.97	1527.03	2LM	Coal
DOU38	-2879542.98	39860.97	1523.83	2LL	Coal
DOU39	-2879542.98	39860.97	1522.03	2:1PT	Sandstone
DOU40	-2879542.98	39860.97	1521.03	1M	Coal
DOU41	-2879542.98	39860.97	1548.73	4LPT	Sandstone

Table A2-13: Coordinates for samples collected at Forzando Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
FOR1	-2905525.00	54580.00	1542.00	4U	Coal
FOR2	-2905549.00	54588.00	1541.00	4L	Coal
FOR3	-2905546.00	54579.00	1540.00	4F	Shale
FOR4	-2905001.00	57200.00	1562.00	4R	Siltstone
FOR5	-2905000.00	57201.00	1560.00	4U	Coal
FOR6	-2905002.00	57200.00	1559.00	4L	Coal
FOR7	-2905000.00	57199.00	1562.00	4R	Sandstone
FOR8	-2904999.00	57200.00	1559.20	4UPT	Sandstone
FOR9	-2905000.00	57203.00	1558.00	4F	Sandstone
FOR10	-2904499.00	55500.00	1548.00	4F	Sandstone
FOR11	-2904500.00	55503.00	1550.00	4U	Coal
FOR12	-2904505.00	55501.00	1549.00	4L	Coal
FOR13	-2904502.00	55504.00	1551.00	4R	Sandstone

Table A2-14: Coordinates for samples collected at Greenside Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
GRE1	-2872150.00	17400.00	1505.93	4R	Carb-shale
GRE2	-2872150.00	17400.00	1504.93	4U	Coal
GRE3	-2872150.00	17400.00	1503.93	4M	Coal
GRE4	-2872150.00	17400.00	1502.93	4L	Coal
GRE5	-2872150.00	17400.00	1501.93	4F	Sandstone
GRE6	-2871780.00	15840.00	1495.61	4R	Carb-shale
GRE7	-2871780.00	15840.00	1494.61	4U	Coal
GRE8	-2871780.00	15840.00	1493.61	4M	Coal
GRE9	-2871780.00	15840.00	1492.61	4L	Coal
GRE10	-2871780.00	15840.00	1491.61	4F	Sandstone
GRE11	-2873200.00	15680.00	1486.71	4R	Carb-shale
GRE12	-2873200.00	15680.00	1485.71	4U	Coal

GRE13	-2873200.00	15680.00	1484.71	4M	Coal
GRE14	-2873200.00	15680.00	1483.71	4L	Coal
GRE15	-2873200.00	15680.00	1482.71	4F	Sandstone
NGT1	-2895180.00	9510.00	1566.68	5R	Siltstone
NGT2	-2895180.00	9510.00	1565.68	5U	Coal
NGT3	-2895180.00	9510.00	1564.68	5M	Coal
NGT4	-2895180.00	9510.00	1563.68	5L	Coal
NGT5	-2895180.00	9510.00	1562.68	5F	Siltstone
NGT6	-2895774.00	9800.00	1562.23	5R	Siltstone
NGT7	-2895774.00	9800.00	1561.23	5U	Coal
NGT8	-2895774.00	9800.00	1560.23	5M	Coal
NGT9	-2895774.00	9800.00	1559.23	5L	Coal
NGT10	-2895774.00	9800.00	1558.23	5F	Siltstone
NGT11	-2895125.00	10375.00	1562.05	5R	Shale
NGT12	-2895125.00	10375.00	1561.05	5U	Coal
NGT13	-2895125.00	10375.00	1560.05	5M	Coal
NGT14	-2895125.00	10375.00	1559.05	5L	Coal
NGT15	-2895125.00	10375.00	1558.05	5F	Shale

Table A2-15: Coordinates for samples collected at Kleinkopje Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
KK1	-2880961.00	25713.00	1507.00	2RCSH	Carb-shale
KK2	-2880961.00	25713.00	1506.00	2RC	Coal
KK3	-2880961.00	25713.00	1505.00	2TC	Coal
KK4	-2880961.00	25713.00	1504.00	2SC	Coal
KK5	-2880961.00	25713.00	1503.00	2FCSH	Carb-shale
KK6	-2880871.00	25072.00	1500.00	1PTSST	Sandstone
KK7	-2880871.00	25072.00	1499.00	1	Coal
KK8	-2876175.00	25041.00	1505.00	4RSH	Shale
KK9	-2876175.00	25041.00	1503.00	4	Coal
KK10	-2876175.00	25041.00	1502.00	4FSST	Sandstone
KK11	-2873617.00	24993.00	1529.00	2RSH	Shale
KK12	-2873617.00	24993.00	1528.00	2TC	Coal
KK13	-2873617.00	24993.00	1526.00	2SC	Coal
KK14	-2873617.00	24993.00	1525.00	2FSST	Sandstone
KK15	-2876641.00	23340.00	1489.00	1PTSST	Sandstone
KK16	-2876641.00	23340.00	1488.00	1	Coal

Table A2-16: Coordinates for samples collected at Khutala Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
KHU1	-2894484.00	4560.00	1505.44	2	Coal
KHU2	-2894477.00	4559.00	1505.44	2	Coal
KHU3	-2894479.00	4555.00	1505.44	2	Coal
KHU4	-2894472.00	4557.00	1505.44	2	Coal
KHU5	-2894479.00	4562.00	1505.44	2	Coal
KHU6	-2894482.00	4560.00	1505.44	2	Coal
KHU7	-2894479.00	4565.00	1505.44	2F	Sandstone
KHU8	-2894016.00	4345.00	1505.44	2	Coal
KHU9	-2894019.00	4347.00	1498.99	2	Coal

KHU10	-2894019.00	4345.00	1498.99	2	Coal
KHU11	-2888192.54	2600.21	1538.59	4	Coal
KHU12	-2888189.54	2607.21	1538.59	4	Coal
KHU13	-2888184.54	2600.21	1538.59	4	Coal
KHU14	-2887115.83	1330.43	1538.59	4	Coal
KHU15	-2887121.83	1326.43	1538.59	4	Coal
KHU16	-2887115.83	1326.43	1538.59	4	Coal

Table A2-17: Coordinates for samples collected at Koornfontein Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
KOR1	-2895816.18	54045.17	1560.43	2	Coal
KOR2	-2895806.18	54045.17	1560.43	2	Coal
KOR3	-2895806.18	54039.17	1560.43	2	Coal
KOR4	-2895727.39	53997.06	1560.07	2	Coal
KOR5	-2895733.39	53994.06	1560.07	2	Coal
KOR6	-2895733.39	53991.06	1560.07	2	Coal
KOR7	-2895463.33	53900.93	1547.47	2	Coal
KOR8	-2895458.33	53900.93	1547.47	2	Coal
KOR9	-2895458.33	53915.93	1547.47	2	Coal
KOR10	-2895469.47	53967.79	1543.44	2	Coal
KORSST	-2895466.47	53967.79	1539.20	2F	Sandstone
KOR11	-2895466.47	53973.79	1543.44	2	Coal
KOR12	-2895456.47	53967.79	1543.44	2	Coal
KOR13	-2895384.33	53847.18	1543.24	2	Coal
KOR14	-2895388.33	53852.18	1543.24	2	Coal
KOR15	-2895383.33	53860.18	1543.24	2	Coal
KOR16	-2888574.87	54187.52	1539.20	2	Coal
KOR17	-2888569.87	54187.52	1539.20	2	Coal
KOR18	-2888571.87	54191.52	1539.20	2	Coal

Table A2-18: Coordinates for samples collected at Kromdraai Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
KRD1	-2850785.00	9675.00	1478.80	2:1C	Coal
KRD2	-2850785.00	9671.00	1478.80	2:1C	Coal
KRD3	-2850785.00	9673.00	1478.80	2:1C	Coal
KRD4	-2851395.00	9535.00	1479.92	2:1PT	Sandstone
KRD5	-2851395.00	9535.00	1480.52	2:1PT	Sandstone
KRD6	-2851395.00	9535.00	1478.80	1	Coal
KRD7	-2851395.00	9535.00	1479.28	1	Coal
KRD8	-2851395.00	9535.00	1479.80	1	Coal
KRD9	-2851395.00	9535.00	1480.98	2	Coal
KRD10	-2851395.00	9535.00	1481.43	2	Coal
KRD11	-2851395.00	9535.00	1481.88	2	Coal

Table A2-19: Coordinates for samples collected at Lakeside Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
LK1	-2889631.00	8 756	1516.30	2	Coal
LK2	-2890049.00	9 049	1517.08	2	Coal

LK3	-2889362.00	8 903	1517.43	2	Coal
LK4	-2889810.00	8 977	1516.40	2	Coal
LK5	-2889089.00	9 561	1512.60	2	Coal
LK6	-2889181.00	8 970	1516.58	2	Coal
LK7	-2889141.00	9 174	1513.91	2	Coal

Table A2-20: Coordinates for samples collected at Leeufontein Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
LU1	-2889778.00	6 627	1536.25	2	Coal
LU2	-2889763.00	6 417	1508.60	2	Coal
LU3	-2889835.00	6 390	1508.61	2	Coal
LU4	-2890835.00	6 339	1508.54	2	Coal
LU5	-2891835.00	6 249	1508.10	2F	Sandstone
LU6	-2889735.00	6 252	1508.25	2	Coal
LU7	-2889835.00	6 141	1508.63	2	Coal
LU8	-2889935.00	6 096	1508.92	2	Coal
LU9	-2890165.00	6 567	1503.65	2	Coal
LU10	-2889979.00	6 423	1500.20	2	Coal
LU11	-2890072.00	6 390	1501.26	2	Coal
LU13	-2890141.00	6 279	1501.41	2	Coal
LU14	-2890192.00	6 135	1500.47	2	Coal
LU15	-2890465.00	6 273	1500.47	2	Coal
LU16	-2890789.00	6 426	1500.13	2	Coal
LU17	-2890912.00	6 192	1501.65	2	Coal
LU18	-2890915.00	6 339	1502.36	2	Coal
LU19	-2890855.00	6 420	1501.85	2	Coal
LU20	-2890921.00	6 534	1500.47	2	Coal
LU21	-2891044.00	6 303	1501.85	2	Coal
LU22	-2891029.00	6 327	1502.36	2	Coal
LU23	-2890792.00	6 621	1500.20	2	Coal
LU24	-2890639.00	5 076	1506.46	2	Coal
LU25	-2890792.00	4 776	1508.05	2	Coal
LU26	-2890912.00	4 809	1504.27	2	Coal
LU27	-2890963.00	4 881	1500.54	2	Coal
LU28	-2890867.00	4 743	1508.24	2	Coal
LU29	-2891005.00	4 551	1506.53	2	Coal
LU30	-2890732.00	4 710	1508.99	2	Coal
LUP1	-2888898.00	6 497	1514.80	2	Coal
LUP2	-2888941.00	6 507	1514.60	2	Coal
LUP3	-2888950.00	6 459	1515.69	2	Coal
LUP4	-2888908.00	6 707	1510.28	2	Coal

Table A2-21: Coordinates for samples collected at Middelburg Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
M1	-2865344.78	47482.93	1550.90	1	Coal
M2	-2865344.78	47482.93	1552.33	1	Coal
M3	-2865344.78	47482.93	1553.19	1SST	Sandstone
M4	-2865344.78	47482.93	1553.82	2ASST	Sandstone
M5	-2865344.78	47482.93	1554.40	2A	Coal

M6	-2865344.78	47482.93	1555.54	2A	Coal
M7	-2865344.78	47482.93	1556.11	2A	Coal
M8	-2865344.78	47482.93	1556.57	2A	Coal
M9	-2865344.78	47482.93	1560.79	2	Coal
M10	-2865344.78	47482.93	1561.91	2RSH	Carb-shale
M11	-2877251.58	40629.11	1524.44	1	Coal
M12	-2877251.58	40629.11	1525.65	1	Coal
M13	-2877251.58	40629.11	1527.21	2F	Sandstone
M14	-2877251.58	40629.11	1527.23	2	Coal
M15	-2877251.58	40629.11	1529.31	2	Coal
M16	-2877251.58	40629.11	1531.75	2	Coal
M17	-2877251.58	40629.11	1533.40	2	Coal
M18	-2877251.58	40629.11	1554.74	4A	Coal
M19	-2877251.58	40629.11	1556.26	4A	Coal
M20	-2877251.58	40629.11	1557.20	4	Coal
M21	-2877251.58	40629.11	1557.40	4F	Siltstone
M22	-2877251.58	40629.11	1558.34	4F	Sandstone

Table A2-22: Coordinates for samples collected at Optimum Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
OPT1	-2877246.00	59362.00	-	4L	Coal
OPT2	-2877235.00	59369.00	-	4L	Coal
OPT3	-2877240.00	59354.00	-	4PT	Sandstone
OPT4	-2876863.00	59200.00	-	2	Coal
OPT5	-2876857.00	59212.00	-	2	Coal
OPT6	-2875120.00	64245.00	-	2U	Coal
OPT7	-2875126.00	64240.00	-	2U	Coal
OPT8	-2875120.00	64237.00	-	2R	Sandstone
OPT9	-2876474.00	73360.00	-	2U	Coal
OPT10	-2876481.00	73352.00	-	2U	Coal
OPT11	-2876485.00	73361.00	-	2PT	Sandstone
OPT12	-2876480.00	73369.00	-	2L	Coal
OPT13	-2876477.00	73356.00	-	2L	Coal

Table A2-23: Coordinates for samples collected at Rietspruit Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
R2RO	-2890602.00	20301.00	1515.00	2	Siltstone
R2M	-2890613.00	20307.00	1513.00	2	Coal
R2M2	-2890616.00	20315.00	1511.00	2	Coal
R2LW	-2890620.00	20308.00	1505.00	2	Coal
R4UROOF	-2891141.00	21320.00	1547.00	4	Siltstone
R4U	-2891144.00	21325.00	1545.00	4	Coal
R4PT	-2891147.00	21318.00	1543.50	4	Siltstone
R4L	-2891150.00	21315.00	1542.00	4	Coal
R4FUG	-2889456.00	20000.00	1541.00	4	Sandstone
R4FLG	-2889452.00	20010.00	1540.00	4	Sandstone
R4F1	-2889457.00	20004.00	1539.00	4	Sandstone
R4F2	-2889449.00	20001.00	1538.50	4	Sandstone
R4F3	-2889453.00	20007.00	1538.00	4	Sandstone

Table A2-24: Coordinates for samples collected at South Witbank Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
SW1	-2893355.00	12037.00	1531.40	4	Coal
SW2	-2893357.00	12039.00	1531.40	4	Coal
SW3	-2893355.00	12029.00	1531.40	4	Coal
SW4	-2893194.00	12809.00	1533.20	4	Coal
SW5	-2893190.00	12803.00	1533.20	4	Coal
SW6	-2893188.00	12794.00	1533.20	4	Coal
SW7	-2893068.00	12920.00	1532.20	4	Coal
SW8	-2893070.00	12925.00	1532.20	4	Coal
SW9	-2893074.00	12920.00	1532.20	4	Coal
SW10	-2893078.00	12916.00	1532.20	4	Coal

Table A2-25: Coordinates for samples collected at Tavistock Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
TAV1A	-2891594.45	17389.50	1537.40	4U	Coal
TAV1B	-2891593.45	17389.50	1537.40	4U	Coal
TAV1C	-2891595.45	17389.50	1537.40	4U	Coal
TAV2A	-2891593.45	17387.50	1535.80	4M	Coal
TAV2B	-2891593.45	17389.50	1535.80	4M	Coal
TAV2C	-2891593.45	17391.50	1535.80	4M	Coal
TAV3A	-2891590.45	17389.50	1534.10	4L	Coal
TAV3B	-2891588.45	17389.50	1534.10	4L	Coal
TAV3C	-2891596.45	17389.50	1534.10	4L	Coal
TAV4A	-2891593.45	17394.50	1534.40	4PT	Carb-shale
TAV4B	-2891593.45	17393.50	1534.40	4PT	Carb-shale
TAV4C	-2891593.45	17388.50	1534.40	4PT	Carb-shale
TAV5A	-2890966.90	16215.47	1537.90	4U	Coal
TAV5B	-2890966.90	16217.47	1537.90	4U	Coal
TAV5C	-2890966.90	16219.47	1537.90	4U	Coal
TAV6A	-2890963.90	16217.47	1536.80	4M	Coal
TAV6B	-2890967.90	16217.47	1536.80	4M	Coal
TAV6C	-2890970.90	16217.47	1536.80	4M	Coal
TAV7A	-2890969.90	16217.47	1534.40	4L	Coal
TAV7C	-2890966.90	16220.47	1534.40	4L	Coal

Table A2-26: Coordinates for samples collected at Union Colliery

SiteName	Ycoord	Xcoord	Zcoord	Seam No.	Rock Type
UN1	-2903670.25	100603.23	1682.00	DUMP2	Coal
UN2	-2903667.25	100604.23	1682.00	DUMP2	Coal
UN3	-2903526.26	101073.20	1670.00	DUMP3	Coal
UN4	-2903528.26	101076.20	1670.00	DUMP3	Coal
UN5B	-2906494.87	100345.40	1682.00	DUMPBD	Coal
UN6B	-2906490.87	100341.40	1682.00	DUMPBD	Coal

Table A2-27: Major element oxide concentrations for Arnot Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
ARA1	52.46	2.61	21.07	8.64	0.02	0.05	3.74	0.50	0.00	1.63	0.34	0.68	7.79	99.53
ARA2	47.76	2.20	19.98	1.41	0.22	0.01	0.06	0.09	0.04	1.44	0.03	1.12	24.82	99.18
ARA3	78.92	3.30	7.71	2.42	0.03	0.04	0.19	0.10	0.04	1.14	0.02	0.25	6.45	100.61
ARA4	37.49	0.83	22.32	0.78	0.19	0.01	0.15	0.09	0.03	0.70	0.04	1.73	35.02	99.38
ARA5	8.56	0.24	4.56	1.11	0.83	0.00	0.23	0.63	0.00	0.02	0.02	3.13	79.32	98.65
ARA6	58.28	1.92	31.81	1.05	0.04	0.01	0.09	0.11	0.05	0.72	0.04	0.25	4.92	99.29
ARA7	53.46	1.13	22.56	0.77	0.07	0.01	0.15	0.06	0.06	1.50	0.05	1.22	18.34	99.38
ARA8	50.32	1.08	23.98	0.76	0.07	0.01	0.10	0.06	0.05	1.18	0.05	1.28	20.42	99.36
ARA9	9.53	0.32	4.21	0.21	0.33	0.00	0.45	2.12	0.00	0.06	0.03	5.11	76.49	98.86
ARA10	8.69	0.28	5.34	0.07	0.24	0.00	0.41	1.47	0.01	0.06	0.15	3.83	76.17	96.72
ARA11	82.30	1.29	7.56	0.97	1.29	0.02	0.16	0.22	0.10	1.78	0.03	0.17	4.94	100.83
ARA12	67.72	1.50	5.11	3.94	0.09	0.01	0.00	0.00	0.03	0.60	0.03	1.54	19.55	100.12
ARA13	11.13	0.28	8.29	2.25	1.77	0.00	0.05	0.00	0.00	0.12	0.05	3.02	73.15	100.11
ARA14	41.85	0.97	20.23	0.60	0.22	0.01	0.14	0.07	0.01	0.71	0.05	1.61	33.12	99.59
ARA15	19.56	0.53	8.90	0.42	0.40	0.00	0.14	0.19	0.00	0.32	0.02	3.73	64.33	98.54
ARA16	75.14	0.70	13.19	2.30	0.21	0.03	0.36	0.17	0.17	4.19	0.06	0.21	4.21	100.94
ARB1	61.87	2.14	7.33	4.15	0.99	0.02	0.00	0.01	0.09	1.10	0.02	0.31	20.96	98.99
ARB2	16.79	0.91	8.41	0.27	0.45	0.00	0.09	0.16	0.00	0.18	0.01	3.74	67.33	98.34
ARB3	77.87	1.26	6.09	1.30	0.05	0.05	1.58	3.19	0.04	1.59	0.02	0.20	7.20	100.44
ARB4	71.16	0.89	14.43	0.79	0.06	0.01	0.02	0.24	0.05	1.18	0.04	0.55	10.98	100.40
ARB5	10.35	0.44	6.33	0.36	0.74	0.00	0.18	0.37	0.01	0.42	0.03	2.48	78.13	99.84
ARB6	71.77	0.64	7.90	2.62	0.45	0.05	1.36	3.74	0.04	1.12	0.03	0.30	9.57	99.59
ARB7	6.93	0.13	5.22	0.06	0.43	0.00	0.14	0.81	0.00	0.02	0.04	3.46	81.12	98.36
ARB8	89.66	0.81	4.50	1.42	0.37	0.01	0.00	0.07	0.08	0.55	0.08	0.23	2.92	100.70
ARB9	46.10	1.13	21.95	0.66	0.15	0.00	0.15	0.08	0.03	0.75	0.06	1.73	26.22	99.01
ARB10	17.88	0.25	12.21	0.78	0.76	0.00	0.06	0.00	0.00	0.09	0.03	5.23	62.36	99.65
ARB11	47.38	1.02	25.40	1.27	0.10	0.02	0.32	0.17	0.02	0.92	0.05	1.79	21.31	99.77
ARB13	60.63	0.96	15.21	4.91	0.08	0.13	1.65	2.51	0.07	3.89	0.08	0.55	8.77	99.44
ARC1	39.89	1.69	16.97	1.05	0.18	0.01	0.10	0.08	0.02	0.75	0.03	2.06	36.22	99.05

ARC2	6.31	0.33	4.11	1.89	1.17	0.00	0.25	0.97	0.00	0.11	0.01	8.44	76.27	99.86
ARC3	81.07	1.28	7.45	1.25	0.03	0.04	0.17	0.55	0.04	1.42	0.03	0.28	6.06	99.67
ARC4	52.88	1.04	19.91	0.90	0.10	0.01	0.12	0.06	0.06	1.45	0.04	1.26	21.85	99.68
ARC5	3.09	0.21	2.46	2.87	1.90	0.00	0.23	1.02	0.00	0.10	0.00	9.93	78.93	100.74
ARC6	10.72	0.43	5.57	0.21	0.27	0.00	0.08	0.84	0.00	0.03	0.00	7.72	74.15	100.02
ARC7	84.99	2.18	5.65	2.96	0.53	0.02	0.00	0.04	0.03	0.37	0.03	0.23	3.57	100.60
ARD1	34.53	1.39	14.04	0.82	0.25	0.01	0.05	0.12	0.02	0.71	0.03	2.23	44.97	99.17
ARD2	9.84	0.51	6.08	1.64	0.94	0.00	0.18	0.65	0.00	0.16	0.04	5.64	74.22	99.90
ARD3	76.66	0.71	4.42	2.62	0.14	0.07	1.63	4.71	0.02	1.29	0.02	0.26	7.84	100.39
ARD4	54.67	0.97	19.85	0.81	0.08	0.01	0.05	0.05	0.05	1.48	0.06	1.38	20.13	99.59
ARD5	14.37	0.50	5.44	0.09	0.18	0.00	0.07	0.38	0.00	0.03	0.00	10.71	66.59	98.36
ARD6	8.59	0.38	6.44	3.22	0.67	0.00	0.29	1.47	0.00	0.10	0.02	3.46	75.44	100.08
ARD7	84.76	3.44	6.14	1.85	0.03	0.02	0.00	0.17	0.01	0.21	0.12	0.29	3.15	100.19

Table A2-28: Major element oxide concentrations for Arnot-North Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
3936	57.33	1.10	22.10	7.11	0.05	0.10	0.10	0.04	0.18	1.47	0.21	0.87	8.62	99.28
3937	57.70	1.15	21.64	5.50	0.04	0.03	0.17	0.11	0.17	1.86	0.14	1.05	9.76	99.32
3938	13.98	0.55	8.74	1.28	0.37	0.00	0.09	0.40	0.14	0.18	0.07	4.52	69.38	99.70
3939	47.62	1.24	14.47	3.55	0.32	0.03	0.08	0.45	0.21	0.72	0.17	2.95	28.31	100.12
3940	69.89	1.21	15.32	2.57	0.86	0.03	0.29	0.18	0.26	2.32	0.07	0.73	7.05	100.78
3941	54.54	1.38	11.39	14.34	0.14	0.22	1.25	2.68	1.57	2.83	0.51	0.35	9.20	100.40
3942	57.40	1.04	19.65	8.55	0.05	0.18	0.41	0.09	0.20	2.54	0.11	1.76	7.60	99.58
3943	42.42	0.93	20.19	10.86	0.43	0.21	0.43	0.38	0.19	1.26	0.38	1.26	20.74	99.68
3944	43.51	0.89	16.15	16.35	0.58	0.23	0.75	0.40	0.20	2.02	0.17	0.62	18.40	100.27
3945	16.57	0.40	6.84	1.65	0.65	0.00	0.03	0.10	0.14	0.19	0.07	2.44	70.48	99.56
3946	59.80	3.80	10.96	3.84	0.51	0.05	0.00	0.11	0.19	1.32	0.05	0.69	17.64	98.96
3947	74.53	2.06	10.43	2.33	0.15	0.04	0.01	0.33	0.17	2.71	0.05	0.28	5.85	98.94
3948	50.86	1.18	20.19	14.00	0.05	0.21	0.36	0.04	0.18	2.24	0.18	1.12	8.47	99.08
3949	58.48	1.52	20.28	5.18	0.05	0.05	0.06	0.28	0.15	0.90	0.20	1.19	10.58	98.92
3950	52.72	2.17	14.55	5.04	0.09	0.04	0.04	0.60	0.15	0.71	0.11	2.61	20.38	99.21
3951	21.93	0.61	6.86	2.47	0.67	0.00	0.02	0.26	0.14	0.23	0.04	3.09	63.04	99.36

3952	67.55	4.25	10.97	3.47	0.16	0.04	0.00	0.15	0.15	0.96	0.04	0.56	10.67	98.97
3953	61.04	0.85	10.08	11.05	0.43	0.25	0.98	2.52	0.53	2.30	0.15	0.43	9.89	100.50
3954	57.23	1.20	20.56	3.96	0.04	0.04	0.21	0.51	0.21	1.22	0.18	1.76	12.29	99.41
3955	24.49	0.52	8.97	1.79	0.53	0.00	0.07	0.35	0.15	0.32	0.06	3.72	59.05	100.02
3956	84.73	2.25	5.17	0.86	0.32	0.00	0.00	0.04	0.20	0.86	0.03	0.34	5.10	99.90
3957	55.72	2.31	12.99	2.04	0.62	0.00	0.00	0.21	0.17	1.28	0.06	1.18	23.09	99.67
3958	72.97	4.09	8.49	4.11	0.42	0.07	0.00	0.19	0.19	1.74	0.03	0.44	6.87	99.61
3959	55.59	2.15	11.48	2.16	0.22	0.04	0.02	0.18	0.15	0.76	0.03	0.94	25.70	99.42

Table A2-29: Major element oxide concentrations for Bank Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H2O	LOI	Total
BAN1	3.27	0.15	3.77	0.61	0.77	0.00	0.30	2.77	0.00	0.11	0.54	1.13	85.53	98.95
BAN2	5.87	0.20	5.46	0.45	0.62	0.00	0.25	1.69	0.00	0.15	0.39	1.71	81.41	98.20
BAN3	6.25	0.36	5.77	0.47	0.61	0.00	0.13	1.30	0.00	0.39	0.66	1.86	81.15	98.95
BAN4	0.95	0.18	3.03	0.58	0.77	0.00	0.56	3.22	0.00	0.03	0.55	1.24	89.05	100.16
BAN5	6.48	0.49	6.26	0.04	0.33	0.00	0.18	0.61	0.02	0.12	0.01	1.30	82.98	98.81
BAN6	5.53	0.21	3.91	0.24	0.49	0.00	0.15	0.98	0.00	0.07	0.07	0.62	85.73	98.00
BAN7	12.14	0.99	8.34	0.09	0.32	0.00	0.31	0.97	0.02	0.11	0.01	2.23	73.01	98.54
BAN8	3.99	0.18	3.84	0.62	0.68	0.00	0.36	1.44	0.00	0.20	0.01	2.14	85.48	98.94
BAN9	0.57	0.16	2.94	0.96	0.76	0.00	0.24	1.23	0.00	0.13	0.26	2.09	89.48	98.82
BAN10	49.79	1.07	24.34	1.71	0.07	0.01	0.45	0.31	0.06	1.22	0.34	1.20	18.68	99.25
BAN11	54.37	0.90	23.21	1.36	0.08	0.00	0.53	0.21	0.02	2.40	0.03	2.34	13.73	99.18
BAN12	8.54	0.15	2.84	0.78	0.81	0.00	0.04	0.00	0.00	0.32	0.00	6.64	80.54	100.66
BAN13	5.79	0.12	2.17	1.70	1.05	0.00	0.00	0.00	0.00	0.15	0.00	16.64	72.36	99.98
BAN14	26.48	0.28	10.49	20.03	0.93	0.44	1.70	3.24	0.00	2.07	1.76	2.30	29.42	99.14
BAN15	55.18	0.94	22.37	1.50	0.08	0.01	0.63	0.21	0.02	2.42	0.03	2.53	13.89	99.81
BAN16	8.17	0.10	2.65	3.15	1.82	0.00	0.02	0.00	0.00	0.19	0.00	2.87	81.03	100.00
BAN17	13.35	0.21	4.52	1.97	1.12	0.00	0.10	0.00	0.00	0.37	0.00	2.64	75.63	99.91
BAN18	56.34	0.72	14.48	7.41	0.75	0.02	1.85	0.35	0.18	4.66	0.08	3.79	9.37	100.00
BAN19	7.56	0.55	6.24	0.32	0.33	0.00	0.08	0.85	0.00	0.05	0.07	2.35	80.25	98.65
BAN20	5.67	0.66	6.03	0.06	0.23	0.00	0.12	1.50	0.00	0.07	0.10	1.69	83.38	99.51

BAN21	5.64	0.44	6.17	0.77	0.52	0.00	0.15	1.78	0.00	0.08	0.21	1.74	82.13	99.63

Table A2-30: Major element oxide concentrations for Bankfontein Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
BK1	3.45	0.24	3.76	0.10	0.40	0.00	0.00	0.03	0.00	0.03	0.23	5.94	85.37	99.55
BK2	0.94	0.01	2.24	2.31	2.06	0.00	0.14	6.31	0.00	0.00	3.48	5.54	76.73	99.76
BK3	10.15	0.29	7.72	0.15	0.38	0.00	0.01	0.00	0.00	0.19	0.00	2.50	78.32	99.71

Table A2-31: Major element oxide concentrations for Borehole 1 (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
BH1-1	27.24	0.50	13.11	3.10	0.51	0.00	0.98	0.17	0.51	1.40	0.00	9.53	42.87	99.93
BH1-2	26.11	0.34	10.98	0.76	0.65	0.00	0.34	0.17	0.36	0.68	0.00	14.15	45.74	100.28
BH1-3	83.89	0.15	3.13	5.47	1.57	0.02	0.00	1.40	0.12	1.06	0.01	0.25	3.10	100.17
BH1-4	5.08	0.12	6.08	0.60	1.46	0.00	0.48	2.81	0.22	0.82	2.05	13.90	67.11	100.73
BH1-5	6.30	0.31	4.78	0.25	0.80	0.00	0.39	2.34	0.25	0.35	0.31	3.06	82.66	101.80
BH1-6	6.47	0.31	5.42	0.25	0.92	0.00	0.59	2.78	0.50	0.41	0.07	11.61	70.23	99.56
BH1-7	63.91	1.15	19.84	0.96	0.07	0.02	0.06	0.06	0.67	2.12	0.05	1.32	9.46	99.69

Table A2-32: Major element oxide concentrations for Borehole wedge 1 (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
BHW1-1	84.30	0.31	7.46	1.31	0.26	0.02	0.00	0.43	0.96	3.24	0.03	0.08	1.65	100.05
BHW1-2	81.35	0.44	8.90	2.01	0.73	0.02	0.08	0.19	0.95	3.28	0.04	0.19	2.44	100.62
BHW1-3	81.00	0.38	6.08	1.53	0.44	0.02	0.00	3.10	0.74	2.77	0.03	0.15	3.74	99.98
BHW1-4	45.77	0.53	10.44	17.38	1.79	0.15	1.82	3.12	0.28	2.50	0.10	0.63	17.17	101.68
BHW1-5	69.21	0.60	6.39	6.25	2.00	0.05	0.18	2.80	0.31	1.82	0.02	0.54	11.87	102.04
BHW1-6	13.09	0.57	5.53	0.96	0.68	0.00	0.15	0.70	0.11	0.08	0.01	5.88	72.06	99.82
BHW1-7	13.64	0.44	5.68	1.36	0.85	0.00	0.42	2.15	0.11	0.07	0.00	6.26	69.57	100.55
BHW1-8	8.08	0.34	3.53	1.10	0.92	0.00	0.49	2.75	0.08	0.04	0.00	9.76	73.03	100.12
BHW1-9	6.70	0.21	3.94	0.80	0.71	0.00	0.23	1.44	0.09	0.04	0.02	11.05	75.33	100.56
BHW1-10	66.93	0.68	14.24	2.48	0.44	0.02	0.14	0.35	0.24	0.77	0.04	0.76	13.50	100.59

BHW1-11	56.11	0.65	27.34	0.98	0.04	0.00	0.08	0.04	0.28	3.08	0.06	0.73	9.86	99.25
BHW1-12	76.91	0.52	13.71	0.66	0.04	0.01	0.00	0.00	0.25	3.04	0.02	0.27	4.24	99.67

Table A2-33: Major element oxide concentrations for Borehole wedge 2 (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
BHW2-1	77.50	0.27	9.45	2.04	0.84	0.01	0.06	0.24	1.77	3.16	0.02	0.37	5.14	100.87
BHW2-2	31.93	0.65	13.72	2.27	0.85	0.00	0.37	0.00	0.35	0.89	0.01	6.99	40.35	98.38
BHW2-3	27.94	0.22	14.91	5.90	2.87	0.00	0.40	0.00	0.40	0.71	0.00	3.72	42.46	99.54
BHW2-4	66.85	0.86	15.41	2.86	0.92	0.01	0.23	0.03	0.75	3.49	0.03	0.69	7.64	99.77
BHW2-5	67.73	0.41	7.83	9.22	2.46	0.05	0.36	1.41	0.67	3.03	0.03	0.31	5.76	99.27
BHW2-6	18.04	0.52	6.99	1.18	0.52	0.00	0.11	0.45	0.10	0.10	0.00	5.39	65.84	99.24
BHW2-7	8.20	0.15	4.14	0.69	0.33	0.00	0.50	2.95	0.10	0.08	0.00	8.43	74.64	100.21
BHW2-8	2.13	0.14	2.14	2.77	1.88	0.00	0.57	4.38	0.06	0.04	0.00	13.92	71.53	99.56
BHW2-9	43.67	1.34	26.09	1.37	0.11	0.01	0.23	0.19	0.28	1.16	0.05	1.36	23.51	99.37

Table A2-34: Major element oxide concentrations for Borehole wedge 3 (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
BHW3-1	85.36	0.39	4.98	0.96	0.15	0.02	0.00	0.29	0.38	2.82	0.02	0.22	4.54	100.13
BHW3-2	4.91	0.28	2.85	2.70	2.47	0.00	0.14	0.82	0.04	0.30	0.00	5.64	80.09	100.24
BHW3-3	52.80	0.26	5.80	8.83	1.39	0.01	0.81	0.15	0.29	2.80	0.03	1.61	26.18	100.96
BHW3-4	10.58	0.14	5.40	1.77	1.57	0.00	0.38	0.71	0.18	0.27	0.00	4.15	74.53	99.68
BHW3-5	38.63	0.66	14.73	4.88	0.39	0.03	1.13	0.28	0.45	2.07	0.03	3.60	32.95	99.83
BHW3-6	71.67	0.26	8.39	1.95	0.09	0.07	0.12	6.36	1.32	2.52	0.04	0.27	6.62	99.68
BHW3-7	53.98	0.19	5.77	9.33	1.31	0.11	3.57	3.49	0.24	2.61	0.09	0.81	18.81	100.31
BHW3-8	5.72	0.28	3.16	2.78	2.61	0.00	0.08	0.63	0.05	0.33	0.01	2.78	81.37	99.80
BHW3-9	66.65	0.75	17.27	1.41	0.16	0.01	0.17	0.00	0.24	3.37	0.03	0.56	9.28	99.90
BHW3-10	77.49	0.90	9.69	2.60	1.04	0.01	0.24	0.00	0.52	1.80	0.04	0.36	5.57	100.26
BHW3-11	9.40	0.40	5.16	0.45	0.58	0.00	0.16	0.67	0.09	0.14	0.17	4.16	79.02	100.40
BHW3-12	6.89	0.26	4.26	1.33	1.04	0.00	0.40	1.92	0.09	0.11	0.21	4.68	77.38	98.57
BHW3-13	7.04	0.29	5.13	0.36	0.77	0.00	0.23	1.52	0.10	0.25	0.34	4.27	77.83	98.13

BHW3-14	65.38	0.51	17.92	1.24	0.21	0.00	0.00	0.02	0.24	1.96	0.03	0.63	11.41	99.55

Table A2-35: Major element oxide concentrations for Borehole wedge 4 (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
BHW4-1	13.63	0.25	6.44	1.62	1.23	0.00	0.30	0.41	0.16	0.41	0.00	3.31	72.51	100.27
BHW4-2	54.31	0.83	13.24	10.09	1.54	0.02	0.75	0.18	0.59	2.40	0.05	0.97	15.86	100.83
BHW4-3	11.91	0.29	5.89	3.98	3.18	0.00	0.16	0.35	0.11	0.54	0.01	2.70	71.01	100.13
BHW4-4	70.36	0.66	13.66	4.46	1.33	0.01	0.03	0.13	0.41	2.05	0.04	0.00	7.63	100.77
BHW4-5	83.80	0.41	4.26	3.09	0.99	0.01	0.00	0.08	0.21	1.24	0.02	0.29	6.20	100.60
BHW4-6	11.43	0.37	6.12	0.50	0.36	0.00	0.32	1.27	0.13	0.18	0.01	4.21	75.11	100.01
BHW4-7	29.15	0.73	10.67	0.47	0.15	0.00	0.32	0.62	0.19	0.34	0.00	3.18	53.65	99.47
BHW4-8	19.28	0.40	9.22	0.24	0.19	0.00	0.39	1.52	0.16	0.11	0.00	4.30	63.42	99.24
BHW4-9	9.59	0.39	4.88	0.22	0.39	0.00	0.44	1.99	0.13	0.07	0.00	3.39	78.45	99.94
BHW4-10	2.93	0.17	2.45	3.50	2.29	0.00	0.33	3.20	0.08	0.01	0.04	3.74	81.24	99.97
BHW4-11	74.11	0.60	12.73	0.82	0.11	0.00	0.00	0.00	0.30	3.75	0.02	0.43	6.78	99.65

Table A2-36: Major element oxide concentrations for Borehole wedge 5 (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
BHW5-1	43.56	0.82	17.12	8.05	1.45	0.03	0.87	0.15	0.55	2.29	0.08	1.53	23.19	99.69
BHW5-2	10.64	0.36	6.59	5.99	2.97	0.00	0.11	0.27	0.07	0.40	0.02	2.02	69.03	100.04
BHW5-3	56.15	0.99	21.39	3.21	0.93	0.02	0.52	0.06	0.57	2.47	0.05	0.95	12.77	100.08
BHW5-4	85.19	0.79	7.46	0.93	0.03	0.01	0.00	0.00	0.16	2.77	0.02	0.27	2.09	99.72
BHW5-5	82.04	1.04	7.66	2.81	0.09	0.03	0.00	0.03	0.14	2.29	0.03	0.25	3.36	99.77
BHW5-6	90.21	0.31	2.75	3.05	0.07	0.02	0.09	0.03	0.14	0.73	0.02	0.13	2.23	99.78
BHW5-7	89.25	0.40	3.79	2.74	0.09	0.02	0.00	0.07	0.11	1.45	0.07	0.13	2.11	100.23
BHW5-8	58.46	0.87	19.57	5.48	0.83	0.03	0.20	0.05	0.47	1.96	0.04	0.71	11.68	100.35
BHW5-9	69.16	0.72	14.40	4.26	0.00	0.01	0.02	0.03	0.46	1.77	0.04	0.46	8.63	99.96
BHW5-10	8.51	0.53	4.88	3.50	2.18	0.00	0.09	0.82	0.07	0.17	0.32	6.50	72.22	99.79
BHW5-11	4.79	0.34	4.97	0.34	0.71	0.00	0.28	1.58	0.10	0.14	0.42	5.97	80.34	99.98

BHW5-12	9.51	0.75	4.26	0.46	0.46	0.00	0.63	2.58	0.10	0.15	0.11	8.61	72.13	99.75
BHW5-13	7.36	0.49	4.92	0.26	0.73	0.00	0.28	1.71	0.12	0.25	0.26	4.38	79.09	99.84
BHW5-14	59.33	0.59	22.31	1.18	0.10	0.01	0.13	0.21	0.29	1.80	0.03	0.98	12.22	99.18
BHW5-15	66.24	0.62	19.81	0.75	0.03	0.01	0.04	0.08	0.25	2.14	0.03	0.75	8.58	99.33

Table A2-37: Major element oxide concentrations for Delmas Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
DEL1	36.32	0.79	17.96	0.51	0.23	0.00	0.38	0.22	0.20	0.53	0.06	2.96	39.13	99.29
DEL2	11.76	0.43	7.46	2.74	1.35	0.00	0.27	2.30	0.15	0.34	0.28	3.08	70.47	100.63
DEL4	1.00	0.17	3.18	11.07	5.49	0.00	0.12	2.71	0.07	0.16	0.44	3.15	71.43	98.99
DEL5	2.84	0.23	2.94	3.04	1.52	0.00	0.17	3.07	0.09	0.22	0.97	5.15	80.36	100.60
DEL6	53.62	1.15	26.00	0.73	1.00	0.00	0.26	0.31	0.22	0.73	0.08	0.33	14.91	99.34
DEL7	4.84	0.41	4.62	0.07	0.83	0.00	0.11	3.69	0.13	0.18	0.46	4.34	80.64	100.32
DEL8	5.31	0.19	4.25	9.22	7.64	0.00	0.50	2.54	0.07	0.11	0.29	3.16	66.92	100.20
DEL9	1.56	0.06	1.95	2.16	1.74	0.00	0.51	6.42	0.11	0.10	1.44	4.97	78.31	99.33
DEL10	6.94	0.44	4.93	0.06	0.70	0.00	0.22	1.98	0.09	0.25	0.24	3.24	79.49	98.58
DEL11	0.08	0.19	2.76	0.09	0.96	0.00	0.30	2.79	0.08	0.20	1.40	6.11	85.30	100.26
DEL12	4.45	0.32	4.04	2.09	2.59	0.00	0.18	4.86	0.07	0.28	0.63	2.64	78.41	100.56
DEL13	6.61	1.62	3.24	0.69	1.37	0.00	0.13	0.61	0.08	0.51	0.01	5.31	79.26	99.44
DEL14	11.78	0.51	8.78	0.64	0.92	0.00	0.56	1.85	0.10	0.49	0.27	3.69	69.24	98.83
DEL15	2.62	0.24	2.73	2.63	3.65	0.00	0.25	2.54	0.07	0.44	0.54	4.06	79.77	99.54
DEL16	8.12	0.78	6.79	0.59	1.15	0.00	0.40	1.87	0.07	0.29	0.09	2.16	77.94	100.25
DEL17	2.79	0.44	3.49	3.31	3.43	0.00	0.24	1.73	0.06	0.23	0.58	5.16	79.12	100.58

Table A2-38: Major element oxide concentrations for Douglas Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
DOU1	41.55	1.06	13.86	0.38	0.18	0.00	0.00	0.03	0.03	0.38	0.03	0.62	41.24	99.36
DOU2	8.74	0.36	4.68	1.22	0.88	0.00	0.18	1.57	0.00	0.07	0.00	2.76	79.55	100.01
DOU3	10.28	0.46	5.69	0.04	0.37	0.00	0.08	0.33	0.00	0.09	0.00	3.51	79.29	100.14
DOU4	73.91	0.83	4.45	1.07	0.12	0.09	0.90	6.81	0.00	0.41	0.02	0.18	10.72	99.51
DOU5	46.34	0.95	15.26	0.60	0.28	0.00	0.02	0.04	0.05	0.64	0.03	0.63	35.16	100.00
DOU6	5.05	0.19	3.29	0.34	0.80	0.00	0.22	1.48	0.00	0.07	0.00	2.96	84.35	98.74
DOU7	39.41	1.15	22.70	0.44	0.20	0.01	0.14	0.26	0.03	0.34	0.02	0.74	34.10	99.54
DOU8	0.62	0.12	2.18	6.12	3.08	0.00	0.15	1.56	0.00	0.01	0.04	8.20	74.41	99.33
DOU9	3.90	0.13	2.77	1.32	1.05	0.00	0.66	4.16	0.00	0.01	0.75	3.65	80.22	98.62
DOU10	14.14	0.53	9.83	3.79	1.89	0.00	0.49	2.02	0.01	0.22	0.21	1.82	63.13	98.08
DOU11	48.09	1.02	23.96	1.86	0.14	0.01	0.25	0.13	0.05	1.05	0.34	0.80	21.79	99.49
DOU12	48.21	0.97	29.38	1.19	0.06	0.01	0.43	0.39	0.08	2.77	0.04	0.71	15.70	99.94
DOU13	7.14	0.22	3.45	0.75	0.64	0.00	0.60	4.30	0.00	0.05	0.35	1.65	80.21	99.36
DOU14	8.55	0.38	4.44	1.28	0.83	0.00	0.21	1.33	0.00	0.09	0.15	1.67	79.58	98.51
DOU15	25.73	0.60	11.12	1.14	0.80	0.00	0.08	0.00	0.00	0.44	0.03	0.41	57.88	98.23
DOU16	62.96	1.08	19.95	1.12	0.10	0.01	0.07	0.03	0.04	1.72	0.06	0.55	12.58	100.27
DOU17	56.48	0.94	22.47	2.42	0.23	0.01	0.74	0.26	0.03	2.85	0.04	2.13	11.10	99.70
DOU18	8.89	0.19	3.43	1.31	1.01	0.00	0.02	0.00	0.00	0.26	0.00	4.62	80.37	100.10
DOU19	74.52	0.53	12.39	1.95	0.63	0.02	0.29	0.09	0.35	2.57	0.05	0.50	6.00	99.89
DOU20	58.36	1.09	21.94	1.38	0.15	0.00	0.02	0.06	0.03	1.41	0.06	0.56	13.63	98.69
DOU21	51.49	0.43	4.25	18.03	5.25	0.01	0.00	0.14	0.08	1.21	0.15	0.16	19.06	100.26
DOU22	0.53	0.22	2.76	6.78	4.66	0.00	0.13	3.38	0.00	0.08	1.59	1.24	78.72	100.09
DOU23	41.13	1.38	28.72	1.31	0.18	0.03	0.56	1.65	0.02	0.45	0.06	0.83	23.49	99.81
DOU24	49.04	1.11	26.51	1.51	0.08	0.01	0.45	0.27	0.03	1.26	0.14	0.83	18.94	100.18
DOU25	21.89	1.02	13.13	0.28	0.27	0.00	0.05	0.21	0.00	0.13	0.04	1.38	59.88	98.28
DOU26	11.48	0.31	9.51	0.56	0.56	0.00	0.12	2.93	0.00	0.25	1.92	1.44	69.45	98.53
DOU27	2.84	0.29	3.42	0.57	0.79	0.00	0.00	1.44	0.00	0.12	0.14	0.60	88.61	98.83
DOU28	0.70	0.41	2.74	0.74	0.91	0.00	0.00	0.97	0.00	0.12	0.10	1.66	90.32	98.67

DOU29	68.99	1.73	16.85	0.79	0.06	0.01	0.00	0.02	0.04	0.69	0.03	0.31	10.58	100.10
DOU30	52.99	1.13	26.04	1.64	0.06	0.02	0.41	0.11	0.04	1.49	0.18	0.77	15.10	99.98
DOU31	6.24	0.29	4.06	1.42	1.40	0.00	0.04	0.77	0.00	0.18	0.39	4.25	81.09	100.13
DOU32	17.81	0.67	6.63	0.16	0.31	0.00	0.04	0.51	0.00	0.06	0.61	14.29	57.96	99.06
DOU33	6.10	0.32	3.23	1.46	1.46	0.00	0.22	0.67	0.00	0.06	0.07	2.49	83.80	99.88
DOU34	55.75	1.17	23.15	2.69	0.26	0.01	0.03	0.07	0.03	1.97	0.04	0.81	13.88	99.86
DOU35	54.20	1.80	15.18	4.59	0.52	0.03	1.43	0.75	0.05	1.29	0.09	0.61	19.26	99.80
DOU36	8.21	0.41	6.48	0.13	0.31	0.00	0.04	0.28	0.00	0.11	0.00	2.91	81.04	99.92
DOU37	7.99	0.27	3.91	0.12	0.63	0.00	0.09	1.25	0.00	0.07	0.00	1.25	84.67	100.25
DOU38	17.61	0.40	7.46	0.10	0.27	0.00	0.17	0.65	0.00	0.13	0.00	1.42	72.00	100.21
DOU39	47.42	1.16	10.19	1.02	0.23	0.03	0.74	2.95	0.01	0.41	0.02	0.67	34.42	99.27
DOU40	12.49	0.27	3.91	3.41	1.67	0.00	0.01	0.20	0.00	0.01	0.00	0.57	77.47	100.01
DOU41	62.38	2.20	9.26	1.64	0.07	0.02	0.27	0.79	0.02	0.16	0.02	0.48	22.41	99.72

Table A2-39: Major element oxide concentrations for Forzando Colliery (values presented as wt%)

SiteName	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**S**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**H_2O^-**	**LOI**	**Total**
FOR1	6.82	0.17	3.03	0.19	0.43	0.00	0.48	2.71	0.05	0.00	0.00	5.41	79.79	99.08
FOR2	5.98	2.19	4.04	1.00	1.11	0.00	0.31	3.15	0.05	0.10	0.70	3.99	75.11	97.72
FOR3	57.90	1.14	20.83	2.32	0.24	0.02	0.19	0.39	0.18	1.14	0.04	0.88	14.71	99.98
FOR4	55.35	1.30	21.83	0.74	0.15	0.02	0.18	0.31	0.17	1.09	0.04	1.25	17.59	100.02
FOR5	9.33	0.23	5.67	1.22	0.94	0.00	0.20	1.24	0.03	0.14	0.01	1.71	78.33	99.05
FOR6	12.89	0.29	5.74	0.61	0.71	0.00	0.30	1.55	0.06	0.16	0.00	1.76	75.50	99.57
FOR7	76.99	0.49	12.59	1.62	0.26	0.01	0.01	0.04	0.53	4.23	0.04	0.25	3.28	100.34
FOR8	42.58	0.67	14.02	4.46	0.60	0.01	0.16	0.17	0.08	1.24	0.03	1.33	35.22	100.57
FOR9	38.54	0.99	18.23	10.37	1.73	0.01	0.12	0.17	0.21	0.92	0.07	1.20	27.58	100.14
FOR10	57.18	1.30	18.82	6.87	0.82	0.02	0.13	0.05	0.16	1.04	0.04	0.63	13.56	100.62
FOR11	4.69	0.13	3.50	0.38	0.60	0.00	0.09	0.98	0.01	0.00	0.00	3.18	86.36	99.91
FOR12	9.79	0.24	4.96	0.31	0.72	0.00	0.39	1.82	0.02	0.09	0.00	1.17	80.28	99.79
FOR13	79.08	0.48	10.11	2.65	0.60	0.02	0.00	0.05	0.46	3.67	0.03	0.21	3.22	100.58

Table A2-40: Major element oxide concentrations for Greenside Colliery (values presented as wt%)

SiteName	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**S**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**H_2O^-**	**LOI**	**Total**
GRE1	24.43	0.49	9.43	5.77	1.70	0.03	1.30	3.84	0.00	0.52	0.02	1.12	51.26	99.91
GRE2	8.29	0.35	6.29	3.33	1.92	0.00	0.25	2.11	0.00	0.10	0.49	1.77	74.95	99.85
GRE3	7.06	0.43	5.61	5.81	3.03	0.00	0.13	1.51	0.00	0.08	0.27	1.59	74.04	99.56
GRE4	9.83	0.37	4.79	1.07	0.78	0.00	0.10	1.63	0.00	0.03	0.00	2.25	78.46	99.31
GRE5	68.06	0.39	6.43	6.84	1.93	0.02	0.47	0.14	0.06	1.66	0.02	0.37	14.56	100.95
GRE6	46.84	1.04	20.39	0.43	0.11	0.00	0.03	0.06	0.06	0.82	0.06	0.74	28.66	99.24
GRE7	3.92	0.23	3.68	0.83	0.84	0.00	0.06	3.34	0.00	0.06	1.33	2.08	83.53	99.90
GRE8	5.78	0.28	4.20	0.47	0.61	0.00	0.08	3.10	0.00	0.08	1.56	2.99	80.92	100.07
GRE9	5.74	0.25	3.04	1.21	0.89	0.00	0.28	2.95	0.00	0.00	0.13	2.02	83.03	99.54
GRE10	69.83	1.76	16.95	0.82	0.07	0.01	0.00	0.03	0.15	0.70	0.03	0.30	8.69	99.34
GRE11	41.37	0.99	21.39	0.48	0.17	0.01	0.24	0.31	0.11	0.69	0.03	1.29	32.83	99.91
GRE12	3.92	0.26	2.86	2.60	1.97	0.00	0.54	3.29	0.00	0.05	0.03	3.04	80.99	99.55
GRE13	10.68	0.39	4.29	0.11	0.36	0.00	0.35	2.59	0.00	0.03	0.00	2.41	78.66	99.87
GRE14	4.61	0.38	2.09	3.08	2.18	0.00	0.74	3.77	0.00	0.00	0.01	2.67	79.45	98.98
GRE15	92.94	0.12	2.76	0.87	0.17	0.02	0.19	0.71	0.09	0.67	0.01	0.21	1.71	100.47
NGT1	52.99	0.92	17.97	4.95	0.56	0.04	1.43	0.40	0.21	3.16	0.09	2.46	14.48	99.66
NGT2	29.27	0.47	11.15	0.58	0.34	0.00	0.28	0.08	0.00	0.62	0.00	2.98	54.79	100.56
NGT3	6.90	0.08	3.10	0.23	0.48	0.00	0.04	0.00	0.00	0.16	0.00	3.19	85.22	99.40
NGT4	9.69	0.13	4.13	2.69	1.68	0.00	0.07	0.00	0.00	0.31	0.00	2.99	78.14	99.83
NGT5	54.87	0.91	22.26	2.90	0.03	0.00	1.02	0.35	0.03	2.97	0.04	4.46	9.73	99.57
NGT6	53.86	0.91	17.70	4.16	0.99	0.02	1.53	0.39	0.22	3.22	0.08	2.82	14.33	100.23
NGT7	21.85	0.31	7.04	0.42	0.41	0.00	0.24	0.08	0.00	0.51	0.00	1.98	67.23	100.07
NGT8	9.10	0.16	2.91	0.22	0.44	0.00	0.06	0.03	0.00	0.17	0.00	2.78	84.02	99.89
NGT9	8.01	0.12	3.63	0.84	0.83	0.00	0.08	0.05	0.00	0.33	0.00	2.40	83.66	99.95
NGT10	51.60	0.86	21.41	2.70	0.64	0.00	0.95	0.32	0.04	2.64	0.05	4.12	14.34	99.67
NGT11	52.86	0.91	17.77	6.10	0.65	0.05	1.68	0.44	0.32	3.16	0.10	2.03	13.94	100.01
NGT12	16.02	0.18	6.47	1.43	0.94	0.00	0.23	0.09	0.00	0.39	0.00	1.77	72.56	100.08
NGT13	6.88	0.07	3.23	0.75	0.66	0.00	0.13	0.13	0.00	0.16	0.00	2.64	85.01	99.66
NGT14	21.32	0.28	6.05	1.16	0.79	0.00	0.28	0.01	0.02	1.04	0.00	1.96	67.44	100.35

NGT15	52.94	0.87	21.48	3.22	0.05	0.01	1.16	0.35	0.08	3.01	0.04	4.29	11.64	99.14

Table A2-41: Major element oxide concentrations for Kleinkopje Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
KK1	10.39	0.88	7.68	0.59	0.47	0.00	0.35	1.90	0.00	0.11	0.65	1.62	74.04	98.68
KK2	1.03	0.00	1.15	8.09	8.36	0.00	0.42	16.90	0.00	0.00	0.50	0.91	61.76	99.12
KK3	11.88	0.88	8.85	0.43	0.29	0.00	0.08	1.05	0.00	0.12	1.17	1.65	72.64	99.04
KK4	27.65	0.98	15.99	2.36	0.17	0.00	0.54	1.97	0.03	0.80	1.19	1.26	46.15	99.09
KK5	54.70	1.66	26.40	0.66	0.04	0.01	0.07	0.07	0.03	0.80	0.04	0.82	14.13	99.43
KK6	87.99	0.79	5.89	0.71	0.03	0.01	0.00	0.07	0.03	1.33	0.02	0.02	2.78	99.67
KK7	7.46	0.34	4.39	0.47	0.33	0.00	0.16	1.50	0.00	0.12	0.00	2.36	82.97	100.10
KK8	64.52	1.16	20.36	0.63	0.04	0.01	0.02	0.05	0.03	1.93	0.05	0.65	10.38	99.83
KK9	2.06	0.21	2.75	2.67	1.73	0.00	0.54	3.40	0.00	0.07	0.11	1.68	83.23	98.45
KK10	96.02	0.05	1.16	0.80	0.05	0.01	0.00	0.00	0.00	0.27	0.01	0.10	1.03	99.50
KK11	46.82	1.07	25.31	2.91	0.08	0.04	0.70	0.38	0.05	1.97	0.32	0.83	19.51	99.99
KK12	9.03	0.37	6.89	0.51	0.51	0.00	0.09	2.03	0.00	0.24	0.59	2.11	75.96	98.33
KK13	0.00	0.55	2.10	0.19	0.83	0.00	0.05	0.64	0.01	0.31	0.01	1.64	92.70	99.04
KK14	65.85	1.57	20.01	1.27	0.58	0.00	0.04	0.15	0.04	3.11	0.12	0.28	7.40	100.42
KK15	91.04	0.29	4.55	1.00	0.59	0.03	0.00	0.01	0.01	0.87	0.02	0.32	1.34	100.07
KK16	3.74	0.25	4.10	0.14	0.44	0.00	0.00	0.55	0.00	0.02	0.44	2.05	87.99	99.72

Table A2-42: Major element oxide concentrations for Khutala Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
KHU1	4.98	0.19	5.99	2.07	1.30	0.00	0.30	1.62	0.00	0.07	0.00	3.11	80.42	100.05
KHU2	4.03	0.30	4.96	0.88	0.89	0.00	0.31	2.17	0.01	0.09	0.18	3.52	81.99	99.33
KHU3	3.46	0.19	5.11	0.50	0.61	0.00	0.64	4.33	0.02	0.10	1.38	2.14	81.34	99.81
KHU4	16.08	0.77	14.07	0.16	0.21	0.00	0.05	0.32	0.02	0.06	0.04	1.51	65.41	98.71
KHU5	10.45	0.76	8.78	0.75	0.65	0.00	0.19	1.25	0.00	0.15	0.07	11.33	65.54	99.92
KHU6	5.53	0.11	3.86	1.56	0.97	0.00	0.01	1.61	0.00	0.00	0.00	10.51	75.03	99.19

KHU7	72.37	0.73	10.05	1.49	0.30	0.01	0.00	0.05	0.00	0.30	0.02	0.55	14.48	100.35
KHU8	5.58	0.16	4.87	5.75	3.40	0.00	0.10	1.54	0.00	0.04	0.00	12.01	65.88	99.33
KHU9	8.51	0.44	7.86	0.28	0.51	0.00	0.19	1.55	0.00	0.10	0.08	6.29	74.45	100.26
KHU10	4.73	0.44	5.12	0.71	0.67	0.00	0.63	3.95	0.00	0.07	0.07	3.29	78.36	98.04
KHU11	3.99	0.50	4.48	6.17	3.65	0.00	0.45	3.18	0.00	0.12	0.39	6.32	70.21	99.46
KHU12	14.72	0.55	6.97	0.70	0.65	0.00	0.86	4.24	0.01	0.48	0.20	9.66	60.65	99.69
KHU13	9.85	0.57	6.43	0.61	0.56	0.00	0.40	1.99	0.01	0.16	0.19	4.34	73.92	99.03
KHU14	14.23	0.45	7.57	0.32	0.64	0.00	0.27	1.98	0.01	0.36	0.85	10.62	62.42	99.72
KHU15	8.30	0.46	5.62	0.44	0.72	0.00	0.48	3.65	0.00	0.20	0.58	5.03	75.14	100.62
KHU16	2.58	0.22	3.66	0.08	0.85	0.00	0.02	1.81	0.00	0.12	0.91	5.06	84.33	99.64

Table A2-43: Major element oxide concentrations for Koornfontein Colliery (values presented as wt%)

SiteName	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**S**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**H_2O^-**	**LOI**	**Total**
KOR1	5.83	0.21	3.88	0.59	0.59	0.00	0.40	2.16	0.23	0.16	0.07	2.32	81.65	98.09
KOR2	8.42	0.23	4.71	0.89	0.57	0.00	0.29	1.83	0.04	0.14	0.00	3.14	78.82	99.07
KOR3	12.27	0.42	5.66	0.36	0.31	0.00	0.27	1.53	0.03	0.10	0.00	3.16	74.63	98.73
KOR4	2.01	0.13	3.42	1.98	1.58	0.00	0.37	6.33	0.45	0.13	0.34	1.88	79.59	98.20
KOR5	4.73	0.26	3.78	0.74	0.56	0.00	0.39	3.12	0.06	0.10	0.45	3.06	80.97	98.21
KOR6	5.33	0.18	2.89	0.17	0.29	0.00	0.29	2.12	0.01	0.00	0.00	3.13	84.39	98.80
KOR7	5.99	0.34	6.08	0.53	0.52	0.00	0.37	1.48	0.07	0.21	0.05	2.01	81.64	99.29
KOR8	6.12	0.35	4.84	0.93	0.69	0.00	0.42	2.89	0.03	0.05	0.18	2.18	80.22	98.90
KOR9	8.91	0.27	4.79	3.81	1.68	0.00	0.36	1.42	0.01	0.08	0.00	1.75	75.99	99.07
KOR10	7.48	0.55	6.63	0.28	0.38	0.00	0.34	1.93	0.02	0.11	0.07	2.49	81.43	101.71
KORSST	43.34	0.79	13.08	5.22	0.07	0.16	6.12	8.42	1.71	0.62	0.11	1.36	19.74	100.74
KOR11	3.75	0.20	4.19	1.59	0.90	0.00	0.49	2.22	0.02	0.01	0.01	3.02	81.62	98.02
KOR12	15.62	0.44	6.74	0.64	0.48	0.00	0.37	1.55	0.02	0.16	0.00	2.25	70.81	99.08
KOR13	6.74	0.25	5.13	0.18	0.31	0.00	0.49	2.13	0.10	0.16	0.32	3.22	79.20	98.23
KOR14	4.47	0.29	5.03	1.44	0.82	0.00	0.36	2.38	0.02	0.05	0.21	3.36	81.45	99.88
KOR15	3.14	0.08	3.58	1.59	1.17	0.00	0.35	8.95	0.01	0.00	0.99	3.06	75.31	98.24
KOR16	0.56	0.19	2.59	2.57	1.12	0.00	0.12	1.22	0.01	0.08	0.20	2.28	87.45	98.40

KOR17	6.08	0.21	3.93	0.57	0.55	0.00	0.20	1.32	0.01	0.05	0.00	2.18	83.31	98.41
KOR18	12.95	0.43	7.61	0.96	0.55	0.00	0.11	0.39	0.02	0.09	0.00	1.84	73.76	98.71

Table A2-44: Major element oxide concentrations for Kromdraai Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
KRD1	13.78	0.66	11.27	0.77	0.70	0.00	0.01	0.00	0.00	0.17	0.24	6.11	66.83	100.54
KRD2	9.65	0.50	8.23	1.95	1.22	0.00	0.00	0.01	0.00	0.20	0.22	10.47	66.67	99.12
KRD3	11.19	0.76	10.08	0.45	0.53	0.00	0.00	0.00	0.00	0.12	0.28	7.57	69.15	100.13
KRD4	91.25	1.21	3.15	1.26	0.96	0.00	0.00	0.00	0.11	0.09	0.02	0.27	1.62	99.94
KRD5	87.21	1.44	3.13	4.01	1.44	0.01	0.00	0.00	0.03	0.12	0.02	0.33	1.94	99.68
KRD6	4.01	0.45	4.63	0.26	0.57	0.00	0.00	0.00	0.00	0.01	0.02	5.94	84.08	99.97
KRD7	0.00	0.26	2.18	0.22	0.59	0.00	0.00	0.00	0.00	0.00	0.07	8.92	87.68	99.92
KRD8	5.57	0.34	4.69	0.80	0.78	0.00	0.00	0.00	0.00	0.00	0.02	2.22	83.78	98.20
KRD9	3.39	0.21	3.11	1.31	1.36	0.00	0.00	0.00	0.00	0.10	0.00	1.66	88.54	99.68
KRD10	6.11	0.45	6.65	1.76	1.23	0.00	0.00	0.00	0.00	0.05	0.14	2.28	81.20	99.87
KRD11	3.31	0.24	4.02	2.15	1.51	0.00	0.00	0.29	0.00	0.06	0.64	2.00	84.22	98.44

Table A2-45: Major element oxide concentrations for Lakeside Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
LK1	2.11	0.08	2.17	7.51	1.44	0.00	0.40	3.25	0.04	0.00	0.00	3.30	78.76	99.06
LK2	12.50	0.26	7.67	0.15	0.17	0.00	0.06	1.32	0.00	0.19	0.01	5.11	71.62	99.06
LK3	3.89	0.10	2.96	1.56	1.09	0.00	0.08	0.77	0.02	0.05	0.00	6.06	83.09	99.67
LK4	4.49	0.05	4.61	8.36	5.12	0.00	0.09	2.04	0.00	0.08	0.00	3.77	71.52	100.13
LK5	12.24	0.24	7.76	0.69	0.55	0.00	0.23	1.32	0.00	0.12	0.00	4.12	72.93	100.20
LK6	3.93	0.16	3.69	0.79	0.60	0.00	0.06	0.70	0.04	0.00	0.01	4.89	84.93	99.80
LK7	4.07	0.16	4.69	3.70	2.45	0.00	0.24	2.70	0.02	0.02	0.00	4.42	77.28	99.75

Table A2-46: Major element oxide concentrations for Leeufontein Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
LU1	5.00	0.20	3.48	0.92	0.64	0.00	0.08	0.89	0.04	0.04	0.00	4.38	82.37	98.04
LU2	3.87	0.13	3.10	0.11	0.32	0.00	0.09	0.80	0.00	0.04	0.00	4.76	86.02	99.24
LU3	0.32	0.11	1.93	1.05	1.10	0.00	0.15	5.48	0.00	0.01	0.00	5.26	83.92	99.33
LU4	1.88	0.08	2.42	0.03	0.39	0.00	0.26	1.44	0.00	0.01	0.00	3.79	89.08	99.38
LU5	50.88	1.08	29.00	1.67	0.13	0.03	1.76	6.12	0.00	0.40	0.06	0.19	7.85	99.17
LU6	4.12	0.15	3.07	1.00	0.91	0.00	0.45	2.77	0.05	0.01	0.01	4.95	81.87	99.36
LU7	32.77	0.95	6.80	0.13	0.23	0.00	0.07	0.13	0.04	0.08	0.02	3.54	53.82	98.58
LU8	33.81	1.36	9.76	0.32	0.26	0.00	0.11	0.14	0.02	0.28	0.03	3.72	49.92	99.73
LU9	4.20	0.12	3.00	0.71	0.60	0.00	0.24	1.50	0.01	0.03	0.00	3.85	85.29	99.55
LU10	4.18	0.22	2.57	0.31	0.43	0.00	0.14	1.40	0.00	0.04	0.00	5.50	84.33	99.12
LU11	9.74	0.36	4.85	0.34	0.35	0.00	0.20	1.35	0.00	0.04	0.01	5.75	75.47	98.46
LU13	4.32	0.14	2.76	0.08	0.55	0.00	0.04	0.67	0.01	0.07	0.00	3.64	87.31	99.59
LU14	2.21	0.10	2.37	4.89	3.23	0.00	0.79	4.33	0.00	0.01	0.00	3.22	77.91	99.06
LU15	6.40	0.26	4.70	0.15	0.28	0.00	0.32	1.86	0.02	0.04	0.00	5.24	80.65	99.92
LU16	8.82	0.28	5.23	0.14	0.31	0.00	0.37	0.99	0.00	0.18	0.00	4.98	79.06	100.36
LU17	2.46	0.33	3.81	1.47	1.10	0.00	0.35	3.20	0.03	0.04	0.20	4.80	82.05	99.84
LU18	2.85	0.41	3.08	0.06	0.31	0.00	0.06	0.42	0.04	0.03	0.00	5.80	86.28	99.34
LU19	0.00	0.10	1.85	6.27	4.36	0.00	0.23	2.72	0.04	0.03	0.03	3.17	81.09	99.89
LU20	0.27	0.05	2.18	3.73	2.61	0.00	0.19	2.28	0.03	0.02	0.00	3.01	84.68	99.05
LU21	30.03	1.24	15.42	0.27	0.15	0.00	0.07	0.00	0.04	0.05	0.00	3.17	47.89	98.33
LU22	5.67	0.20	3.99	0.08	0.22	0.00	0.07	0.74	0.04	0.02	0.00	4.88	83.52	99.43
LU23	4.09	0.12	3.16	1.61	1.07	0.00	0.24	1.62	0.03	0.00	0.00	3.07	84.92	99.93
LU24	0.51	0.16	2.97	0.86	0.92	0.00	0.13	1.93	0.00	0.00	0.00	3.46	89.01	99.95
LU25	3.32	0.20	4.64	3.83	2.26	0.00	0.77	2.65	0.00	0.02	0.14	4.58	77.51	99.92
LU26	0.00	0.11	2.60	1.33	1.17	0.00	0.22	1.90	0.00	0.08	0.24	4.73	87.22	99.60
LU27	9.14	0.70	8.18	0.16	0.31	0.00	0.05	0.10	0.00	0.19	0.12	6.06	74.66	99.67
LU28	7.48	0.41	6.98	0.96	0.99	0.00	0.42	1.87	0.00	0.10	0.23	5.17	75.05	99.66
LU29	3.79	0.47	4.82	0.13	0.40	0.00	0.13	0.87	0.00	0.18	0.10	4.45	84.60	99.94

LU30	0.00	0.17	2.24	2.03	1.27	0.00	0.23	1.46	0.00	0.08	0.00	4.72	87.27	99.47
LUP1	3.44	0.46	4.33	2.37	1.97	0.00	0.03	1.08	0.00	0.15	0.00	6.26	79.61	99.70
LUP2	0.00	0.15	1.62	2.76	2.15	0.00	0.06	1.92	0.00	0.03	0.05	7.59	83.68	100.01
LUP3	0.00	0.20	0.44	0.68	0.97	0.00	0.28	3.54	0.00	0.03	0.00	3.36	90.13	99.63
LUP4	6.93	0.37	6.75	1.06	1.32	0.00	0.05	0.32	0.00	0.56	0.53	6.32	75.72	99.93

Table A2-47: Major element oxide concentrations for Middelburg Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
M1	17.01	0.73	8.38	2.75	0.72	0.00	0.07	0.00	0.00	0.14	0.00	1.33	66.88	98.01
M2	7.89	0.37	4.40	1.85	0.68	0.00	0.02	0.01	0.00	0.08	0.00	1.30	83.08	99.68
M3	87.98	0.55	6.30	0.95	0.02	0.01	0.00	0.00	0.03	0.58	0.02	0.25	2.83	99.52
M4	77.01	0.56	10.71	0.94	0.03	0.02	0.00	0.20	0.01	0.58	0.02	0.37	9.33	99.78
M5	10.09	0.50	6.12	1.48	0.80	0.00	0.47	2.03	0.00	0.15	0.00	1.62	75.36	98.63
M6	15.62	1.24	9.56	0.46	0.22	0.00	0.19	0.75	0.01	0.18	0.00	2.64	67.86	98.73
M7	6.47	0.50	5.70	1.74	0.45	0.00	0.21	1.21	0.00	0.17	0.06	2.81	78.91	98.23
M8	8.09	0.37	7.51	3.33	1.37	0.00	0.21	0.65	0.00	0.11	0.02	2.32	74.56	98.54
M9	11.63	0.70	9.53	0.68	0.45	0.00	0.11	0.48	0.00	0.12	0.53	2.34	73.02	99.59
M10	37.49	1.54	31.06	1.05	0.24	0.01	0.24	0.10	0.00	0.52	0.23	1.68	25.77	99.93
M11	11.30	0.48	5.50	0.55	0.27	0.00	0.08	0.55	0.00	0.14	0.00	1.59	79.28	99.74
M12	10.73	0.38	5.45	1.22	0.72	0.00	0.08	1.57	0.01	0.15	0.00	1.54	76.37	98.22
M13	79.19	0.38	4.42	1.63	0.19	0.03	1.39	3.23	0.25	0.47	0.01	0.35	8.71	100.25
M14	12.76	0.33	7.65	0.35	0.41	0.00	0.20	1.34	0.03	0.08	0.00	1.69	75.51	100.35
M15	2.79	0.35	3.87	0.98	0.74	0.00	0.10	0.75	0.03	0.04	0.00	2.19	87.66	99.50
M16	3.71	0.36	4.51	2.90	1.73	0.00	0.41	2.40	0.03	0.06	0.24	3.22	80.29	99.86
M17	4.50	0.22	4.92	0.36	0.51	0.00	0.23	4.69	0.00	0.13	1.42	3.18	80.07	100.23
M18	8.96	0.26	3.77	0.60	0.46	0.00	0.34	2.68	0.00	0.07	0.00	4.16	78.33	99.63
M19	16.69	0.47	5.83	3.80	0.72	0.00	0.10	0.35	0.00	0.17	0.00	5.11	66.56	99.80
M20	7.59	0.21	3.19	4.68	2.89	0.00	0.00	0.00	0.00	0.23	0.01	0.95	80.30	100.05
M21	77.48	0.69	12.20	1.10	0.24	0.01	0.00	0.03	0.06	2.82	0.03	0.49	4.77	99.92
M22	62.16	0.90	18.73	3.00	0.45	0.02	0.43	0.11	0.04	2.81	0.06	0.73	10.99	100.43

Table A2-48: Major element oxide concentrations for Optimum Colliery (values presented as wt%)

SiteName	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**S**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**H_2O^-**	**LOI**	**Total**
OPT1	15.94	0.27	6.88	7.38	4.11	0.00	0.08	0.02	0.00	0.24	0.00	4.95	58.44	98.31
OPT2	0.00	0.14	1.45	0.21	0.77	0.00	0.03	0.43	0.00	0.00	0.00	2.10	94.72	99.85
OPT3	79.66	0.70	11.28	0.48	0.01	0.01	1.01	0.03	0.10	2.94	0.05	0.23	3.42	99.92
OPT4	7.23	0.25	4.52	0.35	0.62	0.00	0.51	1.33	0.00	0.06	0.00	8.32	76.31	99.50
OPT5	4.03	0.09	2.83	0.30	0.61	0.00	0.12	0.42	0.00	0.07	0.00	2.65	87.66	98.78
OPT6	14.35	0.38	7.30	0.20	0.41	0.00	0.03	0.16	0.00	0.17	0.01	2.46	72.95	98.42
OPT7	3.43	0.19	2.75	0.04	0.59	0.00	0.08	1.15	0.00	0.12	0.06	2.63	87.41	98.45
OPT8	69.03	0.36	5.28	9.20	2.70	0.04	0.18	3.96	0.03	1.05	0.03	0.26	7.73	99.85
OPT9	7.24	0.30	4.36	0.08	0.43	0.00	0.00	0.00	0.00	0.05	0.02	4.07	82.60	99.15
OPT10	7.65	0.33	5.43	0.09	0.23	0.00	0.13	0.41	0.00	0.09	0.09	4.47	81.51	100.43
OPT11	89.35	0.44	4.73	1.38	0.38	0.01	0.00	0.00	0.05	0.78	0.02	0.16	2.81	100.11
OPT12	11.01	0.78	4.51	0.15	0.62	0.00	0.00	0.00	0.00	0.08	0.04	3.11	79.61	99.91
OPT13	7.74	0.34	4.34	0.11	0.48	0.00	0.33	0.88	0.00	0.10	0.00	2.46	83.07	99.85

Table A2-49: Major element oxide concentrations for Rietspruit Colliery (values presented as wt%)

SiteName	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**S**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**H_2O^-**	**LOI**	**Total**
R2RO	53.64	1.06	22.35	2.01	0.14	0.01	0.56	0.37	0.54	1.61	0.10	1.10	15.95	99.44
R2M	7.35	0.33	5.92	0.36	0.40	0.00	0.07	1.87	0.00	0.10	1.40	2.47	78.05	98.32
R2M2	3.63	0.10	3.68	1.52	1.57	0.00	0.14	6.08	0.00	0.13	0.65	2.47	78.80	98.77
R2LW	2.34	0.21	3.97	0.30	0.49	0.00	0.44	2.77	0.04	0.05	0.93	3.24	84.02	98.80
R4UROOF	53.88	0.93	20.00	2.43	0.41	0.02	0.76	0.16	0.21	2.35	0.06	0.85	17.29	99.35
R4U	27.63	0.37	11.21	0.92	1.06	0.00	0.31	0.52	0.03	0.56	0.00	1.73	54.44	98.78
R4PT	53.74	0.95	23.10	0.58	0.26	0.01	0.29	0.17	0.61	1.25	0.04	0.99	17.23	99.22
R4L	10.77	0.45	5.06	0.38	0.74	0.00	0.37	1.39	0.00	0.13	0.09	2.26	77.78	99.42
R4FUG	80.67	1.59	8.99	0.54	0.54	0.01	0.00	0.05	1.38	0.16	0.02	0.27	5.56	99.78
R4FLG	75.43	3.84	5.03	6.10	0.34	0.20	0.50	0.35	1.55	0.25	0.03	0.20	6.38	100.20
R4F1	63.67	3.55	17.22	1.95	0.24	0.05	0.15	0.14	1.48	0.27	0.02	0.73	10.47	99.94

R4F2	52.73	5.68	25.73	1.48	0.05	0.03	0.24	0.15	1.75	0.87	0.03	0.94	10.07	99.75
R4F3	73.17	1.98	10.37	2.39	0.79	0.06	0.16	0.14	1.30	0.32	0.02	0.59	9.44	100.73

Table A2-50: Major element oxide concentrations for South Witbank Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
SW1	8.75	0.23	5.45	1.90	1.66	0.00	0.32	3.59	0.16	0.08	0.21	7.31	70.28	99.94
SW2	17.37	0.46	8.17	0.18	0.52	0.00	0.28	1.82	0.14	0.08	0.03	2.41	66.85	98.31
SW3	16.01	0.49	7.63	0.20	0.61	0.00	0.24	1.69	0.16	0.11	0.09	2.58	68.23	98.04
SW4	7.62	0.35	3.88	0.14	0.72	0.00	0.32	2.88	0.08	0.07	0.70	3.42	78.23	98.40
SW5	11.75	0.33	5.32	2.11	1.77	0.00	0.52	3.35	0.06	0.13	0.41	2.66	70.60	99.01
SW6	20.90	0.65	8.68	0.66	0.65	0.00	0.30	1.43	0.09	0.22	0.03	2.73	61.78	98.12
SW7	6.54	0.26	4.25	0.55	0.90	0.00	0.32	2.56	0.09	0.11	1.04	9.66	73.52	99.80
SW8	4.93	0.23	3.13	1.00	1.20	0.00	0.42	3.38	0.09	0.11	1.00	2.94	80.39	98.82
SW9	9.86	0.33	4.69	0.33	0.81	0.00	0.30	2.19	0.07	0.19	0.74	2.79	77.58	99.88
SW10	5.53	0.22	4.71	1.60	1.65	0.00	0.29	3.79	0.08	0.05	0.37	2.98	77.21	98.48

Table A2-51: Major element oxide concentrations for Tavistock Colliery (values presented as wt%)

SiteName	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	S	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	LOI	Total
TAV1A	6.50	0.11	3.84	1.82	1.69	0.00	0.60	5.13	0.00	0.10	1.82	2.38	74.79	98.78
TAV1B	4.28	0.11	4.15	0.25	0.64	0.00	0.39	4.01	0.00	0.12	3.07	3.08	79.69	99.79
TAV1C	3.48	0.14	3.38	3.28	2.35	0.00	0.23	3.55	0.00	0.06	2.06	2.43	78.76	99.72
TAV2A	6.29	0.24	4.11	0.14	0.64	0.00	0.30	3.36	0.00	0.08	2.01	2.02	80.78	99.97
TAV2B	6.69	0.22	4.66	0.56	0.84	0.00	0.45	4.54	0.00	0.08	1.72	2.39	76.32	98.47
TAV2C	10.74	0.52	5.33	0.19	0.56	0.00	0.41	1.89	0.00	0.10	0.21	2.50	77.18	99.63
TAV3A	8.21	0.23	2.84	1.30	1.01	0.00	0.24	1.53	0.00	0.01	0.08	2.36	80.83	98.64
TAV3B	8.58	0.28	3.47	0.36	0.64	0.00	0.25	2.02	0.00	0.02	0.07	2.52	80.39	98.60
TAV3C	5.79	0.14	3.16	4.86	3.26	0.00	0.49	4.26	0.00	0.00	0.08	5.96	70.84	98.84
TAV4A	53.87	1.02	23.25	0.64	0.06	0.01	0.18	0.13	0.04	1.35	0.04	1.08	17.52	99.19
TAV4B	53.90	1.04	23.17	0.65	0.07	0.00	0.18	0.09	0.04	1.43	0.04	1.12	17.66	99.39
TAV4C	53.87	1.03	23.15	0.63	0.06	0.01	0.22	0.10	0.04	1.39	0.04	1.15	17.44	99.13

TAV5A	5.98	0.61	4.43	0.98	1.36	0.00	0.14	1.65	0.00	0.37	1.10	2.89	80.35	99.86
TAV5B	10.32	0.56	7.86	0.67	1.09	0.00	0.29	1.48	0.00	0.42	0.98	2.38	74.09	100.15
TAV5C	11.04	0.47	7.02	0.64	1.00	0.00	0.21	0.74	0.00	0.38	0.62	2.60	74.97	99.69
TAV6A	5.64	0.26	3.62	1.04	1.29	0.00	0.30	3.32	0.00	0.14	0.80	2.76	79.09	98.26
TAV6B	5.62	0.29	5.22	0.35	0.77	0.00	0.33	2.42	0.00	0.14	0.65	2.23	81.66	99.68
TAV6C	5.49	0.31	4.95	0.76	0.99	0.00	0.35	2.42	0.00	0.15	0.77	3.47	80.11	99.77
TAV7A	6.04	0.33	3.79	2.05	1.49	0.00	0.48	2.52	0.00	0.07	0.23	2.83	78.30	98.13
TAV7C	23.58	0.83	12.89	0.16	0.32	0.00	0.18	0.20	0.03	0.28	0.01	2.22	59.22	99.92

Table A2-52: Major element oxide concentrations for Union Colliery (values presented as wt%)

SiteName	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**S**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**H_2O^-**	**LOI**	**Total**
UN1	6.59	0.29	4.44	0.75	1.28	0.00	0.10	1.25	0.00	0.12	0.04	2.83	81.90	99.59
UN2	5.96	0.32	4.35	0.68	1.05	0.00	0.11	0.98	0.00	0.12	0.04	3.36	82.75	99.72
UN3	6.27	0.25	4.35	0.96	0.88	0.00	0.02	0.52	0.00	0.12	0.02	4.34	81.08	98.81
UN4	6.65	0.24	4.25	0.67	0.78	0.00	0.02	0.51	0.00	0.12	0.01	5.64	80.53	99.42
UN5B	7.16	0.25	3.87	0.67	0.86	0.00	0.00	0.16	0.00	0.20	0.00	2.46	83.32	98.95
UN6B	5.79	0.25	3.47	0.64	0.93	0.00	0.00	0.09	0.00	0.10	0.00	4.79	83.44	99.50

Table A2-53: Trace element concentrations for Arnot Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
ARA1	-	28.90	393.20	109.10	360.00	19.20	30.20	35.80	89.00	136.10	481.80	112.70	119.40	94.60
ARA2	-	29.70	318.30	78.70	389.80	11.40	25.00	33.20	528.10	89.70	657.80	145.40	102.50	76.50
ARA3	-	21.00	244.40	42.10	210.50	12.30	3.60	11.80	257.70	12.90	336.40	27.60	20.20	7.70
ARA4	-	0.80	200.40	60.00	182.60	9.30	7.50	25.90	307.90	64.10	403.10	31.70	50.00	16.70
ARA5	63.59	1.87	77.53	81.22	48.67	3.48	40.44	6.67	27.17	9.81	24.82	7.28	38.22	-
ARA6	-	38.60	285.10	62.20	229.10	11.40	15.20	8.80	174.90	13.60	72.30	44.80	19.40	7.10
ARA7	-	41.70	315.80	85.20	250.70	15.60	25.20	27.10	201.70	20.90	185.80	116.10	39.60	5.40
ARA8	-	31.90	278.70	82.20	235.30	13.90	24.70	17.50	140.70	21.50	134.80	67.50	37.70	6.80
ARA9	99.48	3.61	202.54	158.02	79.02	9.01	14.94	10.85	43.50	7.53	48.49	10.55	34.81	-
ARA10	89.49	3.61	293.05	239.42	59.73	7.96	11.87	7.51	27.77	6.99	17.37	32.22	14.15	-
ARA11	-	17.10	145.80	34.10	268.80	15.60	7.10	9.90	268.60	11.60	142.50	110.60	45.70	22.30
ARA12	-	30.50	221.80	49.20	228.60	14.40	27.40	11.30	89.90	22.00	115.00	89.70	26.40	0.00
ARA13	0.00	10.40	255.09	114.56	116.17	5.93	43.56	23.78	150.80	21.80	191.91	56.77	26.85	-
ARA14	-	32.30	346.50	62.30	168.30	10.60	6.20	18.20	171.00	26.10	215.20	33.60	27.40	6.30
ARA15	15.77	21.62	167.48	103.48	155.14	10.73	43.75	21.90	87.62	17.17	86.32	10.52	14.57	-
ARA16	-	126.30	605.40	117.30	248.10	14.50	16.70	6.50	35.20	1.50	46.80	33.00	18.50	4.40
ARB1	-	33.70	224.40	57.50	190.90	17.50	16.10	12.50	187.20	24.10	194.50	56.70	382.20	69.10
ARB2	34.18	9.15	231.88	98.39	103.58	10.33	27.95	11.47	110.22	46.01	111.20	15.60	51.66	-
ARB3	-	37.40	271.20	135.30	237.30	12.60	15.60	9.50	162.70	2.90	58.10	36.10	25.30	4.50
ARB4	-	27.10	257.60	103.10	205.40	12.20	14.00	13.40	122.50	8.30	95.70	44.60	20.00	0.70
ARB5	59.59	18.61	309.79	140.54	103.13	6.75	15.19	12.20	123.32	12.87	109.52	18.73	61.51	-
ARB6	-	27.00	209.50	319.40	160.80	11.10	12.00	7.40	79.10	6.60	28.50	30.00	20.90	6.80
ARB7	88.74	2.56	200.70	118.99	42.13	7.51	4.63	4.17	57.34	4.52	66.63	10.34	21.76	-
ARB8	-	6.60	95.90	31.70	119.20	8.20	0.60	1.50	87.00	3.00	103.40	38.50	32.60	6.90
ARB9	-	25.70	260.70	50.60	248.10	13.70	18.60	12.20	131.20	20.20	166.00	60.80	32.50	8.90
ARB10	0.00	9.03	168.40	85.22	91.95	7.23	38.32	18.98	41.91	15.64	64.90	15.51	37.87	-
ARB11	-	51.70	236.50	62.90	151.90	16.90	9.80	18.90	109.60	30.20	129.40	32.40	27.50	5.10
ARB13	-	143.00	538.30	207.10	359.00	19.80	30.10	18.40	68.20	5.50	74.70	77.90	16.90	16.50
ARC1	-	5.80	247.40	51.70	232.40	8.50	15.50	36.40	412.80	42.00	542.70	66.90	69.00	21.40

ARC2	139.86	4.92	157.12	112.85	83.68	3.43	40.94	13.45	105.94	15.44	86.24	26.48	60.72	-
ARC3	-	34.50	223.10	61.60	336.70	13.90	19.50	7.70	178.00	6.30	69.30	47.20	17.00	5.10
ARC4	-	38.80	317.80	50.90	224.70	12.60	183.60	16.40	152.60	19.50	17.50	43.60	37.90	7.00
ARC5	63.22	5.68	270.30	116.35	33.12	4.95	9.05	3.23	15.37	13.75	23.90	10.14	38.54	-
ARC6	103.67	2.07	236.15	96.66	80.86	9.28	13.90	7.30	33.79	6.39	24.55	11.54	5.59	-
ARC7	-	4.60	134.20	45.70	142.50	10.30	0.80	3.80	130.60	7.00	298.10	24.90	48.40	10.10
ARD1	-	2.00	251.50	49.10	243.00	5.20	23.20	24.80	341.30	20.40	335.00	50.10	43.40	21.30
ARD2	117.44	6.11	156.03	101.34	113.18	6.00	44.86	17.73	233.61	18.03	174.29	23.99	61.46	-
ARD3	-	29.40	186.40	208.80	181.60	10.10	14.00	8.60	101.60	3.30	39.60	21.60	32.60	1.90
ARD4	-	38.40	300.60	58.60	191.70	11.40	37.60	20.20	167.60	19.60	135.00	82.50	27.40	6.10
ARD5	33.51	2.40	256.08	91.20	101.17	10.47	22.24	9.80	39.87	5.66	32.92	8.84	19.15	-
ARD6	269.78	6.77	173.14	122.53	87.72	7.41	12.31	6.47	109.58	19.98	654.02	45.93	19.32	-
ARD7	-	0.00	174.60	70.10	113.80	9.00	1.30	7.90	171.30	10.20	1276.00	76.20	6.70	3.50

Table A2-54: Trace element concentrations for Arnot-North Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
3936	-	93.50	461.40	320.10	320.10	25.20	57.10	23.20	232.40	42.70	187.90	110.10	59.60	36.50
3937	-	98.70	387.20	132.70	350.80	23.10	58.10	25.00	183.00	30.70	154.40	88.80	30.70	26.00
3938	194.23	0.00	6.50	14.60	19.10	0.00	0.00	0.00	3.30	0.00	0.00	2.30	0.20	-
3939	-	27.70	783.90	435.00	210.30	13.50	24.50	25.00	276.50	29.80	270.40	66.70	45.70	29.00
3940	-	89.80	310.50	88.60	300.70	17.40	31.00	12.90	361.40	49.20	237.70	112.70	38.90	16.50
3941	-	119.70	495.50	165.10	302.40	19.90	58.50	28.20	65.20	34.00	85.00	135.20	7.50	53.90
3942	-	135.90	551.30	190.50	317.10	22.40	62.40	20.50	179.60	50.20	211.50	146.30	57.00	42.40
3943	-	73.70	467.70	641.20	226.30	22.50	61.00	26.40	215.30	54.60	204.10	150.40	69.40	54.90
3944	-	92.70	371.70	167.30	345.40	24.30	45.50	17.00	125.70	36.80	135.90	135.00	54.00	64.30
3945	117.62	0.00	310.40	136.70	75.50	0.00	0.00	14.50	156.30	0.00	102.50	22.10	15.50	-
3946	-	37.60	330.20	75.40	594.60	24.70	19.40	15.90	752.80	29.50	338.20	71.10	42.40	23.90
3947	-	76.80	364.10	52.90	347.60	18.00	25.10	11.10	371.30	20.40	178.70	87.10	24.10	15.70
3948	-	166.00	450.60	142.60	312.20	27.60	48.00	21.60	178.00	47.40	206.30	248.70	86.40	69.40
3949	-	51.30	362.10	372.60	474.20	28.50	62.80	23.00	218.90	36.90	148.50	70.20	45.60	23.20
3950	-	27.30	427.60	180.70	283.80	18.70	35.90	22.10	261.20	30.00	578.40	95.10	68.50	33.60
3951	98.65	0.00	272.20	63.10	119.50	1.10	0.10	14.50	260.20	0.00	198.50	26.40	47.50	-

3952	-	25.60	222.30	53.70	360.70	20.20	18.60	18.40	429.30	30.70	1018.70	89.30	46.40	14.90
3953	-	92.30	336.60	76.80	312.80	19.50	41.20	17.70	171.70	47.50	151.10	104.40	33.40	40.00
3954	-	60.00	593.50	361.80	431.90	9.30	229.50	37.10	239.90	92.90	134.80	68.20	59.40	16.50
3955	237.44	0.00	457.70	119.00	135.60	0.40	37.90	31.40	544.10	4.60	684.40	32.50	46.00	-
3956	-	20.10	194.70	45.60	142.00	12.90	11.80	6.50	149.20	9.20	329.80	22.20	17.80	1.10
3957	215.67	30.20	370.60	80.00	328.30	14.80	34.70	20.20	491.40	29.50	594.00	74.00	63.70	-
3958	-	51.30	385.80	88.70	383.90	25.50	22.50	13.10	489.40	19.80	241.70	62.10	51.60	21.00
3959	-	16.10	227.40	63.50	391.40	15.60	31.30	27.30	285.80	27.50	362.00	52.90	37.80	16.60

Table A2-55: Trace element concentrations for Bank Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
BAN1	78.64	5.48	652.38	407.09	17.82	4.97	7.19	3.13	1.03	6.44	12.96	5.39	8.00	-
BAN2	80.13	7.22	734.42	482.43	23.54	4.86	7.58	6.67	11.59	8.20	17.93	7.74	8.68	-
BAN3	63.07	12.81	802.73	646.05	40.12	4.70	21.26	7.30	15.52	9.78	25.06	11.99	14.20	-
BAN4	110.52	3.46	524.21	540.07	9.90	4.56	7.30	4.48	8.80	7.74	13.85	3.30	12.81	-
BAN5	82.83	4.88	421.63	88.31	86.87	10.06	12.74	7.51	32.15	6.02	26.06	2.86	8.08	-
BAN6	108.91	3.62	413.80	213.10	40.37	7.39	5.71	1.15	5.46	5.83	16.99	2.13	8.54	-
BAN7	91.62	5.83	307.75	148.11	233.50	17.21	30.44	12.72	71.98	9.37	54.45	8.32	24.55	-
BAN8	142.96	6.00	865.77	172.14	42.73	6.60	4.81	4.17	0.00	6.82	14.88	17.97	33.56	-
BAN9	143.49	5.57	932.92	613.00	0.00	3.44	2.51	2.81	2.92	8.51	13.75	3.49	24.33	-
BAN10	-	57.80	530.70	527.70	256.10	17.70	38.60	24.60	218.50	34.70	178.50	127.70	51.30	27.60
BAN11	-	138.80	257.20	54.70	225.40	16.90	23.30	14.70	142.10	5.10	72.20	60.50	12.80	3.70
BAN12	0.00	13.96	24.38	17.34	43.09	7.59	4.46	1.67	2.12	6.41	18.50	1.36	0.00	-
BAN13	0.00	5.56	0.00	2.85	44.31	6.56	2.52	0.10	0.00	7.32	11.13	2.53	0.00	-
BAN14	-	204.60	188.40	113.20	159.80	11.30	78.80	17.70	51.30	3.60	35.20	38.00	15.30	127.00
BAN15	-	139.90	246.70	68.70	200.70	15.60	22.10	16.10	166.80	5.70	66.70	59.60	19.50	6.50
BAN16	0.00	6.55	0.00	3.76	42.26	6.81	3.09	1.46	0.00	9.93	9.40	0.88	0.00	-
BAN17	0.00	15.26	6.50	9.12	79.46	13.99	8.63	3.44	0.58	9.51	18.64	4.77	0.00	-
BAN18	-	388.40	315.10	93.10	293.20	10.00	32.60	21.60	103.50	5.40	86.20	83.50	34.60	36.10
BAN19	36.20	2.94	524.79	184.85	98.71	10.22	18.49	10.64	44.65	9.53	31.03	4.53	10.90	-
BAN20	61.05	3.90	712.45	355.64	100.37	11.65	18.24	9.07	3.45	10.19	36.57	4.30	7.29	-

BAN21	68.19	4.60	830.46	584.36	58.94	6.82	15.27	8.13	25.43	14.17	25.55	3.62	9.55	-

Table A2-56: Trace element concentrations for Bankfontein Colliery (values presented as ppm)

SiteName	**Mn**	**Rb**	**Ba**	**Sr**	**Zr**	**Nb**	**Y**	**Sc**	**Cr**	**Cu**	**V**	**Zn**	**Ni**	**Co**
BK1	5.92	0.00	392.35	448.17	41.24	8.83	12.04	3.32	27.37	11.02	20.55	3.89	17.54	-
BK2	106.40	0.00	25.76	286.29	34.28	7.19	16.91	2.99	0.00	8.48	1.29	3.13	32.68	-
BK3	3.75	19.72	51.43	18.34	328.47	15.68	9.38	0.23	65.71	9.37	40.14	26.10	28.50	-

Table A2-57: Trace element concentrations for Borehole 1 (values presented as ppm)

SiteName	**Mn**	**Rb**	**Ba**	**Sr**	**Zr**	**Nb**	**Y**	**Sc**	**Cr**	**Cu**	**V**	**Zn**	**Ni**	**Co**
BH1-1	75.98	94.60	204.56	118.78	248.29	14.91	23.86	10.43	52.37	24.87	51.70	71.27	34.27	-
BH1-2	21.01	38.54	117.58	105.80	176.78	10.93	26.35	10.95	40.51	15.31	43.40	21.27	5.58	-
BH1-3	-	30.80	113.90	107.90	108.50	9.50	6.90	1.30	46.10	4.80	5.50	16.10	11.90	14.20
BH1-4	85.15	16.78	3950.45	3962.84	0.00	0.00	33.98	7.72	20.65	27.38	16.91	17.79	11.03	-
BH1-5	92.26	11.60	1491.04	1035.59	4.90	4.29	10.14	8.45	27.02	19.86	27.60	10.60	9.42	-
BH1-6	115.42	11.28	1539.55	793.86	44.94	4.86	19.10	8.13	25.83	12.73	35.06	9.50	12.41	-
BH1-7	-	54.60	446.70	112.90	459.10	18.20	19.60	10.60	81.50	9.80	90.10	37.80	18.20	0.80

Table A2-58: Trace element concentrations for Borehole wedge 1 (values presented as ppm)

SiteName	**Mn**	**Rb**	**Ba**	**Sr**	**Zr**	**Nb**	**Y**	**Sc**	**Cr**	**Cu**	**V**	**Zn**	**Ni**	**Co**
BHW1-1	-	87.90	432.10	120.40	127.50	7.70	8.70	5.80	42.30	0.00	34.30	19.50	5.80	0.40
BHW1-2	-	91.10	447.40	113.60	187.90	9.90	10.20	3.10	51.10	0.00	50.00	28.80	7.50	5.20
BHW1-3	-	74.60	364.30	267.00	179.20	9.00	11.70	5.40	42.50	0.00	41.50	17.40	5.40	0.40
BHW1-4	-	119.50	312.60	148.70	209.90	18.40	34.60	18.40	126.90	7.80	101.90	76.60	28.10	66.80
BHW1-5	-	63.70	238.30	253.80	247.20	14.30	25.40	7.00	106.10	6.20	54.70	23.80	15.30	18.80
BHW1-6	55.55	6.60	178.46	159.69	103.59	3.68	93.76	8.66	58.54	15.69	53.21	6.05	23.87	-
BHW1-7	112.13	5.81	257.81	365.33	80.00	7.24	44.02	10.01	32.70	17.99	32.36	2.10	22.42	-
BHW1-8	186.18	4.15	331.73	612.99	33.83	3.49	37.20	7.40	44.45	14.56	32.16	1.24	10.44	-
BHW1-9	132.07	2.84	228.30	235.55	59.16	0.00	155.66	9.91	87.97	9.22	44.31	1.60	24.22	-
BHW1-10	-	19.90	187.50	59.20	147.90	11.10	49.30	13.40	149.00	0.00	129.90	18.10	26.00	9.10

BHW1-11	-	78.60	420.30	91.80	58.80				73.90	0.00	76.30	38.80	20.10	1.00
BHW1-12	-	72.10	459.10	75.50	143.50	12.4		6.30	38.50	0.00	42.10	20.00	10.90	0.00

Table A2-59: Trace element concentrations for Borehole wedge 2 (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
BHW2-1	-	92.50	423.00	115.00	130.70	8.60	8.50	2.90	51.90	1.90	37.60	20.90	9.60	3.50
BHW2-2	3.91	65.25	235.16	154.48	216.21	21.52	44.67	11.26	45.15	39.09	70.01	31.26	20.09	-
BHW2-3	6.49	47.57	183.95	152.03	195.71	7.40	33.99	6.05	46.14	38.78	78.95	29.02	30.24	-
BHW2-4	-	143.80	389.20	91.30	605.80	22.90	44.60	12.20	136.00	10.10	95.50	58.20	32.50	8.90
BHW2-5	-	97.50	424.30	158.90	183.30	13.70	20.90	11.50	121.90	15.20	81.50	19.40	16.40	23.40
BHW2-6	31.86	7.91	173.09	139.11	137.06	12.46	23.55	8.45	24.33	18.36	38.57	2.92	6.91	-
BHW2-7	172.90	4.90	333.80	434.91	34.56	5.29	10.36	6.47	9.74	8.93	9.40	0.77	2.70	-
BHW2-8	248.56	3.96	291.34	918.37	0.00	3.57	2.78	6.67	30.56	14.28	18.39	2.88	64.02	-
BHW2-9	-	35.90	294.10	88.00	209.20	19.50	3.80	14.50	232.60	2.60	165.00	34.80	37.30	11.20

Table A2-60: Trace element concentrations for Borehole wedge 3 (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
BHW3-1	-	77.70	365.70	76.60	275.10	8.10	9.60	2.20	47.30	0.00	24.40	6.80	5.10	0.00
BHW3-2	40.28	11.51	269.11	163.43	138.14	5.56	39.33	18.15	133.88	13.45	140.88	8.66	1.36	-
BHW3-3	-	161.90	276.90	110.90	122.60	6.50	15.00	8.60	91.00	3.00	55.90	13.50	12.20	38.00
BHW3-4	61.05	11.97	98.43	150.55	93.95	5.73	13.91	5.63	18.90	9.75	27.55	14.42	1.65	-
BHW3-5	-	145.70	359.60	142.00	189.40	8.70	23.40	22.10	164.00	9.00	137.80	80.00	42.20	42.90
BHW3-6	-	79.50	329.70	285.00	126.50	8.70	16.90	7.40	32.20	2.60	25.40	26.30	13.60	3.10
BHW3-7	-	188.40	149.10	182.70	124.20	13.00	25.80	13.10	42.10	5.10	31.40	20.80	11.00	93.50
BHW3-8	30.51	11.12	213.36	111.52	293.04	5.35	39.09	21.38	167.44	14.82	190.66	10.28	5.57	-
BHW3-9	-	124.60	419.80	60.00	494.40	20.00	29.30	10.20	158.10	12.50	122.10	55.60	35.60	8.10
BHW3-10	-	68.40	240.50	86.50	1222.60	26.40	46.80	4.00	205.10	9.50	53.70	46.60	32.90	13.00
BHW3-11	122.90	7.72	336.55	353.64	203.07	6.93	15.56	9.07	95.39	12.17	66.36	16.36	4.86	-
BHW3-12	189.48	5.83	444.93	671.78	20.77	4.15	9.69	7.30	19.10	14.86	26.20	0.87	10.31	-
BHW3-13	138.25	8.72	1366.50	1832.38	0.00	0.00	9.69	8.86	66.90	17.00	56.67	5.46	24.59	-

BHW3-14	-	47.90	386.60	63.10	106.30	12.60	0.00	6.50	68.50	0.00	71.10	14.90	35.70	6.60

Table A2-61: Trace element concentrations for Borehole wedge 4 (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
BHW4-1	38.15	18.39	99.72	132.69	103.16	7.39	18.51	7.93	19.95	12.21	12.55	5.45	15.92	-
BHW4-2	-	125.50	319.70	100.90	520.20	20.40	35.20	15.70	144.80	9.60	74.50	79.50	37.30	34.30
BHW4-3	20.67	24.47	159.16	109.16	104.29	6.37	41.62	6.88	55.30	16.51	59.93	16.21	14.30	-
BHW4-4	-	86.90	306.30	78.60	420.30	24.60	42.60	7.90	75.10	13.00	51.20	62.50	39.90	19.50
BHW4-5	-	39.20	178.80	44.40	299.90	13.80	14.50	4.00	54.60	5.40	41.70	23.30	9.20	7.70
BHW4-6	86.64	9.01	256.40	193.62	139.06	6.27	31.81	10.74	60.78	10.58	88.59	39.38	5.54	-
BHW4-7	54.29	9.00	381.20	183.50	183.50	10.50	14.70	21.10	42.16	24.59	46.29	5.33	25.32	-
BHW4-8	37.96	30.92	299.66	218.51	199.05	20.96	29.12	9.39	40.02	16.82	24.31	10.58	9.01	-
BHW4-9	64.90	10.12	325.22	301.49	103.47	11.17	18.85	11.06	21.10	8.99	27.71	13.18	16.71	-
BHW4-10	99.74	5.32	357.96	411.35	48.10	7.44	17.46	5.53	43.15	18.22	23.74	11.22	31.19	-
BHW4-11	-	93.40	608.20	93.00	211.40	12.80	10.50	3.10	73.70	0.00	51.90	12.50	11.20	0.00

Table A2-62: Trace element concentrations for Borehole wedge 5 (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
BHW5-1	-	110.00	376.80	114.00	206.60	14.00	31.90	18.20	146.80	16.80	116.20	94.10	36.90	36.60
BHW5-2	18.80	18.30	234.79	140.58	445.11	3.82	53.19	8.66	141.74	26.45	126.70	30.52	19.66	-
BHW5-3	-	109.90	378.70	80.40	504.40	21.50	50.90	10.90	207.40	18.60	144.10	103.30	52.00	20.50
BHW5-4	-	88.60	279.20	43.90	1212.40	25.10	41.20	5.20	181.10	2.50	47.50	36.10	10.60	0.00
BHW5-5	-	77.40	256.40	43.60	2063.50	34.10	61.10	2.90	85.70	1.00	57.80	39.80	10.60	5.40
BHW5-6	-	18.20	77.90	28.00	272.00	12.20	11.60	0.10	44.60	3.90	27.80	31.40	6.80	9.40
BHW5-7	-	41.30	146.10	83.40	574.00	15.90	22.00	2.90	50.60	2.20	31.60	18.70	8.50	7.80
BHW5-8	-	94.70	289.40	70.70	553.40	28.70	45.10	12.00	201.80	22.90	96.70	77.40	49.20	26.70
BHW5-9	-	74.50	243.10	68.30	744.10	23.60	42.00	8.40	163.90	14.30	64.40	56.70	37.40	15.40
BHW5-10	145.36	9.79	313.87	420.53	685.28	4.03	31.03	8.86	92.70	22.19	51.18	8.59	30.08	-
BHW5-11	136.38	6.42	781.83	1096.17	1.52	3.75	11.94	5.42	16.81	12.82	29.71	25.45	80.19	-

BHW5-12	162.20	8.33	525.16	653.64	90.04	11.16	15.84	7.93	21.44	14.61	48.37	4.45	28.38	-
BHW5-13	145.58	11.52	608.15	958.87	11.50	4.27	26.64	11.06	85.98	10.52	85.27	6.38	39.88	-
BHW5-14	-	49.30	447.00	83.20	77.50	15.10	0.00	10.60	89.90	0.00	105.80	24.80	25.70	4.90
BHW5-15	-	51.00	482.50	70.90	131.30	14.10	1.10	5.60	61.40	0.00	69.00	26.50	17.30	-

Table A2-63: Trace element concentrations for Delmas Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
DEL1	-	5.30	752.70	256.20	198.90	8.70	13.70	35.80	209.80	0.00	154.60	7.40	13.30	2.30
DEL2	194.95	18.31	598.85	905.96	96.17	7.06	23.58	7.35	65.21	23.76	38.46	8.66	41.18	-
DEL4	54.24	0.00	259.74	506.57	26.15	8.18	11.05	0.30	0.00	39.28	11.53	3.16	10.05	-
DEL5	188.86	0.00	412.18	696.16	20.34	5.00	19.14	2.63	21.10	15.30	24.44	3.21	4.48	-
DEL6	-	77.70	441.70	108.40	366.10	16.70	13.20	5.20	169.40	3.20	59.80	12.80	69.30	14.70
DEL7	28.35	0.80	539.31	786.79	63.51	10.07	16.74	3.26	18.46	15.94	32.60	5.58	14.00	-
DEL8	57.90	0.00	143.15	365.56	58.39	10.61	6.99	0.00	0.00	53.77	11.53	5.19	6.04	-
DEL9	175.31	0.00	394.41	755.95	6.04	3.28	19.88	5.02	5.76	10.73	8.29	4.52	4.38	-
DEL10	43.57	3.79	509.26	949.52	57.53	8.08	16.26	3.47	29.11	14.00	35.98	2.64	11.58	-
DEL11	64.83	0.36	560.35	1505.83	15.96	3.12	18.91	3.09	12.58	15.15	18.39	1.37	14.12	-
DEL12	37.59	3.31	348.36	576.08	28.32	9.64	11.61	2.14	9.00	11.90	27.49	5.46	2.60	-
DEL13	30.78	41.45	195.64	112.68	650.61	10.13	17.63	37.70	1049.21	36.73	468.68	7.45	102.38	-
DEL14	81.35	21.49	991.41	1553.61	79.70	9.13	16.95	6.01	21.20	20.60	37.87	2.68	10.34	-
DEL15	62.76	0.38	1284.51	1013.35	31.19	6.16	20.77	4.45	42.61	13.01	26.01	3.23	6.41	-
DEL16	53.08	11.19	257.33	300.67	97.09	16.83	12.00	0.90	11.78	15.67	50.34	1.28	10.24	-
DEL17	52.60	0.00	546.56	727.53	48.48	8.40	11.48	3.40	29.71	15.59	36.65	6.62	6.61	-

Table A2-64: Trace element concentrations for Douglas Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Mn
DOU1	-	0.00	115.20	16.30	331.40	14.30	29.10	20.20	287.70	3.20	231.70	39.90	18.80	-
DOU2	97.23	0.00	119.20	126.17	84.67	10.00	19.81	4.48	27.02	11.24	26.77	29.52	83.63	97.23
DOU3	32.05	0.00	150.43	84.05	123.10	10.42	38.22	5.99	37.58	6.54	39.73	9.13	13.11	32.05
DOU4	-	7.70	125.60	498.10	294.70	13.10	20.40	12.90	86.10	0.60	50.70	29.00	15.70	-
DOU5	-	16.70	230.50	46.00	241.00	13.40	8.60	20.50	180.90	31.70	217.60	29.30	30.10	-
DOU6	100.59	0.00	171.30	146.48	61.96	9.09	12.59	4.73	41.41	7.80	40.81	20.20	25.40	100.59
DOU7	-	1.90	214.00	53.40	210.10	9.60	2.00	11.50	269.10	36.40	151.40	27.80	46.90	-
DOU8	165.82	0.00	191.38	173.61	37.79	6.47	3.41	1.60	27.37	22.53	28.01	12.69	21.75	165.82
DOU9	129.34	0.00	404.67	528.99	26.47	5.67	9.08	1.46	0.00	8.83	8.94	25.84	3.05	129.34
DOU10	68.46	26.21	394.28	491.09	202.71	14.43	16.98	10.36	47.44	26.10	57.75	11.37	25.99	68.46
DOU11	-	43.40	658.40	879.00	239.30	17.70	27.20	24.30	238.00	25.60	129.90	115.60	32.80	-
DOU12	-	84.10	472.30	73.40	95.20	17.30	3.30	10.20	163.80	0.00	119.20	68.10	29.90	-
DOU13	272.11	0.00	388.53	354.97	51.43	8.19	14.74	5.33	15.87	10.10	8.12	3.10	25.80	272.11
DOU14	125.29	0.00	465.29	315.28	82.62	8.96	9.12	5.18	25.93	16.15	28.28	2.14	24.96	125.29
DOU15	41.52	43.28	293.65	116.80	657.48	10.76	30.59	3.85	74.77	24.64	39.73	22.84	19.73	41.52
DOU16	-	61.00	320.90	117.80	545.00	24.30	39.40	10.60	167.30	18.80	173.20	88.30	26.30	-
DOU17	-	176.50	272.20	66.60	225.20	16.90	25.80	16.60	192.20	8.60	95.70	64.50	41.40	-
DOU18	3.74	12.50	26.15	26.11	83.72	9.86	11.40	2.15	2.77	6.62	17.42	1.62	9.88	3.74
DOU19	-	88.10	346.40	76.60	196.50	10.20	14.70	10.90	75.30	10.70	62.80	52.60	14.50	-
DOU20	-	57.60	289.70	76.80	508.50	28.40	36.80	10.60	169.70	15.50	146.70	127.90	28.70	-
DOU21	-	39.40	287.30	118.10	591.80	18.70	27.90	0.00	63.50	12.00	23.80	77.50	23.20	-
DOU22	134.53	0.00	929.53	1095.64	224.92	0.61	37.80	19.71	124.32	36.71	99.75	40.14	61.86	134.53
DOU23	-	9.20	296.40	93.70	368.90	24.00	33.10	23.20	243.90	27.80	194.50	47.10	50.50	-
DOU24	-	53.10	403.50	255.50	250.60	21.10	21.60	16.10	186.40	30.40	128.00	144.90	40.10	-
DOU25	18.37	17.48	192.16	92.01	347.92	29.03	38.03	17.92	19.95	18.58	85.57	5.09	22.55	18.37
DOU26	73.43	30.57	2348.00	3160.53	0.00	0.00	30.29	17.85	36.03	27.76	27.63	3.84	15.14	73.43
DOU27	42.47	0.00	331.21	229.55	74.04	9.69	18.65	5.28	17.61	9.71	35.22	6.08	7.82	42.47
DOU28	60.19	0.00	155.45	117.83	118.55	11.20	12.58	9.79	105.49	11.83	89.29	7.82	40.44	60.19

DOU29	-	27.40	99.90	25.70	293.10	18.70	7.40	3.60	257.70	5.40	155.00	24.90	27.40	-
DOU30	-	74.70	440.00	382.10	246.60	22.90	44.30	20.00	162.10	29.80	145.30	133.20	31.20	-
DOU31	49.59	8.65	947.85	743.95	152.90	5.75	22.35	12.44	50.47	13.73	63.99	9.99	49.83	49.59
DOU32	26.40	2.59	1136.62	1110.60	121.17	9.57	22.61	12.11	47.19	14.40	38.00	1.44	16.73	26.40
DOU33	66.91	0.00	195.75	172.34	89.97	9.12	9.78	7.65	51.27	10.03	44.13	33.47	44.28	66.91
DOU34	-	56.30	387.80	65.90	285.60	20.30	8.10	3.80	171.70	1.80	110.80	62.80	32.30	-
DOU35	-	49.40	368.70	210.80	815.50	26.20	33.40	15.40	358.90	20.60	114.90	72.10	77.10	-
DOU36	16.16	1.24	161.20	84.96	184.02	12.55	19.80	8.96	40.17	9.80	50.51	7.35	34.84	16.16
DOU37	39.26	0.97	178.46	74.72	111.86	12.22	17.85	3.87	24.68	8.22	31.68	5.94	0.91	39.26
DOU38	74.51	6.35	132.07	96.17	104.46	12.65	21.72	7.02	40.12	10.63	34.87	7.00	26.63	74.51
DOU39	-	5.60	227.40	223.30	209.50	9.80	16.10	12.00	199.40	3.60	154.90	22.00	38.00	-
DOU40	25.32	14.70	24.48	55.76	85.40	9.42	14.83	2.97	18.01	23.18	17.53	23.62	202.47	25.32
DOU41	-	0.00	98.40	41.70	250.30	12.90	18.60	21.10	359.50	4.30	258.70	64.30	68.70	-

Table A2-65: Trace element concentrations for Forzando Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
FOR1	213.69	2.38	159.99	290.07	35.97	5.91	8.07	4.38	6.06	7.22	9.59	2.45	6.58	-
FOR2	96.45	7.79	577.84	600.97	23.65	6.13	3.27	4.90	0.00	10.11	15.31	1.70	9.12	-
FOR3	-	35.30	251.80	101.50	401.00	17.20	15.50	9.70	81.60	18.90	93.60	39.10	37.90	4.50
FOR4	-	29.70	286.10	70.60	279.80	16.40	7.60	11.50	74.80	15.50	99.60	20.20	16.40	1.40
FOR5	136.86	5.78	170.37	162.28	144.36	3.94	50.98	20.76	69.44	12.47	68.12	14.07	24.79	-
FOR6	116.84	12.04	157.05	192.61	80.40	9.93	8.30	5.94	5.14	7.36	23.52	19.52	20.07	-
FOR7	-	127.50	605.60	140.40	152.30	13.60	12.20	6.50	58.10	24.10	60.10	46.80	10.90	3.30
FOR8	-	34.70	325.00	76.30	318.20	8.40	22.50	16.60	141.70	9.10	68.70	31.50	22.90	14.20
FOR9	-	32.40	204.10	68.20	279.60	17.60	18.90	14.10	139.90	23.60	157.30	63.20	74.00	38.40
FOR10	-	35.70	276.40	64.00	477.60	23.60	18.30	10.40	70.90	16.60	81.80	53.30	45.70	17.00
FOR11	210.36	1.95	115.23	107.85	42.47	5.57	23.74	7.40	28.74	5.22	16.64	3.49	27.13	-
FOR12	229.67	6.99	501.83	254.58	67.02	9.10	4.82	6.36	0.00	7.20	20.53	0.76	11.73	-
FOR13	-	105.20	518.80	114.80	162.50	11.30	10.60	6.10	29.30	0.00	32.70	21.90	7.20	7.60

Table A2-66: Trace element concentrations for Greenside Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
GRE1	-	6.00	391.80	231.30	370.70	10.00	16.00	24.60	217.40	0.00	401.70	33.80	23.50	28.10
GRE2	107.52	7.27	807.81	943.30	20.01	4.86	17.22	9.28	24.23	26.93	31.82	7.24	17.18	-
GRE3	76.61	5.34	401.85	344.68	74.88	7.17	8.17	4.48	12.28	32.43	27.31	5.97	17.31	-
GRE4	122.12	2.22	254.72	154.08	83.96	7.34	14.66	7.09	31.50	15.34	24.98	7.61	23.71	-
GRE5	-	46.20	242.50	66.80	186.00	9.60	8.50	4.90	181.80	10.00	89.80	225.00	185.50	47.40
GRE6	-	23.20	363.70	102.50	325.80	20.40	17.50	15.20	177.50	7.00	116.70	16.90	19.50	0.60
GRE7	45.82	3.97	477.60	470.67	29.04	5.52	13.94	5.63	13.63	10.39	26.44	2.49	13.52	-
GRE8	70.40	6.96	1189.80	996.83	0.00	1.88	14.86	4.38	6.71	11.62	22.01	1.18	12.97	-
GRE9	160.25	1.44	429.16	446.27	26.21	4.23	15.28	5.63	20.90	10.51	18.39	2.99	29.42	-
GRE10	-	87.50	519.80	77.80	248.60	16.70	8.40	5.40	177.40	0.00	92.80	15.70	20.00	0.50
GRE11	-	15.10	285.20	59.20	268.60	15.30	16.80	18.40	188.90	7.30	129.60	20.00	20.60	-
GRE12	78.37	2.59	425.15	253.09	41.06	8.30	4.36	5.32	13.38	18.62	2.66	2.52	9.46	-
GRE13	146.44	2.86	349.21	226.09	79.28	8.16	18.60	8.76	32.80	8.93	25.28	1.28	12.27	-
GRE14	122.01	1.24	421.41	248.95	55.40	10.48	15.95	7.40	17.56	16.69	27.58	8.81	52.45	-
GRE15	-	11.10	65.00	62.50	78.30	6.20	1.30	0.60	31.70	0.00	18.10	7.60	4.50	0.00
NGT1	-	153.00	382.40	83.00	221.40	14.10	24.20	18.20	138.30	7.20	110.10	102.90	33.80	26.50
NGT2	2.26	36.09	79.45	26.86	340.10	41.81	29.60	5.94	3.42	15.09	34.63	5.58	0.90	-
NGT3	0.00	5.34	93.40	69.99	34.57	8.12	1.70	0.62	0.00	4.45	7.80	1.07	0.00	-
NGT4	1.51	12.54	36.32	32.82	76.28	6.84	9.07	5.94	2.77	10.67	16.04	3.40	0.00	-
NGT5	-	227.60	243.00	59.90	171.20	14.60	26.60	19.10	180.20	10.50	99.90	61.20	29.40	15.60
NGT6	-	16.20	395.30	97.70	227.10	13.60	24.30	15.00	134.50	6.70	108.60	103.60	34.40	25.50
NGT7	1.88	26.44	101.47	38.00	234.95	29.03	20.43	7.61	15.32	8.36	34.52	9.83	0.32	-
NGT8	-	0.00	5.68	143.39	80.95	7.50	2.90	0.83	0.00	3.73	11.99	0.53	0.00	-
NGT9	5.03	14.71	127.43	51.68	60.48	6.51	11.31	5.21	10.54	6.46	17.77	2.98	0.55	-
NGT10	-	197.70	303.40	94.80	174.90	12.60	31.40	19.50	182.20	9.90	88.00	144.70	276.70	138.10
NGT11	-	158.30	423.40	158.10	234.20	15.80	26.60	13.40	124.80	6.60	105.40	95.50	33.00	34.80
NGT12	0.00	19.57	132.19	76.06	187.44	19.61	17.39	3.44	0.28	11.74	18.96	8.22	0.00	-
NGT13	1.88	5.92	192.99	105.72	34.32	7.12	0.94	0.42	0.00	5.17	5.80	0.00	0.00	-
NGT14	7.50	65.71	751.48	83.19	152.52	8.54	25.62	11.37	107.09	11.95	59.18	9.67	12.39	-

NGT15	-	252.00	557.00	202.10	182.50	14.50	28.50	19.30	203.60	10.30	117.10	74.40	58.40	41.00

Table A2-67: Trace element concentrations for Kleinkopje Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
KK1	71.34	8.01	1560.21	904.74	109.80	13.07	24.48	8.66	39.07	15.34	59.37	6.62	10.41	-
KK2	12.36	2.84	129.32	472.18	0.00	3.03	3.52	9.39	0.00	33.41	0.00	12.12	9.93	-
KK3	33.54	11.98	2362.01	1926.10	62.54	9.13	25.68	7.09	47.66	24.13	49.75	15.27	11.57	-
KK4	90.61	59.15	947.77	1353.70	219.31	29.11	62.37	10.01	63.92	60.07	71.33	105.51	31.64	-
KK5	-	25.10	235.60	48.60	390.20	23.20	20.60	20.90	334.50	59.90	352.50	92.80	38.00	4.20
KK6	-	35.50	130.10	41.10	576.40	16.10	14.10	1.00	102.40	1.90	43.30	14.10	10.10	0.00
KK7	141.80	3.50	87.67	83.33	79.34	10.11	12.89	5.74	14.37	4.22	25.20	10.75	25.38	-
KK8	-	74.90	305.70	100.50	602.60	31.60	43.50	9.30	165.20	10.60	124.90	94.70	25.40	0.40
KK9	270.12	3.04	271.34	284.08	65.55	7.47	5.39	4.59	11.04	14.59	17.88	5.06	14.63	-
KK10	-	0.00	8.80	11.50	62.90	4.10	0.00	0.00	50.60	0.00	21.10	2.30	5.40	0.00
KK11	-	92.50	461.60	336.60	183.80	13.00	67.70	25.90	225.00	45.10	246.40	145.10	13.00	40.20
KK12	58.28	12.79	514.37	511.68	82.11	7.35	22.68	9.18	32.60	13.33	32.41	19.06	15.85	-
KK13	132.97	14.54	404.98	135.92	132.65	8.70	8.28	7.40	59.39	15.52	71.14	10.16	26.48	-
KK14	-	108.90	367.30	101.30	1091.30	36.10	57.20	13.40	146.90	8.20	164.10	90.00	28.40	2.20
KK15	-	14.00	77.40	29.00	276.70	8.70	3.60	3.10	58.40	0.00	30.40	30.40	9.20	0.80
KK16	0.00	1.98	93.43	126.60	7.20	5.03	28.86	7.20	26.32	4.37	30.17	45.89	24.74	-

Table A2-68: Trace element concentrations for Khutala Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
KHU1	104.61	3.07	202.47	131.33	54.75	6.00	7.94	5.74	10.09	12.97	16.02	4.53	21.83	-
KHU2	153.78	4.43	373.36	191.93	74.09	8.13	12.00	6.26	17.26	9.79	22.15	4.87	5.32	-
KHU3	110.89	7.35	1588.35	1076.34	0.00	0.48	20.51	6.47	15.52	13.04	16.04	7.84	3.33	-
KHU4	9.59	5.55	172.39	153.63	216.86	19.67	29.11	13.25	65.36	18.16	64.46	7.61	12.01	-
KHU5	99.70	8.48	321.41	239.12	274.33	12.68	15.51	6.57	50.12	15.56	68.06	9.86	10.22	-
KHU6	51.17	1.15	40.38	60.57	78.64	7.34	10.37	4.38	12.03	8.03	16.02	4.66	29.11	-

KHU7	-	0.70	55.70	23.90	448.70	13.30	11.50	2.40	104.70	0.00	43.30	12.10	10.10	5.30
KHU8	104.46	2.68	46.40	85.06	45.67	5.21	10.83	3.65	0.93	17.57	12.67	3.71	19.44	-
KHU9	83.76	6.73	369.74	340.53	65.28	10.12	14.53	5.94	12.88	10.94	27.79	2.89	9.13	-
KHU10	138.43	4.24	365.51	332.17	96.77	8.19	23.11	10.12	18.36	15.16	33.22	2.60	3.36	-
KHU11	90.83	5.58	285.68	430.99	31.16	9.18	9.89	5.01	8.35	27.30	33.19	3.28	15.61	-
KHU12	138.02	28.30	489.07	477.59	96.29	11.23	17.83	11.16	25.53	19.00	37.27	3.77	5.42	-
KHU13	120.17	6.67	639.62	852.84	60.55	8.40	19.20	13.45	61.68	19.11	39.05	2.29	9.00	-
KHU14	67.93	22.43	849.83	870.34	56.52	6.69	24.04	11.26	30.21	14.71	39.81	4.32	4.22	-
KHU15	127.66	10.58	803.54	927.44	13.59	5.16	16.96	7.72	20.50	14.09	31.22	2.55	4.46	-
KHU16	32.38	6.64	697.24	513.71	17.56	5.41	21.75	6.57	47.98	9.81	38.35	2.81	23.19	-

Table A2-69: Trace element concentrations for Koornfontein Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
KOR1	124.59	0.77	341.88	393.65	43.68	7.65	11.66	1.03	7.05	7.17	15.53	6.66	2.40	-
KOR2	106.15	0.46	20.66	274.32	74.37	9.03	16.04	4.36	15.37	8.92	13.15	10.13	3.52	-
KOR3	91.62	0.00	14.29	165.45	112.28	12.40	20.21	5.37	28.22	10.64	21.71	15.77	1.78	-
KOR4	108.13	1.41	339.22	665.69	36.98	6.79	7.74	4.32	0.00	11.38	8.05	4.67	3.77	-
KOR5	111.60	0.00	238.87	646.52	53.02	6.98	18.31	2.65	6.16	8.03	13.18	5.69	1.99	-
KOR6	88.10	0.00	0.00	301.46	63.07	7.32	15.10	1.37	14.82	6.17	11.84	6.22	1.18	-
KOR7	102.07	6.69	415.46	334.32	87.28	10.69	7.81	5.07	4.66	9.68	21.23	5.07	1.92	-
KOR8	136.74	0.00	301.85	573.22	71.59	10.21	11.88	3.84	12.18	11.84	20.93	6.02	3.86	-
KOR9	209.25	0.00	100.88	177.98	93.03	9.16	8.40	1.90	23.64	17.79	14.88	6.20	23.03	-
KOR10	139.74	5.65	298.25	374.00	117.34	13.44	17.91	5.53	20.65	10.53	32.30	5.50	2.41	-
KORSST	-	14.70	292.10	498.40	65.10	10.60	19.10	38.50	764.30	96.70	329.20	94.30	194.90	83.00
KOR11	140.70	0.00	100.49	344.53	58.57	7.02	13.83	1.67	7.85	10.17	11.96	4.88	3.48	-
KOR12	99.69	3.12	90.73	168.04	125.53	10.74	16.71	5.73	54.95	13.86	34.17	11.44	13.02	-
KOR13	111.37	5.09	747.17	728.20	26.41	6.08	6.19	2.98	10.74	8.18	17.20	7.77	0.00	-
KOR14	113.89	0.00	94.51	308.12	86.85	9.99	11.16	1.82	7.30	10.23	17.12	6.28	11.11	-
KOR15	141.74	0.00	54.59	804.30	21.33	3.07	15.82	4.59	0.00	13.97	2.56	3.51	0.00	-
KOR16	149.67	0.00	329.63	395.61	42.43	6.29	14.55	2.80	6.11	12.37	17.15	4.90	2.34	-

KOR17	82.76	0.00	113.17	125.88	60.32	9.10	11.76	2.35	17.15	6.65	16.15	5.28	1.42	-
KOR18	62.99	0.00	153.07	80.79	78.94	13.65	15.90	4.33	9.49	11.08	27.04	3.33	6.82	-

Table A2-70: Trace element concentrations for Kromdraai Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
KRD1	6.57	8.85	893.67	524.21	158.53	12.21	24.78	10.04	45.29	15.49	44.67	29.32	13.24	-
KRD2	8.83	8.13	652.82	386.60	130.54	11.35	22.20	8.56	32.35	16.71	35.62	17.19	11.24	-
KRD3	3.93	8.50	983.96	662.79	143.76	14.08	27.15	9.16	43.25	15.52	50.99	10.90	11.51	-
KRD4	-	0.00	24.60	28.10	603.20	21.90	9.40	3.30	88.10	0.00	33.50	252.60	91.30	72.50
KRD5	-	0.00	25.20	20.80	662.00	26.10	12.50	0.00	104.60	2.70	37.40	91.40	215.90	164.40
KRD6	2.82	0.00	23.47	65.70	91.49	12.06	13.83	3.83	23.19	4.45	13.49	17.03	10.95	-
KRD7	1.86	0.00	78.94	175.27	58.92	8.29	14.08	1.07	24.23	5.15	34.84	28.15	8.30	-
KRD8	1.59	0.00	12.46	73.27	69.60	9.11	14.47	1.57	19.00	5.48	28.49	48.38	15.89	-
KRD9	3.69	0.00	246.89	67.08	96.20	10.19	6.48	0.00	11.24	6.91	22.07	8.27	37.11	-
KRD10	0.79	0.00	472.37	345.47	85.75	10.67	13.59	3.39	30.66	16.30	31.14	17.51	15.66	-
KRD11	2.80	0.00	1457.91	787.10	62.61	7.16	11.01	3.41	15.82	15.37	21.82	57.07	55.02	-

Table A2-71: Trace element concentrations for Lakeside Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
LK1	96.3	3.0	107.8	97.4	24.10	4.13	2.16	0.52	0.00	22.32	1.40	4.23	54.03	-
LK2	14.92	13.3	147.3	163.9	100.37	7.56	27.61	11.10	23.49	8.81	17.47	6.32	10.61	-
LK3	41.96	0.0	79.6	91.8	40.21	7.82	5.79	0.00	7.30	6.95	7.70	5.59	8.72	-
LK4	80.53	0.0	145.8	138.0	83.45	11.30	8.65	4.91	1.48	23.36	7.40	4.79	4.90	-
LK5	106.51	4.2	178.8	127.5	72.47	8.16	12.54	2.26	9.10	9.65	15.96	8.98	3.82	-
LK6	24.24	0.0	132.3	90.1	65.25	10.13	13.34	3.75	15.07	6.48	19.07	4.16	7.33	-
LK7	78.06	0.0	161.4	192.8	55.75	9.30	9.13	1.66	0.00	15.56	15.15	8.68	20.99	-

Table A2-72: Trace element concentrations for Leeufontein Colliery (values presented as ppm)

SiteName	**Mn**	**Rb**	**Ba**	**Sr**	**Zr**	**Nb**	**Y**	**Sc**	**Cr**	**Cu**	**V**	**Zn**	**Ni**	**Co**
LU1	29.88	0.00	153.62	119.38	69.64	9.10	16.34	5.82	28.42	7.92	20.09	14.30	12.63	-
LU2	35.05	0.00	143.91	67.69	41.18	8.80	7.73	0.00	0.83	3.79	10.86	5.28	3.46	-
LU3	111.61	0.00	192.23	280.90	33.16	7.89	11.20	2.29	0.00	9.00	8.40	12.62	13.49	-
LU4	61.28	0.00	216.71	125.14	32.56	8.85	5.56	0.00	0.00	5.31	7.26	1.85	10.79	-
LU5	-	3.10	109.60	194.30	75.40	6.70	1.70	4.70	40.30	0.00	13.80	11.30	9.10	0.00
LU6	187.22	0.00	216.18	143.99	45.59	7.45	9.48	1.80	5.06	7.24	9.34	6.15	17.10	-
LU7	17.12	2.52	157.55	65.52	216.75	20.77	23.46	0.10	20.10	19.25	40.16	19.08	7.08	-
LU8	25.39	44.41	189.04	71.30	259.40	31.82	46.51	10.31	58.79	22.38	79.22	7.62	16.23	-
LU9	71.29	0.00	216.82	120.99	43.19	8.66	6.99	0.00	3.22	5.45	9.91	4.87	20.27	-
LU10	50.55	0.00	215.36	111.84	58.41	9.34	9.83	2.07	9.10	6.56	17.88	2.93	27.43	-
LU11	59.14	0.00	240.27	139.79	90.63	10.40	14.83	3.85	13.73	8.33	22.17	8.71	17.99	-
LU13	82.90	2.25	123.85	95.41	17.67	6.92	6.07	2.92	8.40	5.66	14.42	3.98	7.23	-
LU14	143.40	0.00	212.10	227.27	59.80	10.62	7.06	2.13	0.00	15.02	6.99	3.49	34.40	-
LU15	60.72	0.00	234.11	170.29	58.32	8.67	8.72	2.87	6.51	5.71	18.31	9.73	9.35	-
LU16	27.82	6.47	214.10	109.51	84.96	10.37	15.65	3.97	14.27	7.12	17.58	23.80	31.66	-
LU17	108.74	0.00	576.63	469.51	50.10	9.51	12.06	2.38	8.25	11.93	23.33	9.71	12.99	-
LU18	35.95	0.00	324.93	94.57	75.84	9.74	12.60	4.03	28.37	7.66	28.22	12.02	10.00	-
LU19	92.01	0.00	272.79	218.09	36.91	8.67	6.33	0.00	0.38	14.08	7.24	4.40	33.45	-
LU20	50.67	0.00	225.66	211.66	30.09	8.21	7.36	1.55	2.32	10.39	12.50	1.65	71.44	-
LU21	14.56	3.30	228.48	85.40	358.17	36.81	37.19	7.80	83.88	23.65	69.95	5.54	9.50	-
LU22	31.03	0.00	282.29	116.74	50.55	7.96	14.52	1.57	12.03	4.84	15.02	5.09	6.11	-
LU23	72.59	0.00	204.39	139.00	46.02	8.77	7.18	0.00	2.12	6.94	8.26	9.67	15.01	-
LU24	58.54	0.00	288.91	266.08	41.16	8.12	13.14	2.44	11.67	7.04	12.75	9.56	33.10	-
LU25	147.22	0.00	439.87	447.31	50.92	6.77	11.88	2.37	7.05	14.37	12.21	4.30	7.34	-
LU26	71.21	0.00	722.44	487.65	21.34	6.17	9.97	0.27	4.22	7.92	11.21	2.83	8.36	-
LU27	12.75	9.76	511.92	370.02	121.45	11.70	24.60	5.03	32.80	10.00	43.48	4.24	10.47	-
LU28	103.23	0.23	744.61	555.25	80.77	8.93	13.80	3.57	10.44	11.93	21.82	4.34	15.37	-
LU29	51.41	5.00	512.53	283.38	90.23	9.43	14.14	6.03	34.34	10.29	34.06	12.64	15.68	-

LU30	70.24	0.00	398.42	133.56	65.56	7.76	10.41	1.36	4.51	10.75	11.40	11.62	12.57	-
LUP1	59.04	5.17	62.59	49.72	131.31	14.34	13.39	7.03	47.19	15.57	54.02	12.35	42.09	-
LUP2	68.68	0.00	90.00	162.38	42.66	8.29	4.50	0.00	4.42	9.66	14.56	3.58	8.69	-
LUP3	123.18	0.00	231.89	148.97	66.45	12.65	8.34	4.07	13.93	8.26	18.12	3.94	44.11	-
LUP4	9.86	21.97	1440.99	817.38	53.93	7.23	29.54	6.74	20.40	17.18	38.54	8.67	9.44	-

Table A2-73: Trace element concentrations for Middelburg Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
M1	200.01	7.29	106.17	26.37	177.91	16.94	32.46	9.69	44.20	20.24	52.91	15.20	63.60	-
M2	136.93	0.00	185.33	45.88	84.08	8.85	26.62	7.95	42.36	10.46	53.26	10.47	59.22	-
M3	-	11.40	60.70	15.70	230.40	11.10	9.50	1.00	71.70	5.30	32.90	37.90	20.60	5.30
M4	-	12.20	102.50	22.70	151.50	10.60	5.40	9.70	96.50	11.90	68.00	35.10	17.90	3.30
M5	100.12	4.97	288.41	130.48	118.57	11.69	24.28	6.91	33.20	14.41	40.41	8.10	28.21	-
M6	59.69	12.45	312.52	100.94	218.67	27.38	33.43	12.08	68.35	14.65	71.39	5.36	23.07	-
M7	131.22	0.00	443.67	217.31	89.18	10.68	14.46	3.34	32.45	10.85	30.28	3.90	16.87	-
M8	75.77	0.00	152.43	101.43	129.22	9.33	22.54	7.98	54.81	20.27	43.62	11.12	14.88	-
M9	27.28	8.92	1108.43	1041.17	146.84	9.20	34.09	14.21	73.23	17.09	61.34	16.00	20.44	-
M10	-	12.50	406.50	356.70	370.30	25.70	26.30	33.00	225.40	6.20	167.90	44.50	41.30	8.20
M11	64.98	0.00	119.15	87.23	111.25	11.26	21.26	6.96	57.49	12.20	42.62	27.13	28.64	-
M12	79.89	0.00	157.19	129.56	95.98	10.78	16.25	5.10	22.09	12.92	24.58	13.59	23.91	-
M13	-	8.80	160.60	340.10	121.80	9.20	6.40	6.10	59.50	5.30	20.10	12.30	20.80	3.50
M14	89.11	0.00	186.64	172.35	85.77	9.99	18.56	6.31	20.15	11.28	21.47	8.39	6.68	-
M15	51.40	0.00	412.60	117.29	67.18	10.34	8.99	3.51	13.38	7.83	23.70	4.12	4.55	-
M16	105.11	0.00	617.67	405.17	84.46	8.00	14.35	4.12	13.93	14.27	21.77	3.95	7.63	-
M17	55.89	4.37	540.59	768.34	73.09	6.28	18.99	6.31	7.15	11.20	15.37	4.58	22.96	-
M18	197.90	0.00	225.66	219.19	74.29	8.37	13.98	4.85	27.67	7.84	25.06	6.63	24.12	-
M19	401.72	9.05	129.82	67.22	159.88	10.82	26.99	11.00	25.08	19.94	36.38	15.52	25.57	-
M20	8.09	39.85	98.13	66.73	225.49	9.38	18.59	5.04	51.72	21.28	54.29	18.31	15.57	-
M21	-	102.70	250.50	51.60	687.60	25.80	39.30	4.20	92.40	5.50	45.00	22.20	18.70	0.00
M22	-	112.30	364.70	78.90	320.70	15.50	22.90	15.00	168.90	5.30	113.10	81.90	33.20	14.10

Table A2-74: Trace element concentrations for Optimum Colliery (values presented as ppm)

SiteName	**Mn**	**Rb**	**Ba**	**Sr**	**Zr**	**Nb**	**Y**	**Sc**	**Cr**	**Cu**	**V**	**Zn**	**Ni**	**Co**
OPT1	6.19	14.04	73.35	58.96	81.89	7.81	15.64	9.18	54.11	38.96	47.13	15.67	69.13	-
OPT2	62.26	2.10	90.03	92.04	29.44	7.95	3.35	1.46	14.12	7.05	15.31	1.21	12.23	-
OPT3	-	84.40	400.40	63.00	295.90	14.80	15.90	4.50	52.40	0.00	45.00	43.60	10.40	0.00
OPT4	92.12	0.00	106.10	129.97	98.82	8.10	9.82	1.33	39.87	7.42	21.17	4.66	10.18	-
OPT5	27.68	0.00	144.23	112.98	42.19	9.94	7.92	0.00	21.10	6.54	19.63	2.90	14.48	-
OPT6	18.66	3.12	236.52	133.65	94.82	9.23	42.07	16.16	22.69	7.08	29.60	27.57	19.19	-
OPT7	43.41	0.00	389.67	273.74	25.60	6.94	22.19	10.76	6.86	7.84	20.34	50.18	26.46	-
OPT8	-	32.90	143.80	153.20	174.20	13.20	21.60	4.20	50.50	10.40	26.40	49.90	164.30	27.20
OPT9	9.93	0.00	154.67	61.50	55.27	5.51	44.07	11.51	23.34	9.87	23.90	64.32	15.19	-
OPT10	38.00	0.00	445.05	272.23	61.39	8.90	17.14	5.97	18.21	6.81	19.28	8.27	6.93	-
OPT11	-	14.20	159.70	34.30	129.50	8.50	5.50	1.70	56.60	4.00	29.90	16.20	14.50	5.10
OPT12	1.17	4.21	276.57	71.94	101.00	7.09	58.52	20.23	62.07	17.16	73.92	28.49	13.70	-
OPT13	38.73	0.00	334.39	96.97	70.69	9.61	17.67	4.89	18.66	8.83	25.95	11.24	20.48	-

Table A2-75: Trace element concentrations for Rietspruit Colliery (values presented as ppm)

SiteName	**Mn**	**Rb**	**Ba**	**Sr**	**Zr**	**Nb**	**Y**	**Sc**	**Cr**	**Cu**	**V**	**Zn**	**Ni**	**Co**
R2RO	-	68.90	436.60	252.80	308.50	19.80	31.50	21.40	190.20	23.00	144.10	121.20	36.30	17.70
R2M	47.34	16.22	1003.04	2662.77	15.36	0.00	74.22	7.90	30.85	18.71	31.84	13.94	29.33	-
R2M2	24.37	0.46	374.10	681.40	26.71	6.50	19.36	5.16	1.68	14.55	10.72	3.84	8.17	-
R2LW	75.70	7.05	3291.85	2070.25	0.00	0.00	22.64	3.72	8.20	13.26	16.91	2.68	6.03	-
R4UROOF	-	103.50	379.50	75.10	235.40	14.80	29.40	20.70	197.30	9.90	135.60	94.20	41.40	19.20
R4U	42.23	92.85	154.51	101.66	156.39	14.69	25.48	4.45	20.05	20.27	33.03	14.78	14.73	-
R4PT	-	53.40	292.00	78.50	252.30	19.00	32.20	19.50	148.80	12.40	120.00	69.00	25.80	8.30
R4L	59.21	8.75	337.71	282.43	89.31	10.21	25.88	8.41	30.81	10.22	49.86	4.26	11.61	-
R4FUG	-	0.00	48.10	18.30	633.50	21.70	15.50	7.20	102.80	12.90	113.00	105.10	11.90	5.30
R4FLG	-	5.40	135.00	37.20	408.70	22.50	17.30	12.20	253.80	42.50	269.20	168.60	13.30	27.20
R4F1	-	0.00	271.00	32.20	304.50	15.50	5.90	19.80	84.10	149.00	496.70	136.20	17.40	10.60

R4F2	52.73	5.68	25.73	1.48	0.05	0.03	0.24	0.15	1.75	0.87	0.03	0.94	10.07	99.75
R4F3	73.17	1.98	10.37	2.39	0.79	0.06	0.16	0.14	1.30	0.32	0.02	0.59	9.44	100.73

Table A2-76: Trace element concentrations for South Witbank Colliery (values presented as ppm)

SiteName	**Mn**	**Rb**	**Ba**	**Sr**	**Zr**	**Nb**	**Y**	**Sc**	**Cr**	**Cu**	**V**	**Zn**	**Ni**	**Co**
SW1	103.98	0.91	501.40	792.59	51.20	7.05	12.40	5.63	12.73	16.08	28.30	0.34	16.92	-
SW2	76.86	6.81	356.77	452.37	136.41	12.91	17.97	4.57	22.04	13.73	40.68	0.86	12.27	-
SW3	59.97	8.64	425.12	368.18	101.03	12.74	18.33	6.58	24.33	18.64	41.59	1.32	10.15	-
SW4	88.85	4.15	952.47	1325.14	31.55	3.57	14.63	6.39	20.80	13.88	29.71	0.55	9.36	-
SW5	129.53	11.60	484.34	618.11	89.72	8.43	15.16	5.43	8.55	19.28	28.88	2.10	10.60	-
SW6	60.11	17.86	354.04	399.35	116.28	15.04	17.67	7.30	22.69	18.07	44.67	1.86	10.60	-
SW7	87.54	9.71	1267.68	1227.75	0.00	1.97	7.82	4.80	13.63	11.88	24.74	0.73	3.22	-
SW8	89.41	9.27	1194.83	1272.62	0.00	1.81	9.10	5.01	12.38	13.43	22.07	1.37	3.29	-
SW9	66.51	12.47	826.70	814.07	31.01	4.95	11.48	6.57	15.92	10.03	29.87	2.48	3.12	-
SW10	131.55	5.37	538.91	810.27	28.19	6.15	10.39	5.01	5.26	16.43	15.34	1.37	19.25	-

Table A2-77: Trace element concentrations for Tavistock Colliery (values presented as ppm)

SiteName	**Mn**	**Rb**	**Ba**	**Sr**	**Zr**	**Nb**	**Y**	**Sc**	**Cr**	**Cu**	**V**	**Zn**	**Ni**	**Co**
TAV1A	137.24	5.93	1290.49	1774.47	0.00	0.00	23.06	7.20	9.05	19.73	15.80	2.67	8.77	-
TAV1B	96.60	20.10	2902.38	3646.04	0.00	0.00	22.89	2.82	7.35	19.84	14.77	1.99	16.10	-
TAV1C	101.84	0.40	1180.33	1957.58	0.00	0.00	26.16	1.28	4.22	21.45	13.56	4.50	23.62	-
TAV2A	82.24	10.25	1344.32	2237.95	0.00	0.00	28.78	4.15	9.89	16.66	19.58	42.31	19.91	-
TAV2B	104.36	7.00	1409.73	1824.59	0.00	0.00	13.25	3.20	3.27	16.96	15.72	32.23	16.63	-
TAV2C	95.18	5.27	520.46	443.18	104.05	11.36	17.68	6.28	32.15	13.10	35.71	1.68	15.83	-
TAV3A	82.90	0.00	235.71	258.58	47.41	7.30	9.59	3.34	22.59	11.64	19.45	5.73	19.47	-
TAV3B	73.10	0.00	237.29	263.01	58.98	8.36	10.69	3.71	27.29	8.31	23.52	8.02	17.24	-
TAV3C	176.06	0.00	237.68	382.26	36.14	6.25	8.09	2.41	9.25	20.48	11.83	7.86	38.49	-
TAV4A	-	57.00	311.80	85.30	221.80	19.70	26.60	14.70	142.30	20.70	103.80	33.30	24.70	13.80
TAV4B	-	59.00	326.00	85.00	214.00	20.00	24.50	14.10	135.20	22.60	104.30	34.60	24.90	10.00
TAV4C	-	57.40	315.00	83.90	218.10	19.50	25.70	14.70	141.90	22.30	99.10	35.60	24.10	11.10

TAV5A	36.92	40.81	1205.43	1223.07	50.67	7.01	30.32	12.11	32.85	15.65	93.02	2.77	12.25	-
TAV5B	39.82	63.71	927.72	1126.92	55.05	6.29	28.92	9.19	29.31	14.20	77.71	3.63	10.49	-
TAV5C	34.06	60.80	952.36	954.58	74.40	7.01	20.10	12.41	43.55	14.72	84.51	4.22	8.62	-
TAV6A	52.60	0.00	801.33	945.41	41.09	6.09	17.74	5.66	15.57	13.95	23.98	1.82	17.85	-
TAV6B	56.38	4.20	746.49	1123.31	38.04	4.43	14.76	5.53	19.70	12.85	25.01	1.52	11.45	-
TAV6C	60.58	2.75	677.33	945.24	40.26	5.18	17.75	6.39	20.30	12.79	25.90	1.64	10.66	-
TAV7A	104.29	0.00	344.33	601.71	54.47	7.87	14.34	4.62	20.50	16.31	25.21	1.05	15.45	-
TAV7C	20.14	46.84	160.85	120.67	180.80	22.01	23.97	6.57	26.52	21.08	55.15	2.42	9.03	-

Table A2-78: Trace element oxide concentrations for Union Colliery (values presented as ppm)

SiteName	Mn	Rb	Ba	Sr	Zr	Nb	Y	Sc	Cr	Cu	V	Zn	Ni	Co
UN1	44.30	2.48	238.19	209.91	82.55	9.88	14.33	6.27	27.22	10.52	33.92	13.98	26.38	-
UN2	40.57	0.00	254.70	202.87	84.57	11.06	14.25	7.30	29.36	8.95	37.19	4.84	33.03	-
UN3	3.9.74	1.81	239.42	160.04	82.85	10.37	12.99	6.00	50.92	8.89	37.89	7.45	21.31	-
UN4	24.95	1.48	226.90	158.80	77.46	9.62	13.12	3.18	64.12	7.64	35.19	9.75	22.96	-
UN5B	10.49	7.60	230.81	107.68	73.92	9.99	10.92	4.52	31.90	7.23	36.25	1.92	12.73	-
UN6B	9.08	0.00	212.29	113.05	76.56	10.16	16.84	5.08	45.05	8.98	42.92	2.60	13.98	-

Table A2-79: Mineral composition of samples for Arnot Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Apatite	Ill./ Smec.	Fsp	Siderite	Gibbsite	Gypsum	Anatase	Halite	Hematite	Total
ARA2	26.40	52.90	0.10	0.20	0.40	-	9.00	5.40	2.70	-	-	2.80	-	-	99.90
ARA3	69.90	10.20	0.10	0.40	-	-	11.70	-	4.00	-	-	3.40	0.10	-	99.80
ARA4	13.70	74.30	-	0.40	0.30	0.10	5.00	3.10	1.70	-	-	1.20	-	-	99.80
ARA5	16.60	59.60	5.70	2.60	5.60	-	1.10	-	7.40	-	-	1.30	-	-	99.90
ARA6	18.20	72.20	-	0.20	-	-	3.40	2.30	1.60	-	-	1.80	-	-	99.70
ARA7	27.10	55.60	-	0.40	0.10	0.10	8.60	5.40	1.40	-	-	1.30	-	-	100.00
ARA8	22.80	62.80	-	0.20	0.10	0.10	6.90	4.30	1.40	-	-	1.30	-	-	99.90
ARA9	21.50	48.50	17.80	4.50	2.00	0.30	2.90	-	0.90	-	-	1.50	-	-	99.90
ARA10	11.50	64.90	11.40	4.30	1.50	1.80	3.00	-	-	-	-	1.40	-	-	99.80
ARA11	71.00	9.20	0.30	0.30	1.70	-	9.10	5.90	1.00	-	-	1.30	-	-	99.80
ARA12	73.40	9.60	-	-	0.10	-	7.20	-	7.60	-	-	1.80	-	-	99.70
ARA13	4.20	71.70	-	0.40	8.20	0.40	4.30	-	10.20	-	-	1.00	-	-	100.40
ARA14	23.70	62.60	-	0.40	0.40	0.20	9.90	-	1.20	-	-	1.40	-	-	99.80
ARA15	25.70	58.00	0.90	0.90	1.50	-	9.50	-	1.50	0.40	-	1.60	-	-	100.00
ARA16	50.50	9.80	0.20	0.80	0.30	0.10	21.00	13.10	3.60	-	-	0.70	-	-	100.10
ARB1	50.10	12.00	-	-	4.80	-	5.40	3.80	20.30	-	-	2.10	-	1.40	99.90
ARB2	22.00	64.50	0.90	0.60	1.90	-	5.90	-	0.80	0.30	-	3.00	-	-	99.90
ARB3	68.00	6.60	5.70	3.40	-	-	8.00	4.80	2.10	-	-	1.30	-	-	99.90
ARB4	55.10	31.70	0.40	-	-	0.40	6.30	4.00	1.30	-	-	1.00	-	-	100.20
ARB5	10.40	57.70	2.70	1.80	4.40	0.30	19.40	-	1.10	-	-	2.00	-	-	99.80
ARB6	61.50	14.00	6.80	2.90	0.60	-	5.70	3.50	4.10	-	-	0.70	-	-	99.80
ARB7	5.10	78.60	6.60	1.80	1.70	0.60	1.20	-	-	0.70	2.90	0.80	-	-	100.00

ARB8	83.40	8.00	-	-	0.50	0.20	2.80	2.20	2.10	-	-	0.80	-	-	100.00
ARB9	24.30	62.50	-	0.40	0.20	0.20	9.60	-	1.30	-	-	1.40	-	-	99.90
ARB10	9.10	82.20	-	0.30	2.70	0.20	2.50	-	2.50	-	-	0.70	-	-	100.20
ARB11	18.70	65.70	0.20	0.80	0.10	0.10	10.70	-	2.30	-	-	1.20	-	-	99.80
ARB13	34.90	16.80	4.30	3.50	0.10	0.20	19.60	11.50	7.90	0.10	-	1.00	-	0.10	100.00
ARC1	27.40	57.70	0.10	0.30	0.30	0.10	5.60	3.40	2.40	-	-	2.50	-	-	99.80
ARC2	7.50	53.70	9.30	2.90	8.20	-	3.00	-	13.60	-	-	1.80	-	-	100.00
ARC3	72.10	11.10	0.90	0.40	-	-	7.40	4.50	2.10	0.10	-	1.30	-	-	99.90
ARC4	31.70	50.50	-	0.30	0.20	0.10	8.70	5.50	1.70	-	-	1.30	-	-	100.00
ARC5	-	35.50	12.00	3.20	16.20	-	6.60	-	24.80	-	-	1.40	-	-	99.70
ARC6	19.70	66.00	7.20	0.80	1.70	-	1.40	-	1.00	-	-	2.10	-	-	99.90
ARC7	77.60	11.20	-	-	0.70	-	3.70	-	4.50	-	-	2.20	-	-	99.90
ARD1	29.70	51.90	0.30	0.20	0.60	0.10	12.50	-	2.10	-	-	2.40	-	-	99.80
ARD2	10.30	59.50	4.50	1.60	5.10	0.40	6.80	-	9.40	-	-	2.20	-	-	99.80
ARD3	68.90	3.80	8.40	3.40	0.20	-	6.40	3.80	4.20	0.10	-	0.70	-	-	99.90
ARD4	33.30	49.50	-	0.10	0.10	0.20	8.80	5.40	1.50	-	-	1.20	-	-	100.10
ARD5	34.00	57.80	2.90	0.60	1.00	-	1.30	-	0.30	-	-	2.20	-	-	100.10
ARD6	3.30	57.50	9.70	2.30	3.20	-	3.80	-	18.40	-	-	1.40	-	-	99.60
ARD7	77.50	14.60	-	-	-	0.30	1.10	-	3.00	-	-	3.40	-	-	99.90

Table A2-80: Mineral composition of samples for Arnot-North Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
3936	28.70	43.10	-	0.20	-	0.50	14.50	-	11.30	0.10	-	1.10	0.50	0.10	100.10
3937	28.30	44.50	-	0.40	-	0.30	9.50	6.80	9.00	-	-	1.20	-	-	100.00
3938	11.40	68.60	1.80	0.60	1.60	0.60	6.00	-	6.30	-	-	1.80	1.20	-	99.90

3939	37.50	41.90	0.50	0.20	0.50	0.50	4.80	5.00	7.40	0.10	-	1.60	-	-	100.00
3940	47.00	25.00	0.20	0.60	1.10	0.20	11.80	8.80	3.80	0.20	-	1.20	-	-	99.90
3941	29.00	6.80	3.50	2.60	0.20	1.20	14.00	20.90	16.20	-	-	1.40	-	4.30	100.10
3942	28.10	34.60	-	0.90	-	0.30	12.60	8.70	13.70	0.10	-	1.00	-	0.20	100.20
3943	16.90	47.60	-	1.00	0.60	1.00	6.90	5.60	19.10	-	-	1.00	-	0.30	100.00
3944	20.40	30.00	0.30	1.60	0.80	0.40	10.50	7.60	27.20	-	-	0.90	-	0.30	100.00
3945	27.40	52.20	-	0.20	2.80	0.50	6.30	-	7.90	-	-	1.30	1.40	-	100.00
3946	50.80	22.90	-	-	0.80	0.10	7.70	6.20	7.00	-	-	4.40	-	-	99.90
3947	58.40	11.30	0.50	-	0.20	0.10	14.10	9.30	3.80	-	-	2.10	-	-	99.80
3948	22.80	31.30	-	0.70	-	0.40	21.60	-	20.50	-	-	1.10	0.40	1.00	99.80
3949	34.30	45.10	-	0.10	-	0.50	9.30	-	8.60	-	-	1.60	0.40	-	99.90
3950	39.90	38.20	1.00	0.10	0.10	0.30	4.20	3.90	9.60	-	-	2.60	-	-	99.90
3951	36.50	40.80	1.00	-	2.30	0.30	6.20	-	9.90	0.30	-	1.60	1.00	-	99.90
3952	56.10	23.40	0.20	-	0.20	0.10	5.20	4.20	5.90	-	-	4.60	-	-	99.90
3953	44.60	6.50	4.00	2.00	0.50	0.30	22.40	-	17.20	-	-	0.80	1.30	0.30	99.90
3954	31.60	46.70	0.50	0.50	-	0.40	6.50	5.50	6.80	0.10	-	1.30	-	-	99.90
3955	32.40	47.80	1.20	0.40	1.60	0.30	7.70	-	6.40	-	-	1.30	0.90	-	100.00
3956	79.30	7.80	-	-	0.40	-	4.50	4.30	1.30	-	-	2.30	-	-	99.90
3957	46.40	31.20	0.30	-	1.00	0.20	8.00	6.20	3.80	-	-	2.90	-	-	100.00
3958	60.90	11.50	0.30	-	0.60	-	9.00	6.70	6.70	-	-	4.20	-	-	99.90
3959	51.60	31.10	0.30	-	0.40	-	4.90	4.40	4.40	-	-	2.80	-	-	99.90

Table A2-81: Mineral composition of samples for Bank Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
BAN1	-	35.90	23.10	4.00	6.20	8.00	6.90	-	4.00	10.90	-	0.90	-	-	99.90
BAN2	-	59.00	11.50	2.90	4.30	5.00	8.20	-	2.40	5.60	-	1.10	-	-	100.00
BAN3	-	48.10	4.20	1.50	4.20	8.40	21.10	-	2.60	8.00	-	1.90	-	-	100.00

BAN4	0.50	10.80	31.50	8.30	7.00	9.20	2.10	-	4.10	25.10	-	1.30	-	-	99.90
BAN5	-	71.40	4.80	2.20	1.00	-	6.90	-	-	8.10	2.30	2.80	-	-	99.50
BAN6	5.90	66.90	11.50	2.30	4.60	1.20	5.10	-	1.20	-	-	1.50	-	-	100.20
BAN7	7.80	74.00	6.30	2.40	1.50	-	4.10	-	-	-	-	3.70	-	-	99.80
BAN8	0.60	41.90	17.70	5.30	6.10	-	13.90	-	4.80	8.40	-	1.20	-	-	99.90
BAN9	-	-	15.70	5.00	9.70	6.10	10.70	-	11.90	39.30	-	1.60	-	-	100.00
BAN10	21.70	57.90	-	1.10	0.10	0.90	13.80	-	3.10	-	-	1.20	-	-	99.80
BAN11	24.30	49.80	0.30	1.20	0.10	-	13.20	7.50	2.40	-	-	1.00	-	-	99.80
BAN12	32.30	31.10	-	0.60	7.10	-	21.90	-	6.10	-	-	1.00	-	-	100.10
BAN13	24.10	34.00	-	-	10.80	-	12.00	-	18.10	-	-	1.00	-	-	100.00
BAN14	20.70	-	1.70	3.60	1.20	4.20	19.20	-	48.30	-	-	0.30	-	-	99.20
BAN15	26.20	47.30	0.30	1.50	0.10	-	13.30	7.60	2.60	-	-	1.00	-	-	99.90
BAN16	25.70	27.70	-	-	12.60	-	10.30	-	22.90	-	-	0.50	-	-	99.70
BAN17	31.10	34.70	-	0.90	6.00	-	15.40	-	11.10	-	-	0.90	-	-	100.10
BAN18	34.10	-	0.50	4.10	1.00	0.20	46.30	-	12.10	-	-	0.80	-	-	99.10
BAN19	1.10	79.60	7.20	0.90	2.20	0.90	2.60	-	1.90	0.70	-	2.90	-	-	100.00
BAN20	-	63.20	13.70	1.40	1.50	1.30	3.90	-	-	11.30	-	3.70	-	-	100.00
BAN21	-	56.10	13.60	1.60	3.40	2.50	4.00	-	5.10	11.50	-	2.20	-	-	100.00

Table A2-82: Mineral composition of samples for Bankfontein Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
BK1	0.80	69.20	-	-	4.60	5.50	3.00	-	-	14.60	-	2.40	-	-	100.10
BK2	-	9.40	14.60	1.40	12.50	38.60	-	-	13.10	10.40	-	-	-	-	100.00
BK3	3.50	83.50	-	-	2.30	-	8.90	-	0.30	-	-	1.40	-	-	99.90

Table A2-83: Mineral composition of samples for Borehole 1 as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
BH1-1	17.90	38.90	0.60	3.80	1.20	-	25.50	-	8.70	0.20	-	0.90	2.40	-	100.10
BH1-2	27.00	49.00	0.70	1.60	1.90	-	15.10	-	2.10	-	-	0.80	2.00	-	100.20
BH1-3	77.50	1.50	2.50	-	2.00	-	5.30	4.00	5.30	-	-	0.10	-	1.80	100.00
BH1-4	-	6.70	0.90	4.40	8.20	21.00	35.70	-	1.30	18.80	-	0.50	2.40	-	99.90
BH1-5	-	45.40	18.00	4.70	5.10	3.20	16.60	-	1.20	1.90	-	1.20	2.80	-	100.10
BH1-6	-	39.90	21.00	5.40	4.90	0.70	17.90	-	-	3.10	-	1.40	5.60	-	99.90
BH1-7	38.90	34.00	-	0.10	-	0.10	22.10	-	1.60	-	-	1.20	1.80	-	99.80

Table A2-84: Mineral composition of samples for Borehole wedge 1 as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
BHW1-1	68.60	-	0.70	-	0.30	-	16.40	11.60	2.00	-	-	0.30	-	-	99.90
BHW1-2	60.80	0.70	0.20	0.20	0.90	-	16.50	17.20	2.90	-	-	0.40	-	-	99.80
BHW1-3	68.80	-	5.50	-	0.60	-	14.00	8.40	2.30	-	-	0.40	-	-	100.00
BHW1-4	27.20	11.50	5.30	3.80	2.30	0.20	12.50	9.30	27.10	-	-	0.50	-	0.20	99.90
BHW1-5	59.10	4.90	5.10	0.40	2.70	-	9.40	8.00	9.50	0.20	-	0.60	-	-	99.90
BHW1-6	25.80	53.00	4.90	1.30	3.50	-	3.20	-	4.90	-	-	2.30	1.10	-	100.00
BHW1-7	23.10	46.30	13.00	3.00	3.70	-	2.40	-	6.10	-	-	1.50	0.90	-	100.00
BHW1-8	17.90	38.50	22.50	4.70	5.40	-	1.80	-	6.20	0.40	-	1.60	0.90	-	99.90
BHW1-9	11.50	55.20	14.60	2.80	5.30	-	2.30	-	5.60	-	-	1.20	1.30	-	99.80
BHW1-10	52.80	31.80	0.60	0.30	0.60	0.10	8.30	-	4.10	-	-	0.70	0.70	-	100.00
BHW1-11	17.20	52.70	-	0.20	-	0.10	16.00	11.40	1.60	-	-	0.70	-	-	99.90

BHW1-12	54.80	17.10	-	-	-	-	15.50	10.80	1.10	0.10	-	0.50	-	-	99.90

Table A2-85: Mineral composition of samples for Borehole wedge 2 as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
BHW2-1	61.70	-	0.40	0.10	1.10	-	29.10	-	2.90	-	-	0.30	4.50	-	100.10
BHW2-2	25.30	47.20	-	1.40	1.90	-	15.50	-	5.70	0.20	-	1.10	1.60	-	99.90
BHW2-3	12.10	52.20	-	1.40	6.00	-	5.80	8.70	13.40	-	-	0.40	-	-	100.00
BHW2-4	40.50	17.50	-	0.50	1.20	-	18.20	16.70	4.40	-	-	0.90	-	-	99.90
BHW2-5	50.20	0.50	2.50	0.80	3.20	-	15.30	14.20	11.40	-	-	0.40	-	1.60	100.10
BHW2-6	30.70	52.80	2.50	0.70	2.10	-	3.20	-	5.30	-	-	1.60	0.80	-	99.70
BHW2-7	14.60	44.60	24.10	4.80	1.90	-	3.70	-	4.40	-	-	0.70	1.20	-	100.00
BHW2-8	-	20.00	38.30	5.90	11.80	-	2.00	-	17.70	2.90	-	0.70	0.70	-	100.00
BHW2-9	13.30	66.80	0.30	0.60	0.20	0.10	13.80	-	2.60	-	-	1.60	0.80	-	100.10

Table A2-86: Mineral composition of samples for Borehole wedge 3 as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
BHW3-1	80.20	-	0.50	-	0.20	-	14.80	2.30	1.60	-	-	0.40	-	-	100.00
BHW3-2	6.70	26.40	8.40	1.70	18.30	-	17.30	-	18.50	0.50	-	1.60	0.60	-	100.00
BHW3-3	54.40	-	0.20	2.10	2.20	-	22.60	-	17.10	-	-	0.30	0.90	-	99.80
BHW3-4	15.40	46.10	5.10	3.20	8.20	-	10.90	-	8.60	-	-	0.60	1.90	-	100.00
BHW3-5	21.60	33.80	0.60	3.40	0.70	-	14.60	13.50	10.80	-	-	0.90	-	-	99.90
BHW3-6	51.80	2.00	11.30	0.30	0.10	-	12.70	18.20	3.10	-	-	0.30	-	-	99.80
BHW3-7	34.30	-	6.10	7.60	1.70	0.20	11.20	-	32.70	-	-	0.20	0.60	5.30	99.90

BHW3-8	8.20	28.60	6.00	0.90	18.20	-	17.90	-	17.80	-	-	1.50	0.70	-	99.80
BHW3-9	40.80	25.60	-	0.40	0.20	-	17.80	12.10	2.30	-	-	0.80	-	-	100.00
BHW3-10	64.10	9.80	-	0.50	1.40	-	18.20	-	3.80	-	-	0.90	1.30	-	100.00
BHW3-11	15.70	60.10	4.10	1.70	3.80	2.00	7.10	-	2.30	-	-	2.00	1.20	-	100.00
BHW3-12	8.40	48.00	14.40	4.10	6.60	2.40	5.40	-	8.20	-	-	1.30	1.10	-	99.90
BHW3-13	3.20	57.40	10.10	2.60	5.20	4.20	13.20	-	1.20	-	-	1.50	1.30	-	99.90
BHW3-14	42.40	36.00	-	-	0.30	-	10.60	8.10	2.10	-	-	0.50	-	-	100.00

Table A2-87: Mineral composition of samples for Borehole wedge 4 as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
BHW4-1	19.30	45.90	2.60	2.30	5.60	-	14.60	-	7.30	-	-	0.90	1.50	-	100.00
BHW4-2	33.90	19.00	0.20	1.70	2.10	0.10	12.90	12.50	16.70	-	-	0.90	-	-	100.00
BHW4-3	13.60	34.10	2.00	1.10	13.40	-	17.70	-	16.20	-	-	0.90	0.90	-	99.90
BHW4-4	49.10	21.80	0.10	-	1.70	-	10.40	9.30	6.70	-	-	0.70	-	-	99.80
BHW4-5	78.30	3.20	-	-	1.30	-	6.40	5.40	4.70	-	-	0.40	-	-	99.70
BHW4-6	16.50	56.30	9.20	2.80	1.90	-	7.40	-	2.60	0.40	-	1.50	1.40	-	100.00
BHW4-7	33.90	50.80	2.30	1.40	0.40	-	7.20	-	1.50	-	-	1.50	1.00	-	100.00
BHW4-8	22.60	61.00	7.40	2.30	0.70	-	3.00	-	0.80	-	-	1.10	1.10	-	100.00
BHW4-9	17.40	52.00	16.10	4.20	2.30	-	3.20	-	0.80	0.80	-	1.80	1.50	-	100.10
BHW4-10	-	29.60	27.40	3.40	14.30	0.50	0.50	-	22.40	-	-	0.80	1.00	-	99.90
BHW4-11	53.30	11.10	-	-	0.10	-	19.80	13.70	1.30	-	-	0.60	-	-	99.90

Table A2-88: Mineral composition of samples for Borehole wedge 5 as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Apatite	Ill./ Smec.	Fsp	Siderite	Gibbsite	Gypsum	Anatase	Halite	Hematite	Total
BHW5-1	19.80	33.30	-	2.20	2.20	0.20	13.50	13.00	14.60	0.10	-	1.00	-	-	99.90
BHW5-2	6.60	38.90	1.30	0.70	17.00	-	11.70	-	22.10	-	-	1.10	0.50	-	99.90
BHW5-3	25.30	40.50	-	1.20	1.30	0.10	13.10	12.40	5.10	-	-	1.10	-	-	100.10
BHW5-4	71.30	3.10	-	-	-	-	14.10	9.20	1.50	-	-	0.80	-	-	100.00
BHW5-5	68.70	6.20	-	-	0.10	-	11.60	7.60	4.50	0.10	-	1.10	-	-	99.90
BHW5-6	85.90	0.80	-	0.20	-	-	7.30	-	4.90	0.10	-	0.30	0.40	-	99.90
BHW5-7	81.50	1.20	-	-	0.10	0.20	7.30	5.00	4.40	-	-	0.40	-	-	100.10
BHW5-8	30.70	38.00	-	0.40	1.10	-	10.20	9.80	8.80	-	-	0.90	-	-	99.90
BHW5-9	50.60	22.30	-	-	-	-	18.10	-	7.00	-	-	0.70	1.20	-	99.90
BHW5-10	10.40	42.80	2.90	0.80	11.30	3.00	6.80	-	18.60	0.50	-	2.10	0.70	-	99.90
BHW5-11	-	51.20	10.90	3.50	5.40	5.90	8.30	-	1.30	9.90	-	2.00	1.50	-	99.90
BHW5-12	18.30	40.70	18.70	5.70	2.50	1.10	6.40	-	2.30	-	-	3.20	1.10	-	100.00
BHW5-13	6.10	53.10	12.50	3.00	4.80	3.10	12.80	-	0.40	-	-	2.50	1.60	-	99.90
BHW5-14	30.40	48.50	0.30	0.30	0.10	-	9.70	8.00	2.00	-	-	0.60	-	-	99.90
BHW5-15	39.30	38.90	-	-	-	-	11.20	8.40	1.30	-	-	0.60	-	-	99.70

Table A2-89: Mineral composition of samples for Delmas Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Apatite	Ill./ Smec.	Fsp	Siderite	Gibbsite	Gypsum	Anatase	Halite	Hematite	Total
DEL1	22.40	63.80	0.40	1.30	0.50	0.20	8.30	-	1.10	-	-	1.20	0.80	-	100.00
DEL2	7.50	48.60	10.50	1.70	5.30	2.00	10.30	-	11.60	-	-	1.30	1.20	-	100.00
DEL4	-	0.80	8.80	0.60	16.30	2.40	3.70	-	57.70	8.90	-	0.40	0.40	-	100.00

DEL5	-	18.30	16.50	1.80	10.00	11.70	11.30	-	21.60	6.40	-	1.20	1.20	-	100.00
DEL6	22.20	65.10	0.40	0.60	1.40	0.20	3.90	4.20	0.80	-	-	1.20	-	-	100.00
DEL7	-	42.20	24.40	1.20	1.60	5.50	9.20	-	-	5.80	6.40	2.10	1.70	-	100.10
DEL8	-	7.20	5.30	1.40	37.10	0.90	1.50	-	42.30	3.80	-	0.30	0.20	-	100.00
DEL9	-	9.90	36.50	4.80	10.10	15.30	4.50	-	12.10	5.20	-	0.30	1.30	-	100.00
DEL10	3.90	54.60	12.40	2.40	1.40	3.00	13.20	-	-	-	5.50	2.30	1.20	-	99.90
DEL11	-	-	7.90	5.60	3.60	29.20	1.30	-	-	36.70	12.30	1.70	1.80	-	100.10
DEL12	0.30	24.40	28.60	1.50	13.20	5.90	11.10	-	8.70	4.20	-	1.30	0.70	-	99.90
DEL13	12.80	22.90	6.40	1.70	10.60	-	30.80	-	2.90	0.80	-	9.80	1.20	-	99.90
DEL14	2.20	58.90	8.70	3.80	3.90	2.10	16.00	-	2.00	-	-	1.70	0.80	-	100.10
DEL15	-	3.20	16.90	2.70	24.20	6.60	22.70	-	13.20	8.40	-	1.20	0.90	-	100.00
DEL16	-	57.50	12.80	3.50	6.10	0.90	11.90	-	1.70	1.70	-	3.20	0.70	-	100.00
DEL17	-	16.60	8.60	2.50	21.90	6.80	11.40	-	18.60	10.70	-	2.20	0.80	-	100.10

Table A2-90: Mineral composition of samples for Douglas Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
DOU1	39.60	51.10	-	-	0.40	0.10	6.10	-	0.90	-	-	1.70	0.10	-	100.00
DOU2	14.60	52.70	13.20	1.80	5.30	-	3.30	-	7.40	-	-	1.70	-	-	100.00
DOU3	17.60	69.60	1.50	0.90	0.90	-	4.60	-	-	-	2.50	2.40	-	-	100.00
DOU4	70.30	8.10	12.50	2.00	0.20	-	4.20	-	1.70	-	-	0.90	-	0.10	100.00
DOU5	39.50	47.80	-	-	0.50	0.10	9.20	-	1.20	-	-	1.40	0.20	-	99.90
DOU6	8.10	53.90	18.90	3.30	7.40	-	5.00	-	1.30	0.70	-	1.40	-	-	100.00
DOU7	16.70	74.70	0.60	0.40	0.40	-	4.70	-	0.90	-	-	1.60	0.10	-	100.10
DOU8	-	5.30	11.90	1.40	27.20	0.40	0.40	-	41.70	11.20	-	0.50	-	-	100.00
DOU9	3.40	34.70	29.00	7.10	6.90	9.00	0.50	-	8.40	0.30	-	0.70	-	-	100.00
DOU10	5.50	57.00	7.80	2.60	6.00	1.20	5.50	-	13.00	-	-	1.30	-	-	99.90
DOU11	20.40	63.20	-	0.60	0.20	0.90	6.10	3.90	3.40	-	-	1.20	-	-	99.90

DOU12	8.20	63.00	0.60	1.00	-	0.10	14.90	9.00	2.00	-	-	1.00	-	-	99.80
DOU13	13.20	36.50	30.30	5.60	3.60	3.60	2.20	-	4.00	-	-	1.00	-	-	100.00
DOU14	15.50	51.00	9.90	2.20	5.20	1.70	4.40	-	8.20	-	-	1.90	-	-	100.00
DOU15	26.70	58.00	-	0.40	2.30	0.20	5.00	2.80	3.30	-	-	1.40	-	-	100.10
DOU16	38.40	43.50	-	0.20	0.10	0.20	9.20	5.50	1.90	-	-	1.20	-	-	100.20
DOU17	25.50	43.30	0.40	1.60	0.30	-	15.10	8.70	4.00	-	-	1.00	-	-	99.90
DOU18	26.60	38.90	-	-	7.80	-	15.50	-	9.80	-	-	1.10	-	-	99.70
DOU19	55.00	16.30	-	0.60	0.80	0.10	13.20	10.40	2.90	-	-	0.50	-	-	99.80
DOU20	32.20	51.70	-	-	0.20	0.20	7.70	4.60	2.40	-	-	1.20	-	-	100.20
DOU21	47.70	4.10	-	-	7.40	0.40	6.60	4.40	29.10	-	-	0.50	-	-	100.20
DOU22	-	0.9	8.9	1.1	23	14.4	3.1	-	33.8	14.2	-	0.8	-	-	100.20
DOU23	7.50	78.4	3.2	1.3	0.3	0.2	5.1	-	2.3	-	-	1.6	-	-	99.90
DOU24	16.80	66.4	0.2	1.1	0.1	0.4	7	4.2	2.7	-	-	1.2	-	-	100.10
DOU25	14.90	76.4	0.7	0.3	0.8	0.2	3.1	-	0.8	-	-	2.5	-	-	99.70
DOU26	-	68.7	2.3	0.8	2.3	14.4	8	-	2.1	0.5	-	1	-	-	100.10
DOU27	0.60	37.3	18.5	-	8.4	2.7	9.9	-	4.6	15.5	-	2.4	-	-	99.90
DOU28	0.70	-	16.7	-	13.1	2.6	13.4	-	8.7	40.2	-	4.6	-	-	100.00
DOU29	50.70	38.6	-	-	-	-	7.3	-	1.3	-	-	1.8	-	-	99.70
DOU30	21.40	57	-	0.9	-	0.5	15.9	-	2.8	-	-	1.2	0.1	-	99.80
DOU31	7.00	51.6	2.7	0.5	10.8	5.4	10.6	-	9.7	-	-	1.7	-	-	100.00
DOU32	33.70	55.1	-	0.3	1.4	4.9	2	-	0.4	-	-	2.3	-	-	100.10
DOU33	13.80	47.8	6.5	2.9	11.8	1	3.8	-	10.5	-	-	2	-	-	100.10
DOU34	26.20	50.7	-	-	0.4	0.1	10.6	6.2	4.5	-	-	1.3	-	-	100.00
DOU35	37.70	34.8	1.3	3.4	0.8	0.2	7.3	4.5	8.1	-	-	2	-	-	100.10
DOU36	2.50	83.1	2.7	0.5	2.2	-	6	-	0.4	0.4	-	2.2	-	-	100.00
DOU37	18.60	69.2	2	0.5	2	-	4.3	-	1	0.3	-	2.3	-	-	100.20
DOU38	28.90	58.8	3.9	1.2	1.2	-	4.3	-	-	0.2	-	1.3	-	-	99.80
DOU39	49.00	31.4	7.3	2.2	0.4	-	5.8	-	2.2	-	-	1.6	-	-	99.90
DOU40	18.20	30.3	1.1	-	16.4	-	0.3	-	32.7	-	-	0.8	-	-	99.80
DOU41	62.70	26.9	1.7	0.7	0.1	-	2	-	3.2	-	-	2.7	-	-	100.00

Table A2-91: Mineral composition of samples for Forzando Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
FOR1	18.50	42.80	27.40	5.70	3.10	-	-	-	0.60	-	-	1.00	0.70	-	99.80
FOR2	4.70	41.50	17.70	2.90	6.30	7.30	4.40	-	4.90	-	-	9.70	0.60	-	100.00
FOR3	32.80	49.20	0.70	0.40	0.30	0.10	6.20	5.10	3.90	-	-	1.20	-	-	99.90
FOR4	30.30	54.40	0.50	0.40	0.20	0.10	6.20	5.00	1.30	0.10	-	1.50	-	-	100.00
FOR5	10.70	58.00	9.70	1.90	5.30	-	6.20	-	6.80	-	-	1.00	0.30	-	99.90
FOR6	22.90	49.60	10.60	2.40	3.50	-	6.10	-	2.50	0.50	-	1.10	0.60	-	99.80
FOR7	56.30	-	-	-	0.30	-	38.90	-	2.50	-	-	0.50	1.30	-	99.80
FOR8	32.80	39.80	0.30	0.50	1.10	-	8.80	5.80	9.80	-	-	0.90	-	-	99.80
FOR9	17.40	47.90	0.20	0.30	2.70	0.20	5.50	5.20	19.20	0.20	-	1.20	-	-	100.00
FOR10	33.50	42.60	-	0.30	1.10	-	5.40	4.40	11.10	-	-	1.40	-	-	99.80
FOR11	4.40	70.10	13.90	1.50	6.10	-	-	-	2.70	-	-	1.00	-	-	99.70
FOR12	17.40	53.60	14.80	3.80	4.20	-	4.10	-	0.80	-	-	1.10	-	-	99.80
FOR13	58.30	3.70	-	-	0.80	-	18.50	14.20	4.00	-	-	0.50	-	-	100.00

Table A2-92: Mineral composition of samples for Greenside Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
GRE1	21.10	36.00	11.70	4.70	3.80	-	4.50	2.50	14.70	-	-	0.80	-	-	99.80
GRE2	2.50	53.00	9.30	1.90	8.70	4.10	3.50	-	15.90	-	-	1.20	-	-	100.10
GRE3	1.10	45.10	6.90	0.90	13.10	2.10	2.70	-	26.70	-	-	1.40	-	-	100.00
GRE4	18.70	53.40	13.20	1.00	4.50	-	1.40	-	6.20	-	-	1.70	-	-	100.10
GRE5	62.20	7.60	0.20	1.10	2.70	-	9.10	5.60	11.10	-	-	0.40	-	-	100.00

GRE6	27.40	61.00	-	-	0.20	0.20	5.40	3.70	0.80	-	-	1.40	-	-	100.10
GRE7	-	44.10	16.50	0.70	6.20	18.10	3.50	-	5.50	4.00	-	1.30	-	-	99.90
GRE8	3.80	53.10	10.10	0.90	4.20	19.70	4.30	-	2.60	-	-	1.50	-	-	100.20
GRE9	11.70	40.90	26.70	3.20	6.20	1.60	-	-	8.30	-	-	1.30	-	-	99.90
GRE10	49.90	39.80	-	-	-	-	3.60	3.30	1.30	-	-	1.80	-	-	99.70
GRE11	20.60	65.50	0.70	0.70	0.30	-	9.40	-	0.90	.	-	1.30	-	-	99.40
GRE12	2.20	32.50	27.90	5.50	12.20	0.30	2.40	-	15.80	-	-	1.20	-	-	100.00
GRE13	24.60	46.60	20.40	3.30	2.00	-	1.30	-	-	-	-	1.70	-	-	99.90
GRE14	9.40	23.00	29.40	6.80	12.30	-	-	-	17.40	-	-	1.70	-	-	100.00
GRE15	88.30	1.50	1.20	0.40	0.20	-	6.70	-	1.30	-	-	0.10	-	-	99.70
NGT1	27.00	29.80	0.60	3.30	0.80	0.20	17.30	11.60	8.50	-	-	1.00	-	-	100.10
NGT2	32.50	49.10	0.30	1.30	0.90	-	13.30	-	1.70	-	-	1.00	-	-	100.10
NGT3	25.00	54.00	-	0.70	5.10	-	13.30	-	1.20	-	-	0.70	-	-	100.00
NGT4	20.90	35.70	-	0.70	10.10	-	14.50	-	16.70	-	-	0.60	-	-	99.20
NGT5	25.00	33.80	0.60	2.30	-	-	31.50	-	5.00	-	-	1.00	-	-	99.20
NGT6	28.20	28.60	0.60	3.50	1.40	-	17.70	11.90	6.90	-	-	1.00	-	-	99.80
NGT7	38.30	40.60	0.40	1.50	1.60	-	15.30	-	1.50	-	-	0.90	-	-	100.10
NGT8	38.40	42.10	-	0.90	4.00	-	12.10	-	1.10	-	-	1.10	-	-	99.70
NGT9	21.00	41.80	0.60	1.10	6.90	-	21.40	-	6.30	-	-	0.80	-	-	99.90
NGT10	25.00	36.10	0.50	2.20	0.90	0.10	29.50	-	4.50	-	-	1.00	-	-	99.80
NGT11	26.00	26.90	0.60	3.80	0.90	0.30	16.90	12.30	10.20	-	-	1.00	-	-	98.90
NGT12	27.40	45.20	0.60	1.70	4.20	-	13.60	-	6.50	0.20	-	0.60	-	-	100.00
NGT13	20.80	50.20	1.70	2.00	6.20	-	11.80	-	6.70	-	-	0.50	-	-	99.90
NGT14	38.00	20.30	-	1.80	3.10	-	31.30	-	4.50	-	-	0.80	-	-	99.80
NGT15	25.10	32.00	0.60	2.60	-	0.10	32.70	-	5.60	-	-	0.90	-	-	99.60

Table A2-93: Mineral composition of samples for Kleinkopje Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
KK1	4.30	68.10	6.90	2.70	2.20	5.70	4.10	-	2.70	-	-	3.30	-	-	100.00
KK2	-	4.10	54.10	1.60	20.00	2.20	-	-	17.20	0.80	-	-	-	-	100.00
KK3	4.60	74.40	-	0.60	1.30	9.70	4.20	-	2.00	0.20	-	3.10	-	-	100.10
KK4	12.10	60.40	1.20	1.90	0.40	4.80	6.80	4.20	6.30	0.20	-	1.70	-	-	100.00
KK5	23.40	66.40	-	0.20	-	0.10	4.30	2.70	1.10	-	-	1.80	-	-	100.00
KK6	80.30	3.90	-	-	-	-	13.50	-	1.10	0.10	-	0.80	-	-	99.70
KK7	12.10	56.00	15.10	1.90	2.40	-	6.80	-	3.40	0.40	-	1.90	-	-	100.00
KK8	38.60	42.60	-	-	-	0.10	10.20	5.90	1.10	-	-	1.20	-	-	99.70
KK9	-	18.80	30.40	5.90	11.60	1.40	3.70	-	18.40	8.70	-	1.10	-	-	100.00
KK10	95.10	0.70	-	-	-	-	2.70	-	1.30	-	-	-	-	-	99.80
KK11	14.30	59.00	-	1.70	0.10	0.80	11.00	6.60	5.20	-	-	1.20	-	-	99.90
KK12	2.30	64.70	9.40	0.80	2.80	5.80	10.10	-	2.50	-	-	1.60	-	-	100.00
KK13	-	-	15.10	1.70	14.20	-	-	-	-	53.20	5.80	9.10	-	-	99.10
KK14	36.00	33.90	-	-	0.80	0.30	15.90	9.20	1.80	-	-	1.60	-	-	99.50
KK15	84.40	4.40	-	-	0.80	-	8.70	-	1.30	-	-	0.30	-	-	99.90
KK16	0.50	67.80	-	-	5.00	9.20	1.80	-	-	13.70	-	2.20	-	-	100.20

Table A2-94: Mineral composition of samples for Khutala Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
KHU1	-	45.70	13.50	2.90	7.80	-	3.30	-	12.80	13.20	-	0.90	-	-	100.10
KHU2	-	42.00	19.20	3.60	6.40	2.40	5.00	-	5.60	14.10	-	1.70	-	-	100.00

KHU3	0.30	28.50	21.00	6.30	3.70	15.20	4.70	-	2.50	16.90	-	0.90	-	-	100.00
KHU4	-	91.00	1.30	0.30	0.70	0.30	1.60	-	0.40	2.20	-	2.10	-	-	99.90
KHU5	-	75.10	7.60	1.50	3.10	0.60	5.50	-	3.30	0.70	-	2.80	-	-	100.20
KHU6	5.70	57.10	16.90	-	7.30	-	-	-	12.20	-	-	0.60	-	-	99.80
KHU7	67.20	25.50	-	-	0.40	-	3.40	-	2.50	-	-	0.80	-	-	99.80
KHU8	-	41.60	10.10	0.80	16.00	-	1.50	-	28.20	1.20	-	0.60	-	-	100.00
KHU9	0.30	71.20	10.90	1.70	2.80	0.80	4.20	-	0.90	5.40	-	1.90	-	-	100.10
KHU10	-	40.80	30.20	6.80	3.40	0.70	3.40	-	2.70	9.90	-	2.00	-	-	99.90
KHU11	-	23.50	15.70	3.10	15.50	3.00	4.00	-	27.30	6.30	-	1.60	-	-	100.00
KHU12	16.10	38.00	19.80	5.10	2.30	1.30	13.40	-	2.30	-	-	1.50	-	-	99.80
KHU13	8.10	59.60	12.50	3.40	2.90	1.80	6.40	-	2.90	-	-	2.30	-	-	99.90
KHU14	16.00	53.10	5.10	1.90	2.70	6.60	12.00	-	0.70	0.20	-	1.50	-	-	99.80
KHU15	5.80	48.80	20.50	4.00	3.70	5.40	7.90	-	1.50	0.50	-	1.80	-	-	99.90
KHU16	-	33.90	3.20	-	3.00	17.60	9.80	-	-	20.40	10.00	1.80	-	-	99.70

Table A2-95: Mineral composition of samples for Koornfontein Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
KOR1	6.20	45.70	20.50	4.70	4.20	0.90	8.90	-	3.80	0.70	-	1.20	3.20	-	100.00
KOR2	12.90	50.70	15.70	2.90	3.50	-	6.70	-	5.60	0.30	-	1.10	0.50	-	99.90
KOR3	22.20	54.80	11.20	2.30	1.60	-	4.10	-	1.80	-	-	1.70	-	-	99.70
KOR4	-	11.30	42.30	3.10	8.20	3.20	5.20	-	9.90	11.60	-	0.50	4.60	-	99.90
KOR5	0.60	47.50	24.70	4.50	3.90	5.80	5.50	-	5.10	-	-	1.40	0.80	-	99.80
KOR6	13.40	50.80	26.50	4.30	2.60	-	-	-	1.00	-	-	1.30	-	-	99.90
KOR7	-	52.80	12.90	4.00	3.40	0.60	10.70	-	3.10	9.90	-	1.70	0.90	-	100.00
KOR8	1.60	55.60	22.40	4.20	4.20	2.00	2.40	-	5.60	-	-	1.70	-	-	99.70
KOR9	11.90	42.90	9.60	2.90	8.20	-	3.00	-	20.30	-	-	1.00	-	-	99.80
KOR10	-	65.90	13.70	3.60	2.00	0.80	4.80	-	1.30	5.10	-	2.50	0.30	-	100.00

KORSST	11.50	22.10	14.60	12.70	-	0.30	3.10	15.90	16.80	-	-	0.80	-	2.20	100.00
KOR11	-	43.50	21.80	5.70	6.40	-	0.60	-	11.90	8.70	-	1.10	-	-	99.70
KOR12	24.60	51.90	9.20	2.60	2.00	-	5.30	-	2.70	-	-	1.50	-	-	99.80
KOR13	2.30	59.40	15.60	5.30	2.00	3.90	8.20	-	0.80	-	-	1.30	1.30	-	100.10
KOR14	-	45.20	19.00	3.80	5.30	2.50	2.50	-	9.80	10.10	-	1.50	-	-	99.70
KOR15	-	23.50	48.00	2.60	5.30	8.20	-	-	7.10	4.90	-	0.30	-	-	99.90
KOR16	-	2.40	14.00	2.10	11.80	3.90	6.60	-	29.80	27.80	-	1.60	-	-	100.00
KOR17	8.70	60.20	15.00	2.70	4.50	-	3.20	-	4.20	-	-	1.30	-	-	99.80
KOR18	14.40	69.30	2.60	0.90	2.70	-	3.40	-	4.90	-	-	1.60	-	-	99.80

Table A2-96: Mineral composition of samples for Kromdraai Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
KRD1	0.80	84.10	-	-	2.80	1.80	5.30	-	2.90	-	-	2.10	-	-	99.80
KRD2	0.20	70.00	-	-	6.00	2.00	7.70	-	10.00	2.10	-	1.90	-	-	99.90
KRD3	-	82.00	-	-	2.50	2.40	4.40	-	1.80	4.20	-	2.80	-	-	100.10
KRD4	87.60	7.20	-	-	1.20	-	0.90	-	1.60	-	-	1.20	-	-	99.70
KRD5	83.10	6.80	-	-	1.80	-	1.20	-	5.10	-	-	1.40	-	0.40	99.80
KRD6	-	71.30	-	-	6.20	-	0.80	-	1.30	16.30	-	3.80	-	-	99.70
KRD7	-	-	-	-	17.10	3.70	-	-	1.90	72.10	-	5.90	-	-	100.70
KRD8	-	83.60	-	-	7.10	-	-	-	6.60	-	-	2.40	-	-	99.70
KRD9	-	54.90	-	-	15.80	-	9.00	-	13.40	5.00	-	1.90	-	-	100.00
KRD10	-	62.40	-	-	7.90	1.70	2.50	-	11.40	11.80	-	2.30	-	-	100.00
KRD11	-	41.30	-	-	12.60	9.80	3.90	-	18.00	12.80	-	1.60	-	-	100.00

Table A2-97: Mineral composition of samples for Lakeside Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
LK1	-	8.70	7.50	1.70	19.80	-	1.10	-	58.50	2.50	-	-	-	-	99.80
LK2	12.20	68.40	9.00	0.50	0.80	-	7.30	-	0.60	-	-	1.00	-	-	99.80
LK3	3.10	52.80	10.60	1.30	10.80	-	3.90	-	15.50	0.90	-	0.80	-	-	99.70
LK4	-	26.70	11.20	0.60	20.30	-	2.50	-	34.30	4.30	-	-	-	-	99.90
LK5	10.90	67.30	8.60	1.80	2.60	-	4.40	-	3.20	0.40	-	0.90	-	-	100.10
LK6	-	67.90	10.00	1.00	6.30	-	-	-	8.10	4.50	-	1.30	0.80	-	99.90
LK7	-	34.70	20.00	2.10	13.10	-	0.80	-	20.10	8.20	-	0.70	-	-	99.70

Table A2-98: Mineral composition of samples for Leeufontein Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
LU1	6.70	59.90	11.60	1.20	6.00	-	2.90	-	8.70	0.80	-	1.50	0.70	-	100.00
LU2	1.50	73.20	14.00	1.90	4.00	-	3.90	-	-	-	-	1.30	-	-	99.80
LU3	-	3.50	61.00	2.00	8.80	-	0.60	-	7.40	15.90	-	0.70	-	-	99.90
LU4	-	42.80	25.00	6.20	1.50	-	1.10	-	-	15.10	6.90	0.90	-	-	99.50
LU5	14.80	64.30	10.00	3.40	0.20	-	3.70	-	2.40	-	-	1.00	-	-	99.80
LU6	3.00	45.30	29.40	5.70	7.00	-	0.60	-	7.10	-	-	0.90	0.80	-	99.80
LU7	56.40	37.60	0.40	0.30	0.70	-	1.80	-	0.20	-	-	2.20	0.20	-	99.80
LU8	44.30	44.50	0.40	0.50	0.70	0.10	5.60	-	0.80	0.20	-	2.70	-	-	99.80
LU9	4.70	55.40	20.30	3.80	5.90	-	2.30	-	6.60	-	-	0.90	-	-	99.90
LU10	9.80	52.70	21.70	2.60	4.80	-	3.50	-	2.60	-	-	1.90	-	-	99.60
LU11	19.50	58.60	11.80	2.10	2.20	-	2.00	-	1.90	-	-	1.80	-	-	99.90

LU13	-	41.30	25.10	1.80	12.30	-	-	-	9.40	8.60	-	1.30	-	-	99.80
LU14	-	17.80	30.30	6.50	16.30	-	0.40	-	25.10	3.20	-	0.40	-	-	100.00
LU15	4.60	65.50	19.00	3.90	2.10	-	2.30	-	0.60	-	-	1.50	-	-	99.50
LU16	12.90	59.90	9.20	4.10	2.10	-	9.40	-	0.40	0.60	-	1.50	-	-	100.10
LU17	0.50	25.30	29.10	4.10	7.80	2.60	2.20	-	10.30	15.80	-	1.80	0.40	-	99.90
LU18	-	64.70	7.10	1.40	3.10	-	3.40	-	-	12.20	2.40	4.60	1.10	-	100.00
LU19	-	-	21.70	2.20	25.40	0.30	-	-	36.70	12.80	-	0.50	0.50	-	100.10
LU20	-	2.10	24.90	2.40	20.50	-	1.20	-	29.50	18.50	-	-	0.50	-	99.60
LU21	22.40	72.70	-	0.30	0.40	-	0.90	-	0.70	-	-	2.40	0.20	-	100.00
LU22	7.10	75.40	10.10	1.10	2.20	-	1.50	-	-	-	-	1.50	0.80	-	99.70
LU23	2.30	51.60	18.80	3.30	8.90	-	-	-	13.70	-	-	0.80	0.50	-	99.90
LU24	-	9.90	31.40	2.50	10.80	-	-	-	8.80	35.30	-	1.50	-	-	100.20
LU25	-	27.90	18.00	6.60	11.90	1.30	0.80	-	21.00	11.60	-	0.80	-	-	99.90
LU26	-	-	25.60	4.20	13.60	5.10	-	-	14.50	36.00	-	1.00	-	-	100.00
LU27	-	79.60	-	0.50	1.80	1.30	8.70	-	0.50	4.80	-	3.20	-	-	100.40
LU28	-	61.70	11.70	3.70	5.30	2.30	4.20	-	4.60	4.90	-	1.70	-	-	100.10
LU29	-	44.80	9.80	2.00	3.80	1.70	13.40	-	-	20.80	-	3.50	-	-	99.80
LU30	-	-	23.70	4.40	14.80	-	-	-	24.40	31.10	-	1.50	-	-	99.90
LUP1	-	32.20	11.00	0.40	14.50	-	8.60	-	16.70	14.00	-	2.60	-	-	100.00
LUP2	-	-	26.70	1.00	22.30	0.90	-	-	27.90	20.00	-	1.20	-	-	100.00
LUP3	-	-	65.30	6.10	12.90	-	-	-	6.70	6.90	-	2.10	-	-	100.00
LUP4	-	40.00	-	0.50	8.10	5.90	26.70	-	5.30	11.70	-	1.80	-	-	100.00

Table A2-99: Mineral composition of samples for Middelburg Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
M1	20.20	58.40	-	0.40	2.70	-	4.10	-	12.00	-	-	2.10	-	-	99.90
M2	14.50	58.60	-	-	4.90	-	4.50	-	15.00	-	-	2.10	-	-	99.60

M3	80.70	11.30	-	-	-	-	5.90	-	1.50	-	-	0.60	-	-	100.00
M4	67.60	23.50	0.30	-	-	-	6.20	-	1.60	-	-	0.60	-	-	99.80
M5	10.00	53.50	13.70	3.70	3.90	-	5.70	-	7.60	-	-	1.90	-	-	100.00
M6	12.60	69.70	4.10	1.20	0.90	-	5.60	-	2.00	-	-	3.80	-	-	99.90
M7	-	57.80	9.90	2.20	2.80	0.70	8.30	-	12.70	3.20	-	2.40	-	-	100.00
M8	0.30	59.00	4.20	1.70	6.60	-	4.10	-	17.70	5.00	-	1.40	-	-	100.00
M9	1.00	81.40	-	0.80	2.10	4.40	4.30	-	3.20	0.40	-	2.50	-	-	100.10
M10	-	88.40	-	0.60	0.40	0.60	6.20	-	1.90	-	-	1.80	-	-	99.90
M11	21.50	59.20	4.60	0.80	1.60	-	6.50	-	3.60	-	-	2.20	-	-	100.00
M12	17.00	52.00	11.70	0.70	3.90	-	6.30	-	6.80	-	-	1.60	-	-	100.00
M13	74.90	7.50	5.90	3.00	0.20	-	4.80	-	2.60	-	-	0.40	0.70	-	100.00
M14	13.60	67.80	8.80	1.60	1.90	-	3.00	-	1.40	0.40	-	1.20	0.30	-	100.00
M15	0.60	42.70	10.80	1.70	7.60	-	3.20	-	10.00	20.00	-	2.80	0.60	-	100.00
M16	-	33.20	17.10	4.00	10.20	2.60	2.80	-	17.90	10.20	-	1.70	0.40	-	100.10
M17	-	37.80	23.50	2.30	3.10	15.60	6.10	-	1.60	9.10	-	1.00	-	-	100.10
M18	20.90	42.20	22.70	3.40	2.80	-	3.30	-	3.60	-	-	1.20	-	-	100.10
M19	29.40	40.80	1.90	0.60	2.80	-	5.20	-	17.80	-	-	1.40	-	-	99.90
M20	19.00	41.20	-	0.30	11.10	-	12.00	-	15.50	-	-	0.90	-	-	100.00
M21	58.60	15.50	-	-	0.30	-	14.50	8.60	1.70	-	-	0.70	-	-	99.90
M22	36.00	33.00	-	0.90	0.60	0.10	14.70	8.60	4.90	0.20	-	0.90	-	-	99.90

Table A2-100: Mineral composition of samples for Optimum Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
OPT1	6.60	32.70	-	0.40	20.30	-	5.10	-	34.10	-	-	0.60	-	-	99.80
OPT2	-	-	18.60	1.50	22.90	-	-	-	-	53.60	-	3.40	-	-	100.00
OPT3	60.40	12.10	-	2.10	-	0.10	14.80	9.10	0.80	-	-	0.70	-	-	100.10

OPT4	10.60	58.90	13.10	5.90	4.40	-	3.30	-	1.50	0.80	-	1.40	-	-	99.90
OPT5	5.90	66.00	7.60	2.60	7.90	-	7.10	-	2.10	-	-	0.90	-	-	100.10
OPT6	21.50	66.40	1.00	0.20	2.10	-	6.70	-	0.50	-	-	1.50	-	-	99.90
OPT7	-	58.50	13.30	1.70	1.80	1.40	11.80	-	-	-	9.50	1.90	-	-	99.90
OPT8	60.80	4.50	6.90	0.40	3.40	-	10.40	-	11.60	0.10	-	0.40	-	1.20	99.70
OPT9	14.70	77.00	-	-	2.60	-	3.70	-	-	-	-	2.20	-	-	100.20
OPT10	6.70	77.80	3.10	1.60	1.80	1.30	5.40	-	-	-	-	2.00	-	-	99.70
OPT11	82.90	7.50	-	-	0.50	-	3.90	2.60	2.10	-	-	0.40	-	-	99.90
OPT12	20.10	67.10	-	-	3.10	0.50	5.70	-	-	-	-	4.30	-	-	100.80
OPT13	15.30	59.40	9.40	4.20	3.00	-	6.00	-	-	0.70	-	2.00	-	-	100.00

Table A2-101: Mineral composition of samples for Rietspruit Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
R2RO	24.20	50.00	0.50	1.30	0.20	0.30	8.90	10.00	3.50	-	-	1.20	-	-	100.10
R2M	1.80	71.60	0.60	1.10	1.90	15.10	4.40	-	2.10	-	-	1.40	-	-	100.00
R2M2	-	26.40	39.30	1.20	8.50	6.40	5.50	-	7.30	5.00	-	0.40	-	-	100.00
R2LW	-	29.20	18.30	6.10	4.20	14.50	3.30	-	1.70	20.70	-	1.40	0.70	-	100.10
R4UROOF	30.10	34.90	0.20	1.80	0.60	0.20	26.40	-	4.20	-	-	1.00	0.60	-	100.00
R4U	29.00	49.50	2.00	1.40	2.90	-	11.90	-	2.10	0.30	-	0.80	-	-	99.90
R4PT	24.50	55.30	0.20	0.70	0.40	0.10	7.10	9.80	0.90	-	-	1.10	-	-	100.10
R4L	20.50	51.80	10.10	3.50	4.20	-	5.80	-	1.20	-	-	2.00	-	-	99.10
R4FUG	70.40	21.50	-	-	0.70	-	1.60	-	0.60	-	-	1.60	3.50	-	99.90
R4FLG	67.70	10.40	0.50	1.00	0.40	-	2.50	-	9.50	-	-	3.80	3.90	0.20	99.90
R4F1	43.80	41.90	0.20	0.30	0.30	-	2.80	-	3.10	-	-	3.60	3.80	-	99.80
R4F2	20.90	57.20	0.20	0.50	-	-	8.60	-	2.30	-	-	5.60	4.40	-	99.70
R4F3	62.00	24.00	0.20	0.30	1.00	-	3.30	-	3.60	-	-	2.00	3.40	-	99.80

Table A2-102: Mineral composition of samples for South Witbank Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Apatite	Ill./ Smec.	Fsp	Siderite	Gibbsite	Gypsum	Anatase	Halite	Hematite	Total
SW1	7.90	46.00	20.00	2.40	7.60	1.80	2.80	-	8.20	-	1.80	0.80	1.40	-	100.70
SW2	22.90	59.10	9.40	1.80	2.00	0.20	2.40	-	-	-	-	1.40	1.10	-	100.30
SW3	21.70	58.10	8.90	1.60	2.50	0.70	3.50	-	-	-	-	1.60	1.30	-	99.90
SW4	15.00	45.00	16.00	3.40	3.10	8.20	3.50	-	-	0.50	2.50	1.70	1.00	-	99.90
SW5	17.20	38.60	16.00	3.50	7.30	3.10	4.10	-	8.30	0.40	-	1.10	0.50	-	100.10
SW6	27.00	52.40	6.50	1.70	2.20	0.20	5.80	-	2.00	-	-	1.70	0.60	-	100.10
SW7	6.90	49.90	10.90	3.40	5.90	12.50	5.60	-	2.40	-	-	1.30	1.20	-	100.00
SW8	6.00	35.50	19.30	4.60	8.10	12.30	5.70	-	5.50	0.60	-	1.20	1.20	-	100.00
SW9	18.00	45.60	9.70	2.80	4.60	7.80	8.50	-	0.70	-	-	1.50	0.80	-	100.00
SW10	-	47.50	25.00	2.60	9.00	3.70	2.10	-	7.70	0.60	-	0.90	0.90	-	100.00

Table A2-103: Mineral composition of samples for Tavistock Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Apatite	Ill./ Smec.	Fsp	Siderite	Gibbsite	Gypsum	Anatase	Halite	Hematite	Total
TAV1A	6.90	33.30	18.40	4.80	8.20	16.10	3.80	-	8.10	-	-	0.40	-	-	100.00
TAV1B	0.30	40.00	-	4.30	4.30	37.90	6.30	-	0.60	5.90	-	0.60	-	-	100.20
TAV1C	-	30.20	6.80	2.20	13.50	21.70	2.70	-	18.90	3.50	-	0.60	-	-	100.10
TAV2A	6.80	49.80	5.70	3.20	3.20	24.30	4.10	-	-	-	1.70	1.20	-	-	100.00
TAV2B	4.50	46.40	17.10	4.00	4.50	17.00	3.40	-	2.20	-	-	0.90	-	-	100.00
TAV2C	18.40	53.70	12.30	3.70	3.10	2.10	4.30	-	-	-	-	2.20	-	-	99.80
TAV3A	26.30	38.40	13.80	2.70	7.10	1.00	0.50	-	8.90	-	-	1.30	-	-	100.00

TAV3B	23.80	45.70	18.40	2.80	4.40	0.90	1.10	-	1.50	-	-	1.50	-	-	100.10
TAV3C	7.00	27.10	25.30	3.50	14.30	0.60	-	-	21.60	-	-	0.50	-	-	99.90
TAV4A	27.70	53.80	0.20	0.40	-	0.10	15.30	-	1.10	-	-	1.20	0.10	-	99.90
TAV4B	27.70	52.90	-	0.40	0.10	0.10	16.20	-	1.20	-	-	1.20	0.10	-	99.90
TAV4C	27.80	53.20	-	0.50	-	0.10	15.80	-	1.10	-	-	1.20	0.10	-	99.80
TAV5A	1.10	43.70	2.00	1.60	9.40	13.90	19.90	-	5.10	-	-	3.30	-	-	100.00
TAV5B	1.60	61.10	1.30	2.30	5.20	8.60	15.70	-	2.20	-	-	2.10	-	-	100.10
TAV5C	9.10	58.70	-	1.80	5.20	5.90	15.40	-	2.30	0.20	-	1.90	-	-	100.50
TAV6A	5.80	39.60	20.20	3.10	8.30	9.40	7.00	-	5.40	-	-	1.30	-	-	100.10
TAV6B	-	53.90	14.50	3.60	5.10	7.90	7.30	-	1.10	5.00	-	1.50	-	-	99.90
TAV6C	-	50.30	12.80	3.70	6.50	9.20	7.60	-	3.90	4.10	-	1.60	-	-	99.70
TAV7A	6.80	41.70	18.40	4.70	8.90	2.50	3.30	-	12.20	-	-	1.50	-	-	100.00
TAV7C	18.50	70.00	0.80	0.90	1.00	-	6.50	-	0.30	-	-	1.90	0.20	-	100.10

Table A2-104: Mineral composition of samples for Union Colliery as determined by normative calculation using SEDNORM (values presented as wt%)

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Apatite**	**Ill./ Smec.**	**Fsp**	**Siderite**	**Gibbsite**	**Gypsum**	**Anatase**	**Halite**	**Hematite**	**Total**
UN1	6.70	58.00	12.20	1.20	9.40	0.50	6.80	-	3.50	-	-	1.70	-	-	100.00
UN2	4.20	61.60	10.30	1.40	8.40	0.60	7.50	-	3.80	-	-	2.00	-	-	99.80
UN3	6.60	62.80	5.60	-	7.20	-	7.70	-	7.30	0.60	-	1.60	-	-	99.40
UN4	9.50	63.50	5.80	-	6.60	-	7.90	-	4.70	-	-	1.60	-	-	99.60
UN5B	15.60	55.00	1.90	-	7.50	-	13.60	-	4.70	-	-	1.70	-	-	100.00
UN6B	12.20	62.40	1.30	-	9.40	-	7.90	-	4.80	-	-	2.00	-	-	100.00

Table A2-105: Mineral composition of samples for Arnot Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
ARA2	X	X	-	-	-	-	-	-	-	-	X	-
ARA3	XX	x	-	-	-	-	-	-	-	-	-	-
ARA4	X	XX	-	-	-	-	-	-	-	-	<x	-
ARA5	X	X	-	<x	<x	-	-	-	-	-	-	-
ARA6	X	XX	-	-	-	-	-	-	-	-	x	-
ARA7	XX	X	-	-	-	-	-	-	x	-	x	-
ARA8	X	XX	-	-	-	-	-	-	x	-	<x	-
ARA9	x	X	-	X	-	<x	-	-	-	-	-	-
ARA10	x	X	-	x	-	-	-	-	-	-	-	-
ARA11	XX	x	-	-	x	-	-	-	-	-	<x	-
ARA12	XX	X	-	-	-	-	-	-	x	-	-	-
ARA13	X	X	-	-	x	-	-	-	-	-	-	-
ARA14	X	XX	-	-	-	-	-	-	x	-	-	-
ARA15	X	X	-	-	-	-	-	-	-	-	-	-
ARA16	XX	x	-	x	-	-	-	-	-	-	X	-
ARB1	XX	x	-	-	x	-	-	-	-	-	x	-
ARB2	X	X	-	<x	-	<x	-	-	-	-	-	-
ARB3	XX	x	-	X	-	-	-	-	-	-	<x	-
ARB4	XX	X	-	-	-	-	-	-	<<x	-	<x	-
ARB5	X	X	-	-	-	-	-	-	-	-	-	-
ARB6	XX	x	x	X	<x	-	-	-	-	-	<x	-
ARB7	<x	XX	-	x	-	-	-	-	-	-	-	-
ARB8	XX	x	-	-	-	-	-	-	-	-	<x	-
ARB9	X	XX	-	-	-	-	-	-	x	-	-	-
ARB10	X	XX	-	-	<x	-	-	-	-	-	-	-
ARB11	X	XX	-	-	-	-	-	-	<x	-	-	-

ARB13	X	X	X	-	-	-	-	-	x	-	X	-
ARC1	X	XX	-	-	-	-	-	-	-	-	x	-
ARC2	x	X	-	x	x	<x	-	-	-	-	<x	-
ARC3	XX	x	-	-	-	-	-	-	-	-	<x	-
ARC4	X	XX	-	-	-	-	-	-	X	-	x	-
ARC5	x	x	-	x	x	-	-	-	-	-	-	-
ARC6	X	X	x	-	-	<x	-	-	-	-	-	-
ARC7	XX	x	-	-	-	-	-	-	-	-	-	-
ARD1	X	XX	-	-	-	x	-	-	-	-	-	-
ARD2	x	X	-	<x	x	-	-	-	-	-	-	-
ARD3	X	X	x	-	x	-	-	-	-	-	<x	-
ARD4	XX	X	-	-	-	-	-	-	<x	-	<x	-
ARD5	X	X	-	-	-	<x	-	-	-	-	-	-
ARD6	x	X	x	<x	<x	-	-	-	-	-	-	-
ARD7	X	x	-	-	-	-	-	-	-	-	<x	-

Table A2-106: Mineral composition of samples for Arnot-North Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
3936	XX	X	-	-	-	<x	-	-	x	-	-	-
3937	XX	X	-	-	-	<x	-	-	x	x	-	-
3938	x	X	-	-	x	x	-	-	-	-	-	-
3939	XX	X	-	<x	-	-	-	-	<x	<x	-	-
3940	XX	X	-	-	-	-	-	-	x	x	-	x
3941	XX	X	x	x	-	-	-	-	-	X	-	X
3942	XX	X	-	-	-	-	-	-	x	X	-	-
3943	X	XX	-	-	-	-	-	-	x	<x	-	X
3944	X	x	-	-	-	-	-	-	X	x	-	X
3945	X	X	-	-	x	-	-	-	x	-	-	-
3946	XX	X	-	-	-	-	-	-	-	x	-	x

3947	XX	X	-	-	-	-	-	-	-	X	-	x
3948	X	XX	-	-	-	-	-	-	X	-	-	X
3949	X	XX	-	-	-	-	-	-	X	-	-	X
3950	XX	X	-	-	-	-	-	-	<x	x	-	-
3951	XX	X	-	-	x	-	-	-	-	-	-	-
3952	XX	X	-	-	-	-	-	-	-	<x	-	x
3953	XX	X	x	-	-	-	-	-	-	-	-	X
3954	X	XX	-	-	-	-	-	-	-	x	-	-
3955	X	X	-	-	x	-	-	-	-	-	-	-
3956	XX	x	-	-	-	-	-	-	-	x	-	-
3957	XX	X	-	-	x	-	-	-	-	X	-	x
3958	XX	x	-	-	-	-	-	-	-	x	-	x
3959	XX	X	-	-	-	-	-	-	-	<x	-	x

Table A2-107: Mineral composition of samples for Bank Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
BAN1	-	x	x	x	<x	-	x	-	<x	-	-	-
BAN2	<x	X	-	x	<x	x	-	-	-	-	-	-
BAN3	x	X	<x	<x	<x	-	<x	-	-	-	-	-
BAN4	-	X	x	X	<x	x	<x	-	-	-	-	-
BAN5	x	X	-	<x	-	x	-	-	-	-	-	-
BAN6	-	X	-	<x	-	<<x	-	-	-	-	-	-
BAN7	X	XX	<x	x	-	<x	-	-	-	-	-	-
BAN8	-	x	x	x	<x	<x	-	-	-	-	-	-
BAN9	-	x	x	x	x	x	-	-	-	-	-	-
BAN10	X	XX	-	-	-	-	-	-	<<x	-	-	-
BAN11	X	X	-	-	-	-	-	-	<x	<x	-	-
BAN12	X	x	-	-	<x	<x	-	-	-	-	-	-
BAN13	X	x	-	-	x	x	-	-	-	-	-	-
BAN14	x	<x	-	-	-	-	-	-	<x	-	-	XX

BAN15	XX	X	-	-	-	<x	-	-	<x	<x	-	-
BAN16	X	x	-	-	X	-	-	-	-	-	-	-
BAN17	X	x	-	-	x	-	-	-	-	-	-	-
BAN18	X	x	-	-	-	-	-	-	x	-	-	-
BAN19	<x	XX	<x	<<x	-	X	-	-	-	-	-	-
BAN20	<x	XX	x	<<x	-	X	-	-	-	-	-	-
BAN21	<x	X	x	<x	<x	x	-	-	-	-	-	-

Table A2-108: Mineral composition of samples for Bankfontein Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
BK1	-	XX	-	-	-	X	-	-	-	-	-	-
BK2	<x	x	X	<x	X	-	X	-	-	-	-	-
BK3	x	XX	-	-	-	-	-	-	-	-	-	-

Table A2-109: Mineral composition of samples for Borehole 1 as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
BH1-1	X	x	-	-	X	-	-	-	-	-	-	-
BH1-2	XX	x	-	<x	-	-	-	-	-	-	-	<<x
BH1-3	X	X	-	-	-	-	-	-	x	x	-	-
BH1-4	<x	x	-	x	-	x	-	XX	-	-	-	x
BH1-5	-	X	x	x	-	x	-	-	-	-	-	-
BH1-6	-	x	x	x	-	-	-	-	x	-	-	-
BH1-7	XX	X	-	-	-	-	-	-	X	-	-	-

Table A2-110: Mineral composition of samples for Borehole wedge 1 as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
BHW1-1	XX	x	-	-	-	-	-	-	-	x	-	-
BHW1-2	XX	x	-	-	-	-	-	-	-	x	-	-
BHW1-3	XX	<x	-	-	-	-	-	-	-	x	-	-
BHW1-4	X	<x	-	-	-	-	-	-	-	<x	-	x
BHW1-5	X	<x	x	-	-	-	-	-	-	<x	-	-

BHW1-6	X	X	-	-	<x	-	-	-	-	-	-	-
BHW1-7	X	X	x	x	<x	-	-	-	-	-	-	-
BHW1-8	x	x	x	x	<x	-	-	-	-	-	-	-
BHW1-9	x	x	x	x	<x	-	-	-	-	-	-	-
BHW1-10	XX	x	-	-	-	-	-	-	<x	-	-	-
BHW1-11	x	X	<x	-	-	-	-	-	<x	x	-	-
BHW1-12	XX	x	<x	-	-	-	-	-	-	<x	-	-

Table A2-111: Mineral composition of samples for Borehole wedge 2 as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
BHW2-1	XX	<x	-	-	-	-	-	-	-	-	-	-
BHW2-2	X	X	-	-	<x	-	-	-	-	-	-	-
BHW2-3	x	X	-	-	X	x	-	-	-	<x	-	-
BHW2-4	X	x	-	-	-	-	-	-	<<x	x	-	-
BHW2-5	X	<x	-	-	-	-	-	-	-	x	-	-
BHW2-6	X	x	<x	<x	-	-	-	-	-	-	-	-
BHW2-7	x	x	-	x	-	-	-	-	-	-	-	-
BHW2-8	<x	<x	x	x	x	-	-	-	-	-	-	-
BHW2-9	x	XX	-	-	-	-	-	-	x	-	-	-

Table A2-112: Mineral composition of samples for Borehole wedge 3 as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
BHW3-1	XX	-	<x	-	-	-	-	-	-	x	-	-
BHW3-2	x	<x	<x	-	x	-	-	-	-	-	-	-
BHW3-3	XX	<x	-	-	<x	-	-	-	x	-	-	-
BHW3-4	x	x	-	<x	x	-	-	-	-	-	-	-
BHW3-5	x	x	-	-	-	<x	-	-	<x	-	X	-
BHW3-6	XX	<x	-	-	-	-	-	-	-	X	-	-
BHW3-7	x	-	-	-	-	-	-	-	<<x	-	-	-
BHW3-8	<x	<x	-	-	<x	-	-	-	-	-	-	-

BHW3-9	X	x	-	-	-	-	-	-	-	x	-	-
BHW3-10	XX	x	-	-	-	-	-	-	-	-	-	-
BHW3-11	x	x	<<x	-	-	-	-	-	-	-	-	-
BHW3-12	x	x	-	<x	<x	-	-	-	-	-	-	-
BHW3-13	x	x	x	-	-	-	-	-	-	-	-	-
BHW3-14	X	X	<x	-	-	-	-	-	<x	x	-	-

Table A2-113: Mineral composition of samples for Borehole wedge 4 as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
BHW4-1	x	x	-	<x	<x	-	-	-	-	-	-	-
BHW4-2	X	X	-	-	x	-	-	-	x	x	-	-
BHW4-3	x	x	-	-	x	-	-	-	-	-	-	-
BHW4-4	XX	X	-	-	x	-	-	-	<x	<x	-	-
BHW4-5	XX	<x	-	-	<x	-	-	-	-	<x	-	-
BHW4-6	x	x	-	x	-	-	-	-	-	-	-	-
BHW4-7	X	XX	-	<x	-	-	-	-	-	-	-	-
BHW4-8	x	X	x	<x	-	-	-	-	-	-	-	-
BHW4-9	x	x	x	<x	-	-	-	-	-	-	-	-
BHW4-10	<x	x	x	<x	x	-	-	-	-	-	-	-
BHW4-11	X	x	-	-	-	-	-	-	-	x	-	-

Table A2-114: Mineral composition of samples for Borehole wedge 5 as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
BHW5-1	x	x	-	-	<x	-	-	-	<x	<x	-	-
BHW5-2	x	x	-	-	x	-	-	-	-	-	-	-
BHW5-3	X	X	-	-	-	-	-	-	<x	<x	-	-
BHW5-4	XX	<x	-	-	-	-	-	-	-	<x	-	-
BHW5-5	XX	<x	-	-	-	-	-	-	-	<x	-	-
BHW5-6	XX	-	-	-	-	-	-	-	-	-	-	x
BHW5-7	XX	-	-	-	-	-	-	-	-	<<x	-	<<x

BHW5-8	X	x	-	-	-	-	-	-	-	<x	-	-
BHW5-9	X	x	-	-	-	-	-	-	-	-	-	x
BHW5-10	x	x	-	-	x	-	-	-	-	-	-	-
BHW5-11	<x	x	-	x	-	-	-	-	-	-	-	-
BHW5-12	x	x	-	x	-	-	-	-	-	-	-	-
BHW5-13	x	X	x	x	-	-	-	-	-	-	-	-
BHW5-14	x	X	-	-	-	-	-	-	<x	<x	-	-
BHW5-15	X	x	-	-	-	-	-	-	-	<x	-	-

Table A2-115: Mineral composition of samples for Delmas Colliery as interpreted from XRD scans

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Montm**	**Fluorapatite**	**Crandallite**	**Ill./ Smec.**	**K-fsp**	**Plag**	**Siderite**
DEL1	X	XX	-	-	-	<x	-	-	-	-	-	-
DEL2	x	XX	x	x	x	-	-	-	-	-	-	-
DEL4	-	x	X	-	X	-	-	-	-	-	-	-
DEL5	-	x	X	-	x	-	x	-	-	-	-	-
DEL6	XX	X	-	<x	<x	-	-	-	-	<x	<<x	-
DEL7	-	X	X	-	-	<x	-	-	-	-	-	-
DEL8	-	X	x	X	XX	-	-	-	-	-	-	-
DEL9	-	x	X	X	x	<x	x	-	-	-	-	x
DEL10	<x	X	x	x	-	x	-	-	-	-	-	-
DEL11	-	<x	-	-	-	-	x	-	x	-	-	-
DEL12	-	X	XX	-	x	<x	<x	-	-	-	-	-
DEL13	-	X	x	x	<x	-	-	-	-	-	-	-
DEL14	<x	XX	-	X	<x	<x	-	-	-	-	-	-
DEL15	-	x	-	x	x	-	<x	-	-	-	-	-
DEL16	-	XX	x	x	<x	<x	-	-	-	-	-	-
DEL17	-	X	x	<x	X	x	<x	-	-	-	-	-

Table A2-116: Mineral composition of samples for Douglas Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
DOU1	X	X	-	-	-	-	-	-	-	-	-	-
DOU2	x	x	x	x	<x	-	-	-	-	-	-	-
DOU3	X	X	<x	-	-	<x	-	-	-	-	-	-
DOU4	XX	x	X	x	-	-	-	-	-	-	-	-
DOU5	XX	X	-	-	-	-	-	-	<<x	-	-	-
DOU6	x	X	x	x	<x	-	-	-	-	-	-	-
DOU7	X	XX	-	-	-	-	-	-	-	-	-	-
DOU8	<x	x	x	<<x	X	-	-	-	-	-	-	-
DOU9	-	x	X	x	x	-	<x	-	-	-	-	-
DOU10	X	X	x	x	x	-	-	-	-	-	-	-
DOU11	X	XX	-	-	-	-	-	-	-	<x	-	-
DOU12	X	XX	<x	<x	-	-	-	-	X	x	-	-
DOU13	x	X	X	x	<x	<<x	-	-	-	-	-	-
DOU14	x	X	<x	x	<x	<x	-	-	-	-	-	-
DOU15	X	XX	-	-	<x	-	-	-	-	<<x	-	-
DOU16	XX	X	-	-	-	-	-	-	-	<x	-	-
DOU17	XX	X	-	-	-	-	-	-	<x	<x	-	-
DOU18	X	x	-	<<x	x	<x	-	-	-	-	-	-
DOU19	XX	X	-	<<x	-	-	-	-	<x	x	-	-
DOU20	XX	X	-	-	-	-	-	-	-	<x	-	-
DOU21	XX	<x	-	-	X	-	-	-	-	x	-	-
DOU22	-	<x	X	<<x	X	-	X	-	-	-	-	-
DOU23	x	XX	x	x	-	-	-	-	-	-	-	-
DOU24	X	XX	-	-	-	-	-	-	<x	<x	-	-
DOU25	X	XX	x	-	-	<<x	-	-	-	-	-	-
DOU26	X	XX	x	-	-	-	X	-	-	-	-	-
DOU27	-	X	X	-	-	<<x	-	-	-	-	-	-
DOU28	-	x	x	-	x	<x	-	-	-	-	-	-

DOU29	XX	X	-	-	-	-	-	-	-	-	-	-
DOU30	X	X	-	-	-	-	-	-	-	-	-	-
DOU31	X	X	x	-	x	<x	-	-	-	-	-	-
DOU32	XX	X	-	-	-	<<x	-	-	-	-	-	-
DOU33	x	X	-	x	<x	<<x	-	-	-	-	-	-
DOU34	X	XX	-	<<x	-	-	-	-	<<x	<x	-	-
DOU35	X	X	-	x	-	-	-	-	<x	<x	-	-
DOU36	x	XX	-	-	-	<x	-	-	-	-	-	-
DOU37	X	X	-	-	-	<<x	-	-	-	-	-	-
DOU38	X	X	-	x	-	<<x	-	-	-	-	-	-
DOU39	XX	X	x	x	-	-	-	-	-	-	-	-
DOU40	X	X	-	<x	X	<x	-	-	-	-	-	-
DOU41	XX	X	x	x	-	-	-	-	-	-	-	-

Table A2-117: Mineral composition of samples for Forzando Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
FOR1	X	x	x	x	-	-	-	-	-	-	-	-
FOR2	X	x	x	<x	<x	-	x	-	-	-	-	-
FOR3	XX	X	-	-	<x	-	-	-	x	<x	-	-
FOR4	XX	X	-	<x	-	-	-	-	x	<x	-	-
FOR5	X	X	<x	<x	<x	-	-	-	-	-	-	-
FOR6	X	X	<x	<x	<x	-	-	-	-	-	-	-
FOR7	XX	x	-	-	-	X	-	-	-	-	-	-
FOR8	XX	X	-	-	<x	-	-	-	x	x	-	-
FOR9	X	XX	-	-	x	-	-	-	x	x	-	-
FOR10	XX	X	-	-	x	-	-	-	x	x	-	-
FOR11	x	XX	x	x	<x	-	-	-	-	-	-	-
FOR12	X	X	x	x	<x	-	-	-	-	-	-	-
FOR13	XX	x	-	x	<x	-	-	-	-	X	-	-

Table A2-118: Mineral composition of samples for Greenside Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
GRE1	X	X	x	x	x	-	-	-	-	<x	-	-
GRE2	x	X	<x	<x	x	-	-	-	-	-	-	-
GRE3	<x	X	x	<x	x	-	-	-	-	-	-	-
GRE4	x	X	x	<x	x	<<x	-	-	-	-	-	-
GRE5	XX	x	-	-	x	-	-	-	-	<x	-	-
GRE6	XX	X	-	-	-	-	-	-	-	<x	-	-
GRE7	<x	x	x	<x	<x	<<x	x	-	-	-	-	-
GRE8	x	X	x	-	<x	-	x	-	-	-	-	-
GRE9	x	x	X	x	x	<x	-	-	-	-	-	-
GRE10	X	X	<x	<x	-	-	-	-	<x	x	-	-
GRE11	X	XX	-	<<x	-	-	-	-	<x	-	-	-
GRE12	-	x	x	x	x	-	-	-	-	-	-	-
GRE13	X	X	x	x	-	<<x	-	-	-	-	-	-
GRE14	x	x	x	x	x	-	-	-	-	-	-	-
GRE15	XX	<x	-	x	-	-	-	-	<x	-	-	-
NGT1	XX	X	-	-	-	-	-	-	X	-	X	-
NGT2	X	XX	-	-	-	X	-	-	-	-	-	-
NGT3	x	x	-	-	-	<x	-	-	-	-	-	-
NGT4	X	x	-	-	X	-	-	-	-	-	-	-
NGT5	X	X	-	-	-	x	-	-	x	-	-	-
NGT6	X	X	-	-	-	x	-	-	x	x	-	-
NGT7	XX	X	-	-	-	x	-	-	-	-	-	-
NGT8	X	x	-	-	-	<x	-	-	-	-	-	-
NGT9	x	x	-	-	<x	<<x	-	-	-	-	-	-
NGT10	XX	X	-	-	-	<x	-	-	x	-	-	-
NGT11	X	X	-	-	-	-	-	-	X	X	-	-
NGT12	X	x	-	-	x	x	-	-	-	-	-	-
NGT13	x	x	-	-	x	x	-	-	-	-	-	-

NGT14	X	x	-	-	x	-	-	-	-	-	-	-
NGT15	X	X	-	-	-	<x	-	-	<x	-	-	-

Table A2-119: Mineral composition of samples for Kleinkopje Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
KK1	-	X	<x	x	<x	-	<x	-	-	-	-	-
KK2	-	<x	XX	<x	x	-	<x	-	-	-	-	-
KK3	x	X	-	-	-	-	X	-	-	-	-	-
KK4	X	X	<x	<x	-	-	X	-	x	<x	-	-
KK5	X	XX	-	-	-	-	-	-	-	x	-	-
KK6	X	<x	-	-	-	-	-	-	-	-	-	-
KK7	x	X	X	<x	-	-	-	-	-	-	-	<<x
KK8	XX	X	-	-	-	-	-	-	-	x	-	-
KK9	<x	x	x	x	X	-	-	-	-	-	-	-
KK10	XX	-	-	-	-	-	-	-	-	-	-	-
KK11	X	X	-	-	-	-	-	-	<x	<x	-	-
KK12	x	X	x	<x	<x	-	<x	-	-	-	-	-
KK13	-	<x	<x	-	-	-	-	-	-	-	-	-
KK14	XX	x	-	-	-	-	-	-	-	<x	-	<x
KK15	XX	-	-	-	-	-	-	-	<x	-	-	-
KK16	x	X	-	-	-	-	<x	-	-	-	-	-

Table A2-120: Mineral composition of samples for Khutala Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
KHU1	-	X	<x	x	<x	-	-	-	-	-	-	-
KHU2	-	X	<x	<x	<x	-	-	-	-	-	-	-
KHU3	-	X	x	x	<x	-	X	-	-	-	-	-
KHU4	<x	XX	<x	-	-	-	-	-	-	-	-	-
KHU5	x	X	<x	<x	-	-	-	-	-	-	-	-
KHU6	x	X	x	-	<x	-	-	-	-	-	-	-

KHU7	XX	X	-	-	-	-	-	-	-	-	-	-
KHU8	x	X	<x	<<x	x	-	-	-	-	-	-	-
KHU9	-	X	x	<x	-	-	-	-	-	-	-	-
KHU10	-	X	X	x	<x	-	-	-	-	-	-	-
KHU11	<x	x	<x	<x	x	-	<x	-	-	-	-	-
KHU12	X	x	x	X	-	-	-	-	-	-	-	-
KHU13	x	XX	<x	x	-	-	-	-	-	-	-	-
KHU14	X	X	x	<x	-	-	<x	-	-	-	-	-
KHU15	X	X	x	x	<x	-	<x	-	-	-	-	-
KHU16	-	x	<x	-	-	-	x	-	-	-	-	-

Table A2-121: Mineral composition of samples for Koornfontein Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
KOR1	-	x	X	X	x	X	-	-	-	-	-	-
KOR2	X	X	x	x	<x	<x	-	-	-	-	-	-
KOR3	X	XX	x	x	-	<x	-	-	-	-	-	-
KOR4	-	<x	XX	x	x	<x	-	-	-	-	-	-
KOR5	-	XX	X	X	x	<x	<x	-	-	-	-	-
KOR6	x	X	x	x	x	<x	-	-	-	-	-	-
KOR7	-	XX	<x	x	<x	<x	-	-	-	-	-	-
KOR8	-	XX	x	x	<x	x	-	-	-	-	-	-
KOR9	X	X	<x	x	x	-	-	-	-	-	-	-
KOR10	-	XX	x	x	-	-	-	-	-	-	-	-
KORSST	X	x	x	x	-	-	-	-	-	-	X	X
KOR11	x	XX	-	X	<x	<<x	-	-	-	-	-	-
KOR12	XX	X	x	x	-	-	-	-	-	-	-	-
KOR13	-	X	<x	x	<x	-	<<x	-	-	-	-	-
KOR14	-	X	<x	x	<x	-	-	-	-	-	-	-
KOR15	-	X	XX	x	<x	-	<x	-	-	-	-	-
KOR16	-	x	X	<x	<x	<x	<<x	-	-	-	-	<<x

KOR17	x	X	-	x	<x	-	-	-	-	-	-	-
KOR18	X	X	-	x	-	-	-	-	-	-	-	-

Table A2-122: Mineral composition of samples for Kromdraai Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
KRD1	<x	X	-	-	-	-	-	-	-	-	-	-
KRD2	<x	XX	-	-	x	-	-	-	-	-	-	-
KRD3	x	XX	-	-	<x	<x	-	-	-	-	-	-
KRD4	XX	x	-	-	<x	-	-	-	-	-	-	-
KRD5	XX	<x	-	-	x	-	-	-	-	-	-	-
KRD6	-	X	-	-	-	-	-	-	-	-	-	-
KRD7	-	x	-	-	-	x	-	-	-	-	-	-
KRD8	-	X	-	-	-	<x	-	-	-	-	-	-
KRD9	-	x	-	-	x	<x	-	-	-	-	-	-
KRD10	<x	XX	-	-	x	-	-	-	-	-	-	-
KRD11	-	X	-	-	x	-	<x	-	-	-	-	-

Table A2-123: Mineral composition of samples for Lakeside Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
LK1	x	X	<x	x	XX	-	-	-	-	-	-	-
LK2	X	XX	x	-	-	-	-	-	-	-	-	-
LK3	x	XX	-	-	x	-	-	-	-	-	-	-
LK4	-	x	X	<x	X	-	-	-	-	-	-	-
LK5	X	XX	x	x	<x	-	-	-	-	-	-	-
LK6	-	XX	x	<x	x	<x	-	-	-	-	-	-
LK7	-	XX	X	-	x	-	-	-	-	-	-	-

Table A2-124: Mineral composition of samples for Leeufontein Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
LU1	<x	XX	-	X	-	X	-	-	-	-	-	-
LU2	X	x	x	-	-	-	-	-	-	-	-	-

LU3	<x	X	XX	x	-	x	-	-	-	-	-	-
LU4	x	X	X	X	-	<x	-	-	-	-	-	-
LU5	XX	X	<x	x	-	-	-	-	-	-	-	-
LU6	x	X	x	X	-	-	-	-	-	-	-	-
LU7	XX	X	-	-	-	-	-	-	-	-	-	-
LU8	XX	X	-	-	-	<x	-	-	-	-	-	-
LU9	x	X	<x	<x	<x	-	-	-	-	-	-	-
LU10	x	X	X	x	<x	-	-	-	-	-	-	-
LU11	X	XX	x	x	-	-	-	-	-	-	-	-
LU13	x	XX	x	x	x	-	-	-	-	-	-	-
LU14	<x	x	X	XX	X	-	-	-	-	-	-	-
LU15	x	XX	X	X	-	-	-	-	-	-	-	-
LU16	<x	XX	X	X	x	-	-	-	-	-	-	-
LU17	-	XX	X	X	x	-	-	-	-	-	-	-
LU18	x	XX	-	x	x	<x	-	-	-	-	-	-
LU19	<x	x	XX	x	X	-	-	-	-	-	-	-
LU20	<x	X	XX	X	x	-	-	-	-	-	-	-
LU21	X	XX	-	-	-	-	-	-	-	-	-	-
LU22	x	XX	<x	<x	-	x	-	-	-	-	-	-
LU23	x	XX	X/x	X/x	X/x	-	-	-	-	-	-	-
LU24	-	-	XX	-	<x	-	-	-	-	-	-	-
LU25	-	X	<x	XX	X	-	-	-	-	-	-	-
LU26	-	XX	X/x	X/x	X/x	-	-	-	-	-	-	-
LU27	-	XX	-	-	-	-	-	-	-	-	-	-
LU28	-	XX	x	x	-	-	-	-	-	-	-	-
LU29	-	XX	<x	<x	-	x	-	-	-	-	-	-
LU30	-	XX	-	x	x	-	-	-	-	-	-	-
LUP1	-	XX	x	<x	x	-	-	-	-	-	-	-
LUP2	-	X	X	-	x	-	-	-	-	-	-	-
LUP3	-	<x	XX	X	X	-	-	-	-	-	-	-

LUP4	x	XX	-	-	x	-	x	X	-	-	-	-

Table A2-125: Mineral composition of samples for Middelburg Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
M1	XX	X	-	-	x	-	-	-	-	-	-	x
M2	X	X	-	-	x	-	-	-	-	-	-	x
M3	XX	x	-	-	-	-	-	-	-	-	-	-
M4	XX	x	-	-	-	-	-	-	-	-	-	-
M5	X	XX	x	x	x	-	-	-	-	-	-	-
M6	x	XX	-	x	-	-	-	-	-	-	-	-
M7	-	XX	-	x	x	-	-	-	-	-	-	x
M8	-	XX	-	<x	x	-	-	-	-	-	-	<x
M9	x	XX	-	-	<x	-	x	-	-	-	-	-
M10	x	XX	-	-	-	-	-	-	-	-	-	-
M11	X	X	-	x	-	-	-	-	-	-	-	x
M12	X	X	x	x	x	-	-	-	-	-	-	-
M13	XX	-	-	x	-	-	-	-	<x	-	-	-
M14	X	X	x	x	-	<x	-	-	-	-	-	-
M15	-	X	x	x	x	X	-	-	-	-	-	-
M16	-	XX	x	X	x	X	x	-	-	-	-	-
M17	-	XX	x	x	<x	X	x	-	-	-	-	-
M18	X	X	x	x	-	<x	-	-	-	-	-	-
M19	X	X	-	-	-	-	-	-	-	-	-	x
M20	X	X	-	-	X	-	-	-	-	-	-	-
M21	XX	X	-	-	-	-	-	-	-	x	-	-
M22	XX	X	-	-	-	-	-	-	<x	x	-	<x

Table A2-126: Mineral composition of samples for Optimum Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
OPT1	x	X	-	-	X	-	-	-	-	-	-	-

OPT2	<x	x	x	-	-	-	-	-	-	-	-	-
OPT3	XX	X	-	-	-	-	-	-	-	X	-	-
OPT4	X	x	-	x	<x	-	-	-	-	-	-	-
OPT5	<x	x	-	-	<x	-	-	-	-	-	-	-
OPT6	x	X	<x	-	-	-	-	-	-	-	-	-
OPT7	<x	x	<x	-	-	-	-	-	-	-	-	-
OPT8	XX	<x	x	-	x	-	-	-	-	-	-	-
OPT9	x	X	-	-	-	-	-	-	-	-	-	-
OPT10	x	X	-	<x	-	x	-	-	-	-	-	-
OPT11	XX	<x	-	-	-	-	-	-	-	-	x	-
OPT12	X	X	-	-	-	-	-	-	-	-	-	-
OPT13	x	x	-	x	<x	-	-	-	-	-	-	-

Table A2-127: Mineral composition of samples for Rietspruit Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
R2RO	XX	X	-	-	-	-	-	-	x	-	x	-
R2M	<x	X	x	<<x	x	<<x	X	-	-	-	-	x
R2M2	-	X	XX	<x	x	-	<x	-	-	-	-	<x
R2LW	-	X	X	X	-	-	x	-	-	-	-	-
R4UROOF	XX	X	x	x	-	-	-	-	-	-	-	-
R4U	X	XX	x	x	<x	-	-	-	-	-	-	-
R4PT	XX	X	-	-	-	-	-	-	x	-	<x	-
R4L	X	X	x	x	-	-	-	-	-	-	-	-
R4FUG	-	-	-	-	-	-	-	-	-	-	-	-
R4FLG	XX	x	-	-	-	-	-	-	-	-	-	x
R4F1	XX	X	-	-	-	-	-	-	-	-	-	x
R4F2	X	XX	-	-	-	-	-	-	x	-	-	-
R4F3	XX	X	-	-	-	-	-	-	-	-	-	<x

Table A2-128: Mineral composition of samples for South Witbank Colliery as interpreted from XRD scans

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Montm**	**Fluorapatite**	**Crandallite**	**Ill./ Smec.**	**K-fsp**	**Plag**	**Siderite**
SW1	x	X	X	x	x	-	-	-	-	-	-	-
SW2	X	XX	x	x	-	-	-	-	-	-	-	-
SW3	X	XX	x	x	<x	<x	-	-	-	-	-	-
SW4	x	x	X	x	-	<x	-	-	-	-	-	-
SW5	X	X	X	x	x	<x	-	-	-	-	-	-
SW6	X	X	X	x	x	-	-	-	-	-	-	-
SW7	x	x	x	x	x	<x	x	-	-	-	-	-
SW8	x	x	X	x	x	<<x	x	-	-	-	-	-
SW9	X	X	x	x	x	<<x	<x	-	-	-	-	-
SW10	<x	X	X	x	x	<<x	-	-	-	-	-	-

Table A2-129: Mineral composition of samples for Tavistock Colliery as interpreted from XRD scans

SiteName	**Quartz**	**Kaolinite**	**Calcite**	**Dolomite**	**Pyrite**	**Montm**	**Fluorapatite**	**Crandallite**	**Ill./ Smec.**	**K-fsp**	**Plag**	**Siderite**
TAV1A	<x	x	X	x	x	-	x	-	-	-	-	-
TAV1B	<x	x	-	-	-	-	X	-	-	-	-	-
TAV1C	<<x	<x	-	-	x	-	x	-	-	-	-	-
TAV2A	<x	x	x	<x	-	-	x	-	-	-	-	-
TAV2B	<x	x	x	<x	-	-	x	-	-	-	-	-
TAV2C	x	x	x	<x	-	-	-	-	-	-	-	-
TAV3A	<x	<x	<x	<x	<x	-	-	-	-	-	-	-
TAV3B	<x	x	x	<x	-	-	-	-	-	-	-	-
TAV3C	<x	<x	x	-	x	-	-	-	-	-	-	-
TAV4A	x	X	-	-	-	-	-	-	-	-	-	-
TAV4B	x	X	-	-	-	-	-	-	-	-	-	-
TAV4C	x	X	-	-	-	-	-	-	-	-	-	-
TAV5A	<x	x	<x	-	<x	-	x	-	-	-	-	-
TAV5B	<x	X	<x	-	<x	-	x	-	-	-	-	-
TAV5C	<x	X	-	-	-	-	<x	-	-	-	-	-

TAV6A	<x	x	x	<x	<x	-	<x	-	-	-	-	-
TAV6B	<X	x	<x	<<x	-	-	<x	-	-	-	-	-
TAV6C	<x	x	<x	<x	<x	-	<x	-	-	-	-	-
TAV7A	<x	x	<x	<x	x	-	-	-	-	-	-	-
TAV7C	X	XX	-	-	-	-	-	-	-	-	-	-

Table A2-130: Mineral composition of samples for Union Colliery as interpreted from XRD scans

SiteName	Quartz	Kaolinite	Calcite	Dolomite	Pyrite	Montm	Fluorapatite	Crandallite	Ill./ Smec.	K-fsp	Plag	Siderite
UN1	X	XX	x	x	<x	-	-	-	-	-	-	-
UN2	x	X	<x	-	<x	-	-	-	-	-	-	-
UN3	x	X	-	-	<x	-	-	-	-	-	-	-
UN4	x	X	-	-	-	-	-	-	-	-	-	-
UN5B	X	XX	-	-	-	<<x	-	-	-	-	-	-
UN6B	X	X	-	-	-	<<x	-	-	-	-	-	-

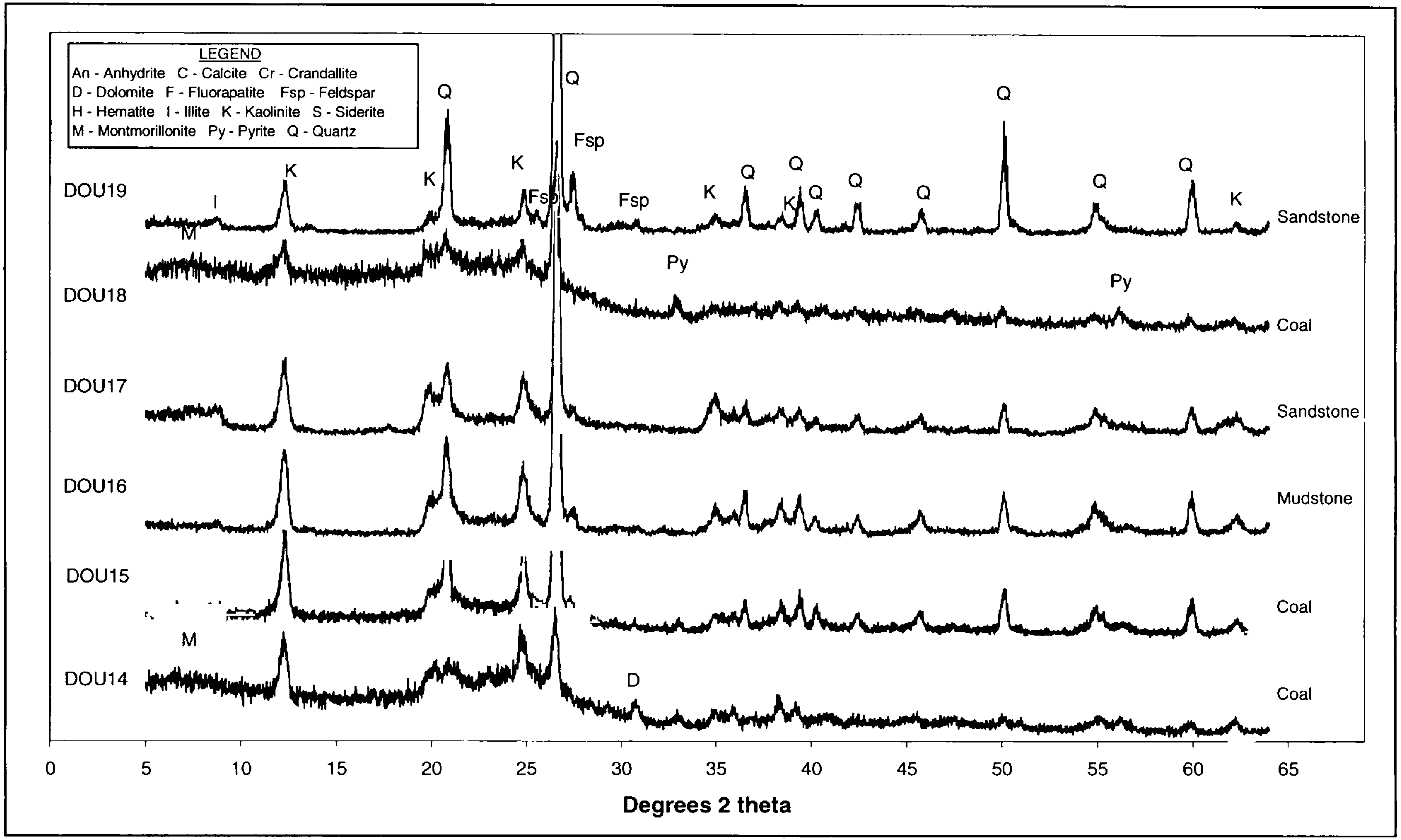

Figure A2-1 – Some X-ray diffraction scans used for qualitative mineralogical interpretation

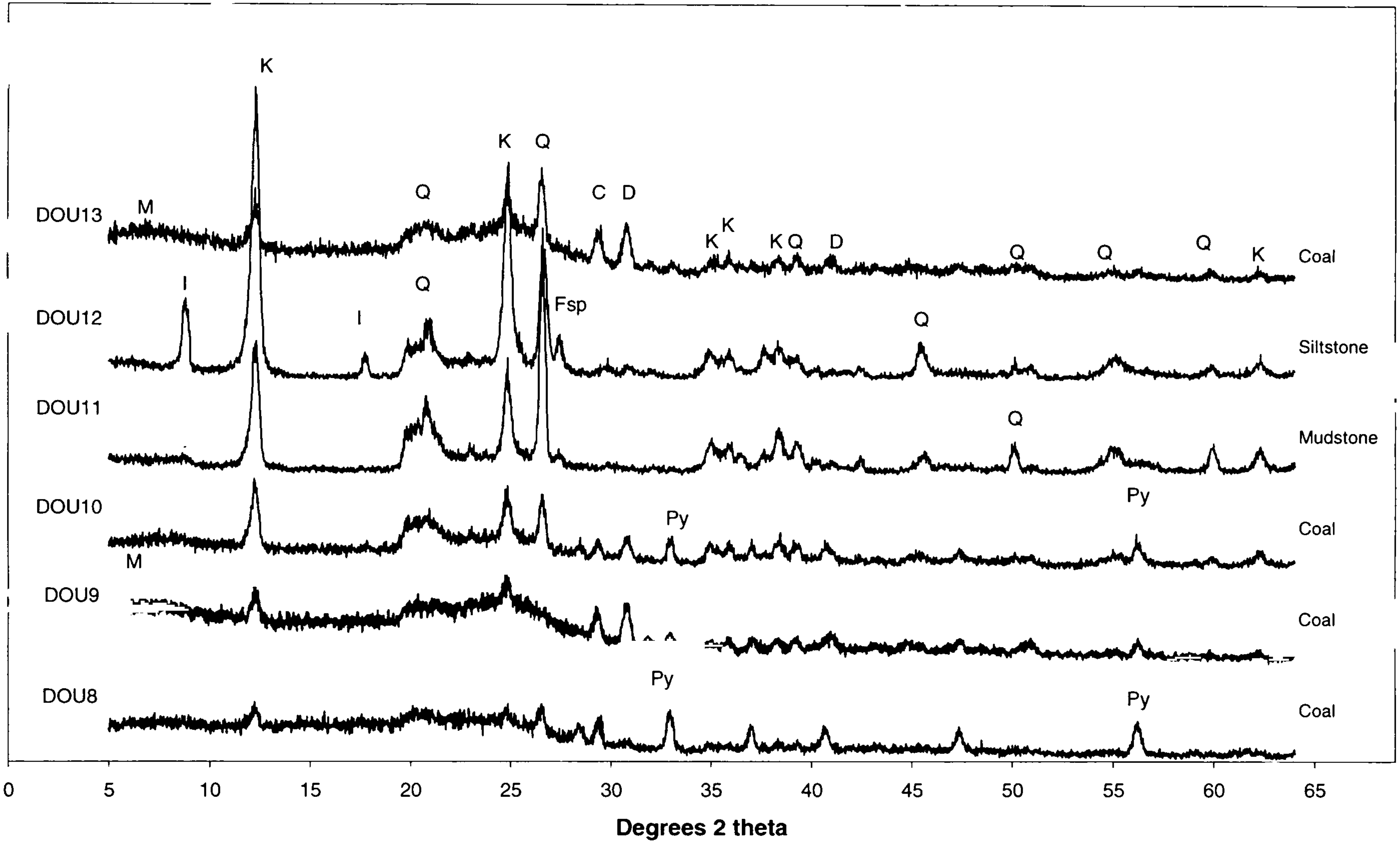

Figure A2-2 – Some X-ray diffraction scans used for qualitative mineralogical interpretation

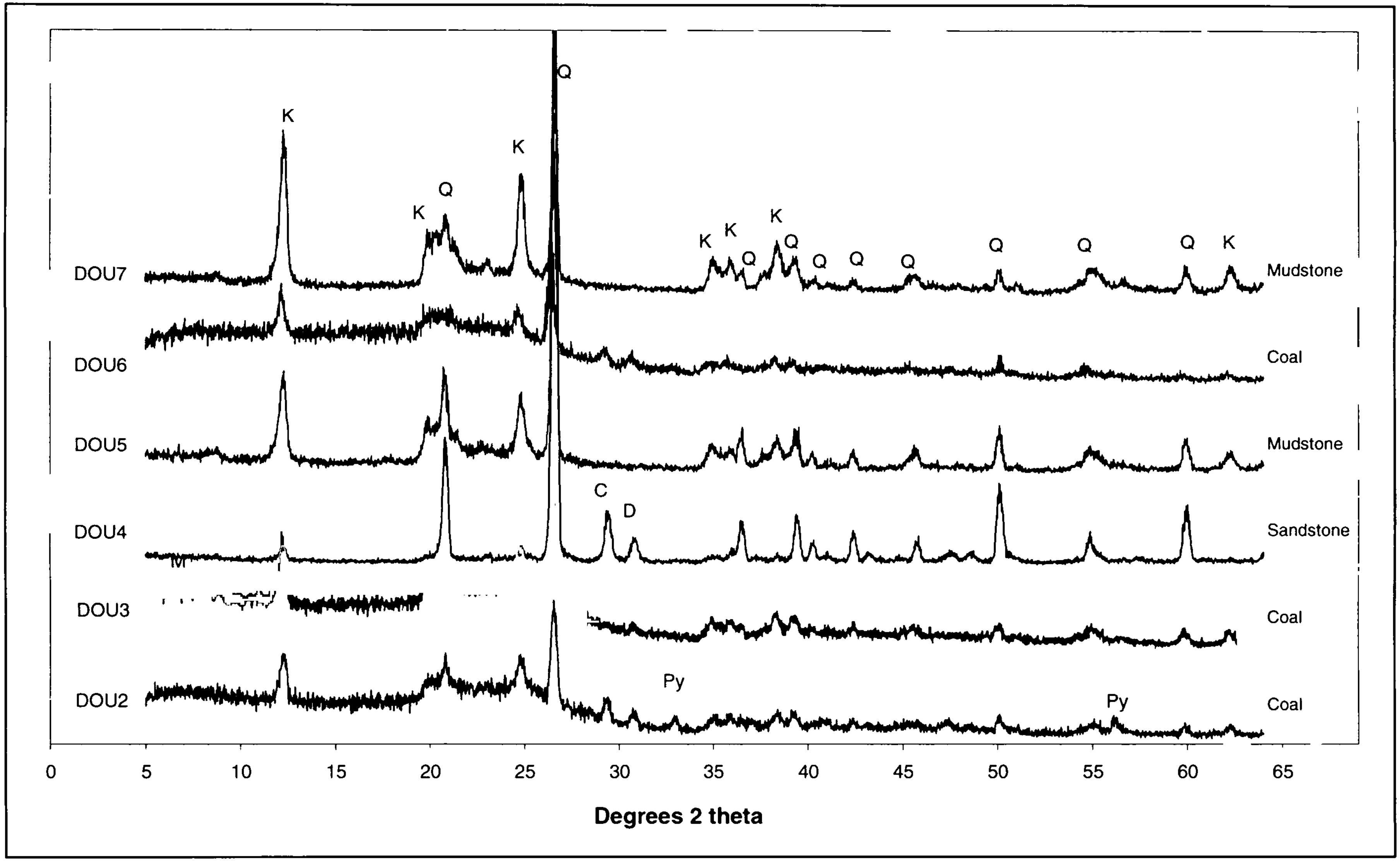

Figure A2-3 – Some X-ray diffraction scans used for qualitative mineralogical interpretation

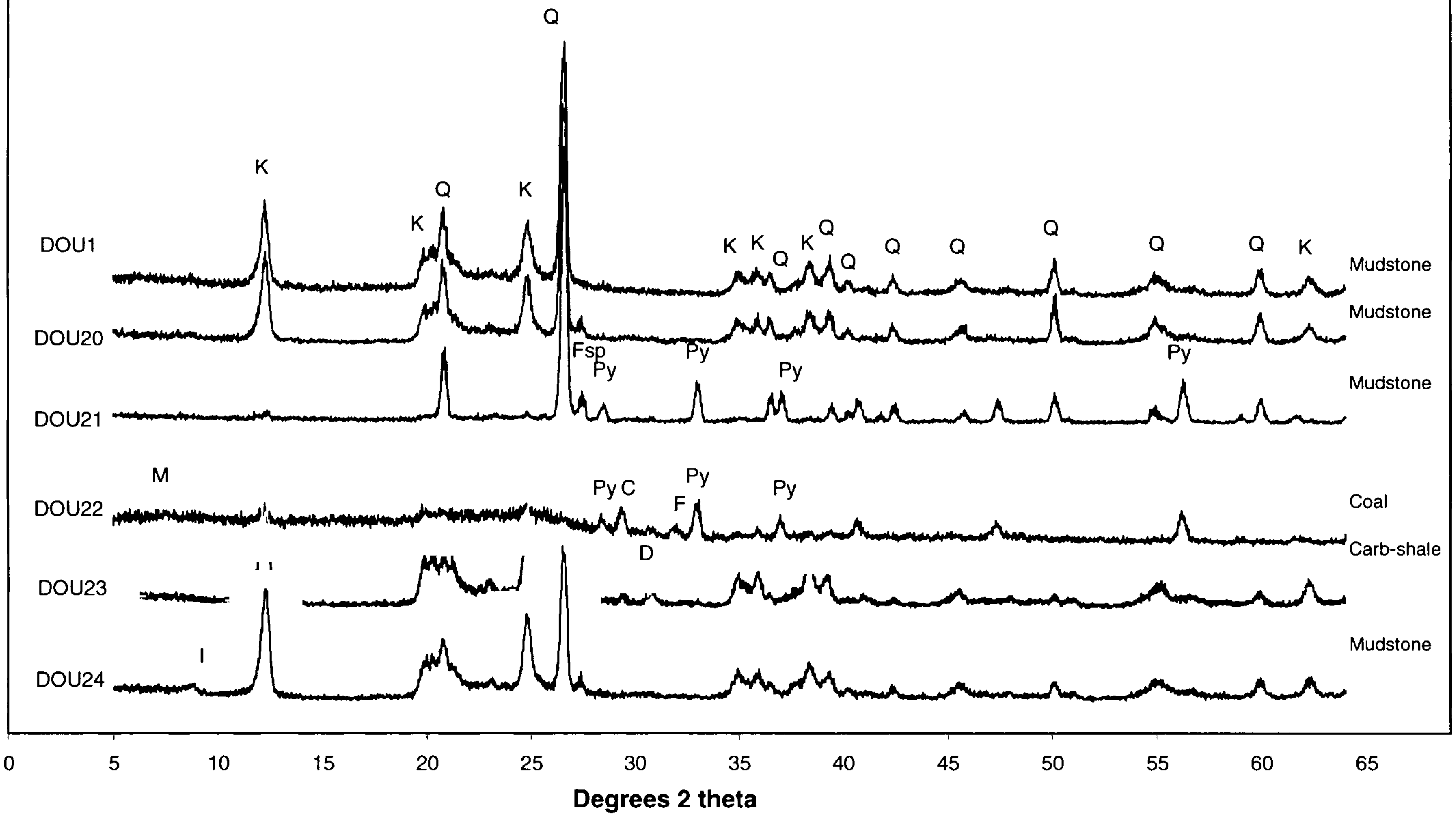

Figure A2-4 – Some X-ray diffraction scans used for qualitative mineralogical interpretation

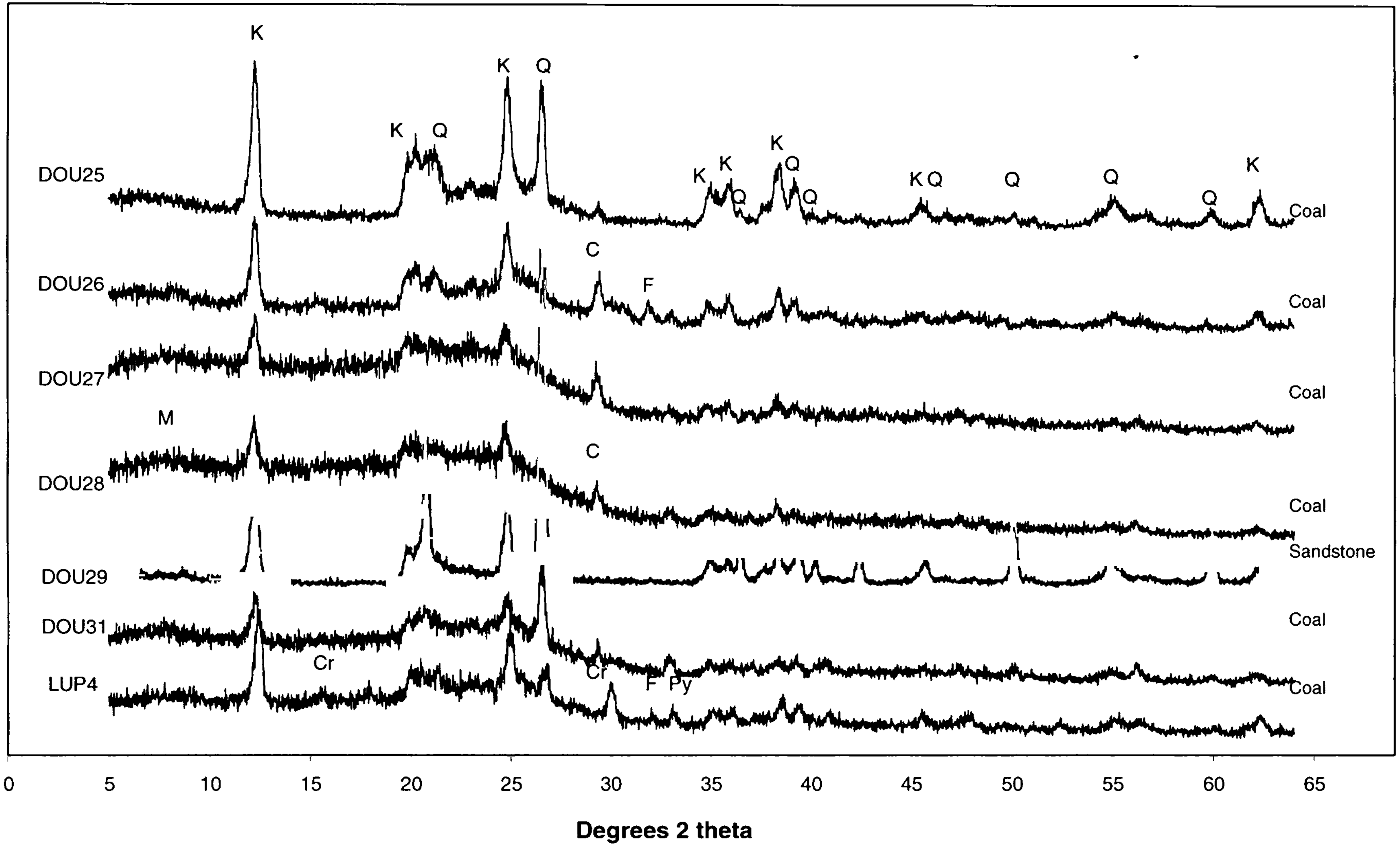

Figure A2-5 – Some X-ray diffraction scans used for qualitative mineralogical interpretation

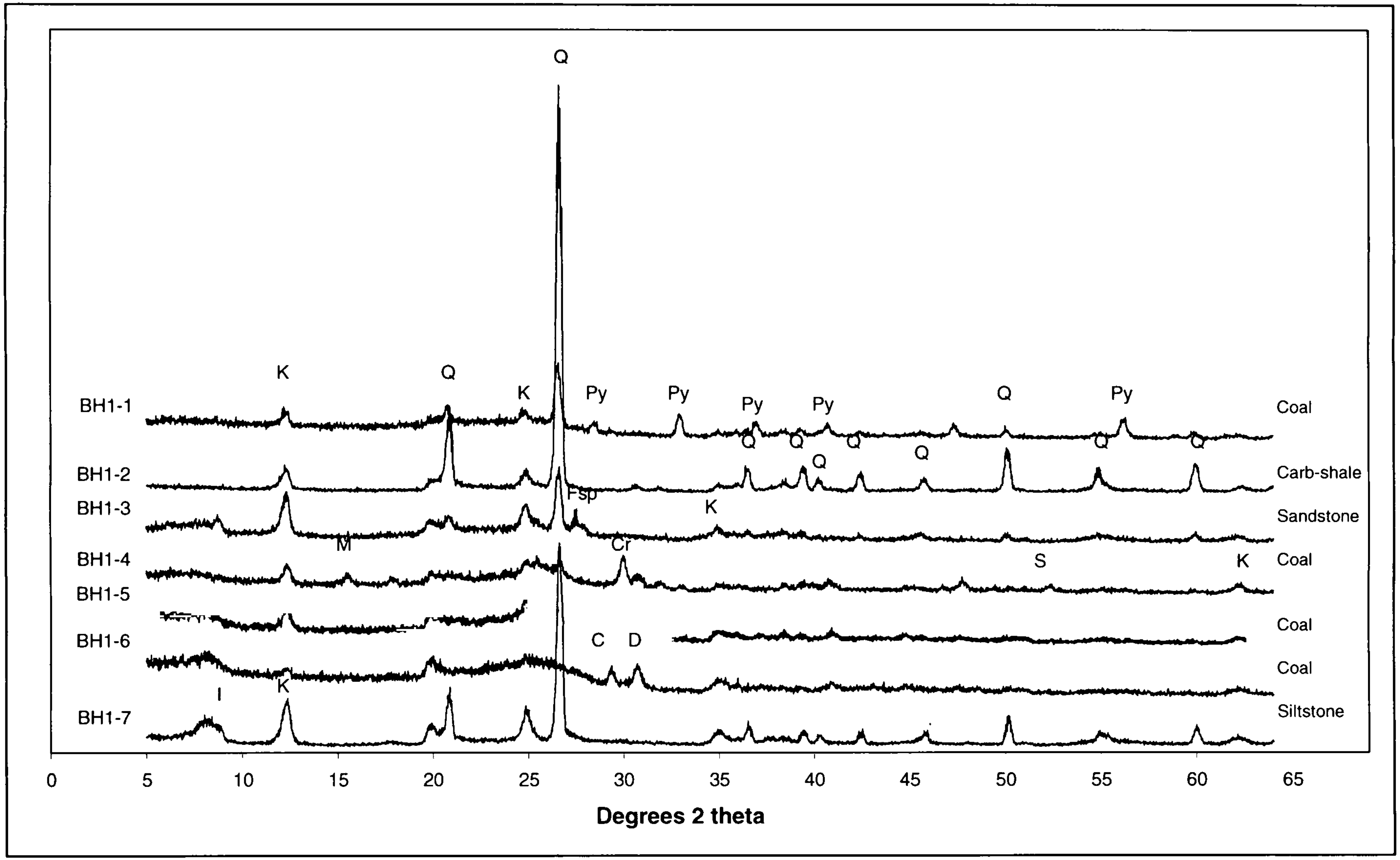

Figure A2-6 – Some X-ray diffraction scans used for qualitative mineralogical interpretation

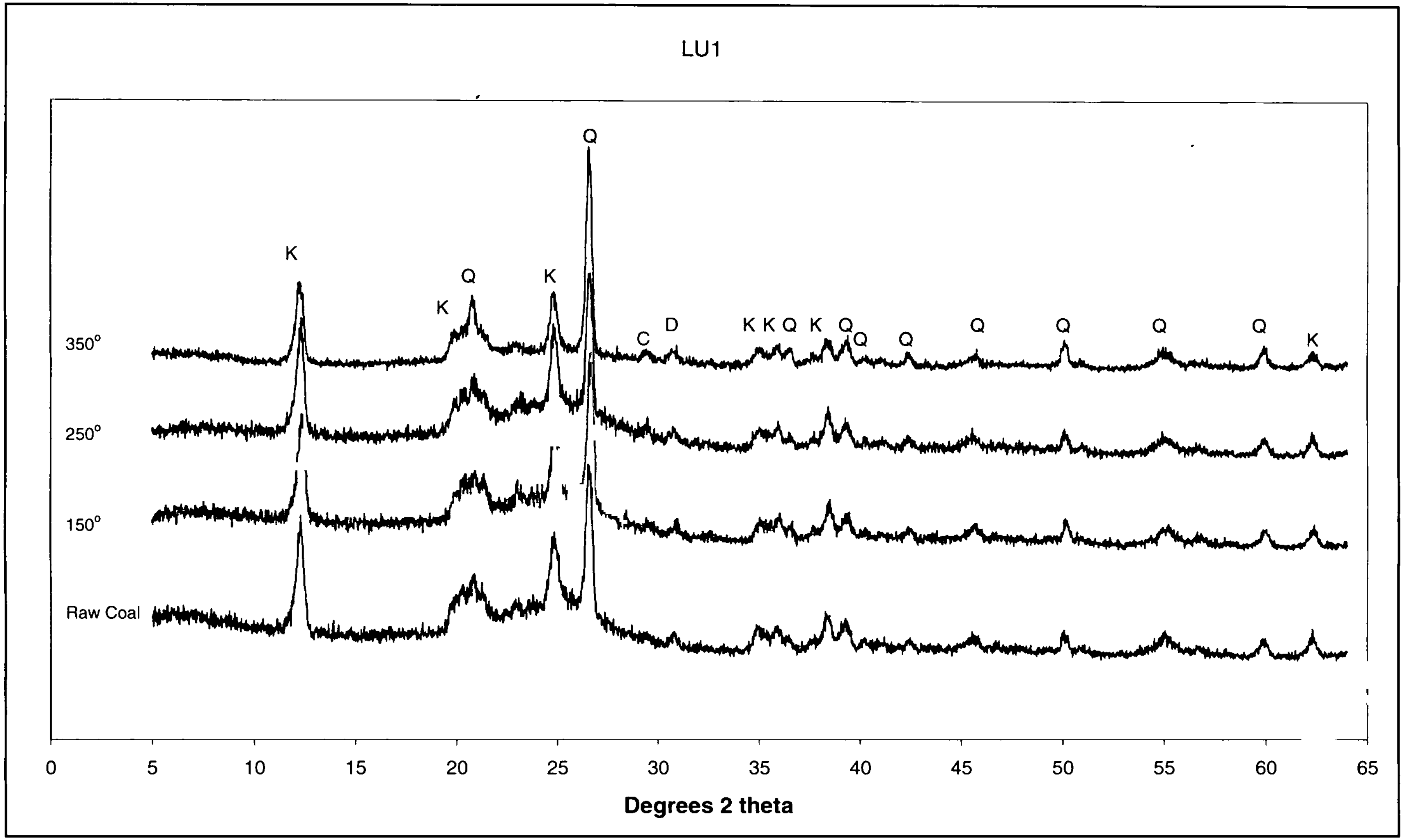

Figure A2-7 – X-ray diffraction scans of sample LU1 heated for experimental purposes

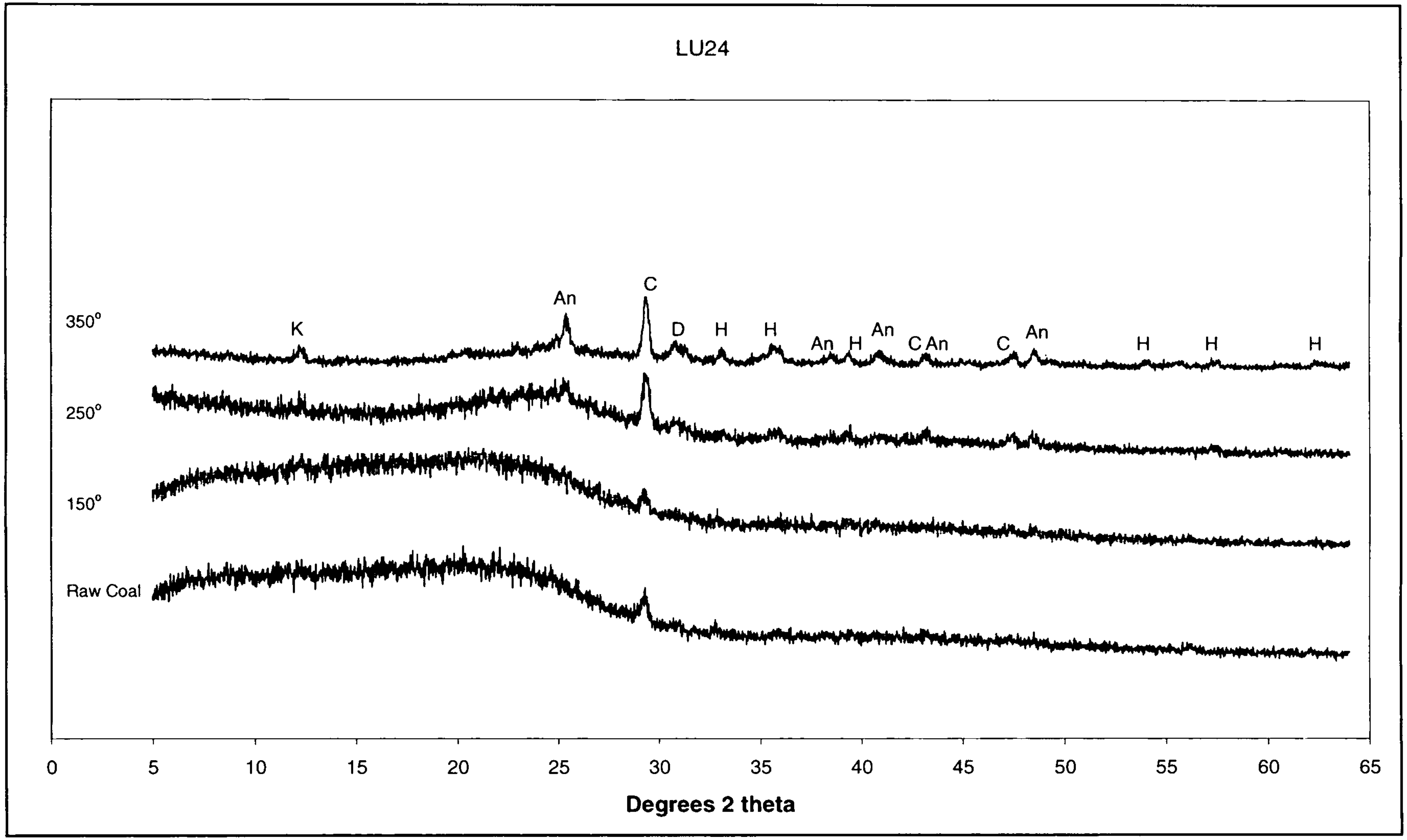

Figure A2-8 – X-ray diffraction scans of sample LU24 heated for experimental purposes

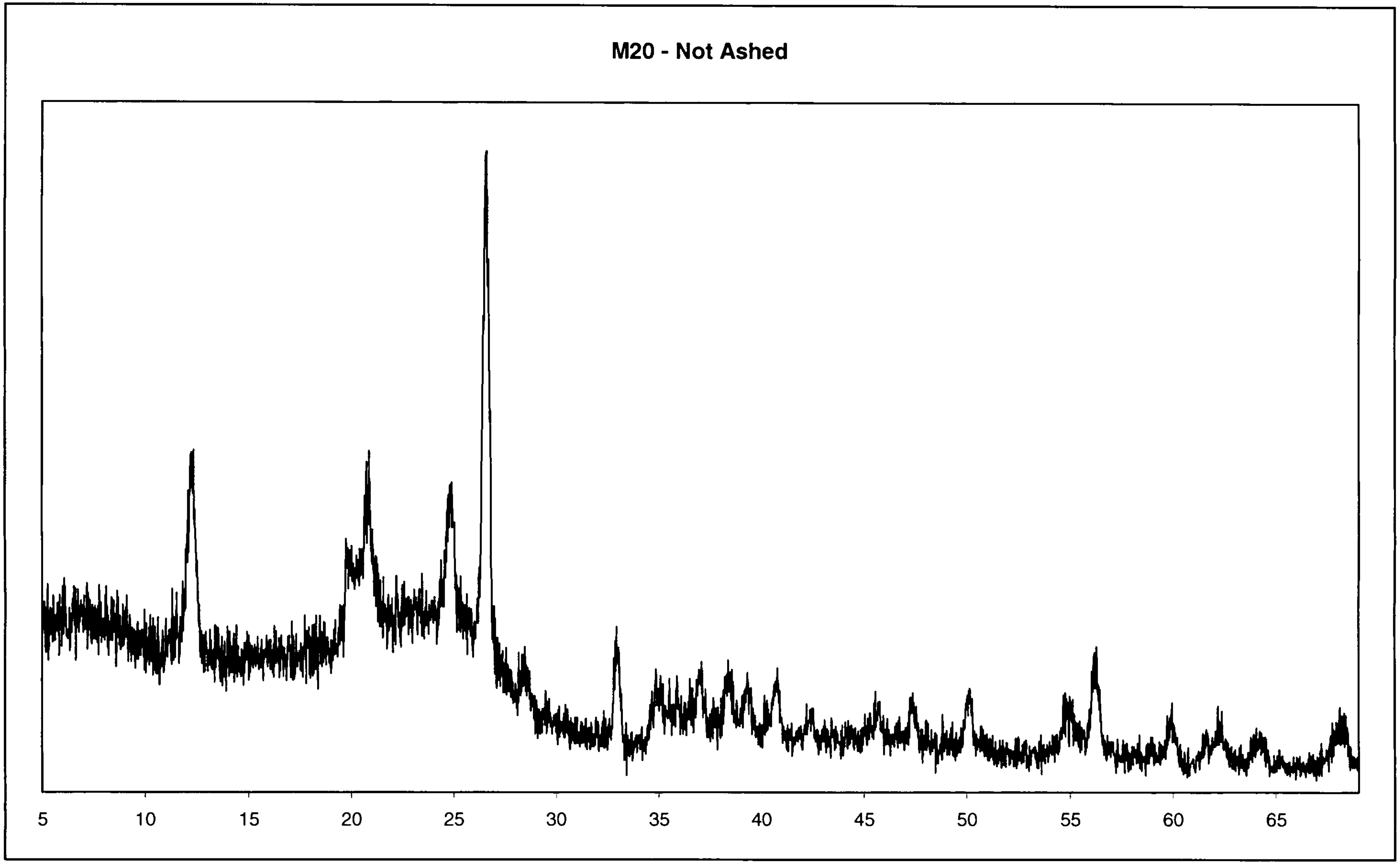

Figure A2-9 – X-ray diffraction scan of sample M20 for experimental purposes

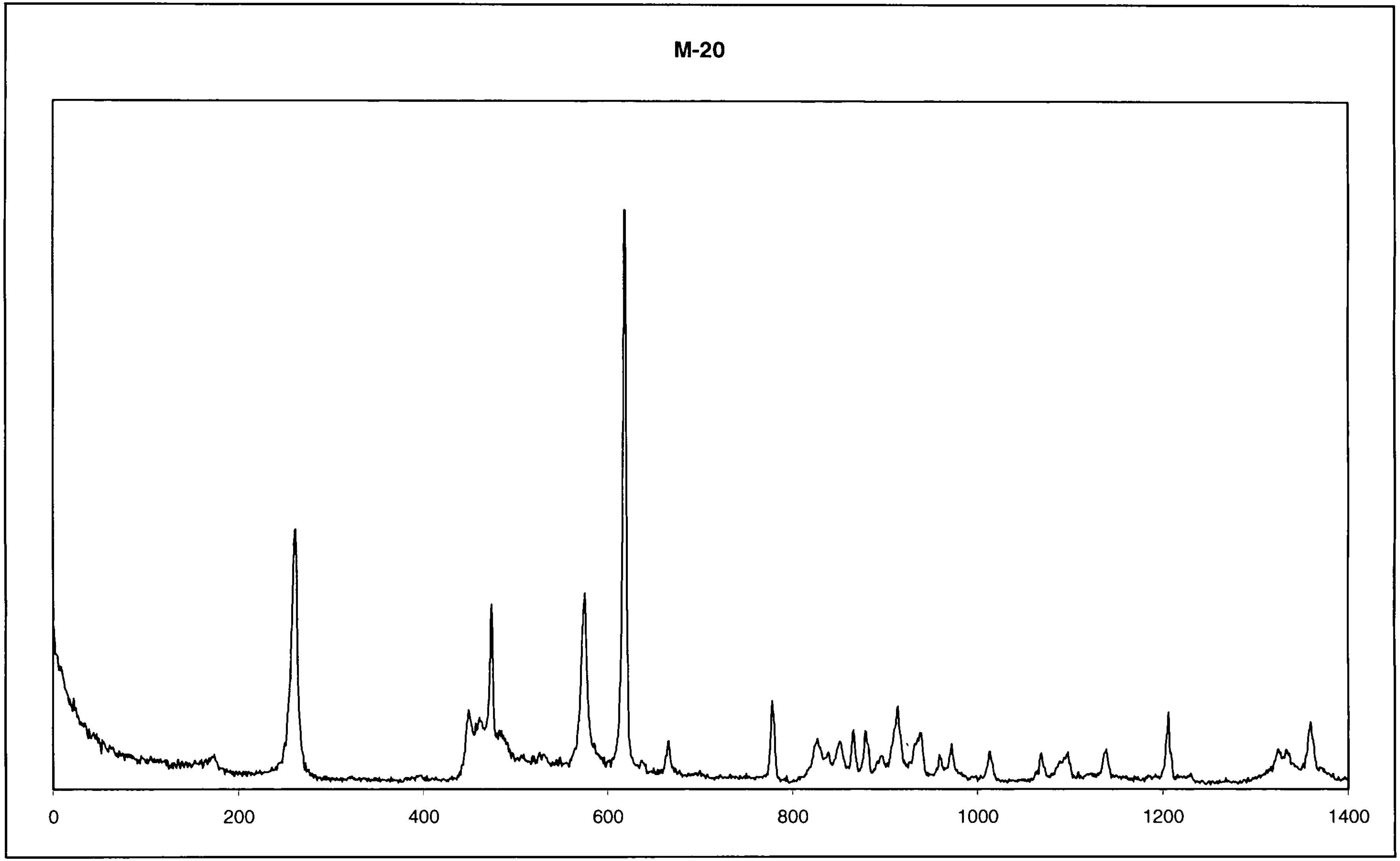

Figure A2-10 – X-ray diffraction scan of sample M20 ashed in LTA for experimental purposes

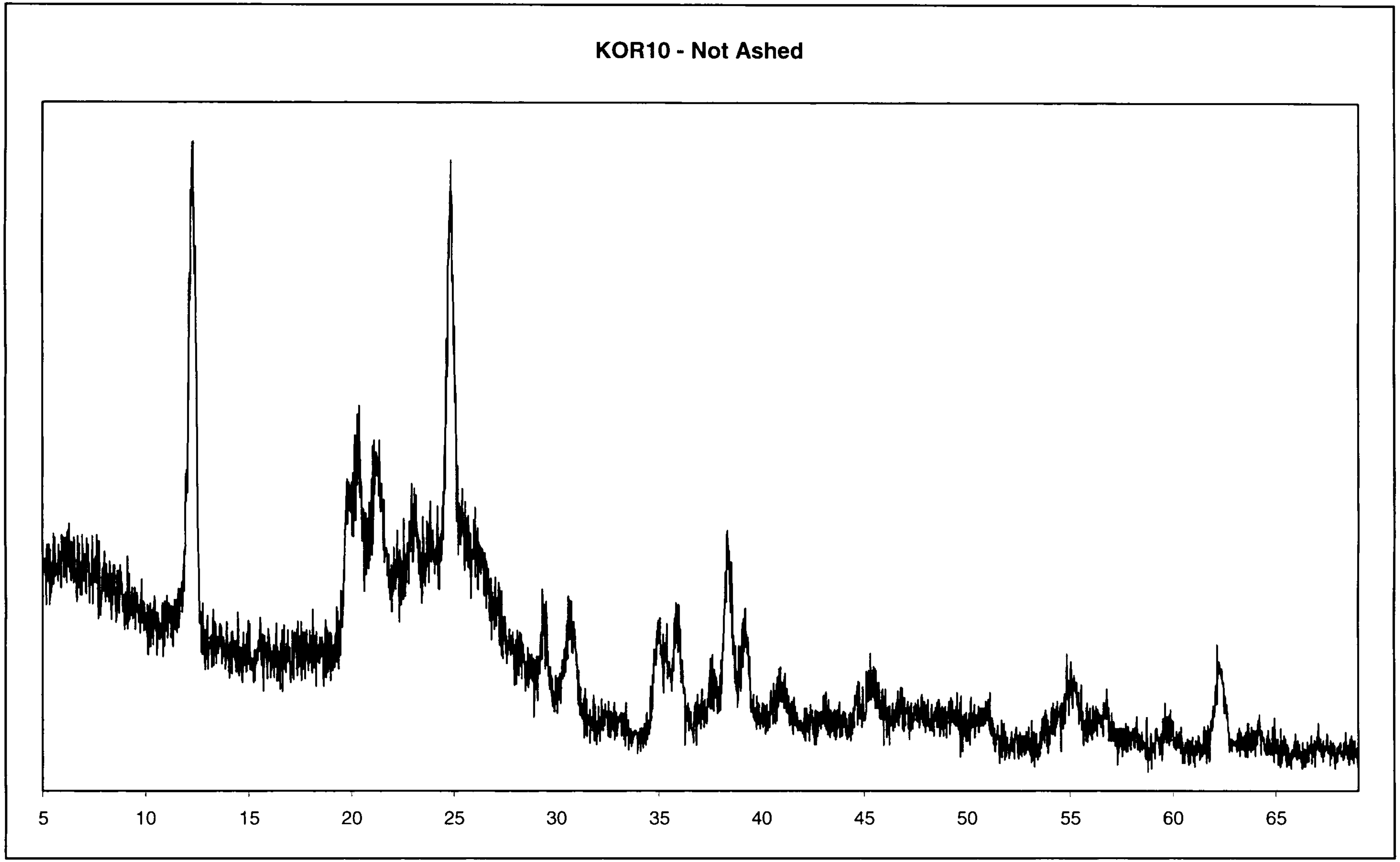

Figure A2-11 – X-ray diffraction scan of sample KOR10 for experimental purposes

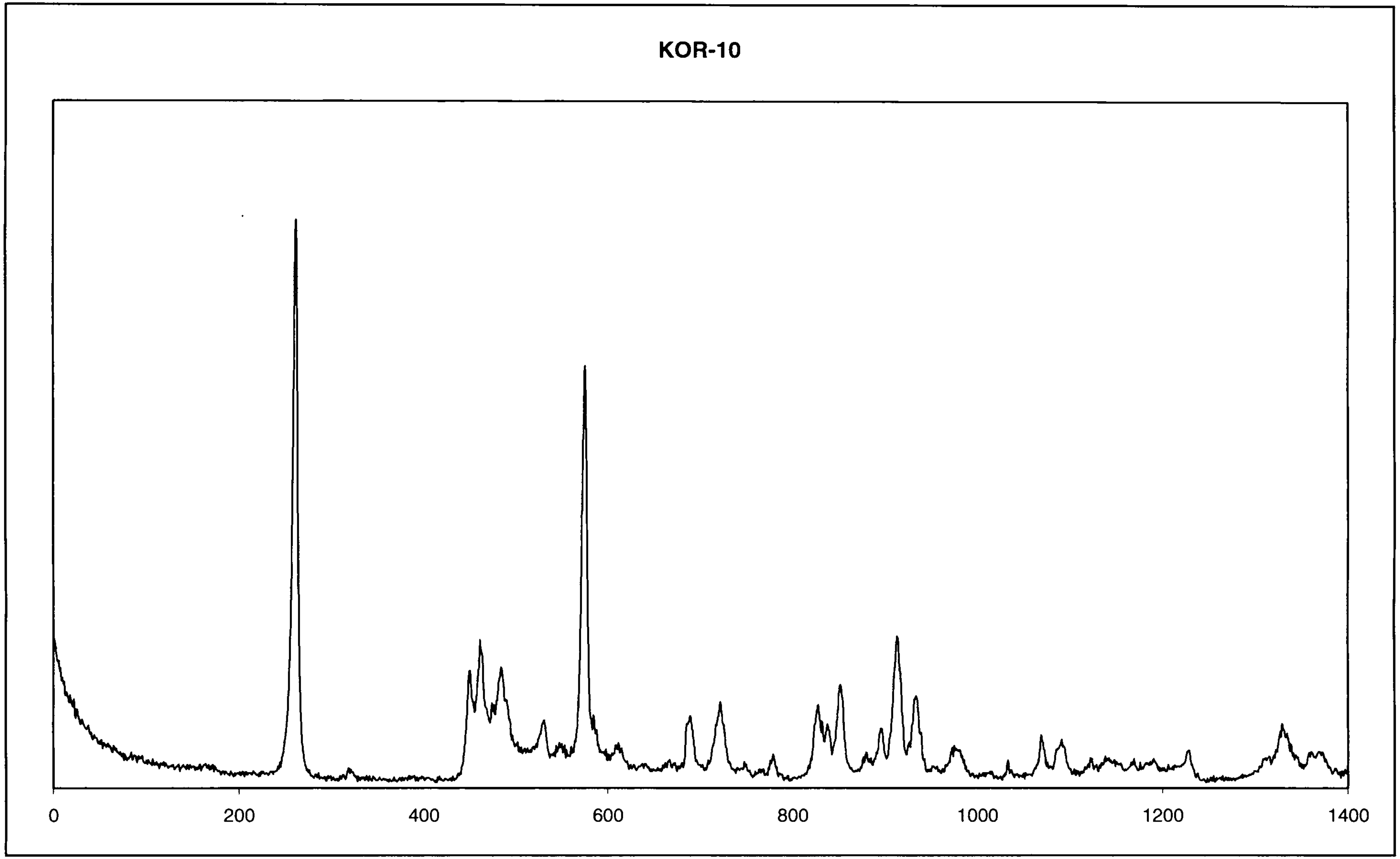

Figure A2-12 – X-ray diffraction scan of sample KOR10 ashed in LTA for experimental purposes

APPENDIX 3

ACID-BASE ACCOUNTING RESULTS

Approximately 52 coal and rock samples were analysed by the Institute for Groundwater Studies (IGS) at the University of the Free State for acid-base determinations. The purpose and techniques applied in this procedure is briefly described below.

3.1 Objective of the procedure

Acid-base determinations provide an assessment of the potential of mining wastes and other rock types to produce acid mine drainage (AMD) conditions. This procedure is exceptionally useful in terms of the prediction of future pollution problems, and provides an advantage in knowing which scenarios might arise, thus planning and implementing precautionary measures is made possible.

3.2 Acid and neutralising potential

The acid potential method used at IGS involves a rapid pyrite oxidation technique. Approximately 120 or 80ml of H_2O_2 reagent is added to 1 to 4g of a pulverised sample and allowed to effervesce. The final pH is measured once boiling has ceased. The supernatant is then analysed for sulphate. Alternatively the % S can be determined by a Leco analyser. The actual acid produced during the oxidation of pyrite by H_2O_2 is termed potential acidity. The reaction which represents the complete oxidation of Fe^{2+} and S_2^{2-} is as follows:

$$FeS_2 + 7.5H_2O_2 = Fe(OH)_3(s) + 2H_2SO_4 + 4H_2O$$

This reaction demonstrates that the complete oxidation of pyrite liberates 2 moles of H_2SO_4 for every mole of FeS_2 oxidised (Cruywagen, 2000).

To determine the neutralising potential 15ml of 0.06N standardised H_2SO_4 is added to 5g of a pulverised sample. The pH of the mixture must be below 2.5 after 24 hours before back titration to a pH of 7 is carried out with 0.06N of NaOH. If the pH is still above 3 after 24 hours, additional acid is added and the process is repeated until the correct pH is obtained (Usher *et al.,* 2001). Further calculations are explained in Chapter 5.

Since, the solubility of calcite for open and closed systems is different, acid and neutralising potential for both cases were determined. In an open system carbon dioxide dissolves into the atmosphere. Therefore, 1 mole of FeS_2 is neutralised by 2 moles of $CaCO_3$. In a closed system carbon dioxide is dissolved in the water and carbonic acid or H_2CO_3, is formed. It follows that the required $CaCO_3$ needed to neutralise 1 mole of FeS_2 is 4 moles (Cruywagen, 2000). Acid-base determinations for an open and closed system will be used in further calculations.

Tables A3-1 and A3-4 contain the acid-base potential results for coal samples from the different seams and some rock samples of floor and roof lithologies for the Highveld and Witbank Coalfields. Results for samples 3936 to 3959 were provided by other sources (Fourie, 2003).

Table A3-1: Acid-base determinations for some coal and rock samples from the Witbank Coalfield (units in kg/t)

Samples	Initial pH	Final pH	Acid (Open)	Acid (Closed)	Base	NNP (Open)	NNP (Closed)
BAN 18	7.55	2.42	5.42	10.85	5.28	-0.15	-5.57
BAN 17	4.66	1.74	56.28	112.57	-1.59	-57.88	-114.16
BAN 16	3.80	1.78	94.09	188.18	-3.97	-98.06	-192.16
BAN 15	8.00	3.19	2.99	5.97	2.59	-0.39	-3.38
ARA-16	7.40	2.90	17.32	34.64	6.81	-10.51	-27.83
ARA-15	7.38	1.50	5.87	11.75	5.50	-0.37	-6.24
DEL 1	8.90	2.68	0.48	0.95	5.62	5.14	4.67
FOR 13	7.13	2.12	54.27	108.55	1.17	-53.10	-107.38
LU 24	7.26	3.23	18.63	37.25	20.16	1.53	-17.09
DEL 2	8.37	2.05	41.75	83.50	54.04	12.29	-29.46
DEL 4	7.00	1.86	348.86	697.72	31.59	-317.27	-666.13
DEL 5	7.63	2.13	26.80	53.61	34.61	7.81	-19.00
FOR 11	8.21	3.16	10.79	21.58	15.45	4.66	-6.13
LUP 2	6.80	1.63	59.94	119.87	13.02	-46.91	-106.85
ARA-14	6.38	2.38	2.14	4.28	1.36	-0.78	-2.92
KHU 13	8.37	4.63	16.18	32.36	47.87	31.69	15.51
FOR 12	8.75	4.70	9.59	19.18	35.77	26.18	16.59
ARA-13	4.96	1.79	79.35	158.69	-1.02	-80.37	-159.71

FOR 10	7.08	1.90	166.31	283.95	-2.50	-168.81	-286.45
ARA-12	6.44	2.38	1.79	3.58	1.71	-0.08	-1.87
DEL 6	7.31	2.15	72.28	144.57	-10.58	-82.87	-155.15
ARA-11	5.31	2.09	101.13	202.26	-5.31	-106.44	-207.57
DOU 7	7.87	4.55	1.11	2.23	7.07	5.95	4.84
DOU 11	7.44	1.64	16.94	33.87	3.27	-13.67	-30.60
3936	6.79	5.81	0.03	0.06	0.75	0.72	0.69
3937	6.36	2.97	0.03	0.06	0.00	-0.03	-0.06
3942	7.34	6.91	0.06	0.12	1.25	1.19	1.13
3943	6.69	3.69	1.81	3.60	4.25	2.44	0.65
3944	6.44	2.39	11.38	22.57	6.00	-5.38	-16.57
3948	6.72	6.15	0.03	0.06	1.25	1.22	1.19
3949	6.42	3.14	0.03	0.06	0.00	-0.03	-0.06
3950	5.70	2.02	1.56	3.10	0.50	-1.06	-2.60
3954	6.86	3.97	0.03	0.06	0.00	-0.03	-0.06
DOU 10	7.91	1.87	95.57	191.15	47.98	-47.60	-143.17
DOU 9	7.91	4.72	32.40	64.81	60.93	28.52	-3.88
DOU 8	7.16	2.04	147.47	294.95	13.81	-133.66	-281.14
ARA-9	8.40	4.86	3.33	6.67	39.26	35.92	32.59
ARA-10	8.34	5.04	0.69	1.38	31.85	31.16	30.47
BAN 6	8.52	5.09	7.67	15.35	15.43	7.76	0.08
BAN 5	8.90	5.36	0.32	0.65	14.83	14.50	14.18
3938	5.27	1.58	5.84	11.59	-2.50	-8.34	-14.09
3945	5.37	1.65	28.81	57.16	1.75	-27.06	-55.41
3951	4.85	1.29	26.44	52.45	0.50	-25.94	-51.95
3955	5.24	1.48	18.03	35.77	0.00	-18.03	-35.77
BAN 4	8.31	5.85	20.70	41.40	48.86	28.16	7.46
3939	5.25	1.82	9.69	19.22	-3.75	-13.44	-22.97
3940	6.25	3.94	1.09	2.17	2.75	1.66	0.58
3941	8.44	7.40	3.19	6.32	20.50	17.31	14.18
3946	6.28	2.77	9.50	18.85	2.00	-7.50	-16.85
3947	7.80	6.65	1.97	3.91	4.50	2.53	0.59
3952	6.34	3.32	2.53	5.02	2.25	-0.28	-2.77
3953	8.25	7.44	2.53	5.02	17.50	14.97	12.48
3956	6.10	2.12	3.59	7.13	-0.25	-3.84	-7.38
ARA-8	6.92	3.01	0.53	1.07	2.21	1.68	1.14
DOU 4	8.89	6.17	4.82	9.64	130.60	125.78	120.96
ARA-6	7.51	4.20	1.55	3.11	7.06	5.51	3.96
3957	5.86	2.13	14.25	28.27	0.00	-14.25	-28.27
DOU 3	8.51	5.17	0.25	0.49	10.35	10.10	9.85
ARA-5	7.60	1.78	37.32	74.64	12.11	-25.21	-62.53
DOU 2	7.90	1.73	42.33	84.65	25.96	-16.37	-58.69
DOU 1	7.95	2.11	0.97	1.93	1.81	0.84	-0.12
ARA-4	6.86	2.53	1.04	2.08	1.92	0.88	-0.16
3958	6.39	3.18	7.63	15.13	2.25	-5.38	-12.88
3959	6.55	3.62	6.59	13.08	3.00	-3.59	-10.08

Table A3-2: Average acid-base potential results for the different lithologies of the Witbank Coalfield (units in kg/t)

Samples	Initial pH	Final pH	Acid (Open)	Acid (Closed)	Base	NNP (Open)	NNP (Closed)
Below 1	6.94	2.86	4.06	8.06	2.24	-1.81	-5.81
1 Seam	8.00	2.89	26.63	53.26	16.14	-10.49	-37.12
2 to 1	6.99	4.25	4.60	9.14	15.45	10.84	6.30
2 Seam	7.18	3.40	32.27	64.44	22.72	-9.55	-41.72
4 to 2	6.72	3.45	24.97	46.68	0.51	-24.46	-46.17
4 SeamL	7.36	3.71	35.04	70.08	27.54	-7.50	-42.54
4SeamPT	6.38	2.38	2.14	4.28	1.36	-0.78	-2.92
4 SeamU	7.55	2.34	84.46	168.92	28.14	-56.32	-140.78
5 to 4	7.76	2.48	16.19	32.37	4.34	-11.85	-28.03
5 Seam	4.23	1.76	75.19	150.38	-2.78	-77.97	-153.16
Above 5	7.55	2.42	5.42	10.85	5.28	-0.15	-5.57

Table A3-3: Acid-base determinations for some coal and rock samples from the Highveld Coalfield (units in kg/t)

Samples	Initial pH	Final pH	Acid (Closed)	Acid (Open)	Base	NNP (Closed)	NNP (Open)
BHW 5-1	6.21	2.18	222.16	111.08	0.40	-221.76	-110.68
BHW 5-2	7.24	1.86	308.58	154.29	-1.85	-310.43	-156.14
BHW 5-3	7.43	2.44	61.35	30.68	1.87	-59.49	-28.81
BHW 2-1	7.66	2.40	46.44	23.22	2.26	-44.18	-20.96
BHW 3-10	5.08	2.28	86.87	43.43	-3.68	-90.55	-47.11
BHW 2-2	8.42	1.81	78.87	39.44	-2.50	-81.37	-41.94
BHW 2-3	7.70	2.01	288.65	144.33	-4.67	-293.33	-149.00
BHW 3-11	7.89	1.65	19.69	9.85	10.00	-9.70	0.15
BHW 3-12	7.73	1.73	95.50	47.75	33.08	-62.42	-14.67
BHW 3-13	8.43	3.89	23.72	11.86	25.77	2.05	13.91
BHW 2-4	6.49	2.32	73.09	36.54	-0.21	-73.30	-36.76
BHW 3-14	7.59	2.20	30.16	15.08	0.51	-29.65	-14.57

Table A3-4: Average acid-base potential results for the different lithologies of the Highveld Coalfield (units in kg/t)

Samples	Initial pH	Final pH	Acid (Closed)	Acid (Open)	Base	NNP (Closed)	NNP (Open)
Below 4	7.04	2.26	51.62	25.81	0.15	-51.48	-25.66
4 Seam	8.03	2.22	101.29	50.64	12.33	-88.95	-38.31
5 to 4	6.72	2.37	64.89	32.44	0.15	-64.74	-32.29
5 Seam	7.24	1.86	308.58	154.29	-1.85	-310.43	-156.14
Above 5	6.21	2.18	222.16	111.08	0.40	-221.76	-110.68

These results were used in further calculations briefly illustrated and discussed in Chapter 5.

APPENDIX 4
BOREHOLE LOGS

The following borehole logs have been provided by the mine geologists at the respective mines.

Legend:

Symbol	Lithology
	OVERBURDEN
	SANDSTONE
▥	MUDSTONE
▤	SILTSTONE
■	SHALE
	CARBONACEOUS SHALE
	COAL
	DOLERITE
	DWYKA TILLITE/ DIAMICTITE

COMPANY, COLLIERY: Sasol Mining,
BOREHOLE NUMBER: V317301 (BH1)
CO-ORDINATES: X = 2947146.93, Y = - 15989.31
SURFACE ELEVATION: 1621.24

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	5.51	5.51			OVERBURDEN
	21.30	15.79			DOLERITE
	23.55	2.25			SANDSTONE, medium grained
▤	25.12	1.57			SILTSTONE, fine grained, laminated
	31.43	6.31			SANDSTONE, coarse grained
▤	52.80	21.37			SILTSTONE, fine grained,

▤					laminated
	65.34	12.54			SANDSTONE, fine grained
▤	65.93	0.59			SILTSTONE, fine grained, laminated
	85.27	19.34			SANDSTONE, fine grained
▤	85.32	0.05			SILTSTONE, fine grained, laminated
	86.22	0.90			SANDSTONE, medium grained
▤	90.45	4.23			SILTSTONE, fine grained, laminated
	91.32	0.87			SANDSTONE, fine grained, irregular and cross bedded
	91.93	0.61			CORE LOSS
	95.03	3.10			SANDSTONE, fine grained, irregular and cross bedded
	95.13	0.10			SANDSTONE, coarse grained, glauconitic
■	95.36	0.23	BH1-1	5H	No. 5 upper COAL seam
■	95.58	0.22	BH1-2	5M	No. 5 middle COAL seam, CARBONACEOUS SHALE
	126.26	30.68			SANDSTONE, coarse grained
▤	128.18	1.92			SILTSTONE, fine grained, laminated
	131.75	3.57			SANDSTONE, medium grained, fine bedded
▤	134.31	2.56			SILTSTONE, very fine grained, laminated
	136.26	1.95			SANDSTONE, medium grained
■	136.30	0.04		4H	No. 4 upper COAL seam CARBONACEOUS SHALE

	137.00	0.70			SANDSTONE, very coarse grained
▤	138.75	1.75			SILTSTONE, fine grained, laminated
	139.28	0.53	BH1-3	ROOF	SANDSTONE, very coarse grained, gritty
■	141.15	1.87	BH1-4 BH1-5	4L	No. 4 lower COAL seam, dull lustrous coal
■	142.69	1.54	BH1-6	4L	No. 4 lower COAL seam, mainly dull coal
▤	143.23	0.54	BH1-7	FLOOR	SILTSTONE, very fine grained, laminated
	144.70	1.47			SANDSTONE, fine to medium grained, fine bedded and laminated
■	144.72	0.02		3	No. 3 COAL seam
	144.81	0.09		3	SANDSTONE, fine to medium grained
■	144.94	0.13		3	No. 3 COAL seam
	145.00	0.06		3	SANDSTONE, fine to medium grained
■	145.29	0.29		3	No. 3 COAL seam
	148.22	2.93			SANDSTONE, medium grained, fine bedded
▤	150.61	2.39			SILTSTONE, carbonaceous
	162.94	12.33			SANDSTONE, medium grained
	178.32	15.38			DOLERITE
▤	191.16	12.84			SILTSTONE, very fine grained, laminated
	228.60	37.44			SANDSTONE, coarse grained
■	233.96	5.36			CARBONACEOUS SHALE

	234.11	0.15			DOLERITE
■	235.41	1.30			CARBONACEOUS SHALE
	240.68	5.27			DWYKA TILLITE

COMPANY, COLLIERY: Sasol Mining,

BOREHOLE NUMBER: S341034 (BHW1)

CO-ORDINATES: X = 2950042.5, Y = -23166.14

SURFACE ELEVATION: 1639.30

	DEPTH	**THICKNESS (m)**	**SAMPLE NO.**	**COAL STRAT.**	**LITHOLOGY**
	3.39	3.39			OVERBURDEN
	17.08	13.69			DOLERITE
	39.87	22.79			DOLERITE
	49.96	10.09			DOLERITE
	64.52	14.56			DOLERITE
	66.02	1.50			SANDSTONE, medium grained
▤	86.39	20.37			SILTSTONE, fine grained, laminated
	90.26	3.87			SANDSTONE, coarse grained
	95.82	5.56			SANDSTONE, fine grained
	101.22	5.40			SANDSTONE, coarse grained
	108.96	7.74			SANDSTONE, fine grained, laminated
	118.09	9.13			SANDSTONE, coarse grained
	128.58	10.49			SANDSTONE, fine grained, irregular and cross bedded
	129.02	0.44			SANDSTONE, coarse grained, glauconitic
■	129.40	0.38		5M	No. 5 middle COAL seam, CARBONACEOUS SHALE
■	129.52	0.12		5L	No. 5 lower COAL seam, dull

■					lustrous coal
■	129.59	0.07		5L	No. 5 lower COAL seam, CARBONACEOUS SHALE
■	129.77	0.18		5L	No. 5 lower COAL seam, mainly bright coal
	150.26	20.49			SANDSTONE, coarse grained
▤	168.88	18.62			SILTSTONE, fine grained, laminated
	174.20	5.32	BHW1-1 BHW1-2 BHW1-3		SANDSTONE, very coarse grained, gritty
▤	175.40	1.20	BHW1-4 BHW1-5	ROOF	SILTSTONE, fine grained, laminated
■	175.51	0.11	BHW1-6	4L	No. 4 lower COAL seam, dull coal
■	176.40	0.89	BHW1-7	4L	No. 4 lower COAL seam, dull lustrous coal
■	176.69	0.29		4L	No. 4 lower COAL seam, dull coal
■	177.07	0.38	BHW1-8	4L	No. 4 lower COAL seam, dull lustrous coal
■	177.49	0.42		4L	No. 4 lower COAL seam, dull lustrous coal
■	178.64	1.15	BHW1-9	4L	No. 4 lower COAL seam, mainly bright coal
▤	179.10	0.46	BHW1-10	FLOOR	SILTSTONE, micaceous and carbonaceous
	258.62	79.52	BHW1-11 BHW1-12		SANDSTONE, coarse grained
	263.10	4.48			DOLERITE
■	273.90	6.72			CARBONACEOUS SHALE
	287.48	13.58			DWYKA TILLITE

■	290.79	3.31			CARBONACEOUS SHALE
	291.57	0.78			DWYKA TILLITE

COMPANY, COLLIERY: Sasol Mining,
BOREHOLE NUMBER: V333144 (BHW2)
CO-ORDINATES: X = 2954192.99, Y = -17751.51
SURFACE ELEVATION: 1605.50

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	0.42	0.42			OVERBURDEN
	2.64	2.22			DOLERITE
	4.11	1.47			SANDSTONE, very fine grained
	9.26	5.15			DOLERITE
	12.54	3.28			DOLERITE
	19.53	6.99			DOLERITE
	28.60	9.07			DOLERITE
	33.10	4.50			DOLERITE
	35.55	2.45			SANDSTONE, fine grained, laminated
▤	36.70	1.15			SILTSTONE, fine grained, laminated
	37.01	0.31			SANDSTONE, medium grained, fine bedded
	37.35	0.34			SANDSTONE, fine grained, cross bedded
	40.14	2.79			DOLERITE
	40.80	0.66			SANDSTONE, medium grained, fine bedded
	44.08	3.28			SANDSTONE, very fine grained, fine bedded
▤	46.97	2.89			SILTSTONE, fine grained,

▤					laminated
	47.06	0.09			DOLERITE
▤	60.86	13.80			SILTSTONE, fine grained, laminated
	66.04	5.18			SANDSTONE, fine grained
	67.85	1.81			SANDSTONE, medium grained, fine bedded
▤	69.94	2.09			SILTSTONE, very fine grained, laminated
	86.97	1.19			SANDSTONE, medium grained, fine bedded
▤	87.97	1.00			SILTSTONE, very fine grained, laminated and bioturbated
▤	88.61	0.64			SILTSTONE, very fine grained, laminated
	90.25	1.64			SANDSTONE, fine grained, fine bedded
▤	93.85	3.60			SILTSTONE, very fine grained, laminated
	94.22	0.37			SANDSTONE, medium grained, fine bedded
▤	95.28	1.06			SILTSTONE, very fine grained, laminated
	98.76	3.48			SANDSTONE, medium grained
▥	98.95	0.19			MUDSTONE, with sandstone bands
	105.25	6.30			SANDSTONE, medium grained, fine bedded
▤	109.93	4.68			SILTSTONE, very fine grained, laminated
	111.11	1.18			SANDSTONE, fine to medium

					grained
▤	111.52	0.41			SILTSTONE, very fine grained, laminated
■	112.63	1.11			CARBONACEOUS SHALE
▤	113.49	0.86			SILTSTONE, very fine grained, laminated
	113.78	0.29			SANDSTONE, fine to medium grained, fine bedded
▤	116.55	2.77			SILTSTONE, very fine grained, laminated, carbonaceous
	130.72	14.17			SANDSTONE, medium to coarse grained
▤	130.89	0.17			SILTSTONE, very fine grained, laminated
	130.99	0.10			SANDSTONE, coarse grained
▤	131.02	0.03		5	No. 5 COAL seam, SILTSTONE, laminated
■	131.05	0.03		5	No. 5 COAL seam, CARBONACEOUS SHALE
▤	139.82	8.77			SILTSTONE, fine grained, laminated
■	140.51	0.69			CARBONACEOUS SHALE
	140.60	0.09			SANDSTONE, medium grained, fine bedded
■	140.99	0.39			CARBONACEOUS SHALE
▥	141.43	0.44			MUDSTONE, massive
▤	142.53	1.10			SILTSTONE, very fine grained, laminated
	146.74	4.21	BHW2-1	ROOF	SANDSTONE, medium grained
■	147.06	0.32	BHW2-2	4H	No. 4 upper COAL seam, CARBONACEOUS SHALE

■	147.25	0.19	BHW2-3	4H	No. 4 upper COAL seam, CARBONACEOUS SHALE with bright coal bands
▤	147.68	0.43	BHW2-4	FLOOR	SILTSTONE, very fine grained, laminated
	147.74	0.06			SANDSTONE, very coarse grained
▤	148.07	0.33			SILTSTONE, very fine grained, laminated
	150.66	2.59			SANDSTONE, fine to medium grained, fine bedded and laminated
	158.23	7.57	BHW2-5	ROOF	SANDSTONE, fine to medium grained, fine bedded
■	158.39	0.16	BHW2-6	4L	No. 4 lower COAL seam, dull lustrous coal
■	158.78	0.39	BHW2-6	4L	No. 4 lower COAL seam, heavy dull coal
▥	158.81	0.03	BHW2-6	4L	No. 4 lower COAL seam, mudstone
■	158.88	0.07	BHW2-6	4L	No. 4 lower COAL seam, heavy dull coal
■	159.20	0.32	BHW2-6	4L	No. 4 lower COAL seam, mainly bright coal
■	159.24	0.04	BHW2-6	4L	No. 4 lower COAL seam, heavy dull coal
■	159.40	0.16	BHW2-7	4L	No. 4 lower COAL seam, dull coal
■	160.36	0.96	BHW2-7	4L	No. 4 lower COAL seam, dull lustrous coal
■	160.95	0.59	BHW2-7	4L	No. 4 lower COAL seam, mainly dull coal

■	161.01	0.06	BHW2-8	4L	No. 4 lower COAL seam, bright coal
■	161.19	0.18	BHW2-8	4L	No. 4 lower COAL seam, mainly bright coal
▤	161.36	0.17	BHW2-9	FLOOR	SILTSTONE, very fine grained, laminated
▤	164.66	3.30			SILTSTONE, very fine grained, laminated and micaceous
	172.78	8.12			SANDSTONE, fine to medium grained, fine bedded and laminated
	180.61	7.83			SANDSTONE, medium grained
	181.62	1.01			SANDSTONE, medium grained, fine bedded
■	182.88	1.26			CARBONACEOUS SHALE
	192.79	9.91			SANDSTONE, medium grained, fine bedded
▤	199.99	7.20			SILTSTONE, very fine grained, laminated
	201.66	1.67			SANDSTONE, fine to medium grained, fine bedded
▤	202.10	0.44			SILTSTONE, carbonaceous and bioturbated
■	202.24	0.14		2	No. 2 COAL seam, heavy dull coal
	204.06	1.82			SANDSTONE, fine to medium grained
▤	204.98	0.92			SILTSTONE, very fine grained, laminated
	207.69	2.71			SANDSTONE, very coarse grained, gritty

	212.21	4.52			SANDSTONE, fine to medium grained
▤	212.53	0.32			SILTSTONE, very fine grained, laminated
	213.76	1.23			SANDSTONE, fine to medium grained
	232.06	18.30			SANDSTONE, medium grained
▤	240.55	8.49			SILTSTONE, very fine grained, laminated
	250.12	9.57			DWYKA TILLITE

COMPANY, COLLIERY: Sasol Mining,

BOREHOLE NUMBER: G293581 (BHW3)

CO-ORDINATES: X = 2933495.01 , Y = -27629.99

SURFACE ELEVATION: 1672.42

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	6.57	6.57			OVERBURDEN
	7.33	0.76			SANDSTONE, coarse grained
	8.15	0.82			DOLERITE
	17.52	9.37			SANDSTONE, very coarse grained, gritty
▤	18.46	0.94			SILTSTONE, fine grained, laminated
	18.65	0.19			SANDSTONE, fine to medium grained, thinly bedded
▤	19.27	0.62			SILTSTONE, very fine grained, laminated, fine bedded
	20.32	1.05			SANDSTONE, fine to medium grained, thinly bedded
	24.56	4.24			SANDSTONE, very coarse

					grained, gritty
	29.30	4.74			SANDSTONE, fine to medium grained
▤	39.71	10.41			SILTSTONE, fine grained, laminated
	70.32	30.61			DOLERITE
▤	72.84	2.52			SILTSTONE, fine to medium grained, laminated
	77.78	4.94			SANDSTONE, fine to medium grained
▤	78.95	1.17			SILTSTONE, fine to medium grained, ripple cross-bedded
	79.94	0.99			SANDSTONE, very coarse grained, gritty
▤	80.04	0.10			SILTSTONE, fine grained, laminated
	81.80	1.76			SANDSTONE, fine to medium grained
▤	86.82	5.02			SILTSTONE, fine to medium grained, laminated
	87.74	0.92			SANDSTONE, fine to medium grained
	97.84	10.10			SANDSTONE, medium to coarse grained
▤	98.67	0.83			SILTSTONE, fine to medium grained, laminated
	100.00	1.33			SANDSTONE, fine to medium grained, fine bedded
▤	107.32	7.32			SILTSTONE, fine to medium grained, laminated
	109.01	1.69			SANDSTONE, fine to medium grained

▤	109.54	0.53			SILTSTONE, fine grained, laminated
	118.93	9.39			SANDSTONE, fine to medium grained, laminated
▤	120.70	1.77			SILTSTONE, fine grained, laminated
	121.05	0.35	BHW3-1	ROOF	SANDSTONE, coarse grained
■	121.09	0.04		5M	No. 5 middle COAL seam, SHALE, fine grained, laminated
	121.12	0.03	BHW3-2	5M	No. 5 middle COAL seam, mainly bright coal
	121.90	0.78	BHW3-3	5M	No. 5 middle COAL seam, SHALE
	121.94	0.04	BHW3-4	5L	No. 5 lower COAL seam, mainly bright coal
	121.97	0.03	BHW3-4	5L	No. 5 lower COAL seam, CARBONACEOUS SHALE
	122.24	0.27	BHW3-5	5L	No. 5 lower COAL seam, CARBONACEOUS SHALE
	138.59	16.35	BHW3-6	FLOOR	SANDSTONE, very coarse grained, gritty
	139.55	0.96			SANDSTONE, fine to medium grained
▤	139.79	0.24			SILTSTONE, fine grained, laminated
	145.61	5.82			SANDSTONE, fine to medium grained, fine bedded
▤	148.24	2.63			SILTSTONE, fine grained, laminated
	149.63	1.39			SANDSTONE, medium to coarse grained

	153.31	3.68			SANDSTONE, fine to medium grained, cross bedded
▤	154.12	0.81			SILTSTONE, fine grained, laminated
	155.46	1.34			SANDSTONE, fine to medium grained, cross bedded
▤	159.54	4.08			SILTSTONE, fine grained, laminated, fine bedded
	159.76	0.22	BHW3-7	ROOF	SANDSTONE, very coarse grained, gritty , glauconitic
■	159.81	0.05	BHW3-8	4H	No. 4 upper COAL seam, mainly bright coal
	159.87	0.06		4H	No. 4 upper COAL seam, SANDSTONE
▤	160.17	0.30	BHW3-9	FLOOR	SILTSTONE, fine to medium grained, fine bedded, micaceous
	164.34	4.17			SANDSTONE, very coarse grained, gritty
	164.54	0.20	BHW3-10	ROOF	SANDSTONE, fine to medium grained, fine bedded
■	164.76	0.22	BHW3-11	4L	No. 4 lower COAL seam, dull lustrous coal
■	164.95	0.19	BHW3-11	4L	No. 4 lower COAL seam, mainly bright coal
■	165.01	0.06	BHW3-11	4L	No. 4 lower COAL seam, dull lustrous coal
▤	165.06	0.05	BHW3-11	4L	No. 4 lower COAL seam, SILTSTONE
■	165.21	0.15	BHW3-11	4L	No. 4 lower COAL seam, dull lustrous coal
■	165.35	0.14	BHW3-11	4L	No. 4 lower COAL seam, bright

■					coal
□	165.38	0.03	BHW3-12	4L	No. 4 lower COAL seam, SANDSTONE
■	165.55	0.17	BHW3-12	4L	No. 4 lower COAL seam, mainly bright coal
■	165.63	0.08	BHW3-12	4L	No. 4 lower COAL seam, dull lustrous coal
■	165.93	0.30	BHW3-12	4L	No. 4 lower COAL seam, dull coal
■	165.97	0.04	BHW3-12	4L	No. 4 lower COAL seam, mainly bright coal
■	166.26	0.29	BHW3-12	4L	No. 4 lower COAL seam, dull lustrous coal
■	166,35	0.09	BHW3-12	4L	No. 4 lower COAL seam, mainly bright coal
■	166.48	0.13	BHW3-12	4L	No. 4 lower COAL seam, dull lustrous coal
■	166.52	0.04	BHW3-12	4L	No. 4 lower COAL seam, mainly bright coal
■	166.73	0.21	BHW3-12	4L	No. 4 lower COAL seam, dull coal
■	166.79	0.06	BHW3-13	4L	No. 4 lower COAL seam, mixed coal
■	167.32	0.53	BHW3-13	4L	No. 4 lower COAL seam, dull lustrous coal
■	167.46	0.14	BHW3-13	4L	No. 4 lower COAL seam, mainly bright coal
■	167.52	0.06	BHW3-13	4L	No. 4 lower COAL seam, dull lustrous coal
■	167.71	0.19	BHW3-13	4L	No. 4 lower COAL seam, mixed coal
▤	169.94	2.23	BHW3-14	FLOOR	SILTSTONE, fine to medium

▤					grained, fine bedded, laminated
	172.44	2.50			SANDSTONE, fine to medium grained, fine bedded
	183.43	10.99			SANDSTONE, medium to coarse grained
▤	183.75	0.32			SILTSTONE, fine grained, laminated
	185.58	1.83			SANDSTONE, irregular bedded, bioturbated
▤	188.58	3.00			SILTSTONE, fine grained, laminated
	189.93	1.35			SANDSTONE, fine to medium grained, irregular bedded, bioturbated
■	190.10	0.17		2	No. 2 COAL seam, mainly bright coal
■	190.21	0.11		2	No. 2 COAL seam, CARBONACEOUS SHALE
■	191.12	0.91			SHALE, fine grained, laminated
▤	191.44	0.32			SILTSTONE, fine grained, laminated
	196.80	5.36			SANDSTONE, fine to medium grained, fine bedded
■	198.81	2.01			SHALE, fine grained, laminated
	240.07	41.26			SANDSTONE, coarse grained, massive
	240.95	0.88			SANDSTONE, coarse grained
▤	242.64	1.69			SILTSTONE, fine grained, laminated

	250.79	8.15			DOLERITE
▤	253.41	2.62			SILTSTONE, fine grained, laminated
	270.48	17.07			DWYKA TILLITE

COMPANY, COLLIERY: Sasol Mining,

BOREHOLE NUMBER: S277075 (BHW4)

CO-ORDINATES: X = 2936351.00, Y = -1032.19

SURFACE ELEVATION: 1566.71

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	0.70	0.70			OVERBURDEN
	7.90	7.20			CORE LOSS
▤	11.27	3.37			SILTSTONE, fine grained, laminated
	14.58	3.31			SANDSTONE, fine grained, laminated
▤	16.04	1.46			SILTSTONE, fine grained, laminated
	20.00	3.96			SANDSTONE, medium grained, fine bedded and laminated
	34.35	14.35			SANDSTONE, fine grained
	34.50	0.15			SANDSTONE, coarse grained
	34.88	0.38			SANDSTONE, fine grained, alternately bedded
	35.37	0.49			SANDSTONE, coarse grained
	37.57	2.20			SANDSTONE, fine grained
	37.74	0.17			CORE LOSS
	38.26	0.52			SANDSTONE, fine grained
	41.24	2.98			SANDSTONE, fine grained, fine bedded

▤	42.12	0.88			SILTSTONE, very fine grained, laminated
	45.45	3.33			SANDSTONE, medium grained, massive
	50.32	4.87			SANDSTONE, coarse grained, massive
■	50.66	0.34	BHW4-1	5	No. 5 COAL seam, bright coal
	50.70	0.04	BHW4-1	5	No. 5 COAL seam, CARBONACEOUS SHALE
	50.78	0.08	BHW4-1	5	No. 5 COAL seam, banded coal
	50.88	0.10	BHW4-1	5	No. 5 COAL seam, mainly dull coal
	50.97	0.09	BHW4-1	5	No. 5 COAL seam, bright coal
	51.05	0.08	BHW4-1	5	No. 5 COAL seam, CARBONACEOUS SHALE
	51.12	0.07	BHW4-1	5	No. 5 COAL seam, mainly bright coal
	51.18	0.06	BHW4-1	5	No. 5 COAL seam, banded coal
	51.27	0.09	BHW4-1	5	No. 5 COAL seam, mainly dull coal
▤	52.40	1.13			SILTSTONE, medium grained, bioturbated
	54.50	2.10			SILTSTONE, fine grained
	60.51	6.01			SANDSTONE, fine grained, fine bedded
▤	69.30	8.79			SILTSTONE, fine grained, alternately bedded
	70.52	1.22			SANDSTONE, coarse grained, massive
	78.90	8.38			SANDSTONE, very fine

					grained, fine bedded
	78.94	0.04			SANDSTONE, coarse grained, gritty
▤	80.80	1.86			SILTSTONE, bioturbated
■	80.81	0.01			COAL, bright coal
	80.87	0.06	BHW4-2	ROOF	SANDSTONE, very fine grained, massive
■	80.89	0.02	BHW4-3	4H	No. 4 upper COAL seam, CARBONACEOUS SHALE
	80.90	0.01	BHW4-3	4H	No. 4 upper COAL seam, bright coal
	80.92	0.02	BHW4-3	4H	No. 4 upper COAL seam, CARBONACEOUS SHALE
	80.93	0.01	BHW4-3	4H	No. 4 upper COAL seam, SANDSTONE
	81.00	0.07	BHW4-3	4H	No. 4 upper COAL seam, SANDSTONE
■	81.07	0.07	BHW4-3	4H	No. 4 upper COAL seam, bright coal
	81.15	0.08	BHW4-3	4H	No. 4 upper COAL seam, mainly dull coal
	81.28	0.13	BHW4-3	4H	No. 4 upper COAL seam, CARBONACEOUS SHALE
	81.60	0.32	BHW4-3	4H	No. 4 upper COAL seam, banded coal
	81.70	0.10	BHW4-3	4H	No. 4 upper COAL seam, CARBONACEOUS SHALE
	82.08	0.38	BHW4-4	FLOOR	SANDSTONE, medium grained
	82.78	0.70	BHW4-5	ROOF	SANDSTONE, coarse grained, gritty
■	83.27	0.49	BHW4-6	4L	No. 4 lower COAL seam,

■					mainly dull coal
■	83.64	0.37	BHW4-7	4L	No. 4 lower COAL seam, CARBONACEOUS SHALE
■	83.76	0.12	BHW4-7	4L	No. 4 lower COAL seam, mainly bright coal
■	83.94	0.18	BHW4-7	4L	No. 4 lower COAL seam, dull coal
■	84.02	0.08	BHW4-7	4L	No. 4 lower COAL seam, CARBONACEOUS SHALE
■	84.06	0.04	BHW4-8	4L	No. 4 lower COAL seam, mainly bright coal
■	84.60	0.54	BHW4-8	4L	No. 4 lower COAL seam, mainly dull coal
■	85.06	0.46	BHW4-9	4L	No. 4 lower COAL seam, dull coal
■	86.55	1.49	BHW4-10	4L	No. 4 lower COAL seam, mainly bright coal
	86.91	0.36	BHW4-11	FLOOR	SANDSTONE, very fine grained, fine bedded and micaceous
	87.75	0.84			SANDSTONE, fine grained, fine and cross bedded
	88.24	0.49			SANDSTONE, medium grained, micaceous
	94.04	5.80			SANDSTONE, medium grained, fine bedded
▤	94.28	0.24			SILTSTONE, fine grained, fine and cross bedded
	109.56	15.28			SANDSTONE, medium grained
	118.53	8.97			SANDSTONE, coarse grained
	118.76	0.23			SANDSTONE, very coarse

					grained, gritty
■	118.77	0.01			COAL, bright coal
	122.26	3.49			SANDSTONE, medium grained
■	122.47	0.21		2	No. 2 COAL seam, mainly bright coal
■	122.68	0.21		2	No. 2 COAL seam, CARBONACEOUS SHALE
■	122.77	0.09		2	No. 2 COAL seam, mainly dull coal
■	122.89	0.12		2	No. 2 COAL seam, CARBONACEOUS SHALE
■	122.99	0.10		2	No. 2 COAL seam, bright coal
■	123.56	0.57		2	No. 2 COAL seam, bright coal
■	123.78	0.22		2	No. 2 COAL seam, mainly bright coal
■	124.00	0.22		2	No. 2 COAL seam, CARBONACEOUS SHALE
■	124.26	0.26		2	No. 2 COAL seam, dull coal
▤	127.58	3.32			SILTSTONE, coarse grained, alternately bedded
	134.22	6.64			SANDSTONE, coarse grained, gritty
	137.54	3.32			SANDSTONE, coarse grained
▤	137.77	0.23			SILTSTONE, very fine grained, laminated
	139.00	1.23			SANDSTONE, coarse grained
▤	139.06	0.06			SILTSTONE, very fine grained, laminated
	139.73	0.67			SANDSTONE, coarse grained
▤	139.94	0.21			SILTSTONE, very fine grained, laminated

	140.46	0.52			SANDSTONE, fine grained, alternately bedded
	141.54	1.08			SANDSTONE, coarse grained
	142.57	1.03			SANDSTONE, fine grained, alternately bedded and micaceous
	145.59	3.02			SANDSTONE, fine grained
	148.89	3.30			DOLERITE
	160.30	11.41			DWYKA TILLITE

COMPANY, COLLIERY: Sasol Mining,

BOREHOLE NUMBER: G2935890 (BHW5)

CO-ORDINATES: X = 2935040.00 , Y = -25124.98

SURFACE ELEVATION: 1630.63

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	0.12	0.12			OVERBURDEN
	23.22	3.22			DOLERITE
▤	25.28	2.06			SILTSTONE, fine grained, laminated
	29.84	4.56			SANDSTONE, coarse grained, fine bedded
▤	36.72	6.88			SILTSTONE, fine grained, laminated
	44.20	7.48			SANDSTONE, fine to medium grained
	49.64	5.44			SANDSTONE, fine to medium grained, fine bedded
▤	50.45	0.81			SILTSTONE, fine to medium grained, fine bedded
▤	59.96	9.51			SILTSTONE, fine grained, laminated

	60.88	0.92			SANDSTONE, fine to medium grained
▤	69.90	9.02			SILTSTONE, fine to medium grained, fine bedded, laminated
	70.58	0.68	BHW5-1	ROOF	SANDSTONE, coarse grained
■	70.71	0.13	BHW5-2	5M	No. 5 middle COAL seam, bright coal
	71.20	0.49	BHW5-2	5M	No. 5 middle COAL seam, SHALE
	71.64	0.44	BHW5-2	5L	No. 5 lower COAL seam, mainly bright coal
	74.98	3.34	BHW5-3	FLOOR	SANDSTONE, coarse grained
▤	75.20	0.22			SILTSTONE, fine grained, laminated
	97.62	22.42			SANDSTONE, very coarse grained
▤	97.90	0.28			SILTSTONE, fine grained, laminated
	98.32	0.42			SANDSTONE, coarse grained
	98.82	0.50			SANDSTONE, fine to medium grained, fine bedded
▤	103.70	4.88			SILTSTONE, fine to medium grained, fine bedded, laminated
	104.57	0.87			SANDSTONE, medium to coarse grained
	104.85	0.28			SANDSTONE, very coarse grained, massive
	109.04	4.19			SANDSTONE, fine to medium grained, fine bedded
▤	113.49	4.45			SILTSTONE, fine to medium

▤					grained, fine bedded, laminated
	113.51	0.02	BHW5-4		SANDSTONE, very coarse grained, gritty , glauconitic
■	113.88	0.37		4H	No. 4 upper COAL seam, mainly dull coal
▤	114.01	0.13			SILTSTONE, fine grained, laminated
	115.72	1.71	BHW5-5		SANDSTONE, medium to coarse grained
	116.70	0.98	BHW5-6		SANDSTONE, very coarse grained
▤	116.74	0.04			SILTSTONE, fine grained, laminated
	117.85	1.11	BHW5-7		SANDSTONE, very coarse grained
	118.31	0.46			SANDSTONE, fine to medium grained, fine bedded
▤	118.64	0.33	BHW5-8		SILTSTONE, fine to medium grained, fine bedded
	118.72	0.08	BHW5-9	ROOF	SANDSTONE, very coarse grained
■	118.73	0.01	BHW5-10	4L	No. 4 lower COAL seam, bright coal
▤	118.76	0.03	BHW5-10	4L	No. 4 lower COAL seam, SILTSTONE
■	118.79	0.03	BHW5-10	4L	No. 4 lower COAL seam, dull lustrous coal
▤	118.82	0.03	BHW5-10	4L	No. 4 lower COAL seam, SILTSTONE
■	118.83	0.01	BHW5-10	4L	No. 4 lower COAL seam, bright coal

▤					grained, fine bedded
	125.75	0.81			SANDSTONE, medium to coarse grained
▤	129.07	3.32			SILTSTONE, fine to medium grained, fine bedded, laminated
	133.10	4.03			SANDSTONE, coarse grained
▤	135.32	2.22			SILTSTONE, fine to medium grained
	138.64	3.32			SANDSTONE, fine to medium grained, bioturbated
▤	138.86	0.22			SILTSTONE, fine grained, laminated
	140.45	1.59			SANDSTONE, fine to medium grained
	141.74	1.29			SANDSTONE, fine to medium grained, laminated
	146.90	5.16			SANDSTONE, fine to medium grained, bioturbated
▤	148.87	1.97			SILTSTONE, fine grained, laminated
	188.53	39.66			SANDSTONE, very coarse grained, gritty
	195.79	7.26			DOLERITE
▤	196.15	0.36			SILTSTONE, fine to medium grained
	196.24	0.09			DWYKA TILLITE

■	119.02	0.19	BHW5-10	4L	No. 4 lower COAL seam, dull coal
■	119.38	0.36	BHW5-10	4L	No. 4 lower COAL seam, dull lustrous coal
■	119.95	0.57	BHW5-10	4L	No. 4 lower COAL seam, mainly bright coal
■	120.48	0.53	BHW5-10	4L	No. 4 lower COAL seam, dull lustrous coal
■	120.53	0.05	BHW5-11	4L	No. 4 lower COAL seam, mainly bright coal
■	120.59	0.06	BHW5-12	4L	No. 4 lower COAL seam, dull coal
■	120.74	0.15	BHW5-12	4L	No. 4 lower COAL seam, bright coal
■	121.64	0.90	BHW5-13	4L	No. 4 lower COAL seam, dull lustrous coal
▤	121.73	0.09	BHW5-13	4L	No. 4 lower COAL seam, SILTSTONE, fine grained, fine bedded, micaceous
■	121.82	0.09	BHW5-13	4L	No. 4 lower COAL seam, bright coal
▤	121.90	0.08	BHW5-14 BHW5-15	FLOOR	SILTSTONE, fine grained, fine bedded, micaceous
▤	123.60	1.70			SILTSTONE, fine to medium grained, fine bedded, micaceous
■	123.85	0.25		3	No. 3 COAL seam, bright coal
□	123.93	0.08		3	SANDSTONE
■	124.27	0.34		3	No. 3 COAL seam, bright coal
▤	124.38	0.11			SILTSTONE, fine grained, laminated
▤	124.94	0.56			SILTSTONE, fine to medium

COMPANY, COLLIERY: Ingwe Mining, Douglas Colliery

BOREHOLE NUMBER: WSD210

CO-ORDINATES: X = 2881667.00, Y = -30130.00

SURFACE ELEVATION: 1580.70

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	6.27	6.27			OVERBURDEN
▤	7.05	0.78			SILTSTONE, micaceous
	11.22	4.17			SANDSTONE, fine grained, laminated, micaceous, muddy
	22.80	11.58	DOU19	ROOF	SANDSTONE, fine grained, laminated, micaceous
■	24.06	1.28	DOU18	5	No. 5 COAL seam
	25.68	1.62	DOU17	FLOOR	SANDSTONE, fine grained, laminated, micaceous and carbonaceous
	32.82	6.94			SANDSTONE, fine grained, laminated, micaceous
	41.14	8.32			SANDSTONE, fine grained, laminated, micaceous and carbonaceous. Carbon content increases downwards
	42.75	1.61			SANDSTONE, coarse grained, gritty
	43.75	1.00			SANDSTONE, fine grained, laminated, micaceous and carbonaceous
	43.86	0.11			SANDSTONE, fine grained, greenish, glauconitic
■	44.06	0.20		4UB	No. 4 upper B COAL seam
	44.70	0.64			SANDSTONE, very fine grained, muddy

■	44.92	0.22			CARBONACEOUS SHALE
■	46.27	1.35		4UA	No. 4 upper A COAL seam
	46.90	0.63			SANDSTONE, coarse grained, gritty
	47.85	0.95			SANDSTONE, fine grained, micaceous and carbonaceous
▤	48.62	0.77			SILTSTONE, with scattered pebbles, carbonaceous, micaceous
	49.20	0.58			SANDSTONE, coarse grained, gritty
▤	50.15	0.95			SILTSTONE, with scattered pebbles, carbonaceous, micaceous
	53.37	3.22			SANDSTONE, coarse grained, gritty
▤	53.71	0.34			SILTSTONE, with scattered pebbles, carbonaceous, micaceous, sandy
▤	53.86	0.15	DOU16	ROOF	SILTSTONE, with scattered pebbles, carbonaceous, micaceous
■	56.84	2.98	DOU15 DOU14 DOU13	4L	No. 4 lower COAL seam
▤	57.11	0.27	DOU12	FLOOR	SILTSTONE, micaceous with thin coal bands
	59.27	2.16			SANDSTONE, very fine grained, muddy
	59.83	0.56			SANDSTONE, medium grained, muddy, micaceous
■	60.24	0.41		3	No.3 COAL seam

▤	61.10	0.86			SILTSTONE, sandy, carbonaceous with thin coal bands
	63.85	2.75			SANDSTONE, fine grained, micaceous
▤	65.88	2.03			SILTSTONE, micaceous and carbonaceous. Carbon content increases downwards
	69.55	3.67			SANDSTONE, very fine grained, micaceous, carbonaceous
▤	74.10	4.55	DOU11	ROOF	SILTSTONE, micaceous and carbonaceous
■	80.12	6.02	DOU10 DOU9 DOU8	2	No. 2 COAL seam
▤	80.18	0.06	DOU7	FLOOR/ ROOF	SILTSTONE, micaceous and carbonaceous
■	80.87	0.69	DOU6	2A	No. 2 A COAL seam
▤	81.23	0.36	DOU5	FLOOR	SILTSTONE, with scattered pebbles, carbonaceous, micaceous
▤	82.27	1.04			SILTSTONE, alternating bands with grit, scattered pebbles, carbonaceous, micaceous
	83.10	0.83	DOU4	ROOF	SANDSTONE, very coarse grained, carbonaceous
■	84.77	1.67	DOU3 DOU2	1	No. 1 COAL seam
▤	85.05	0.28	DOU1	FLOOR	SILTSTONE, micaceous and carbonaceous
	88.70	3.65			DIAMICTITE

COMPANY, COLLIERY: Ingwe Mining, Douglas Colliery
BOREHOLE NUMBER: WSL195
CO-ORDINATES: X = 2879326.00, Y = -28606.00
SURFACE ELEVATION: 1559.30

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	5.85	5.85			OVERBURDEN
	7.97	2.12			SANDSTONE, coarse grained, gritty
■	8.08	0.11			CARBONACEOUS SHALE
■	9.73	1.65		4UA	No. 4 upper A COAL seam
	12.66	2.93			SANDSTONE, coarse grained, gritty
	13.85	1.19			SANDSTONE, very fine grained, micaceous
▤	14.06	0.21			SILTSTONE, with scattered pebbles, carbonaceous, micaceous
	14.13	0.07			SANDSTONE, coarse grained, gritty
▤	14.52	0.39			SILTSTONE, with scattered pebbles, carbonaceous, micaceous
	15.64	1.12			SANDSTONE, coarse grained, gritty
▤	15.75	0.11			SILTSTONE, micaceous and carbonaceous
	17.23	1.48			SANDSTONE, coarse grained, gritty
	17.79	0.56			SANDSTONE, fine grained, muddy
	18.32	0.53			CORE LOSS

	18.61	0.29			SANDSTONE, fine grained, muddy, micaceous
▤	19.00	0.39	DOU20 DOU21	ROOF	SILTSTONE, micaceous and carbonaceous
■	20.20	1.20	DOU22	4L	No. 4 lower COAL seam
	22.28	2.08	DOU23	FLOOR	CARBONACEOUS SHALE, micaceous
	22.44	0.16		4LA	No. 4 lower A COAL seam
	23.25	0.81			SANDSTONE, very fine grained, micaceous
	23.79	0.54			SANDSTONE, very coarse grained, gritty
■	24.00	0.21		3	No.3 COAL seam
	26.32	2.32			SANDSTONE, very fine grained
	29.70	3.38			SANDSTONE, fine grained, laminated, micaceous and carbonaceous. Carbon content increases downwards
▤	31.15	1.45			SILTSTONE, micaceous and carbonaceous
	33.70	2.55			SANDSTONE, very fine grained, micaceous and carbonaceous
▤	36.33	2.63	DOU24	ROOF	SILTSTONE, micaceous and carbonaceous
■	41.00	4.67	DOU25 DOU26 DOU27 DOU28	2	No. 2 COAL seam
	49.50	8.50	DOU29	FLOOR	SANDSTONE, very coarse grained, gritty

■	50.00	0.50		2A	No. 2 A COAL seam
▤	50.18	0.18			SILTSTONE, with scattered pebbles, carbonaceous, micaceous
	50.73	0.36			SANDSTONE, coarse grained, gritty
■	54.15	2.42		1	No. 1 COAL seam
▤	54.30	0.15			SILTSTONE, with scattered pebbles
	55.79	1.49			DIAMICTITE

COMPANY, COLLIERY: Ingwe Mining, Douglas Colliery
BOREHOLE NUMBER: BK364
CO-ORDINATES: X = 2879542.98, Y = -39860.97
SURFACE ELEVATION: 1569.03

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	6.20	6.20			OVERBURDEN
	9.82	3.62			SANDSTONE, very fine grained, micaceous and muddy
	11.27	1.45			SANDSTONE, very fine grained, micaceous
	12.05	0.78			SANDSTONE, micaceous and carbonaceous
	12.08	0.03			SANDSTONE, fine grained, greenish, glauconitic
▤	12.50	0.42			SILTSTONE, micaceous and carbonaceous
	12.61	0.11			SANDSTONE, very fine grained, micaceous and muddy

▤	12.64	0.03			SILTSTONE, micaceous and carbonaceous
■	13.07	0.43		4UB	No. 4 upper B COAL seam
	13.48	0.41			SANDSTONE, very fine grained, carbonaceous
	14.00	0.52			SANDSTONE, micaceous
■	15.66	1.66			CARBONACEOUS SHALE, micaceous
■	16.37	0.71		4UA	No. 4 upper A COAL seam
▤	16.66	0.29			SILTSTONE, micaceous and carbonaceous
	18.54	1.88			SANDSTONE, coarse grained, gritty
▤	20.21	1.67	DOU30	ROOF	SILTSTONE, with scattered pebbles, carbonaceous, micaceous
■	20.42	0.21	DOU31	4L	No. 4 lower COAL seam
	20.45	0.03	DOU41	PT.	SANDSTONE, fine grained parting
■	22.93	2.48	DOU32 DOU33	4L	No. 4 lower COAL seam
	24.76	1.83	DOU34	FLOOR	SANDSTONE, micaceous
	24.85	0.09			SANDSTONE, coarse grained, gritty
■	25.28	0.43		3	No.3 COAL seam
▤	25.47	0.19			SILTSTONE, micaceous and carbonaceous
	27.24	1.77			SANDSTONE, fine grained, micaceous
	28.55	1.31			SANDSTONE, micaceous and carbonaceous
	32.44	3.89			SANDSTONE, very fine

					grained, laminated, micaceous and carbonaceous. Carbon content increases downwards
▤	33.88	1.44			SILTSTONE, micaceous and carbonaceous
	35.91	2.03			SANDSTONE, highly micaceous and muddy
▤	40.52	4.61	DOU35	ROOF	SILTSTONE, micaceous and carbonaceous
■	45.70	5.18	DOU36 DOU37 DOU38	2	No. 2 COAL seam
▤	45.72	0.02			SILTSTONE
■	46.87	1.15		2A	No. 2 A COAL seam
	47.08	0.21	DOU39	PT.	SANDSTONE, very coarse grained, gritty, carbonaceous
■	49.15	2.07	DOU40	1	No. 1 COAL seam
■	49.27	0.12			CARBONACEOUS SHALE
	49.88	0.61			DIAMICTITE

COMPANY, COLLIERY: Ingwe Mining, Middelburg Colliery

BOREHOLE NUMBER: HWG556 `

CO-ORDINATES: X = 2865344.78, Y = -47482.93

SURFACE ELEVATION: 1594.31

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	8.98	8.98			OVERBURDEN
	10.08	1.10			SANDSTONE, fine grained
	12.22	2.14			SANDSTONE, medium grained, muddy
	13.43	1.21			CORE LOSS
	18.11	4.68			SANDSTONE, medium

					grained, muddy
	20.38	2.27			CORE LOSS
	22.61	2.23			SANDSTONE, medium grained, muddy
	22.97	0.36			CORE LOSS
▤	25.21	2.24			SILTSTONE, fine grained
▤	26.68	1.47			SILTSTONE, bioturbated
▤	30.19	3.51			SILTSTONE, fine grained
▤	31.80	1.61			SILTSTONE, muddy
■	32.40	0.60	M10	ROOF	CARBONACEOUS SHALE, with siltstone layers
■	33.52	1.12	M9	2	No. 2 COAL seam, dull lustrous and bright coal with pyrite, siderite and calcite cleats
▤	34.17	0.65			SILTSTONE
■	36.28	2.11			CARBONACEOUS SHALE, with coarse grained sandstone layers
	37.16	0.88			SANDSTONE, coarse grained
■	40.99	3.83	M8 M7 M6 M5	2A	No. 2 A COAL seam, bright lustrous coal with alternating bands of dull coal and carbonaceous shale including pyrite and calcite cleats
	41.12	0.13	M4	FLOOR	SANDSTONE, very coarse grained, gritty
▤	41.50	0.38			SILTSTONE, with scattered pebbles
	41.76	0.26	M3	ROOF	SANDSTONE, very coarse grained, gritty
■	43.41	1.65	M2	1	No. 1 COAL seam, bright

■			M1		lustrous coal with alternating bands of dull coal and carbonaceous shale including pyrite, siderite and calcite cleats
▤	43.71	0.30			SILTSTONE, with scattered pebbles, carbonaceous
	44.07	0.36			CORE LOSS
	45.22	1.15			DWYKA TILLITE

COMPANY, COLLIERY: Ingwe Mining, Middelburg Colliery
BOREHOLE NUMBER: HWS525
CO-ORDINATES: X = 2877251.58, Y = -40629.11
SURFACE ELEVATION: 1590.63

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	11.34	11.34			OVERBURDEN
▤	13.43	2.09			SILTSTONE, fine grained, wavy bedded
	14.64	1.21			SANDSTONE, medium grained, muddy
▤	17.92	3.28			SILTSTONE, fine grained, wavy bedded
	19.23	1.31			SANDSTONE, medium grained, muddy
▤	20.91	1.68			SILTSTONE, fine grained, wavy bedded
■	21.42	0.51	M19 M18	4UA	No. 4 upper A COAL seam, bright lustrous coal with alternating bands of carbonaceous shale including pyrite and calcite cleats

	22.97	1.55			SANDSTONE, medium grained, muddy
▤	24.84	1.87			SILTSTONE, carbonaceous
▤	25.77	0.93			SILTSTONE, fine grained, wavy bedded
	32.29	6.52			SANDSTONE, very coarse grained, gritty
▤	32.43	0.14	M22	ROOF	SILTSTONE, carbonaceous
■	35.89	3.46	M20	4L	No. 4 lower COAL seam, dull lustrous and bright coal with pyrite and calcite cleats
	36.12	0.23	M21	FLOOR	SANDSTONE, medium grained, muddy and micaceous
	37.49	1.37			SANDSTONE, medium grained, muddy
▤	37.74	0.25			SILTSTONE, coarse grained with scattered pebbles
■	38.00	0.26		3	No.3 COAL seam, mainly bright coal bands with pyrite and calcite cleats
	40.04	2.04			SANDSTONE, medium grained, muddy
▤	41.19	1.15			SILTSTONE, fine grained, wavy bedded
	46.77	5.58			SANDSTONE, medium grained, muddy
▤	48.94	2.17			SILTSTONE, fine grained, wavy bedded
▤	49.94	1.00			SILTSTONE, fine grained
▤	52.92	2.98			SILTSTONE, bioturbated
▤	56.12	3.20			SILTSTONE, fine grained

▤	56.91	0.79			SILTSTONE, muddy
■	63.42	6.51	M17 M16 M15 M14	2	No. 2 COAL seam, alternating bands of dull lustrous and bright coal with nodular pyrite and calcite cleats
	63.47	0.05	M13	PT.	SANDSTONE, very coarse grained, gritty
■	66.19	2.72	M12 M11	1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal and carbonaceous shale including pyrite and calcite nodules
▤	66.74	0.55			SILTSTONE, muddy
	70.54	3.80			DIAMICTITE
■	70.68	0.14		1A	No. 1 A COAL seam, dull lustrous coal
	71.19	0.51			DIAMICTITE
	74.72	3.53			DWYKA TILLITE

COMPANY, COLLIERY: Eyesizwe Mining, Arnot Colliery
BOREHOLE NUMBER: ARN4983 (ARA)
CO-ORDINATES: X = 2864883.98, Y = -77952.94
SURFACE ELEVATION: 1678.92

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	2.70	2.70			OVERBURDEN
	7.27	4.57			SANDSTONE, coarse grained
▤	7.63	0.36			SILTSTONE, fine grained
	12.74	5.11			SANDSTONE, fine grained
▤	13.28	0.54			SILTSTONE, fine grained
	15.05	1.77	ARA16	ROOF	SANDSTONE, fine grained
■	15.66	0.61	ARA15	4	No. 4 COAL seam, bright

■					lustrous coal with alternating bands of dull coal
	15.68	0.02	ARA14	PT.	SANDSTONE, fine grained
■	15.87	0.19	ARA13	4	No. 4 COAL seam, bright lustrous coal with alternating bands of dull coal
▤	16.28	0.41	ARA12	FLOOR	SILTSTONE, fine grained
■	16.80	0.52		3	No.3 COAL seam
▤	16.96	0.16			SILTSTONE, fine grained
	18.81	1.85			SANDSTONE, fine grained
	20.00	1.19			SANDSTONE, fine grained with alternating siltstone bands
■	20.13	0.13		3	No.3 COAL seam
	27.30	7.17			SANDSTONE, fine grained
	28.85	1.55			SANDSTONE, fine grained with alternating siltstone bands
▤	33.95	5.10			SILTSTONE, fine grained
	34.75	0.80			SANDSTONE, very coarse grained, gritty with alternating siltstone bands
▤	35.25	0.50			SILTSTONE, fine grained
	35.97	0.72			SANDSTONE, very coarse grained, gritty with alternating siltstone bands
	36.74	0.77			SANDSTONE, fine grained
▤	37.12	0.38			SILTSTONE, fine grained
	40.81	3.69			SANDSTONE, fine grained
▤	41.51	0.70			SILTSTONE, fine grained
	41.90	0.39			SANDSTONE, very coarse grained, gritty
■	42.13	0.23		2U	No. 2 upper COAL seam, bright lustrous coal with

■					alternating bands of dull coal
	43.16	1.03	ARA11	ROOF	SANDSTONE, very coarse grained, gritty
■	46.50	3.34	ARA10 ARA9	2L	No. 2 lower COAL seam, bright lustrous coal with alternating bands of dull coal
▤	48.30	1.80	ARA8	FLOOR	SILTSTONE, fine grained
	48.64	0.34	ARA7		SANDSTONE, very coarse grained, gritty with alternating siltstone bands
	48.77	0.13	ARA6	ROOF	SANDSTONE, very coarse grained, gritty
■	49.42	0.65	ARA5	1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal
▤	49.72	0.30	ARA4	FLOOR	SILTSTONE, fine grained
	50.41	0.69	ARA3		SANDSTONE, very coarse grained, gritty with alternating siltstone bands
■	50.58	0.17		1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal
▤	50.81	0.23			SILTSTONE, fine grained
	52.81	2.00			SANDSTONE, very coarse grained, gritty
▤	52.99	0.18	ARA2		SILTSTONE, fine grained
	53.8	0.81			DWYKA TILLITE
	56.06	2.26	ARA1		BASEMENT

COMPANY, COLLIERY: Eyesizwe Mining, Arnot Colliery
BOREHOLE NUMBER: ARN4982 (ARB)
CO-ORDINATES: X = 2864947.98, Y = -77967.96
SURFACE ELEVATION: 1677.93

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	2.59	2.59			OVERBURDEN
	6.32	3.73			SANDSTONE, coarse grained
▤	6.53	0.21			SILTSTONE, fine grained
	12.13	5.60			SANDSTONE, fine grained
▤	12.57	0.44			SILTSTONE, fine grained
	13.89	1.32	ARB13	ROOF	SANDSTONE, fine grained
■	14.56	0.67		4	No. 4 COAL seam, bright lustrous coal with alternating bands of dull coal
	14.58	0.02	ARB11	PT.	SANDSTONE, coarse grained
■	14.75	0.17	ARB10	4	No. 4 COAL seam, bright lustrous coal with alternating bands of dull coal
▤	15.32	0.57	ARB9	FLOOR	SILTSTONE, fine grained
■	15.87	0.55		3	No.3 COAL seam
▤	16.00	0.13			SILTSTONE, fine grained
	17.66	1.66			SANDSTONE, fine grained, bioturbated
	18.25	0.59			SANDSTONE, fine grained with alternating siltstone bands
▤	18.76	0.51			SILTSTONE, fine grained
	19.16	0.40			SANDSTONE, fine grained with alternating siltstone bands
■	19.27	0.11		3	No.3 COAL seam
	25.73	6.46			SANDSTONE, fine grained
	27.51	1.78			SANDSTONE, very coarse

					grained, gritty with alternating siltstone bands
▤	32.43	4.92			SILTSTONE, fine grained
	33.07	0.64			SANDSTONE, very coarse grained, gritty
	34.68	1.61			SANDSTONE, very coarse grained, gritty with alternating siltstone bands
	35.04	0.36			SANDSTONE, fine grained
▤	36.18	1.14			SILTSTONE, fine grained
	39.35	3.17			SANDSTONE, fine grained
▤	40.08	0.73			SILTSTONE, fine grained
	40.64	0.56	ARB8	ROOF	SANDSTONE, very coarse grained, gritty
■	40.80	0.16	ARB7	2U	No. 2 upper COAL seam, bright lustrous coal with alternating bands of dull coal
	43.39	2.59	ARB6	FLOOR/ ROOF	SANDSTONE, very coarse grained, gritty
■	44.86	1.47	ARB5	2L	No. 2 lower COAL seam, bright lustrous coal with alternating bands of dull coal
▤	46.08	1.22	ARB4 ARB3	FLOOR/ ROOF	SILTSTONE, fine grained
■	46.49	0.41	ARB2	1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal
▤	47.02	0.53	ARB1	FLOOR	SILTSTONE, fine grained
	47.28	0.26			SANDSTONE, very coarse grained, gritty
▤	48.10	0.82			SILTSTONE, fine grained
	48.62	0.52			SANDSTONE, very coarse

					grained, gritty with alternating siltstone bands
■	49.47	0.85		1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal
	50.11	0.64			SANDSTONE, very coarse grained, gritty with alternating siltstone bands
■	50.29	0.18		1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal
	50.49	0.20			SANDSTONE, very coarse grained, gritty with alternating siltstone bands
■	50.54	0.05		1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal
	52.34	1.80			SANDSTONE, very coarse grained, gritty
	53.13	0.79			SANDSTONE, very coarse grained, gritty with alternating siltstone bands
	53.22	0.09			DWYKA TILLITE
	54.88	1.66			BASEMENT

COMPANY, COLLIERY: Eyesizwe Mining, Arnot Colliery
BOREHOLE NUMBER: ARN4994 (ARC)
CO-ORDINATES: X = 2866327.09, Y = -77573.22
SURFACE ELEVATION: 1648.58

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	6.25	6.25			OVERBURDEN

	6.42	0.17			SANDSTONE, medium grained
▤	6.68	0.26			SILTSTONE, fine grained
	6.95	0.27			SANDSTONE, medium grained
▤	7.15	0.20			SILTSTONE, fine grained
	8.09	0.94			SANDSTONE, medium grained and cross-bedded
▤	8.52	0.43			SILTSTONE, fine grained
	13.06	4.54			SANDSTONE, medium grained and cross-bedded
▤	13.44	0.38			SILTSTONE, fine grained
	17.45	4.01			SANDSTONE, very coarse grained, gritty with alternating siltstone bands
	18.38	0.93	ARC7	ROOF	SANDSTONE, very coarse grained, gritty
■	21.37	2.99	ARC6 ARC5	2	No. 2 COAL seam, bright lustrous coal with alternating bands of dull coal
▤	22.49	1.12	ARC4	FLOOR	SILTSTONE, fine grained
	23.21	0.72	ARC3	ROOF	SANDSTONE, very coarse grained, gritty
■	24.10	0.89	ARC2	1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal
■	24.53	0.43	ARC1	FLOOR	CARBONACEOUS SHALE

COMPANY, COLLIERY: Eyesizwe Mining, Arnot Colliery

BOREHOLE NUMBER: ARN4995 (ARD)

CO-ORDINATES: X = 2866352.86, Y = -77469.63

SURFACE ELEVATION: 1648.73

	DEPTH	THICKNESS (m)	SAMPLE NO.	COAL STRAT.	LITHOLOGY
	8.86	8.86			OVERBURDEN
	9.75	0.89			SANDSTONE, medium grained, cross-bedded and weathered
	11.67	1.92			SANDSTONE, medium grained and cross-bedded
▤	11.78	0.11			SILTSTONE, fine grained
	15.32	3.54			SANDSTONE, coarse grained
	19.42	4.10	ARD7	ROOF	SANDSTONE, very coarse grained, gritty
■	22.58	3.16	ARD6 ARD5	2	No. 2 COAL seam, bright lustrous coal with alternating bands of dull coal
▤	23.20	0.62	ARD4	FLOOR	SILTSTONE, fine grained
	23.45	0.25			SANDSTONE, medium grained
	23.91	0.46	ARD3	ROOF	SANDSTONE, very coarse grained, gritty
■	24.34	0.43	ARD2	1	No. 1 COAL seam, bright lustrous coal with alternating bands of dull coal
▤	24.65	0.31	ARD1	FLOOR	SILTSTONE, fine grained
	26.22	1.55			SANDSTONE, medium grained