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# MANAGEMENT OF THE MINERAL RESOURCE RISK ASSOCIATED WITH NEAR-DENSITY MATERIAL IN THE BENEFICIATION PLANT AT LEEUWPAN COAL MINE

by
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# ABSTRACT

Near-density material is material with similar densities to that of the chosen cut-point density during the separation process of coal into product and discard. The problem is usually classified as a beneficiation problem and not as a reserve problem. To overcome the risk associated with near-density material in the beneficiation process, the constraints of the separators must be merged with the constraints of the coal resource.

The problems caused by the presence of near-density material in the beneficiation process of raw coal to a certain percentage ash product, are commonly associated with South African coals. Near-density material is caused by the presence of finely dispersed mineral matter in the coal that can not be separated from the coal by current liberation methods. The mineral matter referred to is directly linked with the original depositional environment of the coal.

The depositional environment of coal formation determined the ash, the mineral matter present and the distribution within the coal matrix. A closer look at the ash distribution reveals that all types of coal, irrespective of depositional environment, has intrinsic ash content grouped around a certain percentage and that the amount of near-density material present in the beneficiation process depends on the percentage ash, in the clean coal product, required. As the ash distribution is the controlling factor on near-density material, any external factor that effects the ash distribution will affect the coal's washability characteristics.

There are various methodologies to define a coal's amenability to being washed to a certain clean coal ash product. All of the methods generate an empirical value of near-density material or the coal's "difficulty" in being washed. All of these methods have their advantages and disadvantages, but the method used is of no consequence if the information is not applied correctly to the coal resource or reserve.

At Leeuwpan Coal Mine a risk matrix is used to relate the values from near-density material calculations to the coal reserves.

The risk values from the matrix is incorporated into the mining blocks so that during the mine planning phase the risk of near-density material can be quantified and minimized.

At Leeuwpan Coal Mine the application of the risk matrix into the planning and exploitation of the coal seams indicated that through resource/reserve management quality problems, due to near-density material can be minimized and that yield can then be optimized. The optimisation of yield leads to a financial gain that increases the value of the reserves.

Therefore by pro-active planning and a good understanding of the resource/reserve the risk associated with near-density material can be managed.

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# 1 INTRODUCTION

The aim of this treatise is to identify and manage the risks associated with near-density material in the coal beneficiation process, relevant to the future coal reserves at Leeuwpan Coal Mine.

Risk Management, defined by Kerzner (2001), is the act or practice of dealing with risk. This process consists of:

- Planning for the risk
- Assessment in terms of identification and analysing the risk
- Developing a risk handling strategy
- Monitoring of the risks to determine the risk improvement

The risk management process defined will be used to find solutions and strategies for dealing with the risks of near-density material in the beneficiation process. Therefore the treatise follows these guidelines in which the risk and its causes are discussed first and thereafter the solutions and strategies to manage the risk.

## *1.1 Problem Statement*

Near-density material is a problem that normally affects the efficiency in the washing of raw coal down to a desired ash product. Coal with a high percentage of near-density material can not be washed down to a desired product, due to misplacement of discard to product and product to discard.

Therefore there is a risk associated with washing coal down to certain product ranges with regards to ash content of the final product. This treatise will conclude with a means to manage the risk through the understanding of near-density material in geological terms and knowledge that could be applied to mineral resource management.

## *1.2 Research Questions and Hypothesis*

In accordance to the risk management process the problem of near-density material, in the separation process, will be investigated by seeing the problem as parts of a whole. This process should result in a better understanding of near-density material, and will assist in the development of risk management strategies.

### 1.2.1 Research Questions

The first problem to be addressed is to define near-density material in terms of the inherent properties of the coal. Then it must be determined what the effect of the identified property is on the washability of the coal.

The second problem is to determine the effect of the coal's depositional environment and modification, due to the dolerite intrusion, on the washability of coal.

The third problem is to evaluate the future reserves at Leeuwpan in terms of near-density material.

The fourth and last problem will be to identify and quantify the risk related to near-density material so that the correct seams may be considered for mine planning in an attempt to manage the risk of near-density material properly.

### 1.2.2 Hypothesis

The first hypothesis is that the near-density material, or the “difficulty” to wash coal, is a function of the ash distribution or mineral matter distribution within the coal. The mineral matter distribution referred to here is those minerals that are intimately mixed with the coal. The amount of near-density material will be at a maximum at the mean of the ash distribution, taken from the washability curves. Therefore all coal has near-density material, but the extent of the problem related to the amount of near-density material would depend on two independent factors namely:

- The unique and characteristic distribution of the mineral matter within the coal, which is measured by the density properties of the coal
- The density cut point applied in the beneficiation plant, which is determined by the wash product requirements such as ash content or calorific value.

The second hypothesis is that the depositional environment determined the ash distribution within the coal seams and that any change in depositional environment will also change the ash distribution. Therefore the depositional environment can be linked to the washability of the coal. Any geological factor, for example a dolerite intrusion, which affected the coal after formation, will affect the ash distribution by causing a change in the abundance relative to density distribution of the ore (or run-of-mine) delivered to the beneficiation plant.

The third hypothesis is that by using the correct technique, which defines the ‘degree of difficulty’ to separate the required product effectively, it will be possible to valuate the resources and reserves more effectively in terms of product optimization and plant design.

The fourth hypothesis states that if the same technique used for valuation purposes can be used to identify risks associated with near-density material then that information can in turn be used to manage the risk.

## *1.3 Definition of Terms*

**Ash distribution**: Refers to the mineral matter content, which is intimately mixed with the coal. It consists of minerals present in the original vegetation from which the coal was formed and finely divided clays and other mineral particles that was transported into the depositional environment by water and wind. These mineral particles and clays cannot be removed by coal preparation techniques during beneficiation.

**Devolatilised coal**: Bituminous coal that has a dry ash-free volatile content of less than 24% (by mass fraction on a dry ash-free basis), but more than 16.5% (by mass fraction on a dry ash-free basis) due to the thermal effect of igneous intrusions. It is important to note that what is referred to as devolatilised coal at Leeuwpan Coal Mine includes low volatile coal.

**Float-sink Analysis**: Term used to describe the separating, of a coal sample, in a laboratory, into two or more relative density fractions, by means of liquids with specific but different relative densities. The separation is between lighter pure coal and the denser impurities associated with it.

**Lean Coal**: High rank coal with volatile matter content between 12.5 – 16.5% based on a dry, ash-free analysis.

**Low Volatile Coal**: Bituminous coal with a maximum of 12.5% volatile matter content (dry, ash-free basis). At Leeuwpan Coal Mine, the low volatile coal was formed due to the thermal effect of a dolerite sill.

**Medium Volatile Coal**: Bituminous coal with volatile matter content not less than 16.5% (dry, ash-free basis).

**Near-density material**: Particles with similar densities to the density of the separation medium during the washing process.

**Proximate analysis**: In this analysis four properties of the coal are established, namely moisture-, ash-, volatile matter- and fixed carbon contents.

**Relative Density**: Ratio of the mass of a certain volume of coal to that of an equivalent volume of water.

**Raw ash**: (Also feed ash, ROM ash.) It is the cumulative ash content of the coal seam before beneficiation.

**Reserve Blocks**: These are the areas within Leeuwpan Coal Mine where economical, extractable coal reserves occur. Figure 1 illustrates the location of these coal blocks within the boundaries of Leeuwpan Coal Mine

**Run-of-mine Coal (ROM)**: Is the feed from the mining area to the beneficiation plant.

**Theoretical Yield**: Yield of a clean coal ash product at a specific RD which is determined in a float-sink analysis.

**Vitrinite Reflectance**: The percentage of normal incident light reflected from the polished surface of vitrinite. The reflectance is used as a measure of the rank of the coal.

**Washability Curves**: These curves show the relationship between ash content and the amount of float or sink produced at any particular relative density cut point.

**Wash table**: Table wherein the result of a float-sink analysis is tabulated. The table usually gives the cumulative yield for various fractions at which the coal was floated and ends of with the analysis of the whole coal (also referred to as the sinks in a cumulative wash table).

## *1.4 Limitations of Study*

The limitations of the study are as follows:

- The study will only be applicable on the seam 2 occurrences at Leeuwpan Coal Mine
- Block OM, OD and OH forms the basis of the study

# 2 LEEUWPAN COAL MINE

## 2.1 Locality

Leeuwpan Coal Mine is situated approximately 10km south-east from the town of Delmas, approximately 80km east of Johannesburg and 70km south-east of Pretoria in the Mpumalanga province. The locality of the mine and reserve blocks considered here are indicated in Figure 1 and its situation within the Witbank Coalfield is shown in Figure 2.

## 2.2 General Geology

Delmas and the coal being mined there lies on the western boundary of the Witbank Coalfield and north of the Highveld Coalfield (Figure 3). The coal seams at Leeuwpan Coal Mine are present within a 16-meter succession. The coal seams are divided on site into a bottom coal zone and a top coal zone. The bottom coal zone may be correlated with seam 1 and seam 2 of the Witbank Coalfield (Snyman, 1998). The top coal zone has not been correlated with the Witbank coal seams, but may most probably be divided into the 4 upper and 4 lower seams and seam 5 respectively, which are separated by shale partings, and characterized by certain empirical characteristics.

According to SACS (1980) the coal seams are assigned to the Karoo Sequence. The coal seams of the Witbank Coalfield occurs in the Vryheid Formation of the Ecca Group (Winter et al., 1987)

At Leeuwpan the coal overlies tillite of the Dwyka Formation. The tillite in turn lies unconformably on the cherts and dolomite of the Malmani Formation of the Transvaal Supergroup (SACS, 1980). Figure 4 shows a reconstruction of the depositional environments of the Dwyka Formation.

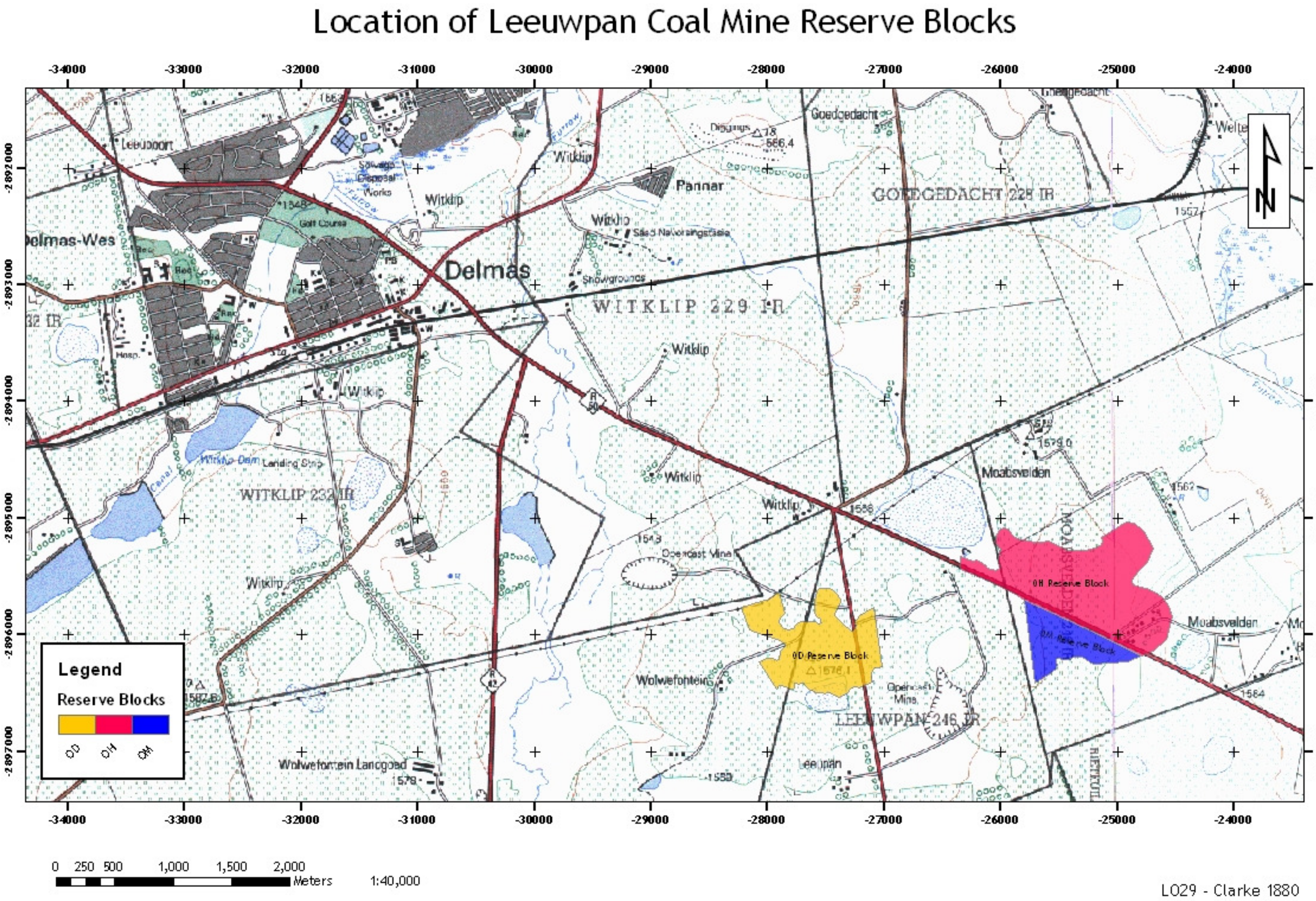


*Figure 1: Locality plan of the reserve blocks at Leeuwpan Coal Mine.*

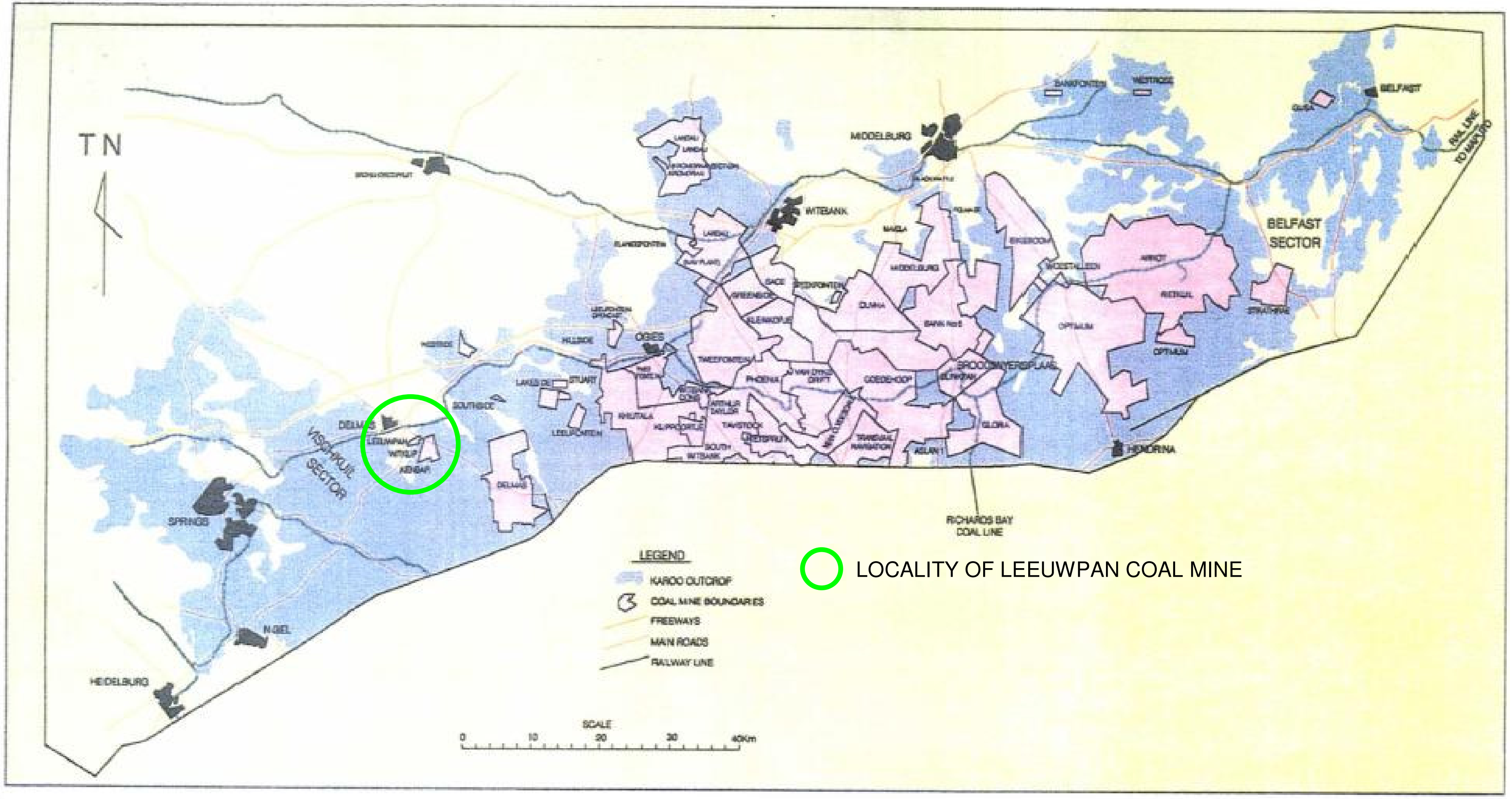


*Figure 2: Locality of Leeuwpan Coal Mine with regards to coal blocks in the Witbank Coalfield (after Barker, 1999).*

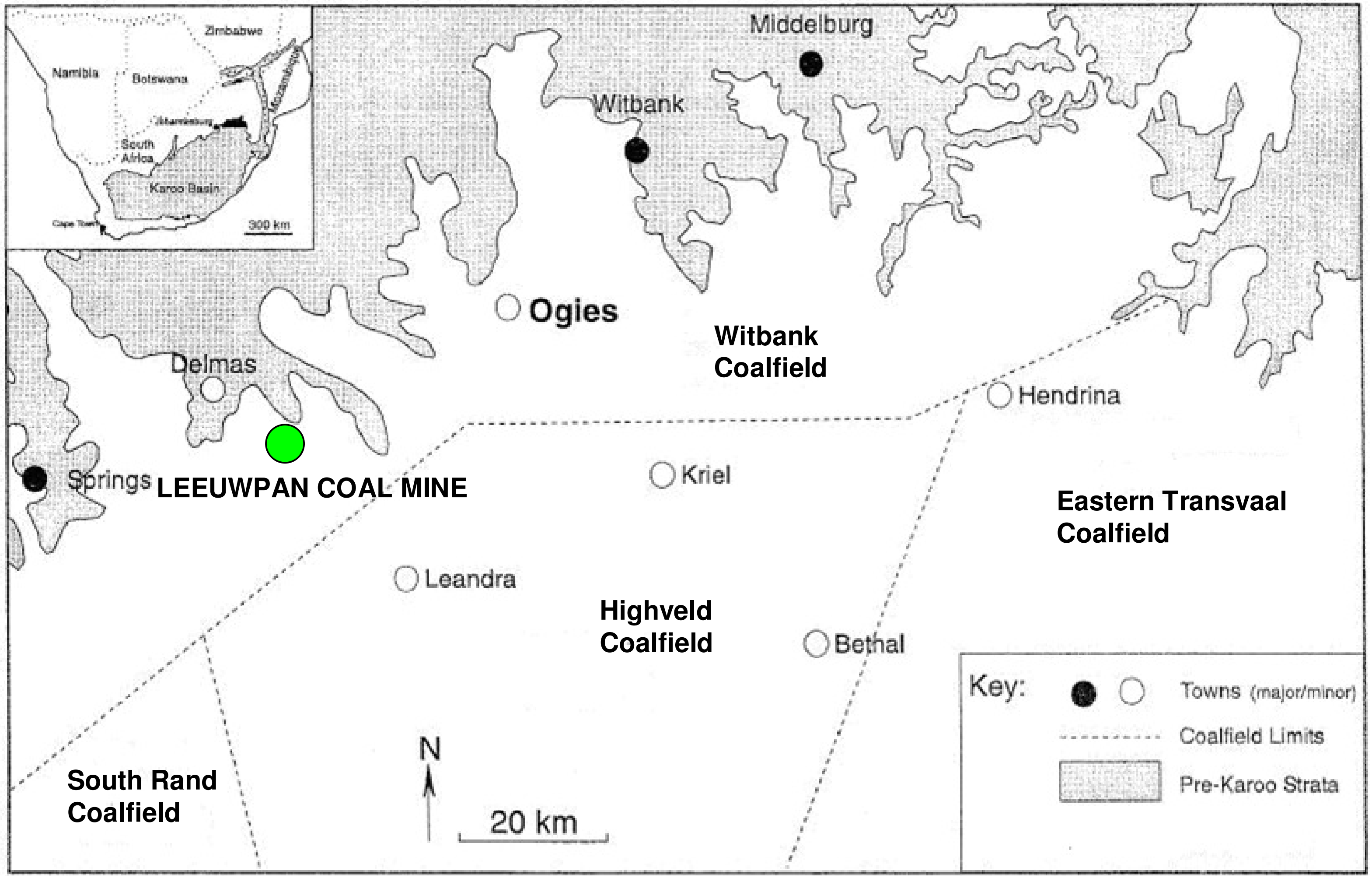


*Figure 3: The location of Leeuwpan Coal Mine with regards to the major Coalfields in Mpumalanga (after Glasspool, 2003).*

Abnormal thickening of the coal seams in the mining area is due to a paleo-karst landscape during peat-formation (Stuart-Williams, 1986).

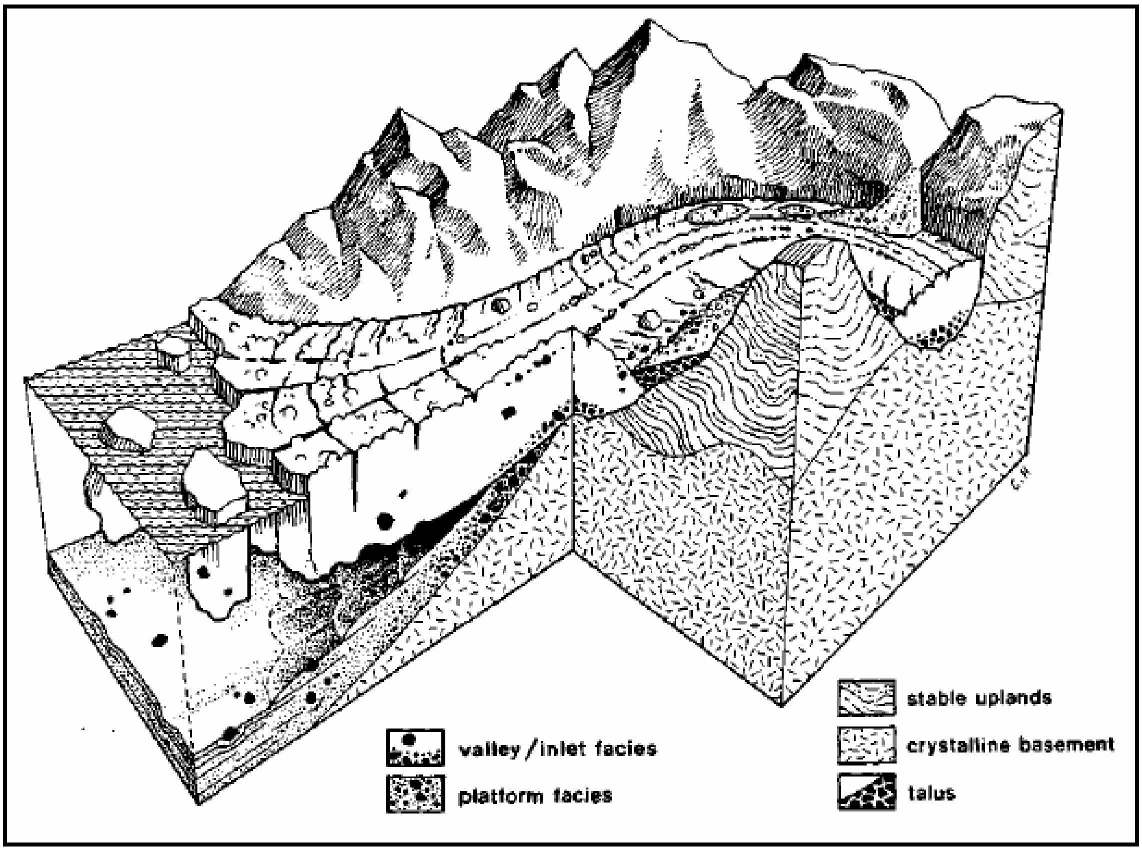


*Figure 4: Reconstruction of the depositional environments associated with the Dwyka formation (after Smith et al., 1993).*

The Vryheid Formation is succeeded, with an erosional contact by, the sandstones of the Volkrust Formation of the Ecca Group (SACS,1980). The remainder of the Karoo Sequence is weathered away and forms clay and sand layers on top of the Vryheid Formation.

A post-Karoo dolerite intrusion also occurs in the area. The transgressive dolerite sill intruded between the Malmani dolomite and Dwyka tillite contacts and cut transgressively through the coal seams in the southern part of the mine area. The intrusion caused the dilasional displacement of the coal seams in this area.

Sills are normally strongly undulating and form domes and basins (Snyman and Botha, 1993), and the karst landscape on which the coal seams were deposited contributed to the current coal seam geometry. The intrusion also caused devolatilisation of some of the coal seams, depending on the thickness of the Dwyka tillite and the dolerite sill. This also resulted in a change of the ratio of the mineral matter content to fixed carbon, due to the fact that some of the volatiles were driven off and some of the coal oxidised and $CO^2$ was lost. The influence of this increase in mineral matter will be addressed in subsequent sections.

## *2.3 Mining*

Leeuwpan Coal Mine is a multi product mine utilising a modified terrace mining method. The coal is mined in two benches, the top bench exploits the top coal zone which correlates with seam 4 and 5 along with their shale partings, and the bottom bench exploits the bottom coal zone which in turns correlates with seam 2. This method is applied due to the quality differences that exist between the two zones. Loading of the coal is done by excavators and hauled by fully articulated 40ton dump trucks. The ROM coal production is approximately 2.7 million tons per annum, and the overburden removed is in the order of 13 million tons per annum.

# 3 NEAR-DENSITY MATERIAL

## *3.1 Definition*

As stated previously near-density material is the material with a similar density as the cut-point density during the washing process. Therefore as this material increases the efficiency of the washing process should decrease.

There are numerous ways of defining the washing process's efficiency for example the probability curve (Tromp curve) in association with the Ecart Probable Moyen. It should be noted that the partition curve is a property of the separator and not of the particles being treated (Woolacott and Eric, 1994). This method is usually applied to determine the separation efficiency of the separator at a certain cut point density. For every density and type of separator the probability curve and Ecart Probable Moyen will be different. Therefore one can determine the efficiency of a separator at different near-density material levels, but this will not lead to a method of predication, due to the fact that these methods are snapshots of a specific type of coal at a specific density.

Therefore the definition of near-density material as stated by Coal Preparation in South Africa (2002) and Majumbar and Barwal (2004) will be used for the remainder of the study.

Near-density material is defined as the material within ±0.1 of the cut point relative density the coal is being washed at.

## *3.2 Leeuwpan Mine's Beneficiation Plant*

### 3.2.1 Overview

Beneficiation of the coal is done by dense medium separation plant consisting of dense medium cyclones and a dense medium drum. The dense medium is a mixture of water and magnetite. The throughput through the plant is approximately 250tons per hour, per module. The plant has two modules, each with a set of coarse cyclones (6-25mm), fine cyclones (1-6mm) and spirals (<1mm). Module 2 is also equipped with a Wemco drum for the coarse fraction (25-55mm). Figure 5 gives a schematic overview of the plant.

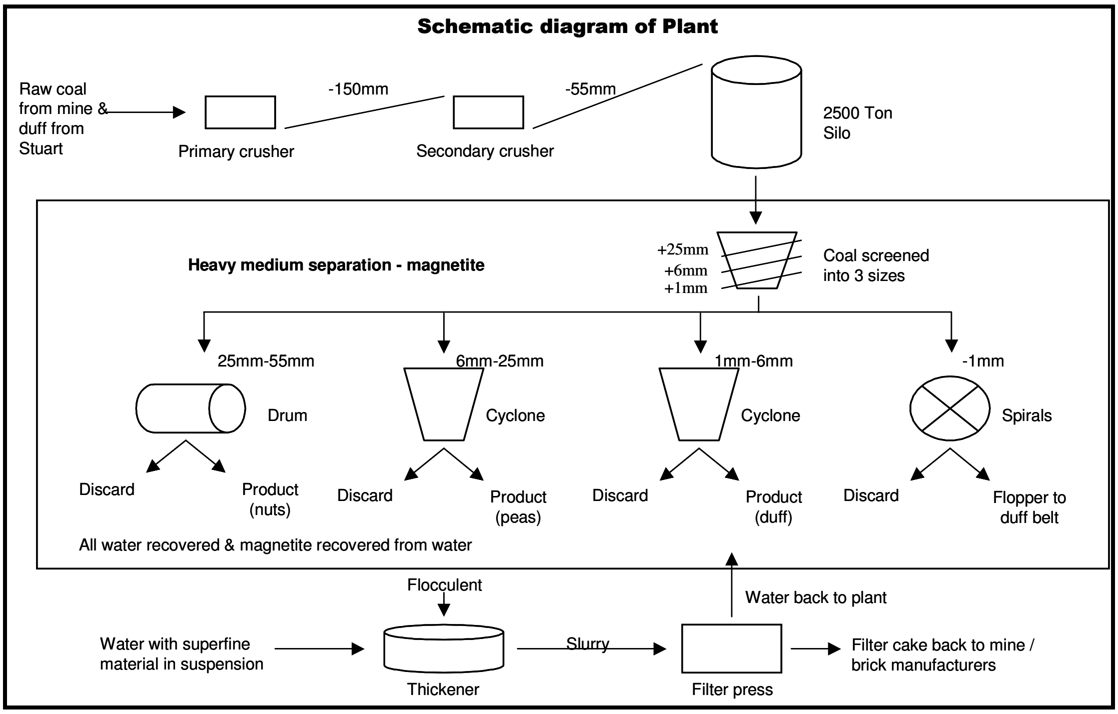


*Figure 5: Schematic overview of the beneficiation plant.*

Various products are produced with different qualities and size fractions. The beneficiation plant produces a variety of coal products by means of batch processing of ROM coal with different feed ash qualities. If the plant is processing bottom zone coal it can vary between products by adjusting the relative densities of the different modules within the beneficiation plant. The products produced are a 16% -, a 15% -, and 12% ash content at different volatile content qualities.

To understand the effects of near-density material on the washing process the principles of separation in a dense medium plant must be studied. The principles of separation are discussed in terms of Coal Preparation in South Africa (2002). The spirals will not form part of this discussion because separation on the spirals is achieved manually and is usually discarded with the filter cake.

### 3.2.2 Principles of Float and Sink separation

It is important to note that the ash content of a piece of coal is generally related to its relative density and hence, by washing the coal to a specific relative density the ash content of the washed coal can be controlled.

The principle on which the dense media separation process relies is the density differences between the coal and shale or discard. Normally the densities of the product and discard are widely separated.

The fact that particle size and shape play no part in the separation in a stationary medium, and that the separation is done entirely on densities, makes this a very efficient process for cleaning coal.

### 3.2.3 Wemco Drum

The Wemco drum separator consists of a cylindrical drum that rotates on bearings. The preferred medium for separation is magnetite.

The raw coal enters at one end of the drum. The clean coal floats and flows over a weir and is discharged at the other end of the drum.

The sinks are lifted from the bottom of the drum by lifters fitted to the inside of the rotating shell. The sinks are discharged into a trough, where a current of medium convey them to a drain and rinse screen. Figure 6 illustrates the working of a Wemco drum.

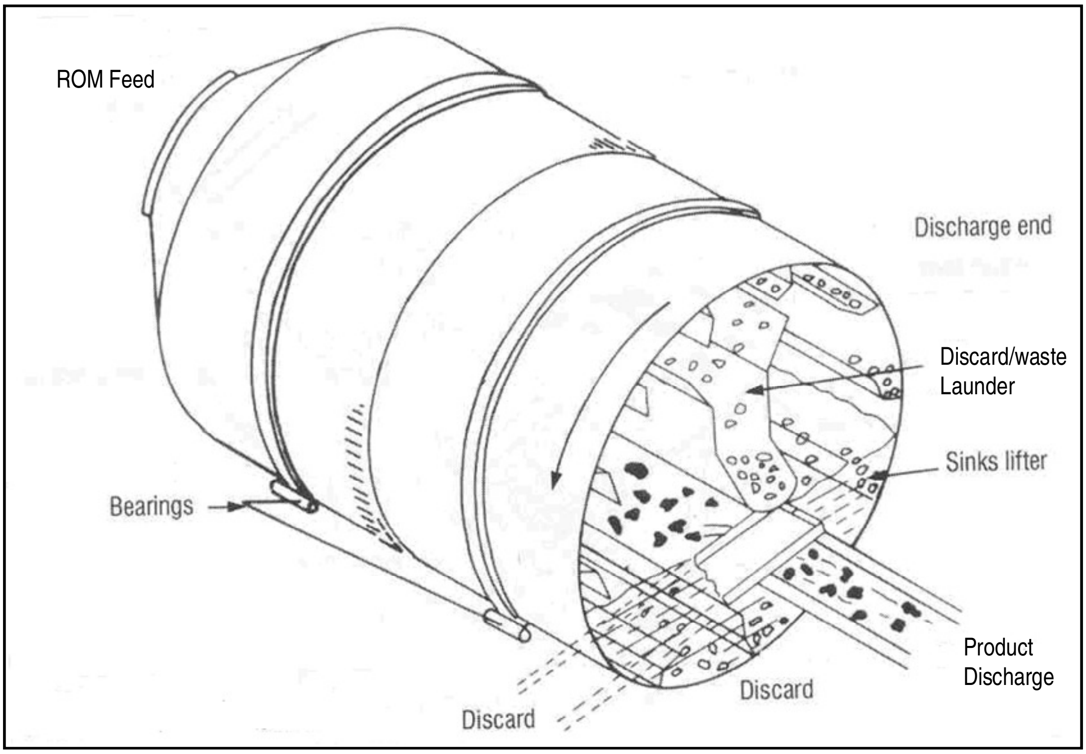


*Figure 6: Schematic illustration of the Wemco Drum (after Coal Preparation in South Africa, 2002).*

### 3.2.4 DMS Cyclone

Figure 7 contains a schematic diagram of a dense medium cyclone. The raw coal (1- 25mm size fraction) to be separated is suspended in a very fine medium and this pulp is fed tangentially through a tapered inlet into a short cylindrical section. The short cylindrical section also carries the vortex finder, which prevents short circuit within the cyclone. Separation is achieved in the cone-shaped part of the cyclone by the action of centrifugal and centripetal forces. The discard portion of the raw coal leaves the cyclone at the apex opening and the clean coal leaves at the overflow top orifice via the vortex.

As the pulp reaches the cone-shape where separation is achieved, centrifugal forces acts on the raw coal particles. Due to the difference in density between the medium and the coal a negative force works onto the coal particles, and those particles will go to the inner spiral or vortex and exit the cyclone at the top via overflow. The same is true for the discard particles except that a positive force works on the particles and therefore the particles are flung to the wall of the cyclone and exit the cyclone at the bottom via the underflow.

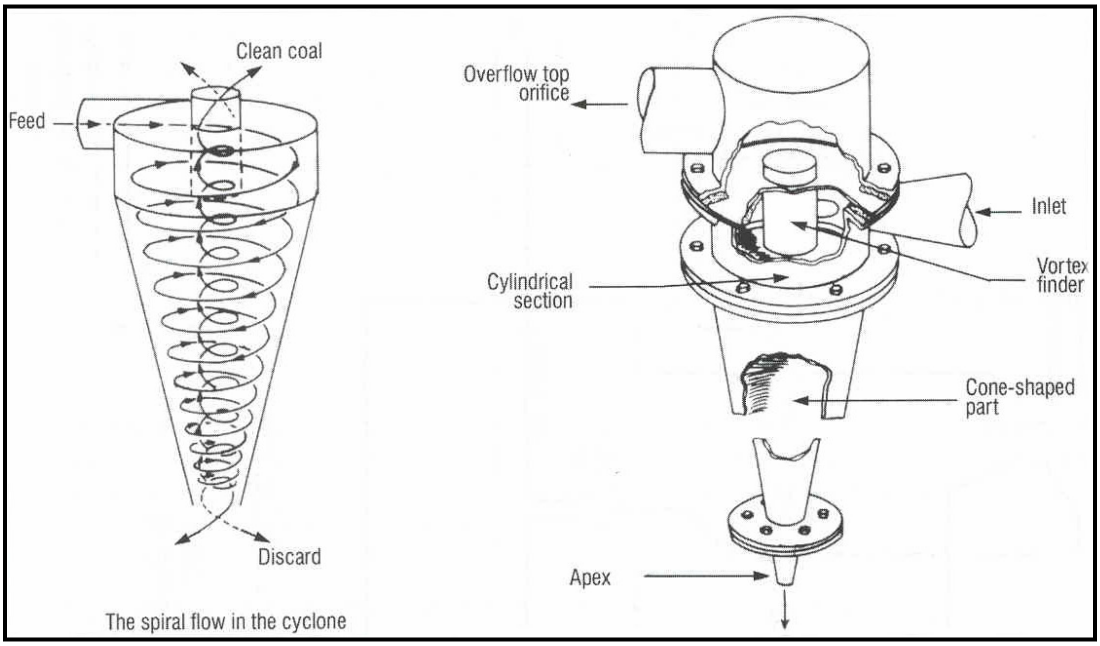


*Figure 7: The Dense Medium Cyclone (after Coal Preparation in South Africa, 2002).*

## 3.3 Effects of Near-density Material on Separation Equipment

Near-density material is the percentage feed coal that gets trapped in a zero velocity zone inside the cyclone. This is due to the fact that the centrifugal and centripetal forces are equal. In essence it blocks the cyclone and the feed coal is forced to the cyclone wall or the vortex finder and misplacement occurs. In other words the cyclone does not beneficiate the coal and the feed coal gets pushed through.

Figure 8 contains a schematic view of the influence of near-density material in the DMS cyclone.

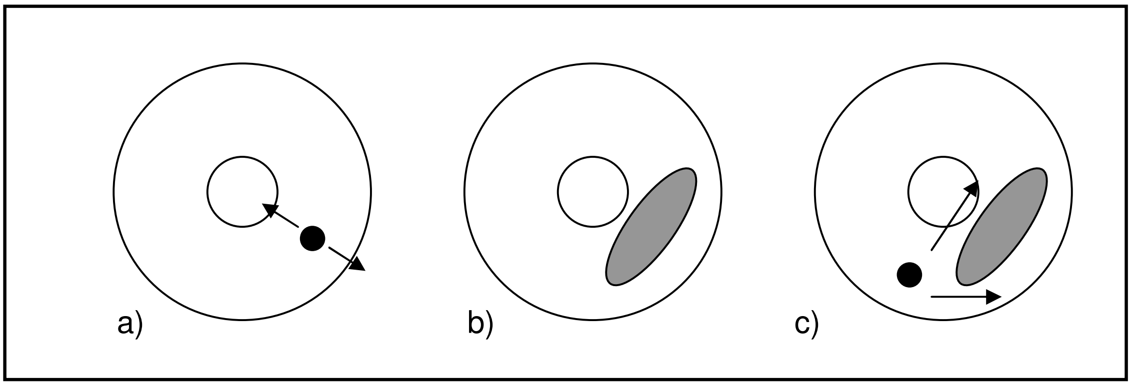


*Figure 8: Schematic cross-section through a cyclone illustrating what happens with near-density material in the beneficiation process, a) a coal particle with centrifugal and centripetal forces working in on it, b) particles with densities close to the cut-point density gets caught in an envelope of zero velocity, c) due to the near-density envelope additional particles gets forced towards the vortex finder or the cyclone wall irrespective of the particles density, which then leads to misplacement.*

When large amounts of near-density material enters the Wemco drum the particles stays in suspension in the separation bath. Due to this build up of material in the separation bath, the material that enters the drum flows over this mass of suspended material without the waste getting separated from the product.

Therefore large amounts of near-density material in the beneficiation process causes quality problems on the product side and destroys value towards the discard density side.

# 4 GEOLOGICAL CONTROL ON NEAR-DENSITY MATERIAL

## *4.1 Depositional Environment*

In the previous section on near-density material it was shown that the relative density at which the coal is being washed is related to the ash content of the coal being processed. Therefore in this section coal will be discussed in terms of its classification and depositional environment and how it affects washability. Thereafter a closer study of the raw ash content and ash distribution of seam 2 at Leeuwpan Coal Mine will be presented.

### 4.1.1 Coal classification and Depositional Environment

According to Snyman (1998) coal can be classified in terms of three independent variables namely grade, type and rank. Grade is the inverse of the percentage inorganic material, or generally referred to as ash, in the coal and is largely determined during the depositional stage of coal formation. Type, or the maceral composition, is determined by the nature of the original plant material and its degree of alteration during the diagenetic stage of coal formation. Rank is the degree of metamorphism that occurred after burial.

In general it is accepted that it is the amount and distribution of the finely dispersed mineral matter, in other terms the grade of the coal, that most effects washing difficulty (Ryan, 1995).

The dispersed mineral matter has various origins namely; wind blown, water transport, original component of the vegetation, and syngenetic or epigenetic emplacement. The source and amount of the dispersed mineral matter and the environment in which the coal formed are related and therefore it may be expected that there will be a relationship between washing difficulty of the coal and depositional environment (Ryan, 1995).

The mineral material of interest to this investigation is the material that is intimately mixed within coal. These minerals include finely dispersed clays, quartz, carbonate minerals and pyrite group minerals. They cannot be removed from the coal substance by coal preparation techniques (Coal Preparation in South Africa, 2002).

Many authors (Glasspool, 2003, Cairncross, 2001, Snyman, 1998, Snyman and Botha, 1993, Smith et al., 1993, Cairncross and Cadle, 1993, Cairncross et al., 1990, Holland et al., 1989, Falcon and Ham, 1988, Cairncross and Cadle, 1987, Winter et al., 1987) have done extensive work on the depositional environment of the Karoo coal seams and have also covered it in numerous reviews.

Before the depositional environment of the coal seams in the Witbank area is discussed it is important to note that coal from the Gondwana provinces have been found to be characteristically rich in minerals, relatively difficult to beneficiate, and highly variable in rank and organic material (Falcon and Ham, 1988). This is due to the climate and environment in which the coal was deposited.

The summation of the depositional environment, with special reference to seam 2, will be based on the summary of Glasspool (2003), which encompass most of the above mentioned authors.

The coal seams of the Vryheid Formation were deposited in the Karoo foreland basin (Smith et al., 1993). The seams of the Vryheid Formation can be divided into two units. The earliest coals, No 1 and 2 seams, formed under periglacial conditions during phased glacial retreat. These early seams were restricted by the paleotopography of the glacially incised valleys in which they were formed. These incised valleys resulted in various degrees of degradation of the plant matter. Some vegetation accumulated *in situ*, while seasonal floods washed other forms in, which was also accompanied by much mineral matter from the mountainous regions of the hinterland. These periglacial peats were deposited at the end of the Dwyka glaciation on low-lying land in glaciofluvial and glaciodeltaic environments in periods of low inorganic material inflow (Glasspool, 2003). This coal is usually low in sulphur, fresh-water in origin, fed by the run-off of the retreating glacier and with limited to brackish and/or marine influence. Furthermore the No. 2 seam is cut by glaciogenic anastomising channels, which accumulated in the eastern basin as a lucustrine swamp (Figure 9) (Falcon and Ham, 1988). These seams are limited to the northern boundary of the Karoo basin (Snyman,1998).

Cairncross et al. (1990) also showed that the No. 2 seam consists of five main bands, which in general comprises of a basal high quality band overlain by a lower quality layer (see Figure 10). He postulated that the upward deterioration was due to the effect of mixing the overlying transgressive sequence and clay with the accumulated peat at the end stages of the peat-forming period. He concluded that the inner seam variations in quality were due to a combination of factors such as water table fluctuations, basin stability and differential compaction associated with the irregular underlying paleotopography.

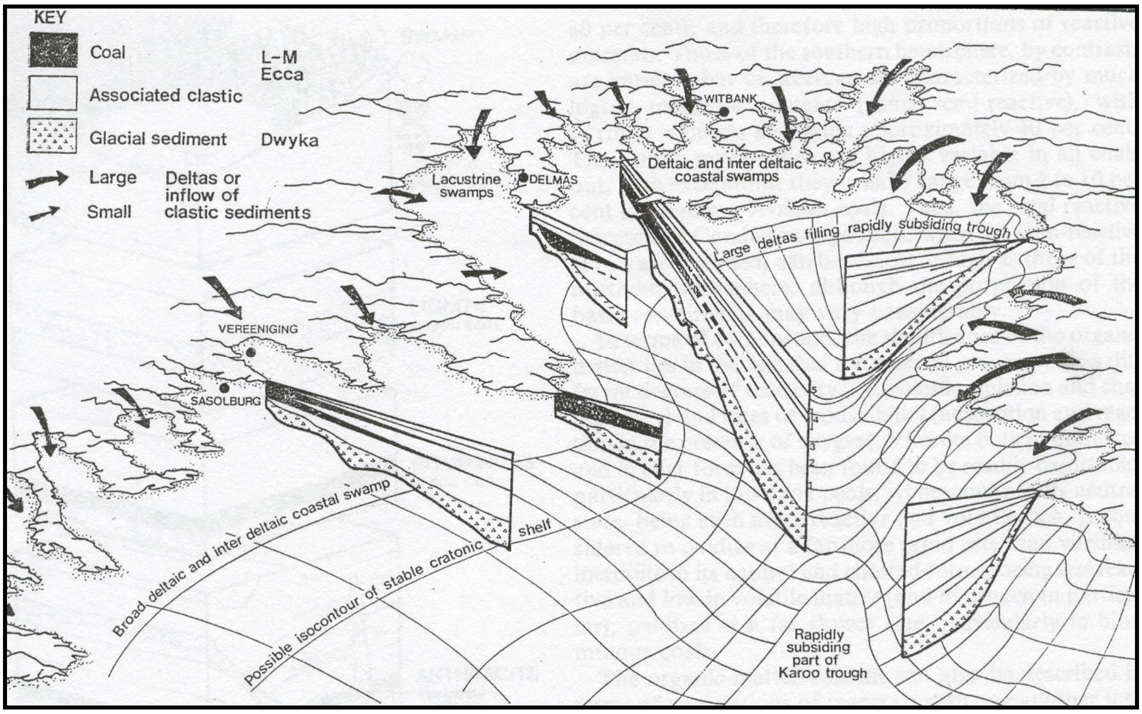


*Figure 9: Depositional environment of the Delmas area compared with the rest of the Karoo basin (after Falcon and Ham, 1998).*

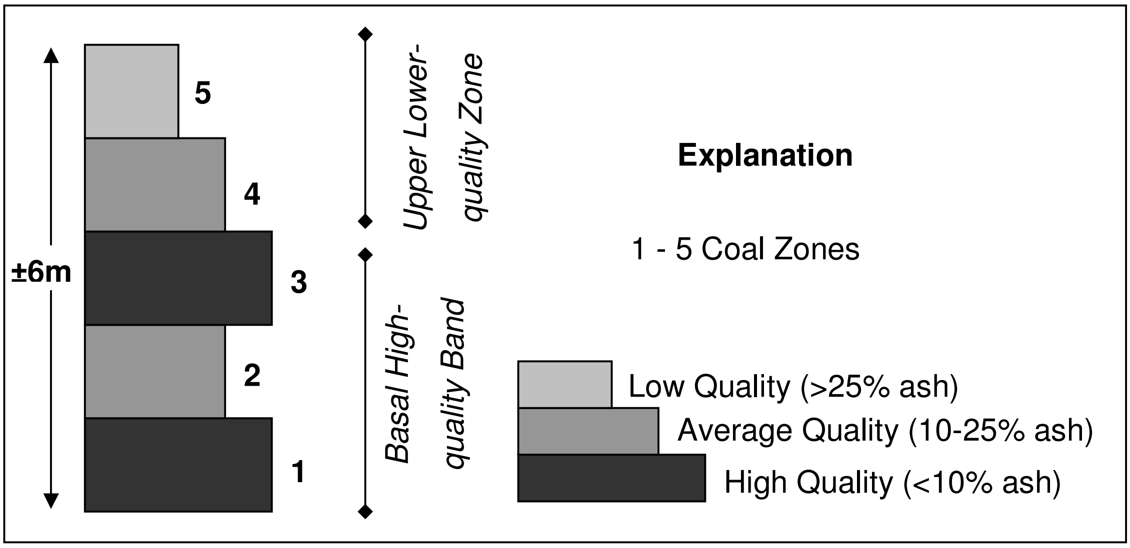


*Figure 10: Coal profile for seam 2 according to Cairncross et al. (1990).*

The latter seams of the Vryheid Formation, No. 3 - to 6 seams, were deposited on an epicontinental environment. These seams were deposited in peat swamps and fluvial channels at the end of a deltaic and fluvial cycle (Caircross et al., 1990). The characteristics of these seams differ from the earlier seams due to the amelioration in the climate, which brought on a change in the flora that constitutes the macerals in the coal.

In the coal seams there are regional differences due to the fact that the main Karoo basin was once open to the sea. Shorelines differed in terms of stability, configuration, and the nature of the hinterland. These factors gave rise to different geometrical developments of the seam, different environments of accumulation, and different suites of minerals and trace elements (Falcon and Ham, 1988).

### 4.1.2 Raw Ash Content Distribution

Before the raw ash content distribution is discussed the analytical procedure used to determine ash content, which is applicable to the raw ash content distribution and to the product ash distribution, must be stated.

Ash content is determined by SABS method 926. Approximately 1 gram of coal is weighed and placed in a cold furnace ventilated by air. The temperature is slowly raised to 800°C and maintained until a constant weight is obtained. The dish is cooled, first in the open air and then in a desiccator, and the weight of the ash in the dish determined. The mass of ash, expressed as a percentage of the amount of coal taken, is the ash content.

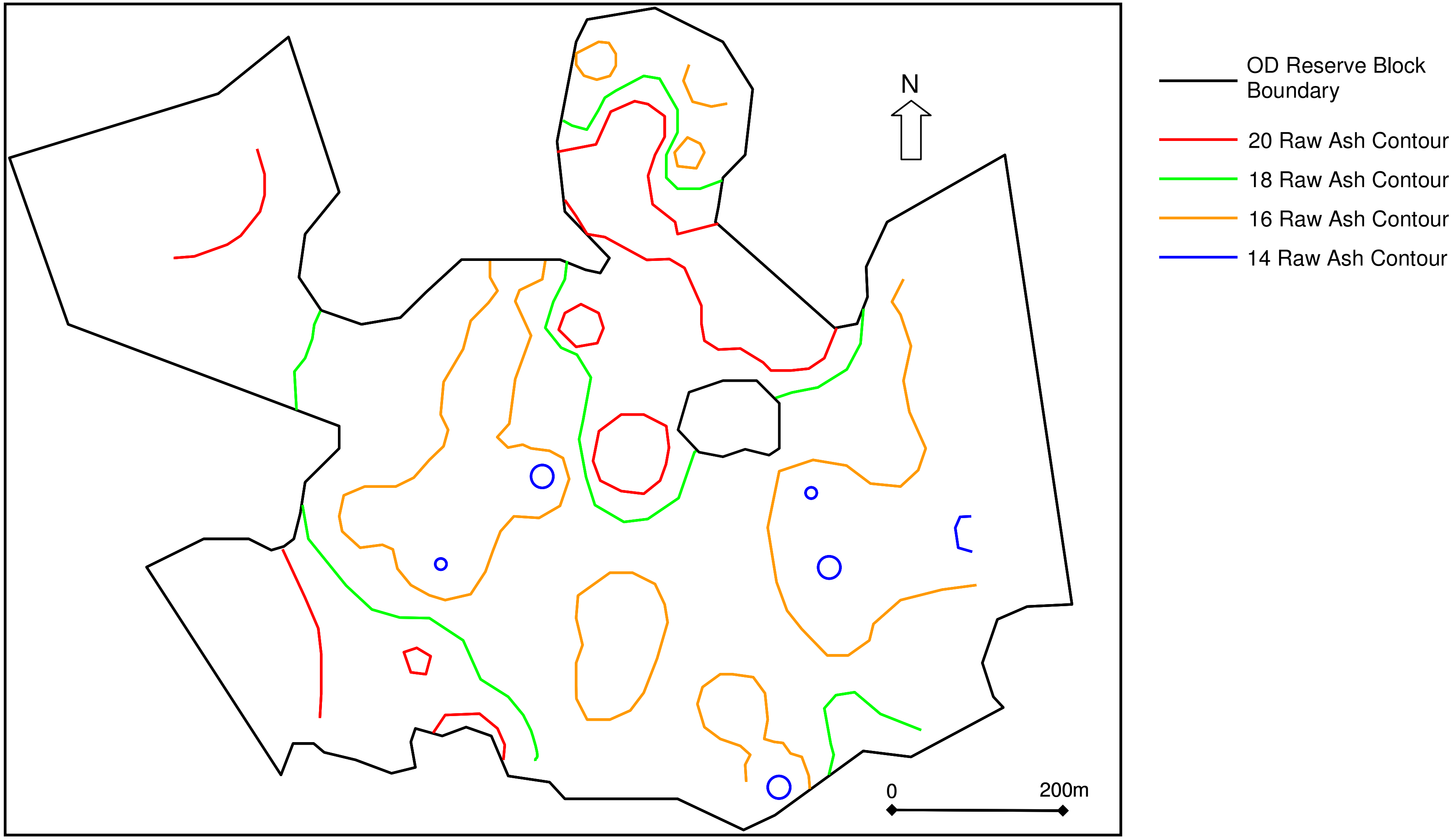


*Figure 11: Raw ash distribution of seam 2 within block OD.*

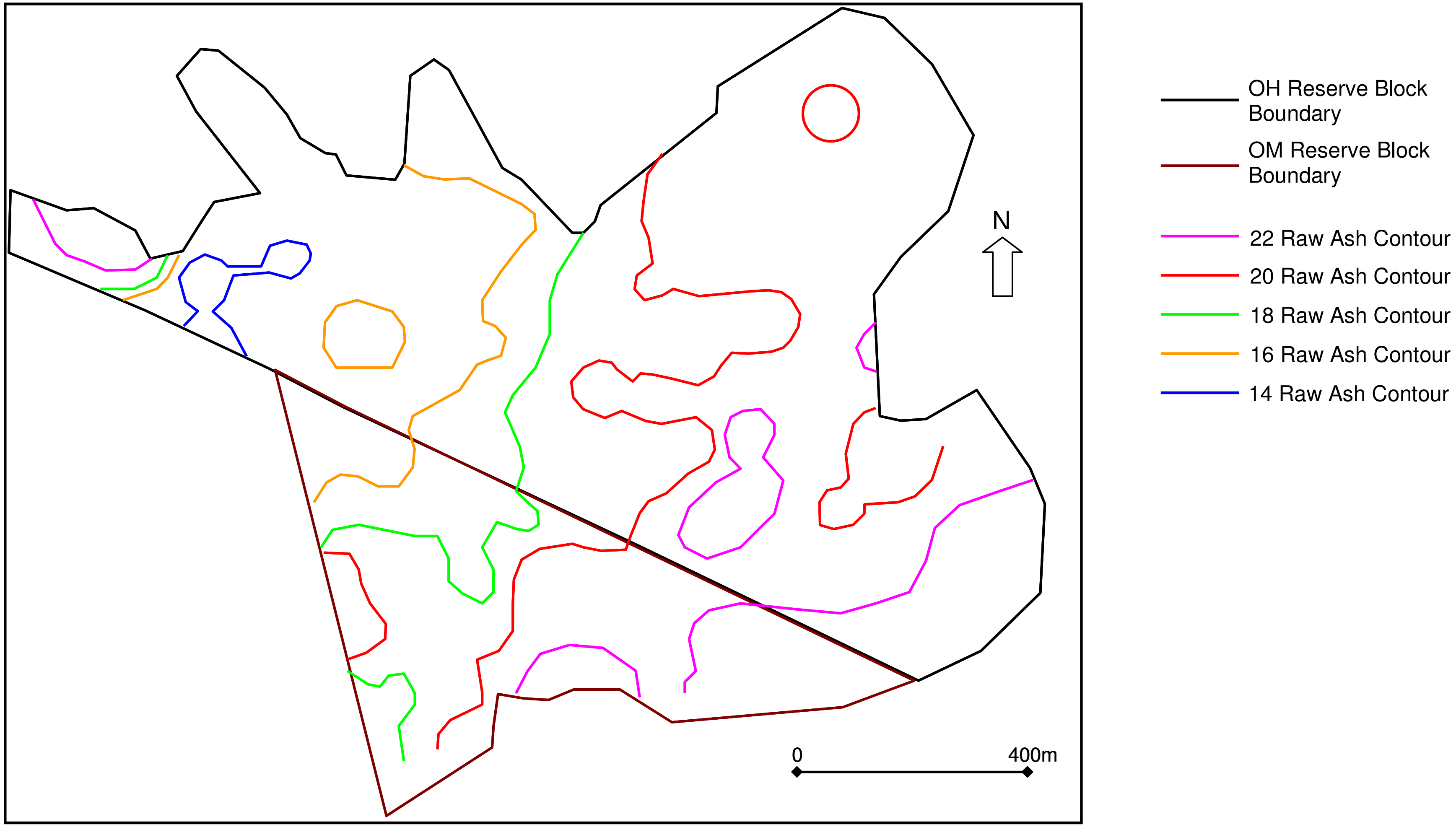


*Figure 12: Raw ash distribution for seam 2 in block OH and OM respectively.*

The raw ash content distribution, as defined under definitions, for seam 2 of the reserve blocks can be obtained from the whole coal analysis of the composite wash tables of the boreholes, which is tabulated in appendix 1. These values are contoured with inverse distance as the interpolator. Figure 11 and Figure 12 contain the result of the raw ash content contours for the various reserve blocks. The raw ash content values are contoured in 2% raw ash content intervals.

Block OH and OM show an increase in raw ash content in an easterly direction towards where the dolerite cuts transgressively through the coal seams. For block OD the raw ash content also increases towards the transgressive dolerite to the south. In the central part of the reserve block the raw ash content also increases, which might be correlated with the proximity of the dolerite sill.

Variations in the raw ash content distribution vertically within seam 2 are based on blasthole data obtained from routine mine grade control (Figure 13) and from diamond boreholes, which were drilled during the exploration phase.

From the drillhole sections depicted in Figure 13 it clearly visible that the raw ash content of seam 2 in section is variable and layer bound. It also shows similarities to the quality section of seam 2 by Cairncross (1990) illustrated in Figure 10.

#### *4.1.2.1 Conclusions*

The raw ash content distribution of seam 2 showed no major or sudden variations. The increase in raw ash content is most probably related to the coal seam’s proximity to the dolerite intrusion (which will be discussed in a later section in more detail) or variation among depositional environments. The raw ash content distribution, laterally and vertically, does not give any information in terms of the washability of the coal. Therefore it can be concluded that raw ash content or the feed ash content to the beneficiation plant has no influence on the “ease” or “difficulty” of producing certain clean coal products.

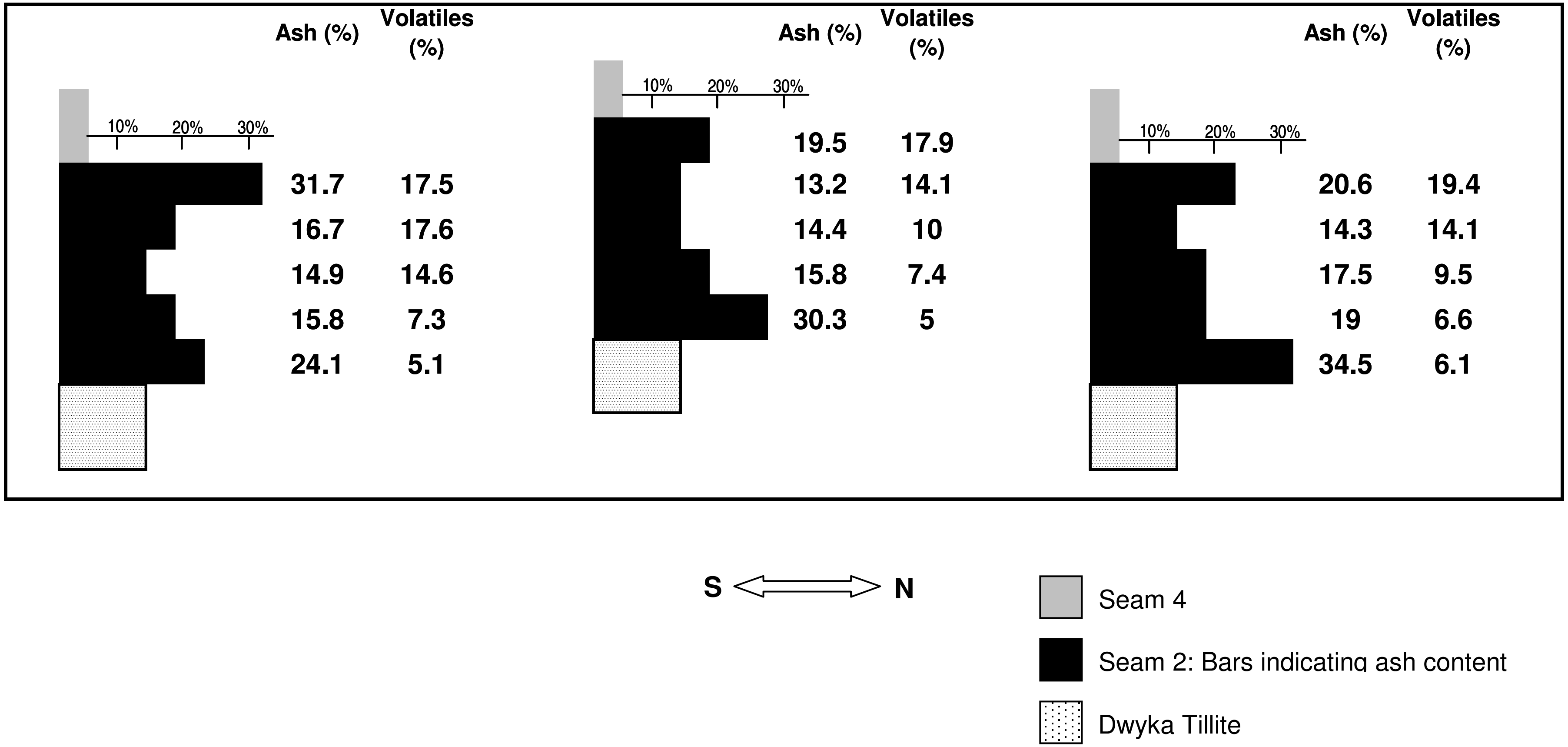


*Figure 13: An idealised cross section through the coal reserves indicating the vertical variance in ash content and volatiles of seam 2. Variation in the ash content is shown on a horizontal scale.*

### 4.1.3 Ash Distribution

The ash distribution of seam 2 in the various blocks will be determined from ash curves drawn for the seam. The ash curve can be defined as the curve obtained from the results of a float and sink analysis by plotting the cumulative yield of the floats at each relative density against the mean ash of the total floats at that density. This shows the relationship between cumulative yield of the floats and ash content. The wash tables for seam 2 and their accompanying washability curves are provided in appendix 2. The lag (data range of specified ash values) used in the plotting of the ash distribution is 2.5% ash intervals. To determine the amount of near-density material around a certain relative density cut point reference has to be made to the washability curves to determine the ash values for the ±0.1 relative density variation as per the near-density material definition.

The ash distribution will indicate if the amount of material around a certain cut point will exceed the 30% near-density material limit, were it will negatively influence the washability of the coal in the beneficiation process at the specified cut point. This will now be illustrated for the different reserve blocks in the following paragraphs.

#### *4.1.3.1 Ash Distributions of the various Reserve Blocks*

The ash distributions with a normal quantile plot and histogram of the data of the various reserve blocks are in Figure 14, Figure 15 and Figure 16. Thereafter the statistical information is tabulated in Table 1.

The normal quantile method is used to test if the distributions are normal. It is based on the fact that the Z-values of a distribution have a linear relationship. Therefore if the Z-values distribution plot’s is in a straight line the distribution is normal.

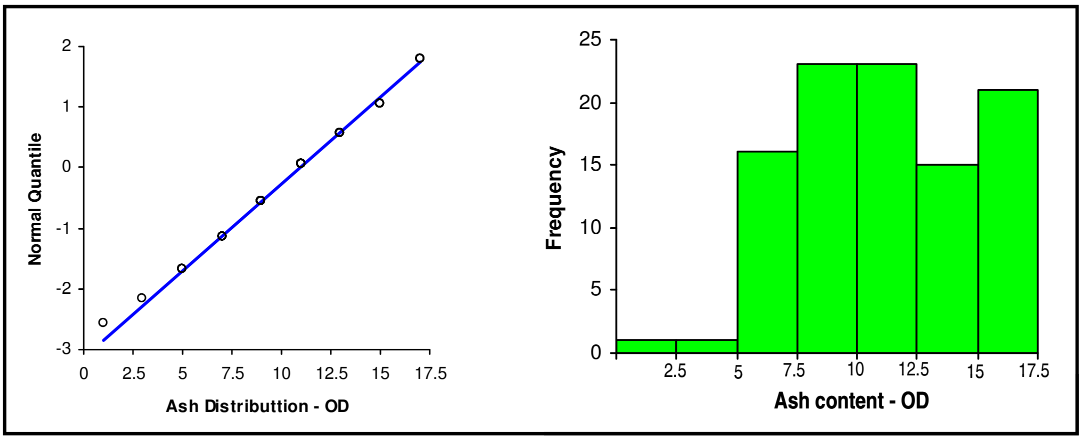


*Figure 14: Ash distribution and histogram for seam 2 in block OD.*

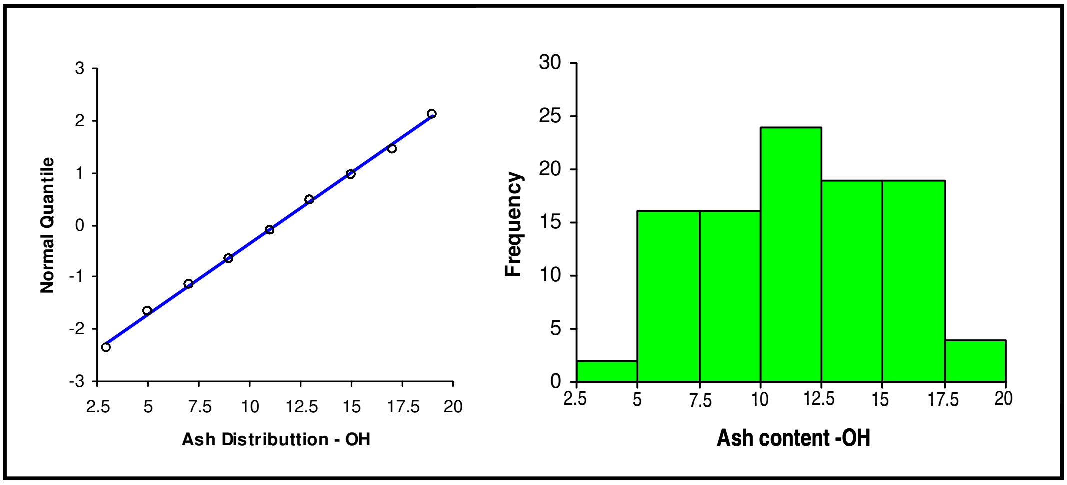


*Figure 15: Ash distribution and histogram for seam 2 in block OH.*

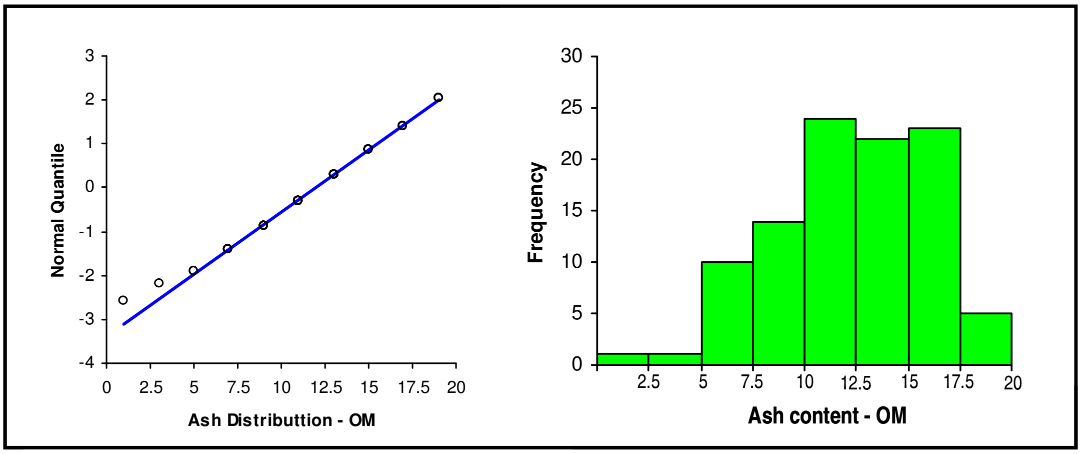


*Figure 16: Ash distribution and histogram of seam 2 in block OM.*

*Table 1: Tabulated descriptive statistics for the ash distribution in seam 2 in the various reserve blocks.*

**Comparative Statistics for seam 2 in the various blocks**

| Block | Mean | Median | Mode | Standard Deviation | Sample Variance | Kurtosis | Skewness |
|---|---|---|---|---|---|---|---|
| OD | 10.92 | 11 | 9 | 3.49 | 12.20 | -0.24 | -0.12 |
| OH | 11.36 | 11 | 11 | 3.67 | 13.44 | -0.32 | -0.01 |
| OM | 11.98 | 12 | 11 | 3.51 | 12.32 | 0.39 | -0.27 |

### *4.1.3.2 Conclusions*

The normal quantile plots and accompanying histograms indicate that ash distribution throughout seam 2 approximate normal distributions (Figure 14, Figure 15 and Figure 16). These distributions are relatively flat, as seen from the negative kurtosis (relative flatness of a distribution compared with a normal distribution), except for block OM, which seems to display a more peaked distribution. These types of distributions are to be expected of a coal forming environment where there were long periods of stability with a constant influx of mineral matter from adjacent areas. The little variations in the distributions can be contributed to the emplacement of the dolerite after coal formation (refer to next section).

In terms of washability, the definition of near-density material states that more than 30% near-density material around a certain cut point has a negative effect on the ease of washing the coal to a desired ash product. From the ash distribution of the reserve blocks at Leeuwpan Mine, it may be seen that a coal product around the mean will be very difficult to produce due to the large amount of material with similar ash contents grouped around the mean. The ease to produce a certain clean coal product only becomes easier at an ash value below a standard deviation to the left of the mean or an ash value above a standard deviation to the right of the mean where the distribution flattens out. Therefore the kurtosis of the ash distribution plays a significant role in the ash product range that can be produced from a specific seam. The more negative the kurtosis of an ash distribution the less the constraint of near-density material may become in the beneficiation process. This is due to the fact that the amount of material with similar ash contents grouped around the mean will decrease due to the flatness of the distribution.

Therefore the ash distribution around the cut point relative density is the only determining factor in the effectiveness of the washability of coal to a certain clean coal product.

## *4.2 Dolerite Intrusion*

The effect of dolerite intrusions on the coal seams of the Ecca Group is well documented. Hagelskamp (1987) studied the effects of numerous dolerite intrusions on the quality parameters of coal at Twistdraai Mine. He found that the ash content only increased close to the contact between the coal and the intrusion. Furthermore he showed that the volatile matter decreased in the vicinity of the intrusions. Therefore the rank of the coal seam is affected by the intrusions.

Snyman and Barclay (1988) showed that the degree of metamorphism and rank of coal by dolerite intrusives varies accordingly to the ratio D/T, where D is the distance between the coal and the intrusive and T is the thickness of the intrusion.

Falcon and Ham (1988) also stated that with an increase in rank the aliphatic peripheral groups are lost and that the aromatic nuclei become larger and aligned in an orderly fashion parallel to the bedding plane. They have also showed that the optical reflectance of vitrinite increases regularly and progressively with an increase in rank, irrespective of the proportion of macerals and minerals present.

Snyman and Botha (1993) stated that where dolerite sills cut through the coal seams, they vertically displace the seams equal to the apparent vertical thickness of the intrusion. These sills may also be undulating and may form basins and domes.

Before the effect of the dolerite intrusion on near-density material, or in other words the washability characteristics of the coal seams, can be determined, it must be established if the dolerite did affect the coal seams in this study area.

### 4.2.1 Effect of Dolerite Intrusion on the Coal Seams

As mentioned above Hagelskamp (1987) showed that the raw ash content increases and the volatile matter decreased in close proximity to dolerite intrusions. Therefore to determine if the dolerite intrusion had any effect on the coal seams at Leeuwpan Coal Mine there must be a negative correlation between the raw ash content and the volatile matter. It should be noted that there are normally a correlation between ash contents and volatile matter of coal, but seam 2 throughout the Leeuwpan area formed in similar environments and therefore the ash distribution in the seam should be similar. Therefore any variation in volatile matter and ash content can be contributed to the dolerite sill.

Scattergram plots of the volatile matter versus the raw ash content should indicate if there exists a correlation between the two data sets. The correlation will be tested with the Pearson's correlation coefficient test, with a null hypothesis test to confirm or reject of the conclusion made. The null hypothesis is that no correlation exists between the volatile matter and the raw ash content.

### *4.2.1.1 Block OD*

Figure 17 shows the scattergram of the data for block OD and Table 2 contains the results of the Pearson's correlation coefficient test.

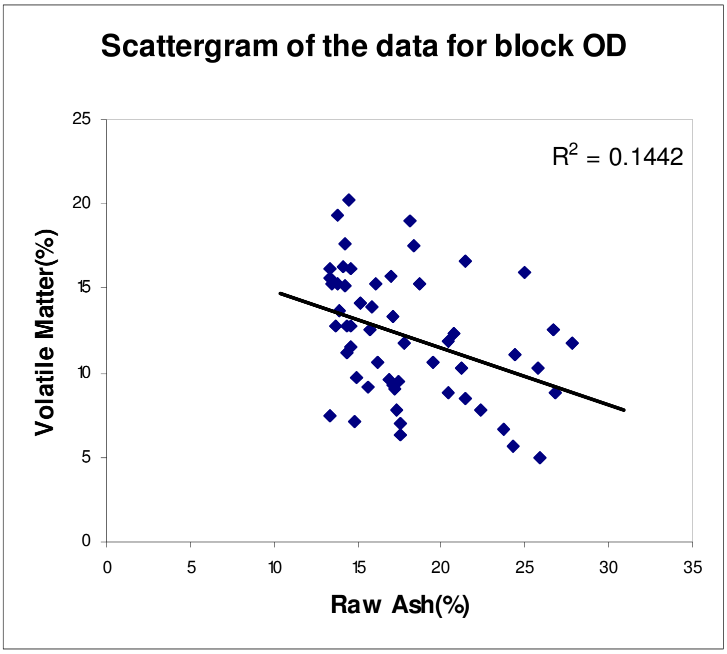


*Figure 17: Scattergram plot of the volatile matter versus the raw ash content of seam 2 in block OD.*

*Table 2: Pearson's coefficient test of correlation for block OD*

| | |
|---|---|
| Observed value (correlation factor) | -0.380 |
| Two-tailed p-value | 0.004 |
| Alpha | 0.05 |

*Two-tailed p-value: Probability under the null hypothesis to obtain a result as extreme as the observed result, at the two tails of the distribution.*

From the scattergram it can be seen that the data does not follow a straight line correlation. There are numerous points scattered around the general trend. There can be multiple reasons for the erratic distribution. These reasons will be discussed under the conclusions of this section.

The conclusion of the Pearson's correlation coefficient test is to reject the null hypothesis test that no correlation exists, due to the fact that the probability is less than the Alpha level. Therefore the negative correlation is significant even though the observed value is low (38% correlation).

#### *4.2.1.2 Block OH*

The scattergram of the volatile matter versus raw ash content for seam 2 in block OH is illustrated in Figure 18 and the results of the Pearson's correlation coefficient test are tabulated in Table 3.

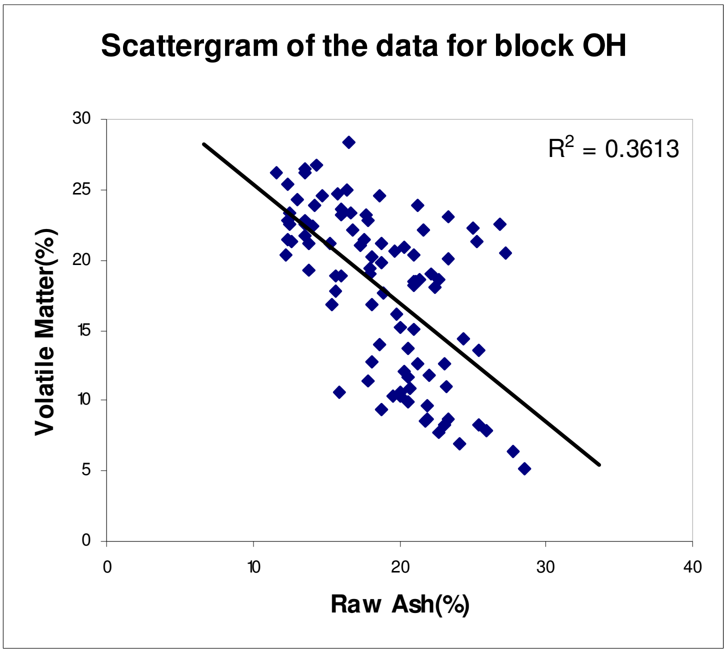


*Figure 18: Scattergram plot of the volatile matter versus raw ash content of seam 2 in block OH.*

*Table 3: Pearson's correlation coefficient test for block OH*

| | |
|---|---|
| Observed value (correlation factor) | -0.601 |
| Two-tailed p-value | 0.0001 |
| Alpha | 0.05 |

*Two-tailed p-value: Probability under the null hypothesis to obtain a result as extreme as the observed result, at the two tails of the distribution.*

The data points in the scattergram plot show a stronger correlation than the data points for block OD. The negative correlation between the volatile matter and raw ash content is 60%, but there are still numerous random points visible.

The Pearson's test of correlation indicates that the null hypothesis of no correlation between the data sets must be rejected as the probability is much less than Alpha value.

### *4.2.1.3 Block OM*

The volatile matter versus the raw ash content for seam 2 in block OM is captured in a scattergram plot in Figure 19. Tabulated result of the Pearson's correlation coefficient test is in Table 4.

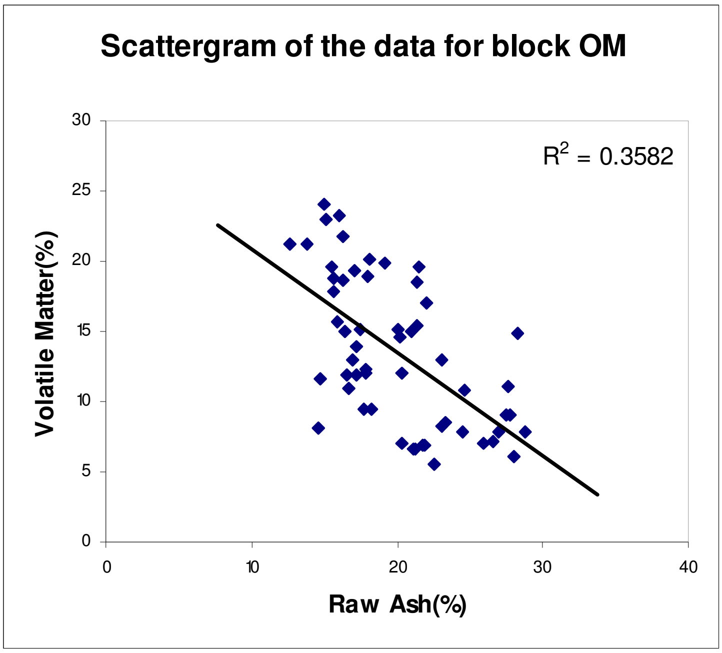


*Figure 19: Scattergram plot of the volatile matter versus the raw ash content of seam 2 for block OM.*

*Table 4: Pearson's correlation coefficient test for block OM*

| | |
|---|---|
| Observed value (correlation factor) | -0.599 |
| Two-tailed p-value | 0.0001 |
| Alpha | 0.05 |

*Two-tailed p-value: Probability under the null hypothesis to obtain a result as extreme as the observed result, at the two tails of the distribution.*

The scattergram plot for the data of block OM clearly indicates that there exists a negative correlation between the volatile matter and raw ash content for block OM. As with the previous two blocks there are random points present. The correlation between the two data sets is 59.9%.

The Pearson's correlation coefficient test re-emphasises the observations of the scattergram. The null hypothesis of the absence of correlation is rejected as the probability is smaller that the Alpha value.

#### *4.2.1.4 Conclusions*

All three the areas under discussion indicated a presence of a significant negative correlation between the volatile matter and the raw ash content for seam 2. The correlation coefficient varies for the three blocks, but with block OH and OM being very similar. These points that do not plot on the line of correlation are most probably due to the geometry of emplacement of the dolerite intrusion and the formational stage of the coal during emplacement. Some of these factors are as follows:

- Variation in thickness of the dolerite intrusion.
- Thickness variations in the thickness of the Dwyka tillite, which occurs between the dolerite intrusion and seam 2.
- The moisture content of the coal seam at the time of emplacement.
- As the seams formed in a paleokarst landscape, the thickness of the seam may also have had an influence.

The significance of a negative correlation between volatile matter and ash contents has been substantiated with the null hypothesis testing of the data sets, and the hypothesis of absence of correlation has been rejected.

It can be concluded that the dolerite intrusion did affect the volatile matter and raw ash content of seam 2. With an increase in the raw ash content the volatile matter decreased, due to the heat of the intrusion. The influence of the intrusion varies throughout the seam due to the contributing factors discussed above, and the emplacement of the dolerite between the Malmani dolomites and the Dwyka tilite.

### 4.2.2 Effect of the Dolerite Intrusion on the Washability of the Coal Seams

Now that it is established that the dolerite intrusion did affect the coal seams, the effect of the intrusion on the washability characteristics of the coal can be determined.

Block OM has a clear zoning from north to south from medium volatile coal to lean coal to low volatile coal (illustrated in *Figure 20*).

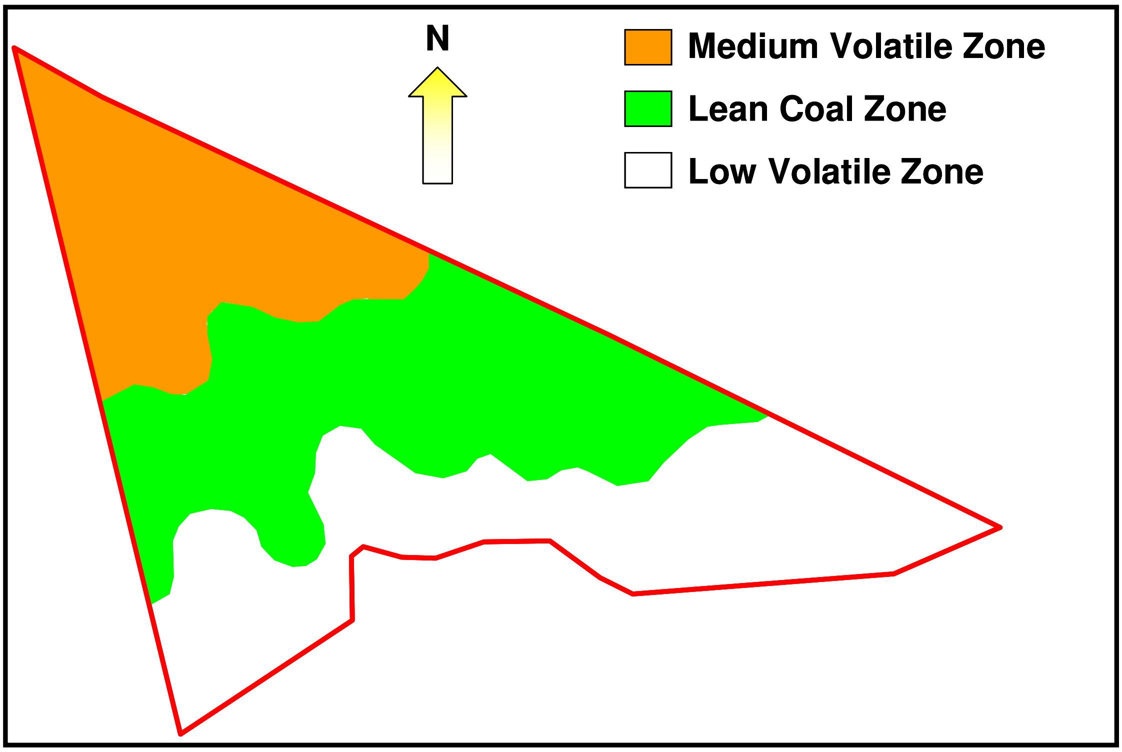


*Figure 20: Volatile zonation of Block OM.*

The ash distribution and histograms of the three volatile zones respectively were constructed and shown in Figure 21, Figure 22 and Figure 23. In the previous section it was shown that the volatile matter decreases as the ash content increases. Therefore the distributions of the three zones should have an increase in the mean ash content towards the low volatile zone. The variance in the mean ash content indicates that the coal will react differently in the beneficiation process when a similar clean coal product is required.

The summarised descriptive statistics of the distribution is tabulated in Table 5. To confirm the variance in the distribution hypothesis testing is done on the means of the distributions.

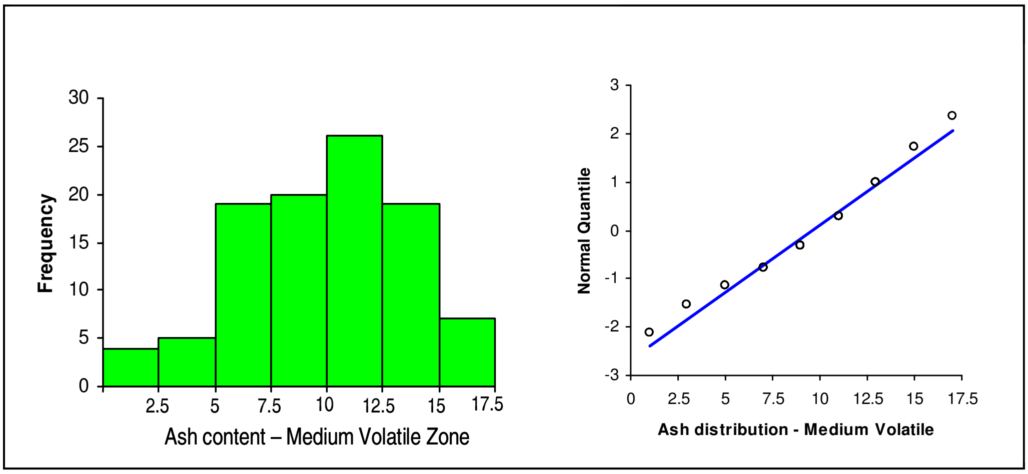


*Figure 21: Ash distribution and histogram for the coal in the Medium Volatile Zone in Block OM.*

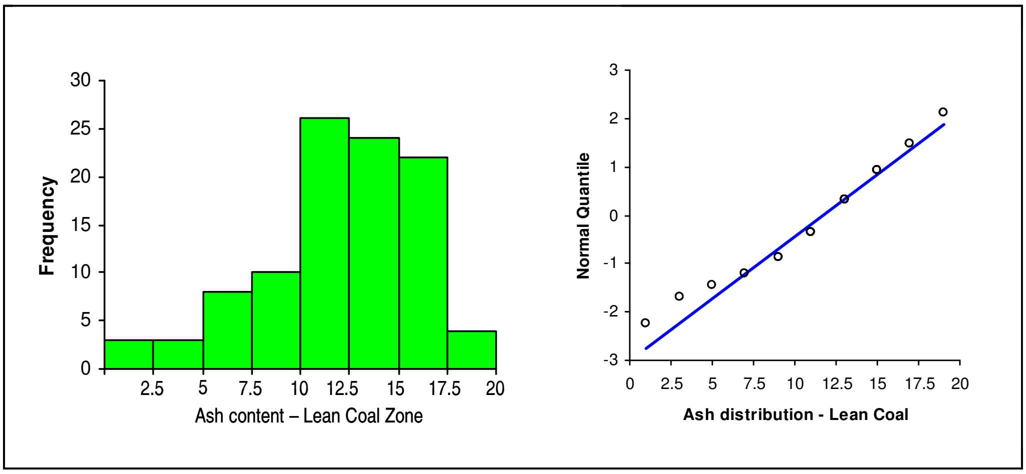


*Figure 22: Ash distribution and histogram of the coal in the Lean Coal Zone in block OM.*

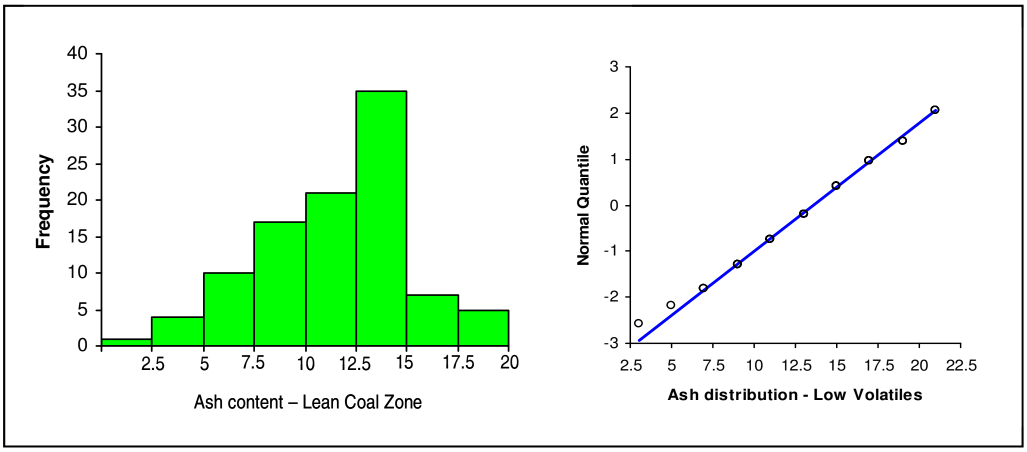


*Figure 23: Ash distribution and histogram of the coal in the Low Volatile Zone in block OM.*

*Table 5: Descriptive statistics of the three different volatile zones present in block OM*

**Descriptive Statistics of Block OM**

| Zone | Mean | Median | Mode | Standard Deviation | Sample Variance | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Medium | 9.6 | 11 | 11 | 3.59 | 12.89 | -0.55 | 0.004 |
| Lean | 11.68 | 12 | 11 | 3.89 | 15.13 | -0.72 | 0.81 |
| Low | 13.62 | 13 | 15 | 3.61 | 13.07 | -0.1 | 0.14 |

To ensure that there is a true difference between the means of the three populations, the data sets are scrutinised by null hypothesis testing. The hypothesis is that the mean of one population equals the mean of one of the other populations.

The formula used for the test statistic comparing two means is as follows:

$$\frac{\left(\bar{x}-\bar{y}\right)-\mu 0}{\sqrt{\frac{s_x^2}{n_1}+\frac{s_y^2}{n_1}}}$$

It is the difference between the two means of two populations with the hypothesised mean subtracted (in this case it is 0). The result is divided by the square root of the sum of the two standard deviations divided by the sample size. The alpha value for this test is 0.05. If the test statistic is beyond the critical value the hypothesis will be rejected. The result of the hypothesis testing is presented in Table 6.

*Table 6: Result from null hypothesis testing of the different volatile populations in block OM*

| **Hypothesis testing of the populations from the different volatile zones in block OM** | | |
|---|---|---|
| Volatile Zone | Test Statistic | Hypothesis accepted or rejected |
| Medium Volatile Zone vs Lean Coal Zone | 3.93 | Rejected |
| Medium Volatile Zone vs Low Volatile Zone | 7.89 | Rejected |
| Lean Coal Zone vs Low Volatile Zone | 3.65 | Rejected |

From the hypothesis testing it is clear that we are studying three significantly different populations within seam 2 in block OM at Leeuwpan Coal Mine.

#### *4.2.2.1 Conclusion*

The descriptive statistics clearly show that the dolerite influenced the ash distribution of seam 2 for the various volatile zones. The mean ash content of seam 2 increases from the medium volatile coal to the low volatile coal. The difference in mean of the distributions indicates a clean coal ash product from the different volatile zones, different recoveries and different amounts of near-density material around the cut point density. The dolerite also influenced the skewness (degree of asymmetry of a distribution around its mean) and kurtosis of the distributions in various ways. The kurtosis is most probably a function of the dolerite emplacement as discussed previously (section 4.2.1).

# 5 NEAR-DENSITY INDEX AND RISK IDENTIFICATION

## 5.1 Introduction

In an earlier section it was clearly demonstrated what the effect of near-density material is on the beneficiation process. The subsequent discussions also indicated the geological control of the depositional environment and the effect of a local dolerite intrusion on the washability characteristics of the number 2 seam.

The next step in the process is to evaluate the reserve block in terms of its washability characteristics and to convert this evaluation into a quantifiable risk applicable in the beneficiation process. Firstly the reserves will be evaluated with the NGM (near gravity material) Index (in the rest of the text the index will be referred to as the near-density material index to conform to nomenclature used throughout the text). Thereafter the valuation will be based on a risk matrix suitable for risk identification.

## 5.2 Near-density Material Index

For the valuation of the reserves, a near-density material index (NDM index) developed by Majumber and Barnwal (2004) for Indian coals, will be used. They developed this index to generate more useful information from sink-float analysis.

The index is based on the fact that coal can be seen as consisting of two major constituents: the part that will form ash and the part that will burn off.

In a sink-float analysis, the ash forming constituent is given as the ash content (usually a percentage) and therefore the non-ash forming constituent will be the remaining material. From the sink-float analysis, recovery curves can be drawn for the non-ash (Rn) and the ash (Ra) forming materials as a function of the cumulative fractional weight of the raw coal as floated. These two curves will define an area between them.

Equations for the calculation of Ra and Rn are:

$$Ra = \frac{Cumulative\_Yield \times Ash\_of\_float}{Feed\_Ash}$$

$$Rn = \frac{Cumulative\_Yield \times (100 - Ash\_of\_float)}{(100 - Feed\_Ash)}$$

The curves of Rn and Ra may be represented by cubic equations of the following form:

$$Rn = ax + bx^2 + cx^3$$

$$Ra = px + qx^2 + rx^3$$

The constants may be empirically derived using the least square method.
The area between Rn and Ra then becomes:

$$= \int_0^1 (ax + bx^2 + cx^3)dx - \int_0^1 (px + qx^2 + rx^3)dx$$

$$= \{6(a-p) + 4(b-q) + 3(c-r)\}/12$$

Near-density material at a certain relative density will give a specific cumulative fractional weight range between the ±0.1 relative densities according to its definition. These cumulative fractional weights can then be plotted on the recovery curves of Rn and Ra, which in turns define another area, namely the area of near-density material given by:

$$= \int_{NDM\,\min}^{NDM\,\max} (ax + bx^2 + cx^3)dx - \int_{NDM\,\min}^{NDM\,\max} (px + qx^2 + rx^3)dx$$

$$= \left[\{6(a-p)x^2 + 4(b-q)x^3 + 3(c-r)x^4\}/12\right]_{x=NDM\,\max}$$

$$- \left[\{6(a-p)x^2 + 4(b-q)x^3 + 3(c-r)x^4\}/12\right]_{x=NDM\,\min}$$

The NDM index is defined as the ratio of the area defined by the near gravity material to the area defined by the recovery curves, where 0 is easy to wash and 1 extremely difficult to wash.

### 5.2.1 Calculation of NDM index for the various Reserve Blocks

The evaluation of the reserve blocks will be done for the three volatile zones into which the reserves are divided as shown before namely, the Medium Volatile Zone, Lean Coal Zone and the Low Volatile Zones. As Leeuwpan Coal Mine is a multi product mine, the evaluation will further more focus on a range of coal products based on the ash content of the specific product that represents current product and future product assemblages.

The NDM index related to each of the products are calculated for each volatile zone and this is plotted to indicate the washing characteristics of the coal at that specific product's density cut point. At the end of the valuation process the findings of this exercise will be summarized.

#### *5.2.1.1 Block OD*

Block OD is the reserve block that was affected most by the dolerite intrusion. The average volatile content of this block is 14.5%. The block was devolatilised sporadically and no lean coal is distinguished here. Therefore the block is modelled into two zones, a Low Volatile Zone and a Medium Volatile Zone. Figure 24 and shows the extent of each zone.

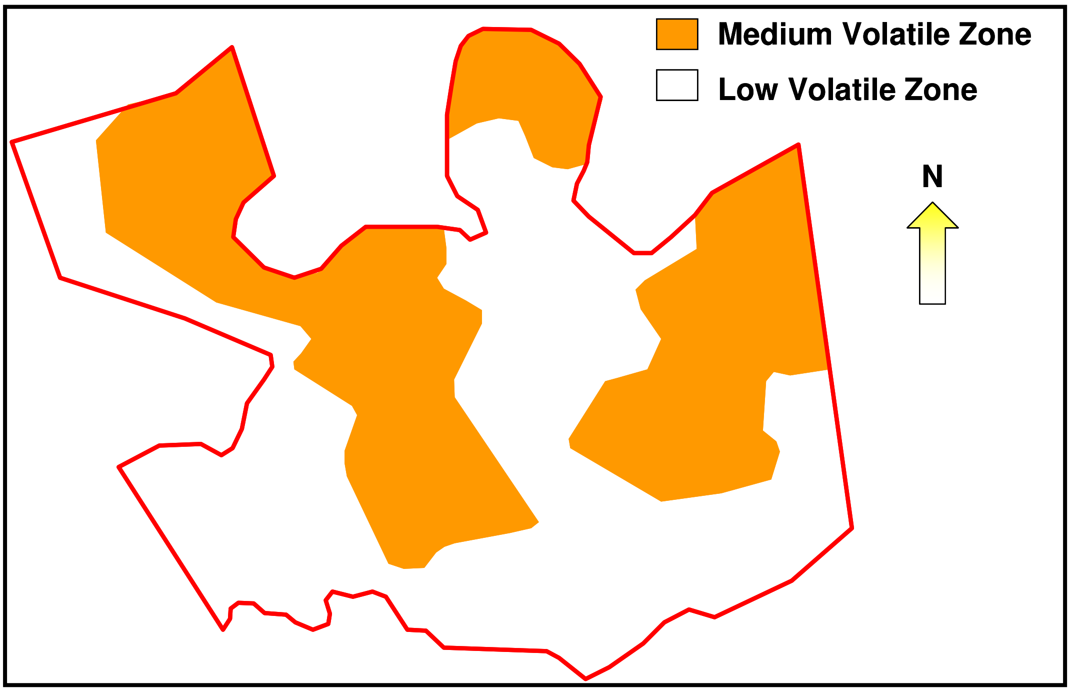


*Figure 24: Extent of Medium Volatile Zone and Low Volatile Coal of seam 2 in block OD.*

The NDM index values for clean coal products at an ash content (air dry) 10%, 12%, 14% and 16% is calculated for both volatile zones. The calculations are based on the formulas discussed earlier in this section. The calculation of the NDM index for the Low Volatile Zone is in Figure 25 and those for the Medium Volatile Zone are shown in Figure 26.

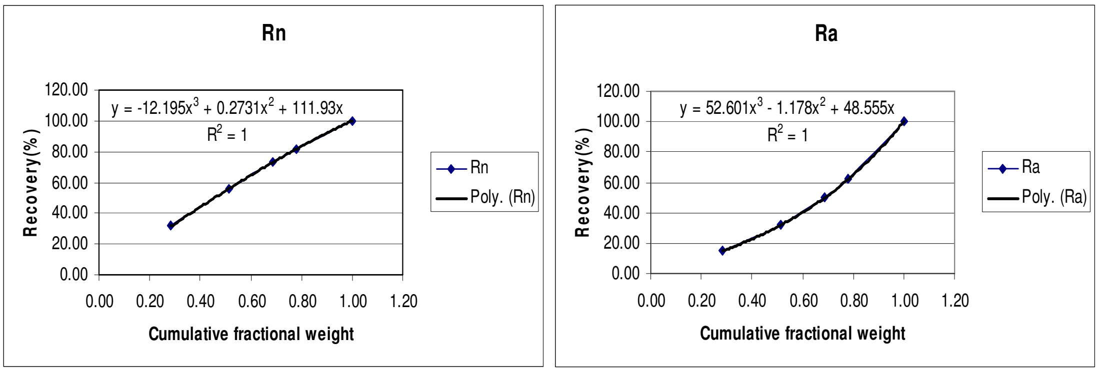
The data from the calculation is summarised in Table 7 and a graphical depiction of the data is given with each point’s theoretical yield in *Figure 27*.

**Calculation of the NDM index for coal from the Low Volatile Zone in block OD.**

**Calculation of Rn and Ra**

| Cumulative Yield | Cumulative Ash | Rn | Ra |
|---|---|---|---|
| 28.52 | 9.85 | 31.67 | 14.93 |
| 51.54 | 11.67 | 56.08 | 31.96 |
| 68.48 | 13.65 | 72.84 | 49.67 |
| 77.99 | 14.96 | 81.70 | 61.99 |
| 100 | 18.82 | 100 | 100 |

Graphical representation of Rn and Ra with their respective equations



**Calculation of NDM index at various clean coal products**

| Clean Coal Product | NDM index |
|---|---|
| 10% Ash | 0.47 |
| 12% Ash | 0.54 |
| 14% Ash | 0.37 |
| 16% Ash | 0.17 |

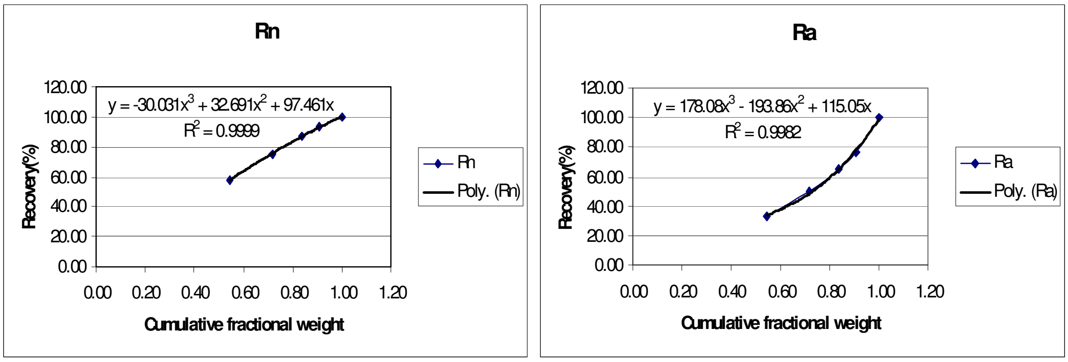
*Figure 25: Calculation of the NDM index for the Low Volatile Zone in block OD.*

**Calculation of the NDM index for the coal in the Medium Volatile Zone in block OD**

**Calculation of Rn and Ra**

| Cumulative Yield | Cumulative Ash | Rn | Ra |
|---|---|---|---|
| 54.32 | 8.86 | 57.86 | 33.35 |
| 71.77 | 9.98 | 75.50 | 49.64 |
| 83.79 | 11.25 | 86.90 | 65.32 |
| 90.77 | 12.13 | 93.21 | 76.30 |
| 100 | 14.43 | 100 | 100 |

Graphical representation of Rn and Ra with their respective equations.



**Calculation of NDM index at various clean coal products**

| Clean Coal Product | NDM index |
|---|---|
| 10% Ash | 0.54 |
| 12% Ash | 0.18 |
| 14% Ash | 0.02 |
| 16% Ash | 0.00 |

*Figure 26: Calculation of the NDM index of the Medium Volatile Zone in block OD.*

*Table 7: Summarised NDM index values at various clean coal products based on ash content for block OD*

| NDM index for seam 2 in block OD | | |
|---|---|---|
| Clean Coal Product | NDM index | |
| (Ash%) | Medium Volatile Zone | Low Volatile Zone |
| 10 | 0.54 | 0.47 |
| 12 | 0.18 | 0.54 |
| 14 | 0.02 | 0.37 |
| 16 | 0.00 | 0.17 |

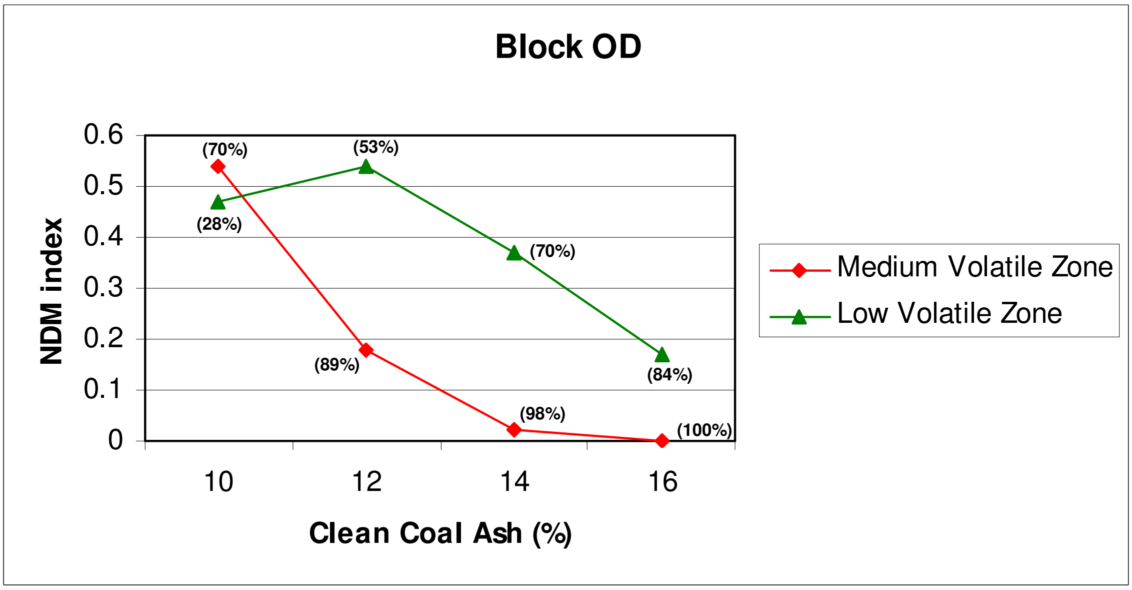


*Figure 27: NDM index values at various clean coal products based on ash contents for the different volatile zones in block OD (the values in brackets indicates the theoretical yield).*

The conclusion and discussion on this graph will be presented with the results from the other two reserve blocks at the end of this section.

### *5.2.1.2 Block OH*

In terms of volatile classification, Block OH is divided into a Medium Volatile Zone and two Low Volatile Zones. The Low Volatile Zones are classified in accordance to their position relevant to the dyke. The two Zones are called the Ridge Area in the middle of the reserve where the dolerite makes a dome and the second area the Border Area, at the eastern border of the reserve where the dolerite cuts transgressively through the succession (see Figure 28).

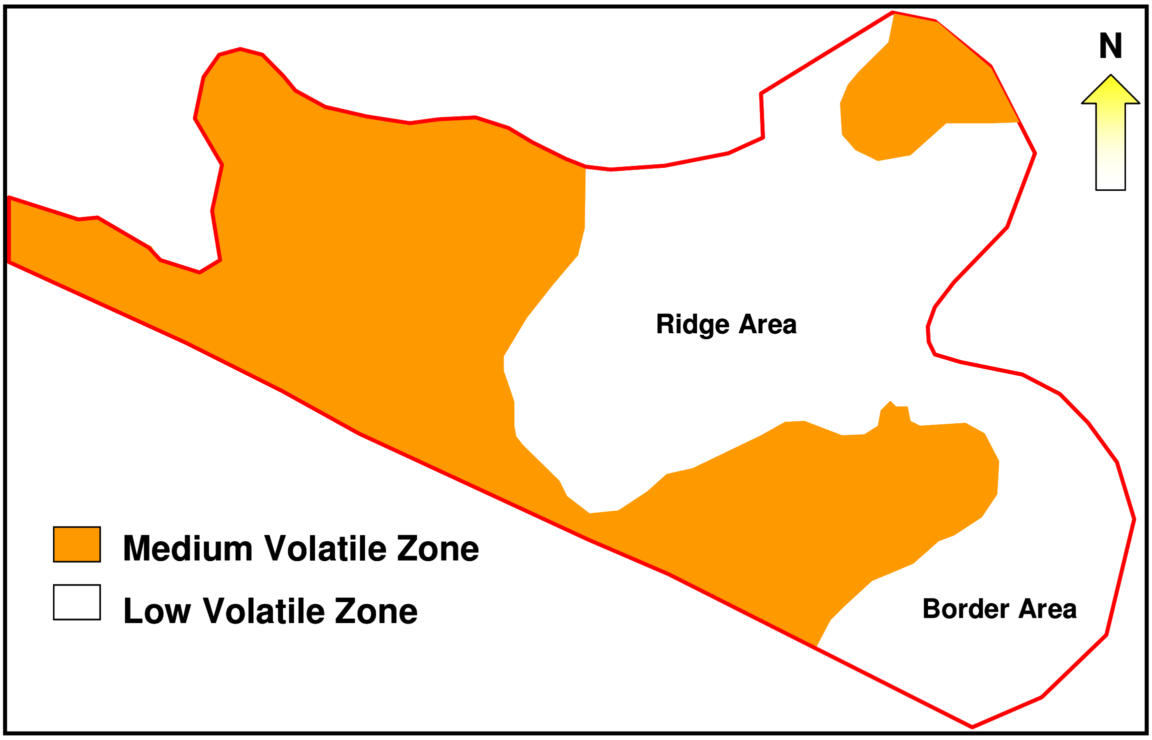


*Figure 28: Distribution of Medium Volatile Zone and Low Volatile Zones in block OH.*

The NDM index calculations for the Medium Volatile Zone and the two Low Volatile Zones (Ridge Area and Boundary Area) are displayed in Figure 29, Figure 30 and Figure 31.

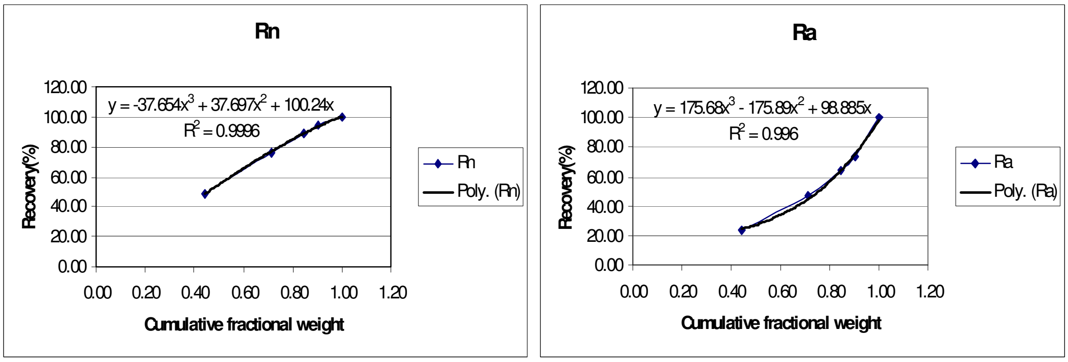
The values obtained from the calculations are summarised in Table 8, and graphically presented in Figure 32.

**Calculation of the NDM index of the coal in the Medium Volatile Zone for block OH**

**Calculation of Rn and Ra**

| Cumulative Yield | Cumulative Ash | Rn | Ra |
|---|---|---|---|
| 44.3 | 9.49 | 48.69 | 23.82 |
| 71.18 | 11.63 | 76.38 | 46.90 |
| 84.79 | 13.28 | 89.29 | 63.80 |
| 90.42 | 14.3 | 94.10 | 73.26 |
| 100 | 17.65 | 100 | 100 |

Graphical representation of Rn and Ra with their respective equations.



**Calculation of NDM index at various clean coal products**

| Clean Coal Product | NDM index |
|---|---|
| 10% Ash | 0.70 |
| 12% Ash | 0.47 |
| 14% Ash | 0.09 |
| 16% Ash | 0.04 |

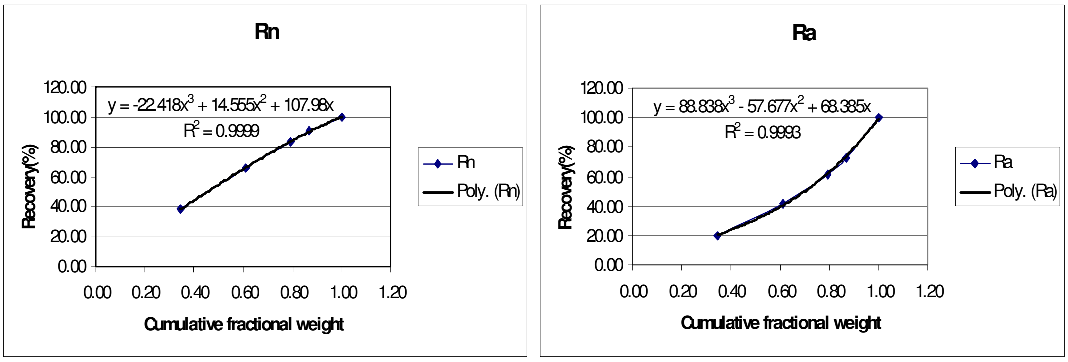
*Figure 29: Calculation of the NDM index at various clean coal products based on ash content for the Medium Volatile Zone of block OH.*

**Calculation of the NDM index of the coal of the Ridge Area, of the Low Volatile Zone for block OH**

**Calculation of Rn and Ra**

| Cumulative Yield | Cumulative Ash | Rn | Ra |
|---|---|---|---|
| 34.5 | 11.58 | 38.20 | 19.83 |
| 61.25 | 13.75 | 66.16 | 41.80 |
| 79.17 | 15.72 | 83.56 | 61.76 |
| 86.81 | 16.99 | 90.25 | 73.20 |
| 100 | 20.15 | 100 | 100 |

Graphical representation of Rn and Ra with their respective equations.



**Calculation of NDM index at various clean coal products**

| Clean Coal Product | NDM index |
|---|---|
| 10% Ash | 0.33 |
| 12% Ash | 0.56 |
| 14% Ash | 0.65 |
| 16% Ash | 0.40 |

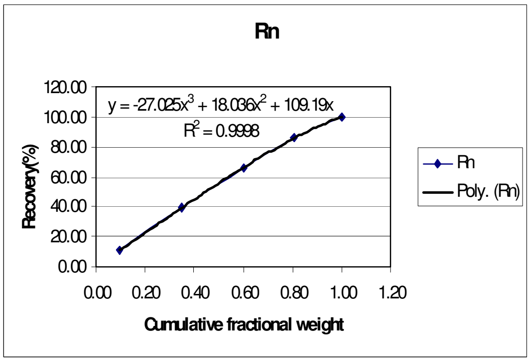
*Figure 30: Calculation of NDM index for the Ridge Area, a Low Volatile Zone, in block OH.*

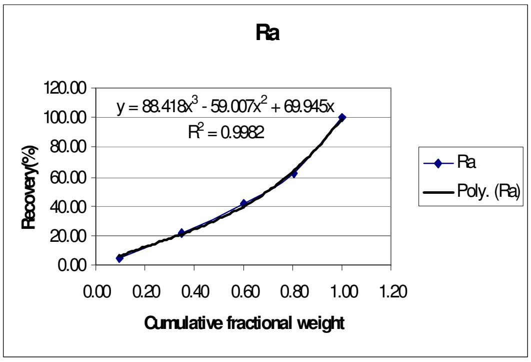
**Calculation of the NDM index of the coal in the Boundary Area, of the Low Volatile Zone for block OH**

**Calculation of Rn and Ra**

| Cumulative Yield | Cumulative Ash | Rn | Ra |
|---|---|---|---|
| 9.68 | 11.2 | 11.22 | 4.63 |
| 35.2 | 14.2 | 39.43 | 21.35 |
| 60.05 | 16.21 | 65.70 | 41.58 |
| 80.51 | 18.1 | 86.09 | 62.25 |
| 100 | 23.41 | 100 | 100 |

Graphical representation of Rn and Ra with their respective equations.





**Calculation of NDM index for various clean coal products**

| Clean Coal Product | NDM index |
|---|---|
| 10% Ash | 0.08 |
| 12% Ash | 0.28 |
| 14% Ash | 0.53 |
| 16% Ash | 0.71 |

*Figure 31: NDM index calculations for various clean coal products based on ash content for the Boundary Area, a Low Volatile Zone, of block OH.*

*Table 8: Summarised NDM index values for seam 2 at various clean coal products based on ash content for block OH*

| NDM index for seam 2 in block OH | | | |
|---|---|---|---|
| Clean Coal Product (Ash%) | NDM index | | |
| | Medium Volatile Zone | Ridge Area, Low Volatile Zone | Boundary Area, Low Volatile Zone |
| 10 | 0.70 | 0.33 | 0.08 |
| 12 | 0.47 | 0.56 | 0.28 |
| 14 | 0.09 | 0.65 | 0.53 |
| 16 | 0.04 | 0.40 | 0.71 |

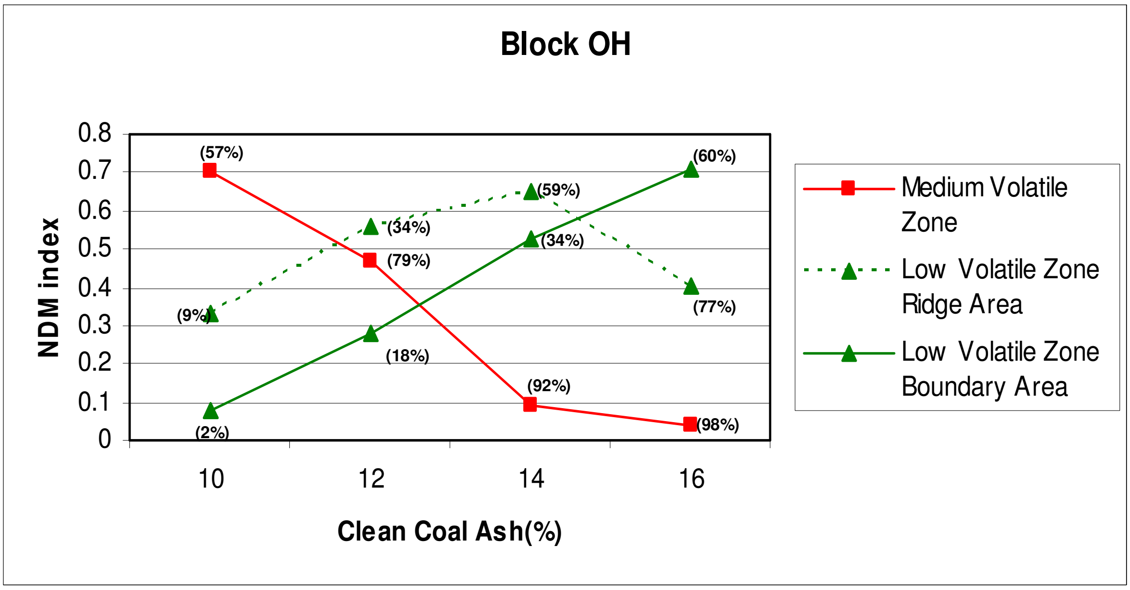


*Figure 32: Graphical representation of the NDM index at various clean coal products with their theoretical yield shown in brackets for seam 2 in block OH.*

The conclusions and findings will be discussed at the end of the section.

### *5.2.1.3 Block OM*

The distributions of the three zones based on volatile content (*Figure 20*) and the influence of the dolerite sill on the washability of the coal have been discussed in section 4.2.2.

Similar to the two previous reserve blocks the calculated NDM index values are listed for the different volatile zones and for various clean coal products and plotted in Figure 33,
Figure 34 and Figure 35. The results are tabulated in Table 9. Summary results are plotted along with the theoretical yield of each clean coal product in Figure 36.

*Table 9: Summarised NDM index values at various clean coal products for seam 2 in block OM*

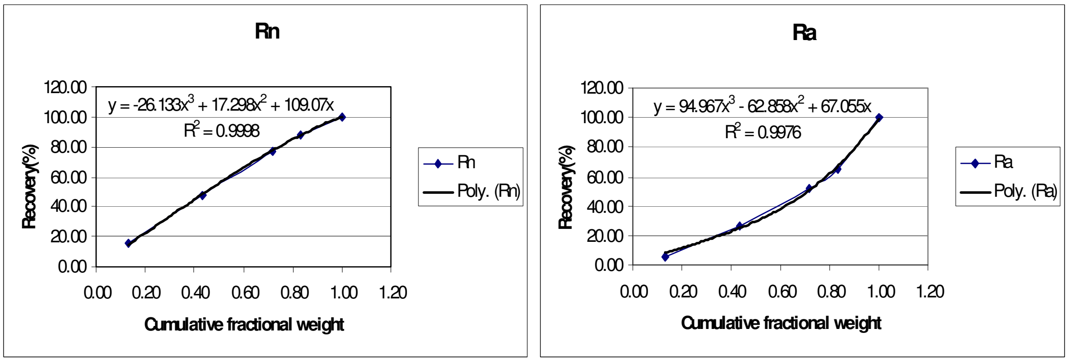
| **NDM index values for seam 2 in block OM** | | | |
|---|---|---|---|
| Clean Coal Product (Ash%) | NDM index | | |
| | Medium Volatile Zone | Lean Coal Zone | Low Volatile Zone |
| 10 | 0.78 | 0.57 | 0.28 |
| 12 | 0.67 | 0.79 | 0.57 |
| 14 | 0.04 | 0.60 | 0.72 |
| 16 | 0.02 | 0.06 | 0.51 |

## Calculation of the NDM index of the coal of the Low Volatile Zone for block OM

**Calculation of Rn and Ra**

| Cumulative Yield | Cumulative Ash | Rn | Ra |
|---|---|---|---|
| 13.31 | 9.92 | 15.29 | 6.12 |
| 43.2 | 13.02 | 47.88 | 26.20 |
| 71.7 | 15.61 | 77.16 | 51.86 |
| 83.3 | 16.79 | 88.39 | 64.81 |
| 100 | 21.58 | 100.0 | 100 |

Graphical representation of Rn and Ra with their respective equations.



**Calculation of NDM index at various clean coal products**

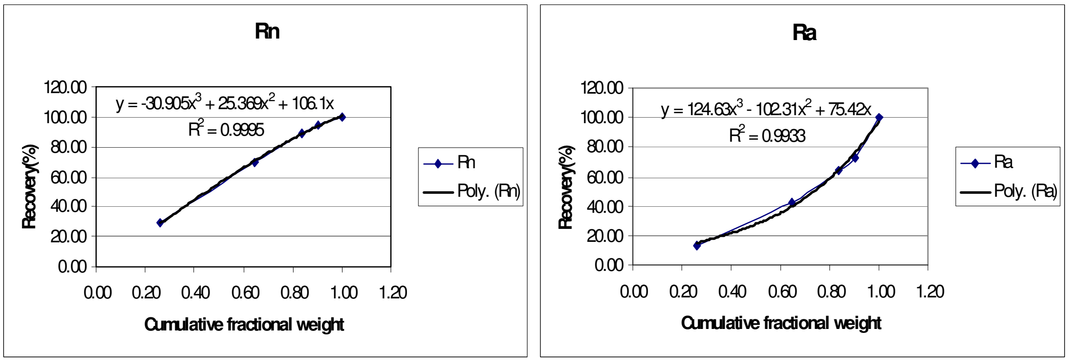
| Clean Coal Product | NDM index |
|---|---|
| 10% Ash | 0.28 |
| 12% Ash | 0.57 |
| 14% Ash | 0.72 |
| 16% Ash | 0.51 |

*Figure 33: NDM index values for the Low Volatile Zone at various clean coal products within block OM.*

## Calculation of the NDM index of the coal of the Lean Coal Zone for block OM

| Calculation of Rn and Ra | | | |
|---|---|---|---|
| **Cumulative Yield** | **Cumulative Ash** | **Rn** | **Ra** |
| 26.15 | 10.32 | 29.27 | 13.58 |
| 64.51 | 13.11 | 69.95 | 42.56 |
| 83.91 | 15.14 | 88.86 | 63.94 |
| 90.19 | 16.05 | 94.49 | 72.85 |
| 100 | 19.87 | 100 | 100 |

Graphical representation of Rn and Ra with their respective equations.



| Calculation of NDM index for various clean coal products | |
|---|---|
| **Clean Coal Product** | **NDM index** |
| 10% Ash | 0.57 |
| 12% Ash | 0.79 |
| 14% Ash | 0.60 |
| 16% Ash | 0.06 |

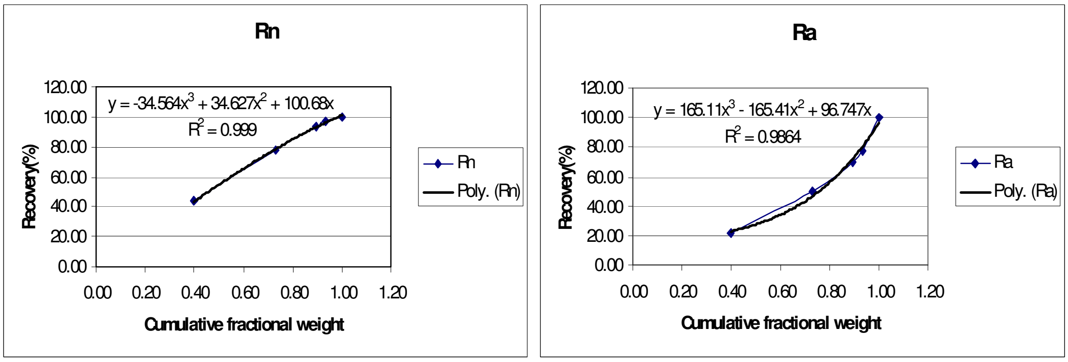
*Figure 34: NDM index values for the Lean Coal Zone in block OM.*

**Calculation of the NDM index of the coal of the Medium Volatile Zone for block OM**

**Calculation of Rn and Ra**

| Cumulative Yield | Cumulative Ash | Rn | Ra |
|---|---|---|---|
| 39.79 | 9.41 | 43.59 | 21.63 |
| 72.88 | 11.92 | 77.63 | 50.19 |
| 89.5 | 13.55 | 93.57 | 70.06 |
| 93.59 | 14.27 | 97.03 | 77.15 |
| 100 | 17.31 | 100 | 100 |

Graphical representation of Rn and Ra with their respective equations.



**Calculation of NDM index for various clean coal products**

| Clean Coal Product | NDM index |
|---|---|
| 10% Ash | 0.78 |
| 12% Ash | 0.67 |
| 14% Ash | 0.04 |
| 16% Ash | 0.02 |

*Figure 35: NDM index values for various clean coal products of the Medium Volatile Zone in block OM.*

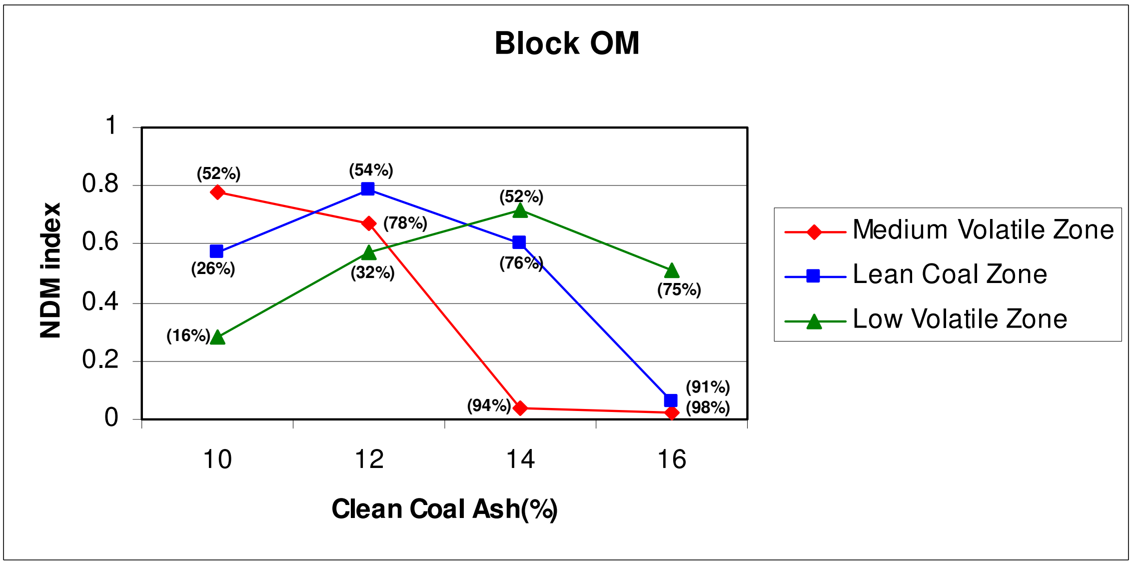


*Figure 36: Graphical plot of the NDM index values for specific clean coal products with their accompanying theoretical yield in brackets for seam 2 in block OM.*

The findings and conclusions of the calculated and plotted NDM index values of different coal products based on ash content is discussed below.

### *5.2.1.4 Observations from the NDM index calculations and graphical plots*

From the graphs of the NDM index versus the ash content of the product the following deductions may be made:

- The graphs clearly identify which coal products based on ash content will be sensitive prone to misplacement and final quality problems due to the amount of near-density material present at the required ash content of the product. These coal products have high NDM index values.
- It clearly indicates which products based on ash content will be effected by near-density material as each product is evaluated separately with a NDM index value.

- The graphs of the NDM index for the different products and their recovery shows that there is no correlation between the theoretical yield of coal at a specific product quality and its NDM index value that is a measure of the washability of the coal at that specific product. As seen in Figure 36, a medium volatile 12% ash coal product indicates that a yield of 78% should be obtained in the beneficiation process. But at this point the NDM index has a high value of 0.6, which can be classified as a “difficult” coal to beneficiate. Due to the high NDM index value, misplacement of material will occur and the required quality of the product will not be obtained or the yield will be far lower than the theoretical yield. Therefore, although the theoretical yield predicted from a sink float analysis might provide an indication of expectancy,, it does not necessarily relate to efficient washability.
- It may be seen that, in reviewing the plot of NDM index values of coal products from the Medium Volatile Zone in the OH reserve block (Figure 32) that the NDM index value increases with a decrease in the ash value of the coal product. This observation holds great importance for the operation of a coal beneficiation plant. Then a 12% ash clean coal product has to be produced (NDM index value = 0.47) from the Medium Volatile Zone in block OH, quality problems may occur due to the washability of the coal. Normal procedure will be to reduce the cut point density the plant is operating at. But from Figure 32 it can clearly be seen that the NDM index value increases as the ash content of the coal product decreases (NDM index value at 10% ash = 0.7). Therefore, the resulting yield from the plant will decrease and the misplacement of material will increase, amplifying product quality problems.
- The graphs for the NDM index values of the different reserve blocks indicate that due to the influence of the dolerite intrusion the assessment of the NDM index for seam 2 should be done per reserve block volatile zone due to the variations observed.

#### *5.2.1.5 Conclusion*

The technique developed by Majumbar and Barnwall (2004) may be used to evaluate the reserves of Leeuwpan Coal Mine. Their method of calculating the NDM index values for various coal products is used to evaluate the washability of the in situ coal reserves. This method is more quantitive and precise than the popular 30% definition of near-density material, traditionally applied.

The result of the graphical representation of the near-density material index indicates that this a very useful method to evaluate any coal resource or reserve with regards to washability. It is a quick and easy method to use and delivers a vast amount of information. Information obtainable relates to the difficulty to produce a certain product and may be utilised to establish blending strategies, in plant design and plant operation criteria as well as mine scheduling.

## *5.3 The risk matrix and its application to the reserves at Leeuwpan Coal Mine*

#### *5.3.1.1 Formulation of a Risk Matrix*

The challenge for a coal mining operation is to constantly meet the changing market demand. It was determined from the valuation process that certain types of coal can only be washed to obtain clean coal qualities with extreme difficulty, and furthermore that there is the added risk of misplacement. The theoretical yield is also variable for the product ranges, and together with variable risk of misplacement the probability to produce specific products is negatively influenced.

Based on the above statements, a risk identification matrix was constructed for Leeuwpan Coal Mine, which incorporates both the NDM index and theoretical yields. When the NDM index values and yields of the coal for various clean coal products are plotted, the influence of any product demand changes on the operation may be readily determined.

On the y-axis, the NDM index of the coal product based on ash content is plotted against the theoretical yield on the x-axis. The plot area can be sub-divided into areas of varying risk, which will constitute the risk matrix. In the risk matrix developed for Leeuwpan Coal Mine, nine risk areas are identified.

The basis for the division, which is arbitrary, refers to the relative ease with which a coal can be washed i.e. an index value less than 0.4 is “easy” to wash, between 0.4 and 0.6 it is “relatively difficult” to wash the coal, and above 0.6 it will be “very difficult” to obtain the product. Therefore the risk increases with an increase in the NDM index value. Similarly, theoretically predicted yields above 75% are regarded as good, yields between 75% and 50% are regarded as moderate and yields of less than 50% are considered poor.

It is obvious that, as the relative density is lowered to produce lower ash coal, less product will be obtained as a result of the lower yield. In the context of Leeuwpan Coal Mine, which has fixed tonnages to deliver, the decrease in yield will have significant repercussions. More time will have to be allocated to produce low yield products and therefore the saleable tonnages will decrease, which in turn has an effect on the operations income. To summarize, a decrease in yield leads to a drop in the profit margin which lead to an increased financial risk.

By using the above-mentioned argument the six areas of the risk matrix are classified as follows: very low risk (E.H), low risk (E.M; RE.M), low to medium risk (RE.M), medium to high risks (E.L; D.H), high risk (RE.L; D.M), and very high risk (D.L).

For illustration purposes Block OM's NDM index and theoretical yield for the different volatile zones is plotted in Figure 37.

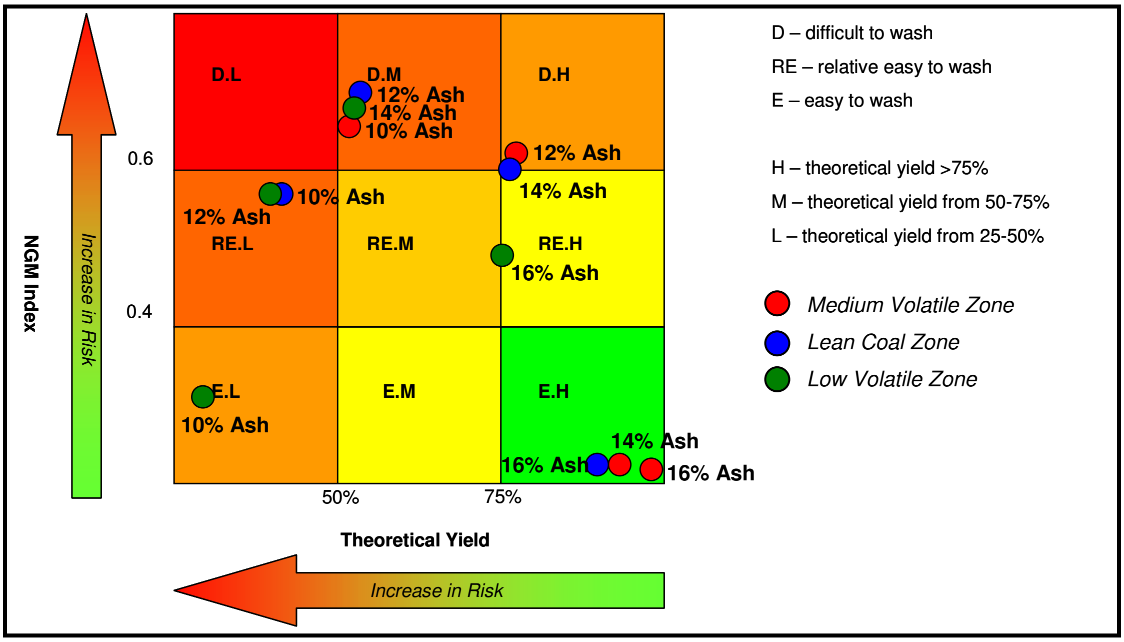


*Figure 37: Coal products based on ash content is plotted on the risk matrix for different volatile matter zones, seam 2, Block OM.*

The matrix provides a visual and effective way to screen the probability to produce a certain coal ash product. The ideal product assemblages normally reports to the E.H. (green) block, the E.M., RE.H. (yellow) blocks and the RE.M. (gold) block. This information may now be applied to the reserves at Leeuwpan Coal Mine.

### *5.3.1.2 Application of Risk Matrix at Leeuwpan Coal Mine*

Now that an effective matrix to indicate the risk and probability for various clean coal products has been established, it may be applied to all the reserves at Leeuwpan Coal Mine.

The reserve blocks are normally divided into smaller mining blocks for scheduling purposes. The NDM index values for a specific clean coal product for each block may be calculated and so its theoretical yield. This information can be inserted into the risk matrix and a probability value (colour) can be given to each block. Figure 38 shows the result of this process for the mining blocks in block OM as determined for a 14% ash coal product.

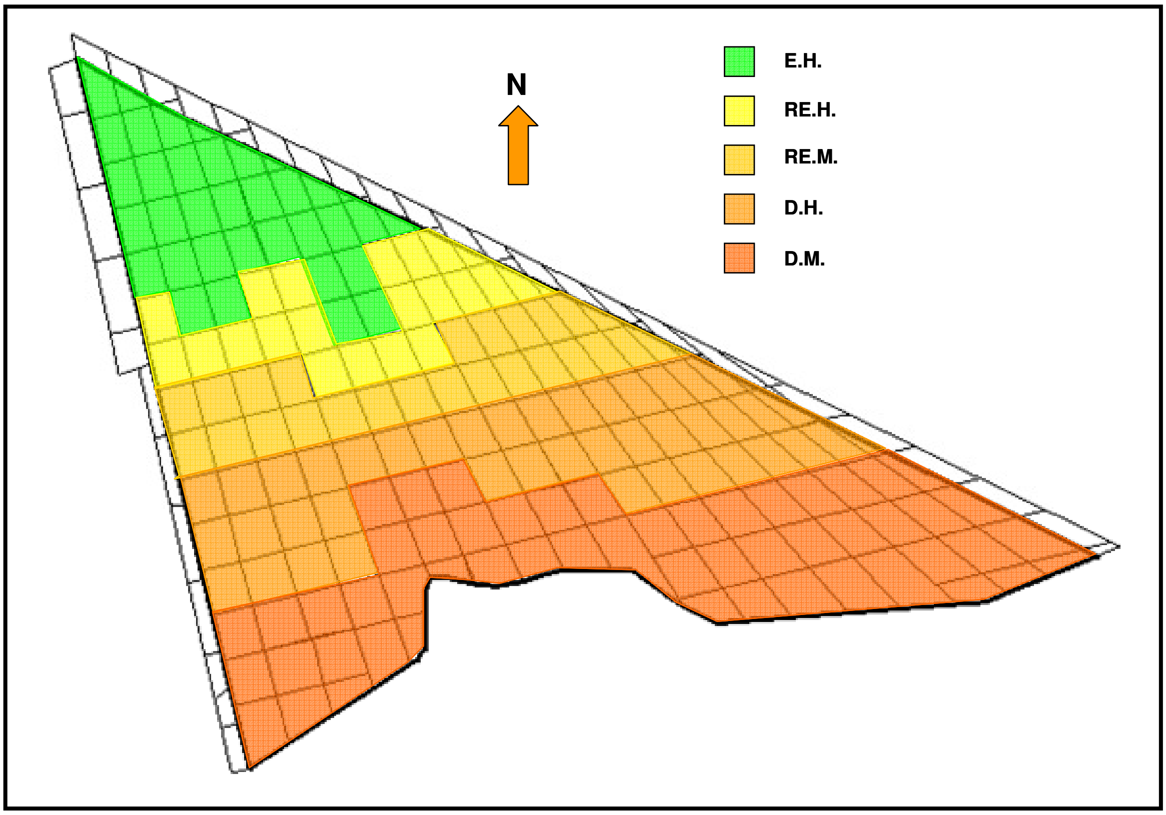


*Figure 38: Risk indicator colours of the mining blocks in reserve block OM for a 14% ash coal product.*

### *5.3.1.3 Conclusion*

The risk matrix, with its nine blocks indicating probable associated beneficiation risk, clearly indicates the probability of producing specific clean coal products from a certain coal seam or volatile zone. According to the risk matrix the optimal product to mine will fall in the E.H. (green) block, due to the "ease" of beneficiation and high theoretical yield.

Thereafter the probability to produce a product decreases due to the increasing "difficulty" to beneficiate, and decreases in the expected theoretical yield. Products that plot outside of the green and yellow areas holds additional risk for the coal mine and a premium should be paid on these products if the market demands it. Therefore the risk matrix is not only a tool for mine planning and the beneficiation plant to optimise product tons and risk management, but is also a tool for the marketers that should be utilised in contract negotiations and product placement in the market.

The largest contribution of the application of the risk matrix is made in the production planning of a coal mine. By building the risk matrix into the mining blocks of a reserve area, the mining schedule can be optimised to minimise the risk of near-density material in the beneficiation process and maximising product yield. This process requires that the marketing plan and the production plan have to be in balance, due to the fact that certain products may only be available in certain time periods and that producing higher risk product tons takes longer to produce than low risk product tons due differences in recoveries and quality control.

The risk matrix may also be applied in the pre-feasibility and feasibility stages of a coal project. The matrix gives an indication of the kind of product that can be obtained with relative ease, which will depend on its placement in the market. The metallurgist can also utilise this information to determine the optimal beneficiation process to ensure that the mine can supply coal, which has a low risk probability, with an optimal yield. This may give the project a strategic advantage as it may be geared to supply coal to a niche market.

The risk matrix is seen as a tool which merges the inherent coal property constraints of the coal resources with the constraints in the washing plant to ensure that optimal value is extracted throughout the process.

# 6 FINANCIAL EVALUATION OF RISK

Now that beneficiation risk can be managed through the incorporation of the risk matrix within the production plan it will be attempted to demonstrate if value is added by its application.

Two scenarios will be looked at to determine the effect on the revenue of Leeuwpan Coal Mine for three products which is produced from seam 2. These products are tabled in Table 10 with their respective ash contents.

*Table 10: Clean coal products produced from seam 2 with associated ash contents*

| Product | Ash content (%) |
|---|---|
| Pulverised coal injection (PCI) to Vanderbijl Steel works | 12 |
| Direct reduction (DR) to Vanderbijl Steel works & Dunswart | 15 |
| Low volatile coal to SALCARB | 16 |

In the first scenario, the average yield for the clean coal ash product for the reserve blocks is used. The calculation of the revenue for this scenario can be seen in Figure 39.

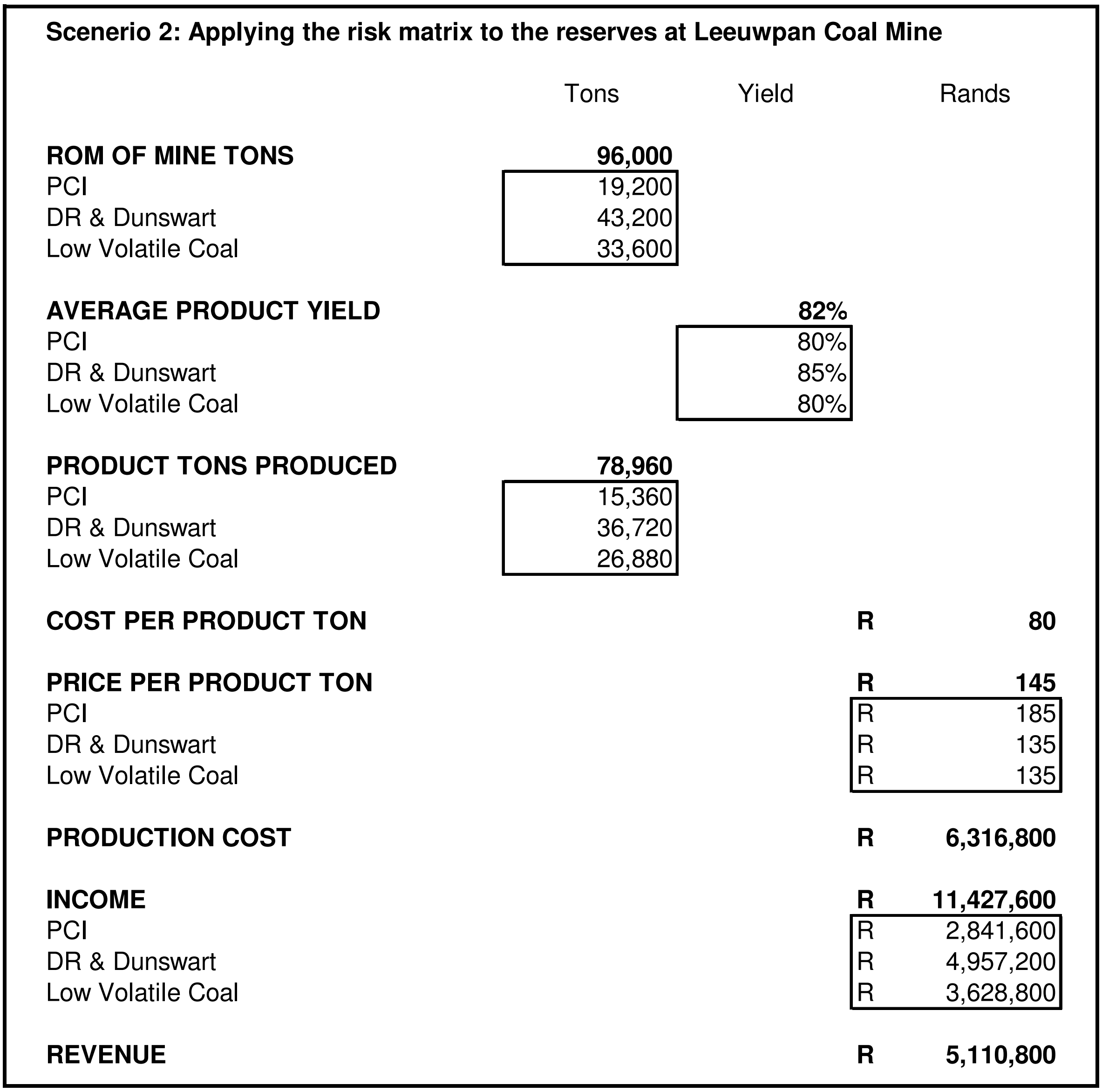
**Scenerio 1: Applying the average yield to the reserves at Leeuwpan Coal Mine**

| | Tons | Yield | Rands |
|---|---|---|---|
| **ROM OF MINE TONS** | **96,000** | | |
| PCI | 19,200 | | |
| DR & Dunswart | 43,200 | | |
| Low Volatile Coal | 33,600 | | |
| **AVERAGE PRODUCT YIELD** | | **68%** | |
| PCI | | 58% | |
| DR & Dunswart | | 72% | |
| Low Volatile Coal | | 68% | |
| **PRODUCT TONS PRODUCED** | **65,088** | | |
| PCI | 11,136 | | |
| DR & Dunswart | 31,104 | | |
| Low Volatile Coal | 22,848 | | |
| **COST PER PRODUCT TON** | | | **R 80** |
| **PRICE PER PRODUCT TON** | | | **R 144** |
| PCI | | | R 185 |
| DR & Dunswart | | | R 135 |
| Low Volatile Coal | | | R 135 |
| **PRODUCTION COST** | | | **R 5,207,040** |
| **INCOME** | | | **R 9,343,680** |
| PCI | | | R 2,060,160 |
| DR & Dunswart | | | R 4,199,040 |
| Low Volatile Coal | | | R 3,084,480 |
| **REVENUE** | | | **R 4,136,640** |

*Figure 39: Revenue calculation for the clean coal ash products based on the average yield from seam 2 at Leeuwpan Coal Mine.*

In the second scenario, the risk matrix is integrated with the production plan. This means that the probability to produce certain coal products at a specific ash content is incorporated within the production schedule. Therefore the blocks most suited to certain products, (products that fall into the green block of the risk matrix), is dedicated to that specific product.

When the applicable blocks are mined the plant will produce the product for which the block was allocated. The reduced risk leads to optimal yields and efficient product quality control. For scenario 2 the ROM is aligned with the product being produced and average yield increases dramatically if the process is managed according to the risk matrix. In Figure 40 the revenue calculation for scenario 2 can be seen.



**Scenerio 2: Applying the risk matrix to the reserves at Leeuwpan Coal Mine**

| | Tons | Yield | Rands |
|---|---|---|---|
| **ROM OF MINE TONS** | **96,000** | | |
| PCI | 19,200 | | |
| DR & Dunswart | 43,200 | | |
| Low Volatile Coal | 33,600 | | |
| **AVERAGE PRODUCT YIELD** | | **82%** | |
| PCI | | 80% | |
| DR & Dunswart | | 85% | |
| Low Volatile Coal | | 80% | |
| **PRODUCT TONS PRODUCED** | **78,960** | | |
| PCI | 15,360 | | |
| DR & Dunswart | 36,720 | | |
| Low Volatile Coal | 26,880 | | |
| **COST PER PRODUCT TON** | | | **R 80** |
| **PRICE PER PRODUCT TON** | | | **R 145** |
| PCI | | | R 185 |
| DR & Dunswart | | | R 135 |
| Low Volatile Coal | | | R 135 |
| **PRODUCTION COST** | | | **R 6,316,800** |
| **INCOME** | | | **R 11,427,600** |
| PCI | | | R 2,841,600 |
| DR & Dunswart | | | R 4,957,200 |
| Low Volatile Coal | | | R 3,628,800 |
| **REVENUE** | | | **R 5,110,800** |

*Figure 40: Revenue calculation for clean coal ash product based on the integration of the risk matrix and production plan.*

There is a revenue difference of R 970,000 between the two scenarios in favour of the scenario based on the production plan based on the risk matrix.

The reason therefore is that Leeuwpan Coal Mine has a maximum throughput and a fixed amount of seam 2 that it can treat during a month. For this reason the only way to increase revenue is to optimise the yield of the product being produced.

In conclusion the application of the risk matrix to the reserve has a positive effect on the net value of any coal project.

# 7 SUMMARY AND CONCLUSIONS

The objective of the treatise is to establish a risk management strategy to effectively manage the risk associated with near-density material in the beneficiation process. The methodology of Kerzner (2001) was followed to ensure a successful risk management strategy.

Four hypotheses were postulated to ensure that the process of risk management could be adhered to. These hypotheses have been proved in the previous sections and will be revisited here in accordance to the risk management process.

- *Assessment in terms of identification and analyzing the risk*

Firstly the problem of near-density material had to be understood in the beneficiation process. The problem with near-density material is that it negatively influences the beneficiation properties of the coal. The higher the amount of near-density material, the more misplacement of discard to product or product to discard can occur. The effect of near-density material varies between the different separations components in the beneficiation plant.

The second part was to establish the origin of the problem of near-density material. If the problem is understood the risk can be managed.

This part of the problem was ascribed to the ash distribution within the coal seam, the depositional environment and the influence of external factors such as the dolerite intrusion.

The ash distribution of seam 2 in the various reserve blocks indicated that all coal has near-density material and that the amount of near-density material is related to the cut-point density in the beneficiation process. Therefore the ash distribution's kurtosis and skewness influences the amount of near-density material within the process at a certain relative density.

It was determined through a literature study of the depositional environment of the Delmas coal, with special reference to seam 2, that the ash distribution of a coal seam is determined by the environment in which the coal was formed. The ash distribution within the seam is a factor of the influx of inorganic material (clay, shale and other minerals) into the depositional environment. To conclude the ash distribution, and therefore the distribution of near-density material, is an inherent quality of the coal seam and cannot be manipulated before the beneficiation process.

Scattergrams of the volatile matter and the ash content of seam 2 in the various reserve blocks indicated that the dolerite intrusion affected the coal at Leeuwpan Coal Mine. The correlation factors between the volatiles and ash content varied for the different reserve blocks due to the variability of the dolerite intrusion, seam thickness, moisture content of the seam and the thickness of the tillite.

Given the fact that the dolerite affected seam 2, it was found that it is probable that it also affected the washability of the coal. The ash distributions of the three different volatile zones in block OM were studied. The distributions mean moved to the left (increased value) from the medium volatile to the low volatiles. From these distributions it is clear that the dolerite had an enormous affect on the ash distribution, and therefore it affects the washability of the coal.

In terms of identification of the risk the NDM index of Majumbar and Barnwall (2004) was utilised to identify the risk of near-density material. This approach gives a graphical visualisation of the amount of near-density material at a specific clean coal ash product. It clearly indicates the washability probability of a certain clean coal ash product.

- *Developing risk handling options*

The NDM index is also a tool to be utilised for risk handling options. It indicates the product ranges that can be produced without a big risk of near-density material in the beneficiation process. It can also be used to inform production personnel on the management of near-density material in the daily operation of a beneficiation process. Finally it can be utilised for coal blending options between various reserve blocks with different ash distributions.

The evolution of the NDM index into the risk matrix provides another method of risk handling. The risk matrix indicates the probability of producing a certain clean coal ash product at Leeuwpan Coal Mine. This probability is based on the washability of the coal as well as the theoretical yield of the specific product. This method should be utilised by marketers in product placement and during the feasibility study of a project. The aim is to produce products with the lowest associated beneficiation risk. The delivery of products with a higher associated beneficiation risk should only be justified if the premium on the price covers the additional production costs.

- *Planning for the risk*

By incorporating the risk matrix into the production plan the risk can pro-actively be planned for and minimised through the beneficiation process. The example used is the incorporation of the risk matrix with the mining blocks of block OM. A production schedule can be constructed to so that the maximum amount of a certain clean coal product can be produced with the least risk of near-density material.

As mentioned earlier the risk matrix should form part of any feasibility study of coal projects to ensure that the plant design conforms to the product risk with regards to near-density material.

- *Monitoring of the risk to determine improvement*

The financial evaluation of the two different scenarios indicated that if the risk is managed an improvement in the net revenue of Leeuwpan Coal Mine will be achieved. This is only possible if the risk can be managed through-out the value chain. With regards to risk management the improvement is due to the fact that the problem of near-density material is understood and that the tools have been developed to manage the risk accordingly.

In conclusion it may be stated that Leeuwpan Coal Mine has now adopted this method of valuation and that this has resulted in changes to the mine plan, which in turn have facilitated both optimal product quality and product yield.

# 8 ACKNOWLEDGEMENTS

The author wishes to thank the management team of Leeuwpan Coal Mine for the opportunity to compile this treatise, and their support in adopting the near-density material index as a means of valuation at Leeuwpan Coal Mine. Lastly I want to thank Frans Schutte and Fanie Boshoff who taught me the finer points of coal geology and beneficiation.

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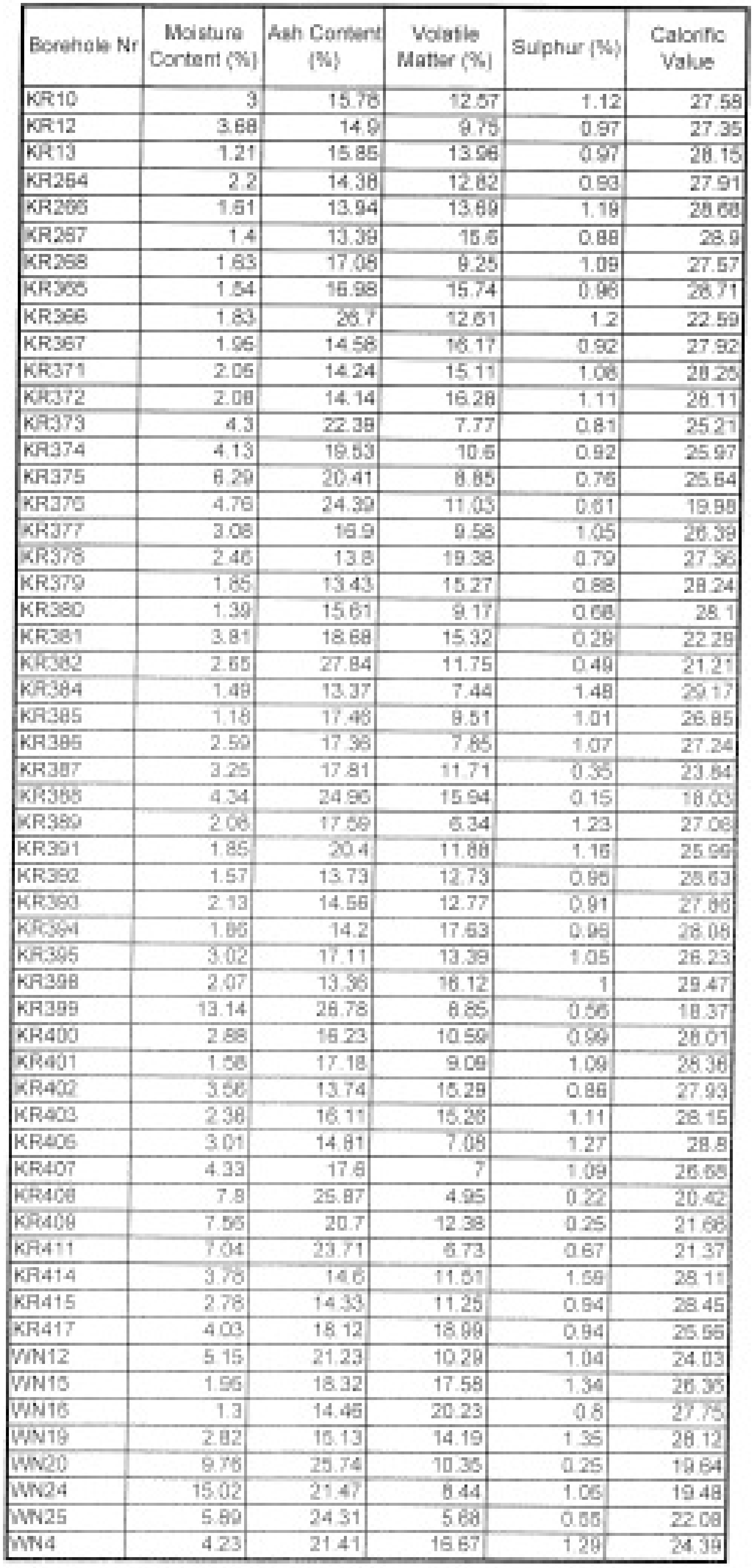
# 10 APPENDIXES

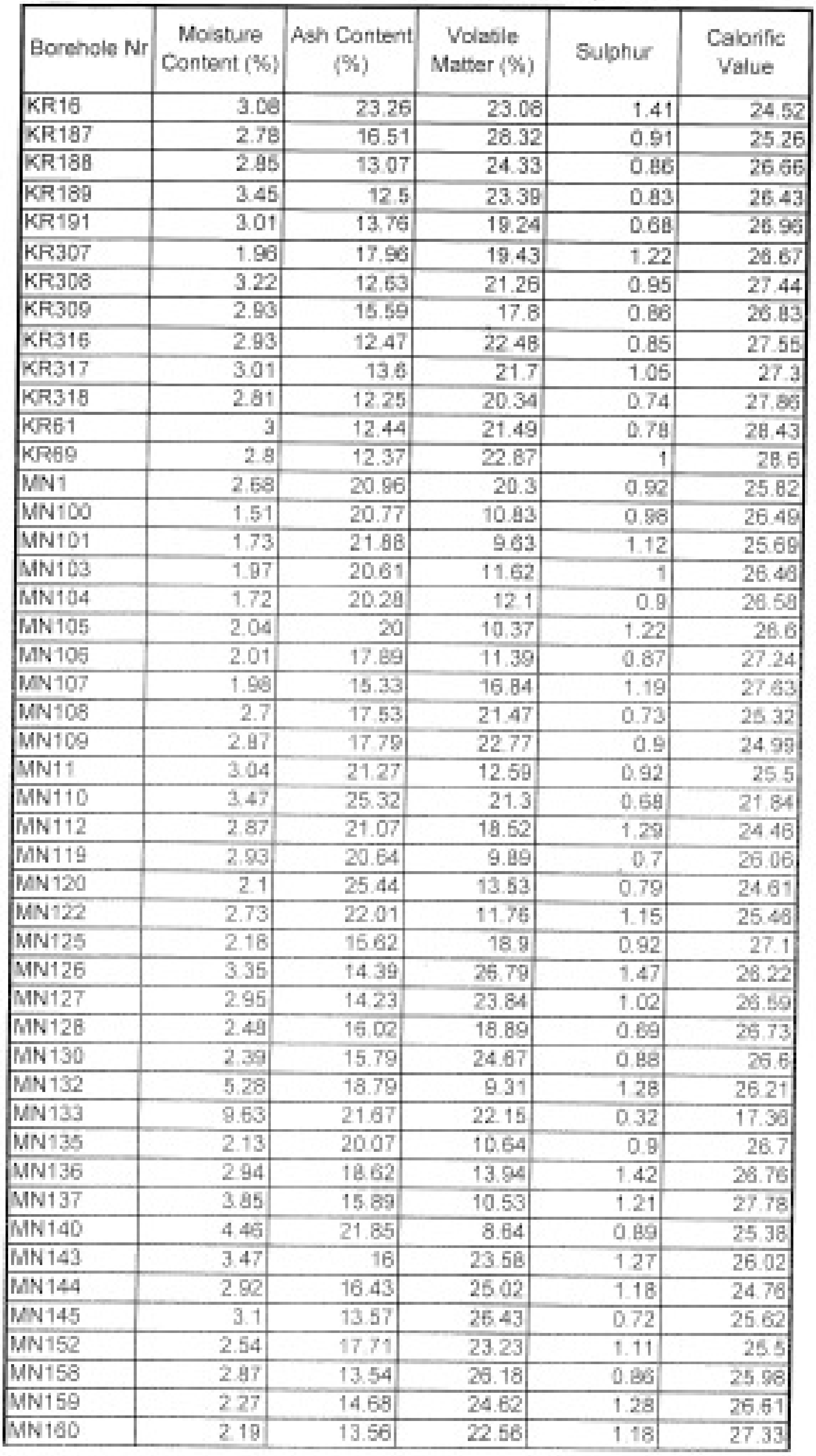
## 10.1 Appendix 1: List of Boreholes with Proximate Analysis

***List of boreholes in block OD with the respective sink values from the proximate analysis for seam 2.***

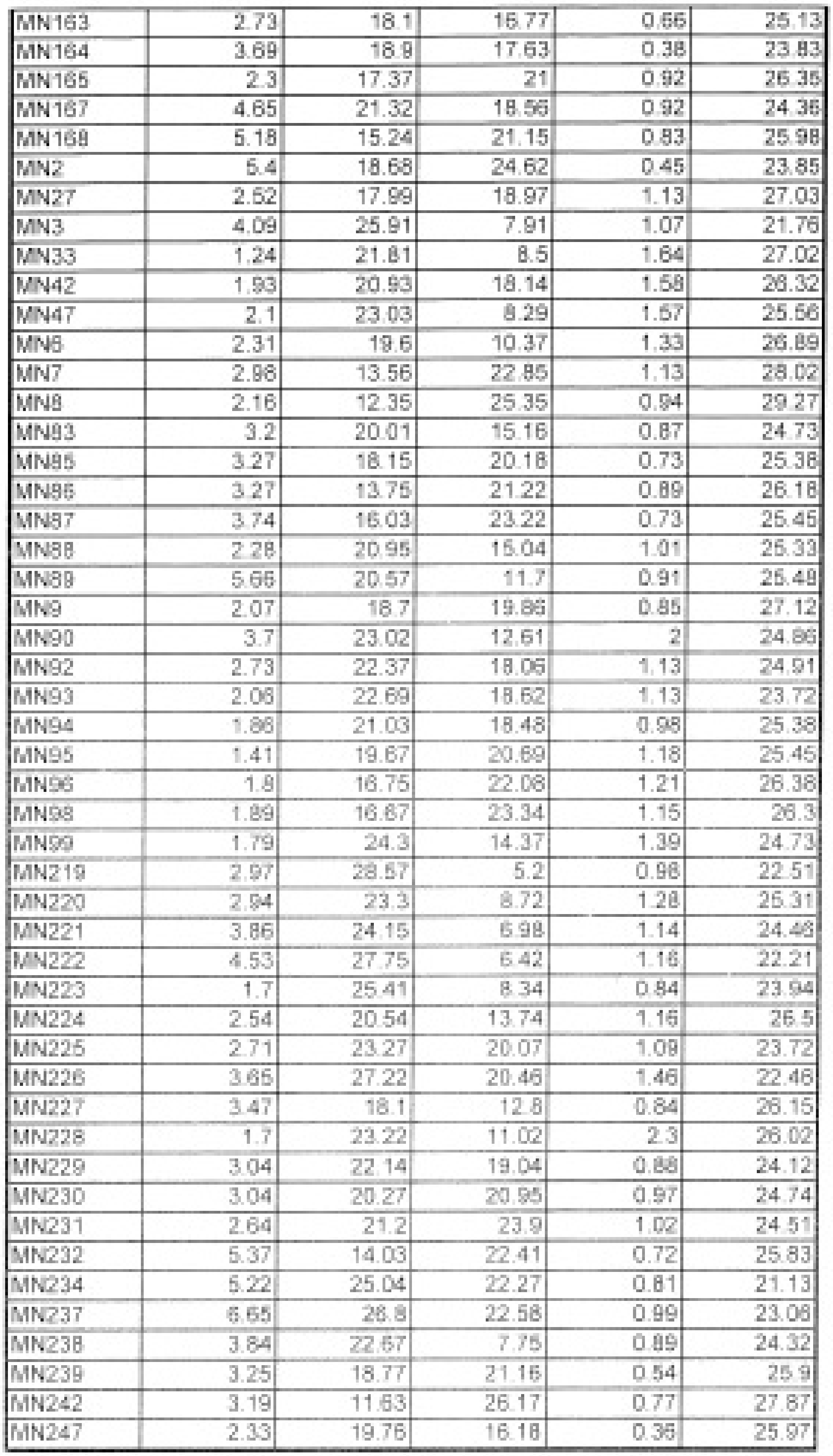


| Borehole Nr | Moisture Content (%) | Ash Content (%) | Volatile Matter (%) | Sulphur (%) | Calorific Value |
|---|---|---|---|---|---|
| KR10 | 3 | 15.76 | 12.57 | 1.12 | 27.58 |
| KR12 | 3.68 | 14.9 | 9.75 | 0.97 | 27.35 |
| KR13 | 1.21 | 15.85 | 13.96 | 0.97 | 28.15 |
| KR264 | 2.2 | 14.38 | 12.82 | 0.93 | 27.91 |
| KR266 | 1.61 | 13.94 | 13.69 | 1.19 | 28.68 |
| KR267 | 1.4 | 13.39 | 15.6 | 0.88 | 28.9 |
| KR268 | 1.63 | 17.08 | 9.25 | 1.09 | 27.57 |
| KR365 | 1.54 | 16.98 | 15.74 | 0.96 | 28.71 |
| KR366 | 1.63 | 26.7 | 12.61 | 1.2 | 22.59 |
| KR367 | 1.96 | 14.58 | 16.17 | 0.92 | 27.92 |
| KR371 | 2.05 | 14.24 | 15.11 | 1.08 | 28.25 |
| KR372 | 2.08 | 14.14 | 16.28 | 1.11 | 28.11 |
| KR373 | 4.3 | 22.39 | 7.77 | 0.81 | 25.21 |
| KR374 | 4.13 | 19.53 | 10.6 | 0.92 | 25.97 |
| KR375 | 6.29 | 20.41 | 8.85 | 0.76 | 25.64 |
| KR376 | 4.76 | 24.39 | 11.03 | 0.61 | 19.98 |
| KR377 | 3.08 | 16.9 | 9.58 | 1.05 | 26.39 |
| KR378 | 2.46 | 13.8 | 19.38 | 0.79 | 27.36 |
| KR379 | 1.85 | 13.43 | 15.27 | 0.88 | 28.24 |
| KR380 | 1.39 | 15.61 | 9.17 | 0.68 | 28.1 |
| KR381 | 3.81 | 18.68 | 15.32 | 0.29 | 22.29 |
| KR382 | 2.65 | 27.84 | 11.75 | 0.49 | 21.21 |
| KR384 | 1.49 | 13.37 | 7.44 | 1.48 | 29.17 |
| KR385 | 1.16 | 17.46 | 8.51 | 1.01 | 26.85 |
| KR386 | 2.59 | 17.36 | 7.85 | 1.07 | 27.24 |
| KR387 | 3.25 | 17.81 | 11.71 | 0.35 | 23.84 |
| KR388 | 4.34 | 24.96 | 15.94 | 0.15 | 18.03 |
| KR389 | 2.06 | 17.59 | 6.34 | 1.23 | 27.08 |
| KR391 | 1.85 | 20.4 | 11.88 | 1.16 | 25.96 |
| KR392 | 1.57 | 13.73 | 12.73 | 0.95 | 28.63 |
| KR393 | 2.13 | 14.56 | 12.77 | 0.91 | 27.86 |
| KR394 | 1.86 | 14.2 | 17.63 | 0.96 | 28.08 |
| KR395 | 3.02 | 17.11 | 13.39 | 1.05 | 26.23 |
| KR398 | 2.07 | 13.36 | 16.12 | 1 | 29.47 |
| KR399 | 13.14 | 28.78 | 8.85 | 0.56 | 18.37 |
| KR400 | 2.88 | 16.23 | 10.59 | 0.99 | 28.01 |
| KR401 | 1.58 | 17.18 | 9.09 | 1.09 | 26.36 |
| KR402 | 3.56 | 13.74 | 15.29 | 0.86 | 27.93 |
| KR403 | 2.38 | 16.11 | 15.26 | 1.11 | 28.15 |
| KR406 | 3.01 | 14.81 | 7.08 | 1.27 | 28.8 |
| KR407 | 4.33 | 17.6 | 7 | 1.09 | 26.68 |
| KR408 | 7.8 | 26.87 | 4.95 | 0.22 | 20.42 |
| KR409 | 7.56 | 20.7 | 12.38 | 0.25 | 21.66 |
| KR411 | 7.04 | 23.71 | 6.73 | 0.67 | 21.37 |
| KR414 | 3.76 | 14.6 | 11.51 | 1.59 | 28.11 |
| KR415 | 2.76 | 14.33 | 11.25 | 0.94 | 28.45 |
| KR417 | 4.03 | 18.12 | 18.99 | 0.94 | 25.56 |
| WN12 | 5.15 | 21.23 | 10.29 | 1.04 | 24.03 |
| WN15 | 1.96 | 18.32 | 17.58 | 1.34 | 26.36 |
| WN16 | 1.3 | 14.46 | 20.23 | 0.6 | 27.75 |
| WN19 | 2.82 | 16.13 | 14.19 | 1.35 | 28.12 |
| WN20 | 9.76 | 25.74 | 10.36 | 0.25 | 19.64 |
| WN24 | 15.02 | 21.47 | 8.44 | 1.06 | 19.48 |
| WN25 | 5.89 | 24.31 | 5.68 | 0.66 | 22.08 |
| WN4 | 4.23 | 21.41 | 16.67 | 1.29 | 24.39 |

***List of boreholes in block OH with the respective sink values from the proximate analysis for seam 2.***

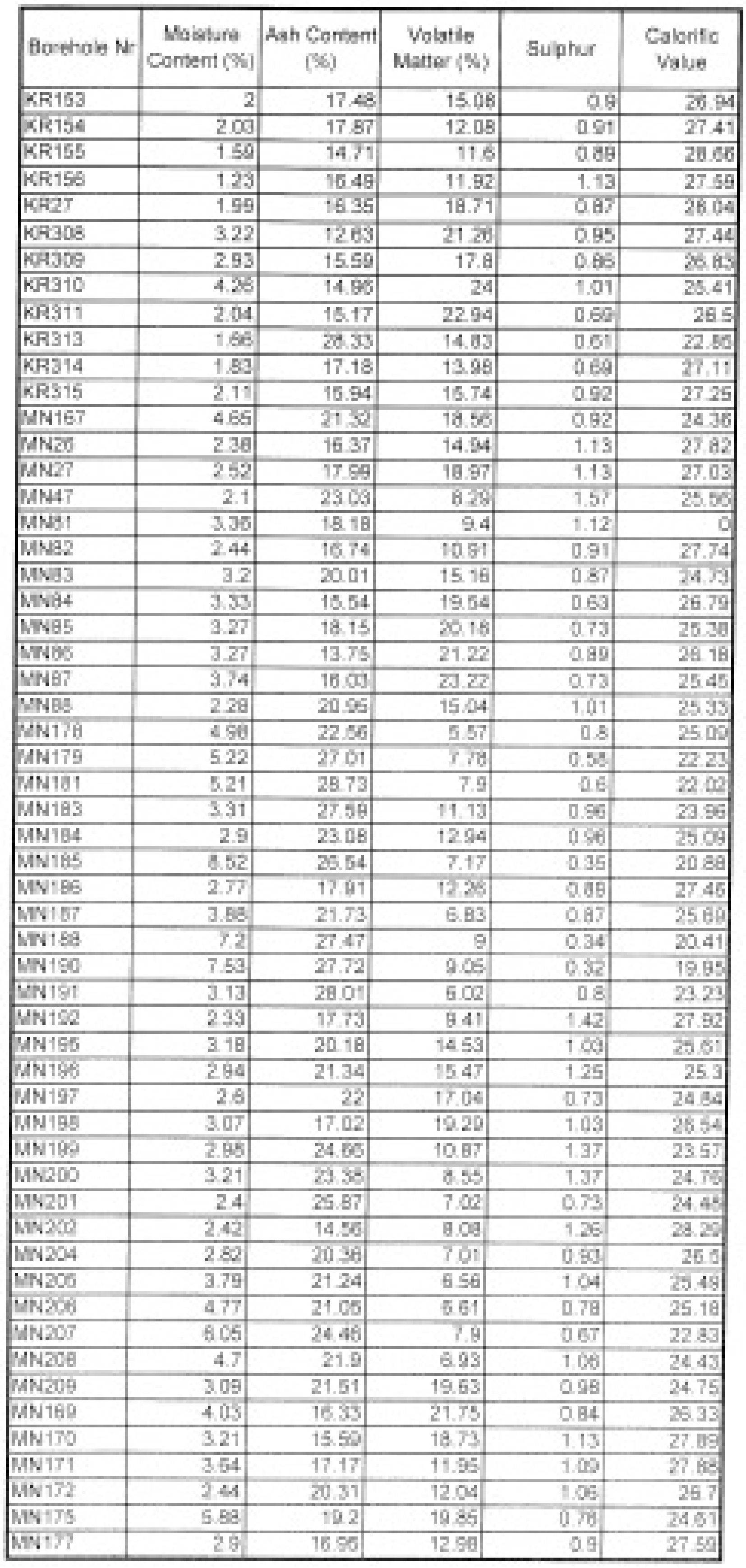


| Borehole Nr | Moisture Content (%) | Ash Content (%) | Volatile Matter (%) | Sulphur | Calorific Value |
|---|---|---|---|---|---|
| KR16 | 3.08 | 23.26 | 23.08 | 1.41 | 24.52 |
| KR187 | 2.78 | 16.51 | 28.32 | 0.91 | 25.26 |
| KR188 | 2.85 | 13.07 | 24.33 | 0.86 | 26.66 |
| KR189 | 3.45 | 12.5 | 23.39 | 0.83 | 26.43 |
| KR191 | 3.01 | 13.76 | 19.24 | 0.68 | 26.96 |
| KR307 | 1.96 | 17.96 | 19.43 | 1.22 | 26.67 |
| KR308 | 3.22 | 12.63 | 21.26 | 0.95 | 27.44 |
| KR309 | 2.93 | 15.59 | 17.8 | 0.86 | 26.83 |
| KR316 | 2.93 | 12.47 | 22.48 | 0.85 | 27.56 |
| KR317 | 3.01 | 13.6 | 21.7 | 1.05 | 27.3 |
| KR318 | 2.81 | 12.25 | 20.34 | 0.74 | 27.86 |
| KR61 | 3 | 12.44 | 21.49 | 0.78 | 28.43 |
| KR69 | 2.8 | 12.37 | 22.87 | 1 | 28.6 |
| MN1 | 2.68 | 20.96 | 20.3 | 0.92 | 25.82 |
| MN100 | 1.51 | 20.77 | 10.83 | 0.98 | 26.49 |
| MN101 | 1.73 | 21.88 | 9.63 | 1.12 | 25.69 |
| MN103 | 1.97 | 20.61 | 11.62 | 1 | 26.46 |
| MN104 | 1.72 | 20.28 | 12.1 | 0.9 | 26.58 |
| MN105 | 2.04 | 20 | 10.37 | 1.22 | 26.6 |
| MN106 | 2.01 | 17.89 | 11.39 | 0.87 | 27.24 |
| MN107 | 1.98 | 15.33 | 16.84 | 1.19 | 27.63 |
| MN108 | 2.7 | 17.53 | 21.47 | 0.73 | 26.32 |
| MN109 | 2.87 | 17.79 | 22.77 | 0.9 | 24.99 |
| MN11 | 3.04 | 21.27 | 12.59 | 0.92 | 25.5 |
| MN110 | 3.47 | 25.32 | 21.3 | 0.68 | 21.84 |
| MN112 | 2.87 | 21.07 | 18.52 | 1.29 | 24.46 |
| MN119 | 2.93 | 20.64 | 9.89 | 0.7 | 26.06 |
| MN120 | 2.1 | 25.44 | 13.53 | 0.79 | 24.61 |
| MN122 | 2.73 | 22.01 | 11.76 | 1.15 | 25.46 |
| MN125 | 2.18 | 15.62 | 18.9 | 0.92 | 27.1 |
| MN126 | 3.35 | 14.39 | 26.79 | 1.47 | 26.22 |
| MN127 | 2.95 | 14.23 | 23.84 | 1.02 | 26.59 |
| MN128 | 2.49 | 16.02 | 18.89 | 0.69 | 26.73 |
| MN130 | 2.39 | 15.79 | 24.67 | 0.88 | 26.6 |
| MN132 | 5.28 | 18.79 | 9.31 | 1.28 | 26.21 |
| MN133 | 9.63 | 21.67 | 22.15 | 0.32 | 17.38 |
| MN135 | 2.13 | 20.07 | 10.64 | 0.9 | 26.7 |
| MN136 | 2.94 | 18.62 | 13.94 | 1.42 | 26.76 |
| MN137 | 3.85 | 15.89 | 10.53 | 1.21 | 27.78 |
| MN140 | 4.46 | 21.85 | 8.64 | 0.89 | 25.38 |
| MN143 | 3.47 | 16 | 23.58 | 1.27 | 26.02 |
| MN144 | 2.92 | 16.43 | 25.02 | 1.18 | 24.76 |
| MN145 | 3.1 | 13.57 | 26.43 | 0.72 | 25.62 |
| MN152 | 2.54 | 17.71 | 23.23 | 1.11 | 25.5 |
| MN158 | 2.87 | 13.54 | 26.18 | 0.86 | 25.98 |
| MN159 | 2.27 | 14.68 | 24.62 | 1.28 | 26.61 |
| MN160 | 2.19 | 13.56 | 22.56 | 1.18 | 27.33 |



| | | | | | |
|---|---|---|---|---|---|
| MN163 | 2.73 | 18.1 | 16.77 | 0.66 | 25.13 |
| MN164 | 3.69 | 18.9 | 17.63 | 0.38 | 23.83 |
| MN165 | 2.3 | 17.37 | 21 | 0.92 | 26.35 |
| MN167 | 4.65 | 21.32 | 18.56 | 0.92 | 24.36 |
| MN168 | 5.18 | 15.24 | 21.15 | 0.83 | 25.98 |
| MN2 | 5.4 | 18.68 | 24.62 | 0.45 | 23.85 |
| MN27 | 2.52 | 17.99 | 18.97 | 1.13 | 27.03 |
| MN3 | 4.09 | 25.91 | 7.91 | 1.07 | 21.76 |
| MN33 | 1.24 | 21.81 | 8.5 | 1.64 | 27.02 |
| MN42 | 1.93 | 20.93 | 18.14 | 1.58 | 26.32 |
| MN47 | 2.1 | 23.03 | 8.29 | 1.57 | 25.56 |
| MN6 | 2.31 | 19.6 | 10.37 | 1.33 | 26.89 |
| MN7 | 2.86 | 13.56 | 22.85 | 1.13 | 28.02 |
| MN8 | 2.16 | 12.35 | 25.35 | 0.94 | 29.27 |
| MN83 | 3.2 | 20.01 | 15.16 | 0.87 | 24.73 |
| MN85 | 3.27 | 18.15 | 20.18 | 0.73 | 25.38 |
| MN86 | 3.27 | 13.75 | 21.22 | 0.89 | 26.18 |
| MN87 | 3.74 | 16.03 | 23.22 | 0.73 | 25.45 |
| MN88 | 2.28 | 20.95 | 15.04 | 1.01 | 26.33 |
| MN89 | 5.66 | 20.57 | 11.7 | 0.91 | 25.48 |
| MN9 | 2.07 | 18.7 | 19.86 | 0.85 | 27.12 |
| MN90 | 3.7 | 23.02 | 12.61 | 2 | 24.86 |
| MN92 | 2.73 | 22.37 | 18.06 | 1.13 | 24.91 |
| MN93 | 2.06 | 22.69 | 18.62 | 1.13 | 23.72 |
| MN94 | 1.86 | 21.03 | 18.48 | 0.98 | 25.38 |
| MN95 | 1.41 | 19.67 | 20.69 | 1.18 | 25.45 |
| MN96 | 1.8 | 16.75 | 22.08 | 1.21 | 26.38 |
| MN98 | 1.89 | 16.67 | 23.34 | 1.15 | 26.3 |
| MN99 | 1.79 | 24.3 | 14.37 | 1.39 | 24.73 |
| MN219 | 2.97 | 28.57 | 5.2 | 0.98 | 22.51 |
| MN220 | 2.94 | 23.3 | 8.72 | 1.28 | 25.31 |
| MN221 | 3.86 | 24.15 | 6.98 | 1.14 | 24.48 |
| MN222 | 4.53 | 27.75 | 6.42 | 1.16 | 22.21 |
| MN223 | 1.7 | 25.41 | 8.34 | 0.84 | 23.94 |
| MN224 | 2.54 | 20.54 | 13.74 | 1.16 | 26.5 |
| MN225 | 2.71 | 23.27 | 20.07 | 1.09 | 23.72 |
| MN226 | 3.65 | 27.22 | 20.46 | 1.46 | 22.46 |
| MN227 | 3.47 | 18.1 | 12.8 | 0.84 | 26.15 |
| MN228 | 1.7 | 23.22 | 11.02 | 2.3 | 26.02 |
| MN229 | 3.04 | 22.14 | 19.04 | 0.88 | 24.12 |
| MN230 | 3.04 | 20.27 | 20.95 | 0.97 | 24.74 |
| MN231 | 2.64 | 21.2 | 23.9 | 1.02 | 24.51 |
| MN232 | 5.37 | 14.03 | 22.41 | 0.72 | 25.83 |
| MN234 | 5.22 | 25.04 | 22.27 | 0.81 | 21.13 |
| MN237 | 6.65 | 26.8 | 22.58 | 0.99 | 23.06 |
| MN238 | 3.84 | 22.67 | 7.75 | 0.89 | 24.32 |
| MN239 | 3.25 | 18.77 | 21.16 | 0.54 | 25.9 |
| MN242 | 3.19 | 11.63 | 26.17 | 0.77 | 27.87 |
| MN247 | 2.33 | 19.76 | 16.18 | 0.36 | 25.97 |

***List of boreholes in block OM with the respective sink values from the proximate analysis for seam 2.***



| Borehole Nr | Moisture Content (%) | Ash Content (%) | Volatile Matter (%) | Sulphur | Calorific Value |
|---|---|---|---|---|---|
| KR153 | 2 | 17.48 | 15.08 | 0.9 | 26.94 |
| KR154 | 2.03 | 17.87 | 12.08 | 0.91 | 27.41 |
| KR155 | 1.59 | 14.71 | 11.6 | 0.89 | 28.66 |
| KR156 | 1.23 | 16.49 | 11.92 | 1.13 | 27.59 |
| KR27 | 1.99 | 16.35 | 18.71 | 0.87 | 26.04 |
| KR308 | 3.22 | 12.63 | 21.26 | 0.95 | 27.44 |
| KR309 | 2.93 | 15.59 | 17.8 | 0.86 | 26.83 |
| KR310 | 4.26 | 14.96 | 24 | 1.01 | 25.41 |
| KR311 | 2.04 | 15.17 | 22.94 | 0.69 | 26.5 |
| KR313 | 1.66 | 26.33 | 14.83 | 0.61 | 22.86 |
| KR314 | 1.83 | 17.18 | 13.98 | 0.69 | 27.11 |
| KR315 | 2.11 | 16.94 | 16.74 | 0.92 | 27.25 |
| MN167 | 4.65 | 21.32 | 18.56 | 0.92 | 24.36 |
| MN26 | 2.38 | 16.37 | 14.94 | 1.13 | 27.82 |
| MN27 | 2.52 | 17.99 | 18.97 | 1.13 | 27.03 |
| MN47 | 2.1 | 23.03 | 8.29 | 1.57 | 25.56 |
| MN81 | 3.36 | 18.18 | 9.4 | 1.12 | 0 |
| MN82 | 2.44 | 16.74 | 10.91 | 0.91 | 27.74 |
| MN83 | 3.2 | 20.01 | 15.16 | 0.87 | 24.73 |
| MN84 | 3.33 | 15.54 | 19.54 | 0.63 | 26.79 |
| MN85 | 3.27 | 18.15 | 20.16 | 0.73 | 25.38 |
| MN86 | 3.27 | 13.75 | 21.22 | 0.89 | 28.18 |
| MN87 | 3.74 | 16.03 | 23.22 | 0.73 | 25.45 |
| MN88 | 2.28 | 20.96 | 15.04 | 1.01 | 25.33 |
| MN178 | 4.98 | 22.56 | 5.57 | 0.8 | 25.09 |
| MN179 | 5.22 | 27.01 | 7.78 | 0.58 | 22.23 |
| MN181 | 5.21 | 28.73 | 7.9 | 0.6 | 22.02 |
| MN183 | 3.31 | 27.59 | 11.13 | 0.96 | 23.96 |
| MN184 | 2.9 | 23.08 | 12.94 | 0.96 | 25.09 |
| MN185 | 8.52 | 26.54 | 7.17 | 0.35 | 20.88 |
| MN186 | 2.77 | 17.91 | 12.26 | 0.89 | 27.46 |
| MN187 | 3.88 | 21.73 | 6.83 | 0.87 | 25.69 |
| MN188 | 7.2 | 27.47 | 9 | 0.34 | 20.41 |
| MN190 | 7.53 | 27.72 | 9.06 | 0.32 | 19.95 |
| MN191 | 3.13 | 28.01 | 6.02 | 0.8 | 23.23 |
| MN192 | 2.33 | 17.73 | 9.41 | 1.42 | 27.92 |
| MN195 | 3.18 | 20.18 | 14.53 | 1.03 | 25.61 |
| MN196 | 2.94 | 21.34 | 15.47 | 1.25 | 25.3 |
| MN197 | 2.6 | 22 | 17.04 | 0.73 | 24.84 |
| MN198 | 3.07 | 17.02 | 19.29 | 1.03 | 26.54 |
| MN199 | 2.96 | 24.66 | 10.87 | 1.37 | 23.57 |
| MN200 | 3.21 | 23.38 | 8.55 | 1.37 | 24.76 |
| MN201 | 2.4 | 25.87 | 7.02 | 0.73 | 24.48 |
| MN202 | 2.42 | 14.56 | 8.08 | 1.26 | 28.29 |
| MN204 | 2.82 | 20.36 | 7.01 | 0.93 | 26.5 |
| MN205 | 3.79 | 21.24 | 6.56 | 1.04 | 25.49 |
| MN206 | 4.77 | 21.06 | 6.61 | 0.78 | 25.18 |
| MN207 | 6.05 | 24.46 | 7.9 | 0.67 | 22.83 |
| MN208 | 4.7 | 21.9 | 6.93 | 1.06 | 24.43 |
| MN209 | 3.09 | 21.51 | 19.63 | 0.98 | 24.75 |
| MN169 | 4.03 | 16.33 | 21.75 | 0.84 | 26.33 |
| MN170 | 3.21 | 15.59 | 18.73 | 1.13 | 27.89 |
| MN171 | 3.64 | 17.17 | 11.95 | 1.09 | 27.88 |
| MN172 | 2.44 | 20.31 | 12.04 | 1.06 | 26.7 |
| MN175 | 5.88 | 19.2 | 19.85 | 0.76 | 24.61 |
| MN177 | 2.9 | 16.96 | 12.98 | 0.9 | 27.59 |

## *10.2 Appendix 2: Wash Tables and Wash Curves for Seam 2 for the various reserve blocks*

Wash tables for seam 2 for the various reserve blocks.

**Wash table for seam 2 for block OD**

| Relative Density | Yield(%) | Ash(%) |
|---|---|---|
| F@1.4 | 34.44 | 9.6 |
| F@1.5 | 55.37 | 11.1 |
| F@1.6 | 70.72 | 12.9 |
| F@1.7 | 79.57 | 14.1 |
| S@1.7 | 100 | 17.7 |

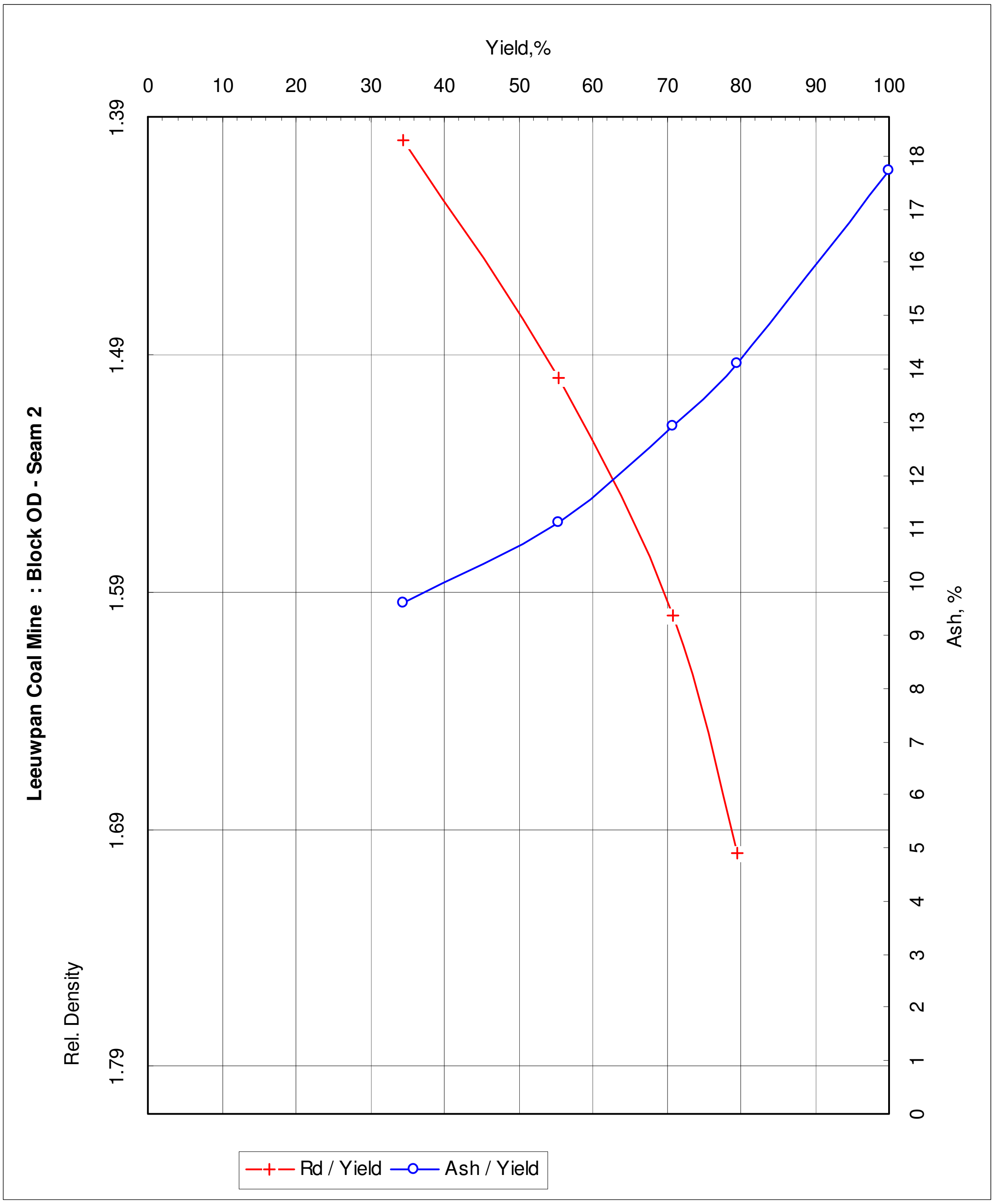
**Wash table for seam 2 for block OH**

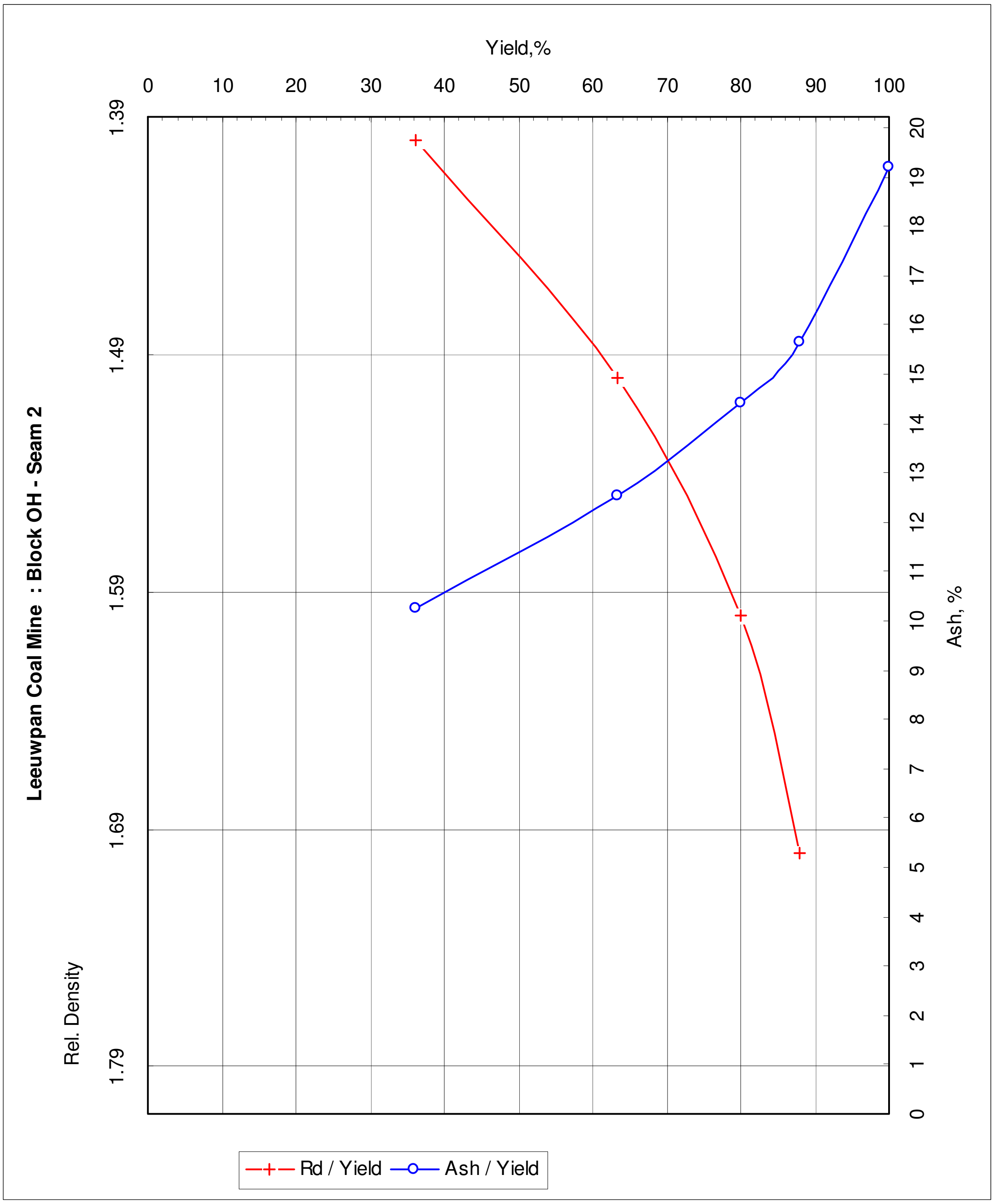
| Relative Density | Yield(%) | Ash(%) |
|---|---|---|
| F@1.4 | 36.17 | 10.3 |
| F@1.5 | 63.34 | 12.5 |
| F@1.6 | 80.05 | 14.4 |
| F@1.7 | 87.85 | 15.7 |
| S@1.7 | 100 | 19.2 |

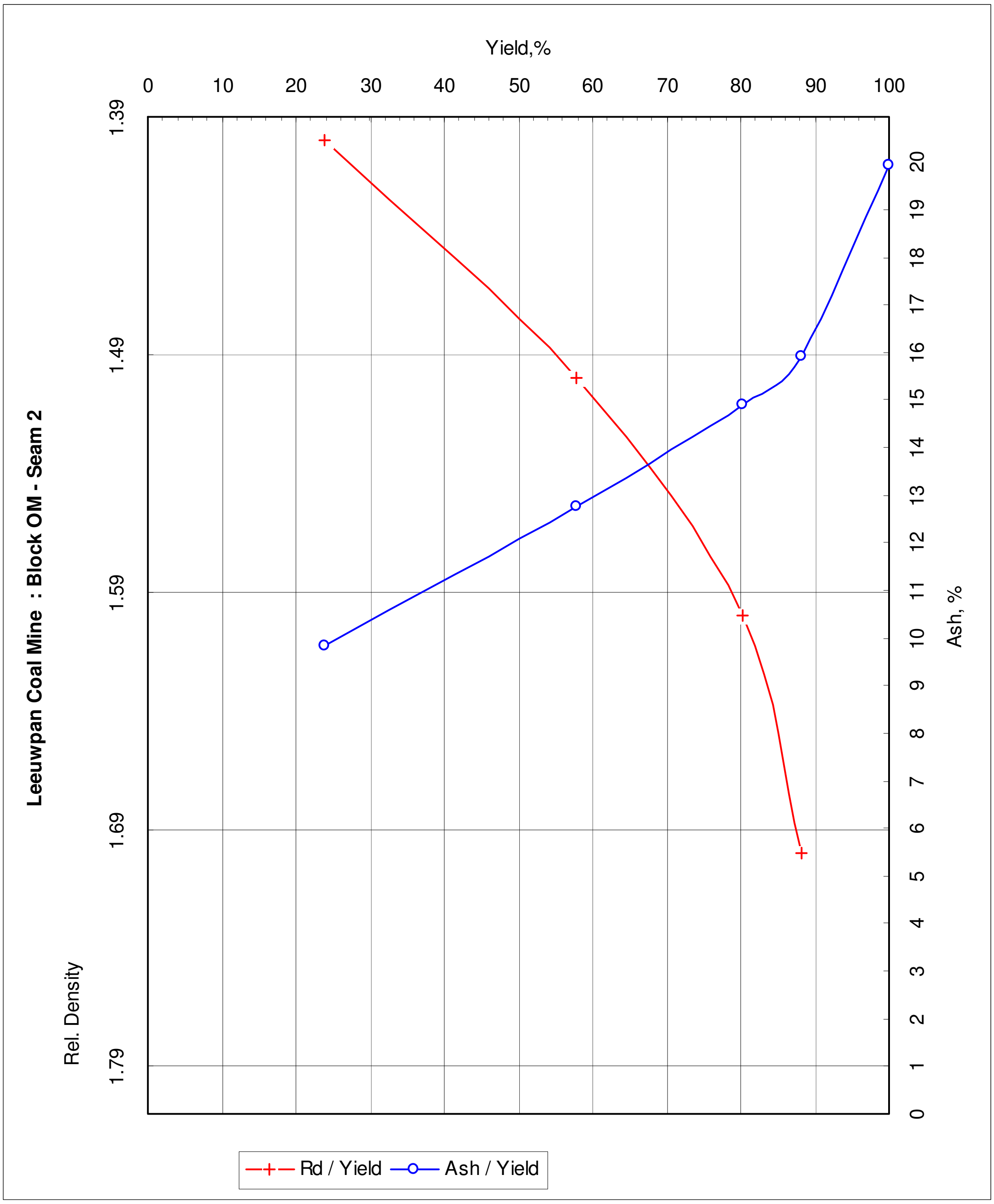
**Wash table for seam 2 for block OM**

| Relative Density | Yield(%) | Ash(%) |
|---|---|---|
| F@1.4 | 23.83 | 9.8 |
| F@1.5 | 57.81 | 12.8 |
| F@1.6 | 80.29 | 14.9 |
| F@1.7 | 88.19 | 15.9 |
| S@1.7 | 100 | 20 |

Note: Ash reporting base: air dry
Volatiles reporting base: absolute dry


Leeuwpan Coal Mine : Block OD - Seam 2
Yield,%
0
10
20
30
40
50
60
70
80
90
100
Rel. Density
1.39
1.49
1.59
1.69
1.79
Ash, %
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Rd / Yield
Ash / Yield


Leeuwpan Coal Mine : Block OH - Seam 2
Yield,%
0
10
20
30
40
50
60
70
80
90
100
Rel. Density
1.39
1.49
1.59
1.69
1.79
Ash, %
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Rd / Yield
Ash / Yield


Leeuwpan Coal Mine : Block OM - Seam 2
Yield,%
0
10
20
30
40
50
60
70
80
90
100
Rel. Density
1.39
1.49
1.59
1.69
1.79
Ash, %
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Rd / Yield
Ash / Yield

## *10.3 Appendix 3: Wash Tables and Wash Curves for the different volatile zones in block OM*

Wash tables for the various volatile zones in block OM

**Wash table for the Low Volatile Zone in block OM**

| Relative Density | Yield | Moisture | Ash | Volatiles | Sulphur | Calorific value |
|---|---|---|---|---|---|---|
| F@1.4 | 13.31 | 2.58 | 9.92 | 16.62 | 0.58 | 29.16 |
| F@1.5 | 43.2 | 2.8 | 13.09 | 13.06 | 0.65 | 28.2 |
| F@1.6 | 71.7 | 3.17 | 15.61 | 11.45 | 0.67 | 27.22 |
| F@1.7 | 83.3 | 3.43 | 16.79 | 11 | 0.67 | 26.68 |
| S@1.7 | 100 | 3.7 | 21.58 | 10.54 | 0.93 | 24.72 |

**Wash table for the Lean Coal Zone in block OM**

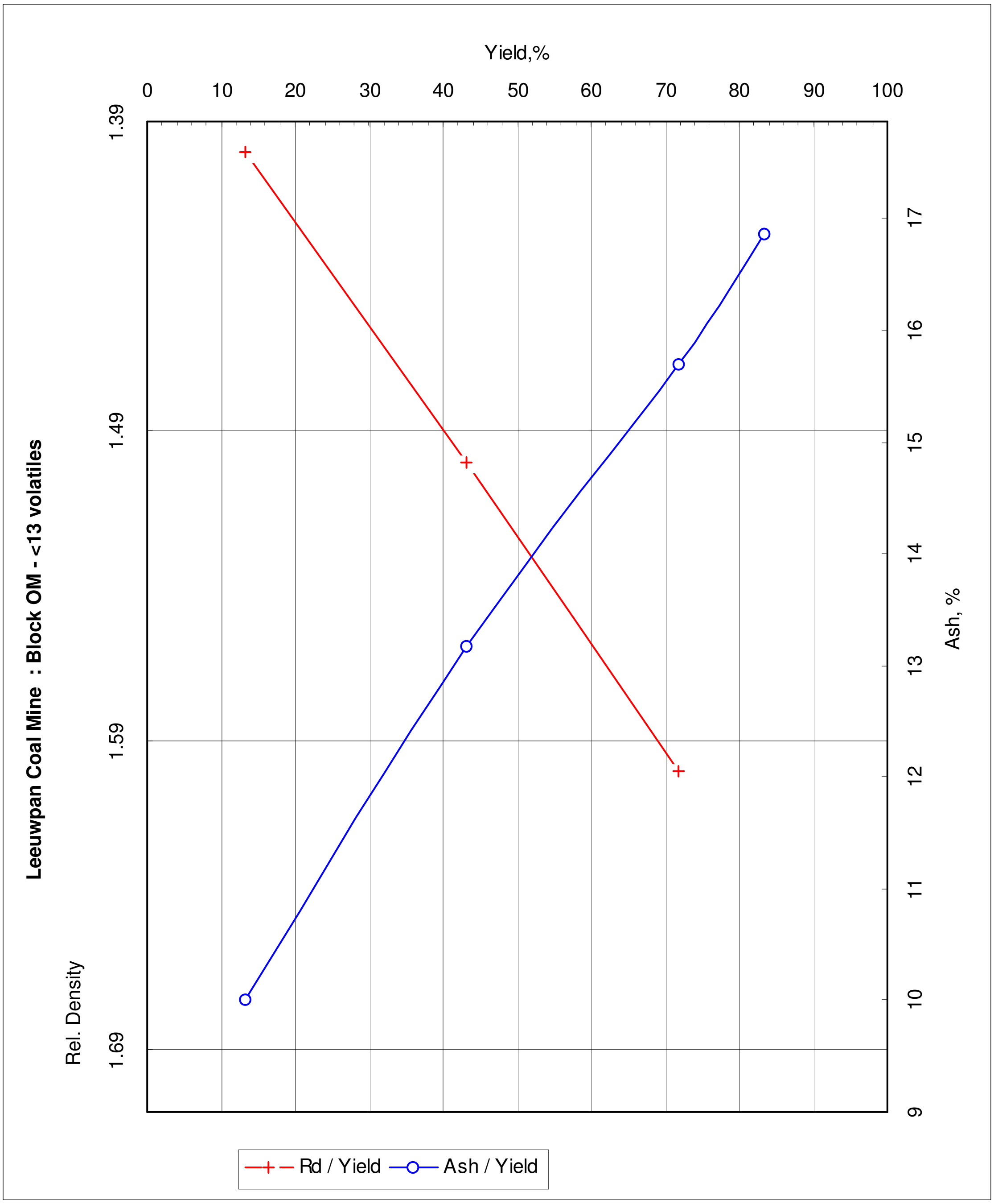
| Relative Density | Yield | Moisture | Ash | Volatiles | Sulphur | Calorific value |
|---|---|---|---|---|---|---|
| F@1.4 | 26.15 | 2.89 | 10.32 | 19.11 | 0.57 | 29.2 |
| F@1.5 | 64.51 | 3 | 13.11 | 17.11 | 0.59 | 28.11 |
| F@1.6 | 83.91 | 3.04 | 15.14 | 16.16 | 0.6 | 27.33 |
| F@1.7 | 90.19 | 3.13 | 16.05 | 15.8 | 0.61 | 26.92 |
| S@1.7 | 100 | 3.15 | 19.87 | 15.27 | 0.91 | 25.45 |

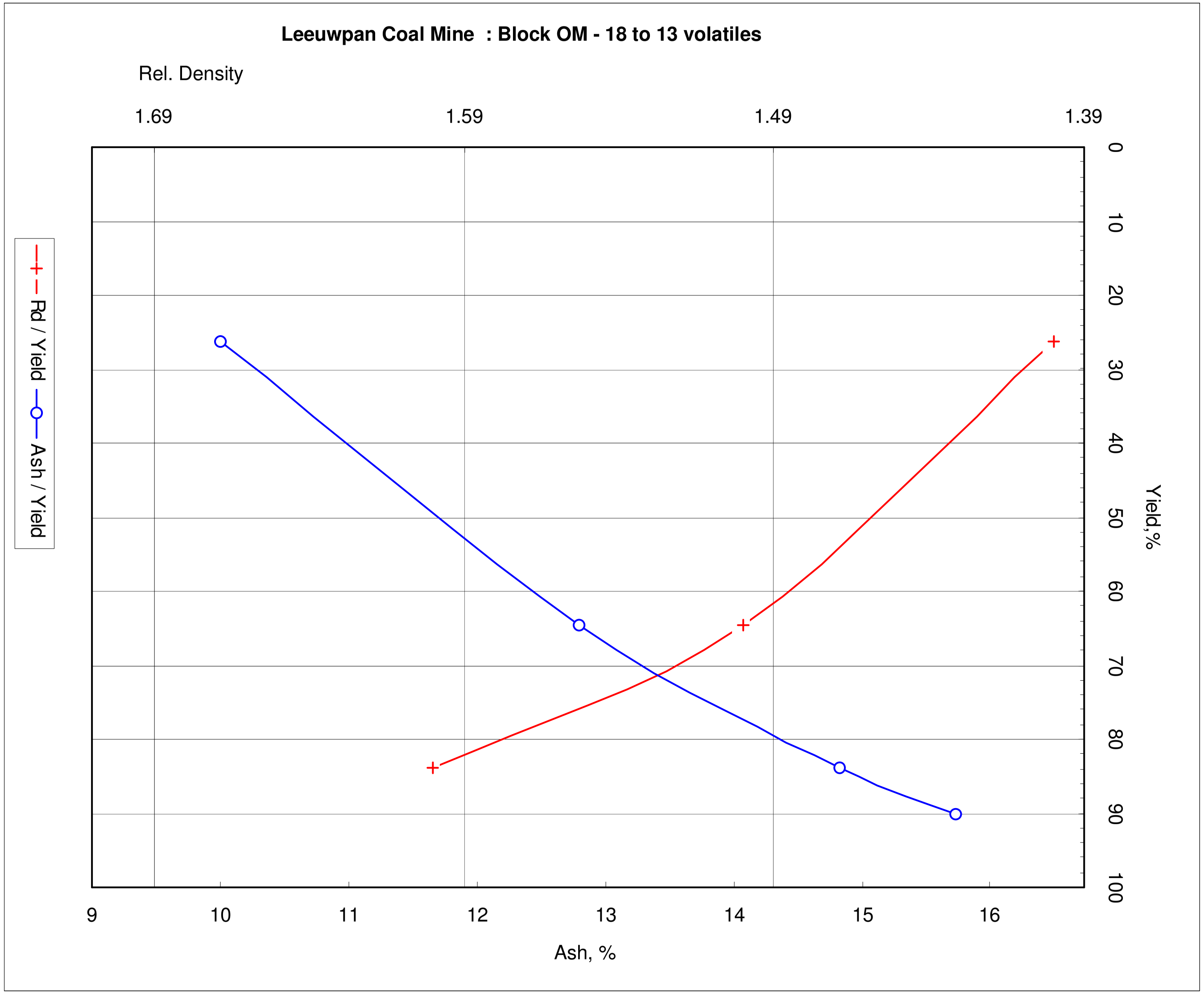
**Wash table for the Medium Volatile Zone in block OM**

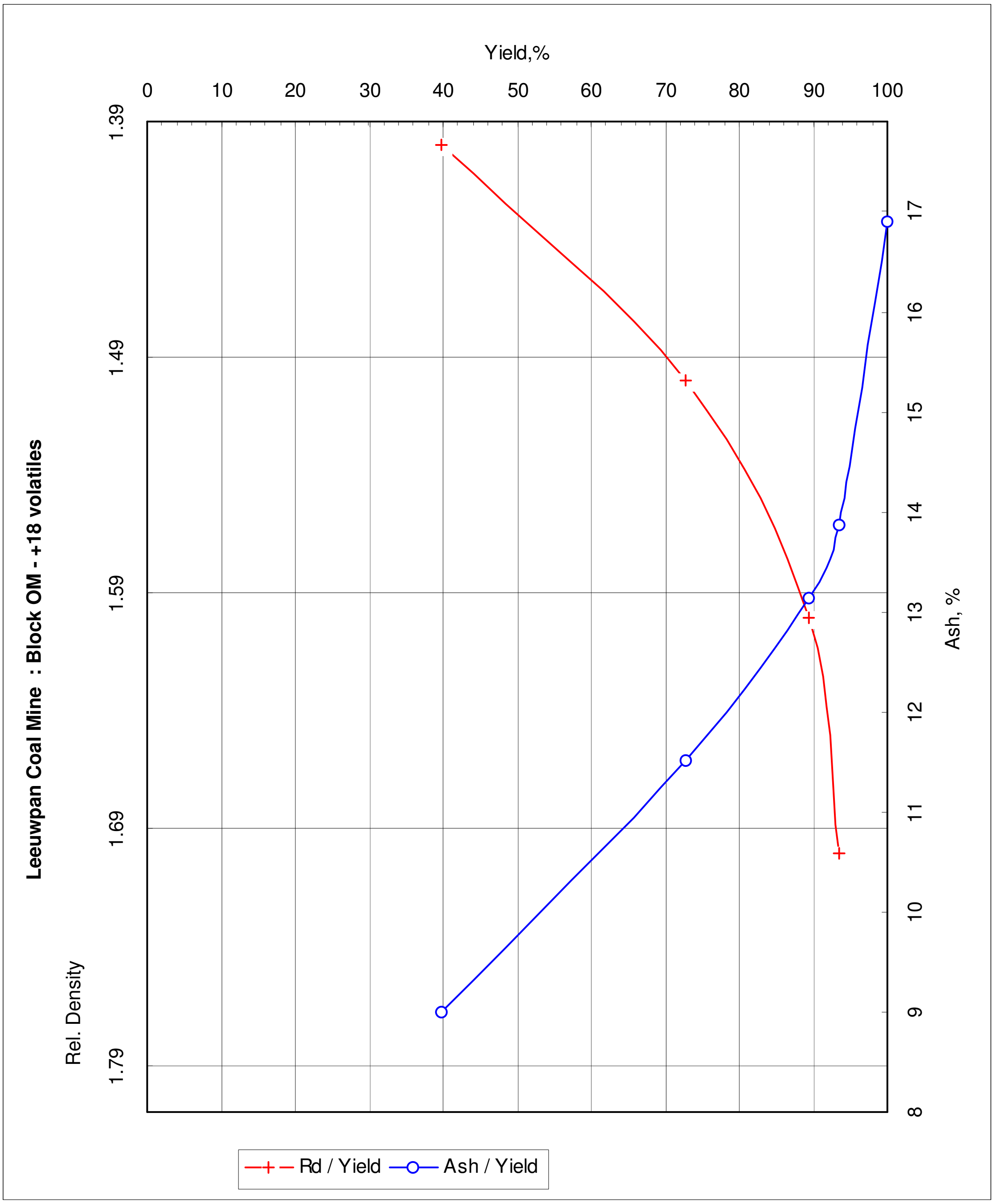
| Relative Density | Yield | Moisture | Ash | Volatiles | Sulphur | Calorific value |
|---|---|---|---|---|---|---|
| F@1.4 | 39.79 | 3.13 | 9.41 | 22.1 | 0.62 | 28.95 |
| F@1.5 | 72.88 | 3.18 | 11.92 | 20.57 | 0.6 | 28.01 |
| F@1.6 | 89.5 | 3.19 | 13.55 | 20.04 | 0.61 | 27.28 |
| F@1.7 | 93.59 | 3.21 | 14.27 | 19.8 | 0.62 | 27.01 |
| S@1.7 | 100 | 3.15 | 17.31 | 19.23 | 0.85 | 25.93 |

Note: Ash reporting base: air dry

Volatiles reporting base: absolute dry


Leeuwpan Coal Mine : Block OM - <13 volatiles
Yield,%
0
10
20
30
40
50
60
70
80
90
100
Rel. Density
1.39
1.49
1.59
1.69
Ash, %
9
10
11
12
13
14
15
16
17
Rd / Yield
Ash / Yield


Leeuwpan Coal Mine : Block OM - 18 to 13 volatiles
Rel. Density
1.69
1.59
1.49
1.39
Yield,%
0
10
20
30
40
50
60
70
80
90
100
Ash, %
9
10
11
12
13
14
15
16
Rd / Yield
Ash / Yield


Leeuwpan Coal Mine : Block OM - +18 volatiles
Yield,%
0
10
20
30
40
50
60
70
80
90
100
Rel. Density
1.39
1.49
1.59
1.69
1.79
Ash, %
8
9
10
11
12
13
14
15
16
17
Rd / Yield
Ash / Yield