ANALYSIS OF TECHNICAL FACTORS FOR UNDERGROUND MINING OF DEEP WATERBERG COAL RESOURCES

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A dissertation submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Masters of Science in Engineering

Johannesburg, 2013

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University

Signed:

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Kelello Chabedi

This ________ day of __________year__________

ABSTRACT

Coal supplies over 90% of South Africa's electrical energy power requirements. The coal mainly comes from the Witbank and Highveld coalfields, which together account for about 75% of South Africa's production. However, the Witbank and Highveld coalfields will be depleted in the next 15 to 25 years. This poses an energy risk for the country unless replacements coalfields are fully developed in time. Of the country's total of 19 known coalfields, the Waterberg coalfield despite its small geographical footprint is a suitable replacement for the Witbank and Highveld coalfields because it contains the largest known coal reserves.

However, exploitation of the Waterberg coalfield faces challenges of mining deep-seated multiple coal seams that are intercalated with mudstone and shale in the top 50-60 m and occurring over a coal thickness in excess of 110m. For example, east of the Daarby fault, coal seams are at a depth in excess of 250m. This challenge is further amplified by the fact that South Africa currently does not have experience in mining deep, multi-seam coal formations.

While the shallow reserves in the western portion of the Waterberg are currently mined by an open-pit, the deep eastern part will need to be exploited by multi-seam underground mining on a scale never before attempted in South Africa. This dissertation has reviewed international practice and concludes that United States experience is the most applicable to the underground mining of the Waterberg reserves. It is probable that total extraction using longwall will be the correct choice of mining method.

Finally, this dissertation has illustrated the essential need for fundamental research if the industry is to successfully transition to the Waterberg. While a horizon of 20-25 years appears far- off to those concerned with day to day production issues, the mining, infrastructure, environmental and social issues are of such magnitude that co-ordinated research will need to be initiated well ahead of mining activities and preferably in the next few years.

DEDICATION

In loving memory of my late father

Mr. David Pitso Chabedi whose love, support and

encouragement have influenced me to be the kind of man that I am.

ACKNOWLEDGMENTS

To undertake a research of this nature requires the input and assistance of many people in giving of their time generously. I wish to therefore express my gratitude to:

- Prof Frederick Cawood, (Head of School, School of Mining Engineering, University of Witwatersrand), for his support, encouragement and for granting time so that I could finish this report.
- Mr Johan Beukes, (Manager Coaltech Research), for his time in discussing many of the issues in the research, his wisdom and knowledge of the coal mining industry.
- Mr J. Claris Dreyer, (former Group Consulting Geologist of EXXARO), for his humility and vast knowledge of the Waterberg coalfield and for his willingness to freely share and discuss the geology of the Waterberg coalfield with me.
- Dr Chris Mark, (former Senior Researcher at NIOSH), for taking the time to have long telephone conversations with me and his advice on how to use the CMRR and AMSS software.
- Mr Xavier Prevost, (Senior Coal Analyst, XMP Consulting), for his knowledge of the South African coal mining industry market.
- Prof Nielen van der Merwe, (Professor of Rock Engineering), for sharing his insights on rock engineering and multi-seam mining in South Africa.
- Prof Huw Ronald Phillips, (Professor of Mining Engineering, University of Witwatersrand), for being my supervisor and for his invaluable academic guidance throughout the research and painstakingly reading through draft chapters.
- Assoc. Prof Cuthbert Muswingwini, (Senior Lecturer, School of Mining Engineering, University of Witwatersrand), for help with proof-reading the entire draft.
- My wife Sephora, son Karabo and daughter Jacobeth for their love, support, patience and sacrifice during the time taken to complete this project.
- To God be the glory for all He has done for me.

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ALPS:	Analysis of Longwall Pillar Stability
AMSS:	Analysis of Multiple Seam Stability
ARMPS:	Analysis of Retreat Mining Pillar Stability
Btu:	British Thermal Units
CV:	Calorific Value
CMRR:	Coal Mine Roof Rating
CoAL:	Coal of Africa
GW:	Giga-watts
IEA:	International Energy Agency
MJ/kg:	Mega Joules per Kilogram
MPa:	Mega Pascal
Mt:	Million tonnes
Mtpa:	Million tonnes per annum
Mtoe:	Million tonnes oil equivalent
NIOSH:	National Institute for Occupational Safety and Health
OECD:	Organisation for Economic Co-operation and Development countries
PCI:	Pulverised Coal Injection
RBCT:	Richard’s Bay Coal Terminal
RMR:	Rock Mass Rating
ROM:	Run of Mine
SAMREC:	South African Mineral Resource Code
SANS:	South African National Standard
SASOL:	South African Synthetic Oil Limited
SF_{SS}:	Single Seam Stability Factor

SNR:	Strategic Natural Resources
TFR:	Transnet Freight Rail
UCS:	Uniaxial Compressive Strength
USA:	United States of America
WCI:	World Coal Institute

1 INTRODUCTION

1.1 Chapter overview

The purpose of this chapter is to give a background on the role of coal as an energy source in the South African mining industry and also in the rest of the world. Firstly, the global electricity demand and the role of coal in electricity generation throughout the major coal producing countries of the world are discussed. Thereafter world coal consumption is discussed in order to contextualise the use of coal in both the first world and the emerging countries. Then the world energy demand in the United States, India and China and the rest of the world are discussed to give a context of the importance of these three countries in the demand of coal. Thereafter, world coal reserves, production and exports and the world coal trade and imports are discussed to give a picture of the importance of the South African coal industry to the rest of the world. Then the global oil price and its impact on global coal export prices are discussed especially in the light of the debate about future energy sources and the world's desire to move towards more environmentally friendly energy sources. Furthermore, the South African coal mining industry will be discussed especially the depletion of the reserves of the Witbank and Highveld coalfields. The depletion of the Witbank and Highveld coal reserves is critical in placing into context the dependence of the South African mining industry on these coalfields for the future of energy supply to the country as a whole. Finally, the purpose of this chapter is to discuss the potential of the Waterberg coalfield as a possible supplier of coal in order to meet the future energy needs of South Africa's domestic market and the lucrative export market.

The concluding remarks of this chapter give a view as to the future of South Africa's energy demand and some of the reasons why coal will remain a major energy source in South Africa for the next 30 years, despite its negative impact on the environment.

1.2 The role of coal as an energy source

According to a study by the World Coal Institute (WCI) coal is still the cheapest, most abundant, affordable, and safe and secure source of energy. Table 1.1 reinforces some of the main reasons why coal is a preferable energy source in developing countries compared to oil, gas, nuclear and renewable sources of energy.

Table 1.1: The role of coal as an energy source (World Coal Institute, Undated)

	Positive Points	Negative Points
Coal	• Abundant, affordable, safe and secure • Easy to transport and store • Widely available	• The most intensive fuel for electricity • Poses technological challenges as part of low global CO_2 growth
Oil	• Convenient • Easy to transport and store • No effective substitute in transportation uses	• Carbon intensive • Price volatility • Resource concentration • Vulnerable to disruption or geopolitical instability • Transport risks
Gas	• Efficient and convenient • Fuel of choice for many uses, such as residential heating	• Carbon intensive • Expensive and risky to transport and store • Requires dedicated, inflexible infrastructure • Price volatility • Resource concentration
Nuclear	• Carbon free generation • Few resource constraints	• Public acceptability low • Waste disposal is problematic • Capital intensive – may be uneconomic in some markets
Renewables	• Low emissions on a life cycle basis • Sustainable	• Generally high costs and intermittent sources • Major expansion will take time • Potential siting problems

Despite its negative environmental impacts such as carbon dioxide emission when coal is combusted, together with the release of methane when coal is mined, coal is still the cheapest, most affordable and widely available source of energy. The positive aspects of coal, as can be seen in Table 1.1 far outweigh its negative aspects and therefore coal is likely to be the preferred energy source of the foreseeable future especially in developing countries. Hydropower might be the cheapest energy source worldwide; however, in South Africa countries neither the terrain nor the rainfall pattern support construction of major hydropower plants.

1.3 Global electricity demand

Venter said in a Strategy Session of Coaltech Research organisation that in the next 30 years global electricity consumption is going to double in all coal producing countries (Venter, 2006). Figure 1.1 indicates that, there is likely to be a major growth in electricity usage in developing countries such as Indonesia, Brazil, India and all of Africa. Figure 1.1 further illustrates that in all developing countries coal resources will play a major role in electricity generation. The conclusion that can be drawn is that the demand for electricity and the future growth for coal are going to be far greater than originally planned especially in developing countries.

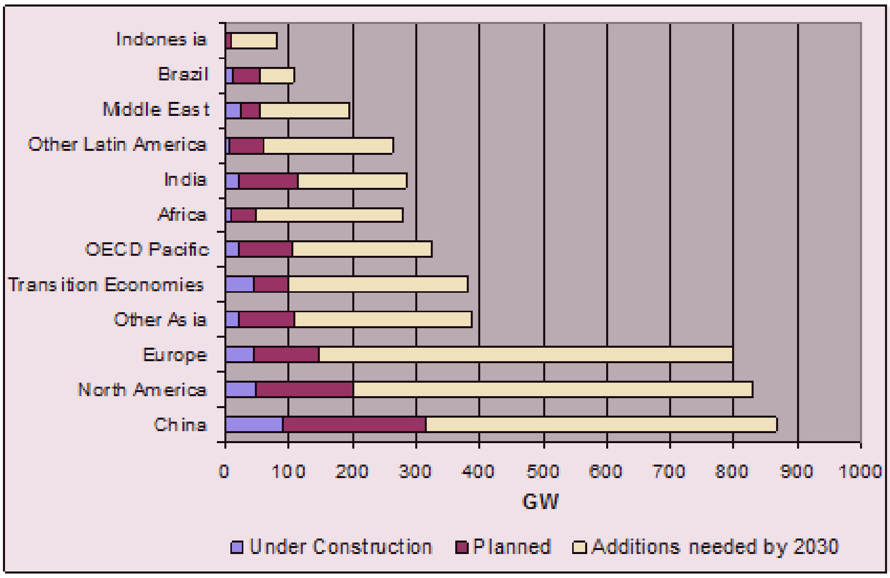


Figure 1.1: Global electricity consumption (Venter, 2006)

The World Bank Report quoted on the website of the World Coal Institute report on the Role of Coal (World Coal Institute, Undated) concluded that for social and economic development reliable energy is key component and coal is well placed to fulfil that role.

1.4 Coal in electricity generation

Figure 1.2 shows that coal is a major source of fuel for generating electricity worldwide and that a number of countries that have coal resources depend heavily on coal for electricity generation in contrast to other sources of fuel like oil and gas. South Africa by far depends heavily on coal for electricity generation in contrast to the developed countries like the United States and Germany. Figure 1.2 indicates that the percentage electricity generation from coal in South Africa is 93% and that this is approximately double the figure for Germany. In other words, there is a dependence on coal as a main energy source in a developing country like South Africa unlike Germany because of the low cost of coal compared to other fuel sources and less emphasis on environmental issues.

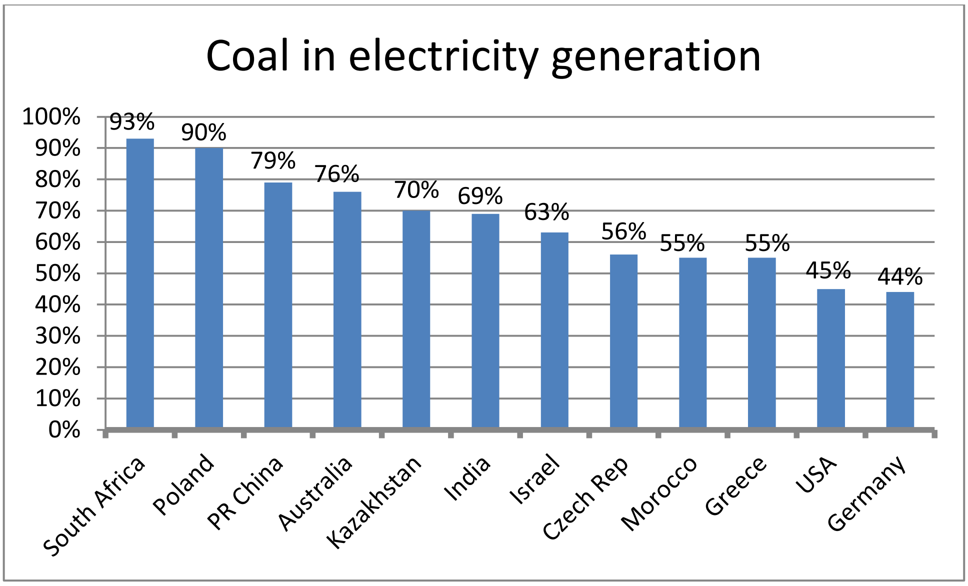


Figure 1.2: The contribution of coal in electricity generation

(Adapted from the (World Coal Association, 2012)

1.5 World coal consumption

World coal consumption is still dominated by China, United States and India according to Table 1.2. Approximately 71% of the total world consumption of coal is accounted for by these three countries. China is by far the largest coal consuming country at approximately 50% or 2640 Million tonnes (Mt), followed by the United States at about 13% or about 720 Mt and then India at just under 424 Mt or about

8%. South Africa’s domestic consumption is about 133 Mt and ranks as the fifth largest coal consumer worldwide.

Table 1.2: Top 10 World Coal Consumption Countries, Adapted from (BP, 2012)

Country	Mt oil equivalent (Mtoe)	%	Rank
China	1 839.40	49.39	1
United States	501.90	13.48	2
India	295.60	7.94	3
Japan	117.70	3.16	4
South Africa	92.90	2.49	5
Russia	90.90	2.44	6
South Korea	79.40	2.13	7
Poland	59.80	1.61	8
Australia	49.80	1.34	9
Ukraine	45.10	1.21	10
Rest	551.80	14.82	
Total	3 724.30	100	

Note: 1million tonnes (Mt) of coal is equivalent to (= 0.697 Mtoe)

1.6 World primary energy supply in Organisation for Economic Co-operation and Development (OECD) countries

According to the International Energy Agency (IEA) total primary energy supply by fuel increased from 5366 Mt in 1973 to 7611 Mt in 2011 in OECD countries. The world dependence on oil decreased from 52.6% to 36.3% in the same time period, whereas natural gas increased from 18.9% to about 25% as depicted in Figure 1.3 and Figure 1.4 respectively. (International Energy Agency (IEA), 2012)

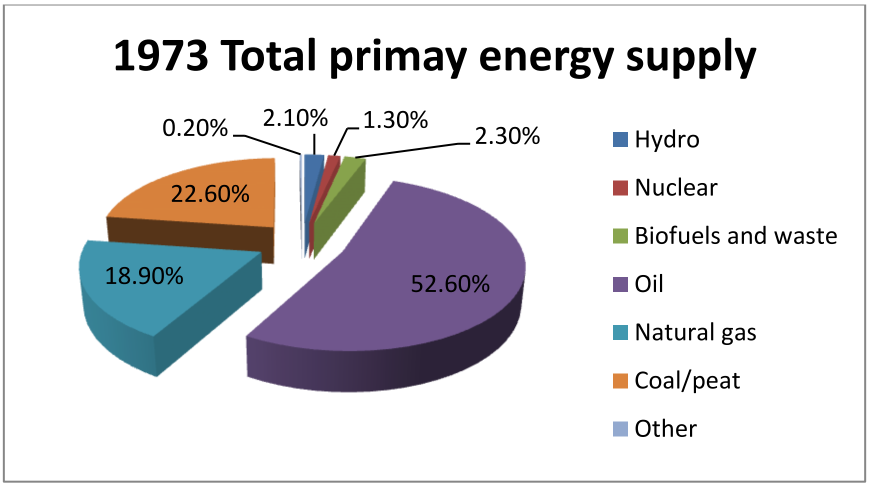


Figure 1.3 : Total primary energy supply in 1973 [Adapted from the (International Energy Agency (IEA), 2012)]

Coal's total energy share on the other hand decreased marginally from 22.6% to 20% from 1973 to 2011. Nuclear energy share interestingly grew from 2.3% to 10.2% over the same period. Hydropower energy's share remained unchanged whereas other fuels such as solar, heat, geothermal and wind grew slightly (International Energy Agency (IEA), 2012).

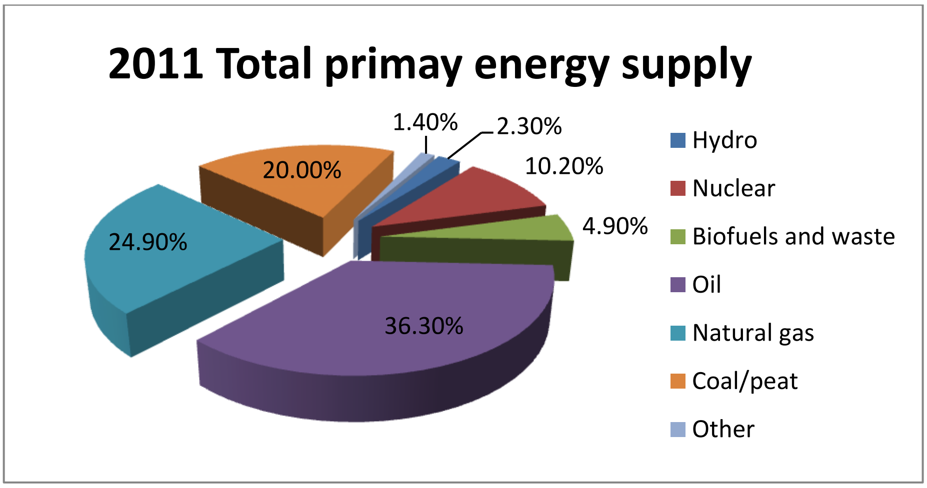


Figure 1.4: Total primary energy supply in 1973 (Adapted from the (International Energy Agency (IEA), 2012)

1.7 OECD total primary energy by region

Figure 1.5 and Figure 1.6 illustrate how the share of coal in OECD Oceania increased from 11.1% in 1973 to 16.6% in 2011 as a result of the shrinking coal industry in OECD Europe and OECD America in the same time period.

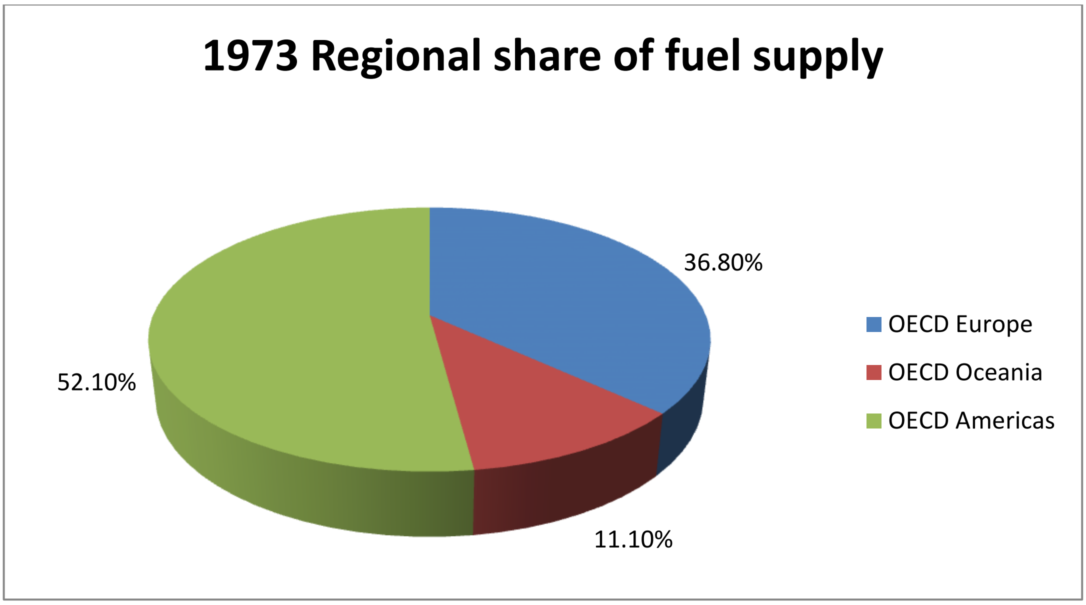


Figure 1.5: OECD total primary energy by region in 1973 (Adapted from the (International Energy Agency (IEA), 2012))

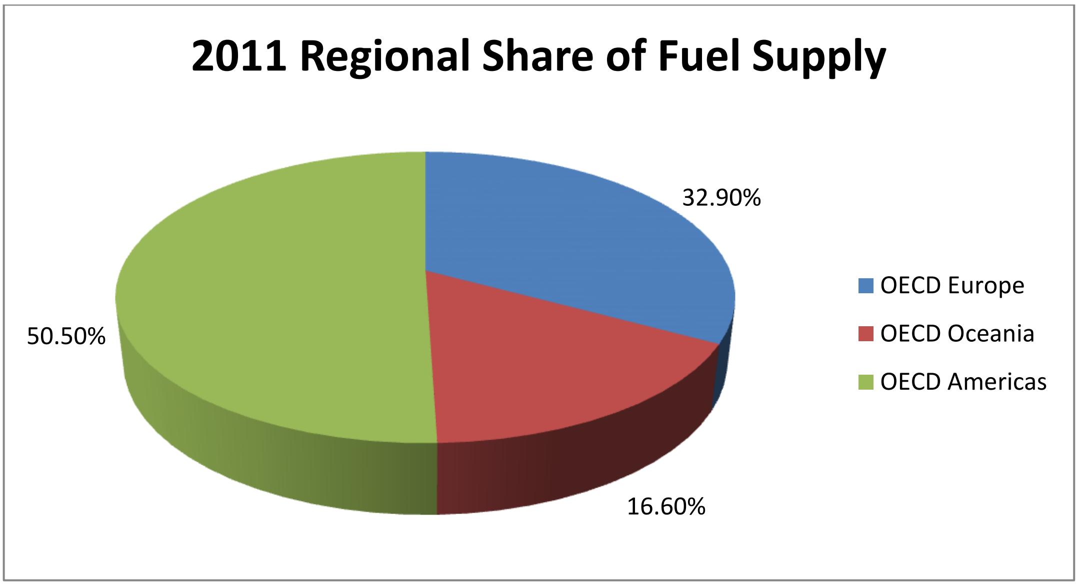


Figure 1.6: OECD total primary energy by region in 2011 (Adapted from the (International Energy Agency (IEA), 2012)

1.8 World coal production

In 1973, the world coal production was approximately 3041 Mt and mainly dominated by Organisation for Economic Co-operation and Development (OECD) countries and non- OECD countries in Europe and Eurasia as shown in Figure 1.7. Production from OECD countries together with non-OECD countries in Europe and Eurasia production were approximately 80% (International Energy Agency (IEA), 2012).

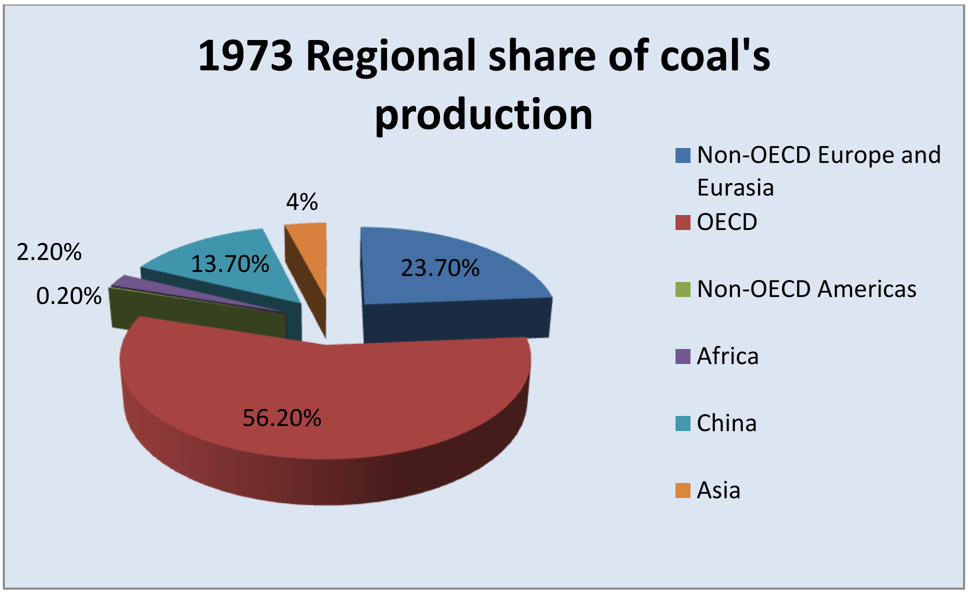


Figure 1.7: Worldwide coal production in 1973 [Adapted from the (International Energy Agency (IEA), 2012)]

Note: Coal production figures includes steam coal, coking coal, lignite and recovered coal.

In 2011, the coal production in OECD and non-OECD Europe and Eurasia dropped to roughly 35% and the production in China and Asia increased to about 60%. Of the 60% production increase, China's contribution is approximately 75%. In summary, the total coal production in 2011 was approximately 7783 Mt and over 45% of this increase is attributed to China as depicted in Figure 1.8. Much of the increasing demand in China is expected to be met in largely by coal. According to the EIA China's installed coal- fired generating capacity will more than double for the next two decades. The development of China's electric power and industrial sectors will require not only large-scale infrastructure investments but also substantial investment in both coal mining and coal transportation [(International Energy Agency (IEA), 2012)]

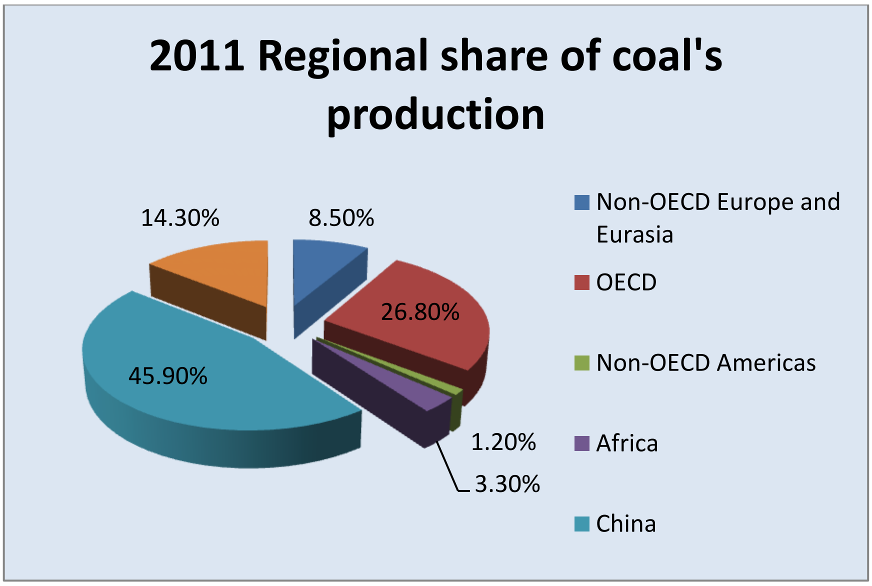


Figure 1.8: Total primary energy supply in 2011 (Adapted from the (International Energy Agency (IEA), 2012)

Table 1.3 lists all the major coal producing countries in terms of reserves, production and export figures. According to Table 1.3 major global producers are located in almost all the continents of the world thus indicating the vast resources and reserves of coal throughout the world. Three countries have major reserves in excess of 50 billion tonnes and they are the United States of America, China and India.

According to Table 1.3 the reserves of South Africa are estimated to be approximately 30 billion tonnes and this is a country that has about 50 million people. South Africa is ranked sixth when coal reserves are considered and the reserves of South Africa and Australia are more or less the same although Australia has only about 22 million people. Other countries with notable reserves are Kazakhstan and Ukraine followed by Colombia.

In terms of production, China is the major producer and produces about three and a half billion tonnes per annum, followed by the USA at about a billion tonnes per annum. Also the rapidly increasing production of China indicates the amount of development and investment that China has made towards technological advances in coal production and technological advances in other industries associated with coal, e.g. steel production. India is the third highest producing country at about 586 million tonnes (Mt) with a population of about 1.2 billion people and most of the coal produced by India is used internally. Australia produces about 400 million tonnes per annum indicating that it is a major exporter of good quality steam and coking coal and is therefore a major competitor on the export market compared to countries like South Africa. Indonesia is the fifth largest coal producing country in the world at about 300Mt per annum and has population of about 240 million people.

Table 1.3: World coal reserves and production in 2011 [Adapted from the (International Energy Agency (IEA), 2012)]

	Reserves			Production		
Country	**Mt**	**%**	**Rank**	**Hard Coal Mt**	**%**	**Rank**
Australia	36800	8.9	5	414	5.3	4
China	62200	15.1	2	3576	45.9	1
Colombia	6434	1.6	9	85.8	1.1	10
India	54000	13.1	3	586	7.5	3
Indonesia	1721	0.4	12	376	4.8	5
Kazakhstan	28170	6.8	7	117	1.5	8
Poland	6012	1.5	10	139	1.8	9
Russia	49088	11.9	4	334	4.3	6
South Africa	30408	7.4	6	253	3.3	7
USA	108950	26.5	1	1004	12.9	2
Rest of the world	12 187	2.1		898.2	11.54	
TOTAL	**411321**	**100**		**7783**	**100**	

1.9 OECD and non-OECD coal consumption

This section covers world coal consumption in OECD countries and non-OECD countries. The OECD countries covered are the USA, Canada, Europe and Asia. The non-OECD countries covered are China and India, Europe and Eurasia, Africa, Central and South America.

1.10 OECD coal consumption

World coal consumption decreased from 46.8 quadrillion Btu (1692 million tonnes) in 2008 to 43.5 quadrillion Btu (1572, 7 million tonnes) in 2010 in the OECD countries and is expected to remain at this level through to 2020. After 2020, the U.S Energy Information Administration predicted that coal consumption will increase to 1688 million tonnes in 2035, mainly because of the increase in natural gas prices in the United States (U.S Energy Information Administration, 2011).

1.10.1 OECD Americas

In 2008, coal use in the United States of America (USA) totalled 22.4 quadrillion Btu (809.87 million tonnes), which is 48 per cent of the OECD total and 92 per cent of total coal use in the OECD Americas region. The USA coal demand is expected to rise to 24.3 quadrillion Btu (878.56 Mt) in 2035. The USA has substantial coal reserves and relies heavily on coal for electricity generation. However, coal's share of total electrical generation is expected to decline from 48 per cent in 2008 to 43 per cent in 2035. Coal accounts for 39 per cent of the total growth in total electricity generation despite the negative impact in coal fired electricity generation (U.S Energy Information Administration, 2011).

Coal use for electricity generation is expected to continue to increase at existing coal- fired power plants and at several new plants currently under construction, together with the start-up of several coal to liquid (CTL) plants towards the end of 2035, which will lead to modest growth in USA coal consumption, averaging 0.3 per cent per annum from 2008-2035. Between 2008 and 2035 U.S.A coal-fired electricity generation which accounts for 22 per cent of the total growth in electricity generation is expected to increase but the high cost estimates for new coal-fired power plants will result in limited projections of new coal-fired capacity (U.S Energy Information Administration, 2011)

It is expected that in the short-term, low natural gas prices will lead to considerable displacement of coal-fired generation from existing plants in the early years of the projection period. Increased generation from natural gas accounts for about 39 per cent of the growth in total U.S.A electricity generation from 2008 to 2035, and increased generation from renewables satisfy 32 per cent of the increase (U.S Energy Information Administration, 2011)

In Canada, coal consumption is expected to decline to about 0.2 quadrillion Btu (7.23 Mt) from 2008 to 2035 primarily because of the Ontario government's plans to phase out the province's coal-fired generating capacity by the end of 2014. In late 2010, Ontario Power Generation retired approximately 1.9 gigawatts of coal-fired generating capacity at two, leaving the province with 4.2 gigawatts of remaining coal-fired capacity. (U.S Energy Information Administration, 2011)

In Mexico and Chile, coal consumption is expected to rise by 0.5 quadrillion Btu (18.08 Mt) from 2008 to 2035, primarily because of increasing demand for electricity. In Mexico, a new 0.7-gigawatt coal-fired generating unit on the country's Pacific coast was brought on line in late 2010, and in Chile 1.7 gigawatts of new coal-fired capacity is nearing completion. Chile's renewed interest in coal-fired generating capacity is based on a lack of reliable natural gas supplies from Argentina coupled with a substantial growth in electricity demand (U.S Energy Information Administration, 2011)

1.10.2 OECD Europe

In OECD Europe it is expected that there will be a slight decline in coal consumption from 12.5 quadrillion Btu (451.9 Mt) in 2008 to 10.4 quadrillion Btu (376.0 Mt) in 2035. Europe's coal consumption equals about 27 per cent of the OECD total. In 2008 major coal consuming countries of OECD Europe included Germany, United Kingdom, Poland, Italy, Spain, Turkey and Czech Republic. Europe relies on coal with a low calorific value and hard coal imports to meet their requirements.

The electricity and industrial sectors accounted for 94 per cent of the coal consumed in OECD Europe in 2008, with electricity producers using 8.7 quadrillion Btu (314.55 Mt) of coal and industrial plants using 3.1 quadrillion Btu (112.1 Mt). Over the projection period, the use of coal declines in both sectors, falling at average rates of 0.9 per cent per year in the industrial sector and 0.5 per cent per year in the electricity sector. (U.S Energy Information Administration, 2011)

From 2008 to 2035 the total installed coal-fired electricity generating capacity in OECD Europe is expected to decline from 200 gigawatts to 169 gigawatts, and coal's share of total electricity generation is also expected to reduce from 25 per cent to 16 per cent. Plans to retire ageing and inefficient generating capacity are, to some extent, offset by new coal-fired capacity. Approximately 20 gigawatts of new coal-fired generating capacity currently are under construction in OECD Europe, which is half represented by projects in Germany. The recent nuclear crisis in Japan and the subsequent decision by the German government to reassess its September 2010 decision to extend the life of 21 gigawatts of nuclear generating capacity, means that the planned retirement of 13 gigawatts of older coal-fired generating capacity may not occur (U.S Energy Information Administration, 2011)

Rather, these older coal plants may be retrofitted with environmental equipment and kept on line to replace the electricity supply lost from a shutdown of Germany's nuclear reactors (U.S Energy Information Administration, 2011).

1.10.3 OECD Asia

From 2008 to 2035 coal consumption in OECD Asia is expected to remain flat because of an expected decrease of about 0.9 quadrillion Btu (32.54 Mt) in coal use in Japan and an expected increase of 0.8 quadrillion Btu (28.9 Mt). Japan is OECD Asia's largest coal consuming nation, but its declining population and expected shift away from coal to alternative sources, including renewables and natural gas, for electricity generation is expected to lower the demand for coal in the future. In the same time frame i.e. from 2008 to 2035 South Korea's coal use is expected to increase by about 1 per cent per year. Most of this increase is expected from the South Korea's power sector which accounts for more than three-quarters of the overall coal consumption, though most of the growth is expected after 2020. (U.S Energy Information Administration, 2011).

Coal consumption in Australia and New Zealand is expected to remain constant through to 2035. Of the two countries, in 2008 Australia's consumption was approximately 96 per cent of the region's total and was the larger coal consumer. Although coal's share of the total generation is expected to decline in the long-term there are substantial coal reserves primarily in Australia and the region continues to rely on coal for electricity generation. In 2035, coal fired plants which currently supply about 65% of the region's electricity are expected to supply about 40%. Generation from both renewables and natural gas are increasing rapidly compared with coal, capturing an increasing share of Australia's and New Zealand's total generation (U.S Energy Information Administration, 2011).

1.11 Non-OECD countries

Fast-paced growth is projected for non-OECD nations, particularly among the Asian economies in contrast to coal consumption in the OECD economies. This growth is led by strong economic growth and rising energy demand in non-OECD Asia. The total coal consumption in non-OECD countries is expected to increase by about 76 per cent from 92.2 quadrillion Btu (3333.5 Mt) in 2008 to 162.5 quadrillion Btu (5875.2 Mt) in 2035. The substantial increase in non-OECD coal consumption illustrates the importance of coal in meeting the region's energy needs. It is expected that coal will account for more than one-third of total non-OECD energy consumption from 2008 to 2035 (U.S Energy Information Administration, 2011).

1.11.1 Non-OECD Asia

From 2008 to 2035, 90 per cent of the projected increase in world coal consumption is expected to come from non-OECD Asian countries. This is as a result of a strong economic growth averaging 5.3 per cent from 2008 to 2035 which is expected for non-OECD Asia, with China's economic growth averaging 5.7 per cent per year and India's 5.5 per cent per year. Much of the increase in demand for energy in non-OECD Asia is expected to be met by coal particularly in the electric power and industrial sectors. (U.S Energy Information Administration, 2011)

Coal use in China's electricity sector is expected to increase to 63.4 quadrillion Btu (2292.2 Mt) in 2035 from 28.7 quadrillion Btu (1039.45 Mt) in 2008, at an average rate of 3.0 per cent per year. In comparison, coal consumption in the U.S.A electricity power sector is projected to grow by 0.2 per cent annually to 21.6 quadrillion Btu (780.9 Mt) in 2035 from 20.5 quadrillion Btu (741.2 Mt) in 2008. China had an estimated 557 gigawatts of operating coal-fired capacity at the end of 2008. To meet the increasing demand for electricity that accompanies the relative strong outlook for China's economic growth from 2008 to 2035, an additional 485 gigawatts of coal-fired capacity per year (net of retirements) is projected. The substantial amount of new capacity represents, on average, 18 gigawatts of new coal-fired capacity additions per year, which is a slower rate of construction than occurred during the five year period ending in 2008, when coal fired capacity additions averaged 55 gigawatts per year. Coal's share of the total generation in China is expected to decline to 66 per cent in 2035 from 80 per cent in 2008 as generation from nuclear, and natural gas each grows more rapidly than generation of coal (U.S Energy Information Administration, 2011).

In 2008, approximately one-half (52 per cent) of China's coal use was in the end-use sectors, and primarily in the industrial sector. From 2008 to 2035 the industrial sector consumption in China is expected to increase by 18.8 quadrillion Btu (679.7 Mt), or 67%. Within this sector, the single largest use of coal is for production of coke, which in turn is used primarily to produce pig iron. Chinese coke plants consumed 457 million tonnes of coal in 2008, representing approximately 34 per cent of total coal consumption in the industrial sector on a tonnage basis. In 2008, China was the world's leading producer of both steel and pig iron, accounting for 50 per cent of world pig iron production and 38 per cent of global raw steel output (U.S Energy Information Administration, 2011).

Coal remains the leading source of energy for China's industrial sector, although its share of industrial energy consumption is expected to decline in the projected period, with electricity and other energy sources making up an increasing share of the total. From 2008 to 2035, electricity's share of total industrial energy use is expected to rise from 18 per cent to 26 per cent, while coal's share drops to 55 per cent from 63 per cent. However, with coal-fired power plants satisfying a substantial portion of China's total power generation requirements throughout the period, the increase in electricity demand in the industrial sector can, to a certain extent, be viewed as an increase in demand for coal. (U.S Energy Information Administration, 2011)

In India, 46 per cent of the growth in coal consumption is expected to be in the industrial sector and the remainder i.e. 54 per cent in the electric power sector. India's coal-fired power plants consumed 6.7 quadrillion Btu (242.2 Mt) of coal in 2008, representing 62 per cent of the country's total coal demand. Coal use for electricity generation in India is projected to grow by 2 per cent per year on average, to 11.4 quadrillion Btu (412.2 Mt) in 2035, requiring an additional 72 gigawatts of coal-fired capacity. As a result, India's coal-fired generating capacity will increase from 99 gigawatts in 2008 to 172 gigawatts in 2035. Despite an increase in coal-fired electricity generation of 107 per cent over the period, growth in generation from natural gas, nuclear power, and renewable energy sources is expected to grow even more rapidly, and the coal share of India's total generation is expected to decline from 68 per cent in 2008 to 51 per cent in 2035 (U.S Energy Information Administration, 2011).

In the other nations of non-OECD Asia, coal consumption grows by an average of 2.1 per cent per year from 2008 to 2035 i.e. 6.3 quadrillion Btu (227.8 Mt) to 11.0 quadrillion Btu (397.7 Mt).

Significant growth in coal consumption is expected in Indonesia and Vietnam in the electric power sector, where considerable amounts of new coal-fired generating capacity are expected to come on line before 2030. Growing demand for energy in the region's electric power and industrial sectors drives the increase in coal use. In Indonesia and Vietnam in the electric power sector, significant growth in coal consumption is expected, where considerable amounts of new coal-fired generating capacity are expected to be built (U.S Energy Information Administration, 2011).

1.11.2 Non-OECD Europe and Eurasia

Coal consumption in non- OECD Europe and Eurasia is expected to decline slightly from the 2008 level of 9.0 quadrillion Btu (325.4 Mt). Russia leads the region's' coal consumption by consuming about 4.5 quadrillion Btu (162.7 Mt) of coal in 2008. Russia consumption is therefore 50 per cent of the total for non-OECD Europe and Eurasia. Coal met 15 per cent of Russia's total energy requirements in 2008, and coal-fired power plants provided 18 per cent of its electricity; in 2035 those shares are slightly lower, at 14 per cent and 16 per cent, respectively (U.S Energy Information Administration, 2011).

In 2035, Russia's coal consumption is expected to increase to 4.9 quadrillion Btu (177.2 Mt). Natural gas continues to be the leading source of electricity generation in Russia throughout the projection period, although its share of total generation is expected to decline substantially, while both nuclear and renewables garner increasing shares of the total. From 2008 to 2035, additional generation from nuclear and renewables, taken together, is expected to account for 82 per cent of the growth in Russia's total electricity supply, with increasing output from coal and natural gas fired power plants supplying 18 per cent. Again from 2008 to 2035, coal consumption in the other countries of non-OECD Europe and Eurasia is expected to decline from 4.5 quadrillion Btu (162.7 Mt) to 3.7 quadrillion Btu (133.8 Mt). For the region as a whole, coal-fired electricity generation is expected to remain near the current level, and as a result the coal share of total generation is expected to decline from 34 per cent in 2008 to 24 per cent in 2035. (U.S Energy Information Administration, 2011)

From 2008 to 2035, nuclear and natural gas energy sources will satisfy much of the additional electricity requirement for non-OECD Europe and Eurasia (excluding Russia), with increased output from nuclear plants expected to meet 38 per cent of the growth and natural-gas-fired plants. (U.S Energy Information Administration, 2011)

1.11.3 Africa

It is expected that the coal consumption of Africa will increase by 90 million tonnes from 2008 to 2035. South Africa dominates the coal consumption of Africa and currently accounts for about 93 per cent of the consumption and is expected to continue to account for much of Africa's total coal consumption over the projected period. Three large coal-fired plants (Camden, Grootvlei, and Komati) that have been closed for more than a decade have been restarted by ESKOM to meet the increasing demand for electricity in South Africa. The combined generating capacity of these three power stations is 3.8 gigawatts (U.S Energy Information Administration, 2011).

In addition, ESKOM is proceeding with the construction of two new coal-fired power plants Kusile in Mpumalanga and Medupi in Lephalale. The two power stations which have a combined generating capacity of 9.6 gigawatts are scheduled to be fully operational by the end of 2017. In April 2010, the World Bank approved a $3.8 billion loan for ESKOM to help with the financing of several energy-related projects, including $3.1 billion allocated for completion of the Medupi plant. (U.S Energy Information Administration, 2011).

A general lack of spare generating capacity plus the power shortages in southern Africa have also led to increased interest in new coal-fired power projects in countries other than South Africa. Of particular significance are major investments being made by several international energy companies to develop the coal reserves in Mozambique and Botswana for the purpose of supplying both international export markets and the domestic coal-fired generating plants (U.S Energy Information Administration, 2011).

In the industrial sector, an increase in coal consumption of about 21.7 million tonnes which accounts for 26 per cent of the total increase for Africa is expected from 2008 to 2035. This increase is as a result of production of steam and process heat for industrial applications, production of coal-based synthetic liquids and production of coke for the steel industry. Currently, two large-scale CTL plants in South Africa (Sasol II and Sasol III) accounting for about 25 per cent of the country's total liquid fuel supply can supply up to 150,000 barrels of synthetic liquids per day. Approximately 25 per cent of the coal consumed in South Africa is for the production of synthetic fuels. In 2035 the production of coal based synthetic liquids in all of Africa is expected to increase to 274,000 barrels per day (U.S Energy Information Administration, 2011).

1.12 Central and South America

In 2008 Central and South America consumed 0.8 quadrillion Btu (28.9 Mt) of coal. Approximately 61 per cent of the region's coal demand was from Brazil in 2008. Colombia, Peru, Argentina, and Puerto Rico accounted for most of the remainder. From 2008 to 2035 coal consumption in Central and South America is expected to increase by 1.5 quadrillion Btu (54.2 Mt), with most of the increase in Brazil, primarily for the production of coke for use in the steel industry. Brazil's steel companies have plans to expand their production capacity considerably over the next several years to meet increasing coal demand for steel in both domestic and international markets. In the near term, coal consumption in Brazil's electricity sector is set to increase with the completion of three new coal-fired power plants which are expected to be completed in 2013. The three new plants will have a combined generating capacity of 1.4 gigawatts (U.S Energy Information Administration, 2011).

1.13 World coal trade

The world's coal trade is mostly from steam coal which accounts for approximately 80% of the coal trade and the balance is from coking coal as shown in Table 1.4. In 2011, the top five producers of steam coal were Indonesia, Australia, Russia, Colombia and South Africa. The top three producers of coking coal in 2011 were Australia, Russia and the United States. Australia is the largest exporter of both steam coal and coking coal combined and Indonesia is currently the largest exporter of steam coal.

Australia is expected to dominate the international coal trade as it continues to expand and improve its inland transportation and port infrastructure to expedite coal to international markets. Australia by virtue of its proximity to the Asian market is the primary exporter of coking coal to this market (U.S Energy Information Administration, 2011).

Table 1.4 Net exporters of hard coal [Adapted from (International Energy Agency (IEA), 2012)]

Net Exporters Hard Coal			
Country	**Mt**	**%**	**Rank**
Indonesia	309	29.68	1
Australia	285	27.38	2
Russian Federation	99	9.51	3
United States	85	8.17	4
Colombia	76	7.30	5
South Africa	70	6.72	6
Kazakhstan	34	3.27	7
Canada	24	2.31	8
Vietnam	23	2.21	9
Mongolia	22	2.11	10
Others	14	1.34	
TOTAL	1041	100	

Indonesia has demonstrated its potential for significant growth in coal exports because of its low relative cost of surface mines, with export levels in 2010 approaching an estimated 330 million tonnes from about 66 million tonnes in 2000. PT Bumi Resources, one of Indonesia’s largest resource companies planned to increase its production at the end of 2012 to 122 million tonnes from 69 million tonnes in 2009. PT Adaro Energy, another Indonesian company also planned to expand coal production by over 40 million tonnes from 2009 to 2014 (U.S Energy Information Administration, 2011).

Areas of uncertainty for Indonesia’s coal exports include the adequacy of its internal transportation infrastructure; the continued development of new mines; environmental concerns; the rate of growth in its domestic coal consumption; and whether domestic coal demand is given preference over coal exports over the long term. Just as in South Africa during the 2008 power shortages, the Indonesian government officials at the beginning of 2011 stated that it was their government's intention to restrict coal exports under a proposed regulation that, as of 2014, would restrict exports to coal with high thermal content. The new restriction would effectively eliminate 50 to 60 per cent of Indonesia's coal exports as some analysts suggest (U.S Energy Information Administration, 2011).

Domestic infrastructure constraints have impacted negatively on South Africa's coal exports over the past five to eight years resulting in a flat export figure of about 70 million tonnes. The phase five expansion of Richard's Bay Coal Terminal with a total capacity of 91 million tonnes was completed in April 2010 but because of problems with the freight rail infrastructure South Africa export has still to reach the maximum potential of this port. Export levels have continued to be below 70 million tonnes over the past several years because of the limitation of the rail capacity. Despite the problems with the export capacity coal mining will continue to play a significant role in the economy of South Africa. There are several proposed additional investments at the Matola port in neighbouring Mozambique and discussion on a possible railway link with the Waterberg coalfield and an incremental 10 million tonnes at the Richard's Bay Coal Terminal (RBCT) (U.S Energy Information Administration, 2011).

In Russia, the primary limitation on efforts to expand exports is the rail from coal basins to port facilities. Nevertheless, in 2010, Russia was the largest exporter of seaborne coal to Europe with a total of 76 million tonnes and managed to triple its seaborne coal exports from 2000 levels. SUEK (Siberia's coal energy company) has built about 13 million tonnes of annual export capacity to facilitate the coal exports from Russia to Asia through increasing the capacity of the new Pacific port. In addition, about 28 million tonnes of export capacity at the new Muchka Bay Terminal 2 is planned by Mechel. Another terminal to serve the European and North American markets at the Lavan on the Barents Sea with an initial export capacity of 7 million tonnes and a long-term potential of 39 million tonnes has started construction and was expected to be operational by the end of 2014. Less than 10 per cent of the seaborne coal traded internationally is expected to be supplied by Eurasia (U.S Energy Information Administration, 2011).

In 2011, about 110 million tonnes of U.S.A coal exports were expected to be reached after the first half records of 67 million tonnes driven by an overall increase in demand in world coal. The U.S.A coal exports are unable to compete with other countries that have large coal reserves for the Asian markets where much of growth in coal is centred. This is because of the high transportation costs associated with shipping coal from the east of the U.S.A where reserves are mainly centred. However, an estimated 13 million tonnes of coking coal in the third quarter of 2010, compared with 4 million tonnes in the third quarter of 2009 was exported from the U.S.A to the Asian market which was seen as a significant growth (U.S Energy Information Administration, 2011).

A lack of a large coal export terminal on the West Coast, which is closer to both Asian markets and the top U.S. steam coal-producing region in the Powder River basin, is seen as an obstacle to increasing U.S coal exports. Environmental protests and the extensive permitting processes could also impede or delay investments in the western port projects in Longview and Cherry Point, Washington. (U.S Energy Information Administration, 2011).

A continued increase in exports from Colombia is expected to make South America to remain the world third largest coal exporting region in 2035. In 2020, coal production in Colombia is expected to reach 160 million tonnes, up from about 87 million tonnes in 2009. The government of Colombia is expected to make sizable investments in mine capacity, rail infrastructure, and port capacity in order to meet this expansion demand.

About 40 million tonnes per year from 2010 through to 2032 is expected to be produced from Drummond Coal from its El Descanso mine in Colombia. Plans are in place in the Cerrejon mine, jointly owned by Anglo America and BHP Billiton to boost its production by 25 per cent, to 40 million tonnes by 2014. An increase of production from 1.8 million tonnes to about 5 million tonnes by 2012 is also expected from the Hatillo mine.

Like other export countries Colombia is also concerned about increasing coal transportation infrastructure as a result there are plans to build a river to port terminal at Barranquilla of about 39 million tonnes annual capacity. There are also proposals to accelerate the transportation of coal via truck to Colombia’s Pacific Ocean port of

Buenaventura when it is completed in 2013 by building a tunnel. Foreign investors are interested in the Carare railway project which is intended to facilitate coal transportation from the central Colombia to the Carribean coast and it is likely that this project would be reinitiated. Other expansion projects include a coal terminal at the port of Cienaga, Puerto Nuevo, which is expected to handle 66 million tonnes per year by the end of 2013. Another coal export port with a capacity of 20 million tonnes per year and capable of taking larger capesize ships is planned by Brazil's MPX along Colombia's Atlantic seaboard (U.S Energy Information Administration, 2011).

It is expected that many of the projects on the eastward opening of the Panama Canal once completed in 2015 would enhance opportunities for coal exports to Asia for South America and the U.S.A. Vessels capable of carrying 20 per cent coal are expected to transit via the Canal (U.S Energy Information Administration, 2011).

1.14 Coal importers

Table 1.5 indicates that Asia remains the world's largest importer of coal accounting for over 70% of the growth in total world coal imports. The People's Republic of China and Japan are currently Asia's largest importers of coal. China's coal imports are expected to be approximately 310 million tonnes in 2035, as compared to 129.5 million tonnes in 2009. China is expected to continue to surpass Japan as the world largest importer of coal up to 2035 although China is expected to continue to be supplied by its own coal mines through this projection period (U.S Energy Information Administration, 2011).

China's increasing reliance on imports of seaborne coal makes it the largest source of uncertainty with respect to world coal trade projections. Even small percentage shortfalls in China's domestic coal production can have a large impact on the world trade market as a whole because China is the world largest consumer and producer. Every year since 2001 China has increased its coal consumption. As a result it has not needed large increases in imports in most years because it also has increased domestic coal production aggressively. For instance, coal imports rose by less than 9.25 million tonnes in 2004 while consumption increased by 421 million tonnes. China imported about 51 million tonnes of coal in 2007 and imports actually declined to 37 million tonnes in 2008. In 2009, however, its coal imports more than tripled and its coal consumption increased by about 402 million tonnes (U.S Energy Information Administration, 2011).

Table 1.5 Net Importers of hard coal (International Energy Agency (IEA), 2012)

Net Importers			
Country	**Mt**	**%**	**Rank**
People's Rep. of China	177	17.66	1
Japan	175	17.47	2
Korea	129	12.87	3
India	101	10.08	4
Chinese Taipei	66	6.59	5
Germany	41	4.09	6
United Kingdom	32	3.19	7
Turkey	24	2.40	8
Italy	23	2.30	9
Malaysia	21	2.10	10
Others	213	21.26	
TOTAL	1002	100	

In the long run, the growth in China's seaborne coal imports may be slowed or reduced by several factors. For one, freight transportation improvements to support domestic coal production in China have already been implemented, or planned to be implemented. In addition, there would be less need for seaborne coal imports because of strong growth in imports from Mongolia, which are likely to be moved overland rather than by sea. The need to reduce imports would further be reduced because of large expansions of domestic mine capacity and efficiency gains at mining complexes, with some mines such as Inner Mongolia planning to increase production capacity by 500 million metric tonnes by 2015. Reliance on domestic sources of supply is the route likely to be encouraged in China because of high international coal prices, and high-priced imported coking coal would be negatively impacted because of the current low steel prices. Finally, to connect distant Chinese coal sources with electricity demand centres with the use of mine mouth plants in combination with transmission infrastructure would also alleviate the need for imports (U.S Energy Information Administration, 2011).

Australia continues to provide over 60% of Japan’s coal imports i.e. both steam and coking coal on a tonnage basis although there is some domestic production in Japan. Japan has pursued investments in other countries, including Russia and Canada in seeking to diversify its coal supply sources. Also, Japan will continue to import coking coal for its steelmaking plants in the next two decades as it is the second-largest steel producer in the world, after China. (U.S Energy Information Administration, 2011).

South Korea and Taiwan like Japan continue to import most of the coal that they consume presently and will continue to do so through to 2035. Despite sizable increases in coal imports by other countries South Korea (in OECD Asia) and Taiwan (in non-OECD Asia) are expected to maintain a combined 16 per cent share of world imports in 2035 because of their planned increases in coal-fired generating capacity. In the last decade, the two countries together nearly doubled their steam coal imports to a total of about 148 million tonnes, with the increase being met primarily by coal from Indonesia and Australia. Demand for coking coal in the two countries returned to the levels recorded before the global economic slowdown as a result of the growth in the level of steel production in Taiwan which nearly matched its 2008 level and in South Korea exceeded its 2008 level in 2010. (U.S Energy Information Administration, 2011).

With the expectations of additional demand India, like China, has been increasing its coal imports in recent years. In 2035, spurred by rising imports of both coking and steam coal, India’s coal imports are expected to increase to about 2.6 times the 2009 level (on an energy basis). India’s demand for coal continues to grow, but because of poor quality coal and infrastructural issues this has led to a negative impact on the export of coal to the international market.

As a result, India will continue to depend on the imported steam coal to supply its large coal-fired electricity plants especially in the coastal areas. The prospect of strong growth in coal imports is more likely because of the difficulties in expanding India’s coal production. In 2010, environmental sensitivity of the overlying land in India has led to the Environmental Ministry refusal to grant permits to many major Indian coalfields. Estimated shortfalls in India’s domestic coal production could be as high as 220 million tonnes by 2015, up from an estimated 110 million tonnes in 2010 according to a representative from India’s largest coal producer (the state-controlled Coal India, Ltd.). Steam coal imports have doubled since 2008, to 83 million tonnes in 2010 according to preliminary data. India has raised its coal import level by an incremental 22 million tonnes for 2 years in a row. South Africa and Indonesia together currently supply nearly all of India’s imports of steam coal, and the vast majority of its coking coal imports are supplied by Australia (U.S Energy Information Administration, 2011).

In recent years India has had some success in expanding its port infrastructure to support increases in coal imports. Several new ports including Krishnapatnam with an expected capacity of at least 66 million tonnes in 2011 and Gangavaram with an eventual capacity of 39 million tonnes and capable of handling capesize vessels have been commissioned since 2008. In 2010, the new port of Dharma, received its first coal shipments. Based on preliminary data the private port of Mundra alone will have an ultimate capacity of 66 million tonnes, equivalent to about 60 per cent of India’s total coal imports in 2010. By 2015, the expansion of coal-handling capability at the port of Mormugao is expected to be completed and will be capable of handling about 19 million tonnes up from 6 million tonnes, although it is expected that environmental opposition could delay the project.

India will continue to source coking coal from other countries because the domestic resources of coking coal are of a poor quality and occur at greater depth. India plans to expand its steel industry and in 2010, the raw steel output was about 67 million tonnes, however, the long-term plan is to expand this output to between 165 and 198 million tonnes by 2020, with increased imports of coking coal supporting the expansion. In 2010, India’s production of pig-iron was 34 per cent higher than in 2008 and thus making India the fourth largest producer of pig iron. It is unlikely that the demand for coking coal imports will increase in India after 2014 because some plans for new steelmaking capacity, such as ArceloMittal’s new coastal steel plant in Orissa, appear to have been delayed by land acquisition difficulties and environmental issues (U.S Energy Information Administration, 2011).

1.15 Global oil price

Global oil prices have continued to decrease from the high prices experienced during the global financial crisis. Prices of US$140 per barrel were reached in 2008 and in 2012 prices settled at an average of US$112 per barrel as depicted in Figure 1.9. The 2012 prices were slightly higher than the 2011 average prices of US$111 per barrel. The oil prices are affected by tight global crude oil market that began in 2010 and marked the highest crude oil prices since 2008.

Key factors affecting the crude oil prices in 2011 were the civil war in Libya or what is commonly referred to as the Arab Spring and the loss of production of export resulting thereof, the growing demand in China and the Middle East countries which are not part of the OECD and transportation bottlenecks out of the U.S.A especially in the Midwest, the European debt crisis which resulted in lower than expected growth in demand for petroleum products (US Energy Information Administration, 2012).

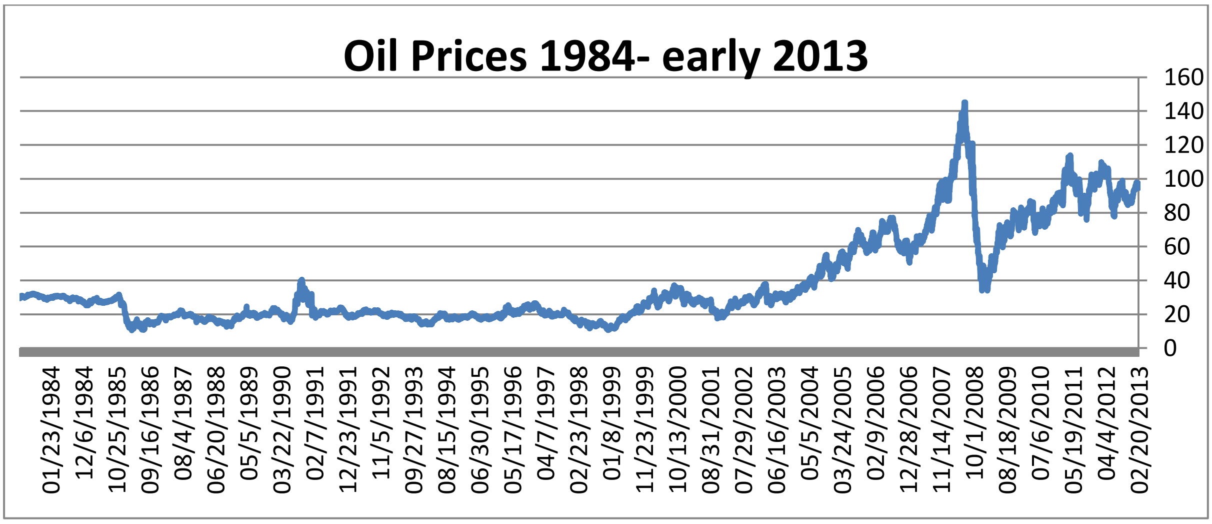


Figure 1.9: Oil prices from 1984 to early 2013 (Adapted from the (US Energy information Administration, 2013)

In 2012 the oil prices rose to US$112 per barrel and some of the key factors behind this increase were the issues of 2011 including the war in Sudan and the political turmoil in Yemen and Syria affecting the oil supply, a tight and volatile market combined with a rising consumption in emerging markets (Halff, 2012). To combat some of these problems the International Energy Agency formed an organisation of OECD countries that can assist member countries to have an effective emergency response tailored to the specific country’s needs that includes having 90 days stock levels and forging strategic international partnerships with countries like Saudi Arabia to immediately supply the deficit required (van der Hoeven, 2012).

In general there is a concern that high oil prices lead to a volatile oil market and therefore governments across the world especially those that are part of the International Energy Agency are advised to consider having a balanced energy mix or a diversification of supply and to provide a supply buffer (Yergin, 2012).

1.16 Resources and reserves of South Africa

The available data on coal resources and reserves of South Africa indicate that the resources and reserves of the current South African coal mining industry are nearing depletion especially some of the resources and reserves of some of the large coalfields like the Witbank and Highveld coalfields. Despite the positive contribution of some of the greenfield projects currently being developed and extension of some of the brownfield projects that are being undertaken in the Witbank and Highveld coalfields, there is however, a general national concern that the South African coal mining industry in its present form is nearing its end unless something drastic is done to revive this industry.

More concerning is the depletion of the Witbank and Highveld coalfields which in the past provided over 78% of the coal produced by the South African coal mining industry. The data available has further indicated that the Witbank and Highveld coalfields have been in operation for over a century and that both coalfields are nearing depletion. The Waterberg coalfield has been identified as an alternative coalfield to augment the depleting resources and reserves of the Witbank and Highveld coalfields (Jeffrey, 2005). All the known data on geological reserves and resources support the choice of the Waterberg Coalfield as a viable and critical coalfield that needs to be exploited in the coming years in order to maintain and guarantee an adequate supply of energy for South Africa (Bredell, 1987). A detailed discussion on the resources and reserves of the Witbank and Highveld coalfields together with the Waterberg coalfield is given in Chapter 3 of this dissertation.

A study of the resources and reserves of the South African coalfields by Bredell estimated the total in-situ resources of South Africa to be approximately 121 billion tonnes and the total recoverable reserves to be around 55.3 billion tonnes (Bredell, 1987), as shown in Table 1.6 and Table 1.7 respectively.

Although this data is old no comprehensive survey of a similar nature has been done since Bredell published his report in 1987. All calculations of resources and reserves in the coal mining industry since then have been done by deducting the reserves mined in the intervening years from the reserves first calculated by Bredell.

The terminology used to define and classify resources and reserves have vastly changed over the years and have evolved from the time that Bredell defined these two terms. First the South African Mineral Resource (SAMREC) code was established in 1998 and became effective in March 2000 with the purpose of bringing local definitions in line with the internationally accepted standards of reporting of mineral resources and reserves. In more recent years the South African National Standard 10320 (SANS10320) of 2004 code was introduced to specifically classify the coal resources and reserves and to differentiate them from any other mineral mined in South Africa. The SAMREC Code and the SANS10320 classification of resources and reserves are used in all recent estimates of the remaining coal reserves in South Africa. Therefore, it is imperative that when the figures of resources and reserves that Bredell calculated are used, care should be taken to define precisely what he meant. According to Bredell resources and reserves are defined as follows:-

“Total In-Situ Resources: This refers to all raw, in-situ resources of a particular geological confidence category, irrespective of thickness, depth or quality or exploitability. It includes a substantial amount of resources which can be regarded as permanently unexploitable due to geological constraints such as faults or due to environmental constraints such as towns or dams” (Bredell, 1987 pp.5,8).

“Raw Reserves: That portion of the raw in-situ exploitable resources which can currently or in the foreseeable future be recovered economically, taking into account mining losses and presently unmineable resources” (Bredell, 1987 pp.8). These raw reserves refer to recoverable reserves.

1.17 Total in-situ resources

In terms of the data presented in Table 1.6 , which are the figures produced by Bredell in 1987 , the Waterberg in-situ resource represents over forty five (45%) of the total in-situ resources of coal in South Africa. On the other hand the Highveld and Witbank coalfields combined equal only about twenty seven (27%) of the total in-situ resources. Other coalfields are marginal or below double digits as indicated in Table 1.6.

The total resources of the other twelve coalfields add up to twenty –seven per cent (27%). It is important to note that although the resources of the Witbank and Highveld Coalfields lag behind the in –situ resources of the Waterberg, they are however far more significant compared to the resources of the other coalfields. The significance of these resources is in terms of the quality of the individual seams and the thicknesses of the various seams found within the lithology of these coalfields.

In light of the 47% in-situ resources of the Waterberg it should not be surprising why the coal mining industry needs to investigate the Waterberg coalfield before the depletion of the resources in the Witbank and Highveld coalfields. The coal mining industry has not exploited the Waterberg coalfield reserves as much as it has exploited the Witbank and Highveld Coalfields due to the complex geology in the Waterberg.

Some of the major reasons for this marginal exploitation of the Waterberg are the thick and shallow coal resources of the Witbank and Highveld coalfields. The number two (No. 2) and number four (No. 4) seams of these two fields are typically 4 to 6 m in thickness. Witbank is close to Johannesburg and in the early days of mining the major market was the gold mining industry and the city of Johannesburg. In addition, the quality of the coal is an added benefit because it is of such good quality that it meets the metrics of both the local thermal power stations and other major industries such as the CTL markets and the international thermal markets. Two of the quality requirements are the calorific value just above twenty seven mega joules per kilogram (27 MJ/kg) and a low ash content which in the current markets is an ash content below sixteen per cent (16%).

Table 1.6: Total in-situ resources [Adapted from (Bredell, 1987)]

Coalfield	Mt	Percentage (%)
Witbank	16 241	13.40
Highveld	16 909	14.00
E. Transvaal	7 525	6.20
Utrecht	1 067	0.90
Klip River	1 157	1.00
Vryheid	321	0.30
South Rand	3 072	2.50
Sasolburg	4 757	3.90
OFS (Remainder)	8 876	7.30
Waterberg	55 614	45.90
Springbok Flats	3 250	2.70
Limpopo	256	0.20
Soutpansberg	1 450	1.20
Kwa-Zulu	256	0.20
Kangwane	467	0.40
Total	121 218	100

The coal described above is beneficiated before being exported and therefore the export market is not supplied with raw or unwashed coal. The export coal is mostly shipped to the European and Asian markets through the Richard’s Bay Coal Terminal (RBCT).

The Witbank and Highveld coalfields have an established infrastructure in terms of roads and railway networks that cover most of the mines in that region. The infrastructural capacity continues to give investors and the coal mining companies the assurance that the export coal will reach the customers safely, cost effectively and without disruption. Water is also available in the region to enable the mining and beneficiation of coal to be accomplished without much difficulty. One of the biggest advantages of the Witbank and Highveld coalfields over the Waterberg and other coalfields of South Africa is the availability of skilled labour in the area which has been in employment for over seven decades. Of course, labour is not a fixed asset and can move to a new coalfield. Although the current labour force is ageing it is safe to say that the mining companies have been working on their succession plans to ensure that there are no labour shortages forecast for the immediate future of this region.

1.18 Recoverable reserves

Bredell reported the total recoverable reserves indicated in Table 1.7. In 1987 the Waterberg coalfield had around 15.4 billion tonnes of total recoverable tonnes compared to a total of 23 billion recoverable tonnes for the Witbank coalfield and 20 billion recoverable tonnes for the Highveld coalfield. The Waterberg coalfield is the largest coalfield in South Africa.

Table 1.7: Total recoverable reserves [Adapted after (Bredell, 1987)]

Coalfield	Mt	Percentage (%)
Witbank	12 460	22.50
Highveld	10 979	19.80
E. Transvaal	4 698	8.50
Utrecht	649	1.20
Klip River	655	1.20
Vryheid	204	0.40
South Rand	730	1.30
Sasolburg	2 233	4.00
OFS (Remainder)	4 919	8.90
Waterberg	15 487	28.00
Springbok Flats	1 700	3.10
Limpopo	107	0.20
Soutpansberg	267	0.50
Kwa-Zulu	98	0.20
Kangwane	147	0.30
Total	55 333	100

It is worth noting that the total recoverable reserves in 1987 indicate that up to 28% of South African reserves lie in the Waterberg, 22.5% come from the reserves in the Witbank and approximately 20% of the reserves are in the Highveld and that these three coalfields add up to 70 per cent of the total recoverable reserves in South Africa.

In terms of ranking the coalfields by taking into consideration the total recoverable tonnes of 121 billion tonnes, the Waterberg was the largest coalfield at 28%, the Witbank coalfield at 22.5%, the Highveld coalfield at 19.8%, the Orange Free State at 8.9%, the Eastern Transvaal at 8.5% and the rest at 12.3% as shown in Table 1.7. The Waterberg coalfield is therefore a significant coalfield from a reserve standpoint and worth investigating especially in light of the significant increase in production fort the Witbank coalfield over the last 20 years.

1.19 The effect of recent production on reserves

It is possible to estimate current reserves by subtracting known production in the subsequent years from the 1987 figure. This has been done twice, in 2006 and 2010. From Table 1.8 the Waterberg coalfield has been marginally exploited. Every year since 2006 the only mine operating in the Waterberg has produced around 40 million tonnes which gives a total of around 160 million tonnes mined between 2006 and 2010. Therefore in total the Waterberg has produced 734 million tonnes Run of Mine (ROM) from 1982 to 2010.This figure is shown in Table 1.9. Between 1982 and 2006 the Witbank and Highveld coalfields have produced about 4.6 billion tonnes of the 6.2 billion tonnes of the total ROM coal produced in South Africa (Table 1.8). This figure represents over 78% of the production of all the coal produced annually in South Africa. In addition both coalfields have produced less than 1 billion tonnes from 2006 to 2010. Therefore in total the Witbank and Highveld coalfields have produced about 5.5 billion tonnes from 1982 to 2010 as confirmed by Table 1.9**.**

It must be noted that about 5.5 billion tonnes of coal have been from the Witbank and Highveld fields predominantly using the bord and pillar mining method at an extraction ratio of about 50% and therefore it is important to investigate the life of these coalfields. That means if one includes the coal sterilised in the form of the pillars left underground from this mining method about 11 billion tonnes have been removed from the reserves. Therefore, the reserves left from these two coalfields are about 6.5 billion tonnes.

At the current mining rate of about 250 million tonnes per annum it means that the life expectancy of the Witbank and Highveld coalfield is just over 25 years. The recovery figure of 50% assumed above for bord and pillar mining method is reasonable if one takes into account that not all the coal will be mined when factors such as dykes, thin coal, boundary pillars and barrier pillars and the depth of mining are taken into account.

Table 1.8 : Reserves and ROM production (Depart of Mineral Resources and Energy Affairs, 2007)

Coalfields	Reserves	Production	Reserves	%
	1982 (Mt)	**1982-2006 (Mt)**	**2006 (Mt)**	%
Witbank	12461.00	3434.20	9026.80	29.66
Highveld	10919.60	1235.30	9684.30	31.44
Ermelo	4658.10	237.20	4420.90	14.29
Waterberg	1950.50	587.30	1363.20	11.41
Sasolburg	2233.00	465.90	1767.10	5.76
South Rand	730.00	14.50	715.50	2.31
Utrecht	609.80	69.10	540.70	1.74
Kliprivier	617.00	82.50	534.50	1.73
Soutpansberg	267.00	8.40	258.60	0.83
Kangwane	147.00	0.60	146.40	0.47
Vryheid	179.60	77.60	102.00	0.33
Nongoma	38.80	30.40	8.40	0.03
Total	**34 224**	**6 243**	**27 981**	**100**

Also one has to factor in the reality that mining in the Witbank and Highveld coalfields is over a century old; therefore most mines are very mature and reaching the end of their life. It is therefore reasonable to expect that the mineable reserves will become smaller because of the decisions taken by previous management to mine the good coal at the beginning of the mine and leave out the difficult coal for the next generation. Therefore the life of mine of the Witbank and Highveld coalfields is about 15-25 years if the recovery factor and management decisions are taken into account.

Figure 1.10 illustrates how the life of the Witbank and Highveld coalfields will pan out if the production in both coalfields is estimated to be between 200 million tonnes per annum and 250 million tonnes per annum going into the future. It can be concluded that the life of these two coalfields is between 15 and 25 years if the annual production is between 200 and 250 million tonnes per annum. While the implications for coal mining are serious, the impact on South Africa is much more serious if nothing else is done to deal with the depletion of these two coalfields.

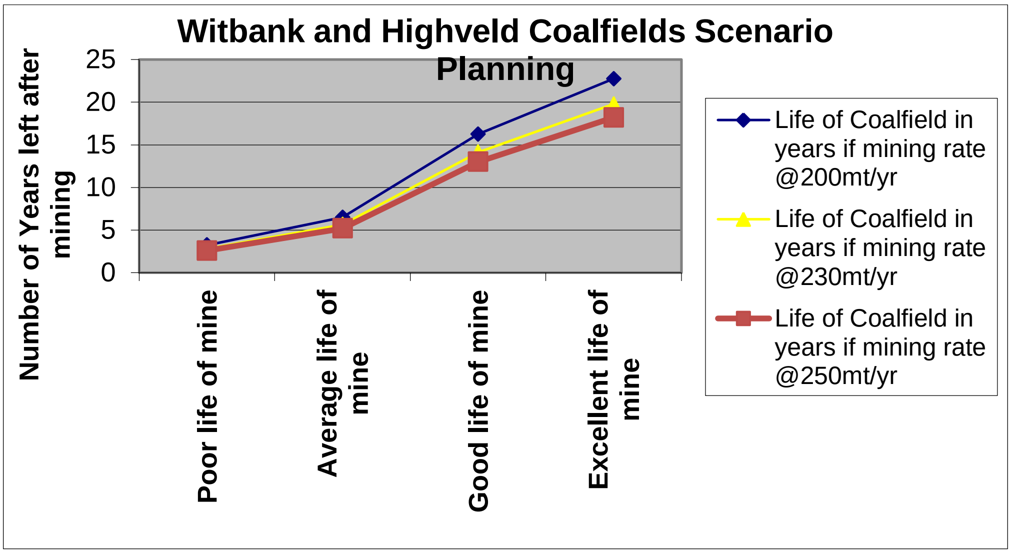


Figure 1.10: The life of mine reserves of the Witbank and Highveld coalfields

The Witbank and Highveld coalfields combined produced over 78% of the ROM mined in South Africa in 2010 as indicated in Table 1.10. They are two of the most important coalfields in South Africa today as indicated by the amount of ROM produced over the years. In essence, these two coalfields drive the South African coal mining industry as indicated by the 5.5 billion tonnes mined from these two coalfields from 1982 to 2010. In addition, these two coalfields supply ten of the thirteen coal-fired power stations owned by ESKOM with coal. These coalfields have a combined generation capacity of about 28 giga-watts (GW) out of the 37 GW total capacity in South Africa.

If these two coalfields were to become exhausted there would serious electricity supply implications in South Africa and the country’s economy as a whole will be brought to a standstill. Also, the Highveld coalfields supply about 46 million tonnes of coal per annum to the South African Synthetic Oil Limited (SASOL) complex in Secunda through the five mines owned by SASOL in that region. The coal supplied by the Highveld coalfields to SASOL is turned into fuel and offsets some of the fuel requirements of the country. From this discussion, it is clear that the Witbank and

Highveld coalfield are critical coalfields in South Africa today and there are huge power and cost implications when these two coalfields were to run out of coal.

Table 1.9 The South African Run of Mine production by coalfield (Mt), 1982-2010 (Prevost, 2011)

SA RUN-OF-MINE PRODUCTION BY COALFIELD (TONS) 1982-2010

YEAR	ERMELO	HIGHVELD	KANGWANE	KLIPRIVIER	NONGOMA	SOUTHRAND	S'PANSBERG	UTRECHT	V-SASOLBURG	VRYHEID	WATERBERG	WITBANK	TOTAL
1982	8 910 194	34 015 629		8 783 500				4 725 669	14 790 313	6 786 437	10 849 833	84 017 886	172 879 461
1983	8 771 802	25 037 306			5 000 024	315 117		4 445 891	13 475 211	4 867 435	10 707 044	98 130 525	173 585 355
1984	10 036 842	28 809 820			6 614 211	3 532 571	63 862	4 540 335	13 522 272	5 307 564	13 698 922	111 032 879	197 159 278
1985	12 051 349	31 254 543		7 684 553	223 558	3 156 705	178 684	5 014 278	11 893 139	5 919 488	14 902 320	121 380 480	213 659 097
1986	12 956 470	32 418 804		7 478 540	892 572	2 840 113	210 557	4 801 096	13 818 605	5 149 588	15 677 466	123 334 551	219 578 362
1987	10 741 736	31 905 838		6 466 224	819 022	2 377 132	259 950	4 342 702	16 446 852	7 463 546	14 738 816	118 841 249	214 403 067
1988	9 326 968	35 733 297		5 872 173	882 161	2 311 589	260 876	4 429 081	18 342 888	6 170 495	16 115 593	126 000 208	225 445 329
1989	11 343 211	36 960 072	24 955	6 277 039	973 123		259 711	5 035 567	16 138 526	5 398 170	15 786 885	125 046 603	223 243 862
1990	6 892 428	39 669 195		5 857 195	822 378		364 903	3 719 538	17 691 809	5 116 562	15 521 662	118 268 815	213 924 485
1991	5 115 038	40 352 242		5 042 849	899 249		347 092	3 655 678	17 899 949	3 935 228	22 192 250	122 697 336	222 136 911
1992	4 018 875	41 075 956		3 449 453	888 269		435 659	2 666 051	18 258 644	3 166 156	18 829 108	119 527 186	212 315 357
1993	7 697 699	50 727 604		3 750 390	1 100 487		380 555	3 385 059	20 758 429	2 330 545	20 100 131	119 131 992	229 362 891
1994	8 347 119	45 379 451		2 661 154	955 369		414 817	3 109 985	19 905 232	1 914 398	25 605 670	134 641 645	242 934 840
1995	13 012 949	56 127 144		3 903 113	993 811		445 070	2 374 843	20 342 338	2 143 567	27 984 825	131 330 365	258 658 025
1996	6 718 861	47 675 398		3 950 703	1 070 996		508 067	2 689 792	20 364 309	1 664 673	26 439 041	154 923 932	266 005 772
1997	7 436 087	60 029 897		2 667 521	900 584		565 245	2 425 121	19 721 645	1 378 373	30 371 365	155 949 632	281 445 470
1998	7 579 661	54 551 170		2 198 935	1 128 948		628 526	2 016 733	19 887 536	1 063 870	27 456 680	172 966 500	289 478 559
1999	8 651 380	77 543 052		1 557 042	1 003 325		363 328	1 231 468	21 051 507	1 579 319	27 400 890	146 786 901	287 168 211
2000	9 761 741	65 335 024		1 948 744	864 278	17 924	387 915	773 584	21 829 443	762 097	29 632 837	161 048 084	292 361 671
2001	9 521 609	75 369 653	180 009	163 734	746 311		398 018	1 285 366	22 228 250	1 174 712	30 776 665	155 049 930	296 894 257
2002	9 672 250	63 472 768	191 352	216 782	800 208		390 988	1 260 680	22 903 475	813 685	33 219 443	152 223 012	285 164 643
2003	12 984 726	63 942 762	174 094	164 744	670 334		393 449	1 032 092	23 418 516	659 718	33 772 905	164 877 653	302 090 993
2004	12 540 258	61 109 942	42 225	92 952	809 754		438 669	165 838	22 838 259	775 612	35 263 829	173 287 739	307 365 076
2005	12 203 965	66 548 675	40 707	803 763	637 091		418 279		19 827 204	1 420 598	34 334 562	170 111 642	306 346 486
2006	11 816 173	70 276 514	14 045	711 966	723 801		355 772		18 639 738	1 393 072	35 946 210	172 678 665	312 555 956
2007	10 531 625	69 441 178	229 279	2 030 651	878 243		463 476		19 665 721	629 863	36 733 514	171 156 547	311 760 097
2008	11 878 263	70 530 347	49 950	2 530 510	934 028		328 027		18 502 065	596 444	36 664 907	171 805 519	313 820 060
2009	10 095 839	69 749 362	144 821	1 905 540	773 500		300 776		20 406 970	375 900	36 695 873	175 494 892	317 257 966
2010	9 223 949	68 589 962	220 033	2 318 095	734 493		337 360		20 407 368	279 071	36 673 993	178 504 561	317 288 885
TOTAL	279 839 067	1 513 632 605	1 311 470	90 487 865	33 740 128	14 551 151	9 899 631	69 126 447	544 976 213	80 236 186	734 093 239	4 130 246 929	7 502 140 930
%	3.73	20.18	0.02	1.21	0.45	0.19	0.13	0.92	7.26	1.07	9.79	55.05	**100**

Note: Table entries with no values are an indication of a coalfield which has been depleted and total figure is therefore an estimate of what has been mined up to 2010

Whereas it would be easy to build new coal mines if the coal were available, it is very costly to build a new power-station and to establish infrastructure that supports mining. It is going to take planning and money to ensure that there is a phase out of the Witbank and Highveld coalfields and that production of coal is moved to any of the remaining coalfields.

1.20 Discussion on the resources and reserves in the Waterberg coalfield

Since 1987 the production from the Witbank and Highveld coalfields has always exceeded that from the Waterberg. Therefore, it is important that this research focuses more on the resources and reserves of the Waterberg in order to give a more realistic picture of the future of energy supply in South Africa.

Table 1.10 :ROM production and reserves 1982-2010 (Prevost & Falcon, 2011)

Coalfields	**Reserves**	**Production**	**Reserves**	
	1982 (Mt)	**1982-2010 (Mt)**	**2010 (Mt)**	%
Witbank	12461.00	4130.20	8330.80	25.16
Highveld	10919.60	1513.60	9406.00	28.40
Waterberg *	7441.40	734.10	6707.30	20.25
Ermelo	4658.10	279.80	4378.30	13.22
Sasolburg	2233.00	545.00	1688.00	5.10
South Rand	730.00	14.50	715.50	2.16
Utrecht	609.80	69.10	540.70	1.63
Kliprivier	617.00	90.50	526.50	1.59
Soutpansberg	267.00	9.90	257.10	0.78
Kangwane	147.00	1.30	145.70	0.44
Vryheid	179.60	80.20	99.40	0.30
Nongoma	38.80	33.70	5.10	0.02
Total	**40302.30**	**7184.80**	**33117.50**	**100.00**
*** The Waterberg figure was updated using Exxaro's annual report for 2011**				

Table 1.10 applies to the reserves mined by all the mines up to 2010 and is simply a modification of Table 1.8. However; the biggest difference between these two tables is the reserves of the Waterberg. The reserves of the Waterberg were estimated by Bredell in 1987 as 15.5 billion tonnes and by the Department of Minerals and Resources in 2007 as 2 billion tonnes as indicated in Table 1.8 and more recently by Exxaro as 7.4 billion tonnes as indicated in Table 1.10.

Overall, these figures indicate that there is an abundance of coal resources and reserves at the Waterberg but much of these resources are in remote areas with little infrastructure as noted by (Lind & Phillips, 2001). Also, there has not been much information from exploration by different companies and the Department of Minerals Resources in updating these figures. According to Lind and Phillips this situation is a cause for concern and should be a topic of a major research initiative (Lind & Phillips, 2001).

In order to ensure security of supply for South Africa’s energy needs in the future, it is critical that, before the coal resources and reserves in the Witbank and Highveld coalfields “run out” as discussed in an earlier paragraph, that adequate research is done to understand the geology and consequently the mining or exploitation of the Waterberg coalfield. Second, it is also important to keep an update on the different mining projects taking place on the ground at the Waterberg. Lastly, it is crucial to keep challenging the industry to prepare and plan for the future of the coal mining industry by investigating fully the resources and reserves in South Africa and think of alternative ways of exploiting all the coalfields including the Waterberg coalfield.

1.21 The South African future energy demand

A study by ESKOM in 2006 predicting the future energy demand for the next 100 years indicated that demand for energy in South Africa is going to increase (Figure 1.11). The energy demand will increase from 200,000 to 1,600,000 GWh per annum between 2000 and 2099 which represent an increase of about 700%. Figure 1.11 further illustrates the role that coal is expected to play in the next 70 years (ESKOM, 2006).

Figure 1.11 also indicates that the demand for coal fired generating capacity will increase from 200,000 to 600,000 GWh per annum from the year 2000 to 2075 before being surpassed by alternative sources of energy around 2080. Alternative sources of energy refer to nuclear, gas, oil and renewables. From Figure 1.11, it is apparent that coal will remain a major energy source for the next 50 years before alternative sources of energy can make a significant contribution to the replacement of coal.

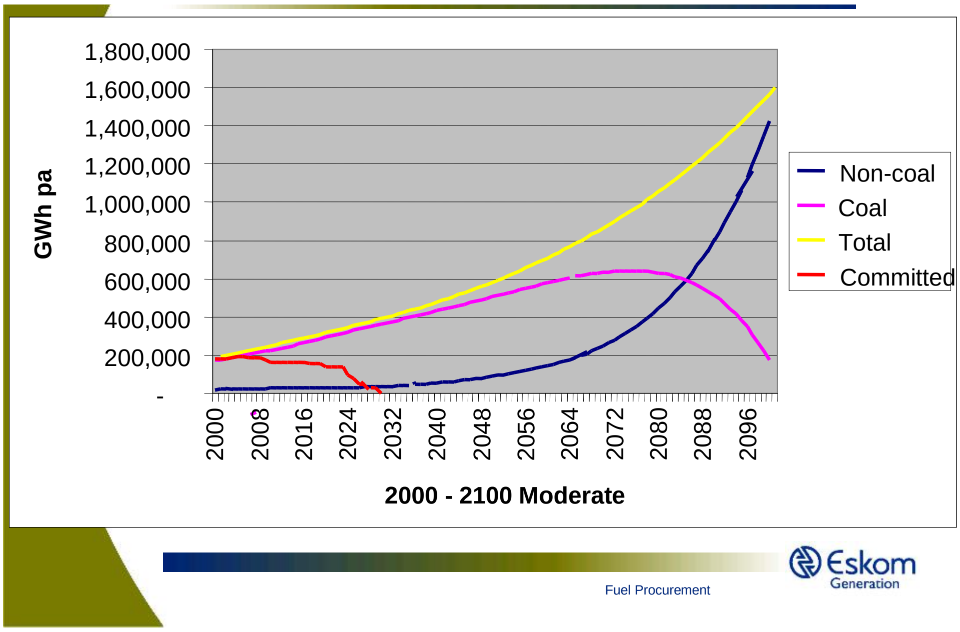


Figure 1.11: 100 – Year Energy demand for South Africa (ESKOM, 2006) and (Dempers, 2011)

According to the power utility ESKOM, South Africa would need about two billion tonnes in new coal supplies to meet the demand of its current coal fired power stations over their operational lives. ESKOM further estimated that about fifteen new power stations mainly in the Witbank or Mpumalanga area are required. These power stations would have to come on line in the near future and that about R100 billion would have to be invested over the next seven years. Furthermore, the quality of the coal resources left in the Mpumalanga province, where most of the power stations are located was negatively impacting ESKOM and the power utility noted that the coal quality has not been as good as it has been in the past. In other words ESKOM needs good quality coal and that the Witbank/Mpumalanga area cannot sustain the demands of ESKOM going forward. It was concluded by ESKOM that the acceleration of the exploitation of the Waterberg coalfield should be given priority (Dempers, 2011).

The RBCT export capacity is 91 million tonnes since the addition of the Phase 5 extension to the terminal in 2010 to accommodate all the Black Economic Empowerment companies. RBCT is planning to increase the capacity further to 110 million tonnes in the near future (Siwisa-Damasane, 2013). However, the export volumes are far below the export capacity. According to the (Chamber of Mines of South Africa, 2012) export volume have been falling from a high of 71 million tonnes in 2005 to 58 million tonnes in 2008 and started increasing slightly from 60.5 million tonnes in 2009 to 69 million tonnes in 2011. According to (Mining Weekly, 2011) the main reason why the export volumes are below the RBCT export capacity is attributable to logistical constraints, railway line inefficiencies and labour strikes encountered by Transnet Freight Rail (TFR). It is clear that South Africa is losing a lot of revenues in the export market and as a result it is important to increase the rail capacity and exploit more good quality coal from the Waterberg Coalfield. TFR has committed itself to stabilise the railway lines to return to the normal export volumes of above 72 million tonnes. (Mining Weekly, 2011) stated that TFR’s goal in 2011 was to increase the rail capacity to 81 million tonnes by 2014/2015 and the company is further investigating system capacity beyond the 81 million tonne level to match the export terminal’s expanded capacity, in the long term. It is therefore, expected that since the Waterberg has been identified as the next big coalfield that there should be long term plans to connect this region with the rail networks of the Witbank and Highveld coalfields.

1.22 Concluding remarks and structure of the dissertation

The purpose of this first chapter was to discuss the role of coal in South Africa and globally. From the discussions it emerged that coal is an important energy source and will be used worldwide in the next 30 years despite its negative environmental impacts. Coal usage especially in electricity generation is very high in countries such as South Africa and China and is about fifty per cent in developed countries such as the United States and Germany. It is unlikely that this will change especially for developing countries where coal is seen as a cheap source of energy where there are vast amounts of coal resources and reserves. The discussion outlined the resources and reserves of the South African coal mining industry and the need to seek other coalfields to sustain coal production in the country because the two major coalfields, the Witbank and Highveld coalfields are “running out” of coal. It was established that the Waterberg coalfield is a viable alternative coalfield that needs further investigation because it has significant amounts of coal resources and reserves.

The second chapter discusses the resources and reserves available in South Africa and how these resource and reserves are currently mined. In addition, the current mining and depletion of these resources is analysed.

The third chapter discusses the unique geology of the Waterberg coalfield. The geology of the Vryheid and Grootegeluk formations is discussed in detail together with the resources and reserve estimates of the Waterberg coalfield.

The fourth chapter discusses the current mining in the Waterberg coalfield with emphasis on the scale of mining and the size of the equipment, the size of the plant and the quantity and quality of coal produced. In addition, the problems experienced by mining at the Waterberg will be highlighted.

The fifth chapter discusses the underground mining considerations of the deep coal reserves east of the Daarby fault, the mining horizons selected and possible mining methods that could be used to exploit the seams.

The sixth chapter discusses the multi-seam mining of the deep coal reserves i.e. the sequence of mining and the lessons learnt from multi-seam mining of the United States of America.

The seventh chapter contains the conclusions and recommendations

2 THE COAL RESOURCES AND RESERVES OF SOUTH AFRICA

2.1 Introduction

This chapter discusses in more detail the current resources and reserves mined by underground and surface mining methods in South Africa. In addition exploration and new projects undertaken by various mining companies will be discussed including the life of mine of each coalfield. Current mining activity and the challenges of mining the resources and reserves of each coalfield are considered. The coalfields discussed are indicated in Figure 2.1 which is the latest figure of all the coalfields in South Africa. Firstly, the coalfields in the Northern and North West part of South Africa (Figure 2.1) will be discussed and analysed. These are the Limpopo, Soutpansberg and Waterberg coalfields. Then the coalfields in the Central basin will be discussed and these include the Witbank, Highveld and Ermelo coalfields. Then the coalfields in the South West part of South Africa which include the Free State and South Rand coalfields will be discussed. The Natal coalfields will subsequently be discussed and analysed, including the coalfields in the Utrecht, Vryheid and Klip River. Lastly the Molteno Coalfield in the Eastern Cape will be discussed.

In conclusion the depletion of resources in the various coalfields, especially in the Witbank and Highveld, will be contrasted with the remaining reserves of the Waterberg coalfield. The purpose of the chapter is to indicate the decreasing resources and reserves of all the coalfields in South Africa especially the Witbank and Highveld coalfields and to indicate that in the context of diminishing resources and reserves the Waterberg coalfield has the most resources and reserves that are the least explored.

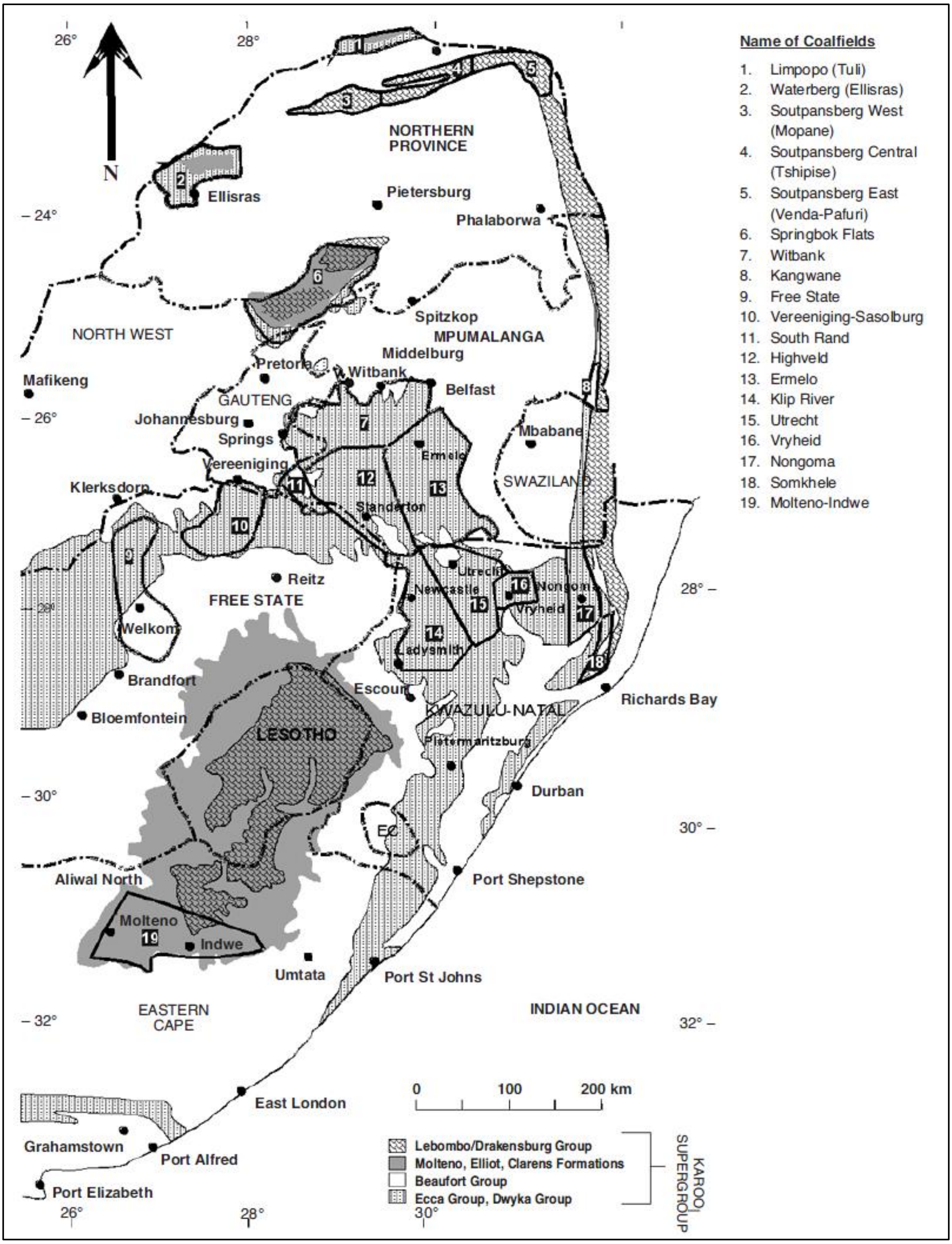


Figure 2.1:Coalfields of South Africa (Jeffrey, 2005)

2.2 Limpopo coalfield

The Limpopo coalfield is located in the northern part of South Africa. It is part of the Vryheid Formation and consists of top and bottom seams which are flat lying at a dip of about 2 degrees North and Northwest. There are dykes in most parts of the coalfield and currently no mining is taking place because the area is environmentally sensitive and very remote and therefore has very little infrastructure. Only the South Central Sector of this coalfield is thoroughly prospected and has the majority of the mineable in-situ resources. According to Jeffrey’s analysis of the stratigraphy to a depth of 200m the coal in this coalfield will require extensive roof support because it consists of very soft rocks such as interlaminated mudstone, siltstones and shales. Jeffrey further asserts that the coal consists of very thin coal bands with a washed characteristic yield of between 47-53 per cent, with ash values ranging between 10-12 per cent and volatiles of between 35.5 and 36.5 per cent. The sulphur content is about 1% and the swelling index is very high with average indices of between 8 and 8.5 (Jeffrey, 2005).

2.3 Soutpansberg coalfield- western, central and eastern

The Soutpansberg coalfield is situated in the south of the Limpopo province. According to Dreyer, a geologist who worked on the Limpopo province coalfields, the coalfield has a strike length of 190km and extends from Waterpoort in the west to the Kruger National park in the east. Structurally, the Soutpansberg is characterized by sub-parallel strips of Karoo rocks dipping at 3 degrees to 20 degrees north, and terminating down faulted against strike faults along the northern margins and occasionally against the southern margins (Sullivan, et al., 1994). The nature of the coal deposits gradually changes from a multi-seam coal-mudstone association that is 40m thick in the west (Waterpoort area) to two individual seams in the East (Tshikondeni area) where the upper seam is about 3m thick and the lower seam is about 2m thick. The coal seams are intensely disturbed by faults and dolerite intrusions. Soutpansberg coal is predominantly bright and high in vitrinite. Dull coal occurs at the base of the multi seam coal-mudstone association in the Waterpoort area as well as in the upper part of the lower seam at Tshikondeni. The coal rank increases from west to east. The volatile content in the west is 35% and decreases to about 25% in the east. Although exploration has proven significant resources in certain areas, Tshikondeni is the only area that can be exploited economically at present because of the excellent quality of the coking coal (Sullivan, et al., 1994). Tshikondeni currently mines the Madzaringe formation (Figure 2.2 and Figure 2.3) at depth of +/-200 to 230m using four shafts for primary access.

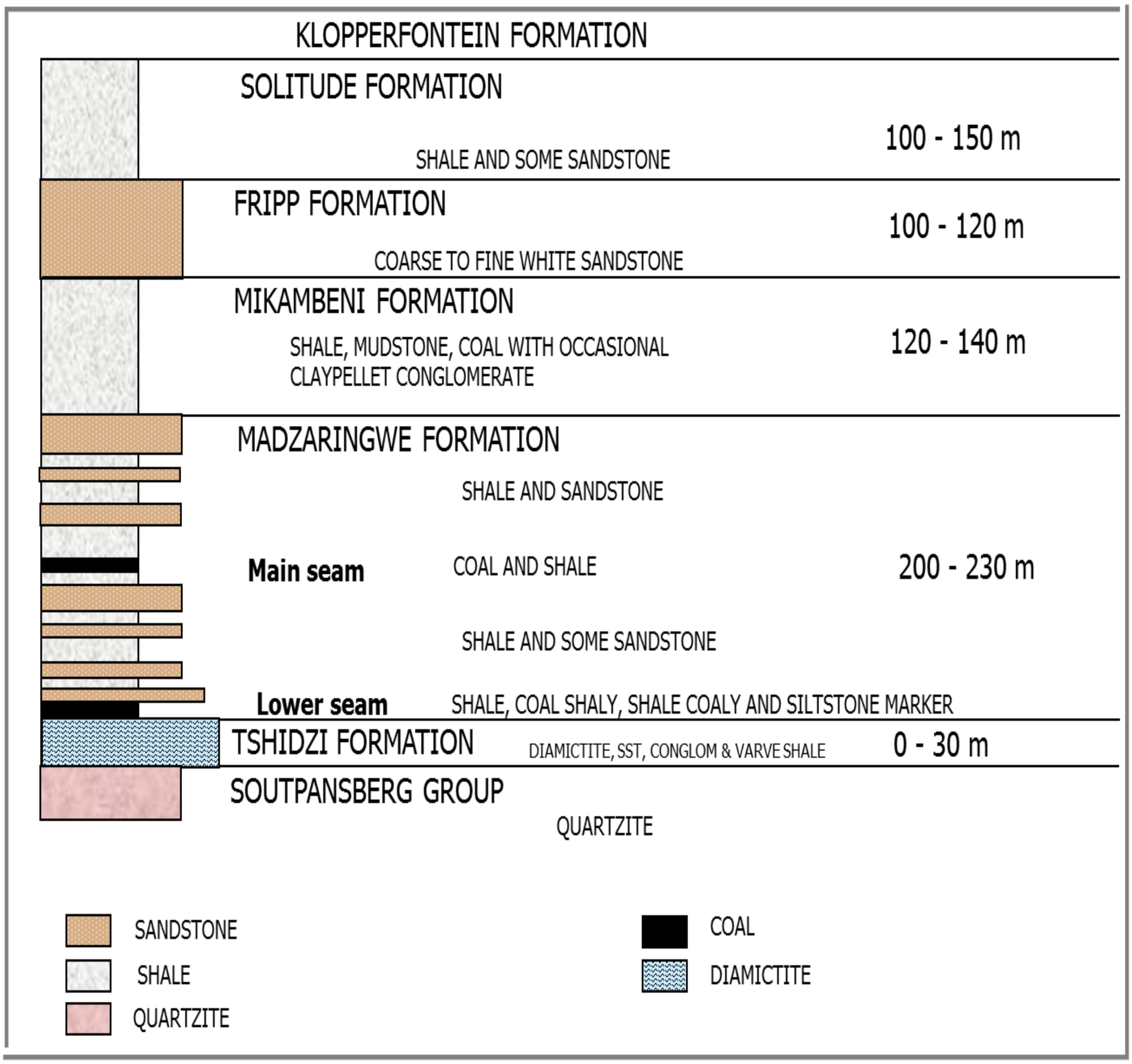


Figure 2.2: A simplified Stratigraphic column of Mopane,Tshipise and Pafuri coalfields (Sullivan, et al., 1994)

The coal horizon mined is the 7BC as indicated in Figure 2.3 with a seam height of about 2.6m. The mining method used to exploit the underground seam is bord and pillar with both conventional (drill and blast) and mechanised sections. In some of the underground sections, pillar extraction is already taking place. The average tonnage mined per month is about 45 000 tonnes. The annual production is about 420 000 tonnes per annum. There are plans to expand the current life of mine to 2016. The extension of the mining will involve resources and reserves in mini pits which will extend the life of mine by about another 10-15 years up to about 2031. The current production is premium hard coking coal which is the highest quality of coking coal presently mined by any coalfield in South Africa (Tshikondeni, 2011).

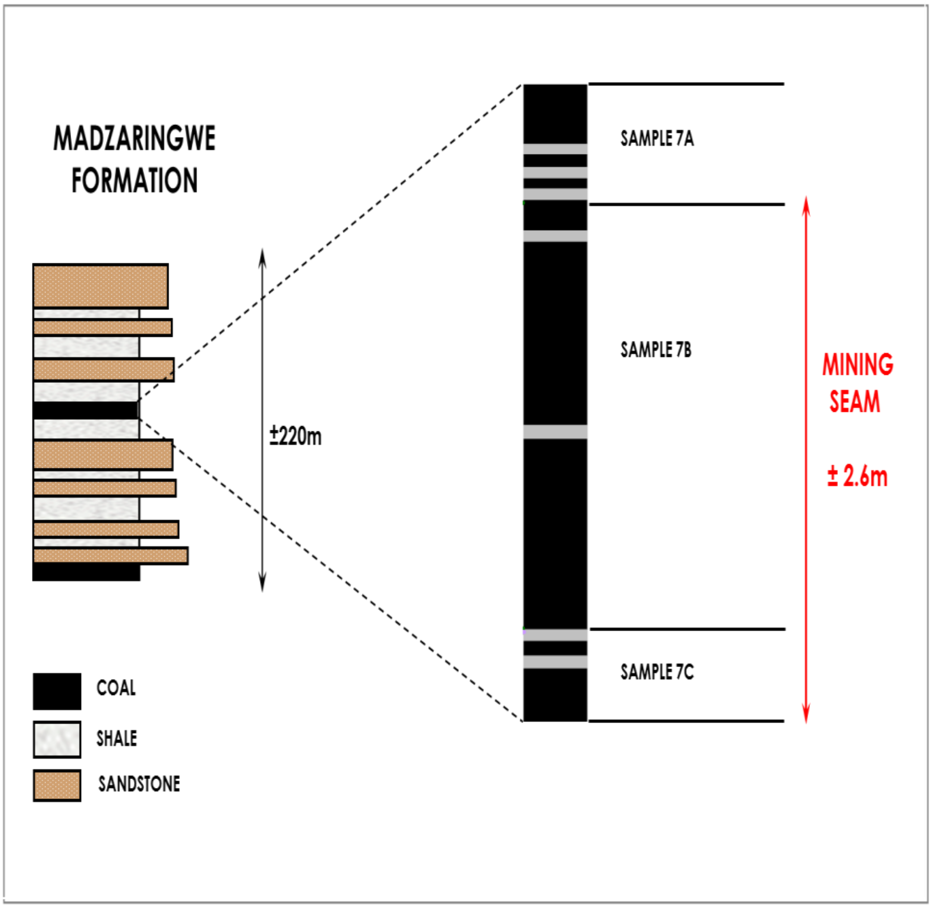


Figure 2.3:Madzaringwe Formation lithological profile (Sullivan, et al., 1994)

Presently, there are various mining companies prospecting for coal in the area. One of the companies called Coal of Africa (CoAL) already has a Greenfield project in the pipeline at a feasibility stage to produce an annual sales production of 5 million tonnes at full production from an opencast and underground colliery called Vele. The Vele Colliery project will produce coking coal at a fixed mining target of 14 million tonnes per annum of Run of Mine (ROM). Of the total production, 2.5 tonnes per annum of coal will be for ArcelorMittal domestic consumption. The life of mine expected for this project is 32 years based on an estimated gross in-situ tonnes of 813.5 million (Molekoa, 2011). One of the key challenges of this project is that it is located in an environmentally sensitive area, the Mapunbugwe National Heritage site. This heritage site is close to the Kruger National Park and as a result many environmentalists are aggrieved that CoAL has been granted a licence to mine by the Department of Mineral Resources. The aggrieved environmental organisations are lobbying the government and the public for this licence to be revoked and are citing many reasons why mining should not be allowed in this area. So far they have not succeeded but they are determined to stop mining of any kind in this area.

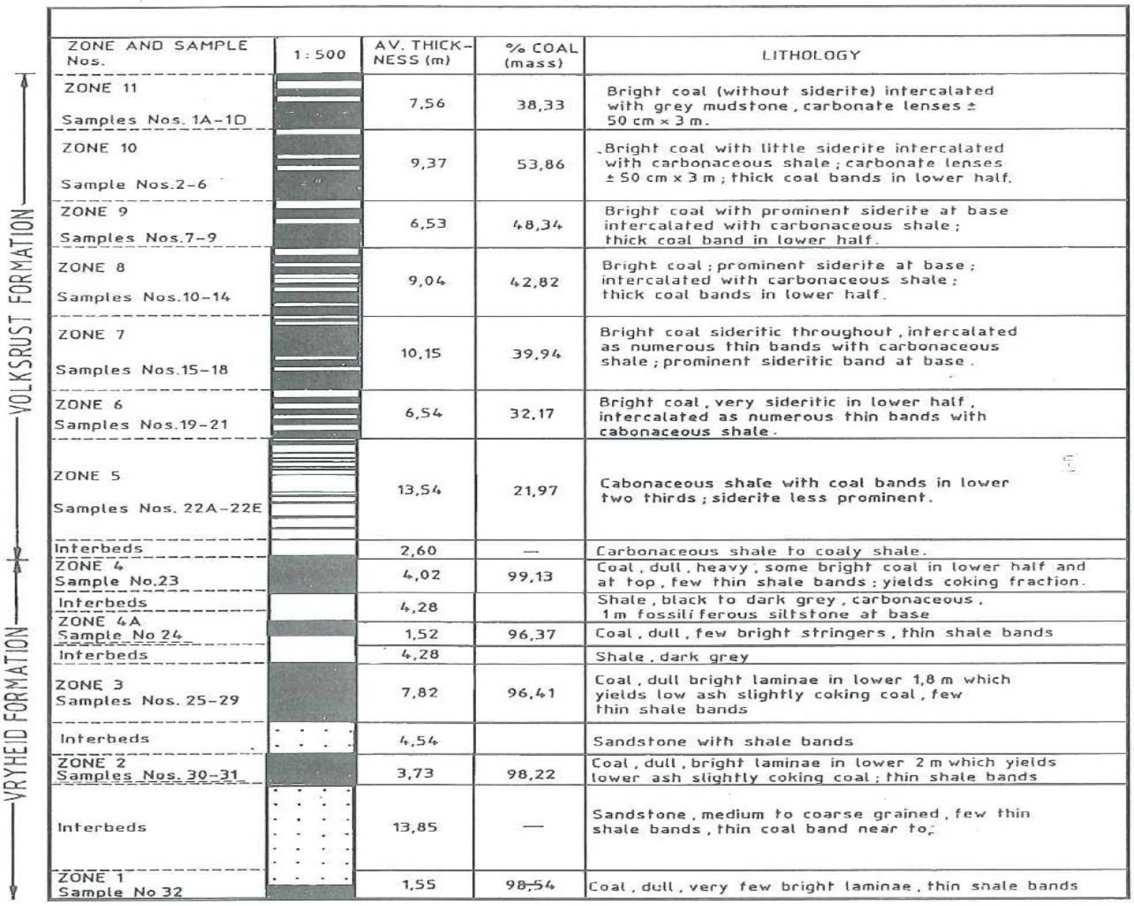
2.4 Waterberg coalfield

The Waterberg coalfield is situated in the Western part of the Limpopo province of South Africa, approximately 25 km west of the town of Lephalale. The Waterberg coalfield has an approximate 88km east- west strike length and has a north-south width of +/- 40km. Although the Waterberg is very small in area compared to other coalfields like the Witbank and Highveld coalfields it has a total seam thickness of about 110m which makes the in-situ reserves of the Waterberg to be large.

The geology of the Waterberg is such that there are two formations being mined i.e. Upper zone called the Grootegeluk Formation and the lower zone called the Vryheid Formation. The Grootegeluk Formation is about 60m in thickness and the Vryheid Formation is about 50m thick. A typical stratigraphic column of the Waterberg coalfield showing all the 11 coal zones being mined is shown in Figure 2.4.

The Waterberg has only one opencast mine called the Grootegeluk Colliery. The opencast mine supplies coal to the 3900 Megawatt Matimba power station which is owned by ESKOM or the Electricity Supply Commission. There are plans to expand Grootegeluk Colliery since Exxaro, the company which owns Grootegeluk, is to also supply coal to another power-station under construction called Medupi in this area.

A detailed description of the geology of Waterberg and the future of this colliery is discussed in the next chapters of this dissertation. The Waterberg coalfield consists of coal which is liable to spontaneously combust. To mine this coal successfully requires a power station custom build to accommodate this coal and a plan to store the discard on surface. The details of how this coal is mined are discussed in Chapter 4.



ZONE AND SAMPLE Nos.	1 : 500	AV. THICK-NESS (m)	% COAL (mass)	LITHOLOGY
ZONE 11 Samples Nos. 1A-1D		7,56	38,33	Bright coal (without siderite) intercalated with grey mudstone, carbonate lenses ± 50 cm × 3 m.
ZONE 10 Sample Nos.2-6		9,37	53,86	Bright coal with little siderite intercalated with carbonaceous shale; carbonate lenses ± 50 cm x 3 m; thick coal bands in lower half.
ZONE 9 Samples Nos.7-9		6,53	48,34	Bright coal with prominent siderite at base intercalated with carbonaceous shale; thick coal band in lower half.
ZONE 8 Samples Nos.10-14		9,04	42,82	Bright coal; prominent siderite at base; intercalated with carbonaceous shale; thick coal bands in lower half.
ZONE 7 Samples Nos.15-18		10,15	39,94	Bright coal sideritic throughout, intercalated as numerous thin bands with carbonaceous shale; prominent sideritic band at base.
ZONE 6 Samples Nos.19-21		6,54	32,17	Bright coal, very sideritic in lower half, intercalated as numerous thin bands with cabonaceous shale.
ZONE 5 Samples Nos. 22A-22E		13,54	21,97	Cabonaceous shale with coal bands in lower two thirds; siderite less prominent.
Interbeds		2,60	—	Carbonaceous shale to coaly shale.
ZONE 4 Sample No.23		4,02	99,13	Coal, dull, heavy, some bright coal in lower half and at top, few thin shale bands; yields coking fraction.
Interbeds		4,28		Shale, black to dark grey, carbonaceous, 1 m fossiliferous siltstone at base
ZONE 4A Sample No 24		1,52	96,37	Coal, dull, few bright stringers, thin shale bands
Interbeds		4,28		Shale, dark grey
ZONE 3 Samples Nos. 25-29		7,82	96,41	Coal, dull bright laminae in lower 1,8 m which yields low ash slightly coking coal, few thin shale bands
Interbeds		4,54		Sandstone with shale bands
ZONE 2 Samples Nos. 30-31		3,73	98,22	Coal, dull, bright laminae in lower 2 m which yields lower ash slightly coking coal; thin shale bands
Interbeds		13,85	—	Sandstone, medium to coarse grained, few thin shale bands, thin coal band near to;
ZONE 1 Sample No 32		1,55	98,54	Coal, dull, very few bright laminae, thin shale bands

Figure 2.4: A typical stratigraphic column of the Waterberg coalfield (Dreyer, 1994)

2.5 Springbok Flats

The Springbok Flats is situated about 90 km north of Johannesburg and about 40km from Pretoria. The coal seams are best developed in the central portion of the field and are considered to be part of the Limpopo Province. The coalfield is large measuring about 209 km long by 50 to 60 km wide along a southwest-northeast line. The coalfield has a single coal zone which is 3m to 7m in thickness in the upper zone. The coal zone is located stratigraphically between the mudstone of the Beaufort Group and the siltstone of the Vryheid formation of the Karoo sequence. The coal seams are very deep lying between 200 and 1000 m and are shale and mudstone bounded [(De Jager, 1983) and (Barker, 2012)].

Bredell estimated the resources of the Springbok Flats to be 3, 25 billion tonnes and the reserves to be 1.7 billion tonnes in 1987. This represented about 3% of the total recoverable reserves at that time (Bredell, 1987). Currently no mining is taking place because of the complicated geology and structure. The geology and structure involve several faults and dolerite sills and the coal is very deep as indicated in Figure 2.5.

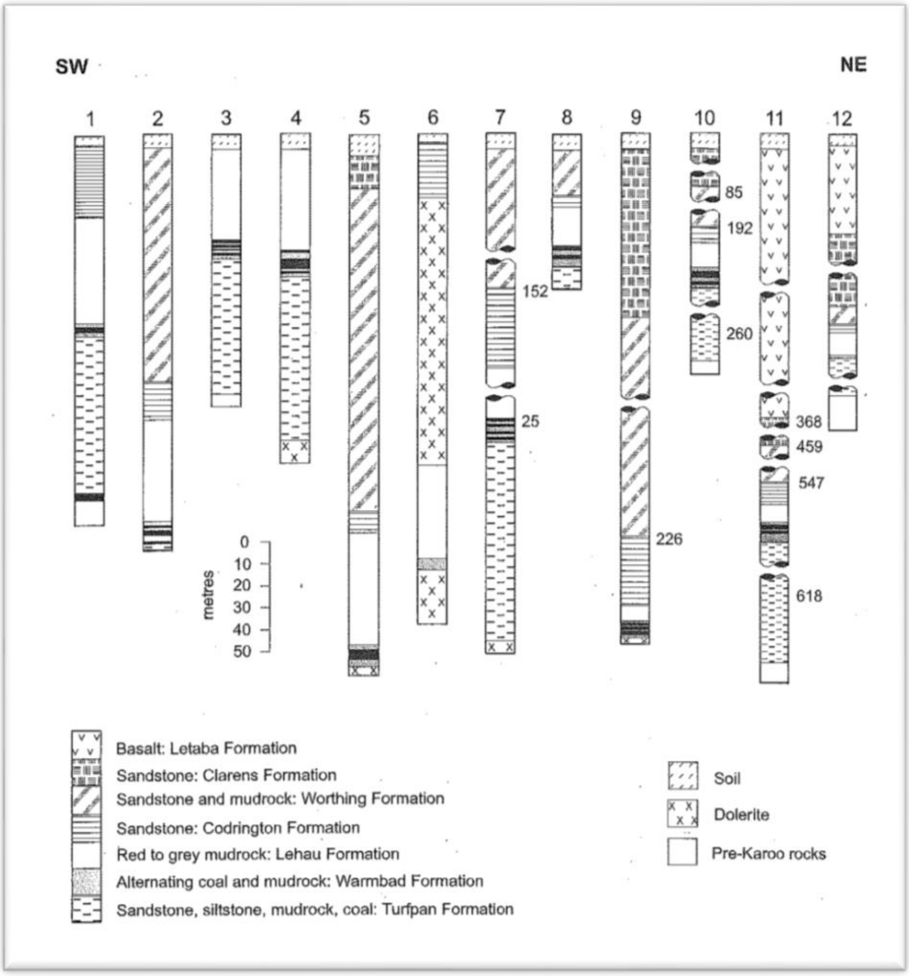


Figure 2.5: Borehole sections in a zone from southeast to northwest through the Springbok Flats coalfield [Source: (Snyman, 1986)]

The majority of the coal west of the coalfield is devolatized by dolerite intrusions and contains a uranium mineralized zone of 1m thick in the upper part of the Upper Coal zone. Some of the seams in the coalfield are thin (i.e. less than 1.5m) at greater depth and contain low qualities (i.e. less than 16MJ per kg) and the roof conditions are very poor. As a result of these problems no mining has taken place in the past. However because of the untapped resource there is a potential for mining [(De

Jager, 1983) and (Jeffrey, 2005)]. The presence of uranium concentrations and the intercalated nature of the coal and shale are some of the major problems that mining companies would have to contend with when considering mining.

In 2012, Banzi Geotechnics identified a mineable resource of 200 million tonnes over an area of about 11000 hectares at a depth between 60-300 metres with a mean depth of 260m. The mining height of this deposit is said to be 1.25m with a mean raw ash of about 25% (Barker, 2012). Recently, there have been some local mining companies such as Anglo American, Umbono and off-shore companies exploring the area to earmark it for potential coal bed methane extraction (Barker, 2012).

2.6 Witbank and Springs coalfield

The Witbank and Springs coalfield is one of the major coalfields in South Africa and covers a large area. It extends 180km in an east-west direction from Springs in the east to Belfast in the west, and is approximately 40km wide in a north-south direction.

The coal seams in this coalfield are generally not affected by folding or severe faulting, except where associated with dolerite intrusions. Dolerite sills generally about 50 m thick occur throughout the coalfield and result in large-scale displacements where they transgress the coal seams. Where these sills transgress or occur in close proximity to the coal seams, they result in large areas of burnt coal. The most prominent dyke in the area, the Ogies Dyke which is about 15 m thick, has resulted in an accompanying burnt zone of up to 300 m wide. Off-shoots of this dyke are common and appear to be more prominent in the south of the coalfield [(Snyman, 1986) and (Smith & Whittaker, 1986)].

There are five major seams that are mined in this area (Figure 2.6). The seams are named from the bottom upwards. The deepest seam is the number 1 seam and the seam closer to surface is the number 5 seam. The depths of these seams for underground mining vary from about 30 metres to about 110 metres. The number 1 seam is about 1.5 to 2.0 m thick. It has a competent grit roof and a hard sandstone floor. In other areas of the coalfield it is patchily developed due to pre-Karoo topography.

The number 2 seam has an average thickness of 6 m and contains the majority of the reserves of the coalfield and is the most economic seam for export steam coal. The roof conditions are fair to poor when exposed as a result of the shale present there, but roof conditions are considered good when 1 m to 2 m of coal is left in the roof. Floor conditions are normally good and consist of hard sandstone or grit.

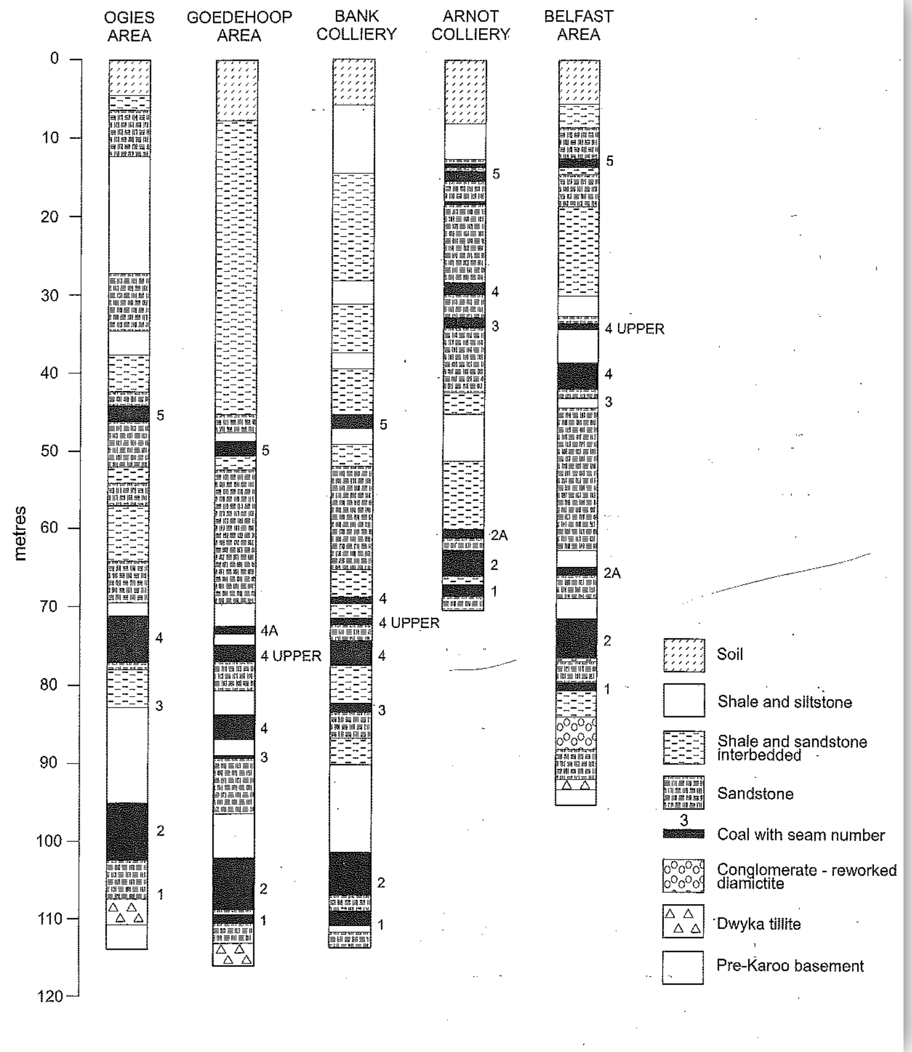


Figure 2.6: A typical stratigraphic column in the Witbank Coalfield (Snyman, 1986)

The number 3 seam is about 0.5m and sporadically developed and is considered thin and unsuitable for mining; however it has a high quality. The number 4 seam is 2.5 m to 5.0 m thick and widens to the west where it is in excess of 6.0 m. It is commonly split as number 4A, 4 Upper and 4 Lower seams. Mining is usually restricted to the lower 3.5 m of the coal seam as a result of the poor quality of the upper part of the seam and the poor roof conditions that result if the shale is exposed. It is the second most economic seam in this coalfield with lower qualities than the number 2 seam. The No. 5 seam has an average thickness of 1.5 m to 2.0 m. It is found approximately 25 m above the No. 4 seam and is on average 30 m below the surface. The laminated sandstone forms a poor roof and the laminated micaceous sandstone floor presents heaving problems in some areas. The recoverable reserves of the Witbank coalfield were initially estimated to be 12.4 billion tonnes by Bredell in 1987. As discussed in Chapter 1 the reserves of this coalfield are nearing depletion. In a worst case scenario the life of this coalfield is between 15 – 25 years.

2.7 Highveld coalfield

The Highveld coalfield is situated south of the Witbank coalfield. Its eastern boundary is formed by a straight line through Hendrina, Davel and Morgenzon in the Mpumalanga province (Snyman, 1986). The Highveld coalfield covers approximately 7,000 square kilometres and extends from Smithfield basement ridge southwards to beyond Standerton and the Vaal River. It contains sedimentary rocks of the Dwyka Formation and the Ecca Group of the Karoo sequence. North-west to south-east trending pre-Karoo glacial valleys controlled the deposition of plant material along the northern and western boundaries. The coal in the south and east was deposited on slightly undulating wide valleys and ridges (School of Mining Engineering, Undated).

The strata overlying the No. 4 seam (the seam of major economic importance in the coalfield) consist of thick competent sandstone which generally forms good roof. Dolerite sills and dykes from the intrusives of the Drakensberg Formation cover large areas of the coalfield. There are two major sills in the coalfield, named the Older and Younger sills. The Older dolerite sill is non-porphyritic, generally coarse grained and heavily jointed. It occurs at or near the surface and weathers relatively easily. It attains a thickness of up to 90 m and consists of composite sills or a series of splits (which can be up to 40 m thick). The younger sill is porphyritic. It varies from 5 m to 80 m in thickness and has a finer grain than the older sill. These sills transgress the coal horizon in various places resulting in the formation of burnt coal and the displacement of seams, particularly in the central and southern parts. Numerous dykes of varying thickness are encountered in the coalfield [(School of Mining Engineering, Undated) and (Jordan, 1986)].

All the coal seams encountered in the Witbank coalfield are present in the Highveld Coalfield. The depth of mining is between 0 and 300 metres. The No. 1 and No. 3 coal seams are thin and discontinuous throughout the coalfield. The No. 4 seam is the most economically viable coal seam. It is split into the No. 4 upper and No. 4 lower seams by a parting that increases from 2 m in the north to 15 m in the south. The No. 4 Upper only attains mineable thickness in limited areas in the western portion of the coalfield. The No. 4 lower is well developed over large areas and has an average thickness of 4 m. The roof of the No. 4 lower varies considerably and can consist of grit, coarse to fine-grained sandstone, inter-laminated sandstone and siltstone, shale or coal. The sandstone in particular provides a good roof. The floor consists of fine to medium-grained sandstones, which result in fair to good conditions (School of Mining Engineering, Undated). The depth of the No.4 seam ranges from 50m in the Leandra area to about 200m in the New Denmark mine as indicated in Figure 2.7.

The No. 2 seam is mined in places. It is a thick seam and laterally continuous in local basins and valleys in the northern and western parts of the coalfield, attaining a thickness of up to 8 m thick. The roof is variable and can consist of siltstone, sandstone or mudstone; with the sandstone being the most competent. The variation in the floor strata is similar to the roof strata with the sandstone forming a good floor. The No. 5 seam is mineable only in the northern portion of the coalfield where its thickness is at a maximum. The roof of this seam consists of a medium to coarse-grained sandstone that results in a good roof. The soft, highly micaceous siltstone (which becomes slippery and friable on exposure) causes a serious problem in the floor of this seam (School of Mining Engineering, Undated).

The Highveld coalfield supply coal to major power stations like Kriel and Matla which were built in the 1970’s. Together with Tutuka power station near Standerton, the coalfield in this area is expected to produce about 60 million tonnes to the power stations. The power stations are capable of generating about 11 gigawatts of electricity (Lurie, 2004). The Highveld coalfield also houses the largest coal to liquid complex in South Africa that has about five mines built around the complex in the late 70’s. It is unique in that it is the only coalfield in South Africa that has both longwall and shortwall operations at Anglo Coal’s New Denmark and Exxaro’ s Matla collieries. Although most of the coal in this coalfield is supplied to local power stations there is also a small percentage of coal supplied to the export steam coal market.

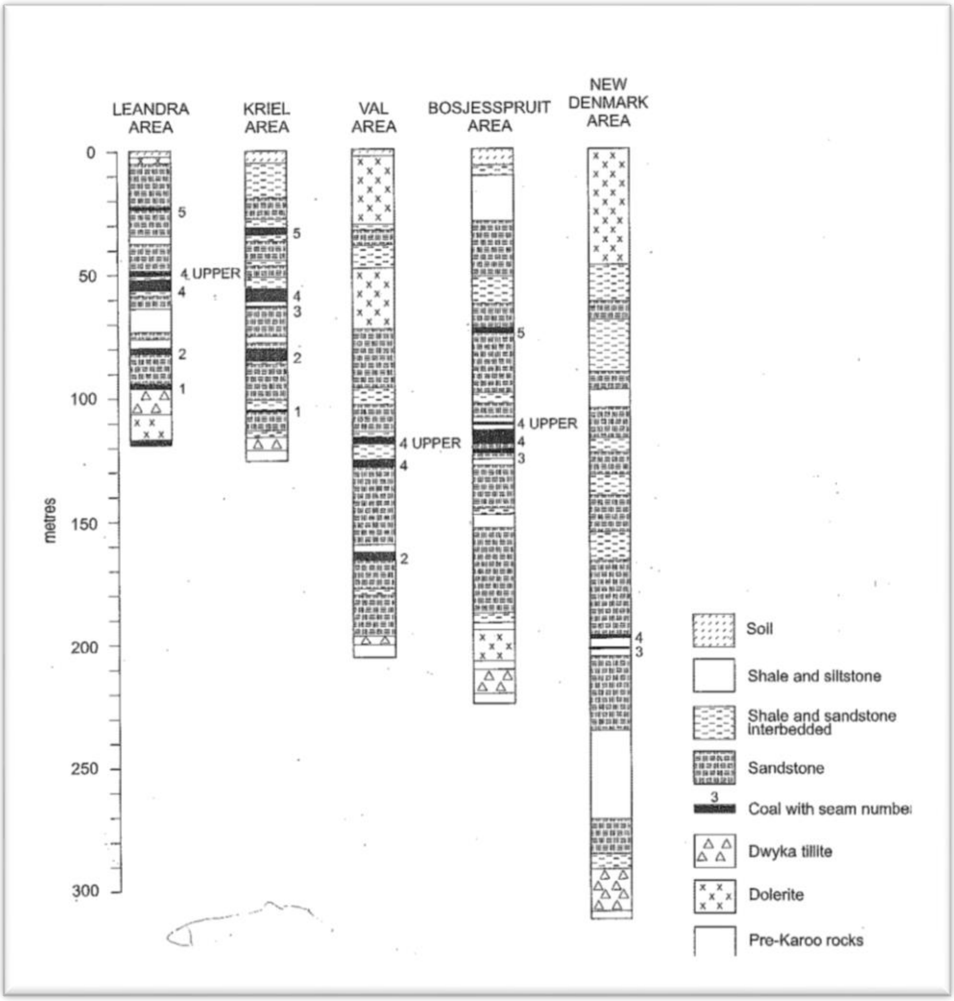


Figure 2.7: A typical stratigraphic column of the Highveld coalfield (Snyman, 1986)

The reserves in this coalfield were estimated to be approximately 11 billion tonnes by Bredell in 1987 and therefore this is the second most important coalfield in South Africa in terms of production supply to major power stations and coal to liquid supplying the SASOL plants. As discussed in Chapter 1 the Highveld coalfield has been largely exploited to date and together with the Witbank coalfield has a remaining life of about 15 - 25 years.

2.8 Ermelo (formerly the Eastern Transvaal) coalfield

The Ermelo coalfield is situated east of the Highveld coalfield and centred on the town of Ermelo in Mpumalanga. The coalfield extends up to Carolina in the north, Morgenson in the west, Sheepmoor in the east and Wakkerstroom in the south as shown in Figure 2.8. Coal was produced on a small scale by many small to medium mines and in 1975 there were three collieries that produced about 3 million tonnes, in 1985 about ten collieries produced approximately 8 million tonnes. About 85 per cent of the tonnage was from Ermelo and Usutu mines (Snyman, 1986). The Ermelo mines are now closed and the Usutu mines which were tied to Camden power station are also closed. Camden has however been taken out of mothball. There are some operating mines in the area and some exploration for coal in this region. In the late 1980's Majuba mine in this area was closed due to a presence of dolerite sills and high production costs. The coal in this coalfield is generally of a very high quality and therefore good for export purposes, but very thin.

Dykes are common over the whole coalfield while sills appear to be more numerous in the south. Eight major sills have been identified in the coalfield. These sills have significant effects on the mineability of the coal as they displace the seams and cause structural complication and devolatilisation of the coal. In early 2004 there were about 26 defunct collieries located in this field, and about ten operating collieries (Lurie, 2004).

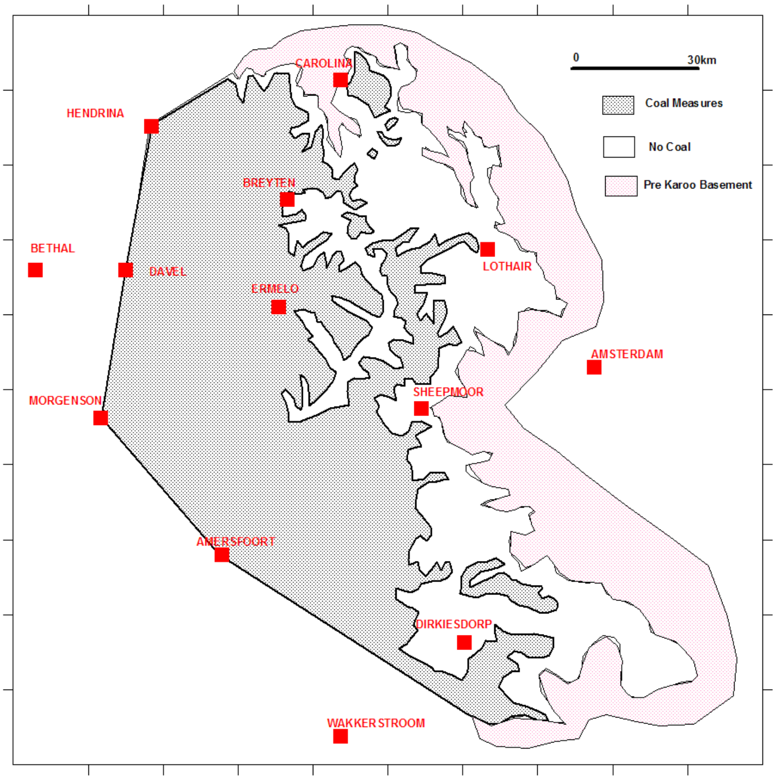


Figure 2.8 The Ermelo coalfield –distribution and limits (Snyman, 1986)

The Ermelo coalfield can be considered an extension of the Vryheid coalfield, and has the same sequence, although the nomenclature is different. The B, C, D and E seams as indicated in Figure 2.9 correspond to the Alfred, Gus, Dundas and Coking seams. The main seam is the C seam which consists of mainly bright coal and is about 1.5m thick with about 13 to 18 per cent ash. The B seam has been mined to a lesser degree, sometimes being 3m thick; mainly dull in appearance and with about 20% ash (Horsfall, 1992). The depth of mining is about 100m at its deepest.

In terms of seam thickness the B lower seam and the upper seam are about 0-3m thick though they may coalesce in the south. The C seam lower is about 1.5 m thick. The C seam upper is about 0.7 to 4m thick but sandstone, siltstone, or mudstone partings split the seam into two or three portions in such a way that the seam is on average about 1.5 m thick. The D seam is about 0.6 m thick and the E seam is about 3m thick (Jeffrey, 2005).

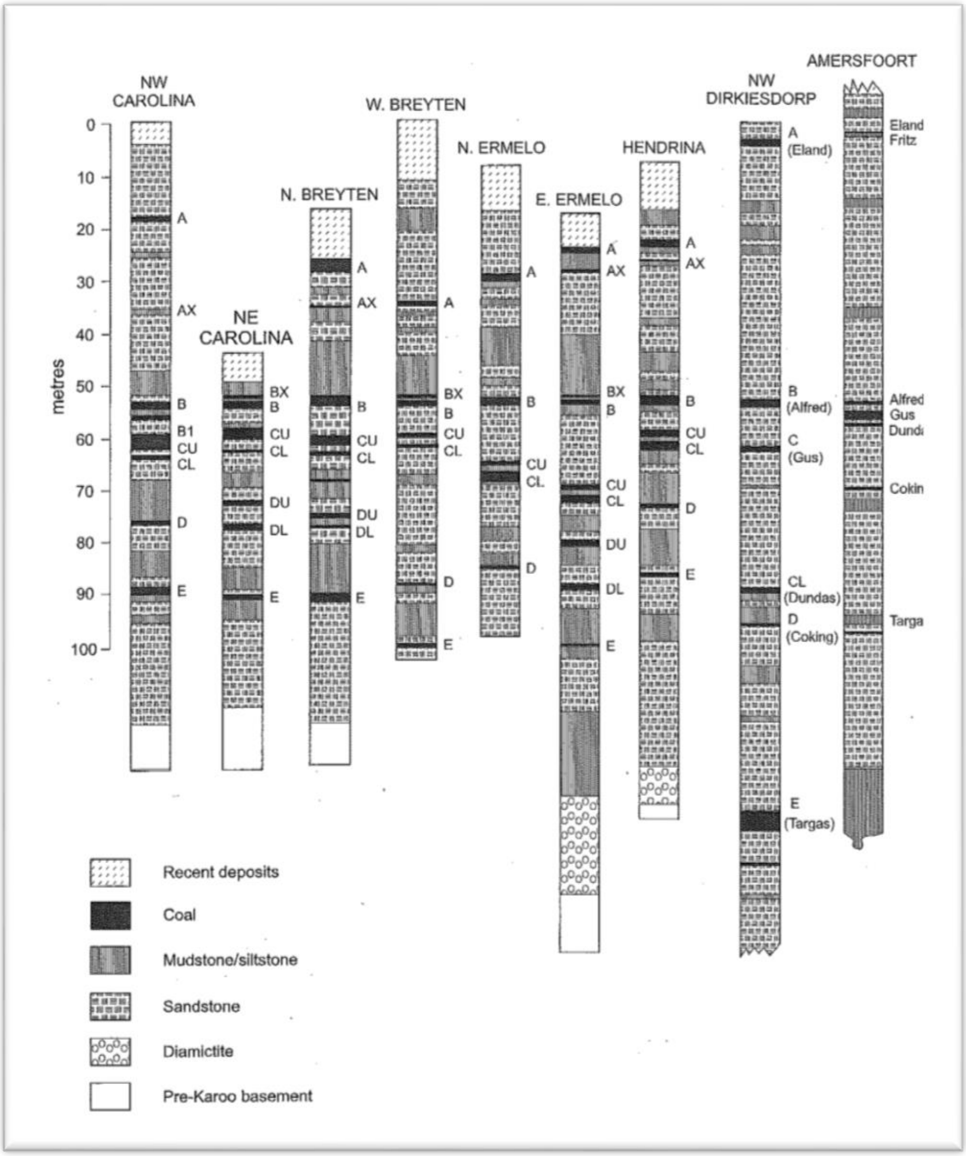


Figure 2.9: A simplified typical Ermelo coalfield stratigraphic column (Snyman, 1986)

In 1987, Bredell estimated the resources at 7.5 billion tonnes and the recoverable reserves at about 4.7 billion tonnes and about 280 million tonnes were mined at the end of 2010. The Ermelo coalfield reserves at the end of 2010 were about 8.5 % of the total recoverable reserves in South Africa making this coalfield the 5th biggest coalfield.

2.9 Kangwane coalfield

The Kangwane coalfield is located to the north of the Swaziland border and stretches for 70km in a north-south direction and extends for 40km in an east-west direction as indicated in Figure 2.1. Coal in the Kangwane coalfield occurs in the Vryheid and

Volksrust formations. The coal in the Vryheid formation is about 10m thick but very erratic in distribution and of low grade. It is referred to as the 1 Seam. Coal in the Volksrust formation occurs at a depth between 300m and 400m above the 1 Seam. The seams in the Volksrust formation are named from the bottom upwards as 2/4, 6 and 8 seams and are about 2 m in thickness. Seams in the southern part of the coalfield in the Vryheid formation occur over a thickness of about 70m and are referred to as 3, 5/6, 7 and 9 seams from the bottom upwards. The 3 and 5/6 seams are well developed compared to the 7 and 9 seams (Snyman, 1986).

In general the strata in this coalfields dips between 3 and 20^0 towards the east and is very faulted from north to south with faults typically displacing the strata for about 100m. In addition to the faults there are dolerite dykes and sills which turned the coal to anthracite. In the past Nkomati Anthracite mine produced about 60 000 tonnes per annum of anthracite washed coal with a CV of greater than 29 MJ/kg and ash content of between 14.5 to 15.7%. About 10% of the resource can be mined with opencast mining methods. However, the structural difficulty and complexity of the coalfield meant that very little exploitation has been done over the years (Snyman, 1986). Bredell in 1987 estimated the reserves at about 150 mt and approximately 1.3 mt have been mined from 1982 to 2010 (Bredell, 1987) and (Prevost & Falcon, 2011).

2.10 Free State-Sasolburg coalfields

The Free State-Sasolburg coalfields are located about 70km south of Johannesburg between the towns of Vereeniging and Sasolburg. In the past only two mines were operational in this field i.e. the Sigma and New Vaal Collieries (Snyman, 1986) Sigma is an underground mine owned by Sasol Mining and New Vaal Colliery is a strip mine owned by Anglo Coal.

In addition to Sigma Colliery, Sasol also owns a strip mine called Wonderwater and both mines produce coal for the petrochemical company, i.e. the SASOL 1 complex. New Vaal Colliery is one of the biggest strip mines and produces about 18 million tonnes for the local ESKOM's Lethabo power station. In total the coal mines in this coalfield produce about 20 million tonnes per annum. The coal in this region is generally thick i.e. 5 to 10m. It is also dull and of a poor quality typically with a high ash content between 20% and 50% and a low calorific value on average 16MJ per kilogram. The depth of the coal is on average about 40 metres for the strip mines and between 20m and 50m for the underground mines.

A typical stratigraphic column of the coalfields in the Free State Coalfield is shown in Figure 2.9 representing the Sigma basin. Of significance is the number 5 drill core which corresponds to Sigma Colliery. Then Figure 2.9 which represents the opencast at New Vaal Colliery. Both stratigraphic columns will be discussed.

The Sigma basin contains three seams i.e. the No1 seam, no. 2 A and no 2B. The No. 1 seam is developed in the deeper parts with a mineable thickness of about 3m, the No. 2A seam is said to be often absent and the No. 2 B seam is the principal seam being exploited. The No. 2 B seam has a maximum seam thickness of about 8m with ash contents that vary between 23% and 38%. Although the coal is of a low quality it is suitable for the coal to liquid SASOL market. Therefore, the entire output from Sigma Colliery is supplied to the SASOL complex in Sasolburg (Lurie, 2004).

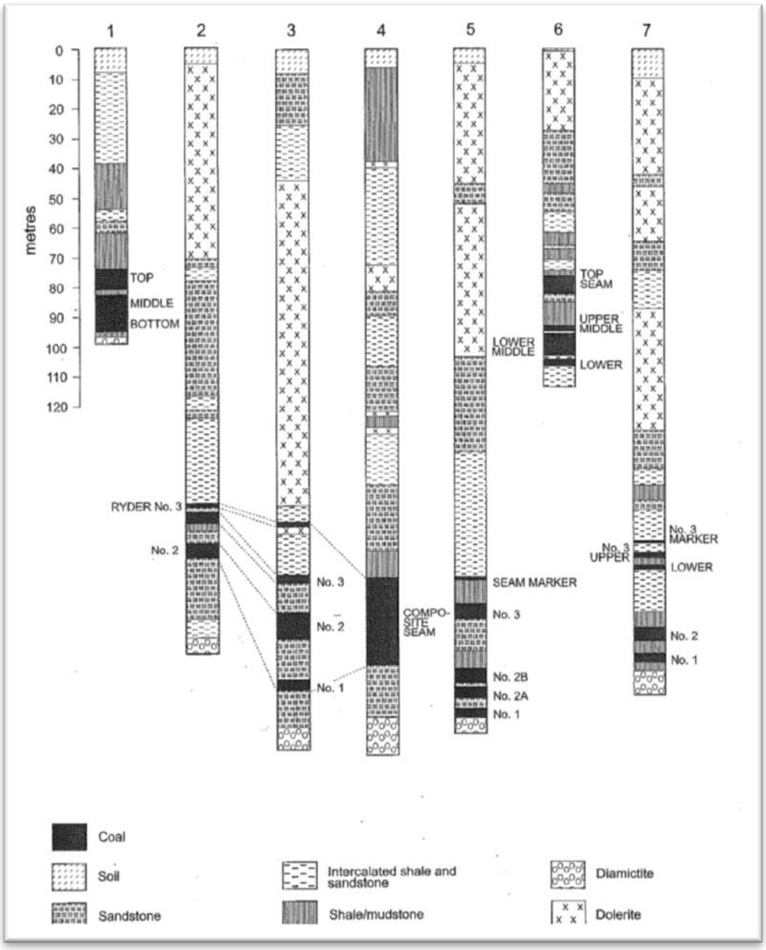


Figure 2.10 A typical stratigraphic column of the Free Sate coalfields (Snyman, 1986)

Three seams named No.1,No. 2 and No. 3 from the bottom or more commonly known as the Top, Middle and Bottom seams are mined south of Vereeniging. A typical stratigraphic column of New Vaal Colliery is indicated in Figure 2.11.

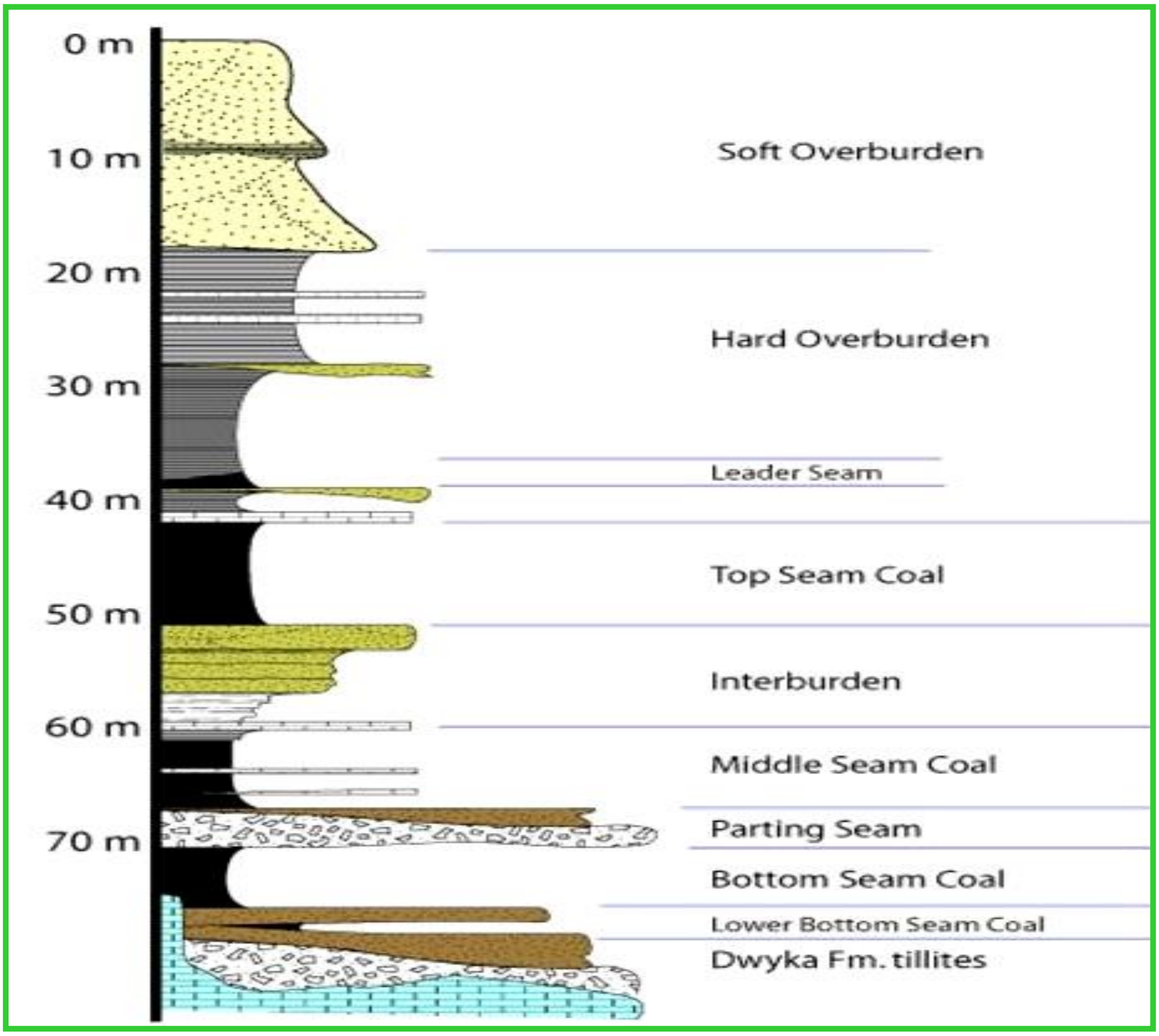


Figure 2.11: A typical stratigraphic column at New Vaal Colliery opencast (New Vaal Colliery, 2010)

2.10.1 The top seam or no.1 seam

The Top seam is about 15m in the north of this coalfield and variable in thickness and quality. It is mainly dull in appearance with ash contents of up to 15%. In the southern part it thins to about 3m with ash contents of up to 20%. The calorific value of the top seam is very poor and has been measured to be between 12-13 MJ per kg.

2.10.2 The middle seam or No.2 seam

The middle seam is about 7m in thickness and also tends to be variable in thickness. The middle seam is dull with very little bright coal and has about 20% ash and more. The upper and lower are often separated by a shale band of about 1m. This band varies in position but it is often found in the middle of the seam. The calorific value of the middle seam is between 15-17 MJ per kg (Horsfall, 1992).

2.10.3 The bottom or No.3 seam

The bottom seam is about 2 to 3 m in thickness and very dull with ash contents above 20%. The calorific value of the bottom seam is greater than top and middle seams and has been measured to be greater 19 MJ per kg (Horsfall, 1992).

The resources of the Free State coalfield were estimated at about 8.8 billion tonnes and the reserves at about 5 billion tonnes by Bredell in 1987. The resources are about 7.3% and the reserves about 8.9% of the total of resources and reserves South Africa. The Free State, by virtue of its vast resources and reserves, is the 4th largest coalfield in South Africa.

2.11 South Rand coalfield

The South Rand coalfield occurs within a deep, southward-trending valley which starts north of Springs and extends towards the Vaal Dam. It is effectively isolated from the Highveld coalfield by inliers of pre-Karoo formations. A significant feature is the presence of large granite domes which form paleohighs in the centre of the basin. The coalfield is also affected by severe faulting with throws of up to 35m, the presence of the dolerite sill of about 100m in thickness and numerous dykes, up to 10 m thick and of variable orientation (Snyman, 1986).

The South Rand underground reserves in the past were very difficult to mine with current underground mining methods because the seams were steeply dipping. It was established that the quality of the coal was also very poor because the ash content of the coal is very high and the calorific values consequently very low. Before any major breakthrough could be made in terms of exploiting the coal there is also a need for ESKOM to build a power station to accept this coal as they did at Lethabo power station for the coal at the New Vaal Colliery opencast mine (Prevost, 2013).

The resources of the South Rand were estimated to be approximately 3 billion tonnes with just less than 1 billion tonnes i.e. 750 million mineable by Bredell in 1987.

2.12 Kwa-Zulu Natal coalfields

There are three important coalfields in Kwa-Zulu Natal named the Utrecht, Vryheid and Klip River coalfields**.** These coalfields will be grouped together to represent the depleting coalfields in the Natal region.

2.12.1 Utrecht coalfield

The Utrecht coalfield lies within the Utrecht and Paulpietersburg districts in Kwa-Zulu Natal. It is separated from the Vryheid coalfield to the east by a fairly narrow strip where the seams have been removed by erosion (Snyman, 1986). There are four coal seams of economic importance in the Utrecht coalfield. They are similar to the coalfields of the Vryheid coalfield and that is the Coking Coal, Dundas, Gus and Alfred seams. The coking coal is not more than 1.5 m in thickness. The Dundas seam is less than 2 metres in thickness and is characterised by dull, bright and shaly coal. The Gus seam is well developed and economically the most important seam. It is about 1 metre in the South and split by a sandstone parting in the north. The Alfred seam is persistent and about 3-4 metres south of Utrecht. It is generally a mixture of bright and dull lustrous coal.

A typical stratigraphic column of all the three major coalfields in Kwa-Zulu Natal is indicated in Figure 2.12. The seams in this coalfield have been a major source of moderately good coking coal and require little beneficiation. The rank of the lower Dundas varies from medium volatile bituminous to anthracitic, with the coal mined as a source of bituminous coal in the north-eastern corner and as anthracite in the southern part.

However the sulphur content can be high and in excess of one per cent (Spurr, et al., 1986). The Gus seam is subdivided into three coal quality zones with the upper part comprising mainly dull coal, the central part predominantly bright coal and the bottom section mainly poor quality coal with shale partings. The seam has a high methane gas concentration. The Alfred seam is of a better quality in the Utrecht Coalfield, particularly towards the bottom portion of the seam. The seam is generally high in ash and sulphur content but beneficiation can produce high, low ash coal with low sulphur and phosphorous (Jeffrey, 2005).

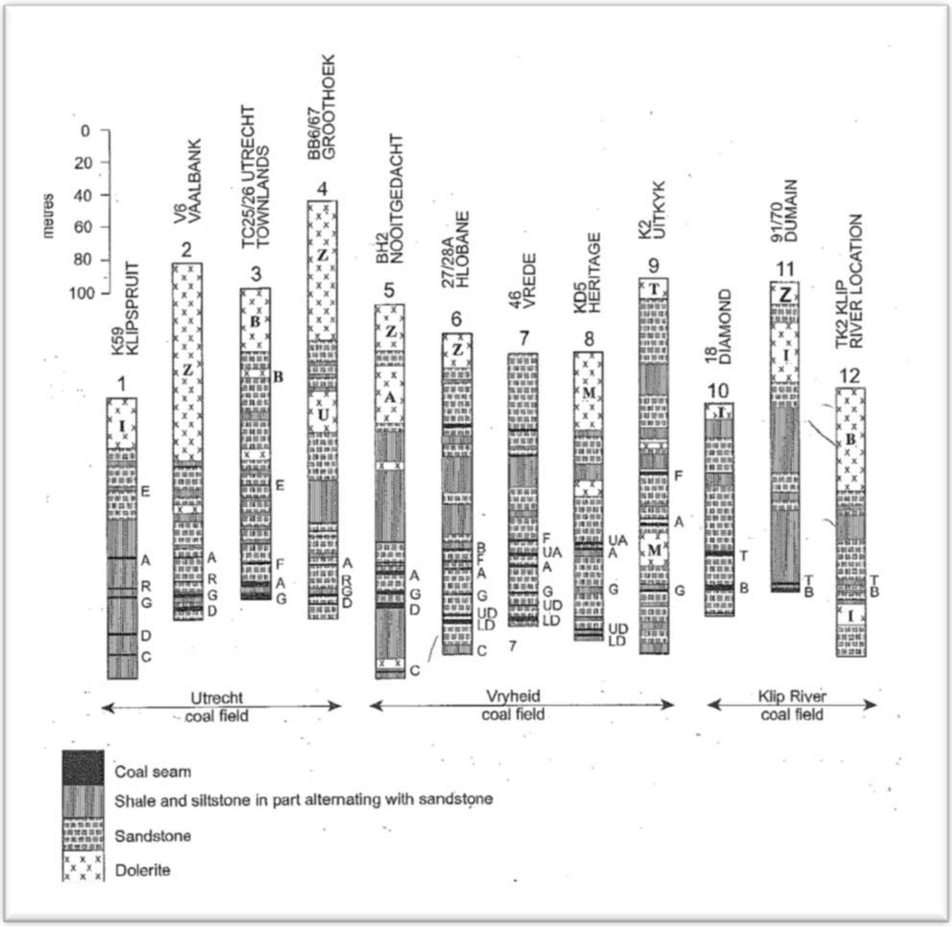


Figure 2.12: A typical stratigraphic column of the Utrecht, Vryheid and Klip River coalfields (Snyman, 1986) Vryheid coalfield

The Vryheid coalfield is one of three major coalfields found in KwaZulu-Natal in the northern side of Durban in the town of Vryheid. The Vryheid Coalfield covers an area of approximately 2,500 km² of which approximately 15% is underlain by coal seams (Bell & Spurr, 1986). The stratigraphy of the Vryheid Coalfield is composed of the basal Dwyka Group which is, in turn, succeeded by sediments of the Ecca and Beaufort Groups.

The coal zone varies from 150 to 200m and the coal seams in descending order are the Fritz, Alfred, Gus, Dundas, coking and Targas seams (Lurie, 2004). The Vryheid coalfield used to be the second most economic coalfield after the Witbank coalfield. However, the coalfield's production has decreased to less than 9% of the total Run of Mine coal produced in 2010. There are 9 seams within the Main Coal Zone and only four (4) are exploited in the north and five (5) in the central portion. The four main seams exploited from the bottom upwards are the Coking, Dundas, Gus and Alfred (Horsfall, 1992).

The coking seams split into upper and lower portions in parts of the area. The coking seam is seldom less than one metre thick, often has an ash content of about 10 per cent, and consists of bright coal. It is normally mined as coking coal with excellent coking properties requiring little beneficiation. The Dundas Seam is well developed and split into the upper Dundas which is about 0.15 to 1.2 m thick and usually too thin to be mined alone. It also makes good coking coal. The Dundas lower is about 0.1 to 2.5 m thick and occurs between 1.5 to 6.5m below the Upper Dundas. It consists of interbanded bright and dull coal. The Gus seam is extensively developed and is between 0.5m to 2m in thickness. It consists of finely interbanded bright and lustrous coal. The Alfred seam is less than 1 metre and sometimes may be dull and inferior in quality. The Gus and Alfred seams sometimes thicken to about 4m, when the coal is mainly dull in appearance, and similar to the No.2 and No. 4 seams of the Witbank (Jeffrey, 2005).

2.12.2 Klip River coalfield

The Klip River coalfield is situated between the towns of New Castle and Dundee. There are two main seams, named the Top and the Bottom seams in this coalfield. Both seams tend to be between 1 and 2 m thick but in places the Top seam may exceed 4 m. The Top seam is equivalent to the Alfred seam and is better developed than the bottom seam. The bottom sea is equivalent to the Gus seam. Both seams tend to be bright in appearance, the Top seam generally having more dull coal. Coking properties are often present. Ash contents may vary from less than 15 per cent to about 20 per cent except where there Top seam becomes thick and ash contents are likely to exceed 20 per cent. Where the seam is thick it contains a high proportion of dull coal (Horsfall, 1992). The recoverable reserves of the Natal coalfields were estimated by Bredell in 1987 to be approximately 2.5 billion tonnes.

2.13 The Molteno/Indwe coalfield

The Molteno or Indwe coalfield is in the Eastern Cape Province. Only the Indwe, Guba and the Molteno seams in the Molteno-Indwe coalfield have economic potential in places; however, they are mainly of poor quality. Prevost indicated that the raw qualities of the seams have high ash content between 31 and 51 per cent and the washed qualities have an ash content between 26 and 27 per cent, high moisture content between 7 and 11 per cent, low volatile matter between 7 and 12 per cent and a calorific value of between 24 and 26 MJ per kilogram [(Prevost, 2002) and (Jeffrey, 2005)]. No mining exists in the area; however there were plans in the late 2010 by Strategic Natural Resources (SNR) to mine coal with resources of about 90 million tonnes and half of the resources are said to be in the measured category and the rest in the inferred stage. This mining group plans to mine the Elitheni coal mine near Indwe in the Eastern Cape (Strategic Natural Resources, 2012). A typical stratigraphic column of the Molteno or Indwe coalfield is shown in Figure 2.13.

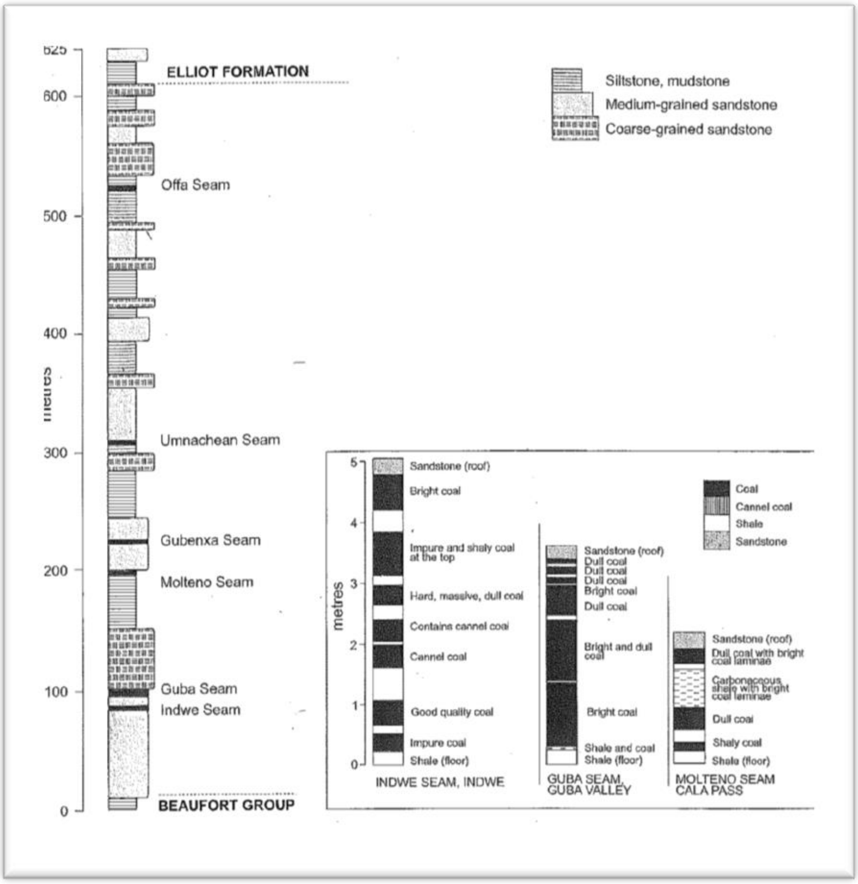


Figure 2.13: A typical stratigraphic column between Elliot and Indwe and lithological composition of the three lower seams (Snyman, 1986)

2.14 The past mining of the Witbank and Highveld coalfields

A review of all the coalfields of South Africa shows that the Witbank, Highveld and Waterberg coalfields are the three most important coalfields that need further analysis because of their significant amount of reserves. Therefore, in order to forecast trends on the future of the South African coal mining industry an analysis of the Witbank and Highveld coalfields reserves should be thoroughly undertaken. In Chapter 1 and specifically Table 1.10, it was stated that about 20 billion tonnes of coal reserves remain in the Witbank and Highveld coalfields; however much of this coal is trapped in underground pillars because of the bord and pillar mining method employed. Roughly for every tonne mined one tonne is left underground in the form of pillars. In essence about 50% of the reserves have been left underground in the Witbank and Highveld coalfields for over a century

It follows that pillar extraction from mines where these pillars can be recovered safely, would need to be continually undertaken in order to improve the overall extraction ratio from 50% to about 75%. However, where pillar extraction cannot be utilised because of safety issues the coal will remain locked up in these pillars until a safe method of mining these pillars is introduced. From personal knowledge of the Witbank and Highveld coalfields, pillar extraction is not carried out extensively by the mining companies. It is believed that this is because of the dangers associated with the unstable roof inherent in this method of mining. It is therefore, safe to assume that the status-quo is very unlikely to change drastically in the future.

Underground mining in the Witbank and Highveld coalfields is unlikely to change from bord and pillar to another mining method such as longwall because of the geology of these coalfields. The Witbank and Highveld coalfields are intruded by dykes and sills thereby making longwall mining difficult to introduce. The life of the Witbank and Highveld coalfields is still going to be limited by bord and pillar mining and the reserves will continue to be depleted until the Waterberg is thoroughly investigated as a next possible future coalfield.

2.15 The future mining of the Waterberg coalfield

The Waterberg coalfield on the other hand has only been marginally exploited because of infrastructural constraints such as inadequate road and rail capacity. Other constrains include the distance to the Richards’s Bay Terminal and inadequate water availability. However with the increasing energy demand and the need for coal in South Africa, this coalfield will need to be explored and exploited in the coming years. From Table 1.10 only 734 million tonnes have been mined in the Waterberg from 1982 to 2010 because mining has been limited to only one opencast mine and consequently the reserves have only marginally been depleted. The Waterberg coalfield has been shown in Table 1.10 to contain about 7.5 billion tonnes of opencast reserves. A minimal exploration of the underground reserves has been done, therefore very little is known of the underground reserves of the Waterberg coalfield. To illustrate how little the mining industry knows about the Waterberg coalfield, Bredell in the late eighties estimated the Waterberg resources to be 55,614 Mt and twenty year later Kumba Resources (now known as Exxaro) estimated the in-situ inferred resources at 78 billion tonnes (Venter, 2006).

The increasing need for energy in South Africa combined with decreasing coal resources in the traditional coalfields in the Central basin necessitates that additional coalfields should be explored and brought on stream to meet the present and future energy needs of South Africa. In early 2007 ESKOM, the power utility provider, started cutting off residential and industrial power because there was not enough coal to supply the increasing demand of energy in South Africa. At that time there was a debate about the depletion of the coal stock levels at every power station and the coal mining industry capacity to meet the rising power requirements of the country as whole. Although the power cuts have stabilised since then, a number of projects that require additional power such as the smelter in Richard’s Bay were shelved and most gold and platinum mine’s power supply were rationed. This means that the demand for energy and coal resources in particular will continue to rise against a backdrop of decreasing coal resources and reserves in South Africa.

As a result of the power cuts a lot of projects have been commissioned country-wide in search of additional coal power. A few companies have explored the avenue of supplying their own power needs and enlisting what they referred to as independent power suppliers. In the interim ESKOM has nearly completed an additional dry coal power station at the Waterberg to meet the future energy requirement of South Africa. A number of companies are exploring the Waterberg (Medupi) at present and thus emphasizing the need for additional power and the need to understand the Waterberg coalfield as a whole.

2.16 Concluding remarks

This chapter has covered the status of the different coalfields in South Africa with emphasis on the geology and present and future mining of the different coalfields. Table 2.1 summarises the significance of each coalfield in terms of historic contribution, current status and future potential.

Table 2.1: Significance of the coalfields in South Africa in terms of historic production, current reserves and future potential [Adapted from Table 1:10]

Coalfields	Reserves	Historic Production	Current Reserves	Future Potential	Significance
	1982 (Mt)	**1982-2010 (Mt)**	**2010 (Mt)**	%	
Witbank[1]	12461.00	4130.20	8330.80	25.16	Significant
Highveld[2]	10919.60	1513.60	9406.00	28.40	Significant
Waterberg[3]	7441.40	734.10	6707.30	20.25	Significant
Ermelo[4]	4658.10	279.80	4378.30	13.22	Significant
Sasolburg/Veerniging[5]	2233.00	545.00	1688.00	5.10	Significant
South Rand[6]	730.00	14.50	715.50	2.16	Insignificant
Utrecht[7]	609.80	69.10	540.70	1.63	Insignificant
Kliprivier[7]	617.00	90.50	526.50	1.59	Insignificant
Vryheid[7]	179.60	80.20	99.40	0.30	Insignificant
Nongoma[7]	38.80	33.70	5.10	0.02	Insignificant
Soutpansberg[8]	267.00	9.90	257.10	0.78	Significant
Kangwane[9]	147.00	1.30	145.70	0.44	Insignificant
Limpopo[10]		No mining in the past		Prospecting	Insignificant
Molteno/Indwe[11]		No mining in the past		Prospecting	Insignificant
Total	**40302.30**	**7184.80**	**33117.50**	**100.00**	

[1] Witbank: Very significant coalfield with over 8 billion mineable reserves which is equal to over a quarter of the reserves and is surrounded by most of the country's power stations. It has thick coal seams and is where most of the coal mining has occurred.

[2] Highveld: The second most significant coalfield with over 9 billion tonnes of coal mineable reserves containing about 30% of the reserves. Together with the Witbank coalfields these coalfields have produced over 75% ROM and will continue to do so for the next decade.

[3] Waterberg: The third largest coalfield in South Africa with just under 7 billion tonnes of mineable coal reserves which do not include the underground coal reserves on the eastern side of the Daarby fault at depth greater than 250m. This coalfield is marginally mined with only one open pit mine. However, it is said to contain the future resources and reserves of South Africa. The Waterberg will be significant in the coming years as more power stations will be built in that area. Presently, Medupi power station is being built and will be supplied with coal for the next 30-40 years.

[4] Ermelo: This coalfield was significant in the past and contains fewer than 15% of mineable reserves. Future potential is minimal.

[5] Sasolburg/Veerniging: The fifth biggest coalfield in South Africa with mostly poor quality coal suitable for a power station as is the case with the supply of coal to Lethabo power station by New Vaal Colliery. Future plans include mining the coal with underground coal gasification methods.

[6] South Rand: Very little mining in the past because of steeply dipping seams and poor quality coal. This coalfield has potential only if the coal can be mined for a power station because of high ash content.

[7] Natal coalfields (include Utrecht, Kliprivier, Vryheid and Nongoma): These coalfields were very significant in the past because of mining high quality coking coal. However, because the seams are thin and less than 1.5m most of the coal in these coalfields is mined out.

[8] Soutpansberg: The coal in the northern part of the country has been difficult to mine in the past because it is undulating and faulted. The discovery of coking coal at Vele colliery with a potential of about 15 million tonnes per annum has rendered this area significant as future potential coal source.

[9] Kangwane: Contains high quality anthracite coal but the resources and reserves are small and therefore not very significant. Very little mining has been done in the past and is not expected to increase in the future because of complex geology.

[10] Limpopo: No historic production in the past, however, lately there has been a discovery of coal and various projects such as the Makhado project with a potential of 1-2 mtpa by CoAL and therefore note very significant. The Limpopo province coalfields such as the Limpopo, Wateberg and Soutpansberg are very far from the Central Basin where most of the mining is taking place and are therefore not very close or linked to the current rail and road infrastructure. Therefore the cost per tonne of mining coal in these coalfields will be higher unless markets are discovered close to these areas and the potential for export market is realised.

[11]Molteno/Indwe: No mining in the past because of poor quality coal in the area. Lately the Elitheni mine has discovered coal with a resource potential of about 90 million tonnes which is not very significant.

The aim of this chapter is to indicate that not many of the coalfields have enough resources and reserves to supply the current energy requirements and sustain future energy demands of South Africa unless the Waterberg coalfields is further explored and exploited. Apart from the Witbank and Highveld coalfield which produce about 77% of the production in South Africa and with a remaining life of about 15 -25 years, not much significant coal mining is happening in other coalfields. The next chapter will focus exclusively on understanding the uniqueness of the Waterberg in terms of geology and the need to have different mining approaches to exploit it.

The Waterberg on the other hand has only been marginally exploited because of infrastructural constraints such as inadequate road and rail capacity; distance to the port and water problems. However with the increasing energy demand and the need for coal in South Africa this coalfield will need to be further explored and exploited in the near future.

The next chapter will focus exclusively on understanding the uniqueness of the Waterberg as it envisaged being the future coalfield of South Africa. Before any mining approaches can be undertaken in this vast coal resource there is a need to understand the unique geology of this coalfield. The next chapter will concentrate solely on explaining the uniqueness of the geology of the Waterberg coalfield and its package of 110m deep thick seams.

3 THE UNIQUE GEOLOGY OF THE WATERBERG COALFIELD

3.1 Introduction

In this chapter the unique geology of the Waterberg coalfield will be discussed with emphasis on the Vryheid and the Grootegeluk Formations with a combined seam thickness of 110 m. The emphasis will be on the uniqueness of the Waterberg coalfield geology with its package of eleven coal zones which occur only at the Waterberg and not anywhere else in South Africa. The implications of mining these 11 “coal zones” at depths greater than 250m on the Eastern side of the Daarby fault have not been fully explored because mining has been confined to the Western side of the fault where the coal seams are shallow. It is therefore imperative to understand and interpret the geology of the shallow surface mine at Grootegeluk and use this knowledge to plan for deep level underground mining on the Eastern side of the fault. The conclusion of this chapter is that the geology of the Waterberg requires an understanding of multiple seam mining because of the depth of the seams. South Africa does not yet have the mining experience required to mine multiple seams at depths greater than 250m and therefore it is important to examine how other countries carry out multi-seam mining at greater depths and explore how those lessons could be applied to the Waterberg.

3.2 The Geology of the Waterberg

The Waterberg coalfield is situated in the Western part of the Limpopo province of South Africa, approximately 25 km west of Lephalale. The Waterberg coalfield has an approximate 88km east - west strike length and has a north-south width of about +/- 40km within the Republic of South Africa but, extends westward into Botswana shown in Figure 3.1. Although the Waterberg coalfield has a small area i.e. 88km by 40km compared to other coalfields like the Witbank coalfield (180 km by 40km) and the Highveld coalfield (700km by 700km), it has eleven coal zones that occur over a depth of 110m and therefore has significant resources and consequently reserves that have still to be explored and mined. The Waterberg area represents about 3% of the surface area of coalfields in South Africa but is estimated to contain approximately 45% of the in-situ coal reserves (De Korte, 1994). The stratigraphy of the Waterberg coalfield and the different coal zones will be discussed in Sections 3.3 to 3.6 of this chapter.

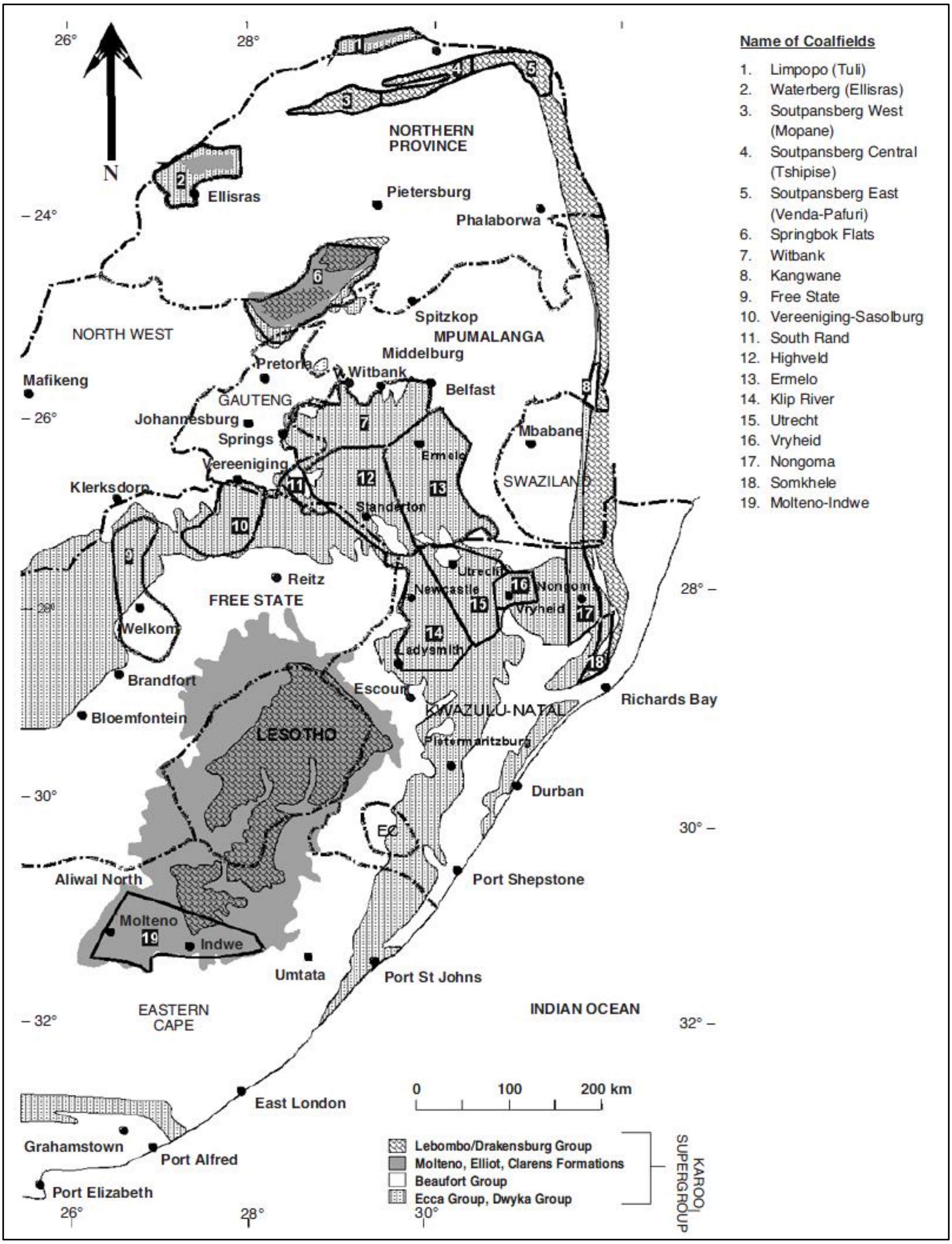


Figure 3.1: Location of the Waterberg coalfield shown as coalfield number 2 (Jeffrey, 2005)

The Waterberg coalfield is bounded by faults on both the southern and northern margins and can be called a graben- (a depressed block of land bounded by faults). In the south, the Eenzaamheid fault forms the southern limit of the Waterberg coalfield. In the north, the Zoetfontein fault forms the northern limit (Dreyer, 1994) as shown in Figure 3.2.

The Daarby fault, with a throw of approximately 250m divides the coalfield into two halves i.e. a shallow western part with opencastable reserves which is approximately one third and a deep eastern part which is approximately two thirds where coal occurs at a depth of 200-400m below surface (Dreyer, 1994). The faults are largely responsible for the fact that the coal occurs at fairly shallow depths at Grootegeluk Colliery on the western part. However, the composite nature of some faults has rendered other areas unmineable (Snyman, 1986).

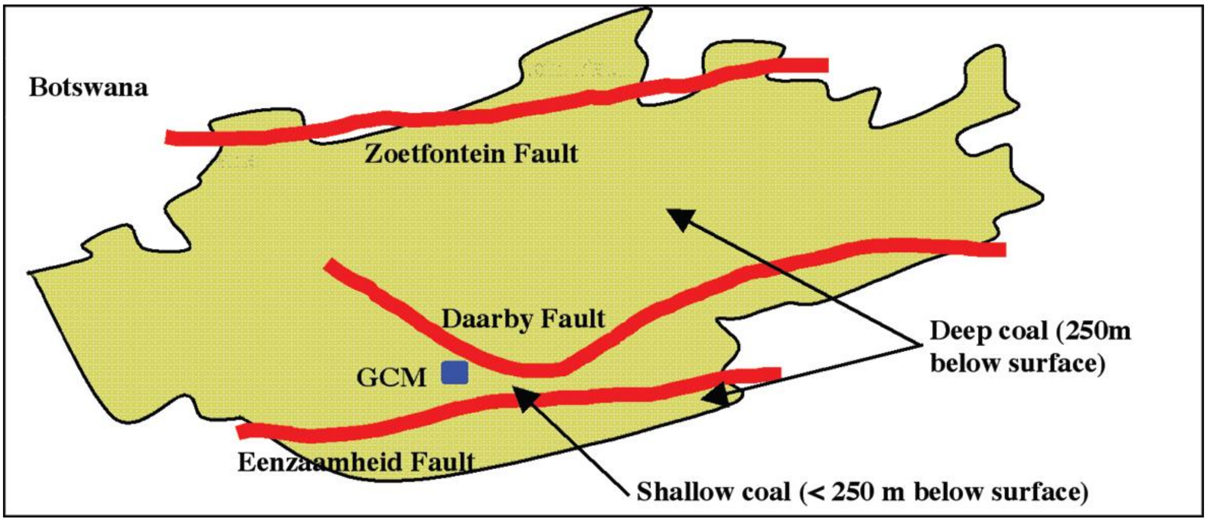


Figure 3.2: Deep and shallow coal areas (Jeffrey, 2005)

The coal seams of the Waterberg coalfield occur in the Volkrust and Vryheid Formations of the Karoo Supergroup. Eleven coal seams occur over a stratigraphic thickness of at least 110 metres. The lower five seams fall within the Vryheid Formation and the upper six within the Volksrust Formation.

3.3 The geological section

An east to west geological section across the Waterberg Coalfield is shown in Figure 3.3. The section indicates that the eastern part of the Waterberg has coal seams that are occurring at depth of over 250m and that western part of the Waterberg has shallower coal seams at depths just above 20m. The Daarby fault divides the Waterberg deeper seams from the shallower seams.

The western side shows coal zones that begin at a depth of about 20m up to a maximum depth of about 130m. However, as the section progresses more towards the West of the Grootegeluk geological section the overall stratigraphy increases from about 130m up to about 180m in depth within a radius of 35 km. Currently mining at the western side is exclusively opencast although in future there will be a possibility of underground mining because of the increasing depth.

On the eastern side of the Daarby fault the coal zones begin at a depth of 190m and increase up to a depth of 310m maximum according to the current cross section. Underground mining on the eastern side of the Daarby fault must be investigated because surface mining is not possible at these depths. The possibility of mining all of these deep coal resources is the subject of this dissertation and will be discussed in Chapter 5.

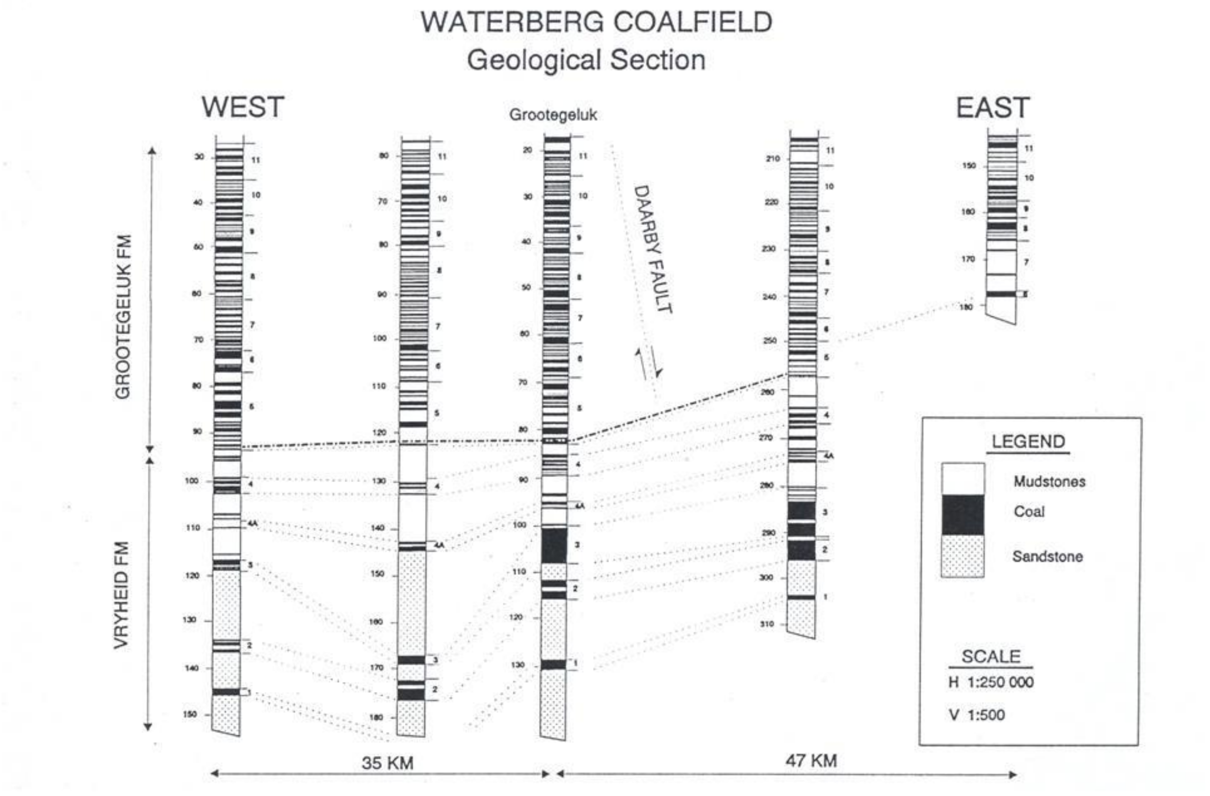


Figure 3.3: An east – west section of the Grootegeluk and Vryheid formations in the Waterberg coalfield (Dreyer, 1994)

3.4 Description of the Vryheid formations

The Vryheid formation or the middle Ecca is 50m thick and consists of carbonaceous shale and sandstone with interbedded dull coal seams varying in thickness from 1.5 to 8 m. There are five coal zones numbered from the bottom upwards. The coal zones are predominantly dull and are numbered from Zone 1 to Zone 4A. Zone 4 is numbered twice i.e. as Zone 4 and Zone 4A because of its thickness. Although the coal is generally dull and therefore of poor quality, there is however, bright coal or good quality coal developed at the base of Zones 2 to 4. This is the coal that is used in pulverised coal injection (PCI) and specialised steel industry (CHAR). In general, the majority of the coal in this zone, because of its rank and composition, is suitable for a power station. The percentage of coal by mass in each of the zones of the Vryheid formation is above 96%. The coal in the Vryheid formation is very similar in lithology to the coal seams of the Central Basin especially the Witbank Coalfields i.e. five coal seams separated by layers of shale and sandstones (Dreyer, 1994).

3.5 Description of the coal Zones 1-4

A description of the Zone 1 to 4 is given in the next paragraphs to give an understanding of the thickness of the coal and the floor and roof contacts in preparation for mining method selection. The following descriptions are inferred from analysing the stratigraphic column of the Grootegeluk Formations.

Zone 1, has an average thickness of 1.5 m and is presently not considered to be economically minable by opencast methods because of the 14m sandstone lying on top of it.

Zone 2 is on average 4m thick and reaches a maximum thickness of 6m and the basal portion of this zone yields a fraction with slight coking characteristics. Zone 2 is the most constant of all the Middle Ecca zones across the entire Waterberg coalfield. Zone 2 and 3 are separated by a medium to coarse grained sandstone of about 4.5m thick.

Zone 3 is the thickest coal zone at an average thickness of 7,5m up to a maximum thickness of 8.5m.The thickness of the shale between Zone 3 and 4 is about 4m.

Zone 4A is on average 1.52 m thick and is separated from Zone 4 by a dark grey to black carbonaceous shale of 4.2m in thickness but this may change in the eastern part of coalfield where there are deeper coal zones.

Zone 4 is on average 4m thick and is separated from Zone 5 of the Volksrust formation by interbedded shales of about 2m in thickness (Dreyer, 1994).

3.6 Description of the Volkrust formation and Zones 5 to 11

The Volkrust or Grootegeluk formation or the upper Ecca is about 60-70m thick and consists of seven coal zones numbered 5 to 11. The coal beds are relatively thin and interbedded with numerous mudstone and carbonaceous mudstone layers. The coal consists of a multitude of intercalated bright coal and mudstone layers. Gouws (1976) as referenced in (Snyman, 1986) explained that the coal from Zones 5-11 has to be washed or beneficiated to get two products i.e. blend coking coal and middlings for the power station from the ROM of about 45 to about 65% in ash content. Botha (1984) as referenced in (Snyman, 1986) further elaborated that Zones 4 and 5 has a high phosphorous content ($P_2O_{5)}$ in contrast with about 0.08% in the ash of the other upper zones seams which make these two zones unsuitable as a source of metallurgical coal.

The float product (at a relative density of 1.4) of -25 mm coal from a borehole in the central, deep sector of the coal field shows the coal properties in Zones 6 to 11 as shown in Table 3.1.

Table 3.1: Coal properties (float at 1.4 R.D; air dry) central deep sector, Waterberg, (Snyman, 1986)

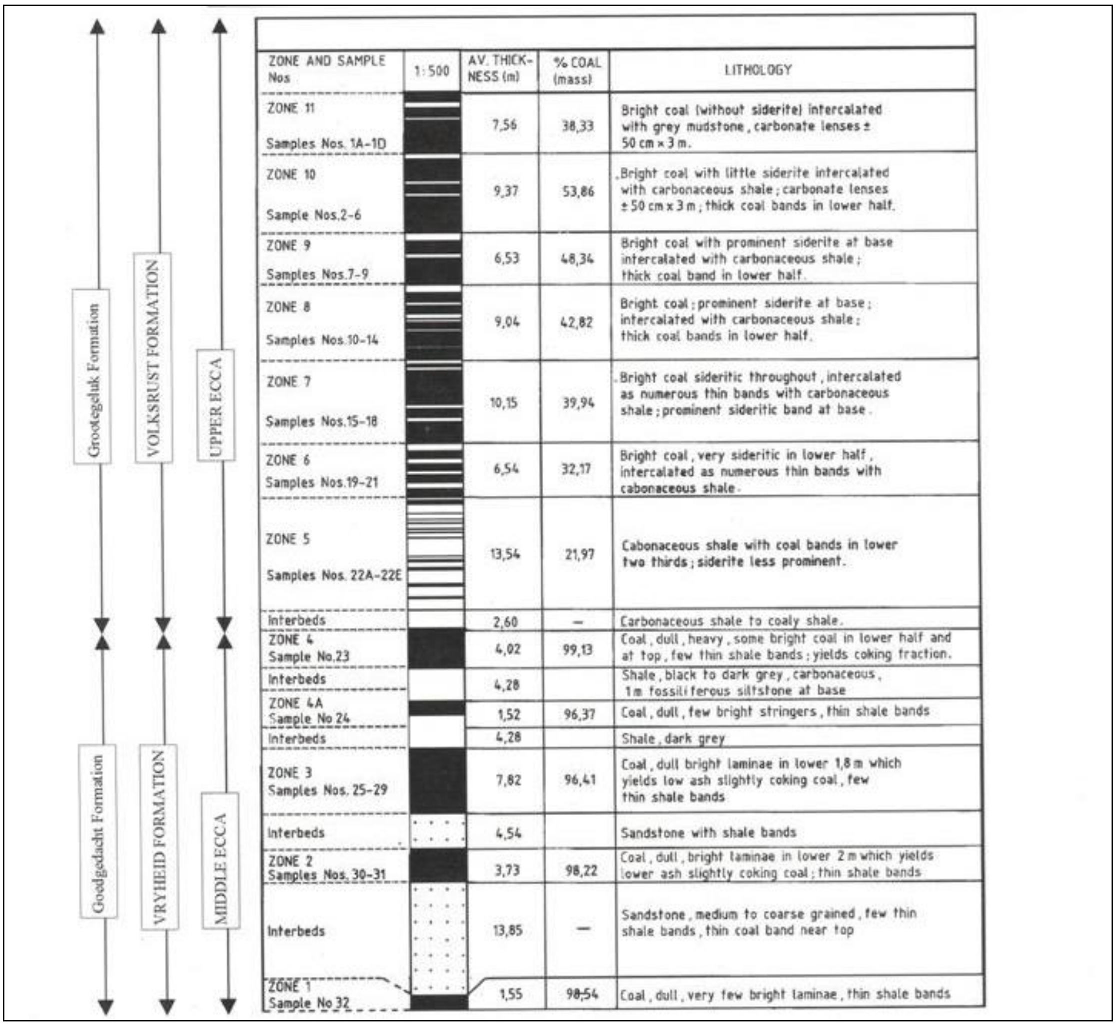
Zone	CV	% H2O	% Ash	% VM	Sw Index
11	28.20	3.40	11.80	35.40	4.50
10	27.80-28.40	2.70-3.00	11.60-13.80	36.00-36.80	3.50-5.50
9	28.60-29.00	3.00	9.80-10.80	35.20-36.00	4.00-4.50
8	29.30	2.90	9.50	35.90	5.50
7	29.30	3.10	10.10	34.80	2.50
6	30.20	3.00	7.40	35.20	3.50

The Grootegeluk formation displays a well-developed cyclic repetition of coal and shale assemblages that can be divided into seven zones. Zones 6 to 11 typically start with bright coal at the base and the ratio of coal to shale decreases from the base of the zone upwards. Zone 5 is the exception because the coal in this zone is more evenly distributed throughout the zone.

The Grootegeluk formation shows an increase in carbon content with depth and range from massive bluish grey shale at the top i.e. Zone 11 to carbonaceous shale in Zone 5. Lower down in the succession both the coal and mudstone layers are thinner and alternate more frequently (Faure, et al., 1996).

In general, the coal to mudstone ratio decreases with depth i.e. the percentage mass of coal increases from 53% in Zone 10 to 21% in Zone 5. Zone 5 occurs at a greater depth than Zone 10 which is close to surface. The thickness of the coal zones in the Grootegeluk formation varies between 6.5 to 13.5 m as indicated in Figure 3.4.

In the Waterberg coalfield there is no noticeable increase in rank with increasing depth. The air dried volatile content of the coal remains at 35-36% from the sub-outcrop to a depth of 400m (Dreyer, 1994). About 60 to 70 per cent of the coal resources are found in the deeper part of the coalfield on the eastern part and, because of the stratigraphic characteristics of the coal, underground mining at depths above 200m on the western part of the Daarby fault should be investigated.



ZONE AND SAMPLE Nos	1:500	AV. THICKNESS (m)	% COAL (mass)	LITHOLOGY
ZONE 11 Samples Nos. 1A-1D		7,56	38,33	Bright coal (without siderite) intercalated with grey mudstone, carbonate lenses ± 50 cm × 3 m.
ZONE 10 Sample Nos.2-6		9,37	53,86	Bright coal with little siderite intercalated with carbonaceous shale; carbonate lenses ± 50 cm x 3 m; thick coal bands in lower half.
ZONE 9 Samples Nos.7-9		6,53	48,34	Bright coal with prominent siderite at base intercalated with carbonaceous shale; thick coal band in lower half.
ZONE 8 Samples Nos.10-14		9,04	42,82	Bright coal; prominent siderite at base; intercalated with carbonaceous shale; thick coal bands in lower half.
ZONE 7 Samples Nos.15-18		10,15	39,94	Bright coal sideritic throughout, intercalated as numerous thin bands with carbonaceous shale; prominent sideritic band at base.
ZONE 6 Samples Nos.19-21		6,54	32,17	Bright coal, very sideritic in lower half, intercalated as numerous thin bands with cabonaceous shale.
ZONE 5 Samples Nos. 22A-22E		13,54	21,97	Cabonaceous shale with coal bands in lower two thirds; siderite less prominent.
Interbeds		2,60	–	Carbonaceous shale to coaly shale.
ZONE 4 Sample No.23		4,02	99,13	Coal, dull, heavy, some bright coal in lower half and at top, few thin shale bands; yields coking fraction.
Interbeds		4,28		Shale, black to dark grey, carbonaceous, 1m fossiliferous siltstone at base
ZONE 4A Sample No 24		1,52	96,37	Coal, dull, few bright stringers, thin shale bands
Interbeds		4,28		Shale, dark grey
ZONE 3 Samples Nos. 25-29		7,82	96,41	Coal, dull bright laminae in lower 1,8 m which yields low ash slightly coking coal, few thin shale bands
Interbeds		4,54		Sandstone with shale bands
ZONE 2 Samples Nos. 30-31		3,73	98,22	Coal, dull, bright laminae in lower 2 m which yields lower ash slightly coking coal; thin shale bands
Interbeds		13,85	–	Sandstone, medium to coarse grained, few thin shale bands, thin coal band near top
ZONE 1 Sample No 32		1,55	98,54	Coal, dull, very few bright laminae, thin shale bands

Figure 3.4: The stratigraphic column of the Grootegeluk and Vryheid formation of the Waterberg in the Grootegeluk coal mine area (Dreyer, 1994)

3.7 The Waterberg resource and reserve

The reserves of the Waterberg coalfield were estimated by De Jager as 18 billion recoverable tonnes (De Jager, 1983). The reserves estimate was based on 400 boreholes covering a stratigraphic column of about 110m. The reserve estimate covered the lower and upper portion of the Vryheid and Grootegeluk Formation, and therefore all the 11 coal zones of the Waterberg coalfield were covered in the geological report. The De Jager report estimated the Waterberg reserves after considering a minimum height of 2.0 m and a maximum height of 3.5 m (De Jager, 1983).

Following on from the De Jager report, a geological report by Bredell in 1987 indicated that there are over 15.8 billion tonnes of recoverable reserves in the Waterberg as indicated in Table 1.7.

The reserves were classified as low grade bituminous, high grade bituminous and coking coal. The bulk of the reserves are of lower quality with a CV of less than 25 MJ per kg. (Bredell, 1987) defined coal reserves as only that portion of the total coal resources of which the nature and distribution have been fairly well established and which is at present economically recoverable.

Since each value of the reserves was estimated under a different set of circumstances, using different criteria (for example depth, seam thickness and cut – offs), and different classification systems and at different times within different sets of economic constraints, variations in the estimate can be expected.

Table 3.2: Waterberg coalfield recoverable reserves (Mt) (Jeffrey, 2005)

Waterberg Coalfield recoverable reserves (Mt)			
Total	Low grade bituminous (CV < 25.5 MJ/kg)	High grade bituminous (CV >25.5 MJ/kg)	Coking coal (CV> 28 MJ/kg)
15 847	13 111	1697	679

Also there is a need to consider the importance of the distribution and quality of these reserves, current lack of knowledge and mining methods could be used in the future to exploit them, and the alternative resources that could act as viable economic replacements (Jeffrey, 2005).

Estimates of the reserves have been an on-going process for many years ever since the Bredell report of 1987. However, no official figures have been published by the government and as a result there are various sources currently estimating reserves. The Department of Mineral Resources estimated the recoverable reserves of the Waterberg to be 1.95 billion tonnes and over 7 billion at the end of 2010 but Bredell estimated the figure to be about 15 billion tonnes and Prevost estimated the figure to be around 6.7 billion at the end of 2012 after analysing the annual reports of Exxaro.

Table 3.3: Reserves and ROM production at the end of 2011 (Prevost, 2013)

Coalfields	Reserves	National Reserve %
Witbank	8 155.10	25.10
Highveld	9 338.90	28.75
Waterberg*	6 670.10	20.53
Ermelo	4 367.30	13.44
Veerniging-Sasolburg	1 667.80	5.13
South Rand	715.50	2.20
Utrecht	540.00	1.66
Kliprivier	523.90	1.61
Soutpansberg	256.80	0.79
Kangwane	145.60	0.45
Vryheid	98.80	0.30
Nongoma	4.70	0.01
Total	32 485	100
*** Updated for 2012 from annual reports of Exxaro**		

3.8 Concluding remarks

The unique geology of the Waterberg coalfield has been explained with emphasis on the eleven coal zones that occur within the coal bearing stratigraphic column of the Grootegeluk and Vryheid Formations. The Waterberg coalfield has been shown to have a small surface area compared to the other major coalfields like the Witbank and Highveld coalfields. Though the coalfield has a small surface area, it has thickness of coal of about 110m making it one of the largest coal reserves in South Africa. The resource has not been fully explored and according to the latest estimates it has a recoverable reserve just under 6.8 billion tonnes at the end of 2012 but these reserve estimates do not include the underground resources and reserves at depths greater than 250m**.** Presently there is no coalfield in South Africa with anything like the 11 packages of coal with a coal thickness of about 110m that is mined. There are inadequate skills in mining multiple seams of this scale. Therefore, in order to mine the Waterberg underground resources and reserves in the near future there is a need to study multi-seam mining in other countries. The next chapter will cover the current mining at the Waterberg with emphasis on the Grootegeluk open pit, mining method, equipment used and the size of the plant.

The purpose of the chapter is to cover the scale of mining in the Waterberg at present and the problems experienced before exploring future opportunities for mining underground mining reserves.

4 CURRENT MINING IN THE WATERBERG

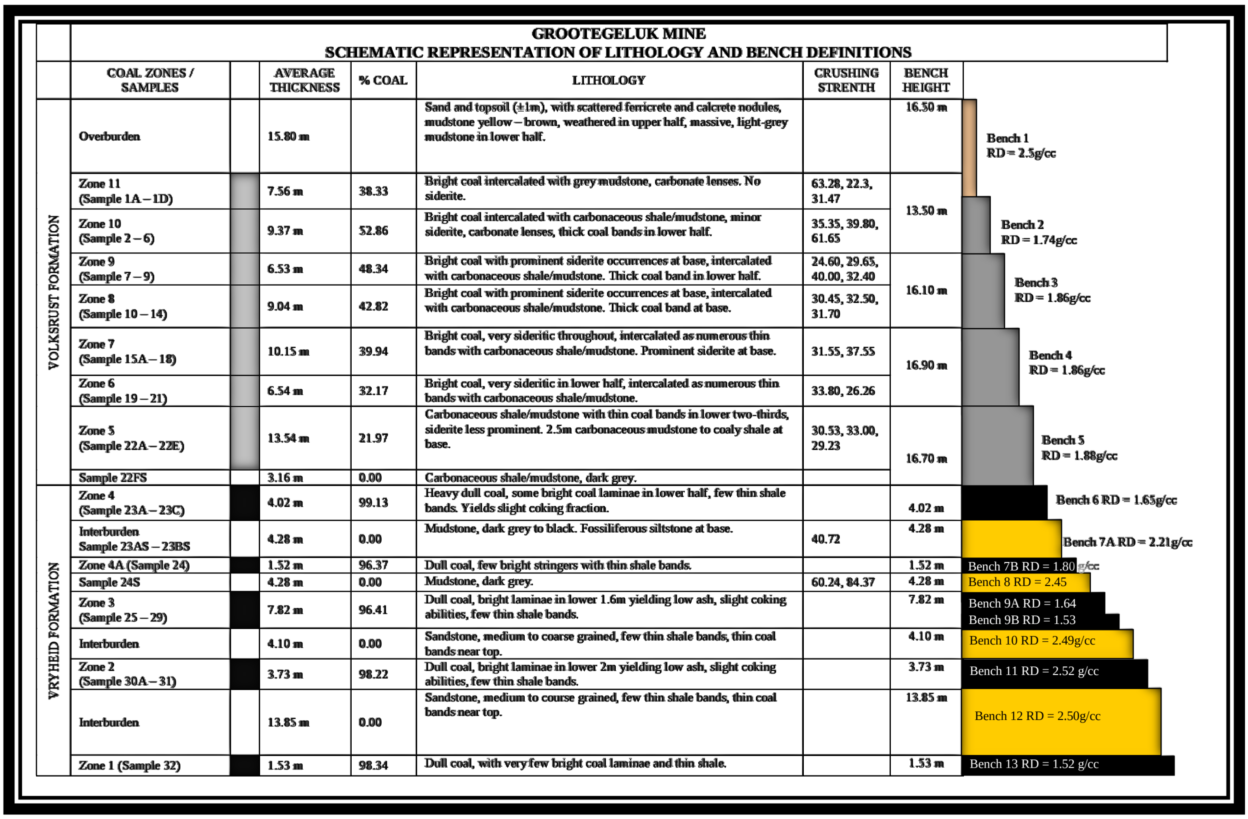
4.1 Introduction

The purpose of this chapter is to discuss the current mining in the Waterberg especially at the Grootegeluk open-pit mine. Specifically the mining of the waste and coal using thirteen different benches at Grootegeluk is discussed with an emphasis on the separate mining of the Upper and Middle Ecca formations. The emphasis is on the quantity and quality of the coal produced and the different markets supplied in order to make the mine sustainable. The latter parts of the chapter focus on the equipment used and the six beneficiation plants that are unique to the Grootegeluk complex. Lastly, the problems of spontaneous combustion and how it was solved will be briefly discussed. To summarise, the focus of the chapter is on the history of the mine, the scale of the mining operation and size of equipment and the size of the plant and types of coal products produced and the problems experienced.

4.2 Current mining in the Waterberg

Grootegeluk coal mine is the only operating mine in the Waterberg, and is an open-pit mine situated in the shallow, western part of the Waterberg Coalfield. The mine was commissioned in 1980 to supply coal to ESKOM’s Matimba power station and a blend coking coal to ISCOR now (Mittal Steel) as a bi-product. Matimba is the largest direct dry-cooling power station in the world and has a minimum lifespan of 35 years at 3800 tonnes of coal per hour. The annual send-out power of the station is approximately 24 000 gigawatts hours (ESKOM, 2013).The blended coking coal is mined mostly from the bright coal of the Upper Ecca. The intercalated nature of coal and shales in the Upper Zones prevent any form of selective mining. The only feasible and economic way of mining the Grootegeluk Formation is through opencast benches. The benches are designed in such a way that they allow the entire seam in the selected zone to be mined according to geological markings (Dreyer, 1994).

Figure 4.1 indicates how mining of overburden, interburden and coal is carried out on different benches. There are 13 benches in total, some mining waste (overburden and interburden) and others mining coal. Of the 13 benches, eight benches are mining coal and the remainder mining waste.



GROOTEGELUK MINE
SCHEMATIC REPRESENTATION OF LITHOLOGY AND BENCH DEFINITIONS

	COAL ZONES / SAMPLES		AVERAGE THICKNESS	% COAL	LITHOLOGY	CRUSHING STRENTH	BENCH HEIGHT
VOLKSRUST FORMATION	Overburden		15.80 m		Sand and topsoil (±1m), with scattered ferricrete and calcrete nodules, mudstone yellow – brown, weathered in upper half, massive, light-grey mudstone in lower half.		16.50 m
	Zone 11 (Sample 1A – 1D)	▒	7.56 m	38.33	Bright coal intercalated with grey mudstone, carbonate lenses. No siderite.	63.28, 22.3, 31.47	13.50 m
	Zone 10 (Sample 2 – 6)	▒	9.37 m	52.86	Bright coal intercalated with carbonaceous shale/mudstone, minor siderite, carbonate lenses, thick coal bands in lower half.	35.35, 39.80, 61.65	
	Zone 9 (Sample 7 – 9)	▒	6.53 m	48.34	Bright coal with prominent siderite occurrences at base, intercalated with carbonaceous shale/mudstone. Thick coal band in lower half.	24.60, 29.65, 40.00, 32.40	16.10 m
	Zone 8 (Sample 10 – 14)	▒	9.04 m	42.82	Bright coal with prominent siderite occurrences at base, intercalated with carbonaceous shale/mudstone. Thick coal band at base.	30.45, 32.50, 31.70	
	Zone 7 (Sample 15A – 18)	▒	10.15 m	39.94	Bright coal, very sideritic throughout, intercalated as numerous thin bands with carbonaceous shale/mudstone. Prominent siderite at base.	31.55, 37.55	16.90 m
	Zone 6 (Sample 19 – 21)	▒	6.54 m	32.17	Bright coal, very sideritic in lower half, intercalated as numerous thin bands with carbonaceous shale/mudstone.	33.80, 26.26	
	Zone 5 (Sample 22A – 22E)	▒	13.54 m	21.97	Carbonaceous shale/mudstone with thin coal bands in lower two-thirds, siderite less prominent. 2.5m carbonaceous mudstone to coaly shale at base.	30.53, 33.00, 29.23	16.70 m
	Sample 22FS		3.16 m	0.00	Carbonaceous shale/mudstone, dark grey.		
VRYHEID FORMATION	Zone 4 (Sample 23A – 23C)	■	4.02 m	99.13	Heavy dull coal, some bright coal laminae in lower half, few thin shale bands. Yields slight coking fraction.		4.02 m
	Interburden Sample 23AS – 23BS		4.28 m	0.00	Mudstone, dark grey to black. Fossiliferous siltstone at base.	40.72	4.28 m
	Zone 4A (Sample 24)	■	1.52 m	96.37	Dull coal, few bright stringers with thin shale bands.		1.52 m
	Sample 24S		4.28 m	0.00	Mudstone, dark grey.	60.24, 84.37	4.28 m
	Zone 3 (Sample 25 – 29)	■	7.82 m	96.41	Dull coal, bright laminae in lower 1.6m yielding low ash, slight coking abilities, few thin shale bands.		7.82 m
	Interburden		4.10 m	0.00	Sandstone, medium to coarse grained, few thin shale bands, thin coal bands near top.		4.10 m
	Zone 2 (Sample 30A – 31)	■	3.73 m	98.22	Dull coal, bright laminae in lower 2m yielding low ash, slight coking abilities, few thin shale bands.		3.73 m
	Interburden		13.85 m	0.00	Sandstone, medium to course grained, few thin shale bands, thin coal bands near top.		13.85 m
	Zone 1 (Sample 32)	■	1.53 m	98.34	Dull coal, with very few bright coal laminae and thin shale.		1.53 m

Figure 4.1: A schematic diagram of the lithology and bench definitions of the Upper and Middle Ecca at Grootegeluk (EXXARO Resources Ltd, 2012)

Three benches numbered two to four (2-4) mine coal in the Upper Ecca or Grootegeluk formation. These benches correspond to Zones 6 to 10 numbered from 10 at the top and 6 at the bottom. The coal that is mined from these benches is bright coking coal with a high vitrinite content.

The yield of this bright coal is between 8 to 15 per cent because of the large proportions of impurities. The impurities are typically as high as 60 per cent because of non - selective mining. The rest of the coal is middlings for the power station at a yield of 30 per cent to 40 per cent. The coal from the Upper Ecca is contaminated and therefore requires a high density de - stoning step to remove the bulk of the contamination (De Korte, 2010).

The geological structure of the Upper Zone formation, is less complicated and the coal is generally acceptable for blend coking coal characteristics.

Although, bench 5 is part of the Upper Ecca formation no mining of coking coal takes place on this bench because of high phosphorous content. Instead the coal from this bench is currently mined to yield a product suitable for combustion by ESKOM (De Korte, 1994).

The lower benches numbered six to eleven (i.e.6, 7, 9 and 11) are used to mine coal in the Middle Ecca or Vryheid Formation. The coal in the Middle Ecca is mostly dull and of poor quality and is specifically mined for the power station. The coal seams or coal zones are separated from each other by prominent sandstone and shale interlayers.

Part of the coal is mined for metallurgical purposes. The coal is used as a semi coking coal, as well as to produce CHAR (i.e. coal that is produced by a carbonization process at low temperatures resulting in a solid residue high in carbon and can also be used in the COREX process). CHAR can also be described as devolatilised coal used as a reductant in the ferro-alloy industries. COREX is a direct reduction process to make iron where non-coking coal is used to reduce iron ore to iron.

In summary, there are different approaches to beneficiating the Volkrust Formation and the Vryheid Formation. The Volkrust Formation is beneficiated for semi-soft coking coal and thermal coal while the Vryheid Formation is beneficiated mostly for thermal coal (De Korte, 2010).

Bench 12 is not mined at present because the interburden must be removed to expose the coal in Bench 13.

Bench 13 is not mined at present because the coal in this bench is thin and therefore uneconomic. The thickness of the coal is about 1.5 metres. The sandstone above bench 13 is about 13 metres thick as shown in Figure 4.1.

The geological contacts of the coal zones coincide with the zone boundaries and make the benches to be between 15 and 17 m in height. The bench heights make it possible to mine the zones easily with opencast machines such as trucks and shovels. Mining then extends to bench 5 and at maximum the depth from surface is 80 metres (Dreyer, 1994).

4.3 Mining of the different benches

The mining of all the benches is described in detail below in order to give an understanding of how the thick coal zones of 110m package of the Waterberg stratigraphy are presently exploited by open pit mining. First, it is important to take into account that benches that correspond to mining horizons are selected and that the height of these benches range from 10m at the lowest to an average of about 16m. The height of the benches also takes into account the size of available mining machinery. The benches start from the top to the bottom as opposed to the coal zones that start from the bottom upwards.

The first bench (Bench 1) which starts from surface corresponds to Zone 11 and is an overburden bench. It is estimated to be about 15-20 metres high in the western part of the coalfield and the overburden has a density of about 2.5 tonnes per cubic metre (t/m^3). At this depth the stripping ratio is low and acceptable for open-pit mining. One can expect a lot of waste stripping and topsoil stripping on this bench as is typical of any surface mine.

The second bench (Bench 2) corresponds to Zone 10 and it is the first coaling bench which is estimated to be about 9.4 m high and has an average coal density of about 1.74 t/m^3.

The next benches are also coaling benches i.e. benches 3 and 4. These benches are about 16m in height and have a coal density of about 1.86 t/m^3. Bench 3 corresponds to zones 9 and 8. Bench 4 corresponds to zones 7 and 6.

Bench 5 corresponds to zone 5 and is also a coaling bench which is about 16.7 m high with a density of 1.88t/m^3. Bench 5 contains a high phosphorous content and does not meet the quality requirements for a blend coking coal for Mittal Steel. However, the coal is considered suitable for a power station market. The first five benches discussed are found in the Upper Ecca or the Volksrust/Grootegeluk formations and therefore have a mixture of bright coal with high vitrinite content by South African standards. The layers of bright coal are interbedded and interlaminated with carbonaceous mudstone (De Korte, 1994).

The benches that follow form part of the Middle Ecca or the Vryheid Formation which is composed mostly of very dull coal, sandstone and carbonaceous shale. Bench 6 corresponds to zone 4 and is a coaling bench that is about 4 m high with a density of 1.65 t/m^3. The coaling benches of the Middle Ecca benches are about 4m on average except bench 11 and 7B which are less than 2m.

Bench 7 is divided into a waste and a coaling bench. Consequently, Bench 7A is an interburden bench which is about 4.3m with a density of 2.21 t/m^3 and Bench 7B corresponds to zone 4A and is a coaling bench where the seam is about 1.5 m thick and has a density of 1.80 t/m^3.

Bench 8 is a waste bench which is about 4.3m high with a density of 2.45 t/m^3 and Bench 9 corresponds to zone 3 and is a coaling bench which is about 7.82 m high. This coaling zone is mined in two benches i.e. bench 9A and 9B with densities of 1.64 t/m^3 and 1.53 t/m^3.

Bench 10 is an interburden bench, mining sandstone and is about 3.73m high with a density of 2.5 t/m^3 and Bench 11 correspond to zone 2 and is coaling bench which is on average estimated to be 3.73m with a relative density of 2.52 t/m^3.

Bench 12 is an interburden bench and is on average estimated to be 3.85m with a density of 2.5t/m^3. Bench 13 corresponds to Zone 1 and is a coaling bench which is estimated to have a seam thickness of 1.5m with a density of 1.52 t/m^3. Figure 4.1 gives a comprehensive summary of the benches in terms of their numbering, percentage coal in each bench or zone, lithology, bench height and density.

4.4 Mining equipment at Grootegeluk mine

Mining at Grootegeluk open pit mine is done using the truck and shovel method. In general, the overburden and inter-burden are mined by electric hydraulic shovels (Demags) and the coal is mined primarily by electric rope shovels (P&H). There are five (5) P&H shovels and three (3) Demags. Two Caterpillar front end loaders (994’s) are used to mine coal mainly from benches that do not have high mining faces. These loaders also provide extra capacity to coal benches as they can be moved to assist in case a rope shovel breaks down. The sizes of the front end loaders and electric shovel and the tonnes per hour mined by each shovel are indicated in Table 4.1.

Table 4.1: Types of Shovels

Type of shovel	Tonnes per hour capacity
P&H 2300 electric rope shovel	2100
Demag 285 hydraulic shovel	1800
Demag 455 hydraulic shovel	2100
Caterpillar 994	1400

According to the information gathered during a mine visit there are 26 haul trucks on the mine in total. The fleet is composed of fourteen (14) Komatsu 730E's, eight (8) Hitachi EH 3500's and four (4) Hitachi EH 4500's. The payload, expected productivity and diesel consumption are given in Table 4.2.

Table 4.2: Types of Trucks

Type of truck	Payload (tonnes)	Expected productivity (tonnes per hour)	Diesel consumption (litres per hour)
Komatsu 730E	180	390	70
Hitachi EH 3500	190	405	72
Hitachi EH 4500	240	450	105

The bigger trucks which are the Hitachi EH 4500's carry the most payload and consequently consume more diesel. However, it should be noted that the productivity of the trucks depends on the distance travelled to and from the tip and is a function of how the dispatcher allocates trucks to the different ramps. The expected productivity of the Komatsu 730E is comparable and very similar to that of the Hitachi EH 3500. All trucks are equipped with electric wheel motors. They therefore use both diesel and electricity. Main haulage roads have pantograph lines on which the trucks connect to save diesel on the uphill road to the beneficiation plants. During the travel on electricity the trucks can achieve a minimum speed of 24 km/h. Hitachi EH 4500's trucks can travel faster than the other trucks as they have AC drive motors while the rest have DC drive motors. The current mining depth is about 130m with an average stripping ratio of 0.49 m^3/t. The stripping ratio is the ratio of the volume of the overburden or waste mined to the volume of the tonnes of coal mined in most surface mines is usually between 6 and 8 but due to the thickness of the coal in Grootegeluk mine the stripping ratio is low.

4.5 Quality and quantity of coal mined

In 2011, the mine produced 57 million tonnes ex-pit. The ROM produced was 39.4 million tonnes per annum (Mtpa) and the total waste produced was 17.6Mtpa. The breakdown of the waste produced is 9.6 Mtpa overburden and 8Mtpa of interburden. The tonnes produced by the plant after the coal was washed were 19.6Mtpa of sales.

The final product produced by the plant is distributed as 75% for Matimba power station, about 12.5 % for the semi - soft coking coal and 12.5 % for the metallurgical coal. The annual production breakdown of coal produced by the plant is shown in Table 4.3.

In 2005 Fauconnier, the then Chief Executive of Kumba Mining commented that the Grootegeluk mine houses the largest complex of coal beneficiation plants in the world, allowing diversity of products and is also the lowest cost coal in South Africa a free-on-rail basis (Fauconnier, 2005).

Table 4.3: Final Product produced by Grootegeluk Mine (tonnes per annum)

Plant	Semi soft coking coal Mtpa	Steam coal power station Mtpa	Metallurgical coal Mtpa	PCI Coal Mtpa	Total
GG1	1.72	6.35	0	0	8.07
GG2	0	4.26	0	0	4.26
GG3	0	1.30	0	0	1.30
GG4/5	0	0	1.33	1.14	2.47
GG6	0.74	2.74	0	0	3.48
Total	2.46	14.65	1.33	1.14	19.58

4.6 Beneficiation

There are different approaches for beneficiation of the coal for the Volksrust and Vryheid Formation. The Volkrust Formation is washed mainly for coking coal and thermal coal whereas the Vryheid formation is beneficiated mainly for thermal coal. The Volkrust Formation contains a large proportion of impurities typically approximately 60%. This necessitates beneficiation of the raw coal. The beneficiated bright coal product, by virtue of its high vitrinite content and other properties, is suitable as a blend coking coal [(De Korte, 2010) and (De Korte, 1994)].

It is important to emphasize that since there is no selective mining there is a high level of contamination resulting in low yields. The yields for coking coal are about 10-

15% and for thermal coal are about 30 to 40%. The high level of contamination requires a high density de-stoning step to remove the bulk of the contamination. A second low density process divides the coal into a semi-soft coking coal and a thermal coal.

The coal from the Upper Ecca requires high capacity processing plants and the coal contains high amounts of dense material. The coal requires very efficient separation process that is the dense medium process and has to be crushed to a small top size (about 15mm) to liberate the coking fraction. The coal is also very friable and generates a lot of fines during handling and crushing. Therefore effective fine coal processing techniques are required. After beneficiation of the coal there is a need to dewater the products.

The Upper Ecca, employs two stages of preparation on benches 2, 3 and 4. A first, high density separation stage is employed to remove the impurities from the raw coal. The float product from the first-stage processing is re-treated at a lower relative density to yield a blend coking coal containing approximately 10% ash and a middling product containing approximately 35% ash. The blend coking coal is utilized by Mittal Steel in the production of metallurgical coke, while the middling fraction is used for power generation at the nearby Matimba power station (De Korte, 1994).

The coal from Zone 5 is currently beneficiated in a single high –relative density process to yield a product suitable for combustion by ESKOM.

The Vryheid formation consists of five coal seams, numbered Zone 1, Zone 2, Zone 3, Zone 4A and Zone 4. As stated before some of the coal especially from Zones 2 and 3 is suited for use in the thermal market in the raw state meaning that no beneficiation takes place. This coal requires crushing and screening only. Coal from Zone 4 requires high density beneficiation to lower the ash content. Coal from Zones 2 and 3 is processed to produce a pulverized coal injection (PCI) product. Zone 1 is very thin and considered uneconomic at present.

In summary the mine produces three products, namely semi soft coking coal, power station (steam or thermal) coal and metallurgical coal. Semi soft coking coal is produced mainly from the Upper Ecca. Thermal coal is produced mainly from the

Middle Ecca and Upper Ecca. Metallurgical coal i.e. PCI is produced from the Middle Ecca.

In general raw coal at Grootegeluk mine is of high ash content and as a result, large coal beneficiation plants are needed to meet the production targets for both the metallurgical and thermal markets. For this reason six plants have been erected since 1980 to produce the required quantities of coal (De Korte, 2010).

4.6.1 Discussion of the Grootegeluk beneficiation plants

Coal from the Waterberg coalfield is beneficiated differently to Witbank coal i.e. it requires six large, separate plants to beneficiate the coal in order to meet the customer requirements as shown in Table 4.3 and Figure 4.2.

Grootegeluk 1 (GG1) produces semi - soft coking and steam coal as middlings. The semi - soft coking coal is mixed with coking from Tshikondeni mine to produce the blend coking coal required by the market. The plant is a two stage wash plant with low phosphorous percentages and high ROGA and swell characteristics for coking properties. The ROGA index is an indication of the caking capacity of the coal (MineSkill Australia, 2010). The coal for this plant is supplied from benches two to four.

Grootegeluk 2 (GG2) is a single wash plant that produces steam coal for the power station from benches two to four at a relative density of 1.8. The coal requires high density beneficiation to lower the ash content (De Korte, 2010).

Grootegeluk 3 (GG3) is a crush and screen plant which takes coal from Zone 4 or Bench 6 with a calorific value of 20.5 per cent and ash content of about 35 per cent and produce only steam coal for the Matimba Power Station. As discussed before this is dull coal but the coal is suitable to be used at the power station as raw feed thus saving on the washing costs.

Grootegeluk 4 and 5 (GG4 and GG5) produce pulverised injection (PCI) or duff with a high calorific value in the range of about 27.4 MJ per kilogram and ash of less than 17 per cent and steam coal. They also have a low phosphorous content to control emissions that are harmful to the environment. This coal produces CHAR which is used in the specialised steel industry. The coal for these two plants is mined from benches 9 and 11.

Grootegeluk 6 (GG6) is a new plant that produces semi soft coking coal and middlings for the power station also from benches 2 to 4.

The beneficiation plants that handle the coal from the various mining benches are shown in Figure 4.2 (EXXARO Resources Ltd, 2012).

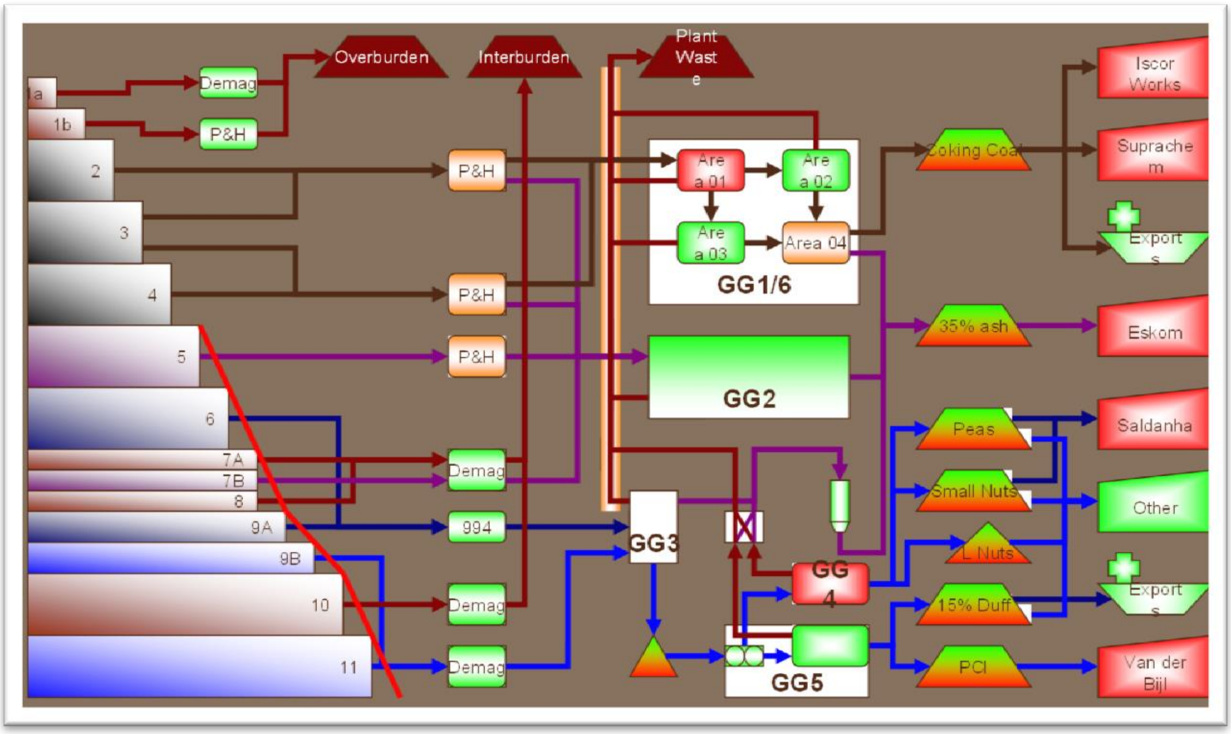


Figure 4.2: Material Flow and mining equipment of the different zones (EXXARO Resources Ltd, 2012)

4.7 Spontaneous combustion

Grootegeluk Mine coal and waste material has a propensity for spontaneous combustion because of the rank of the coal amongst other factors and the carbonaceous nature of the overburden and interburden. The ROM has a yield of about 50 per cent, implying that half of the production that the mine produces ends up as discard after the beneficiation process. The plant discards have a high propensity for spontaneous combustion. The inter-burden material is also prone to spontaneous combustion due to its carbonaceous nature. The problem associated with this large quantity of waste is safe storage and disposal in a way that will prevent the occurrences of fires (Adamski, 2003). The discard materials that need to be handled are mixtures of discards from various plants and waste from benches with unknown properties. Thorough knowledge of the chemical and physical properties of all the different materials and mixtures was considered to be a pre-requisite for the design of safe waste dumps/heaps (Adamski, 2003). Through research it was discovered that the Grootegeluk Mine plant discards are coarse, burn easily and are very reactive. The most dangerous combination of these was a mixture of coarse and fine materials which represented Grootegeluk Mine pit waste (interburden from benches 7 and 8).

According to Adamski in his Ph. D thesis (Adamski, 2003), the above findings were recommended by one of the experts in the field of spontaneous combustion, Professor Glasser. Glasser recommended crushing and segregating material before stacking. It was recommended to place fine material on top of coarse material (Glasser, 1983). The thin, low permeable material would block air transportation. To minimise permeability, it was recommended also to compact dumps surface and slopes. Further advice was to stack a thin layer of middlings over the whole dump. However, the harsh climate of sun, rain and wind made for a very maintenance intensive process to ensure oxygen did not gain entry through cracks in the surface, compacted layer. Research by Adamski led to the conclusion that this layer, due to high reactivity and low permeability, if compacted, could prevent oxygen from entering into the waste dumps due to two reasons. Firstly, the thin, low permeable layer of middlings would absorb oxygen and secondly due to low permeability it would restrict the airflow into the dumps (Adamski, 2003).

Grootegeluk mine needed a safe method of disposing and storing the discard material from the plant i.e. middlings and the waste material produced form the pit. After much research and experimentation a backfill method that involves stacking the material in the pit into –prebuilt and sealed compartments was found to be a solution for the Grootegeluk spontaneous combustion problem. This method took into account aspects such as the critical time (8 weeks for slopes and 3 months for surface areas) that reactive material can be exposed to air. The critical time determined the stacking rate as well as the dimensions of the backfilling compartments. To maintain the constant stacking rate the compartments width had to be fixed.

The 110m deep pit was to backfilled to the natural ground level. The backfilling was done using four levels. The first level will contain interburden material. The second and third levels contain plant discards while the fourth-sealing level will contains material with a layer of about 1m thick top-rehabilitated topsoil. The heights of the various levels were subsequently changed due to changes in production rates, to allow a safe stacking rate. The effect of backfilling in the pit was not only to place discards from the plants but also to use inert material and pit waste that would otherwise need to be hauled out of the pit (Adamski, 2003).

4.8 Concluding remarks

Grootegeluk Colliery is one of the biggest open-pits in the world and mines about 60 million tonnes of waste and coal from the pit to meet their production requirements. The Run of Mine coal produced is about 40 Million tonnes per annum and the difference is mined as waste. About 50% of the ROM is produced as waste which is prone to spontaneous combustion. The mine operates a large fleet of haul trucks and shovels to produce coal and waste including discards. In order to meet their production requirements coal and waste from the 13 benches has to be mined meticulously. Grootegeluk has one of the largest plants in South Africa producing three types of products i.e. semi-soft coking coal, steam coal and metallurgical coal in order to offset the mining costs and meet the customer requirements. The mine has experienced and successfully solved the problem of spontaneous combustion which is a major problem for surface coal mines. The current mining at Grootegeluk opencast mine will assist in understanding the geology and mining of the underground reserves on the east of the Waterberg coalfield where the reserve are deep and can only be mined by underground mining methods. Therefore, the next chapter will cover the proposed mining method of exploiting the deep underground reserves east of the Daarby fault.

5 UNDERGROUND MINING CONSIDERATIONS OF THE DEEP COAL RESERVES EAST OF THE DAARBY FAULT

5.1 Introduction

The purpose of this chapter is to analyse the geology of the Waterberg east of the Daarby fault. The purpose of the geological analysis is to propose a possible mining method for the deep underground coal east of the Daarby fault. The analysis will involve the study of the hardness of the roof and floor to understand how competent they are for mining purposes. This chapter will also explore the possibility of multi-seam mining should the roof and floor be found to be competent. Furthermore, since multi-seam mining is the only possible method of mining the coal horizons at the Waterberg, mining in other countries with similar conditions will be studied in order to determine the economics of mining the Waterberg seam packages by underground methods.

The approach followed in this chapter is to determine how many mining horizons could be mined economically, followed by the geotechnical analysis of the seams, and finally to give an indication of some of the mining methods that could be employed to mine the seams of the deep coal east of the Daarby fault.

5.2 Mining Horizons

In order to determine how mining of the coal zones would be carried out it is first critical to determine the thickness of the coal in order to determine the mining horizons. The first approach is to determine how many mining horizons can be mined at a depth greater than 250m (Figure 3.2). The stratigraphic column of the opencast coal zones on the western side of the Daarby fault has been analysed in order to give the likely geological conditions that would be encountered. As discussed earlier, the geology on the western side of the Daarby fault is the only source of reliable borehole and bulk sampling of the Grootegeluk area which have been started in the 1950's (De Korte, 1994). It is assumed that the geology of the Waterberg underground zones would not change drastically because of the fault and this would limit the understanding of how mining would be undertaken at a depth greater than 250m.

Claris Dreyer who was employed on site for over 30 years was consulted and asked to provide any additional information that could negatively impact this approach (Dreyer, 2011). Dreyer confirmed that a limited number of boreholes have been drilled on the eastern side of the Daarby fault where underground mining would be undertaken. From the discussions with Dreyer and Van Heerden in 2011 and a visit to the mine, it was determined that limited structural mapping and seismic work had been done and no known anomalies so far been identified. As drilling progresses and the mine is at liberty to share this information it is likely that information superceding this dissertation will become available.

To get an understanding of the geology the Waterberg, two visits were undertaken to the mine, the first in June 2009 and the second in July 2011 to understand the geological information from the exploration boreholes and to make decisions on the subsequent mining of the underground reserves. The drill core information from an exploration borehole on Grootegeluk mine which was gathered on the second visit is presented in Figure 5.1 and Figure 5.2.

The drill core was shown to the mining delegates at the Waterberg Conference field visit organised by the Fossil Fuel Foundation on the 28th of July 2011 by the management of Grootegeluk Colliery. Conference participants were able to inspect the core and observe first-hand the geological contacts of the different zones and the thicknesses of the seams and the differences between the Vryheid and the Grootegeluk Formations. On this visit it was important to be accompanied by Mr Claris Dreyer who is an expert geologist on the Waterberg coalfield in order to ensure that someone could answer all the technical questions.

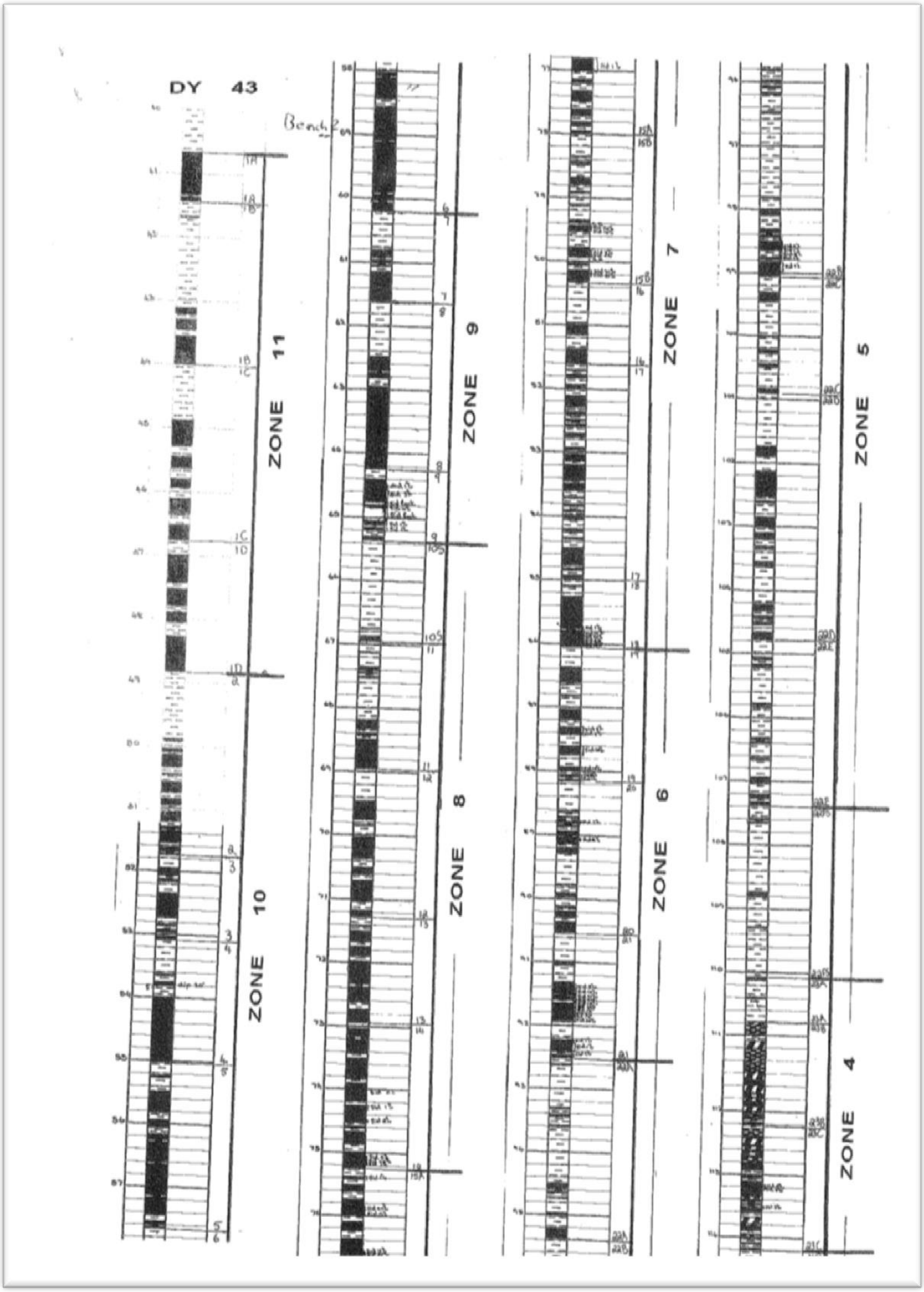


Figure 5.1: The stratigraphic column of the Grootegeluk and Vryheid formation of the Waterberg in the Grootegeluk Coal Mine area (Grootegeluk Mine, 2011)

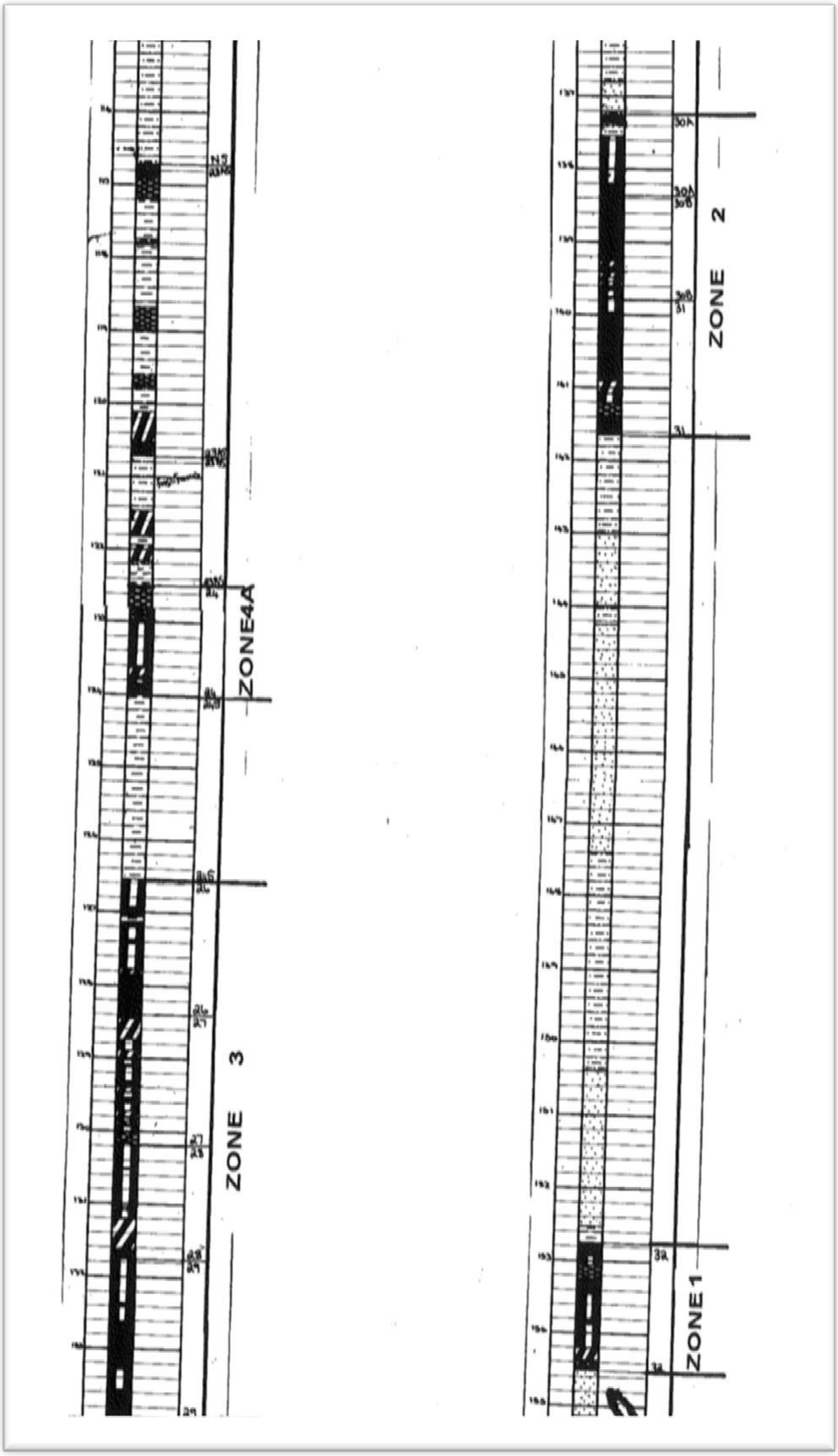


Figure 5.2 : The stratigraphic column of the Grootegeluk and Vryheid formation of the Waterberg in the Grootegeluk coal mine area (Grootegeluk Mine, 2011).

From the information gathered the indications are that mining of the Volksrust or Upper Ecca or Zones 5-11 by traditional bord and pillar mining method or longwall would be difficult due to the intercalated nature of the coal and shale of the Upper Ecca because of no clear roof and floor contacts. Claris Dreyer believes that the friability of the roof and floor which is made up mostly of coal and shale in the Upper Ecca will make mining impossible by traditional coal mining methods (Dreyer, 2011). However his comments need to be tested by undertaking an in-depth analysis of the competency of the roof and floor in order to understand whether there is a possibility of mining the coal within these zones using traditional methods or not. A geotechnical analysis as well as a literature study needs be done to determine if any mining horizons in the Upper Ecca would be mined.

An analysis of the coal in the Middle Ecca or the Vryheid Formation i.e. Zones 1-4 must also be done to determine how many coal mining zones can be mined by traditional mining methods. In fact, this information may prove that it is impossible to mine.

Table 5.1 indicates that Zones 1-3 can be mined by underground methods since both zones have a sandstone roof and floor contacts except Zone 3 where the roof is composed mainly of shale. But before any mining could be done the Uniaxial Compressive Strength (UCS) of Zones 1 to 3 and competency of both the roof and floor needs to be quantified. This will be done in the next sections.

The next paragraphs analyse the thicknesses of the coal horizons in the different zones in order to determine which seams are economic and which are uneconomic. The aim is to determine which mining horizons are mineable and can produce high tonnages, low cost coal needed for electricity generation. Thin seams are generally uneconomic and difficult to mine especially seams which are less than 1.5m in thickness. The thickness of zone 1 is less than 1.5m thus making Zone 1 uneconomic at a depth of about 300m. Zone 1 can be mined with low seam mining using special low seam equipment in future as it is done in other countries. However, to produce the high tonnages required at the Waterberg at low cost needed for electricity generation is unlikely from this zone despite the low ash contents of this seam. It is therefore; appropriate considering current information to propose that the seam in this zone is likely to be uneconomic.

Table 5.1: Coal Zones in the Middle Ecca (Chabedi & Phillips, 2012)

Zone	Coal Thickness (m)	Roof	Floor	Parting (m)	% Ash
4	4.10	Shale	Shale		43
Parting				4.30	
4A	<1.50	Shale	Shale		
Parting				4.20	
3	8	Shale	Sandstone		30
Parting				4	
2	4	Sandstone	Sandstone		25
Parting				14	
1	1.50	Sandstone	Sandstone		21

Zone 2, on the other hand, with a thickness of over 4m and a competent sandstone roof and floor has a great potential to be mined by traditional mining methods such as longwall or bord and pillar for a power station product. The ash content of 25% for Zone 2 is suitable for a power station product. Zone 3 has a thickness of over 8m and an ash content of about 30%. The floor of Zone 3 is competent i.e. sandstone; however the strength of the roof is likely to incompetent because it consists of shale. A shale roof is likely to be problematic when longwalling and therefore should be investigated further. In the worst mining conditions where the roof is found to incompetent or friable, there is always a possibility of leaving coal in the roof to combat this problem. Incompetent roof in the Witbank and Highveld coalfields where the seams are thick are mined this way. Zone 3 because of its thickness is likely to produce the high tonnages required for low cost electricity generation.

Zone 4A is less than 1.5m and is not considered for mining at this stage for the same reasons given for Zone 1. Zone 4A is more problematic because both the roof and the floor are friable and composed of shale which is likely to be weak. Lastly, Zone 4 which is the at the top of the Vryheid Formation has a thick coal seam of about 4m; however, the roof and floor are soft since they consists of shale. So it would be difficult to attempt mining this zone by traditional mining methods which would require support and specialised machinery if mining by traditional mining methods is investigated.

It can be concluded from the analysis above that in the Vryheid or Middle Ecca formation that the mining of Zones 2 and 3 by traditional mining methods is possible because of the minimum coal thickness of 4m in each of the two mining zones. Zone 2 is likely to be mined because it has competent sandstone in the roof and floor. Zone 3 on the other hand has a competent floor and there is a possibility of leaving about 1 to 2m coal in the roof because it consists of shale which is known to be a soft rock therefore enabling mining to take place without hindrance from the roof.

However, before mining can take place in Zones 2 and 3 the interburden thickness between the two zones must be taken into account. Zone 2 is lower than Zone 3 and the two zones are separated by a parting of about 4 to 5m. Therefore, further geotechnical analysis should be done to determine the possibility of mining and the sequencing of mining if both zones are to be mined. Too often in the past large reserves have been sterilised by an incorrect sequence of mining.

Despite the problems likely to be encountered in mining the Vryheid or Upper Ecca in the deeper portions of the coalfield, the size of this resource is such that it will undoubtedly be attempted. The first General Manager of Iscor who started mining at Grootegeluk Colliery, Ben Alberts, proposed in an article about the coal reserves of the Waterberg that it was possible to mine, at depths of 100-450m, at least two zones in the Upper Ecca with acceptable ash contents. He proposed the selective mining of Zone 10/9 and 9/8 such that they yield ash contents are 36.3 % and 25.9 % respectively. Alberts proposal can be seen on the right hand side of Figure 5.3 as indicated by the blue arrow. However, for that to take place the mining heights of the zones needed to be 6.1m and 2.4m respectively (Alberts, 1987).

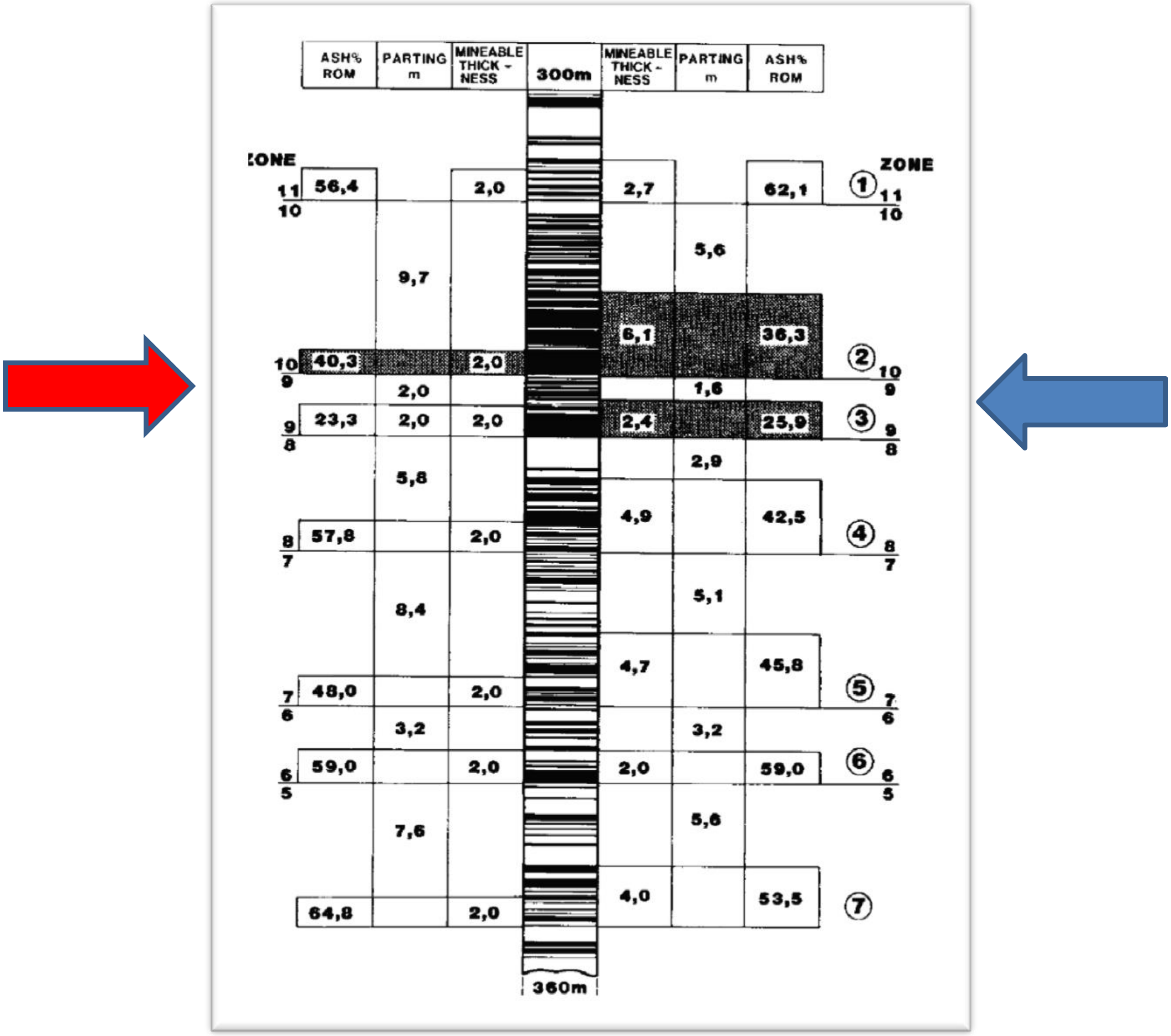


Figure 5.3: **Upper coal Zones 5-11 [Adapted from (Alberts, 1987)]**

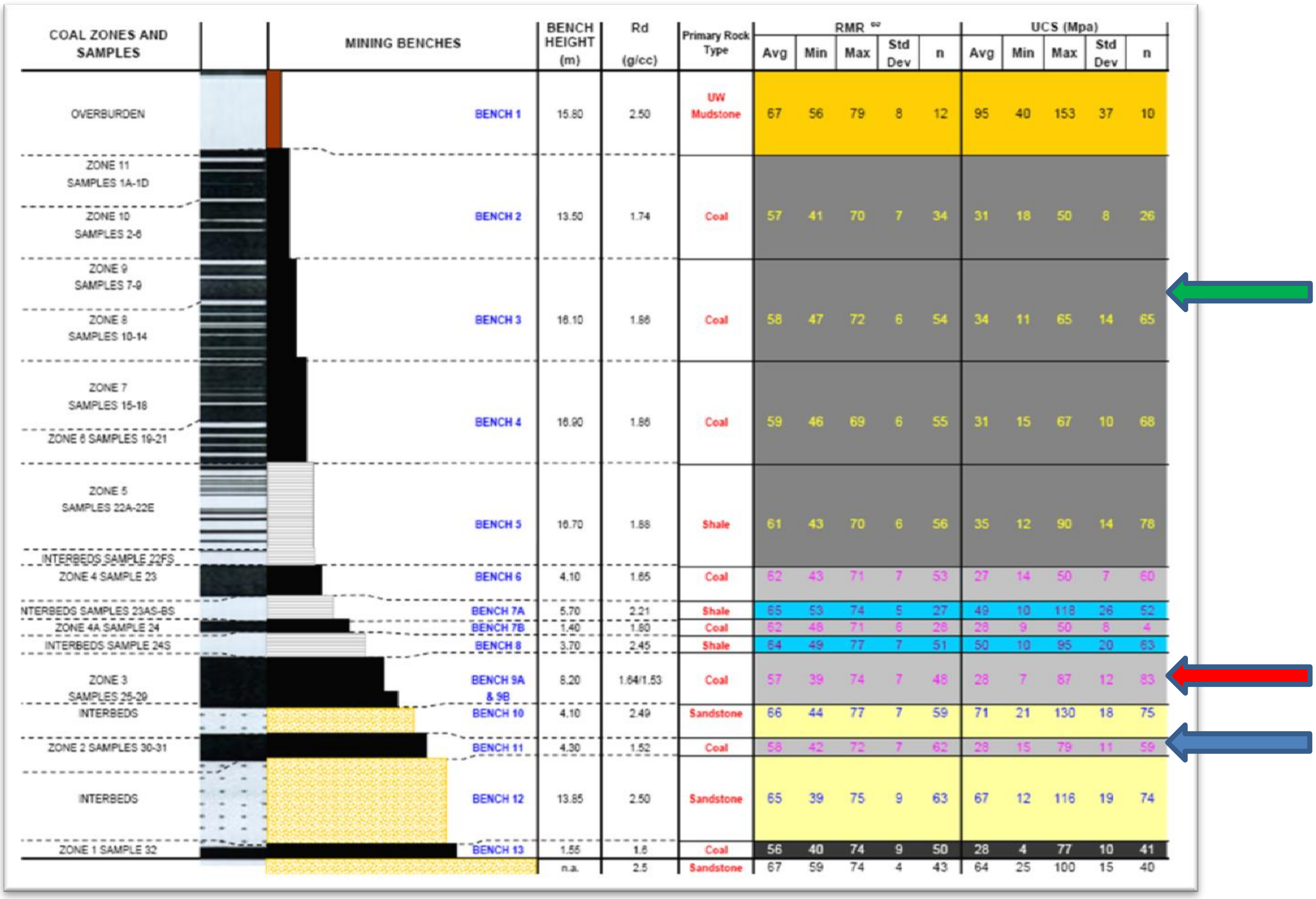
Alberts adapted his mining heights by analysing and interpreting the recoverable underground reserves that were estimated by De Jager in 1983 (De Jager, 1983) on the left hand side of Figure 5.3 as indicated by the red arrow. De Jager had estimated that when mining Zone10/9 and 9/8 at 2m mining horizons the in-situ or raw or unwashed ash contents of the zones would be 40.3% and 23.3% respectively. Again, these two ash figures are indicated in Figure 5.2 on the left hand side of the diagram. It can be concluded using Alberts analysis that an attempt to mine zones 10/9 and 9/8 or units 2 and 3 in order to produce high tonnages at low cost as indicated in Figure 5.3 should be attempted. Alberts further suggested that unit 3 or Zone 9/8 can be mined at an ash content of 25.9% without beneficiating the coal. It should however be noted that Alberts has not suggested how the mining could be done he simply proposed that it is possible for mining to be done. The coal can be mined raw for ESKOM’s power station thus saving on the beneficiation costs thus further lowering the mining costs.

The mining of both Zone 10/9 and 9/8 would pose difficulties especially when the interburden thickness of 1.6m is taken into account. From a geotechnical point of view the interburden thickness is thin for mining both zones/seams. It is safe to propose that the thin interburden between the two zones will not allow mining of the lower zone without roof collapses and damaging the coal in the bottom coal zone. Therefore to mine one of the Zones i.e. 9/8 with a 2.4m thickness at an ash content of 25.9% would be the best option. The reason is that the coal can be taken to the plant unwashed with a yield of 100%.

It can be concluded that three mining horizons can be mined by underground mining, two mining horizons in the lower Ecca and one mining horizon in the upper Ecca as discussed in the above paragraphs. These mining horizons are Zone 2, Zone 3 and Zone 9 with corresponding coal thicknesses of 4m, 8m and 2.4m. No mining methods have been suggested so far, as the contact of the roof and floor has to still be analysed before a final decision can be made. The next section of the report will outline the geotechnical analysis of the zones considered for mining.

5.3 Geotechnical analysis

In order to determine the competency of the roof and floor to enable mining by traditional methods a study of the geotechnical data of Zones 2, 3 and 9 needs to be considered. The Rock Mechanics Department at Exxaro reproduced Figure 5.4 which shows the lithology of the rocks in the different zones, the coal zones and sample numbers, mining benches, bench heights, relative density of each rock type, primary rock type and Rock Mass Rating (RMR) and the Uniaxial Compressive Strength (UCS) and the number of samples taken.



COAL ZONES AND SAMPLES	MINING BENCHES	BENCH HEIGHT (m)	Rd (g/cc)	Primary Rock Type	RMR ^{89}					UCS (Mpa)				
					Avg	Min	Max	Std Dev	n	Avg	Min	Max	Std Dev	n
OVERBURDEN	BENCH 1	15.80	2.50	UW Mudstone	67	56	79	8	12	95	40	153	37	10
ZONE 11 SAMPLES 1A-1D ZONE 10 SAMPLES 2-6	BENCH 2	13.50	1.74	Coal	57	41	70	7	34	31	18	50	8	26
ZONE 9 SAMPLES 7-9 ZONE 8 SAMPLES 10-14	BENCH 3	16.10	1.86	Coal	58	47	72	6	54	34	11	65	14	65
ZONE 7 SAMPLES 15-18 ZONE 6 SAMPLES 19-21	BENCH 4	16.90	1.86	Coal	59	46	69	6	55	31	15	67	10	68
ZONE 5 SAMPLES 22A-22E INTERBEDS SAMPLE 22FS	BENCH 5	16.70	1.88	Shale	61	43	70	6	56	35	12	90	14	78
ZONE 4 SAMPLE 23	BENCH 6	4.10	1.65	Coal	62	43	71	7	53	27	14	50	7	60
NTERBEDS SAMPLES 23AS-BS	BENCH 7A	5.70	2.21	Shale	65	53	74	5	27	49	10	118	26	52
ZONE 4A SAMPLE 24	BENCH 7B	1.40	1.80	Coal	62	46	71	6	28	28	9	50	8	4
INTERBEDS SAMPLE 24S	BENCH 8	3.70	2.45	Shale	64	49	77	7	51	50	10	95	20	63
ZONE 3 SAMPLES 25-29	BENCH 9A & 9B	8.20	1.64/1.53	Coal	57	39	74	7	48	28	7	87	12	83
INTERBEDS	BENCH 10	4.10	2.49	Sandstone	66	44	77	7	59	71	21	130	18	75
ZONE 2 SAMPLES 30-31	BENCH 11	4.30	1.52	Coal	58	42	72	7	62	28	15	79	11	59
INTERBEDS	BENCH 12	13.85	2.50	Sandstone	65	39	75	9	63	67	12	116	19	74
ZONE 1 SAMPLE 32	BENCH 13	1.55	1.6	Coal	56	40	74	9	50	28	4	77	10	41
		n.a.	2.5	Sandstone	67	59	74	4	43	64	25	100	15	40

Figure 5.4: The Geotechnical Analysis of the Waterberg Coalfield (Adapted from (Koen, 2010)

Figure 5.4 shows that Zone 2 has a seam thickness of 4.3m and an average Rock Mass Rating of 56 and an average UCS of 28 MPa for the coal. The RMR of the floor and roof of Zone 2 are 65 and 66 respectively as indicated by the blue arrow. The RMR is a geo-mechanical classification of rocks developed by Bieniawski in the early seventies (Bieniawski, 1989). According to the RMR classification Zone 2 has a rating that is classified as II as indicated in Table 5.2.

A rating between 61 and 80 is classified as good meaning that rocks in this range make acceptable floor and roof contacts which is not surprising since the roof and floor rocks are made up of sandstones. Zone 3 on the other hand has an RMR of 57 and UCS of 28 MPa according to the Rock Engineering specialist at Exxaro. However, the floor has an RMR of 66 and an RMR of 64 for the roof as shown by the red arrow in Figure 5.4.

Table 5.2: Rock Mass Classification (Bieniawski, 1989)

Rock Mass Classes Determined from Total Ratings					
Rating	100 - 81	80 - 61	60 - 41	40 - 21	< 21
Class No.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

Therefore both the roof and floor have very good rock contacts according to Table 5.2 and can be classified as competent and very good for mining purposes.

Lastly, Zone 9 which has been described as having soft rocks mixed with shale has an RMR of 58 and UCS of 34MPa and according to the RMR classification, the rock is classified as III and described as fairly competent according to Table 5.2. Discussions with the rock engineers at the mine and outside the mine confirm that mining can be expected to proceed reasonably well, however, additional support of the roof would have to be done. All of these decisions would be made once a further research has been done to analyse the competency of the roof based on the coal mass roof rating developed by Mark and Molinda. (Mark & Molinda, 2005) developed a system based on RMR to say whether mining will be safe and when extra support would be needed. Therefore, it is reasonable to expect Zone 9 to have a reasonable chance of mining taking place by traditional mining methods.

The provisional geotechnical analysis indicates that Zones 2 and 3 have the potential to be mined with underground mining methods because the roof and floor are competent. Zone 9 on the other hand has an RMR which indicates that mining by traditional methods will be reasonably successful due to the roof and floor which are fairly competent.

5.4 Mining methods

The price of coal is different for different markets and in South Africa the price for the local thermal market or ESKOM is very low in comparison to the price of coal for the export market. In order to meet the requirements of the local power station a mining method with a high production and low cost that ensures adequate supply to a power station for the next 40 years or so is needed. Therefore, in choosing a mining method to supply the local thermal market at the Waterberg the aim is to choose a mining method that can produce high tonnages at a low cost.

The aim of the geotechnical analysis was to suggest the possible mining methods for exploiting the three coal horizons identified above. The first step is to suggest all the possible mining methods that can be used on such thick coal seams i.e. seam heights between 2.4m and 8m that can potentially produce high tonnages at a low cost for a power station. One could potentially use more exotic mining methods like sub-level caving and longwall sublevel caving using a single conveyor or two conveyors and multi-slice longwalling methods but the aim of mining the coal at the Waterberg is to target high production, low cost and safe mining methods. From the open pit it is important to target high production and low cost mining methods that can off-set the high costs of beneficiating the poor quality coal at the Waterberg.

This research has, therefore, been limited to high productive mining methods such as bord and pillar mining and pillar extraction and retreat longwalling. These mining methods are appropriate when one considers production, safety and costs associated with mining at the Waterberg coalfield. It seems likely that longwall would be the first choice mining method especially when one considers that the quality of the roof in some of the zones such as Zones 9 and 3 is not very competent. Longwalling would produce the high tonnages required to meet the needs of the second power station in the Waterberg coming on line. The high tonnages produced by longwalling would also be at a low cost and extracted very safely. At depths greater than 250m where the roof is anticipated to be very friable and soft longwall would be a better option than bord and pillar or bord and pillar done in conjunction with pillar extraction.

Longwall would still involve the development of the chain roads with continuous miners. These chain roads will mostly be done in roof conditions that are friable such as in Zones 9 and 3. Therefore, in mining the chain roads care should be taken that the development is done safely with the installation of additional support where the roof is incompetent. The mining at the Waterberg by open-pit mining produces high tonnages i.e. approximately 40 million tonnes per annum at a low cost. From this tonnage about 20 million tonnes end up as sales for the power station. Therefore, the mining method chosen has to replace the current tonnage requirements plus the additional tonnage requirements in order to meet the needs of the second power station coming on line.

When mining the underground reserves longwall has the best potential for meeting the high production requirements at a low cost. It must be borne in mind that underground mining would not involve the removal of the overburden, therefore the tonnage requirements would not be same as the open-pit, but it would still be high and have to be produced at a low cost since the majority of the coal will be sold to ESKOM.

Bord and pillar with continuous miners cannot be ruled out completely in particular where longwalling cannot be done because of the complex geology and the sequencing and stress interactions that are likely to occur at greater depths between seams that are very close to each other. It is anticipated that in Zones 2 and 3 where the parting is very thin bord and pillar in the lower seam might be a better option than longwall. As discussed earlier, all of these decisions would be made once further research has been done to analyse the competency of the roof based on the roof rock mass rating and the analysis of the multi-seam mining is done in Chapter 6 of this dissertation.

5.5 Concluding remarks

In this chapter three potential mining horizons were selected based on the thicknesses of the coal and the geotechnical evaluation of the roof and floor. It is recommended that Zones 2 and 3 of the Middle Ecca and Zone 9 of the Upper Ecca are suitable for underground mining. Longwall mining and bord and pillar mining with continuous miners and pillar extraction were chosen as possible mining methods instead of mining methods such as sub-level caving, longwall sub-level caving and multi-slice longwalling because of the high production and productivity requirement of the mining method selected.

Longwall and bord and pillar were recommended as two appropriate mining methods that are able to handle the complex geology at the Waterberg that are able to produce the high tonnage requirements at a low cost unless the structural geology and mapping of the underground deeper seams proves otherwise. Longwall where the roof is incompetent was shown to be the appropriate mining method to use that ensures that exposure to the roof is minimised.

Discussions with geologists on site and conclusions drawn from geological drill core information confirm that the deep coal on the eastern side of the Daarby fault have the same lithology as the coal at Grootegeluk mine and therefore no major anomalies are expected. The next chapter will concentrate on the multi-seam mining of the different zones. At this stage of the analysis it can be predicted that longwall and bord and pillar will be appropriate but the questions of how the different zones would be mined and in what order have not been answered. The importance of the thickness of the parting between the seams and how that affects the mining of the upper and the lower seams has also not been explained.

6 MULTI-SEAM MINING OF THE DEEP WATERBERG RESERVES

6.1 Introduction

In this chapter multi-seam mining of the thick coal seams of the Waterberg by underground mining methods will be discussed. First, the experience of multi-seam mining in South Africa in the Witbank coalfields with bord and pillar at a depth less than 100m will be reviewed and thereafter the thin multi-seam mining at the Natal coalfields with mostly bord and pillar and partial pillar extraction at a depth of less than 160m will be discussed. Then multi-seam mining experience in the United States of America (USA) and other countries where the depth of mining is greater than 250m will be discussed. The purpose of the chapter is to illustrate how the underground coal in the Waterberg, east of the Daarby fault with a total thickness greater than 110m will be exploited using the experience of mining in other countries. The aim of this chapter is to assess whether the USA experience of multi-seam mining is applicable to the deeper portion of the Waterberg coalfield. Lastly, this chapter will discuss how the three identified mining horizons as identified in Chapter 5 of this dissertation will be mined by underground mining methods taking into account the sequence of mining and the parting thickness between the seams.

6.2 Multi-seam mining in South Africa

The multi-seam mining experience in South Africa is mostly in the Witbank coalfields at depths of less than 85m for the No.2 seam and 65m for the No.4 seam. The No.2 seam is extensively mined by bord and pillar mining whereas the No4 seam is mined to a small extent with pillar superimposition being carried out depending on the thickness of parting distance. Where the No.5 seam is present pillar extraction is generally not carried out in order not to damage the No.5 seam and to prevent subsidence (Hill, 1995).

Multi-seam mining has also been carried out in the Natal coalfields but the seams are generally thin i.e. less than 1-2m thick occurring at an average depth of about 150-160m. The thickness of the coal meant that as many as four to five seams had to be exploited in the past. The grade of the coal is anthracite and coking coal therefore total extraction with bord and pillar mining with subsequent overmining and under mining was employed (Hill, 1995). The term overmining means that the lower seam has been mined first and the upper seam is the active seam i.e. mined second. Undermining on the other hand means the upper seam has been exploited first and the lower seam is the active seam (Mark, 2007). Although multi-seam mining on a small scale has been conducted in South Africa, most of the mining has been done at depths less than 160m, and total extraction was mostly by bord and pillar mining with pillars recovered through secondary mining. Very little longwalling of more than two seams at the same time has been undertaken as is common in other countries like the USA.

Therefore to mine a package of seams greater than 110m in thickness with longwall mining at a depth greater than 250m, as is the case in the Waterberg coalfield, will be a new experience for the South African coal mining industry. It is against this background that the coal mining industry has to look to other countries like the USA for such mining experience in order to exploit the underground reserves of the Waterberg coalfield. Multi-seam mining with total extraction mining methods such as longwall is mostly practised in the USA at depths between 150m and 700m. Multi-seam mining has recently been applied in the Australian mines and therefore will not provide all the needed answers for the Waterberg coalfield challenges.

6.3 Factors affecting multi-seam mining

Van der Merwe and Madden (2010) stated that multi-seam mining is generally affected by a number of factors such as:-.

1. Parting thickness- The greater the parting thickness between two seams being mined then the less the interaction that will occur.

2. Parting characteristics- Sandstones and shales are dominant rock types in most of South African coalfields and each rock type will influence a multi-seam situation differently.

   Sandstone layers tend to be relatively massive grained and are known to span much wider panels than thinly laminated shales. Therefore, the stiffness of the sandstone layers in the parting tends to dampen the effect of stress transfer from one seam to another.

The effect of having a sandstone roof compared to a shale roof was studied before a decision could be made on what coal seams to mine with multi-seam mining at the Waterberg coalfield.

3. Mining method- Low extraction methods such as bord and pillar have a lesser influence on other seams than high extraction mining methods layouts. Longwall mining has already been selected to exploit the underground seams in the Waterberg, it is therefore expected that there would be high stress environments experienced when seams in close proximity are exploited.

4. Relative location of layouts. In high extraction layouts such as longwall as is the case with the exploitation of the Waterberg underground seams the gate roads of the lower seams should be located below the goaf of the previous upper seam in order to protect them from high stresses from the upper seam.

5. Percentage recovery of the coal seams – it is expected that when longwall is undertaken that the high percentage recovery of the upper seams would create better conditions in the lower seams. Remnant pillars where possible would be avoided because they are likely to cause stress transfer over large vertical distances.

In addition to these factors (Mark, et al., 2007) also stated the following factors that affect multiple seam interaction should be taken into account in underground mining at the Waterberg coalfield:-

1. Depth of cover – it is expected that as the depth of mining at the Waterberg increases that there would be a greater potential stress concentration caused by multiple seam mining.
2. Mining sequence – overmining should be avoided when the Waterberg underground seams are exploited because of the possible damages that would occur on the upper seams and consequent subsidence that would occur. Instead undermining should be undertaken in order to maximise the potential for mining.
3. Immediate roof geology- weak roofs and floors are more likely to be damaged by multiple seam interactions. The analysis of the roof should be carried out in

detail in order to determine how competent the roof is to allow mining by longwall.

As discussed in the introductory paragraph multi-seam mining with longwall mining as proposed in Chapter 5 is required in order to determine the extent and sequencing of underground mining at the Waterberg underground seams. The aim of this chapter is to assess if it is possible to mine the Waterberg coalfield underground seams with multi-seams using the USA multi-seam mining experience.

6.4 Hazards associated with multi-seam mining

There are several hazards associated with multi-seam mining but these are the three main hazards:-

6.4.1 The mining of more than one seam

The mining of more than one seam is likely to result in the interaction between the adjacent seams where the seams are in close proximity, especially where the parting is thin. This could lead to the collapse of the interburden resulting in significant damage to both seams, loss of equipment and life. Also, when the lower seam is mined first the upper seam is likely to be damaged as a result of subsidence.

6.4.2 Spontaneous combustion

The risk of air leakage between adjacent seams and the risk of spontaneous combustion in the shales and other rock types, disturbed coal seams and thick coal seams resulting in partial mining of the seam is expected because the coal seam at the Waterberg as explained by (Adamski, 2003) is liable to spontaneous combustion.

6.4.3 Water

When water accumulates in the upper seam there is a danger of this water finding its way to the bottom seam especially since longwalling will be done. Flooding and drowning of the personnel in the lower seams is likely to occur.

These hazards can be addressed in several ways as discussed in the next paragraphs.

6.5 Undermining

Mark (2007) described undermining as when the upper seam is exploited or mined first and the lower seam is the active seam i.e. lower seam is mined second as shown in Figure 6.1. Full extraction mining in the overlying seam in any undermining situation causes significant damage to the lower seams due to the load transfer from highly stressed remnant structures. Where the seams are relatively deep and the interburden is relatively thin, significant load transfer will occur.

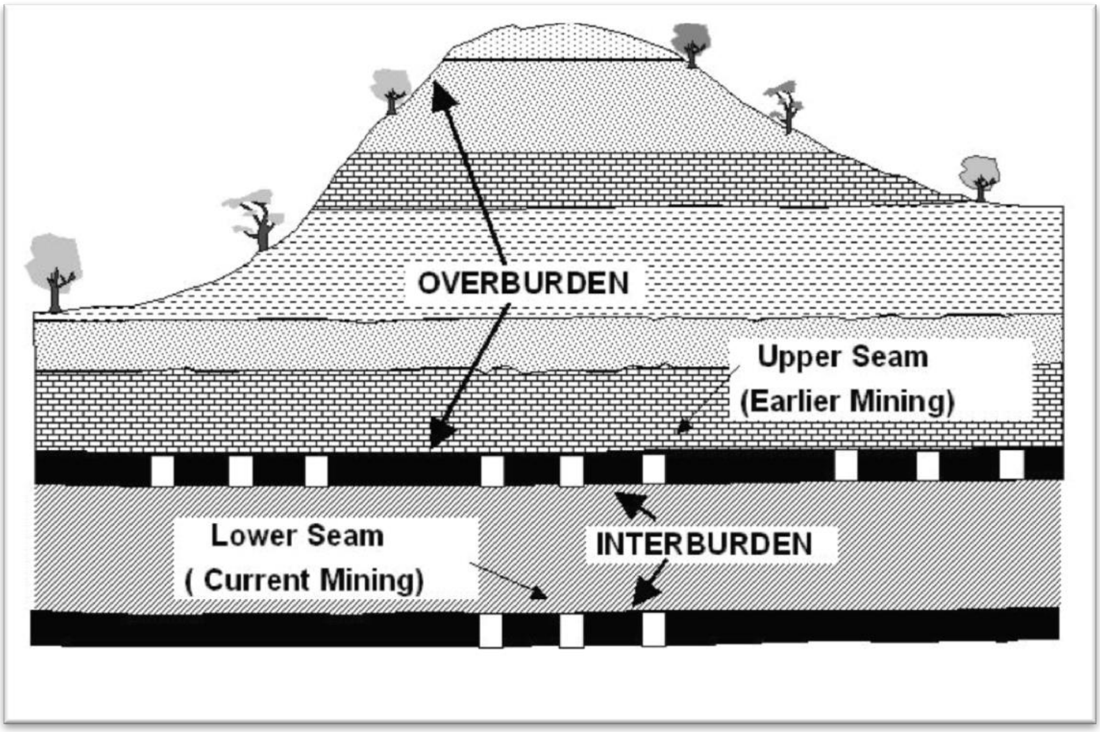


Figure 6.1: Undermining interaction (Mark, 2007)

Two types of remnant structures that cause undermining interaction have been identified as:

- Goaf-solid boundaries, with the goaf on one side and as a result the goaf-solid boundary carries a single distributed abutment load, or
- Isolated remnant pillars that are surrounded by the goaf on two or more sides and as result the isolated remnant pillar is subjected to two overlapping abutments as shown in Figure 6.2 and Figure 6.3 (Mark, et al., 2007).

It follows then that the stress concentrations on the goaf-solid boundary will be significantly smaller than on an isolated remnant pillar and that the impact on the underlying seams would be proportionally lesser and the reverse is also true i.e. the stresses on the isolated remnant pillar are significantly higher than on goaf-solid boundary and the impact the on the underlying seams would be proportionally greater (Mark, et al., 2007). According to Mark and other researchers, undermining interactions in the United States have been known to occur at depths greater than 500 feet i.e. 150m and where the interburden was less than 110 feet or 33m (Mark, et al., 2007). This is significant given that the underground Waterberg seams lie at depths greater than 250m.

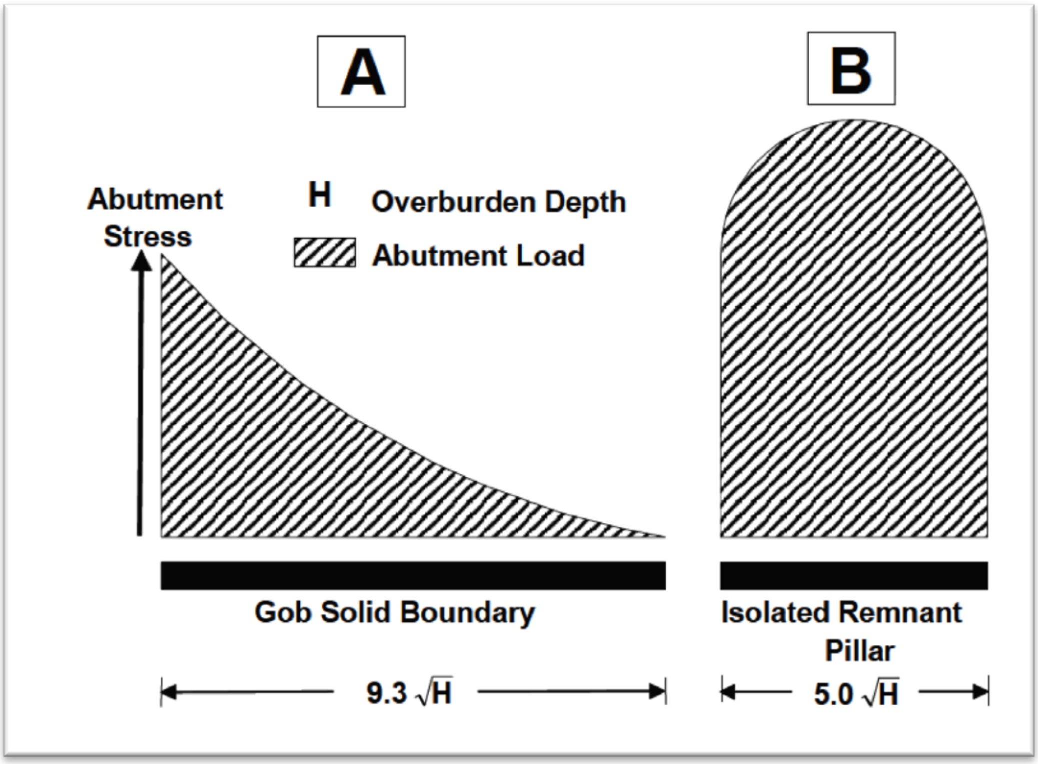


Figure 6.2: Stress concentrations in multiple seam mining. (A) Gob/Goaf solid boundary and (B) Remnant pillar isolated in the gob/goaf (Mark, 2007)

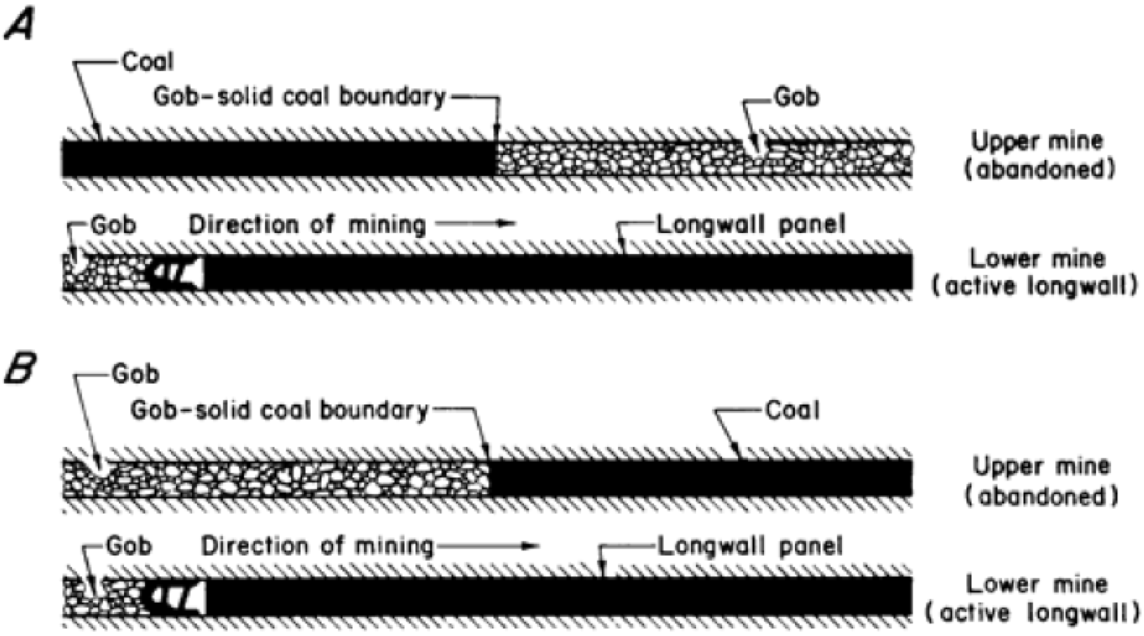


Figure 6.3: Stress concentrations in multiple seam mining. (A) Gob/Goaf solid boundary and (B) remnant pillar isolated in the gob/goaf (Mark, 2007)

6.6 Overmining

Overmining occurs when the lower seam has been mined first and completed and the upper seam is mined second i.e. upper seam is the active seam (Figure 6.4). Just as in an undermining situation load transfer occurs in this situation and that means that both the isolated remnant pillars and the goaf-solid boundaries will cause stress concentration in the seams above and below. In addition, however, subsidence of the overlying beds will occur with the full extraction of the lower seam (Mark, et al., 2007). The implication of this on mining is that overmining should be avoided where multi-seam mining is undertaken.

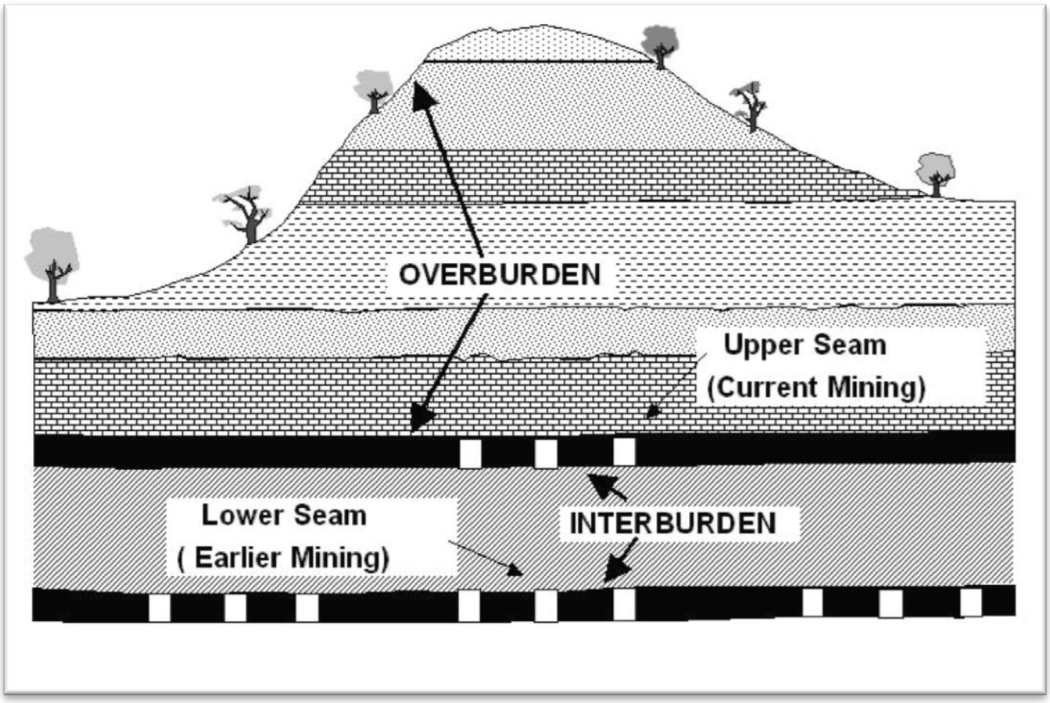


Figure 6.4: Overmining (Mark, 2007)

(Mark, 2007) illustrated the damage that occurs within the overburden because of subsidence caused by overmining. He identified five broad zones as shown in Figure 6.5 and described below:-

a).The complete caving zone which normally extends two to four times the extracted seam height (h)

b).The partial caving zone which extends up to 6–10h and in which the beds are completely fractured but never lose contact with one another

c).The fracture zone which can extend as far as 24h above the lower seam. In this zone the subsidence strains are sufficient to cause new fracturing in the rock and create direct hydraulic connections to the lower seam.

d).The dilated zone which extends up to 60h. In this zone the permeability is enhanced but little new fracturing is created.

e).The confined zone which extends from the top of the dilated zone to about 165m below the surface. In this zone subsidence normally causes no change in strata properties other than occasional bed slippage.

The implication of this model is that when the thickness of the interburden is more than 6 to 10 times thicker than the lower seam coal, the upper seam will be unaffected by overmining and consequently should be intact though the roof will be damaged or fractured (Mark, et al., 2007).

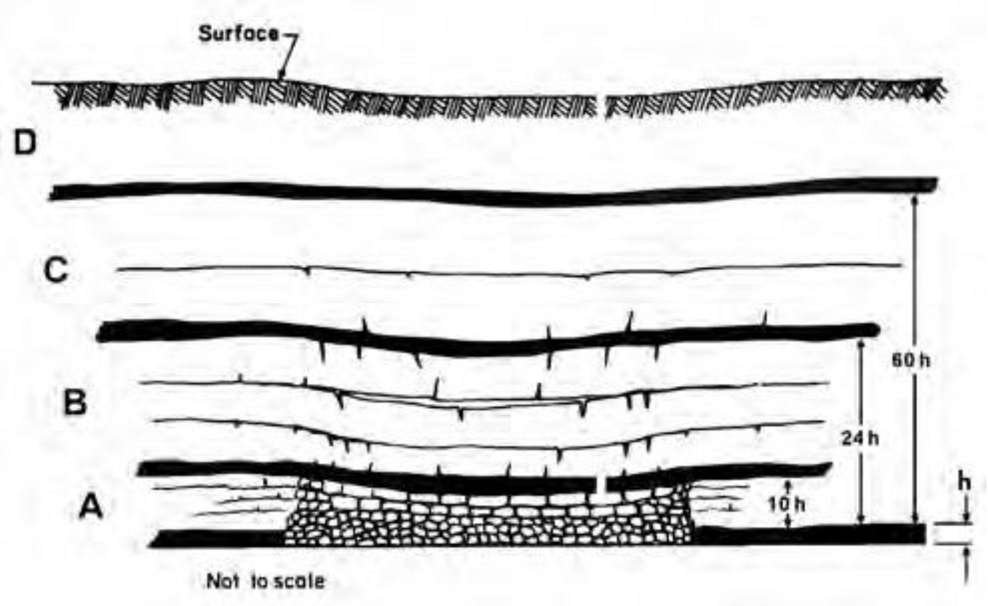


Figure 6.5: Overburden response to full-extraction mining: (A) caving zones, (B) fracture zone, (C) dilated zone, and (D) confined zone (Mark, 2007)

According to Van der Merwe and Madden (2010) there are four characteristics associated with overmining which are:

a) Caving of the upper strata which will create fracturing due to subsidence
b) Remnant pillars in the lower seam will cause differential subsidence to occur. This creates areas of instability due to tensile zones over the pillar goaf boundary
c) Remnant pillars cause stress concentrations, which will be transferred to the upper seam workings. This may cause pillar spalling or floor heave
d) Areas within an incomplete parting plane controlled goaf may be destressed.

6.7 Dynamic interaction

Dynamic interaction is caused by active mining above or beneath open entries that are in use. Active subsidence of the open overlying workings occurs when a lower seam is longwalled or pillared and this is the most severe form of dynamic interaction. Abutment stresses associated with full extraction in an overlying seam or development mining above or below can also be the cause of damage.

If the open workings were developed after the full extraction was completed the conditions associated with dynamic interactions would be easy. The reason is that the disturbance is not static or concentrated in a single area but that dynamic interactions subject the pre-existing workings to a travelling wave of subsidence and/or abutment stresses. In addition, when unmined ground is disturbed by either overmining or undermining the presence of a mine opening removes the confinement. When confinement is lost this greatly weakens the rock mass and exposes it to tensile stresses.

6.8 Ultra-close mining

Ultra-close mining is the final form of interaction and only form that is not affected by development mining and involves the failure of the interburden between the two seams. The self-weight of the rock plus that of any machinery working on it can cause the interburden beam to fail either through shear or by tension (Figure 6.6). When the two seams being mined have an interburden thickness of more than 6-9 m apart ultra-close mining is unlikely to occur. However, the minimum safe working thickness for massive sandstone should be about 2m and for shale it should be greater 6m (Haycocks & Zhou, 1990).

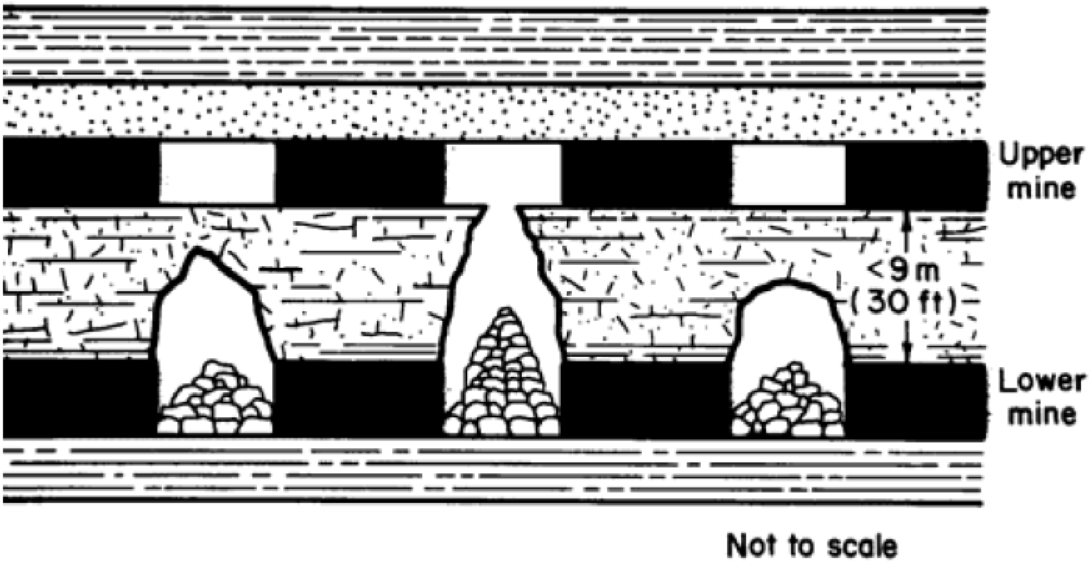


Figure 6.6: Ultra - close mining (Mark, 2007)

6.9 Lessons learnt from local and international experience when multi-seam mining is done

6.9.1 Undermining instead of overmining

When mining is undertaken, undermining should be the preferred method of mining instead of overmining. Overmining leads to subsidence and high stress interactions between the adjacent seams (Mark, 2007).

6.9.2 Parting thickness

Where the parting is thin i.e. 6 to 10 times less than the seam being mined and the composition of the parting is weak i.e. rocks are composed of shales instead of a competent and massive sandstone interburden failure is likely (Mark, 2007).

6.9.3 Goaf–solid boundaries instead of isolated remnant pillar

Care should be taken when longwalling beneath an upper seam i.e. the bottom longwall should retreat underneath the goaf of an upper longwall seam where the stresses are low instead of retreating underneath the solid boundaries of the upper longwall where peak stresses result (Mark, 2007).

The bottom seam inter-panel pillar or barrier pillar has to be wider than the upper seam inter-panel pillar in order to compensate for the additional load transfer from the highly stressed upper seam inter-panel pillar if pillars or panels are to be superimposed (van der Merwe & Madden, 2010).

6.9.4 Water from the upper seam goaf

Where water is encountered in the goaf of the upper seam the panels should be mined uphill so that water accumulates in the goaf and not on the face (van der Merwe & Madden, 2010). Planning should also be done to quantify water in the upper longwall so that a control and an evacuation plan can be implemented when mining the bottom seams (Mark, et al., 2007; Mark, 2007).

6.9.5 Ventilation of multi-seam mining

Normally the ventilation of multi-seam mining is no more difficult than the ventilation of multiple working areas in a single seam. However, experience of mining the Waterberg coal measure at Grootegeluk (Adamski, 2003) has shown that the seams and the carbonaceous shales have a high propensity for spontaneous combustion. Any cracks formed between upper and lower working can generate the condition to initiate spontaneous combustion. Ventilation planning will need to ensure pressure balance between the workings to minimise airflow between them in areas where the cracks can occur.

6.10 Considerations for mining the underground reserves at the Waterberg

The lessons learnt locally and internationally on multi-seam mining will be applied when underground mining in the Waterberg is considered. In order to mine the underground seams at the Waterberg consideration of the geology and rock mechanics of the roof has to be done. The geology of the Waterberg is such that the roof is not competent hence it requires a mining method like longwall that allows goafing to take place with less ground to be supported. However, the roof must be competent enough so that once it has been supported it should have long enough stand-up time to allow mining to be completed. In order to ensure that there is enough stand-up time the Coal Mine Roof Rating (CMRR) of the various seams to be exploited must be done.

6.11 Coal Mine Roof Rating (CMRR)

CMRR is a system developed to quantify the quality of the roof using geological information for coal mines. This system takes into the account geological characteristics and engineering design of the roof. It integrates many years of geological studies in underground coal mines in the USA with worldwide experience with rock mass classifications. It differs from the rock mass rating (RMR) in that it begins with the understanding that structural competence of mine roof rock is determined primarily by the discontinuities that weaken the rock fabric. CMRR allocates a rating that is specifically designed for bedded coal rock (Mark & Molinda, 2005).

This system was applied to analyse the core information provided by Grootegeluk Colliery in order to assess the integrity of the roof when underground mining will be done. The CMRR of Zones 9, Zones 3 and 2 were calculated using the CMRR software developed at the National Institute for Occupational Safety and Health (NIOSH) of the USA. The inputs to the software are summarised in Table 6.1. The inputs that were used in the CMRR software were based on drill core information obtained from Grootegeluk Colliery. The output of the process is a CMRR value for each zone which was then used to estimate the competency of the roof and provide a benchmark for the support design. The CMRR value is calculated by taking into account the UCS rating, discontinuity rating and a moisture sensitivity rating. The CMRR software can be obtained from http://www.cdc.gov/niosh/mining/works/coversheet1812.html and provides a step by step process to assist the user with the inputs required to calculate the CMRR value of any type of roof. It would have been great to have actual input data from current drilling to fill Table in 6.1 instead of using average values from a core sample. Unfortunately companies mining in the area are sensitive to releasing information on the Waterberg because they consider it strategic to their competitive advantage. However, doing so would have been in the national interest because of the importance of the Waterberg coalfield.

Table 6.1: Inputs to the Coal Mass Roof Rating software for a core

	Zone 9	Zone 3	Zone 2
	Inputs		
Type of roof	**Shale and coal**	**Shale/mudstone**	**Sandstone**
Average UCS	34	50	71
Moisture sensitivity	Yes	Not	Not
Point Load Estimates	Weak	Weak	Moderate
Groundwater	Damp	Dry	Dry
Roof above bolt	Strong	Strong	Strong
	Outputs		
CMRR	37.3	39.8	54.1

6.12 Results of the CMRR

According to (Mark & Molinda, 2005) if the CMRR is less than 45 then the roof is considered to be weak and requires extensive support. If the CMRR is greater than 65 then the roof is considered strong and therefore mining the chain pillars could be done with wider roadways. From Table 6.1, Zone 9 has a CMRR value of less than 38 while Zone 2 has a CMRR of about 54. This means that more support would be required when Zone 9 is mined than when Zone 2 is mined. Also when Zone 9 is mined, narrower bord widths and immediate support for example with a bolter miner should be done in anticipation of the weak roof that is expected. A study that was done by (Mark & Molinda, 2005) in the United States shows that if the CMRR is greater than 55 extended cuts can be mined up to 12m without roof collapse. However, when the CMRR was less than 37 extended cuts cannot be mined and roof collapses can occur.

While this geotechnical information is useful in predicting the behaviour of the roof, when underground mining is pursued in the future, the actual support designs of the Waterberg underground mining will be validated from real geotechnical information that will be gathered from the eastern side of the Daarby fault through further drilling.

6.13 Analysis of Multiple Seam Stability (AMSS)

The next step that should follow from the CMRR rating of the various roofs is to analyse the strength of the interburden between the various zones, the sequencing and interaction of the various seams to be mined i.e. the geometry and mining parameters of the various longwall to be mined. The software used to determine the above is the Analysis of Multiple Seam Stability i.e. AMSS. The AMSS software allows the user to input a variety of geometric and mining parameters which then assist mine planners to understand the potential interaction of the various seams and to take steps to reduce the risk of ground control failure. The program automatically runs the necessary LaM2D (La Model) and Analysis of Longwall Pillar Stability (ALPS) or the Analysis of Retreat Mining Pillar Stability (ARMPS). The primary output from AMSS is a three-level (green/yellow/red) prediction of the intensity of the multiple seam interaction that is likely to be encountered (Mark, et al., 2007).

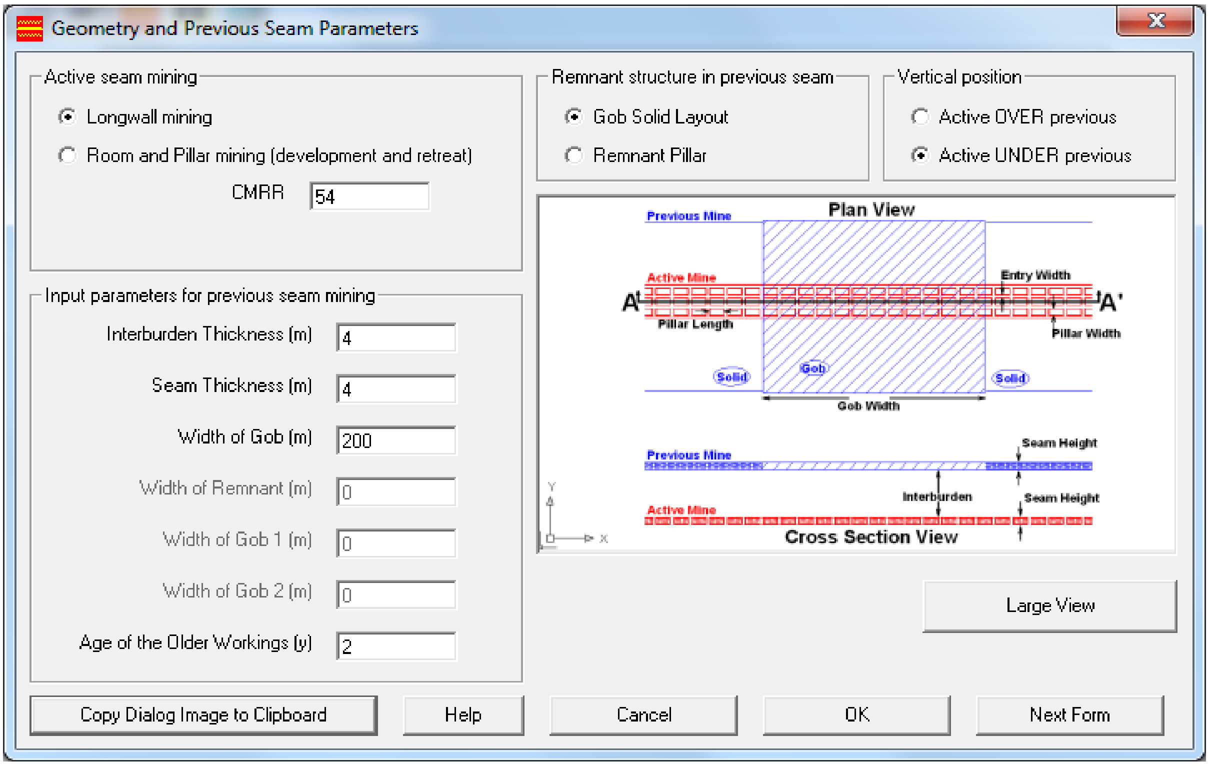
The first step is the evaluation of pillar design by calculating the single seam stability factor (SF_{SS}) using ALPS or ARMPS. It then generates a LaM2D analysis that provides the additional multiple seam stress so that the final, multiple seam SF_{SS} can be determined. The second step of the AMSS process then builds upon the statistical findings that overmining is much more difficult than undermining, goaf-solid boundaries cause less problems than isolated remnant pillars, and stronger roof significantly reduces the risk of multiple seam interactions (Mark, et al., 2007).

The output predicted by the AMSS is quantified and presented in terms of three levels of risk: GREEN (where a major multiple seam interaction is considered unlikely), YELLOW (where adding a pattern of cable bolts or other equivalent supplemental support could greatly reduce the probability of a major interaction), or RED (a major interaction should be considered likely, and it may be desirable to avoid the area entirely) (Mark, et al., 2007).

Therefore it is through this type of analysis that the mining of Zones 2 and 3 with a parting distance of 5m between them was analysed. Zone 9 is about 50m above Zone 3 and therefore the thickness of the rocks between them does not pose so great a risk of seam interaction. It is therefore the aim of this analysis to provide answers about the mining and sequencing between Zones 2 and 3.

Two scenarios were considered. The first scenario is to mine both Zones 3 and 2 simultaneously with a retreat longwall mining method. The inputs for scenario 1 are as shown in Figure 6.7 and Figure 6.8. When option 1 is pursued it should be considered that no mining is done underneath the chain road pillars of the previous longwall i.e. Zone 3. The reason for not mining underneath the chain road pillars is the high stresses that would be experienced, making subsequent longwall mining in Zone 2 impossible. If option 1 is chosen it would involve the stacking of chain roads and the possibility of superimposing of the main development pillars.

The AMSS software can be obtained from http://www.cdc.gov/niosh/mining/works/coversheet1808.html and provides a step by step process to assist the user with the inputs required to predict the interaction due to multiple seam mining. The AMSS software assists in identifying the location and likely severity of multi-seam interactions and provides useful information to mine planners to adjust the roof support, pillar design, or mine layout to minimize the hazard (Mark, et al., 2007).



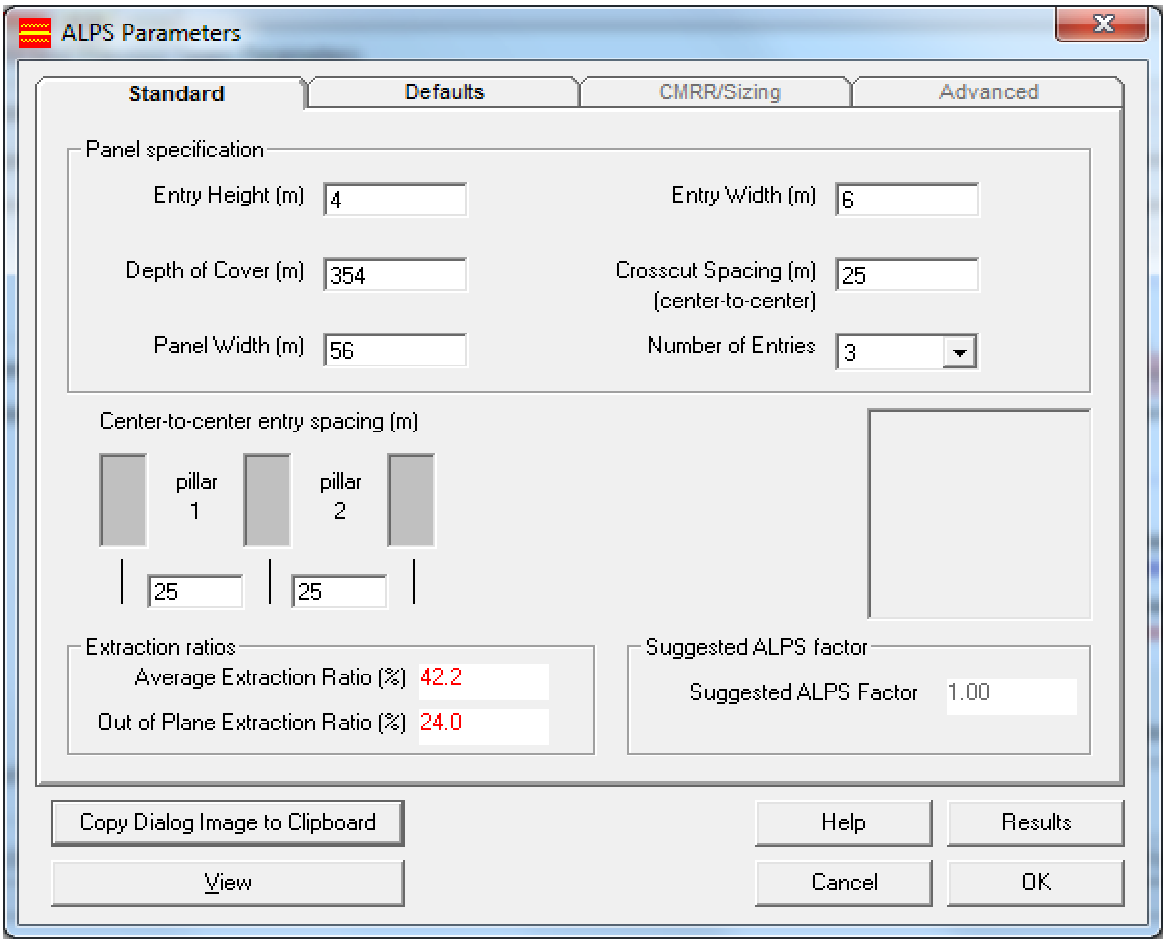
Active seam mining
● Longwall mining
○ Room and Pillar mining (development and retreat)
CMRR 54

Remnant structure in previous seam
● Gob Solid Layout
○ Remnant Pillar

Vertical position
○ Active OVER previous
● Active UNDER previous

Input parameters for previous seam mining
Interburden Thickness (m) 4
Seam Thickness (m) 4
Width of Gob (m) 200
Width of Remnant (m) 0
Width of Gob 1 (m) 0
Width of Gob 2 (m) 0
Age of the Older Workings (y) 2

Figure 6.7: AMSS input data for scenario 1



Panel specification

Entry Height (m) 4

Entry Width (m) 6

Depth of Cover (m) 354

Crosscut Spacing (m) (center-to-center) 25

Panel Width (m) 56

Number of Entries 3

Center-to-center entry spacing (m)

25 25

Extraction ratios

Average Extraction Ratio (%) 42.2

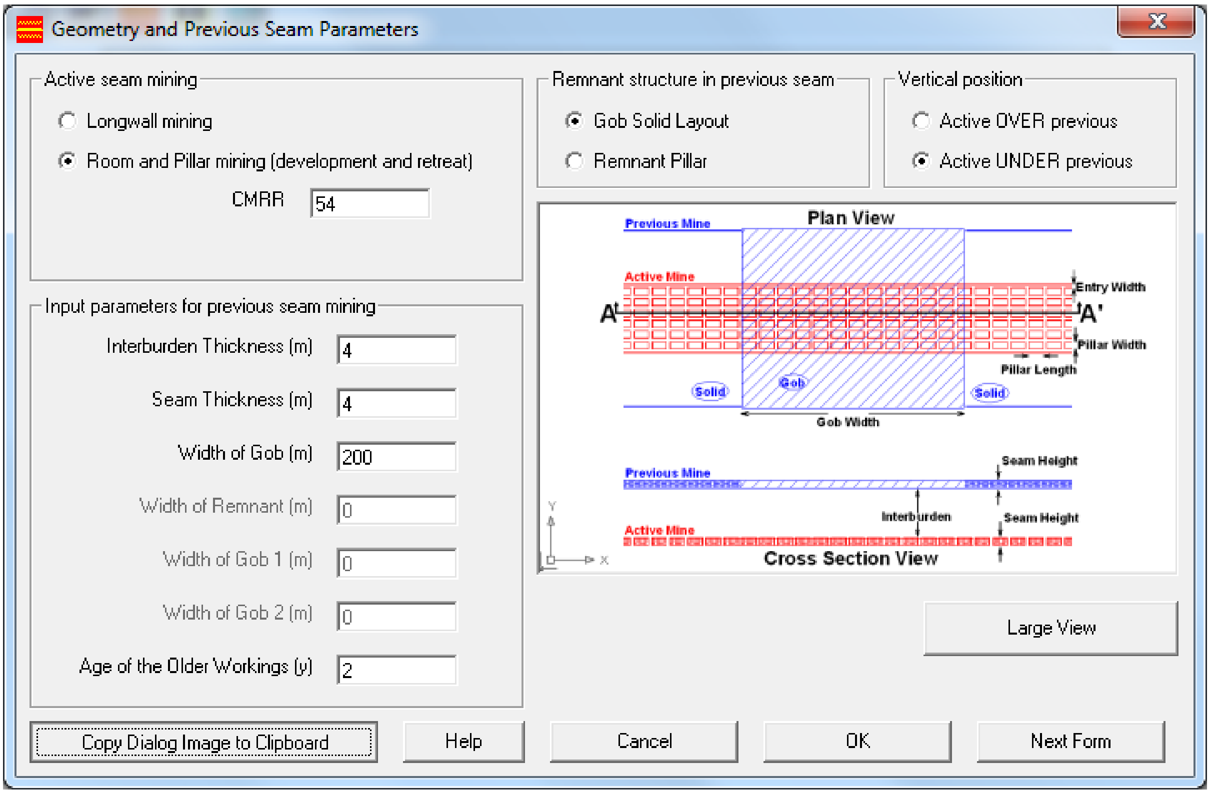
Out of Plane Extraction Ratio (%) 24.0

Suggested ALPS factor

Suggested ALPS Factor 1.00

Figure 6.8: AMSS chain roads input

The second option is to mine Zone 3 with a longwall and to mine Zone 2 with bord and pillar. The inputs for scenario 2 are as shown in Figure 6.9 and Figure 6.10



Geometry and Previous Seam Parameters

Active seam mining

○ Longwall mining

● Room and Pillar mining (development and retreat)

CMRR 54

Remnant structure in previous seam

● Gob Solid Layout

○ Remnant Pillar

Vertical position

○ Active OVER previous

● Active UNDER previous

Input parameters for previous seam mining

Interburden Thickness (m) 4

Seam Thickness (m) 4

Width of Gob (m) 200

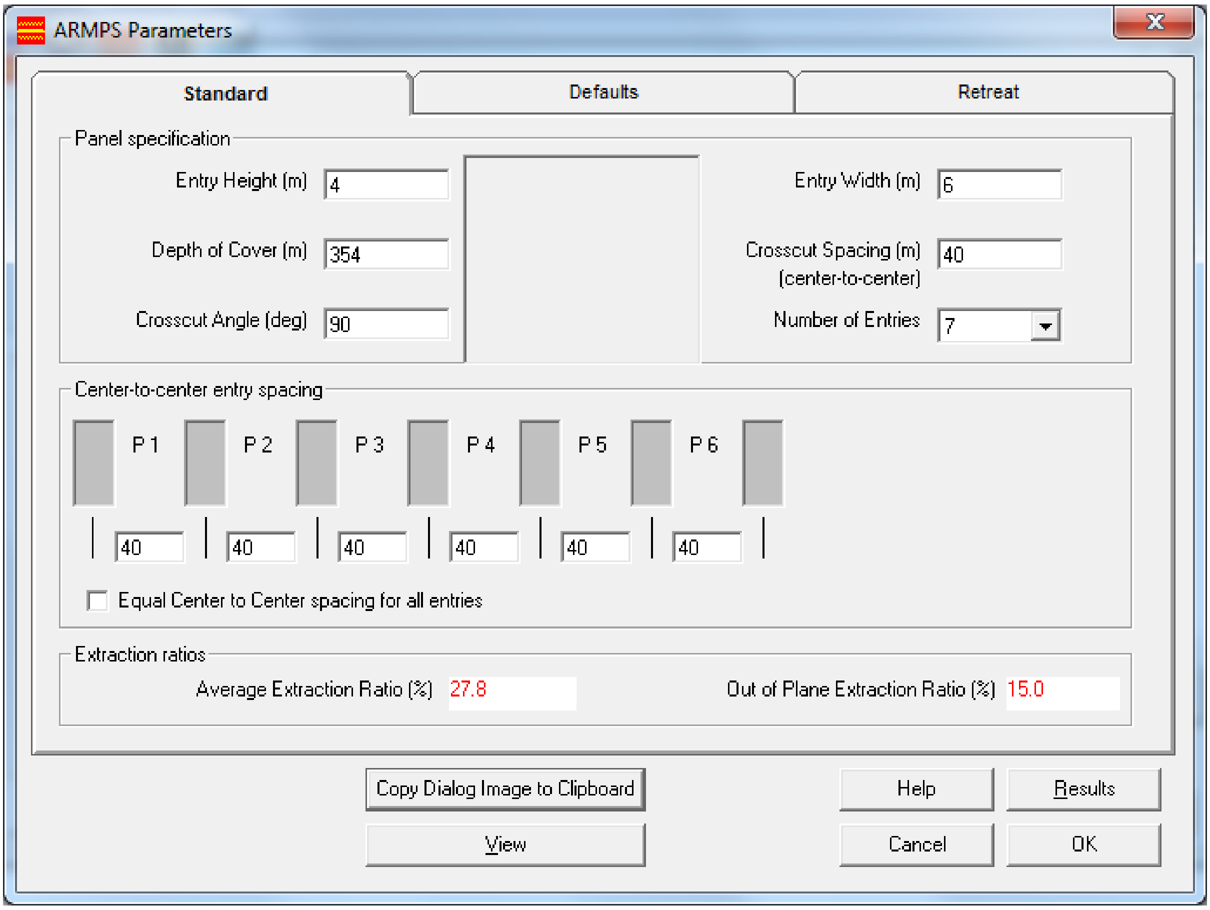
Width of Remnant (m) 0

Width of Gob 1 (m) 0

Width of Gob 2 (m) 0

Age of the Older Workings (y) 2

Figure 6.9: AMSS input data for scenario 2



ARMPS Parameters

Panel specification

Entry Height (m) 4

Depth of Cover (m) 354

Crosscut Angle (deg) 90

Entry Width (m) 6

Crosscut Spacing (m) (center-to-center) 40

Number of Entries 7

Center-to-center entry spacing

P 1	P 2	P 3	P 4	P 5	P 6
40	40	40	40	40	40

☐ Equal Center to Center spacing for all entries

Extraction ratios

Average Extraction Ratio (%) 27.8

Out of Plane Extraction Ratio (%) 15.0

Figure 6.10: AMSS bord and pillar input

This option involves mining under the main development of Zone 3, the barrier pillar between the longwall and the main development and the mining under the goaf of Zone 3. Mining under the chain road pillars is not advisable as it would involve high stresses to be experienced by the bord and pillar mining of Zone 2. It would also involve the stacking of chain roads and the possibility of superimposing the main development pillars. Furthermore, this option would be possible if the longwall in Zone 3 is advanced several panels ahead of the bord and pillar in Zone 2

6.14 Results of the AMSS

Having discussed the mining of all the three zones and the results of the CMRR it is important to finally discuss how the mining of both Zones 2 and 3 with an interburden thickness of 4 to 5m and the roof of 4m coal using the AMSS model will be carried out. It is important to establish by modelling both seams whether there is a possibility of even considering mining because of the thin interburden.

After running the AMSS software for scenario 1 the results show a red level of risk (Appendix 4). This means that a major interaction should be considered likely in the chain roads even if a pattern of supplemental roof support is installed. It is advised that the area be avoided.

Again, after running the AMSS software for scenario 2 the results also show a red level of risk (Appendix 5). This means that a major interaction should be considered likely in the chain roads even if a pattern of supplemental roof support is installed. It is advised that the area be avoided.

It is therefore concluded the mining of Zone 3 and 2 by either a combination of two longwalls or a longwall and a bord and pillar is impossible without a major multiple seam interaction primarily as a result of the thin interburden of 4m between the two seams. The multiple seam stability model indicates that both options would not be possible as the predicted conditions are in the RED category meaning that the conditions would not allow any mining even when major roofbolting is installed.

It is therefore concluded that the mining two seams in the Middle Ecca by a high production tonnage mining method such as longwall is not possible. Neither is the combination of mining with a longwall mining method and a bord and pillar mining method possible. This means that only one seam in the Middle Ecca can be mined successfully. When a decision is taken about which seam to mine from either Zone 3 or 2 from a rock mechanics point of view Zone 2 would be better because of the roof conditions. In the final analysis two seams can be mined from the Waterberg deep underground reserves i.e. Zone 9 in the Upper Ecca with extra support and with difficult mining conditions expected and Zone 2 in the Middle Ecca.

6.15 Concluding remarks

The purpose of this chapter was to determine if mining of the three zones identified i.e. Zones 9, 3 and 2 were possible by high output, low cost longwall mining methods. First the research has indicated that it is possible to mine Zone 9 which has a CMRR of less than 40 by longwall mining methods. However, additional support would be required in the longwall gates as the conditions are expected to be very difficult. It should also be mentioned that some mines in the USA within the NIOSH database are known to be mining with longwall mining methods although they have roof with a CMRR of just above 30. A number of these mines are mining in excess of 5Mtpa using longwall mining methods but using additional roof support and narrower bord widths when the change roads are developed. It was concluded to mine Zone 9 even if the CMRR is below 40 by a traditional, high output longwall method just as is the case in other parts of the world but to do so with additional roof support and narrower bord widths as well. The difficulty of mining Zone 9 in essence has to do with the intercalated nature of the coal and mudstone.

The research has also indicated that it was possible to mine Zones 3 and 2 by longwall in a descending order, or undermining if only the CMRR of both zones were taken into account. However, when the interburden thickness was taken into account the research has indicated that it will not be possible to simultaneously mine Zones 2 and 3 with a 9m thick layer between them made up of 4-5m of sandstone parting and 4m of coal. The options of longwalling both seams or longwalling the top zone and then mining the bottom zone by bord and pillar both give unsatisfactory mining conditions. Failure of the interburden is predicted and thus dangerous mining conditions are anticipated as indicated by the AMSS model. The conclusion is that it is only possible to mine one zone in the Middle Ecca i.e. Zone 2.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

South Africa relies on coal as a primary source of energy and will continue to do so for at least the next four or five decades. Coal supplies over 90 per cent of the electrical energy requirements of South Africa because it is still a cheap, abundant, safe and secure source of energy. In addition, South Africa does not have oil resources and neither does its terrain and rainfall pattern support substantial hydropower generation. Other sources of hydropower are available in Southern Africa but geographical distance and political uncertainties make dependence on these hydro-electric schemes risky. Also, at this stage the prospect of gas from fracking is still at an early stage and is unlikely to be a replacement of coal as a source of energy within the foreseeable future. As was noted in the introductory chapter, all other forms of energy are much more expensive than coal in South Africa. However, post -apartheid South Africa needs a cheap source of energy because there is a need to drive the economy in order to alleviate poverty and social development. To achieve the above objectives South Africa has to contain electricity price escalations and the cheapest way to achieve this is through coal. This argument is clearly supported by ESKOM's construction and investment in two of the largest coal fired power stations in the world in the Witbank, Highveld and the Waterberg coalfields.

Presently quoted reserves in South Africa are calculated by subtracting what has been mined from the geological report published by Bredell in 1987. In reality these reserves are overestimated considerably because for every tonne mined underground roughly one tonne is left in the form of pillars. In addition, there is a lot of coal left underground because of dykes, boundary pillars and barrier pillars. Also, it is reasonable to expect that the reserves are much smaller if decisions taken by previous managers to mine the good coal first at the beginning of the mine and leave out the difficult coal for the next generation are taken into account. The depletion of the Witbank and Highveld coalfields is now within planning horizons i.e. the next 20 years but the question of when and at what rate is subject to various views.

Known coal geological reserves indicate that the logical replacement of the Witbank and Highveld coalfields is the Waterberg coalfield, despite the fact that the country has 19 known coalfields. The timing of this transition is subjective because of the extent to which pillars can be recovered, the difficulty of pursuing pillar extraction and the dangers associated with pillar extraction in the Witbank and Highveld coalfields. The life of the Witbank and Highveld coalfields will depend on how well the reserves in these two important coalfields are managed but at some point there will be a need to replace production from these coalfields. The scenario discussed in this dissertation indicates that at current production rates the replacement period for the Witbank and Highveld coalfields is between in the next 15-25 years.

The Waterberg coalfield is the future of coal mining in South Africa because of the reserves that lie not only on the shallow western side of the Daarby fault but because of the major proportion of the reserves that lie within the deeper eastern reserves of the fault which have still not be been properly explored and included in the current reserves. There is still scope for production on the western side of the Daarby fault where Grootegeluk is currently mining and where the next mine is planned to supply the upcoming Medupi power station. However, the Waterberg coalfield is very different to the Witbank and Highveld coalfields because of the package of coal seams with a thickness in excess of 110m and the intercalated nature of the first 50m at the top of the stratigraphy.

The geology of the Waterberg coalfield is very complex unlike the geology of the Witbank and Highveld coalfields and South Africa does not have the mining experience to mine the multi-seams at the Waterberg at depths greater than 250m. Mining in South Africa has been mostly confined to the Witbank and Highveld coalfields where the geology is well known and less complex and mining of the more difficult Natal coalfields in now a matter of history. The complexity of the geology in the Waterberg coalfield necessitated some research into multi-seam mining and in the course of this study information was obtained from NIOSH in the United States of America. Multi-seam mining has been done in South Africa before in the Witbank and Highveld coalfield but the mining has been confined to coal seams at a depth of less than 150m and mostly in two seams. Multi-seam mining of a package of seams with a thickness of 110m at a depth of greater than 250m has not been done in

South Africa therefore experience from countries such as the United States had to be pursued.

Scenarios for the underground mining of the deep Waterberg reserves have been analysed and discussed. The analysis indicates a total extraction method is the right choice of mining to accommodate all the different zones of the geological stratigraphy. Longwall which is a high production, low cost mining method is the best mining method able to meet the long-term needs of the power stations in this region. Longwall will be able to handle the complex geology envisaged at the Waterberg underground deposit. The mining scenario proposed indicates that probably two zones can be mined by longwall i.e. Zone 2 or Zone 9. However, Zone 9 will prove to be very challenging to mine because of the intercalated nature of the coal and shale. The dissertation has started a process of considering where mining has to begin on the package of seams at the Waterberg. When the zones were looked at very closely it was concluded that undermining instead of overmining would be ideal to mine the Waterberg underground coal. The biggest disadvantage of overmining is that it leads to subsidence and the damage of the overlying seams.

The spontaneous combustion of the coal is one of the critical issues that need to be managed when underground mining is undertaken. If longwall mining is pursued small proportions of air can be drawn into the previously mined areas. If this air finds its way through the broken shale in the interburden it will eventually lead to spontaneous combustion of the lower seams especially where thick seams are not totally extracted.

7.2 Recommendations

As stated in the introductory paragraphs no comprehensive geological report about the country’s coal resources and reserves is available since the last report produced by Bredell in 1987. Some work has been undertaken funded by Coaltech and this has been taken into account but a more detailed examination of the nation’s coal inventory is required. It is therefore recommended that the first step is to have an updated, detailed and comprehensive geological report produced by the government with the help of mining companies detailing the state of the national resources and reserves at present. This report should especially detail the resources and reserves of the Waterberg and include the resources and reserves of the deep underground seams east of the Daarby fault.

Since it is expected that the Witbank and Highveld coalfields will be depleted in the next 15 to 25 years, government should incentivize mining companies exploring in the Waterberg to invest in the research that will assist in identifying all the challenges that are likely to be encountered in the mining of the Waterberg in order to ensure once the Witbank and Highveld coal reserves are depleted, the Waterberg resource is mined safely, effectively and efficiently and that there is no electricity crisis in the future

The geology of the Waterberg coalfield is complex and as discussed in Chapter 3 and 5, drilling on the eastern side of the Daarby fault where underground mining is anticipated is continuing. Once the mining company exploring this area has demarcated sufficient resources to warrant underground mining, the mining approaches proposed in Chapter 6 should be evaluated for extracting these resources.

All the exploration and research needed to understand how to exploit the Waterberg coalfield must continue to be done by mining companies but should be co-ordinated and funded by government so that the future of the country’s resources and reserves are mined optimally and according to a plan. If this is not done two scenarios are envisaged

a) Electricity generation is undertaken using much more expensive technologies, thereby failing to alleviate poverty or assist in the creation of jobs.

or

b) Electricity supply will fail to match demand and the economy will stall.

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APPENDIX 1 CMRR FOR ZONE 9

Inputs

1.	Drill Core Information	
2.	Bolt Length	1.8 (m)
3.	Ground Water Adjustment	Damp
4.	Surcharge Adjustment	Roof above bolts is much weaker than the bolted interval
5.	Unit Description	SHALE
6.	Thickness	.2 (m)
7.	Depth to Unit	298 (m)
8.	Average Axial IS	1.619048 (MPa)
9.	Average Axial UCS	34 (MPa)
10.	No Diametral PLT Data Available	
11.	No Fractures Observed	
12.	PLT Estimate	Weak
13.	Moisture	Moderately Sensitive

Output – CMRR Value

1.	Unit Rating	37.3
2.	Unit Rating (adjusted)	30.3

Output- CMRR value without adjusting for moisture sensitivity conditions

1.	UCS = 34.0 (MPa)	Rating = 12.3
2.	PLT Estimate = Weak	Rating = 25.0
3.	Subtotal (Fracture/RQD/Diametral)	Rating = 25.0
4.	CMRR Total for Unit [1]	Rating = 37.3
5.	CMRR Total for Unit [1]	Rating = 34.3

APPENDIX 2 CMRR FOR ZONE 3

Inputs

1.	Drill Core Information	
2.	Bolt Length	1.8 (m)
3.	Ground Water Adjustment	Dry
4.	Surcharge Adjustment	Roof above bolts is stronger than bolted interval
5.	Unit Description	CARBONACEOUS SHALE
6.	Thickness	2 (m)
7.	Depth to Unit	346 (m)
8.	Average Axial UCS	50 (MPa)
9.	No Diametral PLT Data Available	
10.	No Fractures Observed	
11.	PLT Estimate	Weak
12.	Moisture	Not sensitive

Output -CMRR value without Adjusting for Moisture Sensitivity Conditions.

1.	UCS = 50.0 (MPa)	Rating = 14.8
2.	PLT Estimate = Weak	Rating = 25.0
3.	Subtotal (Fracture/RQD/Diametral)	Rating = 25.0
4.	Total for unit	Rating = 39.8

APPENDIX 3 CMRR FOR ZONE 2

Input

1.	Drill Core Information	
2.	Bolt Length	1.8 (m)
3.	Ground Water Adjustment	Dry
4.	Surcharge Adjustment	Roof above bolts is stronger than bolted interval
5.	Unit Description	SANDSTONE
6.	Thickness	4 (m)
7.	Depth to Unit	350 (m)
8.	Average Axial UCS	71 (MPa)
9.	No Diametral PLT Data Available	
10.	No Fractures Observed	
11.	PLT Estimate	Moderate
12.	Moisture	Not sensitive

Output CMRR with or without Adjusting for Moisture Sensitivity Conditions.

1.	UCS = 71.0 (MPa)	Rating = 18.1
2.	PLT Estimate = Moderate	Rating = 36.0
3.	Subtotal (Fracture/RQD/Diametral)	Rating = 36.0
4.	Total for Unit [1]	Rating = 54.1

APPENDIX 4: MULTIPLE SEAM MINING BETWEEN ZONES 3 AND 2

[**MULTIPLE SEAM PARAMETERS]**

[Inputs]

Active Seam Mining Mode	Analysis of Longwall Pillar Stability
Previous Mining	Gob Solid Layout
Vertical Position	Active UNDER Previous
Interburden Thickness	4 (m)

[PREVIOUS SEAM PARAMETERS]

Seam Thickness	4 (m)
Width of Gob	200 (m)
Age of Workings	2 years

[ACTIVE SEAM PARAMETERS]

CMRR	54

[ALPS DATA]

Entry Height	4 (m)
Depth of Cover	354 (m)
Panel Width	56 (m)
Entry Width	6 (m)
Number of Entries	3
Crosscut Spacing	25 (m)
Centre to Centre Distance #1	25 (m)
Centre to Centre Distance #2	25 (m)

[ALPS DEFAULT PARAMETERS]

In Situ Coal Strength	6.21 (MPa)
Abutment Angle	21 (deg)
Unit Weight of Overburden	25.45 (kN/m3)

[**AMSS Output]**

[MULTIPLE SEAM PILLAR STABILITY FACTORS]

Development Stability Factor	0.44
TAILGATE Loading	0.31

Tailgate pillar SF is less than the suggested value of 1.00

The pillar design may be inadequate to prevent a major multiple seam interaction. Consider increasing the pillar size by changing the entry spacing, the crosscut spacing, and/or the pillar width.

[**PREDICTED CONDITIONS]**

Development: RED: A major interaction should be considered likely even if a pattern of supplemental roof support is installed. It may be desirable to avoid the area entirely.

Tailgate: RED: A major interaction should be considered likely even if a pattern of supplemental roof support is installed. It may be desirable to avoid the area entirely.

In addition to installing a pattern of roof support, the likelihood of a major interaction may be reduced by increasing the pillar size by changing the entry spacing, the crosscut spacing, and/or the pillar width.

[WARNING MESSAGES]

The NIOSH multiple seam data base contains few cases where the interburden thickness is less than 10 m. The AMSS predictions may not be valid.

When the interburden is less than 10 m, an ultra-close interaction is possible. Consider stacking the pillars.

When the interburden thickness is less than 10 times the lower seam height, the upper seam may be in the fracture zone of subsidence.

Special precautions may be necessary.

The NIOSH multiple seam data base contains few cases where less than 5 years had elapsed time since mining was completed in the lower seam.

If subsidence is not complete, a 'dynamic' interaction may occur.

[CALCULATED STRESSES]

Single seam development stress	15.60 (MPa)
Multiple seam stress	17.84 (MPa)
Total vertical stress (Development)	33.44 (MPa)
Tailgate abutment stress	6.21 (MPa)
Total vertical stress (Tailgate Loading)	39.65 (MPa)

[SUGGESTED CRITICAL INTERBURDEN AND STRESS]

Critical Interburden for Development	48.5 (m)
Allowable Total Vertical Stress	4.80 (MPa)

If a pattern of supplemental roof support is installed, then:

Critical Interburden for Development	22.0 (m)
Allowable Total Vertical Stress	21.97 (MPa)
Critical Interburden for Tailgate Loading	58.1 (m)
Allowable Total Vertical Stress	4.80 (MPa)

If a pattern of supplemental roof support is installed, then:

Critical Interburden for Tailgate Loading	31.6 (m)

Allowable Total Vertical Stress 21.97 (MPa)

[ALPS STABILITY FACTORS - STANDARD GEOMETRY]

Classic ALPS ALPS (R)

Development Loading............0.94 0.94

Headgate Loading...............0.76 0.76

Bleeder Loading................0.65 0.65

*** Tailgate Loading...............0.50 0.50

Isolated Loading...............0.47 0.47

[**ALPS STABILITY FACTORS - STANDARD GEOMETRY - MULTI SEAM CONDITIONS]**

Classic ALPS MS ALPS (R) MS

Development Loading............0.44 0.44

Headgate Loading...............0.40 0.40

Bleeder Loading................0.36 0.36

*** Tailgate Loading...............0.31 0.31

Isolated Loading...............0.30 0.30

[ALPS PILLAR LOAD BEARING CAPACITY]

PILLAR #1

for Pillar Width (m) 19.0

and Pillar Length (m) 19.0

Width/Height Ratio 4.75

Unit Pillar Strength (MPa)	14.59
Pillar Load Bearing Capacity (kN) / (m) of gate entry	2.11E+05

Unit Pillar Strength (R) (MPa)	14.59
Pillar Load Bearing Capacity (R) (kN) / (m) of gate entry	2.11E+05

PILLAR #2

for Pillar Width (m)	19.0
and Pillar Length (m)	19.0
Width/Height Ratio	4.75
Unit Pillar Strength (MPa)	14.59
Pillar Load Bearing Capacity (kN) / (m) of gate entry	2.11E+05
Unit Pillar Strength (R) (MPa)	14.59
Pillar Load Bearing Capacity (R) (kN) / (m) of gate entry	2.11E+05

TOTAL PILLAR SYSTEM LOAD BEARING CAPACITY [ALPS Classic]

Total Load (kN) / (m) of gate entry	4.21E+05

TOTAL PILLAR SYSTEM LOAD BEARING CAPACITY [ALPS (R)]

Total Load (kN) / (m) of gate entry	4.21E+05

[ALPS SINGLE SEAM LOADS ON PILLAR SYSTEM (kN) / (m) of gate entry]

Development Loading	450 495
Headgate Loading	550 935
Bleeder Loading	651 375
*** Tailgate Loading	835 181

Isolated Loading	903 067

[**ALPS MULTIPLE SEAM LOADS ON PILLAR SYSTEM (kN) / (m) of gate entry]**

MS Development Load	708 081
MS Headgate Load	744 124
MS Bleeder Load	780 168
*** MS Tailgate Load	873 819
MS Isolated Load	903 067

APPENDIX 5: MULTIPLE SEAM MINING BETWEEN ZONES 3 AND 2 WITH LONGWALL AND BORD AND PILLAR

[MULTIPLE SEAM PARAMETERS]

Active Seam Mining Mode	.Analysis of Retreat Mining Pillar Stability
Previous Mining	Gob Solid Layout
Vertical Position	Active UNDER Previous
Interburden Thickness	4 (m)

[PREVIOUS SEAM PARAMETERS]

Seam Thickness	4 (m)
Width of Gob	200 (m)
Age of Workings	2 years

[ACTIVE SEAM PARAMETERS]

CMRR	54

[ARMPS DATA]

Entry Height	.4 (m)
Depth of Cover	354 (m)
Crosscut Angle	90 (deg)
Entry Width	6 (m)
Number of Entries	7
Crosscut Spacing	40 (m)
Center to Center Distance #1	40 (m)
Center to Center Distance #2	40 (m)

Center to Center Distance #3	40 (m)
Center to Center Distance #4	40 (m)
Center to Center Distance #5	40 (m)
Center to Center Distance #6	40 (m)

[ARMPS DEFAULT PARAMETERS]

In Situ Coal Strength	6.21 (MPa)
Unit Weight of Overburden	25.45 (kN/m3)
Breadth of AMZ	51 (m)

AMZ set automatically

Pressure Arch Factor	0.89

Pressure Arch Factor set automatically

[ARMPS RETREAT MINING PARAMETERS]

Loading Condition	DEVELOPMENT LOAD (NO NEARBY GOB)

[AMSS Output]

[MULTIPLE SEAM PILLAR STABILITY FACTORS]

Development	1.17

Development pillar SF is less than the suggested value of 1.50

The pillar design may be inadequate to prevent a major multiple seam interaction. Consider increasing the pillar size by changing the entry spacing, the crosscut spacing, and/or the pillar width.

[PREDICTED CONDITIONS]

Development: RED: A major interaction should be considered likely even if a pattern of supplemental roof support is installed. It may be desirable to avoid the area entirely.

In addition to installing a pattern of roof support, the likelihood of a major interaction may be reduced by increasing the pillar size by changing the entry spacing, the crosscut spacing, and/or the pillar width.

[WARNING MESSAGES]

The NIOSH multiple seam data base contains few cases where the interburden thickness is less than 10 m. The AMSS predictions may not be valid.

When the interburden is less than 10 m, an ultra-close interaction is possible. Consider stacking the pillars.

When the interburden thickness is less than 10 times the lower seam height, the upper seam may be in the fracture zone of subsidence.

Special precautions may be necessary.

The NIOSH multiple seam data base contains few cases where less than 5 years had elapsed time since mining was completed in the lower seam.

If subsidence is not complete, a 'dynamic' interaction may occur.

[CALCULATED STRESSES]

Single seam development stress	12.47 (MPa)
Multiple seam stress	9.69 (MPa)
Development abutment stress	0.00 (MPa)
Total vertical stress (Development)	22.16 (MPa)

[SUGGESTED CRITICAL INTERBURDEN AND STRESS]

Critical Interburden for Development	31.0 (m)
Allowable Total Vertical Stress	4.80 (MPa)

If a pattern of supplemental roof support is installed, then:

Critical Interburden for Development	9.3 (m)
Allowable Total Vertical Stress	5.72 (MPa)

[ARMPS STABILITY FACTORS - SINGLE SEAM CONDITIONS]

Development	2.07

[ARMPS STABILITY FACTORS - MULTI SEAM CONDITIONS]

Development	1.17

[WARNINGS - MULTI SEAM CONDITIONS]

Analysis of the ARMPS case history data base suggests that when the depth of cover is greater than 300 m, the risk of pillar failure is increased when the ARMPS SF is less than 1.5 or (1.3 if the panel width is less than 130 m and the Barrier Pillar SF exceeds 2.0.)