1 INTRODUCTION TO SOUTH AFRICAN COAL MINING AND EXPLORATION

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CHAPTER OUTLINE

- The history of coal mining in South Africa
- The importance of coal mining in South Africa
- Coal reserves
- The geology of the South African coalfields
- The importance of cost-effective mining
- The importance of continued exploration
- The role of geophysics (and this book)

This chapter provides some basic geological and mining background information and sets the scene in terms of the key operational challenges experienced by local coal miners and the role that geophysics can play in addressing these challenges.

The history of coal mining in South Africa

Coal was discovered in KwaZulu-Natal, Mpumalanga and the Eastern Province, and first documented between 1838 and 1859. The first commercial mining took place near Molteno, in the Eastern Cape, in 1870[1]. The discovery of diamonds at Kimberley in 1870 and gold on the Witwatersrand in 1886 increased the demand for coal, with new mines opening in Vereeniging in 1879 and Witbank in 1895. Further developments occurred in KwaZulu-Natal, Gauteng and Mpumalanga (currently home to about 84% of local coal production)[2], followed by the Free State and Limpopo. The majority of coal is derived from open-cast mines (±53%) and underground bord-and-pillar operations (40%), while stoping (4%) and longwall mining (3%) make up the balance.

The importance of coal mining in South Africa

Coal is South Africa's most plentiful and cheapest source of energy. The coal has a low to moderate heat value and high ash content, but mining the coal is cheap when compared with the international industry. The major economic development that took place in South Africa after the Second World War was driven by the cheap, readily available electricity generated by the newly constructed coal-fired power stations[2]. The low costs continue to have a strong positive impact on the country's prosperity and economic development[3].

Coal currently provides about 70% of South Africa's primary energy[4]. Ninety per cent of the country's electricity is produced by coal-fired thermal generation, while Sasol's coal conversion technology, operational since 1955, provides approximately half of South Africa's liquid fuel requirement. Although natural gas, renewable energy sources and nuclear energy are forecast to contribute increasingly to the primary energy supply, coal will remain our major energy source into the foreseeable future, due to its relative abundance and low cost. In addition to its internal consumption, South Africa exports bituminous coal to Europe, India and China, as well as smaller amounts to other international destinations. Coal was the fourth largest foreign exchange earner in 2011 (after platinum, gold and iron ore) in the commodities sector. Figures 1.1 and 1.2 illustrate the coal consumption of the various local market sectors by mass and percentage.

Figure 1.1 Coal value chain, 2009[5]

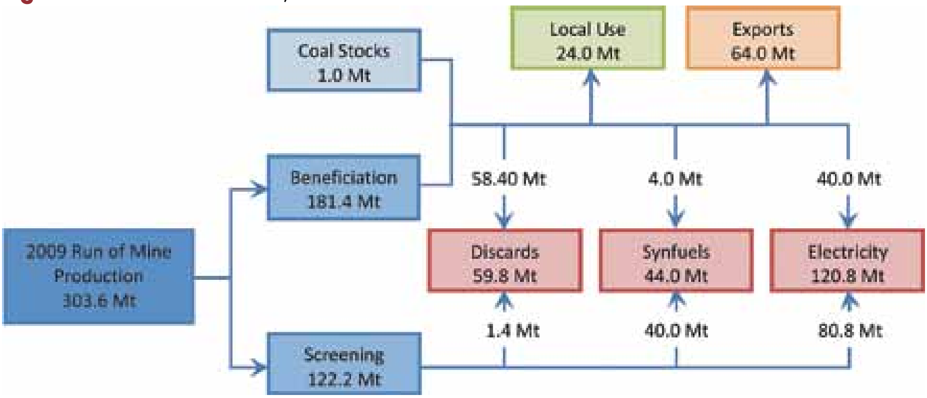
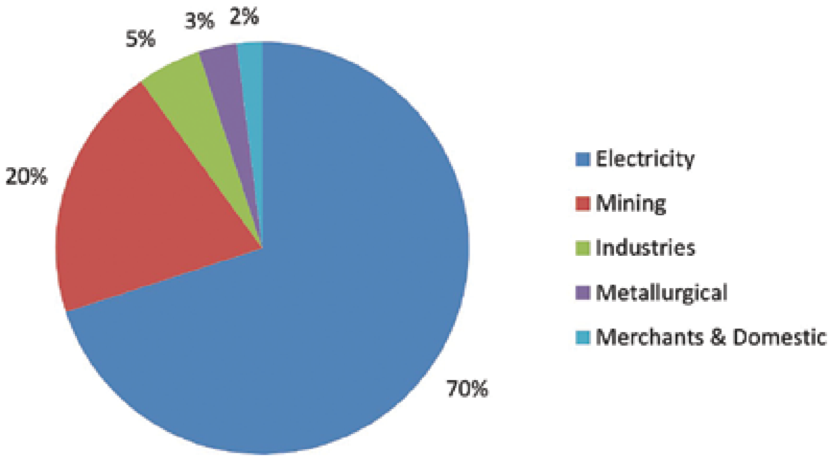


Figure 1.2 Local coal sales by user, 2009[5]



▶ Coal reserves

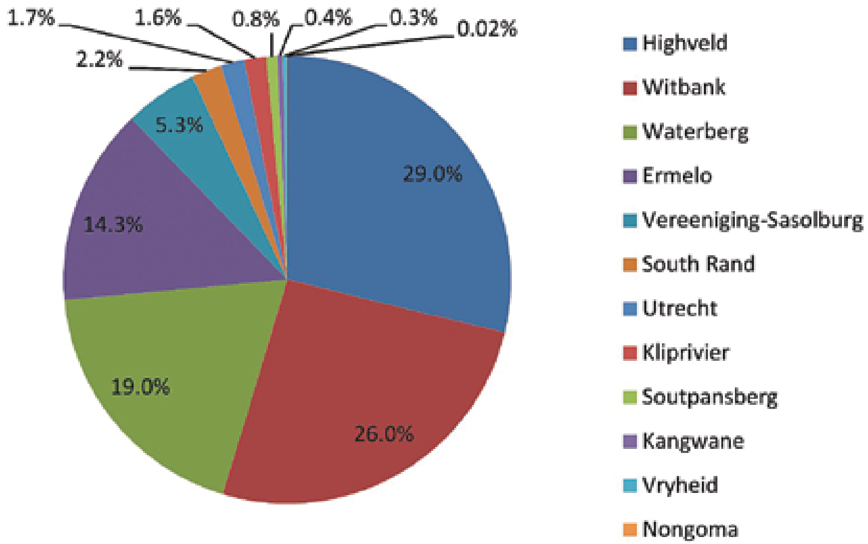
Table 1.1 gives the remaining coal reserves as at 2009 (except for the Waterberg Coalfield, which has been updated to 2010). Figure 1.3 shows the percentage reserves of each of the major coalfields.

Table 1.1 South African Coal Reserves 2009/2010[5, 6]

COALFIELD	RESERVES 1982 (MT)	ROM PRODUCTION 1982–2009 (MT)	REMAINING RESERVES 2009 (MT)	% OF TOTAL
Ermelo	4 658.1	270.6	4 387.5	14.0
Highveld	10 919.6	1 445.0	9 474.6	30.3
Kangwane	147.0	1.1	145.9	0.5
Klip River	617.0	88.2	528.8	1.7
Nongoma	38.8	33.0	5.8	0.02
South Rand	730.0	14.5	715.5	2.3
Soutpansberg	267.0	9.6	257.4	0.8
Utrecht	609.8	69.1	540.7	1.7
Vereeniging-Sasolburg	2 233.0	524.6	1 708.4	5.5
Vryheid	179.6	80.0	99.6	0.3
Waterberg *	7 441.4	697.4	6 744.0	15.8
Witbank	12 461.0	3 951.7	8 509.3	27.2
Total	**40 302.3**	**7 184.8**	**33 117.5**	**100**

* Updated for 2010

Figure 1.3 Coal reserves of South Africa, 2010[5]



The importance of the coal industry to South Africa has motivated the Department of Mineral Resources to oversee a re-assessment of the coal reserves and resources that is being undertaken by the Council for Geoscience. The publication of the figures is expected in 2014.

▶ The geology of the South African coalfields

Coal is found in South Africa in 19 coalfields (Figure 1.4), located mainly in KwaZulu-Natal, Mpumalanga, Limpopo and the Free State, with lesser amounts in Gauteng, the North West Province and the Eastern Cape. Table 1.2 summarises pertinent geological information about the coal seams in most of these coalfields, while Table 1.3 contains coal quality information.

Figure 1.4 Coalfields of South Africa[7]

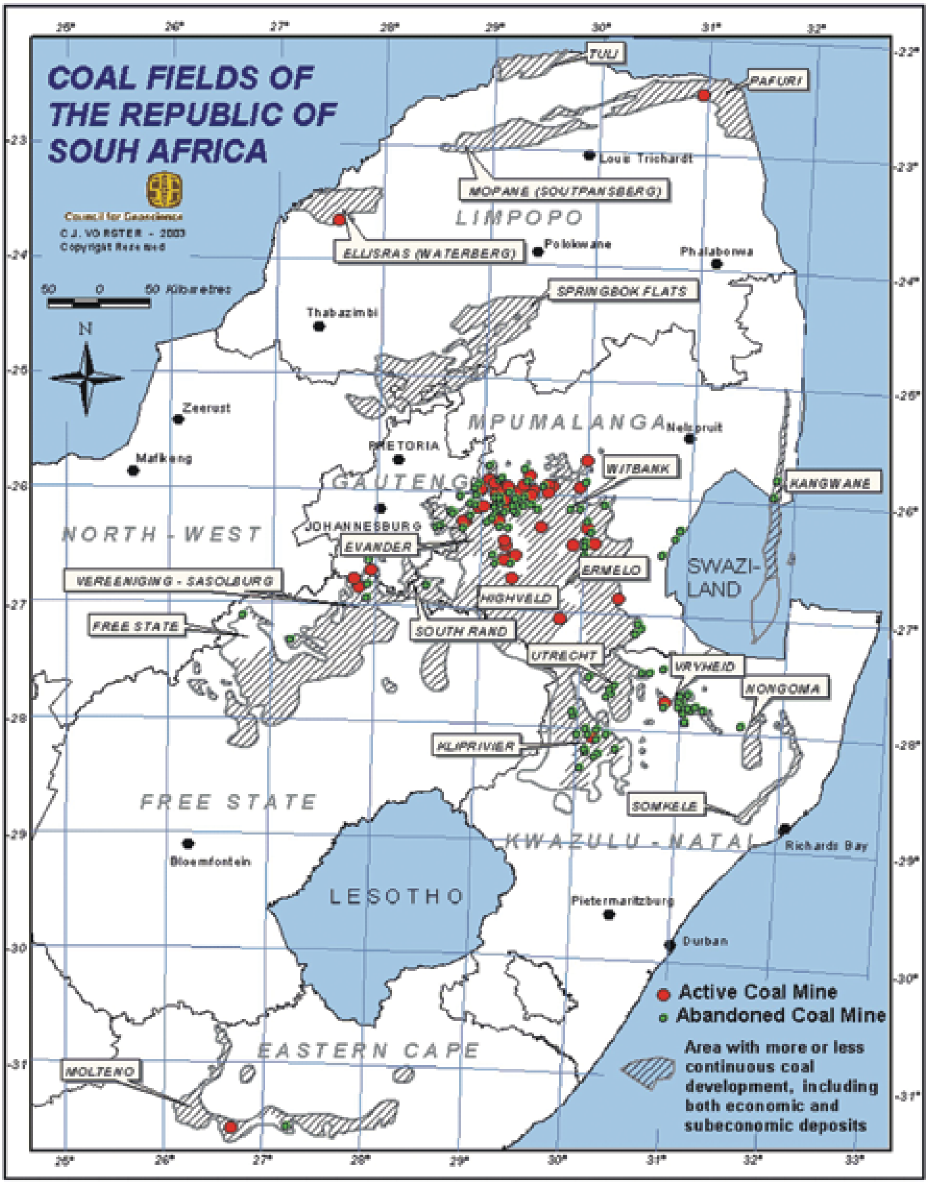


Table 1.2 Summarised Geology of the Coalfields of South Africa[4]

COALFIELD	DEPTH	FORMATION	BASIN TYPE	SEAMS (Coal seams listed from the base upwards)	
Ermelo	0–100	Vryheid		• E Seam 0–3 m • D Seam 0.6 m • C Lower Seam 1.5; sandstone partings • C Upper Seam well developed; 0.7–4 m; sandstone/siltstone/mudstone split seam into 2–3 plies • B Lower & B Upper Seam; 0–3 m; coalesce in south • A Seam 0–1.5 m; isolated outliers	
Free State				• Top Seam < 2 m • Bottom Seam widely distributed; 2.5–8 m; dull, banded coal • Middle Seam • Dwyka Seam	
Highveld	0–300	Vryheid	East–west graben – down-throw 22 m	• No. 5 Seam 1–2 m • No. 4A Seam occurs above No. 4 Upper in place; thin; discontinuous • No. 4 Seam 1–12 m; laterally continuous; most economically important; 2–15 m sandstone between No. 4 Upper (1–4 m) & No. 4 Lower (4–12 m) Seam	
				• No. 3 Seam thin; discontinuous; poor quality • No. 2 Seam 1.5–4 m; irregular shale partings 0.1–1.0 m; no zoning as per Witbank Coalfield • No. 1 Seam thin; mainly discontinuous	
Klip River				• Top Seam equivalent to the Alfred; better developed than Bottom Seam; 3.3 m in north, 1.5 m in south[1]	
				• Bottom Seam equivalent to the Gus Seam; 1.3 m in north, 0.5 m in south	
Limpopo (Tuli)	200	Vryheid	Synclinal folded basin	• Top (Upper) Seam • Bottom (Lower/Basal) Seam	

	GEOLOGY	IGNEOUS INTRUSIONS
	Seams dip gently southwest, minor folding	Dykes (2–5 m) common Up to 8 sills (10–250 m) transgress & uplift the seams; seams devolatilised/destroyed by dolerite over large areas
	The coal zone (50 m) thins north; seams interlaminated with sandstone/mudstone – predominantly dull coal with high ash content	Dolerite sills (max. thickness = 150 m) common; result in major displacements[8]; render 40–50% of the coal resources in this coalfield not mineable[1, 9]
		Dykes (1–4 m) ubiquitous (major direction east–west; minor north–south, north-east), resulting in destruction and burning of the seams; poor roof & groundwater conditions due to dykes
		Transgressive or conformable sills (up to 80 m thick) resulted in faulting & tilting of the coal
	Gentle southerly dip	Dykes (northwest–southeast, northeast–southwest) common; associated with minor displacements
		9 dolerite sills – 4 major sills (Zuinguin, Utrecht, Ingogo & Talana) – have caused major displacement (up to 137 m[10])
	Seams flat lying (2° dip north & northwest); no current exploitation (environmentally sensitive, remote); extensive roof support needed – interlaminated mudstones, thin coal bands, siltstones, carbonaceous shale[11].	Several large dykes

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COALFIELD	DEPTH	FORMATION	BASIN TYPE	SEAMS (Coal seams listed from the base upwards)
Molteno-Indwe				• Indwe Seam 2–6 m; consistently developed; composite seam of interbedded coal/shale bands
				• Guba Seam 24–30 m above Indwe, but seams rarely developed together in same locality; generally less persistent; 2.8 m thinning to south & north; bright coal at base followed by alternating bands of bright/dull coal • Cala/Cala Pass/Molteno/Piet/Upper Seam[12] 2 coal bands each 0.35–0.40 m separated by carbonaceous shale 1.2 m thick; medium volatile bituminous-anthracitic; high chlorine (0.15%) content[1] • Ulin/Gubenxa Seam[1] discontinuous band consisting of thin coal lenses, coaly silt, mud, shale; developed 20 km southwest of Elliot
Nongoma		Vryheid & Emakwezini	Preserved within graben	• Emakwezini Fm: A, B, C Zones (Umsebe Prospect); 3 very thin coal seams of inferior quality (ZAC**) • Vryheid Fm: Two thinner seams occur 0.7 m above & 0.3 m below the Main Seam respectively • Vryheid Fm: B Zone coal occurs 35 m above A Zone • Vryheid Fm: Main Seam 1–3 m
Somkhele		Emakwezini		• Upper Seam 1 • Upper Seam 2 • Main up to 10.6 m • Lower Seam
South Rand				• Ryder Seam (2.5 m, irregularly developed)
				• No. 3 Seam (2–11 m)
				• No. 2 or Main Seam (2–20 m, correlated with No. 4 Seam in Witbank/Highveld Coalfields) • No. 1 Seam (> 3 m, dull lustrous coal)
Soutpansberg: Mopane (W); Tshipise; Venda-Pafuri (E)	> 100			• Venda-Pafuri: No. 2 Seam 6.00 m • Venda-Pafuri: No. 1 Seam 0.55 m

** Zululand Anthracite Colliery

	GEOLOGY	IGNEOUS INTRUSIONS
	6 coal seams, 4 lower seams more persistent. Faults (few km long, displacements < 50 m but throws > 300 m) have been recorded	North–south & east–west vertical to sub-vertical dykes (up to 20 m)
		200 m thick sills cover 30% of Molteno-Dordrecht-Indwe region; erosion resistant; cap the hills
		Dykes occur throughout the coalfield[1] Umsebe Prospect: 2 sills (17–35 m & 15–65 m; 10–40 m apart above the upper coal zone). 25 m thick sill transgresses coal zones; no major devolatilisation
	Called the A, B, C, & D Seams respectively in north-west; dip 15–30° south; intense faulting – major faults striking southwest[1] subdivide the area into five blocks	Numerous dolerite intrusions
	One main coal zone (1 m seam – 20 m composite seam split by sandstone, shale & conglomerate partings); major east–west trending faults (displacements up to 35 m)	Numerous dykes (0.1–10 m) devolatilise coal
		Sills of variable orientation
		Most of central part overlain by a 100 m dolerite sill[1, 13]
	Mopane (shallow) & Tshipise (deep): coal poorly, inconsistently developed; no economic potential defined[14]. Faulting common – resulting in small fault bounded resource blocks. Venda-Pafuri: thick interbedded seam deposit type	Dolerite dykes & sills also common

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COALFIELD	DEPTH	FORMATION	BASIN TYPE	SEAMS (Coal seams listed from the base upwards)	
Springbok Flats	0– > 1 000	Vryheid & Volksrust		• Upper Seam 0.8–1.2 m; zone of potential economic interest • Middle Seam 2–4 m • Lower Seam	
Utrecht		Vryheid		• Eland Seam • Alfred Seam persistent, 3–4 m south of Utrecht, bright – dull-lustrous coal[15] • Gus Seam well developed; economically most important; thin in south; sandstone band in north • Dundas Seam 2 m mixed dull, bright, shaly coal • Coking Seam < 1.5 m, good quality	
Vereeniging-Sasolburg	25– > 250			• No. 3 well developed; 0–5 m	
				• Sigma & Coalbrook basins: No. 2 Seam (split into Nos. 2A & 2B – each up to 8m thick by 1.5 m mudstone parting) • Sigma & Coalbrook basins: No. 1 Seam 0–5 m; sometimes split into Nos. 1A, 1B & IC by sandstone partings • Cornelia basin: Bottom, Middle & Top Unit	
Vryheid				• Eland Seam	
				• Alfred Seam < 1 m • Fritz Seam < 0.5 m; bright coal • Gus Seam extensively developed; 0.5–2 m; finely interbanded bright & lustrous coal • Dundas Seam well developed; split into Upper (0.15–1.2 m, usually too thin to be mined alone; coking coal) & Lower (0.1–2.5 m; 1.5–6.5 m below Upper Dundas; interbanded bright & dull coal) • Coking Seam < 1 m • Targas Seam uneconomic	

	GEOLOGY	IGNEOUS INTRUSIONS
	Vryheid Fm.: Lower coal zone; poor lateral development. Volksrust Fm: Upper coal zone; laterally persistent; 5–8 m thick (max. = 12 m); uranium-mineralised zone (1 m thick) in upper part of Upper coal zone & immediate roof strata; significant mineralisation of entire coal zone near pre-Karoo inliers. U_3O_8: 0.2–0.7 kg/ton[12]	Majority of coal west of Warmbad-Pienaarsrivier devolatilised by dolerite intrusions
		5 major dolerite sills (Zuinguin (> 150 m), B, Utrecht, Ingogo & No. 10) with associated faulting (throws > 15 m[9])
	Southern extension of South Rand Coalfield; subdivided into Sigma, Cornelia & Coalbrook basins; east–west striking graben – displacement 70 m in the west & 5 m in the east of Cornelia Basin	Numerous dolerite dykes, especially in south
		Two sills transgress the seams in the Sigma Basin
	9 seams within the Main Coal Zone (only 4 exploited in north, 5 in central portion)	Dykes (up to 10 m) associated with minor faulting[16]
		5 sills: concordant. Zuinguin (oldest) – transgressive; Ngwibi, Matshongololo, Nyembi, Enyati – devolatilised coal; caused major displacement (up to 150 m)

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COALFIELD	DEPTH	FORMATION	BASIN TYPE	SEAMS (Coal seams listed from the base upwards)	
Waterberg (Ellisras)	15– > 400	Vryheid & Grootegeluk	Fault-bounded graben-type basin	• Grootegeluk Fm: 60 m thick; autochthonous, thick interbedded seam deposit type (carbonaceous mudstones interbedded with thin coal seams); 7 coal zones, multiple seams; lateral quality consistent although coking coal yield varies widely; produces greatest % ROM coal • Vryheid Fm: 55 m thick; allochthonous, multiple seam deposit type; 4 coal zones, 5 seams (1.5–9.0 m thick), lateral quality variations; steam coal	
Witbank		Volksrust		• No. 5 Seam 0–2 m; erosional remnants	
				• No. 4 Seam 2.5–6.5 m; split into Nos. 4 A, 4 Upper, 4 Lower by mudstone/siltstone; economically important; lower quality than No. 2 Seam • No. 3 Seam 0.5 m; high quality; generally uneconomic • No. 2 Seam 4.5–20 m; up to 6 quality zones; most economically important for export steam coal • No. 1 Seam 0–3 m; patchily developed due to pre-Karoo topography	

Witbank Coalfield
(Image Landsat © 2014 AfriGIS (Pty) Ltd Image © 2014 DigitalGlobe © 2014 Google)

	GEOLOGY	IGNEOUS INTRUSIONS
	Seams are flat lying to gently undulating	Dykes (0–1 m) common (east, northeast, north); most prominent dyke: Ogies dyke (15 m thick, 100 km long, strikes east–west)
		Sills (15–50 m) transgress seams causing tilting & displacement of seams – mining blocks at different elevations lead to mining problems[17]; degree & extent of coal burning associated with intrusions poses a serious problem to mining & to resource estimation[17]

Witbank Coalfield
(Bruce Cairncross)

Table 1.3 Quality Characteristics of the Coalfields of South Africa[4]

COALFIELD	COAL QUALITY
Ermelo	The Ermelo Coalfield's E Seam is of reasonable quality but the economic potential of the seam decreases southwards as it becomes torbanitic and/or shaly whereas in other areas it might be too thin to be viable for mining[18]. The D Seam is of good quality and has no clastic partings but has a high proportion of vitrain with minor durain bands[1, 18]. The C Lower Seam is the most important seam as it is the main source of export coal[9]. The C Upper Seam is generally of poorer quality, has no in-seam partings and may be torbanitic in the upper part; however, the lower part of the seam is usually of good quality, making it the main target for mining. It is typically mined to supplement the C Lower[1, 9]. The B Seams are low quality, dull coal that contains fewer vitrain bands than the lower portion of the C Upper Seam[18].
Free State	The Free State Coalfield's Bottom Seam is of low-grade steam coal with poor washing characteristics[8]. The Top Seam comprises lustrous coal with bright stringers & is of better quality[8].
Highveld	The No. 2 Seam contains low-grade bituminous coal with an ash content of 22–35% & a CV of 20–23 MJ/kg. In areas such as Leandra, where the No. 2 Seam is of better quality & has good washability characteristics, a coal product of 27 MJ/kg at yields of greater than 70% can be produced. The No. 4 Seam contains mainly low-grade bituminous coal with an ash content of 20–35% & a CV of 18–25 MJ/kg. However, the ash content can increase to 40% & CV can drop to 15 MJ/kg in the topmost 1–2 m. In areas where the seam is much thicker, the ash can be as low as 21% and the CV about 23 MJ/kg in the bottom 3–4 m of the seam[19]. The No. 4 Upper Seam quality is extremely variable but the seam generally contains low-grade bituminous coal with approximately 25% ash content and a CV of 22 MJ/kg[19]. The No. 5 Seam has better quality coal than the other seams, with a raw in situ CV of > 25 MJ/kg, and ash & volatile matter contents of 19% & 32% respectively. It can be a source of metallurgical coal, such as is mined at the No. 2 Mine at Kriel Colliery[9].
Klip River	The Bottom Seam in the Klip River Coalfield (equivalent to the Gus Seam) is high in sulphur & phosphorus, with sulphur usually ranging from 1.3% to 1.8%[1, 10]. The Top Seam (corresponding to the Alfred Seam) has a smaller bright coal proportion than the Bottom Seam[1], but like the Bottom Seam, the rank of the Top Seam ranges from bituminous to anthracitic with generally high sulphur & phosphorus content. In general, the Klip River Coalfield contains bright coal with the rank ranging from bituminous to anthracite; in the central part of the coalfield, good coking coal has been produced in the past.
Limpopo (Tuli)	The washed coal characteristics[11] indicate yields of 47–53% with ash values of 10–12%, volatiles of 35.5–36.5%, sulphur of ~ 1.1% & swelling indices of 8.0–8.5.
South Rand	The South Rand's No. 2 Seam is composed mainly of dull coal but with fairly constant coal quality throughout the seam[13]. The Ryder Seam is generally of low quality with a CV of about 18 MJ/kg & is prone to spontaneous combustion[1, 13].
Soutpansberg	The Soutpansberg Coalfield is known to have some hard coking coal, but little other quality information is available.
Springbok Flats	Analysis of coal qualities in the Springbok Flats Coalfield has resulted in the establishment of a well-defined CV to ash relationship. The linear relationship has been found at all fractional yields[12] & this is very useful in terms of exploration. Down-hole geophysical methods can be used not only to identify coal seams within the Coal Zone but also to determine ash & CV values for the identified seams in each borehole. Sulphur content, in raw coal, ranges from 2 to 4% & averages ±1.5% in the beneficiated product.

COALFIELD	COAL QUALITY
Utrecht	In the Utrecht Coalfield, the seams have been a major source of moderately good coking coal & require little beneficiation[15]. The Lower Dundas Seam rank varies from medium volatile bituminous to anthracitic, with the coal mined as a source of bituminous coal in the northeastern sector of the coalfield & as anthracite in the southern sector. However, the sulphur content can be high – in excess of one per cent[15]. The Gus Seam is subdivided into three coal quality zones with the upper part comprising mainly dull coal, the central part predominantly bright coal & the bottom section mainly poor quality coal with shale partings. The seam has elevated methane gas concentration[1, 15]. The Alfred Seam is of better quality in the Utrecht Coalfield, particularly towards the bottom portion of the seam. The seam is generally high in ash & sulphur content but beneficiation can produce relatively high-quality, low-ash coal with low sulphur & phosphorus[15].
Waterberg (Ellisras)	Little information is published regarding the overall coal qualities of the Waterberg (Ellisras) Coalfield, although it is known that the coal rank increases steadily from west to east[14]. It must be assumed that qualities observed at GCM are representative of the entire coalfield.
Witbank	In some areas of the Witbank Coalfield, the No. 1 Seam is a source of high-grade steam coal suitable for export after beneficiation[1, 17]. According to Barker[9], the No. 1 Seam frequently has very low phosphorus content & in such cases it is usually mined separately as metallurgical feedstock. The No. 2 Seam contains some of the best quality coal. It generally displays a well-defined zoning with up to seven distinct coal zones (five in some areas) of different coal quality, with the three basal zones being mined mainly for the production of low-ash metallurgical coal & export steam coal. The upper part of the seam is generally shaly & unmineable; selective mining takes place within the better quality, lower part of the seam[17]. The No. 4 Seam is generally of poor quality & consists of predominantly dull to dull lustrous coal with the upper portion being of poor quality. Thus mining is restricted to the lower 3.5 m portion of the coal-seam, which is mainly used as a power station feedstock & as domestic steam coal[17]. The No. 5 Seam has been mined as a source of blend coking coal & for metallurgical uses, especially in the central Witbank area where it is of higher quality[17].

▶ The importance of cost-effective mining

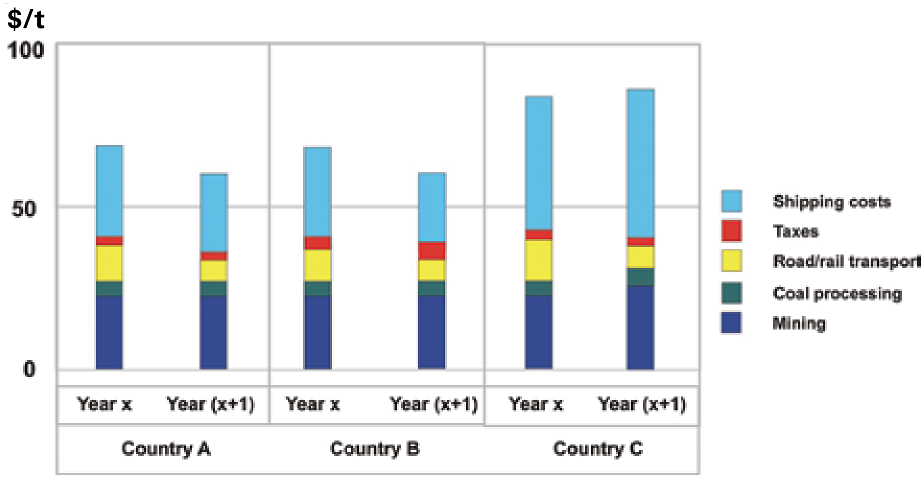
The critical issue of mining cost-effectively needs to be viewed from a global as well as a local perspective. Globally, mining competes with a variety of sectors for financial investment, and generally attracts investors who are risk-seeking and able to endure the ups and downs associated with commodity price cycles. In South Africa, investors have a variety of commodity investment choices. Coal is a bulk commodity – one which has a low market price per unit but is mined in sufficiently large quantities to make it financially viable. Smaller quantities mined will be transported over short distances, while large quantities mined can be carried over longer distances thanks to their higher associated revenues. This is different from platinum or gold (for example), which are mined in limited quantities, transported over shorter distances, but command very high market prices.

Overall profit is determined by subtracting total costs from total revenue. Costs can either be fixed or variable (depending on the quantity of material mined). Maximum profit is therefore achieved by maximising the amount received as income from the quantity of coal sold, while minimising costs.

It is therefore very important to mine as cost-effectively as possible. The correct staff complement must be in place to run the mine: if there are too many people, the wage bill will be too high; if there are too few, then vital business functions will not be achieved. Operating costs such as vehicle repairs, fuel expenditure and mining costs are all-important in reducing variable costs so that an overall profit can be made.

A way to compare coal producers is to construct an industry cost curve. Such a curve plots cumulative production on the X-axis against average cash costs on the Y-axis. Operations with lower cash costs will plot lower on the curve than expensive operations, with tighter margins at the higher end of the curve. It is common practice to target overall cost-effectiveness by attempting to move progressively lower (cheaper) on the cumulative cost curve. The generic cost curve shown in Figure 1.5 illustrates how a producer's cost of producing coal can be tracked over time and compared to that of other producers.

Figure 1.5 Generic example of coal cost curves



The better a coal mining company is at securing favourably priced contracts to generate stable long-term revenues, and at reducing both fixed and variable costs, the more cost-effective its mining will be. Investors will view the financial rewards favourably and there will be profit available for reinvestment, or for acquisitions to increase production or dividend payments.

We need to appreciate how this relates to local coal mining. In South Africa, three different methods are used to extract coal:

- **Bord-and-pillar mining** – only some of the coal is extracted, while the remainder is left in place as pillars to support the overlying rocks. Partial pillar extraction may be done towards the end of mining to win additional coal, but a considerable amount of coal is left in the ground. If sufficient support is left, the roof rocks can remain stable. Continuous miners, shuttle cars and conveyor belts are used to remove the coal.
- **Longwall mining** – the coal is removed entirely and the roof allowed to collapse into the mined-out void. The mining face is protected by hydraulic supports which move forward as mining progresses. Collapse causes fracturing of the overlying rocks and can cause subsidence of the surface if mining is shallower than about 200 m. In such cases, fractures will extend through to the surface. Here too, coal removal is performed by continuous miners, shuttle cars and conveyor belts.
- **Open-cast mining** – topsoil cover is removed to stockpiles, the overburden is blasted and the coal is then blasted and removed. Removal may be performed either by trucks and shovels, or by the use of draglines. During rehabilitation, the broken rock is returned to the pit, followed by the stockpiled topsoil, restoring the original surface contours as far as practically possible. The site is landscaped and the original vegetation type is replanted[2].

Open-cast mining is becoming more common today, as advances in technology and equipment allow economic coal extraction at greater and greater depths. Many abandoned underground coal mines that still have significant reserves are being re-mined using open-cast methods.

The uncomplicated structure of the Witbank coalfield has made it the most significant coal mining area in the country[20]. However, the traditional coal mines in the Witbank, Ermelo and Highveld coalfields are close to exhaustion, as new large mines become rare and smaller mines increasingly common. Together with operational and technological constraints, this has resulted in slow growth of overall coal production. Constraining the cost of coal mining is becoming more and more critical to the continued health of the industry. Exploitation of non-traditional coalfields will be technically more challenging due to their poorer coal quality and more complicated structure, which will lead to an increase in mining costs. In addition, the non-traditional coalfields are further from the industrial centres and export ports, and adequate infrastructure is generally lacking, which results in increased costs for logistics and transport. Thus the local coal mining industry will be facing many challenges in the next few years, as it aims to extract the remaining coal reserves at competitive costs. Local coal producers will have to critically assess the way they have been mining in the past and will be mining in the future; and the harnessing of technologies such as geophysics undoubtedly has a key role to play in the future of coal mining in South Africa.

The importance of continued exploration

The global economic boom that began a decade ago has resulted in a great demand for mineral resources, of which coal is one of the most important, because it is the main source of energy in China and India. Although these two countries have the second and third largest coal resources in the world after the USA, there is at present insufficient domestic coal production in India to meet its needs, while China exports only 2.1% of its annual production[21]. India imports coal from South Africa, and there is a vehement debate in the press between Eskom, government and the coal miners about this issue. The main discussion is about whether South Africa should be exporting the steam coal (at premium export prices) that is needed by Eskom locally. In addition, the critical shortage of anthracite-grade coal, used in steel production, has resulted in record prices for this commodity.

Exploration for new coalfields is very active at present, both in South Africa and in the rest of Africa. In this country, the exploration is mainly geared towards the definition of mineable reserves within known coalfields, and its success in several areas has created environmental issues related to to the establishment of mines. One example is the controversy over mining near the Mapungubwe World Heritage Site in northern Limpopo Province.

Locally, the Eskom coal-fired power stations were built close to mines from which the feedstock was easily derived. These nearby coal reserves are, however, being depleted, and there is a pressing need to convert identified coal resources into mineable coal reserves by continued exploration. This type of 'brownfields' or close-to-mine exploration is vital for sustainable mining. The importance of adequate coal feedstock close to the power station is illustrated by the poor state of roads in the Witbank and Highveld coalfields in Mpumalanga Province because of the heavy coal trucks operating between mine and power station.

The drive towards more Black Economic Empowerment (BEE) involvement in the mining sector has led to the establishment of over 20 junior coal mining and exploration companies in South Africa. Many of these companies own small tracts of mineral rights adjacent to and within the Highveld, Witbank and Ermelo coalfields. These areas need to be adequately explored to exploit the coal and enable the BEE companies to play a significant role in the country's coal supply chain.

There is no doubt that coal exploration will continue to be an important activity both locally and on a global scale as the world's population and economy continue to grow, along with the demand for cheap energy that is needed to sustain that growth.

In summary, continued coal exploration is required for a number of reasons:

- Production from the traditional coalfields needs to be replaced, but should in the meantime be optimised; for example, through the extraction of methane from currently uneconomic deposits.
- The non-traditional coalfields have not been as thoroughly explored and their characteristics are less well known,

▶ The role of geophysics (and this book)

Coal mining companies continue to face the traditional production-related challenges of mining cost-effectively and of extending the life of their mines through optimal extraction and continued exploration. Furthermore, the need to mine safely and in an environmentally responsible manner has placed additional pressures on the mining companies. These challenges often create, or are complicated by, specific operational problems; and it is here that geophysics may play a prominent role. To give some examples: the re-mining of old workings may pose a safety hazard due to the presence of difficult-to-detect near-surface cavities, while in some areas the old workings may be the source of unwanted pollution plumes. In areas where underground mining is being conducted, efforts to mine cost-effectively are sometimes compromised by unexpected igneous intrusions (dykes and sills) that interrupt the continuity of the coal seam. Where the continuity of the seam is not disturbed, variations in seam thickness may adversely affect extraction by causing too much coal to be left in the roof or floor; in other cases it is critical to leave a certain amount of coal in the roof for the purpose of stability. Highly variable seam topographies and sedimentary inclusions also impact negatively on optimal extraction.

Geological maps, borehole information and old mine plans (in the case of re-mining old workings) do not always provide enough detailed information to give coal miners sufficient advance warning about these and other mining problems. Geophysics can in many cases provide useful quantitative information about the subsurface ahead of mining operations, and in close proximity to them; however, we should highlight three key points relating to the successful application of geophysics:

- There is no universal geophysical method that can solve all mining problems. In fact, there are many geophysical methods, based on different physical principles, and each has its strengths, weaknesses and niche applications;
- What works at one site does not always work elsewhere – the applicability of a given geophysical method is site-specific, ie the performance of a geophysical method is not just a function of the strengths and weaknesses of the method, but also of the characteristics of the site;
- Every geophysical method has its characteristic limitations in terms of performance parameters such as range and resolution (mapping accuracy).

It is evident that selecting a geophysical solution for a given coal-mining problem is not always straightforward. In some cases there may be more than one applicable method, while in other cases, there may be no suitable geophysical solution available. This book aims to provide non-experts with a better understanding of those geophysical methods most likely to be applicable to common coal-mining problems.