# CHAPTER 1: SOUTHERN AFRICAN COAL DEPOSITS

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## THE KAROO SUPERGROUP

Southern Africa’s coal seams are hosted in Permian-aged rocks of the Karoo Supergroup, except for the Triassic Molteno Coalfield in South Africa (Langford, 1992; Cairncross, 1987, 2001). The Karoo Supergroup is the most widespread stratigraphic unit in south-central Africa (Figure 1.1), and consists of a sequence of units, mostly of non-marine origin, deposited between the Late Carboniferous/Pennsylvanian and Early Jurassic across Gondwana, over a period of about 120 million years (Schlüter, 2008). Sedimentary deposition continued until the break-up of the supercontinent during the Middle Jurassic (ca. 183 Ma) (Duncan *et. al*., 1997; Cole, 1998; Catuneanu *et al*., 2005; Schlüter, 2008), followed by massive igneous activity, which affected the coalfields by causing intrusions of sills and dykes that created a large igneous province across southern Africa (Catuneanu *et al*., 2005). The Karoo deposition includes several groups, in stratigraphic succession: the Dwyka at the base, followed by the Ecca, Beaufort, Stormberg, and Drakensberg Groups (Figure 1.2). These groups were established in the relatively well-studied Main Karoo Basin (MKB) of South Africa, and extrapolated to other Karoo-aged basins across south-central Africa. Cairncross (1987, 2001) provides lithostratigraphic unit correlations across southern Africa. The lithostratigraphic character of the Karoo sequence changes significantly across Africa, specifically between the north and south of the equator due to the shifts in tectonic and climatic conditions (Catuneanu *et al*., 2005). The northernmost traces of the Karoo Supergroup are recorded in Dwyka glacier deposits of Gabon (Jardine, 1974), at Wadi el Malik in Sudan (Klitzsch and Wyciks, 1987), and the Gulf of Guinea to about Qatar on the eastern shore of the Arabian Peninsula (Wopfner, 1991, 1999). The formation of Karoo coal-bearing successions in the Permian appears to extend only as far north as the Congo Basin, central Tanzania, and central Madagascar.

**Figure 1.1: Distribution of the Karoo Basins in southern Africa. Darker shading indicates proven coalfields within the Karoo Basins (Council for Geoscience).**

**Figure 1.2: A simplified stratigraphy of the Karoo Basin of southern Africa, with a specific focus on the Ecca coal-bearing Formations (not to scale) (Modified after Lurie, 2013).**

In southern Africa, rocks of the Karoo Supergroup cover almost two thirds of the present land surface, including all of Lesotho, almost the whole of the Free State, large parts of the Eastern Cape, Northern Cape, Mpumalanga and KwaZulu-Natal Provinces of South Africa, as well as Botswana, Namibia, Swaziland, Zambia, Zimbabwe, Tanzania, and Malawi. Karoo Supergroup sediments are also found on other continents which were once part of Gondwanaland, i.e. Australia, Antarctica, Falkland Islands, India, and South America. The sediments attain a maximum cumulative thickness of 12 km, as seen in the axis of the MKB, with the overlying basaltic lavas (the Drakensberg Group) at least 1.4 km thick (Adelmann and Kerstin, 1996). The fossils encountered in the Karoo rocks include plants (both macro-and micro-fossils with pollen), rare insects and fish, common and diverse tetrapods (mostly therapsid reptiles, temnospondyl amphibians, and, in the upper strata, dinosaurs), and ichnofossils (trace fossils). Their biostratigraphy has been used as the international standard for global correlation of Permian to Jurassic nonmarine strata (Hancox and Rubidge, 1997).

The sedimentary fill of the Karoo basins during the Karoo times accumulated under the influence of two main controls, namely tectonism and climate. The tectonic regime varied from dominantly flexural in the south, to extensional to the north. Processes of subduction, accretion and mountain building occurred along the Panthalassan (palaeo-Pacific) margin of Gondwana in the south, and extensional processes occurred along the Tethyan margin of Gondwana in the north (Johnson, 1976; Catuneanu *et al*., 2005). The well-studied MKB has been interpreted as a compressional retroarc foreland system formed during the shallow-angle subduction of the palaeo-Pacific plate beneath the Gondwana supercontinent. This subduction led to the building of the wide fold-thrust belt, forming the Cape Fold Belt (CFB) (Schlüter, 2008). The northern Karoo basins are thought to occur in tectonically controlled, compression and extensional related intra- or inter-cratonic grabens and half-grabens (Cairncross, 2001). However, Catuneanu *et al*. (2005) also provide evidence for flexural subsidence in the back-bulge region of the Karoo foreland system. Hence, it could be that the latter preceded the former, and both were at play during peat accumulation. Although the MKB has been proposed as the type basin for coal-bearing deposits of southern Africa (Cadle *et al.,* 1993), the MKB (distal foreland) has different characteristics from the other (extensional rift) Karoo-age basins of southern Africa due to the tectonic regime controls (Catuneanu *et al*., 2005).

Climatic fluctuations were superimposed on the tectonic controls of the basin development, providing a common thread for the sedimentary fill across all Karoo basins in spite of tectonic regime changes (Catuneanu *et al*., 2005). Figure 1.3 shows evidence of a general shift from cold and semi-arid conditions during the Late Carboniferous–earliest Permian, to warmer and progressively hotter climates with fluctuating precipitation during the rest of the Karoo times (Keyser, 1966; Johnson, 1976; Visser and Dukas, 1979; Stavrakis, 1980; Tankard *et al.,* 1982; Falcon, 1986a; Visser, 1991a,b; Catuneanu *et al*., 2005). Correlations of the southern African Karoo basins and sub-basins have been covered in detail by Cairncross (2001), Johnson *et al*. (1996), Catuneanu *et al.* (2005), and reviewed by Hancox (2016).

**Figure 1.3: Progressive climatic and vegetation events during the Karoo depositional sequence (modified after Falcon, 1986).**

## COALFIELDS OF SOUTHERN AFRICA

The coalfields of southern Africa (Figure 1.4) are mostly hosted in the Ecca Permian-aged rocks of the Karoo Supergroup (Langford, 1992; Cairncross, 2001), underlain by the Dwyka and extending through the Ecca and into the Beaufort Groups (excluding the Molteno-Indwe Coalfield). The Ecca Group is at its thickest in the southernmost part of the Karoo Basin, thinning northwards. The thickness is also affected by palaeochannels in the basement and tectonic activity. The rocks reveal a clastic sequence of mudstone, siltstone, sandstone, minor conglomerate and coal, all of which outcrop at various places across southern Africa. According to Catuneanu *et al*. (2005), the Ecca is well-documented in Namibia, Botswana, Zimbabwe, and Tanzania, and less well described in the other southern African countries. In the northern South African coalfields, Zimbabwe, and Mozambique, the coal is hosted in mudstone/shale sequences, and in the MKB, Botswana and Namibia, the coal is more typically hosted interbedded in sandstone sequences (Catuneanu *et al*., 2005). The Vryheid Formation (Middle Ecca) (Figure 1.2) contains the largest occurrence of coal deposits. It is believed to be a clastic wedge, thickest in the northeast and east, and pinching out towards the south and southwest across the MKB (Hobday, 1978; Catuneanu *et al*., 2005). Coal rank ranges from sub-bituminous to high-volatile bituminous to anthracite, affected by geothermal gradients as well as the dolerite intrusions. By far the majority of the coal is bituminous in rank, with no lignite or brown coal deposits reported for the region. Typically, the coals are considered to be high in ash and low in sulphur (compared to Northern Hemisphere coals), and are typically inertinite-rich. However, these are generalisations, as is evident from the following tables.

Coal is the major economic deposit of the Ecca Group across southern Africa, although it does not occur in all Ecca sedimentary sequences. The coal mining industries in South Africa and Zimbabwe are well developed, although on a far smaller scale in Zimbabwe compared to South Africa. In Botswana and Mozambique, coal exploration and relatively small-scale mining occur, for internal consumption in Botswana and for export from Mozambique. Coal mining occurs in Zambia, Tanzania, Malawi, DRC (Democratic Republic of Congo), and Madagascar, again typically on a small scale and for local use. No commercial coal mining occurs in Namibia. The coal quality data summarised in the following tables (Tables 1.1–10) reflects the amount of published information pertaining to the coal deposits in each of the southern African countries, which largely reflects the development of the coal industry in that country. The localities for each coalfield are indicated in Figure 1.4.

**Figure 1.4: Distribution of the major coalfields of southern Africa (modified after Johnson *et al*., 1996; Westscott and Diggens, 1998; Nyambe, 1999; Wopfner, 2002; Catuneanu *et al.* 2005; prepared by the CGS in 2016)**

### 1.1 The coalfields of South Africa

South Africa is considered to be the industrial hub of southern Africa. The country is rich in fifty-four mineral resources and is highly dependent on coal as the major source of energy. Coal is used as a primary energy source in South Africa, and estimated reserves are reported as 55 Gt (based on a 115 Gt resource) (Bredell, 1987). Prevost (2015), however, lists the reserves as 32.15 Gt. Over 90% of South Africa’s electricity is generated from coal combusted in large power stations, and coal is used extensively in the metallurgical and coal-to-liquids industries, and domestically. Detailed overviews of the South African coalfields and associated coal qualities have been published by Falcon (1986b, 1989), Bredell (1995); Snyman (1998), Jeffrey (2005), and Hancox and Götz (2014), Hancox (2016), amongst others. Most of South Africa’s coals are hosted in five basins, namely: 1) the MKB; 2) Springbok Flats Basin; 3) Tuli Basin extending to Zimbabwe and Botswana; 4) Waterberg/Ellisras Basin which extends into Botswana; and 5) the Limpopo/Soutpansberg/Tshipise Basin extending into Botswana, Mozambique, and Zimbabwe. Typically, nineteen coalfields are reported for South Africa, although frequently several are clustered together (as is the case in Table 1). Hancox and Götz (2014) published a detailed assessment of the South African coalfields.

The major differences in coal quality between the MKB and other coal basins in South Africa relate to their tectonic structural differences. The MKB is considered by most authors to be a retroarc foreland basin (Catuneanu *et al.,* 1998), whilst the other basins are structurally controlled intra- or inter-cratonic grabens and half-grabens (Cairncross, 2001). Coal in the Vryheid and Volksrust Formations is predominantly hosted in multi-seam deposits in both basin types, although either one of the formations may be absent. Over 98% of South African coals are medium-rank C bituminous coals, with a very small proportion of prime coking coal and anthracite. There is a general increase in coal rank from the west to the east, largely driven by the thickness of the continental crust and increases to the palaeogeothermal gradient (Snyman and Botha, 1993). The igneous intrusions have resulted in the sterilisation of some coal occurrences due to devolatilisation, and have resulted in rank advance in other locations.

Typically, the coals are high in ash and rich in inertinite across the MKB, although the qualities vary from seam to seam and coalfield to coalfield throughout. For example, of the five seams found in the Witbank coalfield, Number 1 Seam at the bottom and Number 5 Seam at the top are generally vitrinitic in composition with moderate ash contents, whereas the Number 4 seam is known to be inertinite- and ash-rich with minor variations at the base of the seam. Number 2 seam is highly variable from area to area and is characterised by multiple alternating bands of bright and dull coal. The latter was the most commercially important seam, having provided both low-ash blend metallurgical coal products, and low- and high-grade middlings washed products for local and export purposes over the past 40 years. Almost completely mined out now, the Number 2 Seam has been replaced in the marketplace by the Number 4 Seam, which is notably limited in its quality and product variations, being mainly low- to medium-grade steam coal. The Number 5 Seam is a thin seam characterised by low phosphorus, low ash, and high vitrinite and liptinite contents.

For many years this was one of the most important seams for metallurgical purposes and as such was protected from export by legislation. This seam, too, is largely mined out now, having been replaced over time by the vitrinite-rich hard coking coal seams found in the northern coalfields in the Soutpansberg and semi-soft coking coals from the Upper Zones in the Waterberg Coalfields. The Highveld and Ermelo Coalfields have similar numbers of seams to the Witbank Coalfield, but these vary widely in composition. The Highveld Coalfield produces moderate-ash, mixed inertinitic-vitrinitic coals suitable for the Sasol Lurgi gasification coal-to-liquids process. A commercially interesting in-seam deposit of “torbanite” (actually boghead and cannel coal) exists in the Ermelo coalfield. Generally enriched in alginite and abundant fine clay with occasional bands of cannel coal interbedded, all set within a major “normal” coal seam, this deposit has been explored on several occasions over the past 40 years with a view to extraction for direct liquefaction coal-to-liquids production purposes. Economics has precluded its exploitation to date.

The KwaZulu-Natal Coalfields possess up to six coal seams, all thin, generally vitrinite- and pyrite-rich and limited in extent, with certain areas producing pockets of hard and soft coking coal and anthracitic deposits depending on their proximity to the extensive sills and dykes which permeate the coalfields in that province. Coals in the Free State Coalfields are well known for their sub-bituminous and extensively inertinitic- and clay-rich nature, lying as they do on the flank of the KaapVaal granitic Craton. Seams from the latter typically produce low-grade steam coals for power generation.

The northern coalfields of South Africa occur in the Limpopo Province, in the Waterberg, Soutpansberg and Tuli Basins. The better studied Waterberg coals are petrographically unique as they possess Upper Ecca/Lower Beaufort coal “Zones” composed of finely layered clay and vitrinite-rich bands locally known as “bar-code” coals. Difficult to beneficiate (such as in the Grootegeluk Mine) these coals yield low proportions of vitrinite-rich soft coking coals (about 12%) and middlings of low-grade steam coals (35%) with over 50% discarded or used as backfill in the mine. The lower Middle Ecca coals of the Waterberg Coalfield lie below the Upper Coal Zone in the form of three or four clearly discrete inertinite-rich coal seams which are unusually low in ash content. The highly variable grades and petrographic properties in the coal seams of the Waterberg Coalfield have given rise to a complex washing process which typically yields up to seven distinct products for the marketplace.

The petrographic and mineralogical (ash) properties are equally variable in the coalfields of other countries in the region, but detailed information is generally sparse.

An overview of the South African coal qualities is presented in Table 1.1.

**Table 1.1: Summary of coal deposits and coal qualities of South Africa; refer to Figure 1.4 for localities. (The seams are listed with deepest seam first; unless otherwise stated, all qualities are reported on a raw coal, air dried basis). (Main sources of information: Bell, 1986; Snyman, 1998; Jeffrey, 2005; Pinheiro, 1999; Prevost, 2012; Lurie, 2013; Hancox and Götz, 2014; Hancox, 2016; and others listed in the table. Coal qualities are derived from the CGS Coal Core database).**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Coalfields of South Africa** | | | | |
| **Map No.** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
|  |  |  |  |  |
| **1** | **Molteno-Indwe** | Triassic  Molteno Formation | Six seams: Indwe, Guba, Molteno, Gubenxa, Cala, & Piet | The coalfield is located in the Eastern Cape, and extends in an arc from Aliwal North and Jamestown in the west, through Molteno, Dordrecht, Indwe and Elliot, to north of Maclear in the east. The deposit was the first coal discovered in South Africa. The high-ash, generally vitrinite-rich coal is medium-rank A to high-rank A. The coal is currently mined and utilised by small-scale miners for brick making.  Indwe, Guba, and Molteno seams have economic potential in places. However, they are mainly of poor quality. The Indwe and Guba seams have high ash content of 31–51% unwashed and 26–27% when washed, high moisture (IM) content of 7–11%, low volatile matter (VM) of 7 to 12%, and a calorific value (CV) of 23.9–25.9 MJ/kg (De Jager, 1983). No quality data was obtained for Gubenxa, Cala, and Piet seams. |
| **2** | **Somkele/Somkhele** | Beaufort  Emakwezini Formation | Three seams: Lower Main, Upper seam 1, & Upper Seam 2. | The coalfield is located in the province of KwaZulu-Natal (KZN); it stretches from Dukaneni in the south to the Swaziland border in the north, occurring on the south-eastern margin of the MKB. The coalfield has a high frequency of dykes, and is also faulted. The coalfield mainly produces high-quality anthracite, with a low Total Sulphur (TS) (<1%) and very low phosphorus. Small-scale operations are in place. |
| **3** | **Nongoma** | Ecca to Beaufort  Volksrust, Vryheid & Emakwezini Formations | M-1, M, & M+1; or Lower, Middle, Upper; A (A1 & A2), B (B1 & B2). | The coalfield is situated in central KZN and stretches from east of Gluckstadt in the west, where it shares a common boundary with the Vryheid Coalfield, to a north-south running boundary in the east, where it abuts against the Somkhele Coalfield in the MKB. The coal formed in a fault-bounded graben, which is also faulted, and is anthracitic/high-rank C–B. Most large mines in this coalfield have been abandoned, with a few small-scale miners in operation.  The A coal seam has a thin A1 seam and a thicker A2 seam with raw ash values of between 28 and 33%; CV between 20.98 to 22.73 MJ/kg; IM between 1.38 to 1.90%; VM between 6.21–7.05%. Anthracite occurs in the lower A zone. The B seam consists of two seams, namely B1 and B2 with raw ash values that range from 22.5 to 33.5%; CV ranges from 21.55 to 22.92%; IM 1.28 to 2.11%; VM ranging from 6.25 to 7.18%; and Fixed Carbon (FC) that ranges from 58.95% to 61.14%. Anthracite occurs in the upper part of the B Zone. |
| **4** | **Vryheid** | Ecca  Vryheid Formation | Up to 9 seams, including Coking, Dundas, Gus, Alfred, & Fritz | The coalfield is separated from the Utrecht Coalfield by an area that is devoid of coal due to erosion from the Cenozoic to recent times. The potential coal-bearing area extends from the town of Kingsley in the west to Louwsburg in the east and from Nkambule in the north to Gluckstadt in the south in the MKB. The coal is medium-rank bituminous/medium-rank A bituminous. Most large mines in this coalfield are abandoned, with a few small-scale miners in operation.  The Coking seam is thin, but of a high quality, previously yielding a good coking coal. The Dundas coal seam is mined as coking or steam coal (Bell and Spurr, 1986) with average coal qualities of: ash = 19.09%, CV = 19.75 MJ/kg, IM = 1.67%, VM = 7.21%, and FC = 38.64% . Average coal qualities for the Gus seam are: ash = 22.2%, VM = 6.70%, CV = 18.99 MJ/kg, and IM = 1.73%. The Alfred seam is of low grade with poor coking coal quality, with an average CV of 18.84 MJ/kg, ash content of 22.47%, IM of 1.86%, VM of 6.8%, and FC of 49.58%. The Fritz seam is generally of fairly high grade but with a high sulphur content (Bell and Spurr, 1986) and is usually mined together with other seams in opencast operations. |
| **5** | **Utrecht** | Middle Ecca  Vryheid Formation | Four seams: Coking, Dundas, Gus, & Alfred. | The coalfield, hosted on the edge of the MKB, is located in the southern part of KZN, between Newcastle and Vryheid, separated from the Klipriver Coalfield by the Buffalo River. These coals have been a major source of moderately good coking coal following beneficiation (Spurr *et al*., 1986). A lot of the coal has been destroyed by dolerite sill intrusions. Most large mines in this coalfield are abandoned, with a few small-scale mining operations.  The Coking seam has average coal qualities: ash = 9.1%, VM = 23.8%, CV = 31.4 MJ/kg, and IM content = 1.6% (Spurr *et al.,* 1986). The Lower Dundas seam rank varies from medium-volatile bituminous to anthracitic, with the coal mined as a source of bituminous coal in the north-eastern sector of the coalfield and as anthracite in the southern sector (ash = 10.3%, VM = 28.3%, CV = 30.2 MJ/kg, and IM = 1.9%) (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. Average coal qualities are: ash = 14.3%, VM = 10.6%, CV = 29.5 MJ/kg and IM = 1.4% (Spurr *et al.,* 1986). 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 and TS but beneficiation can produce relatively high-quality, low-ash coal with low TS and phosphorus; average coal qualities: ash = 40.2%, VM = 11.7% and IM = 1.2% (Spurr *et al*., 1986). |
| **6** | **Klip River** | Ecca  Vryheid Formation | Five seams: Extra-bottom, Bottom, Elands, Fritz, & Top. | The coalfield, hosted in the MKB, has its apex in the north beyond the town of Newcastle and continues to Ladysmith in the south and to Dundee in the south-east. In general, the 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. Average raw coal qualities are: ash = 23.31%, VM = 19.68%, CV = 23.32 MJ/kg, and IM = 1.47%. This coalfield is currently mined for steam and export coal.  The Extra-bottom seam, not usually mined, has average coal qualities: CV = 25.85 MJ/kg, IM = 1.42%, ash = 24.57%, VM = 19.91%, and FC = 51.35%. The Bottom seam (equivalent to the Gus seam) has high sulphur (1.3 to 1.8%) and phosphorus contents (Bell and Spurr, 1986a), but is extracted economically; average coal qualities are: CV = 22.41 MJ/kg, IM = 1.7%, ash = 24.06%, VM = 18.39%, and FC = 51.76%. The Elands seam has average coal qualities: CV = 25.65 MJ/kg, IM = 1.12%, ash = 20.52%, VM = 21.75% and FC = 61.54%. The Fritz coal seam has average coal qualities: CV = 20.94 MJ/kg, IM = 1.25%, ash = 22.83%, VM = 20.74% and FC = 53.79%. The Top seam (corresponding to the Alfred seam) is extracted economically. The rank ranges from bituminous to anthracitic with generally high sulphur and phosphorus content, and average coal qualities: CV = 21.73 MJ/kg, IM = 1.84%, ash = 24.57%, VM = 17.62%, and FC = 52.53%. |
| **7** | **Ermelo** | Ecca  Vryheid Formation | Five seams: Seams E–A. | Ermelo Coalfield is located in the Mpumalanga Province in the MKB, and extends from Carolina in the north to Wakkerstroom in the south. Sills and dykes impact mining and have devolatilised areas of the relatively thin coal seams, but overall the coal quality is better than that of the Witbank and Highveld Coalfields. The coalfield produces medium-rank C bituminous coal. The average coal qualities are: CV = 22.57 MJ/kg, ash = 26.74%, IM = 3.11%, VM = 23.64%, FC = 46.72%, and TS = 1.65%. This coalfield is currently mined for steam and beneficiated export coal.  The 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. Average raw coal qualities are: ash = 26.74%, VM = 24.57%, FC = 45.36 CV = 22.68 MJ/kg, and IM = 1.65% (Greenshields, 1986). The D seam is of good quality and has no clastic partings but has a high proportion of vitrain with minor durain bands (Greenshields, 1986; Snyman, 1998); it can be correlated to the Coking Coal Seam of the Utrecht Coalfield. The D seam average raw coal qualities are: ash = 24.79%, VM = 23.34%, FC = 45.75%CV = 24 MJ/kg, IM = 2.86%, and TS = 1.47%. The C seam is the principal seam, with average raw coal qualities: ash = 27.0%, VM = 23.34%, FC = 46.59% CV = 22.28 MJ/kg, IM = 3.36% and TS = 1.3. The B seam average raw coal qualities are: ash = 24.86%, VM = 23.42%, FC = 48.98%, CV = 23.31 MJ/kg, TS = 2.5%, and IM = 3.31%. It is also of low quality, a dull coal that contains fewer vitrain bands compared with the lower portion of the C upper seam (Greenshields, 1986). The A seam is thin and not economical. |
| **8** | **Highveld** | Ecca  Vryheid Formation | Five seams: No. 2 (upper & lower) Seam, No. 4 (upper &lower) Seam, & No. 5 Seam. | This large coalfield of the central MKB is located in south-eastern Mpumalanga Province, immediately south of the Witbank Coalfield, separated by the Smithfield Ridge which influenced the depositional environment between the two coalfields. Coal quality is typically lower and coals are deeper in the Highveld Coalfield than in the Witbank Coalfield. The coal is medium-rank D to primarily C bituminous. Sills and dykes have affected the coal quality and lateral continuity of the seams. This coalfield is mined extensively as a coal gasification feed, steam coal, and export coal.  The No. 2 seam contains low-grade bituminous coal with an ash content of 22–35%, IM 3.8%, 19.9% VM, and 20–23 MJ/kg CV. The No. 4 seam contains mainly low-grade bituminous coal with an ash content of 20–35%, IM of 2.5%, 19.9% VM and 18–25 MJ/kg CV. However, the ash content can increase to 40% and CV can drop to 15 MJ/kg in the upper one to two metres. The No. 4 Upper seam quality is extremely variable, but the seam generally contains low-grade bituminous coal with approximately 25% ash and a CV of 22 MJ/kg (Jordaan, 1986). The No. 5 seam has better quality coal than the other seams, with a raw *in situ* CV of > 25 MJ/kg, ash and VM of 19% and 32%, respectively. It can be a source of metallurgical coal but is usually too thin to mine economically. |
| **9** | **Witbank** | Ecca Vryheid Formation | Five seams: No 1 to No 5 Seam at the top. | The northern part of the MKB is home to the Witbank Coalfield, and is the primary coal mining area in the country, feeding the mine-to-mouth power stations. It extends from Springs to Belfast, and covers in excess of 568 000 ha. The coal is medium-rank C bituminous, inertinite-rich, of variable ash content (generally high). The seams are mostly flat-lying to gently undulating with a gentle southern regional dip. Large areas of the coalfield have been affected by Jurassic age dolerite sills and dykes, frequently devolatilising the coal and affecting mine planning. This coalfield is mined extensively for steam and beneficiated export coal.  The No. 1 seam frequently has very low phosphorus content, and in such cases it is usually mined separately as metallurgical feedstock. Average raw coal qualities for the No. 1 seam: ash = 25.4%, VM = 21%, CV = 24 MJ/kg, and IM = 1.7% (Smith and Whittaker, 1986b). The No. 2 seam contains some of the best-quality coal and accounts for about 70% of the coal resources in the coalfield. It generally displays a well-defined zoning with up to seven (five in some areas) distinct coal zones of different coal quality, with the three basal zones being mined mainly for the production of low-ash metallurgical coal and beneficiated export steam coal. Seam thicknesses vary from 6.5m in the central part, to 3m towards the east and west. Average raw coal qualities for the No. 2 seam: ash = 23.3%, VM = 21.5%, CV = 21.2 MJ/kg, and IM = 5.3% (Smith and Whittaker, 1986b). The No. 3 seam is generally extremely thin and not mined.  The No. 4 seam consists of predominantly dull to dull lustrous coal and is generally of poorer quality, with average raw coal qualities: ash = 27.6%, VM = 20.7%, CV = 22.2 MJ/kg, and IM = 2.6% (Smith and Whittaker, 1986b). Mining is restricted to the lower 3.5m portion of this coal seam, which is mainly used as a power station feedstock and as domestic steam coal. The No. 5 seam has been mined as a source of blend coking coal especially in the central Witbank area where it is of higher quality with a low phosphorus content. Average raw coal qualities: ash = 13.1%, VM = 32%, CV = 28.7 MJ/kg, and IM = 2.5% (Smith and Whittaker, 1986). This seam is shallow and frequently eroded, but can be up to 2m thick. |
| **10** | **South Rand** | Ecca  Vryheid Formation | Three seams: Nos. 1–3, & Ryder. | The South Rand Coalfield covers an area of some 60,000 ha (Henderson, 1986), situated between the town of Heidelberg in the north and Vaal Dam in Gauteng Province. The relatively thick coal seams, situated in a palaeovalley on the northern margin of the MKB, have average coal quality values: CV = 18.6 MJ/kg, ash = 34.2%, VM = 20.8%, IM = 1.1%, FC = 41.4%, and S = 1.1% (CGS coal core database). The coalfield is relatively severely faulted, and affected by the igneous intrusions. There is currently no coal mining occurring in the area.  No 1 to No. 3 coal seams have three coal zones comprised of Upper, Middle, and Lower coal zones. No. 1 seam has an average thickness of 2.8m (Henderson, 1986) and is composed of dull-lustrous coal with scattered bright streaks and bands. The No. 3 seam is on average 5m thick and is a widespread coal seam that was mined extensively in various areas of the Springfield Colliery. No. 2 seam is composed mainly of dull coal but with fairly constant coal quality throughout the seam (Henderson, 1986). The Ryder seam is poorly developed and generally of low quality with a CV of about 18 MJ/kg; it is prone to spontaneous combustion (Henderson, 1986). |
| **11** | **Vereeniging–Sasolburg** | Ecca  Vryheid Formation | Variable coal seams located in 3 sub-basins; No 1, 2A & 2B, Bottom/Middle and Top. | The Vereeniging–Sasolburg Coalfield is located in the Free State Province extending from just south of the town of Vereeniging in the north, to approximately 20 km north of Heilbron in the south, and from Sasolburg in the west to Deneysville in the east. The coalfield covers an area of 208 494 ha within the MKB. It is sub-divided into three basins separated by pre-Karoo ridges which affected seam thickness, namely the Cornelia, Coalbrook, and Sigma basins (Steyn and Van der Linde, 1986). The coal was used for petrochemicals and is still mined for steam coal.  The coal zone in the Sigma sub-basin is between 30 and 40m thick and contains four coal seams termed C1, C2A, C2B and C3 (De Beer *et al*., 1991). Seams C1 and C2 have an average CV of 18 MJ/kg, and ash of 31.5%; Seam 3 has a CV of 19.3 MJ/kg with an ash% of 29.8.  The Cornelia sub-basin main coal zone is approximately 30m thick and contains three coal seams, referred to as the Bottom, Middle and Top seams. All of the three seams have an average CV of about 16 MJ/kg and a 37.5% ash content (Steyn and Van der Linde, 1986).  The Coalbrook sub-basin has three coal units: No. 1, No. 2, and No. 3 coal units. The No. 3 has more than one seam, namely the No. 3 Upper (3U) and No. 3 Lower (3L) seams (Steyn and Van der Linde, 1986). In terms of raw coal quality, the No. 1 seam has a CV of 21.7 MJ/kg and 24.3% ash; No. 2 seam has indicated ash of 28.9% and CV of 19.6 MJ/kg; and the combined No. 3 seam has indicated CV of 19.9 MJ/kg and ash of 29.3% (Steyn and Van der Linde, 1986). |
| **12** | **Free State** | Ecca  Vryheid Formation | Three seams: Bottom, Middle, & Top; or the No 1–4 seams | The large Free State Coalfield, reflecting the western section of the MKB, is located in the north-western Free State Province, stretching from the Vaal River in the north to Theunissen in the south, overlying nearly all of the Free State goldfields. The coal is predominantly inertinite-rich, medium-rank D bituminous, and has been affected by sills and dykes. There are a few small mines in this coalfield, and an underground coal gasification project is in progress.  The Bottom seam (No. 2 seam) is an inertinite-rich, low-grade steam coal with poor washing characteristics with average raw coal qualities: ash = 27.7%, VM = 21.4%, CV = 20.5 MJ/kg, IM = 5.6%, TS = 1.4% (Gilligan, 1986). The Top seam consists of a lustrous coal with bright stringers and is of better quality than the Bottom seam (Gilligan, 1986), but is not continuous. Little is published about the inertodetrinite-rich Middle seam (No. 3 seam). |
| **13** | **Kangwane** | Ecca Vryheid to Volksrust Formations | Four seams: No. 1–4. | The Kangwane Coalfield, situated in the eastern part of the Mpumalanga Province, extends from near Komatipoort in the north, to the Swaziland border in the south, and covers an area of some 210,000 ha in the eastern MKB. The coalfield is structurally complex, comparable to the Somkele and Nongoma Coalfields, intruded by sills and dykes. Seam nomenclature is not standardised, with up to 14 coal seams defined during the various drilling programmes. Generally there are only four to five discrete coal seams present, usually relatively thin, but they may reach mineable widths in places. Due to the dolerite intrusions, semi-anthracite to anthracite coal occurs, and coal qualities are similar to those in the Somkhele Coalfield, but with a higher ash content. Raw coal qualities for the combined No. 2, 3, 4L, and 4U seams: ash % = 23.61, CV = 21.03 MJ/kg (Meyer, 2012). There is only one operating coalmine which has been in operation since 1987. |
| **14** | **Springbok Flats** | Ecca  Vryheid & Volksrust Formations | Three seams: Lower, Middle & Upper seams. | The coalfield is situated within an elongate basin covering 800 000 ha, north of Pretoria in the Limpopo Province. The coals formed in a fault-bounded half-graben/graben. The coal is predominantly medium-rank C bituminous, and dolerite sills and dykes have been encountered. This coalfield is not currently mined, primarily due to the high uranium content (Christie, 1989; Ndhlalose, 2015).  TS content in raw coal ranges from 2% to 4% and averages ±1.5% in the beneficiated product. Raw values of between 40.8 and 60.7% ash, CV 18–10.6 MJ/kg, IM of up to 6%, and VM of 13.3 to 24.3% and higher have been documented (Ndhlalose *et al.* 2015). |
| **15** | **Waterberg/Ellisras** | Ecca  Vryheid & Volksrust Formation | Zones 1–4 Vryheid, & Zones 5–11 Volksrust Formation | The large graben/half-graben, fault-bounded Ellisras sub-basin hosts the coalfield, situated in Limpopo Province, 400 km NW of Johannesburg. It is immediately north of the Waterberg mountain range and extends into Botswana. It is believed to contain 40–50% of South Africa’s remaining coal resources. The coal is medium-rank C bituminous. The Daarby Fault divides the coalfield into a deeper and shallower portion. There is one operating opencast coal mine in the coalfield, and two coal-fired power stations. The average coal qualities: ash = 26.70%, IM = 1.8%, VM = 22.6%, FC = 35.8%, TS = 0.9%, and CV = 9.0 MJ/kg. Eleven coal zones are identified. Zones 1–4 occur in the Vryheid Formation, a 55m thick package, mainly sandstone-hosted, and are comparable to the Witbank Coalfield, dull but low ash. The remaining seven zones occur in the overlying Volksrust (Grootegeluk) Formation, highly interbedded. The upper zone is vitrinite-rich and high in mineral matter and requires beneficiation. Zone 6 reports a high phosphorus content, but the other upper benches are used as coking coal and power station feed. The lower benches are mined for metallurgical industry and power station feed. |
| **16** | **Soutpansberg** | Upper Ecca  Madzaringwe Formation | Four seams: seam A, seam B, seam C and seam D | The coalfield is situated to the north of the Soutpansberg Mountain Range in the Limpopo Province and includes the Mopane, Thsipise, and Pafuri sub-basins. The coal is preserved in various down-faulted half-grabens. The coal is medium-rank C–A, increasing in rank from west to east, as does the coke strength after reaction, and the yield (Sparrow, 2012). Where developed, the coal is generally bright, rich in vitrinite, but high in mineral matter. The Soutpansberg Coalfield is known to contain hard coking coal, but little other quality information is available. Literature indicates that it is only the eastern sector that has reasonable potential prospects for mining (Van Heerden, 2004), where 2 main seams occur. Currently there are no commercial mines in this coalfield as the Tshikondeni Mine closed in 2015. The coal seams in the central and western sector are faulted and occur at depths greater than 300m (Van Heerden, 2004). The western (Mopane) sub-basin coals exhibit multi-seam coal-mudstone associations with up to seven discrete seams. |
| **17** | **Limpopo (Tuli)** | Upper Ecca  Madzaringwe Formation | 3 seams: Bottom, Middle, Top, with sub-divisions | The structurally controlled coalfield is situated in the northernmost extremity of the Limpopo Province, some 70 km west of the town of Messina, and extends into Botswana and Zimbabwe, covering 120 000 ha. In the area of exploitable coal, three distinct coal horizons are developed in the Madzaringwe Formation. The coal is medium-rank C–B bituminous and is vitrinite-rich (when washed); it could find a market as a coking coal. It is interlaminated carbonaceous mudstones and coal. This coal is not currently mined.  Raw coal characteristics indicate average coal quality: ash = 56.7%, VM = 17.0%, FC = 24.5%, IM = 2.0%, and CV = 12.2 MJ/kg (Ortlepp, 1986, and CGS coal core database). |

### 1.2 The coalfields of Swaziland

Swaziland shares a common border with Mozambique and South Africa and is a landlocked country. The coalfields of Swaziland run north-south with an average width of fifteen kilometres, primarily located in the eastern side of the country (Maphalala, 2006). The elongated eastward dipping sequences of the Karoo strata are complicated mainly by large-scale strike faults, resulting in downthrows equal to 300m in places (Maphalala, 2006).

The Karoo Supergroup in Swaziland attains an average thickness of approximately 1 000m. Accumulations of Dwyka tillite are thickest in southern Swaziland relative to the northern regions where thicknesses of up to 50m have been reported (Scogings and Lenz, 1961; Cairncross, 2001). The dolerite sill intrusions are the main cause of devolatilisation of coal and vertical displacements of strata (Cairncross, 2001; Maphalala, 2006). The coal in the southern regions, to the west of the Lebombo Mountains, has been particularly affected, with volatile matter content in the Maloma area averaging 6% (Maphalala, 2006). Hence, these coals fall into the anthracitic range of rank.

The Vryheid Formation contains the main mineable coal deposits and comprises arkosic sandstone, shale, siltstone, and several coal seams. The coals occur in two coal zones found respectively in the Upper and Middle Ecca series of the Karoo Supergroup (Maphalala, 2006). Up to 18 seams can be present with three, the Main, Nos. 1, and 2 (Upper) Seams, being the most important. These have been correlated with the Dundas, Gus, and Alfred seams of the KZN Coalfield. The seams are thicker in the north and are flat-lying (Cairncross, 2001). Mineable coal seams are found in the Lower Coal Zone, with average thickness of 1m (Cairncross, 2001). The mining geology is relatively difficult due to the intrusions by dolerite dykes and sills, which are often accompanied by faulting (Cairncross, 2001).

The coalfields are briefly discussed in Table 1.2, with the locations indicated in Figure 1.4.

**Table 1.2: Summary of coal deposits and coal qualities of Swaziland (Harkin, 1952; Hunter, 1962; Maphalala, 2006).**

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| --- | --- | --- | --- | --- |
| **Coalfields of Swaziland** | | | | |
| **Map No.** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
| **18** | **Maloma** | Ecca  Vryheid Formation | Lower Coal Zone | The Maloma coal deposit is situated at the end of the elongated coalfield, in the southern region of Swaziland. Maloma has 35.3 Mt of mineable anthracite coal with an estimated annual production of 300–600 thousand tonnes. Analytical specifications indicate: IM 1.60%, 9.25% ash, FC 84.45%, TS 0.76%, phosphorus 0.01%, VM 5.40%, and CV 31.39 MJ/kg. The Maloma Colliery exports anthracite to South Africa. |
| **19** | **Lubhuku** | Ecca  Vryheid Formation | Main Coal Seam from Lower Coal Zone | The Lubhuku Coalfield is located in the central eastern part of Swaziland. The coal is mainly semi-anthracite to anthracite, almost similar [similar? very similar? Almost identical?] to the KZN anthracite. Average coal quality values for the Main Seam: IM = 1.4%; ash = 13.2%; VM = 11.4%; TS = 0.43%; CV = 29.70 MJ/kg; FC = 76.2%. Unwashed coal is suitable for thermal power station use, only used domestically. |
| **20** | **Mhlume** | Ecca | Main Seam | The coalfield is located in the north-east of Swaziland and produces anthracite on a small scale. The CV is above that of normal anthracite in places. The Main Seam in this area averages 3m and has the following coal characteristics: ash = 13.6%; IM = 1.5%; VM = 4.4%; CV = 25.5 MJ/kg; FC = 80.3%. The anthracite could be used for metallurgical purposes, heating and as a source of fuel for boilers. |
| **21** | **Mpaka** | Ecca | Two coal zones. Lower coal zones with multiple seams. | The Mpaka Coalfield is situated in the central part of the country. The coal of this area is bright banded and bituminous, and semi-anthracite to anthracite. Coal has been mined from the Main Seam, which averages 3m in thickness (ranging 1–8m). Average coal quality values for the Main Seam: IM = 1.4%; ash = 12.3%; VM = 11.4%; TS = 0.4%; CV = 25.58 MJ/kg; FC = 75%. Washed coal from Mpaka mine has been successfully sold to Kenya for cement manufacturing and to Asian countries for manufacturing smokeless briquettes for domestic heating and cooking. |

### 1.3 The coalfields of Botswana

Geographically, Botswana is 582,000 km2 (48th largest country globally by area) with a population of just two million. Whilst the coal industry is relatively under-developed, it has been estimated that Botswana may have the largest coal resource of southern Africa (212 Gt according to Chatupa, 1991). Coal is currently mined for consumption in the only coal-fired power station in the country, and over 90% of electricity is generated from coal. Smith (1984), Clark *et al.* (1986), Cairncross (2001), Bordy and Catuneanu (2002), Catuneanu *et al.* (2005), Bordy *et al.* (2010), Barbolini and Bamford (2014), and Hancox (2016) have provided insights into the coalfields of Botswana, but large areas remain unstudied.

Botswana has a central intracratonic rift basin infilled with Karoo-aged rocks (Green, 1966; Key *et al*., 1998), most of which is covered by Tertiary to Recent Kalahari sedimentary deposits, ranging from a few metres to a few hundred metres in thickness (Hutchins and Reeves, 1980). The Kalahari-Karoo Basin is elongated northeast–southwest, a trend mirrored in the basins of Namibia to the west (Bordy and Catuneanu, 2002). The coals occur in the middle and upper Ecca, primarily preserved in the eastern and south-western flanks of the Kalahari-Karoo Basin. According to Cairncross (2001), there is possible correlation of the Kalahari Karoo sequence of Botswana with the strata in Zimbabwe (Hwange area), Namibia and with the Limpopo Province coalfields of South Africa.

Areas prospected for coal in Botswana are centred primarily on the eastern flanks of the Kalahari–Karoo Basin and more recently in the south-western regions, where up to 12 coalfields are recognised (Hancox, 2016). Coal deposits occur in the areas of Morupule–Moijabana, Mmamabula–Mmamantswe, Letlhakeng, Dutlwe, Serule, Foley–Dukwe, Ncojane, Orapa, and Bobonong-Tuli (Clark *et al*, 1986; Body and Catuneanu, 2002; Aviva, 2008; Barbolini and Bamford, 2014). Data from coal exploration and geophysical surveys indicate that a single depositional environment is an over-simplification and that local facies discontinuities, structural highs, and faulting create stratigraphic complexities in the Karoo Supergroup. It is assumed that the petrographic composition of Botswana coals reflects Gondwana trends, being medium-rank D/C, with a predominance of inertinite over vitrinite, but ongoing research (N. Wagner, personal communication) may indicate otherwise. The Morapule Coalfield is currently the only coal deposit mined in the country feeding the only coal-fired power station. Eight coalfields are summarized in Table 1.3, with the locations indicated in Figure 1.4.

**Table 1.3: Summary of coal deposits and coal qualities of Botswana. (Clark *et al*., 1986; Spalding, 1999; Body and Catuneanu, 2002; Barbolini and Bamford, 2014; Hancox, 2016).**

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| --- | --- | --- | --- | --- |
| **Coalfields of Botswana** | | | | |
| **Map No.** | **Coalfield** | Age | **Coal seams** | **Coal quality** |
| **22** | **Bobonong/Tuli** | Ecca | Generally thin coal seams | The Tuli Basin, a correlative of the Limpopo Coalfield in South Africa, is located in the east of the Kalahari-Karoo Basin. Coal seams are intersected at 11 coal zones, with the thickest seam (1.5m) intersected at the depth 80m; content of ash = 10.9%, VM = 35.7%, and CV 28.4 MJ/kg. The coal is typically vitrinite-rich, medium-rank C bituminous coal. |
| **23** | **Morupule and Moijabana** | Ecca  Morapule & Serowe Formations | 3 seams: Morupule Main Seam, No.2, Lotsane (A,B,C).  Serowe bright | The Morupule and Moijabana coal deposits occur in the eastern Botswana region and are hosted in the southeast central Kalahari sub-basin. Two depositional sub-basins have been identified in the Morupule–Moijabana area, with only three seams of economic importance. At present, only the Morupule Main Seam is exploited, consisting of 60m carbonaceous fines and coals. Average qualities (raw coal): ash = 21,1%, VM = 24,3%, CV = 24,4 MJ/kg, and TS = 1,44%, typically inertinite-rich, medium-rank D/C (sub-bituminous). The Lotsane Seam contains bright coal, high-ash, 0.6–4.5m thick. The Serowe Bright Seam is mostly poorly developed, averaging 1.8m with bands of bright, high-TS coal, and mudstone horizons. |
| **24** | **Ncojane** | Ecca | Two coal zones | This coalfield is located in south western Botswana. Coal is intersected in two zones, with coal seams less than 1.6m thick. These seams are typically very low CV, high-ash, and high-moisture. |
| **25** | **Serule** | Ecca | Upper & basal | The coalfield is located north of Morupule and has previously been investigated as a source of coking coal. The main coal occurrences are in two seams; raw coal data for the upper and basal seams indicate a high-ash (>30%), medium-rank bituminous coal. |
| **26** | **Mmamabula (southern Morupule)** | Ecca | Middle (Morapule Main Seam) | The coalfield is situated 130 km south of Morupule. Three coal seams are present, with the Middle seam the thickest and most laterally extensive. Average qualities (raw data) for the Middle seam: ash = 20.8%, VM = 25%, CV = 23.95 MJ/kg, and TS = 2.19% . |
| **27** | **Letlhakeng (Southern end of Morupule) and Dutlwe (Kweneng)** | Ecca | E2b & G1; Dutlwe: Six–seven, seams, two seams economical | The Letlhakeng Coalfield is located to the west of the Mmamabula area. Coal occurs in four localities, with two each either side of an upthrust block of pre-Karoo-basement. There are two main economic seams, namely: E2b and G1. The qualities (raw coal) for these two main seams respectively: ash = 18.7% and 23.3%, VM = 28.3% and 25.3%, CV = 25.04 MJ/kg and 22.83 MJ/kg, and TS = 1.86% and 1.41%.  Dutlwe Coalfield is located west of Letlhakeng where the Karoo strata are completely covered by unconsolidated Kalahari sands. The Ecca Group equivalents contain coal, but seams are relatively thin in the upper part of the coal zone. Below this zone, six to seven coal seams have been intersected, with only two identified mineable seams thickening eastwards (1.5–4.0m). The coals of the two seams are of low-grade, high-ash with low to medium sulphur content. |
| **28** | **Foley and Dukwe** | Ecca | 1 coal zone | These coalfields are present in the eastern Botswana region. Foley Coalfield has a seam with the thickness of about 2m at relatively shallow depths. Coal from this area is mainly used for local power generation. Quality parameters indicate: VM = 25%; ash = 17.7%; TS = 0.7%; FC = 57.3%; CV = 24.65 MJ/kg  The Dukwe Coalfield coal zone is hosted in carbonaceous mudstone, up to 70m thick. The best sample analysed from borehole core was at the depth of 120m; thickness 2.1m, with content of ash = 22.1%, VM = 25.4% and CV = 24.8 MJ/kg. |
| **29** | **Orapa** | Ecca | Three coal seams | This coalfield is located in the interior of the Kalahari Karoo Basin of Botswana. Little is known about the coal geology of Orapa. Quality parameters indicate: ash = 13.4–38.6%, VM = 21.6–37.6% ,and CV = 15.9–23.4 MJ/kg. The coals are variable in quality, and there is evidence of possible heat influence in the bottom seam. |

### 1.4 The coalfields of Namibia

The eastern half of Namibia is covered by post-Karoo sediments of the Kalahari Group. It is possible that Karoo sediments underlie a portion of this area, and may contain coals of similar aspect to those found in Botswana (Stravrakis, 1985). However, there is little published about the coals from this country.

The Ecca Group is subdivided into the Dwyka Group, Prince Albert, Whitehill, and Vreda Formations and these collectively attain a maximum thickness of 1 200m (Kingsley, 1985; Marsh and McDaid, 1986). The Dwyka Group consists of a basal diamictite overlain by a succession of mudstones that contain dropstones and fossils such as starfish, bivalves, crinoid remains and gastropods (Stavrakis, 1985). The Prince Albert Formation has been subdivided into three members, the arenaceous lower Nossob Member, the overlying shaly Mukorob Member and the uppermost sandstone-rich Auob Member, which also contains the coal seams. The coal seams are Artinskian in age and occur interbedded with argillaceous and arenaceous strata (Stavrakis, 1985).

The main coal seam (Impala) is located approximately 30m above the base of the Auob sandstone, and the so-called Upper seam, 50m above the main seam (Kingsley, 1990). The two arenaceous members (Nossob and Auob) thin towards the south, becoming distally laterally replaced by shale and limestone. The Auob is overlain by the Whitehill Formation, which is in turn overlain by sandstones and minor shales assigned to the Vreda Formation. Dolerite sills have extensively intruded the sequence, particularly the upper part of the Auob Member. No coal is currently mined in Namibia, but there has been some exploration, and the largest deposit is a high-grade metallurgical coal deposit. As there is little information pertaining to the coal deposits in Namibia, only one coalfield is discussed in Table 1.4, with the locations indicated in Figure 1.4.

**Table 1.4: Summary of coal deposits and coal qualities of Namibia. (Stavrakis, 1985; Maphala, 2006).**

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| --- | --- | --- | --- | --- |
| **Coalfields of Namibia** | | | | |
| **Map number** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
| **31** | **Aranos (Kalahari Basin**) | **Ecca** | Two seams: Impala & Upper Seams | The coalfield lies in the Kalahari Basin in the south-eastern region of Namibia. Coal occurs in two zones: a lower coal seam called the Impala coal seam, and an upper coal zone that is found in the Whitehill Formation. Average qualities (raw data), based on 12 borehole samples, yielded the following results: IM = 2.7% (min. 1.3, max. 4.9); ash = 37% (min. 15.4, max. 64.0); VM = 15% (min. 5.8, max. 24.3); TS = 0.96% (min. 0.20, max. 2.10); CV = 18.18 MJ/kg (min. 7.70, max. 27.09). |

### 1.5 The coalfields of Zimbabwe

Zimbabwe is a landlocked country to the north of South Africa, with a significant, underutilised coal resource occurring in several separate coalfields. Over 11 Gt of *in situ* coal reserves are estimated for the country, with 2.5 Gt considered to be open-cast reserves (Bartholomew, 1992). About half of Zimbabwe’s electricity is supplied by coal. The Hwange Coalfield is the only coalfield that has been exploited to any meaningful extent, providing metallurgical and steam coal, although the Sengwa Coalfield is being developed. According to Hancox (2016), only 3.6 Mt was produced in 2013.

Karoo-aged strata occur in two main regions separated by the Zimbabwean Craton: the Zambezi Basin in the north-west and the Save-Limpopo area in the southeast, close to the border with South Africa and Mozambique (Drysdall and Weller, 1966). A small coal basin lies adjacent to the South African border to the south of the country, namely the Tuli Basin. The main coal deposits of Zimbabwe occur to the west and northwest in the mid-Zambezi Basin (Duguid, 1986a), where thicker and good quality coals occur compared to the southern coalfields. The deposits in the south-east are covered by the flood basalts that terminated Karoo sedimentation, but in the northern mid-Zambezi Basin, much of this cover has been removed by erosion.

The northwest includes the coalfield districts of Hwange (previously Wankie) and Lubimbi, with Sessami-Kaonga to the east of these. In these coalfields, the current economic deposit is the Hwange Main Seam (basal seam), a medium-to high-volatile bituminous coal, comprising of a lower horizon coking coal up to 4m in thickness, and an upper horizon steam coal up to 8m thick, all generally with low sulphur contents. The coal is mined for metallurgical export coal and local steam coal. In the southern coalfields of Bubye and Tuli, the coals have variable qualities. Some low-sulphur coking coal has been identified in the Tuli Coalfield (Hall, 2012). The locations discussed in Table 1.5 are indicated in Figure 1.4.

**Table 1.5: Summary of coal deposits and coal qualities of Zimbabwe (Duguid, 1986b; Bartholomew, 1992; Hancox, 2016; CGS database).**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Coalfields of Zimbabwe** | | | | |
| **Map No.** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
| **35** | **Southern coalfields: Tuli/Bubye/Sabie/Mazunga Coalfields** | **Ecca** | Two coal zones with variable seams | These coalfields are situated on the southern edge of the Zimbabwean craton in the Limpopo Belt, and are not presently mined. The Sabie Basin Coalfield contains semi-anthracite coals. The coal also has high ash content and the sequences are intersected by a multiplicity of faults and dolerite sills and dykes.  The Tuli Block coals are very thin, high in ash and extensively displaced by east-north-east faulting and dolerite intrusions.  The Bubye Coalfield is north of the Limpopo River and has up to six coal seams. Only the eastern portion of the Bubye deposit contains coal of suitable thickness and quality. Some coking coals are found here. |
| **36** | **North-eastern Coalfield: Hwange** | **Ecca** | One main seam: Hwange Main Seam | The coalfield is located in the western and north-western parts of Zimbabwe in the Milibizi Basin. It is the best-documented seam in Zimbabwe. Coking coal occurs at the base of the seam, and the overall quality of coal deteriorates vertically, particularly the ash content, which increases at an almost constant rate. A vertical increase in inertinite also takes place within the seam, and the top part is recovered as steam coal. Average run-of-mine coal quality for the Hwange coalfield: VM = 24%; FC = 65.7%; ash = 9.7%; IM = 0.76%; and CV = 31.4 MJ/kg |

### 1.6 The coalfields of Zambia

Zambia is a landlocked country dependent on agriculture. Most power is derived from hydroelectric operations on the Zambezi River, but, according to Hancox (2016), coal-fired capacity is also being built. Coal seams occur in the Ecca Group of the Karoo Supergroup. The Karoo strata occur in river valleys controlled by down-faulting into graben-like structures (Tavener-Smith, 1960). The Karoo-aged sediments in the Mid-Zambezi Valley contain the lower Siankondobo Sandstone, which is unconformably overlain by the Gwembe Coal Formation and the Madumabisa Mudstone Formation. The Upper Karoo sequence is a series of arenaceous continental sedimentary rocks and mudstones, capped by basalts of the Baroka Formation (Hancox, 2016). Coal is contained in the Gwembe Formation, which can achieve 280m. The economic Main Seam is the middle facies member of this formation (Hancox, 2016). The coalfields are faulted.

The main coal areas in Zambia are located in the Southern Province with about 80 Mt of proven coal deposits (Zambia Development Agency Report, 2014). The Luano, Luangwa North, and Lukusashi deposits are located in the Luangwa Valley, while Kahare, Chunga and Lubaba are located in the Western Province of the country. The Barotse and Hot Springs coal deposits occur to the west of the above-mentioned coalfields. Hancox (2016) reports three coal-bearing sub-basins in the Mid-Zambezi Valley: Nkandabwe, Siankondobo, and Mulungwa Coalfields; the latter hosts the Maamba Colliery. Coal exploration has also been conducted in the Gwembe and Kandabwe Coalfields, but more detailed exploration is still required in Zambia. The coals are typically non-coking with relatively high inertinite contents. Zambia remains the smallest coal producer in southern Africa (Zambia Country Mining Guide, 2013). The locations discussed in Table 1.6 are indicated in Figure 1.4.

**Table 1.6: Summary of coal deposits and coal qualities of Zambia. (African Energy Resources Limited Report, 2012; Hancox, 2016; CGS database)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Coalfields of Zambia** | | | | |
| **Map number** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
| **38** | **Gwembe and Kandabwe** | **Ecca** | Coal zone containing numerous thin seams of 10–20m. | Gwembe and Kandabwe Coalfields are located in the southern region of Zambia. The lower portions of the seams are of superior quality compared to the upper parts. Both coalfields have medium-to low-volatile bituminous coal. Coal quality average values: ash = 38.23%, IM = 1.58%, and CV = 19.92 MJ/kg. |
| **39** | **Luano Valley** | **Ecca** | Coal zone containing numerous thin seams | The Luano Valley Coalfield is found in the far eastern region of Zambia, where coal occurs in the southern end of the valley. The coals are typically thin, laterally discontinuous, and of low quality (high-ash). Little information is available about the quality of the Luano Valley Coalfield. |
| **40** | **Barotse basin/Hot Springs** | **Ecca** | Coal zone containing numerous thin seams | The Barotse basin encompasses two linear, marginal troughs: the Chunga Trough, extending from Kahare to the Hot Springs Coalfield, north of Mubwa, and the Kafue Trough, extending from Mulobezi east-north-east to Kafue. Analytical results of coal sampled in this areas yield an ash content of 15–30%, VM = 25% maximum, and CV = 19.8 and 25.3 MJ/kg (Money, 1972). |

### 1.7 The coalfields of Mozambique

There are no official resource or reserve estimates for the Mozambique coalfields (Vasconcelos, 2009), although Mozambique has abundant and yet largely unexplored coal resources. Almost all electricity in Mozambique is obtained from hydropower (Hancox, 2016). Despite the fact that several large multinational companies have invested significant resources into developing the coalfields, production is low due to poor infrastructure and political instability. The Zambezi Basin, an east-west trending graben-controlled basin, contains the Karoo Supergroup coal-bearing strata in Mozambique (Lachelt, 2004; Hatton and Fardell, 2012). Four coalfields occur in Mozambique, of which the Tete Province sub-basins are the most important. The Tete Province Coalfield is located in the mid-Zambezi Valley in an area south and west of southern Malawi, and the sub-basins are: i) Chicoa-Mecucue; ii) Sanangoe-Mefidezi; iii) Moatize (also referred to as the Moatize Coalfield); and iv) Nkondezi-Muarazi-Minjova (Hatton and Fardell, 2012). Other less well-known coalfields are Chiromo, close to the eastern Zimbabwe border, and Itule and Metangula in northern Mozambique, west of Malawi (Cairncross, 2001). The Msanbansovu deposit, west of Tete, is now the location of the Cabora Bassa Dam, a large hydroelectric project location, and thus the coals have been sterilised. Falcon *et al.* (1984) established that the Chicoa-Mecucue seams occurred in the lower Ecca to the lower Beaufort.

The coal-bearing Karoo succession in the Tete Province attains a stratigraphic thickness of 900m. The basin has a number of tectonically controlled sub-basins, with the coal located in the Ecca aged Productive Series (now referred to as the Moatize Formation), which can attain thicknesses of 320 to 400m. The Moatize Formation is characterised by a cyclic bar-code series of coal, carbonaceous mudstone, and mudstone, with sandstone, rhythmite and mudstone partings (Lakshminarayana, 2015), and is the main economically significant coal deposit. Six coal seams (or zones) are identified in the Moatize Formation. Coal is also hosted in the lower Vuzi and upper Matinde Formations (Hancox, 2016), but is less well developed.

Typically the coals from Mozambique occur in thick sequences, and are vitrinite-rich medium- to low-volatile coals (medium-rank A to high–rank C/B coals), suitable for the metallurgical industry (coking coal). Unfortunately, the ash content is typically high, but the sulphur content is typically low (Vasconcelos, 2009). Despite recent exploration activity, there is limited public domain information pertaining to the coalfields of Mozambique. The locations discussed in Table 1.7 are indicated in Figure 1.4.

**Table 1.7: Summary of coal deposits and coal qualities of Mozambique. (Neto, 1976; Cairncross, 2001; Vasconcelos, 2009; Lakshminarayana (2015).**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Coalfields of Mozambique** | | | | |
| **Map No.** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
| **41** | **Tete Province, 4 sub-basins, the best known being the Moatize** | **Ecca**  **Moatize Formation** | Moatize Formation with 6 coal seams: (bottom) Sousa Pinto, Chipanga, Bananeiras, Intermedia, Grande Falaise and Andre (top) | The Tete Province extends from Zumbo to Mutarara, a >500km length tectonic basin. The Western and Eastern Tete Karoo Basin is separated by the Cahora Bassa Horst. Many seams outcrop. Rank varies from 1.28–1.51% RoVmr in the Moatize sub-basin, increasing with depth. The Chipanga is the main coal zone, and is mined at Moatize. The lower section is of coking coal quality: IM = 1%; VM = 18%; ash = 20%; TS = 1%; CV = 28.5 MJ/kg. The Chipanga seam reports 72–79 vol% vitrinite top to bottom.  Others provide qualities in the Moatize: IM 1.39%; Ash 44%; VM 25%; FC 35%, CSN 1–7. |
| **42** | **Metangula** | **Ecca** |  | Northern Mozambique.  Mineral-rich 28–48 vol%, vitrinite 36–51 vol%; liptinite 1.9–2.5 vol%. |

### 1.8 The coalfields of Malawi

Coal is an important and underutilised source of energy in Malawi with one operating mine (Mchenga) in the Livingstonia Coalfield supplying the local market. Most energy is obtained from hydroelectric power, although this can be unreliable. Malawi has two small coal basins, one in the far north and one in the far south, with potential for only limited reserves of coal. The coal varies in thickness, from up to 100m in the north to 600m in the south. The southern coalfields are located close to the Mozambiquean Moatize coal district, and the northern deposits are more comparable to the Tanzanian deposits (Cairncross, 2001). The multiple thin coal seams generally occur with interbedded mudrocks and commonly, arkosic sandstones and subordinate conglomerates. The argillaceous beds contain thin multiple coal seams, hosted in the fault-bounded half-graben outliers, unconformably overlying the Precambrian Basement (Cairncross, 2001).

According to the published literature (Ministry of Energy and Mines of Malawi, 2009; Hancox, 2016), there are thirteen coalfields in the northern region and two in the southern part of the country, with the estimated coal reserves totalling up to 800 million tonnes. The best-known deposits occur in the Ngana, Livingstonia, Lufira, Mwabvi, Lengwe, North Rukuru, and Nthalire (sub) basins (Ministry of Energy and Mines of Malawi, 2009), or the Sumba and Chiromo (south) and Ngana and Livingstonia (north) deposits according to Cairncross (2001). The coal is low-rank to medium-rank bituminous, high in ash and volatile matter, low in sulphur (Henry, 1990). The locations discussed in Table 1.8 are indicated in Figure 1.4.

**Table 1.8: Summary of coal deposits and coal qualities of Malawi (Cairncross, 2001; Ministry of Energy and Mines of Malawi, 2009).**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Coalfields of Malawi** | | | | |
| **Map No.** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
| **44 and 45** | **Southern Coalfields (Lengwe and Mwabvi/Sumba, and Chiromo)** | Ecca |  | The southern coalfields have coal seams which are exposed at the surface. The quality of the coal improves with depth, and coals from shallower level require washing. Average coal qualities are as follows: ash content ranges from 44% to 59.2%; TS content ranges from 0.51 to 0.76%; CV ranges from 11 MJ/kg to 17.5 MJ/kg. Vitrinite content ranges 9–18 vol%; liptinite content is around 0 vol%; inertinite content is 34 vol%; and observable mineral matter content ranges from 48–57 vol%. |
| **46 to 48** | **Northern Coalfield (Livingstonia, Nthalire, North Rukuru, and Ngana)** | Ecca |  | The seam thickness of the northern coalfields varies from 0.5m–15m. Average coal qualities: ash = 25.98%, TS = 0.61% and CV = 24.65 MJ/kg. Vitrinite content ranges from 3% to 46%; liptinite content ranges from 0 to 11 vol%, and inertinite content ranges from 0 to 86 vol%. Observable mineral matter content ranges from 0 to 61 vol%; |

### 1.9 The coalfields of Tanzania

Compared to most southern African coal deposits, the Tanzanian coals have been relatively well studied, although coal does not contribute significantly to the economy of the country (Hancox, 2016). The country has a fairly diversified energy mix, and does not appear to rely on coal as an energy source. The Karoo basins in Tanzania contain mainly Upper Carboniferous, Permian and Triassic terrestrial sediments deposited in narrow, elongated, intracratonic, partly fault controlled and disconnected grabens and half-grabens (McKinlay, 1965). Boundary faults post-date the deposition and were active probably during the middle Jurassic as a result of the break-up of Gondwana (Wopfner, 1990). The basins are separated by Precambrian basement rocks.

The coal basins in the southwest extend along a northwest-southeast corridor which encompasses Lake Rukwa and Lake Nyasa and continues to the south into Zambia (Luangwa) and Malawi (Livingstonia). In the southeast, the Ruhuhu and Selous Basins trend northeast to southwest. The Selous Basin continues into Mozambique, where it is known as the Metangula Basin. The type sections of the Upper Carboniferous to Triassic succession in eastern Africa are located in the Ruhuhu Basin, which contains a complete sequence of about 2900m Karoo strata (Wopfner and Kreuser, 1986; Kreuser and Semkiwa, 1987; Markwort, 1991). The Ruhuhu Basin contains the Mchuchuma, Ngaka North, Mbalawala, and Lumecha coal basins (Hancox, 2016)

The oldest Karoo rocks comprise from 0 to 140m of glacial to periglacial strata of late Carboniferous to early Permian age. These strata have been formally named the Idusi Formation (Diekmann, 1993), or Kl in terms of the previous terminology of McKinlay (1954). Economically important coal seams are developed in the overlying sandstone-coal and shale-coal-sandstone facies in the coal-bearing Mchuchuma Formation. This formation has been correlated lithostratigraphically with the Ecca group of South Africa, the black shale and main coal seam unit of the Hwange Coalfield, and the Bira coal measures of the Gwembe Coalfield in Zimbabwe (Thompson, 1981; Catuneanu *et al.*, 2005). Unconformably overlying the Mchuchuma Formation is the Mbuyura Formation with a feldspathic Scarp sandstone member at the base (Kaaya, 1992). The Mbuyura Formation is approximately equivalent to K3 in the terminology of McKinlay (1954).

Climatic warming after deposition of the Idusi, Mchuchuma, and Mbuyura Formations was accompanied by the deposition of non-economic to marginally economic coal deposits. The transition from the Mbuyura Formation to the overlying coal-bearing Mhukuru Formation (Semkiwa, 1992), termed K4 by McKinlay (1954), is marked by the appearance of dark carbonaceous shales. The Mhukuru Formation consists of fluvial-lacustrine sandstones, carbonaceous mudrocks, coal and coaly streaks. The formation is over 300m thick at the type locality in the Mhukuru Sub-basin, but the thickness varies considerably in the Ruhuhu Basin. The locations discussed in Table 1.9 are indicated in Figure 1.4.

**Table 1.9: Summary of coal deposits and coal qualities of Tanzania (Semkiwa *et al.,* 1998; Wopfner, 1990)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Coalfields of Tanzania** | | | | |
| **Map No.** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
| **49** | **Ruhuhu** | Ecca  Mchuchuma  Formation | Coal seams are hosted in sandstone | The Ruhuhu Coalfield is rich in inertinite and has a relatively high sulphur content. Average coal qualities: ash = 14.2%, VM = 24.0%, FC = 60.3%, TS = 0.5–1.0%, and CV = 34.2 MJ/kg. |
| **53** | **Songwe-Kiwira** | Ecca Mchuchuma  Formation | Seam Number 9 to 1. | Songwe-Kiwira Coalfield is situated near the northern tip of Lake Nyasa. Coal reserves (proven and indicated) are in the order of 616 Mt and are currently being exploited by medium-size underground coal mines (Kiwira and Ilima Coal Mines). Ash yields are elevated in all seams, ranging from 22.37 to 49.30 wt.%. TS is highly variable, ranging from 0.17 wt.% at the Kiwira Mine (#5 seam) to 9.20 wt.% in the #6 seam at the Mwalesi Section. CV of the seams ranges from 15.2 to 25.7 MJ/kg (dry). Coals in the upper part of the coal-bearing sequence are low-rank bituminous (#2 seam, upper and lower beds) and grade into low-to medium-rank bituminous coals in the stratigraphically older seams at Mwalesi, Kiwira, and Ilima Mines. |
| **54** | **Galula** | Ecca  Mchuchuma  Formation | Elephant River 1 thin seam; at Chisi River 4 seams. | The coalfield is situated on the southwestern escarpment of the Rukwa rift valley, bound on the southwestern margin by a fault block formed by the main rift fault which has a general northwest-southeast trend. The economically workable coal seams in the Galula Coalfield occur in the north-western part, i.e. in the area northwest of Elephant River. The ash yield of the thickest coal seam sampled is 23 wt% and 34 wt% for the top and bottom parts respectively, with VM of 30.4% and CV = 26 MJ/kg. |
| **55** | **Muze** | Ecca  Mchuchuma  Formation | Two coal-bearing units, a lower and an upper. | The Muze Coalfield is situated on the floor of the Rukwa Rift Valley, approximately 10km east of the Mkomolo and Namwele deposits. The southwestern extension of the coalfield is terminated by a northwest-trending major rift fault. The lower unit is exposed in the Kalakala river bed and appears to contain uneconomic coal. The upper coal zone occurs approximately in the middle of the coal measures and contains economic seams. The rank of the coal is of low-rank A to medium-rank D bituminous coal with vitrinite reflectance of 0.48–0.52% RoVmr (percent mean random vitrinite reflectance). The coals contain considerable amounts of ash = 39.08%, IM = 4.24%, VM = 24.99%, FC = 31.70%, TS = 2.67%, and CV = 16.46 MJ/kg. |
| **56** | **Namwele-Mkomolo** | Ecca  Mchuchuma  Formation | Thin coal seams | The Namwele-Mkomolo Coalfield lies near the western shoulder of the Rukwa Rift Valley and has a general northwest-southeast trend similar to the rift valley. The coal measures are exposed in the eastern margin of the coalfield and have been traced along strike for a distance of 4 km from Namwele to Mkomolo (McConnel, 1950). Proximate analysis results indicate high ash yield values (22–50 wt%), VM = 22.3%, and CV = 21.36MJ/kg for the economically significant coal seams ( > 50 cm). |

### 1.10 The coalfields of Democratic Republic of Congo (DRC)

Democratic Republic of Congo (DRC) has small separate basins of coal-bearing Karoo sediments which occur in the southeast of the country at Luena and Lukuga. The coal measures are considered to be Ecca equivalents (Catuneanu *et al*., 2005). The coal seams are up to 2.0m in thickness and are disrupted by faulting. The coals are bituminous with high ash contents and are used locally for electricity generation. Production output in the 1950’s was apparently in the order of 300 ktpa, but by 1999 it was only 100 ktpa, mostly from Lukuga (Spalding, 1999). Coal mining is likely to increase in Congo (Kinshasa) because of the envisioned expansion of the Luena Mine by 2019.

The Karoo Group in the DRC comprises of the Lukuga Formation and overlying Haute Lueki Formation (Lepersonne, 1977; Cahen and Lepersonne, 1978). The Lukuga Formation is preserved in tectonic grabens related to the East African rift, in the Lukuga Basin along the border of Lake Tanganyika, and in the Luena Basin in the Upemba depression of Central Katanga (Cambier, 1930), in U-shaped glacial valleys on the eastern margin of the Congo Basin (Boutako, 1948), as well as in the Dekese sub-basin of the Congo Basin (Cahen *et al*., 1960). Its base displays typical diamictites and varval clay [I can't find this term – varved clay?] of the Gondwana glaciation, equivalent to the Dwyka Conglomerate diamictites of the Karoo type locality in South Africa, attributed to the Late Carboniferous (320Ma).

The remaining part of the Lukuga Formation is represented by post-glacial claystones and sandstones (Dekese sub-basin) and coal-bearing measures (Lukuga and Luena grabens), correlated to the Ecca Subgroup of South Africa (Daly *et al*., 1991; Catuneanu *et al*., 2005; Johnson *et al*., 2006). The Haute Lueki Formation is present along the eastern margin of the Congo Basin, overlying the Lukuga Formation with a slight unconformity (Lepersonne, 1977). The base of the Haute Lueki Formation has been paleontologically dated as Early Triassic, equivalent to the Beaufort of South Africa. The locations discussed in Table 1.10 are indicated in Figure 1.4.

**Table 1.10: Summary of coal deposits and coal qualities of the DRC (Spalding, 1999; Johnson *et al.,* 2006).**

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| --- | --- | --- | --- | --- |
| **Coalfields of the DRC** | | | | |
| **Map No.** | **Coalfield** | **Age** | **Coal seams** | **Coal Quality** |
| **57** | **Luena** | Ecca  Lukuga Formation | Four seams | The Luena Coalfields are in the northern Shaba and southeast of Kamina and about 120 km north of Tenke, in the Haut-Lomami district. Luena Mine is currently an open pit mine which has been operational since 1920. Reserves are known to be about 20 Mt (Andrews *et al.,* 2008).The washed coal has an ash content of about 15% and CV of 24.69 MJ/kg. It has a relatively high volatile content of 35% and is not suitable for coking. |
| **58** | **Tanganyika** | Ecca  Lukuga Formation |  | The lower sections of the Tanganyika Coalfield are comprised of excellent coking coal and contain ash contents of less than 10%, but the TS content can be relatively high. The upper sections of the coal seams are higher in ash and are used for power generation. |
| **59** | **Lukunga** | Ecca  Lukuga Formation | Five coal seams | Lukuga coalfield is situated in the Tanganyika District, northern Katanga. An underground mine was operated there in the 1920s by Geomines. *In situ* reserves at Lukuga have been estimated at 1 billion tons but the economically recoverable reserves are 600 Mt (Spalding, 1999). The area is block faulted and this makes exploitation difficult.  The coal quality: IM 5–7%, ash = 15–20%, VM = 31–32%, CV = 21–25 MJ/kg. |

## CHAPTER CONCLUSION

This chapter provides a consolidation of available coal quality data (primarily chemical) and its potential use pertaining to the coalfields of southern Africa. It is evident that the South African coal deposits are far better documented than those of the other southern African countries. However, overall, an in-depth understanding of coal formation as well as petrographic data is generally lacking for southern African coal deposits compared to Northern Hemisphere counterparts. This book does not intend to provide petrographic data for the region, but rather aims to enhance the general understanding of coal formation and petrographic composition (via the photographic plates) in this Gondwana region.

Natural gas, potential shale gas, and coal bed methane (CBM) deposits have been omitted from the discussion as there currently are no extraction points in southern Africa for the latter two, and natural gas occurrence is beyond the scope of this book. Natural gas extraction occurs in Mozambique’s Pande gas field, and along the west coast of southern Africa, with further exploration being conducted elsewhere. Shale gas exploration is occurring in the MKB of South Africa, and CBM exploration is ongoing in Botswana. Cole *et al.* (1998) and Geel *et al.* (1992) provide some recent information on the shale gas deposits of South Africa.

For those interested in a broader geological explanation, contextualising the Karoo Basin sediments in the southern African geological context, Truswell (1977), Catuneanu *et al.* (2005), and McCarthy and Rubidge (2005) are recommended readings.