New airborne geophysical data from the Waterberg coalfield

South Africa's major future energy source

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Abstract

The Waterberg Coalfield in the Limpopo Province of South Africa contains vast resources of coal that will ensure the country's energy security well into the future. The coalfield is situated in the Karoo-age Ellisras Basin and at present hosts only one mining operation. Although the coalfield was discovered in 1920, relatively little drilling has taken place in the Ellisras Basin overall, and the structural complexities are not well defined. Coaltech Research Association commissioned a detailed airborne magnetic and radiometric survey over the Ellisras Basin in 2007 in order to enhance the structural understanding of the area. The CSIR undertook the management of the survey, conducted by the Council for Geoscience, and the interpretation of the data. This paper presents some preliminary findings of the interpretation which is in progress. The overall magnetic susceptibility of the Ellisras Basin is low; however, application of a phase operator revealed subtle anomalies that indicate non-magnetic structures or pre-Karoo features underneath the Ellisras Basin. Further investigation is required. The radiometric data complemented the magnetic data in defining the basin boundaries, and revealed more features than expected, such as large block faulting. In addition, samples of rocks from several geological units were collected and their physical properties measured to facilitate the geophysical interpretation. This work is ongoing. Integration of the magnetic, radiometric and Landsat interpretation data indicates that many of the linear structures are non-magnetic, and hence difficult to detect. A proposed solution to this problem is an airborne electromagnetic survey over the Ellisras Basin. Although costly, such a survey would greatly benefit future coal resource estimates, and result in improved and more sustainable utilisation of the Waterberg Coalfield.

1. General introduction

South Africa is highly dependent on coal to generate electricity (77% from coal, 23% from hydropower stations and Koeberg), as are many other countries. Thus, the output of the coal mining industry in South Africa is predominantly supplied to Eskom (108.7 million metric tonnes (Mt) in 2006) and exported as steam coal (68.8 Mt in 2006), with 43.7 Mt used in the synthetic fuels sector (Prevost 2007). Although the first coal deposits in the country were discovered in the Eastern Cape, the coalfields mined at present are situated mainly in Mpumalanga Province. These comprise the Witbank, Highveld and Ermelo coalfields. Most of the collieries are dedicated to supplying feedstock to nearby power stations. Mining in the Witbank coalfield began in the late 1880s, soon after the discovery of the Witwatersrand goldfields. The Witbank and Highveld coalfields account for 80% of current South African coal production. Although the remaining coal reserves in these three coalfields are sufficient for the next 95 years at current production levels (Prevost 2007), the vast resources identified in the Waterberg (formerly Ellisras) Coalfield ensure South Africa's energy security well into the future (Figure 1).

In addition, there is capacity to generate coal export revenue as well, which would boost the local economy in impoverished Limpopo Province. Estimates of the total amount of resources in the Waterberg Coalfield are highly uncertain because it has been relatively underexplored compared to the Witbank and Highveld coalfields. Prevost (2007) gives an estimate of 11% out of a total reserve figure of 27 981 Mt for South Africa, which amounts to 3 078 Mt. However, some sources speculate that total resources in the Waterberg alone are sufficient to last for the next 500 years at current production levels. There is at present only one mine in the Waterberg Coalfield, Grootegeluk, which is the sole supplier to the Matimba Power Station. Medupi, a new power station of similar capacity to Matimba is currently under construction nearby (www.eskom.co.za) and will also source its coal from Grootegeluk.
2. The importance of the current study

This study was initiated by the Geology and Geophysics Sub-committee of the Coaltech Research Association (CRA). It was established in 1999 as the Coaltech 2020 Research Programme (www.coaltech.co.za). It is a collaborative initiative of the CSIR to develop technology and apply research findings to ensure that the South African coal industry remains sustainable in the future. The estimated year when production from the traditional coalfields begins to decline is 2020. Partners and major funders in the project include the main South African coal mining companies, the Department of Minerals and Energy, the Chamber of Mines and the Universities of Pretoria and the Witwatersrand.

Although the coal deposits in the Waterberg Coalfield were discovered in 1920 near the town of Lephale (Ellisras), the Grootegeluk mine was only established in the late 1970s by the Iron and Steel Corporation (ISCOR) of South Africa. ISCOR was privatised in 1989, and in 2001 unbundled as Kumba Resources and ISCOR (which was bought by Mittal in 2005). Kumba Resources separated into Kumba Iron Ore and Exxaro Resources in 2006, with the coal assets now owned by the latter.

The Waterberg Coalfield is highly faulted and all the structures and their effects have not been identified and studied to date. To this end, CRA funded a detailed airborne geophysical survey of the Waterberg Coalfield with a view to obtaining new data that will result in a better structural understanding of the area. The CSIR Applied Geoscience Research group was commissioned to manage the survey, which was conducted by the Geophysics Division of the Council for Geoscience of South Africa, and to interpret the results. The interpretation of the magnetic and radiometric data is currently in progress and results to date are reported below. Precise location of the faults will greatly impact on the delineation and estimation of both shallow, easily exploited and deep coal resources. This will contribute to removing some of the uncertainty concerning the coal resources in the area, and facilitate both governmental and mine planning for the future.

In addition, the airborne geophysical survey can potentially detect geological structures that are deep-seated, below the coal-bearing Karoo basin, which, properly interpreted, can add to our understanding of the basement rocks to the Karoo, as explained in the geological setting to follow.

3. Geological setting

The Waterberg Coalfield is located in the western part of Limpopo Province of South Africa, and extends into neighbouring Botswana where extensive coal exploration activity is currently (2006-2008) taking place. The coal-bearing rocks belong to the Karoo Supergroup in southern Africa that was deposited between ~260 and ~190 Ma ago. The Ellisras Basin is separated by some 320 km from the main Karoo Basin in which the Witbank, Highveld and Ermelo coalfields are located. It formed as a graben structure bounded by basin-edge faults, on older, basement rocks that belong to the Limpopo Belt (to the north) and the Waterberg Group (to the south). The development of the basin was probably controlled by basement structures that were re-activated over time, and were probably active post-Karoo deposition. The Ellisras Basin straddles the complex contact between the Limpopo Belt and the Kaapvaal Craton, on which the Waterberg Group is developed, and thus any studies that add to the database would enhance our understanding of this fascinating and interesting part of the geology of southern Africa.

(As indicated above, the newly-termed Waterberg Coalfield was formerly known as the Ellisras
Coalfield. However, the name "Waterberg Group" is used in the geological literature for rocks that are much older than the coal-bearing Karoo rocks, and that were deposited in the "Waterberg Basin". To avoid confusion, the term "Ellisras Basin" (not Lephalale) will be used with regard to the coal-bearing rocks, as this name is used in the latest compendium of South African geology (Johnson et al. 2006a).

3.1 Stratigraphy
The area covered by the airborne geophysical survey encompassed three broad geological terrains, from north to south, the Limpopo Belt, the Ellisras Basin and the Kaapvaal Craton. The following brief overview of the stratigraphic sequence is summarised from three chapters in Johnson et al. 2006a.

Limpopo Belt (Kramers et al. 2006)
Complexly deformed and highly metamorphosed rocks comprise the Central Zone of the Limpopo Belt. These rocks include some of the oldest in South Africa, and both meta-sedimentary and meta-igneous varieties are developed. Most of the rocks are Archaean in age (>2500 Ma) although recent work has identified rocks that may have developed between 2000 and 2200 Ma ago. The rocks which are developed immediately to the north of the Ellisras Basin belong to the Malala Drift Suite composed mainly of quartzo-feldspathic gneisses which are meta-sedimentary in origin. These rocks were involved in two orogenic episodes ~2560- 2690 Ma and ~2000 Ma ago, the detailed complexities of which are still debated and require further study.

Waterberg Group (Barker et al. 2006)
South of the Ellisras Fault, the rocks of the Waterberg Group form a prominent plateau. Although there is no direct age date on these sedimentary rocks, they overlie the Bushveld Complex (~2065 Ma), and are intruded by dolerite sills, dated at 1890 Ma. These rocks were deposited in an intra-continental rift basin on the Kaapvaal Craton that was bounded to the south by the Thabazimbi-Murchison Lineament Zone. The Waterberg outcrops are bounded to the north by the Ellisras Fault, but the original basin margin is probably hidden under the Ellisras Basin.

The Mogalakwena Formation of the Waterberg Group is the geological unit that abuts against the Karoo rocks in the Ellisras Basin. It is composed mainly of coarse-grained sandstones, conglomerates and minor mudstones that were deposited in braided rivers.

Karoo Supergroup (Johnson et al. 2006b)
The coal-bearing rocks belong stratigraphically to the Karoo Supergroup. The separation of the Ellisras Basin from the main Karoo Basin resulted in no direct continuation of rock units between the two basins, and hence a separate formal stratigraphic column was constructed for the Ellisras Basin. There is, however, a close correlation between the two areas based on fossil evidence. The rock succession is composed of minor diamictites, conglomerates sandstones and mudstones with local development of coals. The economically most important unit is the Grootegeluk Formation that is up to 110 m thick in the south. This formation consists of cycles of coal, carbonaceous shale and mudstone that were deposited in flood plains adjacent to abandoned deltas. Plant material accumulated in the swampy flood plains and eventually formed the peat and, after lithification, coal seams.

Selective open cast mining of these coal seams at Grootegeluk Mine enables production of a range of coal suitable for power station feedstock, coking and metallurgical usage. At present all the coal is consumed locally.

Recent cover
Weathering of the Limpopo Belt and Karoo rocks has resulted in a relatively flat topography which is covered by a surficial layer of soil and in places, sand. This has resulted in rock outcrops being scarce, one of the reasons for undertaking the airborne geophysical survey. Surficial processes such as calcretisation and laterisation have locally occurred, further altering the bedrocks and making identification difficult. Thus to confirm the bedrock interpreted from the geophysics it will be necessary to undertake drilling. Fortunately a large amount of coal exploration drilling has been conducted recently in the Ellisras Basin, and it would probably only be necessary to drill a small number of newly-identified structures/intrusive rocks.

3.2 Structure
Faulting is the main structural element that has affected all the rocks, regardless of age. The re-activation of faults through time has also influenced the depositional basins, and of most economic importance are the post-Karoo faults that have controlled the depths of the coal seams.

The fault elements that were covered by the airborne survey include:
Northern contact of the Ellisras Basin with the Limpopo Belt, which is the western extension of the Melinda Fault;

Southern contact of the Ellisras Basin with the Waterberg Basin, which is the Eenzaamheid and Ellisras Fault;

Buried contact between the Limpopo Belt and the Waterberg Basin/Kaapvaal Craton beneath the Ellisras Basin; and

Post-Karoo faults, including the important Daarby Fault, that disrupt the coal seams.

Significant folding is mainly confined to the Limpopo Belt rocks and is responsible for the geophysical fabric north of the Ellisras Basin. The Waterberg and Karoo rocks are flat-lying.

3.3 Intrusive rocks
The most important intrusive rocks are those that cut through the coal-bearing rocks and disrupt the seams. They are common in the Witbank and Highveld Coalfields, but occur less frequently in the Waterberg Coalfield. The airborne geophysical survey has identified a number of structures that can be dykes. These need confirmation by field checking and drilling.

4. Geophysical Survey conducted in 2007
An airborne geophysical survey was conducted across the South African side of the Ellisras Basin. The survey covered about eight 1:50 000 topographic sheets (Figure 2). The airborne geophysical survey was flown in a north-south direction at a 200 m line spacing and the flying height was 80 m. The survey speed was 230 km/h, and a sampling frequency was 10 Hz. This translates to a measurement every 6.5 m on the ground.

The survey was flown in blocks of 5 km by 5 km, with tie lines every 1 km. The tie lines are flown at an east – west direction. The purpose of the tie lines are to facilitate the levelling of the data.

The magnetic data was collected with a caesium vapour magnetometer with a resolution of 100 pT. The radiometric data was collected with a 80 litre, NaI crystal and the elevation was measured using a laser altimeter.

The contact between the Ellisras Basin and the Limpopo Mobile Belt can easily be seen. It also shows that there are few strongly magnetised structures evident in the Ellisras Basin.
The DTM data show clearly the erosional valley of the Makolo River close to Lephalale (Ellisras). It also shows the position of the open cast Grootegeluk Mine.

The total count (TC) data of the area shows very clearly the Ellisras Basin and the Limpopo Belt to the north. The TC data shows the regional geology distribution and several more features such as large block faulting. Many unexpected features were detected in the Ellisras Basin. This is due to the radiometric method sampling close to the surface and thus picking up subtle features. The TC channel incorporates the counts of a large range of energies and is in effect a broad band (BB) channel. It also shows radioactive material eroding from the source (Waterberg sandstones) in the south into the sediment load of the northward-flowing Mokolo River. These sandstones are mainly the feldspar-enriched Kranskop Sandstones. The feldspar indicates that the original source area of these sandstones was granitic in composition. This granitic source could have been in the north (Limpopo Belt gneisses) or in the south (Bushveld Complex granites).

The uranium count data show a similar pattern but not as distinct as the total count data. The amount of uranium that is present in the river sediment and the south is very low.

The thorium count is higher than the uranium count. Thorium is a daughter element of uranium, and the higher thorium count supports the fact that the sediment is a second generation source of radioactivity. This means that this source is much older than the original source (granites).
The potassium count data are sensitive to the radioactive isotope of potassium and help to map the distribution of feldspar and feldspar-rich sandstones, which is usually the erosional product of granites. The Waterberg Group rocks to the south and south-east also show up well in the image.

The Landsat 7 image of the area also shows the terrain of the area and some very narrow lineaments (Figure 9). These need field checking.

5. Geophysical interpretation
The magnetic structure of the Ellisras Basin is of overall very low intensity. A phase operator was calculated on the magnetic data (Phasemag) to detect the smaller, more subtle variations in the data (Figure 10). This operator detected all the smaller anomalies in the data, which indicates that most of the structures are either not really magnetic, or are in the Ellisras Basin below the Karoo cover, and are hence pre-Karoo in age.

This needs drill-verification. Field work completed to date indicates that the suspected dykes which were investigated are totally weathered (Figure 11).

The complete data set was used to do a lineament interpretation. All the interpreted faults from the airborne geophysical survey are also indicated (Figure 12).

The strike direction of the lineaments is different from the strike direction on the Botswana side of the coalfield, but that is due to a large regional basin structural control.
6. Physical Properties

In order to do the geophysical interpretation of the data, it was necessary to sample the rocks which crop out in the study area. This was done by using a small 25 mm diamond core drill.

Samples of lavas (Karoo Supergroup) were taken in the Grootegeluk Mine. Samples of the Kranskop Sandstones (Waterberg Group) and Molteno Sandstones (Karoo Supergroup) were also collected. These samples were then measured for their density, resistivity, seismic velocity and magnetic susceptibility. Table 1 and Table 2 show the physical property results.

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Table 1: Physical property results: densities and seismic velocities.
Table 2: Physical property results: magnetic susceptibilities.

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<tr>
<th>SITE</th>
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7. Conclusions
The airborne geophysical survey has contributed greatly towards new knowledge of the Ellisras Basin. It has shown that the basin has undergone much more structural disturbance than was previously suspected. This survey has also shown that a large number of lineaments and faults occur throughout the basin, although they do not have significant magnetic signatures. This poses the question: How many such structures remain undetected at present because they are non-magnetic in nature? The question can most likely be satisfactorily answered by an airborne electromagnetic survey flown over the entire Waterberg Coalfield. Such a survey will be more expensive to conduct than the completed airborne magnetic and radiometric survey, but will produce much additional geological data that will greatly enhance the structural understanding of the Ellisras Basin. This in turn will facilitate better coal resource delineation, and ultimately improved and more sustainable exploitation of one of South Africa’s vital coalfields.

8. References


9. Endnote

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