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The structure of the Karoo-age Ellisras Basin in Limpopo Province, South Africa in the light of new airborne geophysical data: a preliminary report

C.J.S. Fourie[1], **G. Henry[1]** and L.P. Marè[2]

1. Council for Scientific and Industrial Research, South Africa, sfourie@csir.co.za; ghenry@csir.co.za
2. Geophysics Division, Council for Geoscience, South Africa, leoniem@geoscience.org.za

ABSTRACT

The Waterberg Coalfield is destined to become the major source of energy for South Africa in the future. In 2008, Coaltech Research Organisation funded an airborne magnetic and radiometric survey over the Karoo-age Ellisras Basin in which the coalfield is developed. Interpretation of the magnetic data has provided a novel half-graben model for the structure of this basin. The northern boundary is the block-faulted Melinda Fault Zone, with the southern, less-faulted part of the basin sloping gently to the north. The thickness of the Karoo Supergroup reaches 1 500m in the eastern part of the basin, and decreases to the west. The new geophysical data has contributed much to the understanding of the geological evolution of this important coalfield.

Key words: Karoo, Waterberg Coalfield, Ellisras Basin, airborne geophysics, half-graben

INTRODUCTION

The Waterberg Coalfield is destined to be the most important source of coal in South Africa in the future when the remaining reserves of coal in the Witbank and Highveld coalfields are depleted (Jeffrey, 2005a, b; Fourie et al, 2008). Although the coalfield was discovered in 1920, the first commercial mining only started in the late 1970s with the establishment of the Grootegeluk Mine, now owned by Exxaro. The current (2009) construction of a second coal-fired power station in addition to Matimba (that sources feedstock from Grootegeluk Mine) underlines the importance of the coalfield to South Africa's energy security. The total coal resources and reserves in the coalfield are, however, not well constrained, with widely varying estimates: Bredell (1987) quotes a figure of 15 487 million metric tonnes (Mt) of recoverable coal reserves, while de Jager (1983) estimated total in situ mineable reserves of 49 923 Mt. Jeffrey (2005a) explains the difficulties of such coal resource and reserve estimations. In view of the importance of the Waterberg Coalfield, Coaltech Research Organisation (CRO) funded an airborne geophysical survey in 2008 with the prime objective of obtaining data to elucidate the geology of the coalfield. These results are of great benefit to the coal mining and exploration companies active in the area, and would result in improved estimates of the coal resources and reserves by better delineation of the geological setting. Fourie et al. (2008) published some preliminary results, and Fourie (2009) submitted an internal report to CRO. Here we report on the results of the 2D interpretation of the airborne magnetic survey by Fourie.

There are few good rock outcrops in the Waterberg Coalfield (Brandl, 1986) and the geological mapping and interpretation in the area have been assisted by borehole cores. These were drilled mainly by the Geological Survey of South Africa (now the Council for Geoscience) on a reconnaissance basis in the mid-20th Century (Snyman, 1998), and later by mining companies. Few sedimentological studies, mostly unpublished, have been carried out (Ryan, 1966; Beukes, 1985; Siepker, 1986, summarised by Brandl, 1986; Faure et al, 1996a; b). These authors recognised the fault-bounded nature of the coalfield, but its sub-surface structure had not been clarified.

GEOLOGICAL SETTING

The coalfield is developed in the Karoo-age (~310 - 180 million year (Ma) old) Ellisras Basin (Johnson et al, 2006b), and not the Waterberg Basin in which the ~1950 Ma old Waterberg Group rocks were deposited. The town of Ellisras has recently been renamed Lephalale, but "Ellisras Basin" will be retained until the South African Committee for Stratigraphy (SACS) approves a change.

The preserved Ellisras Basin in South Africa (Figure 1) is approximately 90 km long (EW) and 35 km wide (NS). It extends westward, and greatly enlarges where the basin enters Botswana. Extensive coal exploration is currently being done in the Botswana section of the Ellisras Basin. The northern boundary is defined by the Melinda Fault Zone (MFZ), with rocks of the Limpopo Belt outcropping to the north of it. The southern boundary is the Eenzaamheid Fault Zone (EFZ), to the south of which Waterberg Group rocks outcrop. To the east, the Karoo rocks unconformably overly Limpopo Belt mafic rocks (north) and Bushveld Complex-age (~2065 Ma)(Brandl, 1986) rocks to the south. Comprehensive descriptions of these floor rocks to the Karoo rocks are given by Johnson et al. (2006a).

The Limpopo Belt comprises highly deformed and metamorphosed sedimentary, volcanic and igneous rocks that were involved in at least two major orogenies ~2690-2560 Ma and ~2000 Ma ago (Johnson et al., 2006a). The rocks to the north of the MFZ belong to the Mala Drift Suite composed mainly of quartzo-feldspathic gneisses. The mafic rocks to the north-east have been included in the Messina Suite by Brandl (1986).

The Mogalakwena Formation of the Waterberg Group abuts against the EFZ to the south of the Ellisras Basin. It consists mainly of coarse-grained sandstone, conglomerates and minor mudstones that dip gently to the north.

The Villa Nora lobe of the Bushveld Complex forms the floor of the Ellisras Basin to the south-east, with both layered basic rocks and granite developed. The lobe is in fault contact with the Messina Suite to the north.

The Ellisras Basin is separated by about 320 km from the main Karoo Basin to the south where the Witbank and Highveld Coalfields are situated. A separate Karoo Supergroup stratigraphy was proposed by Siepker (1986) and formalised by SACS (Johnson et al., 2006b). Nine formations are recognised, consisting of sandstones, siltstones, mudstones, coals with minor diamictites and basaltic lavas. Interpreted depositional environments include glacial lacustrine at the base of the sequence, braided and meandering rivers with adjacent overbank splay deposits, deltaic plains (coal-bearing), alluvial fans, and desert settings in which aeolian rocks were deposited (Siepker, 1986; Faure et al, 1996a; Cairncross, 2001). The rocks are sub-horizontally disposed, with very gentle dips towards the basin axis. The total thickness of the sequence is variable with a reported maximum of about 800 m (Johnson et al., 2006b). We report a new estimate below.

With the exception of the plateau underlain by the Waterberg Group rocks to the south, much of the area is covered by extensive soils and sands, with very few rock outcrops. This is one of the main reasons for the many stratigraphic/exploration holes drilled, and a strong motivation for undertaking the current research initiative.

AIRBORNE GEOPHYSICAL SURVEY

The survey extends over eight 1:50 000 topographical sheets that covered the whole South African section of the Waterberg Coalfield. It was flown in a north-south direction at a 200m line spacing at a flying height of 80m. The aircraft speed was 230km/h and the sampling frequency was 10 Hz. This translates to a measurement every 6.5m on the ground.

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

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

The airborne magnetic data was processed to obtain a phase magnetic map. The phase magnetic operator calculates an analytical signal at angles of 45°. The phase magnetic map indicates that the Ellisras Basin has experienced a large amount of tectonic activity in its evolution (Fourie, 2009; Fourie et al., 2008). The total field magnetic data was used to model two profiles (Figure 1). The profiles were chosen to be orientated north-south in order that they cross the important geological structures at right angles and thus make the magnetic modelling easier. A regional magnetic field was removed from the data. The modelling was performed using magnetic physical property data obtained from field samples. These data include the magnetic susceptibility and the magnetic remanence of the samples. The profiles were modelled using the Magix XL software package.

RESULTS

The modelled results and interpretation are shown in Figures 2 and 3. The main features to note are (Fourie, 2009):

- the asymmetric north-south profile of the floor of Ellisras Basin, with a gentle slope from south to north up to the basin axis, and a faulted, steeper slope from the basin axis northward to the edge of the basin;
- the block faulting to the north of the basin axis that comprises the MFZ (Melinda Fault Zone);
- Waterberg Group rocks form two-thirds to three quarters of the floor of the Ellisras Basin, exclusively on the southern side;
- the maximum thickness of the Karoo Supergroup in the eastern Profile 1 is up to 1500m, almost twice the published maximum;
- the thickness of the sub-Karoo Waterberg Group rocks along Profile 1 is greater than that along Profile

2; the Waterberg Group sequence thins rapidly towards the MFZ along both profiles.

DISCUSSION

The tectonostratigraphic development of the Karoo basins in South Africa has been well studied, especially because of the important coal deposits in the main basin. The retro-arc foreland basin model first proposed by Johnson (1991) was refined by Catuneanu et al. (1998; 2005). This model was challenged by Turner (1999) and Tankard et al. (in press, 2009). With regard to the Ellisras Basin, Catuneanu et al. (2005) consider it to be part of the back-bulge flexural province of the Karoo foreland system. Turner (op cit.) proposed a component of Gondwana rifting as a major control on the tectonic development of the Karoo basins. Tankard et al. (op cit.) prefer an alternative explanation for the long-wavelength component of Karoo subsidence as resulting from lithospheric deflection due to mantle flow coupled to distal subduction. Their basin evolution model comprises three stages: (i) crustal uplift; (ii) fault-controlled subsidence, and (iii) long periods of regional subsidence during which faulting were subordinate.

The north-south asymmetrical profile of the Ellisras basin is typical of that to be expected in a half-graben, with a steep fault-bounded side and a more gently sloping side. Rifting is a major expression of tensional tectonics in the earth's crust, and continues to be a topic of research. The currently active East African Rift System (EARS) provides a present day model of the rifting process, summarised by Rosendahl (1987) and Chorowicz (2005). Rosendahl and his co-workers based much of their interpretation on seismic surveys, and one of the fundamental findings was that half-grabens were abundant in the EARS, and that these could evolve with time into more symmetrical full graben systems. The steep bounding fault (zone) is commonly listric in shape, and can comprise more than one fault.

The MFZ is interpreted to be complexly structured with fault-bounded blocks that rotated as a result of extension during Ellisras Basin evolution. The less steeply-dipping side appears unfaulted, but the presence of the Daarby Fault indicates that there is a good probability that some syn-Karoo faulting also occurred there. These smaller faults may have escaped detection by the airborne geophysical because they are too small and/or they do not have a significant magnetic signature.

Also of significance is the fact that the MFZ abuts against the Waterberg Group rocks in the subsurface, with none of the latter rocks developed on Limpopo Belt rocks. This suggests that the MFZ possibly formed the northern boundary of the Waterberg Basin, and that this long-lived tectonic lineament that originated in the Archaean era has been re-activated several times (Brandl, 1986; Catuneanu et al. (2005); Johnson et al. (2006b)). It now forms the northern outcrop limit of the Ellisras Basin.

The half-graben nature of the Ellisras Basin has a probable counterpart in the Tuli Basin, about 200km to the northeast, as reported by Bordy and Catuneanu (2001). It is thus likely that many of the smaller Karoo basins developed distal to the main one in South Africa are a result of rifting. The present novel finding can be used to support the interpretations of Turner (1999), Catuneanu et al. (2005) and Tankard et al. (in press, 2009) because all three models include a rifting component at some stage during Karoo Basin evolution. More detailed sedimentological research is needed to define the timing of deposition in relation to tectonic development in the Ellisras Basin before firmer conclusions can be drawn as to which is the most appropriate tectonostratigraphic model.

CONCLUSIONS

The CRO-funded airborne geophysical survey of the Waterberg has provided a wealth of data that will be important to gain a better understanding of the important coal-bearing Ellisras Basin. Preliminary 2D modelling of the magnetic data has provided novel evidence for a half-graben geometry of this basin. The northern MFZ, within Limpopo Belt rocks, is block-faulted and dips relatively steeply to the south; the southern part of the basin is less faulted with a more gentle north-dipping Waterberg Group floor. The southern profile indicates a maximum thickness of 1500 m for the Karoo Supergroup, almost twice that previously reported.

The interpretation confirms the previous rift-related development of some of the Karoo basins outside the main one, with probable half-graben as opposed to full graben geometries. It does not, however, favour any one of the proposed Karoo Basin evolution models by Turner (1999), Catuneanu et al. (2005) or Tankard et al. (2009). This would require more detailed sedimentological research and better geochronology to unravel the complexities of how the Ellisras Basin developed during the Karoo era. In addition, there are many non- or very weakly-magnetic geological structures in the Ellisras Basin that have not been detected by the reported airborne survey. Although relatively expensive, an airborne electromagnetic survey would be ideal to delineate these structures. Future ground geophysical research would include 2D and 3D seismic and magnetotelluric (MT) surveys. The comprehensive geophysical data set from these surveys would greatly enhance the geological understanding of the economically vital Waterberg Coalfield.

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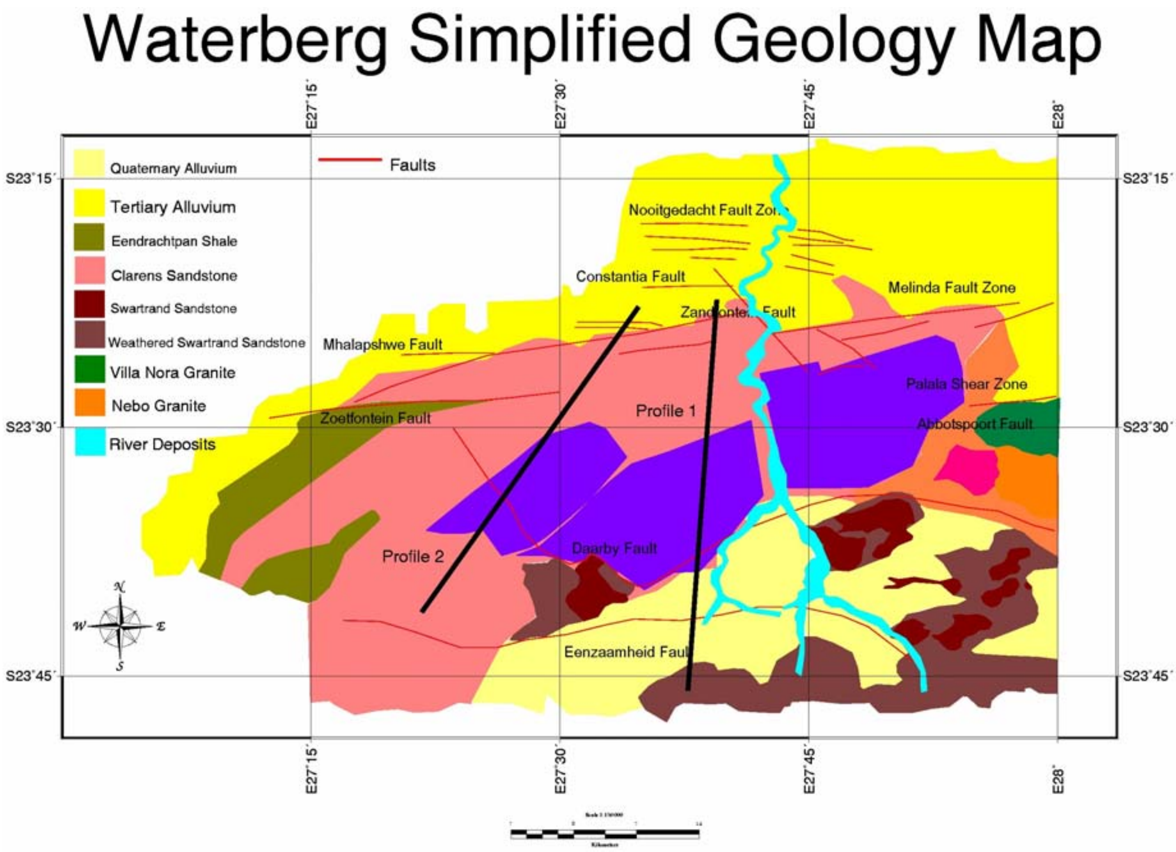

Figure 1: Simplified geological setting of the Ellisras Basin, showing the location of the 2D modelling profiles. The geology was derived from interpretation of the ternary image of the airborne radiometric data and from the 1:250 000 scale Ellisras geological map sheet.

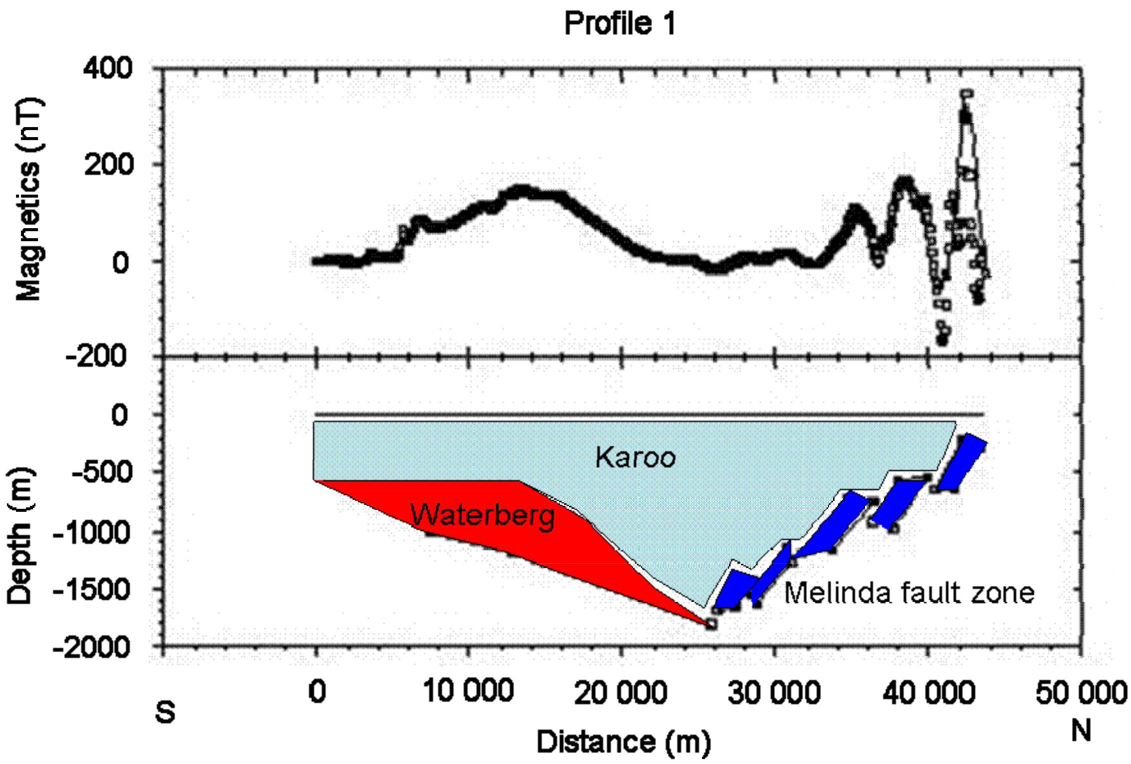

Figure 2: Modelled result of Profile 1. Note asymmetry of the basin and the block-faulted northern margin.

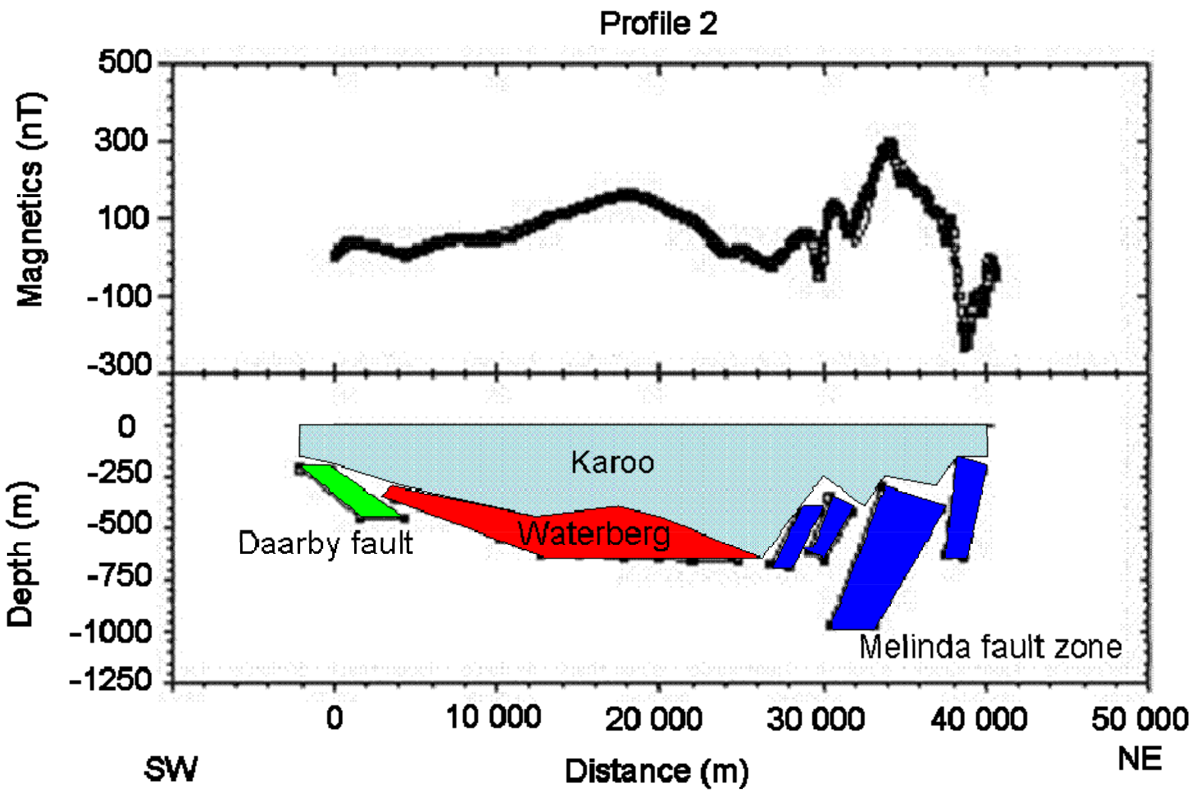

Figure 3: Modelled result of Profile 2. Similar to Fig. 2, with a thinner Karoo sediment fill, and the presence of the Daarby Fault. The asymmetry of the half-graben is more pronounced.