Comparing magnetic and magnetotelluric data for the Beattie Magnetic Anomaly, South Africa

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1 Introduction

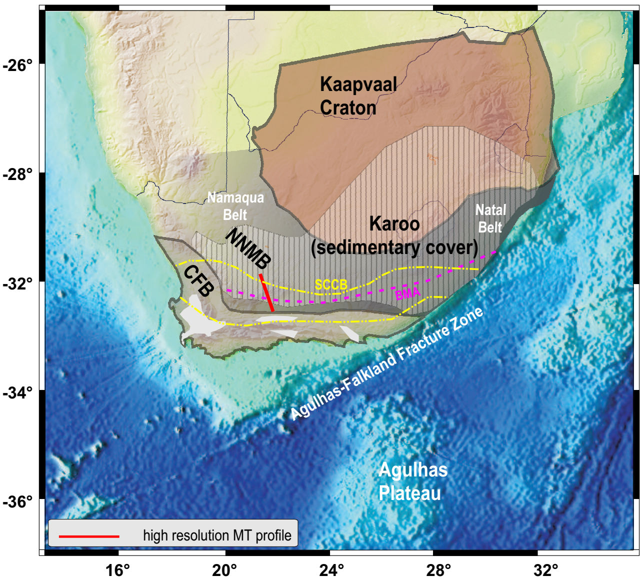

Figure 1: The southern part of the African continent consists of an assemblage of different continental domains. The Archean nucleus is the Kaapvaal craton. In the Proterozoic the Namaqua Natal Mobile Belt (NNMB) accreted in the south, followed by the collision of the Permo-Triassic Cape Fold Belt (CFB). Our study area crosses the boundary of the NNMB and the CFB. The shaded zone indicates the area where sediments of the Karoo Basin obscure older tectonic units.

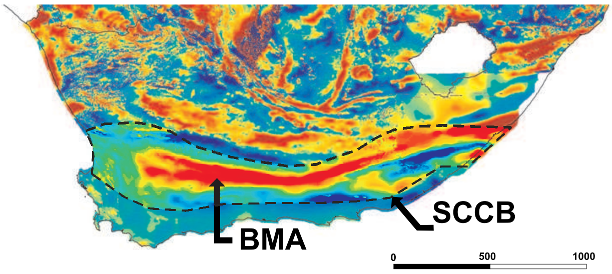

Figure 2: Magnetic total field, compiled at 1:1 million by Anglo American Corp Ltd., in the the CIGCES database; also in the AMMP database [*Barrett*, 1993]: The BMA (red and magenta colours) and the SCCB (outlined by dashed line) are continental scale geophysical anomalies. They stretch from east to west for more than 1000km across the entire southern South Africa. In some areas they are parallel to the boundary of the NNMB and the CFB.

The Beattie Magnetic Anomaly (BMA) and the Southern Cape Conductive Belt (SCCB), two of Earth's largest continental geophysical anomalies extend across the southern African continent in EW direction. The BMA was first discovered by *Beattie* [1909] (see Fig.2). More than half a century later *Gough et al.* [1973] reported on measurements using an array of 24 three-component magnetometers which lead to the identification of a 140km broad and over 1000km long SCCB. Because of the spatial correlation of both geophysical anomalies a common source in form of a 50km broad and 30km deep reaching southward dipping sliver of serpentinzed paleo-oceanic crust was proposed by many authors since then (e.g. *Pitts et al.* [1992]). However, both anomalies are in close vicinity to the boundary of the Namaqua Natal Mobile Belt (NNMB) and the Cape Fold Belt (CFB) which might suggest a tectonic interpretation. *Corner* [1989] inferred that mineralized thrust zones within the NNMB granitoid basement were a more likely explanation for the anomalies. To resolve structural details of both geophysical anomalies two modern, high resolution magnetotelluric experiments were conducted in March, 2004, and November, 2005, along a 250km long

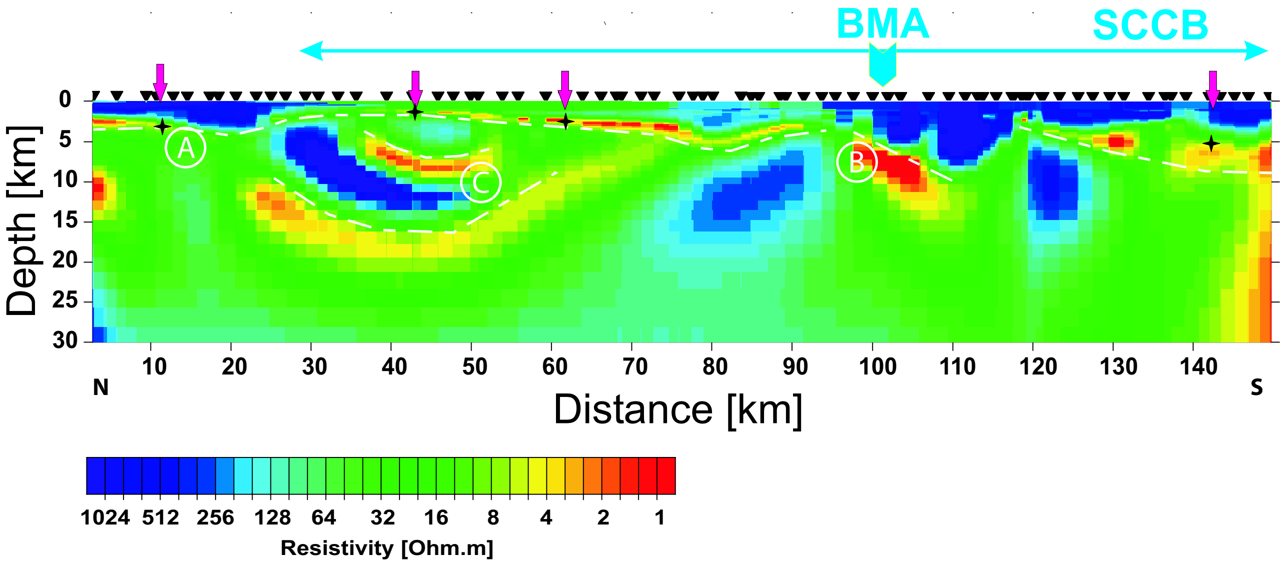

Figure 3: Conductivity model obtained from the 2D inversion algorithm by *Rodi and Mackie* [2001]. Site locations are indicated by black triangles. The surface-trace of the BMA and the extent of the SCCB are indicated by cyan arrows. The new data reveal several previously unknown conductive structures (red and yellow colours). The most prominent conductivity anomaly (B) is located beneath the surface trace of the BMA. A couple of conductive structures stacked above and below a resistive layer (C) define a large synform, $\sim 50\,km$ across, within the NNMB. A shallow sub-horizontal band of high conductivity (A) can be observed in the upper $5\,km$, deepening towards in the southern part of the section, near Prince Albert, where the Karoo basin is known to be thickest. Magenta arrows at the surface indicate the location of deep boreholes which were projected onto the profile. The black stars below map the carbonaceous and pyritiferous black shales of the Whitehill Formation.

NS profile between Mossel Bay and Fraserburg. A 2D conductivity model of the northern $150km$ of the profile exhibits three distinct zones of high conductivity: (i) Beneath the surface trace of the maximum of the BMA we observe a high conductivity anomaly at 5-10 km depth. (ii) A shallow, regionally continuous sub-horizontal band of high conductivity, that can be related to a 50-70 m thick pyritic-carbonaceous marker horizon using deep borehole information and (iii) several highly conductive synformal features in the mid crust are newly imaged beneath the onset of the Great Escarpment.

2 Magnetotelluric model

The resistivity section in Fig. 3 is the result of a 2D inversion using the RLM2DI algorithm after *Rodi and Mackie* [2001] (http://www.geosystem.net). The TE and TM mode data are jointly inverted with the intermediate inclusion of the vertical magnetic field data. Preset error bounds of 5% for TM apparent resistivity and 100% for TE apparent resistivity and 0.6^o for TE and TM mode phases were applied. We started the inversion from a homogeneous halfspace model including topography with a mesh of 207 horizontal and 158 vertical cells and a regularization parameter $\tau = 15$. Red and yellow colours indicate zones of high electrical conductivity, whereas blue colours show zones of low electrical conductivity. A zone of very high electrical conductivity $(1\Omega m)$, at a depth of approximately $5 - 10km$, seems to be associated with the BMA. Another conductivity anomaly is located beneath the northern boundary of the SCCB, extending from the shallow crust down to $20km$ depth. These high conductivity anomalies may image faults which are mapped further to the east and separate different terranes. The conductivity model furthermore reveals an extensive sub-horizontal band of high conductivity $(2\Omega m)$ in the upper $5km$ of the Karoo Basin. For this shallow anomaly we have information from deep boreholes. The boreholes projected onto the profile are marked with red arrows. The borehole logs indicate that the Whitehill Formation consists of carbonaceous blackshales and pyrite. The black stars mark the depth region of the Whitehill For-

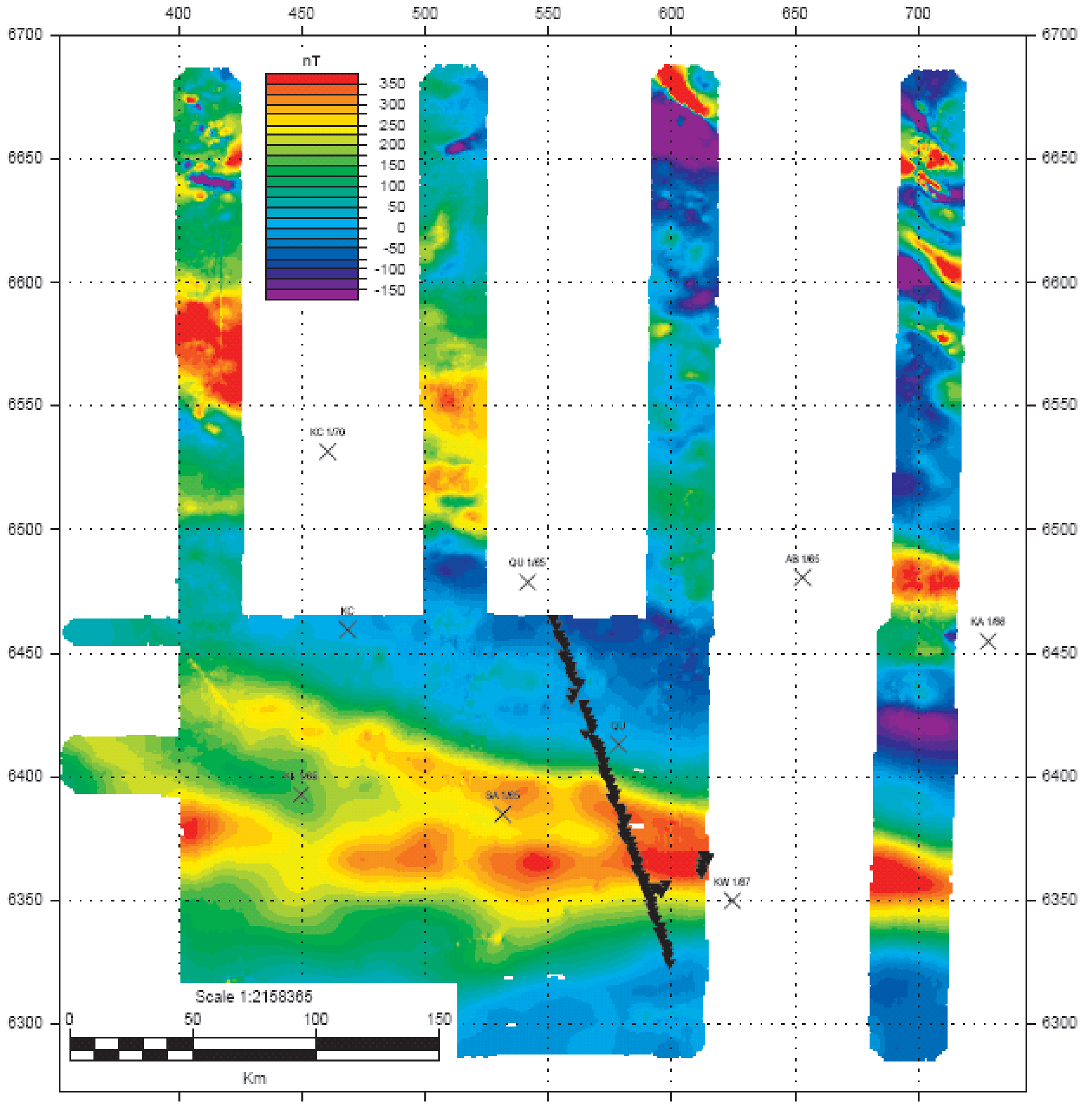

Figure 4: Aeromagnetic data supplied by the Council for Geoscience. Black triangles mark the location of MT sites; crosses indicate borehole locations.

mation which coincides well with the location of the sub-horizontal high conductivity band.

3 Magnetic modelling

The aim of the magnetic modelling is to answer the question if both geophysical anomalies have a common source. Thereby we test whether a magnetic feature consistent with the conductivity anomaly associated with the BMA could explain the observed magnetic field. The aeromagnetic data were kindly supplied by the Council for Geoscience, Pretoria, South Africa. The magnetic lines were flown in the early 1980's and the compiled data set contains of the flight path, altitude and magnetic total-field variations. For modelling purposes eight NS running profiles, which are $2km$ apart, are combined with two $10km$ spaced (one NS and one EW running) profiles to form a complete array over the MT profile's area.

The profiles were integrated into a single, draped, constant altitude ($100m$) array using the Magnetic 2.75D Modeling component within the WinGLink software package. The external field was removed from the total field data using the IGRM for the date 1982. The external field for the region has a magnetic inclination of -66.2^o and a total intensity of $28358nT$. The residual map was projected onto the MT profile and interpolated using an interpolation radius of 5km and a spline weight of 5. All magnetic bodies were assumed to

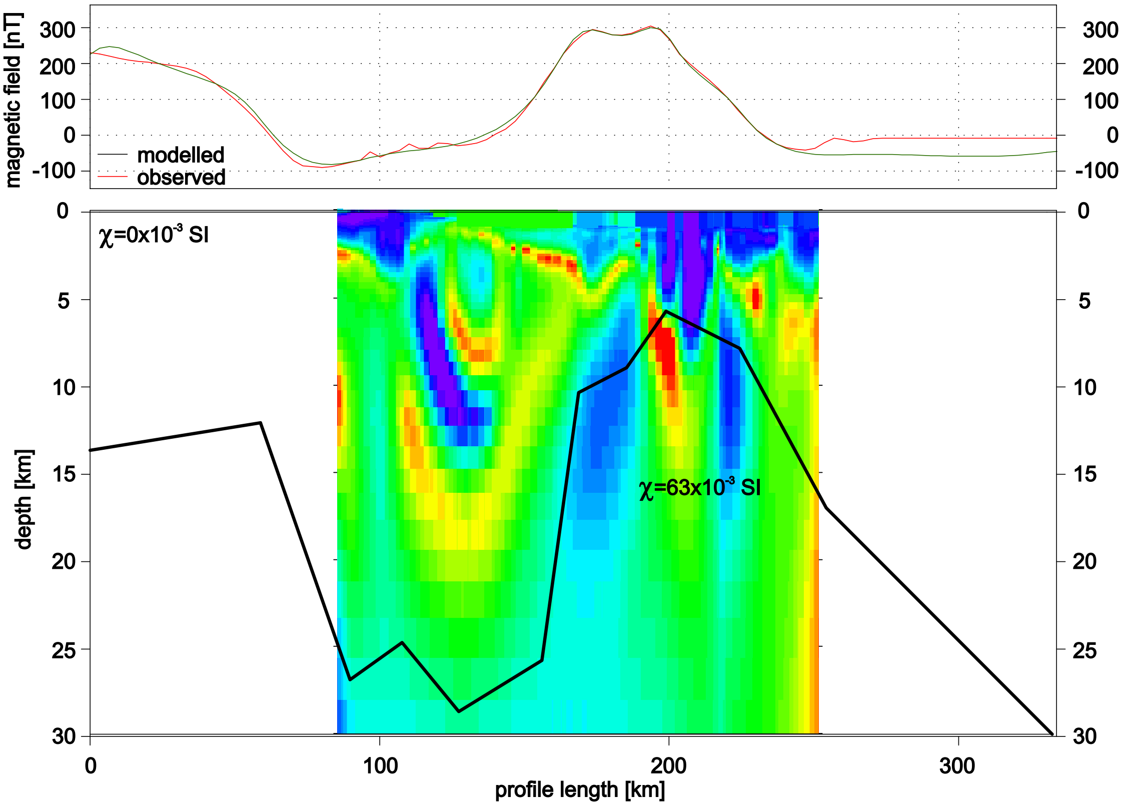

Figure 5: With a simple 2D model we are able to explain the magnetic signature of the BMA quite well. A comparison with the electrical conductivities clearly shows that the extent of a magnetic body has to be much larger than the conductivity anomaly observed beneath the surface trace of the BMA. However, areas of rocks with high magnetization might correlate with more resistive zones.

be homogenously magnetized from induced magnetism, and given infinite strike perpendicular to our profile.

One model favored is depicted in Fig. 5. It employs a lower susceptibility than that of *Pitts et al.* [1992] and is in the upper range of susceptibility values possible for granites and other intermediate igneous rocks. In general a multitude of models can fit the response, but it seems certain that the BMA and the SCCB are not of the same source. The conductivity feature (B) in Fig. 3 cannot fit the required BMA's source volumetrically to explain the observed magnetic response. However, the resistive area around the anomaly (B) possibly correlates with the magnetic body. As the favoured interpretation for this conductivity anomaly is graphite enrichment along a shear planes [*Weckmann et al.*, 2006], such a shear plane could cut through the magnetic body without changing the magnetic response significantly.

4 Conclusions and outlook

The comparison of the results from the new MT data across the SCCB and the BMA and magnetic modelling reveal that a common source for both geophysical anomalies is unlikely. In order to explain the observed magnetic response a at least $150 km$ wide magnetic body in the mid and lower crust is required. A similarly extended high conductivity feature does not agree with the MT data. More insights will be the incorporation of reflection and refraction seismic data (recorded recently along the same profile by GFZ) into interpretations for the BMA.

5 Acknowledgments

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References

Barrett, S. (1993), The african mapping project., *International Institute for Aerospace surveys and Earth Sciences,ITC, Journal Special Issue*, pp. 122–131.

Beattie, J. (1909), *Report of the magnetic survey of South Africa*, vol. R. Soc. Lond., Cambridge University Press, London.

Corner, B. (1989), The Beattie anomaly and its significance for crustal evolution within the Gondwana framework, *Extended Abstracts, South African Geophysical Association, First Technical Meeting*, pp. 15–17.

Gough, D., J. de Beer, and J. van Zijl (1973), A magnetometer array study in southern Africa, *Geophys. J. R. astr. Soc.*, *34*, 421–433.

Pitts, B., M. Mahler, J. de Beer, and D. Gough (1992), Interpretation of magnetic, gravity and magnetotelluric data across the Cape Fold Belt and Karoo Basin, in *Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa*, edited by M. de Wit and I. Ransome, pp. 27–32, Balkema, Rotterdam, Netherlands.

Rodi, W., and R. L. Mackie (2001), Nonlinear conjugate gradients algorithm for 2D magnetotelluric inversion, *Geophysics*, *66*, 174–187.

Weckmann, U., O. Ritter, A. Jung, T. Branch, and M. de Wit (2006), New Magnetotelluric measurements across the Beattie magnetic anomaly and the Southern Cape Conductive Belt, South Africa, *J. Geophys. Res.*, p. submitted.