Magnetotelluric imaging across a Neoproterozoic collision zone: Damara belt and surrounding tectonic bocks

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ABSTRACT

The **S**outhern **A**frican **M**agnetotelluric **Ex**periment (SAMTEX) is the largest ever land-based magnetotelluric (MT) project. The main objective of the project is to define the geo-electric structure across the region in order to gain a better understanding of Archean and Proterozoic tectonic processes. Only the MT profiles crossing the Rehoboth Terrane, the Neo-Proterozoic Ghanzi-Chobe/Damara belts and the southern Angola craton are the focus of this study. One of the ways in which geo-electrical structural information is obtained is by detailed analysis of the measured impedance tensor. The decomposition technique was applied to the MT data and indicates significant depth and along-profile variations in geo-electric strike and dimensionality on all transects crossing these three tectonic units (i.e. Rehoboth Terrane, Angola craton and the DMB). The geo-electric strikes are generally parallel to the north-east trending tectonic fabric as inferred from the magnetic data, but the significant strike variations with depth are expressions of heterogeneity in the lithospheric structure. The Rehoboth terrane, south of the DMB, exhibits a strongly one dimensional (1D) to moderate 2D structure, with preferred strike directions in the range 20^0-45^0 for the crust-mantle period (i.e. depth) range, indicating little crust-mantle decoupling. The DMB appears to be moderately 2D at lower crustal and upper mantle depths (10-100s) with no consistent/preferred strike direction and significant phase differences between the conductive and resistive directions. North of the DMB and into the Angola craton there are significant variations in geo-electric strike direction and dimensionality at most sites for lower-crustal and upper mantle lithosphere. Our results further indicate that the profiles have to be divided into smaller areas having similar strike directions to allow for 2D inversion modelling.

Key words: Magnetotellurics, Damara, Rehoboth

INTRODUCTION

Magnetotelluric (MT) measurements offer important insights into the electrical structure of the Earth. The **S**outhern **A**frican **M**agnetotelluric **Ex**periment (SAMTEX) is the largest ever land-based magnetotelluric (MT) project (Figure1), with more than 650 MT stations (broadband + long period). The main aim of the project is to define the geo-electric structure across the region in order to gain a better understanding of Archean and Proterozoic tectonic processes. Current tectonic boundaries in Southern Africa are defined using only aeromagnetic data. One of the overarching objectives of the SAMTEX project is to constrain these boundaries. MT data was acquired along a number of profiles crossing the Proterozoic Rehoboth Terrane, the Neo-Proterozoic Ghanzi-Chobe/Damara belts (collectively termed the DMB) and the southern Angola craton.

Apart from the upper crustal scale MT study of Ritter et al., 2003, there has not been any attempt to investigate the geometrical relation of the boundary between the Damara belt and particularly the Angola craton to the north, at lithospheric depths.

This current study aims to constrain these particular boundaries by investigating the lateral and depth variations in geo-electrical structural dimensionality and directionality of MT data responses. Using the Groom-Bailey (1989) decomposition analysis we gain an understanding of the geo-electrical strike direction, dimensionality and anisotropy properties of the region.

TECTONIC SETTING

The Southern African tectonic landscape is made of number of Archean cratons surrounded by orogenic belts. This work focuses specifically on the collision belt between the Rehoboth terrane and the Angola Craton. The Damara belt records the closure of an inland basin during the Neo-proterozoic to early Paleozoic collision of the Rehoboth terrane to the south and the Angola Craton to the north (Gray, et al., 2008; Begg et al, 2009). Recent results by Muller et al., 2009, indicate a relatively thinned lithosphere and an early Proterozoic stabilization age for the “enigmatic” Rehoboth terrane south of the Damara belt. There is still debate as to how far south the Angola craton extends into Namibia (Begg et al, 2009) and the boundary is only constrained using aero-magnetic data.

GEO-ELECTRIC STRIKE ANALYSIS

Obtaining useful information on the electrical structure of the Earth is a multi-step process which involves applying robust MT data processing and analysis techniques. Geo-electrical structural information, which can be correlated with different processes in the Earth’s crust and mantle, is obtained by applying the Groom and Bailey (1989) decomposition technique (GB), implemented in the STRIKE code of McNeice and Jones (2001). The GB method is preferred as it decomposes the distortion tensor into determinable (twist and shear) and indeterminable (anisotropy and gain) parts. The physical basis of the technique, discussed at length by also McNeice and Jones (2001), is given by equation 1;

$$\underline{\underline{Z}}_{obs} = \underline{\underline{R}}_{\theta}\ \underline{\underline{C}}\ \underline{\underline{Z}}_{2D}\ \underline{\underline{R}}_{\theta}^{T} \tag{1}$$

where Z_{obs} is the measured impedance in acquisition coordinates, R_{θ} is the rotation matrix , C is the telluric distortion tensor and Z_{2D} is the regional 2D impedance tensor in strike coordinates.

GB decomposition tries to identify the most consistent regional 2D strike direction, by separating the effects of local 3D in-homogeneities from the regional 2D inductive response and correct for local galvanic (electrical) distortion.

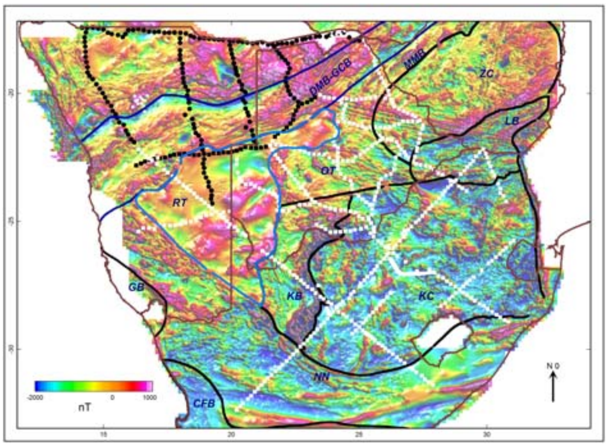

Figure 1. Magnetic image of southern Africa showing locality of all SAMTEX MT stations (black and white circles). The black filled circles show the stations that are the focus of this study. The outlines of the tectonic boundaries, including the Damara belt, are shown (courtesy S. Webb, University of the Witwatersrand). Tectonic domains abbreviated as follows: KC Kaapvaal Craton; ZC Zimbabwe Craton; LB Limpopo Belt; NN Namaqua-Natal Mobile Belt; KB Kheis Belt; MMB Magondi Mobile Belt; DMB-GCB Damara and Ghanzi-Chobe Belts; GB Gariep Belt; CFB Cape Fold Belt.

Figure 2 shows the results of applying this decomposition to our data.

Each site was analysed separately for each of the depth bands (Figure 2).

The geo-electric strikes are generally parallel to the north-east trending tectonic fabric as inferred from the magnetic data, but the significant strike variations with depth are expressions of heterogeneity in the lithospheric structure.

The Rehoboth terrane, south of the DMB, exhibits a strongly one dimensional (1D) to moderately 2D structure, with preferred strike directions in the range 20^0- 45^0 for the crust-mantle depth range, indicating little crust-mantle decoupling. The DMB appears to be strongly 2D at lower crustal and upper mantle depths with no consistent/preferred strike direction and significant phase differences between the conductive and resistive directions. North of the DMB into the Angola craton strike directions are generally 0^0 (or 90^0) and there is moderate variations in dimensionality at most sites for lower-crustal and upper mantle lithosphere.

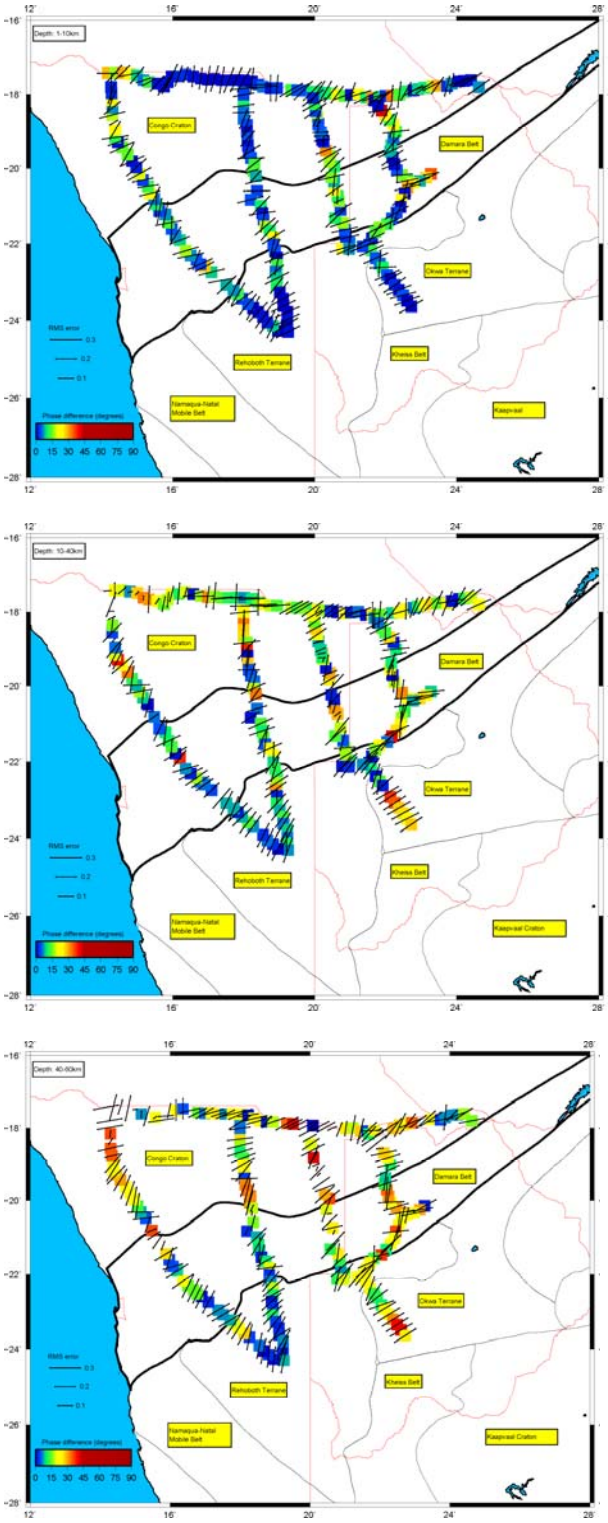

Figure 2. Geo-electric strike directions determined from GB decompositions are shown for each site at 3 different depth bands reflecting increasing depths of investigation (from top to bottom). The colour represents the maximum phase difference between the TE and TM modes (i.e. strength of anisotropy: blue means that part of lithosphere is 1D and red suggests strongly 2D structure). The length of the arrow is scaled by the RMS misfit of the data to the distortion model. Long arrows mean data fits the model of 3D distortion. High RMS error implies either that the observed MT data are highly locally distorted or are regionally 3D (rather than 2D) in structure.

Careful observations of these maps suggest a correlation between the change in strike directions and the magnetically defined tectonic boundaries in some areas.

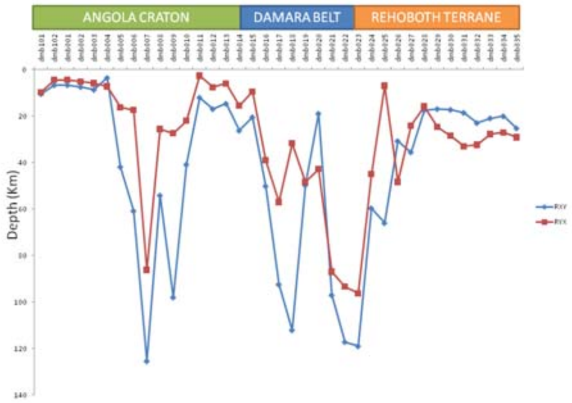

Figure 3. Approximate penetration depths along the N-S DMB profile at period 100s. Note large variation in depth of penetration along profile on both TE and TM modes.

One of the difficulties in dealing with long profiles and the large station spacing (20km) is that the penetration depths at similar periods are not the same along profile (Jones, 2006). This is illustrated in Figure 3, where the penetration depths for each of the modes (TE and TM) are derived by applying Schmucker C-function. As a result obtaining the more meaningful and consistent strike directions was a performed using approximate depth instead of period.

CONCLUSIONS

Our results indicate variations in strike direction from the Rehoboth terrane to the Damara belt, and from the Damara belt to the Angola Craton in the north. Furthermore we observe significant depth variations in strike direction and dimensionality at lower crustal depths indicating possible crust-mantle decoupling.

The lateral and depth variation in structural directions indicate that the profiles have to be divided into areas having similar strike directions in order to be modelled using 2D inversion techniques.

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