Structural directions and dimensionality of the Damara Mobile Belt and neighbouring terranes

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ABSTRACT

The boundaries and lithospheric structures of the Damara Mobile Belt and Ghanzi-Chobe Belt (collectively the DMB), part of the Pan-African Mobile Belt that records ocean closure about an apparent collisional triple junction during Gondwanan assembly of southern Africa, are poorly known, primarily because the belt lies beneath thick Kalahari sand cover. The boundaries have been interpreted to date primarily on the basis of potential field data patterns. Several magnetotelluric (MT) traverses acquired across the DMB, and forming part of the broader Southern African MT Experiment (SAMTEX), have provided lithospheric strike and dimensionality information and deep 2-D electrical resistivity images that show significant differences between the lithosphere of the Rehoboth terrane and the Congo craton.
(SAMTEX: http://www.dias.ie/~mh/samtex_html/participants.html).

Key words: Magnetotellurics, Lithosphere, Kaapvaal Craton, Kalahari Craton, Congo Craton, Damara Mobile Belt, Proterozoic.

INTRODUCTION

The Damara Mobile Belt (DMB) and Ghanzi-Chobe Belt (GCB) (abbreviated together to DMB) in northern Namibia and northern Botswana (Figure 1) are Neoproterozoic/earliest Paleozoic orogens that record the purported rifting and subsequent convergence and final collision between the Congo craton to the north, and terranes to the south collectively termed the Kalahari craton.

Much of the DMB is under cover, and there have been no lithospheric probing geophysics conducted on it before now. The thickness, internal structure and geometry of the DMB's lithosphere are all totally unconstrained.

Deep soundings, using the electromagnetic technique magnetotellurics, were performed on three profiles crossing the DMB as part of the Southern African MT Experiment (SAMTEX), which has acquired data at over 500 MT stations across the sub-continent since mid-2003 (Figure 1).

To date, we have processed the data to response functions, undertaken geoelectric strike analyses, and initiated 2-D modelling. We find the strikes are generally consistent with the ENE-WSW trend of the DMB-GCB. We have focussed on the western (DMB) profile, and found both along-strike variation and depth-variation in geoelectric strike. Piece-wise models are being developed for the DMB profile to account for the varying strike direction.

Geological Setting

The Damara Mobile Belt (DMB)/Ghanzi-Chobe Belt (GCB) (Figure 1) represent the southern boundary of the Congo craton, and the northern boundary of the Kalahari craton. Each of these regional-scale cratons in southern Africa contains internal Archean and Proterozoic terranes, the most renowned of which is the Kaapvaal craton of South Africa.

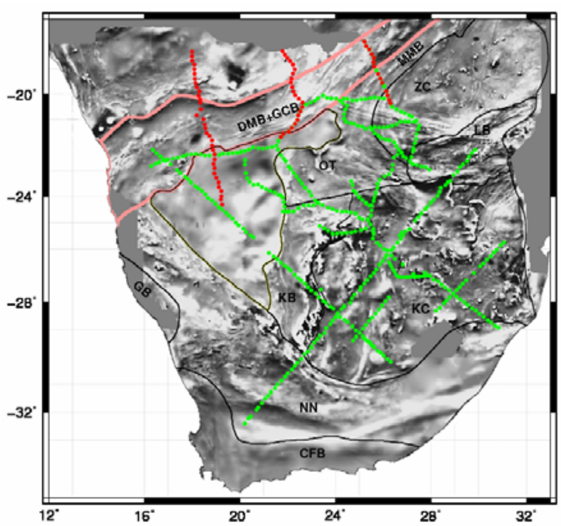

Figure 1: Magnetic image of southern Africa showing locality of MT stations along the three profiles crossing the DMB-GCB (red dots), and along all other SAMTEX stations (green dots). The outline of the DMB-GCB (thick pink line) and other major tectonic boundaries (thin black lines) are shown (boundaries 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.

The DMB-GCB belt is east-northeast trending, and the exposed rocks exhibit the preservation of bivergent symmetry typical of collisional belts. It forms a deeply eroded section of the Pan-African Mobile Belt, and records ocean closure about an apparent collisional triple junction during Gondwanan assembly. The southern edge of the Congo craton is interpreted to be the overriding plate, with the northern edge of the Kalahari craton forming the downgoing plate (Figure 2, taken from Gray et al. (2006).

The DMB in northern Namibia is classified into three zones, the Northern, Central and Southern Zones.

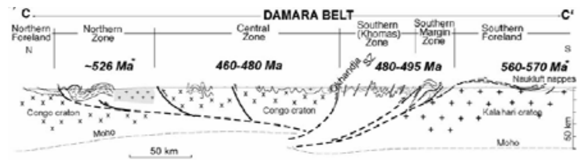

Figure 2: Structural cross-section of the Damara Belt in northern Namibia. (Taken from Gray et al., 2006). (Note: North to the left.)

MT DATA ACQUISITION, PROCESSING AND ANALYSIS

Data Acquisition

As part of the SAMTEX MT Project, three separate north-south trending magnetotelluric profiles were acquired in Southern Africa across the Damara mobile belt (Figure 1). The westernmost profile (sites DMB) begins about 50 km south of the Angola – Namibia border and extends southwards at ~18-19 degrees east, for nearly 600 km. In order to examine the structure of the DMB, the northernmost 30 sites are being processed, analyzed and modelled. The 300 km-long central profile (sites OKA and WIN) is located at ~22 degrees east, extending southward from the Namibia – Botswana border. The easternmost 350 km-long-profile (sites ZIM) runs along the Botswana – Zimbabwe border. Unfortunately due to logistical constraints in crossing into Zambia, the northern extent of the eastern profile does not cross the northern boundary of the Ghanzi-Chobe Belt limiting the along strike comparison of its structure.

Each site along every profile recorded broadband MT data that were installed at approximately 20 km intervals. Each site was composed of 5 lead-lead-chloride electrodes, which measure the electric field of the Earth in 2 perpendicular, horizontal directions, 3 separate coils to measure the magnetic field of the Earth in 3 mutually perpendicular directions, and a Phoenix Geophysics MTU-5A recording unit. At a few of the sites, particularly along the easternmost profile, the vertical magnetic field could not be recorded due either to difficulty in digging in the hard-packed terrane, or to the risk of damage from the local wildlife. Data were recorded in the frequency range of 250 – 0.0001 Hz for 2 – 3 days.

Data Processing

Magnetotelluric response curves were generated for each site along each profile using remote referencing Phoenix processing software, based on Jones and Jödicke (1984). At most of the sites, the apparent resistivity and phase estimates show excellent quality to periods of at least 1,000s, and up to 4,000 – 5,000 s at a few sites.

Data Analysis

The McNeice and Jones (2001) distortion decomposition method was applied to the magnetotelluric response estimates at each of the MT sites along all three of the Damara Mobile belt profiles. This method analyzes the data for galvanic distortions, assesses the dimensionality of the data, and is a tool in determining the most consistent geoelectric strike direction. Single site, one-decade bandwidth, decompositions indicate the preferred geoelectric strike azimuth, as well as the maximum phase difference between the conductive and resistive directions for each MT site.

GEOELECTRIC STRIKE INFORMATION

Plots are shown of the strike angles for the period bands 1-10 s (lower crust, Figure 3a), 10 – 100 s (uppermost mantle lithosphere, Figure 3b), and 100 – 1000 s (middle to lower mantle lithosphere, Figure 3c). The lengths of the arrows indicate how well the data fit the model of 3D distortion of 1D or 2D regional structures – long arrows mean fitting the model well, and short arrows mean fitting the model poorly (which normally indicates that the regional structure at that period is 3D). The coloured squares indicate the phase difference between the two orthogonal directions. A small phase difference (blues) means that that part of the lithosphere at those depths is virtually 1D (<10° phase difference). Large phase differences (reds) mean that it is strongly 2D (>35° phase difference). Greens and yellows indicate weakly 2D structures.

Initial observations of these strike angles and phase splits suggest differences in the 2-dimensional structure of the region at each of the three profiles, therefore each profile has been analyzed separately.

DMB: Western profile

Along the western profile (DMB sites), there appears to be significant differences in the preferred strike direction of the sites that lie to the north of the Damara belt than those that lie to the south. The sites that lie within the Damara Mobile belt show a much smaller phase split, indicating a weaker degree of two-dimensionality. This means that the response curves for these sites are less dependent on the strike angle chosen for modelling. The strongest two-dimensionality (maximum phase split) lies in the 10 – 100 s period range, equivalent to depths of the lower crust and uppermost mantle lithosphere, where, with the exception of few sites, the data are primarily one-dimensional at periods less than ~1 s. Initial analysis of all of the sites along the profile yielded a geoelectric strike angle of approximately 105 degrees for the northernmost sites and 50 degrees for the southernmost sites. Preliminary modelling with data calculated at both of these angles shows that the models are highly sensitive to assumption in the strike angle, particularly at lower crustal and mantle depths. This profile was then divided into separate sections for further strike analysis and modelling.

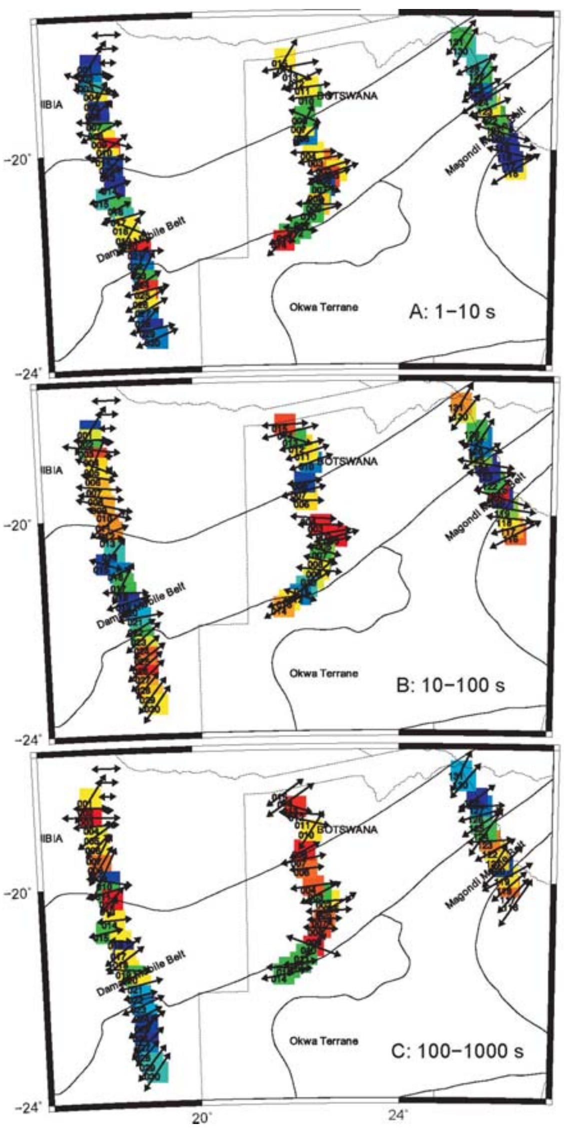

Figure 3: Geoelectric strike directions in period bands (A) 1-10 s (lower crust); (B) 10-100 s (upper mantle lithosphere); (C) 100-1000 s (middle and lower mantle lithosphere). The length of the arrows signifies goodness-of-fit to the distortion model (longer is better), and the coloured squares denotes the phase difference in the two orthogonal directions (blues ≡ 1D; greens/yellows ≡ weakly 2D; reds ≡ strongly 2D).

For the sites that lie within the Rehoboth terrane, south of the Damara Mobile belt, some of the sites indicate the presence of a layer with a geoelectric strike angle of 60 degrees in the period range of 1-6 s, however all of these sites show a preference of a strike angle between 40 – 50 degrees at some period range. At periods greater than 400 s the data return to one-dimensional, i.e., small phase difference between the two orthogonal directions. Multi-site decomposition analysis of all the sites within the Rehoboth terrane, and the southern half of the sites within the Damara belt clearly indicates these two preferred angles (Figure, 3). Although there appears to be a slight preference for two anisotropic layers of differing strikes angles, the sites that lie within the Rehoboth terrane exhibit acceptable RMS misfit values for a strike angle of 45 degrees for the entire frequency range. Models will be generated with data calculated for a strike angle of 60 degrees in order to assess differences in the strike angles and to determine the most accurate two-dimensional crustal structure, but detailed model analysis will be completed for a geoelectric strike angle of 45 degrees at all sites and all frequencies.

For the northern half of the sites along this profile, determining an accurate strike angle is not as straight forward. Several sites do not find an acceptable 2D strike angle, even with single site, single frequency decomposition for certain periods, indicating the presence of three-dimensionality (or that the data error estimates are too small). Multi-site, single-frequency decompositions do not indicate consistent strike angles for any particular frequencies, however multi-site analysis that include only the sites north of the Damara Mobile belt indicate a strike angle of 10 – 15 degrees (i.e., 100 – 105 degrees) at periods between 5 – 250 s. Single site, single frequency analysis for the sites north of the Damara boundary show a strong preference of 5 – 10 degrees (95 – 100 degrees) for periods between ~5 – 200 s at many of the sites. Two sites do not follow this trend, DMB004 and DMB005 both prefer an angle of 25 – 30 degrees at theses periods, indicating the presence of local small-scale structure within the data. Many of the sites show a strike angle of 55 – 60 degrees for periods greater than 100 s. This suggests the presence of two separate layers of anisotropy, one with a geoelectric strike angle of ~5 degrees (95 degrees) and a deeper layer at ~60 degrees. Models will be generated for these sites with the data calculated at both 95 degrees and 60 degrees, where the former will illustrate the structure at periods up to 200 s and the later will focus on periods greater than 200 s.

OKA: Central profile

The OKA profile sites show a general geoelectric strike direction that is simpler than observed on profile DMB. There is reasonable consistency both along the profile and with period (depth), with a direction of 85 degrees - approximately the local direction of the DMB-GCB. Dimensionality is stronger for the whole period range.

ZIM: Eastern profile

The ZIM profile sites exhibit strike directions that are again consistent along the profile and in period (depth), but with an angle slightly rotated to the north, to approx. ENE-WSW, from the OKA profile. Dimensionality is 1-D or weakly 2-D.

2-D LITHOSPHERIC MODELS

Lithospheric scale models are being derived for the three profiles. The OKA and ZIM models are being derived from adopting single strike angles for all sites on the profiles and at all periods, 85 degrees for OKA and 50 degrees for ZIM.

In order to treat the data along the DMB profile with 2-D modelling, sectional models are being developed. A southern half model with period-independent direction, and two northern half models, one for the crust and one for the mantle with different strike angles.

CONCLUSIONS

Although the geoelectric strikes observed at sites on the three profiles crossing the Damara Mobile Belt and Ghanzi-Chobe Belt (GCB) are generally parallel to the dominant tectonic fabric (Figure 3) of the belt, as expressed in the magnetic field, there is significant along-strike variation, significant variation along each profile, and significant variation with period, which translates to depth, both in strike direction and in intrinsic dimensionality. These variations are expressions of structural variations within the lithosphere of the belt and the bounding terranes at different depth levels.

Particularly along the western (DMB) profile we find strong strike and dimensionality variation laterally and vertically. Modelling simultaneously all of the data along the DMB profile with a single strike angle for all periods yields a model that is inconsistent with the data, and that gives erroneous information about the subsurface.

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