Prediction of DC current flow between the Otjiwarongo and Katima Mulilo regions, using 3D DC resistivity forward modelling and magnetotelluric and audio-magnetotelluric data recorded during SAMTEX

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ABSTRACT

SAMTEX (Southern African Magnetotelluric Experiment) is a multinational project that was initiated in 2003 to study the regional-scale electrical conductivity substructure of southern Africa and to infer from it the tectonic processes involved in the formation of the southern African subcontinent. Audio-magnetotelluric (AMT) data recorded during the most recent phase of the experiment are evaluated to investigate the local-scale conductivity substructure in the Otjiwarongo and Katima Mulilo regions, where in future the installation of high-voltage direct current (HVDC) earth electrodes will commence. Both of the AMT surveys are situated close to the edge of the orogenic Damara Mobile Belt in northern and north-eastern Namibia. Previous studies using magnetotellurics (MT), magnetometer arrays and geomagnetic observatory data all provide evidence of the relatively conductive nature of the Damara Mobile Belt. The Damara Mobile Belt represents in part the collision between the Congo and Kalahari cratons during the amalgamation of South Gondwana and its high conductivity is explained by the presence of interconnected fluids and conductive materials (graphites, sulphides). In contrast, the lithospheric structure of the ancient Archaean cratons, the Congo and Kalahari, are generally found to be electrically resistive and therefore it is hypothesized that the return path of DC current, flowing along the path of least resistance between the two electrodes, is most likely to lie somewhere within or in the vicinity of the Damara Mobile Belt. To obtain a better understanding of the current flow we propose using geological information, previous results of studies of the conductivity of the Damara Mobile Belt and surrounding regions and 2D inversion results from the AMT and MT data recorded during SAMTEX in northern Botswana and Namibia, as input to a 3D DC resistivity forward modelling code, and try to predict the return path that the DC current will follow.

Key words: SAMTEX, audio-magnetotelluric, Damara Mobile Belt, 3D DC forward modelling

INTRODUCTION

The SAMTEX (Southern African Magnetotelluric Experiment) project, initiated in 2003, is to date the largest magnetotelluric (MT) experiment ever conducted with more than 700 MT stations installed over an area of more than 1 000 000 km^2 (Jones et al., 2009). In the most recent phase of the experiment, a new consortium member, namely ABB of Sweden for NamPower of Namibia, expressed specific interest in the shallow subsurface in the regions close to towns of Otjiwarongo and Katima Mulilo (Figure 1). The shallow depth of interest required the use of the audio-magnetotelluric method (AMT), a high-frequency equivalent of MT, which provides better resolution of the electrical conductivity substructure at the cost of reduced depths of penetration (to about 10-15 km). The conductivity information in the Otjiwarongo and Katima Mulilo regions is needed for the optimal placement of HVDC earth electrodes in the future. An interesting challenge is now, after obtaining the conductivity substructure, to predict firstly, how the currents will dissipate into the Earth at the two locations and, secondly, what return path the DC currents will follow in between the two locations.

Electric currents will flow along paths of least resistance, i.e. not only where the conductivity is greatest, but also where there is high electrical interconnectivity. Previous studies in Namibia using MT (Ritter et al., 2003), a magnetometer array (De Beer et al., 1982) and geomagnetic observatory data (Korte et al., 2007) suggest that there are distinct regions of higher conductivity in northern Namibia. The relatively high conductivity regions correspond well with the location of the Damara Mobile Belt (DMB). The DMB constitutes the intracontinental branch, together with southern and northern (Kaoko Belt) coastal branches, of a three-armed asymmetric orogenic junction, called the Damara Province (Figure 2) (Tankard et al., p314, 1982). The DMB supracrustal rocks are largely of sedimentary origin that accumulated during rifting in the Early Proterozoic (Tankard et al., p316, 1982). The sedimentary rocks were deformed during the amalgamation of South Gondwana (Ritter et al., 2003). During Mesozoic rifting the South American and African plates split along the coastal branches of the Damara Province but only extension occurred along the DMB (Tankard et al., p14, 1982). The high conductivity in parts of the DMB is explained by the presence of interconnected fluids and/or graphite (Ritter et al., 2003). In contrast, on either side of the DMB there are two Archaean cratons which are more resistive: the Kalahari (a composite craton comprising the Kaapvaal and Zimbabwe cratons and including the enigmatic Rehoboth terrane, shown in Muller et al. (2009) to be different from both of the others) and the Congo. It is therefore hypothesized that return flow of DC current, in between Otjiwarongo and Katima Mulilo, will follow

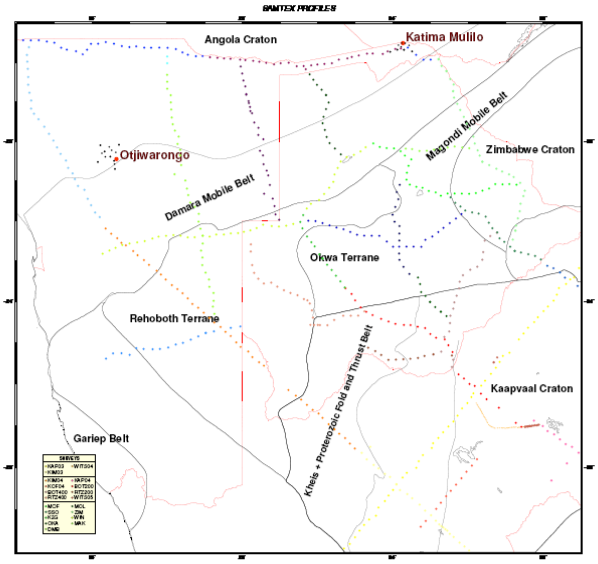

Figure 1. The major lithospheric zones associated with northern South Africa, Namibia and Botswana, overlain by the MT sites installed during SAMTEX. The two clusters of sites close to the towns of Otjiwarongo and Katima Mulilo are the AMT surveys central to this project.

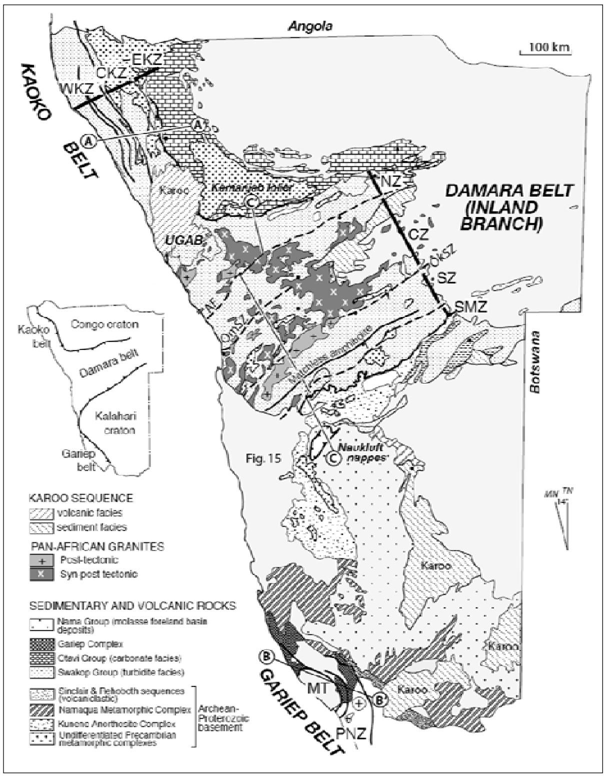

Figure 2. Simplified geological map of Namibia (excluding Caprivi Strip). Shown are the locations of the Damara (intracontinental branch), Kaoko (northern coastal branch) and Gariep Belts (modified from Gray et al., 2006). The southern coastal branch of the Damara Province is overlain by the Namib dessert.

a path that lies either entirely, or almost entirely within the DMB.

AMT DATA PROCESSING

Computation of the AMT response curves from the recorded electric and magnetic field time series are carried out with commercial Phoenix software (based on codes originally developed by Alan G. Jones). Most of the response curves are smooth and acceptable between the periods 0.0001 and 1 second. At some sites bad estimates are obtained in the period range 0.001 to 0.0002 second, generally known as the AMT dead band (Garcia and Jones, 2008).

AMT DATA ANALYSES

MT data are almost always, to varying degrees, influenced by a phenomenon called galvanic distortion. Distortion effects appear in MT data when the inductive scale length, which is essentially the depth of investigation but could also be a lateral distance, is larger than the spatial extent of 3D bodies situated somewhere in-between the Earth's surface and the depth of investigation (Chave and Smith, 1994). To obtain information about the geo-electrical strike, in the presence of distortion, we use a decomposition approach first developed by Groom and Bailey (1989) and later extended into a useful tool for multisite, multifrequency analysis by McNeice and Jones (2001). If the Groom and Bailey RMS errors associated with the estimated strike directions are high, it means that either the data are bad and/or the subsurface structure is not 2D, as assumed, but 3D. The results from the Groom and Bailey decomposition will be compared with the results from another decomposition method, developed by Bahr (1988, i.e. Bahr decomposition), which computes strike direction and indicates dimensionality solely from the MT phase data.

The dense grid-like spacing of the AMT sites in both survey regions makes 3D inversion of the data very plausible. Although 3D inversion codes exist, only one is publicly available and is very computer expensive, so the use of 2D inversion codes is more popular and therefore the AMT data will first be modelled using 2D inversion, and in future compared with the results of 3D inversion.

RESULTS

Geo-electric strike information was obtained using the multi-site multi-frequency decomposition tool of McNeice and Jones (2001). A single strike estimate was obtained individually for all the sites over the entire period range (0.0001 to 1 seconds). Preliminary results show strike variations of between -42 and 42 degrees E of N for the Otjiwarongo sites (Figure 3) and -49 to 90 degrees E of N for the Katima Mulilo sites (the strike estimates contain a 90 degree ambiguity). The large variation in strike direction for the Katima Mulilo sites is accompanied by a small phase difference (apart from one anomalous site, the phase differences do not exceed 4.56 degrees), which indicates that the subsurface structure there can be approximated as 1D. The Otjiwarongo sites show larger phase differences (Figure 3) which are explained by the array's closer proximity to the proposed edge of the DMB (Figure 1) and are therefore more 2D. The small RMS errors associated with all the strike estimates (largest RMS errors are 1.18and 2.44 for the Katima Mulilo and Otjiwarongo sites, respectively) encourages the use of 2D inversion.

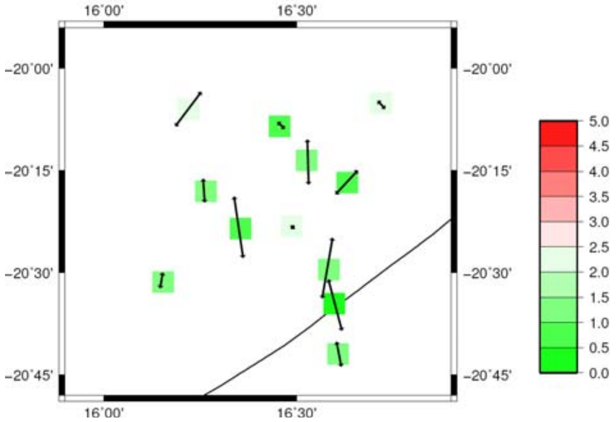

Figure 3. The strike angles determined for the AMT sites close to Otjiwarongo. The orientation of the arrows indicates strike direction, the length shows the phase differences and the colour of the boxes indicates the RMS error associated with the strike estimates. The diagonal line in SE corner is the proposed boundary between the Angola craton and the DMB (see Figure 1).

CONCLUSIONS

Although the Otjiwarongo sites show a large variation in strike direction, the sites with the lowest RMS errors and largest phase differences appears to be sampling the same 2D structure. A 2D inversion will thus be attempted here. The data for the Katima Mulilo sites will be further analysed, but first indications are that the data are approximately 1D; therefore a 1D inversion tool can be used.

We propose to use the derived AMT models in conjunction with geology and results from previous conductivity studies, including SAMTEX MT profiles crossing the DMB, as input to a 3D DC resistivity forward modelling code, to try and predict the return path that the DC current will follow between the Katima Mulilo and Otjiwarongo regions.

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REFERENCES

Bahr, K., 1988, Interpretation of the magnetotelluric impedance tensor: regional induction and local telluric distortion, Journal of Geophysics 62, 119–127.

De Beer, J.H., Huyssen, R.M.J., Joubert, S.J. and van Zijl, J.S.V., 1982, Magnetometer array studies and deep Schlumberger soundings in the Damara orogenic belt, South West Africa, Geophysical Journal of the Royal Astronomical Society 70, 11-29.

Garcia, X. and Jones, A.G., 2008, Robust processing of magnetotelluric data in the AMT dead band using the continuous wavelet transform, Geophysics 73 No.6, 223-234.

Chave, A.D. and Smith, J.T., 1994, On electric and magnetic galvanic distortion tensor decompositions, Journal of Geophysical Research 99, 4669–4682.

Gray, D.R., Foster, D.A., Goscombec, B.C., Passchier, W. and Trouwe, R.A.J., 2006, 40Ar/39Ar thermochronology of the Pan-African Damara Orogen, Namibia, with implications for tectonothermal and geodynamic evolution, Precambrian Research 150, 49–72.

Groom, R.W. and Bailey, R.C., 1989, Decomposition of magnetotelluric impedance tensors in the presence of local three-dimensional galvanic distortion, Journal of Geophysical Research 94, 1913–1925.

Jones, A.G. Evans, R.L., Muller, M.R., Hamilton, M.P., Miensopust, M.P., Garcia, X., Cole, P., Ngwisanyi, T., Hutchins, D., Fourie, C.J.S., Fourie, Jelsma, H., Aravanis, T., Pettit, W., Webb, S., Wasborg, J. and the SAMTEX Team, 2009, Area selection for diamonds using magnetotellurics: Examples from southern Africa, accepted in Lithos.

Korte, M., Mandea, M., Kotze, P., Nahayo, E. and Pretorius, B., 2007, Improved observations at the southern African geomagnetic repeat station network, South African Journal of Geology 110, 175-186.

McNeice, G.W. and Jones, A.G., 2001, Multisite, multifrequency tensor decomposition of magnetotelluric data, Geophysics 66, 158–173.

Muller, M.R., Jones, A.G., Evans, R.L., Grütter, H.S., Hatton, C., Garcia, X., Hamilton, M.P., Miensopust, M.P., Cole, P., Ngwisanyi, T., Hutchins, D., Fourie, C.J., Jelsma, H., Aravanis, T., Pettit, W., Webb, S.J., Wasborg, J. and the SAMTEX Team, 2009, Lithospheric structure, evolution and diamond prospectivity of the Rehoboth Terrane and western Kaapvaal Craton, southern Africa: constraints from broadband magnetotellurics, accepted in Lithos.

Ritter, O., Weckmann, U., Vietor, T. and Haak, V., 2003, A magnetotelluric study of the Damara Belt in Namibia 1. Regional scale conductivity anomalies, Physics of the Earth and Planetary Interiors 138, 71-90

Tankard, A.J., Hobday, D.K., Jackson, M.P.A., Hunter, D.R., Eriksson, K.A., Minter, W.E.L., 1982, *Crustal Evolution of Southern Africa: 3.8 Billion Years of Earth History*, Springer-Verlag Inc., New York, 523pp.