Utilising 3-D magnetotelluric models of southern African mantle to constrain hydrogen content and compositional variations.

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SUMMARY

The magnetotelluric method is the most sensitive geophysical tool in detecting the hydration state of the mantle. Therefore, improved interpretations of electrical conductivity distribution within the Earth is a key measure that has to be taken in order to have a better grasp on lithopsheric-scale geodynamic concepts and the nature of mineralising agents. Progress towards this goal requires detailed comparisons between MT models and xenolith data in order to understand the controls on mantle electrical conductivity.

In this study, new magnetotelluric models from southern Africa were utilised to constrain the composition and hydrogen content by comparing forward models based on the experimental studies made on mantle minerals at high P-T conditions. Many relations between the experimental parameters and information from xenolith data were tested to improve the capabilities of magnetotellurics as an exploration tool in the lithospheric mantle of cratons.

Key words: magnetotellurics, xenoliths, metasomatism, electrical conductivity, South Africa, kimberlite

INTRODUCTION

The magnetotelluric (MT) method is a passive-sourced electromagnetic prospecting tool that can be utilised to acquire electrical conductivity structure up to several hundreds of kilometres. It proved itself useful in providing evidence to wide variety of tectonic problems (e.g. Selway, 2014; Kawakatsu and Utada, 2017) and their practical extensions in exploration of mineral systems (e.g. Heinson et al., 2018). This feature of MT mostly stems from its ability to image zones of past fluid-rock interaction, which are integral in interpretations of mechanisms behind plate tectonics and mineralising agents.

Many factors contribute to rock conductivity, including temperature, pressure, modal mineralogy, hydrogen content of the composite minerals, and interconnectedness of the different mineral phases. There is now enough accumulation of high pressure and temperature experimental data on electrical conductivity, water storage capacity and partitioning of water between nominally anhydrous minerals to modestly constrain the compositional structure of the mantle via how hydrogen binds to nominally anhydrous mantle minerals (Pommier, 2014; Demouchy and Bolfan-Casanova, 2016). Meticulous arrangements between these parameters need to be explored to understand the interlinking concepts behind many phenomena; such as the nature of co-existing mineral assemblages in a metasomatized medium; spatial variations of deeply rooted, hydrogenated and mineralized pathways, or the unique mechanical behaviour of cratonic keels which might be responsible for their elongated lifespan. Electrical conductivity of Earth materials can be employed to act as a mediator between many of these parameters, thus holding great potential in providing insights to many existing problems in tectonically stable environments (Selway, 2014).

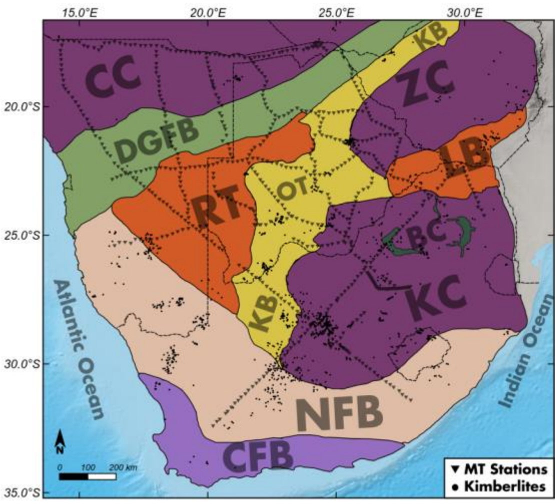

Figure 1. Tectonic map of Southern Africa alongside with MT stations and kimberlite locations (Faure, 2010); modified after Jones et al. (2009). BC: Bushveld Complex, CC: Congo Craton, CFB: Cape Fold Belt, DGFB: Damara-Ghanza-Chobe Belt, KB: Kheis Belt, KC: Kaapvaal Craton, LB: Limpopo Belt, NFB: Namaqua Fold Belt, OT: Okwa Terrane, RT: Reheboth Terrane, ZC: Zimbabwe Craton.

To reduce uncertainty in MT interpretations we have focused on southern Africa, where the electrical structure has been imaged by the extensive SAMTEX project (Jones et al., 2009) and the composition and thermal structure is well constrained by abundant xenoliths (e.g., Begg et al., 2009). The dataset was modelled via employing the 3-D inversion algorithm ModEM (Kelbert et al., 2014). Results of these models were interpreted with the newly-developed software MATE (Mantle Analysis Tools for Electromagnetics), which allows users to, easily tweak all of the experimental parameters in the literature that are involved in producing forward models of electrical conductivity with depth and compare it with MT profiles. In this study, we are aiming to explore all possible scenarios allowed by the experimental constrains and prior information to test several hypotheses.

MAGNETOTELLURIC DATA ANALYSIS AND MODELLING

Magnetotelluric (MT) modeling requires careful data-handling, since a distorted element or an ill-advised choice in modelling application would easily lead to erroneous model production. To combat this, dimensionality analyses were made with the phase tensor method (Figure 2, Caldwell et al. 2004); which demonstrate the dominant 3-D nature of the dataset with high skew angles (Figure 2b) and greatly varying strike angles (Figure 2c). This reflects the geological complexity of the Archean lithosphere, inherited from several stages of tectonic amalgamation and consequent introduction of metasomatic agents (Peslier et al., 2012; Griffin et al., 2009).

After data analysis, some of the stations that show apparent levels of distortion were excluded from the dataset. To decrease the computing time, some redundant stations were also excluded as well, by taking account of the local variations in the data and considering appropriate measures on spatial and geological context. The ocean effect was compensated for by putting in fixed conductive features to the initial model. Several three-dimensional models were run with different inversion parameters to test the robustness of the final output and determine the optimal strategy in using this algorithm. The model shown in Figure 3 was finalised with RMS of 2.35, where no localities show dramatic deviations from the data.

The preliminary model depicts lateral heterogeneity of the lithospheric mantle with pockets of conductive features, some of which coincide well with some major geological features (e.g. Bushveld Complex, BC). These features also correlate well with the kimberlite locations, in which they tend to occur on the conductive anomalies near the edges of resistive features (Figure 3).

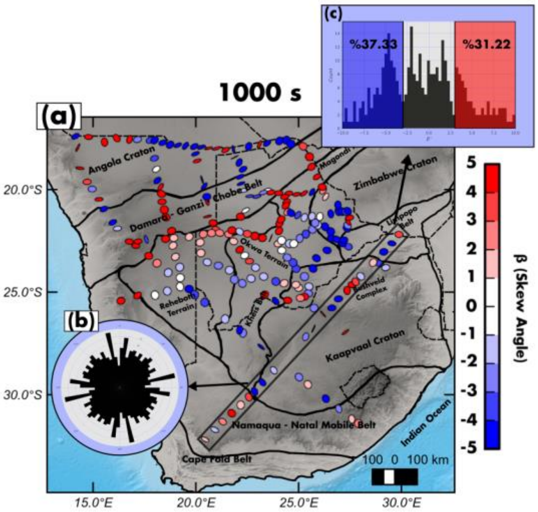

Figure 2. Phase tensor analyses made on SAMTEX MT dataset. (a) Phase tensor ellipses filled by skew angles for a period of 1000 s. (b) Rose diagram of the phase tensor strike variations for the data from KAP03 profile (rectangle in 2(a)) for the period range used for modeling (1 s - 15000 s). (c) Histogram for skew angle variations for the same frequency range of the data from KAP03 profile, demonstrating that the majority of the data do not fall in to the 3-D interpretation range.

Chemical tomography sections computed via garnet-xenolith datasets (Griffin et al., 2003) are shown together with the 150 km section of the 3-D MT model (Figure 3). Prima facie observations suggest that conductive features are coincident with metasomatized-fertile areas of the mantle, except for the Limpopo Belt in which the the harzburgitic (depleted) section is also shown with highly conductive values. This shows the necessity of further forward testing of the models and carrying out a more holistic analysis to interpret the dataset in question.

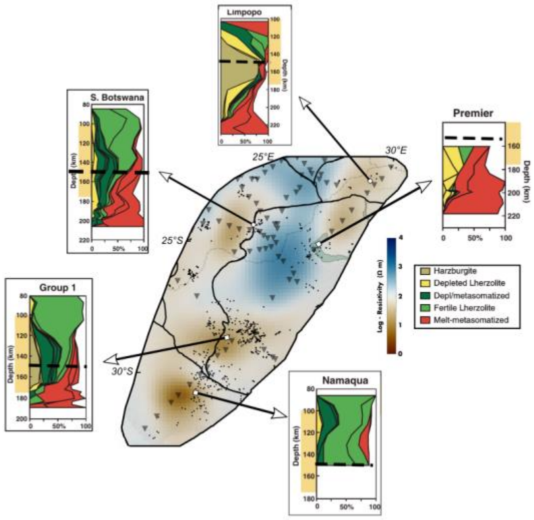

Figure 3. 150 km section from the final resistivity model in the vicinity of Kaapvaal Craton alongside with kimberlite locations (Faure, 2010) and chemical tomography sections of those indicated localities (Griffin et al. 2003).

CONCLUSIONS

MT data from southern Africa was remodelled with means of 3-D inversion. The preliminary models demonstrate the lateral heterogeneity of the lithospheric mantle with large variations in conductivity. These values will be employed to constrain compositional parameters by careful consideration of experimental studies and a prior information.

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