Southern African Magnetotelluric Experiment (SAMTEX): Project Overview and Regional Results

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ABSTRACT

The Southern African Magnetotelluric Experiment – SAMTEX – is a multi-institutional, multi-national, geophysical project being undertaken by a consortium comprising academia, industry and government. The primary objective is to determine the lithospheric geometries of the major Archean cratons and their Proterozoic bounding belts in southern Africa with a view to elucidating Archean and Proterozoic tectonic processes of formation, deformation and destruction, and comparing those processes their modern counterparts. To date, in three phases of acquisition over three years, MT data have been acquired at over 550 sites on over 900 line kilometres in a spatial area exceeding a million square kilometres, making this the largest survey of its kind ever conducted. This paper will review the data acquired and some preliminary images of subsurface structures. In particular, the relationship between lithospheric electrical parameters and diamondiferous kimberlite pipes will be highlighted.

Key words: SAMTEX, magnetotellurics, Zimbabwe craton, Kaapvaal craton.

INTRODUCTION

The plate tectonic paradigm is a remarkably successful model describing the Earth's dominant tectonic process. There is much debate however concerning how far back this paradigm is a valid model to interpret the cryptic rock record. Some argue that it can be validly applied early in Earth's history (e.g., de Wit, 1998), whereas others argue that plate tectonics, *sensu stricto*, is not applicable before ca. 2.5 Byr ago, and that other processes, such as sagduction and mantle plumes, dominated during the Archean era (Davies, 1992; Hamilton, 1998, Bleeker, 2002; Van Kranendonk, 2003). Directly coupled with this question is uncertainty of the formation process of Archean-aged cratonic lithosphere. The extant, competing models reveal our limitations in fundamental information of the subcontinental lithospheric mantle (SCLM), a knowledge gap that can be partially addressed through obtaining physical and geometrical information of fossil structures using geophysical imaging.

To date this information has been obtained primarily using passive seismology, but over the last decade deep-probing magnetotellurics (MT) has been developed and applied to this problem, and has demonstrated that MT data, when combined with other geoscientific information, provides significant constraints on formation processes. This has been shown most convincingly by Davis et al. (2003) in their holistic model of the development of the Slave craton's SCLM that integrated the observations and results from geochronology, geochemistry, petrology, geology, tectonics, and geophysics.

In southern Africa, as a consequence of the world's largest-ever teleseismic study (Kaapvaal Seismic Experiment, www.ciw.edu/mantle/kaapvaal/) followed by the world's largest-ever land-based MT project (Southern African MT Experiment, SAMTEX), the physical properties and geometries of Archean and Proterozoic lithosphere will become as well-known as its extensive geochemical and petrological framework.

The purpose of this paper is to describe the SAMTEX experiment in full – its objectives and achievements to date – and to present examples of data acquired, both high quality and highly noise-contaminated. Some preliminary results will be shown, regarding overall lithospheric geometry for the Kaapvaal craton and neighbouring terranes. Conclusions will be drawn from the MT model about the nature of Kaapvaal lithosphere, compared to lithosphere from other Archean cratons, and about prospective regions for diamond exploration.

THE SAMTEX EXPERIMENT

Broadband (BBMT) and long period (LMT) MT data have been acquired on three phases of acquisition since October 2003 in South Africa, Botswana and Namibia at the sites shown in Figure 1. The BBMT data were acquired every 20 km, on average, except for sites located within the Witwatersrand Basin, using up to nine Phoenix MTU-V5 systems simultaneously. The frequency range of the BBMT data is 300+ Hz to 1,000+ s, and used coils for sensing the magnetic fields.

LMT data were acquired in Phases I and II every 3rd BBMT site, i.e., every 60 km, using the GSC LiMS and EMSOC Phoenix LRMT clones, which records the fields directly using ring-core technology. In Phase I, 26 LiMS/LRMT instruments were deployed on the main NE-SE profile in South Africa. For Phase III only BBMT instrumentation was deployed, and data were acquired at each site on a 2-night/3-night cycle of station pairs in order to obtain high quality estimates to 5,000+ s.

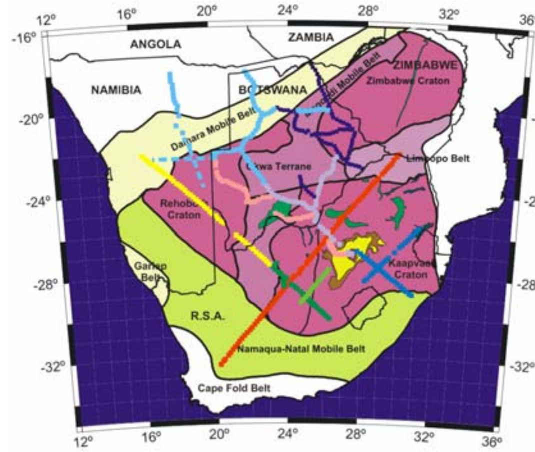

Figure 1. Station locations for the Southern African Magnetotelluric Experiment on a tectonic map of southern Africa (courtesy of Sue Webb).

RESISTIVITY MAPS

Approximate images of the subsurface resistivity structure can be obtained by converting the response curves from the period domain to the depth domain, using an approximate transformation. This is accomplished here using the Niblett-Bostick transform (Jones, 1983) and determining the maximum resistivity with orientation (RhoMAX) at a particular depth. RhoMAX is the most robust measure, and is less affected by structures above.

Below are maps of the RhoMAX at depths of 40 km (Fig. 2, approx. crust-mantle boundary), 100 km (Fig. 3) and 200 km (Fig. 4, middle of the diamond region of the lower lithosphere). Also plotted on Figure 4 are the locations of the kimberlites in the Council for Geoscience's database, with diamondiferous kimberlites in red and non-diamondiferous as black points.

These maps show the strong vertical and lateral variations in resistivity beneath the Southern Africa. There is good correlation of resistive structures to depth in the core of the Kaapvaal craton. Although weaker, there is evidence of a tongue of resistive Zimbabwe craton lithosphere extending westwards to the location of the Orapa kimberlite field.

The Rehoboth "craton" is uncharacteristically conductive throughout its whole lithospheric extent, and does not exhibit the strong resistivity seen for the Kaapvaal craton.

These maps are useful for showing approximate geometries, but should only be taken as indicative, and not fully descriptive, of the 3D resistivity structure.

Accurate description only comes from careful multi-dimensional modelling.

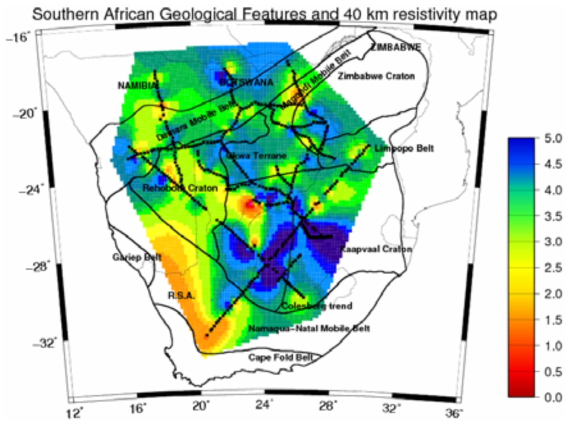

Figure 2. Approximate image of resistivity at a depth of 40 km (approx. crust-mantle boundary).

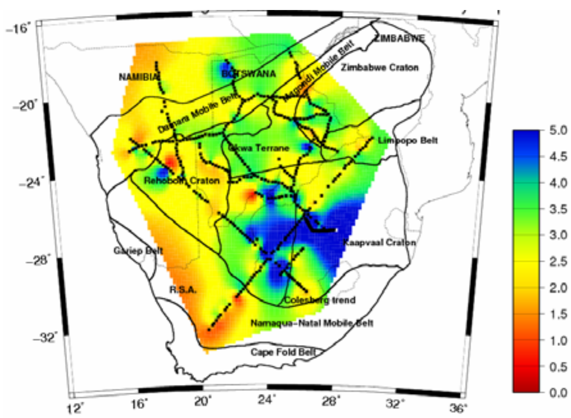

Figure 3. Approximate image of resistivity at a depth of 100 km.

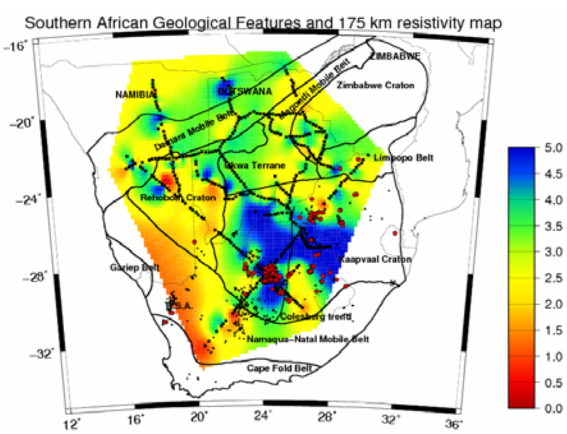

Figure 4. Approximate image of resistivity at a depth of 175 km, together with kimberlite information (diamondiferous as red circles, non-diamondiferous as black dots).

PRELIMINARY MODEL

A preliminary two-dimensional model of the data from the main NE-SW 1350-km-long profile crossing the Kaapvaal Craton, from the Zimbabwe border to within 200 km of Cape Town is shown in Figure 5. This model is representative of many different models produced by different SAMTEX members using various subsets of the data.

The model fits for the northernmost 1/3 of the sites are poorer than for the other sites. The overarching robust result is the difference in lithospheric thickness between the sites on the Namaqua-Natal Mobile Belt (NNMB) and those on the Kaapvaal Craton (KC). The sites on the NNMB exhibit a lithospheric thickness of the order of 150 km, and the kimberlites are non-diamondiferous. In contrast, in the centre of the KC lithospheric thickness is 250 km or greater, and there are no known kimberlites. The transition between the two is the region beneath the Kimberley-Koffiefontein-Jagersfontein diamondiferous kimberlite trend.

This spatial relationship between thin, transitional and thick lithosphere is best viewed in 3D perspective (Figure 6).

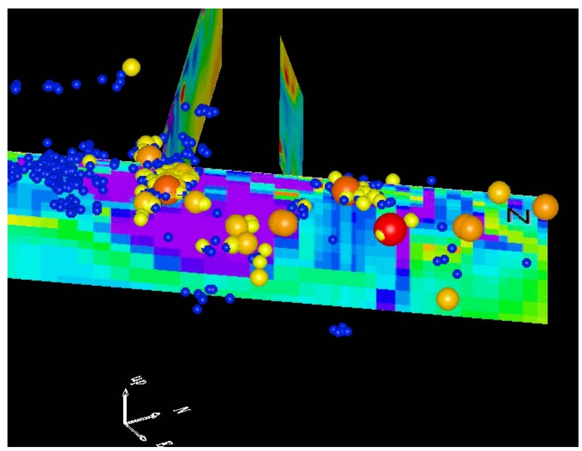

Figure 6. Model of the main profile (Figure 4) showing association with known kimberlite pipes. Blue spheres are non-diamondiferous kimberlite pipes, whereas yellow to red spheres are diamondiferous kimberlite pipes, and the size and colour of the sphere indicates the diameter of the pipe.

CONCLUSIONS

The SAMTEX project is resulting in additional knowledge about the lithospheric mantle from areas that are well-known geophysically and geochemically (predominantly South Africa), and new knowledge from areas about which little to nothing is known (Botswana and Namibia). Over three phases of acquisition, deep-probing MT data are now available at over 500 sites in southern Africa over an area in excess of a million square kilometres. The primary result to date is the identification of thin to thick lithosphere transition from the mobile belt onto the craton, and that the diamondiferous kimberlites occur primarily at that transition. The final 3D model for southern Africa will be integrated with existing geochemistry, petrology, geology and other geophysics to yield improved understanding of Archean processes.

ACKNOWLEDGMENTS

We would like to thank all enthusiastic organisations and individuals participate and the support of the entire SAMTEX team. Without their contribution the efforts of this project would never have been possible. We also would like to thank the National Science Foundation's Continental Dynamics program, Science Foundation Ireland, Council for Geoscience, Geological Surveys Botswana and Namibia, De Beers Group Services, Rio Tinto Mineral Exploration and BHP Billiton for the financial and logistical support.

More SAMTEX information can be found at:
http://www.dias.ie/~mh/samtex_html/participants.html

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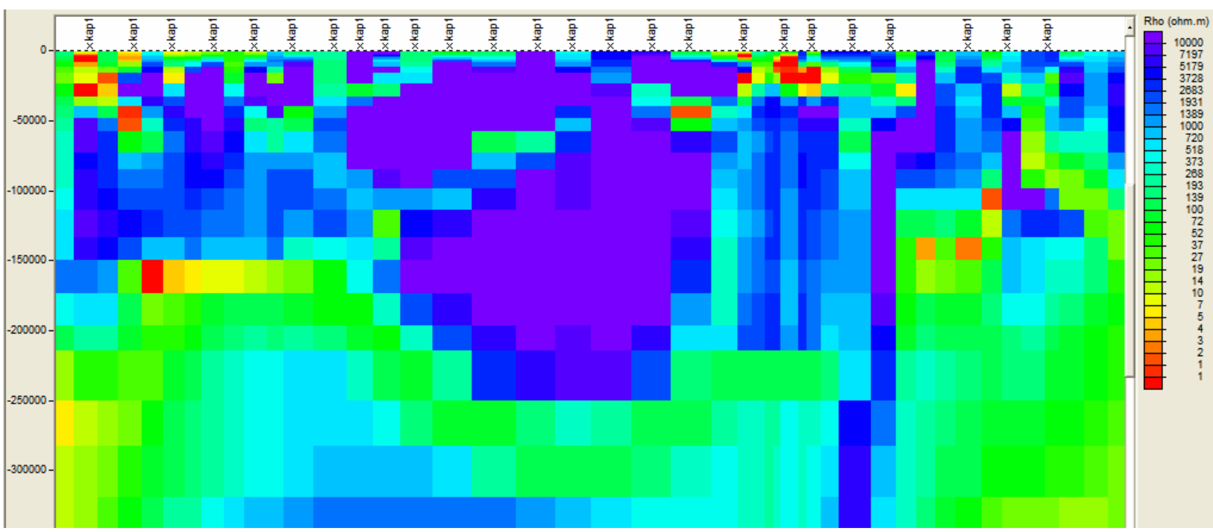

Figure 5. Preliminary model of the LMT data from the main NW-SW profile crossing the Kaapvaal Craton. NE is to the right, and SW to the left.