# The SAMTEX experiment: Overview and Preliminary Results

**Alan G. Jones[1],** Rob L. Evans[2], Mark R. Muller[1], Mark P. Hamilton[1,10,13], Marion P. Miensopust[1,14], Xavier Garcia[1,15], Patrick Cole[3], Tiyapo Ngwisanyi[4], David Hutchins[5], C.J. Stoffel Fourie[6], Shane Evans[7,16], Hielke Jelsma[7], Theo Aravanis[8], Wayne Pettit[9], Sue Webb[10], Jan Wasborg[11], and The SAMTEX Team[12]

1: Dublin Institute for Advanced Studies, 5 Merrion Square, Dublin, Ireland, alan@cp.dias.ie;
2: Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Clark 263, 266 Woods Hole Rd, MA 02543, U.S.A.;
3: Council for Geoscience, 280 Pretoria Street, Silverton, Pretoria 0001, South Africa;
4: Geological Survey of Botswana, Private Bag 14, Lobatse, Botswana;
5: Geological Survey of Namibia, 1 Aviation Road, Windhoek, Namibia;
6: Council for Scientific and Industrial Research, Pretoria, South Africa;
7: De Beers Group Services, Private Bag X01, Southdale 2135, South Africa;
8: Rio Tinto Mining and Exploration,1 Research Avenue, Bundoora, 3081, Victoria, Australia;
9: BHP Billiton, Johannesburg, South Africa;
10: The University of the Witwatersrand, Jan Smuts Avenue, Johannesburg 2050, South Africa;
11: ABB AB, HVDC, Ludvika, SE-77180, Sweden;
12: Other members of the SAMTEX team include: Louise Collins, Colin Hogg, Clare Horan, Jessica Spratt, Gerry Wallace (DIAS), Alan D. Chave (WHOI), Janine Cole, Raimund Stettler (CGS), G. Tshoso (GSB), Andy Mountford, Ed Cunion (RTME), David Khoza (DIAS and BHP-B) and Pieter-Ewald Share (DIAS and CSIR);
13: Now at: EMGS, Stiklestadveien 1, N-7041 Trondheim, Norway;
14: Registered at National University of Ireland, Galway;
15: Now at: Institut de Ciències del Mar (CSIC), Barcelona, Spain;
16: Now at: Moombarriga Geoscience, Box 1184, West Perth WA 6872, Australia.

## ABSTRACT

The Kaapvaal Craton is one of the world’s best natural laboratories for studying the lithospheric mantle given the wealth of xenolith and seismic data that exist for it. The Southern African Magnetotelluric Experiment (SAMTEX) was launched to complement these databases and provide further constraints on physical parameters and conditions by obtaining information about electrical conductivity structures within the lithosphere. Initially, magnetotelluric data acquisition was planned on profiles spatially coincident with the Kaapvaal Seismic Experiment. However with seven more partners joining the original four through the course of the experiment, SAMTEX was enlarged from two to four phases of acquisition, and extended northwards to cover much of Botswana and Namibia. The complete SAMTEX dataset now comprises MT data from over 730 distinct locations in an area of over one million square kilometres, making SAMTEX the largest regional-scale MT experiment conducted to date.

Preliminary images of electrical resistivity and electrical resistivity anisotropy at 100 km and 200 km, constructed through approximate one-dimensional methods, map resistive regions spatially correlated with the Kaapvaal, Zimbabwe and Angola Cratons, and more conductive regions spatially associated with the neighbouring mobile belts and the Rehoboth Terrane. Known diamondiferous kimberlites occur primarily on the boundaries between the resistive or isotropic regions and conductive or anisotropic regions.

**Key words:** SAMTEX, Kaapvaal Craton, mantle lithosphere.

## INTRODUCTION

Only through high-resolution geophysical mapping of the sub-continental lithospheric mantle (SCLM) coupled with petrological and geochemical information from mantle xenoliths will we be able to understand its formation and deformation processes. The structure, geometry and observable in-situ physical parameters (seismic velocities and electrical conductivity) of the SCLM are reasonably well-known in some places, but are either incompletely known or unknown in many others. This disparity in knowledge is particularly acute for Southern Africa, where the seismic properties of the lithosphere beneath South Africa are well-known, but its electrical properties were not, and in sharp contrast the physical properties of the lithosphere beneath Botswana and Namibia were completely *Terra Incognita* prior to our work. The electrical conductivity of the continental upper mantle is highly sensitive to ambient temperature (e.g., Jones 1999, Jones, et al. 2009, Ledo and Jones 2005), to iron content (Jones, et al. 2009), to the presence of an interconnected conducting phase, such as a solid phase like graphite or sulphides (e.g., Duba and Shankland 1982, Ducea and Park 2000, Jones, et al. 2003) or a fluid phase like partial melt (e.g., Park and Ducea 2003), or to bound water through hydrogen diffusion (e.g., Hirth, et al. 2000, Karato 2006, Karato 1990). Given these sensitivities, deep-probing magnetotellurics (MT) can aid in definition of geometries within the lithospheric mantle that contain the cryptic information of its history, especially its formation and deformation processes, such as is exemplified in Davis, et al. (2003).

A secondary objective of the SAMTEX project was to provide industry with an appraisal of the magnetotelluric method of area selection for diamond exploration, following on from the work on the Slave Craton by Jones, et al. (2001, 2003) and of Jones and Craven (2004). During the mid-1990s and later there was interest expressed by some diamond exploration companies in the capabilities of deep-probing magnetotellurics as an effective area selection tool for diamondiferous regions, particularly for imaging the base of the lithosphere – the lithosphere-asthenosphere boundary (LAB). The MT results from the Archean Slave craton in NW Canada, with the identification of an upper mantle conductor – the Central Slave Mantle Conductor (Jones et al., 2001, 2003) – lying directly beneath the richly-economic Eocene kimberlite field (Fipke's so-called Corridor of Hope, Krajick 2001) and also spatially and in depth collocated with an ultra-depleted high Mg# upper lithospheric harzburgitic region (Griffin, et al. 1999), were exciting, interesting and intriguing, not only in terms of geometric controls that could be used in hypothesizing tectonic scenarios for the development of the sub-cratonic lithospheric mantle of the Slave craton (Davis, et al. 2003) but also in terms of diamond exploration potential using MT. Through other deep-probing MT studies in Canada, the Slave's CSMC was shown not to be as unique as first thought as similar conductors have also been found in the lithosphere of the Sask craton (Jones, et al. 2005), directly beneath one of the largest known kimberlite clusters in the world, the Fort-à-la-Corne kimberlite (Jones, et al. 2005), and beneath the western part of the Superior craton (Craven, et al. 2001), where kimberlites have yet to be found.

## THE SAMTEX PROJECT

The SAMTEX project was almost a decade in gestation, starting with a telephone call in Summer, 1996 from Beijing (IGC meeting) to Alan Jones, who was on Slave craton fieldwork in Yellowknife. The middle of the night call, from Leo Fox of Phoenix Geophysics, was the result of a discussion at the IGC between Fox and Eddie Kostlin (Anglo American) about the utility of MT for mapping the LAB. From this call a proposal was in due course funded by De Beers for a small MT survey on the Kaapvaal Craton to be conducted by Jones (then at the Geological Survey of Canada, GSC) and Phoenix, but the work was not undertaken due to long period MT equipment availability issues at the GSC.

Also key to the eventual success of SAMTEX was a meeting between Jones and Edgar Stettler in a discotheque during the 1998 EM Induction Workshop in Sinaia, Romania that led to what has proven to be an absolutely invaluable contribution by the Council for Geoscience (CGS) through all four phases of SAMTEX.

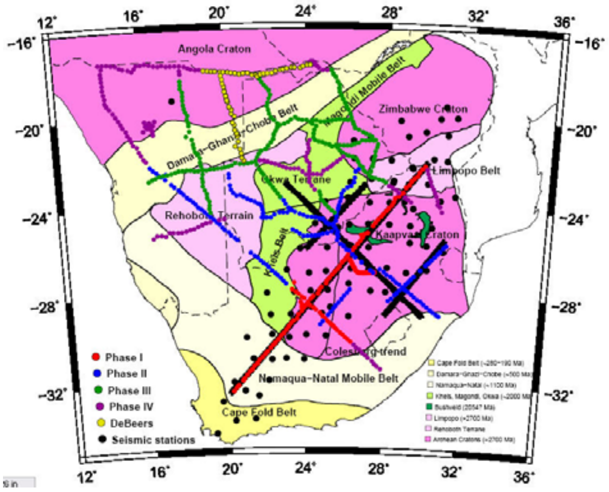

**Figure 1: Map of SAMTEX sites for all four phases of acquisition plus De Beers donated sites, together with SASE locations (black dots). Background is the tectonic subdivision of Southern Africa of Webb.**

In November, 2002 a proposal was submitted to the Continental Dynamics (CD) programme of the National Science Foundation (NSF) led by Rob Evans (Woods Hole Oceanographic Institution, WHOI) with four SAMTEX partners from academia, government and industry, namely WHOI (Evans), Dublin Institute for Advanced Studies (DIAS, Jones), CGS (E. Stettler) and De Beers (Hatch). The proposal was for a relatively simple experiment to acquire data along two orthogonal profiles in predominantly South Africa during two phases of acquisition (black profiles in Fig. 1. The main NE-SW black profile is beneath the red dots of KAP03).

The project was intended to cover the same area as the Southern African Seismic Experiment (SASE) array (black dots in Fig. 1) of the CD-funded MIT-Carnegie Kaapvaal Craton Project, with overarching aims of determining the resistivity structure of the Kaapvaal craton and comparing and contrasting it to seismic models of the craton and also with the resistivity structure of other cratons. The MT proposal was funded by the CD programme in Spring, 2003 and the first phase of fieldwork took place in September-November, 2003. Besides NSF, other funding for Phase I came from De Beers and from a South African Department of Science and Technology grant to the CGS. The MT equipment for that first Phase came from DIAS, from the U.S. EMSOC, and from the Geological Survey of Canada (GSC).

As the SAMTEX project progressed, seven more partners joined the consortium, in chronological order; The University of the Witwatersrand (academia), Geological Survey of Namibia (government), Geological Survey of Botswana (government), Rio Tinto Mining and Exploration (industry), BHP Billiton (industry), Council for Scientific and Industrial Research of South Africa (government), and ABB Sweden (industry) for the Namibian Power Corporation (government). These partners brought in more funding, more personnel, and more logistical support, enabling an expansion of SAMTEX.

We have now completed four far larger phases of acquisition, rather than the two originally planned (compare black profiles to actual station locations in Fig. 1), and, in addition, De Beers donated proprietary MT data to the SAMTEX project (yellow sites in Fig. 1). In total, the SAMTEX dataset now comprises data from a total of more than 730 sites along ~14,000 line kilometres over an area in excess of a million square kilometres. As such, this is by far the largest regional-scale MT project ever undertaken.

The electric and magnetic time series recorded at each location were processed into MT responses using robust methods, namely improved versions of methods 6, 7 and 8 in (Jones 1989). Data quality was generally very high, especially in Namibia and Botswana, but was poor at some locations in South Africa, particularly close to the town of Kimberley and in the Witwatersrand Basin, due to the high amplitude electrical-noise generated by the DC power-supply to both the mines and railway lines.

## QUALITATIVE INFORMATION

Qualitative information on regional-scale resistivity variations can be obtained rapidly from the magnetotelluric impedance tensors at each station through constructing maps of various parameters. It must be appreciated that these maps are images of the actual resistivity distribution; they are not models constructed through either a forward data-fitting exercise or application of a formal inversion of the data for the resistivity model. Conventionally, these maps are created at specific periods thought to be penetrating to crustal or mantle depths. However such fixed-period maps can be highly misleading if crustal conductivity varies significantly across the region, a problem that is extreme for southern Africa (Hamilton 2008, Hamilton, et al. 2006). Thus, it is necessary to perform an approximate depth conversion prior to constructing the maps, which is done here using the Niblett-Bostick (NB) transform from apparent resistivity and phase against period to layer resistivity against depth (Bostick 1977, Jones 1983, Niblett and Sayn Wittgenstein 1960).

We will present image maps of estimated bulk resistivity and a measure of anisotropy for certain depths, and a map of the integrated conductivity between two depth ranges. The depths we have chosen for bulk resistivity and anisotropy are 100 km and 200 km. The first approximates the middle of the lithosphere and the second approximates the base of the lithosphere. For integrated conductivity we show the depth range of 40-200 km, i.e., the mantle lithosphere. Given space limitations in this abstract, we only show the two bulk resistivity maps.

## 100 km and 200 km depth maps

The maps of the maximum (NB) resistivity at (NB) depths of 100 km and 200 km are shown in Figs. 2 and 3 respectively. Mantle lithospheric rocks comprising olivine, pyroxenes and garnet at lithospheric mantle P-T conditions appropriate for the Kaapvaal Craton should have resistivities of the order of 30,000 Ω.m or greater at 100 km (P-T conditions of 3.0 GPa and 740 °C) and of the order of 1,000 Ω.m at 200 km (P-T conditions of 6.3 GPa and 1250 °C) (Jones, et al. 2009, Ledo and Jones 2005). The hotter colours, yellows to reds, are indicative of either hotter conditions and/or the presence of conducting components.

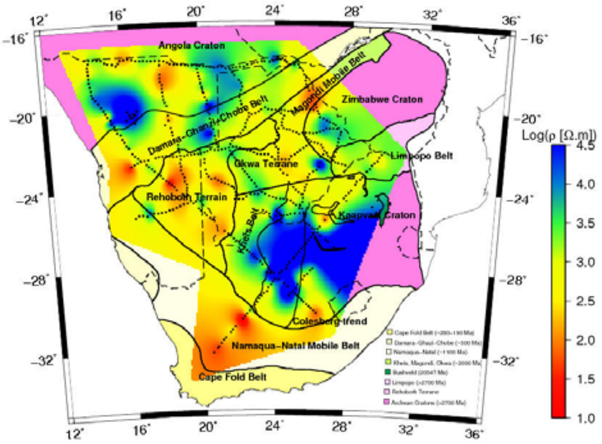

**Figure 2: An image of the resistivity at 100 km depth based on an approximate transformation of the MT responses from period to depth and taking the maximum resistivity found. The colours are log10(resistivity), and the black dots show stations at which data were used. At the P-T conditions for the Kaapvaal Craton mantle rocks at 100 km depth comprising olivine, pyroxenes and garnet are expected to have a resistivity in excess of 30,000 ohm.m, i.e., blue.**

The maps show a very resistive core region of significant spatial extent that is spatially associated with the Kaapvaal Craton. In particular there is strong correlation between the northwestern boundary of the Kaapvaal Craton, as mapped on the surface, and the edge of the high resistivity body. The northeastern part of the Kaapvaal Craton shows lower resistivity, and the more conductive regions spatially coincide with the mapped boundaries of the surface exposures of the Bushveld Complex (Fig. 1). The Bushveld Complex is thought to have affected the seismic structure of the craton, with lower velocities in the mantle (James, et al.

2001), and in our data there is evidence of an effect on electrical conductivity. Resistive deep lithosphere is spatially associated with the Angola Craton (Fig. 3) and with parts of the Zimbabwe Craton, especially its westward tongue on which the Orapa kimberlite field lies (Fig. 3).

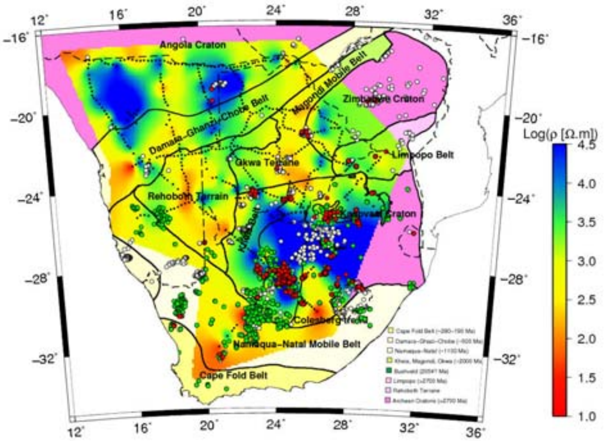

**Figure 3: An image of the resistivity at 200 km constructed in the same manner as Fig. 2. Also shown on the figure are kimberlite locations; red means known to be diamondiferous, green means known to be non-diamondiferous, and white means not defined or unknown. At the P-T conditions for the Kaapvaal Craton mantle rocks at 100 km depth comprising olivine, pyroxenes and garnet are expected to have a resistivity in excess of 1,000 ohm.m, i.e., green to blue.**

On the 200 km depth map (Fig. 3) are also plotted the known kimberlite localities, and they are colour-coded according to whether the kimberlite is known to be diamondiferous (red), known to be non-diamondiferous (green) or either unknown (to us!) or undefined (white). There is an obvious spatial correlation between the edges of resistive regions and diamondiferous kimberlites.

Maps of electrical anisotropy (not included in abstract) show that at 100 km the region outlined as the Rehoboth Terrane is remarkably isotropic, and this isotropy persists to 200 km, although it diminishes in spatial extent. The isotropic region extends eastwards to the eastern half of the Okwa Terrane and along the Magondi Mobile Belt. In contrast, the cratonic regions are highly anisotropic – evidence of strong lateral heterogeneity. Interestingly, in Botswana the diamondiferous kimberlites lie on the edges of the isotropic region (Fig. 5), but this relationship is not upheld in South Africa.

## CONCLUSIONS

Maps of electrical resistivity and resistivity anisotropy derived from approximate methods give robust information about large-scale regional structures. In the case of southern Africa, the maps show evidence of obvious spatial correlations between diamondiferous kimberlite fields and lateral changes in either resistivity or resistivity anisotropy. These spatial correlations of gradients in physical parameters at the edges of cratons being the most prospective diamondiferous regions appear also to hold in seismic parameters.

Based on our results, we conclude that, on a statistical basis, area selection for diamond exploration activities should focus on the edges of cratons where there are gradients in velocity and electrical conductivity, rather than the centres of cratons. These gradients are indicative of rapid shallowing of the deep lithospheric roots, and suggest that either the kimberlite magmas are generally unable to penetrate through thick roots, or that the processes of initiation of kimberlitic eruptive magmas are preferentially at depths shallower than the thickest roots. This is a revision of Clifford´s Rule (Clifford 1966) that implies that the thinner edges of cratons are more prospective than the thicker centres, a suggestion made previously by Griffin, et al. (2004) based on the kimberlite distribution on the North American Plate. However, there are notable exceptions to this; for example the Victor kimberlite field in Atiwapiskat, central Superior Province of Canada in the Hudson’s Bay lowlands, for which it has been proposed that the lithosphere was thermally weakened by the passage of the Monteregian hotspot (Eaton and Frederiksen 2007).

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