Electrical and seismic anisotropy of the southern African lithosphere

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ABSTRACT

The SAMTEX experiment has provided an additional geophysical perspective with which to look at and understand southern Africa. We compare seismic anisotropy from teleseismic shear-wave splitting events recorded during the SASE experiment, with electrical anisotropy measurements from the SAMTEX MT data. The MT data analysis shows more complex results than have previously been observed in other regions, likely due to large-scale conductivity structure affecting the electrical anisotropy response, which is particularly evident in our crustal MT results. The Lithospheric mantle results are less affected, although there is still a large structural effect at some terrane boundaries. In certain regions the data penetrate to asthenospheric depths, and show a good correlation with the seismic results, although in these parts, the results are not significantly different from the lithospheric mantle results. Thus, we have not been able to constrain the depth of the seismic anisotropy using the MT, and it is likely that in some parts, they are responding to different features. It has however provided us with important structural information, and anisotropic information away from terrane boundaries, which is important for understanding the region.

Key words: lithosphere, anisotropy, magnetotellurics, seismology

INTRODUCTION

Electrical and seismic anisotropy sense different physical properties, however the responses of each may be due to the same causative feature. Seismic shear wave splitting anisotropy of teleseismic events has inherently poor vertical resolution, whereas electrical anisotropy from magnetotelluric (MT) data has depth information inherent in the technique due to the skin depth phenomenon. Additionally, as is nearly always the case in geophysics, it is possible to get far more information on a region by looking at different techniques, than by looking at one alone, and thus these two techniques are very complementary. Here we compare seismic anisotropy results from the southern African seismic experiment (SASE), some of which has been reprocessed, with electrical anisotropy measurements from MT data collected as part of the southern African magnetotelluric experiment (SAMTEX). These two experiments provide a large region of nearly collocated stations that cover interesting geological terranes (figure 1).

The first such comparison was made by Ji *et al.* (1996) across the Grenville front in Canada, where they used the obliquity between the seismic and electrical anisotropy to interpret the thrusting direction. This work was followed up by Eaton *et al.* (2004) who used a correlation between electrical and seismic anisotropy to place depth constraints on the location of the seismic anisotropy. It is clear form these studies, and other recent work, that combining these two types of geophysical data for interpretation is a very worthwhile exercise.

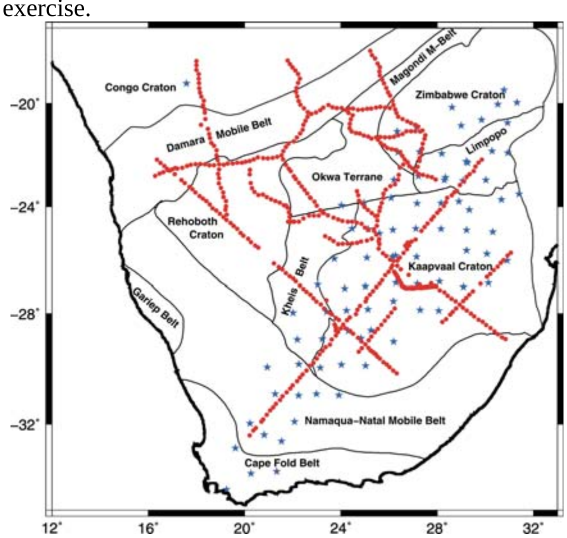

Figure 1: SAMTEX station locations (red), and SASE seismic (blue) stations locations, overlain on a rough geological outline of southern Africa.

METHOD AND RESULTS

MT analysis

We gain information on electrical directionality using the decomposition technique of Groom and Bailey (1989), as implemented by McNeice and Jones (2001), written as GB decomposition from this point on. GB decomposition separates local 3D distortion from the regional 1D or 2D response by factorising/decomposing the measured impedance tensor into a rotation matrix, a distortion tensor, and the regional 2D impedance tensor. One of the outputs from this decomposition is a geoelectric strike direction. This strike direction has 90° ambiguity; however it is possible to avoid this ambiguity by plotting the more conductive direction of the two. This corresponds to the curve with the higher phase, which is not affected by static shift effects. We are therefore able to gain important information on the electrical anisotropy of the region by using this technique.

These plots of electrical anisotropy are commonly displayed as maps of vectors for a given period, which corresponds to a given depth. However, due to the scale of the SAMTEX experiment, and the variable conductivity distribution in the region, a plot such as this would be meaningless, as is demonstrated by figure 2.

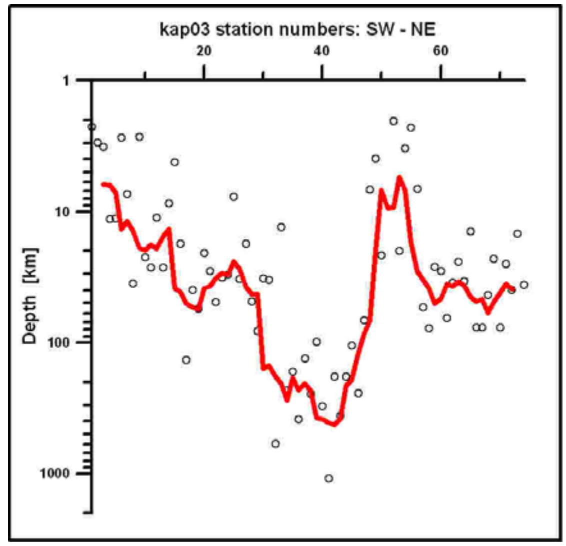

Figure 2: A plot of penetration depth for the main profile from the SW of South Africa to the South Africa-Zimbabwe border, for a period of 100 s, using Niblett–Bostick (Jones, 1983) depth estimates. A given period would be describing many different depths, and therefore to plot the electrically more conducting directions for a given period across the entire region, would be meaningless.

We have therefore analysed the MT data on a site-by-site basis, firstly for a decade-wide band of data representative of the crust, and secondly for a decade wide band of data representative of the lithospheric mantle. In some parts data penetrates into the asthenosphere. There is little data at these long periods, and we have therefore used a multi-site strike analysis (McNeice and Jones, 2001) of 3 to 6 sites to add reliability to the result.

Seismic analysis

The seismic anisotropy which is compared with the MT electrical anisotropy is from the SKS shear wave splitting results of Silver *et al.* (2001). More than 9 sites, representative of different geological regions and splitting parameters, of the 82 sites from the SASE experiment were reanalysed to look for the possibility of two-layer, dipping, or simply more complex anisotropy. We use the same method (Silver and Chan, 1991) as Silver *et al.* (2001) for the reanalysis. Our results are approximately equivalent to those of Silver *et al.* (2001), but there appears to be insufficient data to make more complex deductions about the number of layers or symmetry of the seismically anisotropic layer, where in order to do so, excellent backazimuthal coverage is required.

Results

The results of the MT analysis for crustal depths are shown in figure 3. The electrical anisotropy for lithospheric mantle, and asthenospheric depths, overlain on the seismic SKS shear-wave splitting results are shown in figures 4 and 5 respectively.

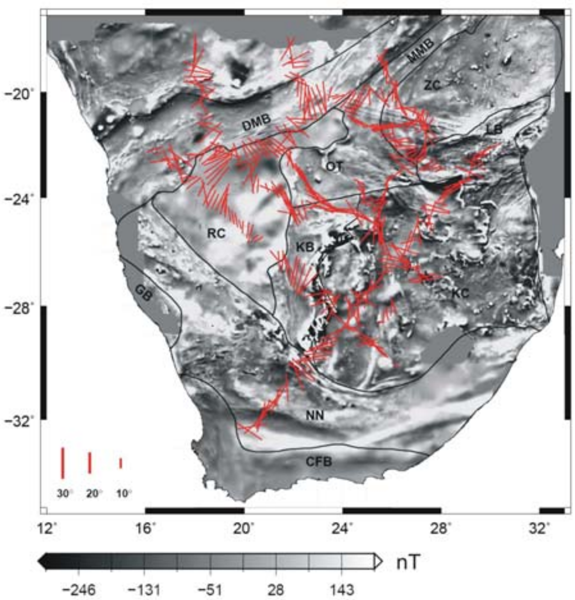

Figure 3: Crustal MT electrically more conductive directions, scaled by phase difference (red lines), overlain on the regional aeromagnetic data of southern Africa, and geological domains determined largely from potential field data. See figure 1 for terrane notations.

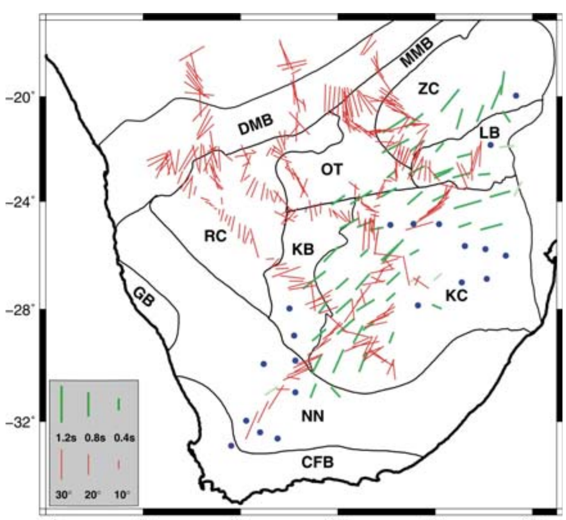

Figure 4: Lithospheric electrical anisotropy scaled by phase difference (red lines), overlain on the seismic anisotropy results (green lines, scaled by delay time) of Silver *et al.* (2001), and geological domains determined largely from potential field data. Blue dots are null seismic values. See figure 1 for terrane notations.

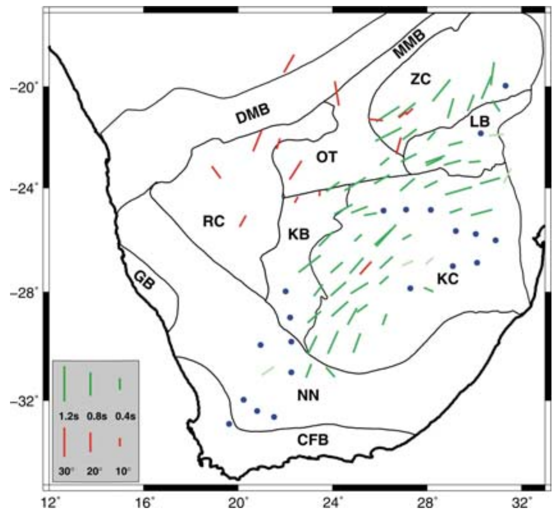

Figure 5: Asthenospheric electrical anisotropy results for multi-site analysis of 3 to 6 sites, scaled by phase difference (red lines), overlain on the seismic anisotropy results (green lines, scaled by delay time) of Silver *et al.* (2001), and geological domains determined largely from potential field data. Blue dots are null seismic values. See figure 1 for terrane notations.

CONCLUSIONS

Our crustal results (figure 3) show a strong correlation with known terrane boundaries. MT strike directions can be a result of either or both of intrinsic anisotropy such as an interconnecting mineral phase or from 2D conductivity structures. The variation of the TE and TM modes for a given depth across a 2D fault or boundary between a conductive and resistive region is portrayed in figure 6.

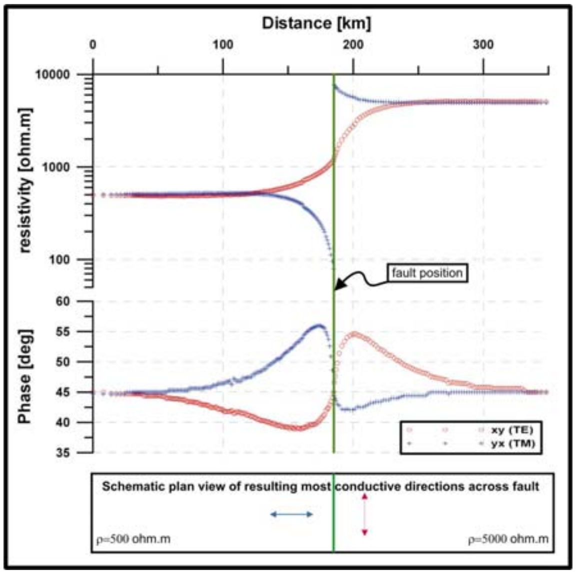

Figure 6: Diagram portraying the MT response for the TE and TM modes at one depth for a quarter-space fault model. The result is that the more conductive directions are parallel to the geological strike on one side of the fault (the resistive side), and perpendicular on the other (the conductive side).

If the strike directions are due to structure, and not small-scale intrinsic anisotropy, we would expect to see a similar effect to that in Figure 6 at geological boundaries that have conductivity contrasts. The near 90° rotation in strike direction can be quite clearly observed in a number of localities in our crustal results (figure 3), e.g. on the southwest edge of the Kaapvaal craton boundary, and at the Limpopo belt - Kaapvaal craton boundary.

It is known that the seismic fast-axis direction of olivine is also the more conductive direction of the mineral, although there is debate as to the magnitude of the conductivity anisotropy caused by the mineral. If the seismic SKS splitting is due to LPO of olivine in the upper lithospheric mantle, we might expect our lithospheric mantle results (figure 4) to show a strong correlation with them. Qualitatively there does appear to be some correlation in places e.g. in the SW Kaapvaal craton. At the SW Kaapvaal craton boundary we no longer see the structural boundary effect we see in the crustal results, and the conductive directions seem to correlate better with the seismic results. It is clear however that in general there is still a strong correlation between lithospheric mantle electrical anisotropy and crustal terrane boundaries e.g. the northern edge of the Damara belt which borders the Congo craton, and also regions where the MT and seismic results do not correlate at all, such as in the Limpopo belt.

Our lithospheric mantle results suggest a few possibilities; perhaps there is a contribution from LPO of olivine to electrical anisotropy, but it is being overwhelmed by large-scale 2D structural effects in certain places; could the seismic anisotropy be from a deeper source; or perhaps the electrical and seismic anisotropy orientations are responses to different causes and therefore will not correlate.

In order to test the second possibility, those sites that penetrate into the asthenosphere were analysed (figure 5). There is a fairly good correlation between the asthenospheric MT results and the seismic anisotropy. However, at these locations, the lithospheric results are also quite similar, and therefore do not aid us significantly in constraining the depth of the seismic anisotropy. It does however indicate that there may be a contribution to the seismic anisotropy from the asthenosphere as well as the lithosphere.

Essential to understanding these results is to make both electrical and seismic anisotropy measurements on mantle nodules, and to collect additional collocated datasets.

ACKNOWLEDGMENTS

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http://www.dias.ie/~mh/samtex_html/participants.html

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