Artifacts of isotropic inversion applied to anisotropic MT data

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SUMMARY

Two-dimensional, isotropic approaches are standard for magnetotelluric (MT) data modelling and inversion. Unfortunately the real subsurface structure is not isotropic everywhere and one should be aware of the possible consequences of applying an isotropic inversion to anisotropic data. The work presented was motivated by finding an unusual conductor that seemed to be downwarped into the lithospheric mantle compared to the neighbouring terranes where it appeared in the mid- to lower-crust. One major difference between the terranes is the presence of the Okavango giant mafic dyke swarm (NE Botswana), where the conductor is imaged to be in the lithospheric mantle. The very limited width of the dykes makes them more an anisotropic feature than a normal 2D structure at MT scale. To examine the possible effect of the dykes, synthetic data, accounting for the dyke swarm by using an anisotropic layer, were generated and then inverted isotropically.

The synthetic test showed that the normal decomposition and strike analysis techniques are not removing these large scale anisotropic effects, and that an isotropic inversion result obtained in the presence of an anisotropic structure has to be treated with caution. The comparison of the synthetic data and the presented case history strongly suggests that the conductor imaged at lithospheric depths is an artifact and the conductor is most likely in the lower-crust as everywhere else in that area.

Keywords: magnetotellurics, inversion, anisotropy

INTRODUCTION

Modelling and inversion tools for magnetotelluric data are based on a number of assumptions one of which is often an isotropic resistivity distribution. For two-dimensional (2D) approaches data are often treated by decomposition and strike analysis techniques as for example the program *strike* by *McNeice and Jones (2001)*. Based on the Groom-Bailey decomposition *(Bailey and Groom, 1987; Groom and Bailey, 1989)* *strike* analyzes galvanic distortions present and determines the most consistent geoelectric strike direction of a data set. The galvanic distortion comprises the effect of near-surface, small-scale heterogeneities in the resistivity distribution physical separated as twist, shear, anisotropy and a scaling factor called gain. These effects are removed by applying *strike* to the data and results in a 2D response curve which can be inverted using standard tools.

Two-dimensional, isotropic inversion result of a profile crossing the Okavango dyke swarm (NE Botswana) showed an unusual conductor at lithospheric mantle depths beneath the dyke swarm, whereas in almost all surrounding terranes a conductor was found in the mid- to lower-crust. As the dykes are, on average, 17 m wide they are more an anisotropic feature than a normal 2D structure at the MT scale. That raised the question, could this lithospheric mantle conductor be an artifact of isotropic inversion applied to data measured above an anisotropic structure? So far no feasibility study investigated how well a resistivity structure is recovered by an isotropic inversion if large scale anisotropy is present that does not vanishes when *strike* is applied. Therefore based on the dyke swarm scenario synthetic test models were designed and the normal procedure of data processing, analysis and isotropic inversion was applied to the synthetic data set and finally compared to the inversion results of the real data set.

SYNTHETIC TESTS

Model design

As the Okavango dyke swarm is situated in the crust above the Archaean Zimbabwe craton, the following simple background model was assumed for the synthetic data. The top 26 km are of variable resistivity, beneath is a 100 Ωm and 10 km thick layer simulating the lower-crust conductor. The lithospheric mantle of the craton is resistive (2000 Ωm) and thick (lithosphere-asthenosphere boundary at about 220 km depth). Figure 1 (left) shows the basic layered background model. As the dykes are mainly dolerites that are assumed to have a resistivity of 30,000 Ωm *(van Zijl, 2006)* and the dilatation of the dykes in that area is estimated to be 12.2% *(Le Gall et al., 2005)*, the three principal anisotropic resistivities ($\rho_x/\rho_y/\rho_z$) could be approximated applying Kirchhoff's Law for parallel and serial connections. Figure 1 (right) shows the model with the anisotropic block in the crust and Table 1 lists the estimated principal anisotropic resistivities for various background values of the top layer.

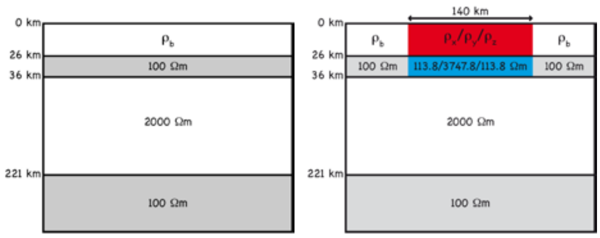

Figure 1. Figure showing the synthetic test models. On the left the simple layered background model is shown, where the resistivity value of the top layer (ρ_b) is variable and the panel on the right shows the same background model but with an anisotropic block introduced in the top two layers (principal resistivities of the anisotropic block are $\rho_x/\rho_y/\rho_z$ for the top layer). Table 1 lists the different resistivity values of the top layer.

Table 1. Table listing the resistivity values of the background resistivity value of the top layer (ρ_b) and the related principal resistivities of the anisotropic block ($\rho_x/\rho_y/\rho_z$) of the models shown in Figure 1. See text for more details.

Model	ρ_b	$\rho_x/\rho_y/\rho_z$
A	100 Ωm	113.8 Ωm /3747.8 Ωm /113.8 Ωm
B	200 Ωm	227.6 Ωm /3835.6 Ωm /227.6 Ωm
C	500 Ωm	568.2 Ωm /4099 Ωm /568.2 Ωm
D	1000 Ωm	1133.7 Ωm /4538 Ωm /1133.7 Ωm
E	2000 Ωm	2257 Ωm /5416 Ωm /2257 Ωm
F	5000 Ωm	5565.9 Ωm /8050 Ωm /5565.9 Ωm

Generation, analysis & inversion of synthetic data

The 2D forward anisotropy code by *Pek and Verner (1997)* was used to calculate the synthetic data sets based on the simple models described above. Following the normal procedure of real data treatment, *strike (McNeice and Jones, 2001)* was applied to the synthetic data to decompose them and generate a data set that is thought to be valid for a 2D inversion approach. The 2D isotropic inversion code by *Rodi and Mackie (2001)* (implemented in the WinGLink software package from Geosystem) was used to invert the synthetic data. As for real observed data the inversion was an iterative process fitting TM phases first, then TE phases, TM resistivities and finally also TE resistivities. Figure 2 shows the inversion results of the layered background model (left) and the model including the anisotropic block (right) for the case of Model D (ρ_b = 1000Ωm). It is obvious that the conductor in the lower crust appears correctly in the background model, but it is downwarped to lithospheric mantle depths beneath the anisotropic block.

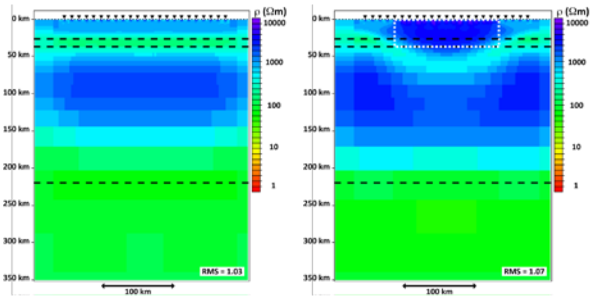

Figure 2. Figure showing the 2D isotropic inversion results of the synthetic data of the layered background model (left) and the model including the anisotropic block (right). These are the results of Model D (ρ_b = 1000 Ωm) and the black dashed lines indicated the layer interfaces of the true model. The anisotropic block in the model on the right is represented by the white dashed box.

Figure 3 shows resistivity-depth profiles through the inversion models of the background and the anisotropic models (for models A-F). These curves are averaged over the lateral extent of the anisotropic block. While all six resistivity-depth profiles of the background models clearly show a conductive layer in the lower crust, in the presence of the anisotropic block the conductive layer appears at greater depths for all six models.

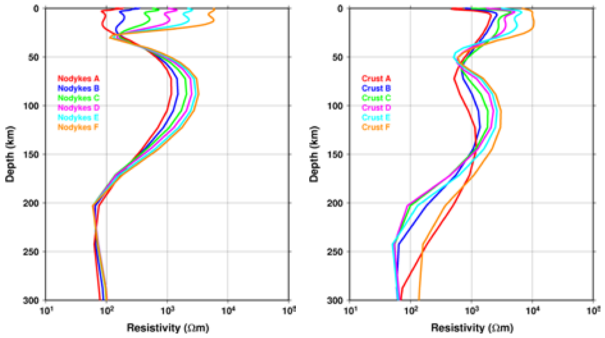

Figure 3. Resistivity-depth profiles through the inversion models in Figure 2 (left – resistivity-depth profiles of the background model, right – of the anisotropic model), averaged over the lateral extent of the anisotropic block. (Different coloured curves represent the resistivity-depth profiles of the different synthetic models as listed in Table 1).

CASE HISTORY

The 2D profile (called ZIM) cross-cut by the Okavango dyke swarm is located in northeastern Botswana and runs along the border to Zimbabwe. (See abstract by Miensopust et al. on 'Lithospheric structures of NE Botswana' (20th EM induction workshop abstracts) for more details on the location and geological settings).

Figure 4 shows the 2D isotropic inversion result and geological interpretation of the ZIM profile. The light blue area between the Okavango dyke swarm (ODS) and the Zimbabwe craton represents the conductor imaged in the upper lithospheric mantle, whereas the conductor in the Ghanzi-Chobe belt is located in the lower crust. Not only the Ghanzi-Chobe belt but also other terranes in southern Africa indicate a conductive layer in the lower crust (e.g., terranes in South Africa and Namibia investigated by *Muller et al. (2009)*).

Figure 5 shows resistivity-depth profiles through the inversion model (Fig. 4) averaged over the Zimbabwe craton including the dyke swarm (ZIM – red), the Magondi mobile Belt (MMB – green) and the Ghanzi-Chobe Belt (GCB – blue). For comparison resistivity-depth profiles of the model by *Muller et al. (2009)* are shown in grey (DMB – Damara Mobile Belt, RBT – Rehoboth Terrane, KBE/KBW – Eastern/Western Kaapvaal Block). The resistivity-depth profiles of the Magondi Mobile Belt, the Ghanzi-Chobe Belt, Damara Mobile Belt and the Western Kaapvaal Block all show a conductor in the mid- to lower-crust. In the case of the resistivity-depth profile of the Zimbabwe craton this conductor is shifted downwards into lithospheric mantle depths, similar to the results of the synthetic data in the presence of an anisotropic structure. Being aware of the presence of an anisotropic structure (the Okavango dyke swarm) it is the most plausible explanation that the conductor was imaged wrongly at greater depths when the data were inverted isotropically.

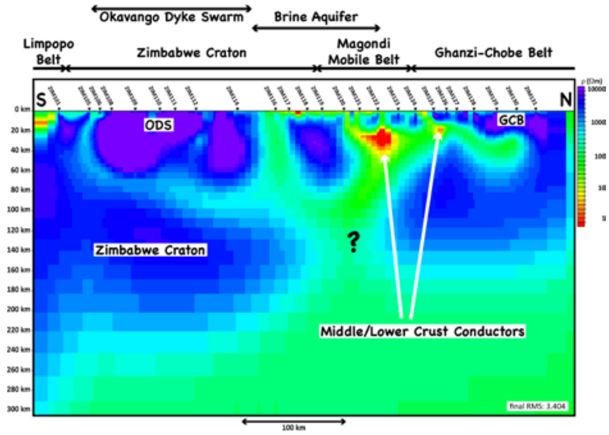

Figure 4. The inversion model (vertical exaggeration = 1.0) of the ZIM profile in relation to the known surface extent of geological terranes and the lateral extent of the Okavango dyke swarm (ODS). (For a more detailed interpretation of this profile see abstract by Miensopust et al. on 'Lithospheric structures of NE Botswana' (20th EM induction workshop abstracts).) The light blue colour between the ODS and the Zimbabwe craton represents a conductor that seems to be located in the upper lithospheric mantle rather than in the lower crust (as for example the "green" conductor beneath the Ghanz-Chobe belt (GCB)).

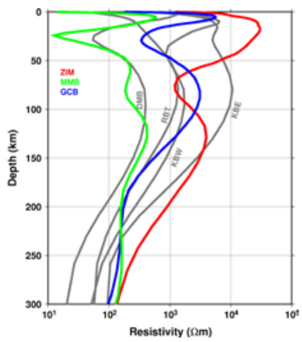

Figure 5. Resistivity-depth profiles through the inversion model of the ZIM profile in colour, averaged over different terranes (red – Zimbabwe craton including dyke swarm, green – Magondi Mobile belt, blue – Ghanzi-Chobe belt). Resistivity-depth profiles of the Damara Mobile Belt (DMB), the Rehoboth Terrane (RBT), the Eastern and Western Kaapvaal Block (KBE/KBW) by *Muller et al. (2009)* are shown in grey for comparison.

CONCLUSIONS

The test of 2D isotropic inversion of the anisotropic synthetic data strongly suggests that the appearance of the conductor below 50 km in the resistivity-depth profile in the presence of the dyke swarm and the deflected conductor in the 2D inversion model are artifacts, and that the conductor is in reality located in the mid- to lower-crust, as is observed in all other resistivity-depth profiles.

One should be aware that false structures or wrongly imaged structures can be introduced by inverting anisotropic data using an isotropic approach.

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