Effects of undetected anisotropy in 2D inversion modelling

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INTRODUCTION

We present a simulation of two-dimensional models with lateral anisotropy and the inversion of their synthetic data responses assuming isotropic structures. The data responses are obtained using the finite-difference algorithm of Pek and Verner [1997]. Once obtained the anisotropic data, we carried out the following steps:

1-Dimensionality analysis and determination of the optimal 2D-strike after Swift [1967] criterion.
2-Rotation of the impedance tensor in direction of the obtained strike
3-2D-inversion (REBOCC algorithm).

The influence of the anisotropy strike α and resistivity contrast has been studied for each of these steps.
Finally this strategy was tested on field data were anisotropy was previously recognised.

Figure 1 defines the direction of the anisotropy strike with respect to the 2D structural strike and the 2 principal resistivities ρ_{min} and ρ_{max} of the anisotropic domain.

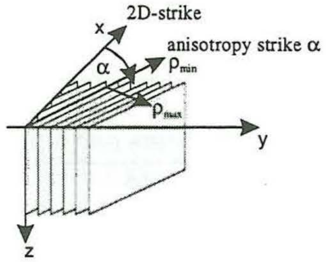

Figure 1: An anisotropic domain, simulated by conductive dykes, with principal resistivities and an anisotropy strike of α with respect to the 2D structural strike

MODEL 1 : **A vertical contact between isotropic and anisotropic media**

The model (Figure 2) consists of a lateral anisotropic medium with principal resistivities of 20Ωm and 1000Ωm in contact with an isotropic domain and covered by a resistive overburden of 1000Ωm. We started with the case $\alpha = 30^o$ and a resistivity of the isotropic medium ρ_2 = 1000Ωm.

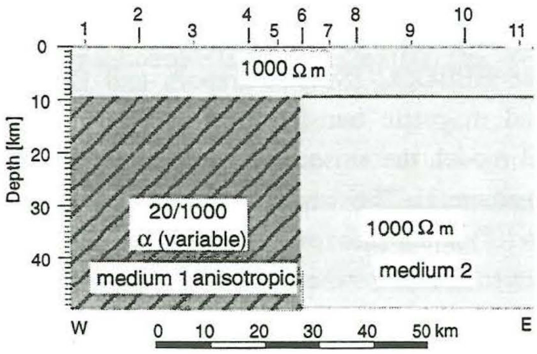

Figure 2: Model 1 consists of a fault (medium1 anisotropic with principal resistivities ρ_{min}=20Ωm/ρ_{max}=1000Ωm and medium 2 isotropic) covered by a resistive overburden of 1000Ωm. We studied different directions of the anisotropy strike α and different resistivities in medium 2.

Analysis of the dimensionality

After obtaining the synthetic data, the analysis of the dimensionality was performed. The Swift criterion did not give a constant 2D strike for all the periods. However, the strike directions vary rather smoothly and the divergence of the strike directions between sites does not exceed 35° (Figure 3).

Influence of the resistivity of medium 2

We studied the influence of the resistivity contrast on the induction arrows and the strike analysis by using different values of the resistivity in medium 2 (ρ_2).

The induction arrows are strongly influenced by the resistivity of medium 2 (Figure 4). They are only perpendicular to the direction of the anisotropy strike α, when $\rho_2 = \rho_{max}$.(1000Ωm). They rotate successively clockwise and for $\rho_2 = \rho_{min}$ (20Ωm) they point perpendicular to the direction of ρ_{max}. This behaviour corresponds to the orientation of the induction arrows perpendicular to the direction of the greatest resistivity contrast.

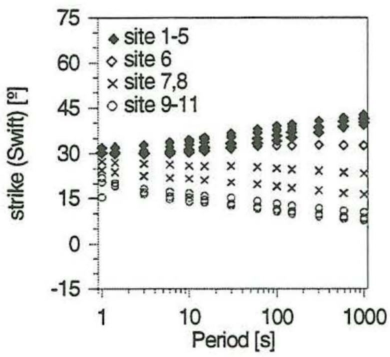

Figure 3: Strike directions, for an anisotropic strike of 30 °, calculated according to the Swift criterion.

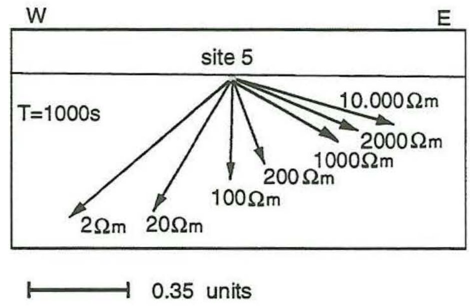

Figure 4: Orientation of the induction arrows for different resistivities in medium 2 (ρ_2). The arrows are perpendicular to the direction of the ρ_{min} for the case when $\rho_2 = \rho_{max}$

Two-dimensional inversion

The inversion with the REBOCC [Siripunvarapom and Egbert, 1996] algorithm (apparent resistivities, phases and magnetic transfer functions) of the 30° rotated data (after Swift) reproduces the original model, the anisotropy is recovered as a sequence of conductive dikes (macro-anisotropy in medium 1). The data fit is not satisfying (Figure 5), due to the fact that the real 2D strike direction (0°) is not recovered and that the inversion model is a 30° projection of the real model. In order to ascertain whether this situation is general we chose different strike directions for the 2D inversion. The sequence of alternating dykes appeared with strike angles between 0° and 55°, the difference between the models lying in the resistivities of the conductive dykes.

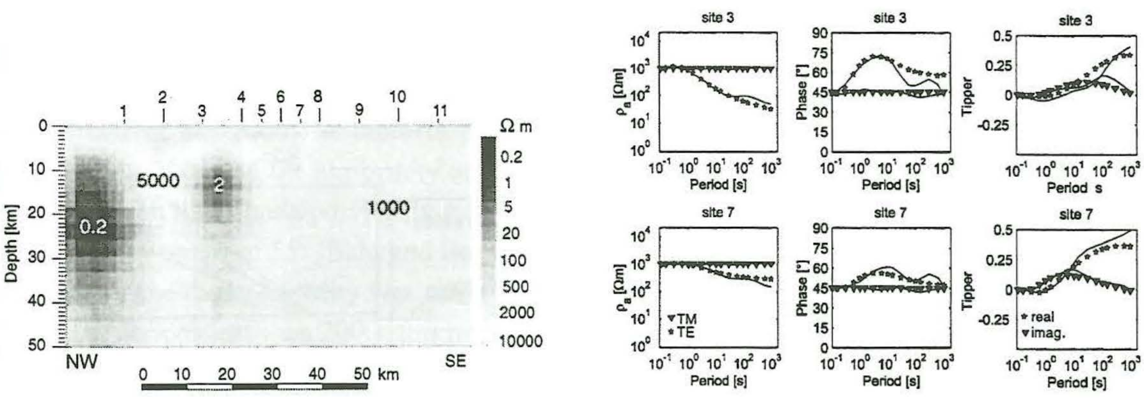

Figure 5: REBOCC inversion model and data fit for 30° rotated data .If the data are rotated to the direction of the anisotropy-strike, the anisotropy is simulated by macroanisotropy.

MODEL 2: **A contact between two isotropic domains underlain by an anisotropic layer**

Model 2 consists of a fault between two media of 20Ωm and 200Ωm underlain by an anisotropic layer with principal resistivities 20/1000Ωm and covered by a resistive overburden (Figure 6)

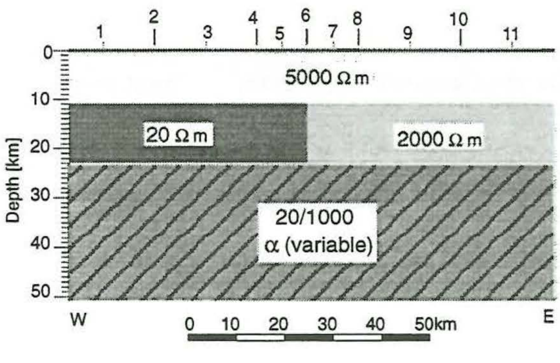

Figure 6: Model 2 consists of a contact between 20 Ωm and 200 Ωm isotropic media, underlain by an anisotropic layer of 20 Ωm/1000 Ωm.

Analysis of the dimensionality

The strike analysis after Swift indicates a preferred strike direction about α, except for the short periods of site 1-6 where the anisotropy cannot be seen, owing to the decreased skin depth caused by the 20Ωm conductor. The strike also depends on the resistivity contrast (Figure 7).

The induction arrows are roughly oriented in direction of α, in contrast to what one could expect (like model1).Their direction is frequency-dependent. At short periods they are almost east-west oriented (2D). At periods of about 100s they are deflected in direction of α, and they become very small at long periods (1D) (Figure 8a).

Influence of the anisotropy strike α

The Swift criterion gave, for all values of α, s a strike direction of approximately α, which coincides with the above result.

Increasing α from 0° the arrows rotate successively until reaching a maximum deflection. For the resistivities given in model 2 this maximum occurs at α = 30 °.(Figure 8b)

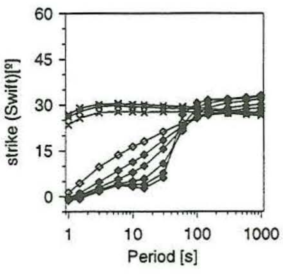

Figure 7 : Strike direction (Swift) for an anisotropy strike of 30°.

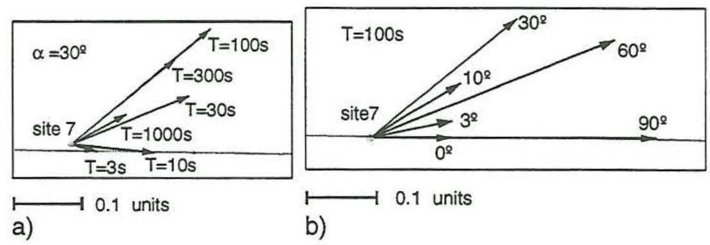

Figure 8 : Orientation of the induction arrows of model 2 for an anisotropy strike of 30° at different periods (a) and at 100 s for various anisotropy strikes (b).

Influence of the resistivity contrast

Again the resistivity contrast has an influence on the direction of the induction arrows, but the effect is less important than in model 1.

Two-dimensional inversion

Figure shows the result of the inversion of the impedance tensor and magnetic transfer functions for 30° rotated data (REBOCC algorithm).The anisotropic layer is modelled by a sequence of alternating conductive dykes (Figure 9).

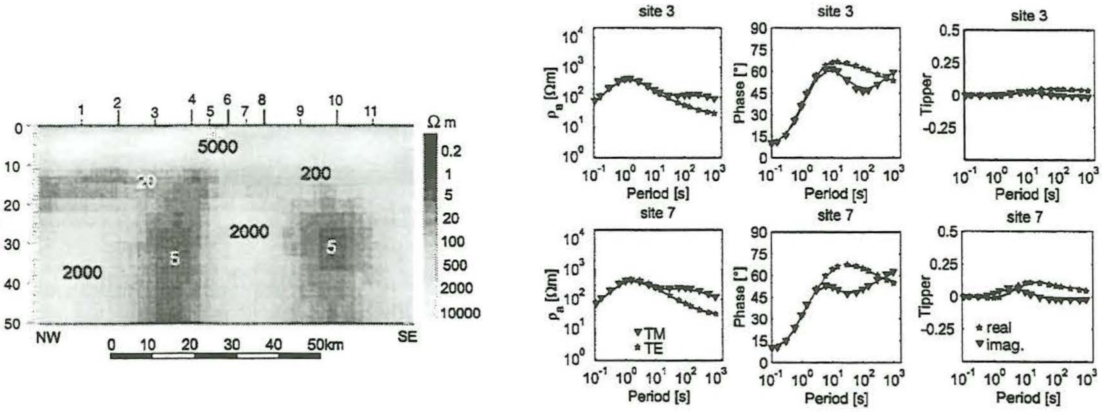

Figure 9: The 2D inversion model for 30° rotated data shows a dyke-like structure, simulating the anisotropic layer of Figure 9.

Data responses of the REBOCC inversion model for site 3 and 7.

APPLICATION TO FIELD DATA

As a real case we used MT data affected by anisotropy. The dataset consists of five long-period (from 10s to 10000s) stations in northern Bavaria, measured by the University of Göttingen in 1997 [Bahr et al., 2000]. A uniform phase splitting, which occurs at all stations at periods between 10s-100s and the uniformity of the magnetic transfer functions indicate an anisotropic structure, which has been previously interpreted with an anisotropic layer at 12 km depth with an anisotropy-strike of 55° [Bahr and Duba, 2000].
Analysis of the dimensionality was made using the Groom-Bailey analysis [Groom and Bailey, 1989]. At periods less than 200 s, this method gave a dominant 2D strike of 55°. (Figure 10)

The data were rotated to 55° and the inversion was made using the REBOCC code. The most striking result is the sequence of conductive and resistive dykes, between 5 and 12 km which simulates the anisotropic layer (Figure 11). Figure 12 shows the data and model responses. The deep structure of the inversion model and the data responses for periods longer than 300s must not be considered given that at these longer periods the strike was different from 55°.

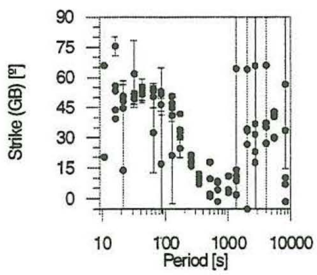

Figure 10: Results of the unconstrained Groom-Bailey analysis for the dataset from northern Bavaria.

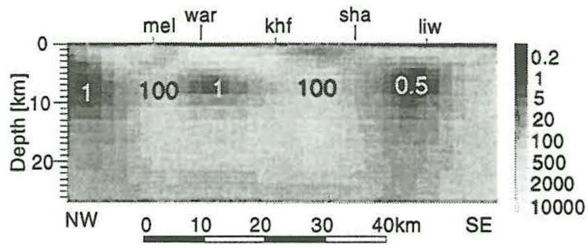

Figure 11. The REBOCC inversion model for the 55° rotated data shows a layer with macro-anisotropy at a depth of approximately 5km.

CONCLUSIONS

The strike direction of a 2D model affected by lateral anisotropy is frequency dependent and also varies along the profile. However, assuming field data with noise and depending on the resistivity contrasts, this departure from the 2D ideal case could be neglected and so a preferred strike direction could be determined. In these cases the analyses of the dimensionality gives a strike direction of approximately the anisotropy strike within a certain range of variation.
2- The induction arrows are severely affected by anisotropic structures. Their direction depends on the anisotropy strike, the resistivity contrasts and the period. Therefore, they are inappropriate to determine the 2D strike direction or the anisotropy strike.
3- The inversion model reproduces the original model with anisotropy if the data are rotated in direction of the anisotropy strike or to any other angle within the range of variation. The anisotropy appears as the typical sequence of conductive and resistive dykes (macro anisotropy).

4- In the absence of evidence for anisotropy on the data, when a 2D inversion model contains a sequence of vertical resistive-conductive zones anisotropy should be suspected for further investigation.

5- This approach, to detect anisotropy from an isotropic inversion model was successfully tested on field data from Bavaria where an anisotropic layer could be recognised.

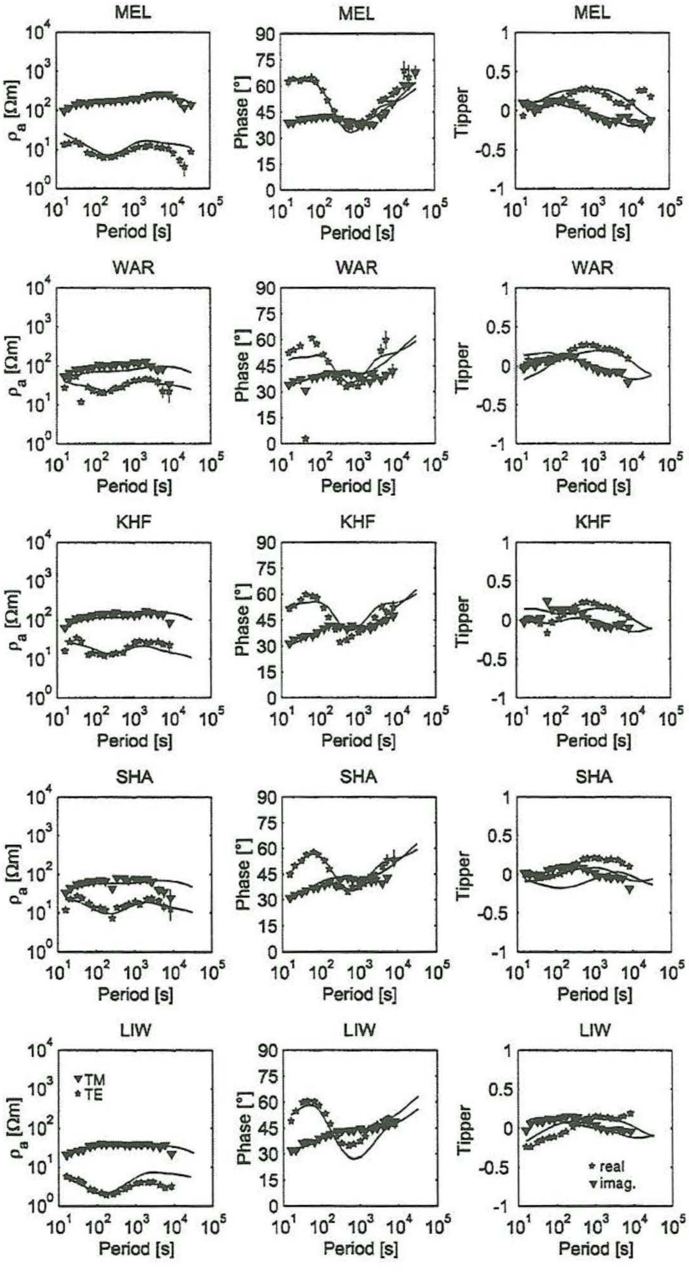

Figure 12: 55° rotated data and responses of the REBOCC inversion model for the dataset from northern Bavaria.

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