Kapitel 9

Summary

This PhD thesis deals with different imaging methods for interpretation of magnetotelluric data. Iterative inversion schemes are commonly used for this purpose. Nowadays there are several algorithms available, which assume a one- or two-dimensional subsurface. The results of the inversion strongly depend on site spacing, the applied modelling grid and the regularization parameters. Usually a unique model cannot be expected as the data can be explained by a variety of models. In case of a data set, which indicates a 3D subsurface, a 2D model can only be an oversimplifying approximation. Generally, the usage of a 3D forward modelling algorithm is possible, however, due to the complexity and the huge amount of modelling parameters only simplified modelling studies are feasible. As the modelling grid and its corresponding conductivities have a strong impact on the convergency of the model, complicated anomalies have to be simplified or enlarged by keeping the product of conductivity and thickness of the anomaly. In applying suitable imaging methods, however, we have the possibility to convert MT data directly in a physical property and to show them as co-ordinate system invariants.
The derived imaging methods are applied on MT data from Namibia, which were recorded at 60 sites with GPS based instruments (S.P.A.M. MK III) in 1999. The main purpose of these measurements was a detailed study of the Waterberg Fault / Omaruru Lineament (WF/OL), a major tectono-stratigraphic zone boundary in the Damara Belt. The results show strong 3D effects: Above and north of the fault we observe phases over 90^o and a strong correlation of parallel electric and magnetic field components resulting in a poor determination of one off-diagonal impedance component. These effects are certainly not caused by instrument failure or strong cultural noise. They provide indications of a complex conductivity distribution in the subsurface, which results in current channelling and deflection. The described 3D effects are not only observable at one single site but at all sites north of the WF/OL. Decomposition methods indicate that the implied distortion model is not applicable to this data.

In this work I seized an idea of Reilly [1979], who derived a conductivity tensor from the measured impedance tensor using tensor algebra formalism. This mathe-

matical formalism is now converted in a physical description of electromagnetic, plane waves in a homogeneous, horizontally anisotropic media. As the propagation constant plays a decisive role in the applied wave equations, I called this method *Propagation Number Analysis (PNA)*. This new formulation allows the realization of the advantages and restrictions of the *PNA*. For each impedance tensor we seek for an anisotropic substitute model which generates the same impedance tensor. The obtained apparent resistivity tensors are subsequently displayed in form of ellipses. The direction of the ellipse's major axis indicates the preferred direction of current flow.

The *PNA* is compared with two methods established in the eighties - EGGERS eigenstate analysis and LATORRACA *Singular Value Decomposition (SVD)* [Eggers, 1982, LaTorraca *et al.*, 1986]. Both methods extract the principle axis of the impedance tensor and use ellipses to plot the eigen vectors. So far the eigenstate analysis and the *SVD* are sometimes used as an alternative to a tensor decomposition. However, their application to measured MT data is uncommon and not thoroughly investigated. By means of a simple 2D model and the measured data from Namibia it is possible to show that both methods are suitable for imaging conductivity structure.

For all three imaging methods a reasonable relation to depth remains a problem, as we obtain plots for a particular frequency. In order to overcome this obstacle, I assigned the Bostick depth for the resistivity ellipses, which can be computed from the determinant of the apparent resistivity tensor. As this calculation of depth is problematic for a complicated 3D subsurface, the development of a more suitable method would be desirable.

Nevertheless, the imaging methods can unravel important information about the conductivity distribution in the measuring area. The application of all three methods is discussed in this work. The apparent resistivity ellipses (PNA) and the LATORRACA ellipses result in a clear image of the subsurface's conductivity distribution. The EGGERS polarization ellipses provide a hardly interpretable image of conductive anomalies. In particular with the resistivity ellipses we can estimate the geometry and the conductivities of anomalies. Although the resistivity ellipses are comparable to LATORRACA's first electric characteristic vector, the interpretation of a single ellipse is easier than the interpretation of a pair of ellipses. The application of the imaging methods reveals that we can identify the highest frequency which shows the influence of the conductive anomaly, but we are not certain about the maximum depth extend of the anomaly. The imaging methods are therefore most useful as an addition - not an alternative - to data interpretation by modelling. Models derived in this work are based on the interpretation of the apparent resistivity ellipses (*PNA*).

By plotting the apparent resistivity ellipses we make out the following conductive anomalies:

- South of the WF/OL we have indications of a layered subsurface by more circular ellipses. Their orientation in NNE direction corresponds to a N-E striking conductivity contrast close to the WF/OL. Generally, we observe increasing conductivities with depth.

- Above and north of the WF/OL elongated ellipses parallel to the fault indicate enhanced conductivities in this direction. The elongated ellipses are observed in a $10km$ broad area.

- In the northern part of the measuring area we obtain elongated ellipses arranged around a ring structure of clastic rocks. This ring structure is the result of doming during the Damara orogeny and subsequent erosion.

For the interpretation of the described anomalies I use three-dimensional and anisotropic two-dimensional model studies. With a 3D model of a circular, high conductive anomaly in a homogeneous half space the modelling results do not fit the data in the northern area in every detail, but we can draw some important conclusions: In order to generate the observed ellipses in the vicinity of the ring structure, a shallow, circular anomaly with an depth extension of approximately $3km$ is necessary. The synthetic results above this anomaly also show phases exceeding 90^o.

But this model cannot explain phases over 90^o in a broad area. However, the results of an anisotropic 2D model fit the observed apparent resistivity and phase curves and the resistivity ellipses. The model consists of a $10km$ broad and $14km$ deep reaching anisotropic block with a resistivity of $100\Omega m$ parallel and $1000\Omega m$ perpendicular to the fault. To generate phases over 90^o an additional $18km$ thick anisotropic layer beneath is required. The direction of enhanced conductivity within this layer cannot be resolved clearly. In order to explain the observed induction arrows with this model as well, a good conductor at a depth of $32km$ beneath the anisotropic features must be introduced. This anomaly is embedded in a layered half space with increasing conductivities. Both, the induction arrows and the resistivity ellipses, indicate a N-S striking anomaly in the western part of the measuring area.

Although the Namibian data set is very complicated, we obtain important information on the WF/OL and its surrounding area. In contrast to many fault systems, such as the San Andreas Fault [Unsworth *et al.*, 1997] or the West Fault in Chile [Hoffmann-Rothe, 2002], the WF/OL seems not to be related to a narrow, subvertical conductivity anomaly, but to an approximately $10km$ wide anomalous zone. The WF/OL also differs from both other fault systems in terms of its depth extend: Whereas the San Andreas Fault and the West Fault show enhanced conductivities down to some kilometers depth, the WF/OL reaches down to at least $14km$ in the middle crust. The induction arrows indicate that the fault zone might reach through the entire Earth's crust. This model of a detailed study across the WF/OL is in agreement with the model of the regional Damara traverse as both consistently reveal the WF/OL as a broad zone of tectonically weakened crust. With a sufficiently dense site spacing we are able to resolve structures within this zone: the

WF/OL appears as a subvertical conductivity anomaly in the regional Damara model, whereas the detailed study results in a conductive ring structure embedded in a macro-anisotropic zone. The site spacing in the eastern and western part of the measuring area is too sparse to be certain if this anomalous zone continues further to the west and east. The importance of dense measurements is also shown by the comparison of the dense main profile with the second profile. The main profile with a site spacing of $500m$ allows a good interpretation of the resistivity ellipses, whereas the image of the second profile with a site spacing of $2000m$ lacks clarity. Similarly, the ring structure in the northern part of the area is only resolved because of the dense site spacing. Without this detailed information shallow anomalies might easily be misinterpreted as deep anomalies.

The conductivity anomalies near the WF/OL are likely to be caused by graphite, as rocks sampled in the field show a high content of graphite. The graphite within the examined shallow rock samples appears to be not interconnected and therefore do not produce high conductivities. However, we can conclude from our observations that the it has to be interconnected at greater depth beneath the weathering layer to explain the observed high conductivities. Conductivity mechanisms such as fluids or fault gouge, as observed in connection with active fault systems, are unlikely. The WF/OL was reactivated several times in the earth's history. Since the WF/OL is a fossile shear zone now, we have no evidence for a hydrothermal alteration zone.