

Magnetotelluric measurements in the vicinity of the Groß Schönebeck geothermal test site

Gerard Muñoz, Oliver Ritter, Thomas Krings

GeoForschungsZentrum Potsdam

Introduction

The EU-funded I-GET (Integrated Geophysical Exploration Technologies for Deep Fractured Geothermal Systems) project is aimed at developing an innovative strategy for geophysical exploration. The basic idea is to integrate all available knowledge, from rock physics to seismic and magnetotelluric (MT) data processing and modelling, exploiting the full potential of electromagnetic and seismic exploration methods to detect permeable zones and fluid bearing fractures in the subsurface.

The Groß Schönebeck (Germany) deep sedimentary reservoir (Figure 2) is representative for large sedimentary basins which exist all over Europe. An existing borehole is currently used as an in situ geothermal laboratory. The Groß Schönebeck test site consist of a doublet made up of the wells GrSk 3/90 and GrSk 4/05 and is located NE of Berlin (Figure 1).

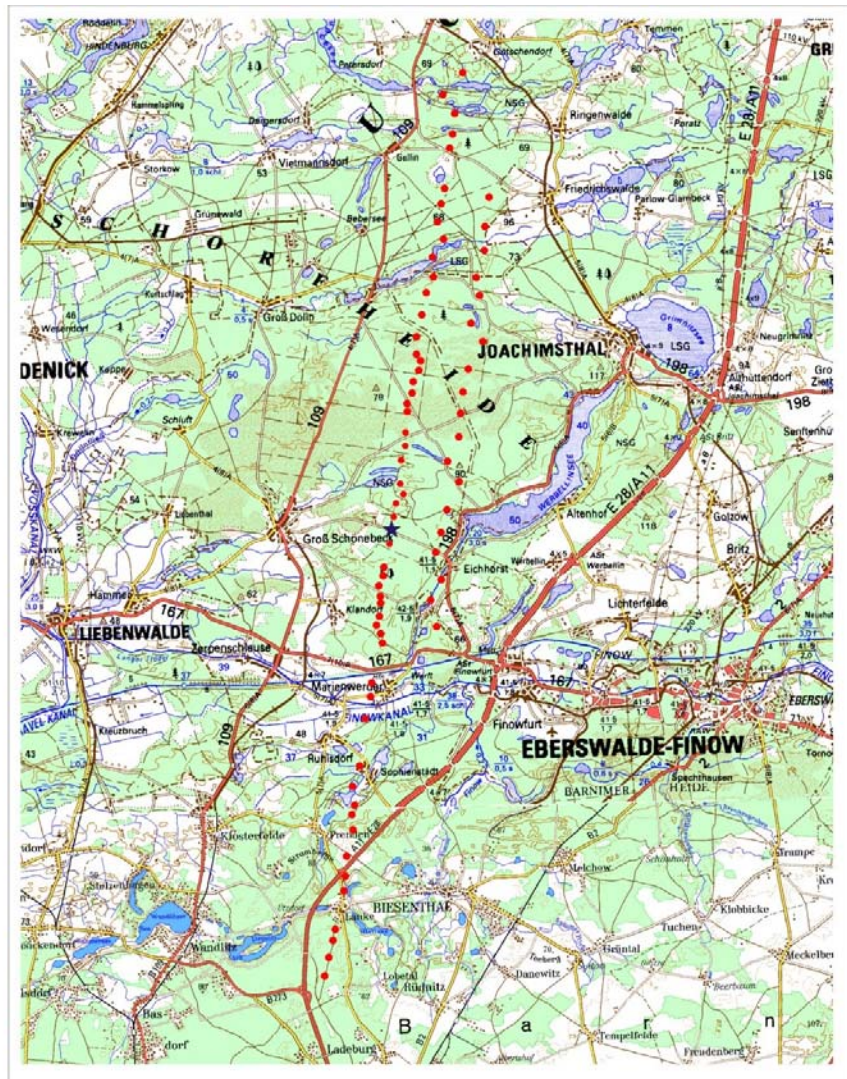


Figure 1. Location of the MT sites (red dots). The long profile located to the west (main profile) was acquired during June - July 2006. The short profile to the east (profile winter) was acquired in February - March 2007. The blue star indicates the location of the boreholes. The dots in the map of Germany indicate the locations of the remote reference sites (blue for the 2006 experiment, red for the 2007 experiment).

The geothermal reservoir is located in the Rotliegend strata of the NE German Basin (NEGB). Initial basin extension occurred between late Carboniferous and early Permian, with several NW-SE trending strike-slip faults dividing the basin in different areas. The movement along these faults is predominantly lateral, with very little vertical displacement. Due to wrench tectonics during the post orogenic period of the Variscan orogeny, weak zones in the NNE-SSW direction

were created; which lead to the development of a graben system (Baltrusch and Klärner, 1993). The extension phase was accompanied by the deposition of volcanic rocks which were subsequently covered by a siliciclastic sequence of alluvial fans, ephemeral stream, playa deposits and Aeolian sands (Rieke et al., 2001). Thick cyclic evaporites and carbonates were deposited during the Zechstein (Permian), overlain by thick strata of Mesozoic and Cenozoic sediments (Moeck et al., 2007).

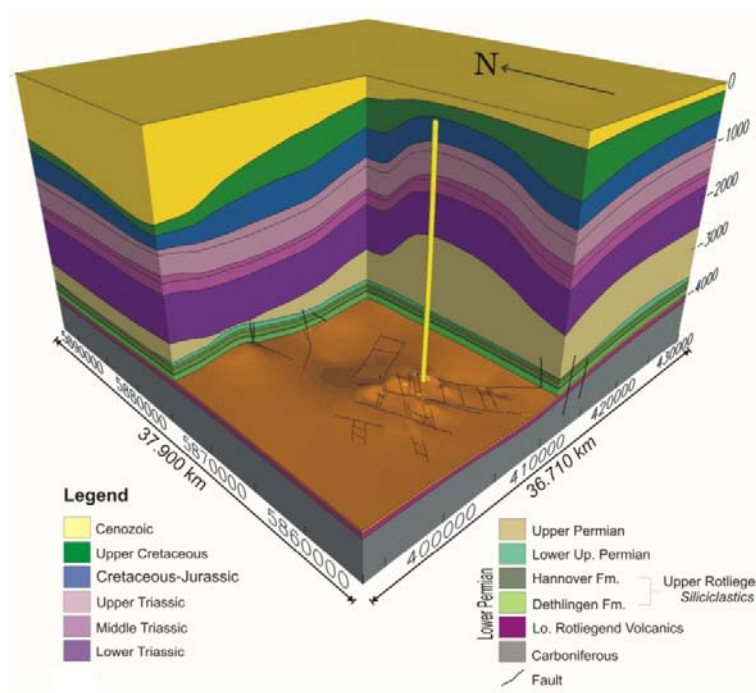


Figure 2. 3D model showing the geological environment of the Groß Schönebeck site. (From Moeck et al., 2007).

Data analysis

MT data was collected along a 40 km-long main profile centred around the well doublet and a shorter, approximately 20 km-long parallel profile located 5 km to the east (Figure 1). The main profile consists of 55 stations with a site spacing of 400 m in the central part (close to the borehole) of the profile, increasing to 800 m towards the profile ends. The parallel profile to the east consists of 18 stations with a site spacing of 1 km. The period range of the observations was 0,001 to 1000 s. At all sites, we recorded horizontal electric and magnetic field components and the vertical magnetic field.

Given the amount of electromagnetic noise present in the survey area, approximately 20 km north of the outskirts of Berlin, a long recording time was necessary to improve the statistical properties of the collected data. To further improve the data quality, additional MT stations were set-up to as remote reference sites for the data processing (Figure 1). The remote site delivering the highest quality was setup on the island of Rügen, approximately 350 km to the north of the profile. The geomagnetic and impedance tensor transfer functions were obtained using the robust processing algorithm described in Ritter et al. (1998), Weckmann et al. (2005), and with modifications by Krings (2007, see this issue) which were developed within the framework of the IGET project. For comparison the data were also processed using the remote reference code of Egbert (1997). Figure 4 show examples of the data.

The dimensionality of the data was analysed using the code of Becken and Burkhardt (2004). This technique examines the impedance tensor from the point of view of polarization states of the electric and magnetic fields. Analysing the ellipticities of polarization of the fields, the regional strike direction can be identified even if the data are affected by galvanic distortion. Figure 3 shows the rose diagrams of the strike analysis for both profiles. The multi-site regional strike direction for these data, according to the technique used is 20° for the main profile and 17° for the parallel profile. This coincides fairly well with the direction of maximum horizontal stress near the borehole, which was determined as $18.5^\circ \pm 3.7^\circ$ (Holl et al., 2005).

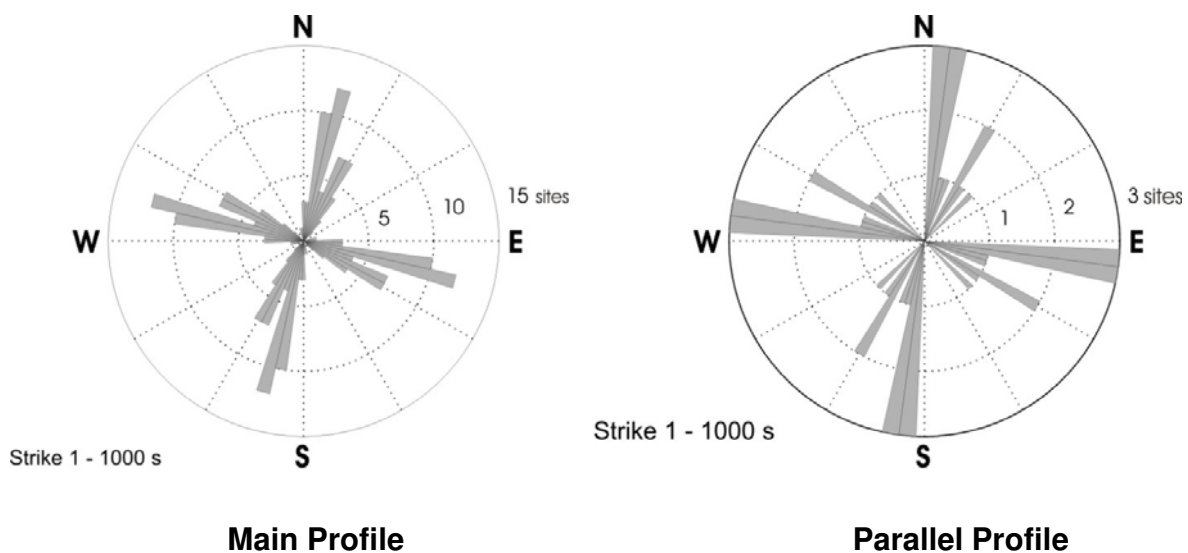
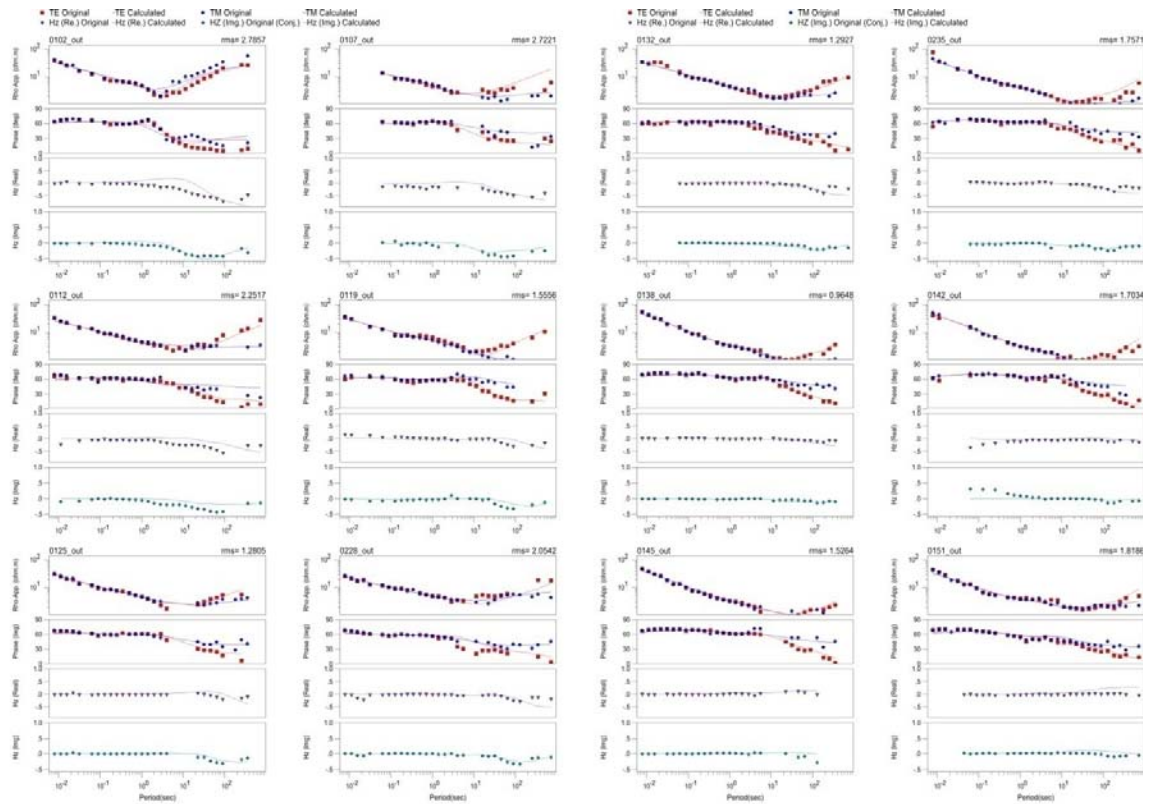


Figure 3. Regional strike direction of the sites of both profiles in rose diagram representation.

A)



B)

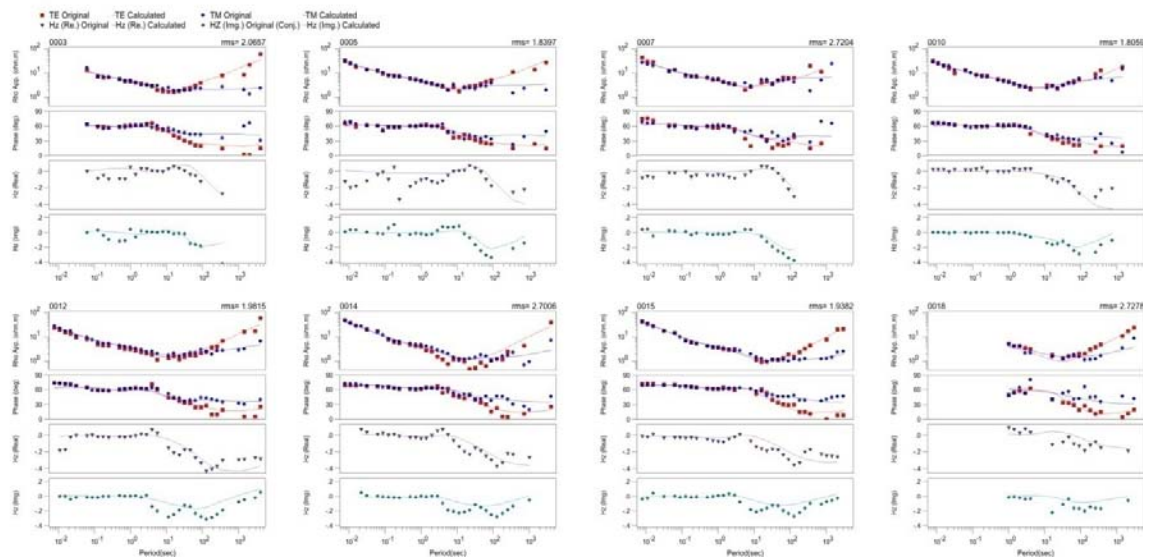


Figure 4. A) Data and model responses for some stations of the main profile. B) Data and model responses for some stations of the parallel profile.

Conductivity model

Prior to the inversion and according to the dimensionality analysis all data of the main profile were rotated to -70° and data of the parallel profile to -73° . The 2D inversion of the MT data was calculated using the algorithm of Rodi & Mackie (2001). For the inversion procedure, both TE and TM modes of apparent resistivity and phases and real and imaginary part of the geomagnetic transfer functions were used, in the frequency range from 1000 Hz to 1 mHz. Using an error floor of 10% for the apparent resistivities, 5° for the phases and 0.05 for the geomagnetic transfer functions an RMS misfit of 2.26 was obtained for the main profile and 2.28 for the parallel profile.

The resistivity model for the main profile (Figure 5) shows a shallow conductive layer extending from the surface down to depths of about 4 km, with an antiform-type shape below the central part of the profile. At a depth range of 4-5 km two conductive bodies are found, separated by a region of moderate conductivity. According to the seismic tomography (Bauer et al., 2006), which shows high velocity values for depths greater than 4 km, a resistive basement was introduced *a priori* in the resistivity model.

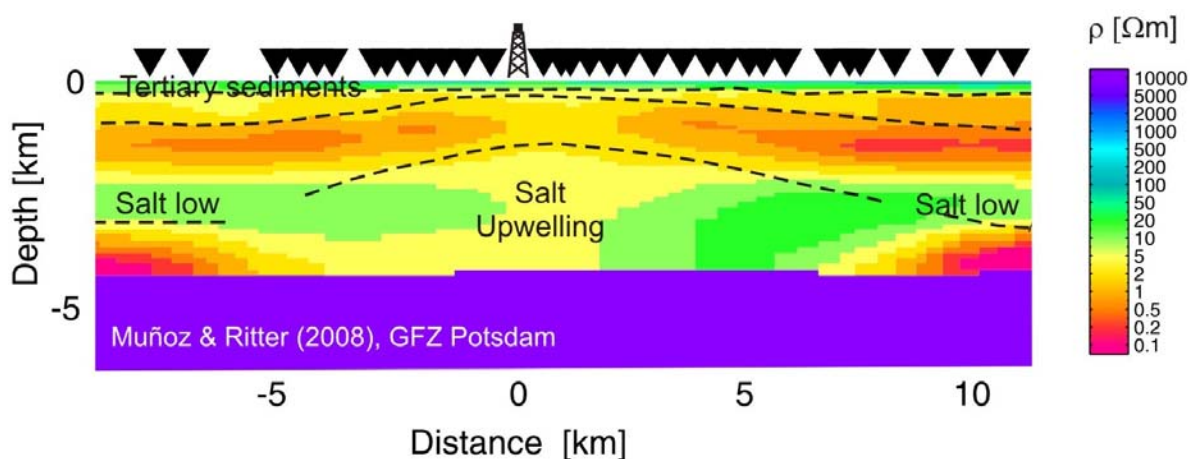


Figure 5. Interpreted MT section of the central part of the model obtained from inversion of the main profile.

At surface, the Tertiary sediments are imaged as a moderately conductive layer (20 – 50 Ωm). The antiform shape of the conductive layer coincides with the sedimentary sequences above the

Buntsandstein. Areas of higher conductivity image the transition to the Cretaceous, where the presence of more porous material could be responsible for the enhanced conductivity. The slightly higher resistivity at the hinge of the antiform can be explained by higher erosion (or lower deposition) rates of the porous material in this elevated area. The deep conductors at the left and right edges above the resistive basement coincide with the Rotliegend level. These conductive bodies occur below the areas where the Zechstein salt layer presents local lows, while we observe only moderate resistivities beneath the salt upwelling in the Rotliegend. The deep high conductivity bodies could be caused by fluids, possibly with salinities in excess of 260 g/l (Giese et al., 2001). With these salinities, a temperature in of 120 °C, and porosities around 15% (Holl et al., 2005) the modelled resistivities can be explained by virtue of Archie's law considering a fracture dominated porosity below the salt lows and a pore dominated porosity below the salt upwelling. Consequently, higher resistivity regions in the Rotliegend could be interpreted as a lower porosity (fracture density) or fluid conductivity. The main lithological unit of the Zechstein lows is anhydrite, which shows brittle behaviour under stress and is therefore perceptible for fracturing. In contrast, upwelling regions are caused by plastic deformation and up-doming of salt which is less susceptible for fracturing.

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References

- Baltrusch S., and Klärner, S., 1993. Rotliegend-Gräben in NE-Brandenburg. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, 144, 173-186.
- Bauer, K., Schulze, A., Weber, M. and Moeck, I., 2006. Combining Refraction Seismic Tomography and Analysis of Wide-Angle Reflections in Geothermal Exploration. AGU Fall Meeting (San Francisco, USA 2006).
- Becken, M. and Burkhardt, H., 2004. An ellipticity criterion in magnetotelluric tensor analysis. *Geophysical Journal International*, 159, 69-82.
- Egbert, G., 1997. Robust multiple station magnetotelluric data processing. *Geophysical Journal International*, 130, 475-496.
- Giese, L., Seibt A., Wiersberg T., Zimmer M., Erzinger J., Niedermann S. and Pekdeger A., 2001. Geochemistry of the formation fluids, in: 7. Report der Geothermie Projekte, In situ-Geothermielabor Groß Schönebeck 2000/2001 Bohrarbeiten, Bohrlochmessungen, Hydraulik, Formationsfluide, Tonminerale. GeoForschungsZentrum Potsdam.
- Holl, H.-G., Moeck, I., and Schandelmeier, H., 2005. Characterisation of the tectono-sedimentary evolution of a geothermal reservoir - implications for exploitation (Southern Permian Basin, NE Germany). Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24–29 April 2005, 1–5.
- Krings, T., 2007. The influence of Robust Statistics, Remote Reference, and Horizontal Magnetic Transfer Functions on data processing in Magnetotellurics. Diploma Thesis, WWU Münster – GFZ Potsdam. 108 pp.
- Moek, I., Schandelmeier, H. and Holl, H.-G., 2007. The stress regime in the Rotliegend of the NE German Basin: Implications from 3D structural modelling. *International Journal of Earth Sciences*, Submitted.
- Rieke, H., D. Kossow, T. McCann, and C. Krawczyk, 2001. Tectono-sedimentary evolution of the northernmost margin of the NE German Basin between uppermost Carboniferous and late Permian (Rotliegend). *Geological Journal*, 36, 19-38.
- Ritter, O., Junge, A. and Dawes, G., 1998. New equipment and processing for magnetotelluric remote reference observations. *Geophysical Journal International*, 132, 535-548.
- Rodi W. and Mackie R.L., 2001. Nonlinear conjugate gradients algorithm for 2-D magnetotelluric inversions. *Geophysics*, 66, 174-187.
- Weckmann, U., Magunia, A. and Ritter, O., 2005. Effective noise separation for magnetotelluric single site data processing using a frequency domain selection scheme. *Geophysical Journal International*, 161, 635-652.