Magnetotelluric profile crossing the GRT1-2 geothermal doublet of the Rittershoffen EGS project, northern Alsace

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ABSTRACT

The Rittershoffen geothermal project includes a doublet of boreholes GRT1-2, which have been drilled till the Paleozoic basement at Rittershoffen, Northern Alsace (France). Well tests production achieved in 2013 and 2014 on both wells revealed, as expected, interesting hydraulic and thermic parameters, which held the project profitable economically. This successful geothermal project is achieved mainly to provide heat to an industrial bio-reffinery. In order to better understand and delineate at depth the geothermal reservoir, magnetotellurics measurements were done following an E-W profile crossing the GRT1-2 boreholes. The obtained resistivity values showed a very conductive anomaly located directly beneath GRT-1 borehole. It is located at ~2.2 km depth.

1. INTRODUCTION

Magnetotelluric (MT) is becoming more and more used as a geophysical imaging method, and more specifically in the field of geothermal exploration because it provides the electrical conductivity, a proxy to rock and pore water properties. As the conductivity contrast between geothermal reservoir and background is generally important (easily more than five times), the efficiency of the MT method increases substantially.

Many previous MT works were achieved in order to get underground imaging (e.g. Wannamaker et al 2004; Harinarayana et al 2006 and references therein) in geothermal application and more specifically in the Rhine Graben area around Soultz-sous-Forêts (e.g. Geiermann and Schill 2010).

Our study is conducted in the Upper Rhine Graben (URG) close to Rittershoffen village and crosses GRT1-2 geothermal boreholes. The objective of this study is to delineate the geothermal reservoir (e.g. weathered / fractured zone where electrical conductivity increases) using MT. Furthermore, we have the possibly to compare with other observations from borehole measurements (i.e. logging). Besides, one major challenge using MT method in the area, is to deal with the high level of the anthropogenic noise which affects considerably the electromagnetic data.

This part of the URG is mainly formed by thick layers of sediments (Cenozoic & Mesozoic) deposited from Permo-Triassic (mainly the Buntsandstein, Muschelkalk and Keuper) and Jurassic (named Lias and Dogger). In some places, Permo-Carboniferous units are found but not continuously and not everywhere (see e.g. Abdelfettah et al., 2014). The thickness of this sedimentary “cover” varies and increases from West to East (Baillieux et al., 2011 and references therein). Below the sediments is the Paleozoic basement. Its depth increases eastward according to the sediments increasing thickness.

2. DATA ACQUISITION

New MT data were acquired in Rittershoffen area (Fig.1), close to the geothermal project. In total, 14 MT sites were investigated along an E-W profile. Because MT is a passive electromagnetic method which relies on natural non-stationary unpredictable events, it was decided to acquire time series continuously during at least three days in each site; this ensures to record usable long periods events and identify potential geothermal activity at 2-3 km depth close to GRT-1 borehole. A sampling frequency of 512 Hz was chosen for data acquisition. By post-processing and after data filtering (mainly railway noise at 50/3 Hz, power line noise at 50 Hz, and their harmonics), we used three successive days time series length to recover the long periods. At the end, we recovered a frequency range between 250 Hz and

0.0156 Hz (0.004 – 64 s), which is broadband enough for investigating our geothermal target.

Remote reference station was also used. The remote site was installed at Welschbruch Geophysical Station (WELSCH), which was synchronized with local sites. This station is installed at about 70 km Southwest of Rittershoffen. We used the same frequency sampling as that used in local sites. Very good correlation between local sites components and remote site was obtained (Fig. 2).

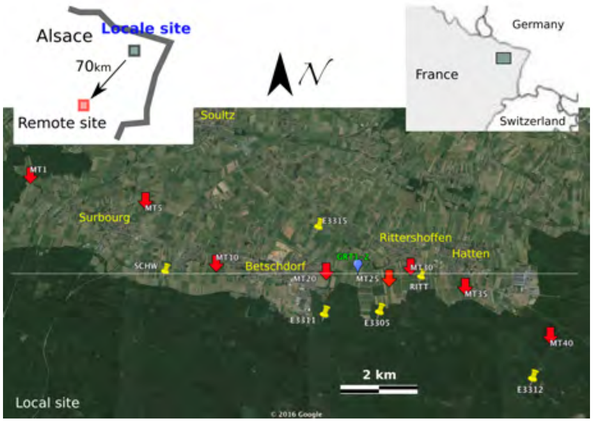

Figure 1: MT site location. Yellow sites were acquired during 2014 fieldwork in frame of MT monitoring (Abdelfettah et al., 2015) project (SMT-monitoring), and the red sites were acquired during Nov-Dec 2015. The continuous white line showed the location where sites were projected, crossing GRT1-2 boreholes.

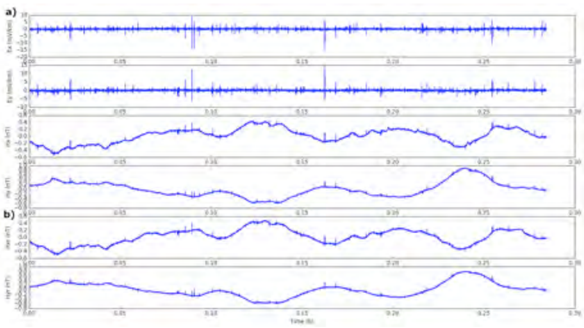

Figure 2: Filtered MT time series recorded at site MT01. The origin (zero) is 14:24 (UT). a) Components of local site (from top): Ex, Ey, Hx and Hy. b) Hx and Hy of the remote station.

3. DATA PROCESSING

Recorded MT time series are often contaminated by a huge anthropogenic electromagnetic noise component (Fig. 3). Indeed, the location of the measurements is motivated by the geothermal target which is located close to small cities (e.g. Betschdorf for MT10-MT20, Rittershoffen for MT25-MT30, Hatten for MT35) and roads (e.g. near site MT40); besides, there is a gas pipeline in the area (near sites RITT and MT35). Therefore, adequate data processing strategy must be followed to reduce the data uncertainties.

After prefiltering and data inspection, we processed the recorded data using Chave's code (Chave and Thomson 2004), which is based on robust statistics and bounded influence to assess the impedance tensor. Besides, MT data of WELSCH site was taken into account to achieve remote processing. We obtained a reliable estimation of apparent resistivity and phase on the targeted frequency range (Fig. 4). Notice that some sites showed low estimation quality in MT dead-band (as classically found at frequencies with low natural geomagnetic activity), for instance at sites MT01, MT05 and MT25.

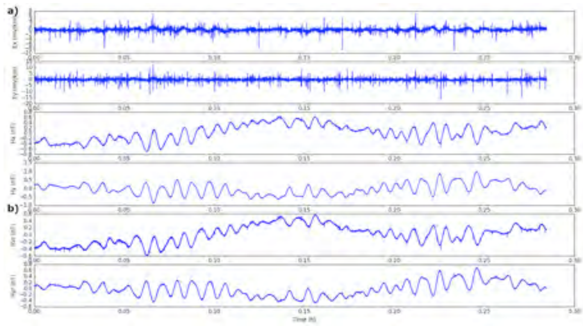

Figure 3: Filtered MT time series recorded at site MT40. The origin (zero) corresponds to 07:48 (UT). a) Components of local site (from top): Ex, Ey, Hx and Hy. b) Hx and Hy of the Remote station. The anthropogenic electromagnetic noise is clearly identified (compared by the natural signal showed in Fig. 2) which affect both middle- and low-frequencies.

Data uncertainties are very important parameters to assess for any geophysical methods, more specifically in passive electromagnetic method. These tolerance values define the confidence interval of the robust estimation of MT impedance have been calculated. It quantifies an accuracy of the obtained apparent resistivity and phase that are directly used in the geological interpretation and later in inversion.

The impedance tensor was estimated over the frequency range between 0.0156 and 240 Hz (0.0041 – 64 s). The estimated apparent resistivities and phases (Fig. 4) show a very good "quality" in high frequency band (from 240 Hz to 1-5 Hz), acceptable quality however is obtained for middle frequency namely MT dead-band (from 1 – 5s to 10s), and good quality was obtained for long periods (>10s).

4. MT IMAGE

Once apparent resistivity and phase estimation have been evaluated, they can be used to recover the underground electrical conductivity variations. Forward modelling and or inversion can be achieved to get the MT response in the study area. Each approach shows limits and advantages: for instance to achieve forward modelling we need to know a priori model based on the geological model and the resistivities of its layers, and the advantage is that one can calculate the contribution from additional bodies in the model (e.g. see sensitivity study done by Sailhac et al., 2016). The inversion however provides non-unique solution/model and relies on a 1D, 2D or 3D assumption, but can provide a resistivity model where no geological information is available. The survey been performed along a profile, a 3D inversion is not feasible, but the profile being almost perpendicular to the main faults, a 2D approach seems reasonable. The best approach depends on the objective of the study and surely their combination with the geological information

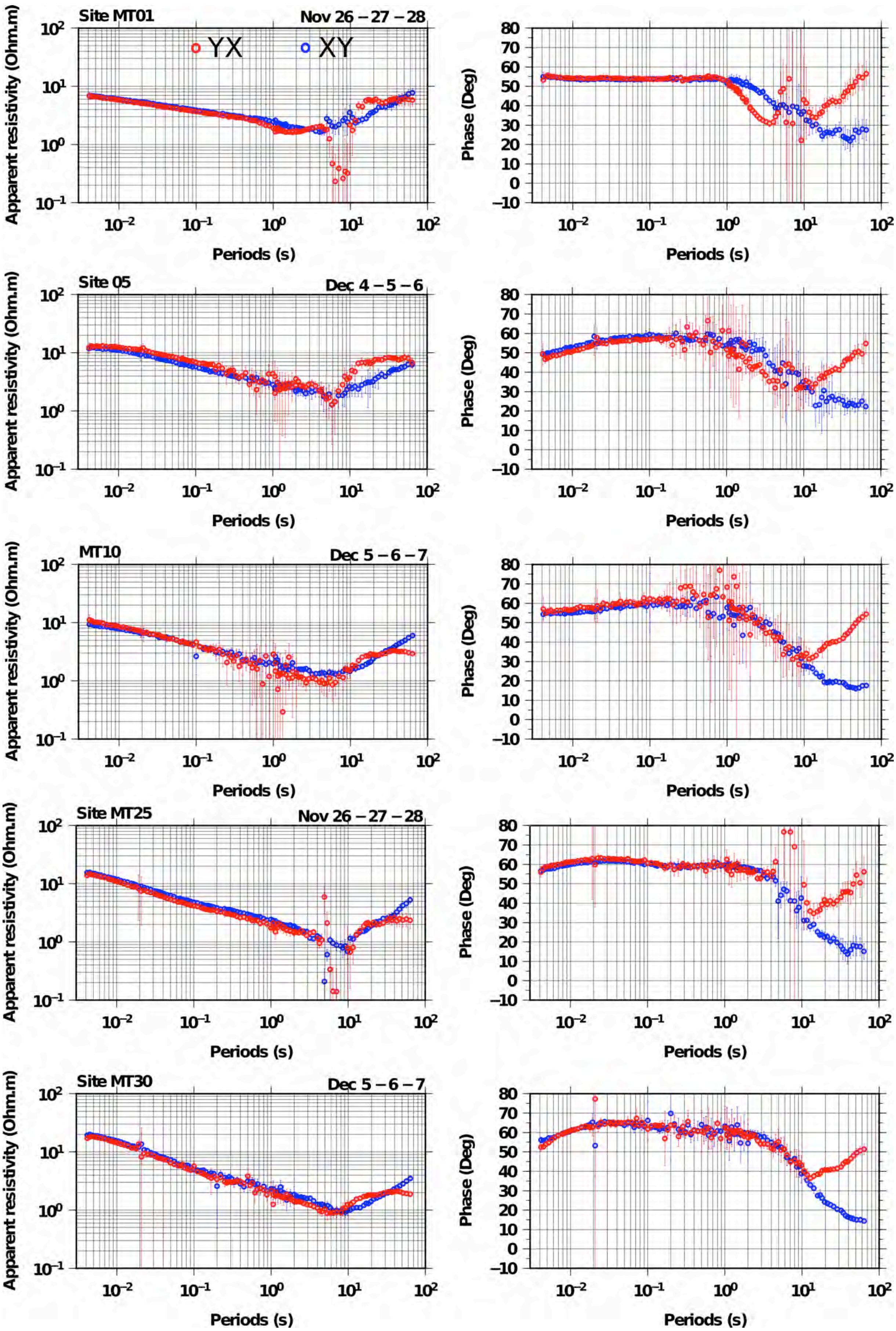

Figure 4: Apparent resistivity and phase for five representative MT sites estimated using Chave's Code. The four components of Z tensor are computed, however and as the XX and YY components showed values close to 0, it is not presented here.

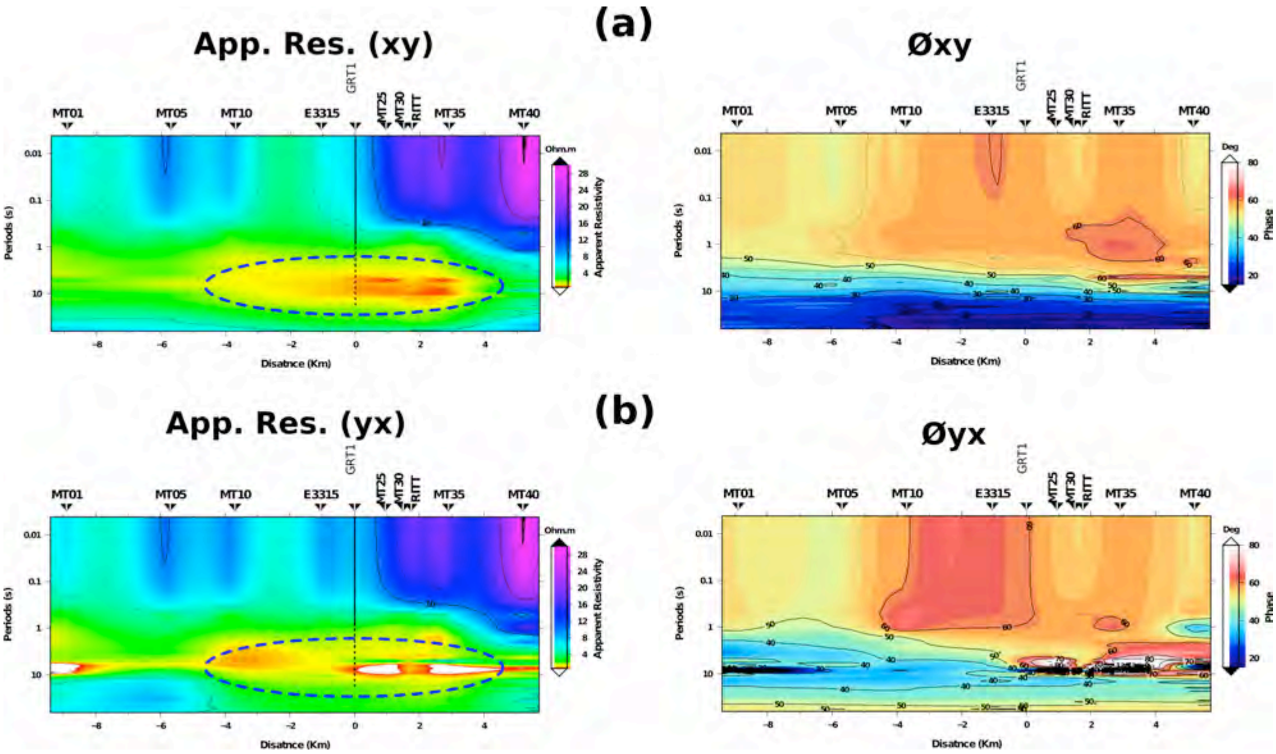

Figure 5: Measured apparent resistivity and phase pseudo-sections showed according to periods for a) XY and b) YX components. In the total, nine sites are only used (see Fig.1 for location). The distance is presented according to GRT-1 borehole and the maximum-presented period is 64 s. Note that the depth of the drawn GRT-1 borehole is only representative.

We present in Fig. 5 the observed pseudo section of the apparent resistivity and phase for the two modes XY and YX. This graphic shows variations of the apparent resistivity and phase according to periods. In these plots, the period is used as an indication to depth; such pseudo-section is comparable to the seismic section before migration where the velocities are showed according to the well-known TWTT parameter (Two Way Travel Time) instead of depth.

Different features have been revealed by these pseudo-sections representation (Fig. 5). From surface (i.e. from 250 Hz) down up to 0.1 – 1 s (1 s at the eastern part), the model shows for the two modes relatively resistive area with mean values around 20 Ω.m. From this limit downward to 50 s, we obtained fairly conductive area with mean values of ~3 – 4 Ω.m. This is mainly true for XY mode, but down to 10 s periods only for YX component especially at the eastern part of the model, below sites MT01 and MT05 (Fig. 5b), where resistivity is much higher and compared to those observed at the shallower part.

The very interesting feature nevertheless is the very conductive (< 1 Ω.m) area observed directly under GRT-1 borehole (see dashed circle on Fig. 5). This conductive anomaly is more homogeneous in XY component whereas, the YX component showed more heterogeneous values. Note that this anomaly seems confined and horizontally limited from MT10 site at the west to mid-distance between MT35 and MT40 from east.

In terms of depth and using skin depth formula, we can estimate the depth of this conductive anomaly. Using an average resistivity of 10 Ω.m (15 Ω.m from surface till 0.2 s and 5 Ω.m from 0.2 s till 2 s) we find that its top may be located at 2.2 km deep which is in good agreement with the permeable zone were hydrothermal water is pumped.

3. CONCLUSIONS

Magnetotellurics measurements were achieved along a profile crossing GRT-1-2 geothermal boreholes of Rittershoffen EGS project during Nov-Dec 2015. Preliminary results showed a very conductive area beneath GRT1-2 doublet, which its top could be located at ~2 s from surface. Using an average resistivity about 10 Ω.m, as showed by observed apparent resistivity values, we find that the top of this conductivity anomaly may be find at only 2.2 km deep. The total vertical depth of GRT-1 is around 2.5 km and the main productive interval was found around this depth. An increase of porosity saturated by brine is consistent with the increase of the bulk electrical conductivity and hence supports the interpretation of this conductive anomaly. We plan to examine more in detail the MT tensor using mainly forward modelling and constrained inversion to delineate it more accurately. A comparison with other models derived from seismic (Maurer et al., 2016) and gravimetric (Abdelfettah et al., 2016) acquisitions in the area will also help in understanding the geometrical constraint of this conductive anomaly.

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REFERENCES

Abdelfettah, Y., Calvo, M., Hinderer, J., Dalmais, E., Maurer, V. : Using gravity in geothermal exploration: the case study of Wissembourg area, northern Alsace (France), Proceedings of European Geothermal Congress, Strasbourg, France, 1-5, (2016).

Abdelfettah, Y., Sailhac, P., Larnier, H., Schill, E.: Fluid injection monitoring of Rittershoffen geothermal project, northern Alsace, using magnetotelluric, Proceedings to European Geothermal Congress, Strasbourg, France (2015).

Abdelfettah, Y., Schill, E., and Khun, P.: Characterization of geothermally relevant structures at the top of crystalline basement in Switzerland by filters and gravity forward modelling, Geophysical Journal, **199**(1), (2014), 226-241, doi: 10.1093/gji/ggu255.

Chave, AD. and Thomson, D.J.: Bounded influence magnetotelluric response function estimation, Geophysical Journal International, **157**(3), (2004), 988–1006, DOI: 10.1111/j.1365-246X.2004.02203.x

Geiermann, J. and Schill, E.: 2-D magnetotellurics at the geothermal site Soultz-sous-Forêts: Resistivity distribution to about 3000 m depth, CR Geoscience, **342**, (2010), 587-599.

Baillieux, P., Schill, E. and Dezayes, Ch.: 3D structural regional model of the EGS Soultz site (Northern Upper Rhine Graben, France): insights and perspectives, Proceedings, 36th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, USA, (2011).

Harinarayana, T., Abdul Azeez, K.K., Murthy, D.N. Veeraswamy, K., Eknath Rao, S.P., Manoj, C. and Naganjaneyulu, K.: Exploration of geothermal structure in Puga geothermal field, Ladakh Himalayas, India by magnetotelluric studies, Journal of Applied Geophysics, **58**, (2006), 280-295.

Maurer, V., Perrinel, N., Dalmais, E., Richard, A., Plevy, L., Genter A.: Towards a 3D velocity model deduced from 2D seismic processing and interpretation in Northern Alsace, Proceedings of European Geothermal Congress, Strasbourg, France, (2016).

Sailhac, P., Larnier, H., Abdelfettah1, Y., Schill, E.: Modelling the sensitivity of magnetotelluric monitoring data to geothermal fluids at depth in Northern Alsace, Proceedings of European Geothermal Congress, Strasbourg, France, (2016).

Wannamaker, P. E., Stodt, J. A., Pellerin, L., Olsen, S. L., Hall, D. B.: Structure and thermal regime beneath South Pole region, East Antarctica, from magnetotelluric measurements: Geophysical Journal International, **157**, (2004), 36-54.