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Fractured reservoirs - Indication from the EGS at Soultz

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The Soultz geothermal site is located in the Upper Rhine Graben, which is part of Cenozoic European Rift Structure. Local heat flow maxima of up to 150 mW m2 in the Upper Rhine valley originate from a strong convectional heat transport mainly in the granitic basement (e.g. Bächler, 2003). Such systems may be exploited using Enchanced Geothermal System (EGS) technology. By definition these systems are characterised by natural permeability, which is improved using stimulation techniques. In the case of the Soultz reservoir natural permeability of about up to 3x10-14 m2 was inferred from the temperature distribution (Kohl et al., 2000). High permeability is often related to active faulting (Gudmundsson et al., 2001). Seismic activity and GPS measurements indicate active faulting in the entire Upper Rhine Graben (Bonjer, 1997, Tesauro et al., 2006, Cardozo et al., 2005).

The granitic basement at Soultz underwent multi-phase tectonic deformation including the Hercynian and Alpine phases. The main faults in the sedimentary cover of Soultz strike N20°E, i.e. they follow the Rhenish direction. At depth a horst structure is present and the top basement is at 1400 m. Within the horst seismic sections reveal faults mainly dipping to the W. In the five deep wells at Soultz 39 fracture zones have been determined on three different scales (Dezayes and Genter, 2008). In the granite the major direction is about N160°E to N-S with steep dipping to the East and West. With depth the strike of the main sets is consistent, the dip orientation, however, changes. Between 1420 to 2700 m TVD, the main fracture set dips to the East. In the sections between 2700 and 4800 m two conjugate sets reveal fractures dipping to the East and to the West and at reservoir depth between 4800 m and 5000 m the westward dipping set is dominant (Valley, 2007; Dezayes and Genter, 2008).

New magnetotelluric (MT) data, as well as inversion of gravity and MT data may be used for estimating relative porosity and permeability changes in EGS fields and thus to provide more information on the fractured reservoir. For the inversion earlier gravity data (summarized in the FIS Geophysik, GGA Hannover, and from BRGM Strassbourg) were interpolated on a 200 m grid. In order to account for the astenosphere anomaly below the Upper Rhine valley a Butterworth filter with a wave length of 80 km was applied. For the inversion of the data a geological 3D model was discretized in a 3D voxel raster. The inversion was carried out with 3D Geomodeller based on the apporach of Mosegaard and Tarantola, 1995). The inversion results show a zone of relativly lower density of about 2500 kg m-3 in the horst of Soultz in respect to the surrounding granitic basement of about 3000 kg m-3, which can be attributed to a increase in porosity in the Soultz horst. In order to investigate this observation more in detail, a 2D MT survey has been carried out on a E-W profile across the Soultz horst approximately on the latitude of GPK4. Along approximately 10 km long profile 13 stations have been measuring for approximately 2 days. A number of 7 stations have been operated with a remote reference station at Vogelsberg (Germany). Using remote referencing, 10 stations could be used for 2D inversion in the period range of 0.06 to 40 s. Before inversion, the stations have been rotated the 52° and Sutarno phase consistent smoothing has been applied. For the inversion an a priori model incorporating the major geological structures of the Rhine valley has been used. The inversion process has been set to minimize deviation from the starting model. The inversion result reveals a zone of high electric conductivity of about 3 m between the Soultz and Kutzenhausen fault. This high electric conductivity can be attributed to major fluid flow in the area around the two faults, thus indicating enhanced permeability. In the granite, those low resistivities can only be explained by interconnected pore space.

In conclusion, gravimetric and magnetotelluric investigation and inversion can be used to investigate porosity and permeability over large distances and calibrated on borehole measurements be used for prediction of productivity of fractured reservoirs.