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Geology, Geophysics and Geochemistry in the Upper Rhine Graben: the frame for geothermal energy use

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ABSTRACT

Deep geothermal energy, namely EGS (Enhanced Geothermal System), has been successfully developed in the Upper Rhine Graben (URG) based on a full geological, geochemical and geophysical characterization of deep fractured reservoirs. Over the last 30 years, many geothermal sites have been developed for electricity generation via binary system (Soultz-sous-Forêts, Bruchsal, Insheim, Landau) to fully thermal project operating at high temperature (Rittershoffen). A series of new geothermal projects for heat and/or power generation in the URG is targeted (Illkirch, Reichstett, Wissembourg, …) which demonstrated the impact of the lessons learnt on the pilot Soultz research project. Based on various geoscientific deep drilling data collected between 2.5 and 5 km depth, it has been shown that geothermal resource corresponding to very saline fluids is trapped into the natural fracture network at the sediments-basement interface.

1. INTRODUCTION

The Upper Rhine Graben (URG) is characterized by several local thermal anomalies associated to hydrothermal convective cells circulating inside a nearly vertical fracture network in the granite basement and in the Triassic fractured sediments above it (Pribnow and Clauser, 2000; Schellschmidt and Clauser, 1996).

From the 90s, a new form of high-temperature geothermal energy (>150°C), schematically described as deep geothermal energy, has experienced a remarkable development in France with the pioneering project of Soultz-sous-Forêts located in Northern Alsace (Gerard and Kappelmeyer 1987; Gerard et al., 2006). This project, initiated on the French side by the French Geological Survey BRGM, was also innovative in its support structure mainly because it brought together European stakeholders of geosciences (BGR, CNRS, GTC, LIAG, MeSy, KIT, Aachen Univ, Heidelberg Univ, Bochum Univ, Mainz Univ, many French Universities or research institutes (Cergy, Nancy, Orléans, Paris, Poitiers, Strasbourg, Mines de Paris, ENSG), but also some Swiss partners (ETH, Geowatt, Neuchatel Univ). and French-German industrial partners (ES, EnBW, Bestec, Pflazwerke, Steag, EDF). Some Japanese team significantly contributed (Tohoku Univ) as well as British institute (CSMA). Based on drilling data collected between 2.5 and 5 km depth, the geological, geochemical and geophysical characterization of deep fractured hard rocks reservoirs has significantly contributed to develop geothermal activity in the URG.

2. GEOTHERMAL PROJECTS IN THE URG

On the French side, in Northern Alsace; ES (Electricité de Strasbourg) is today the major player in deep geothermal energy for industrial applications with the power plant of Soultz and the heat project located at Rittershoffen, calls ECOGI.

From the lessons learned from an adventure begun 30 years ago in Soultz and with a more economic vision of deploying this deep geothermal energy, several industrial projects recently born within 50 km around Soultz in the Rhine Graben in both in France and in Germany (Figure 1). Indeed, geothermal plants have emerged in the Palatinate (Germany) as Insheim or Landau in the Pfalz (Schindler et al., 2010) but also French side, as in Rittershoffen where a high-temperature heat project is operational (Baujard et al., 2015).

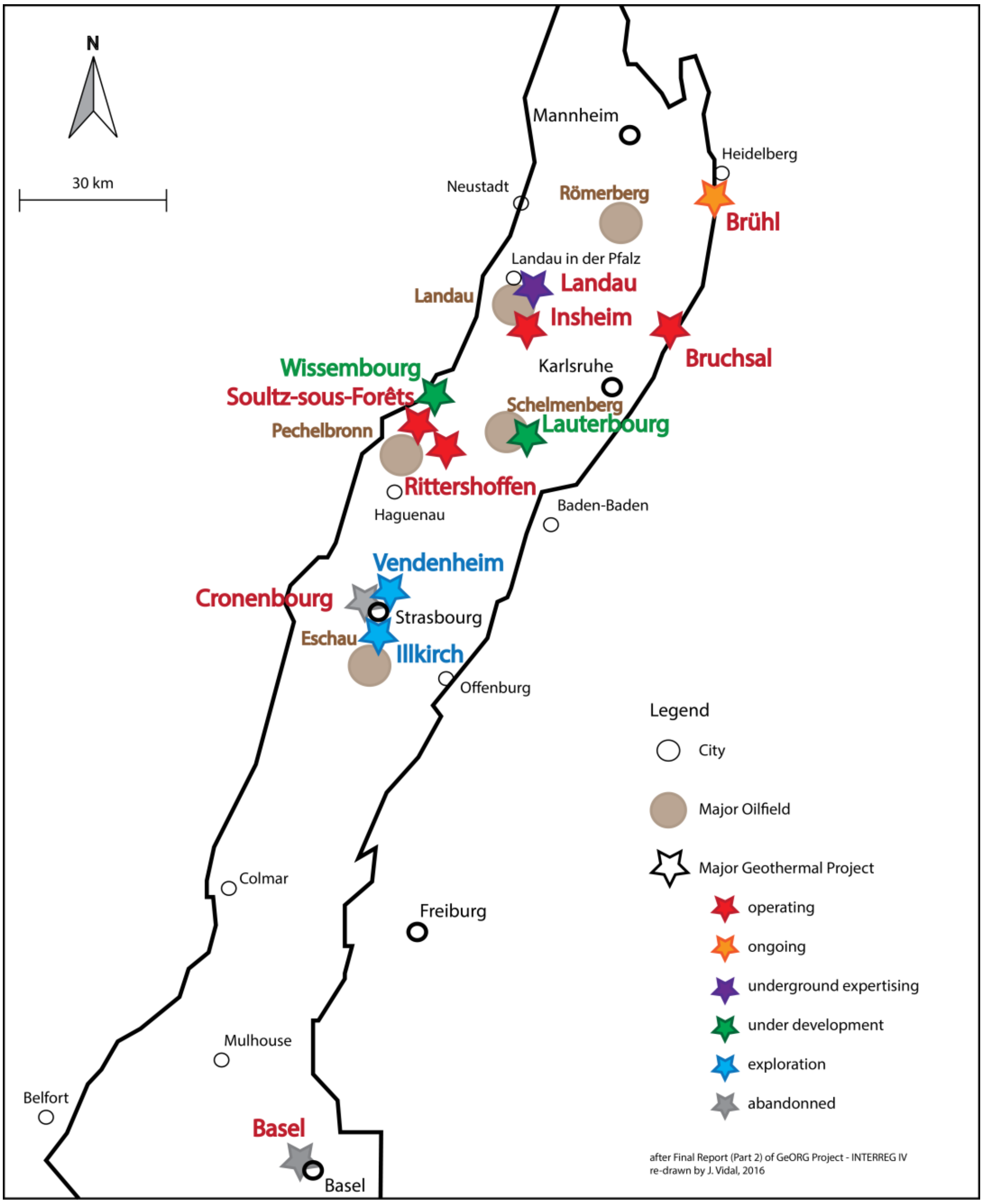

Figure 1. Location of the main deep geothermal projects located in the Upper Rhine Graben

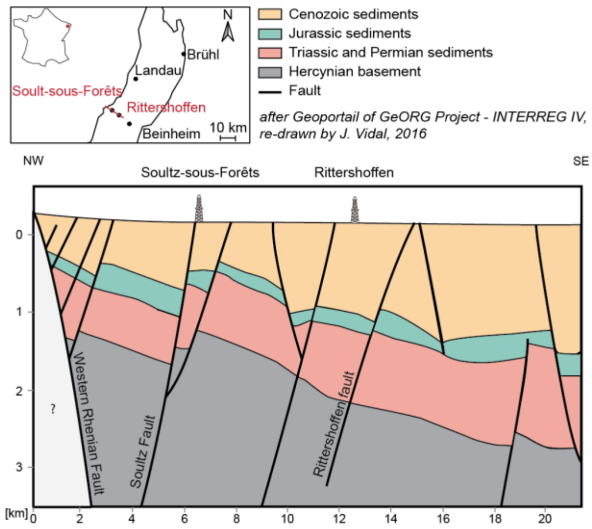

Figure 2: Geological cross-section through Soultz-sous-Forêts and Rittershoffen from Geoportail, 2012

In Soultz, as Landau-Insheim, thermal anomalies that coincide with the oil fields (Figure 1) are interpreted as natural hydrothermal systems (Kohl et al., 2000). Natural hot water circulates very slowly in large convection loops. They move and are channelized in the fracture/fault networks created by the successive brittle tectonic events of the Rhine Graben. Other geothermal projects are operational or in development phase as in Bruchsal or Illkirch, Vendenheim-Reischtett, Eckbolsheim, Lauterbourg and Wissembourg (Figure 1). The French side, in Northern Alsace is the most active geothermal area in France with several industrial operators which have obtained exclusive research license, for high temperature geothermal energy projects (>150°C). Moreover, Outre-Forêt (Northern Alsace) and the Strasbourg area are the two most explored and exploited areas for deep geothermal development (Figure 1).

Before the Soultz geothermal project development, there was only one industrial geothermal project in Alsace driven by oil and gas industry. It was located at Cronenbourg in the suburbs of Strasbourg. A geothermal drilling done in 1980 targeted deep porous Permo-Triassic sandstones to 3000 m deep. However, drilling results were not successful as expected due to the absence of natural permeability. Even though some fractures and faults were cross-cut by this geothermal well, chemical treatment or hydraulic stimulation was not tried. More recently, a deep geothermal project located at Rittershoffen was initiated in 2011 by the company ECOGI, a partnership between the companies Electricité de Strasbourg (ES), Roquette Frères and the French public financial institution Caisse des Dépôts. This project is based on a geothermal doublet that produces geothermal heat from the reservoir at the sediment-basement interface (Baujard et al., 2015). The heat is used for industrial processes in a bio-refinery at Beinheim, located 15 km east of the drill site. A doublet of deep geothermal wells has been drilled to a depth of approximately 2.6 km between 2012 and 2014. Hydraulic tests demonstrated that an industrial flowrate of 70kg/s and a surface temperature higher than 160°C could be achieved (Baujard et al., 2015). Only the injection well was thermally, chemically and hydraulically stimulated. The natural initial permeability of the production well was so good that the second well was not stimulated. The ECOGI project is operating from summer 2016 and produces 24MWth to industry.

3. EGS RESERVOIRS

Initially based on the principle of extracting the heat contained in hot dry crystalline rocks, the Soultz project has significantly evolved with time as it was highlighted by the achievement of deep drilling (Sanjuan et al., 2010). The first main discovery was the abundance of a natural fluid at great depth in the crystalline basement (Sanjuan et al., 2016). At Soultz but also in Rittershoffen, all the geothermal boreholes showed natural permeability indicators with partial to total mud losses in the granite (Genter et al., 2000) or in clastic sediments (Vidal et al., 2015, 2016).

The main geochemical characteristics of the native brines collected from all the geothermal wells penetrating the granite basement underlying the sedimentary cover in the Upper Rhine Graben shows that the salinity is very high (100g/l). The Na–Cl geothermal brine samples collected from the granite show TDS values ranging from 99 to 107 g/l with pH values close to 5. The geothermal fluids have a multiple origin with mixing between primary brine formed by advanced evaporation of seawater and dilute meteoric water, plus contributions from halite dissolution following successive marine transgression-regression cycles from the Triassic to the Oligocene (Sanjuan et al., 2016). Those results were achieved thanks to fluid samples collected in deep boreholes at Soultz, Rittershoffen, Landau and Insheim. Such saline fluids could induce provoke strong corrosion issues on the surface installations as well as scaling precipitation in the geothermal pipes such as barite, and galena (Scheiber et al., 2015 a, b).

The second major finding in the URG is that an initial permeability at depth potentially much larger than expected (Schill et al., 2015). Indeed, the deep crystalline rocks showed that they could contain important natural drains, namely a large network of natural connected fractures. The remaining problem was twofold: connect this natural permeability to the well bore and increase the initial permeability of these deep-crystalline rocks by the application of hydraulic and/or chemical stimulation techniques.

Standard geophysical logging data, and high resolution borehole acoustic image logs have been collected in the Soultz and Rittershoffen wells as well as temperature logs (Figure 3, Figure 4).

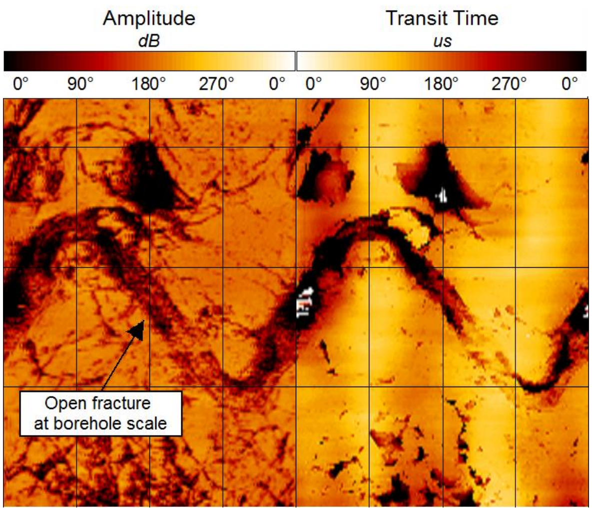

Figure 3. Natural fractures observed on acoustic image logs in the granitic basement at Rittershoffen

Structural core analysis in the granite revealed that natural fluids circulate within Hydrothermally Altered and Fractured Zones (Genter et al., 2000). They are characterized by strong hydrothermal vein alteration with clay minerals deposition (illite) and many secondary minerals (quartz, calcite, ankerite, dolomite, clays, pyrite, hematite, ….). Permeability is strongly related to natural fracture zones which present complex cluster indication with major permeable drains surrounded by damage zone. Natural fractures are organized in clusters. The dominating orientations of the nearly-vertical fractures in the granite are between N20W and N20E. In the well, the geometry of the fracture system is derived from borehole image logs (Figure 3).

Among the many lessons from deep boreholes Soultz, accurate measurement of the temperature profiles up to 5000 m depth provided absolutely unique and valuable information. The analysis of this thermal profile clearly shows that it was not necessary to drill to 5 km deep if we want to access a geothermal resource of hydrothermal type (Figure 4). It is therefore interesting to preferentially drill at the top of this area, not only to reduce drilling costs, but also and especially to increase the likelihood of intersecting significant permeable fractures that will ensure the expected flow rate for future exploitation.

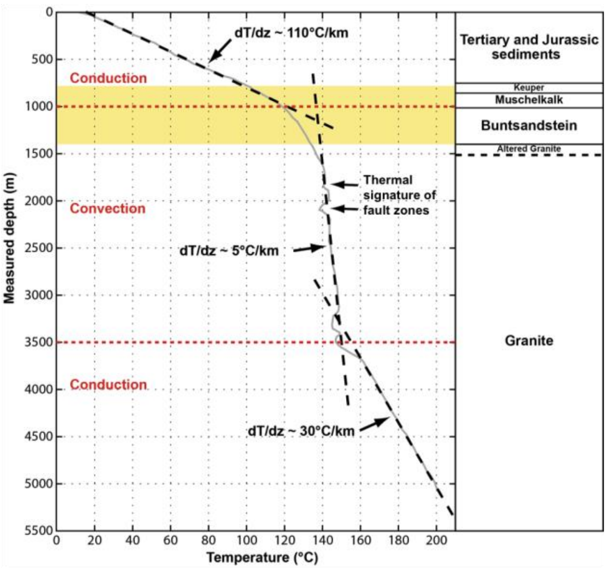

Figure 4. Thermal profile in the GPK2 well at Soultz from Genter et al., 2010

4. ENVIRONMENTAL MONITORING

The geoscientific characterization of the deep-seated fractured reservoirs in the URG based on geology, geophysics and geochemistry is the first step to identify the geothermal resource. However, the occurrence of very natural saline brines as well as the application of water injection techniques or THMC stimulations for reservoir permeability enhancement conducted to monitor some physico-chemical parameters from the earliest stages of a given geothermal project. Five kinds of impacts are identified and monitored from large to local scale influence: induced seismicity and surface deformation, surface water and shallow groundwater resources protection, neighborhood disturbance, such as vibrations or noise emissions, and evolution of the natural radioactivity resulting from the scaling. For example, slow deformation based on GPS measurements, ground leveling or satellite radar interferometry (InSar) are under development in the URG (Heimlich et al., 2015). Ground motion monitoring is also investigated with a permanent or temporary seismological network of sensors which measures induced seismic activity before drilling operations or during the operational phase of a geothermal plant.

5. CONCLUSIONS

The Enhanced Geothermal System (EGS) development in the Upper Rhine Graben, tends to demonstrate that the multi-scale fracture network (from microcracks to local faults) acts as fluid pathways. Thus, a current hydrothermal resource is available in the deep-seated fractured hard rocks of the URG. Those favorable conditions are a key factor for the successful development and use of new heat and/or power generation in this area.

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