EGW 2014

3rd European Geothermal Workshop
Karlsruhe, 15-16 October 2014

Evaluation of THC stimulations from acoustic image logs in the geothermal Rittershoffen well GRT-1 (France)

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Keywords: acoustic borehole images, Thermal-Hydraulical-Chemical stimulation, EGS, Upper Rhine Valley, ECOGI

1.MOTIVATION

In the Upper Rhine Graben (URG), several deep geothermal projects exploit local geothermal energy trapped in the fracture network of Triassic sediments and the granitic basement below (Soultz-sous-Forêts, Landau, Insheim...). Those projects are based on the Enhanced Geothermal System (EGS) technology. The principle of the EGS technology consists in increasing the low natural hydraulic performance of the geothermal reservoir by hydraulic or/and chemical stimulations. These stimulations increase the natural permeability to commercial level.

The ECOGI project located in Rittershoffen (Alsace, France) is an industrial project that targets the geothermal resource at the sediment-basement interface to produce geothermal heat (Baujard et al., 2014). The first geothermal vertical well GRT-1, drilled to 2.6 km deep in 2012, didn't have a sufficient injectivity for the future industrial exploitation and has been thermally, chemically and hydraulically (THC) stimulated in 2013. The open-hole section is composed by fractured Triassic sandstones and Paleozoic altered granite and two-mica granite. The target of the study is an evaluation of the stimulation effect based on analysis and comparison of various borehole data including dynamic data and acoustic borehole images logs collected before and after stimulation.

2. THC TREATMENTS OF GRT-1

Before stimulations, the injectivity of GRT-1 was principally controlled by a major fractured zone in the altered granite visible on borehole images but also on temperature and flow logs. The goal of THC stimulations is the creation of new pathways for the geothermal brine for connecting the well and the reservoir.

Thermal stimulation consists in massive injection from surface of geothermal water at ambient temperature in the hot reservoir in order to encourage thermal cracking within the reservoir host rocks, thereby increasing reservoir permeability (Grant et al., 2013).

Chemical stimulation consists in injecting an acid fluid to dissolve hydrothermal minerals that plug fracture zones and therefore increase well injectivity. This technology, developed for more than one century by oil industry for the stimulation of oil and gas wells, has also been used in geothermal wells for the last 20 years (Burgos et al., 2005). In order to avoid to waste acid fluid in the major permeable structure in GRT-1, packers installation and injection thanks to a coiled tubing were very useful to direct the treatment fluid toward selected zones (Lummer et al., 2014). Fracture fillings in GRT-1 are principally carbonates and anhydrite, the stimulation fluid chosen for chemical operations in GRT-1 is composed by chelating biodegradable agents that penetrate deeper in the formation and stabilize fines. Three zones have been chemically stimulated in the sandstones, in the altered granite and in the two-mica granite.

Hydraulic stimulation consists in massive injection of water with high flow rate in order to increase the pore pressure within the rock mass which promotes the shearing of existing fractures or the creation of induced fractures (Schindler et al., 2008).

After THC treatments, the injectivity of the well GRT-1 has been increased by a factor 5. In order to identify process behind this improvement, this study compares mud logging data (calcimetry, mud losses information), geophysical logs (caliper, Photo Electric Factor), temperature profiles and acoustic borehole image logs run before and after THC treatments. Four temperature profiles have been run; one at the equilibrium before thermal stimulation, one after chemical stimulation, one after hydraulic stimulation and one at the equilibrium five months after stimulations. Thermal gradients after stimulation show negative value at the uppermost part of the open hole, in sandstones and altered granite which is typical of mixing zone of convective system (Guillou-Frottier and Jaupard, 1995). Temperature data are very useful to determine which zones are the most affected by stimulations.

3. IMAGE LOG ANALYSIS

Acoustic borehole images in GRT-1 are Ultrasonic Borehole Image (UBI) run by Schlumberger in 2012 after drilling operations and in 2013 after stimulations. An acoustic wave is sent by transducer toward the borehole wall and then reflected to the tool (Zemaneck et al., 1970). The amplitude data and the transit time data of the reflected wave are recorded and generate two unwrapped 360° borehole images allowing structural characterization of the well. On the amplitude image, natural fractures appear as continuous sine waves and their orientation and dip can be easily calculated. If the sine wave is visible on the transit time image too, the fracture is interpreted as an open structure at least at the borehole scale. If not the fracture is assumed to be completely filled by secondary deposits (at least at the borehole scale).

For the comparison of the pre- and post-UBI, image logs have been processed and filtered in order to highlight some major differences on the borehole wall. Massive injections affected siliceous matrix (sandstones, granite) rocks with thermo-hydro-mechanical modifications that are not clearly visible on image logs. After THC stimulations, four fracture zones with two located in sandstones, one in altered granite and one in two-mica granite show some physical modifications. They have been analyzed, compared and interpreted thanks to borehole data, images logs and temperature logs.

The first zone is located in sandstones from Buntsandstein directly below the casing shoe. This zone is the first target of massive injections during hydraulic stimulations and present thermo-hydro-mechanical modifications. Indeed a negative anomaly of temperature is visible on a vertical height of 8 m below the casing shoe. On temperature profile run at the equilibrium several months after stimulations, this anomaly is not visible anymore.

The second zone is located in a major fracture zone in the sandstones. This zone has been thermally, hydro-mechanically and chemically stimulated (Figure 1). Natural fractures are filled by calcite and maybe anhydrite and present an halo of alteration on borehole images after stimulation. There are clear negative thermal anomalies on temperature profiles after stimulations, always visible five months after operations.

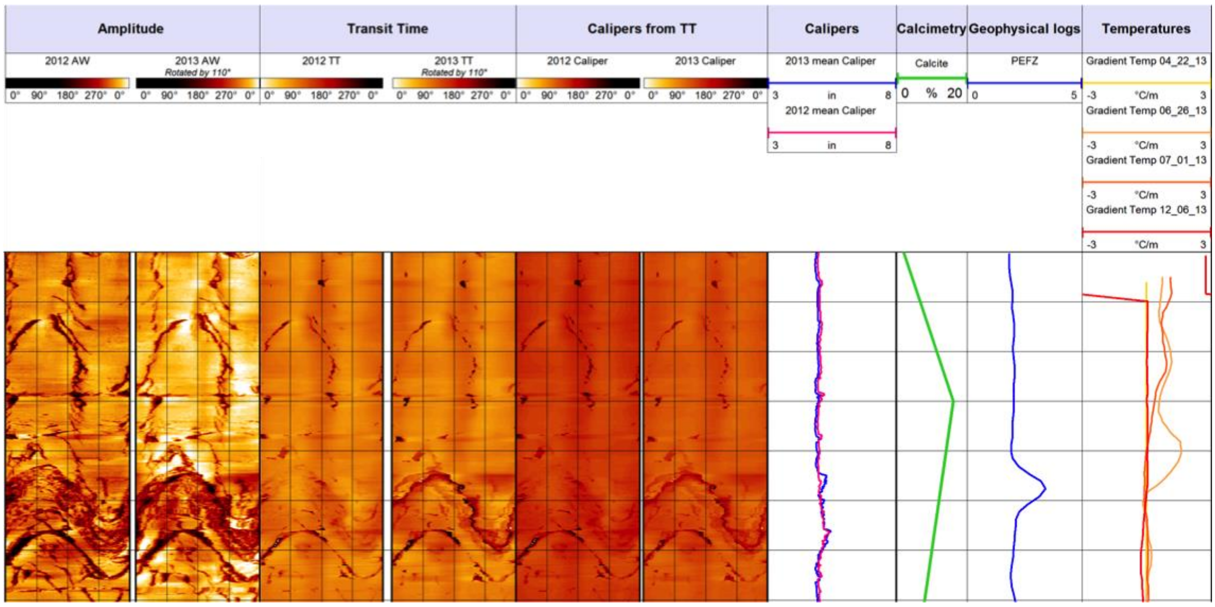

Figure 1: Comparison of UBI logs with amplitude and transit time data before and after stimulations in the fracture zone located in sandstones.

The caliper data are calculated from transit time data and wave velocity. The calcimetry (green) and the photoelectric factor (blue) are also indicated. Four temperature gradients have been run before stimulation (yellow), after thermal stimulation (light orange), after chemical stimulation (heavy orange), after hydraulic stimulation (red) and five months after stimulation operations.

The third zone is located in the altered granite with major permeable fractured zone. In this zone, cuttings revealed abundant secondary geodic quartz and thus the section is probably affected by thermo-hydro-mechanical modifications after massive injections. The strongest temperature anomalies are visible in this zone after stimulations.

The last zone is located in the two-mica granite thermally, hydraulically and chemically stimulated. In this zone, natural fractures are bounded by a halo of alteration. Drilling induced fractures are larger after stimulations. This effect remains very superficial because modifications are only visible on amplitude data and not on post-stimulation transit time data.

4. INTERPRETATION

Chemical modifications related to calcite dissolution have been seen at fracture clusters filled by carbonates in the sandstones and in the two-mica granite (Figure 2). These modifications are superficial and affect the near-well because the acid fluid dissolves minerals in a limited range around the borehole wall. Modifications related to chemical stimulation in the altered granite were not clearly visible on image logs. In similar geological conditions, thermal stimulation causes microfissuration of secondary quartz that increases connectivity at the near well scale (Hosni et al., 2003). These tiny physical modifications are possible in the environment of the major permeable fractures in the altered granite but are not visible on the image logs. Hydro-mechanical effects after massive injections are associated to strong temperature and flow anomalies in the sandstones below the casing shoe and in the major fracture zone in the altered granite. Those kind of anomalies are already identified in the host rocks of the geothermal wells at Soultz-sous-Forêts (Schindler et al., 2008). Besides the well GRT-1 is similar to the well GPK-3 at Soultz; the injectivity is mainly controlled by a major fracture zone in the basement. However the injectivity has been clearly improved in GRT-1, while the injectivity of GPK-3 has been poorly increased (Schindler et al., 2008).

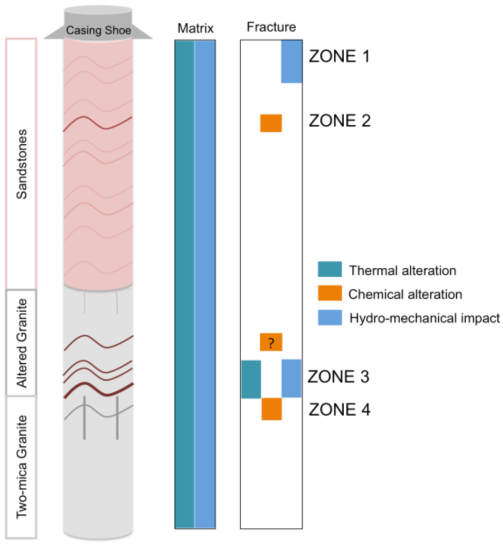

Figure 2 Distribution of zones affected by THC stimulations in the geothermal well GRT-1.

Fine physical changes of the borehole wall from chemical and thermal stimulations are not clearly identified at the UBI resolution (0.4 in for the vertical resolution). In the near-well field, mineral dissolution in fracture fillings enhance the connection between the well and the fractured reservoir. Local changes of the borehole wall derived from a differential analysis of acoustic imagery can not only explain the enhancement of the thermo-hydraulic performance of the well. Additional contributions, not visible on the UBI, for enhancing the post-stimulated flow path especially the connection between the well and the fractured reservoir could be proposed. Induced seismicity is observed during GRT-1 hydraulic stimulation in a range of several hectometers (Maurer et al., 2014). It is difficult to link permeability with observations at the surface of the borehole well but from the experience of Soultz, the hydraulic stimulation is more effective to enhance the permeability of the well than chemical one (Schindler et al., 2008). The cumulative effect of the various stimulations from the near-well field (1-5 m) and far-well field (< 1 km) should contribute to the permeability enhancement of the geothermal well.

ACKNOWLEDGMENT

This work was based on data from ECOGI EGS project at Rittershoffen (France). A part of this work was done in the framework of the LabEx G-Eau-Thermie Profonde which is co-funded by the French government under the program "Investissements d'Avenir".

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