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Temperature and hydraulic properties of the Rittershoffen EGS reservoir, France

Clément Baujard (1), Albert Genter (1), Eleonore Dalmais (1), Vincent Maurer(1),
Régis Hehn (1), Ronny Rosillette (2)

[1] ES-Géothermie, 3a chemin du gaz, F-67500 Haguenau, France

[2] ENSEGID Bordeaux, 1 allée F. Daguin, F-33607 Pessac cedex, France

clement.baujard@es.fr

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ABSTRACT

The ECOGI geothermal doublet, located in Northern Alsace (France) is designed to deliver a power of 24 MWth to the “Roquette Frères” bio-refinery. Two deep wells have been drilled in 2012 (GRT-1) and 2014 (GRT-2). Both wells target the same faulted zone in the crystalline basement.

Numerous temperature logs have been realised in both wells, suggesting a diffusive temperature regime above the Muschelkalk limestone and an advection-dominated temperature regime below the top of this formation, that means mainly in the Buntsandstein sandstone and the granite. Moreover, main flow zones are clearly correlated with temperature anomalies, suggesting important natural flows in the targeted fault zone. Due to a low initial productivity index, an extended well development sequence has been realised in well GRT-1, including low-rate cold fluid injections, localized chemical injections and hydraulic stimulations, and leading to a great improvement of the hydraulic well properties. Thanks to its high initial productivity index, well development was not necessary in GRT-2. Then, numerous pumping tests were carried out in GRT-2 as well as an interference and tracer tests has been done between wells GRT-1 and GRT-2.

Thus, we propose an integrated interpretation of data gathered during these experiments in order to characterize at best the hydrothermal properties of the Rittershoffen EGS reservoir.

INTRODUCTION

The EGS project ECOGI is located in Rittershoffen, a small village located in the Upper Rhine Valley (see Figure 1). The Rittershoffen geothermal site is located within the Upper Rhine Graben (URG) which is part of the European Cenozoic rift system that extends from the Mediterranean to the North Sea coast. The site is located on the Western part of the URG at about 12 km form the major western Rhenane border fault. The URG’s deep thermal structure, which is likely to be related to mantle uplift, shows an important rise up to 24 km depth in the southern URG (Edel et al. 2007). The shallow heat flow in the graben ranges between 100-120 mW/m^2 (Pribnow and Schellschmidt, 2000). Extensive borehole data show that the temperature within the graben at depths of 1-2 km is highly variable, the thermal anomaly between Soultz and Rittershoffen being particularly high (Baillieux, Schill et Edel, et al. 2013) (Baillieux, Schill et Abdelfettah, et al. 2014).

The top basement is located at about 2200m MD in well GRT-1 (Aichholzer et al 2015). The crystalline basement, constituted of altered and fractured granitic rocks from Carboniferous (Cocherie et al 2004) is covered by Tertiary and Secondary sedimentary layers (Georg Project Team 2013). These layers show a horst and graben structure with, in the vicinity of Rittershoffen, 2 horsts, Soultz in the west and Oberroedern in the East, enclosing a lower compartment in which the wells have been drilled (Georg Project Team 2013). Temperature, structural and stress conditions of the underground of the region are very well characterized, thanks to numerous hydrocarbon exploration wells, vintage seismic profiles and to extensive investigations that have been performed in the neighbouring geothermal site of Soultz-sous-Forêts (Kappelmeyer, et al. 1992, Genter, Evans, et al. 2010, Dezayes, Genter et Valley 2010, Valley 2007, Place, et al. 2010, Sausse, et al. 2010, Sanjuan, Millot, et al. 2016). Lessons learn at Soultz in terms of permeable fractured targets have been applied to the Rittershoffen site (Genter, Cuenot, et al. 2015).

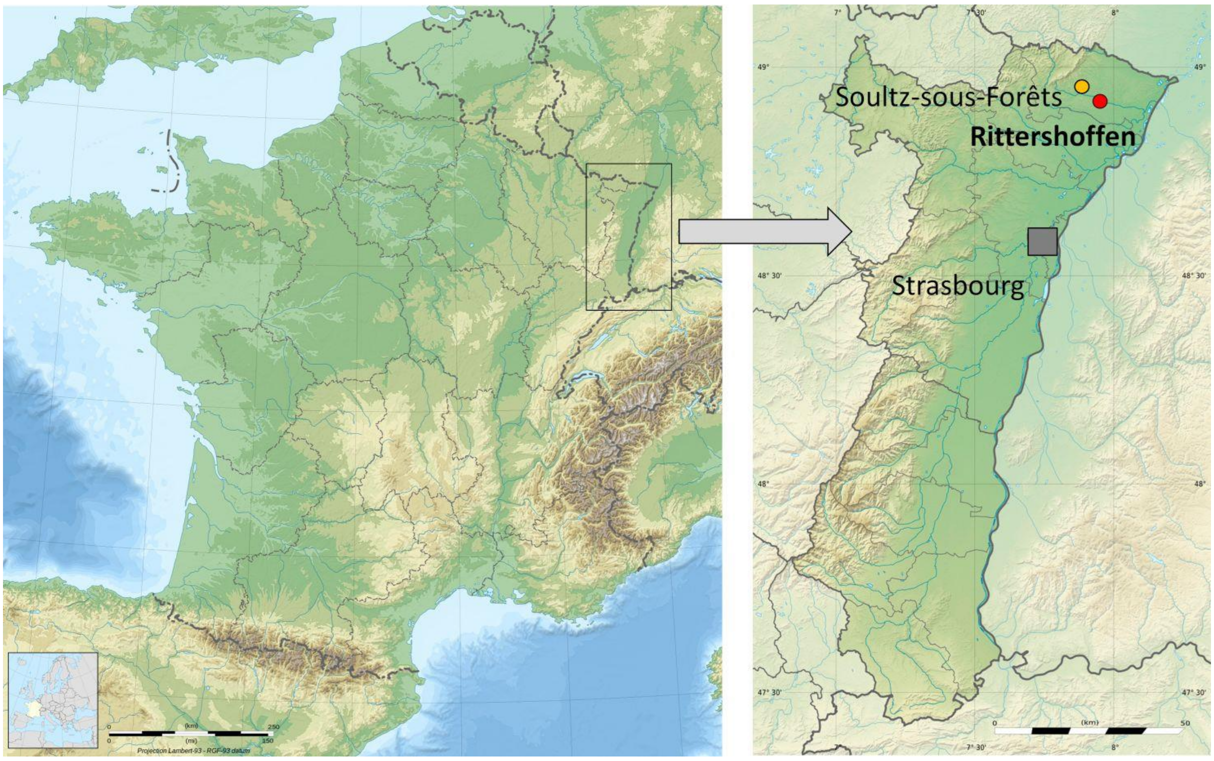

Figure 1: Location of the ECOGI geothermal project in Rittershoffen (Northern Alsace, France) - raster map credits Eric Gaba

The drilling of the first vertical well GRT-1 started in September 2012 and ended in December 2012 when the well reached a depth 2’580 m MD within the fractured granite basement. The drilling of well GRT-2 started mid-March 2014. Final depth of 3’196 m MD was reached end of July 2014. The well was slightly deviated, using a downhole mud motor. The inclination of the well reaches more than 37° and is directed to the North.

Both wells GRT-1 and GRT-2 target the same fault zone, named Rittershoffen fault, in the crystalline basement (see Figure 2). This structure is relatively well known, thanks to vintage seismic profiles from the 80’s available in the vicinity of the project which were reprocessed in 2009 in the framework of the project, leading to an updated lithostructural and stratigraphic interpretation of the Rittershoffen region. It is a N355°E fault zone (becoming more or less North-South at the well site), dipping 45° to the West, and showing an apparent vertical offset of more than 250 m.

In both wells, the open-hole section crosses Buntsandstein and Permian clastic sandstones which cover, a Paleozoic crystalline basement made of hydrothermally altered and fractured granite and intact granite. The architecture of the wells is classical for geothermal well: 30” conductor pipe, 18”5/8 and 13”3/8 casings to the surface, 9”5/8 liner and 8’’1/2 open-hole section (Baujard, et al. 2016).

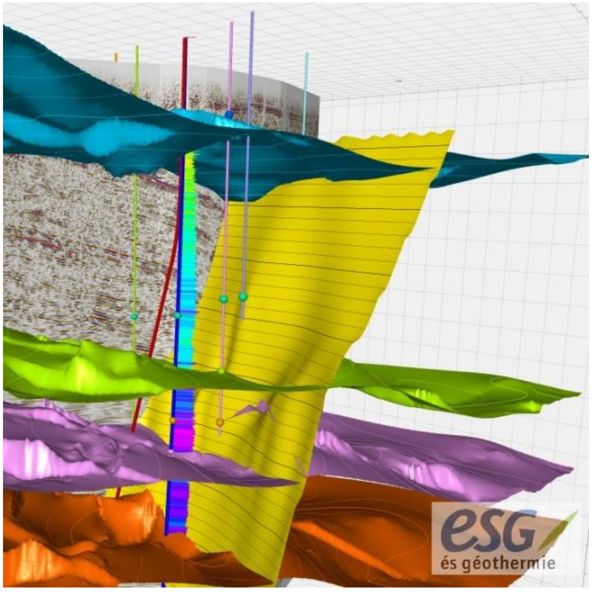

Figure 2: Geologic and structural model showing wells GRT-1 (in blue, represented with a sonic log), and GRT-2 (in red). The different geologic layers are: Top Secondary in blue, Top Keuper in green, Top Buntsandstein in pink and top basement in orange. The fault plane is in yellow.

CHARACTERISATION OF WELL GRT-1

Temperature profile

The most representative log of the thermal equilibrium was realised on April 22th 2013 (102 days after the well shut-in following the production tests in January 2013; the log was realised downwards). The maximum temperature at the bottom hole was measured at 163°C at 2’526 m TVD (Figure 3). From the surface approximately down to the top of the Muschelkalk, the temperature gradient is relatively constant and very high with 8.7°C/100 m. At the top Muschelkalk, the temperature is about 160°C and is characterized by a local small-scale positive anomaly. Below the top Muschelkalk, the mean temperature gradient to the bottom of the well is very low and reaches a value of 0.3°C/100 m. Occurrences of fractures or faults with natural permeability located at the interface between the sedimentary layers and the top basement have been already observed in the geothermal wells of Soultz-sous-Forêts (Vidal, Genter et Schmittbuhl 2015, Genter, Vidal, et al. 2015).

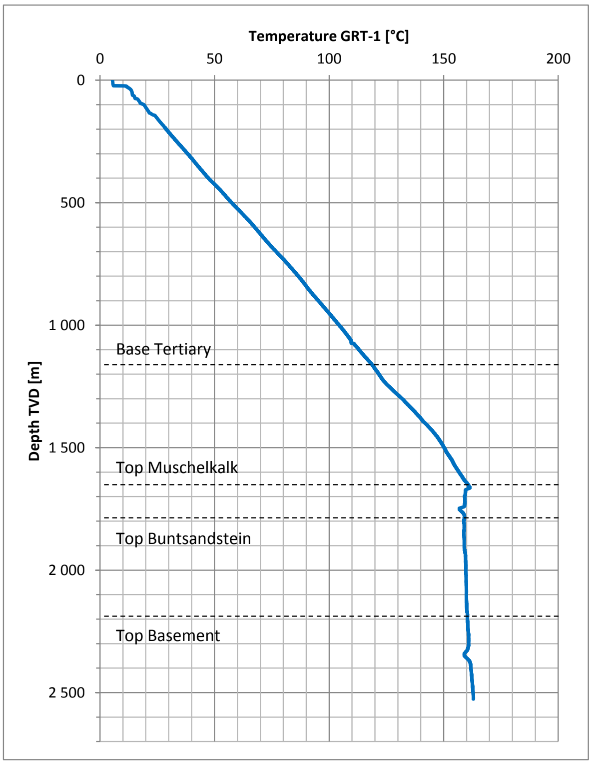

Figure 3: Temperature profile of GRT-1 at thermal equilibrium

Pumping tests

Following the well clean-up phase, a first air-lifted production test was performed between January 3rd and January 6th, 2013 (air injection at 300 m depth). A total of 3’000 m^3 were produced. The PT (Pressure Temperature) probe has been placed close to the casing shoe at 1’910 m MD during production. The production flowrate was extremely erratic. In order to try to stabilize it, the test started with 24h production at a maximal flowrate (50 m^3/h) to heat-up the well. 3 descending short step-rates could be recorded (50 m^3/h, 42 m^3/h and 35 m^3/h, 3 hours each). The maximum recorded downhole temperature was 157°C (still increasing). Unfortunately, the downhole measurements had to be stopped before and during the build-up due to the necessity to cool-down the pressure probe at the surface. The PT logging tool was put in the well again during the build-up phase at 1’907.5 m MD. After a 12 hours build-up, the test was continued with a sequence of 32h of artesian production (average flowrate 35 m /h), but downhole sensors broke-up and no downhole PT could be recorded during this production phase (see Figure 4).

In order to get better data, a second pumping test has been performed January 9th and 10th. A total of 400 m^3 were produced during this test (total production length 12 hours). The production was air-lifted (air injection at 500 m depth, using a booster). Flowrate could be stabilised at 30 m^3/h and the build-up has been fully recorded. The PT probe was positioned in the open-hole section at 2’298 m MD. The maximum recorded temperature at that depth was 158°C (still increasing).

Interpretation

The well productivity at this stage could be estimated to 0.45 l/s/bar.

Classical pressure transient analysis interpretations have been carried out with both wells pumping tests data, using AQTESOLV software. For GRT-1, only drawdown data of the 9/01/2013 and both recovery data of the 5/01/2013 (unfortunately incomplete) and of the 9/01/2013 have been interpreted. As the data quality is quite poor, interpretation of GRT-1 production tests was realised using a single permeability confined aquifer model (Dougherty et Babu 1984).

The assumed fluid density and viscosity for the interpretation are respectively 970 kg/m^3 and $1.75\cdot10^{-04}$ Pa·s. The reservoir thickness is assumed to 500 m This interpretation leads to the estimation of a hydraulic conductivity of $6.1\cdot10^{-08}$ $m\cdot s^{-1}$ and a storage coefficient of $7.2\cdot10^{-07}$ m^{-1}. The skin (Horn 1995) is estimated to 21 [-] (see Figure 5). This interpretation is very uncertain, due to the poor data quality.

Well stimulation

In order to enhance the well properties, an extended well development strategy was applied to GRT-1. It consisted in 3 steps:

- A thermal stimulation of the well, with low-rate cold fluid injections was applied in April

2013. The maximal flowrate was 90 m^3/h, and the total injected volume was 4’230 m^3.

- Then, a targeted chemical stimulation was applied. Environmentally friendly acids were specifically designed for chemical treatment of the well. Chemical injections were applied to three different depth intervals of the well and then chemical injections were applied using open-hole packers at 5 l/s through 2“ coiled tubing (total injected volume 214 m^3).
- A hydraulic stimulation of the well immediately followed the chemical stimulation. Maximum flowrates up to 80 l/s were applied during this stimulation sequence (Baujard et al. 2016).

Detailed about impacts of TCH stimulations derived from borehole image logs is given by Vidal et al. (2016).

Unfortunately, no production test was realised after the stimulation campaign. Nevertheless, an increase of the injectivity of the well was observed, as it increased from 0.6 l/s/bar at the beginning of the thermal stimulation to 2.5 l/s/bar at the end of the hydraulic stimulation.

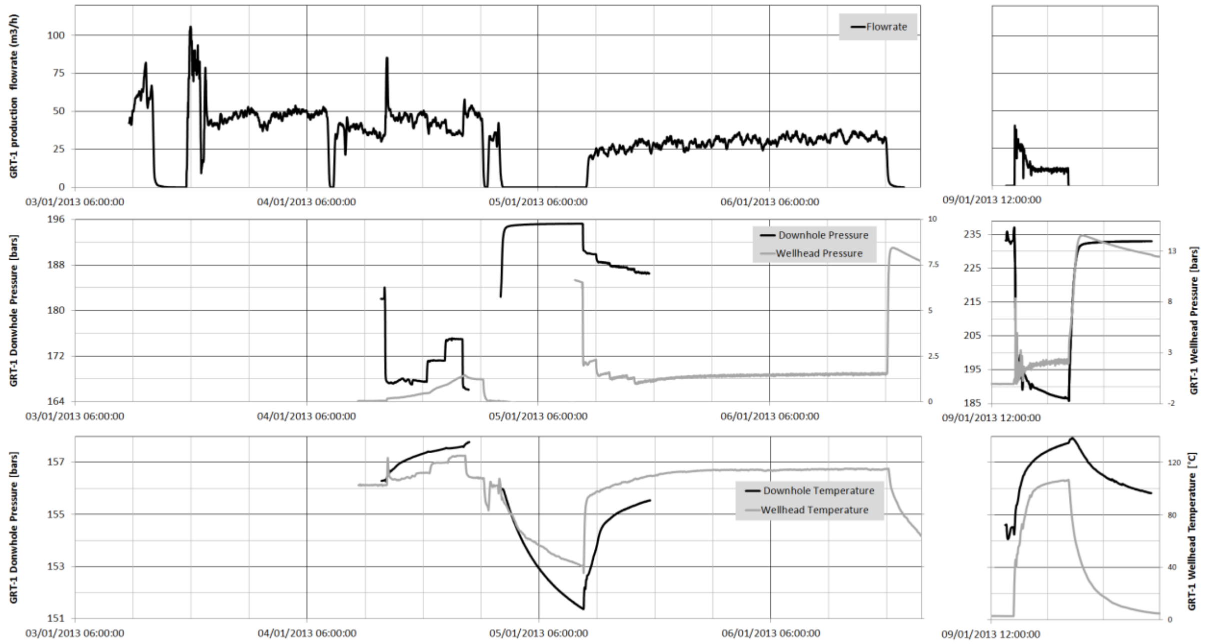

Figure 4: GRT-1 Production tests data (January 2013)

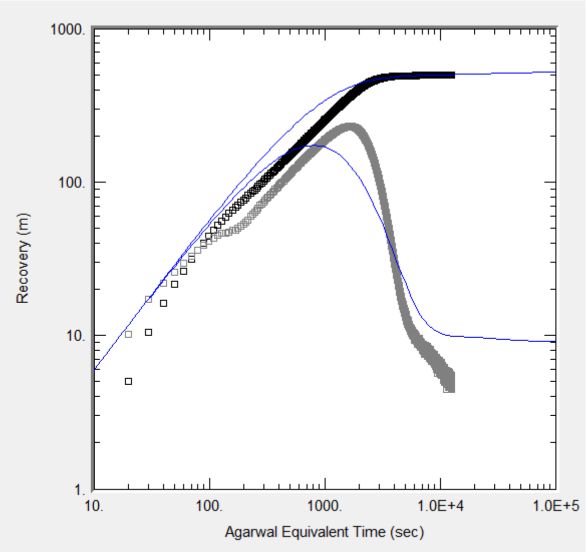

Figure 5: GRT-1 Production tests Pressure Transient Analysis (PTA) of the well recovery. In black: drawdown; in gray: drawdown derivative; in blue: interpretation.

CHARACTERISATION OF WELL GRT-2

Temperature profile

The closest complete log to a thermal equilibrium in GRT-2 was measured in a cased well on September 08th 2014 (37 days after shut-in following the previous production sequence of the well; the log was realised downwards). The maximum temperature at the bottom hole in the granite section is 177.1°C at 2’693 m TVD (Figure 6). The thermal gradient shows very high values from the surface down to the top of the Muschelkalk with around 8.5°C/100 m. At top of the Muschelkalk layers, the temperature reaches about 158°C. Below the Top Muschelkalk, the thermal gradient can be estimated to 1.8°C/100 m. This value is much higher than for GRT-1, explaining the higher bottom-hole temperature of the well. It must be underlined that the well was probably not in a complete thermal steady-state when the temperature profile was acquired.

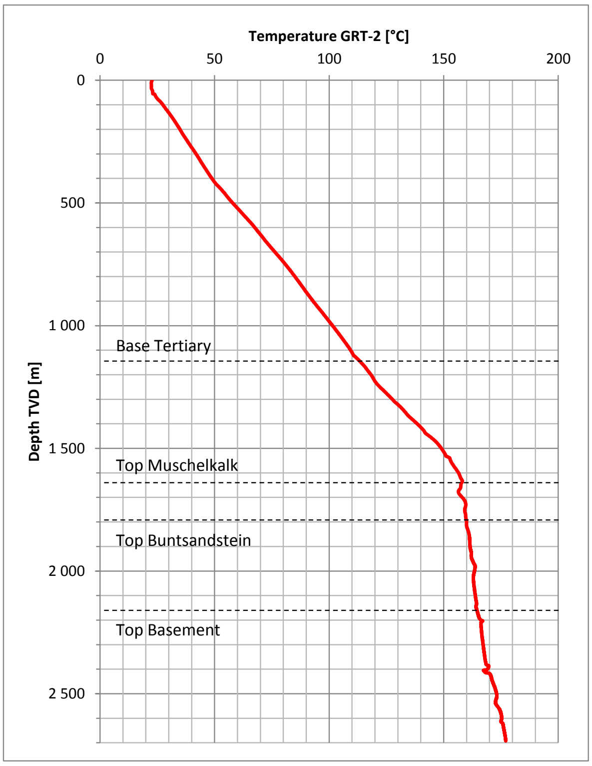

Figure 6: Complete temperature profile of GRT-2

Pumping tests

Several pumping tests were carried out on GRT-2. The first pumping phase could not be interpreted because of pressure measurements inconsistencies between different sensors. The best pumping test is phase 2, which was realised between September 9th 2014 and September 15th 2014. It consisted in a step-rate production test and in a constant-rate production test (see Figure 7). Phase 3 was realised after a tracer test and consisted in step-rate tests of long duration.

During this pumping test, downhole sensors were installed in GRT-1 in order to measure a possible hydraulic connection between both wells.

Interpretation

The well productivity during this production phase could be estimated to 2.8 - 3.5 l/s/bar.

Step-drawdown test (phase 2.1) as well as drawdown and recovery data (phase 2.2) have been used for the interpretation of the hydraulic tests of GRT-2. This time, best results are obtained using a fractured confined aquifer model (Moench, 1984). Observations realised in GRT-1 during GRT-2 test phase 2.2 have been taken into account (GRT-1 acting as an observation well) and measurements could be reproduced by the model.

The same geometrical parameters have been used for the interpretation. A fracture thickness of 40 m is assumed for the fractured aquifer geometry (reservoir total thickness of 500 m as for GRT-1). This interpretation leads to the estimation of a hydraulic conductivity of the matrix and the fracture zone of respectively $5.3 \cdot 10^{-07}$ $m \cdot s^{-1}$ and $2.9 \cdot 10^{-06}$ $m \cdot s^{-1}$. The storage coefficient of the matrix and the fracture zone are respectively estimated to $5.3 \cdot 10^{-07}$ m^{-1} and $7.2 \cdot 10^{-07}$ m^{-1}. The skin is estimated to 1.8 [-] (see Figure 8).

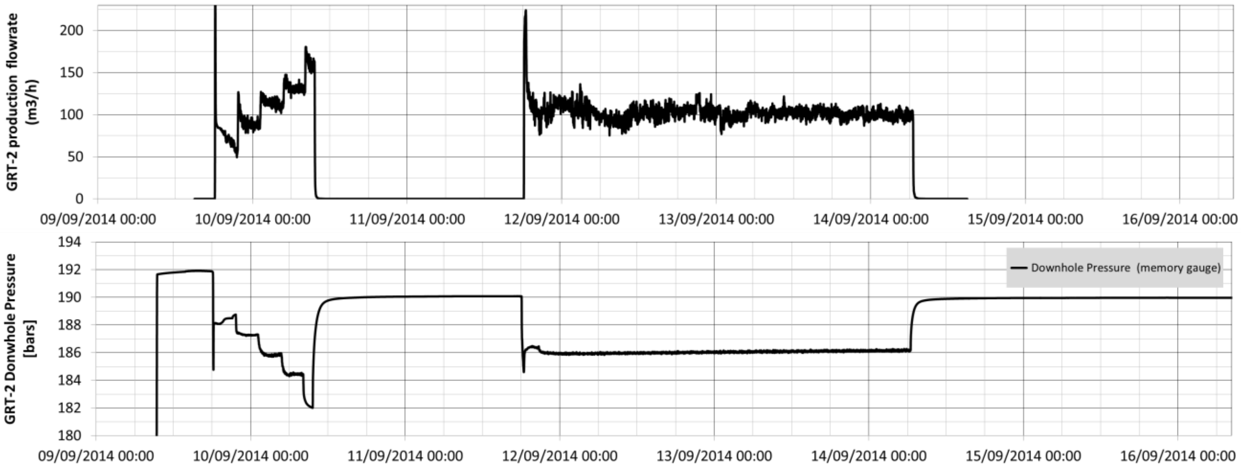

Figure 7: GRT-2 Production tests data – phase 2 (September 2015)

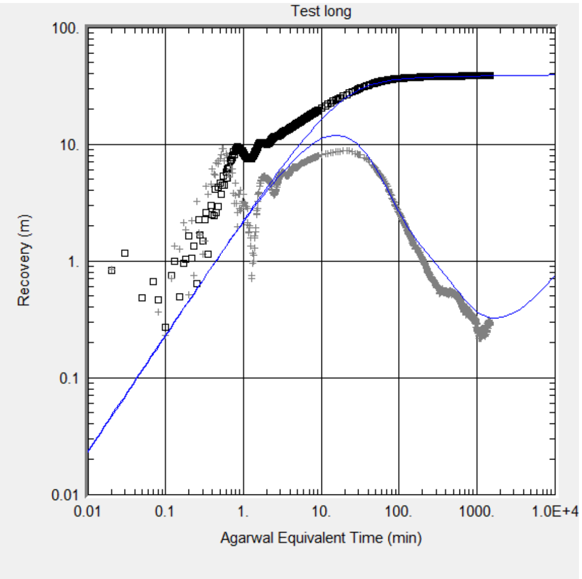

Figure 8: GRT-2 Production tests Pressure Transient Analysis (PTA) of the well recovery. In black: drawdown; in gray: drawdown derivative; in blue: interpretation.

CONCLUSIONS

The hydrothermal characterisation of wells GRT-1 and GRT-2 carried out leads to the following conclusions:

- GRT-1 is characterised by a high skin and seems connected to a low-permeability reservoir;
- Nevertheless, the well development strategy could significantly enhance the injectivity of the well by a factor 5;
- GRT-2 shows a high productivity. The skin is low and it seems connected to a highly conductive reservoir;
- No boundary effect (impermeable limit or constant head) could be highlighted with the tests carried out on GRT-1 and GRT-2;
- A clear connection could be highlighted between both wells: the tracer tests breakthrough occurred after 14 days of circulation at 100 m^3/h (average flowrate); Moreover, a hydraulic connection between GRT-1 and GRT-2 could be identified (pressure front transit time : 30mn);
- The temperature profiles clearly show that the temperature regime is dominated by conductive processes above the Muschelkalk and advective/convective processes below this Triassic layer in the deep-seated hard rocks (sandstone and granite).
- Faulted zone with a significant vertical off-set visible in the sediments are promising geothermal targets in the basement.

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