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Permeability assessment based on drilling data in EGS projects

Case study of Muschelkalk fracture in GRT-1 well for ECOGI Project (Rittershoffen, Alsace, France)

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Introduction

While and just after drilling, various types of logging are performed for various purposes:

- Measurements while drilling (MWD) allows the driller to drive the machine,
- Mud logging is used to follow the lithology of rocks during drilling,
- Wireline logs are used to get in-situ geological information and to derive some petrophysical rock properties, such as porosity and sometimes permeability.

Usually, these loggings are carried by various contractors and results are presented in different reports but not systematically compiled in order to get permeability information in real-time or with a short delay. In that case, getting quickly a general overview of the permeable features during drillhole operation is quite challenging. Moreover, it could be very fruitful to get as fast as possible a semi-quantitative interpretation of the well permeability in order to adjust the following hydraulic production testing program as well as the stimulation strategy in case of EGS project.

The idea of this work is trying to get the maximum of information on the petrophysical properties of the reservoir. After compiling various logs acquired, permeability will be assessed by using MWD and mud logging data. Drillhole GRT-1 of ECOGI project (Rittershoffen, Alsace, France) will serve as a case study. A preliminary analysis of various well logging data has been performed in this well to derive permeability estimates (Dalmais, 2014).

GRT-1 well data compilation

In order to analyze and compare various data acquired along the drillhole, a new Masterlog combining MWD (Geolog, 2013), litho-stratigraphic interpretation (Duringer, 2013 ; Deiller, 2013), wireline geophysical logs (Schlumberger, 2013) and flow logs has been created. As several temperatures and flow logs have been acquired. It was not adequate to show all of them on the Masterlog and the following selection was done.

Displayed temperature logs were chosen according to their date of acquisition:

- 22nd April 2013: 2 months after production tests and before injections tests, considered as equilibrium state
- 1st July 2013: After all stimulation phases

The most reliable flow logs, normalized by $PI*R^{0.7}$, were chosen to be imported in the Masterlog (from Hehn (2014)).

In order to better visualize permeable zones, gradient of temperature and flow logs were processed using WellCad software.

The figure below illustrates data that have been acquired and combined into the masterlog for further analysis.

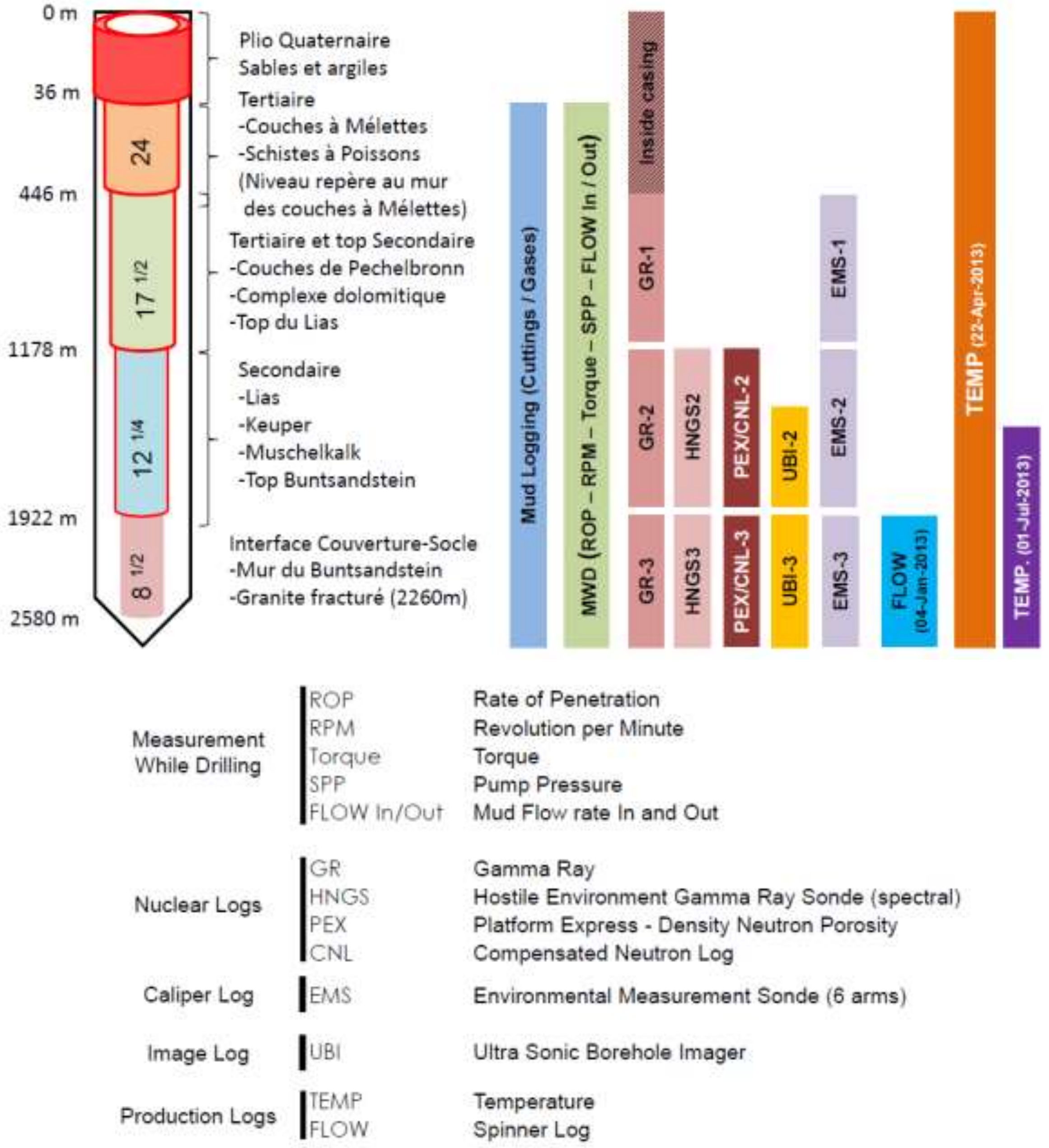

Figure 1 : Data combined in GRT-1 Masterlog by interval of acquisition

Data analysis

Lietard et al. (1999, 2002) and Huang et al. (2011) established an equation to derive fracture aperture from mud losses in the well while drilling. The idea is that mud losses will stop when the overpressure between drilling fluid and formation fluid is unable to overcome the yield stress of the drilling fluid. Therefore, the ultimate volume of losses depends on the yield value of the mud and the magnitude of the overpressure.

After estimating fracture aperture, corresponding hydraulic parameters can be evaluated using the cubic law for flow within fractured media (see Şen, Z. (1995)).

In GRT-1 Well, 3 formations can be of interest for deep geothermal application:

- Muschelkalk limestone
- Buntsandstein sandstone
- Altered / Fractured Granite basement

Comparing various logs combined in the Masterlog shows areas of interest in term of permeability:

- Zone A: 1760 m MD / 1750 m TVD: big fracture in Muschelkalk
- Zone B: 2340 -2370 m MD / 2315-2355 m TVD: granite intensively fractured

Zones A is further detailed in the following sections with some permeability calculation from mud losses.

Analysis of Zone A in Muschelkalk

On Figure 2, some logs show a structure of big size:

- Density (RHOZ-PEX log) diminishes from 2.8 to 1.3 g/cm^3
- Porosity (NPHI- PEX log) increases form 5% to 40% locally
- Caliper (RD1 to 6 – 6 arms caliper EMS log) shows clear breaks in the normal diameter of the hole
- The UBI clearly shows a fracture visible both in amplitude and in transit time, suggesting that it could be a permeable structure which is oriented N280°E.

Other logs confirm the permeability of the structure:

- Temperature logs are perturbed when crossing the area
- Gases and mud are loss in the structure

One can note that anomalies due to the fracture on these logs are not exactly at the same depth than on first set of logs. This might be explained by difficulty in matching precisely depths between MWD and wireline logs.

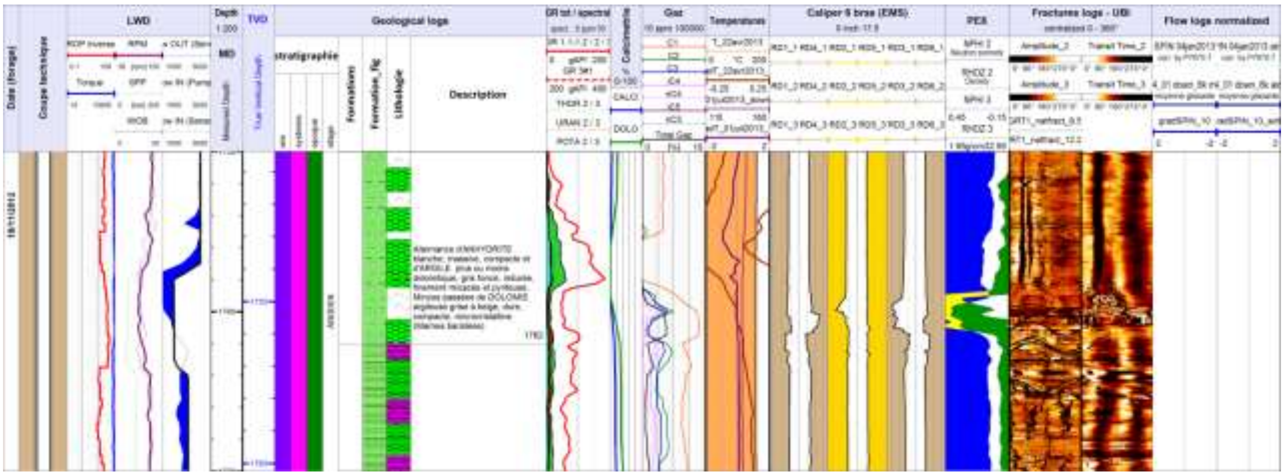

Figure 2 : Masterlog extract between 1750 and 1770m MD (Muschelkalk fracture)

As explained previously, knowing volume of losses, mud yield value and overpressure, one can estimate a “permeable aperture” of corresponding fracture. Some parameters are not known precisely: overpressure derives from an estimate and mud yield value is changing while the mud is adapted to diminish losses. So a calculation in order of magnitude has been performed using ranges.

The calculations give a quite stable result and an aperture around 10 cm can be obtained. The UBI gives in comparison an apparent aperture of 40 cm which is higher. However, this calculation gives an aperture in terms of permeability whereas UBI in terms of geometry. Thus, the trend of fracture aperture calculation is realistic. It is consistent to have a smaller “permeable” aperture but with just one order of magnitude difference from the “structural” aperture. Moreover, permeability in fractured rocks is generally governed by 1D channeling.

Application of cubic law leads than to very high hydraulic parameters. In fact, it is assumed that Darcy law is valid which implies a laminar flow. This can be checked with Reynold number (Re). Considering a production flow rate of 50 l/s, Re is in order of magnitude of 10^4 in our case. So the flow is in turbulent state and cubic law is not valid. This is consistent with the work of Kohl et al (2000) which emphasizes the importance of turbulent flow in Soultz fractured system.

Discussion and conclusion

After combining various logging data into a unique masterlog, 2 permeable zones related to fractures have been identified on GRT-1 well. Using equation established by Lietard et al. (1999, 2002) and Huang et al. (2011), “permeable” fracture aperture have been calculated which are consistent with borehole fracture images.

However, due to turbulence flow regime around the wellbore, it is not possible to derive a permeability using the standard cubic law which assumes a laminar flow. It would be interested to investigate other law taking into account a turbulent flow to derive a more realistic permeability. That one could be then compared with permeability measurements in crystalline rocks at different scales of investigation: laboratory, core, borehole, mine, regional scale (Clauser, 1992).

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