A MULTI-APPROACH GEOTHERMAL RESERVOIR CHARACTERIZATION:

THE SOULTZ-SOUS-FORÊTS EGS EXPERIENCE

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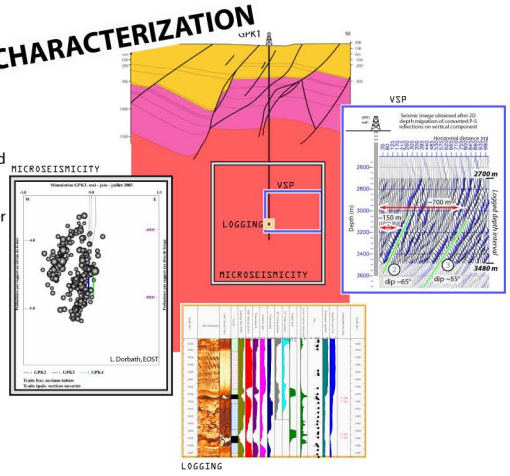
INTRODUCTION

Mapping the geometry of permeable and non-permeable zones in crystalline rocks is of primary importance to characterise the natural fluid flow or to assess the possibility to make artificial fluid circulations, regarding for example nuclear waste site applications, oil and gas recovery or geothermal field development. Our work is focused on the development of methods allowing to define the architecture of these paths within the rock mass.

At the Soultz-sous-Forêts EGS (Enhanced Geothermal Systems) site the fluid flow paths between the injection and the production boreholes are currently poorly constrained and difficult due to the great depth of the hot granite. Thus we present here a synthesis of our ongoing work consisting in an investigation of structures occuring from hectometric to micrometric scales, applied both in the Soultz-sous-Forêts heat exchanger and on an analogue outcropping granitic massif.

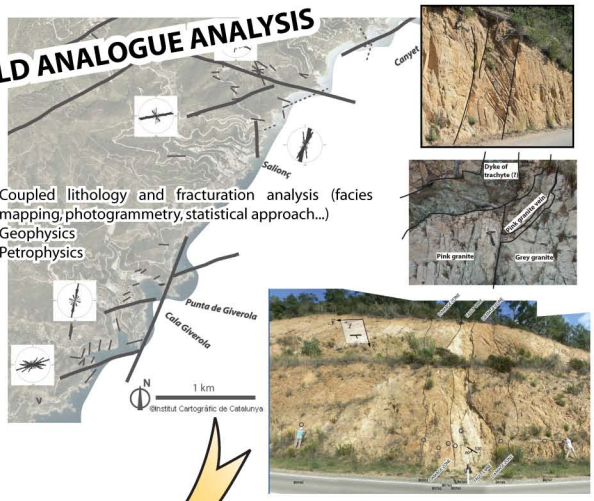
DIRECT *in situ* RESERVOIR CHARACTERIZATION

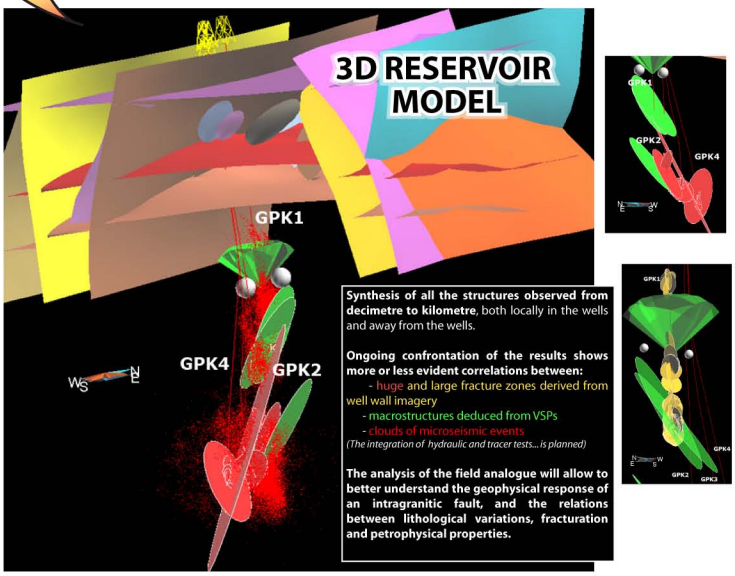
Surface seismic, gravimetry, heat flux and geothermal gradients...
Logging and borehole wall imagery
Hydraulic tests, temperature logging, tracer tests...
Seismic methods (tube waves, VSP)
Microseismicity
Petrophysics on cores
etc ...



FIELD ANALOGUE ANALYSIS

Coupled lithology and fracturation analysis (facies mapping, photogrammetry, statistical approach...)
Geophysics
Petrophysics





Synthesis of all the structures observed from decimetre to kilometre, both locally in the wells and away from the wells.

Ongoing confrontation of the results shows more or less evident correlations between:
- huge and large fracture zones derived from well wall imagery
- macrostructures deduced from VSPs
- clouds of microseismic events

(The integration of hydraulic and tracer tests... is planned)

The analysis of the field analogue will allow to better understand the geophysical response of an intragranitic fault, and the relations between lithological variations, fracturation and petrophysical properties.

The confrontation and the synthesis of the results inferred from these different methods require:

-to assess and quantify the confidence and incertitude of each methods *(e.g. how to deduce a general orientation of a fault zone only from borehole wall imagery? What is the dip and azimuth incertitude for a fault seen by VSP? What is the representativeness on an analogue ? etc...)*

-to identify what kind of structure is really imaged *(e.g. what are the required properties of a fault to get a seismic response? Is there a direct relation between fluid presence and microseismicity? etc...)*

-to take into consideration the huge range of scales (from mm to kilometer)

PERSPECTIVES FOR FUTURE EGS...

From these two complementary approaches, a comparison is proposed so as to complete the Soultz-sous-Forêts EGS multi-scale characterization. As the structural data acquired by logging are collected only locally in the wells, the macro-structural pattern of the reservoir is deduced by seismic methods (VSP and surface seismic). Then, the results of the analogue analysis are useful to complete the conceptual 3D model of the reservoir and understand the fluid flow paths.

In the future, the drilling strategy of an EGS should absolutely take in account a preliminary targeting of permeable structures before and during the drilling phase, as not rigorously done in the past at Soultz-sous-Forêts EGS. Thus, by this way, a better global productivity could be reach by a lower number of producing deviated boreholes **(improvement of the ratio (fluid flows)/(drilling cost))**. In addition, accurate reservoir knowledge could help with benefit the management of the heat resource in the exploitation phase.

Regarding the Soultz-sous-Forêts experiences, specific recommendations can be suggested for future development of this kind of non conventional reservoirs such as EGS (great depth and temperature, crystalline rocks...). We thus propose this **EGS investigation flow chart**:

Exploration phase

- **Synthesis** at regional scale and re-interpretation of **geological and geophysical data** (seismic, gravimetric, electric, potential methods, heat flux...), in order to build a wide 3D model.

- After the identification of a zone of interest to set up an EGS, the major structural sketch could be derived from a **conventional 3D seismic survey** or a dense 2D seismic survey operated in a restricted area.

- After the drilling of the **first well**, which location would be defined from the 3D model, analyze the **logging data** to identify the main zone(s) of interest at depth by refining the temperature measurement, identify the lithology, the fractures intersecting the well, the stress regime... A **VSP survey** is required in order to **map the main faults** in the well vicinity, wether they intersect the well or not.

... and in fonction of the cost analysis and the financial balance...

Development phase

- **Define the trajectories** of the future geothermal wells, by intersecting the observed large fracture zones (and use the technique of deviated drilling if need be). On the long view, after the required development of the method, Seismic While Drilling surveys could complement with benefit the targeting of faults during the drilling phases.

- Combination of results from post drilling logging, VSP acquisitions, core analysis, petrophysical measurements, hydraulic tests, microseismic studies, analogue analysis... would be then be necessary to build a **lithological and structural 3D model**. This accurate knowledge of the basement setting is absolutely required to understand the fluid flows and to **manage the geothermal resource of the reservoir**.

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ENGINE CONTRIBUTIONS

Joachim Place, Charles Naville, Edouard Le Garzic, Yves Geraud, Marc Diraison, An illustration of VSP efficiency to design a geothermal well while drilling. Oral presentation at Workshop ENGINE, Reykjavik, July 2007.

Joachim PLACE, Edouard LE GARZIC, Yves GERAUD, Marc DIRAISON, Preliminary results from fracturation analysis on an analogue granitic batholith and "direct broadcast" of the VSP acquisition at Soultz-sous-Forêts geothermal site. Poster presented at Workshop ENGINE, Volterra, April 2007.

Joachim PLACE, Charles NAVILLE, André GERARD, Marc SCHAMING, Oriented three component VSP method applied to imaging highly dipping faults in the deep granite basement at Soultz-sous-Forêts. Poster presented at Workshop ENGINE, Potsdam, November 2006.

Joachim PLACE, Yves GERAUD, Marc DIRAISON, Research of an analogue of the Soultz-sous-Forêts granite in Catalunia. Poster presented at Workshop ENGINE, Potsdam, November 2006.