Geomechanical characterisation of geothermal exploration borehole for Aquifer Thermal Energy Storage (ATES) development in Geneva, Switzerland

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ABSTRACT

To evaluate the geothermal potential of the Geneva Basin (Switzerland), the GEothermie2020 prospection program started in 2013 that is now continuing with four exploration boreholes. The first borehole has been drilled in 2018. The planned exploration boreholes target various fault system configurations. The exploration program covers a broad range of geothermal applications, including thermal energy storage and recovery in aquifers (ATES) in the framework of the ERA-Net Geothermica HEATSTORE project.

The geological characteristics of reservoir's rocks have a strong influence on key parameters that control the productivity of wells, such as good permeability, sufficient flow and heat. It also affects geomechanical characteristics that are important to evaluate in order to develop geothermal projects. Indeed, geomechanical parameters need to be integrated for geothermal well design and reservoir management.

Thus, this research aims at providing an initial geomechanical characterisation in the Geneva basin. This is achieved by the analysis of the logging data collected during drilling operations at the GEo-01 well. The study focusses on the assessment of the fracture distribution, the stress field, and the mechanical properties of the fractured limestone present around the borehole.

We provide vertical profiles of variations of the strength and elastic moduli of rocks according to the lithology, as well as a best stress estimate for the site. We also evaluate the relation between fracturing and inflows in the well.

The realisation of a local-scaled geomechanical model allows then to understand the dominant process controlling the groundwater flow and heat transport as well as the influence of fault systems on the stress state and fracture distribution.

The Geneva Basin has a large potential for geothermal exploitation thanks to its hydrogeological characteristics. Geomechanical analysis and simulations enhance knowledge related to the stress state of the reservoir and constitute an important decision tool in order to improve the success of any geothermal project, including Aquifer Thermal Energy Storage (ATES).

1. INTRODUCTION

The 2050 Energy transition strategy is one of the key challenges for the Swiss government to phase out nuclear power and to reduce the greenhouse gas emission. The development of renewable energies, such as geothermal energy, is therefore supported and innovative projects emerge in Switzerland.

The GEothermie2020 program, managed by the Industrial Services of Geneva (SIG), aims at characterising the subsurface of the Canton of Geneva by collecting new geophysical data and drilling exploration boreholes. The boreholes target various faults configurations and aquifers at gradually increasing depth.

A priority of this program consists in validating and increasing the geological knowledge of the Geneva Basin and evaluating the geothermal potential of different aquifers. The objective of this study is to characterise the fractures, the mechanical characteristics and the stress state of the formations present around the first exploration well GEo-01. We base our analyses primarily on logging data.

In addition, we aim at constraining the reservoir geomechanical properties controlling the groundwater flow and the heat transport, as well as to evaluate the geothermal potential of the fractured limestone reservoir. This work is on-going and preliminary results are presented in this paper.

2. GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

The Greater Geneva Basin covers a 2'200 km^2 area delimited by the Jura Mountain at the NW and the thrusting front of the Alpine Units at the SE. The main tectonic structures crossing the basin include strike-slip and thrust fault zones (Fig.1).

This basin consists of a crystalline basement incised by grabens filled with Permo-Carboniferous sediments (mostly continental detritic sediments) and overlaid with a thick Mesozoic sedimentary cover composed of limestone and marls. The top of the Mesozoic sequence is composed by the lower Cretaceous Units which top is largely karstified.

At the Tertiary, various cycles of detritic sedimentary deposits coming from the alpine orogeny were deposited on top of the Mesozoic unit and constitute the so-called Molasse (sandstone and marls) (Clerc et al. 2015).

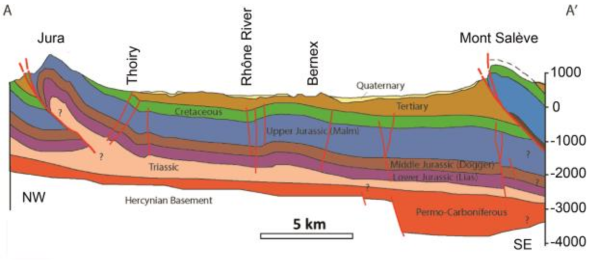

Figure 1: Geological cross-section NW-SE of the Geneva Basin (modified after, Moscariello 2018).

Many units present interesting features for geothermal reservoirs: the upper karstified Cretaceous (limestone), the carbonate reef complex of Malm, the oolitic and bioclastic limestone of Dogger, the upper Muschelkalk, the Permo-Carboniferous sediments in grabens, the altered sediment-basement interface and the potential fault zones in the basement (Clerc et al. 2015).

The groundwater recharge area is located in the Jura Mountain, where meteoritic water infiltrates (Fig. 2). The karstic and fault systems offer preferential flow paths. By drilling close to fault systems, the probability of finding a productive fracture network is increased (Chelle-Michou et al. 2017).

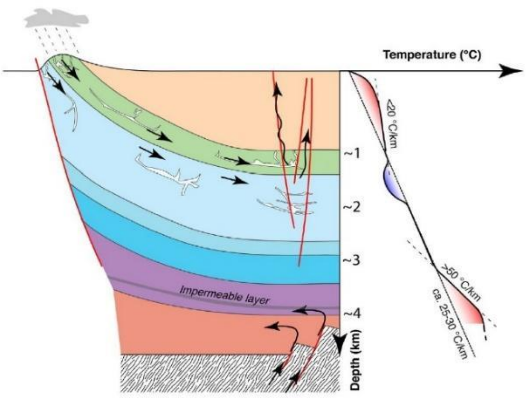

Figure 2: Water infiltration through karstic formations and major fault systems with the geothermal gradient (Chelle-Michou et al. 2017).

The first well of the program, GEo-01 happened to be an artesian well that produces water at 33°C in surface with 50 l/s and 8-12 bars of artesian pressure. It was drilled in 2018 through the Molasse and the Cretaceous units, and reached the top of the Malm at 744 m depth.

The target of this first well was to reach the fractured limestone of the Cretaceous unit. Besides crossing a naturally karstified layer, this well crosscuts a flower structure in a strike-slip fault oriented NNW-SSE, thereby increasing the potential water inflows.

3. DATA ACQUISITION AND ANALYSIS

3.1 Fracturing analyses

Logging have been performed in the well, including optical and acoustic televiewers (Fig. 3). These images allow the identification of fractures and the determination of their orientation, dip angle and aperture. This data is the base for the development of a fracture model for the drilled units.

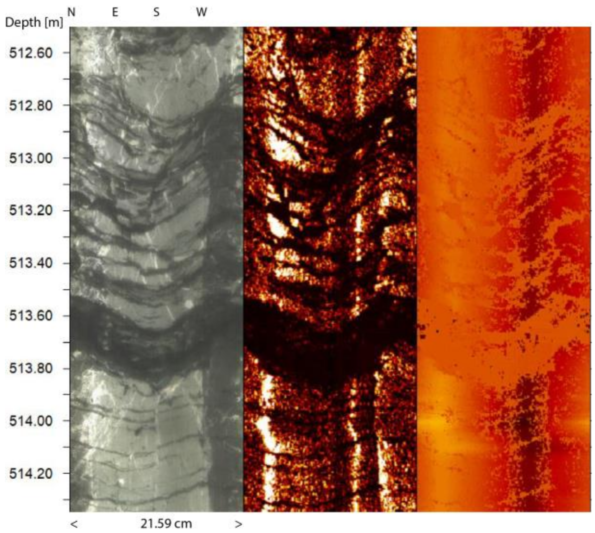

Figure 3: Optical televiewer (left), acoustic televiewer amplitude (middle) and transit time (right) data displaying fractures developed in limestone rock in the GEo-01 well.

The results of fracture identification are presented in the following stereonets, separated according to the lithological units (Fig. 4). The less steep features are interpreted as bedding. We observe that the bedding orientation is quite instable with a tendency to rotate from the northeast toward the south with depth. Moreover, a section between 460-480m (Fig. 5) is characterised by open fractures with steeper angle and may be interpreted as a fault zone crossing the borehole.

Two working hypotheses could explain the bedding orientation instability and dip direction variations: a cross-stratification of the bedding which is common in the Cretaceous (sedimentary hypothesis), or the presence of some tilting blocs related to the flower structure (tectonic hypothesis). Further analyses will help to understand the origin of this variability.

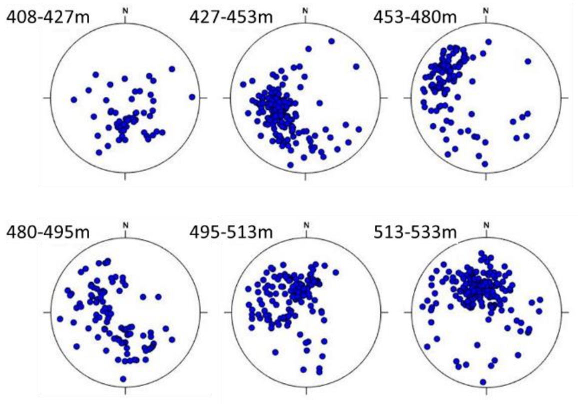

Figure 4: Stereographic projection of the fracture poles (lower hemisphere, equal area) according to stratigraphic limits.

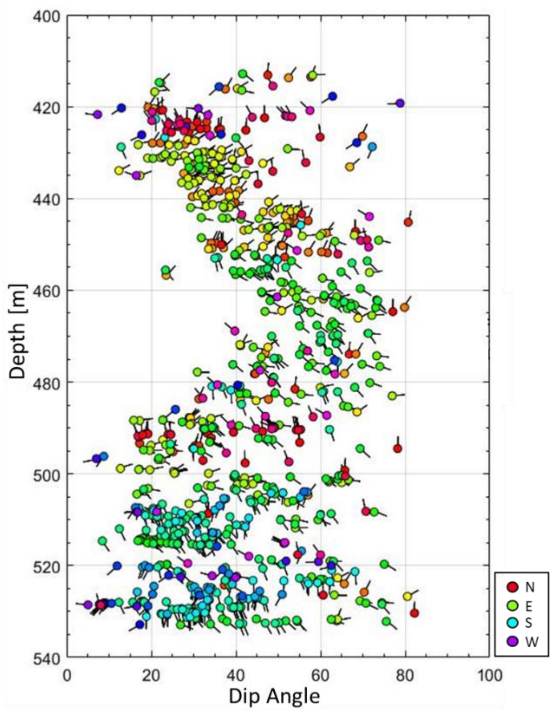

Figure 5: Fracture dip direction (color) and dip angle variations with depth.

3.2 Borehole shape analyses

Transit time measurements made by the acoustic tool can be converted in radius to analyse the shape of the well (Schlumberger 1991). Well ellipticity and instability can be assessed and possibly be related to the orientation of the principal stresses.

We converted the transit time to radius for the GEo-01 well acoustic televiewer. The fluid velocity has not been measured. Thus, we calibrated our conversion on a four-arms caliper log run in the well. The transit time data for the well GEo-01 are noisy and contain numerous incorrect evaluations of the returning wave, particularly in fractured area with low amplitude data. This is visible on Fig. 3 where homogeneous orange areas are visible and correspond to improper evaluation of the transit time. We filtered these improper data in order to keep only data representing a real well radius. This left us with an incomplete geometry of the wellbore, but nevertheless sufficient to evaluate potential well ellipticity. We did this evaluation by fitting ellipses on reconstructed borehole sections using a stable direct least square fit algorithm by Halír and Flusser (1998). This allow us to evaluate the orientation of the best fitted major axis and the ellipticity, i.e. the ratio of the major and minor ellipse axis.

The expected output for a well is a very variable random orientation of the major ellipse axis and a low ellipticity. For GEo-01 this is the case from 380 to 410 m depth, for example (see Fig. 6). However, for some sections, we observe that borehole shows preferential and stable orientation of the major axis, such as between 430-445 m. Such behaviour is yet unexplained and could be related to creeping under far field stress conditions and thus, if this mechanism is validated, could be used as an indicator of the in-situ principal stresses directions. Other sections present a more variable orientation of the ellipse, maybe related to the presence of karst or open fractures. Identification of correlations with the lithological units may also help to explain the variations of orientation and ellipticity of the well.

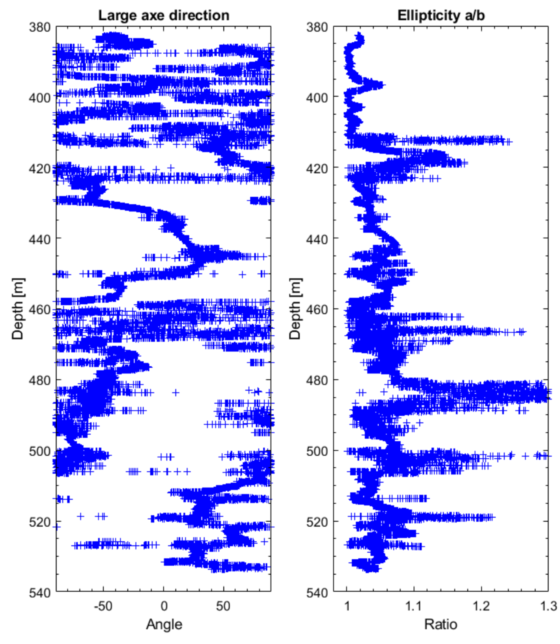

Figure 6: Analyses of the borehole shape and ellipticity based on transit time measurements.

4. PLANNED WORK

Further analyses are on-going in order to develop a Mechanical Earth Model and geomechanical analyses of the reservoir. The approaches of these analyses are presented in the following.

4.1 Mechanical Earth Model (MEM) and mechanical properties

We will compute a Mechanical Earth Model (MEM) by integrating all available data in a way similar to the one proposed for example by Bérard and Prioul (2016). Such method provides an estimation of elastic moduli and rock properties variations according to the lithology.

Mechanical properties and rock strength are obtained from the sonic and density logs (Schlumberger 1991). Elastic moduli are fundamental to estimate the stress state, strain and rock strength surrounding the borehole (Gudmundsson 2011). Indeed, the stiffness of a rock and more particularly stiffness contrasts between formations can induce some important variations of the stress, with stress concentration in some stiffer layers (Bourne 2003; Corkum et al. 2018) and control fault nucleation and propagation (Roche et al. 2013).

Initially, a best estimate stress model (Stephansson and Zang 2012) will be derived. The observation of the well stability and independent assumption of the wellbore wall strength derived by laboratory testing and sonic logs, allow to refine possible bounds on the stress magnitude and to refine the initial best estimate stress model.

In integration with the observed characteristics of the natural fractures, the MEM helps therefore to understand how the production rate influences the opening or closing fractures, and how they can change the permeability surrounding the well (Bérard and Prioul 2016). Such observation can be correlated with the inflow observations during the drilling of GEo-01.

4.2 Geomechanical modelling

In order to characterise the fractured limestone around the borehole, we will perform a local-scaled model with mechanical properties and fracture distribution.

The surrounding material has a high impact on the permeability and porosity of the reservoir, hence on the borehole productivity (Fig. 7). Using this geomechanical analysis, we will improve various scenarios to better understand:

- What controls the flow. How is it related to the presence of faults and fractures.
- How the structural settings such as faults influence the stress field and what are the effects on the fractured network.
- Which parameters influence the well productivity.

Although this model will focus on the decisive conditions controlling the well performance, the results can then be extrapolated to fractured limestone aquifer.

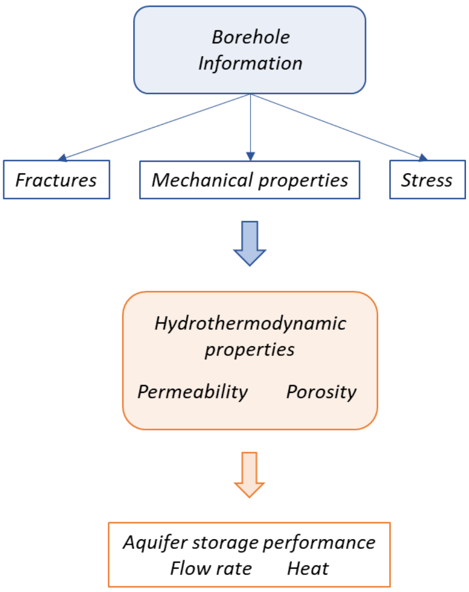

Figure 7: Conceptual scheme of key parameters controlling an aquifer thermal storage reservoir.

5. PRELIMINARY RESULTS AND CONCLUSION

The first observations made on logging data show that the orientation of the natural fractures in Cretaceous limestone is variable. Two sets of fractures stand out, and the presence of a local fault influences their dip direction and dip angle.

Moreover, due to stiffness contrast between layers, some stress variations are expected, although the well does not show any breakout or failure indicator.

The Cretaceous unit composed of fractured limestone seems to have a potential for geothermal exploitation.

The analysis of fracture distribution and the estimation of mechanical and elastic rock properties will allow us to refine best estimate stress scenario for the stress field in the fractured limestone aquifer of the GEo-01 well.

Such kind of simulations help to understand the dominant processes controlling the groundwater flow and heat transport in the targeted reservoir, which are essential for any Aquifer Thermal Energy Storage (ATES) development.

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