Characterisation of a fracture-controlled Enhanced Geothermal System (EGS) in the Trans-Mexican-Volcanic-Belt (TMVB)

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ABSTRACT

Controlling fracture stimulation is fundamental for enhancement of geothermal production.

The development of an enhanced geothermal system (EGS) is one of the goals of the GEMex project, an international collaboration of two consortia, one from Europe and one from Mexico.

In this study, we develop a workflow from fracture characterization at the outcrop all the way to a predictive mechanical model for fracture stimulation from the well borehole. This approach includes the fracture identification and description using the scanline survey method and a solution for processing its output into generating a geological discrete fracture network (DFN). We then used the finite element method to build the mechanical model, discretized with the DFN previously obtained and populated with properties derived from experimental laboratory measurements. Finally, we calculated the fracture propagation using the phase field damage approach, combined with a cohesive-zone model.

This workflow is based on easily accessible data from the field, and gives an accurate mechanical model of the fracture propagation and the pressure distribution for well borehole stimulation. Thanks to its simplicity, this approach can be applied in most EGS case studies as for example in the ultra-deep geothermal system planned for the Netherlands.

1. INTRODUCTION

The Acoculco Caldera in the state of Puebla, East-Central Mexico, is foreseen as EGS development site. Two wells reached temperatures of about 300°C at 2km depth (Fig.1) but found no fluids. To counter the lack of fluids, the developments of an EGS has been considered, increasing the reservoir permeability by fracturing rocks and circulate fluids through them to produce their natural heat, or to connect the wells with a naturally productive area.

To do so, it is essential to understand mechanisms controlling fracture stimulation. It is widely agreed that the major factors implied would be: 1) the local stress state; 2) reservoir pore pressure and temperature conditions; 3) reservoir geometry (layers, fault and fractures); 4) rock mechanical properties; 5) stress changes due to wellbore implementation and fluid circulation. The goal of the study is a concept for the development of an EGS at the Acoculco site.

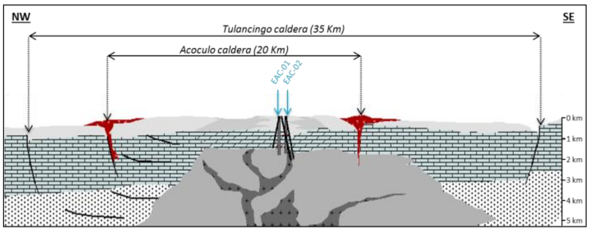

Figure 1: Acoculco caldera section, modified from Lopez (2009).

2. METHODOLOGY

This study consists of a three axis workflow (Fig. 2), going from field measurements of natural fracture systems and sampling of various (potential reservoir) rock types, all the way to hydraulic stimulation and fluid circulation using finite element method simulators.

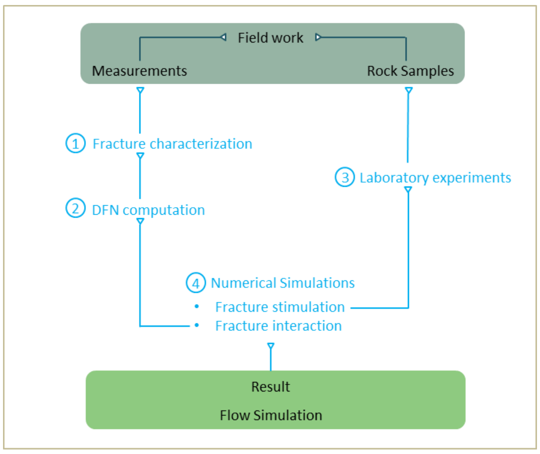

Figure 2: Study workflow.

2.1 Method used to characterize the fracture network

The reservoir fracture characterisation is based on outcrop analogues: we use scanlines (ISRM 1989) to count the fractures and measure fracture properties, most importantly length and aperture. The dataset created from the scanline surveys is automatically processed using a Python script, outputting the statistical distributions of the fracture properties and plotting the scanlines in a georeferenced coordinate system. Thanks to that, we can correlate these scanlines to build a discrete fracture model. To do this extrapolation, we chose to work with the multiple point statistic method, because it preserves the geological patterns when extrapolating. The process consists of: i) creating training images (TIs) using the plotted scanlines; ii) these TIs are analysed as a pixel grid dataset; iii) then, we use a probability map, to define how the TIs should populate the domain, resulting in a statistical and geological accurate discrete fracture network survey method (Bruna 2019).

2.2 Rock physics laboratory

Laboratory experiments were performed to test the most important variables for rock fracturing, such as influence of rock type, confining pressure, temperature and fluid pore pressure. Our experimental set-up can also reproduce operational mechanisms and their impacts, for instance: fluid injection rate or fluid type. In addition to Acoculco rocks, samples from broad analogues have been tested to obtain a better control on the influence of rock types, giving a good statistical representation of each facies.

2.3 Hydraulic stimulation

The predictive mechanical model for hydraulic fracture stimulation is computed in OpenGeoSys (Sachse 2015), an open source finite element simulator, using Phase field in a brittle linear elastic material domain. Phase field is a variation of the Griffith energy release rate, used together with the internal length scale to model the crack seam.

3. RESULTS

3.1 Fracture characterization

Measurements realized in the field correlated with downhole data gave a good control on facies and structural history: changes in stress field orientation; faults and fracture orders and their relative chronology. Combination of fracture network and mineralization helped in understanding the fossil geothermal circulation system.

3.2 Discrete fracture network creation

The fracture identification and description using the scanline survey method is an efficient solution to produce large datasets of reliable data. Processing these data using an automated script helps to identify the most representative values of the fracture network and prevents eventual local anomalies of these properties caused by sampling bias. The multiple point statistics honors fully the input given by the TIs, created from the scanlines, when computing the geological discrete fracture networks (DFN) (fig. 3).

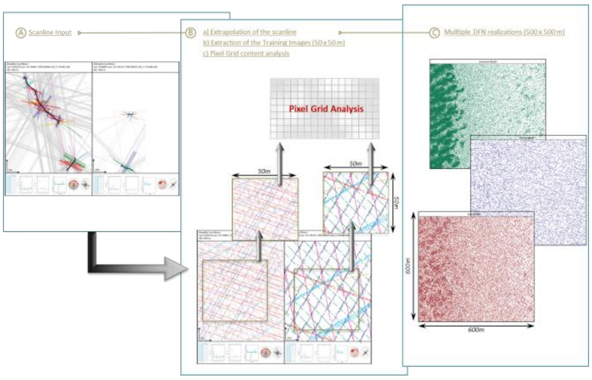

Figure 3: From Scanline surveys to discrete fracture networks using the multiple point statistic method.

3.3 Rock physics measurements

Laboratory experiments helped identify the behaviour of the rock types composing the Acoculco: limestones and marbles intruded by the granitic intrusion, which also caused local skarn formation. We test the mechanical properties to quantify the influence of temperature, pressure and stresses on the rock behaviour. First results showed that the mode I, tensile opening fracturing type in granite is hardly predictable. However, experiments showed that contrary to what was expected, cyclic loading (Fig.4) weakened the rock but is not efficient in improving sample permeability.

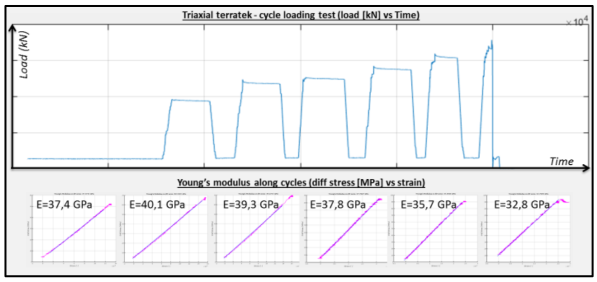

Figure 4: Triaxial cyclic loading test on a granite sample

3.4 Hydraulic Fracture stimulation

Hydraulic fractures were modelled in an assumed perfectly brittle linear elastic domain. First results show that when working with material properties lacking permeability, the crack seam presents no leak-off along its boundaries. As a result, the crack opening is driven by the material fracture toughness and the fluid viscosity (Fig. 5).

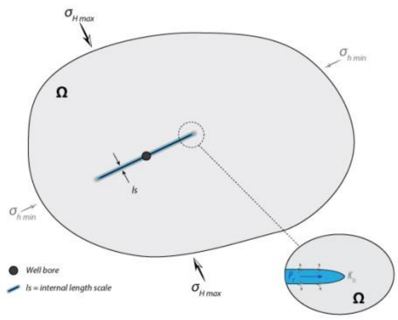

Figure 5: Hydraulic fracture stimulation modelled using Phase field in a domain Ω, a perfectly brittle linear elastic material.

4. CONCLUSIONS

The results of the different stages of this workflow allow to build a final simulation using the Comsol Multiphysics software. This model represents a 2D reservoir, where fluid circulates through the fractured rock, where fluid flow is controlled by the fracture aperture and tectonic stress field.

This simulation calculates, among other parameters, the pressure and temperature profiles at the injection and production wells, and offers an estimate of the permeability of the whole reservoir (Fig. 6).

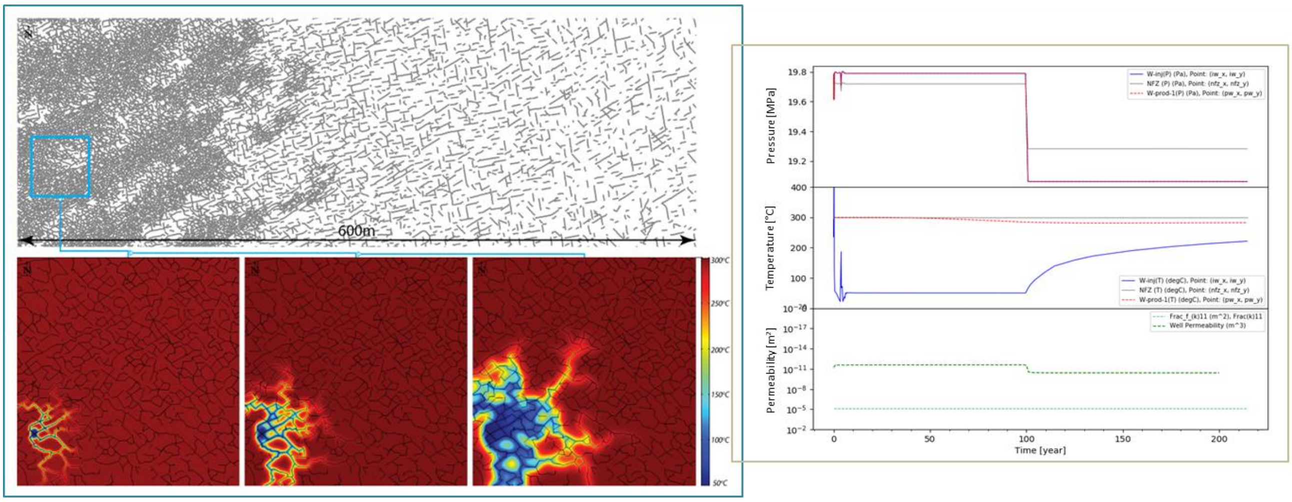

Figure 6: (left) 2D, map view of the fracture reservoir fluid flow model using Comsol Multiphysics – (right, from top to bottom) Pressure plot, temperature plots at injection (blue) and production (red) wells and permeability measurements: (light green) correponds to the maximum fracture permeability, (dark green) represents the Darcy permeability calculated in between the two wells.

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