Fluid pressure drops during stimulation of segmented faults in deep geothermal reservoirs

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1. Introduction

In this study we use the numerical simulator CFRC to analyse pressure drops observed during stimulation of deep geothermal wells (Fig. 1). We develop a conceptual model of a fractured geothermal reservoir to analyse the conditions required to produce pressure drops and their consequences on the evolution of seismicity, fluid pressure, and fracture permeability throughout the system. For this, we combine two fracture sets, one able to be stimulated by shear mode fracturing and another one able to be stimulated by opening mode fracturing. With this combination, the pressure drop can be triggered by a seismic event in the shear-stimulated fracture that is hydraulically connected with an opening-mode fracture. Our results indicate that pressure drops are not produced by the new volume created by shear-dilatancy, but rather by the opening of the conjugated tensile fractures. Finally, our results show that natural fracture/play fault interaction can potentially explain the observed pressure drops at the Rittershoffen geothermal site.

2. Methods

2D CFRC-Boundary element code. Fully-coupled hydro-mechanical problem and the associated induced seismicity (McClure 2012).

The frictional resistance to slip is given by the Coulomb’s law and the evolution of the friction coefficient was defined using a rate- and state formulation (Segall 2010).

3. Geometry and Model Set-up

The geometry of the model consisted of a single fracture defined by several linked segments with different orientations with respect to the maximum compressive stress (εct). Each individual fracture had a length of 60 m and was discretized into 20 cm-long elements (Fig. 2). A constant out-of-plane thickness of h=100 m was considered for all models. Fractures at q=60° are characterised by a critically loaded behaviour, with high associated seismicity and ruptures that can propagate through the entirety of the fracture. On the other hand, fractures at q>60° are characterised as having an aseismic orientation, with slow sliding velocities and unable to produce seismicity (e.g. Gischig 2015; Piris et al. 2017). We assumed strike-slip regime.

SIMULATIONS EVALUATING:

Injection segment orientation (60° or 88°). Model “60-88” and model “88-60” (Fig. 2).

Hydraulic fracture propagation as wing cracks on the 60° tips.

Segment size (50m, 40m, 30m, 20m, 15m, 6m).

Shear dilation angle (0°, 2.5°, 5°).

With similar Rittershoffen configuration (Cornet et al. 2007; Baquero et al. 2017; Meyer et al. 2017) stress state (σ1=50 MPa, σ3=29 MPa), initial fluid pressure of 32.7 MPa and constant injection pressure of 28 MPa. With different segment sizes (80m, 60m, 50m, 40m, 30m, 20m, 15m and 6m).

4. Results

The blue line represents the fracture configuration and the blue dot the injection point. Each fracture segment is 60 m long. Orientation and values of principal stresses and injection pressure (Pinj) are indicated.

5. Discussion

PRESSURE DROP TRIGGERING MECHANISMS

For this setup, pressure drops and seismic magnitudes are lower than those previously described, as stress magnitudes are substantially lower.

Figure 10. Mean pressure drop values observed for all the simulation domain (circles) and felt in the well (squares) for different segment sizes. Error bars indicate the standard deviation.

6. Conclusions

1. The results suggest that two fracture sets can influence pressure drops; one system able to be stimulated by shear (that will produce seismic events) and another one able to be stimulated by opening mode fracturing (that will be aseismic).

2. In the simulations, a pressure drop can be triggered by a seismic event in a shear-stimulated fracture that is hydraulically connected with a tensile of opening mode fracture. The pressure drop is not produced by the new volume created by dilatancy, but rather by the opening of the conjugated tensile fracture.

3. This tensile fracture set may be part of the pre-existing fracture network, or be developed as a hydrofracture during the stimulation phase. However, in our simulations no pressure drops are observed during hydraulic fracture propagation at the tips of a pre-existing fracture.