PROGNOSES FOR INDUCED SEISMICITY AT THE UNITED DOWNS DEEP GEOTHERMAL POWER PROJECT (UPDATE 2)

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1. BACKGROUND

We present the second update of the report ‘Prognoses for Induced Seismicity at the United Downs Deep Geothermal Power Project‘, which was developed within the Horizon 2020 project S4CE (‘Science for Clean Energy‘) and made available on the S4CE SharePoint platform in April, 2019 (retrievable here), as well as a first update. Using a deterministic, physics-based approach, seismicity prognoses for fluid injection tests at the S4CE field site in Cornwall, UK, were developed prior to drilling, and were thus based solely on a greenfield interpretation.

A first update based on the same approach was issued after completion of the first of two planned wells at the United Downs geothermal site (UDDGP).

This second update describes the results of a 30-year thermo-hydraulic-mechanically coupled numerical simulation of circulation taking into account observations from drilling and initial tests of the shallow well (UD2). It is available at the S4CE SharePoint platform serving as an inalterable documentation of the seismicity prognoses and subsequent updates.

Originally, we aimed to develop a prognoses framework that was supposed to be tested at UDDGP as a reference for other (future) geothermal projects. We have worked out seismicity prognoses in parallel to the (ongoing) development of the UDDGP project. In the course of this study, the UDDGP project developer has repeatedly modified the geothermal exploitation strategy including the operational parameters of the drilled wells. Therefore, some of our previous prognoses have become obsolete as they were referring to the original project development plan.

Instead of providing a detailed prognosis of the seismicity response to a certain production/injection scheme (which may change in the future), we restrict our second update to a more general prognosis, which is not depending on details of operational parameters. The second prognosis update accounts for the current interpretation of subsurface conditions prior to (long-term) testing of the two wells.

2. PROGNOSIS UPDATE

Since the last update, a second well has been drilled to a depth of 2214 m. A short-term injection test was carried out during which no seismicity was detected.

These observations were used to 'calibrate' the existing model. We do, however, acknowledge that the injection test predominantly provides information on the near-wellbore region.

In a first step, the hydraulic model was adjusted to attain the observed wellhead pressure at the actually used injection rate. This can only be achieved with a high permeability-model (fault transmissibility in the order of 4 Dm). In previous simulations, high-permeability scenarios have led to unarrested rupture due to the high level of stress criticality resulting from the assumed stress field model and the assumed coefficient of friction. Observations indicate that the previously assumed model overestimates stress-criticality on the target fault. This can be accounted for in two ways: We could either adjust our model of stress magnitudes and fault friction, or introduce an additional term of fault cohesion. We have decided to continue with the latter approach, but are confident that both approaches would have a similar effect on our prognoses.

Keeping our previous model of stress field and coefficient of friction we have used the observation 'no seismicity' in the shallow well (UD2) and the observed seismicity in the deep well (UD1) to estimate a range for fault cohesion using numerical simulations. Fault cohesion is assumed to be homogeneous along the target fault. We conclude that both observations can be (simultaneously) explained when fault cohesion is between 4 and 10 MPa.

The two end-member estimates for fault cohesion were used in a 30-year simulation of geothermal operation. A thermo-hydraulic-mechanically coupled (THM) model was used to simulate Coulomb stress changes on the target fault (Figure 1). Coulomb stresses near the injection well exceed 8 MPa after 30 years of cold water injection. To investigate the range of a possible seismicity response to these stress changes, an upper limit of earthquake magnitude was estimated from the critically stressed area by assuming that the entire area slips in the course of a single earthquake. Figure 2 shows this estimate of maximum earthquake magnitude as a function of time for different stress drop scenarios and the two end-member scenarios for fault cohesion.

Based on these numerical simulation results and the current interpretation of subsurface conditions (which may still change in the future), we make the following prognosis:

1. Fluid injection into the deep well (UD1) is likely to cause an immediate seismicity response already at moderate injection pressure. Our current interpretation of subsurface conditions indicates a high level of stress criticality at a depth of 4.5 km, where the occurrence of larger magnitude events cannot be excluded.
2. Although fluid injection into the shallow well (UD2) at 100 bar has not caused measurable seismicity, thermal stresses accumulate over time and can lead to stress criticality in the vicinity of the injection well. A seismicity response to reservoir cooling is likely. Our current interpretation of subsurface conditions indicates that the associated maximum earthquake magnitude is likely in the range M_w=1 to M_w=3.

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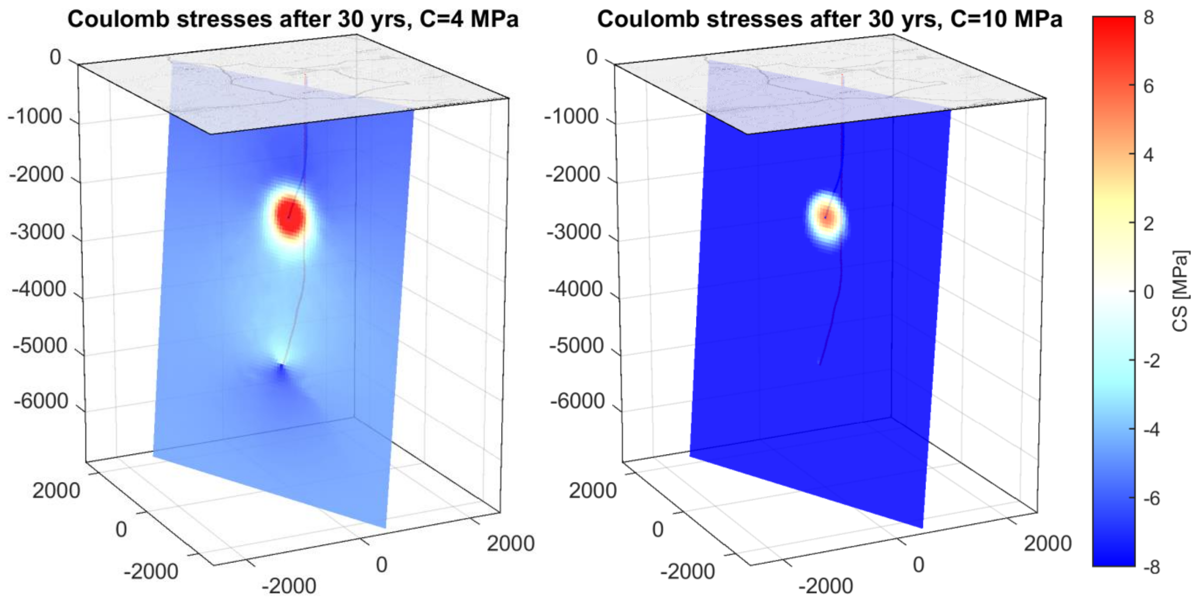

Figure 1: Coulomb stress distribution along the Porthtowan Fault Zone after 30 years assuming fault cohesion of 4 MPa (left) and 10 MPa (right), respectively.

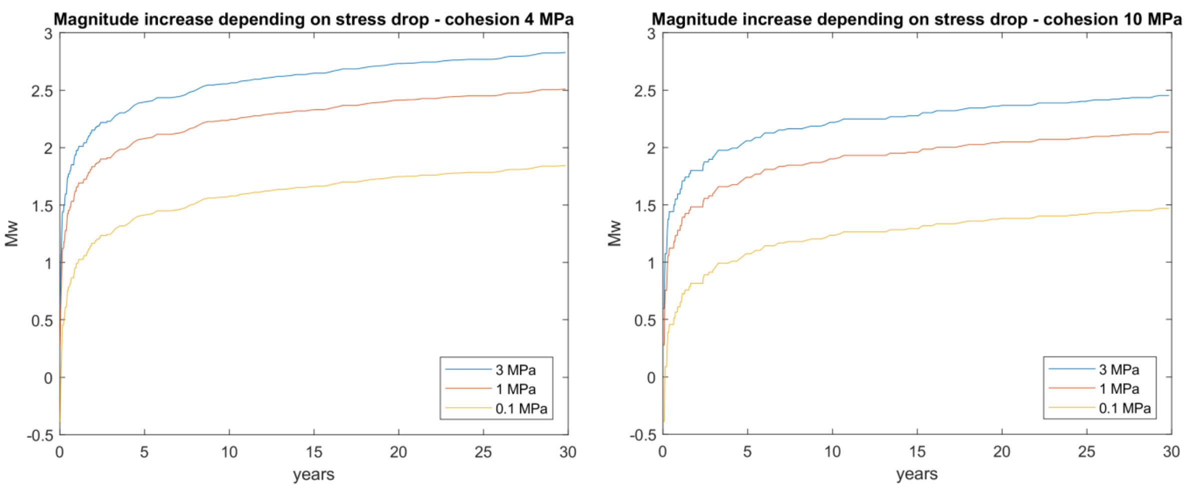

Figure 2: Temporal evolution of maximum earthquake magnitude determined from THM-simulation results. Earthquake magnitude is determined assuming different values for co-seismic stress drop (according to the legend) and fault cohesion of 4 MPa (left) and 10 MPa (right), respectively.