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Permeability Enhancement in Enhanced Geothermal System as a result of Hydraulic Fracturing and Jacking

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A decameter-scale in-situ hydraulic stimulation and circulation (ISC) experiment has been initiated by the newly-founded Swiss Competence Centre for Energy Research – Supply of Electricity (SCCER-SoE) at Nagra's Grimsel Test Site (GTS) as a part of the work-package WP1 of the Deep Underground Laboratory (DUG-Lab) initiative. The experiment area is situated in the southern part of the GTS in a low fracture density volume of the Grimsel granodiorite. The hydraulic properties of the granitic rock mass are supposed to be similar to those expected in the crystalline basement of the alpine foreland where deep enhanced geothermal systems might be developed in future. The main objectives of the multi-disciplinary experiment are to provide a high resolution pre- and post-stimulation characterization of fracture permeability and connectivity, to investigate patterns of preferential flow paths, to describe the pressure propagation during the stimulation phases and to evaluate the efficiency of the fracture-matrix heat exchanger. A comprehensive test & monitoring layout including a fair number of boreholes instrumented with a variety of sensors (e.g. pressure, strain, displacement, temperature, and seismic sensors) is designed to collect detailed data during multiple hydraulic stimulation runs. The diffusion of fluid pressure is expected to be governed mainly by the properties and geometry of the existent fracture network. The hydraulic transmissivity of fractures are in the range of 10^{-7} to 10^{-9} m^2/s whereas the matrix rock has a very low hydraulic conductivity ($K \sim 10^{-12}$ m/s).

As part of the stress measurement campaign during the pre-stimulation phase of the ISC experiment, a series of hydraulic fracturing (HF) and hydraulic tests in pre-existing fractures (HTPF) were conducted. The tests were accompanied by micro-seismic monitoring within several observation boreholes to investigate the initiation and propagation of the induced fractures. Together with results from over-coring tests, these data were used to conclude on the local stress orientation and stress magnitudes. The hydraulic response of the rock mass under hydro-mechanical perturbations was investigated by conducting various hydraulic packer tests (e.g. pulse, constant rate and constant head) in multiple hydraulically isolated borehole sections before and after the stress measurements.

Hydraulic testing of borehole sections which were previously fracked (during HF tests) didn't show a distinct increase in permeability. For the tested borehole sections without natural fractures, this can be explained by the fact that hydraulic fracturing was dominated by fracture normal opening (mode I). In this case, the implemented pressure range (less than 2 MPa) during the hydraulic packer tests was not sufficient to re-open the tensile fractures and permeability would remain unchanged. Conversely, in borehole sections with pre-existing ductile and/or brittle fractures and where HTPF-tests were conducted, the permeability increased by two orders of magnitude, from 10^{-11} m^2/s to$\sim 10^{-9}$ m^2/s (results of hydraulic tests pre and post HTPF). These findings could be explained by permanent enhancement of permeability as a result of shear dilation of existing structures. Considering the efficiency of the hydraulic stimulation process observed at low differential injection pressures, even more significant permeability enhancement is expected during the upcoming stimulation experiments.