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Diagnostic pressure analysis from the in-situ decameter-scale HF experiment

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A total of six hydraulic fracturing (HF) experiments were conducted at the Grimsel Test Site (GTS), Switzerland, with the aim to improve our understanding of processes associated with high-pressure fluid injection in a moderately fractured crystalline rock mass. The HF tests were performed in two inclined boreholes using the same injection interval length (one meter) and a similar injection protocol. The surrounding rock mass is accessed with 12 boreholes which allow high-resolution monitoring of fracture fluid pressure, temperature, strain and micro-seismicity in an exceptionally well-characterized rock mass.

The utilized injection protocol includes i) a breakdown cycle, ii) 2 to 3 fracture propagation cycles with steps of increasing flow rate and cyclic flow rate changes and, finally, iii) a pressure-controlled step-rate test. The shut-in and backflow periods following the main fracture propagation phases are monitored for pressure decay and fluid volume balance. The pressure decay curves after pump shut-in are analyzed using pressure derivative as diagnostic tools to estimate fracture closure pressure, which is related to the minor principal stress component. The Fracture-Compliance method after McClure was used. It assumes a variable fracture compliance, where fracture retains a finite aperture after coming into contact (mechanical closure). Hence, fracture stiffness increases with fracture closure. When the fracture closes, fluid storage decreases. Fracture closure pressure is picked after the first point of deviation from linearity in a G x dP/dG vs. G-time plot. The pressure derivative analysis (PDA) consists of G-function, f1/2-p, t-p loglog and flowback-pressure decay plot. These different plots will be compared with the jacking pressure from the pressure-controlled step-rate test and discussed. Special attention is given to the observed normal fracture stiffness increase during fracture closure using time series of pressure and strain observation points, which are located at one specific fracture. Therefore, the pressure signal in the injection interval is dominated by the early fracture closure around the borehole which is related to the normal fracture stiffness increase. In addition, flow dimension analysis from the pressure derivative curves are presented and compared. Moreover, two different injection fluids with viscosity of 1 cP and 35 cPs were used to evaluate viscosity effects on fracture propagation and in an attempt to upscale our tests to conditions relevant for large-scale reservoir stimulation.