# Preliminary results of six decameter-scale hydraulic fracturing (HF) experiments at the Grimsel Test Site (GTS)

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Six hydraulic fracturing experiments were conducted at the Grimsel Test Site (GTS), Switzerland, to study the geometry of new created fractures and interactions with the pre-existing fracture network. In addition, the hydro-mechanical effects during stimulation were investigated. All six tests followed a similar injection protocol (Figure 1) to study the response of the rock mass at different injection locations and the influence of injection fluid characteristics. For this, water and a xanthan-salt-water (XSW) mixture were injected. The viscosity of the XSW mixture was 35 times higher compared to water. Except HF6, all HFs were initiated borehole intervals covering intact rock. Several monitoring systems were installed to study transient pressure propagation, deformation within the rock mass and along shear zones, and seismic activities.

The GTS is located in the Central Swiss Alps, beneath the mountains of the Grimsel Pass. The in-situ stimulation and circulation (ISC) (Amann et al., 2018) experiment is located in the southern part of GTS. Geologically, the ISC test volume was situated slightly south of the boundary between Central Aare Granite (towards north) and Grimsel Granodiorite (towards south). Overall moderately fractured rock mass is showed a pervasive foliation and was intersected by five major sub-vertical shear zones. The shear zones were subdivided into two sets. The first set (referred to as: S1) included three ductile shear zones that were characterized by a strong increase in degree foliation and mylonitization. All three shear zones had a NEE-SWW strike and were dipping towards SE. The second set (referred to as S3) contained two brittle ductile shear zones, with each localized within a biotite-rich meta-basic dyke. Between the two shear zones the fracture density increased from 0 to 3 fractures per meter (outside from shear zones) to >20 fractures per meter (between S3 shear zones) (Krietsch et al, n.d.). Optical televiewer logging in INJ1 and INJ2 (Fig. 1 B) indicated a preferred fracture orientation striking E-W along the main structural features (S1: red triangles; S3: green diamonds).

**Table 1: Hydraulic and seismic characteristics of the 6 HF experiments.**

| Test | Bore-hole | Depth | Injectivity Enhancement Ratio | Total Injected Volume [l] | Injection recovery [%] | Total Number of recorded events |
|---|---|---|---|---|---|---|
| HF1 | INJ1 | 40.5 | 2240 | 1565 | 24.8 | N/A |
| HF2 | INJ1 | 36.3 | 6710 | 964 | 28.7 | 2204 |
| HF3 | INJ1 | 20.3 | 1760 | 911 | 2.0 | 1997 |
| HF5 | INJ1 | 14.5 | 590 | 1553 | 0.3 | 1969 |
| HF6 | INJ2 | 38.9 | N/A | 1222 | 58.4 | 94 |
| HF8 | INJ2 | 15.7 | 360 | 1142 | 1.8 | 722 |

The initial injectivity of the intact intervals ranged from 2.7E-4 to 5.5E-4 l/min/MPa for all intact intervals. The injectivity enhancement ratio varied from 360 to 6710 (Table 1). The injectivity after stimulation reached values between 0.16 and 0.88 l/min/MPa south of S3. North of S3 shear zones, the post-stimulation injectivity ranged from 1.23 to 3.69 l/min/MPa. The injected volume during each test varied between 911 and 1565 l with an injection recovery of 0.3 to 2.0% south of the S3 shear zones and 24.8 to 58.4% north of the S3 shear zones. The jacking pressure between 5 to 6.4 MPa were observed north of the S3 shear zones and decrease to 2.2 MPa north of the S3 shear zones. Figure 1 C) displays flow-rate versus injection pressure for all HF experiments during different injection cycles. The pressure is read at the latest time of the constant injection rate before the flow rate was ramped up. HF1, HF2 and HF6 showed similar curves at lower injection rates, except for the first propagation cycle (C1). All this tests revealed similar final injectivity, jacking pressure and injection recovery. This can be explained by the controlling effect of pre-existing structures that were connected by the hydraulic fractures during the first propagation cycle. The transient pressure response in the injection intervals indicated that at least two different pre-existing structures were involved. At high flow rate, HF6 had higher interval pressure due to the high fluid viscosity used for this injection. HF3 and HF8 showed similar injectivity, jacking pressure and injection recovery. As there was no back-flow, the fracture near the borehole was assumed to close directly after shut-in. During these two tests, the S3 shear zone drained the injected fluid to the AU-tunnel. HF5 behaved differently as the HF was propagated into one of the seismic observation boreholes during the first propagation cycle. Quantitative analysis of hydro-mechanical rock mass response is current work in progress.

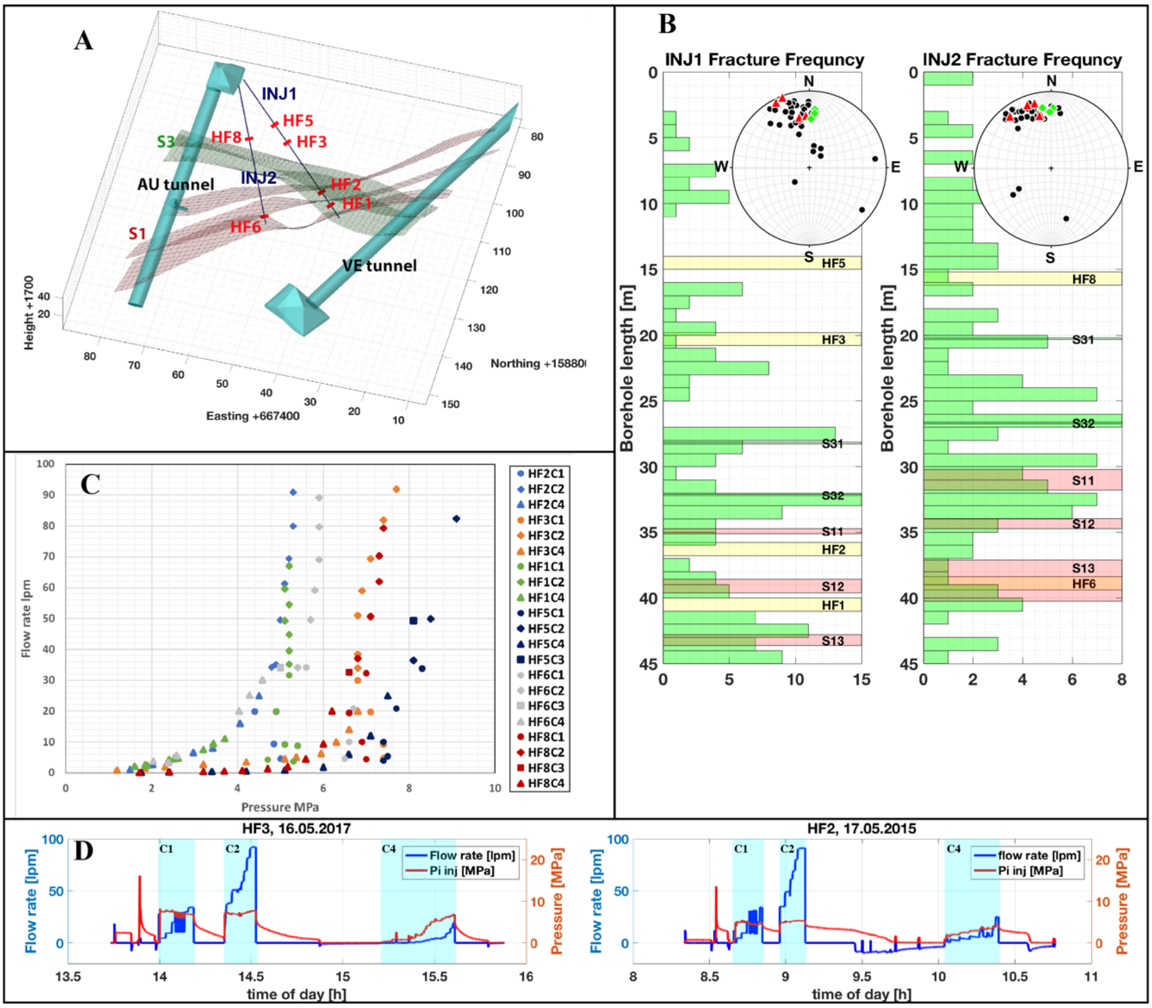

**Fig. 1: A) Experimental volume with the main structures and the locations of the stimulation intervals. B) Fracture density incl. lower hemisphere equal-angle stereonet for the two different injection boreholes INJ1 and INJ2. The yellow bands indicate the position of the hydraulic fractures and the red respective green bands indicate the shear-zones S1 and S3, respectively. C) Flow-rate vs. pressure plot for all experiments sorted by fracture propagation cycle 1 (C1) and 2 (C2), flushing cycle (C3) and pressure step rate test (C4). D) Two injection protocols of HF3 (left) and HF2 (right).**

## *References*

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