Slip tendency and reactivation pressure prediction of natural fractures at the Bedretto Underground Laboratory, Switzerland

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BedrettoLab: SCAN ME

Abstract:

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

1 Introduction

Bedretto Underground Laboratory for Geosciences & Geoenergies (BedrettoLab)

- **Scaled-down in-situ hydraulic stimulation experiments** in a representative granitic rock volume (Fig 1, Ma et al., 2022)
- Overburden: > 1000 m and multiple large fault zones in the volume
- Stress state: transitional between normal and strike-slip faulting (Bröker and Ma, 2022)
- **Stimulation borehole ST1** (399 m long) separated into 14 injection intervals by multi-packer system

Research question

- Hydraulic shearing of pre-existing fractures is a key mechanism for enhancing permeability in engineered geothermal systems (EGS)
- **Challenge:** Prediction of fracture **reactivation pressures** to efficiently design the injection protocol

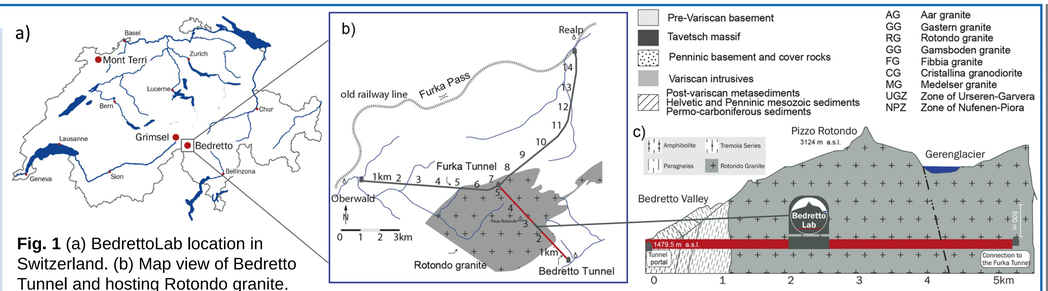

Fig. 1 (a) BedrettoLab location in Switzerland. (b) Map view of Bedretto Tunnel and hosting Rotondo granite. (c) Cross-sectional view of the BedrettoLab w.r.t. the tunnel. (modified after Keller and Schneider (1982) and Ma et al. (2022))

2 Logging & Slip Tendency Estimation

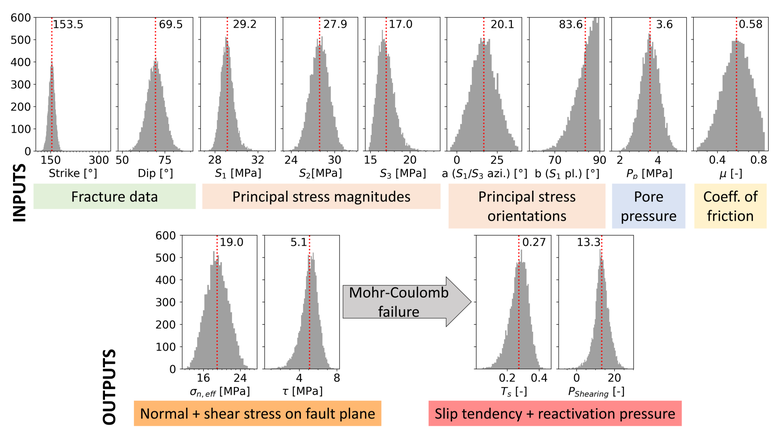

Fig. 3 Monte Carlo simulation (n = 10 000) to calculate the fractures' slip tendency and reactivation pressure.

Methodology

- We used acoustic (**ATV**) and optical (**OTV**) logging to determine the major geological structures (Fig. 2) in **interval 11** (from **132-150 m measured depth**)
- Based on structure orientation and far-field stress tensor (Bröker and Ma, 2022), we set up **Monte Carlo simulations** (n = 10 000, Fig. 3) to calculate shear and normal stress on each structure (Fig. 4)
- Fault criticality was evaluated using the **slip tendency** ($T_s = \tau/\sigma_{n,\mathrm{eff}}$) and **critical pressure to induce slip** according to a Mohr-Coulomb failure criterion

Results

- Multiple open and filled fractures in interval 11 have low mean reactivation pressures between 11.0 and 13.4 MPa and high slip tendency (Fig. 5)
- **Reactivation pressures** are **lower than S_3 magnitude**, so hydraulic shearing will occur prior to hydraulic fracturing

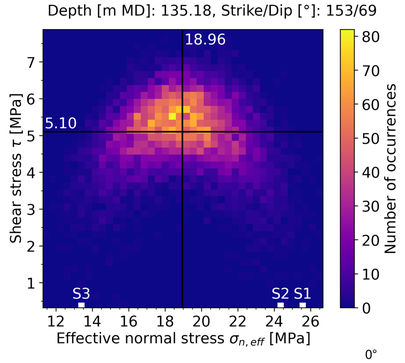

Fig. 4 Shear and effective normal stress on the open fracture based on the Monte Carlo simulation in Fig. 2.

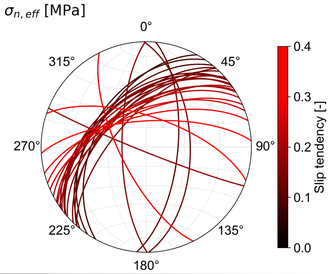

Fig. 5 Stereonet of the fractures in interval 11, colored according to their mean slip tendency from the Monte Carlo simulation.

3 Hydraulic Stimulation

Interval 11 stimulation

- Injection of 2.2 m³ in March 2022 (Fig. 6)
- A **pressure-controlled injection** protocol allowed for the detailed estimation of the reactivation pressure

Fracture reactivation, P-Q plot (Fig. 7):

- Cycle 1: Very low injectivity after the third pressure step → Flow boundary?
- Large increase in injectivity after "breakdown" like feature in interval pressure → Abrupt reactivation: **Breaking cohesion of a fracture?**
- Cycle 2: More gradual reactivation occurs → **Reactivation at 13.3 MPa** (intersection of two linear regressions)

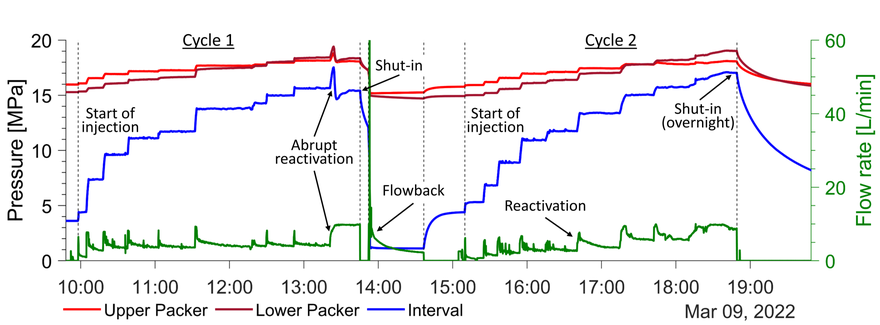

Fig. 6 Injection protocol of the pressure-controlled stimulation in interval 11. The interval pressure was measured downhole, while all other parameters were measured at the surface.

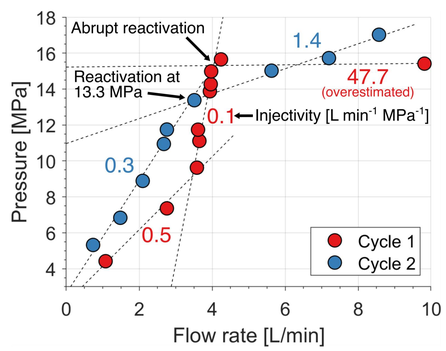

Fig. 7 P-Q plot of the two stimulation cycles. Values were taken at the end of each pressure controlled step shown in Fig. 6.

4 Discussion

- Observed **reactivation pressures agree with calculated values for open fractures**, but filled fractures with lower reactivation pressures exist. These might not be reactivated due to **cohesion**.
- **Monitoring data** (seismic locations, distributed temperature sensing) suggests that mainly the **upper half of the interval was stimulated**. Exact determination of which fracture was reactivated remains difficult, also due to small injected volume → Second stimulation with lager volume in April 2023

References

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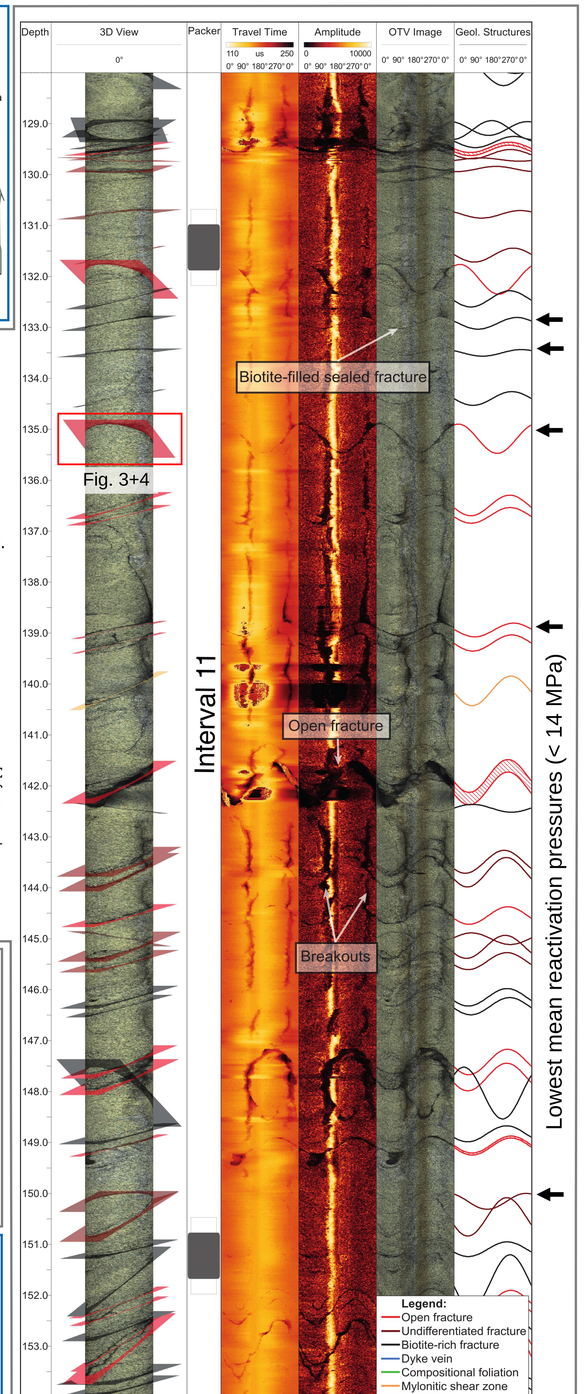

Fig. 2 Optical (OTV) and acoustic (ATV) televiewer logging of interval 11. Logs are oriented to high side. Fracture picks from Wenning et al., 2023.