ETH – Master Thesis project 2023

Source physics of fluid-induced earthquakes

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Scope and motivation

Earthquakes are one of the most significant hazards for human society, and, at the same time, remain the most elusive. Improving the ability to forecast earthquakes is one of the main challenges remaining for the natural sciences. With the European Research Council (ERC) Synergy project **Fault Activation and Earthquake Rupture** (**FEAR**), a consortium of scientists from ETH Zurich in Switzerland, the RWTH Aachen University in Germany, and the Instituto Nazionale di Geofisica e Vulcanologia (INGV) in Italy are conducting a suite of ambitious experiments in the world-unique Bedretto Underground Laboratory for Geosciences and Geoenergy (BedrettoLab), an underground experimental facility in the Bedretto Tunnel, located at 1000m depth under the Swiss Alps. The core idea of FEAR is to gain understanding on how earthquakes start and stop by using hydraulic stimulation to modify stress and initiate small non-damaging earthquakes (magnitude ∼1.0 events on fault patches of 10-50m scale) on candidate faults in the vicinity of the Bedretto Tunnel.

State-of-the-art numerical modeling offers a viable tool to investigate the source processes of fluid-induced earthquakes, since they can investigate the role of different physical mechanisms and their interactions. In return, they provide physics-based constrains into processes that are active along deep faults. In this master thesis project, we seek a motivated student to test how different injection strategies and hydraulic properties on- and off-fault affect the nucleation, propagation, and arrest of fluid-induced earthquakes. This will be done using our newly-developed Hydro-Mechanical Earthquake Cycles (H-MECs) numerical framework (Dal Zilio et al., 2022). This fully coupled numerical framework accounts for full inertial (wave) effects and fluid flow in a finite difference method and poro-visco-elasto-plastic compressible medium.

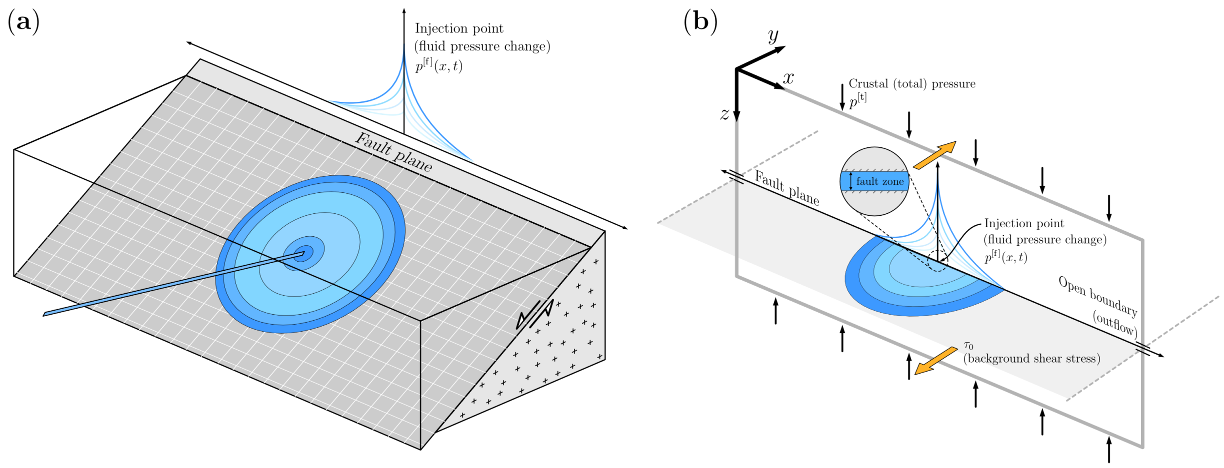

Figure 1: (**a**) Schematic representation of a fluid injection experiment. (**b**) Conceptual 3-D fault model proposed in this master thesis project to simulate injection of fluids and slip on a fault plane with a finite fault zone thickness embedded in a poro-visco-elasto-plastic bulk medium. Snapshots of a sample fluid pressure diffusion scenario is shown for illustration.

Goals

This thesis aims to target the following tasks:

- Understand how fluids influence and control the onset and interplay of slow-slip events and regular earthquakes. Based on the newly-developed H-MECs modeling tool, we aim to reproduce and investigate the seismicity in crustal-scale faults within a single hydro-mechanical computational framework.
- Assess the optimal injection strategies that allow to reproduce either small or relatively large (magnitude ∼1.0) earthquakes.
- Test Each different set of pre-stress conditions: (1) undisturbed conditions — serving as baseline experiment to characterize the natural variability of fault properties (stress conditions, injectivity, and permeability), and (2) stress barrier imposed by tunnel-induced pressure depletion.

We expect a highly-motivated student to be interested in geophysics, and rock rheology, have some experience in Numerical Modeling (e.g., finite difference method) and in programming software (e.g., MatLab, Python, C, C++), and be motivated to work in an international and interdisciplinary team. Questions can be directed to Dr. Luca Dal Zilio (*luca.dalzilio@erdw.ethz.ch*).