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Characterizing fractures and shear zones in crystalline rock using seismic and GPR methods

Joseph Doetsch, Claudio Jordi, Niko Laaksonlaita, Valentin Gischig, Cedric Schmelzbach, and Hansruedi Maurer
ETH Zurich, Department of Earth Sciences, Zurich, Switzerland (joseph.doetsch@erdw.ethz.ch)

Understanding the natural or artificially created hydraulic conductivity of a rock mass is critical for the successful exploitation of enhanced geothermal systems (EGS). The hydraulic response of fractured crystalline rock is largely governed by the spatial organization of permeable fractures. Defining the 3D geometry of these fractures and their connectivity is extremely challenging, because fractures can only be observed directly at their intersections with tunnels or boreholes. Borehole-based and tunnel-based ground-penetrating radar (GPR) and seismic measurements have the potential to image fractures and other heterogeneities between and around boreholes and tunnels, and to monitor subtle time-lapse changes in great detail.

We present the analysis of data acquired in the Grimsel rock laboratory as part of the In-situ Stimulation and Circulation (ISC) experiment, in which a series of stimulation experiments have been and will be performed. The experiments in the granitic rock range from hydraulic fracturing to controlled fault-slip experiments. The aim is to obtain a better understanding of coupled seismo-hydro-mechanical processes associated with high-pressure fluid injections in crystalline rocks and their impact on permeability creation and enhancement. GPR and seismic data have been recorded to improve the geological model and characterize permeable fractures and shear zones. The acquired and processed data include reflection GPR profiles measured from tunnel walls, single-borehole GPR images, and borehole-to-borehole and tunnel-to-tunnel seismic and GPR tomograms. The reflection GPR data reveal the geometry of shear zones up to a distance of 30 m from the tunnels and boreholes, but the interpretation is complicated by the geometrical ambiguity around tunnels and boreholes and by spurious reflections from man-made structures such as boreholes. The GPR and seismic traveltime tomography results reveal brittle fractured rock between two ductile shear zones. The brittle features, which will be critical for the upcoming stimulation experiments, will be characterized in more detail with reflection GPR monitoring of hydraulic tests, such as a saline tracer injection.