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Building a geological model for analysis and numerical modelling of hydraulic stimulation experiments

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Understanding the thermo-hydro-mechanical behaviour of a rock mass during high-pressure fluid injections (e.g., hydraulic stimulation experiments) requires experiments at multiple scales with scale dependent characterization of groundwater pathways and rock mass properties. Therefore, detailed geological knowledge about the test volume is crucial as a baseline for the experiment design, analysis of experimental data and numerical modelling. A recent stimulation experiment, that required a highly precise 3D geological model, is the decameter scale in-situ stimulation and circulation (ISC) experiment, which was carried out in 2017 at the Grimsel Test Site, Switzerland. This experiment featured six hydraulic shearing and six hydraulic fracturing tests. In preparation to the experiment, a comprehensive rock mass characterization was conducted, combining geological mapping, geophysical prospecting and hydraulic testing, as well as in-situ stress measurements. The development of this geological model using Matlab and its key properties are presented in this contribution.
As a starting point for the geological model, discontinuities (i.e. fractures) and shear zones (i.e. brittle-ductile and ductile) were mapped along tunnels (i.e. geodetic measurements) and boreholes (i.e. using optical-televiewer logs), and displayed as discs with true coordinates and orientation. Afterwards, fracture densities throughout the test volume were determined along all boreholes, as well as statistics about fracture orientations. Subsequently, the mapped shear zones were subdivided into two sets, based on fabric and orientation. As a first interpretation of the geological data, we could define a total of five shear zones within these two sets and interpolated them linearly through the volume. This interpretation was validated by geophysical (i.e. seismic tomography and ground-penetration-radar) and hydraulic methods (i.e. cross-hole testing). As a final step we interpolated the shear zones throughout the volume based on a finer grid (i.e. grid size between 0.7 and 2.5 m) and integrated true local orientations of the data points. The final geological interpolation presents our interpretation of the geology at this decameter scale.
The resulting recent geological model has been used for the borehole design, defining sensor locations and choosing the injection intervals for the hydraulic stimulations. Along with comprehensive stress measurements, the geological model has been used to calculate slip tendencies along the geological structures and to design the hydraulic injection protocols. Additionally, we will use this geological model to set up a discrete fracture network (i.e. currently in progress). All numerical models, as well as models for simulating deformation, pressure propagation and seismicity during the hydraulic stimulations of the test volume will be firstly based on this basic geological model, and later on the discrete fracture network model. Soon, we will publish the geological dataset (i.e. geological model visualized in Matlab and the database including all geological observations in figure- and text-files) via ETH-library. Thus, it is available for numerical modelling of hydraulic stimulation experiments and validation of hydro-mechanical codes, based on true field observations.