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Evolution of Preferential Flow Paths during the In-situ Stimulation and Circulation (ISC) Experiment – Grimsel Test Site

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Presence of scale-dependent rock discontinuities such as fractures and faults controls the fluid flow regime as well as transport of dissolved solutes, particles and heat in fractured media. Identification and characterization of these preferential flow paths, therefore, is a critical step toward the development of so-called engineered geothermal systems (EGS). The sustainability of the geothermal reservoirs is rigorously governed by the conductivity and connectivity of the fracture network. In this context, man-made activities such as hydraulic stimulation and non-isothermal fluid circulation can influence the efficiency and productivity of the engineered reservoirs. The best practice in this framework is to develop the EGS reservoirs over a large fracture network rather than channelized preferential flow paths between the injection and production boreholes via granting more residence time to cold injected water to heat up prior to production.

Under the framework of the in-situ stimulation and circulation (ISC) experiment, series of hydraulic shearing and hydraulic fracturing tests were conducted in a moderately fractured crystalline rock mass at the Grimsel Test Site (GTS), Switzerland. A hot water circulation in the stimulated volume that lasted 70 days followed these tests. Multi-scale pre- and post-characterization was performed to quantify the efficiency of the hydraulic stimulation and circulation on the conductivity and connectivity of the preferential flow paths. The characterization phase involved single- and cross-hole hydraulic tests, thermal and solute tracer tests as well as cross-hole GPR and active seismic measurement. The combination of these comprehensive and multi-disciplinary measurements allowed characterizing the evolution of preferential flow paths that were created and/or enhanced during the hydraulic stimulation phase. According to the results, most of the hydraulic stimulation tests were controlled by the existing brittle-ductile shear zone in the stimulated volume via permanent increment of the swept volume without any significant permeability enhancement. During the hot water circulation, however, a reduction in swept volume coinciding with permeability reduction was quantified as a direct thermo-mechanical response of the fractured media to hot water injection. It is believed that this behavior might be temporary and reversible. In this contribution, we demonstrate how the comprehensive analysis of different characterization methods provides quantitative insight to the flow path characteristics. The outcome of this study conceded the dominant characteristics of preferential flow paths during the development of EGS via influencing the flow characteristics permanently and/or temporarily.