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Thermo-hydrodynamic response of sparse fracture systems to heat injection

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Abstract

Understanding how heat is stored and transported in tight rocks with sparse fractures is paramount to predict the thermal evolution of spent fuel, high-level nuclear waste repositories. Here we present field results from two controlled heat injection experiments performed through a borehole array deep-seated in crystalline rock at the Grimsel Test Site (GTS), Switzerland. Active heat injection was carried out by heating water using an electrical flow heater up to 45°C for a duration of 10 days (1st test) and 40 days (2nd test). Fluid injection took place across a discrete, 2-m long interval packing off a single flowing fracture. Distributed temperature sensing (DTS) was achieved by deploying optical-fiber through two open boreholes and three grouted boreholes (1st test) or using three packed-off and three fully-grouted boreholes (2nd test). Fluid pressure was monitored at the well head using piezoresistive transducers. We observed multiple thermal breakthroughs, ranging from fast (< 10 hours) to late (>20 days) arrivals, resulting in a temperature increase up to 10°C at 4 to 5 meters from the injection point (Figure 1). The deployment of optical-fiber loops allowed the detection of 3-D thermal fronts (Figure 2). Two responses are identified: (i) a fast, advection-dominated response which developed across a network of well-connected fractures and (ii) a slower, diffusion-dominated response that propagated through low-permeability rock mass primarily by heat conduction. The 3-D thermal response presented herein will be interpreted in the future using a discrete fracture network model.

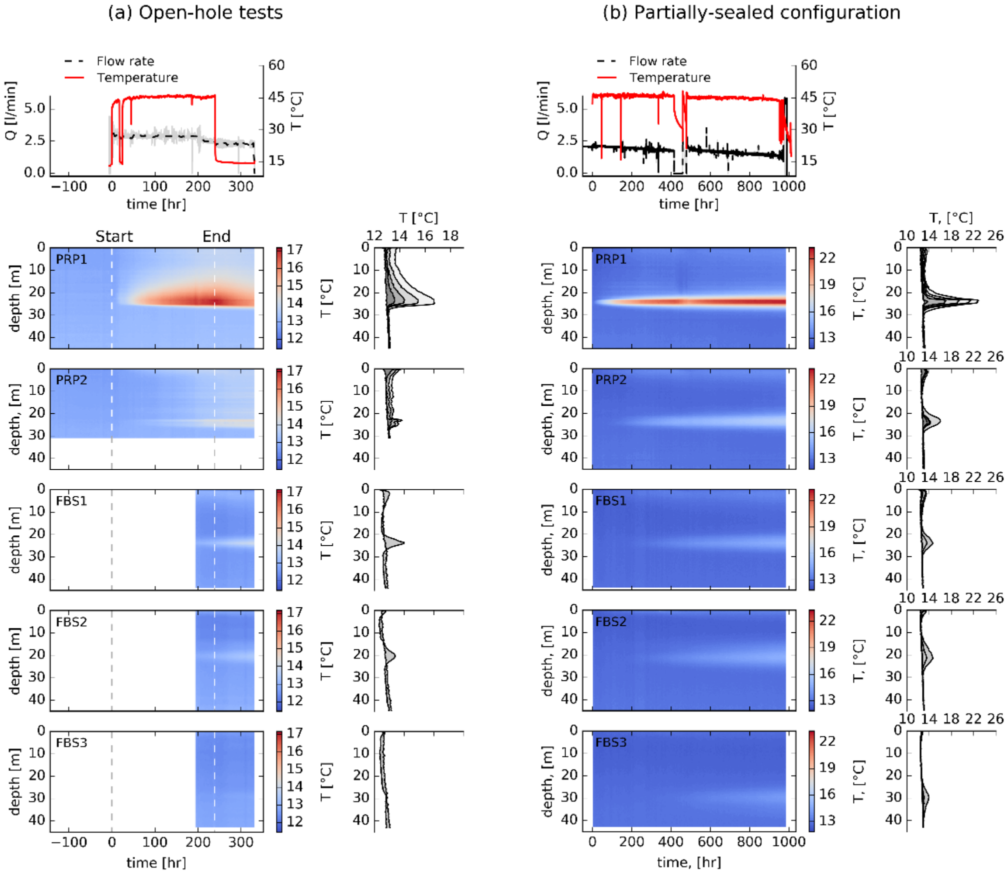

Figure 1: Thermal breakthrough observed during open-hole (A) and partially-sealed heat injection tests (B).

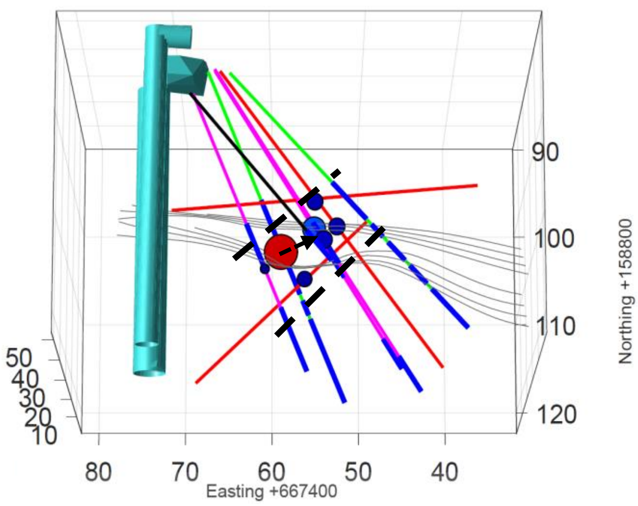

Figure 2: 3D bubble plot showing the location of thermal breakthroughs.