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Characterization of a hydrothermally active fault zone in the Central Alps based on geophysical borehole logging data

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An exhumed near-vertical fault zone embedded in sheared and fractured crystalline rocks in the central Swiss Alps has been drilled to a length of 125 m and geophysically explored. The fault zone shows long-lived and still active hydrothermal circulation to several kilometers depth. A comprehensive suite of borehole logging data were collected along the Grimsel Pass borehole GDP-1 during the summers of 2015, 2016, and 2017. The most complete data set was collected in 2015 directly after drilling under open borehole conditions, comprising optical and acoustic televiewer, borehole caliper, nuclear, electrical, temperature, multi-frequency full-waveform sonic, and constant offset borehole radar logs as well as flowmeter tests. The electrical logs were affected by the drilling mud in 2015 and consequently repeated in 2016 and 2017.

GDP-1 acutely intersects the main brecciated fault core and comprehensively samples the surrounding damage zone. The probed rock mass consists of metagranite and is geochemically homogeneous, but exhibits strong variations in terms of its structural fabric due to ductile and brittle deformation.

The brittle deformation of the damage zone is characterized by fractures of varying aperture and represents the dominant response in all logs. These features are identified from optical televiewer and core data and can be clearly detected in the neutron-neutron, single point resistivity, sonic, and, to a lesser extent, in the normal resistivity logs. Porosity estimates are obtained from borehole radar velocities and calibrated with laboratory measurements made on core samples. Zones of high porosity are related to open fractures and large aperture fractures filled with porous fault gouge material. Since the vertical resolution of the borehole radar is 1-2 m, we utilize the neutron-neutron log to downscale the corresponding porosity estimates to be more representative of the strong fluctuations due to intense fracturing observed on the other log data.

The high-porosity zones associated with brittle deformation are likely to be the main flow pathways in this geological environment. To shed more light on the hydraulic characteristics of the system a combination of self-potential, temperature, and fluid resistivity logs, as well as flowmeter tests are analyzed. A drawback of the flowmeter tests carried out in 2015 is that the borehole conditions did not correspond to the natural flow state. Nevertheless, the data shows two distinct zones of inflow and one outflow zone. The self-potential data recorded in 2016 and 2017 are remarkably repeatable and contain an abundance of anomalies, which are mostly likely of electrokinetic origin. This interpretation is supported by the fact that most of the anomalies can be associated with fracture zones. On a larger scale, we also observe several distinctly different zones in the self-potential signal, which, to a large extent, correlate with the layering observed in the fluid resistivity and an anomaly observed in the temperature measurements. These observations suggest a conduit-like hydraulic behavior dominated by the steeply dipping geological structure and, possibly, the inflow of water from several different sources.