Thermal evolution of the Grimsel Pass hydrothermal system: insights from numerical modeling

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Hydrothermal springs with discharge temperatures of up to 28°C occur beneath the Grimsel Pass in the Transitgas AG tunnel crosscutting through para-autochthonous crystalline units of the Aar massif (Pfeifer et al., 1992). Located at about 1900 m.a.s.l., these springs are the highest thermal discharges documented in the entire Alps (Belgrano et al., 2016). The springs occur over a narrow tunnel section of <100 m and are associated with a major mylonitic shear zone that has experienced brittle overprint during uplift and cooling of the Aar massif. Stable and radiogenic isotope analyses ($\delta^{18}O$, $\delta^{2}H$, ^{3}H, ^{14}C) reveal a meteoric origin and suggest that the springs infiltrated more than 30,000 years ago at an elevation of about 2200-3000 m.a.s.l. (Waber et al., 2016). Moreover, these analyses show that the springs actually correspond to a mixture of an old thermal component with a surface-derived, young cold water component. Applying an enthalpy balance and assuming a contribution of 40-50% yield hypothetical spring temperatures of 45-50°C in the absence of cooling with cold water. Beside the occurrence of warm springs, hydrothermal activity is also manifested by the occurrence of a hydrothermal breccia which is widely exposed at and near the Grimsel Pass. Dating of this so-called Grimsel Breccia demonstrated that the hydrothermal system has been active for at least the last 3.3 Ma years (Hofmann et al., 2004). Furthermore, oxygen isotopes in quartz and adularia, combined with fluid inclusion data, indicate a maximum Breccia formation temperature of 160°C. Taking into account a geothermal gradient of 25°C per km and a mean annual surface temperature of 4°C this temperature estimation suggest that meteoric water infiltrates to a maximum depth of 6.25 km.

For this contribution we present results from a numerical modeling study aiming at (i) unraveling the thermal and hydrodynamic evolution of the Grimsel Pass hydrothermal system and (ii) at evaluating the general geothermal potential of fracture-flow driven hydrothermal systems. The latter is particularly important with respect to Switzerland's ongoing effort in accessing and/or creating such systems for geothermal power production. Numerical simulations were performed using two different approaches. Results obtained from a 3D (dual) continuum model using TOUGHREACT suggest that steady-state temperature distribution is approached in less than 2000 years, which is much faster than the lifetime of the Grimsel-Pass hydrothermal system. Moreover, these 3D simulations demonstrate that the extent of temperature anomalies induced by fracture-flow driven hydrothermal systems are mainly controlled by (i) the reservoir temperature, (ii) the upflow velocity, i.e., by the fault zone permeability as well as the hydraulic head driving hydrothermal circulation, and (ii) the 3D extent of the fault system. Results obtained from a 2D discrete fracture network model using ConnectFlow (AMEC, 2012) coupled to PFLOTRAN (www.pflotran.org) confirm the importance of the upflow velocity in controlling the temperature distribution and thus the geothermal potential of fracture-flow driven hydrothermal systems. Moreover, they demonstrate that the detailed fault-zone geometry such as fracture orientation, -spacing and -aperture plays a key role as well. In conclusions, applied to the Grimsel pass hydrothermal system, our models suggest that the small thermal anomaly observed in the Transitgas AG tunnel results from low discharge rates (<50 L/min) induced by the relatively low fault-zone permeability of about 10^{-13} m^2.

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