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On the geothermal potential of crustal fault zones: a case study from the Pontgibaud fault zone (French Massif Central, France)

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By considering a multidisciplinary approach, the present study aims to understand the potential of a new and novel type of geothermal system for high temperature and electricity production: Crustal Fault Zones (CFZ). Numerous recent studies indicate that crustal-scale fault zones represent efficient conduits for meteoric fluids to flow down to mid-crustal depths (Haines et al., 2016), in particular near the brittle-ductile transition where temperatures may exceed 400°C (Violay et al., 2017). One such example, the Pontgibaud fault zone (French Massif Central), is a 30 km-long and 3 km-wide fault zone. Current fluid circulation is attested by the presence of CO_2-rich thermomineral springs. The local heat flow value of 110 $mW.m^{-2}$ was estimated from a measured temperature gradient of 41°$C.km^{-1}$. The Pontgibaud fault zone has been well studied in the last few years (Bellanger et al., 2017). In particular, vertical resistivity profiles show anomalously low resistivity zones at 3 km depth, which seems to be connected to the other large-scale low resistivity zone at 15 km depth (Ars et al., 2017). With the available geophysical database and additional geological field measurements, a numerical approach dedicated to the understanding of Pontgibaud hydrothermal system will be relevant, as demonstrated by 2D numerical models of Soultz-sous-Forêts geothermal system (Alsace, France) (Guillou-Frottier et al., 2013). There, the numerical models led to the prediction of two additional thermal anomalies, one of them (Rittershoffen, Alsace, France) being currently under exploitation since 2014. The present study aims at investigating the possibility for the Pontgibaud crustal-scale fault zone to host an active hydrothermal system. This multi-disciplinary approach allowed us to formulate a numerical model based on the geological knowledge of the Pontgibaud area. Two main unknown variables play a key role on possible fluid circulation: fault zone geometry (dip) and permeability ratio "R" between the fault zone and its host rocks, which varies from 1 to 300. For a sufficiently permeable fault zone (greater than 4×10^{-15} m^2), buoyancy-driven flow creates a positive thermal anomaly at a depth of 2-5 km. Benchmark simulations indicate that vertical structures promote largest thermal anomalies at shallow depths. Moreover, for a vertical fault zone, the thermal anomaly is larger for high R values. Fluid circulation patterns are described in a regime diagram parameterized by the fault dip, the thermal anomaly and the R ratio. Finally, numerical models of the geologically-constrained Pontgibaud fault zone show that a temperature of 150°C at a depth of 2500 m can be obtained for a fault network permeability of 9×10^{-15} m^2. The resulting thermal regime down to 15 km depth appears consistent with previously obtained resistivity profiles. Using this analytical multi-disciplinary and numerical approach, this work established a potential predictive tool for future high-temperature geothermal operations in a basement context.