The role of fluid chemistry on permeability and fault strength evolution in granite

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Efforts to maintain and enhance reservoir permeability in geothermal systems can contribute to lowering CO$_2$ emissions and sourcing more sustainable energy. The evolution of permeability in geothermal reservoirs is strongly affected by interactions between the host rock and the fluids flowing through the rock's permeable pathways. Mineral dissolution, which results from fluid-rock chemical reactions within the fracture network, can significantly enhance reservoir permeability, whereas the precipitation of secondary mineral phases, that are also the products of fluid-rock reactions, can significantly reduce the permeability of the system. The interplay between these two important processes dictates the long-term productivity and lifetime of the reservoir. In the study reported here, we have attempted to simulate the conditions within a geothermal reservoir from initially induced fracturing to the final precipitation or “clogging” phase. We have performed, sequentially, batch, flow-through and circulating flow experiments on cores of the Carnmenellis granite, the target unit of geothermal projects in Cornwall (UK), to understand the role of mineral dissolution and precipitation in controlling the permeability of the system. The physico-chemical properties of the cores are monitored after each reaction-phase using ICP-OES, SEM, hydrostatic
permeability measurements, and X-ray Computed Tomography.

Our results show that the evolution of the permeability is strongly dependant on the chemistry of the permeating fluid. We find that undersaturated fluids (pH 10-10.5) dissolve the most abundant mineral phases in the granite (quartz and feldspars), thus creating micro-cavities along the main fracture traces that lead to enhanced but essentially pressure-independent permeability. These results suggest that the creation of chemical dissolution in the early stages of geothermal operations could generate permeable pathways that are less sensitive to effective stress and will likely remain open at higher pressures. Similarly, maintaining the circulation of undersaturated and relatively high-pH fluids (pH 10-10.5) through these granitic reservoirs could prevent the precipitation of clogging mineral phases and preserve reservoir permeability in granite-hosted geothermal systems.

By contrast, we find that supersaturated fluids (pH 9-9.5), evolving from extended periods of fluid-rock interaction, promote the precipitation of clay minerals that leads to decreased permeability within the system. In natural systems, such as fault zones, the precipitation of clay minerals on the fault plane can also severely affect the frictional properties of the fault and therefore its slip mode (seismic or aseismic). Triaxial friction experiments on a direct shear configuration were run on samples extracted from well UD-2, part of the United Downs geothermal drilling campaign. The frictional strength of the drilling cuttings from depths around 2370 (at the intersection with the Porthowan’s fault plane) show variations from 0.3 to 0.1, while friction results from unaltered granite show a friction coefficient of 0.6. These results suggest that the frictional properties of the Porthowan fault have been modified, due to the precipitation of new mineral phases.