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Feedbacks between deformation, hydrothermal reaction and permeability evolution in crustal systems: A lab-based perspective

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It is increasingly being acknowledged that crustal permeability is a key parameter impacting a number of geological processes. Clearly permeability is not a static property, but one that varies intricately in response to hydrothermal reaction and deformation of the host rock. Some current models of earthquake nucleation call upon low permeability horizons to allow pore pressures to be driven to high levels, thus facilitating fault slip. Long term evolution of permeability is also crucial to understanding the spatial distribution of various hydrothermal ore deposits and is almost certain to effect the viability of new energy sources, such as the hot dry rock geothermal projects currently being developed.

Several experimental studies were conducted to quantify and understand various aspects of the interactions described above. All the experiments were conducted in triaxial gas vessels, capable of independently controlling confining pressure, pore pressure, temperature and axial load, with the added ability to measure permeability evolution. A series of isostatic experiments on quartzo-feldspathic sand show that up to 2 orders of magnitude permeability reduction occurs as a result of hydrothermal reactions involving smectite precipitation. Importantly, it is shown that permeability evolution is quantitatively linked to the measured pore fluid chemical evolution and that both are described by similar exponential functions. To assess the role of mineral reaction on rock strength, results are presented from higher temperature experiments (927˚C) performed on Fontainebleau sandstone. In these experiments, experimental fault zones were produced and subsequently allowed to heal via pressure solution processes. The results again show significant permeability reduction on very short time scales together with tremendous strength recovery (up to 75%) upon re-fracture.

Finally, a suite of experiments was designed to explore the effect of differential stress on reactivity and permeability evolution. These experiments were conducted using thermally cracked cores of fine grained granite and were characterized by mineral precipitation along grain boundaries. Results show that the dilatant and shear failure regimes are associated with enhanced reaction and permeability reduction rate. This effect is interpreted as being caused by the generation of fresh, reactive mineral surfaces resulting in accelerated dissolution and precipitation. Interestingly, this suggests that a “negative feedback” effect might be operative in natural systems, in which accelerated sealing counteracts enhanced permeability due to dilatancy and/or shear failure.

The results presented elucidate the complex feedbacks between deformation, mineral reaction and the evolution of transport properties. Data provided from this and similar studies are therefore crucial to formulating accurate models for various crustal processes.