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Linking transport, elastic and mechanical properties: an experimental investigation in thermally cracked Westerly granite

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Elastic wave velocities, water permeability k and fracture toughness K_{IC} under mode I were measured in thermally damaged Westerly granite. The heat treatment involved slowly heating four sets of four samples to 250, 450, 650 and 850 ^oC. The fifth set of samples was not thermally treated. A dramatic 80% decrease of K_{IC} was observed with thermal treatment, from 1.4 to 0.2 $MPa.m^{0.5}$. An exponential decrease of k and an increase of elastic wave velocities were observed with increasing effective stress. Hysteresis effects during effective stress release increased with thermal treatment. Thermal cracking not only induced a substantial decrease of the mechanical strength, but also of the dynamic elastic properties of Westerly granite. In particular, normalized atmospheric pressure P-wave compressional velocities matched remarkably well the decreasing trend of normalized fracture toughness.

Using the Kachanov (1994) noninteractive effective medium theory, elastic wave velocities variations were inverted into crack density evolution. Room pressure dimensionless crack densities were unusually high values of $s10$ at 850 ^oC. This geophysical analysis showed to be in close agreement with crack parameters determined optically, such asoptical crack density determination, crack aspect ratio evolutions, and the measured sample porosity with temperature. A decrease of 50% for crack densities larger than 1, 80% for crack densities larger than 5 could then be predicted from elastic wave inversion, in close agreement with our observed experimental variation of K_{IC}. At the microscale, this can be interpreted by the fact that the main fracture is strongly interacting with the pre-existing microcrack fabric. Using the permeability model of Guéguen and Dienes (1989) and crack densities recovered from the elastic wave velocity inversion, we could also successfully predict the evolution of permeability with pressure for direct comparison with the laboratory measurements.

These combined experimental and modeling results illustrate the importance of understanding the details of how the rock microstructure is changing in response to an external stimulus, in order to predict the simultaneous evolution of physical and mechanical properties of rock.