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Modelling the Physical Properties of Volcanic Rocks: from elastic wave measurements to permeability prediction

Alexandre Schubnel

Lassonde Institute, University of Toronto

The high levels of mechanical and thermal stresses acting in volcanic areas, along with fluid circulations at high temperature, are believed to enhance damage and thus control the evolution of hydrothermal permeability networks. Indeed, cracks play a major role in rocks under crustal conditions. Mechanically, cracks make rocks more compliant and expedite fluid flow. A key consequence of microcracks (both density and alignment) is their significant influence upon elastic wave velocity and the development of anisotropy.

Using a few key concepts of fracture mechanics and statistical physics, we accurately model the elastic properties of two volcanic rock end-members: a basalt from Mount Etna and a japanese granite. Via direct comparison between the model results to a well-constrained laboratory dataset, we perform a least square fit inversion of the laboratory data in order to recover the common evolution of crack density and aspect ratio with stress. Overall, the agreement between measured and predicted velocities are good, with average error less than 0.1 km/sec.

At larger scales, macroscopic fluid flow takes place through the crack network above the percolation threshold. Using statistical physics and percolation models, we demonstrate a method which predicts the evolution of permeability using our elastic wave velocity data inversion results. Our modelling forecasts and compares relatively well to the laboratory permeability data set.

This combined modelling method illustrates the importance of understanding the details of specific rock physical properties, and how they change in response to external stimuli.