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Influence of macro-fractures and fault gouge on permeability in basalt

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Fractures are ubiquitous on all scales in crustal rocks. The investigation of fractures and how they influence rock transport properties is therefore important in understanding various many key problems in seismology, volcanology and rock engineering.

Nara et al. (Tectonophysics, Vol.503, pp.52-59, 2011) recently reported that the introduction of a macro-fracture into an otherwise crack-free basalt increased permeability significantly. They also showed that, for "mated" macro-fractures, the permeability of the basalt decreased dramatically with increasing hydrostatic pressure. However, under many geological conditions, macro-fractures in rock are commonly "unmated" due to shear offsets; such as in faults. It is therefore also essential to investigate the influence of unmated macro-fractures on rock permeability. Furthermore, shear faults are commonly filled with fault gouge, and we therefore also need to investigate how fluid flow responds to gouge-filled macro-fractures.

We have investigated these issues through permeability measurements on samples of Seljadur basalt (SB); a fresh, columnar-jointed, intrusive basalt from Iceland. This rock was chosen because it has a very low initial permeability and no visible pre-existing cracks. Permeability measurements were made in a servo-controlled permeameter using the steady-state flow method on core samples of SB prepared in five different ways. (1) Measurements were first made on intact samples. (2) The Brazil disk technique was then used to introduce a single, dominant, axial macro-fracture across the diameter of previously intact samples. Permeability measurements were then repeated on these samples with mated macro-fractures over a range of effective pressures up to 90 MPa. (3) Using the same samples, we then filled the mated macro-fractures with an artificial fault gouge layer (approximately 0.4 mm thick and prepared from ground basalt particles less than 150 μm in diameter). Permeability was again re-measured on the gouge-filled, mated, macro-fractured rock samples. (4) We then ground 0.25 mm off each of the opposite ends of a set of split rock samples to produce samples with unmated macro-fractures and a shear offset of 0.5 mm. Permeability measurements were then made on the unmated, macro-fractured sample. (5) Finally, we made permeability measurements on the unmated, macro-fractured samples with a 0.4 mm thick layer of the same artificial fault gouge.

Our results show that the permeability of intact SB is very low and remains essentially constant over the whole effective pressure range. By contrast, the permeability of the mated, macro-fractured SB was initially some four orders of magnitude higher, but decreased dramatically as pressure was increased and the fracture closed. For the case of unmated, macro-fractured SB, the permeability decreased very markedly when the effective pressure reached 15 MPa, and then showed similar values to the mated, macro-fractured SB. The permeabilities of the macro-fractured SB samples containing fault gouge layers were significantly lower than when no gouge layer was present, but the values were very similar for both mated and unmated samples.

The results demonstrate that open macro-fractures increase permeability significantly, but that the difference between mated and unmated fractures is only significant at low effective pressure. The presence of a fault gouge layer decreases permeability but does not discriminate between mated and unmated fractures.