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The influence of gouge and pressure cycling on permeability of macro-fracture in basalt

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Fractures are ubiquitous and allow crystalline rocks to store and transport fluids. But they are commonly filled with gouge-like materials and normally suffer from polyphasic evolution and multi-cycles of loading and unloading. Therefore, it's essential to investigate the influence of gouge and pressure cycling on transport properties (permeability here) of fracture.

Here, we did several steady-state flow permeability measurements on a sample with 38mm diameter and length of Seljadur basalt, an intrusive basalt from SW Iceland with no visible cracks and exceptionally low initial permeability.

First, using the Brazil disk technique, a macro-fracture was introduced in the sample, and baseline measurements on above unfilled macro-fractured sample under step-wise effective pressures from 5 up to 60 MPa and pressure cycling were done. Second, similar measurements were conducted on the same macro-fractured sample filled with 0.6mm thick artificial fault gouge (milled basalt) layer with the upper limit grain size of 63, 108, 125, 250, 500μm, respectively, to explore the influence of gouge grain size. Third, to investigate the influence of gouge thickness, measurements on the same sample with various thickness of gouge layers of 63 and 250μm were implemented, respectively. Forth, pressure cycling tests were done on 0.6mm thick 63, 125 and 250μm, respectively, to study the influence of pressure cycling. And at last, to understand compaction mechanism of the gouge, after tests, the thickness and grain size changes before and after tests were also measured.

Results showed the adding of fine-grained (63μm here) gouge in fracture decreased its permeability significantly and barely changed with the increasing effective pressure and pressure cycles, while that filled with coarse-grained gouges (108-500μm, respectively) had very similar permeability, and gouge layers decreased its permeability under lower effective pressure, while increased its permeability instead by preventing its closure under higher effective pressure. Generally, the permeability of sample increased with increase of thickness of gouge layer, but that of fracture filled with fine-grained gouge has some variations. For the influence of pressure cycling, with increasing pressure cycles, the permeability of fractures without or with coarse-grained gouge, would keep dropping until a steady state, and the first loading process dropped the most. And in each cycle, under the same pressure, the loading permeability of the sample was always larger than that of unloading for sample without gouge, but it would become the same for sample with coarse-grained gouge when permeability became steady. As to the thickness change, the bigger of the grain size and the thicker of gouge layer, the huger of the thickness reduction (or porosity loss). And fine-grained gouge had far less porosity loss than coarse-grained, which explained its strange behaviors. And the grain size distribution of the gouges after tests barely changed for smaller grained gouges ($\leq$125μm), while for bigger grained gouge ($\geq$250μm), the biggest parts of grain would break after test (the bigger of the grain size, the stronger of the damage), which indicated grain rearrangement was the only factor for porosity and permeability reduction of smaller-grained gouge, but grain crushing has increasing effect with lager-grained gouge as it grain size become bigger. Pressure cycling would also intensify above thickness and grain size changes, but very small for smaller-grained gouges, but apparent for larger-grained gouge, especially on grain size distribution changes, which meant grain crushing might dominate the changes after first loading process for porosity and permeability loss.