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Permeability Evolution in Granular Aggregates: Preliminary Results from Compaction and Shear Experiments

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Fluids exert a strong influence on the deformation behaviour of fault rocks via mechanical effects such as changes in effective stresses and chemical effects including pressure solution, neck growth and free face dissolution. Through these effects, fluids influence the earthquake cycle, especially during interseismic fault strength recovery and dynamic rupture nucleation. In addition, fluids are important in governing the transport and deposition of ore minerals and hydrocarbons. To study these processes it is thus important to understand how fluids flow through fault rocks and how their transport and storage characteristics evolve with time and deformation.

We studied the evolution of fault zone properties by conducting room temperature deformation experiments on crushed natural rock salt (various grain size fractions spanning the range 37-206 μm) saturated with brine in the double-direct shear configuration. Rock salt was used as a rock analogue, because it is well established that solution transfer processes are rapid in this material under room temperature conditions. The suite of experiments consisted of 1) compaction-only experiments and 2) compaction plus shear experiments. Permeability measurements were done using two different techniques. In the first technique we applied a constant pore pressure differential across the sample and measured the flow rate. Permeabilities were obtained using Darcy's law correcting for sample volume change, which was measured independently via changes in fault zone layer thickness. The advantage of this technique is that data reduction and analysis is straightforward, but the measurement is interrupted once the pressure intensifier is fully discharged and must be recharged. To overcome this problem, we used a second technique, in which we applied a sinusoidally cycled fluid pressure pulse with a known amplitude and period on one end of the sample and measured the pressure response on the other side. This technique allows continuous permeability measurement during evolution of fault zone properties, however data reduction and analysis is more complex and uncertainty in permeability values is greater compared with steady-state flow-trough techniques.

Preliminary results from the compaction-only experiments show that permeability is decreases with porosity, but the decrease is less than predicted from Kozeny-Carman type relations. Moreover, the dependence on porosity is weaker for samples with a larger initial grain size distribution. We interpret this response as resulting from isolation of larger pores, which would result in a tortuous flow path and permeability values that are determined by the smallest pore or pore throath. A broader grain size distribution implies a broader pore size distribution. During the compaction, all pores become smaller and the smallest pores disappear, in effect reducing the average pore size and shrinking the size distribution. For a broader distribution, this shift is less (in terms of average pore size) than for a narrower distribution.

Preliminary results from the compaction plus shear experiments show that initial compaction prior to shear leads to major dilatation and permeability increases during shearing. At this point, it is not clear whether the permeability increase is solely due to an increase in porosity in the sample or whether it is a result of the formation of localized zones of deformation (dilational shear bands or Riedel shears). Slide-hold-slide test show a continuous decrease in permeability during the hold periods and a subsequent sharp increase upon re-slide, accompanied by dilation and peak shear strengths.

Similar effects are expected to occur in natural fault rocks under hydrothermal conditions and will have a large effect on seismic recurrence intervals and fluid flow. Thus, a microphysical model is needed to link the compaction and permeability evolution to reliably extrapolate our results to natural conditions. Finally, we plan to investigate the effects of phyllosilicates on the deformation behaviour and fluid flow properties of fault rocks.