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Effects of Grain Size Distribution on the Permeability of Compacting Aggregates: Results from Rock-analogue Experiments and Microphysical Model

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Fluids influence the mechanical and transport behaviour of fault rocks via effective stresses and through chemical effects including pressure solution, neck growth and free face dissolution. These effects influence the earthquake cycle, especially during interseismic fault strength recovery and dynamic rupture nucleation, and govern the transport, evolution and accumulation 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 permeability with porosity and grain size using rock salt as a rock analogue. It is well established that solution transfer processes are rapid in this material under room temperature conditions. The porosity of two layers of salt particles with different initial size distribitions (38-106 μm, 53-106 μm and 63-90 μm) was reduced by a step-wise application of normal strain, keeping the effective normal stress below 5 MPa. Permeability measurements were derived from steady state flow rates using Darcy's law for a constant pore pressure differential of 0.1 MPa across two layers of salt particles under a hydrostatic pressure of 2 MPa.

We found that permeability decreased with decreasing porosity according to a power law with a power close to 3, which is the theoretically derived value, based on flow in a bundle of parallel capillary tubes (i.e. Kozeny-Carman equation). However, the

predictions of the Kozeny-Carman model overestimate the measured permeabilities in all experiments by at least 1 order of magnitude. We believe this is an artifact of the Kozeny-Carman model, which is based on a single particle size, whereas in reality particles in fault gouges have a distribution of sizes. We extend the Kozeny-Carman model using an expression for the tortuosity that is dependent on the actual grain size. Permeabilities are evaluated for multiple calculations ($>$5000) of spheres of variable diameter in a simple cubic packing, as a proxy for pore size distribution.The total permeability was then computed using the geometrical mean (valid for parallel processes) and the harmonic mean (valid for serial proccesses) of the individual particle size calculations. Measured permeabilities best match those calculated from the geometrical mean and an observed lognormal grain size distribution. We conclude that wider grain size distributions, with abundant small grains, will have lower permeabilities than predicted using the average or median value of the grain size. Our results have important implications for the evolution of permeability of natural fault gouges, which typically show a broad range in grain sizes.