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The 4D evolution of porosity during ongoing pressure-solution processes in NaCl using x-ray microtomography

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Pressure-solution creep is a common deformation mechanism in the upper crust. It represents a mass transfer via dissolution-reprecipitation that critically affects the hydraulic properties of rocks. Successful management of safe radioactive storage sites in rock-salt deposits critically depends on an accurate knowledge of the hydro-mechanical behaviour of salt deposits. Despite numerous lab experiments that have been conducted, many aspects of pressure-solution are still poorly understood. There is little knowledge about the spatio-temporal evolution of porosity and permeability during pressure-solution creep. While rates of pressure-solution creep in silicates and carbonates are slow, which makes laboratory investigations of these materials impractical, compaction experiments have demonstrated that NaCl samples deform sufficiently fast to study pressure-solution creep in a lab environment at room temperature and modest loads.

We present results from novel experiments that quantify the 4-dimensional (three spatial dimensions plus time) evolution of pressure-solution processes using in-situ x-ray microtomography. Our experiments are performed in custom made x-ray transparent presses. 5 mm diameter NaCl powder samples with a grain size of 250-300 μm are loaded dry into the press and pre-compacted to produce a starting aggregated material. The sample is then flooded with saturated NaCl solution and loaded uniaxially by means of a pneumatic actuator to a constant uniaxial stress. Different sample mixtures were tested, as well as different uniaxial loads. The resulting deformation of the samples is documented in 3-dimensional microtomographic datasets, acquired at regular time intervals. Image analysis allowed characterization of the microstructural evolution of the NaCl grains and the spatio-temporal distribution of porosity during ongoing mechanical and chemical compaction. The microtomography data have also been analysed with 3D Digital Image Correlation (3D-DIC or DVC) to quantify the fields of displacements in each direction, as well as volumetric and maximum shear strain fields. Following the approach described above, we have been able to quantify and characterize in 4D the evolution of pressure-solution creep and porosity distribution in relation to different sample materials and increasing uniaxial load. The presence of phyllosilicates (biotite) and more competent materials (glass beads) allowed pressure-solution to develop in a much shorter time compared to pure halite sample. The same trend is observed in samples experiencing bigger uniaxial loads (6.6 MPa v 1.6 MPa). We also found that, in the presence of phyllosilicates (biotite), pore size distribution clearly reflects the localisation of pressure-solution processes, as for natural stylolites. In the presence of glass beads, pressure-solution has a greater effect on the pore orientations rather than pore sizes.

Our results extend the current understanding of the effect of pressure-solution creep on the mechanical and hydraulic properties of rocks, with implications for natural rock-salt, salt-based repository systems (nuclear and chemical waste storage) and salt mining.