Title: Analysing salt precipitation-damage coupling in limestone with 4D X-ray tomographic imaging

Authors:

S. Ben Elhadj Hamida[1,2], M.A. Boone[3], V. Cnudde[4,5], P. Moonen[1,2], H. Derluyn[1,2]

[1] Universite de Pau et des Pays de l'Adour, E2S UPPA, CNRS, TotalEnergies, LFCR, Pau, France
[2] Universite de Pau et des Pays de l'Adour, E2S UPPA, CNRS, DMEX, Pau, France
[3] TESCAN XRE, Ghent, Belgium
[4] PProGRess/UGCT, Department of Geology, Ghent University, Ghent, Belgium
[5] Environmental hydrogeology, Utrecht University, The Netherlands

Content: (max. 500 words)

Climate change leads to intensified weathering cycles on landscapes and the built environment. Energy transition strategies such as seasonal storage of biogas or hydrogen in aquifers, introduce cyclic perturbations in the underground environment. In both cases precipitation-dissolution cycles of salts are induced. When precipitation occurs inside the pore space, stresses build up which may eventually crack the material. This might lead to severe deterioration of natural stones, as present in our historic monuments or natural landscapes. In addition, precipitation-dissolution of salts as well as crystallization-induced cracking alter key petrophysical properties of the rock matrix itself, such as its permeability, thus impacting gas injectivity.

Understanding the exact coupling between transport, salt precipitation, crack initiation and propagation in natural porous media remains an open research subject. Experiments in which transport, precipitation and fracture kinetics can be studied simultaneously are essential to advance our insights in these coupled phenomena. To that extent, a 4D micro-tomographic dataset has been analyzed of a Savonnières limestone plug subjected to NaCl precipitation and dissolution. The sample consists of two zones with different wettability, i.e. a hydrophobic and a hydrophilic part, and is initially saturated with a brine solution. Precipitation is induced by drying the sample via the hydrophobized part, creating crystallization-induced fractures at the hydrophobic-hydrophilic interface. Dissolution occurs by subsequently exposing the sample to a highly humid environment, above the deliquescence point of NaCl, which leads to a rewetting of the sample and a dissolution of the salt crystals, as well as a partial closure of the fractures. The sample is imaged at a 9 µm voxel size, every 30 minutes during the first day of drying, and every hour during the second day of drying and the third day of deliquescence. The image processing consists, in a first step, of a global analysis using a customized Python script, allowing to extract information on porosity and pore size changes, the crystal deposition in the pores, and the global deformation of the sample. In a second step, digital volume correlation, using the SPAM software (Stamati et al. 2020), is employed to determine the local displacement fields, and thus the local strain, on the 3D volume of the deforming sample. The spatial and temporal resolution of the acquired dataset, combined with the developed image analysis workflow, allows to highlight the coupling between the stone's pore structure, precipitation/dissolution and fracture kinetics, at the pore scale level. These experimental observations then assist in refining existing poromechanical models of in-pore salt crystallization and crystallization-induced damage.

The authors acknowledge the support from the Research Foundation – Flanders (FWO grants 1276814N and 1521815N) and from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 850853).

References:

Stamati et al., (2020). spam: Software for Practical Analysis of Materials. Journal of Open Source Software, 5(51), 2286, https://doi.org/10.21105/joss.02286