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# Multiphysics degradation process constitutive laws for engineered and geological NWD barriers: experiments and simulations

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Barrier integrity over hundreds, if not thousands years is a critical feature in the concept and the design of NWD repositories. Few performance assessment analyses that include long-term assessment are fragmentary, i.e. e.g. hydro-thermal, within a non-deformable medium, or at best, elastic medium, and among other things include very limited long-term effects of heating and chemical reactions or phase transition, on mechanical and hydro-mechanical properties of the rock medium. Yet, degradation of the main properties of the materials involved has not been given an adequate attention. The main obstacle in the latter is scarcity of experimental knowledge on the specific mechanisms (usually at a micro-scale) and paucity of corresponding constitutive laws of degradation, which link mechanical properties to various environmental variables. Clearly, long-term experiments are limited to a few decades, at best. An interesting alternative are natural analogue studies, in which similarity is sought in the field sites of materials and configurations to those of repositories.

There are numerous scenarios of degradation. In this presentation we report on the progress in the areas of two types of processes in clay-based rocks: drying-cracking and thermo-chemical long-term time evolution of mechanical properties of rocks.
Drying-cracking arises at kinematically constrained interfaces between air and shrinking desaturating medium. That includes the walls of galleries exposed to forced ventilation, or shrinking desaturating rock enveloping rigid canisters. Drying-cracking is a complex series of processes including transport of water, vapor at the scale of a pore, corresponding generation of suction at the scale of a clay assembly leading to deformation/effective stress buildup in the skeleton in the presence of kinematic constraints, leading eventually to the tensile stress concentration at a tip of air entry, while the nominal macro-scale effective stress remains compressive. The air entry is experimentally observed to be a local liquid/air interface instability at the pore scale, located at the largest of pores, in the presence of a complex grain geometry. The interface instability is caused by the evaporation mass removal, affected, especially in clays by the skeleton deformability. Experiments confirm that drying-cracking arises in a medium tending to shrink, but constrained kinematically, shortly after the air-entry phenomena, detected on macro-scale as the onset of desaturation. It is clear, that the effects at micro-scale trigger a meso-scale events that eventually lead to macro-scale, but still localized, cracks. Notably, experiments suggest that at micro-scale, evaporation causes stick and slip of the liquid/air moving interface, significant pressure gradients within the capillary bridge, and an ensuing intense flow of liquid. The resulting challenges in the multi-scale modeling are discussed.

Another example of rock degradation is the long term effect of $CO_2$ in carbonate reservoirs. $CO_2$ acidifies pore water, which substantially increases the rock dissolution rate. That in turn reduces significantly both the elasticity moduli and compressive strength. Modeling of that is again two-scale. On a pore scale, we model a reduction of the thickness of the pore wall upon time dependent mineral removal via chemo-plasticity formulation following Hu and Hueckel, 2007. Upscaling is done through an averaging procedure.