HYDRO-CHEMO-MECHANICAL MODELLING OF BENTONITE SEALING COMPONENTS

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Introduction and Objectives

Swelling clay seals will be used for the closure of Cigéo. Their long-term performance is governed by complex physical and chemical processes involving hydro-chemo-mechanical couplings which can affect the swelling pressure (on which seals safety functions rely on). This work is aimed at the quantitative long-term (i.e. 100 ky) assessment by means of numerical modelling of these coupled processes at the seal scale: two-phase flow (H_2), reactive transport (C), and non-linear mechanics (M), explicitly resolving interfacial processes between the seal and the surrounding materials.

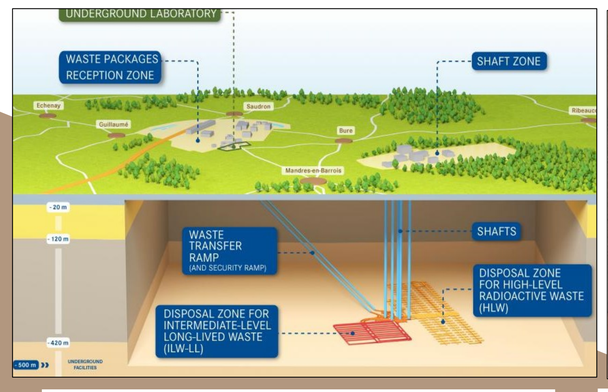
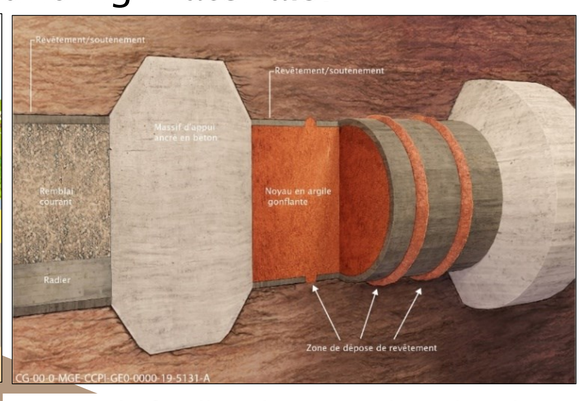


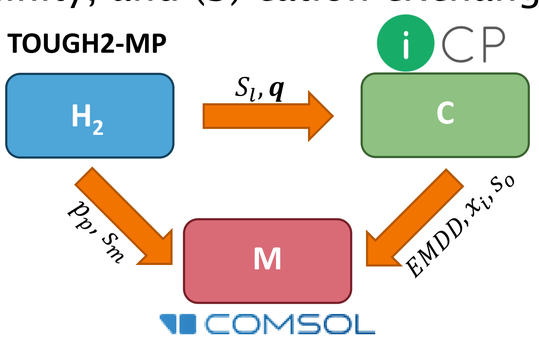
Diagram of the Industrial Centre for Geological Disposal, Cigéo.



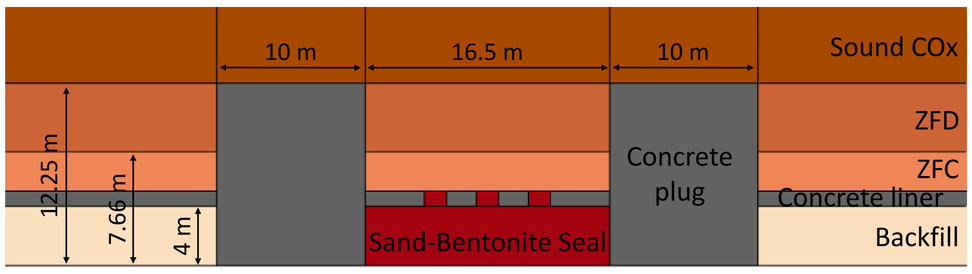
Detail of gallery bentonite-based sealing component in a concept with concrete plugs.

HCM Conceptual and Numerical Model

A coupled H_2CM model for swelling clays has been developed [1]. The H_2M behaviour of bentonite is based on the modified Barcelona Basic Model. The CM couplings are implemented within this constitutive framework, considering the impact in bentonite mechanical properties of: (1) smectite dissolution, (2) porewater salinity, and (3) cation exchange reactions.



The H_2CM models account for two-phase flow due to hydrogen generation, drying of the rock upon excavation and resaturation (see **Poster Clay00019: Towards a full HMC modelling of a repository seal**), and reactive transport processes due to interaction between different materials (iCP [2]). The mechanical behaviour of the system (Comsol Multiphysics) obeys not only to the HM couplings, but also to the impact of chemical interaction of bentonite with surrounding materials. The model is illustrated for a concept with concrete plugs (although plugs may be suppressed in the future real concept).

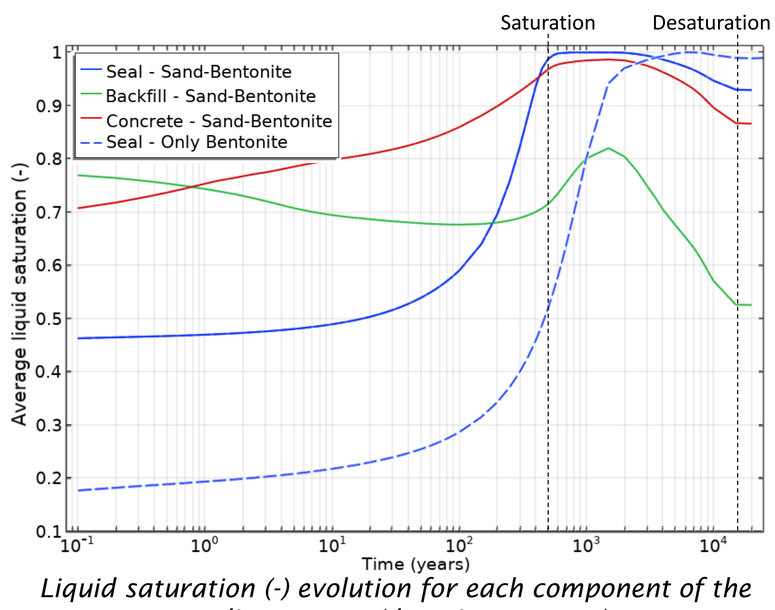


Model geometry (zoom on the seal), dimensions and materials.

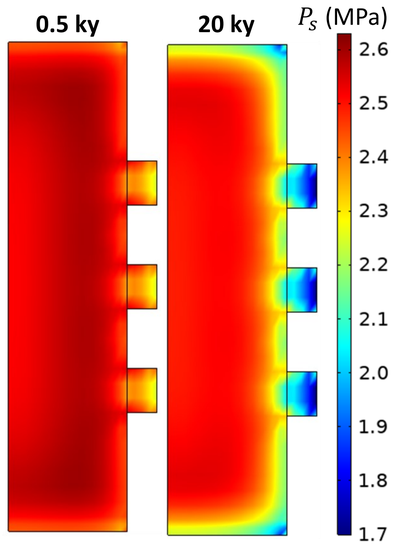
Evolution of the swelling component

H_2M BEHAVIOUR

Water uptake from the host-rock and hydrogen-induced desaturation govern swelling pressure distribution of the seal.



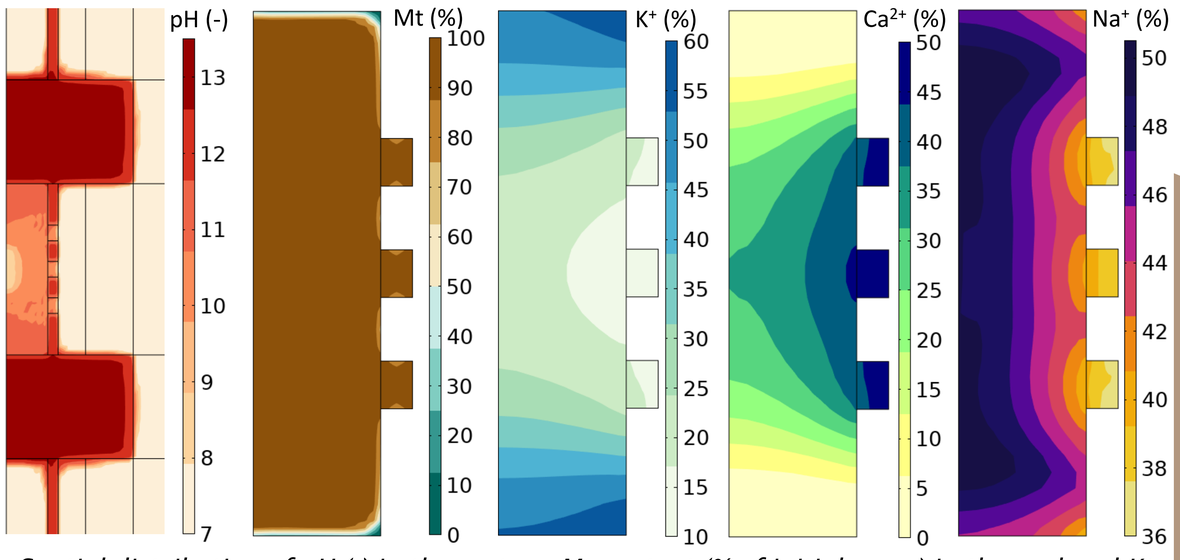
Liquid saturation (-) evolution for each component of the sealing system (domain averages)



Swelling pressure (MPa) at saturation and desaturation

CHEMICAL ALTERATION

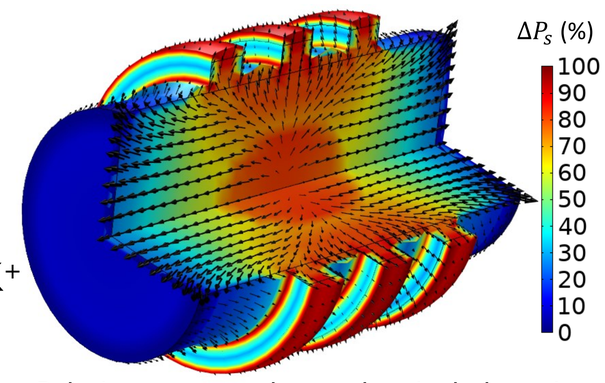
High pH increase, smectite dissolution, and changes in the Na-dominated bentonite interlayer composition. Large impact of the alkalis (K and Na) released from concrete structures and of Ca from the Callovo-Oxfordian (COx) clay.



Spatial distribution of pH (-) in the system, Mt content (% of initial mass) in the seal and K^+, Ca^{2+}, and Na^+ fractions in bentonite exchanger after 20 ky of chemical interaction.

HCM PERFORMANCE

Impact of chemical alteration on swelling pressure. Relative (HCM/HM) values in the seal after 20ky. Reductions due to localized Mt dissolution and K^+ uptake close to the concrete plugs.



Relative pressure due to chemical alteration.

Conclusions and current work

Understanding multi-physical and chemical coupled behaviour of the evolution of repository components over meaningful spatial and temporal scales is essential to demonstrate their long-term performance. The developed H_2CM modelling framework can be used as a tool for long-term safety assessment. Geochemical alteration of bentonite can significantly impact the swelling pressure stability of the seal in the long term. Other processes that play an important role on the performance of the system are currently under study (e.g., COx creep, concrete damage, installation of compressible layers or back-coupling of mineral volume changes and volumetric deformations on transport properties).

[1] Idiart et al. (2020). Applied Clay Science 195, 105717.
[2] Nardi et al. (2014). Computers & Geosciences 69, 10–21.

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