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# Multi-Scale Approach for the Mechanical Behavior of Rock Salt

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## CONTEXT

- In standard engineering practice, rock salt is mechanically modelled using phenomenological laws deduced from laboratory tests at the REV (Representative Elementary Volume) scale
- These tests are inevitably shorter than the relevant time scales that need to be studied for the abandonment of salt caverns
- Rock salt's behavior being complex, it involves multiple mechanisms at the microscale that are neglected by most macroscopic models

### Objectives

- Develop a new constitutive model for the mechanical behavior of rock salt that integrates phenomena observed at the microscale
- Study the long-term evolution of salt caverns including the abandonment phase, considering impacts at various time and spatial scales of different creep mechanisms

## METHODOLOGY

- We perform various combinations of short triaxial and creep tests on natural salt samples to observe the strains induced by a large range of deviatoric stresses, which are vital not to underestimate creep strain at any deviatoric stress [1][2]
- Short triaxial tests at high strain rates serve to investigate specific conditions at the cavern wall. They also serve general geomechanical parameters characterization. Volumetric behavior is also very important during these tests
- In addition to that, multi-stage creep tests will be performed during 6 months with multiple deviatoric stress stages to reproduce cavern abandonment specific conditions as well as the far field
- We then fine-tune our models to these tests' results. This will be supported by microscopic observations of the samples before and after the tests

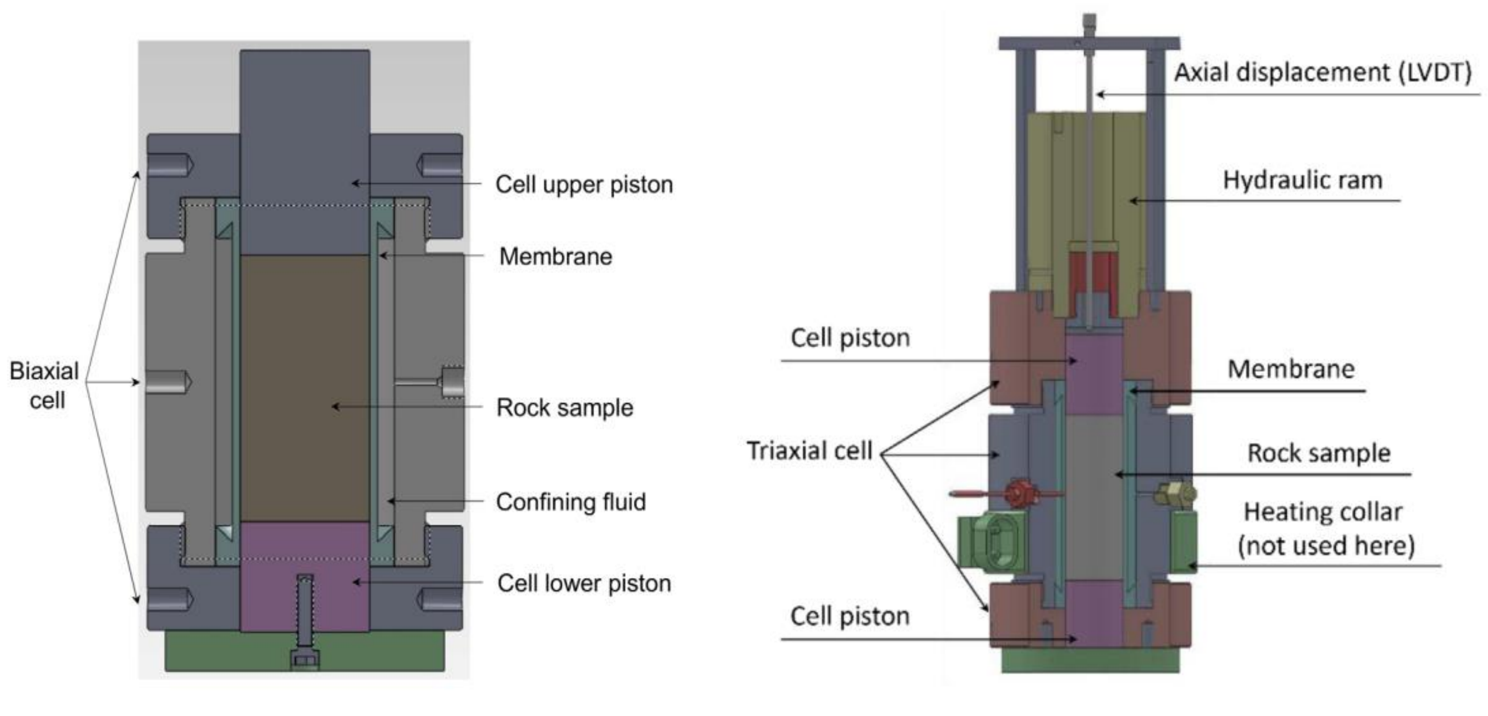


Figure 1. Cutaway view of the triaxial cells that will be used for this thesis (left) and of the creep cells (right). In some tests, triaxial cells will be equipped with heating collars similar to the ones represented on the right cutaway schematic. The results will be used to fine tune models and run numerical simulations.

- After obtaining proper fits for our models to the experimental curves, the newly obtained set of parameters is used in numerical simulation of the studied rock salt structure (generally, a salt cavern)
- To transition a model's equations from microscale to larger ones, two main approaches have been identified:
  - FEM² which consists of embedding small FEM simulation into bigger ones and allows the model to remain microscopical in nature. But this approach is very costly in numerical resources.
  - Homogenization schemes, which assume that the applications of the model will only be above the REV, which is its main disadvantage, besides the loss of microscale information and its inability to capture more localized phenomena and integrating heterogeneities' effects.

## RESULTS

- The first triaxial tests gave deviatoric and volumetric curves, that are both used to fit various models. For now, we use the RTL constitutive model, inspired by Lemaitre's with an added volumetric component that allows us to study dilatancy [3]

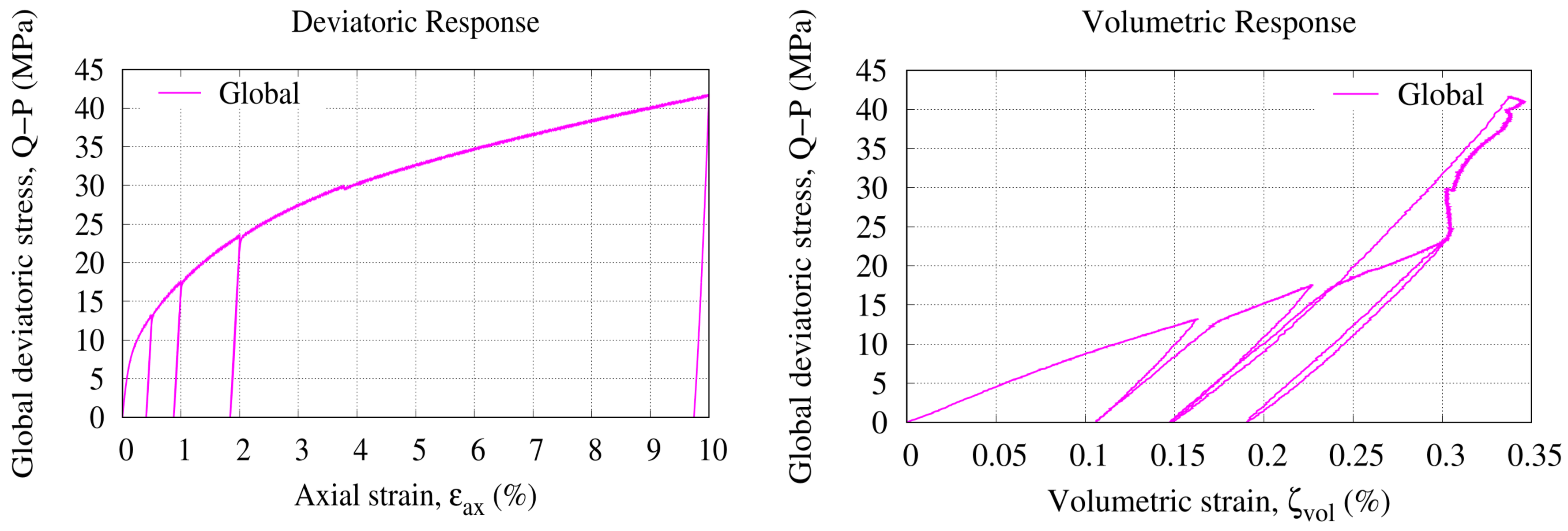


Figure 2. Example of deviatoric and volumetric responses of rock salt during triaxial tests. Volumetric inversion can be seen on the right.

- An inversion of trend can be seen on the volumetric experimental curve. This is supposed to be caused by dilatancy, which is a damage related phenomenon, and very important for cavern design. In experimental conditions, it can also be caused by thermal expansion.

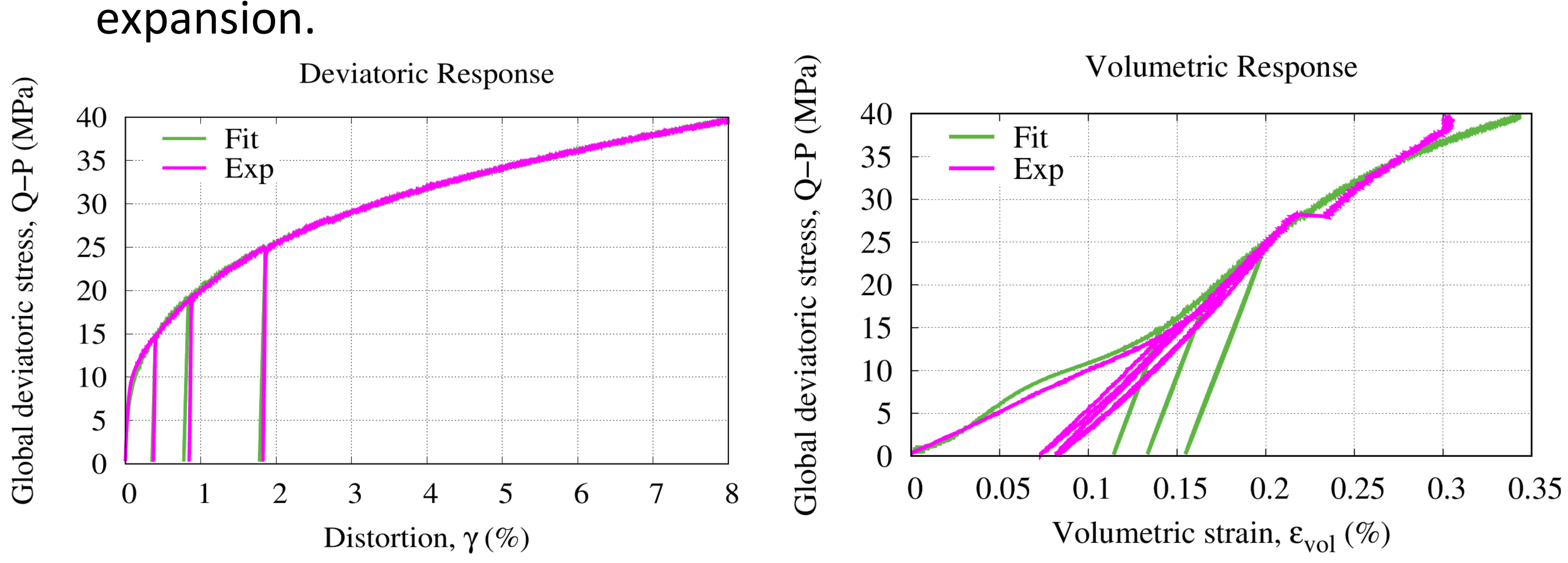


Figure 3. Curve fitting example with the compressive deviatoric part of the RTL model (left) and with the volumetric part (right)

- We then obtain through numerical simulation, the cavern closure evolution curve, the distribution of stresses and strains and eventually other criteria, such as the dilatancy zones. These results are also useful to better define the loading paths in our experiments

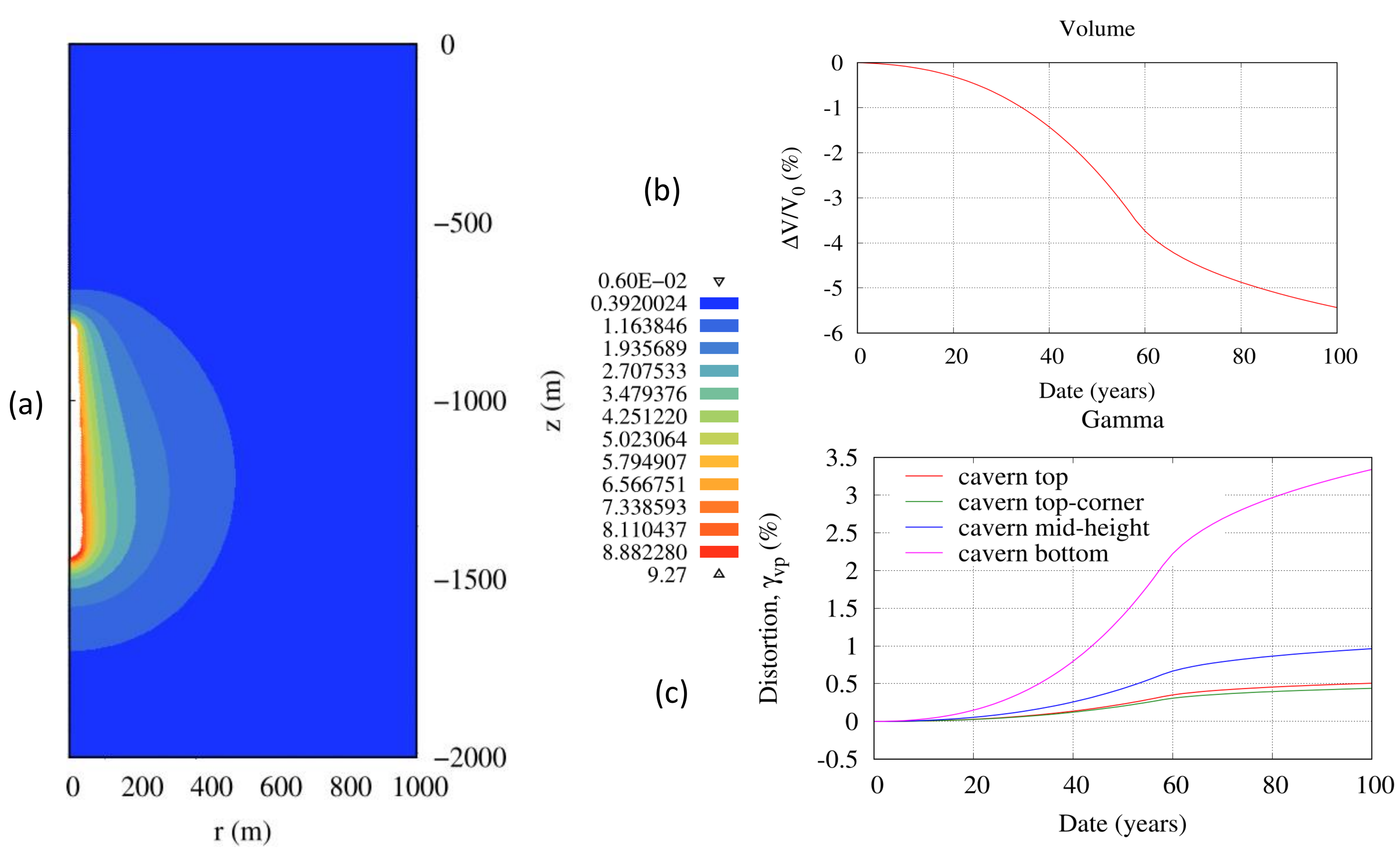


Figure 4. Deviatoric stresses (MPa) distribution in a salt cavern (a) Cavern closure over 100 years of the same cavern (b). The strain evolution of various points of the cavern wall (c). The simulated lifecycle is solution mining for 60 years, followed by 40 years of abandonment. Low deviatoric stresses creep mechanisms were not considered here, hence the short abandonment period.

[1] Bérest P, Brouard B, Karimi-Jafari M (2008a) The effect of small deviatoric stresses on cavern creep behavior. In: SMRI 2008 Fall Technical Conference. Galveston, TX

[2] Blanco-Martín, L., Rouabhi, A., Hadj-Hassen, F. et al. Creep of Rock Salt Under a Large Range of Deviatoric Stresses. Rock Mech Rock Eng 57, 6105–6118 (2024). https://doi.org/10.1007/s00603-024-03841-6

[3] Mejda Azabou. Modélisation et prédiction du comportement macroscopique du sel gemme dans le contexte du stockage souterrain. Sciences de la Terre. Université Paris sciences et lettres, 2021.