# Underground seasonal storage of gas. Testing numerical modelling tools with application to: i) a deep aquifer-layer, ii) salt caverns.

GEO:N project
**SECURE**

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enagas

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A VIDEO PRESENTATION CAN BE DOWNLOADED FROM HERE:

https://we.tl/t-O1X90zB5hW

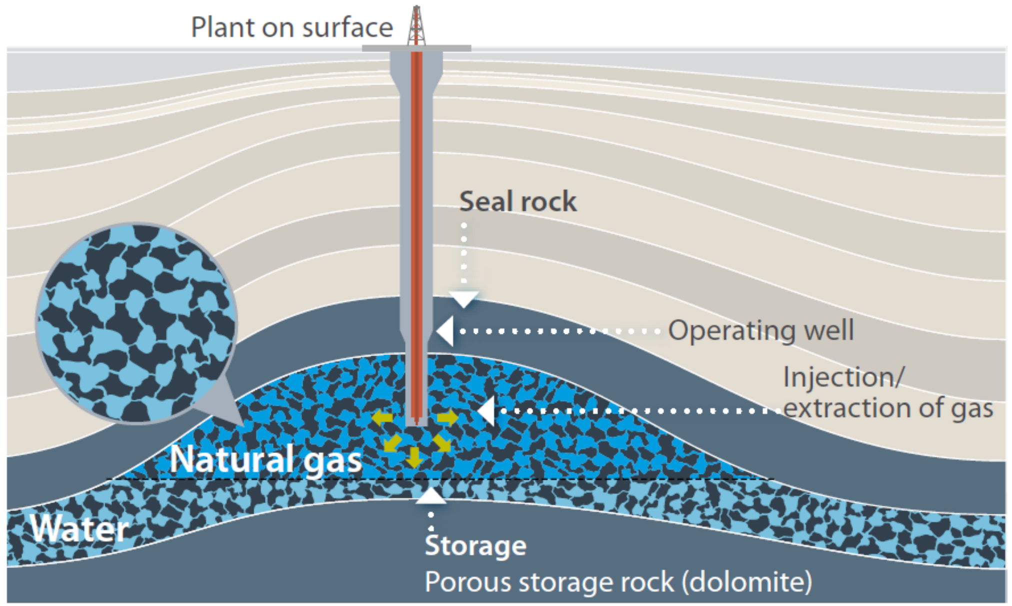
(the link will be active from 06 to 13 May 2020)

# INTRODUCTION: motivations and project aims

- In order to manage seasonal fluctuations in energy consumption, against a rather stable (and limited) production capacity, buffering techniques had been developed. This concept also applies for natural gas, which typically has much higher demand in winter. A common way to deal with demand fluctuations, and take advantage of market price variations, is to store natural gas in underground facilities, such as depleted gas/oil fields, natural aquifers, and cavern formations (natural or excavated) in salt diapirs.

- In order to minimize the risks related with these operations, industries and/or public monitoring centers (depending on specific state regulations) monitor geophysical signals such as surface deformation and induced micro-seismicity during storage and withdrawal (production) of gas.

- Within the framework of the project SECURE, our research team - with a strong background in volcanological and seismological studies - tested modeling techniques used for natural reservoirs, and applied them to anthropic underground gas storage facilities. These systems indeed share similar mechanics and physical properties. In addition, underground gas storage sites, thanks to the extensive monitoring, can represent an opportunity to investigate how reservoirs evolve, modify the surrounding stress state, produce deformation, and possibly induce seismicity.



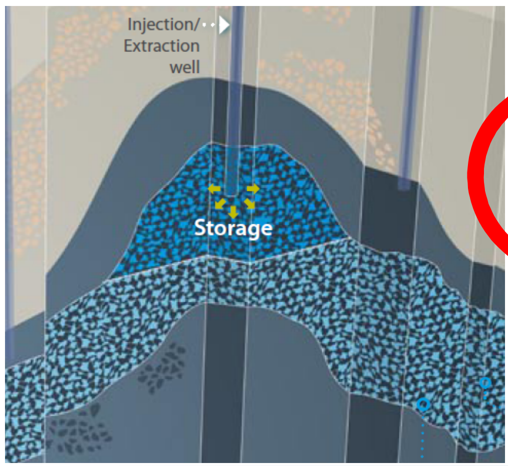
# *INTRODUCTION: motivations and project aims*

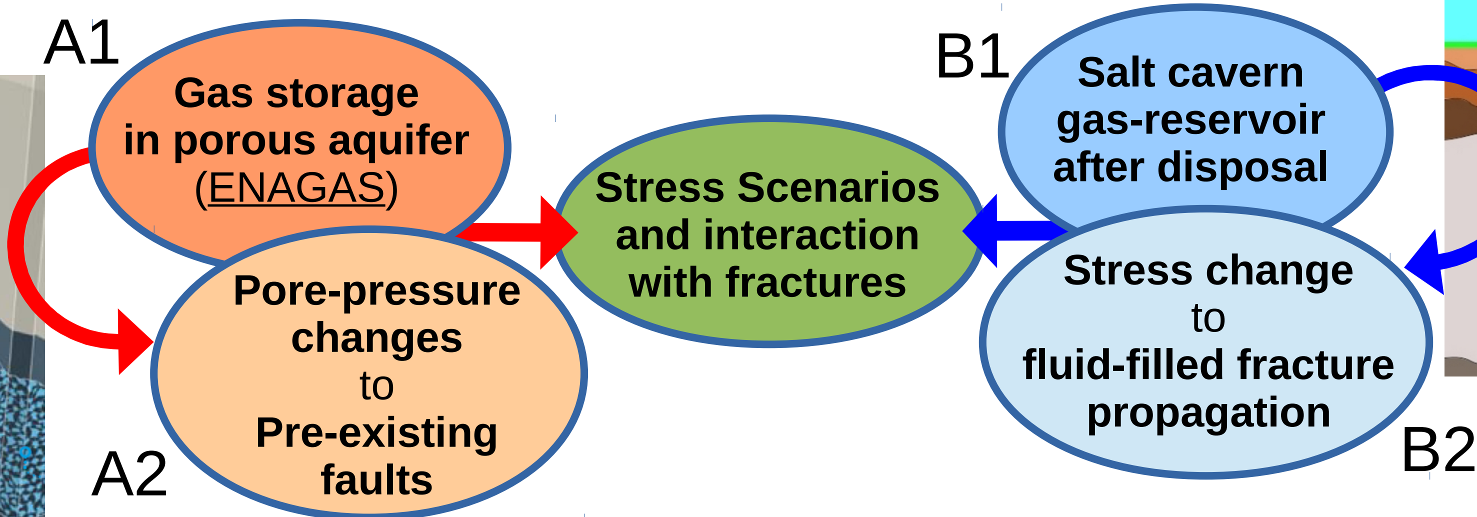
<u>Aims:</u>

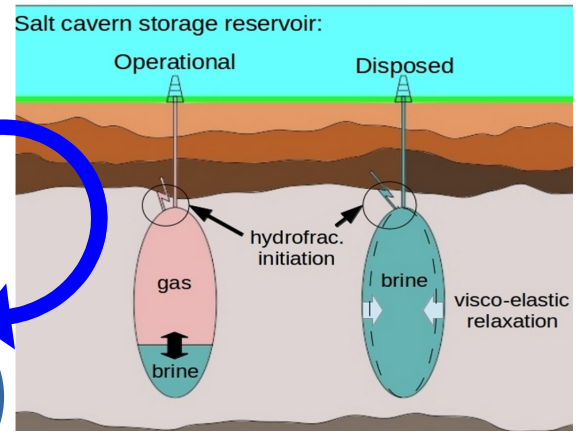
- Address the condition for <u>long term stability</u> of gas storage in <u>deep porous aquifer</u> and <u>salt caverns</u>
- Study pressure changes at reservoirs and the interaction with crustal structures (porous aquifer, A1-A2).
- Address the interaction between stress changes at reservoirs and fluid-filled crack nucleation propagation and arrest (salt caverns, B1-B2).

<u>Approach:</u>

- Developing and testing physics-based models to address the mechanics of a gas storage reservoir on different time scales.
- Make use and integrate modeling schemes and techniques developed for volcanological studies (magmatic intrusions and reservoirs) and test them at gas storage reservoirs.



# INTRODUCTION: motivations and project aims

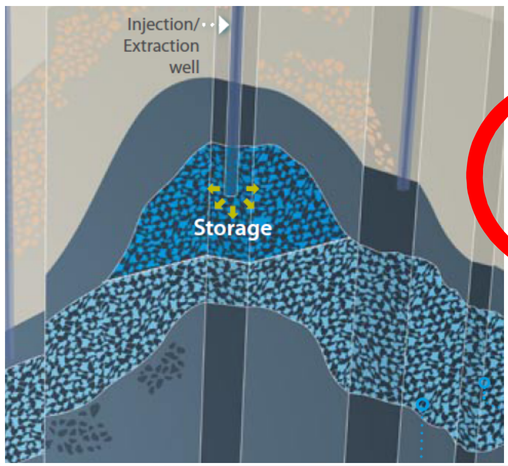
FOCUS ON:

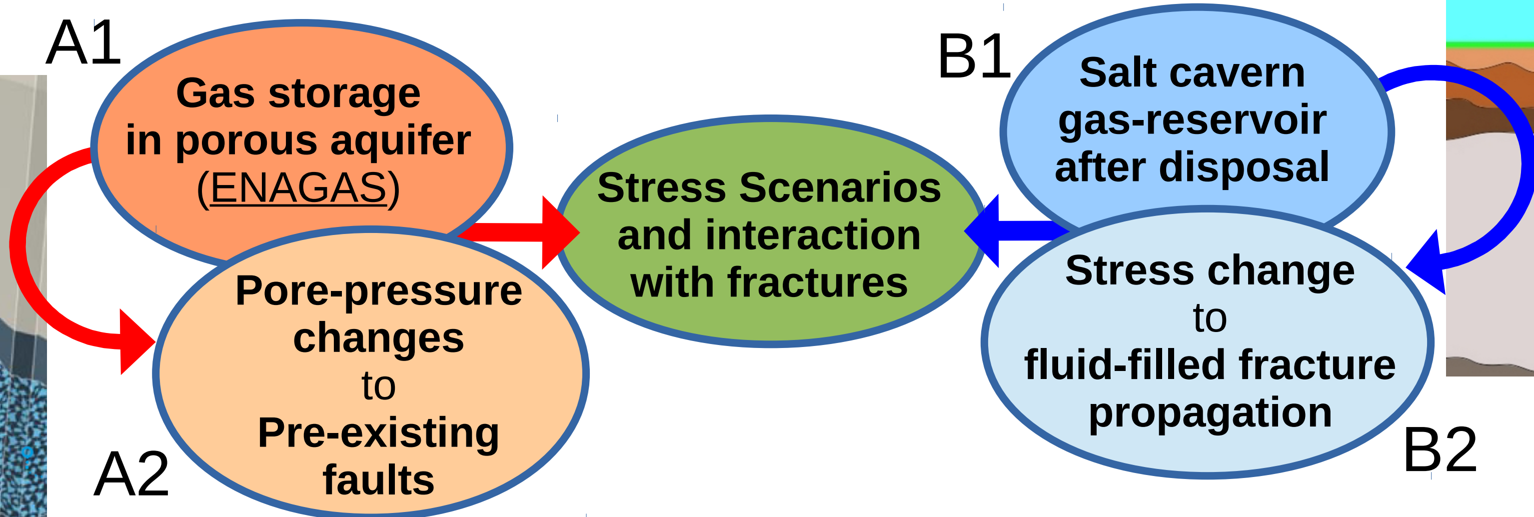
- **A1**: Here we show results obtained with a semi-analytical poro-elastic layered model for pore-pressure diffusion in an aquifer layer during gas injection and extraction.

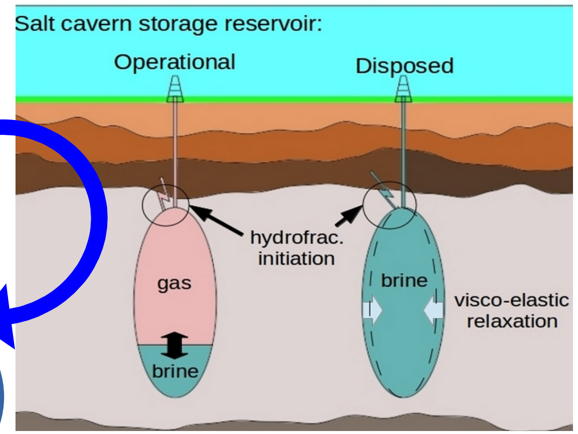
  **Case study**: natural gas storage facility in Spain, in collaboration with ENAGAS, which provided times series of injection/extraction rates, down-hole pressure data, FE model results for pore-pressure diffusion, reservoir geometry, and rock properties.

- **B1**: Results from a Distinct Elements Model on the stability condition of a salt cavity with a constant internal overpressure.

  **Case study**: Caverns excavated with water injection for salt extraction. At the end of the mining process the caverns has been filled with brine and the fluid pressure has been monitored. After several months, surface deformation and seismicity (compatible with internal collapses), have been observed. This case study may be relevant for dismissed salt caverns which had been used as gas storage facilities.



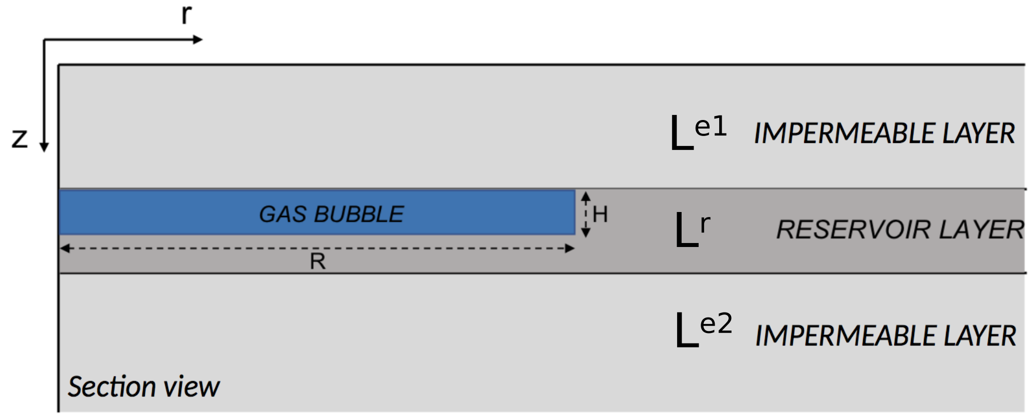



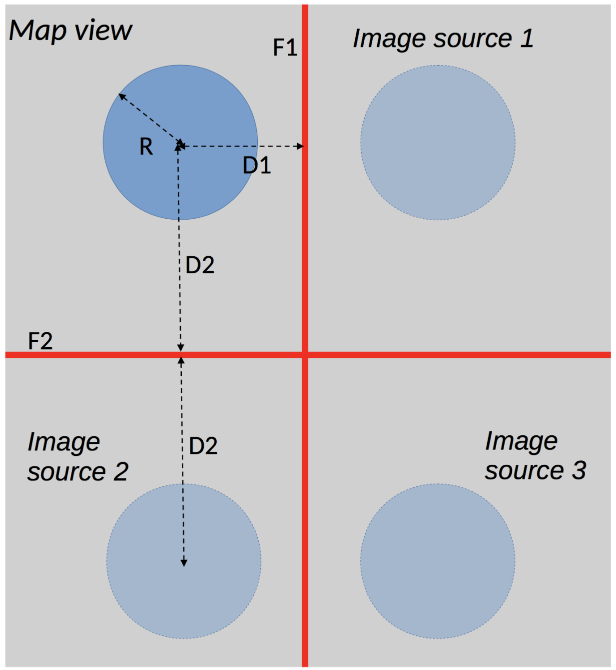



# A1) Poro-elastic model for the aquifer layer: METHOD

We use the software **POEL** (*Wang and Kümpel, 2003*) based on a layered poro-elastic structure.

- **Analytical formulation** (accurate and fast)
- **Full coupling** between pressure and deformation
- **Input:** injection and pumping rate within a volumetric source (*GAS BUBBLE*)
- **Output:** displacement, strain, tilt, pore pressure, Darcy velocity

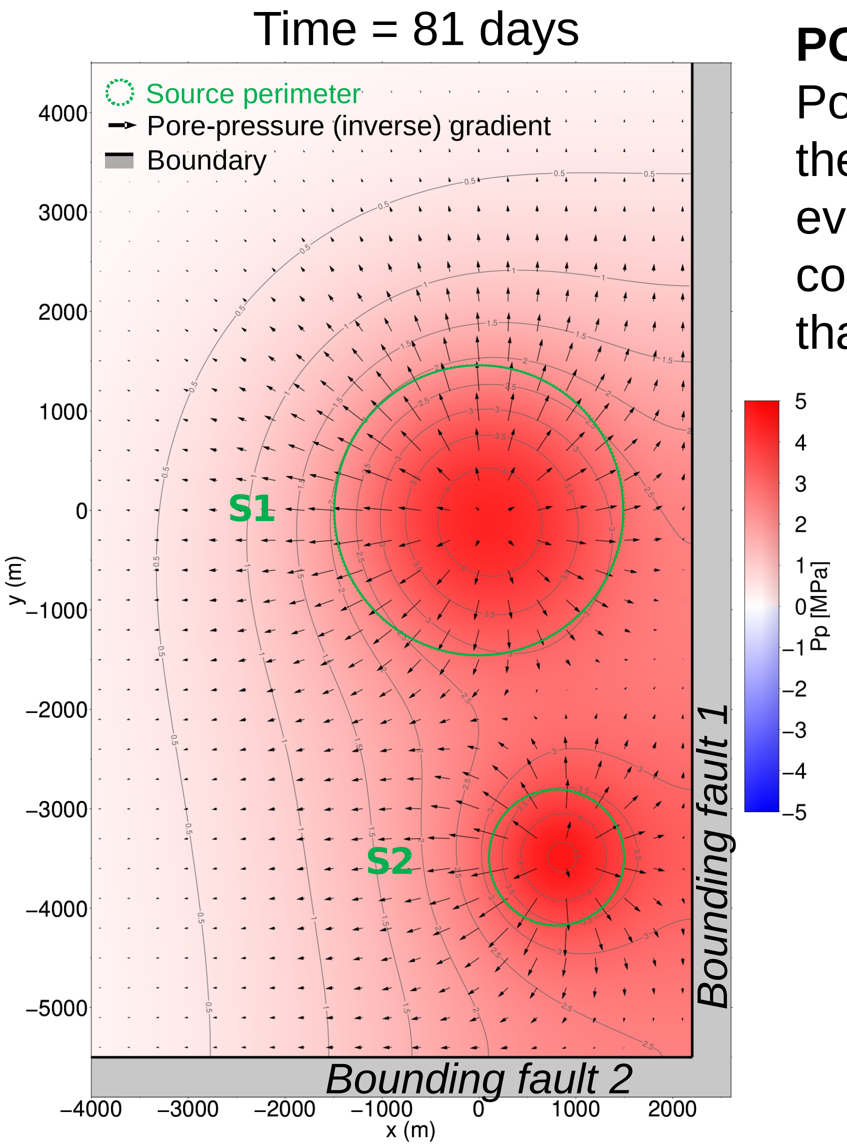


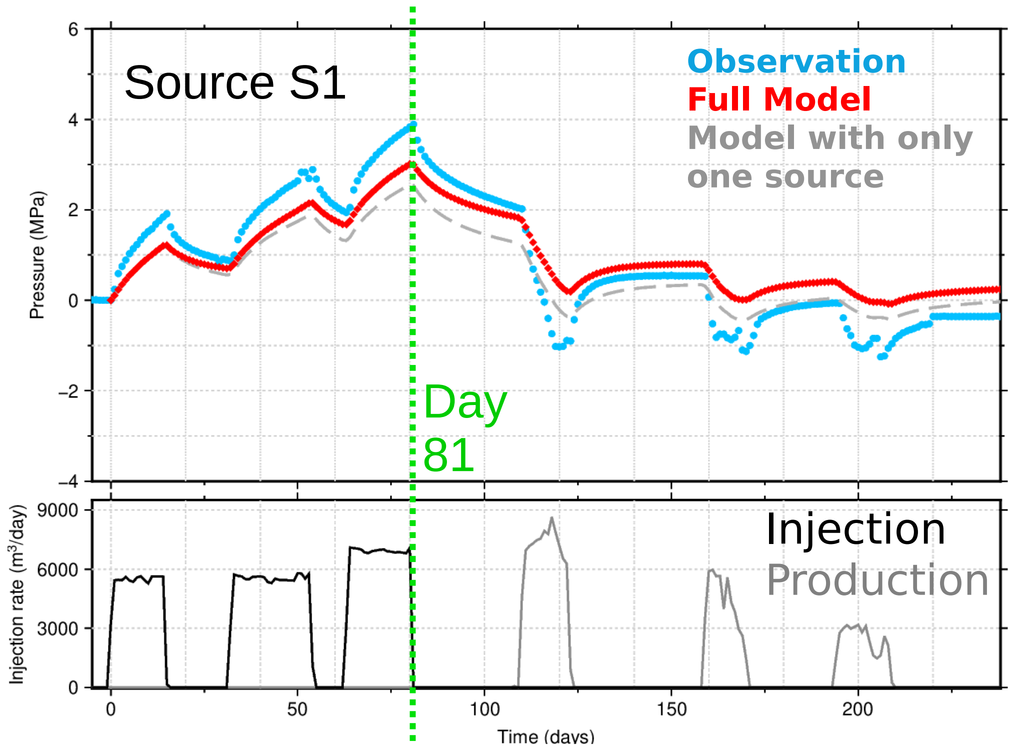

We implement **lateral boundaries** (simulating the effect of impermeable bounding faults) using the image method. In fact, POEL originally accounted for infinite horizontal layers and cylindrical symmetry. We set model parameters (red) for the reservoir layer according to a parametric study optimising the fit with pressure data.

| Layer | Depth [m] | Shear modulus μ [GPa] | Poisson's ratio ν | Undrained Poisson's ratio $\nu_u$ | Skempton's coefficient B | Diffusivity D [$m^2/s$] |
|---|---|---|---|---|---|---|
| $L^{e1(2)}$ | 0-2260 | 25 | 0.28 | 0.4 | 0.5 | $10^{-5}$ |
| $L^{r}$ | 2260-2340 | 21 | 0.28 | [0.28; 0.5] | [0; 1] | [0.1; 12] |

# A1) Poro-elastic model for the aquifer layer: RESULTS




**POEL model solutions for 2 injection/extraction sites S1 and S2:**
Pore pressure spatial distribution (left), and time series (average value within the gas bubble volume, green circles) are displayed here. The pore pressure evolution in time fits well the bottom-hole pressure. Our model results confirm the importance of accounting for impermeable boundaries and show that the semi-analytical solutions implemented in POEL software, despite strong geometrical simplifications due to symmetry constrains, are able to capture the pressure diffusion process within the reservoir.



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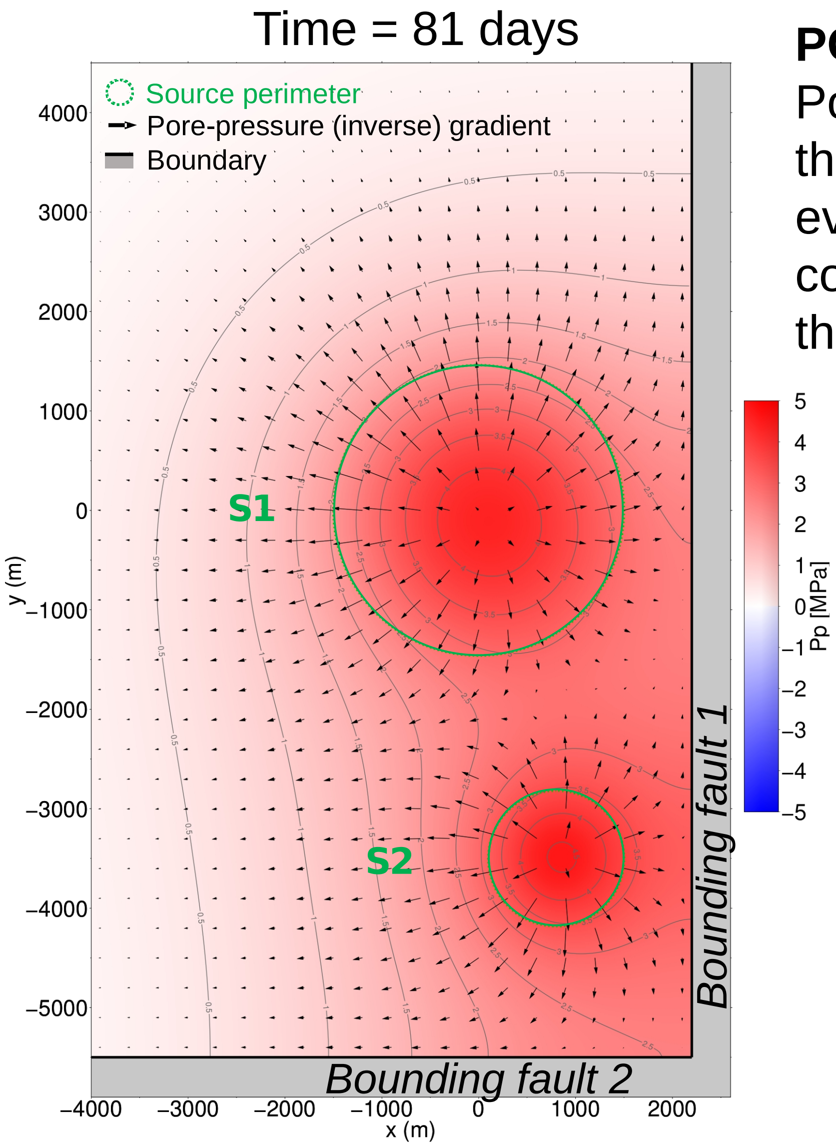


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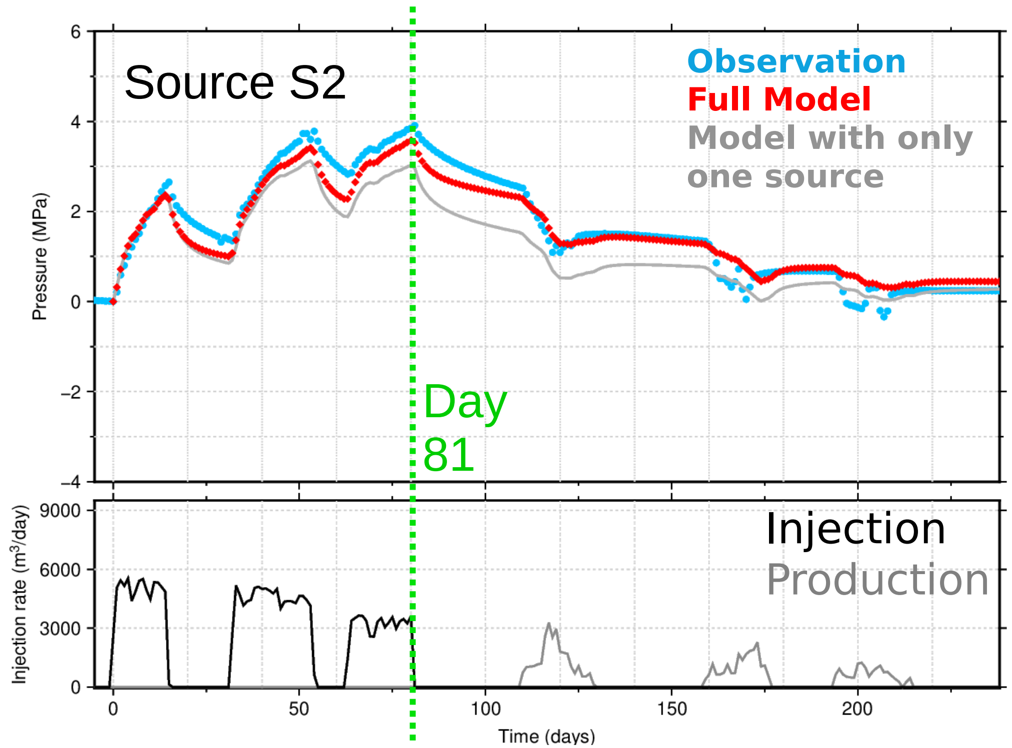
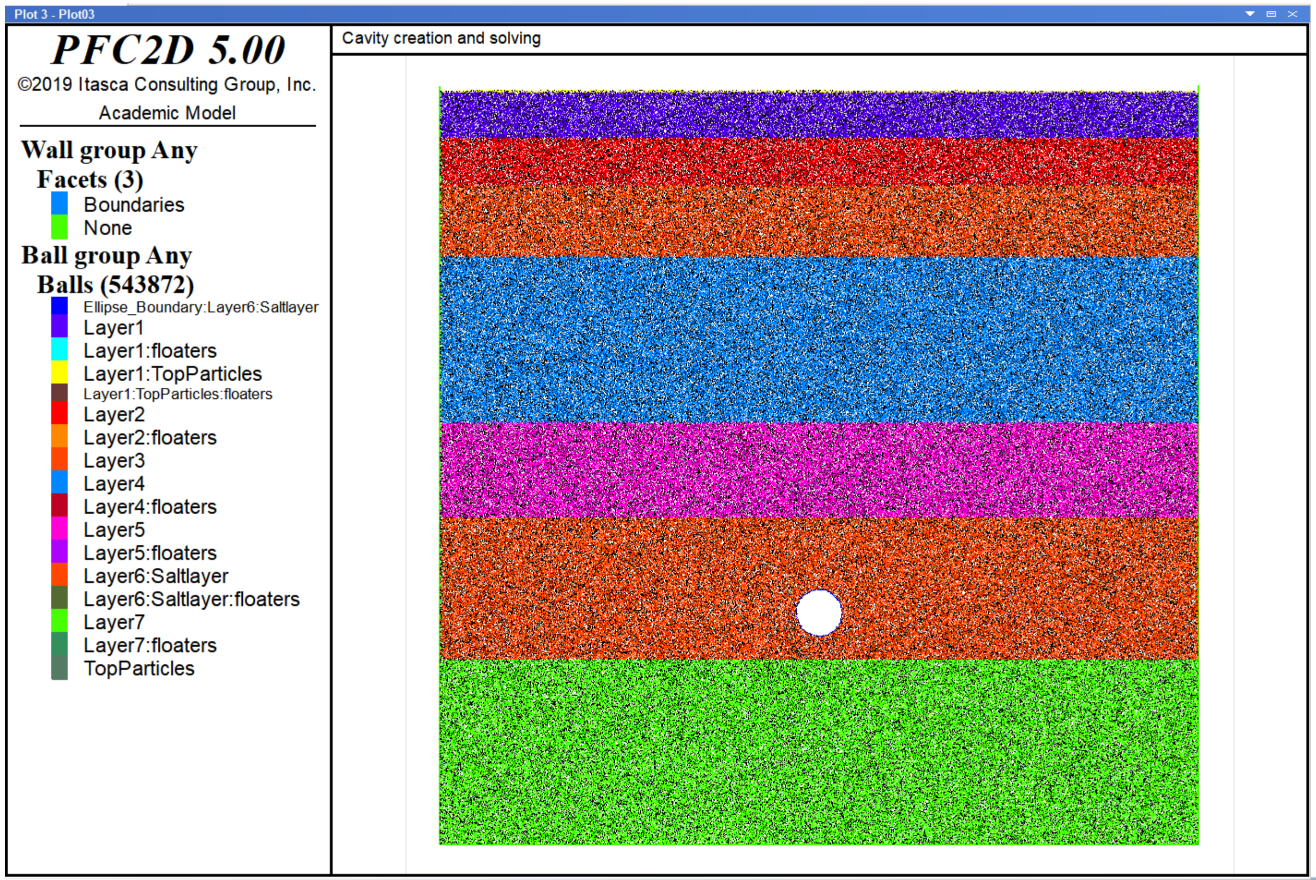


# B1) Stability model for a salt cavern: METHOD

We use the software **PFC2D**, based on a distinct element scheme.
**Model setup:** Quasi-static cavity installation based on *Al-Halbouni et al. 2018* to simulate salt extraction.
**Model parameters:**

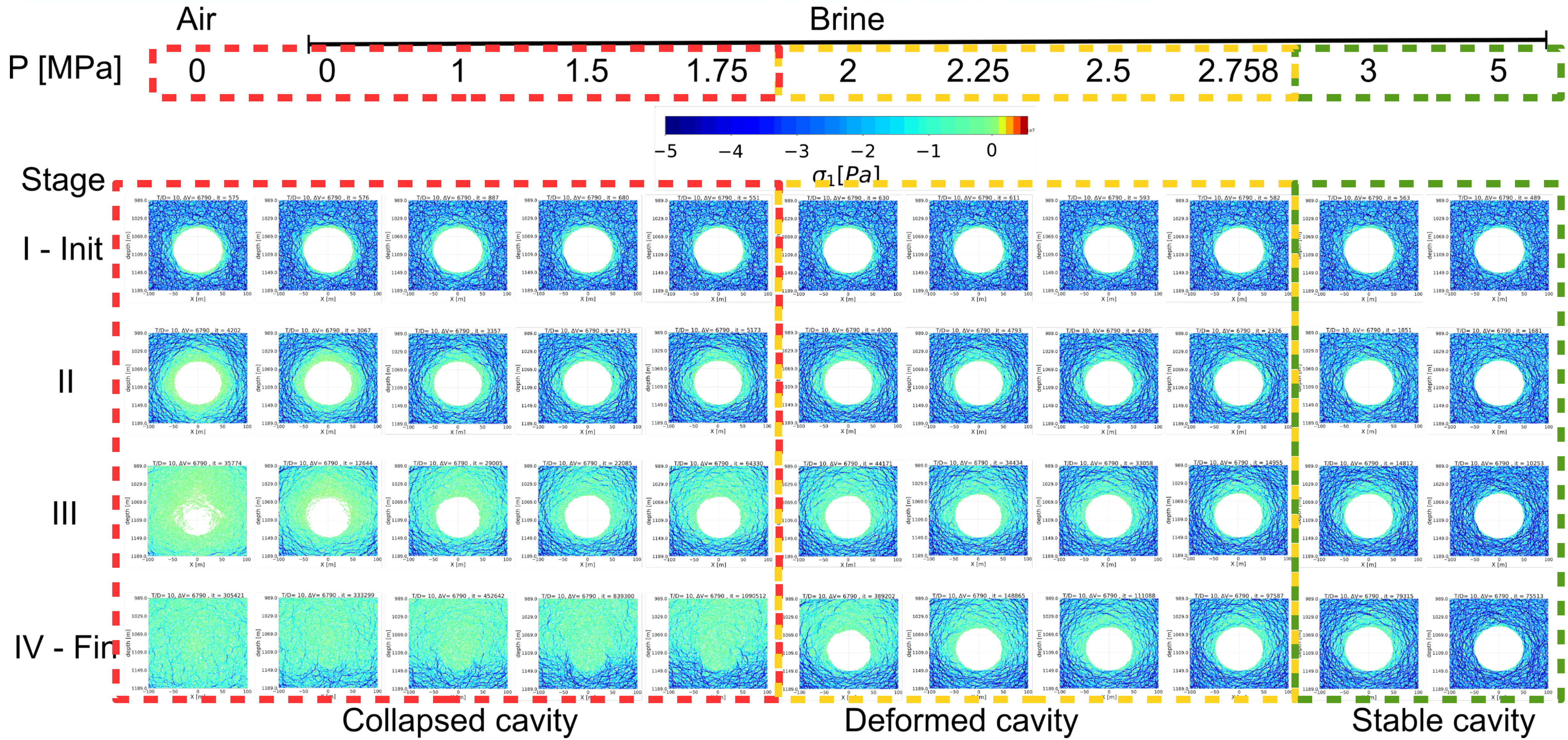
| Height [m] | Width [m] | Mean element radius [m] | Cavity Diameter [m] | Depth (center) [m] |
|---|---|---|---|---|
| 1600 | 1600 | 1.1 | 100 | ~1100 |




The cavity overpressure is obtained by applying the fluid pressure to each element at the surface of the cavity. The fluid pressure at the depth of the injection point within the cavity ($P_{inj}$) is assigned as input parameter. The fluid pressure varies along depth according to a linear hydrostatic pressure profile.
We tested injection pressures between:
**$P_{inj}$ = [0.0; 5.0] MPa**
(with pressure steps of ~0.25 Mpa)

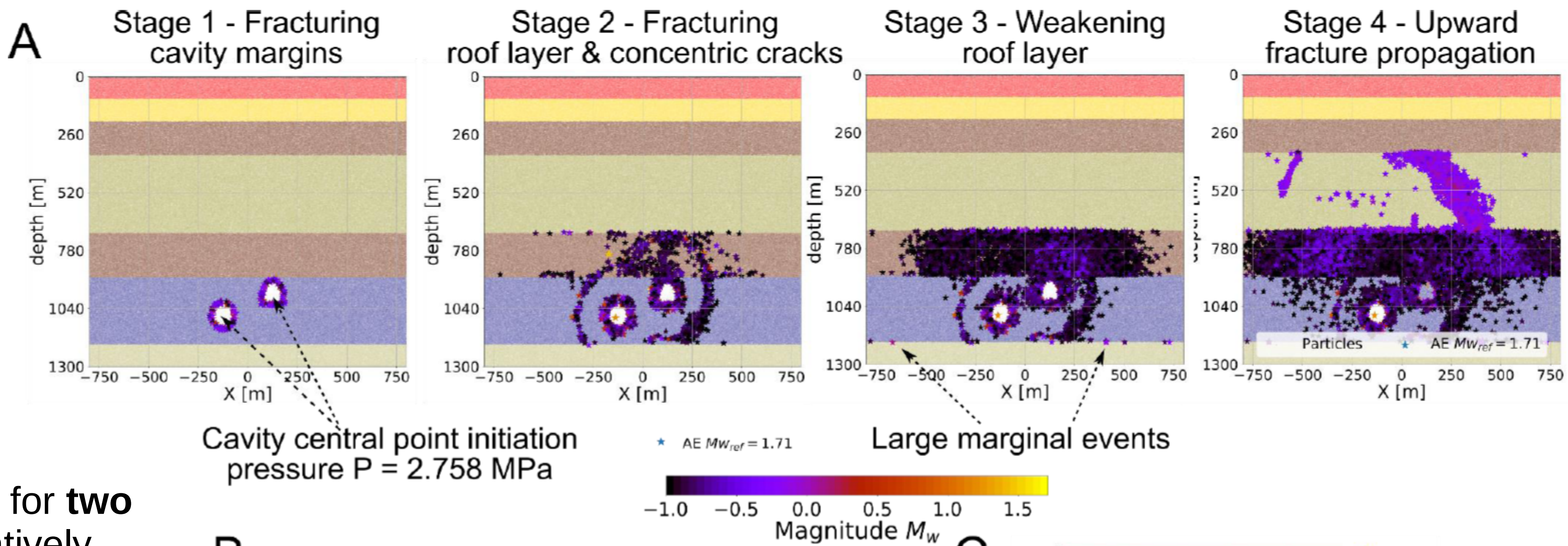
In the next slide we will display results obtained with different $P_{inj}$ values, and how the model evolves (stage I to IV) with focus on its stability.

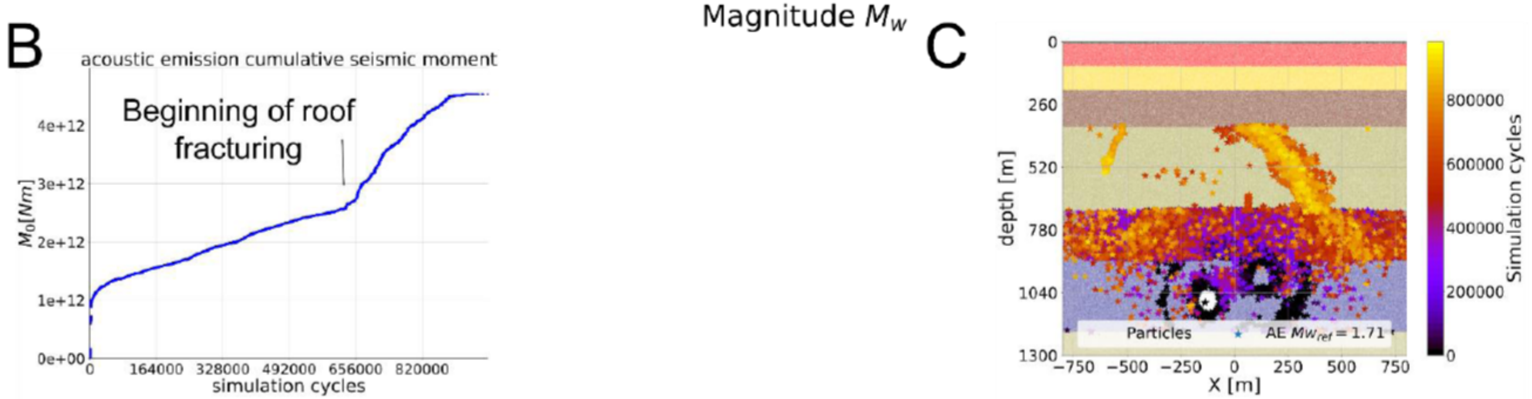
# B1) Stability model for a salt cavern: RESULTS



# B1) Stability model for a salt cavern: RESULTS

Acoustic emissions for cavity injection pressure P=2.758 MPa




- Results obtained for **two cavities** at a relatively short distance, highlight how the stability condition may also be affected by the concentration of cavities.

# CONCLUSIONS

In the context of the model for the gas storage in an aquifer layer (**A1**), we also computed the effect of pore pressure changes at a boundary fault (**A2**) and estimate the expected change in seismic rates according to rate-and-state laws integrated in a mixed physical-statistical earthquake-generation model. This last part is currently in progress, and the results will be compared with micro-seismicity rates provided by ENAGAS for our case study.

In the context of the salt cavern model (**B1**), we are planning to use the stress change induced by the cavity in the surrounding (as it has been computed with the Distinct Element Model), as an input stress scenario for a hydrofracture propagation model (based on a Boundary Element scheme, *Maccaferri et al., 2019*). While the hydrofracture propagation model has been already developed and tested for such purpose (**B2**), we are currently working on its application to the salt cavern case study.