A Multi-Scale Model To Investigate Gas Migrations In Clay Materials

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ON CLAYS IN NATURAL AND ENGINEERED BARRIERS FOR RADIOACTIVE WASTE CONFINEMENT

Context

Deep geological repository:

- Multi-barrier confinement
- Multi-physical processes (THMC)
- Interactions between processes

Major issue:

Corrosion of metal components
↳ Gas release
↳ Gas pressure build-up
↳ Potential gas migrations through the barrier

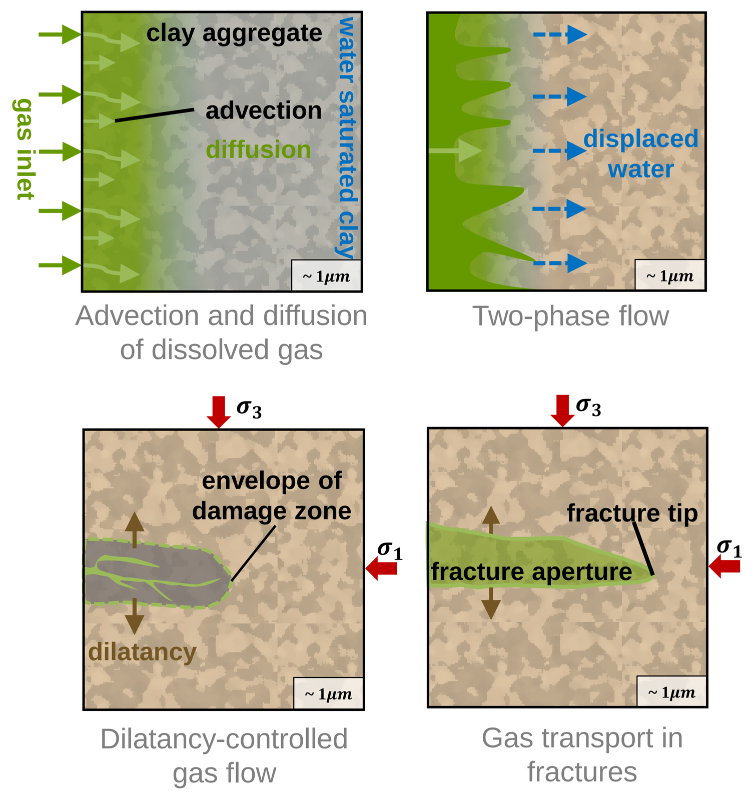


Figure 1: gas transport in clay materials, from [1]

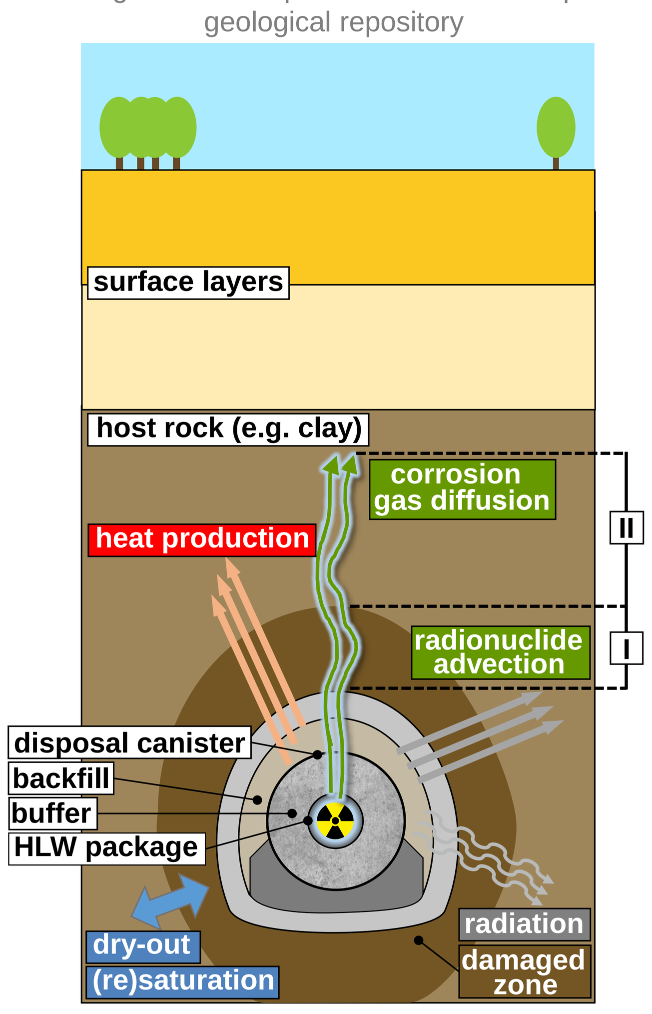


Figure 2: conceptual scheme of a deep geological repository

Mode of gas transport depends on:

- Gas pressure increase (Figure 1, [1])
- Investigated zones (Figure 2)
  - Excavation damaged zone (I)
  - Sound rock layers (II)

Gas transfers in zone II:

- Governed by the rock structure at a micro-level
- Development of a multi-scale model
  - Complexity and heterogeneity of the microstructure (pore network morphology and bedding planes)
  - Hydro-mechanical effects

Application

- Modelling of a lab-scale gas injection experiment [2]

Purpose of the model

Macroscale models ⟷ Multiscale model ⟷ Nanoscale models

- Enriched to discern local phenomena

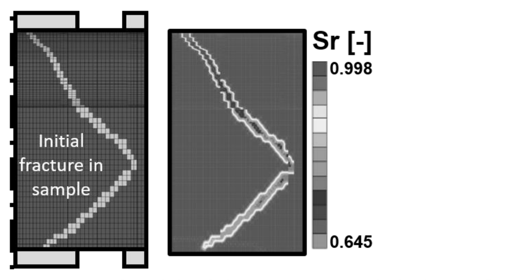


Figure 3: Embedded fracture model, from [3]

- Experimental evidences that defects govern gas flows
- Realistic microstructure including basic ingredients to reproduce macro-properties

- Refined modelling of all the pore structure complexity

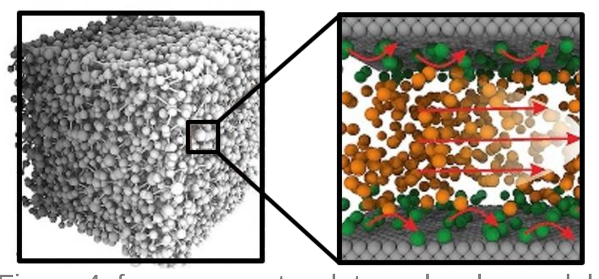


Figure 4: from pore network to molecular model

Description of the model

Representative microstructure

- 1 fracture = bedding plane
- Pore network = assembly of tubes
- Bridging planes

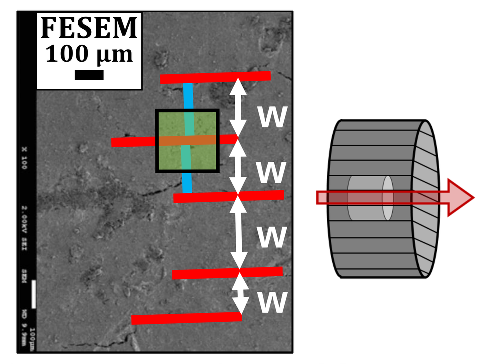


Figure 5: FESEM images [2]

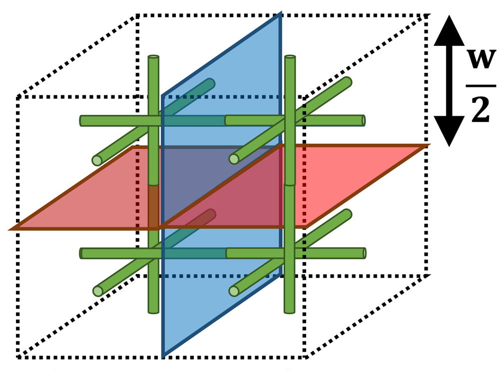


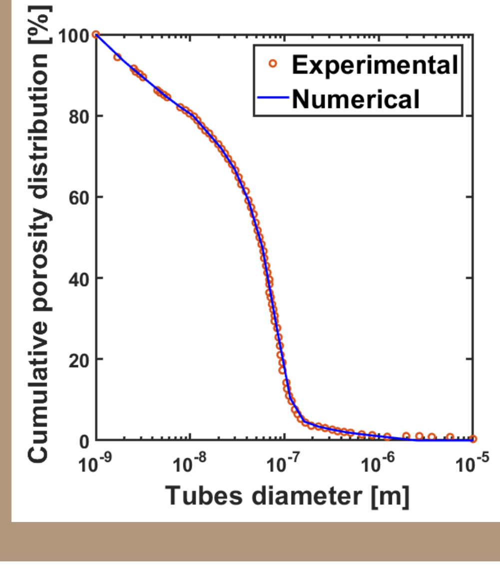
Figure 6: conceptual scheme of microstructure

Experimental characterisation of microstructural components

1. Macroporosity

Fitting of the pore size distribution curve

Effect of small-size pores (tortuosity)

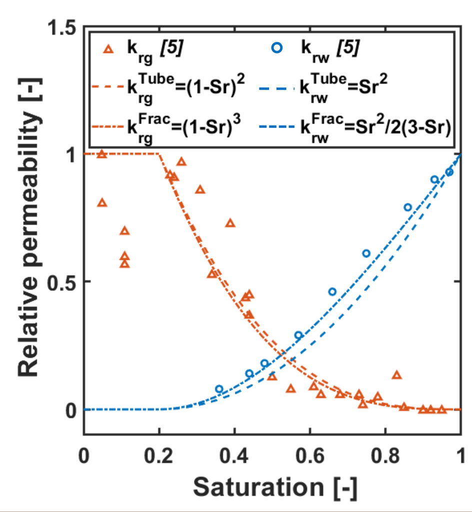


2. Intrinsic permeability

Navier-Stokes equations
Effect of large-size pores

3. Relative permeability

Multi-phase flow



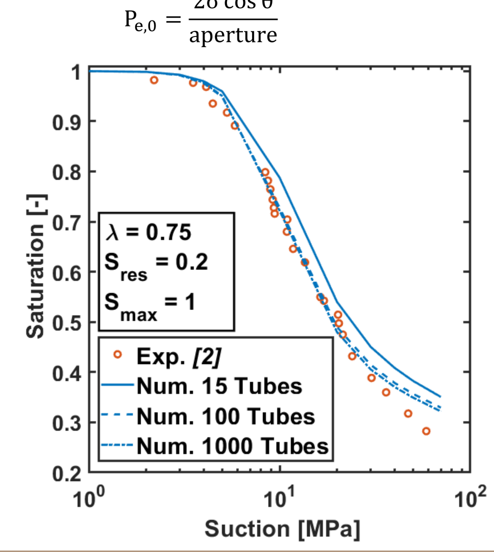
4. Retention curve

Van Genuchten

$$S_r = S_{res} + (S_{max} - S_{res})\left(1 + \left(\frac{s}{P_e}\right)^{\frac{1}{1-\lambda}}\right)^{-\lambda}$$

Laplace equation

$$P_{e,0} = \frac{2\sigma\cos\theta}{\text{aperture}}$$

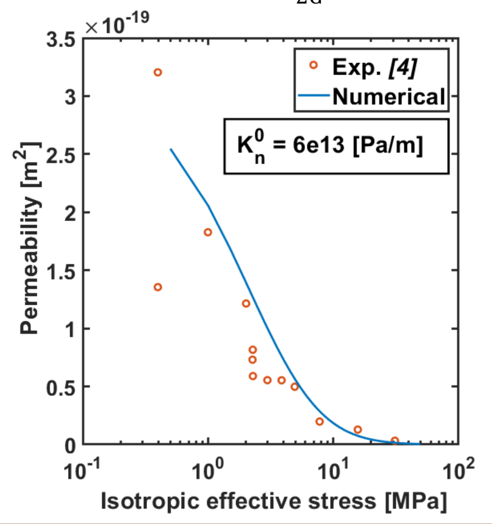


5. Mechanical aperture

Function of the stress state evolution

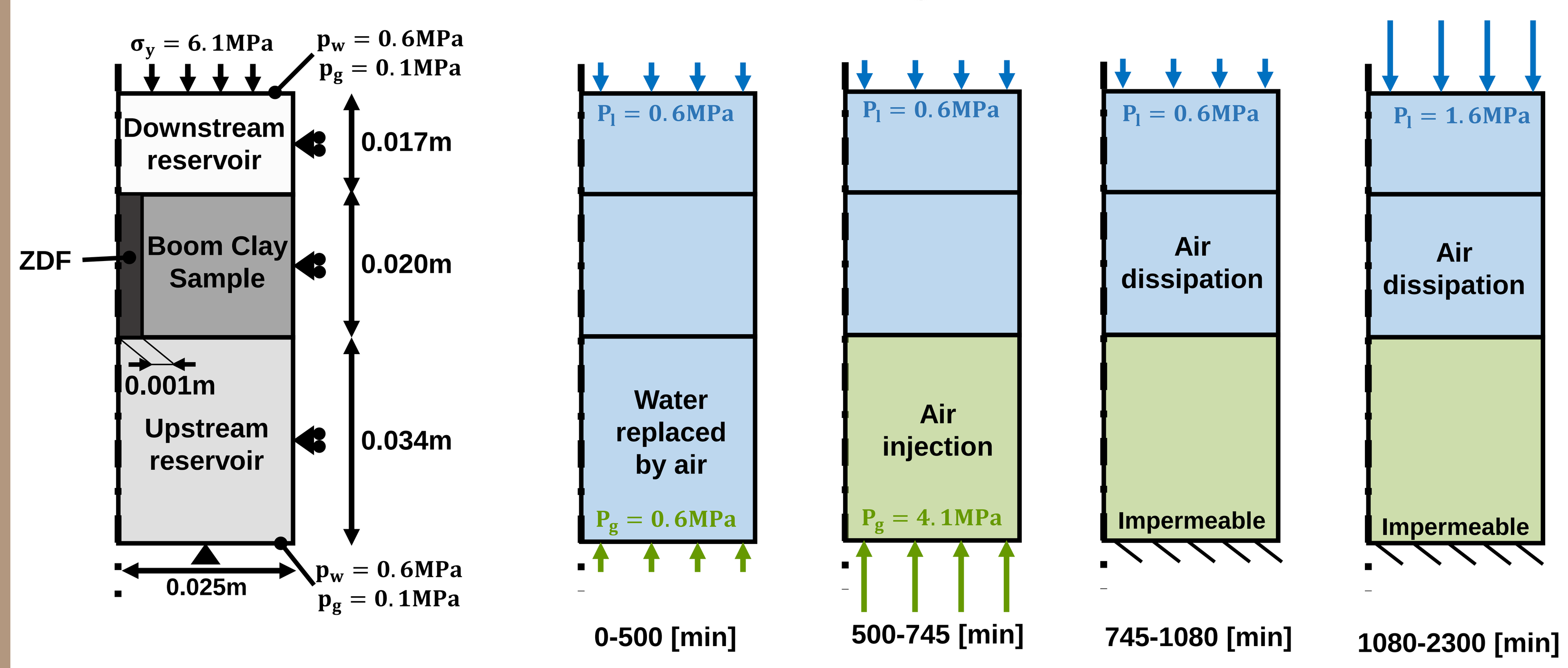
Fracture: $\Delta h = \frac{\Delta\sigma'}{K_n(h)}$ with $K_n = \frac{K_n^0}{\left(1 + \frac{\Delta h}{h_0}\right)^2}$

Tube: $\Delta D = -\frac{D_0}{2G}\Delta\sigma'$



Modelling of a gas injection experiment

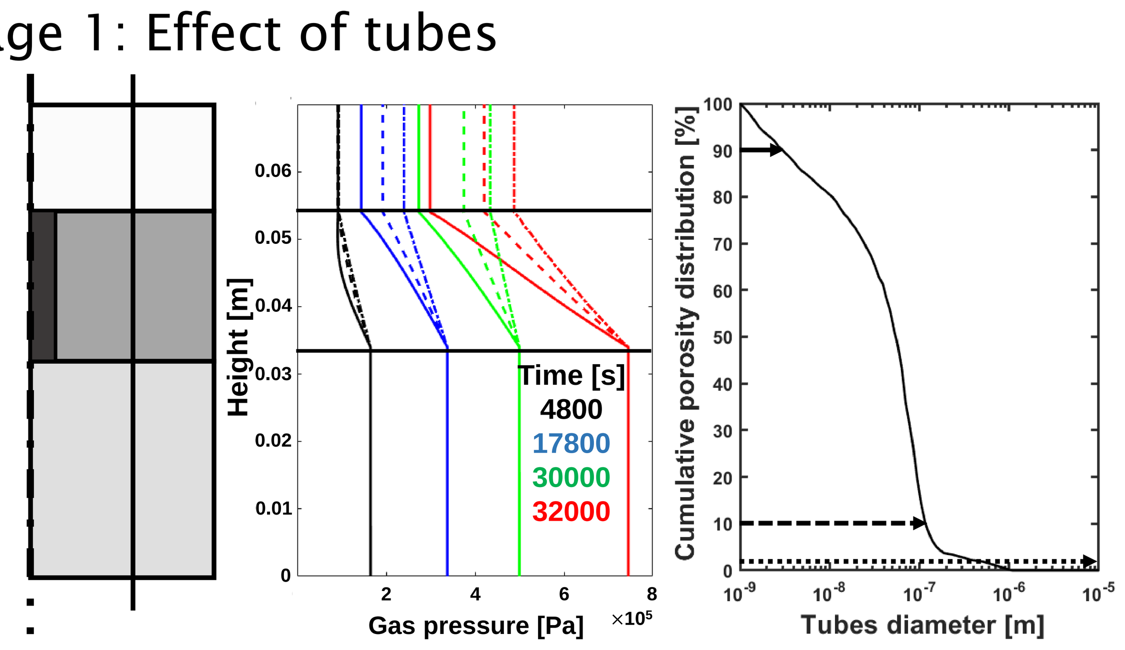
Geometry - Boundary conditions - Stages of the simulation



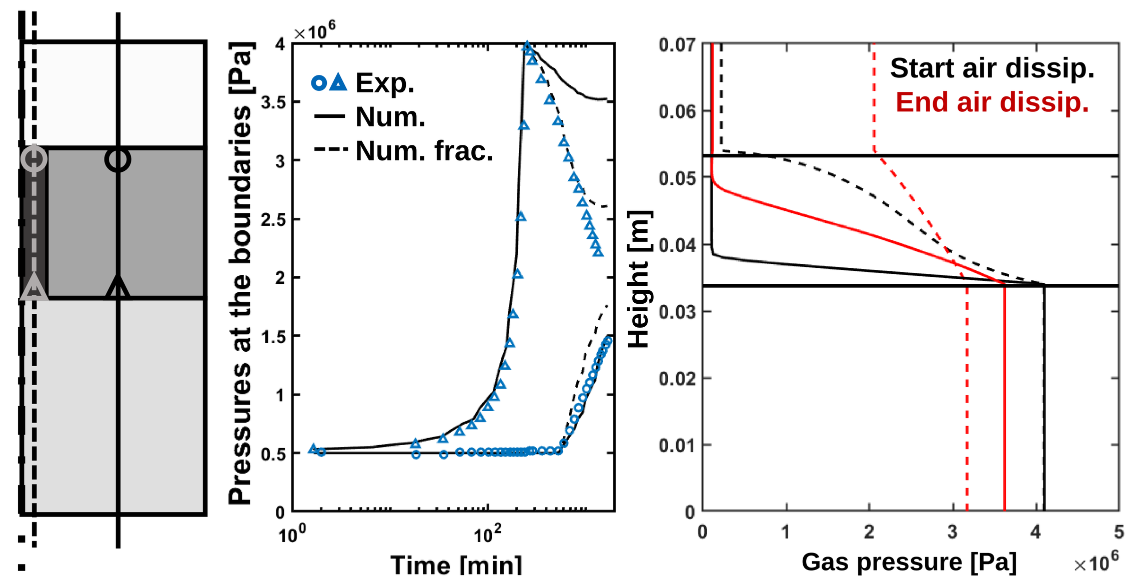
Parameters

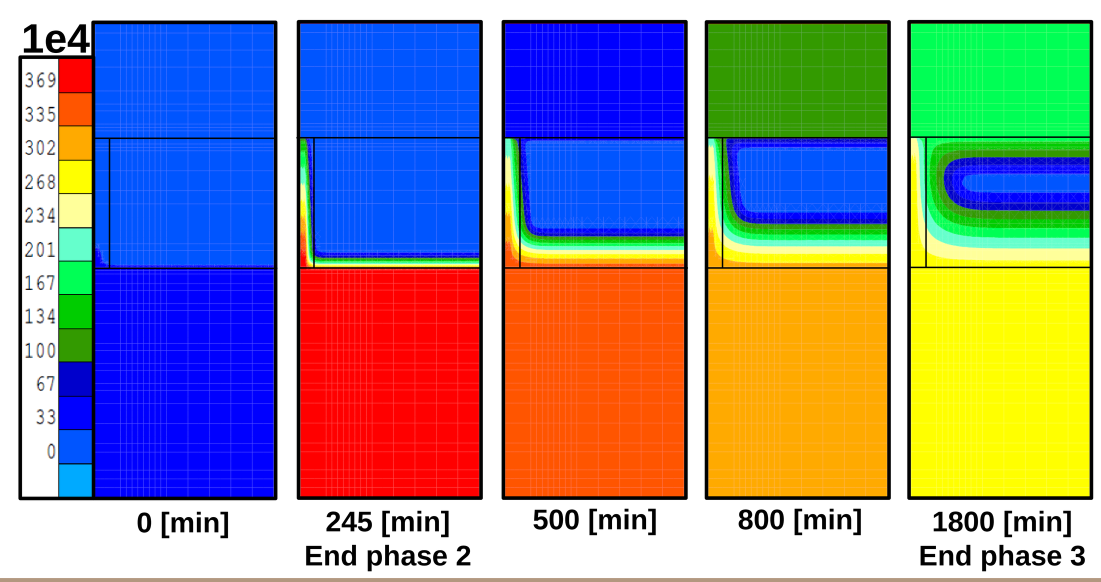
	Boom Clay Matrix	Zone of Fracture Development (ZFD)	Reservoirs
Mechanical	E = 400MPa ν = 0.33		Very stiff elements E = 10000MPa ν = 0.3
Hydraulic	Initial aperture: $1 \cdot 10^{-7}$m	Initial aperture: ↗ by 1 order of magnitude	Highly conductive: n = 0.5 $k = 10^{-10}\text{m}^2$
	Initial permeability: $\sim 4.2 \cdot 10^{-19}\text{m}^2$	Fracture stiffness: ↘ by 2 orders of magnitude	Flat retention curve: $P_{entry} = 0.001$MPa
	Initial porosity: 0.363		
	100 tubes with $D \in [10^{-9}\text{m} ; 10^{-6}\text{m}]$		

Stage 1: Effect of tubes



Stage 2: Gas pressure evolution





Conclusion

We **developed** a multiscale model able to:

1. Simply idealise the microstructure of the rock with fractures and tubes
2. Reproduce mechanisms inherent to gas migrations in sound rock layers

We **showed** that:

1. Macropores, micropores and fractures play different roles in gas flows
2. Preferential flow paths can be generated through fractures with weaker properties

We **plan** to:

1. Link the air entry pressure to fracture/tube aperture
2. To investigate gas flows perpendicular to bedding planes, using bridging planes
3. Make the model general enough to cope with other kinds of host rocks

Reference

[1] P. Marschall et al (2005), *Characterisation of Gas Transport Properties of the Opalinus Clay, a Potential Host Rock Formation for Radioactive Waste Disposal*, Oil & Gas Science and Technology.
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[3] P. Gerard et al (2014), *Modelling of localised gas preferential pathways in claystone*, International Journal of Rock Mechanics and Mining Sciences, 67:104-114.
[4] P. Bésuelle et al (2014), *A Laboratory Experimental Study of the Hydromechanical Behavior of Boom Clay*, Rock Mechanics and Rock Engineering.
[5] G. Volckaert et al (1995), *MEGAS Modelling and experiments on gas migration in repository host rocks*. EUR 16235 MEGAS Final Report Phase 1, p.464.

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