18 years of monitoring pore pressure evolution during and after excavation in the Callovo-Oxfordian claystone: the main insights

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2023
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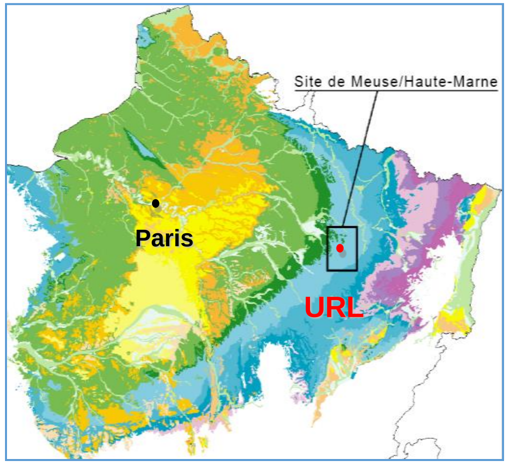
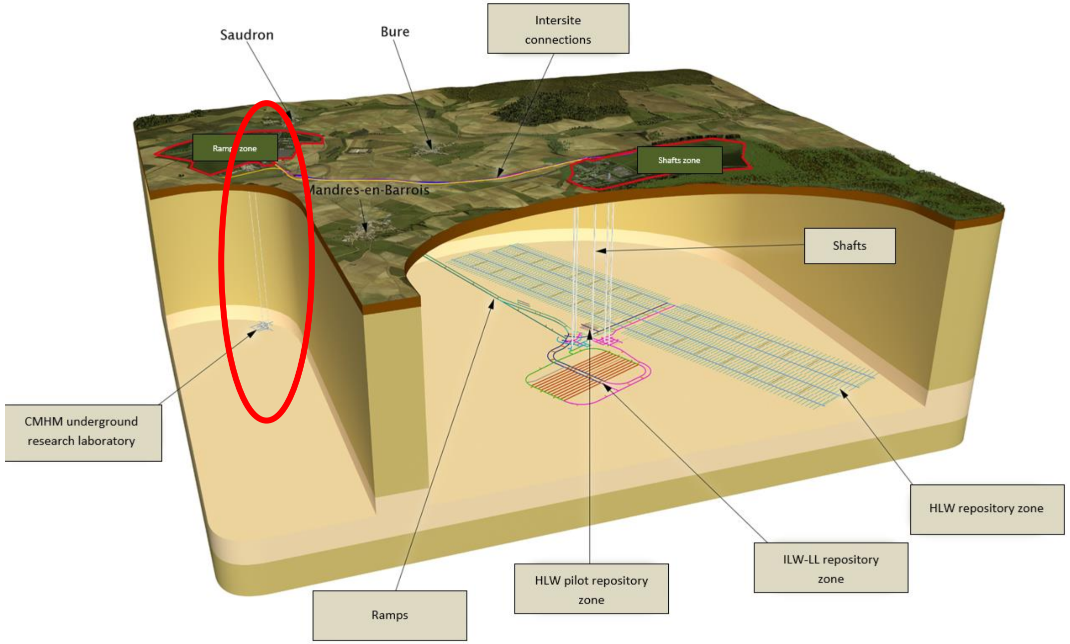
Context
Cigéo Project

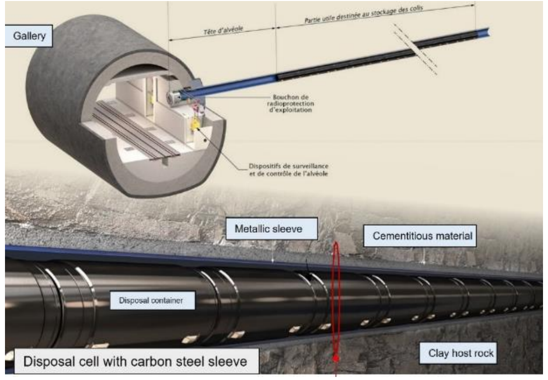
- French National Radioactive Waste Management Agency (Andra) in charge of design and implementation of deep geological repository
  - Cigéo is the planned French HLW and IL-LLW Deep Geological Repository,
    - License application was summit in January 2023
  - Location in East of Paris Basin
  - In the Callovo-Oxfordian claystone

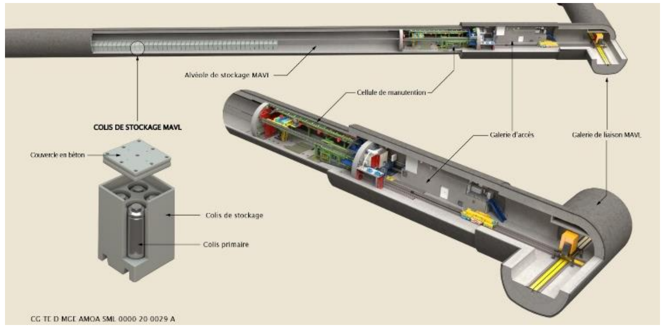


Callovo-Oxfordian claystone

- Age: 160 million year
- Depth at the site: ~500 m
- Thickness at the site: ~130 m
- Anisotropic stress field
- **Properties**
  - ✓ Low hydraulic conductivity, $K \approx 10^{-13}$ m/s
  - ✓ Small molecular diffusion
  - ✓ Significant retention capacity for radionuclide
  - ✓ UCS : ~ 21 MPa







Meuse/Haute-Marne Underground research laboratory
Test of different excavation methods

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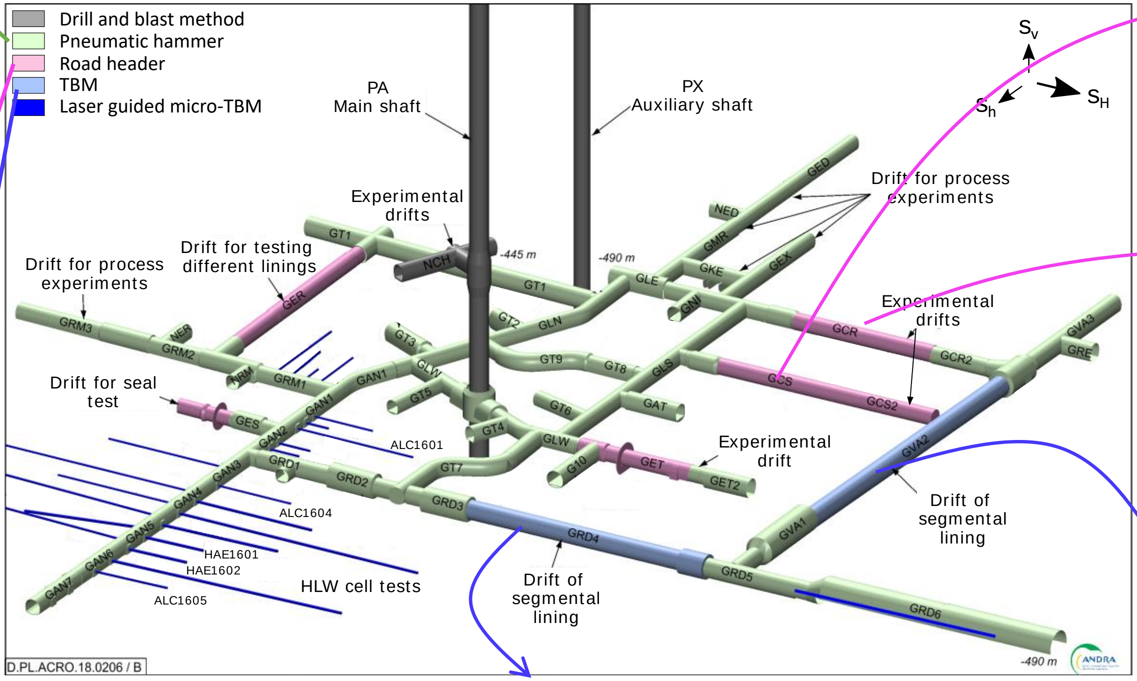
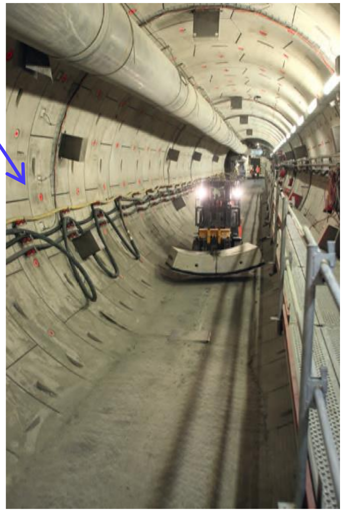
- Test different excavations and supports methods (CTM &TBM) in parallel drifts to better understand the behavior of the drift by comparison
  - Parallel to the major and minor horizontal stress
  - From low support to stiff support like concrete segments

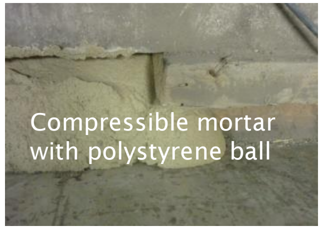


Radial rockbolts (3 m long),
18 cm of fiber reinforced shotcrete,
12 yieldable concrete wedges (hiDcon®)

≈ GCS drift + 27 cm of concrete casted in place 6.5 month after excavation

Segment emplacement method:
- Segment of 45 cm thick
- Gap filling with radial injection of mortar (classical & compressible)





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Feasibility of galleries and MA-VL cells
Monitoring strategy at Meuse/Haute-Marne URL

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Experimental set up: "Mine by experiment"

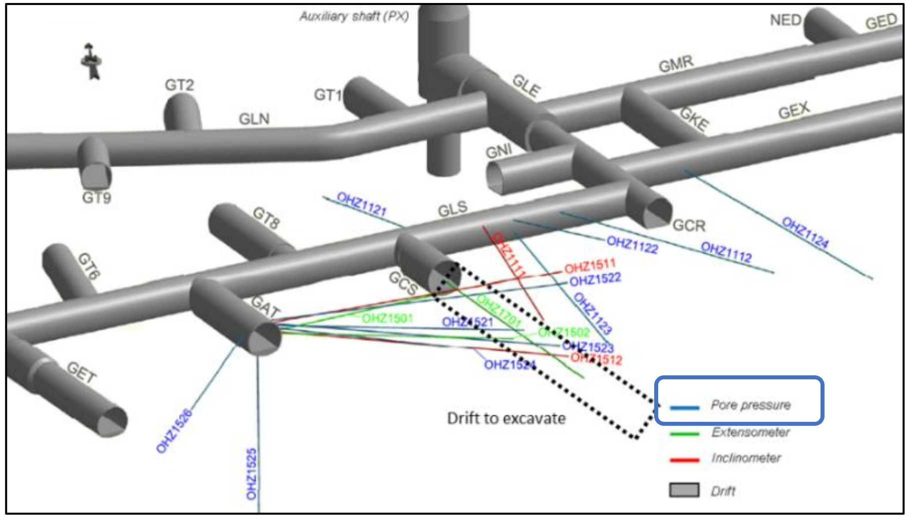
- Boreholes (Displacement, **pore pressure**) emplaced before excavation
- Convergence measurements, geological survey, boreholes (displacement)
- Borehole to characterize damage zone (permeability measurements, velocity survey)

Multipacker system

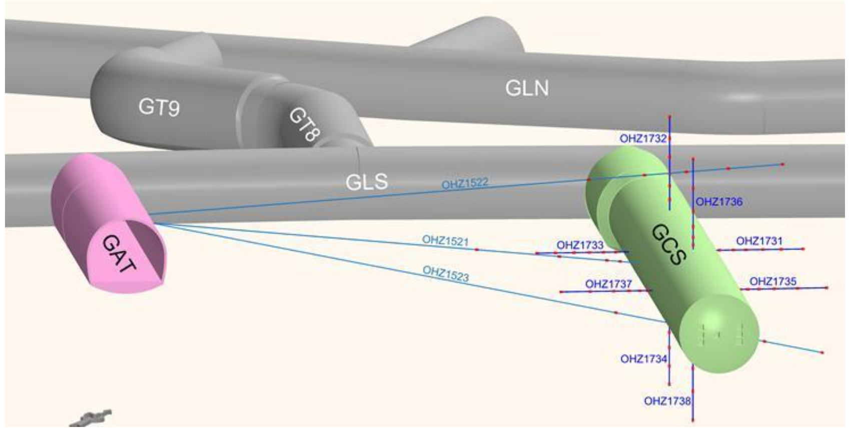
- Allow pore pressure measurement and hydraulic test
- Emplaced at least 2 months before excavation work

Example GCS gallery

Before excavation



After excavation



Large pore pressure survey + permability measurement)

Multipacker system

Feasibility of galleries and MA-VL cells
Excavation induced fractures network

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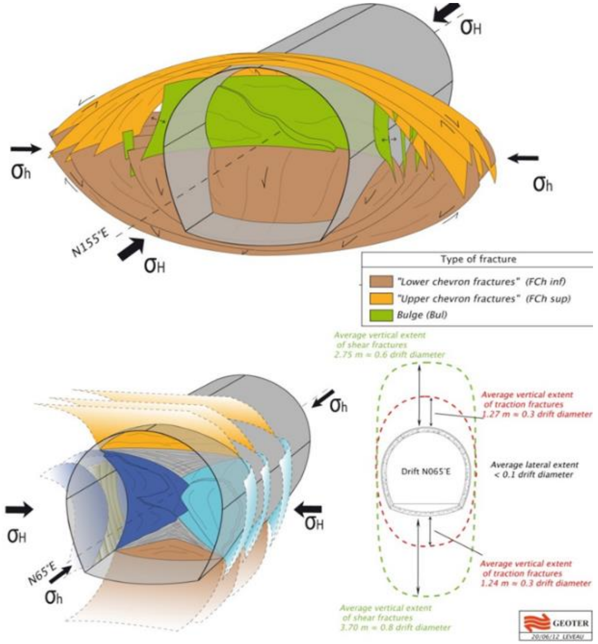
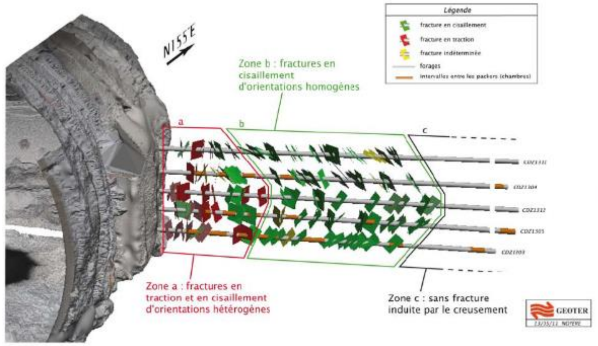
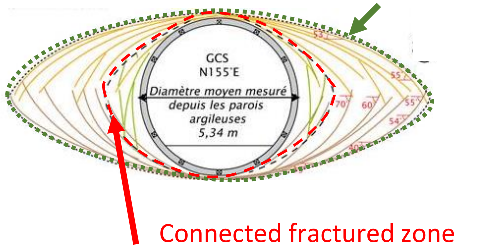
- A significant excavation induced fractures network (shear and tensile fractures) appears
  - Type of fracture are similar but the extend depend of drift orientation versus in situ stress state
  - Extend of shear fracture is larger than tensile fracture
  - Extend is not dependent of the excavation methods but of the time of support emplacement



Structural analysis of core → **Model of fractures**





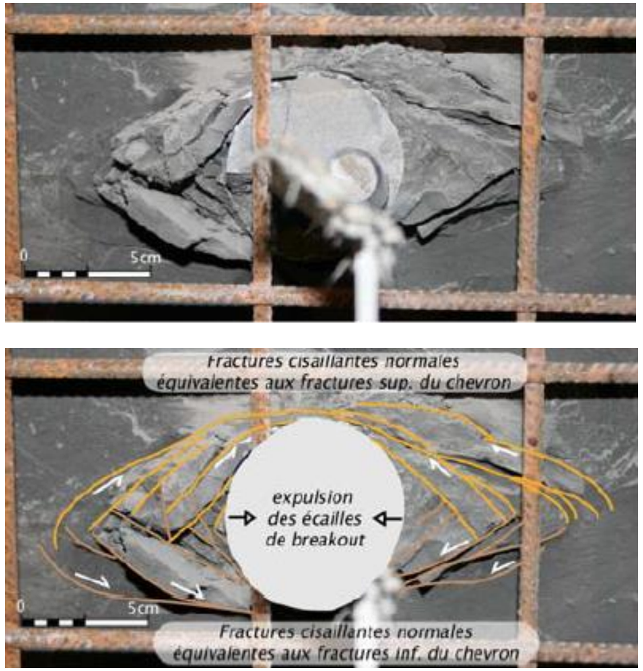
Drift Orientation		Extensional fractures extent			Shear fractures extent		
		Min.	Average	Max.	Min.	Average	Max.
	Ceiling	0.2×D	0.3×D	0.4×D	0.5×D	0.6×D	0.8×D
	Wall	0.1×D	0.1×D	0.2×D	-	-	-
	Floor	0.2×D	0.4×D	0.5×D	0.8×D	0.8 ×D	1.1×D
	Ceiling	-	0.1×D	0.15×D	-	-	-
	Wall	0.01×D	0.2×D	0.4×D	0.7×D	0.8×D	1.0×D
	Floor	-	0.1×D	0.15×D	-	-	-

Armand et al. 2014

Feasibility of galleries and MA-VL cells
Excavation induced fractures network

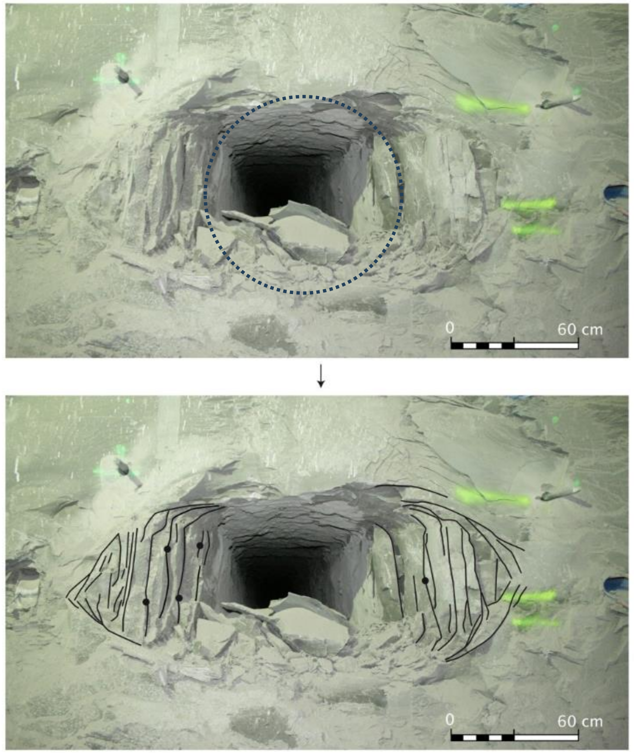
- Similar shape of fracture pattern at different diameter

Size of rock bolt
~0,1 m diameter

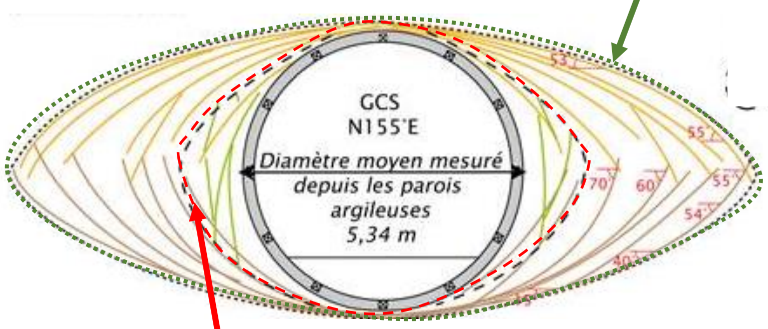


Armand et al. 2014

Size of micro tunnel
~0,75 m diameter



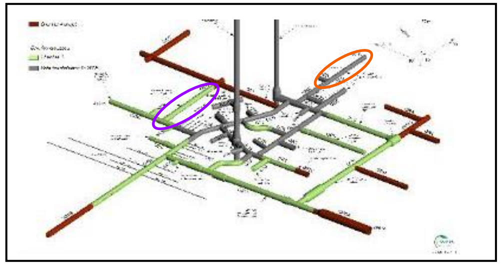
Size of gallery
~ 6 m diameter



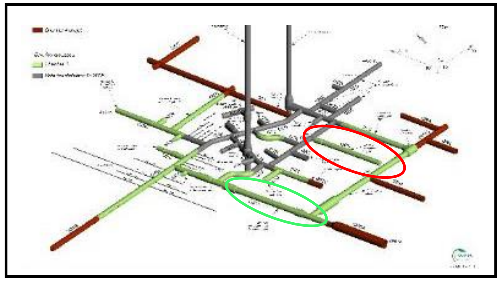
Feasibility of galleries and MA-VL cells
Excavation induced fractures network: permeability

- Permeability around drift
  - High hydraulic conductivity in ZFC
    - Linked with transmissivity of fracture
  - Low hydraulic conductivity in ZFD
    - No more 1 order of magnitude versus COx
- Slightly higher hydraulic conductivity for the TBM compared to the CTM but remains in the same order of magnitude

Example for gallery // σ_h

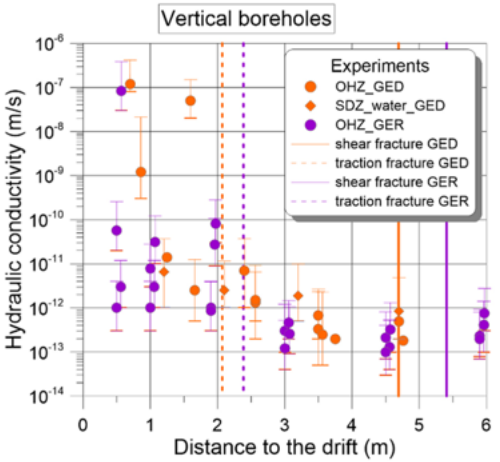


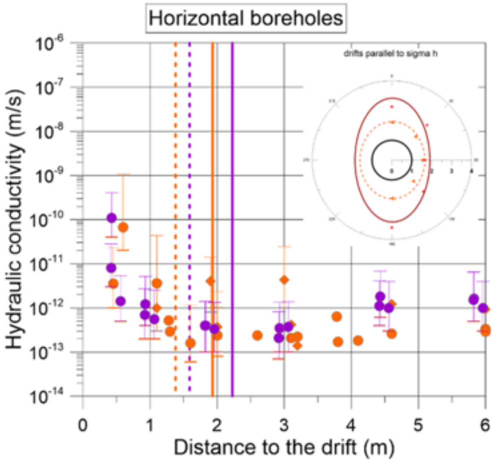
Example for gallery // σ_H

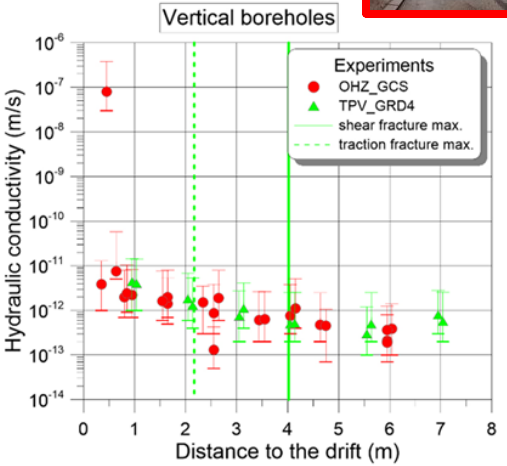


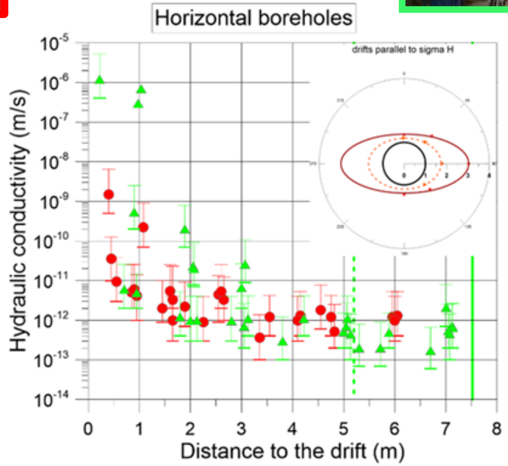
CTM

TBM









Feasibility of galleries and MA-VL cells

Pore pressure response around a drift (//σ_H)

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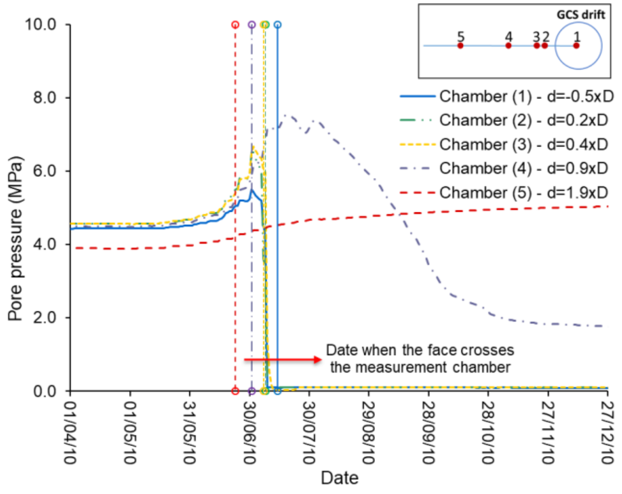
Observed hydromechanical response to excavation for gallery //σ_H

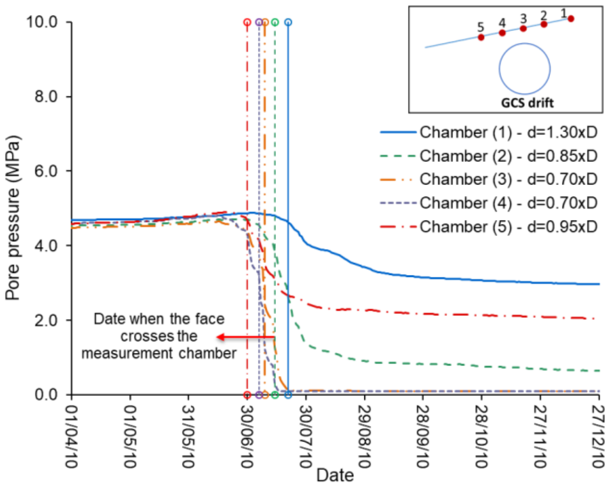
- Significant pore pressure variation during excavation
  - Anisotropic variation
    - related to the elastic anisotropy of the material
    - Excavation damage zone
  - Coupling M=> H (almost undrained behaviour during excavation)
  - Overpressure of several MPa at the wall
  - Drop of pressure at the front crossing

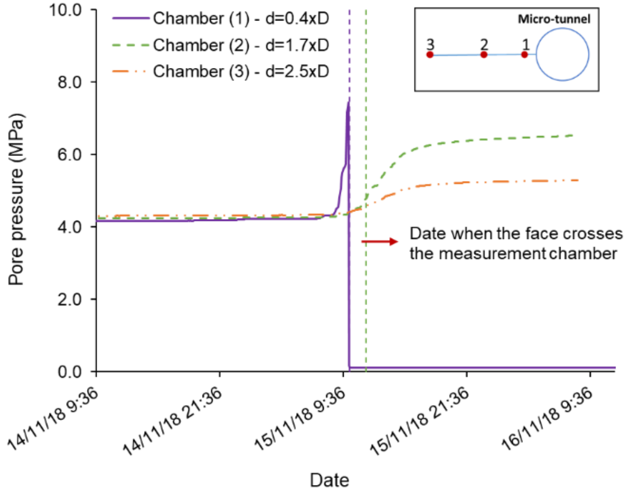
Size of gallery
~ 6 m diameter

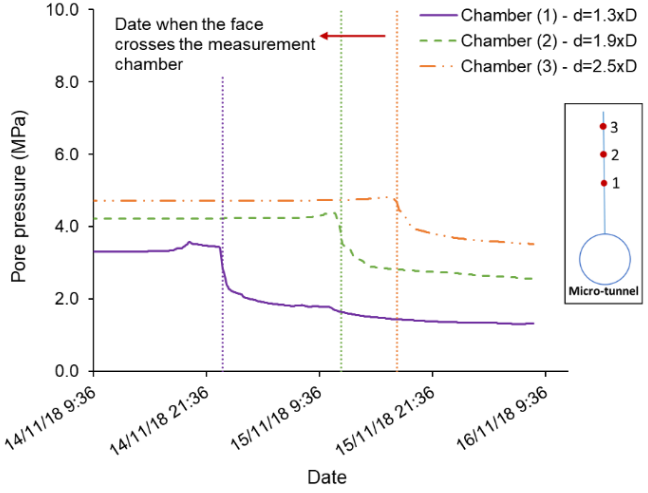
Size of micro-tunnel
~0,75 m diameter

Vu et al. 2020









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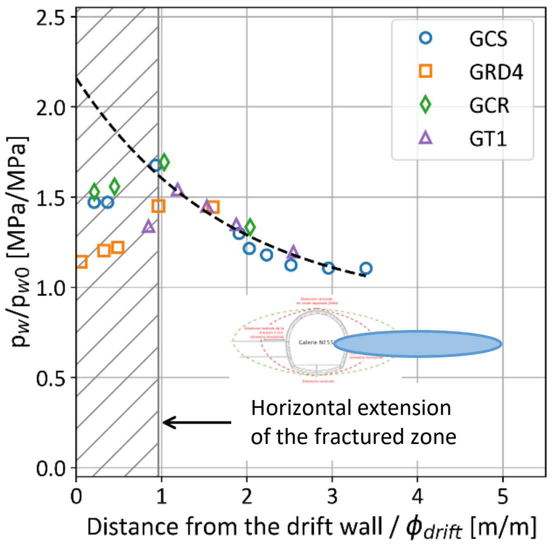
Feasibility of galleries and MA-VL cells

Excess pore pressure around the opening($//\sigma_H$)

- Amplitude of this excess pore pressure is a function of the radial distance from the opening
  - Follows an exponential curve outside the fracture zone
  - Influence range:
    - About $4\times\varnothing_{drift}$ for drift and up to for micro tunnel $6\times\varnothing_{micro\text{-}tunnel}$
    - More limited in vertical direction
- Depend on excavation rate

Gallery
~5 to 6 m diameter

Micro tunnel
~0,75 to 0,95 m diameter



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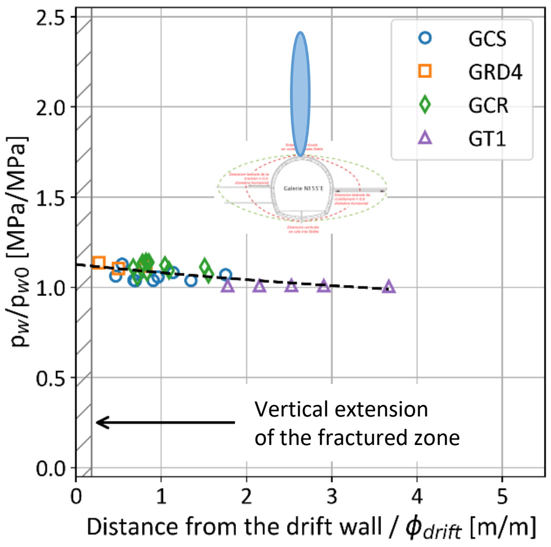

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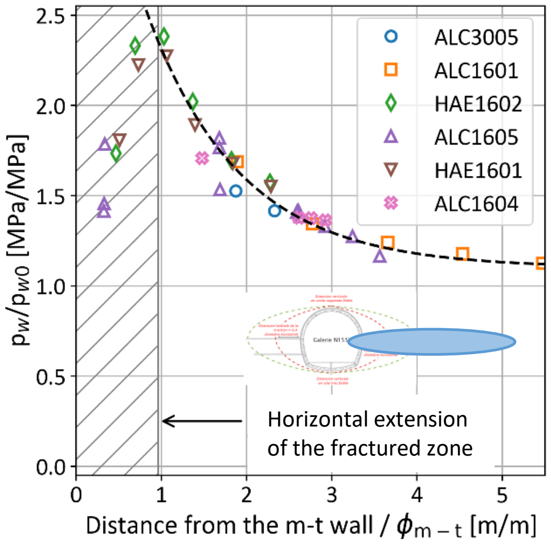
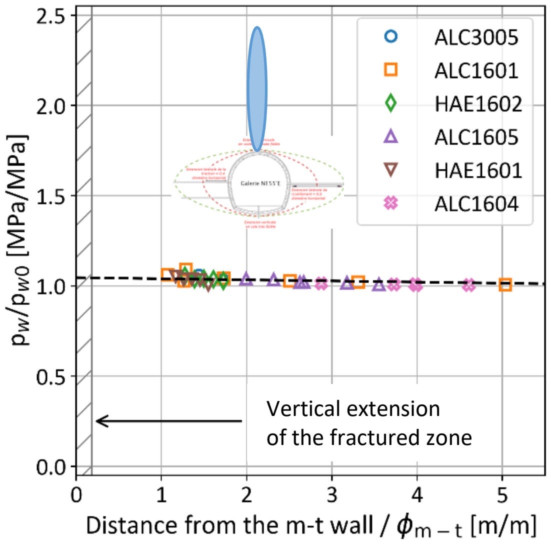


(A)



(B)

Feasibility of galleries and MA-VL cells
Long-term evolution of the hydraulic gradients around drifts

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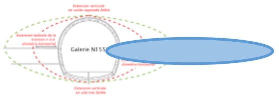
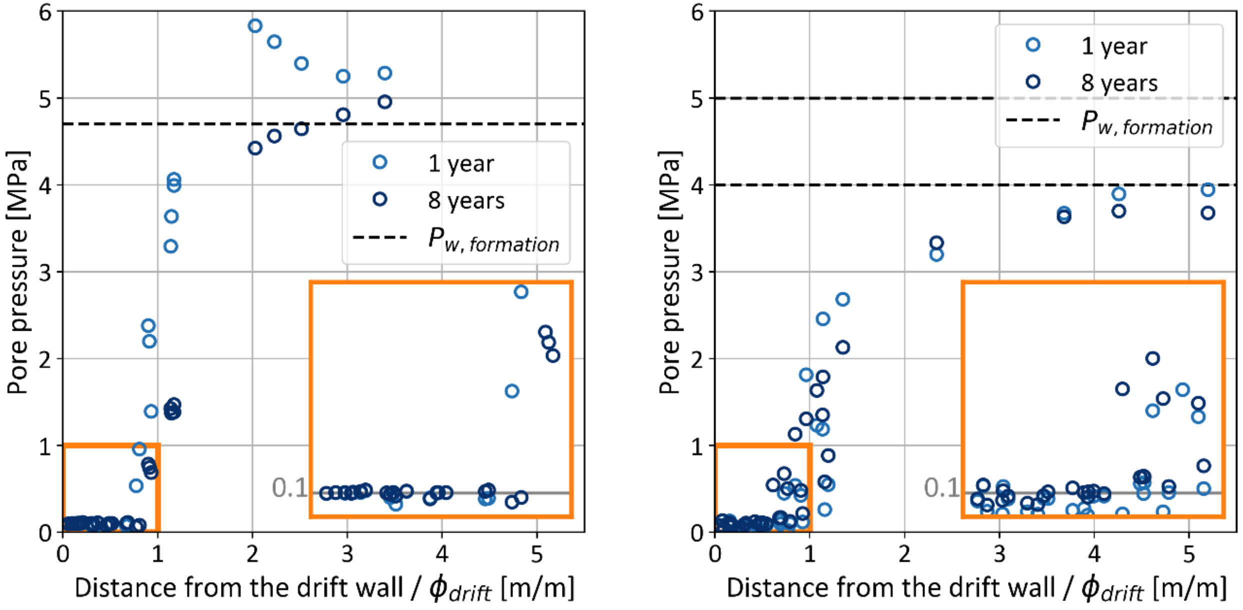
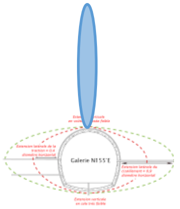
- Pore pressure tends to find a hydraulic equilibrium between the opening wall and the pore pressure in the formation
  - Excess pore pressure has not been completely dissipated and continue to diffuse in the rock mass
  - For the long term behaviour hydraulic diffusion seems to be the prevalent mechanism





(A) (B)



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Conclusion

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Observation of hydro-mechanical response to excavation of underground structures in the Callovo Oxfordian claystone have been recorded at the Meuse Haute-Marne URL over 18 years for diameters from 0.15 m to 9.6 m

- measurements show similar patterns at the scale of micro tunnel (0.7 m to 0.9 m diameter) and of drift (5 m to 10 m diameter) in terms of HM response.
  - In the short-term, the very low permeability leads to an almost "undrained" condition
    - Small volumetric strain induces pore pressure change, showing strong hydro mechanical coupling
    - Excavation produces an anisotropic pore pressure field with over-pressures at the wall
      - That emphasize the mechanical anisotropy
  - In the long term, the excess pore pressure tends to a hydraulic equilibrium between the opening wall and the pore pressure in the formation
    - hydraulic diffusion seems to be the prevalent mechanism, with a spreading of the over-pressures with a decrease of magnitude in the field and toward the drift

- The rate of excavation plays an important role on the magnitude of the over-pressure
- a larger impact in the formation in terms of excess pore pressure and extension even though the EDZ extension is not affected
- Major efforts of modelling are ongoing to better predict and explain the pore pressure evolution especially the sharp drop of pressure.

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Danke Ihnen für Ihre Aufmerksamkeit

Thank you for your attention

Some reference :

- Armand G., Leveau F., Nussbaum C., de La Vaissiere R., Noiret A., Jaeggi D., Landrein P., Righini C., 2014, Geometry and Properties of the Excavation-Induced Fractures at the Meuse/Haute-Marne URL Drifts, Rock mechanic and Rock engineering, Volume 47, Issue 1, pp 21-41
- Armand G., Noiret A., Zghondi J., Seyedi D.M.,2013, Short- and long-term behaviors of drifts in the Callovo-Oxfordian claystone at the Meuse/Haute-Marne Underground Research Laboratory, Journal of Rock Mechanics and Geotechnical Engineering 5,pp 221–230
- Armand G., Plas F., Bosgiraud j-M, 2015, L'apport du laboratoire souterrain de l'Andra pour le choix et la mise au point des techniques de creusement des ouvrages souterrains du projet de stockage de déchet radioactif Cigéo, Tunnels et ouvrages souterrain, n°250, p251-268 (ISSN 0399-0834)
- De La Vaissière R., Armand G., Talandier J., 2015, Gas and water flow in an excavation-induced fracture network around an underground drift: A case study for a radioactive waste repository in clay rock, Journal of Hydrology 521, pp141–156
- Guayacan-Carrillo L.-M., Sulem J., Seyedi D., Ghabezloo S., Noiret A., Armand G. 2016 - Analysis of Long-Term Anisotropic Convergence in Drifts Excavated in Callovo-Oxfordian Claystone, Rock Mech Rock Eng (2016), DOI 10.1007/s00603-015-0737-7, 49:97–114
- Vu M.-N., Guayacán-Carrillo, L.M., Armand G., 2020 .Excavation induced over pore pressure around drifts in Callovo-Oxfordian claystone, European Journal of Environmental and Civil DOI: 10.1080/19648189.2020.1784800