Mine by experiment performed in the Callovo-Oxfordian claystone at the Meuse Haute Marne Underground Research Laboratory (France)

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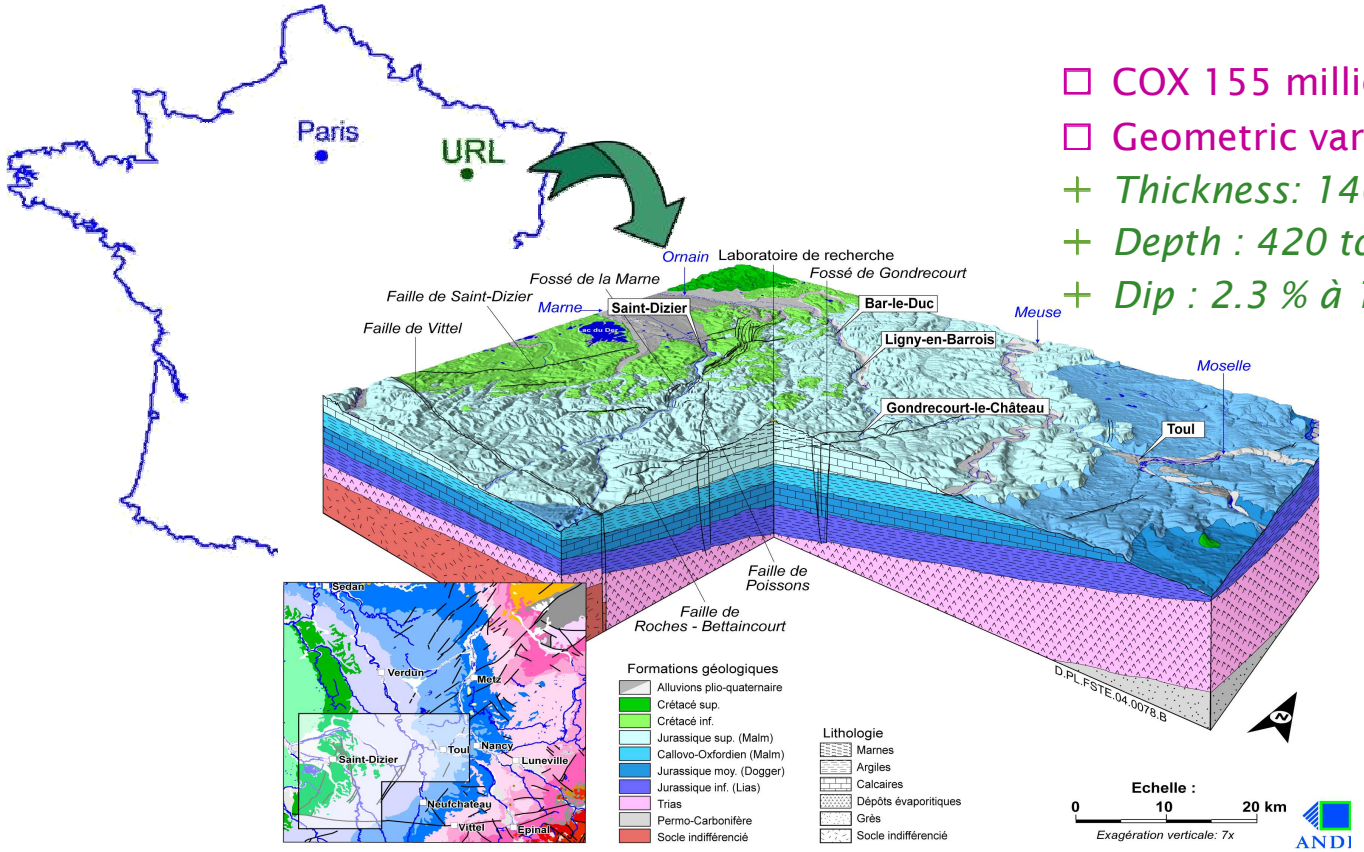
Meuse/Haute-Marne underground research laboratory



- ☐ COX 155 million years old
- ☐ Geometric variation of the COX
  - + *Thickness: 140 to 154 m*
  - + *Depth : 420 to 550 m*
  - + *Dip : 2.3 % à 1.6 %*

- ANDRA (French national radioactive waste management agency) started in 2000 to build an underground research laboratory in East of France to study feasibility of deep geological repository in a claystone layer

Objectives in geomechanic:

- To study hydro mechanical behavior of claystone during drift and shaft excavation (short and long term behavior)
  - Impact of digging and support method
  - Orientation of drift
- To characterize the Excavation Damaged Zone (EDZ)
- To characterize the Thermo Hydro Mechanical behavior
- To perform sealing experiments

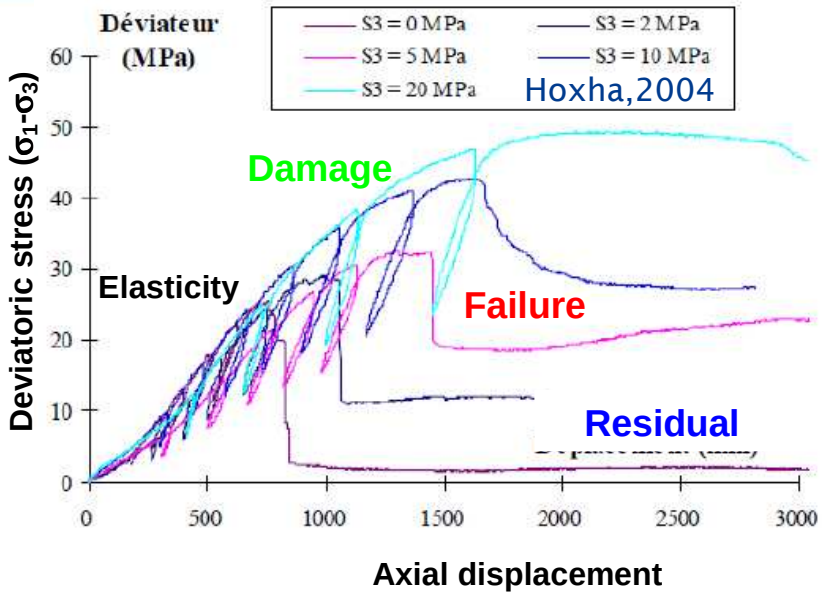
→ In situ measurements will be compared with numerical modeling and will be useful to validate and develop HM model

Rock properties of the COX

Callovo Oxfordian claystone properties at the 490 m level:

- Mineralogy:
  - 50-55% clay minerals
  - 20-25% carbonate
  - around 25% quartz silts
- Very low permeability (5.10^{-20} m²)
- Short-term behavior, triaxial test: non linear and post-peak depending on σ_3
- Long term behavior, uniaxial creep test:
  - Creep strain rate increases non-linearly with the applied deviatoric stress
  - Creep rate (Andra 2005):

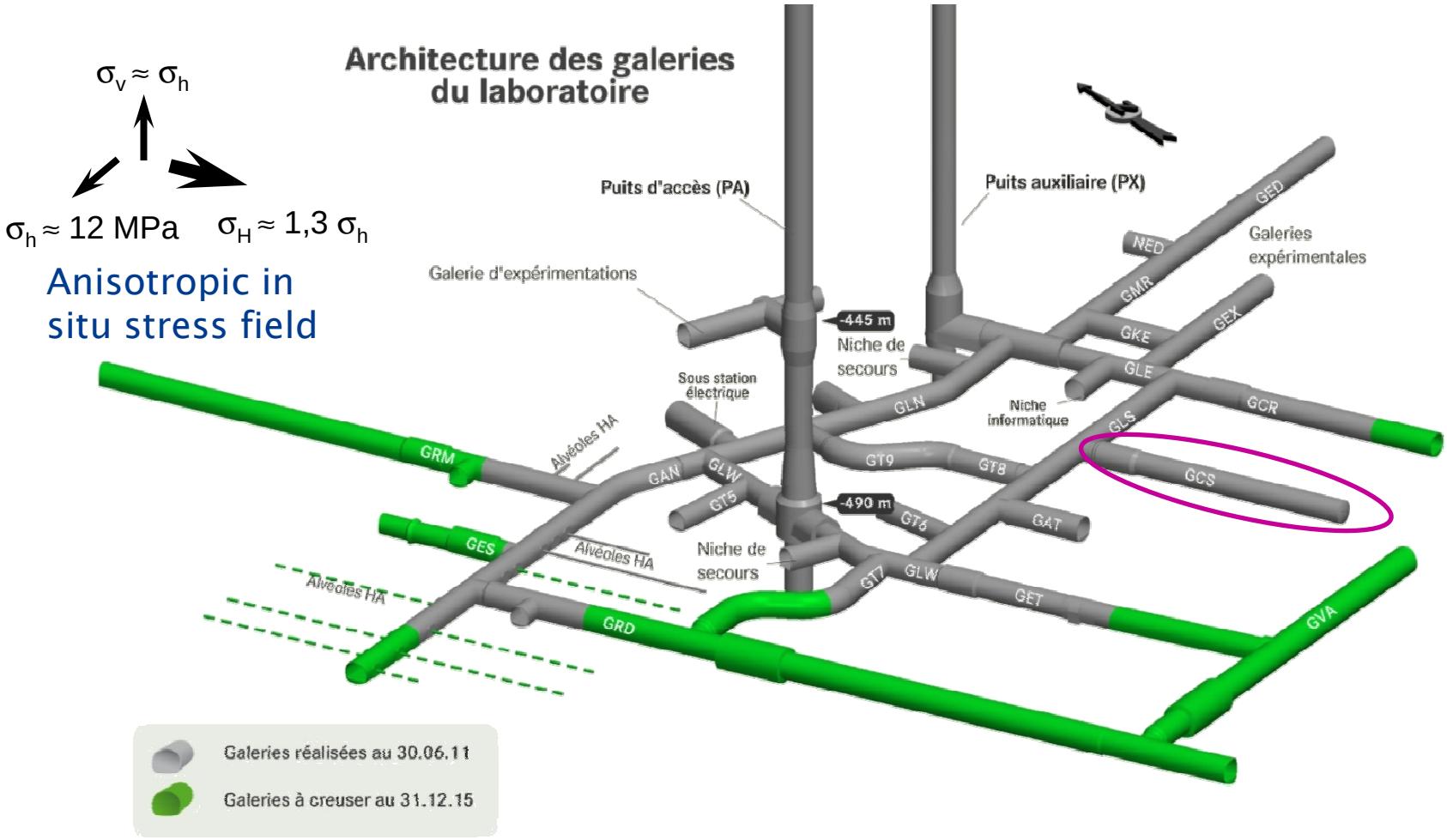
    4.10^{-12} < creep rate <$1.60.10^{-12}$ (test duration 1 to 3 years)
  - Long-term behavior according to the modified Lemaître's model



Rock parameter	Ind.	Value
Bulk specific gravity	ρ	2.39 g/cm³
Porosity	n	16±2%
Young modulus	$E_{\perp}$	4000±1470 MPa
	$E_{//}/E_{\perp}$	1.2 to 1.5
Poisson Ratio	ν	0.29±0.05
Uniaxial compressive strength	**UCS**	**21±6.8 MPa**
Hoek & Brown criteria		
S		0.43
m		2.5
σ_c (MPa)		33.5
Intrinsic permeability	**k**	**5×10^{-20} m²**
Water content	w	7.2±1.4 %

Meuse/Haute-Marne underground research laboratory

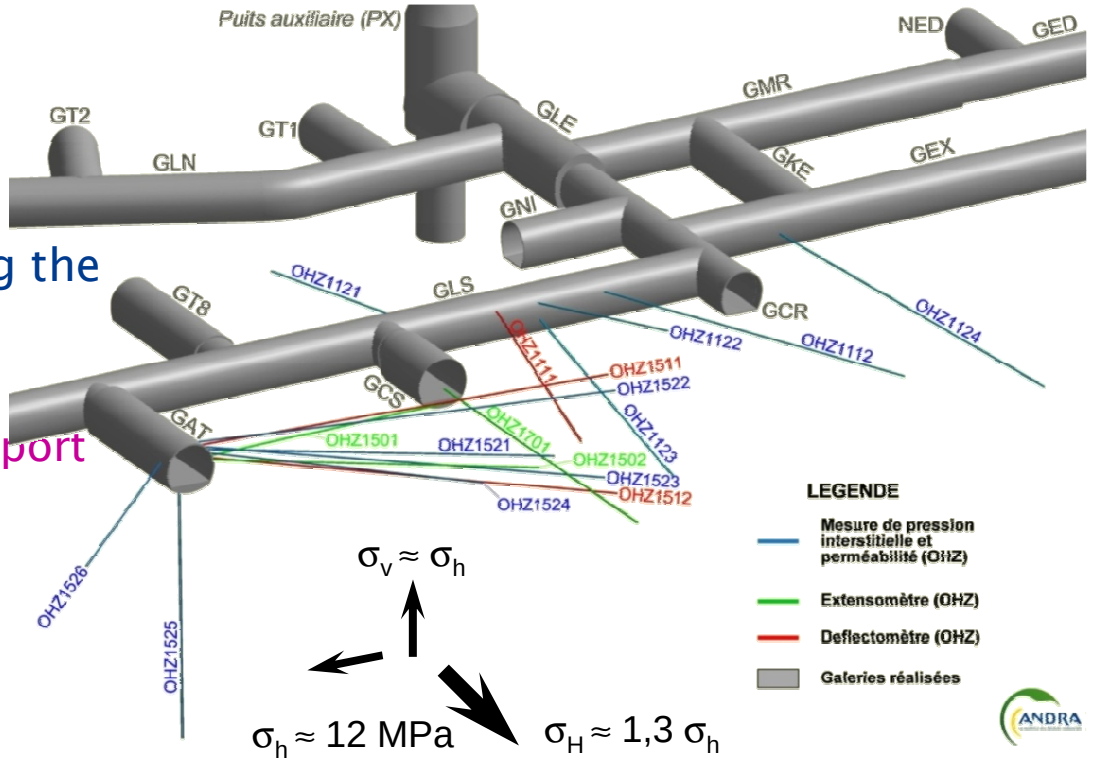
A huge program of experiments is planned to characterize the response of the rock to different drift construction methods



Mine by experiments around the drift GCS

A mine by experiment is state-of-the-art project to characterize excavation induced damage and determine relationships governing the behavior of a rock mass around an underground opening

- Measurements emplaced before the digging
  - Extensometer
  - Deflectometer
  - Pore pressure measurement
- Measurements performed during the excavation work
  - Convergence & extensometer
  - Load & deformation of the support
  - Structural analysis of the front
- EDZ Characterization
  - Permeability measurement
  - Resin injection to characterize fractures aperture
  - Velocity survey



≈ 200 sensors

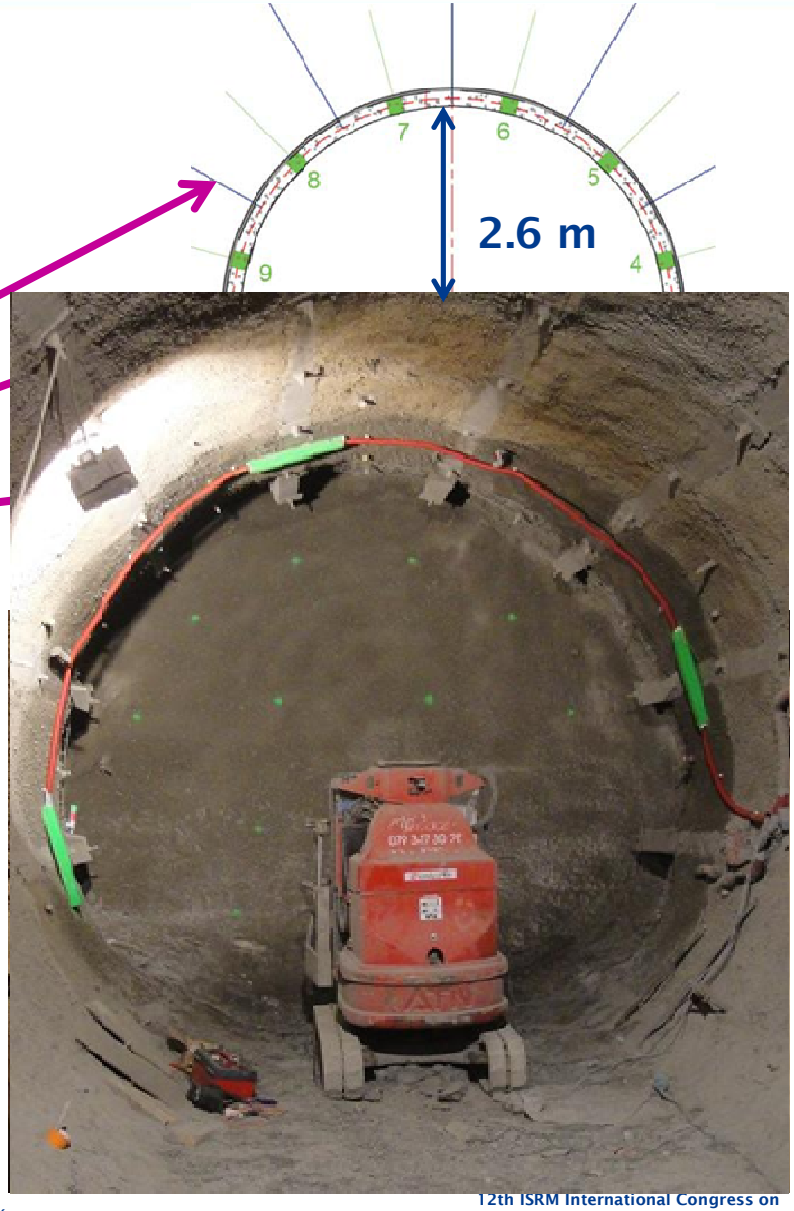
Drift concept and excavation methods

This drift is called “soft concept gallery” (GCS, *Galerie de Conception Souple*)

Drift support is composed of:

- 12 radial rockbolts (3 m long),
- 18 cm of fiber reinforced shotcrete,
- 12 yieldable concrete wedges (hiDcon®)
- At the front face, 13 fiber rock bolts of 12 m long placed every 6 m.

Yieldable concrete wedges is flexible in order to let developing long term tunnel closure (compressive strength 4 ± 0,5 MPa, max strain 40%)



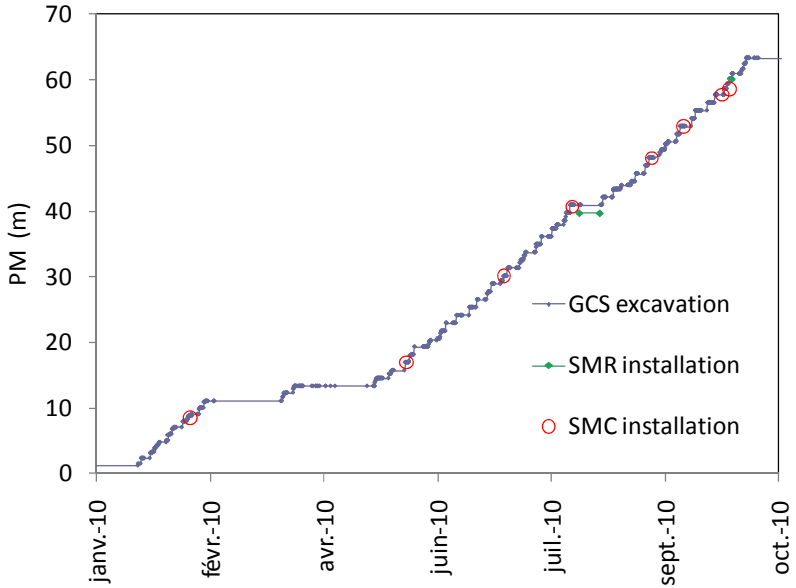
Drift concept and excavation methods

Excavation cycle:

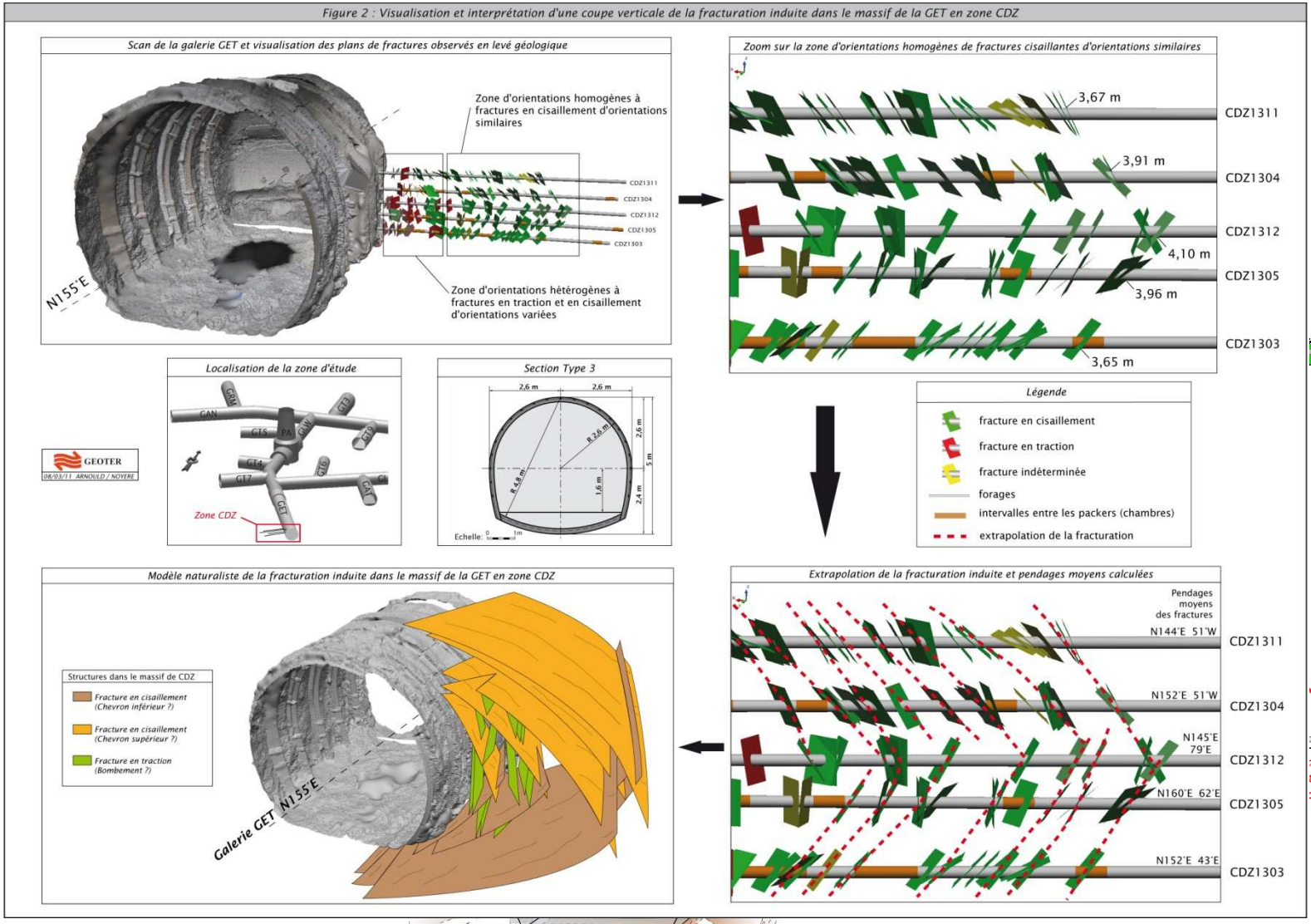
- Excavation with roadheader, muck removal
- First layer of shotcrete (0,03 m thickness),
- Radial bolts
- Installation of the concrete wedge and shotcrete on counter vault (0,18 m thickness) :
- Filling of the counter vault
- Installation of the concrete wedge on vault and shotcrete layers (0,18 m thickness)
- New cycle…

Some numbers…

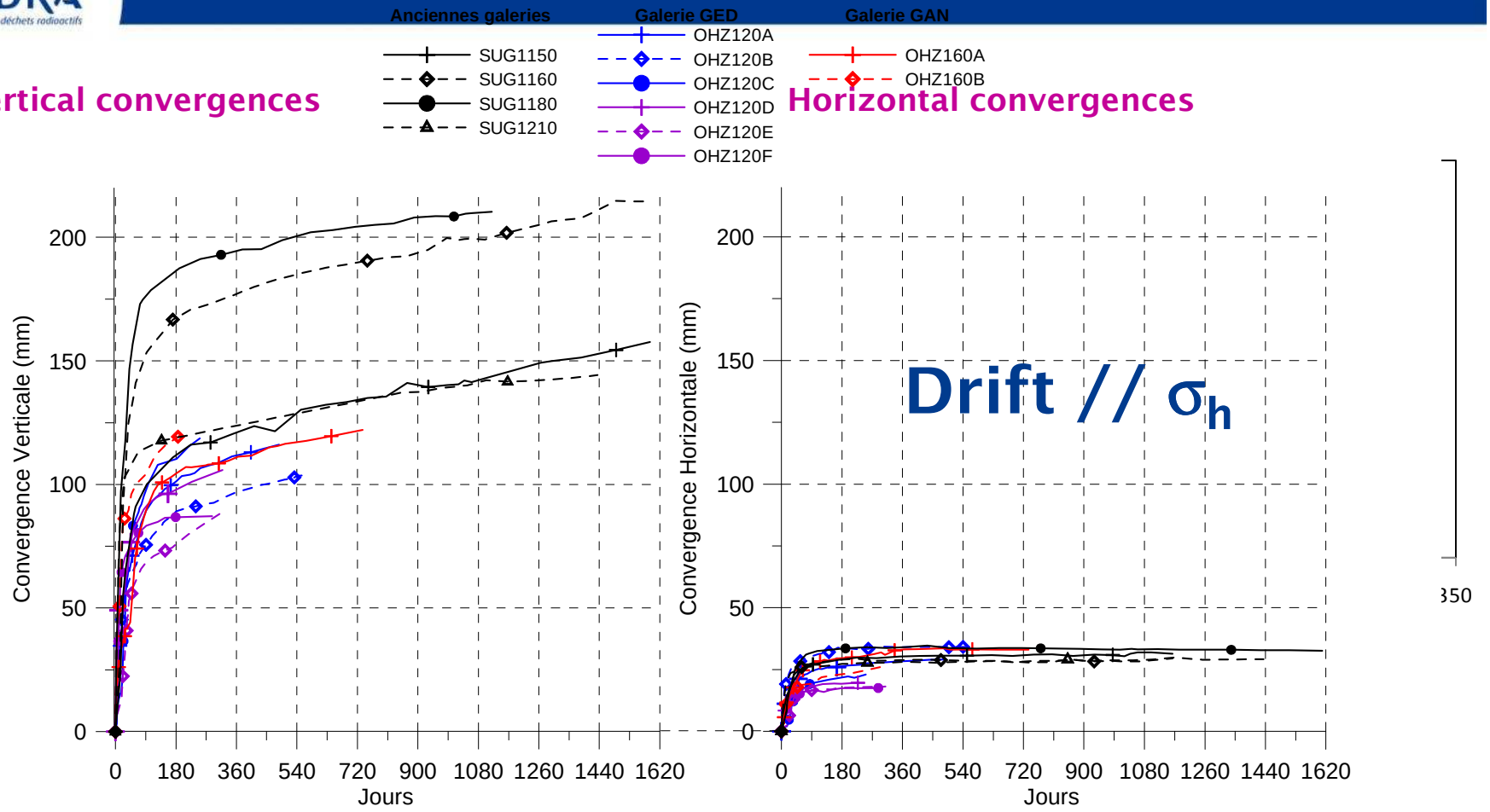
- Beginning: 20/01/10,
- GCS Type: 04/05/10 (PM13)
- Ending: 14/10/2010 (PM 63)
- **Average speed 2.05 m/week**
- Excavation/muck removal steps represent 15% of excavation cycles



Geological survey: induced fractures



Convergence measurements (drift // σ_H)



σ_H. Convergence depends of the drift orientation

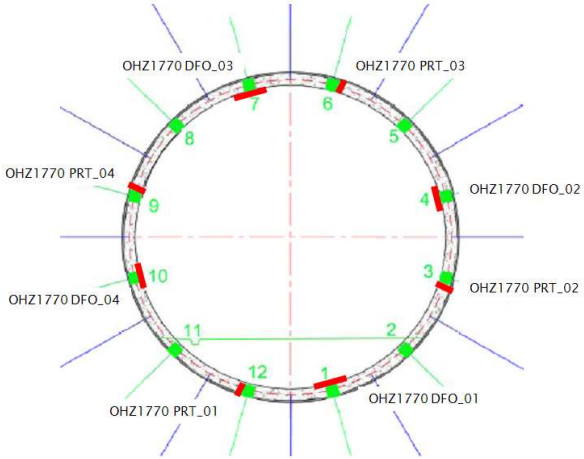
- Highest convergence is observed where the extend of induced fractures is larger

Support behavior

- Support monitoring is composed of 2 instrumented sections dedicated to the study of the compressible wedge behavior (PM 29.5 and 47.5)

a)

b)

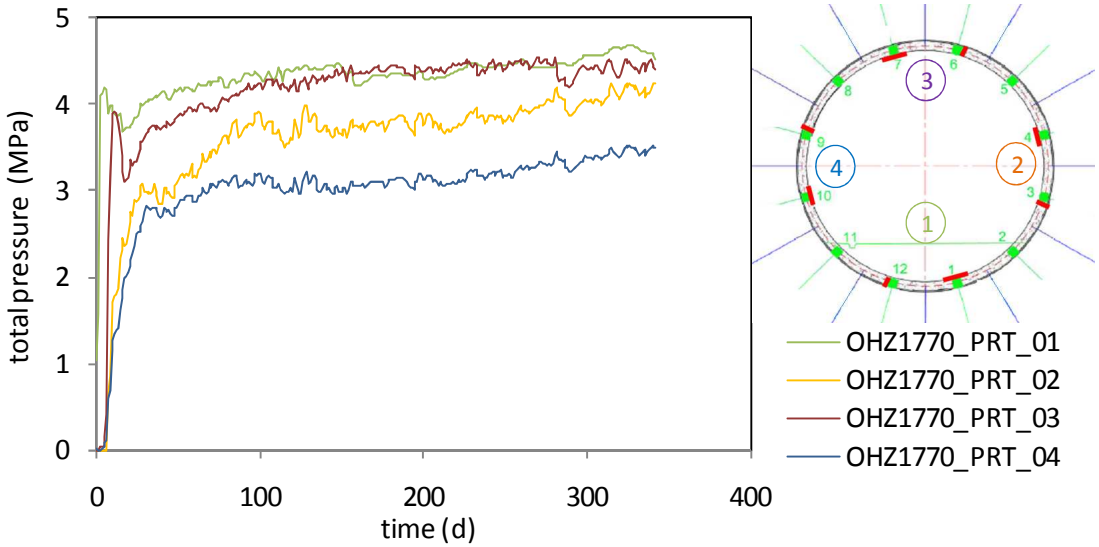


c)

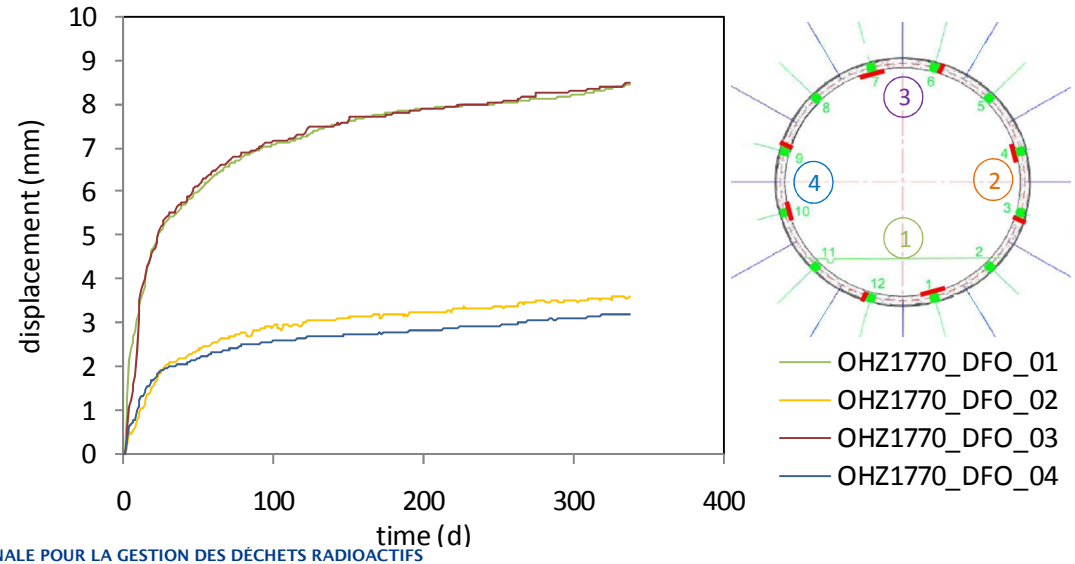
- 4 extensometers (potentiometer)
- 4 total pressure cells (vibrating wire)

Support behavior

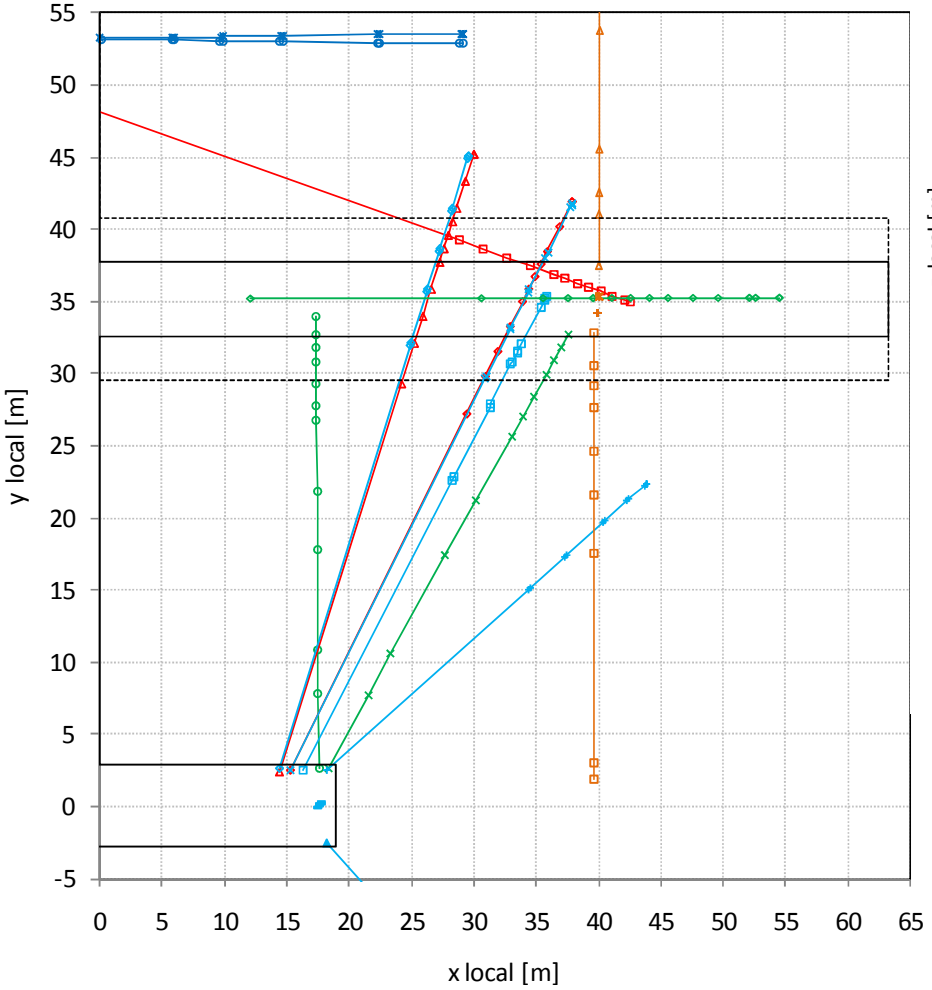
- Loads and displacements increase rapidly after the installation
- Maximum displacement and load are measured in the vertical plane
- Results consistent with convergence measurements

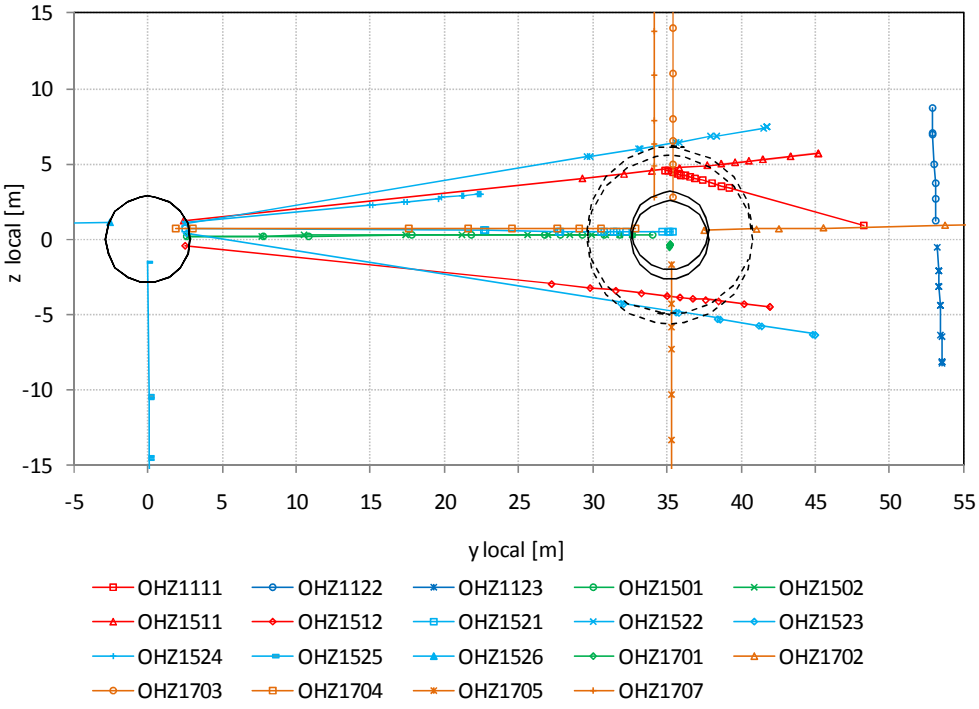


- Plastic behavior of the wedge, the maximum crushing reaches 13.5% (crushing capacity of 40%)



Location of the boreholes network



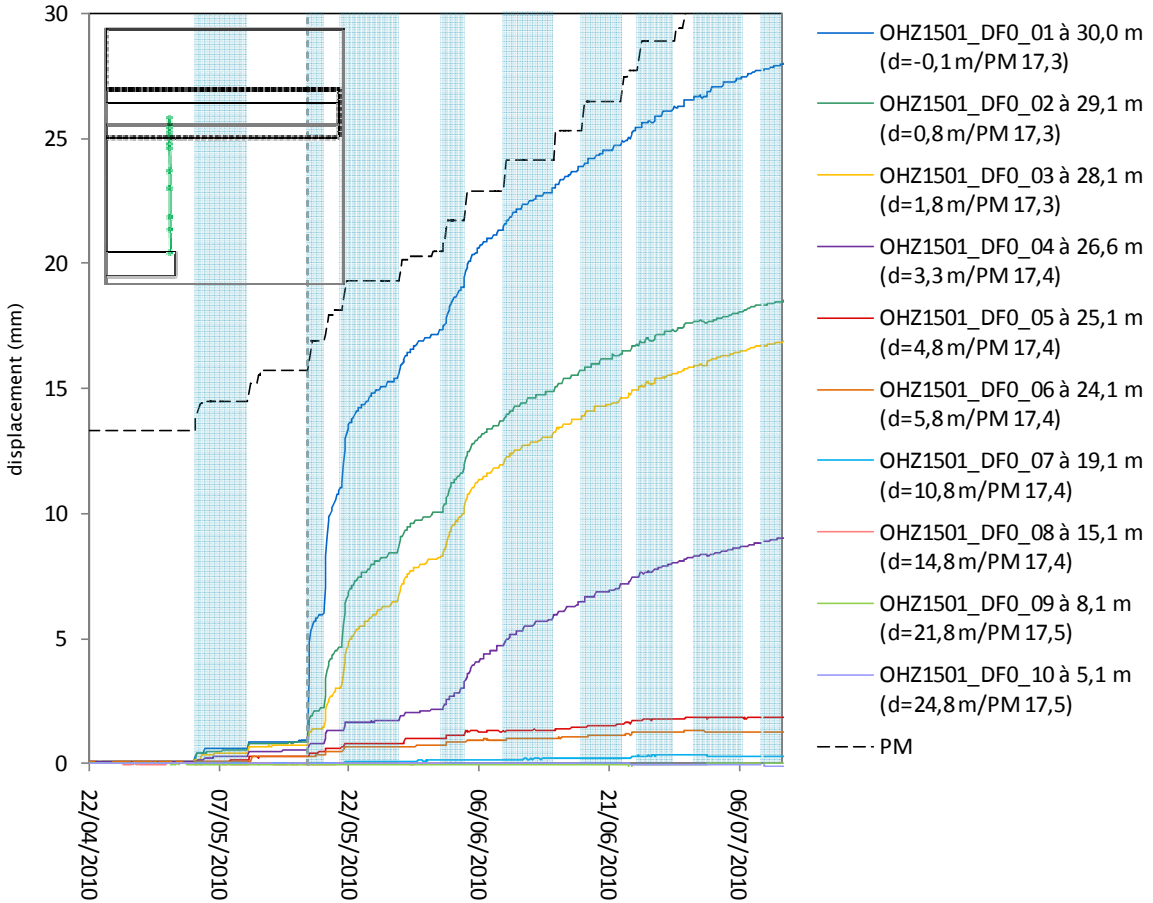


19 boreholes (mine by test et SMR)

- 8 extensometers
- 3 inclinometers
- 8 multipacker systems

Horizontal radial displacement

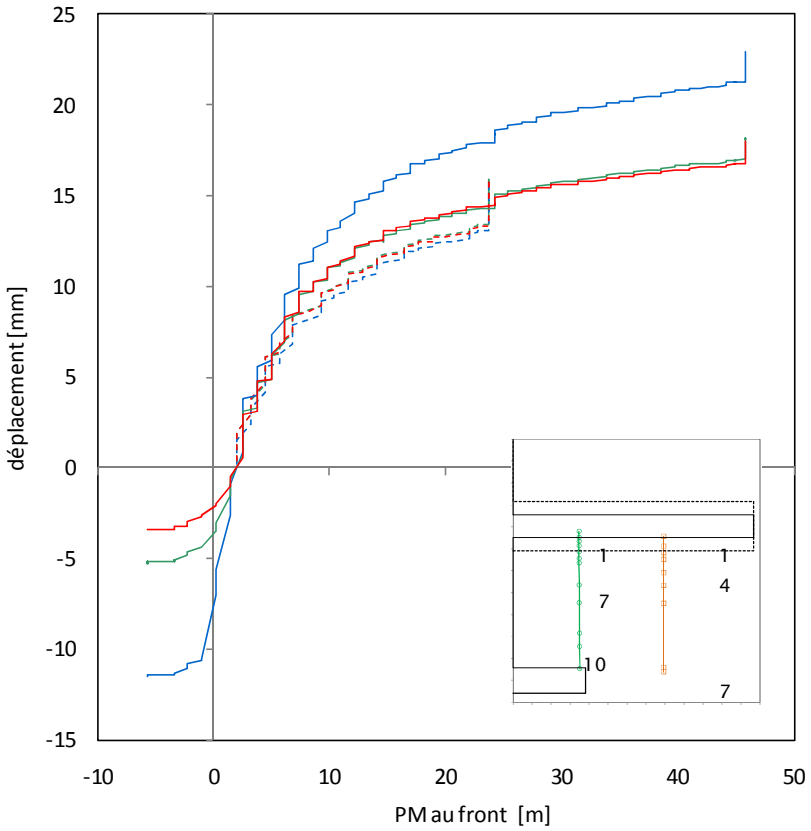
- Extensometer drilled horizontal from the GAT to the GCS and the last anchor (01) is nearly at the sidewall of the GCS



- Steps of excavation are visible:
  - 2 spans ahead the front, around 2.4 m
  - 7 spans beyond the front face, around 8.4 m. At this distance, the long-term behavior is predominant on the instantaneous strain
- At the front face around 15% of the radial displacement has been already spent

Comparaison des extensomètres

Comparaison des mesures de déplacement à l'avancement et issues du mine by test: suivi des déconfinements partiel et total.



OHZ1704_DF0_01 à 29,8 m (PM 39,6)

OHZ1704_DF0_02 à 15,2 m (PM 39,6)

OHZ1704_DF0_03 à 11,2 m (PM 39,6)

OHZ1501_DF0_01 à 30,0 m (d=-0,1 m/PM 17,3)

OHZ1501_DF0_02 à 29,1 m (d=0,8 m/PM 17,3)

OHZ1501_DF0_03 à 28,1 m (d=1,8 m/PM 17,3)

Hypothèse:
les déplacements maximaux correspondent aux déplacements à la fin de l'excavation

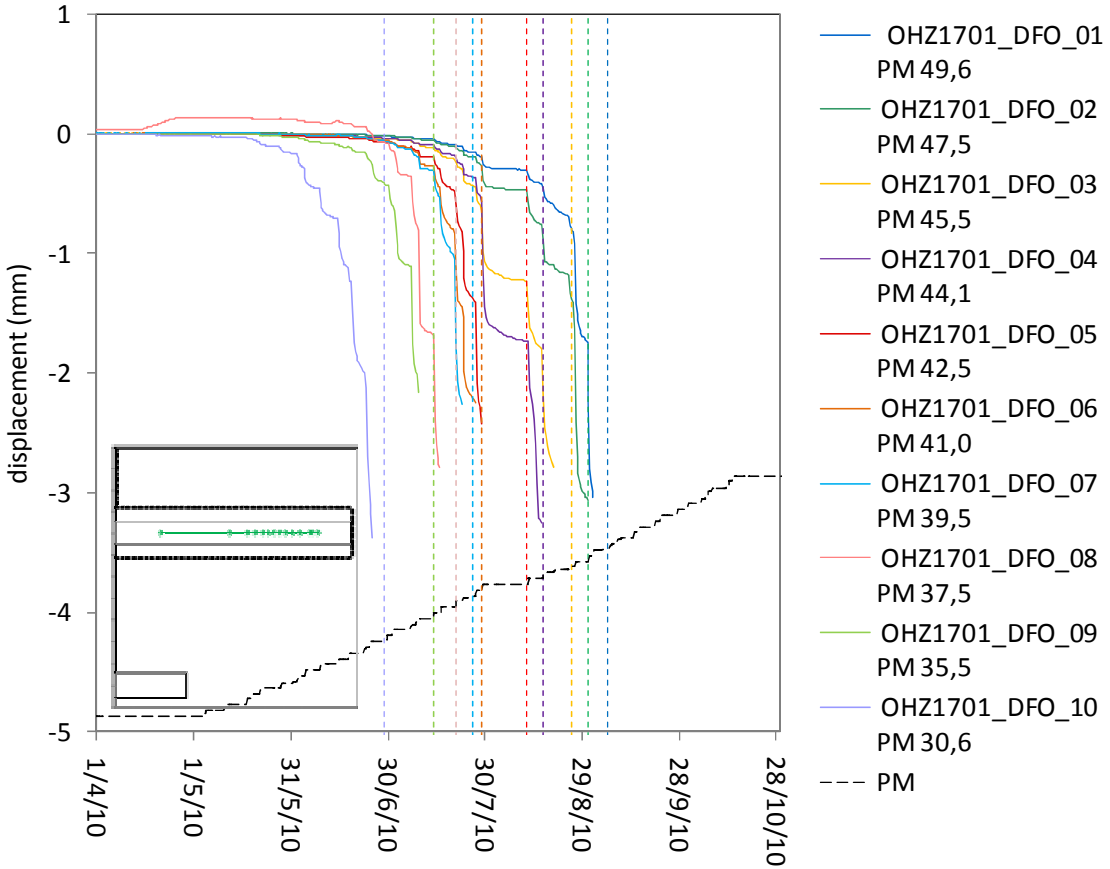
Limite de l'approche :
prise en compte des déformations différées

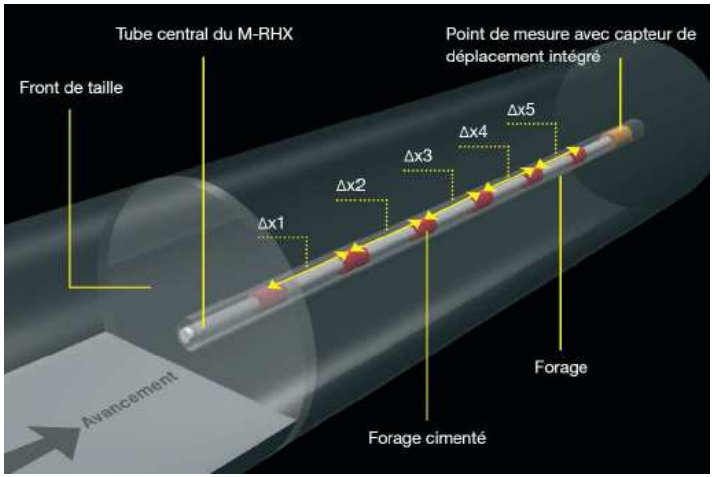
Résultats cohérents entre les différents extensomètres

- Taux de déconfinement au front : ≈ 15%
- Taux de déconfinement à 2 m en arrière du front : ≈ 35 %

Axial displacement

- Reverse head extensometer drilled at the axis of the GCS

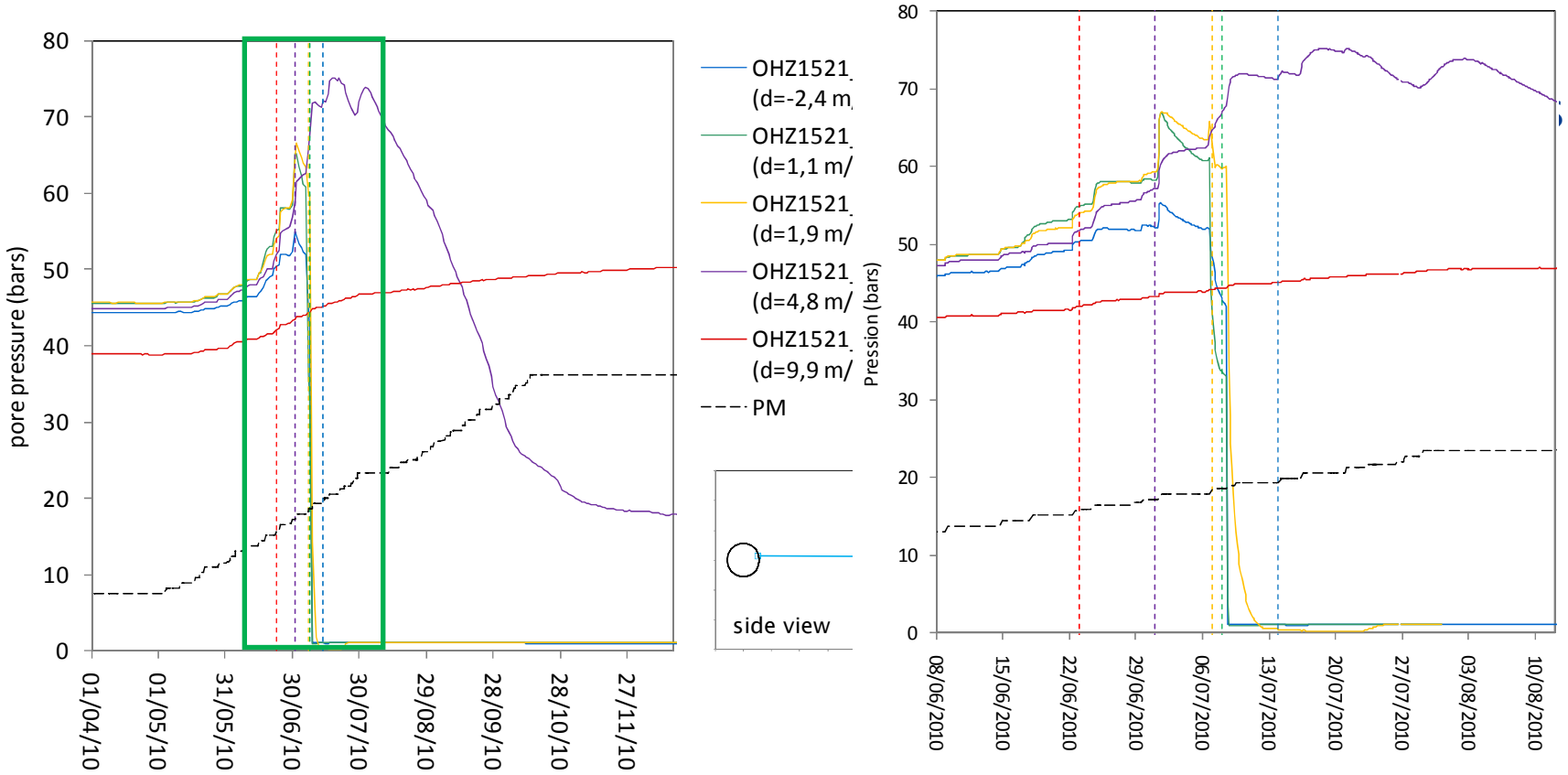




- Steps of excavation are visible 10 m ahead the front face
- At 1.45 m, the average displacement measured is 2.7 mm (after sensors were destroyed)

Pore pressure response (horizontal)

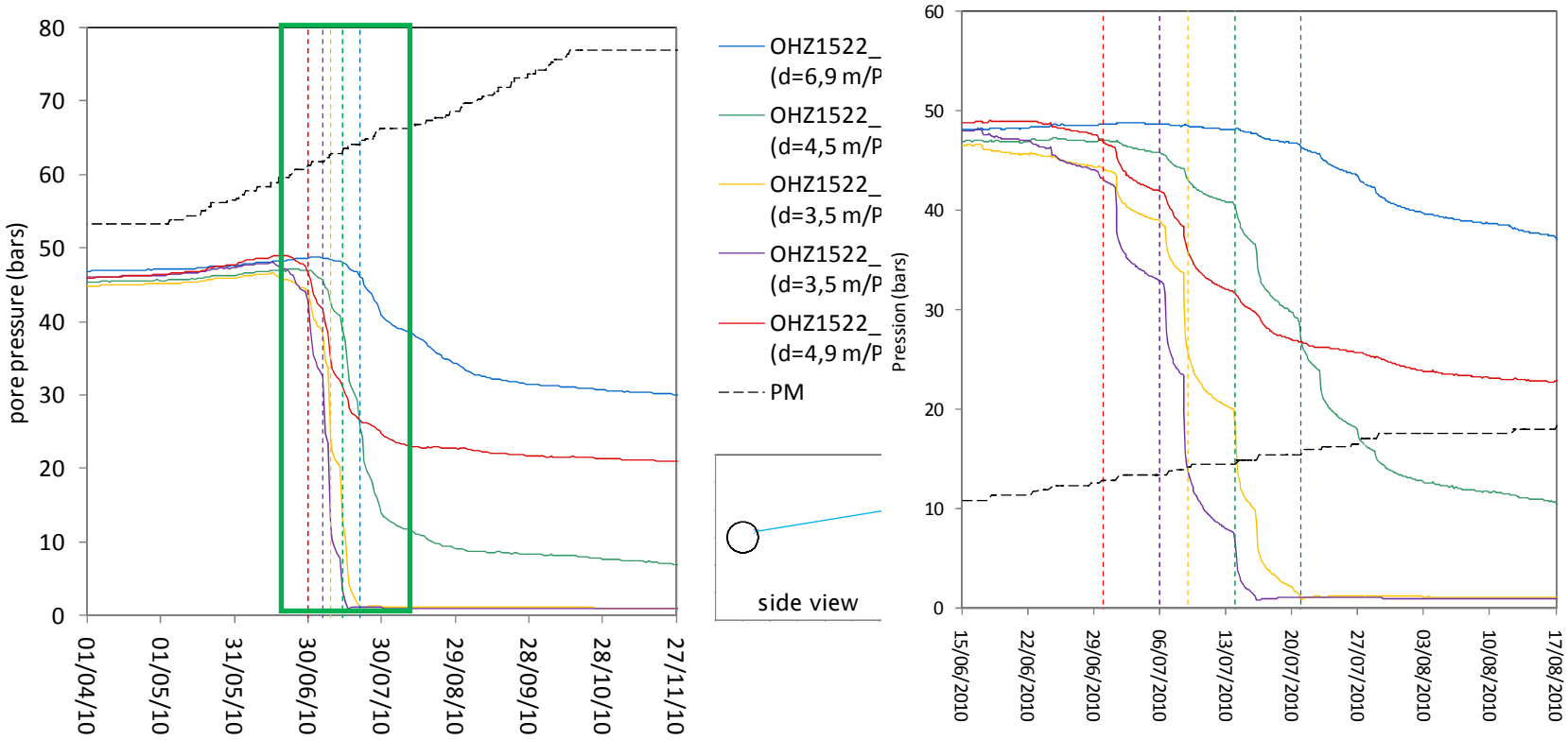
- Multipacker system located oblique horizontal from the GAT to the GCS



- The distance of influence of the excavation is estimated at 20 m
- Overpressure of several MPa (3 MPa in chambers 4 at 4.8 m from the GCS wall)
- Drop of pressure at the front crossing

Pore pressure response (vertical)

- Multipacker system located oblique and rising from the GAT to the GCS



- Lower overpressures in the vertical direction (1order of magnitude difference with the horizontal plane)
- Drop of pressure is observed near the front face and stabilization as a function of the pore pressure gradient
- Despite the initial stress state is nearly isotropic around the GCS drift, the pore pressure response is anisotropic

Conclusions & perspectives

Horizontal and vertical extensions of fractures are consistent with previous observations realized at -490 m in drift excavated in the same direction (σ_H)

Mechanical response:

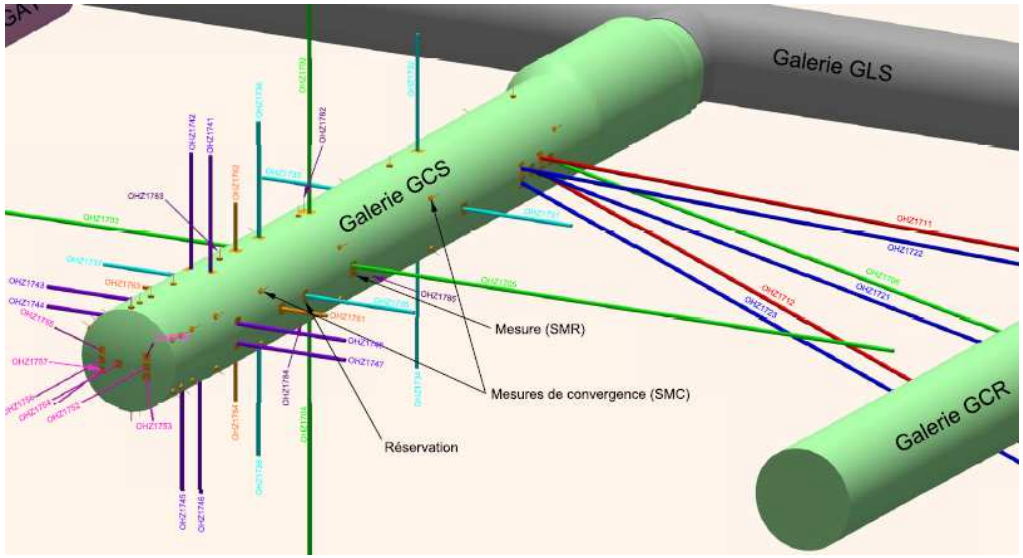
- Horizontal convergences are higher than the vertical ones (ratio ≈2, consistent with location of fractures)
- At the front face, the normalized wall displacement is around 15%
- The mechanical response is detected at 10 m ahead the front and 2.4 m for the radial displacements

Hydraulic response:

- In all directions, pore pressures increase ahead the front face and drop after
- Despite the initial stress state is nearly isotropic around the GCS drift, the pore pressure response is anisotropic
- A small volumetric strain induces pore pressure change. The hydraulic response to the digging is highlighted up to 20 m ahead the front, showing the importance of hydro-mechanical coupling (M => H).

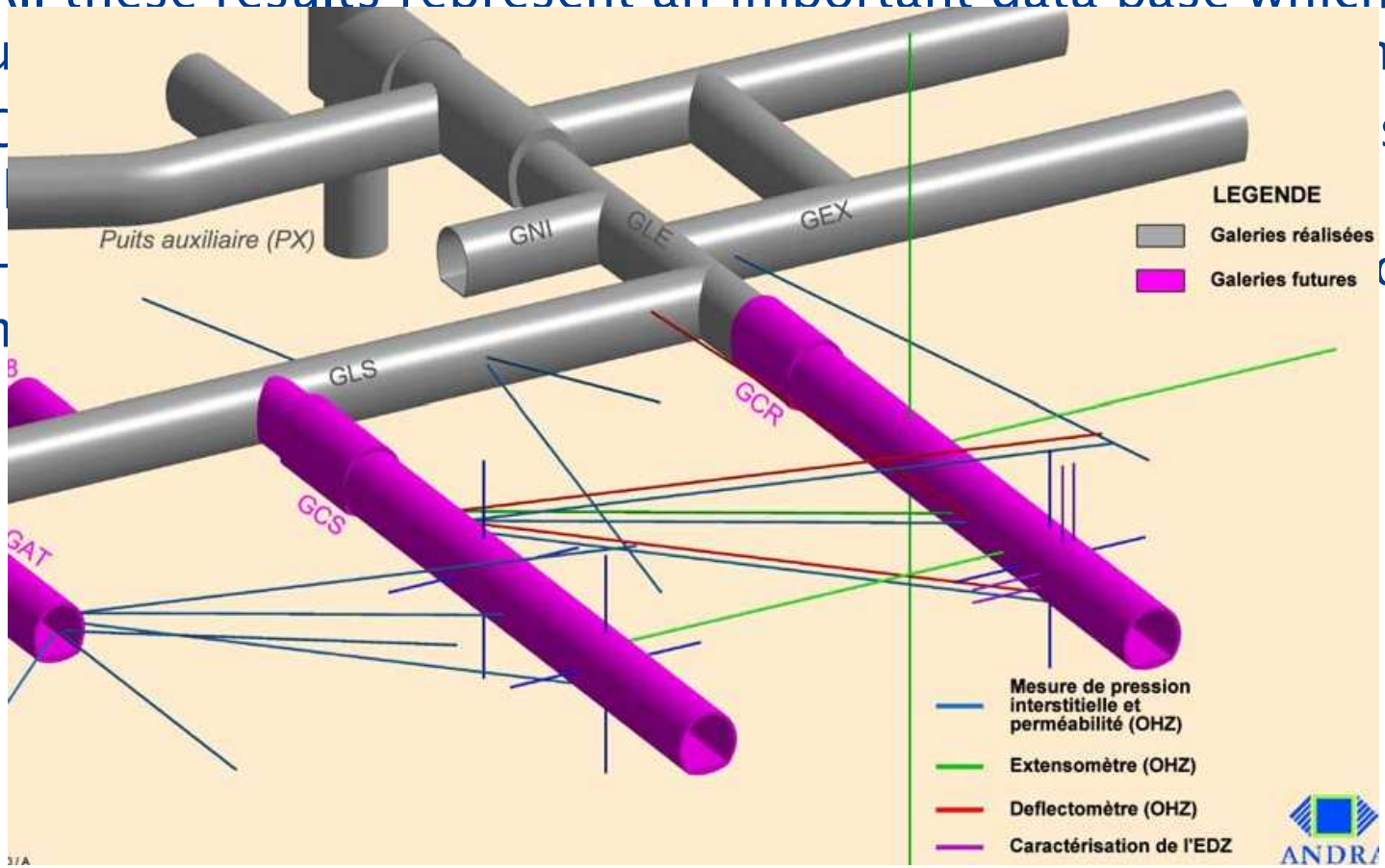
Conclusions & perspectives

- Further analysis has to be conducted on the hydro mechanical behavior, taking into account the result on the ongoing EDZ characterization in the GCS
  - ☐ Permeability measurements
  - ☐ Velocity survey
  - ☐ Resin injection and over coring to measure fractures aperture



Conclusions & perspectives

- All these results represent an important data base which is u… …model
- C… …ssess t…
- H… …one n… …port

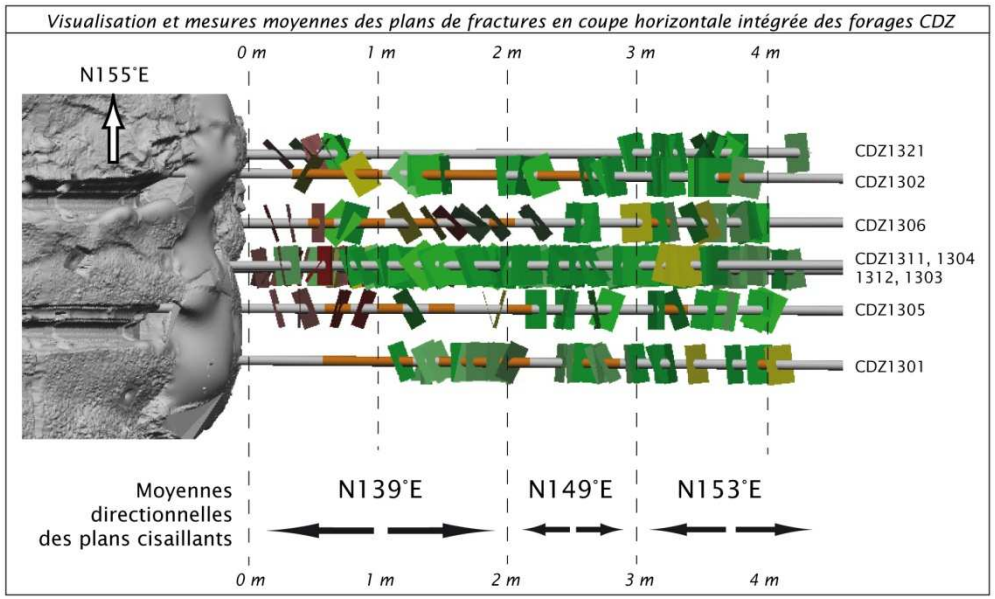


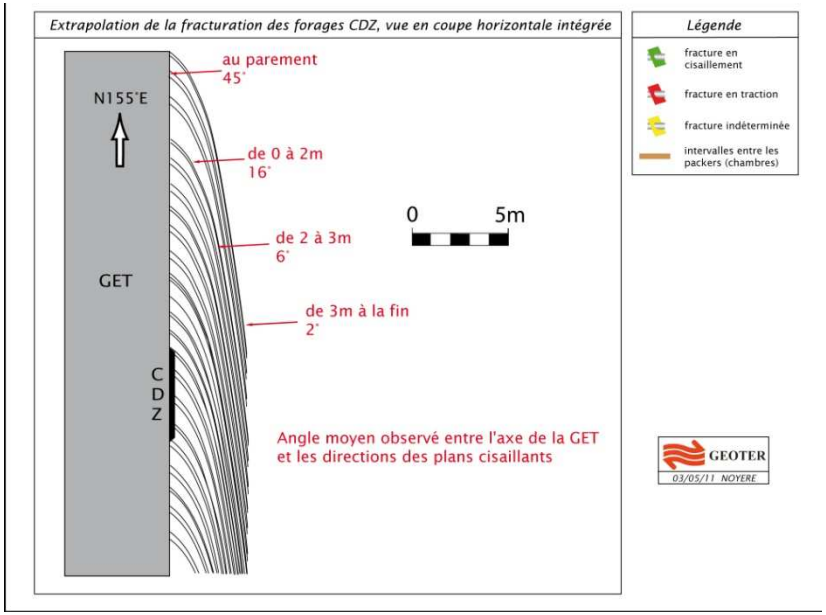
Thank you for your attention

Fracturation induite par le creusement: galerie // σ_H

Apport de l'expérimentation CDZ

Figure 4 : Visualisation et extrapolation d'une coupe horizontale de la fraturation en CDZ





Displacements