BEACON
Bentonite Mechanical Evolution

EB – Engineered Barrier Emplacement Experiment

On behalf of Juan Carlos Mayor

ENRESA, Madrid

Workshop on Mechanical Properties of Bentonite Barriers

Lithuanian Energy Institute

Kaunas 19-20 June 2017

EB Experiment

Acronym EB (Engineered Barrier Emplacement Experiment)	**Location** Mont Terri URL, Switzerland (Opalinus Clay Formation)	**Type** Field scale experiment Full scale (horseshoe section 2,65 m high, 3 m wide; length 6 m)
Project Coordinator Enresa (Spain)	**Start date** May 2002 (hydration starts)	**End date** February 2013 (dismantling ends)
Main partners involved in the project Enresa, Nagra, Aitemin, UPC, BGR, Ciemat, Andra The EB project was co-financed by the EC (contract FIKW-CT-2000-00017) The PEBS project was co-financed by the EC (contract FP7-249681)	**Characteristics of swelling clay** 1. Pre-compacted FEBEX blocks: dry density 1,69 g/cm^3, water content 14,4% 2. Granular bentonite material (GBM): dry density pellets (emplaced) 1,36 g/cm^3, water content 4,2%	**Water Saturation** Artificial and natural
Instrumentation 55 sensors: • pore pressure • relative humidity • total pressure • temperature • rock displacement • canister displacement	**Main elements related to homogenization** Initial heterogeneity of density: • Pellets (upper part of the section), bentonite blocks (bottom) • Initial gaps and voids • Pellets segregation • Presence of hydration tubes	**Interfaces with other material** Bentonite/Opalinus Clay Bentonite/Concrete Bentonite/Canister
Modelling Yes (HM coupled modelling) Code: Code-Bright	**Main processes studied** ☐T ☒H ☒M ☒Swelling pressure ☐Gas transfer ☒Other Water transmissivity of the damaged zone	**Reference concept if pertinent** Nagra concept Enresa concept in clay rock

Main objectives of the experiment

1. "In situ" demonstration of an emplacement technique in horizontal drifts in consolidated clay formations, using pellets as backfill material in the upper part of the clay barrier, and bentonite blocks at the bottom.
2. HM process understanding, including development of new constitutive laws of the GBM for the modelling of the experiment, adjusted with the experimental data both from the monitoring sensors and the dismantling operation after full saturation of the bentonite

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Main features of the EB experiment

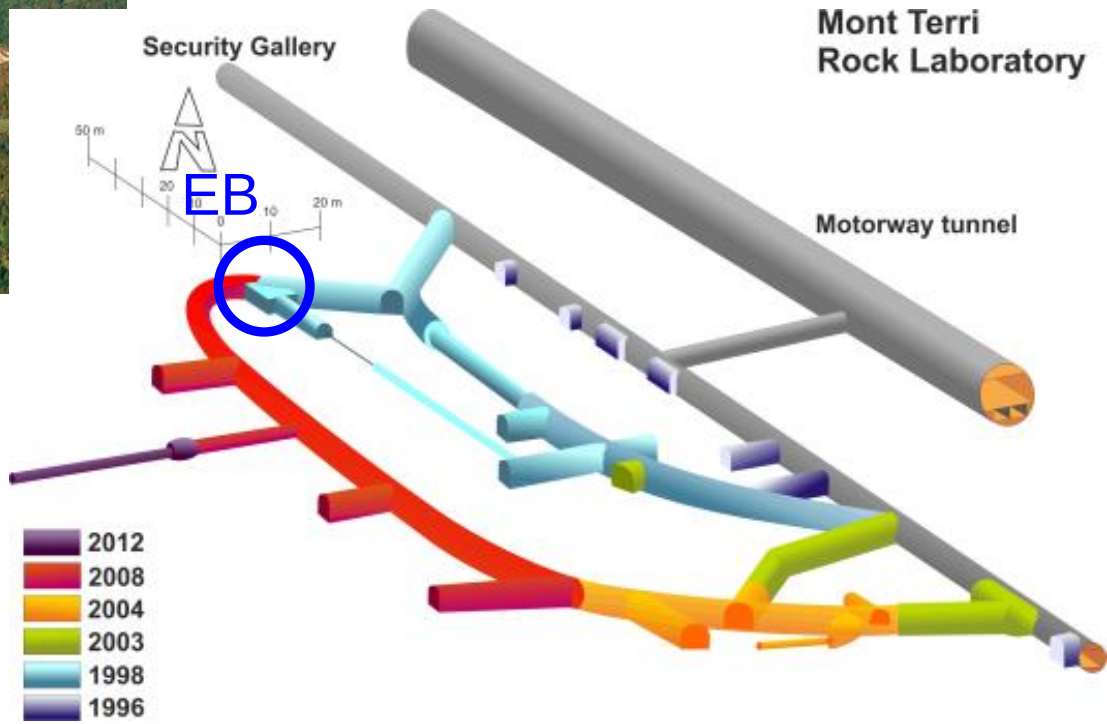
- Acronym: EB (Engineered Barrier Emplacement Experiment)
- Type: Field scale experiment (full-scale)
- Location: Mont Terri URL
- Start/End date: May 2002 – February 2013
- Main partners involved in the project
  - **Enresa**, Nagra, Aitemin, UPC, BGR, Ciemat, Andra
  - The EB project was co-financed by the EC (contract FIKW-CT-2000-00017)
  - The PEBS project was co-financed by the EC (contract FP7-249681)
- Main processes studied:
  - Hydraulic, Mechanical, Swelling pressure, other (water transmissivity in the damaged zone)
- Reference concept:
  - Nagra concept
  - Enresa concept in clay rock

Main features of EB

- Main elements related to homogenization:
  - Pellets (upper part of the section), bentonite blocks (bottom)
  - Initial gaps and voids
  - Pellets segregation
  - Presence of hydration tubes
- Interfaces with other materials:
  - Bentonite/Opalinus Clay
  - Bentonite/Concrete
  - Bentonite/Canister
- Modelling:
  - Yes (HM coupled modelling)
  - Code: Code_Bright
  - Currently a Task in DECOVALEX 2019

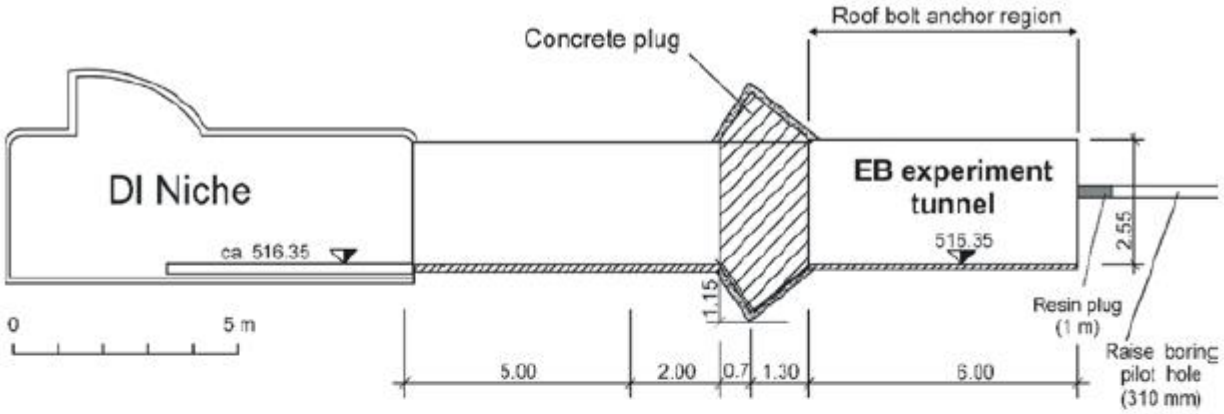
Mont Terri URL: Opalinus clay (Ste. Ursanne, Switzerland)

- Excavated in Opalinus clay. Depth: 270 m. Clay thickness: 170 m

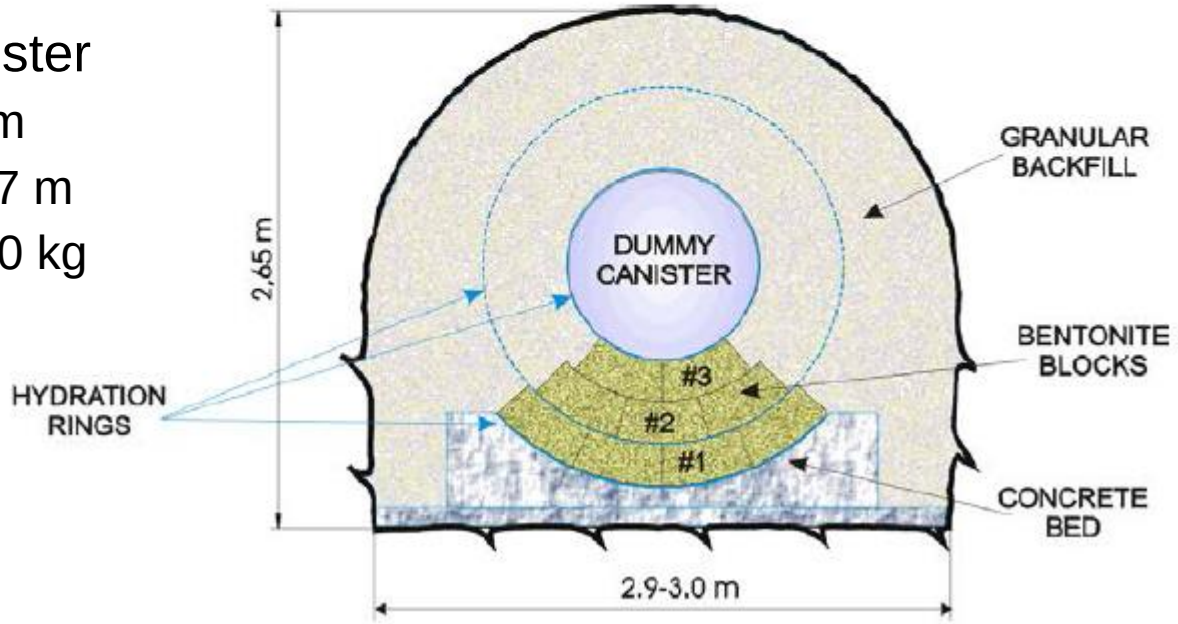


The EB experiment

- The EB niche

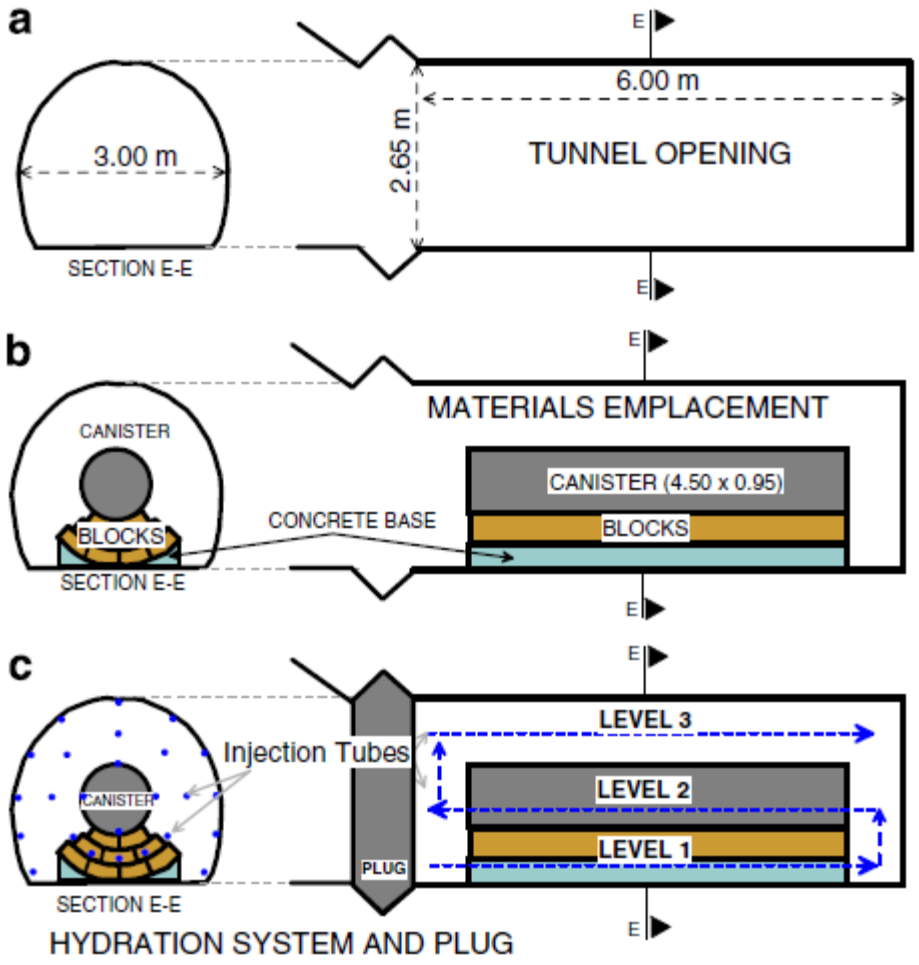


- Dummy canister
  - Length: 4.54 m
  - Diameter: 0.97 m
  - Weight: 11,000 kg



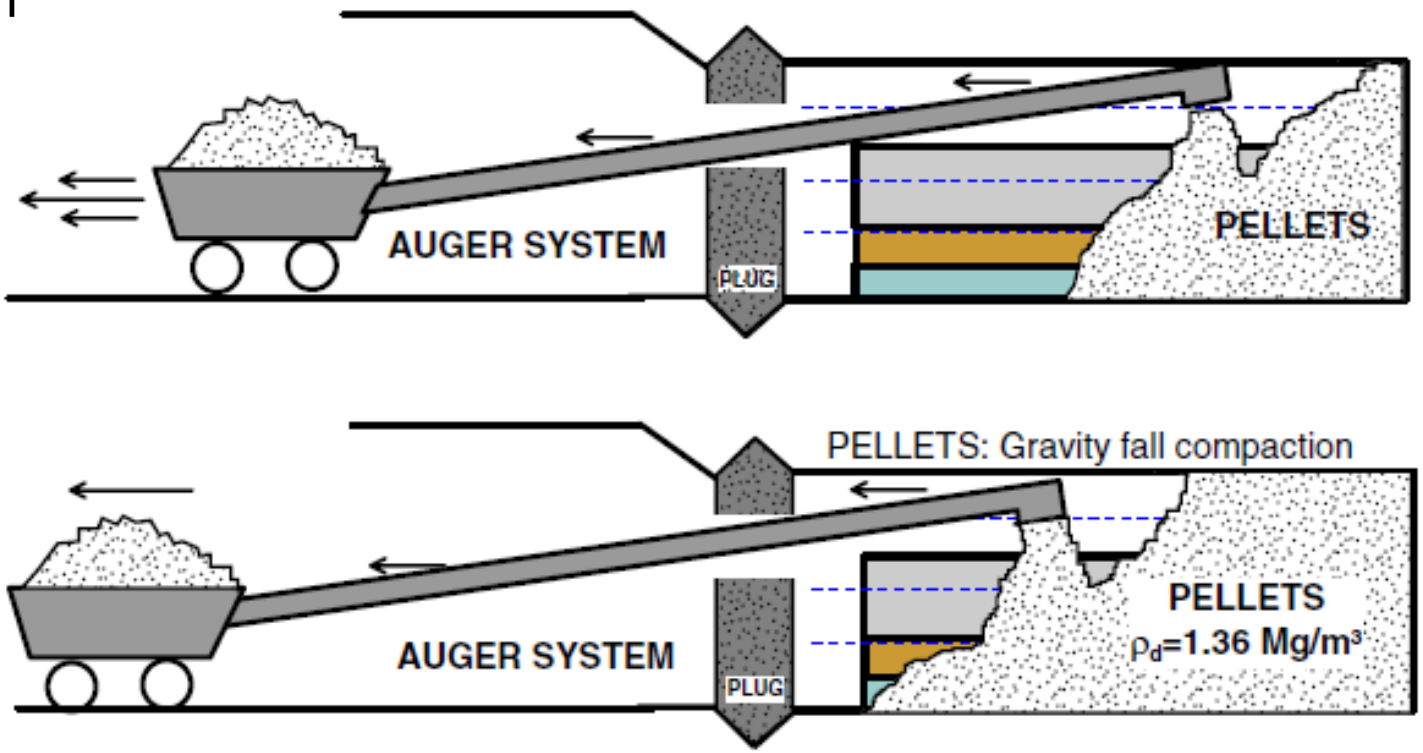
The EB experiment

- Installation



Description of the EB test

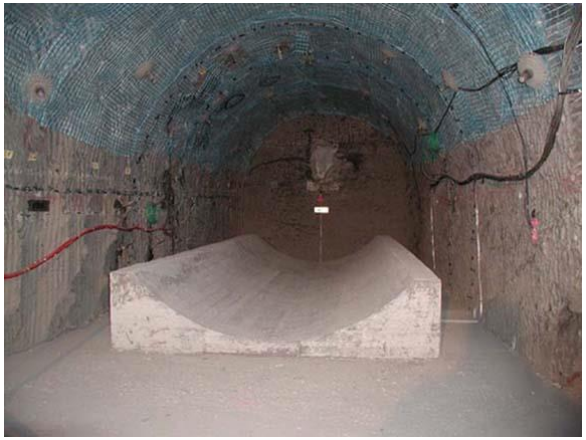
- Installation



- Pellets
  - Average dry density: 1.36 Mg/m^3 (Preliminary tests: 1.28 – 1.52 Mg/m^3)
  - Pellets dry density: 2.1 Mg/m^3
  - Water content: 4.2%
  - D_{50}=6.3 mm, D_{25}=0.25 mm
  - 40,2 t for a volume of 28.4 m^3
- Blocks
  - Dry density: 1.69 Mg/m^3
  - Water content: 14.4%
  - Thickness: 214 mm
  - 36 blocks used

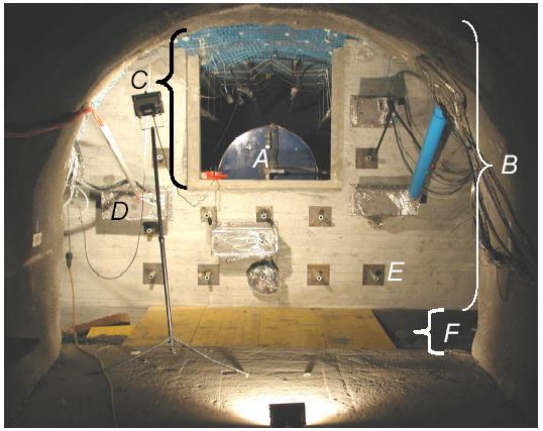
The EB experiment

Tunnel opening

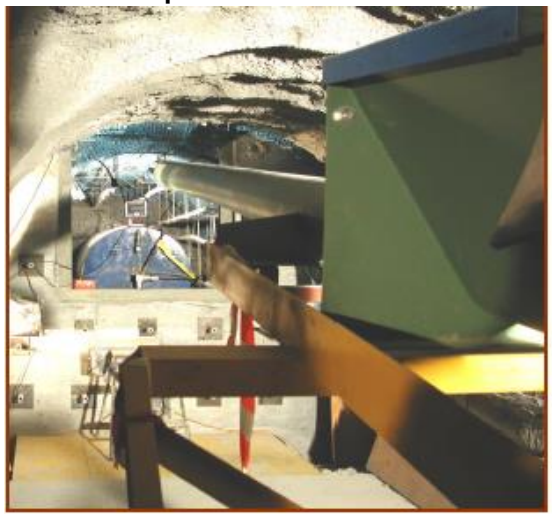


Base and canister

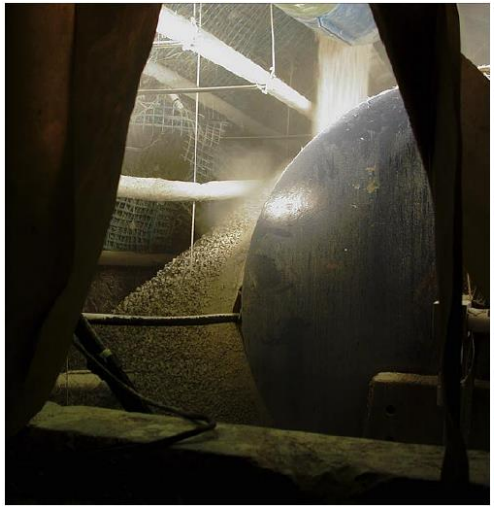
Retaining wall



Emplacement 1



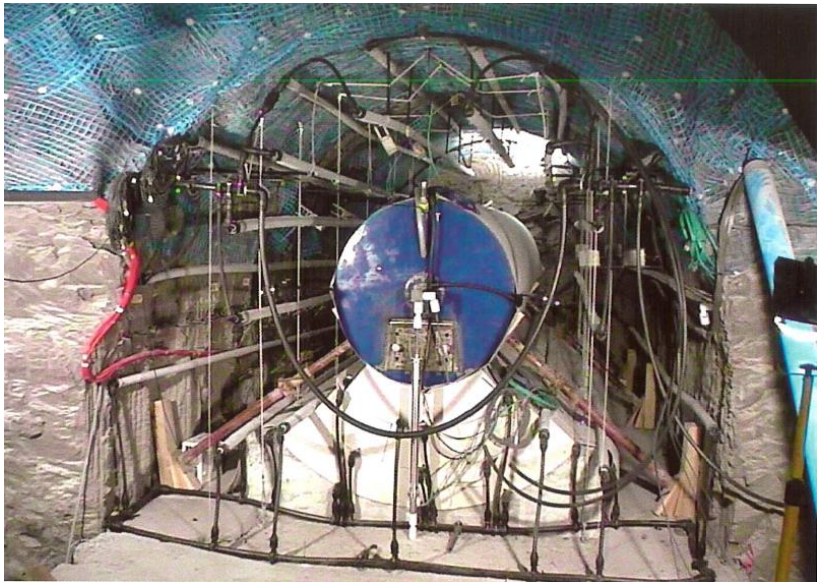
Emplacement 2

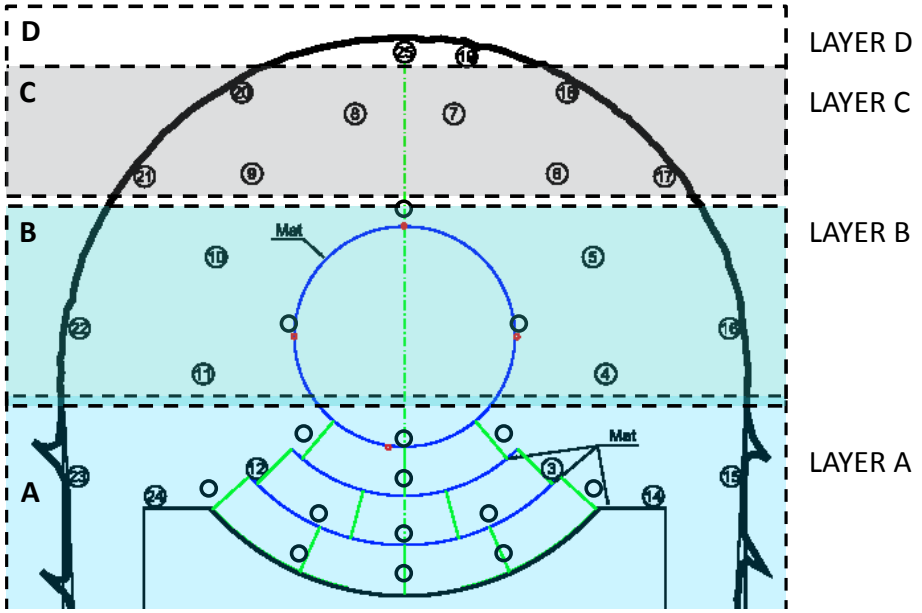


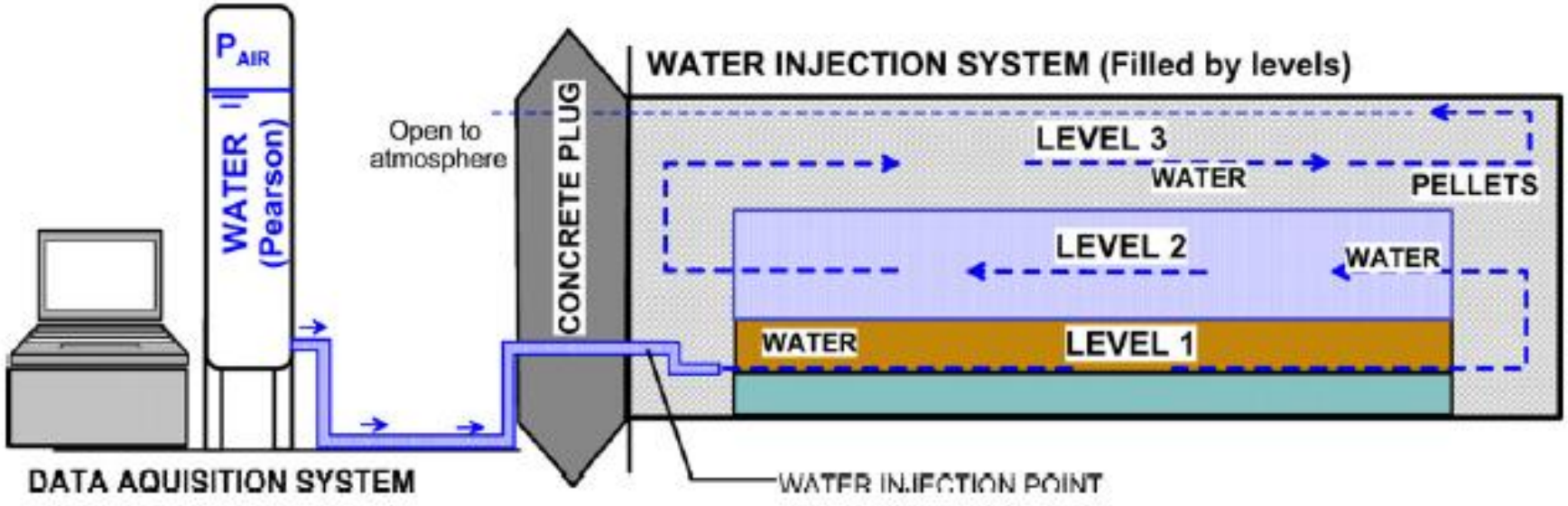
Emplacement 3

The EB experiment

- Hydration system: injection tubes + pervious mats

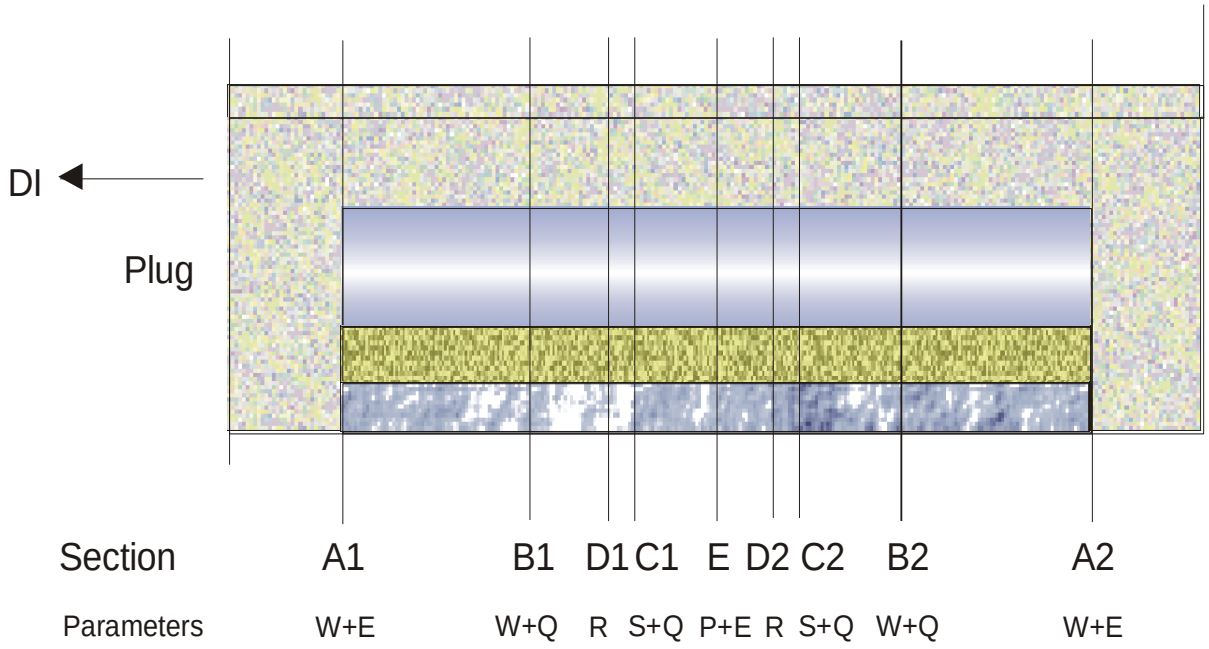






The EB experiment

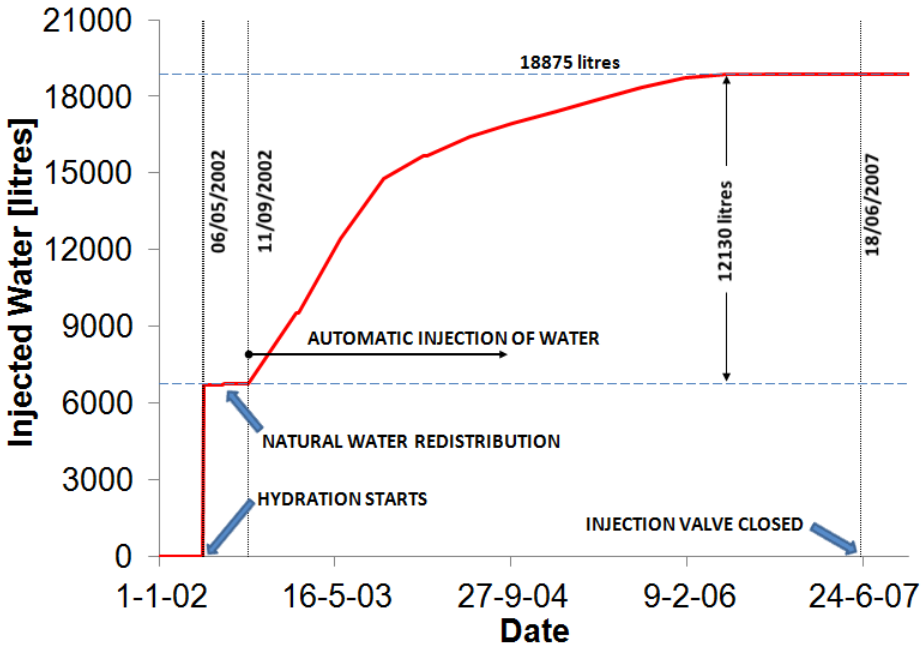
- Instrumentation: monitoring sections
  - Relative humidity sensors (Rock and buffer)
  - Displacement sensors (Canister and rock)
  - Pore pressure (Rock)
  - Total pressure (Buffer)



W: Humidity sensors
E: Extensometer
Q: Pore Pressure (absolute)
R: Electrode chains (resistivity)
S: Seismic sensor
P: Total Pressure (absolute)

The EB experiment

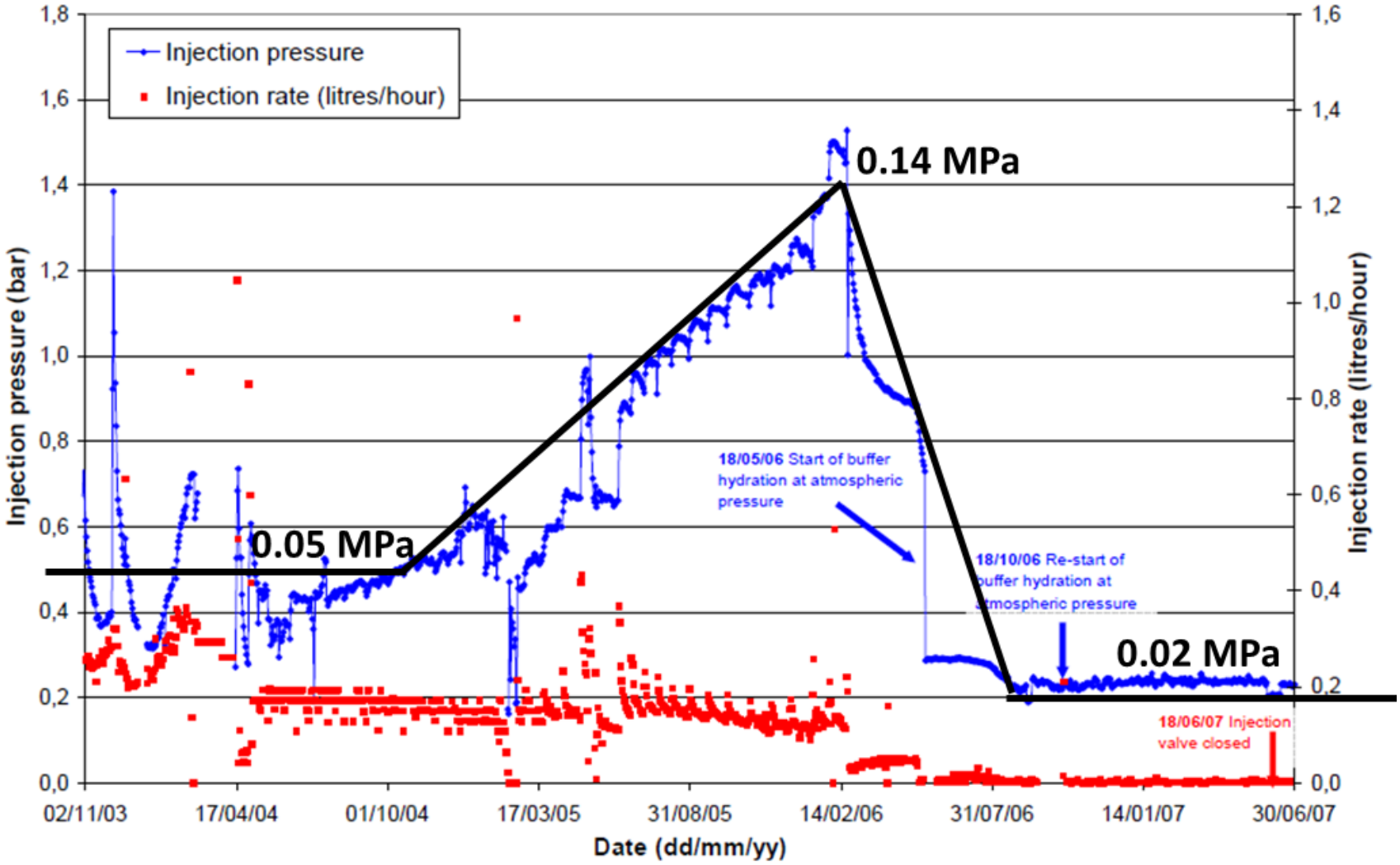
❑ Test and hydration history



- Excavation of the drift followed by 160 days rest
- Installation of the test: 5 days
- Injection of 6,700 l in 2 days
- No water injection: 120 days
- Automatic water injection (1740 days)
  - Liquid flow rate condition is applied during the first 253 days
  - Injection pressure condition is imposed at all the injection points, when the pore pressure close to some injection points reaches 50 kPa
- Injection valve closed up to dismantling (14-1/2013): 1990 days
- Total time (from start of hydration): 3850 days (10.5 years)

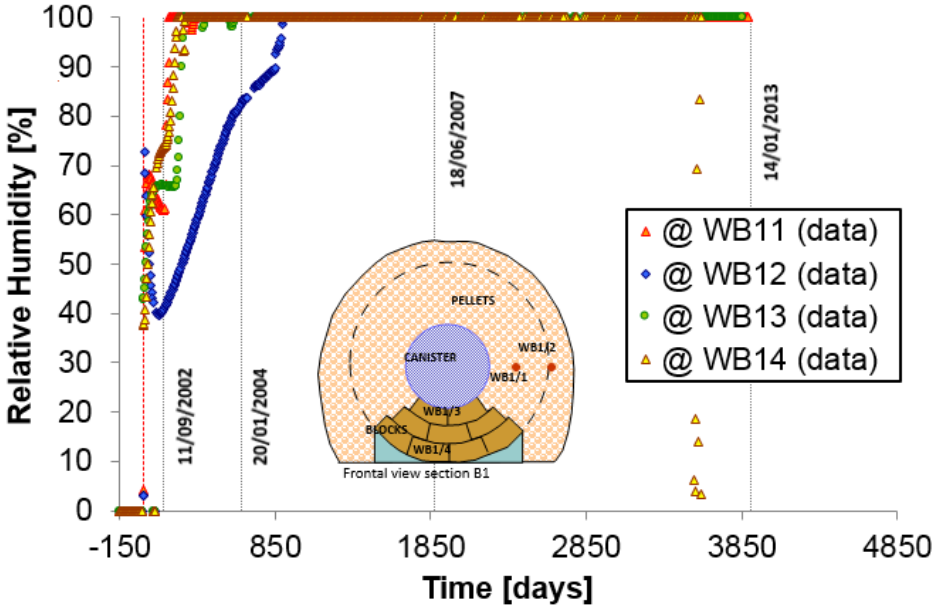
The EB experiment

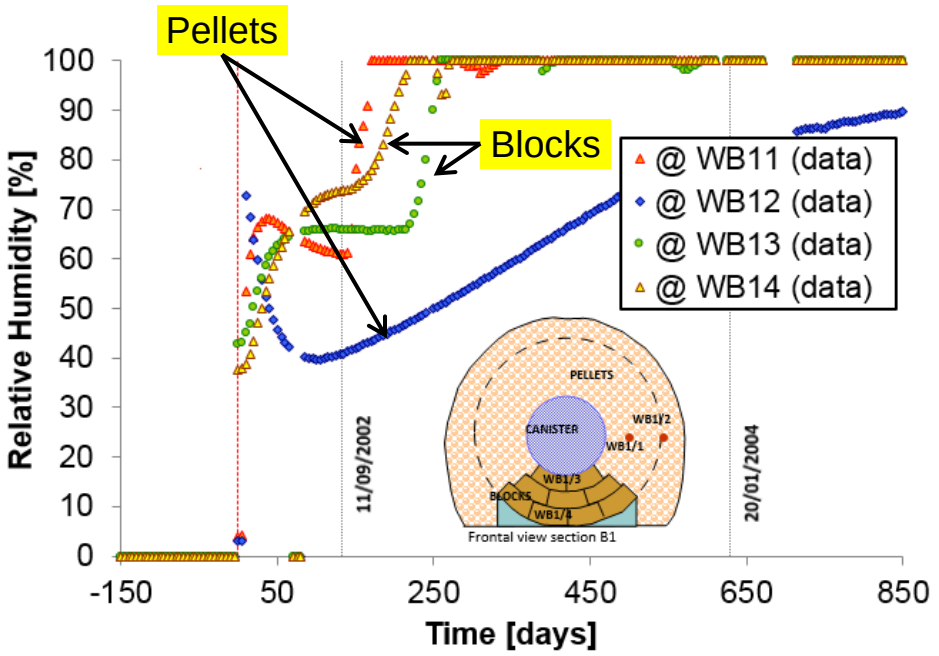
- Hydration history: injection pressure and injection rate

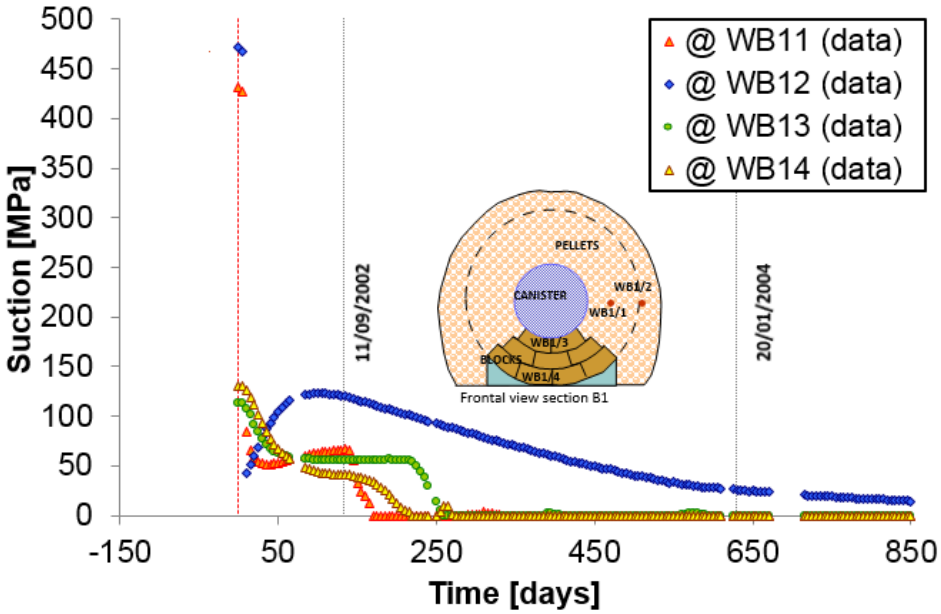


Observations during the test

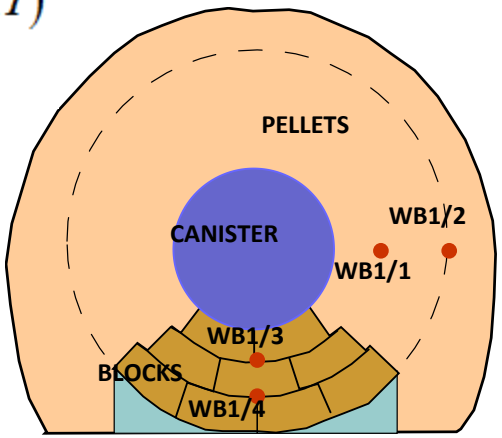
- Relative humidity (buffer)







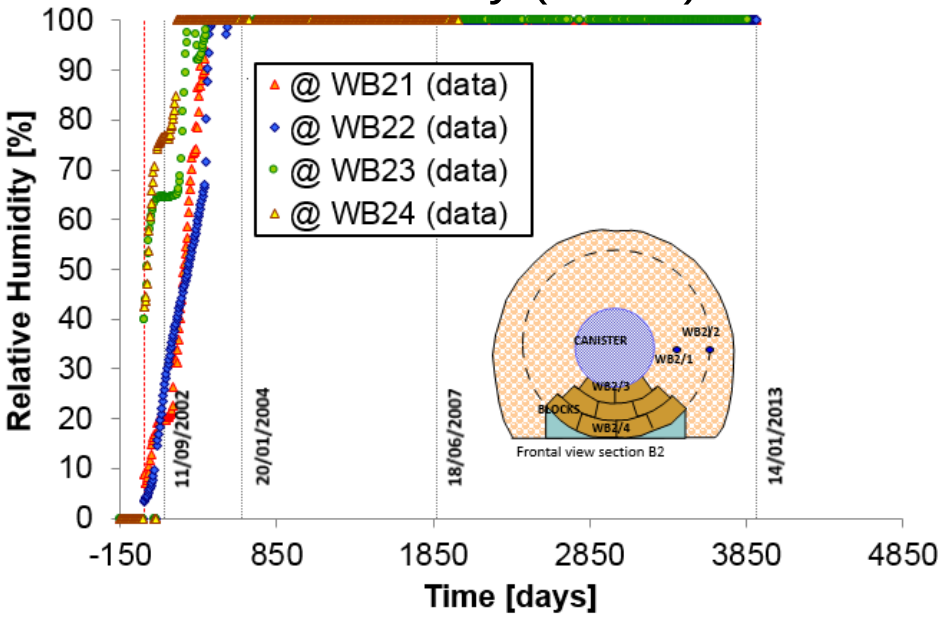
$$\Psi = -\frac{\rho_w RT}{M_w}\ln(RH)$$

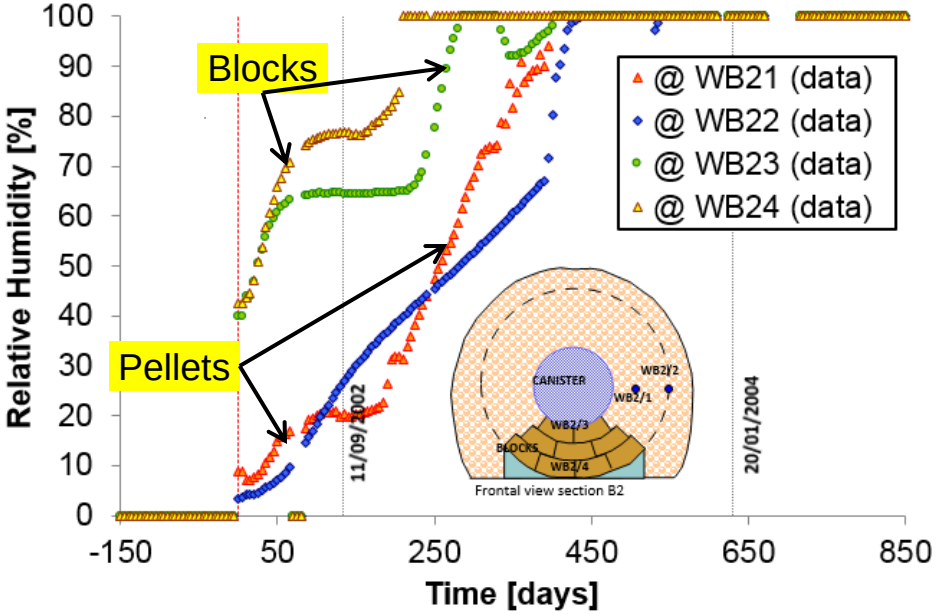


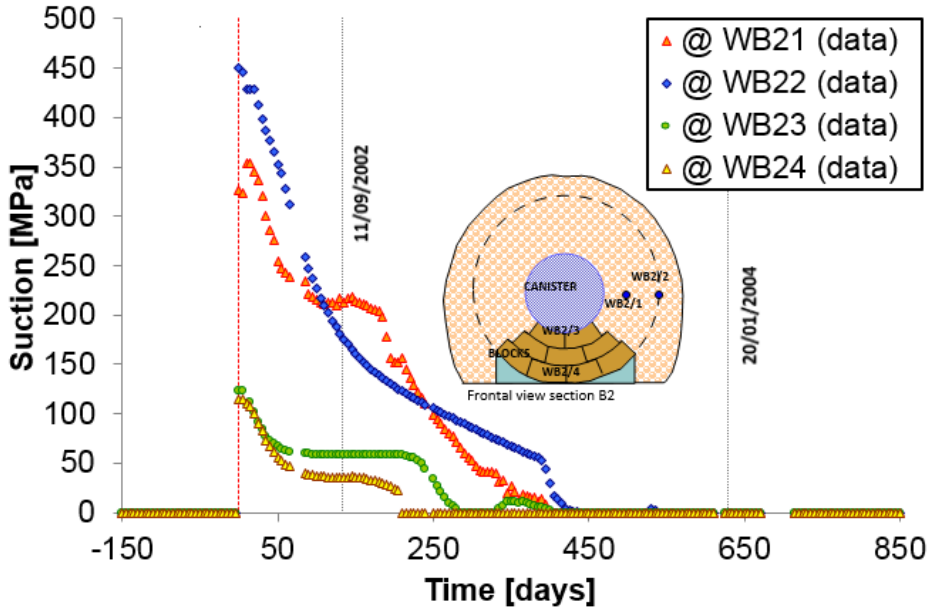
Frontal view section B1

Observations during the test

- Relative humidity (buffer)







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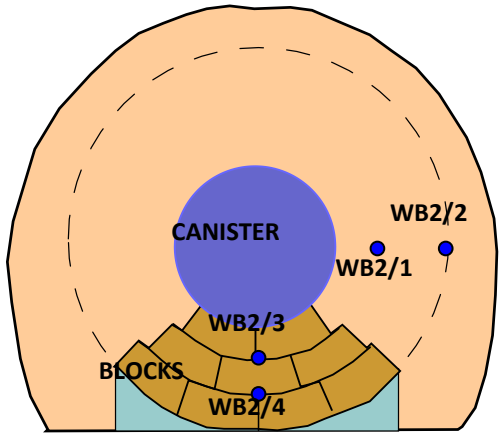
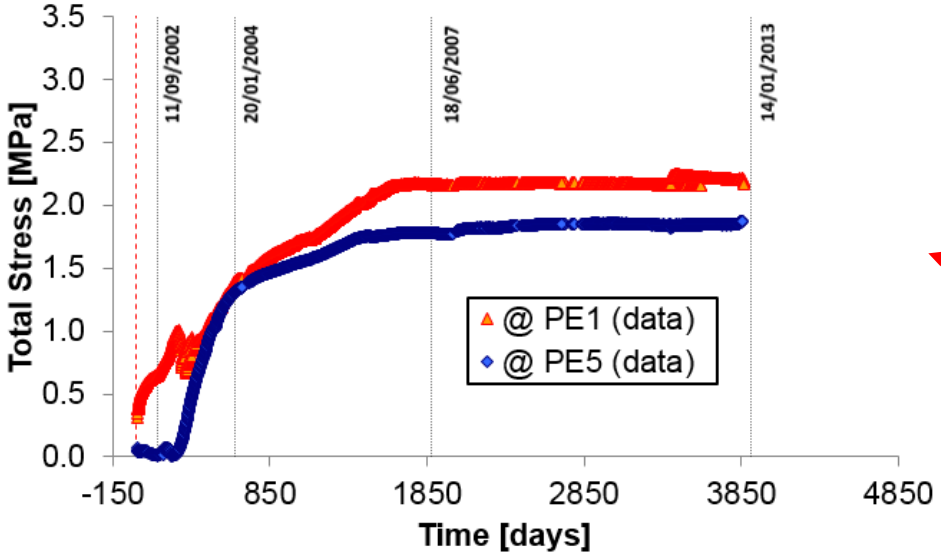
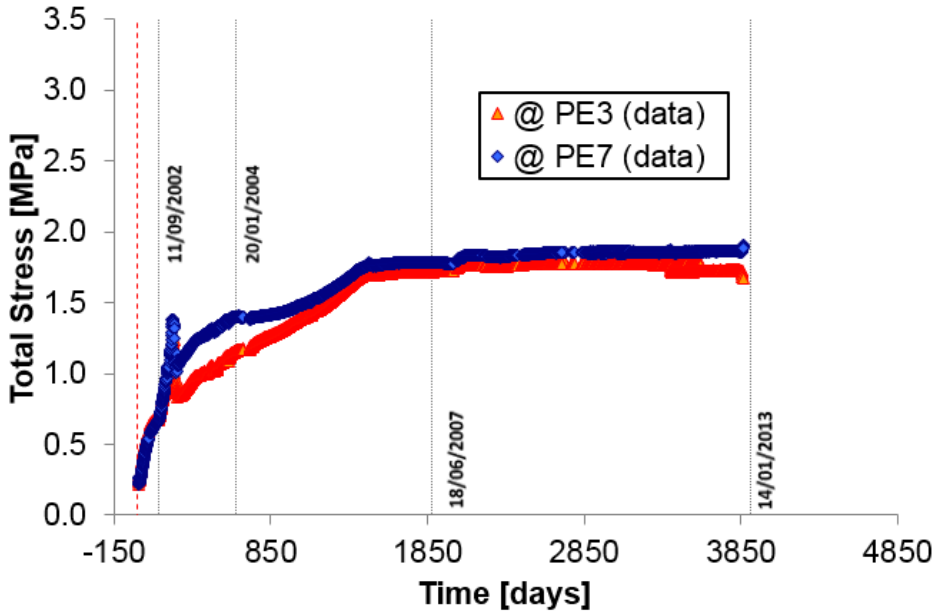


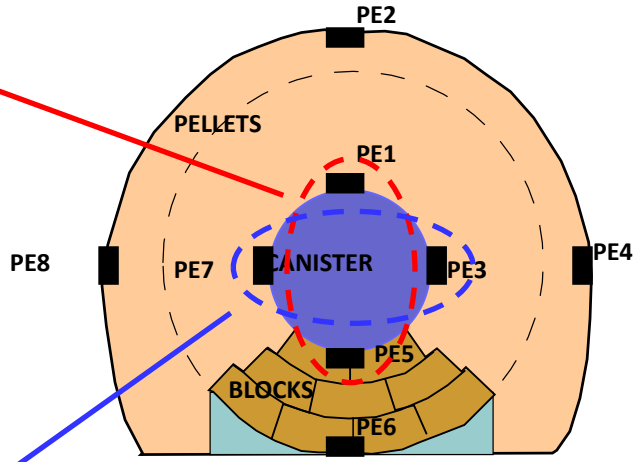
Frontal view section B2

Observations during the test

- Total stress (buffer)



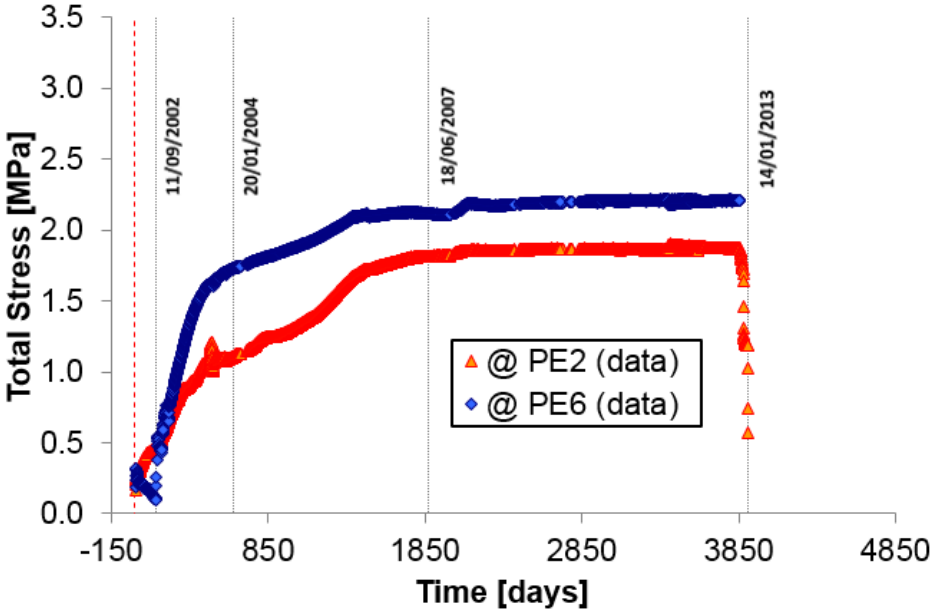


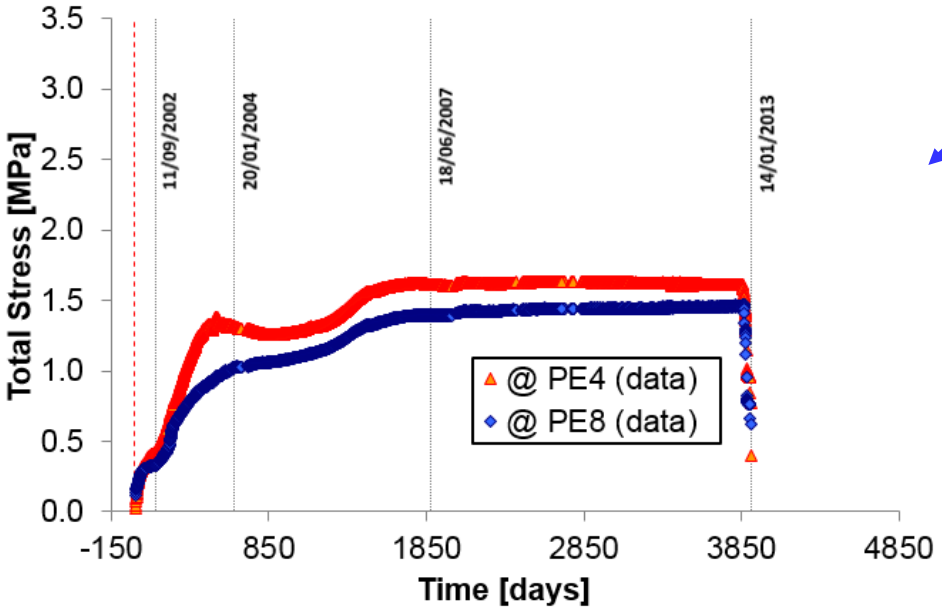


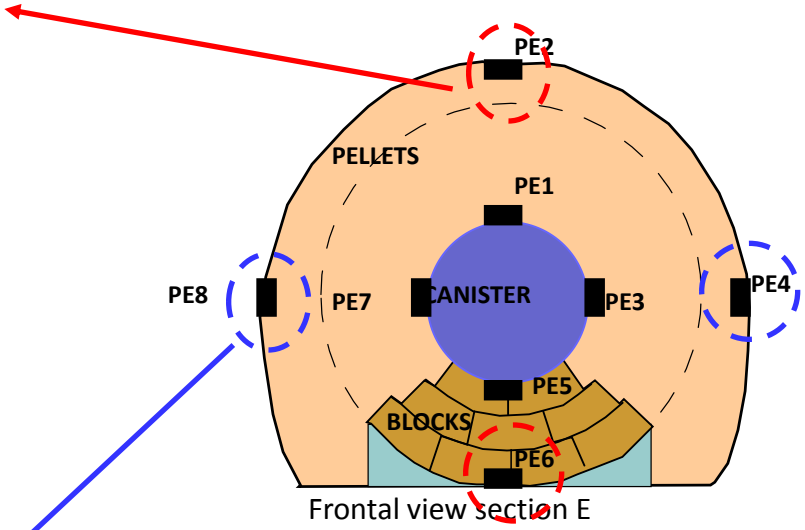
Frontal view section E

Observations during the test

- Total stress (buffer)



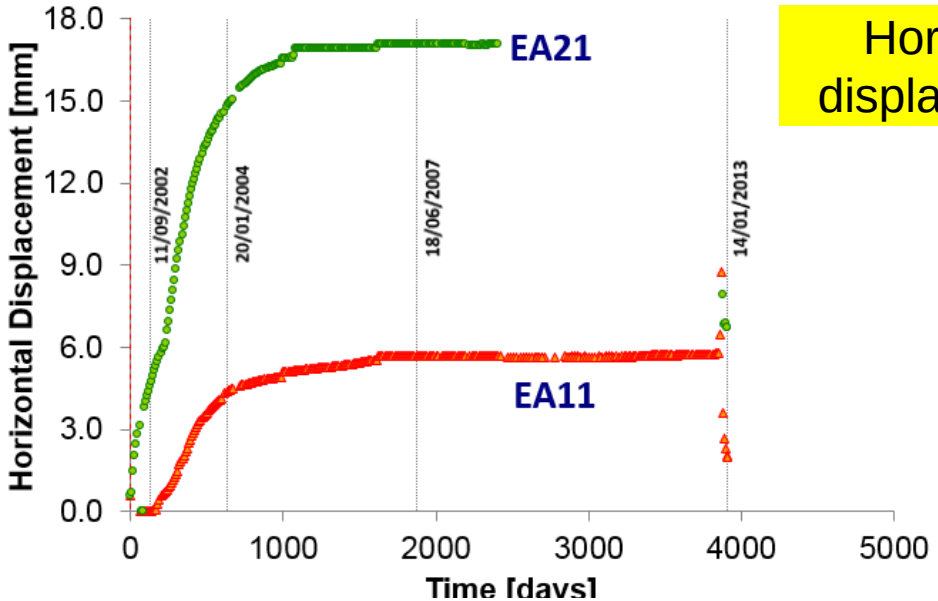




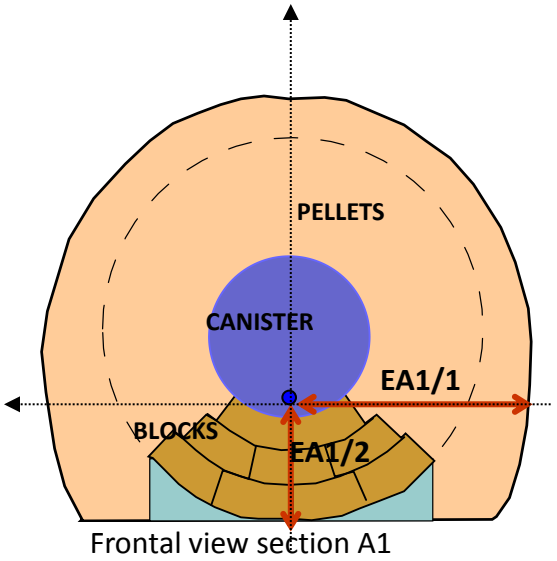
Frontal view section E

Observations during the test

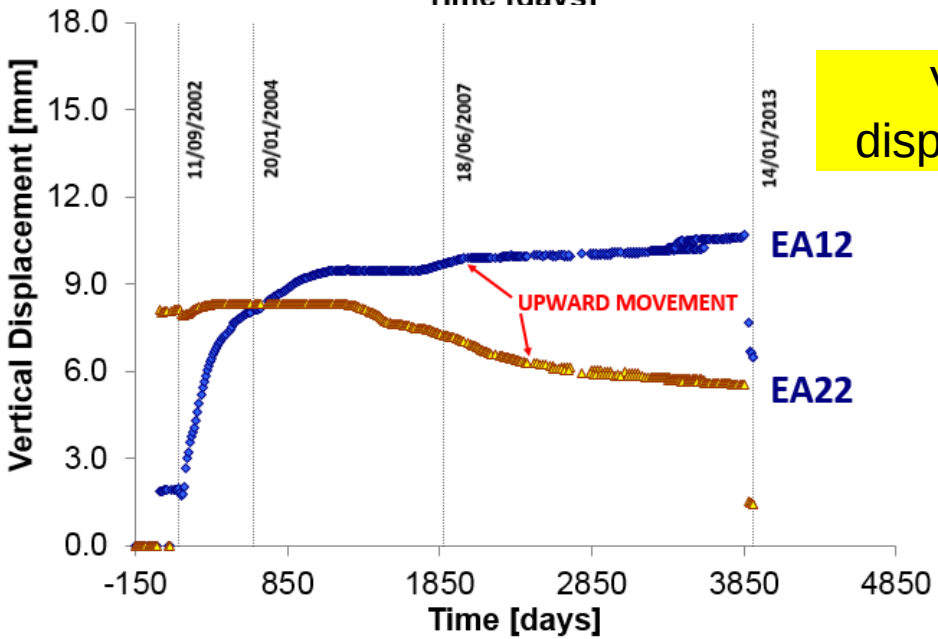
- Canister displacements



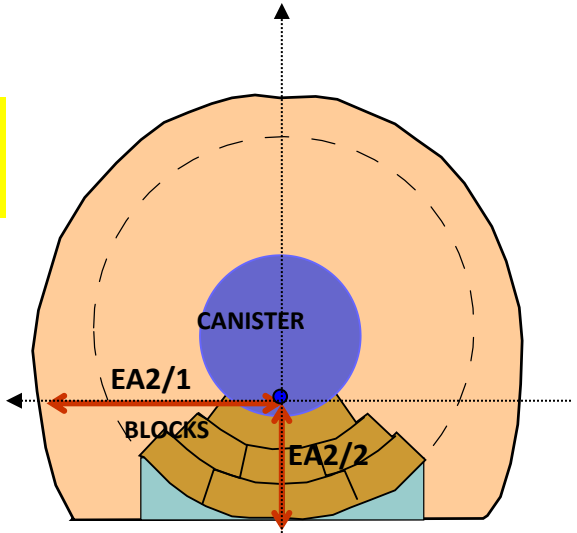
Horizontal displacements



Frontal view section A1



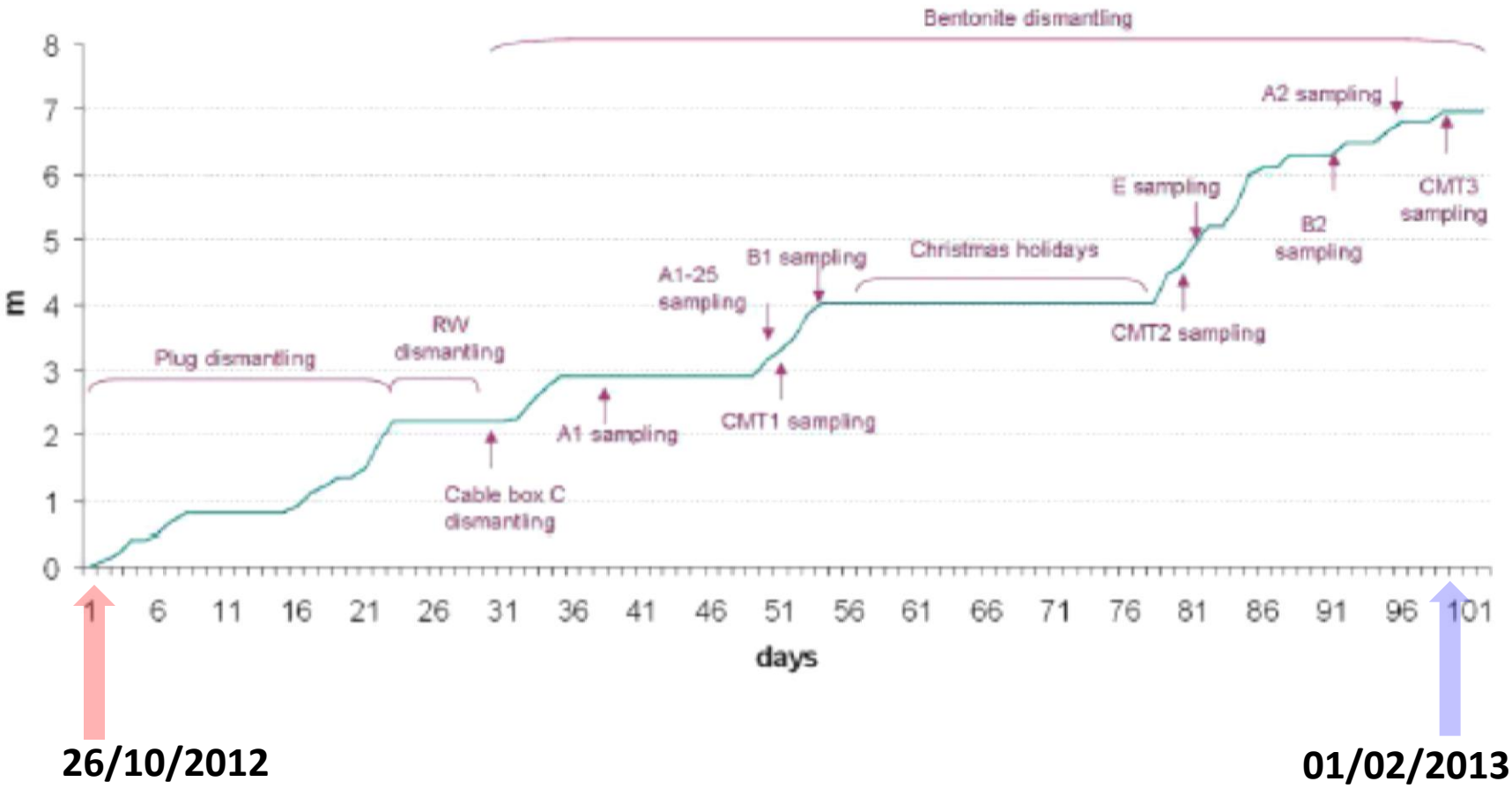
Vertical displacements



Frontal view section A2

Description of the EB test

- Dismantling
  - History



26/10/2012

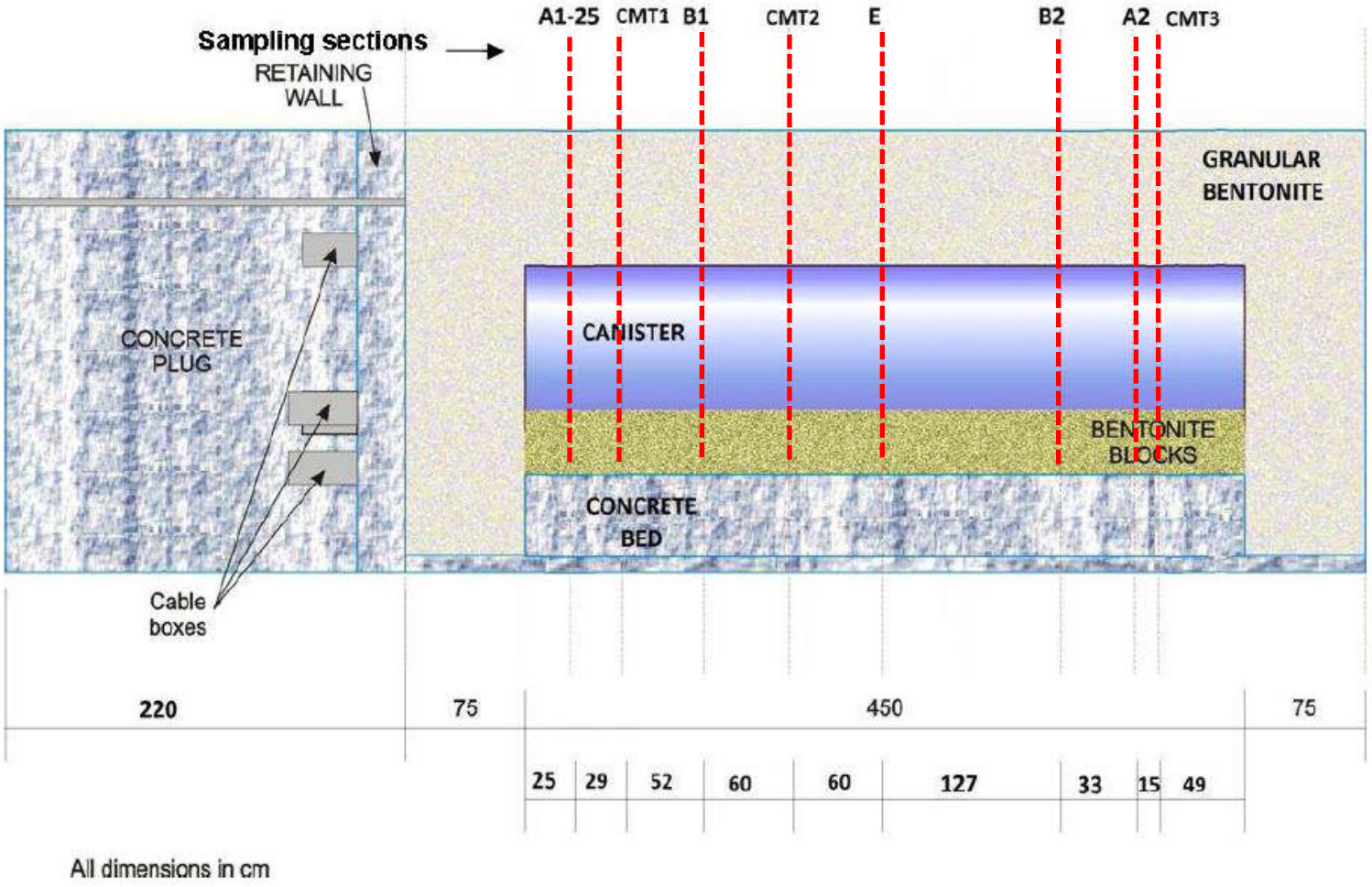
01/02/2013

The EB experiment. Mont Terri laboratory

- Dismantling

Description of the EB test

- Dismantling
  - Sampling sections



Description of the EB test

- Dismantling
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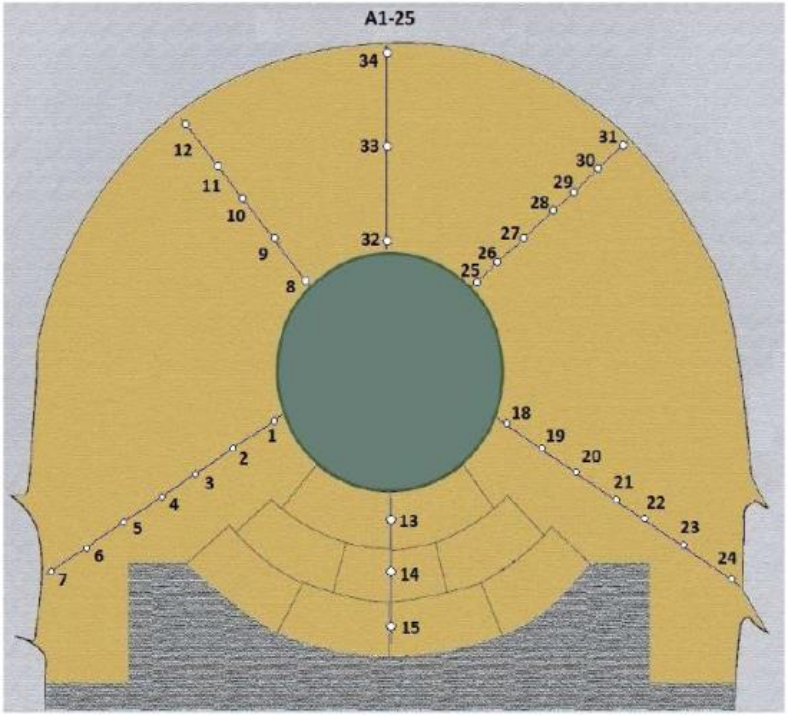
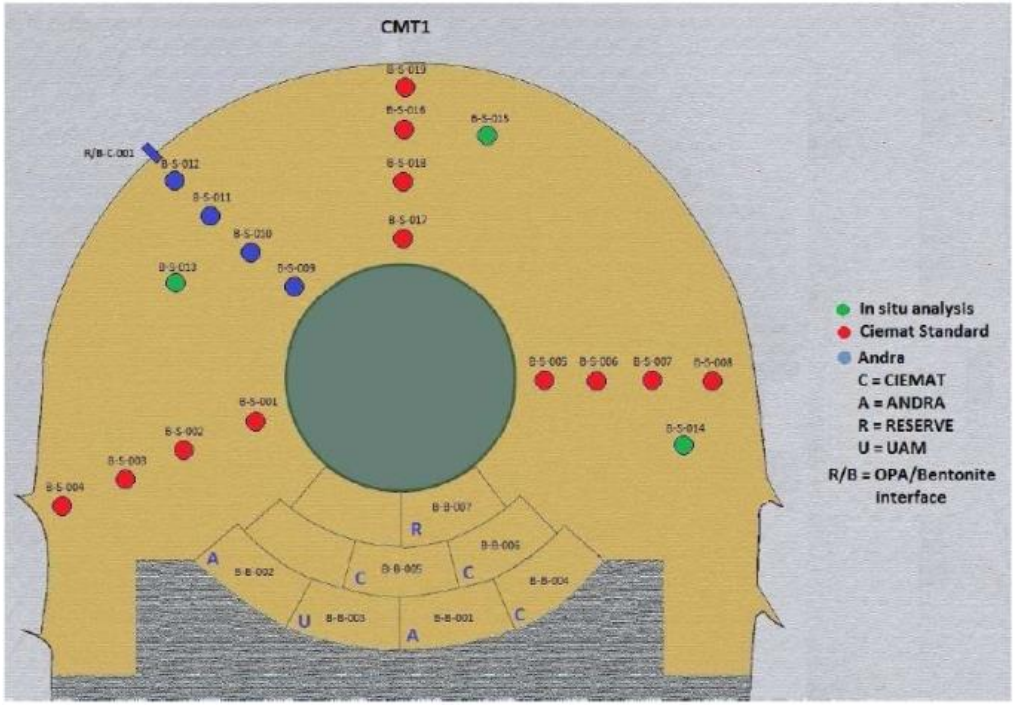


Section A1-25

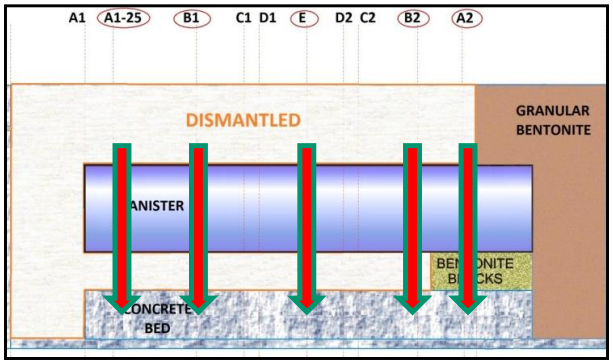


Section CMT-1

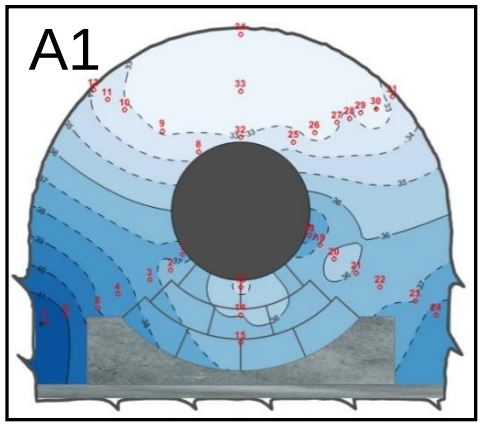
- 203 samples of bentonite for the determination of dry density and water constent

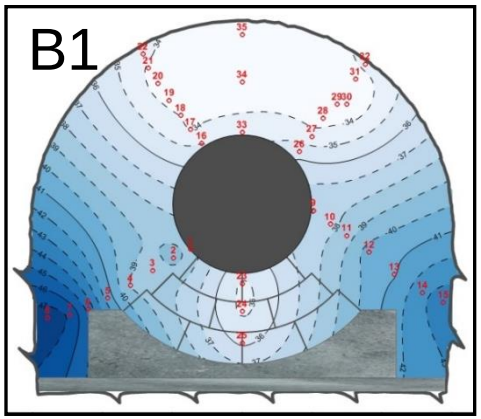
The EB experiment. Mont Terri laboratory

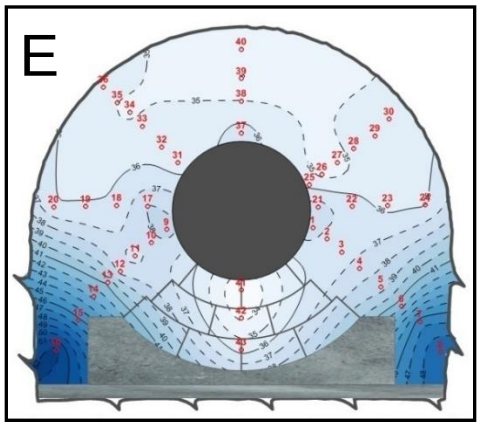
- Water content

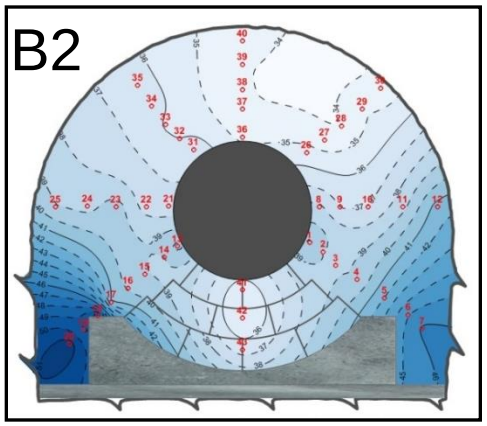


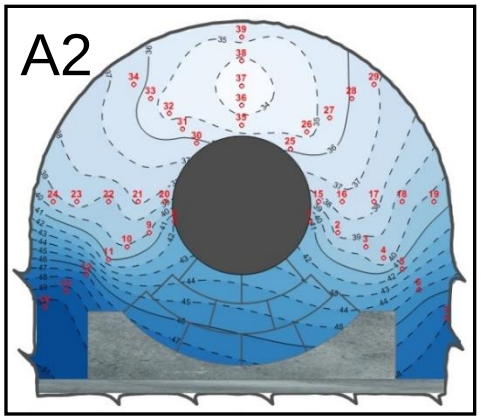
- Engineered barrier basically saturated throughout (Sr > 0.95)
- Water content contours reflect differences in dry density





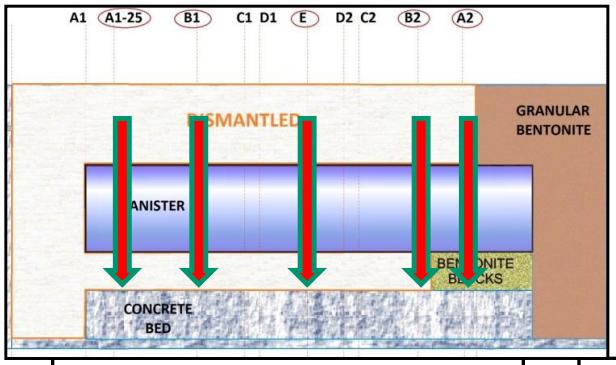


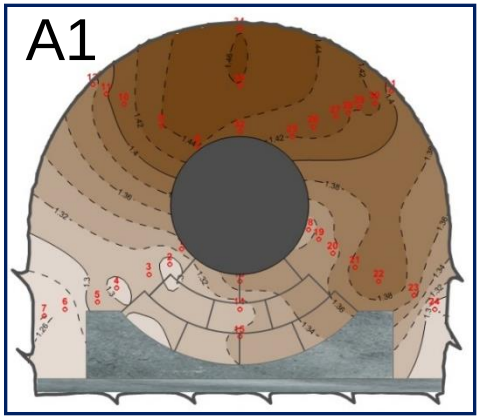


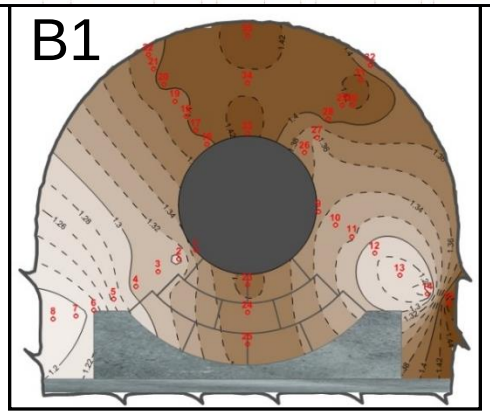


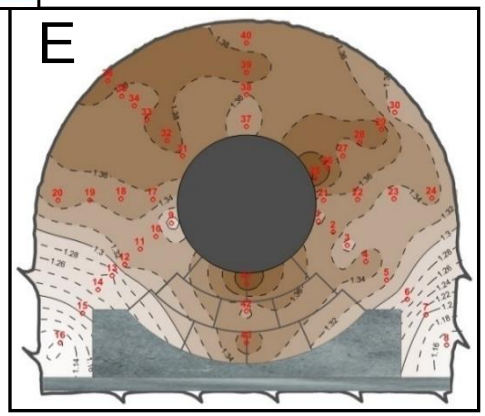
The EB experiment. Mont Terri laboratory

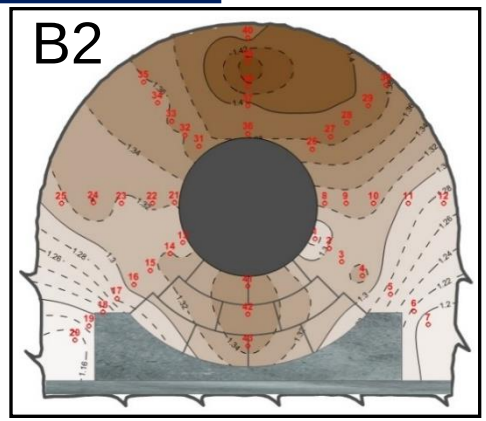
- Dry density

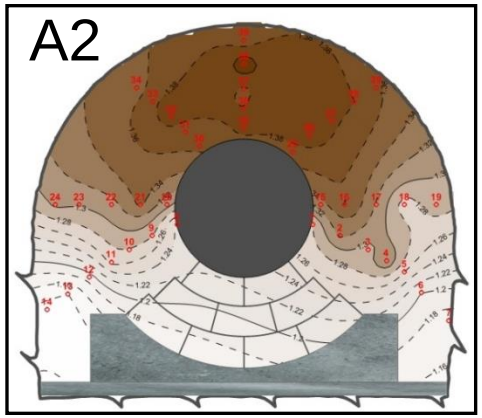






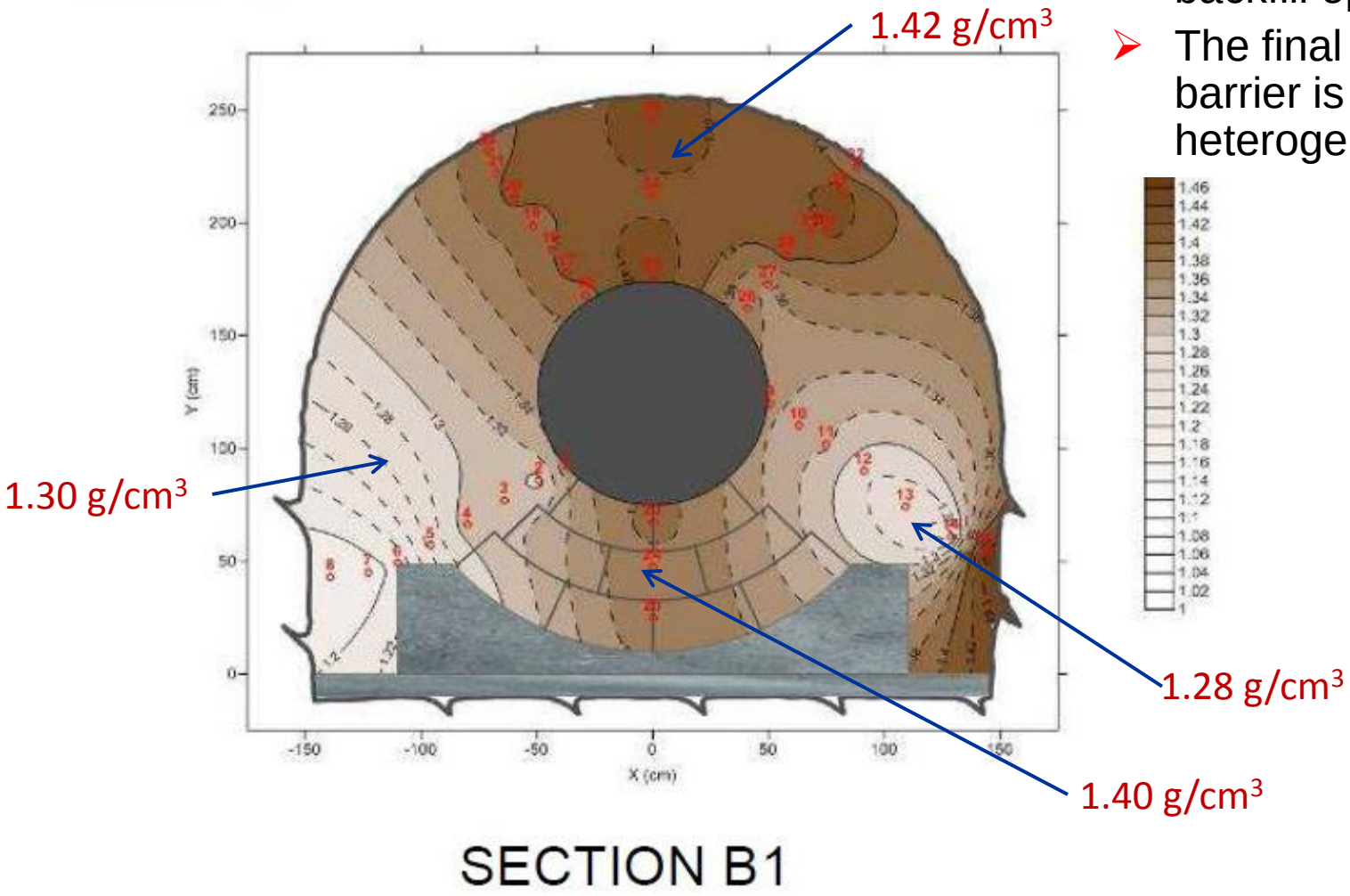






The EB experiment. Mont Terri laboratory

- Dry density



SECTION B1

- Hydraulic conductivity below 5.10^{-12} m/s everywhere using simple backfill operations
- The final state of the barrier is however still heterogeneous.

The EB experiment

- Main points concerning bentonite homogenization and relevant for the project
  - The Engineered Barrier was saturated on dismantling (10.5 years)
  - Homogenization between the two types of bentonite emplaced (blocks and GBM) took place. Nevertheless, still (some heterogeneities persist:
    - Moisture content tends to increase (and the dry density to decrease) towards the bottom of the experiment niche
    - Several potential causes: initial segregation, emplacement difficulties, type and sequence of hydration sequence, geometrical features
- References
  - Engineered barrier emplacement experiment in Opalinus clay for the disposal of radioactive waste in underground repositories". Publicación Técnica ENRESA 02/05 (February 2005)
  - PEBS Project Deliverable D2.1-8. "EB dismantling. Synthesis report". Juan Carlos Mayor (Enresa) and Manuel Velasco (Golder). [http://www.pebs-eu.de/PEBS/EN/Downloads/downloads_node_en.html]

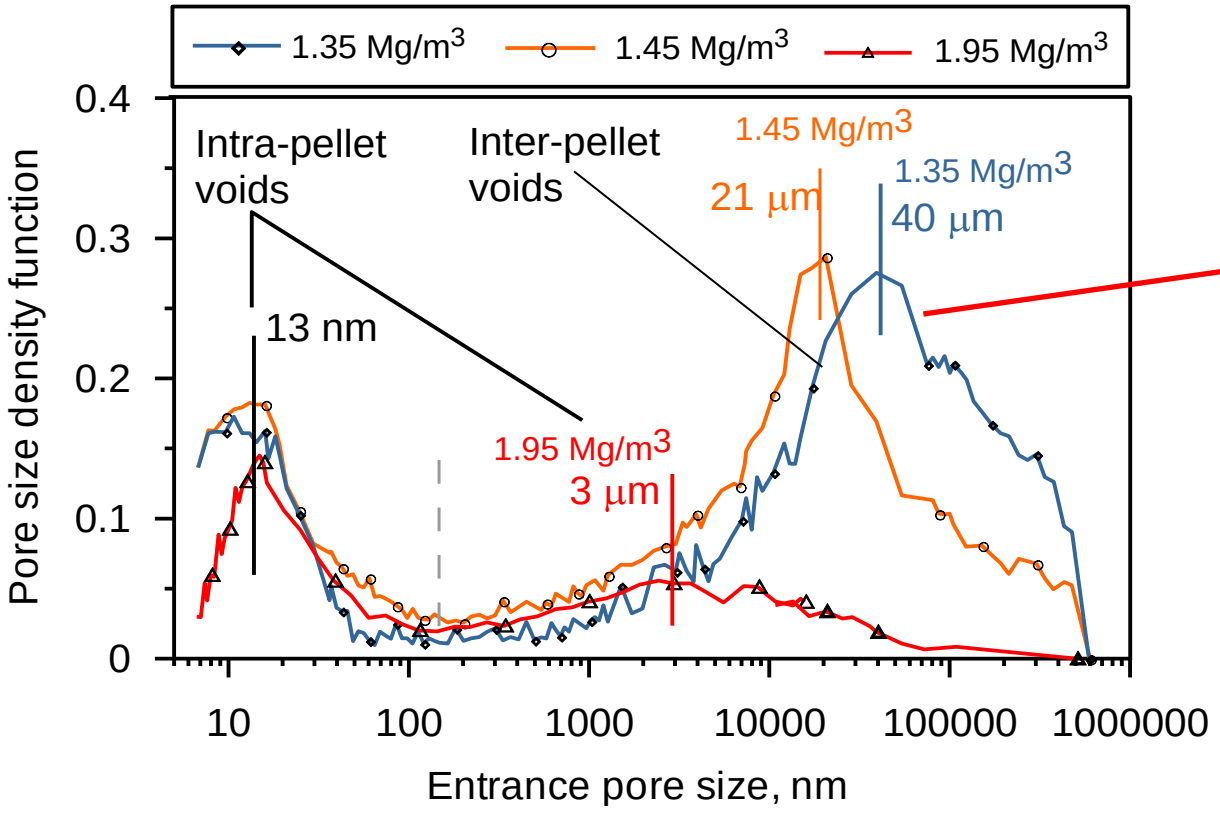
Acknowledgment

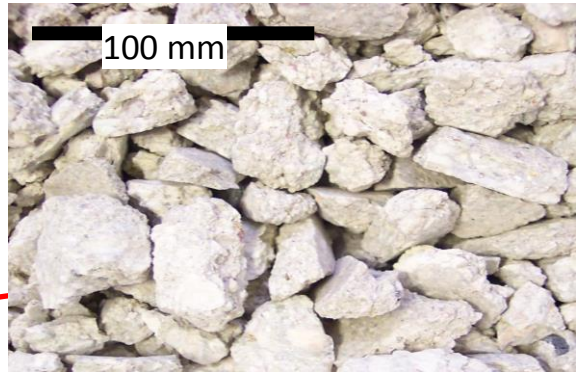
This project receives funding from the Euratom research and training programme 2014-2018 under grant agreement No 745942

The EB experiment. Mont Terri laboratory

- Fabric characterization

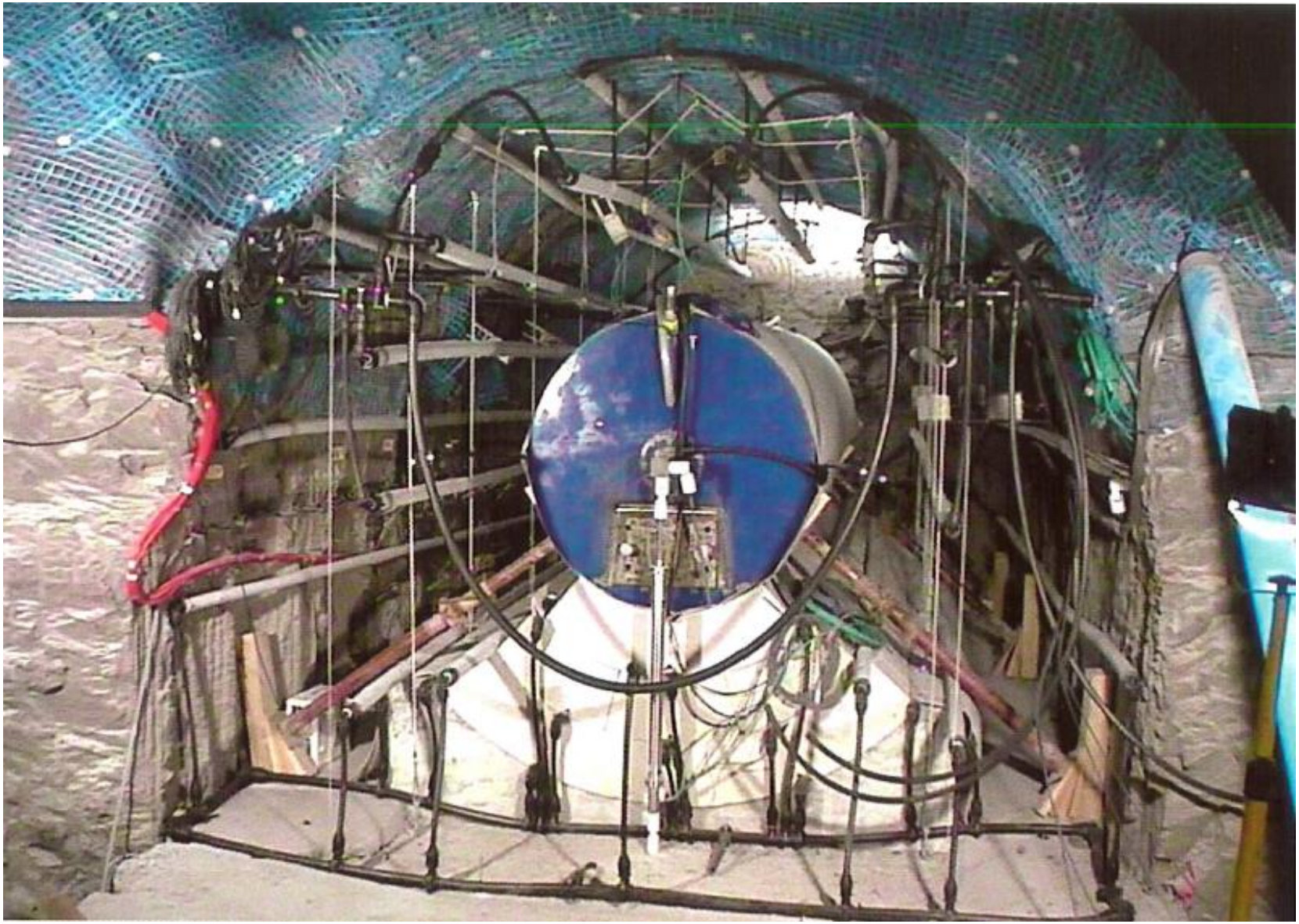
Inter-pellet pores: 20 – 800 μm





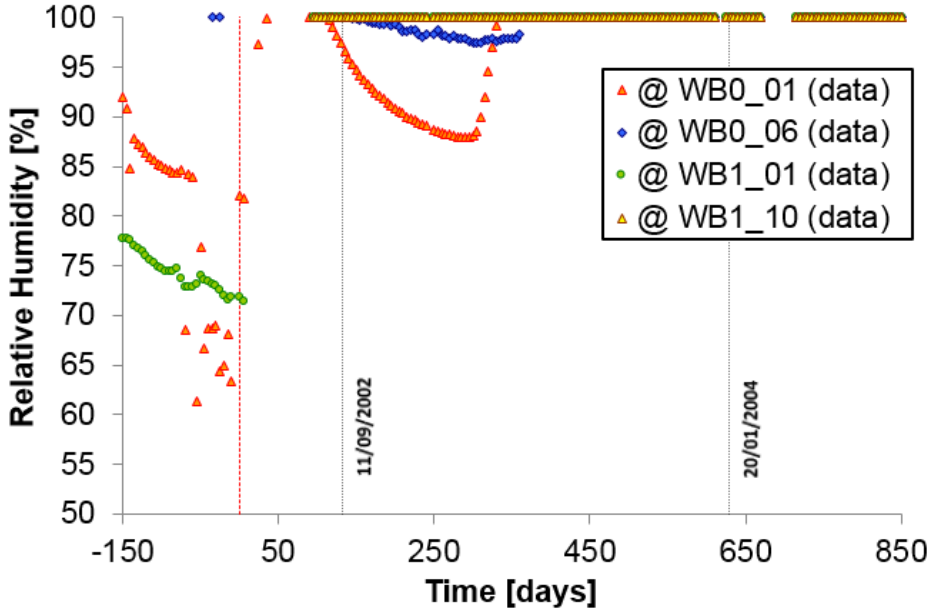
The EB experiment

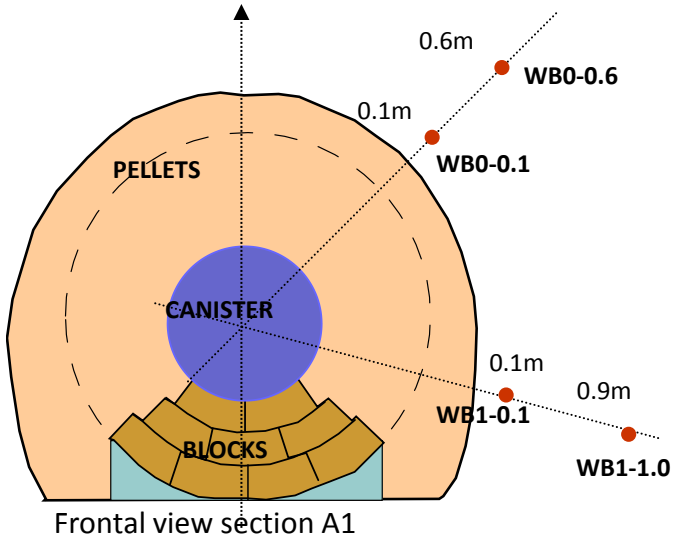
- Layout



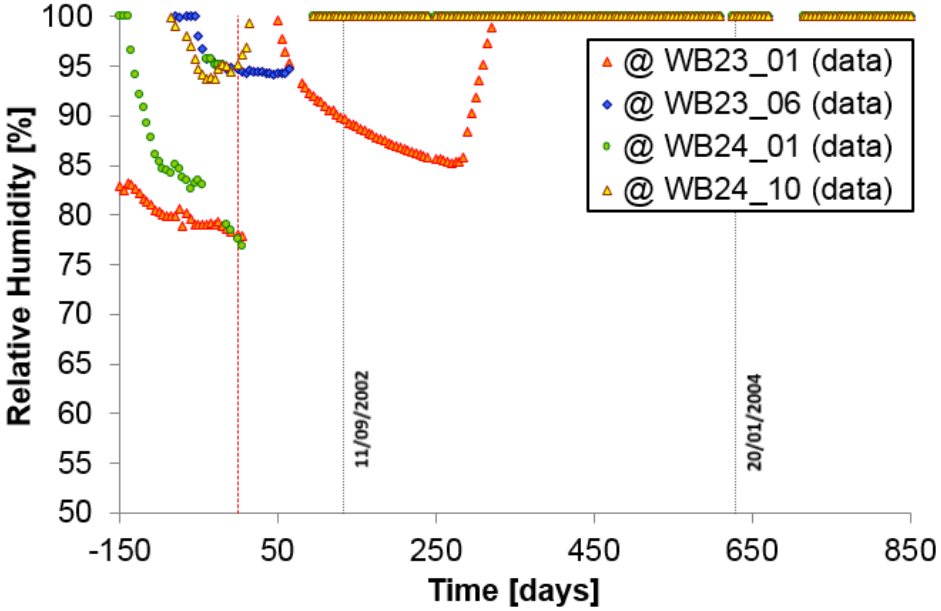
Observations during the test

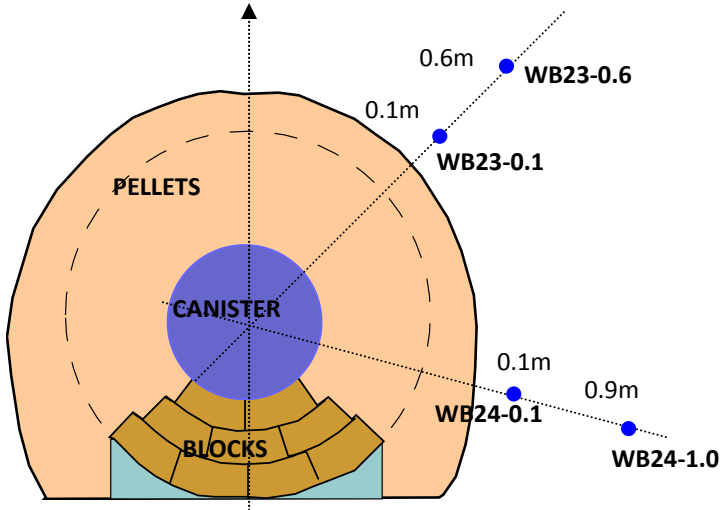
- Relative humidity (rock)





Frontal view section A1

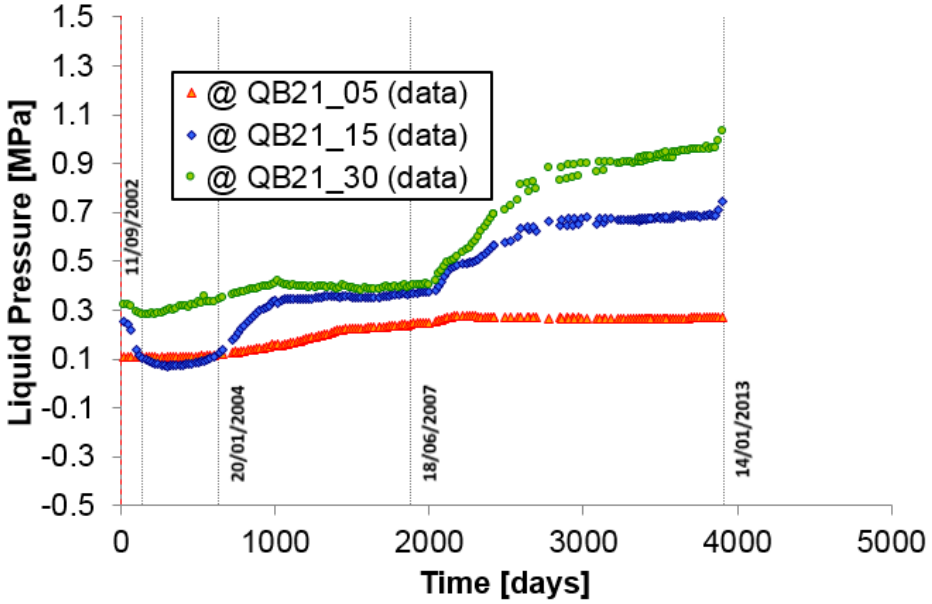


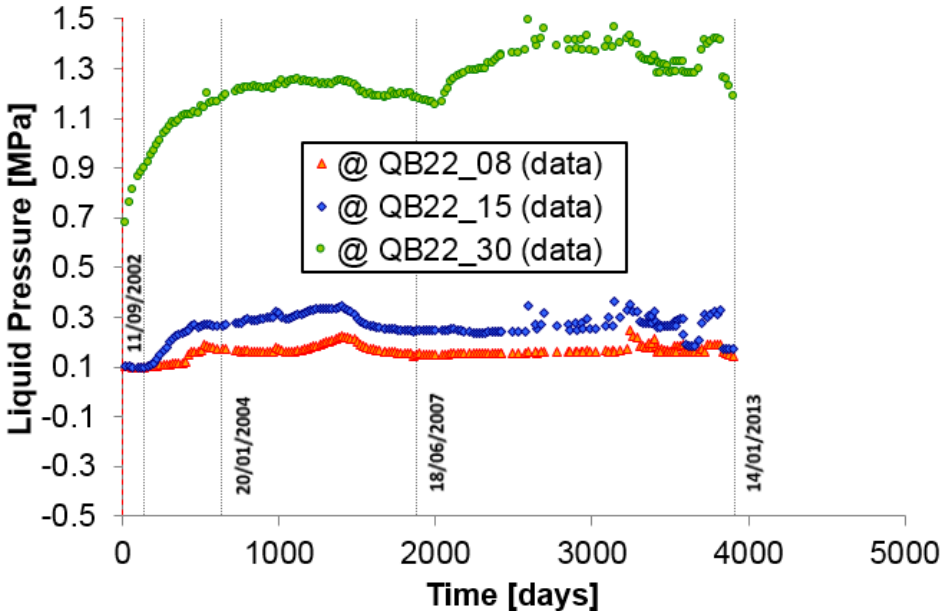


Frontal view section A2

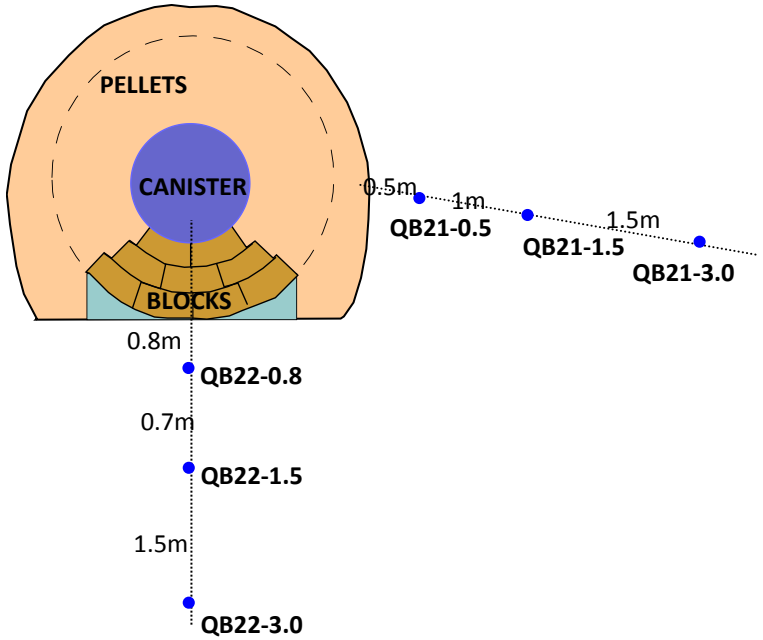
Observations during the test

- Pore pressures (rock)



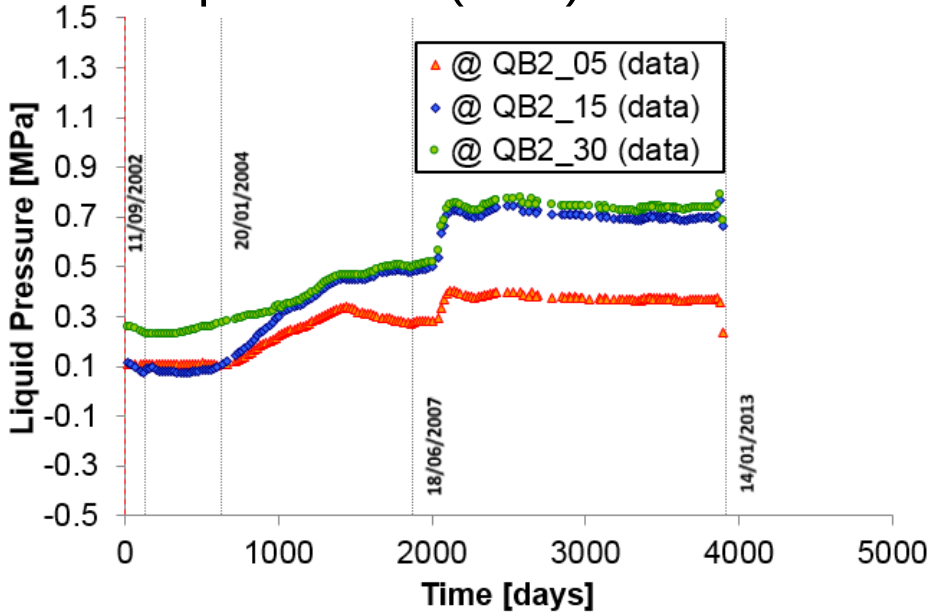


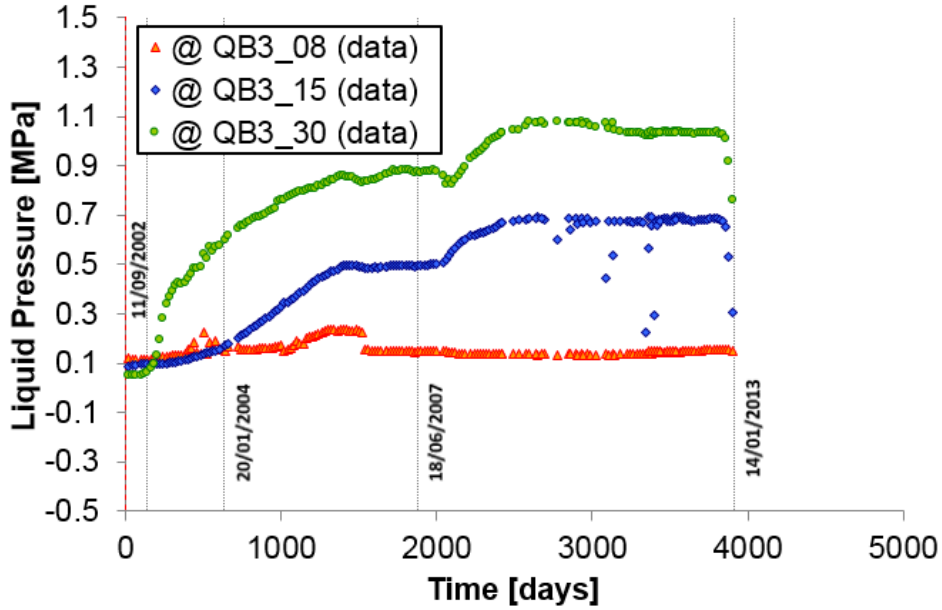
Frontal view section B2

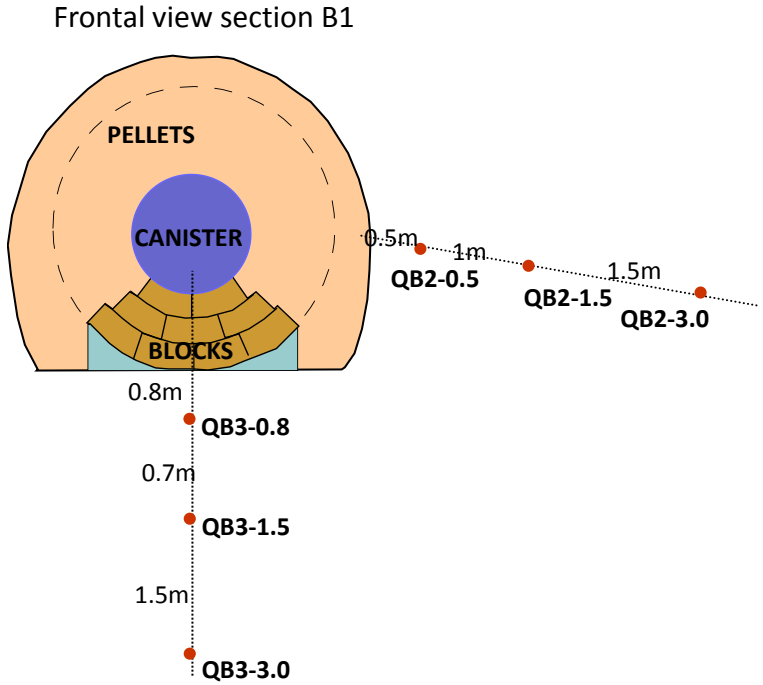


Observations during the test

- Pore pressures (rock)

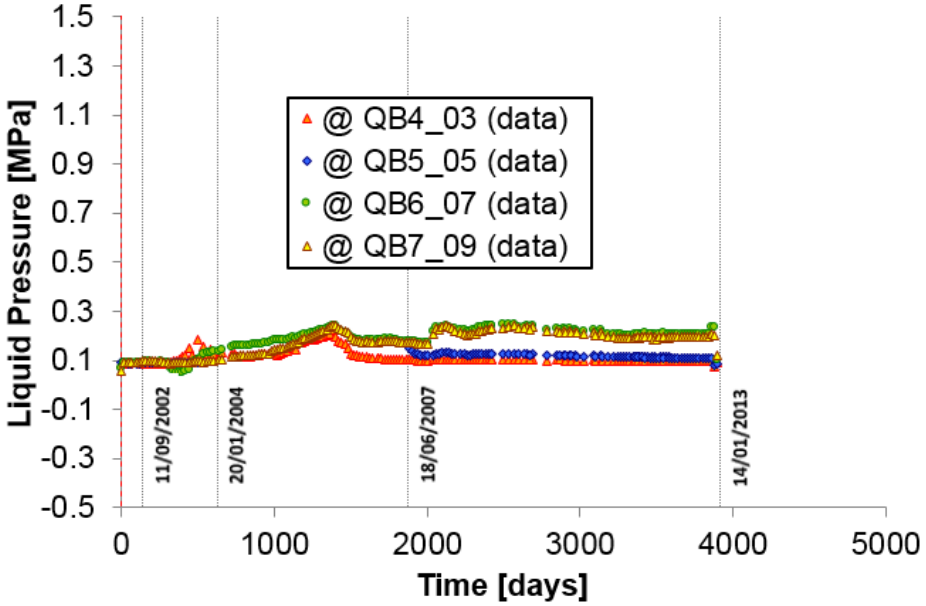


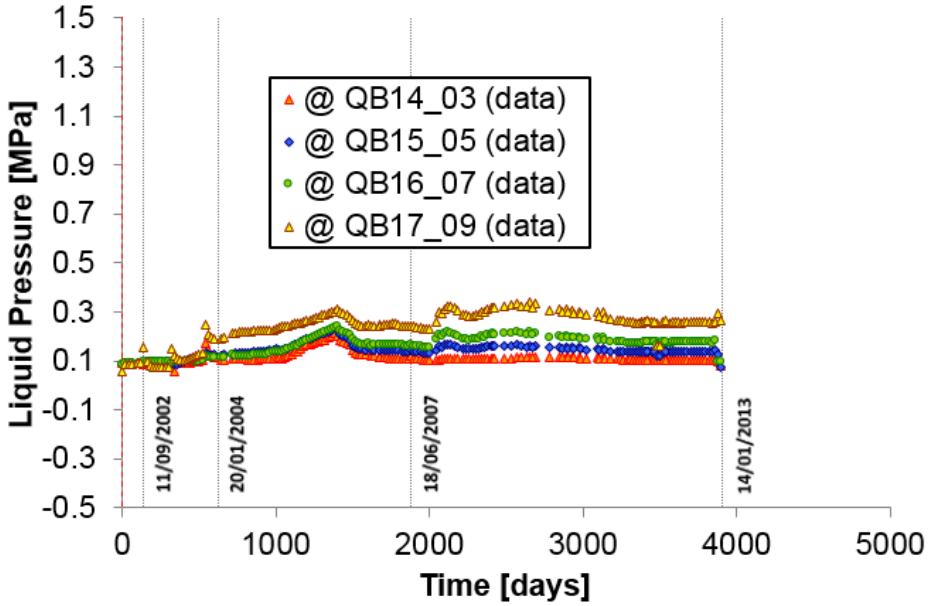




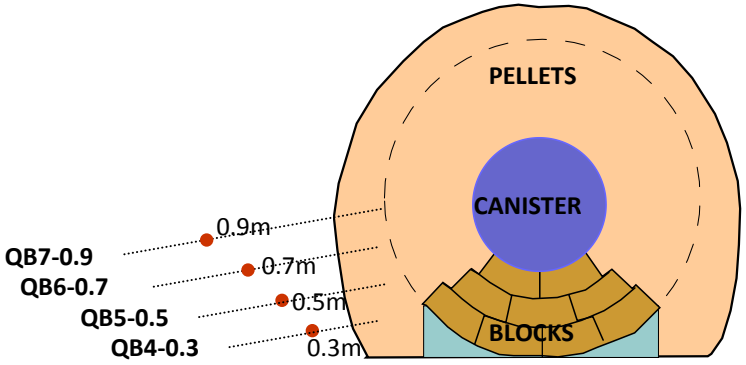
Observations during the test

- Pore pressures (rock)

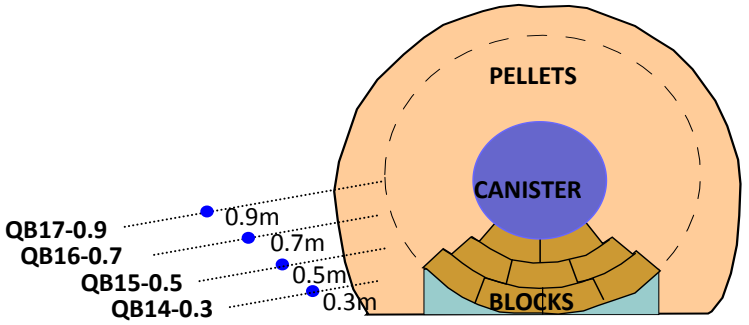




Frontal view section C1



Frontal view section C2



Description of the EB test

- Dismantling
  - History and total pressure evolution