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A TSO research programme on safety of geological disposal and its necessary evolution along the development of a national industrial project

Köln, 5 november 2013

Outline

- Context
- R&D programme overview
- R&D illustrating examples
- Some perspectives

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  - Why?
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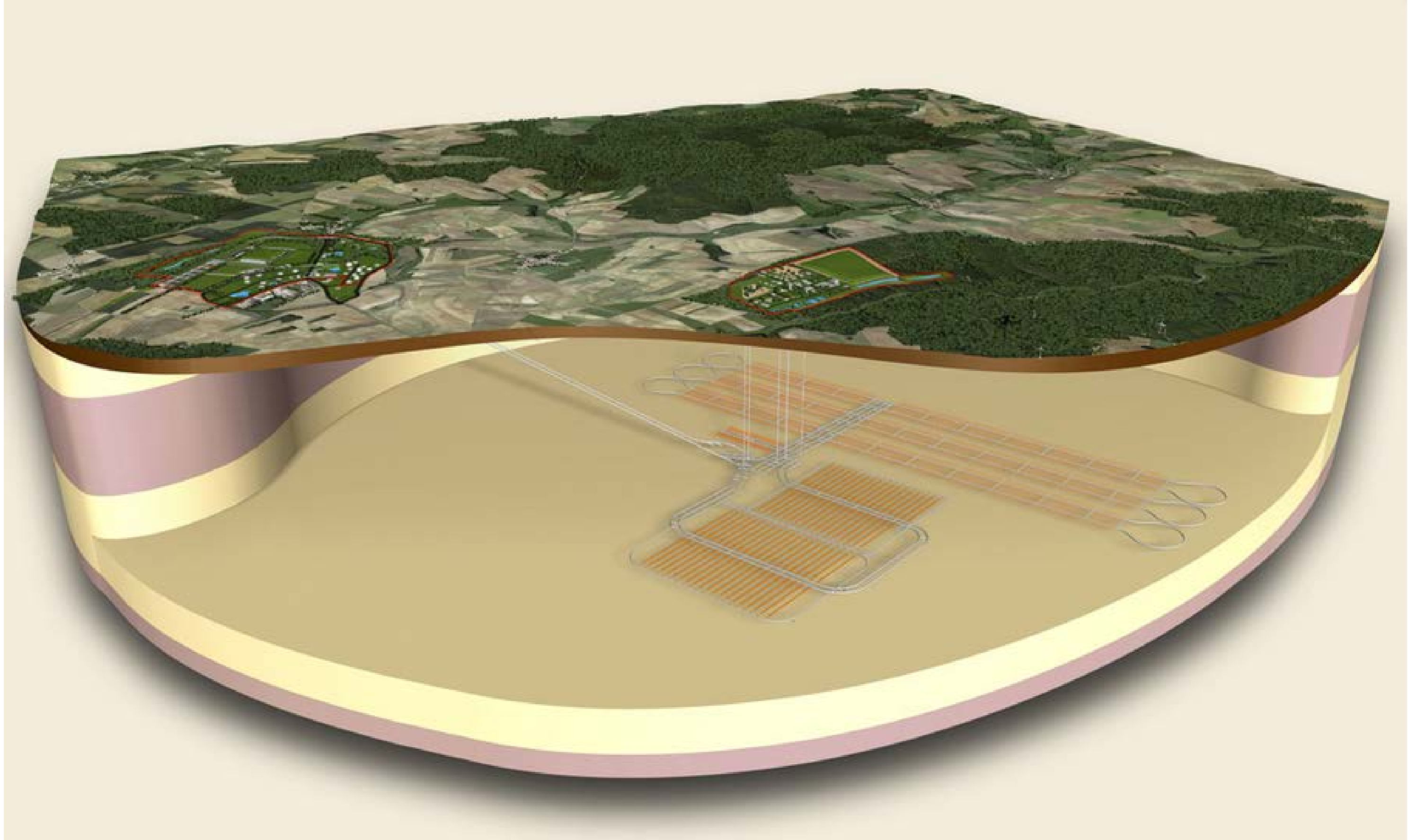
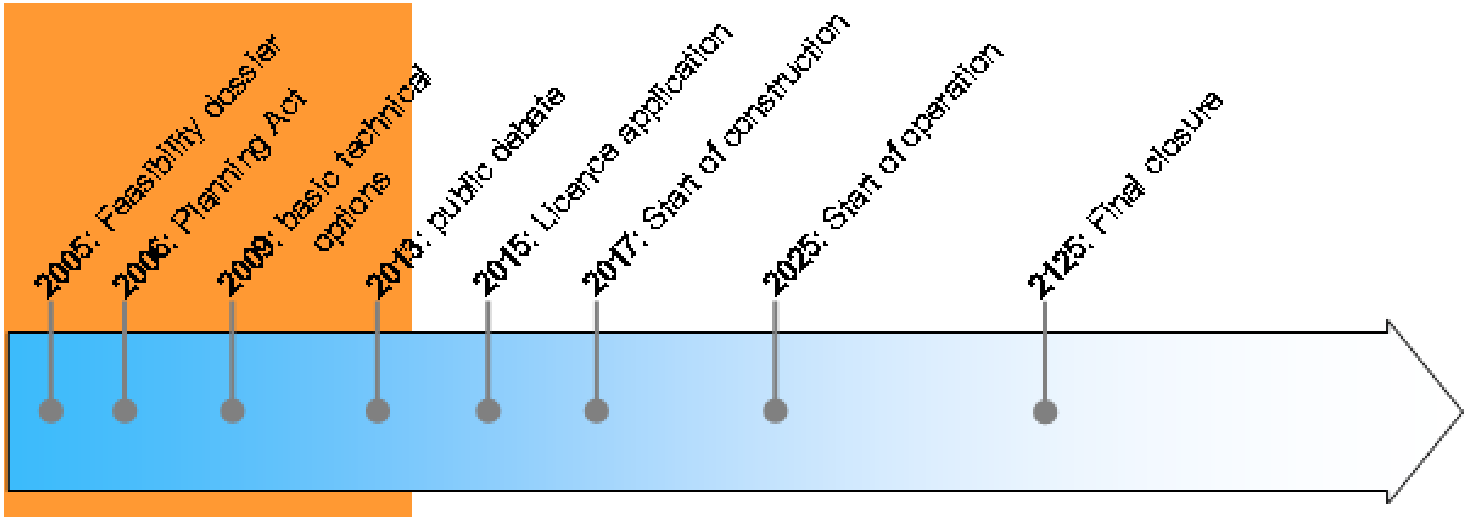
View of the future French DGR (Cigéo, Andra)

- Host-rock: claystone
- Depth > 500 m



Context of IRSN's R&D

- A controlled roadmap and its associated timing



- IRSN's R&D:
  - Strong support to expertise
  - Legitimity
  - Independency, e.g. via its own URL (& communication tool)

Outline

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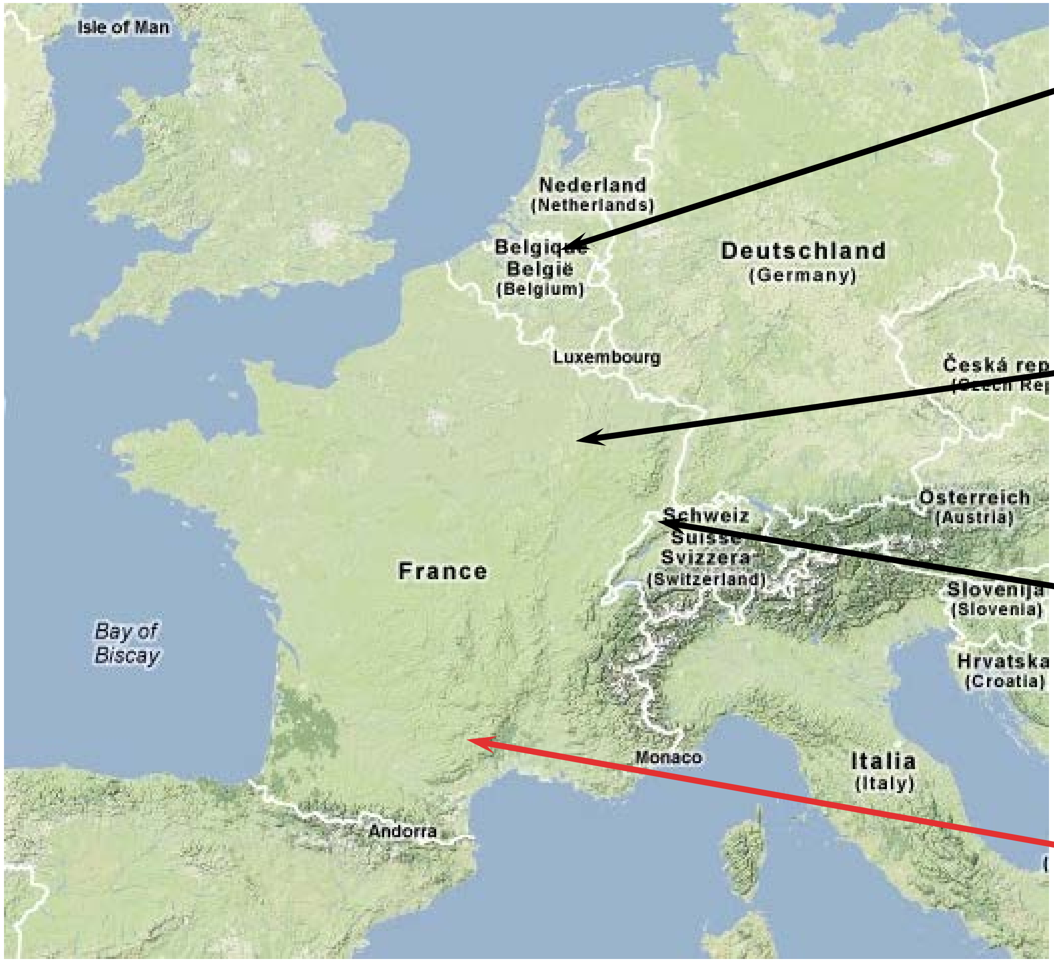
- R&D programme overview
  - Where?
  - What?
- R&D illustrating examples
- Some perspectives

URLs in clayey host-rocks in Western Europe



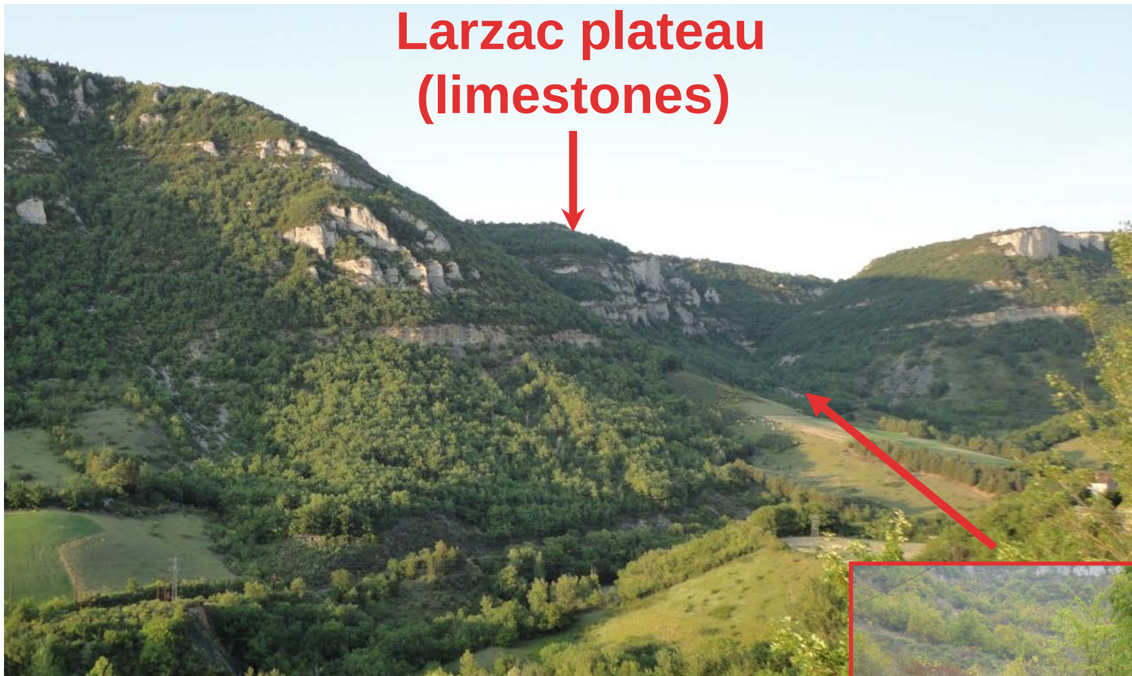
Mol (B)
Boom Clay (soft)

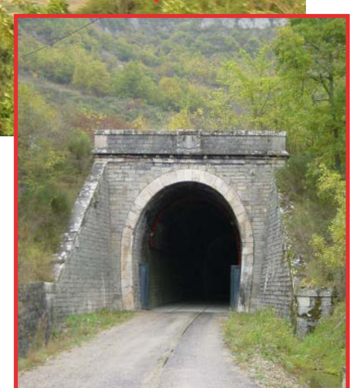
Bure (F)
COx Argillite (indurated)

Mont Terri (CH)
Opalinus Clay (indurated)

Tournemire URL (F)
Toarcian Argillite (indurated)

The Tournemire URL… a general view

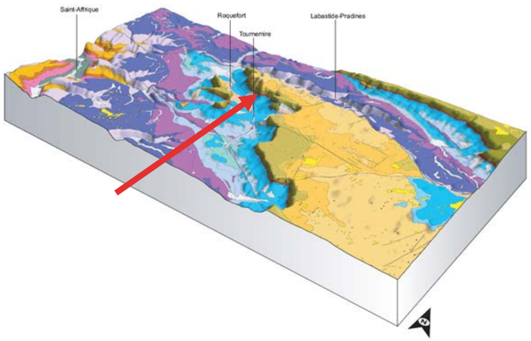




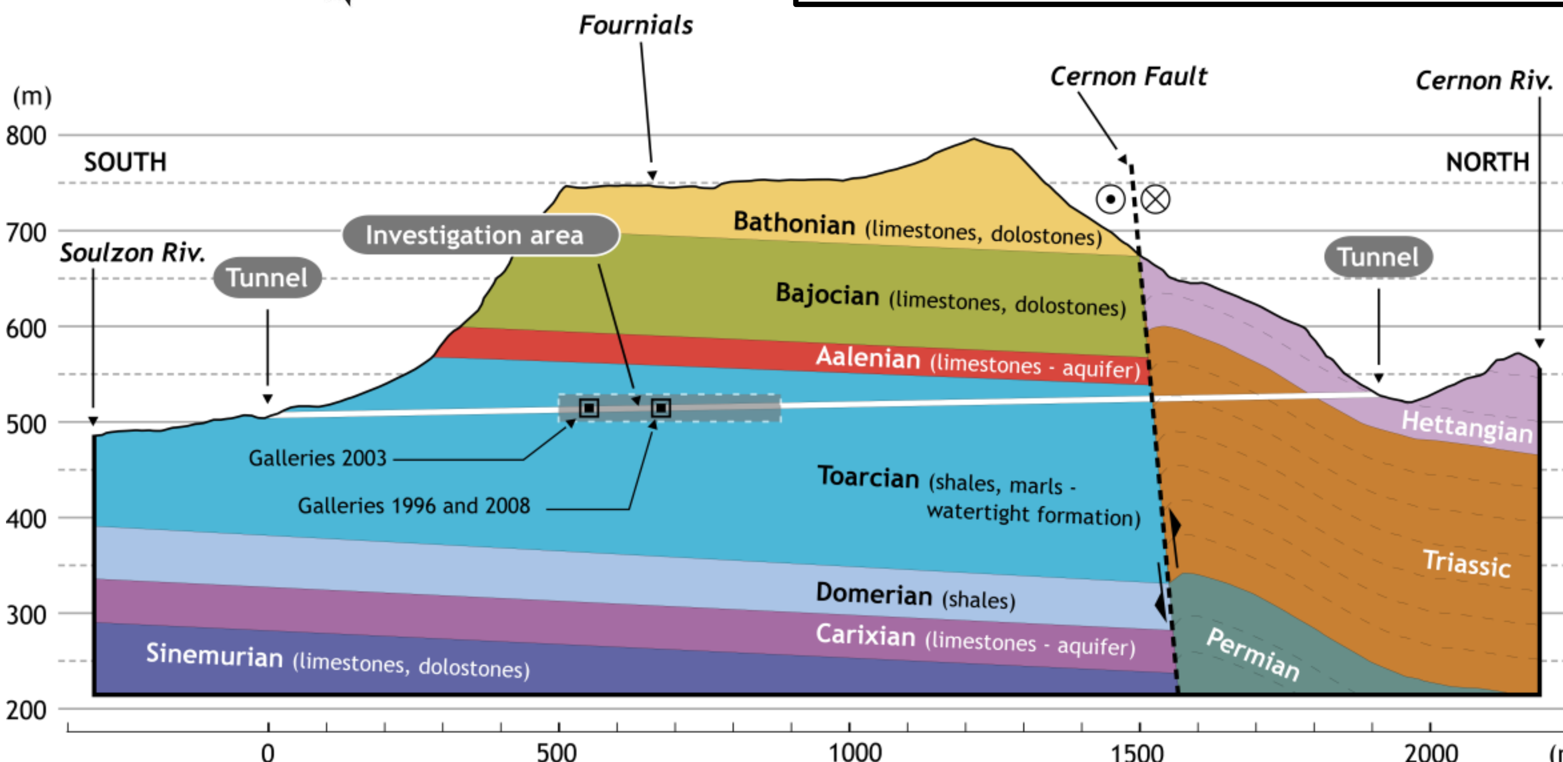
Tunnel
entrance

- 125 years old railway tunnel
- Owned and operated by IRSN since 1992

The Tournemire URL… geological settings

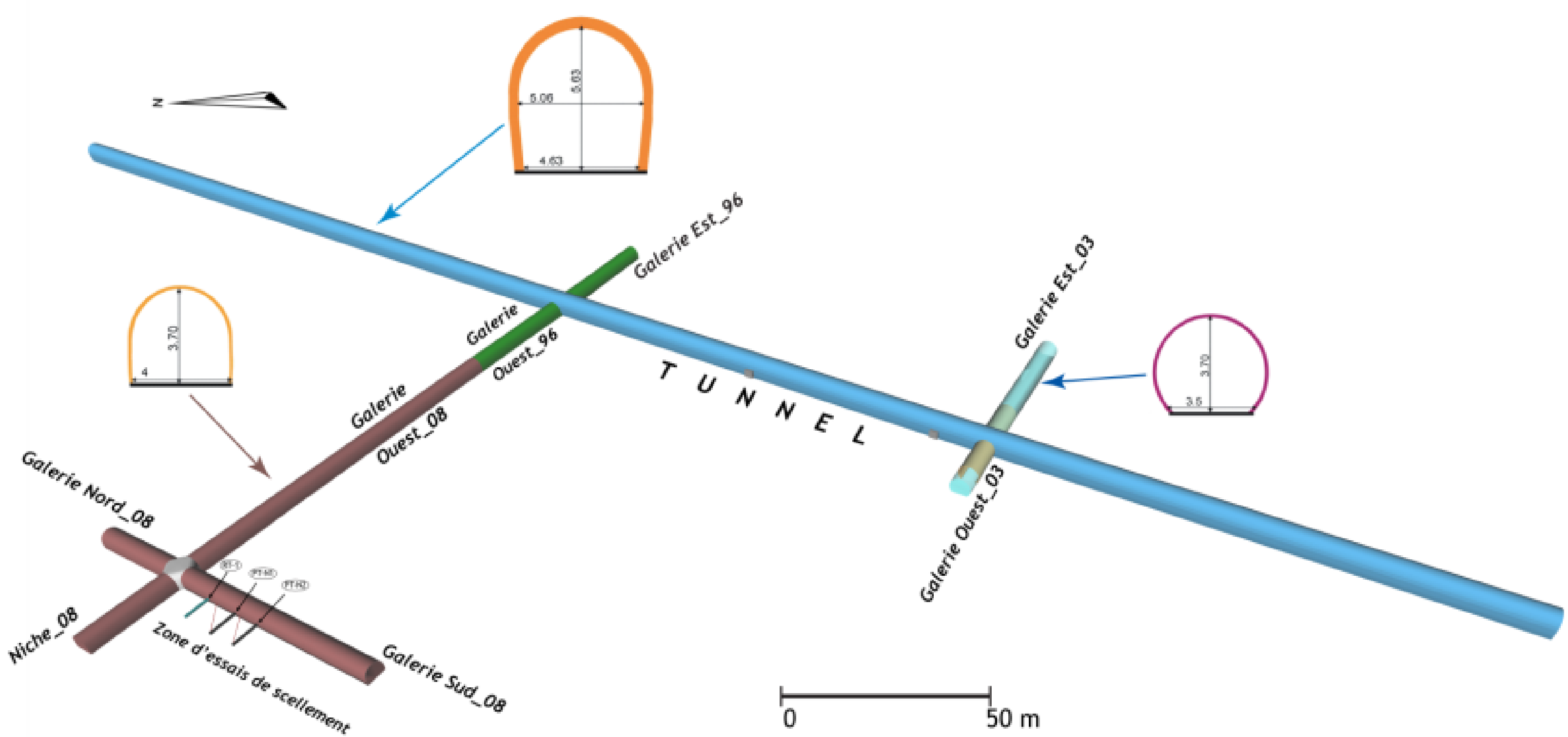


- 250 m deep
- Fully located in an indurated argillite (Toarcian, 180 Ma)
- Overlaid & underlaid by aquifers



The Tournemire URL… a quick tour

- Original tunnel excavated in 1888
- New drifts excavated in 1996, 2003 & 2008
- More than 250 boreholes (cumulated length > 3900 m)
- Used as a scientific tool to support expertise (generic URL)



Overview of the IRSN R&D programme

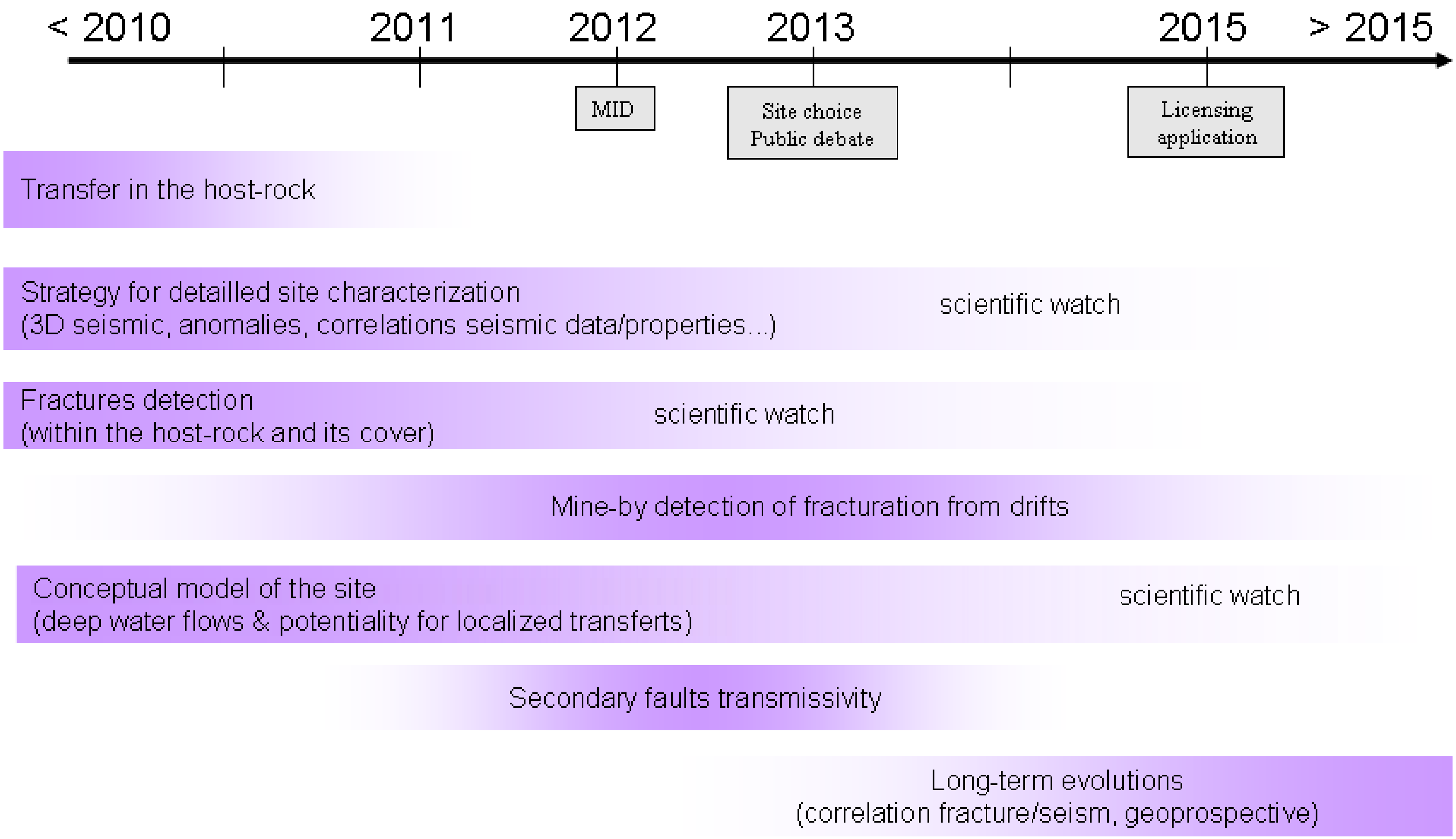
Four types of issues are addressed:

- Adequacy between experimental methods and produced data (validaty range, confidence level)
- Scientific knowledge of complex coupled phenomena & interactions
- Development and use of specific modelling tools
- Identification and confidence in components performances, especially in altered scenarii / required level of performance

… categorized upon four main topics…

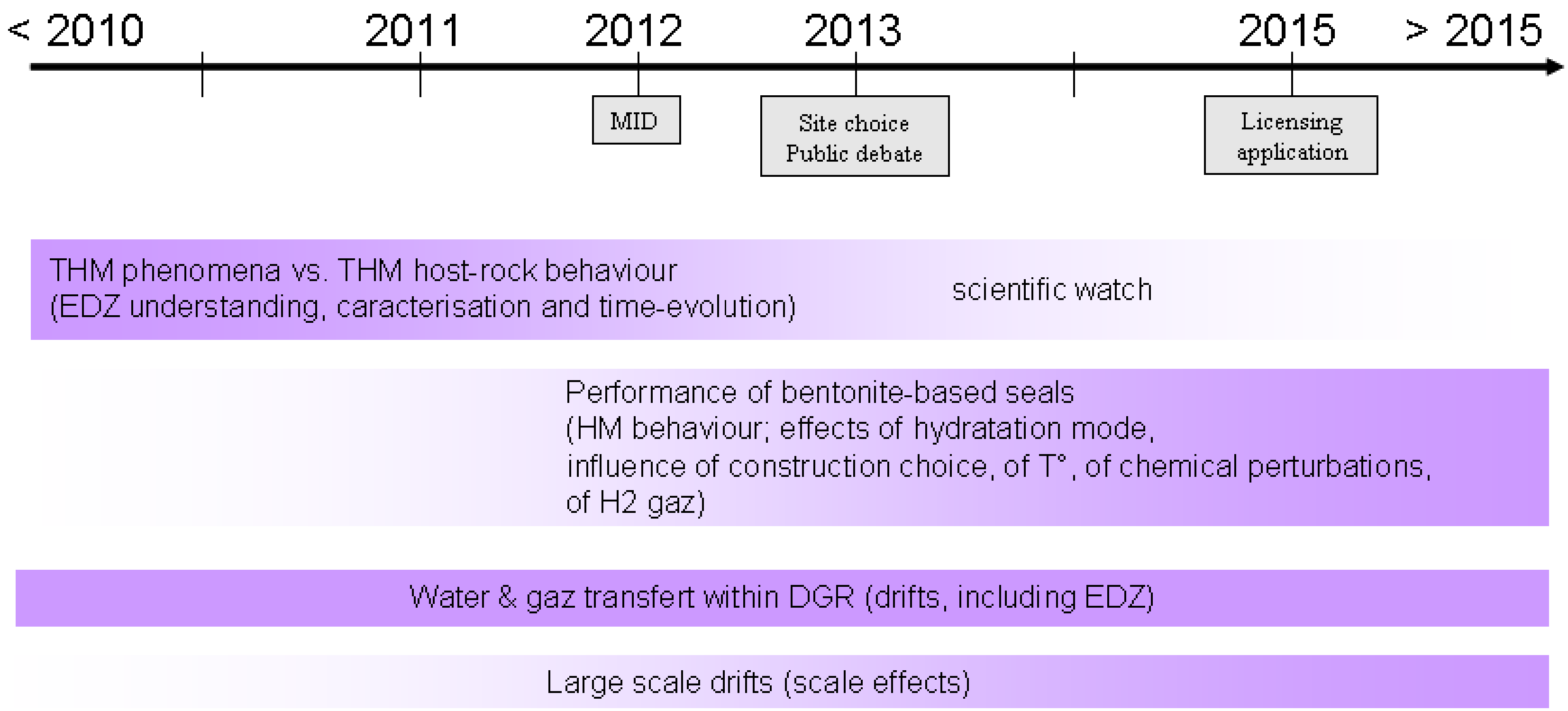
Evolution with time of the research topics

Site characterization & evolution



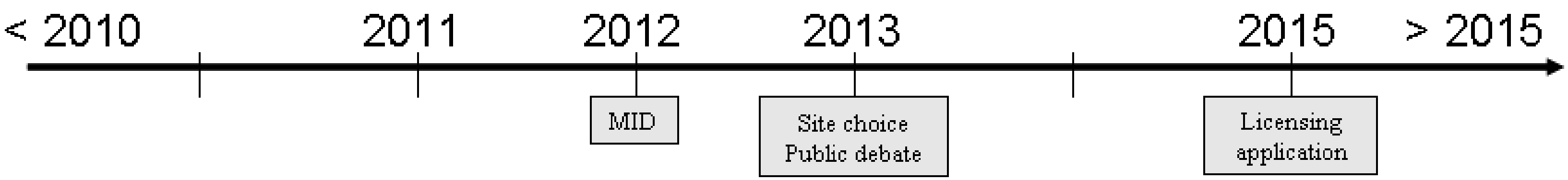
Evolution with time of the research topics

THMC perturbations



Evolution with time of the research topics

Physico-chemical evolution



Characterization of host-rock perturbations at cement/rock interfaces

Characterization of exogeneous materials, their time-evolution and their interactions
(waste containers, concrete, steels, swelling clay)

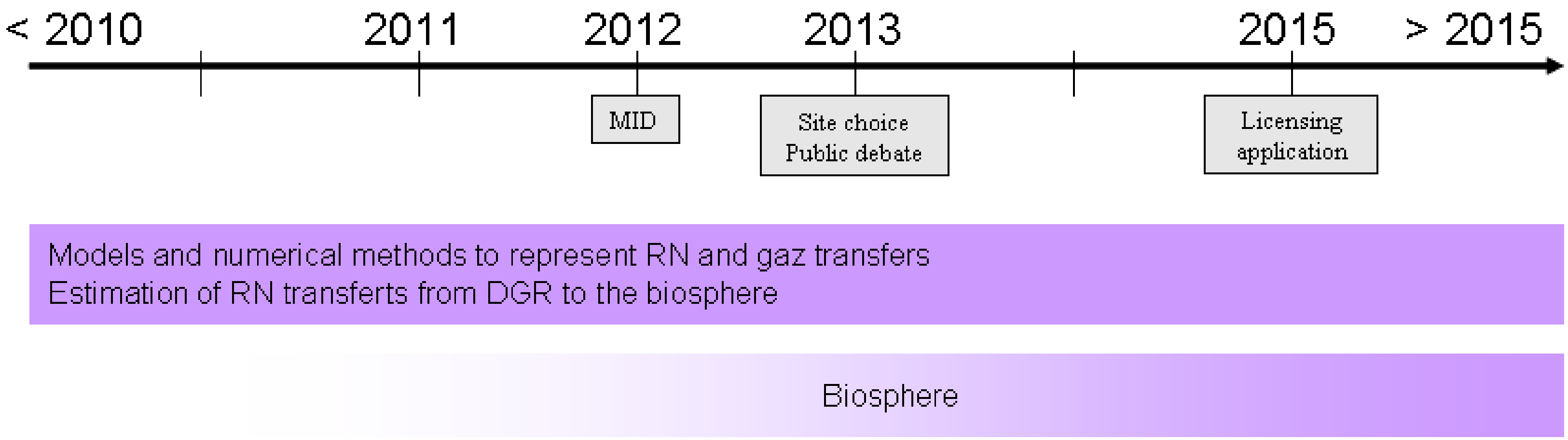
Coupling between chemical perturbations and argilites properties
(oxydizing transient; evolution of transfert and mechanical properties, temperarture effects, micro-organisms effects, H2 effects, radiolysis effects)

Physcial and chemical properties of waste containers

Physico-chemical perturbations and their effects in unsaturated conditions

Evolution with time of the research topics

Global modeling of solutes and gas transfer from the DGR



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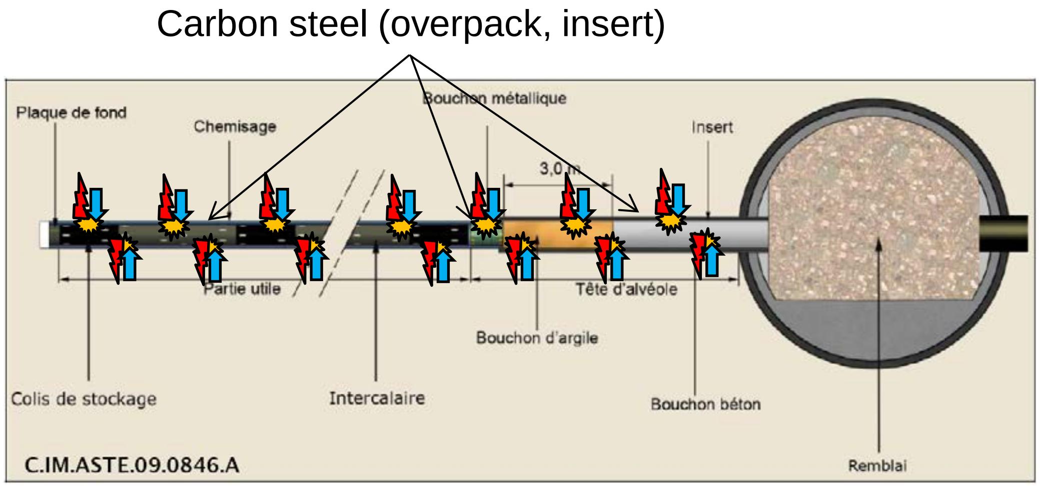
- R&D programme overview
- R&D illustrating examples
  - #1: Oxidizing transient (OXITRAN)
  - #2: Cement temperature experiment (CEMTEX)
  - #3: Sealing performance experiment (SEALEX)
- Some perspectives

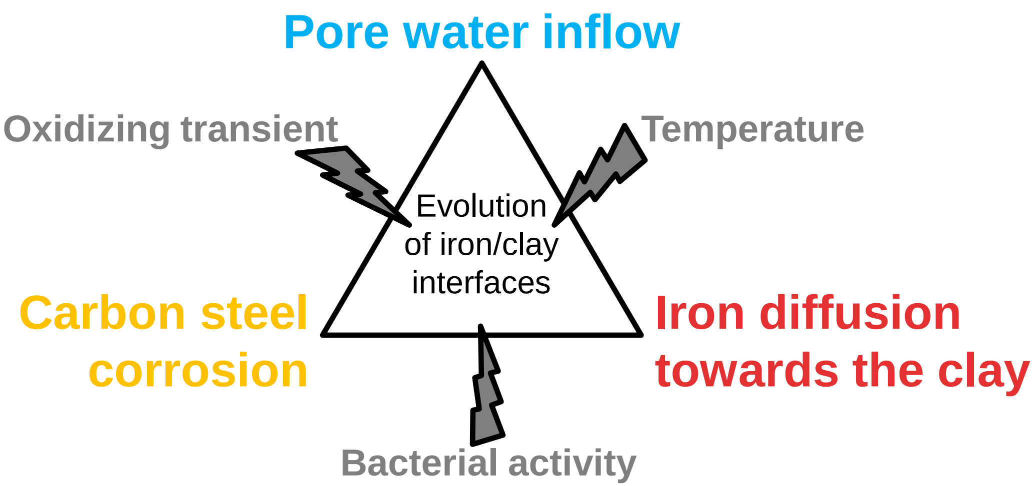


HLW cell after closure (Andra, 2009)

Open issues:

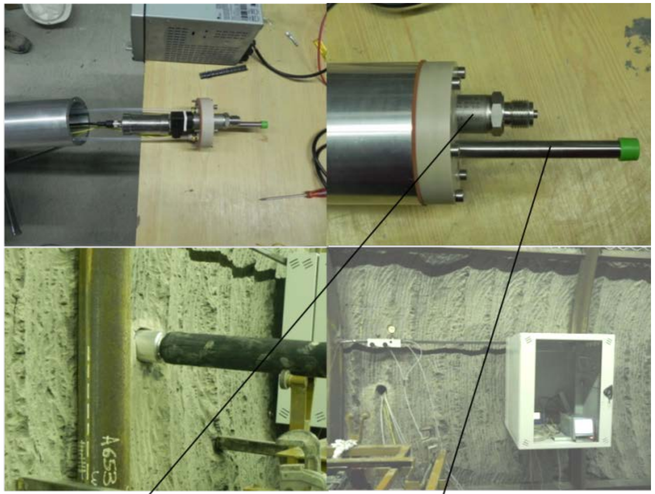
?

- Impact of physical-chemical environments on corrosion rates of carbon steel components?
- Impact of released iron on physical-chemical properties of clayey materials?



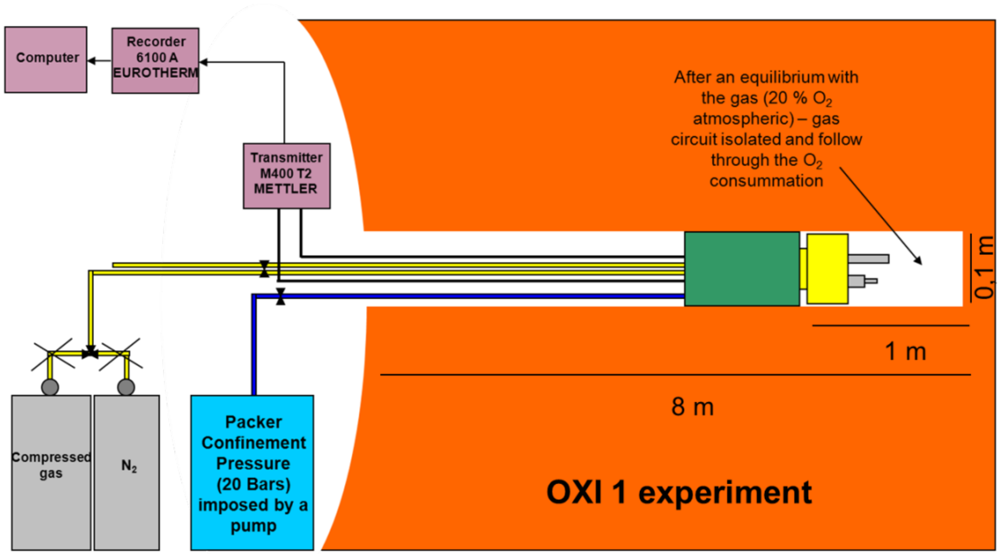
Objectives of the in situ test

- Measure the rate of oxygen consumption upon reaction with:
  - clay host-rock only (pyrite oxidation)
  - both host-rock and carbon steel powder (pyrite and iron oxidation)
- Design & emplacement
  - Stainless steel devices coated with resin
  - Emplaced after drilling under inert atmosphere

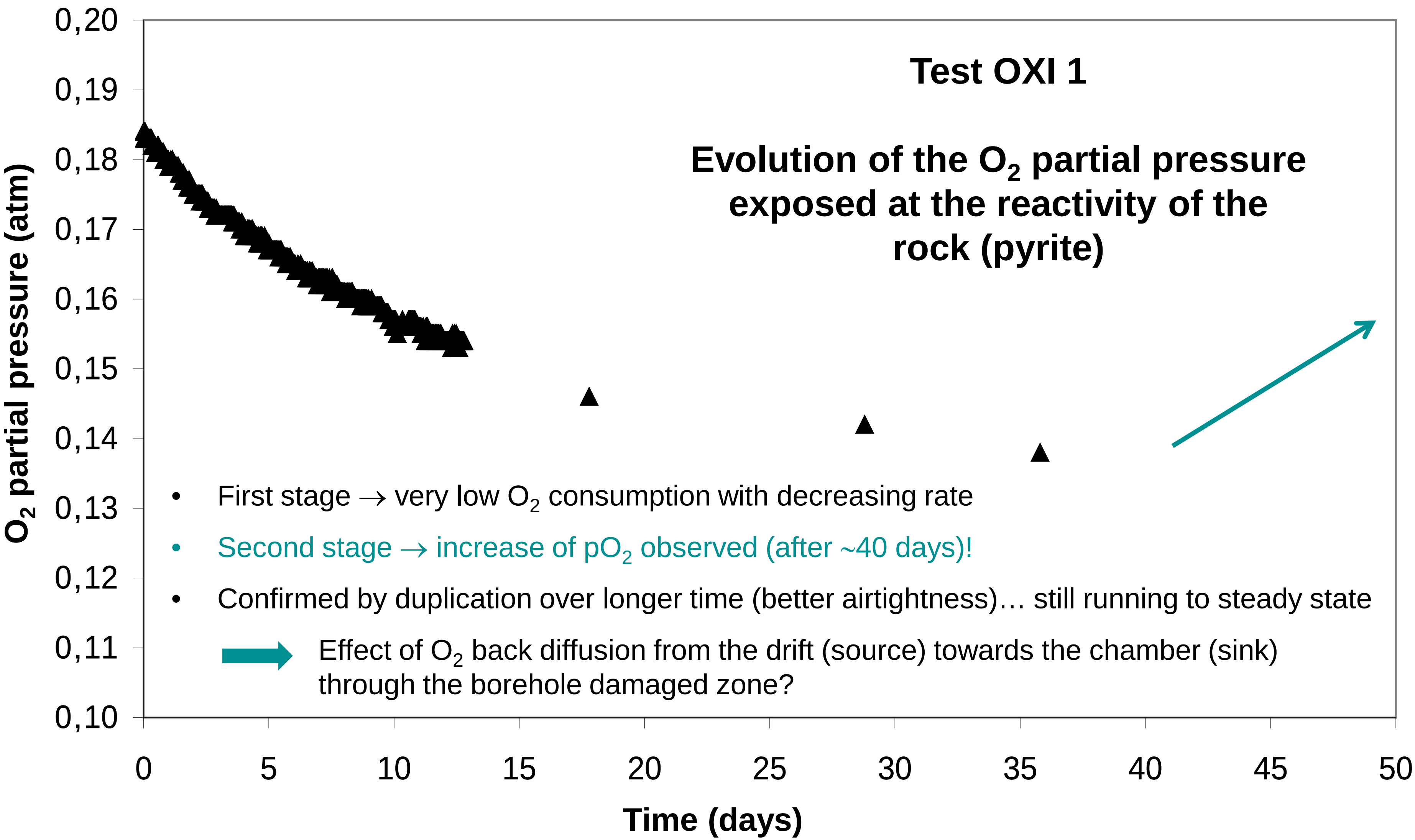


Probe P_{tot} *in situ*

Optical probe *in situ* O_2



Results (preliminary)



- First stage → very low O_2 consumption with decreasing rate
- Second stage → increase of pO_2 observed (after ~40 days)!
- Confirmed by duplication over longer time (better airtightness)… still running to steady state

➡ Effect of O_2 back diffusion from the drift (source) towards the chamber (sink) through the borehole damaged zone?

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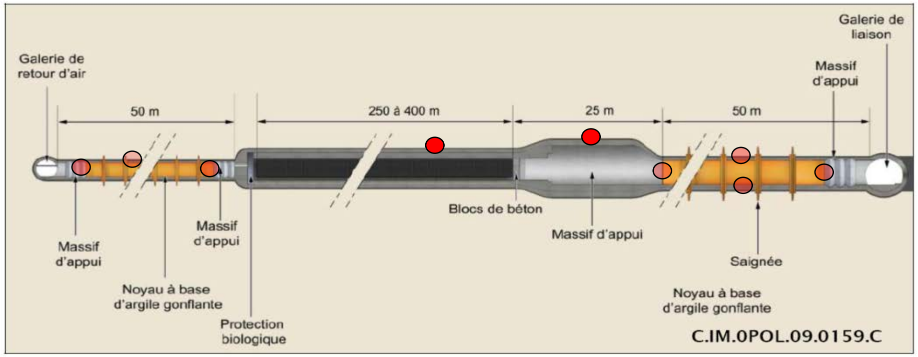
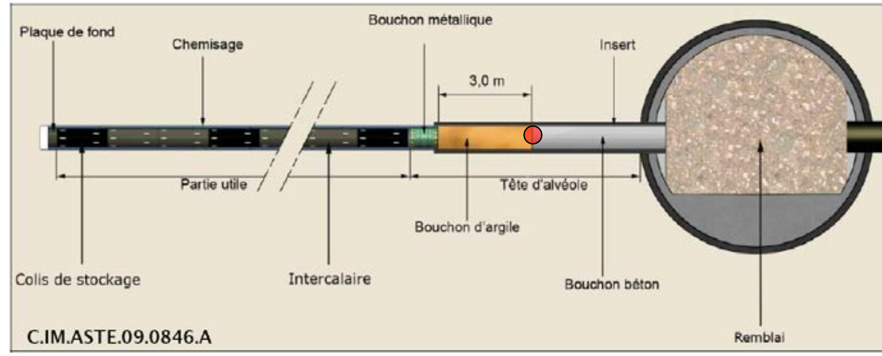
- Concrete-based structures in contact with clayey materials (argillite, bentonite)



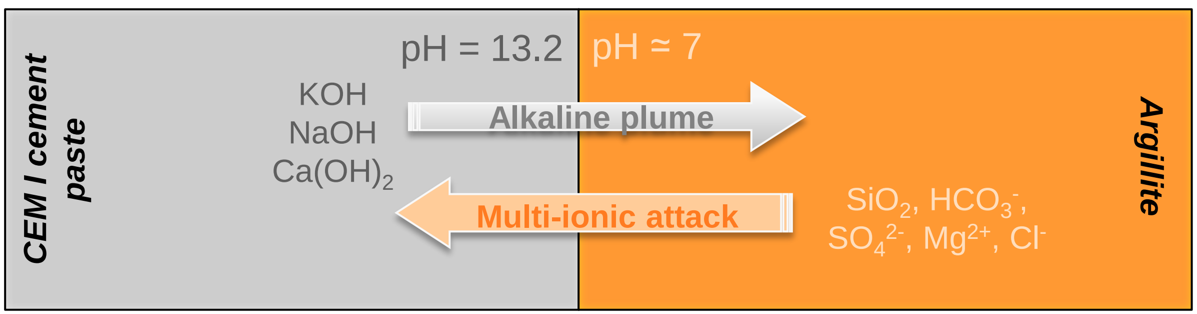
IL-LLW after closure (Andra, 2009)



HLW cell after closure (Andra, 2009)

- Cement vs. clayey materials: 2 materials with highly contrasted chemistry

at 25°C :



- **Open issues:**

?

- ❑ Effectiveness of low-pH cements usage vs. CEM I? Effect of temperature (up to 70°C)?
- ❑ Alteration of the swelling & confining properties of **clayey materials** upon the alkaline plume?
- ❑ Alteration of the chemical & mechanical properties of **concretes** upon multi-ionic attack from the clay pore water?

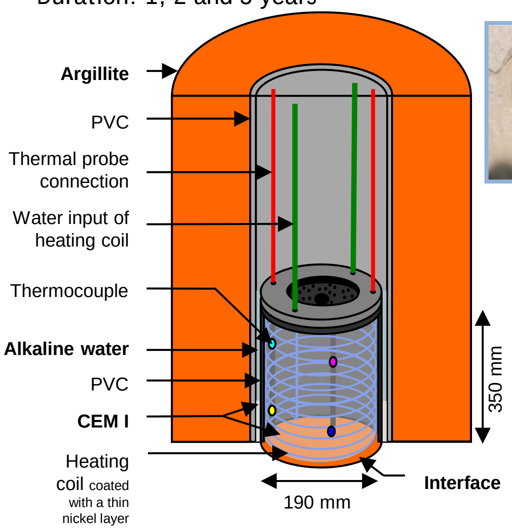
Objectives of the tests

- Evidence cement / argillite interactions under T°:
  – Mineralogical perturbations
  – Effect on transport properties (diffusion)

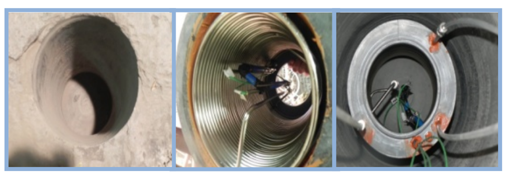
see poster (Lalan et al.)

CEMTEX in situ

- 6 experiments under saturated conditions (3 CEM I and 3 low-pH cement pastes) and prescribed temperature (70°C)
- **In situ casted concrete**
- Duration: 1, 2 and 5 years



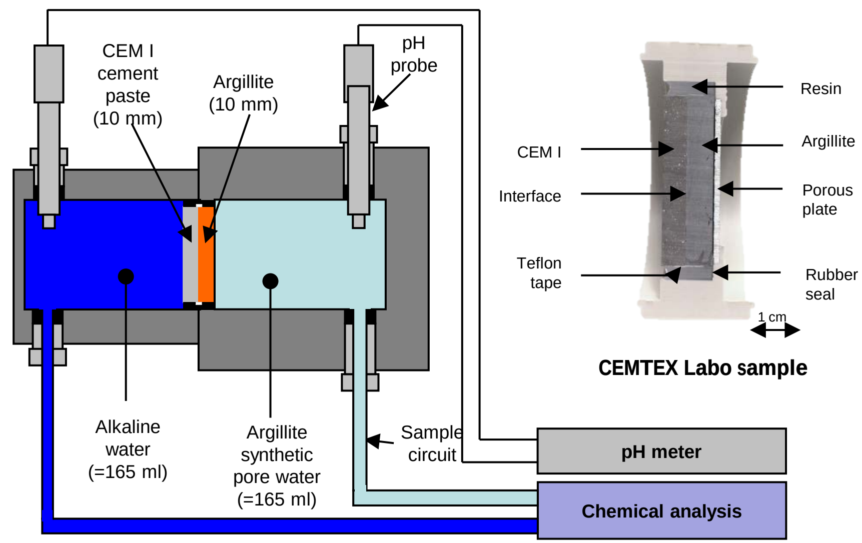
CEMTEX in situ borehole device



Polished borehole in argillite (left)
Heating coil (center)
Device top view (right)

CEMTEX lab

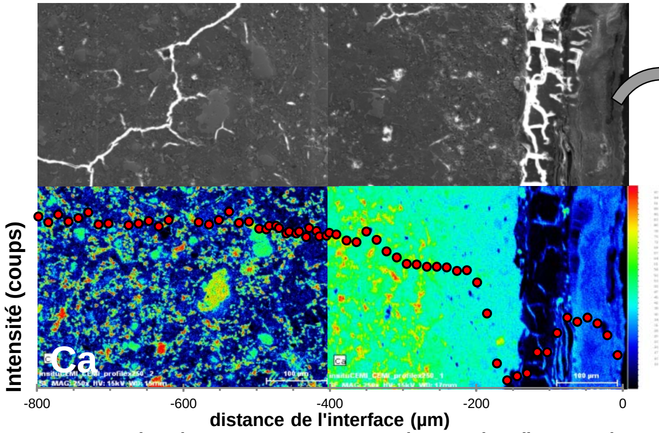
- Dedicated diffusion cells designed to reproduce cement paste/argillite interfaces in saturated conditions
- **Pre-casted concrete**
- Cells emplaced into a thermal chamber to prescribe 70°C

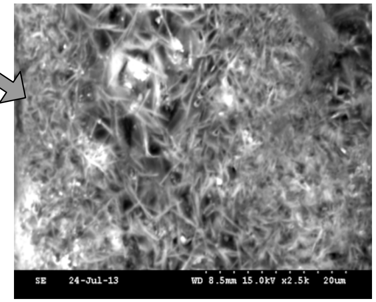


CEMTEX Labo sample

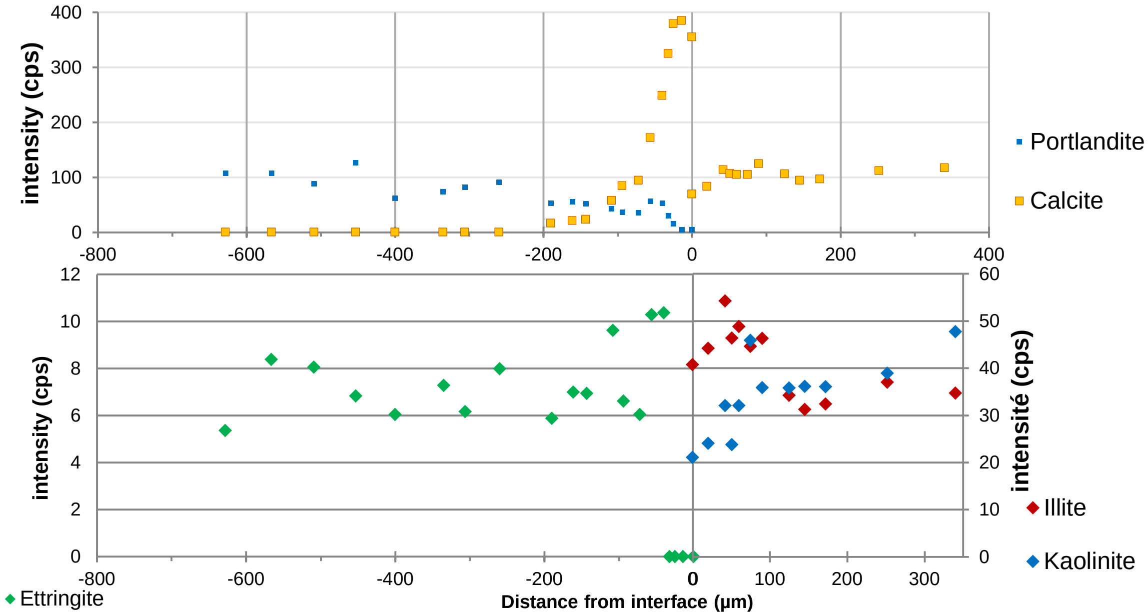
Diffusion cell

CEMTEX in situ: mineralogical perturbations





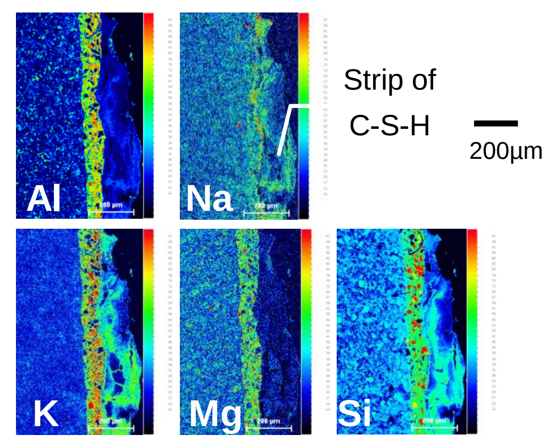
SEM map (top), EDX-Ca map & intensity (bottom), SEM CSH map (right) of the cement side



XRD profiles build from peaks at 4.92Å (portlandite), 3.04Å (calcite), 9.70Å (ettringite), 10Å (illite) and 7,10Å (kaolinite)

Evidence of physical-chemical processes at interface:

- Decalcification of the cement paste
- Carbonation of the cement paste
- Ettringite precipitation in the cement paste
- Possible illitization and CSH precipitation in the argillite
- Precipitation of a CSH strip at the interface (and of a zeolite strip)

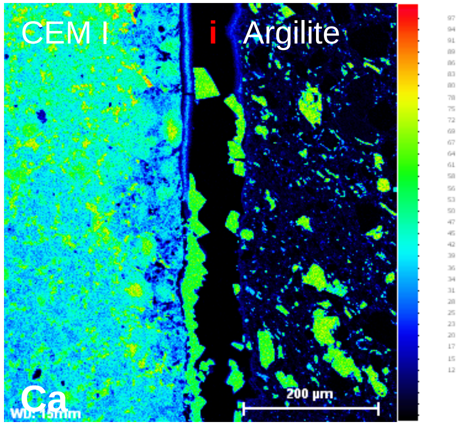


Element maps (SEM-EDX) of the interface on the CEM I side

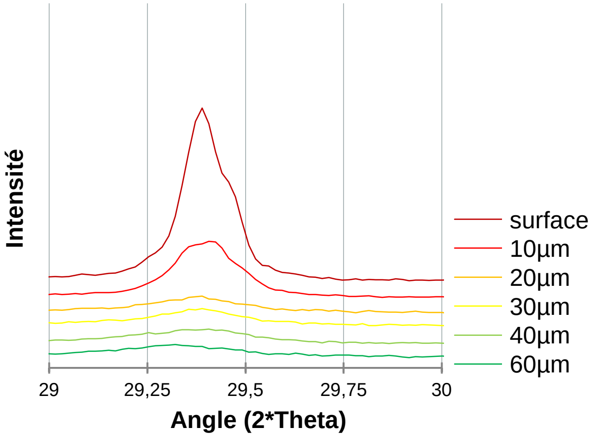
CEMTEX lab: mineralogical perturbations

- Evidences of similar physical-chemical mechanisms:
  - Decalcification
  - Precipitation of ettringite
  - Possible illitization and CSH precipitation in the argillite
  - CSH precipitation at interface

- Though... several differences :
  - Lack of zeolite precipitation
  - Carbonation as a crust at interface



Detail of the Ca map (SEM-EDX)



Main peak of calcite (3.04Å) in the CEM I (XRD)

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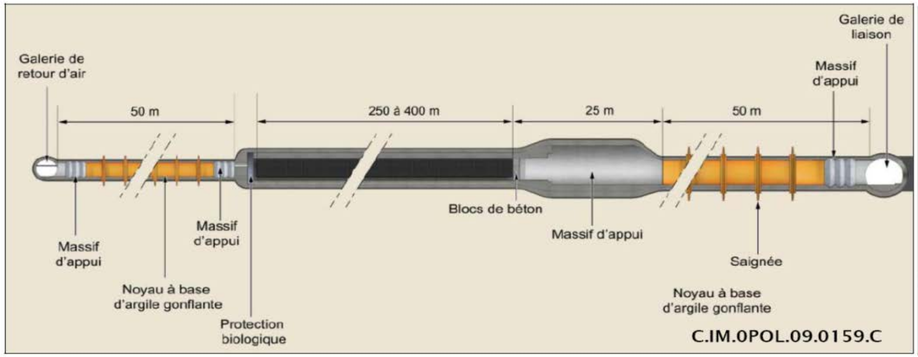
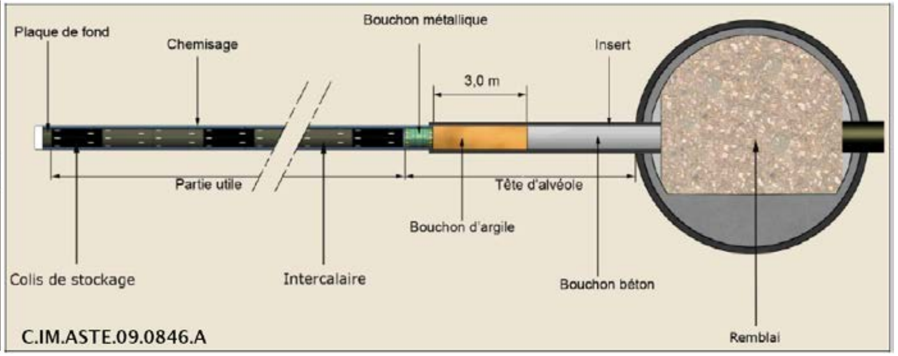
- Numerous seals (bentonite based) foreseen to close the DGR





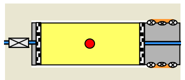
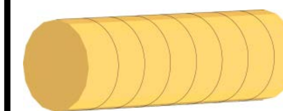
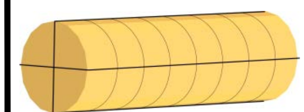
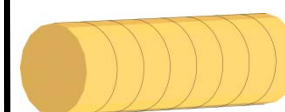
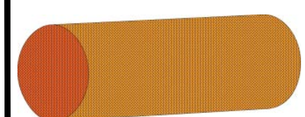
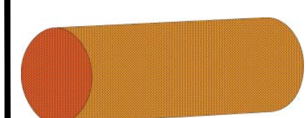
Objectives of the in situ tests

Influence of main parameters with respect to the overall hydraulic performance of swelling clay cores, at long-term:

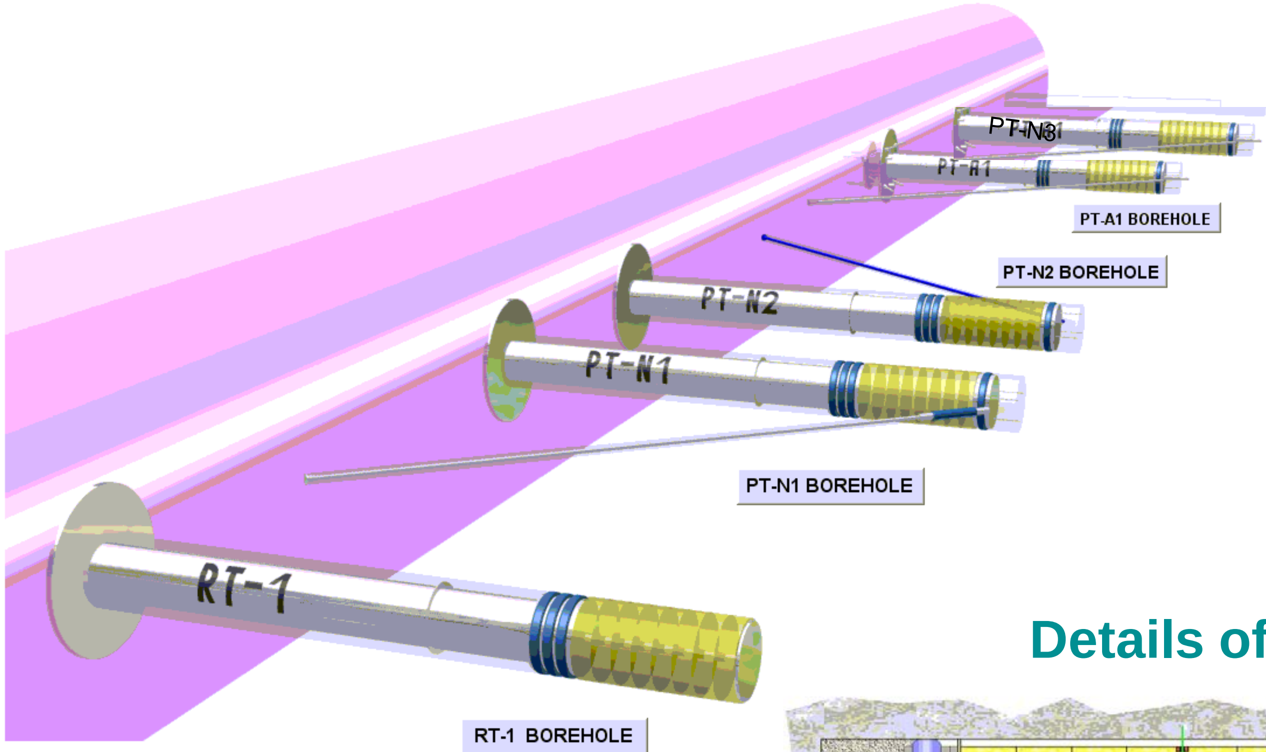
?

- In nominal situations for different core compositions (pure MX80, sand/MX80 mixtures)?
- For different technological choices (impact of intracore geometry, construction joints)?
- In altered situations (loss of mechanical confinement)?

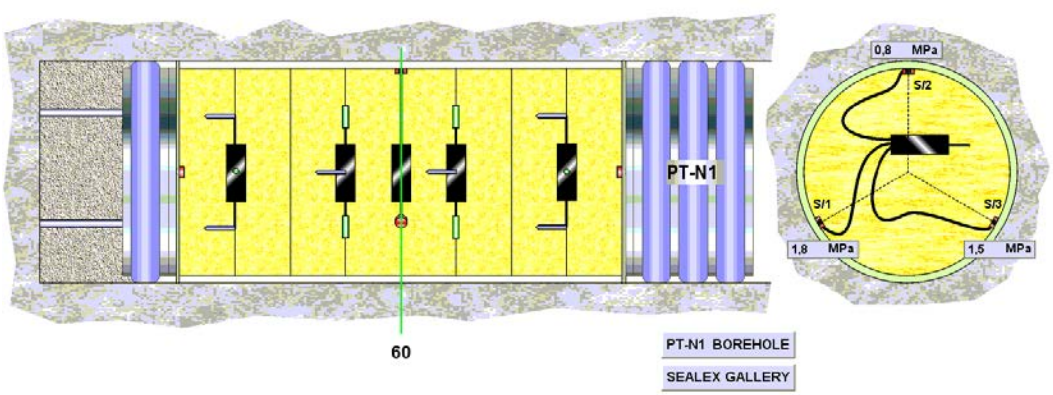
Progressive experimental parametric approach

	Reference Tests	Performance Tests	Intra-core geometry Core conditioning Composition (MX80/sand)	Core view	Altered conditions	Emplacement date
Base case	RT-1	PT-N1	Monolithic disks Precompacted (70/30)		No	12/2010 06/2011
Variations / Base case	-	PT N2	Disks + internal joints (4/4) Precompacted (70/30)		No	12/2011
	-	PT A1	Monolithic disks Precompacted (70/30)		Confinement loss	06/2012
	-	PT-N3	Pellets/powder In situ compacted (100/0)		No	01/2013
	-	PT-N4	Pellets/powder In situ compacted (100/0)		Confinement loss	*10/2013*

View of the SEALEX in-situ tests



Details of PT-N1 test



Installation of RT-1 test

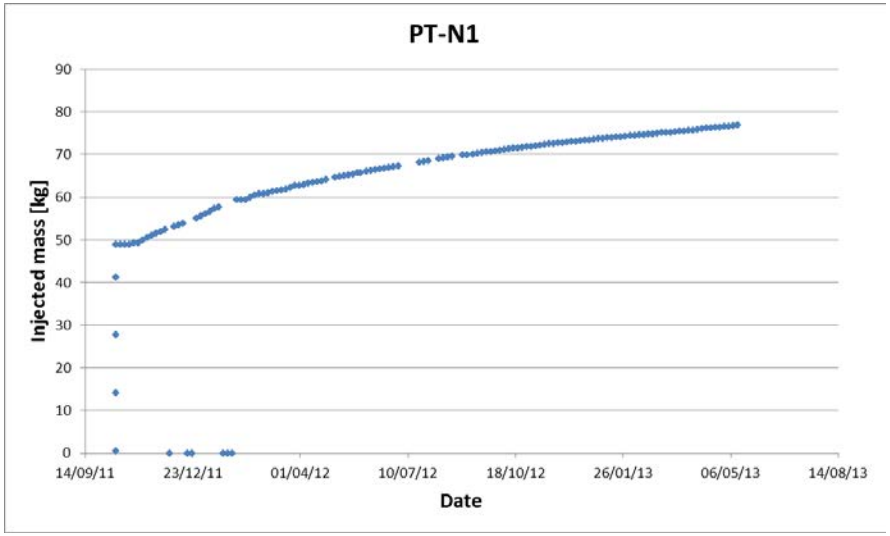
View of of one ring, with installed sensors (total stress, pore pressure, relative humidity)

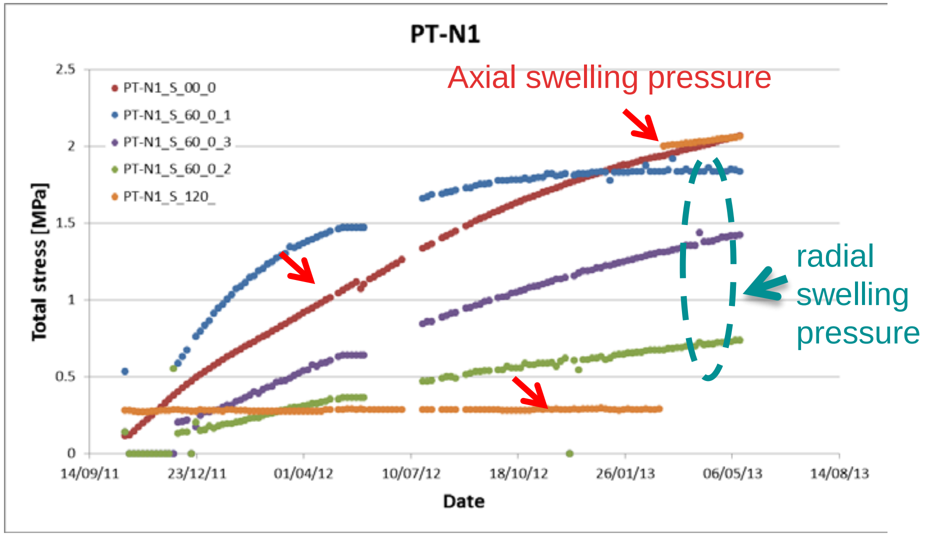
Installation of the downstream lid, with o-rings and hydration surface (geotextile)

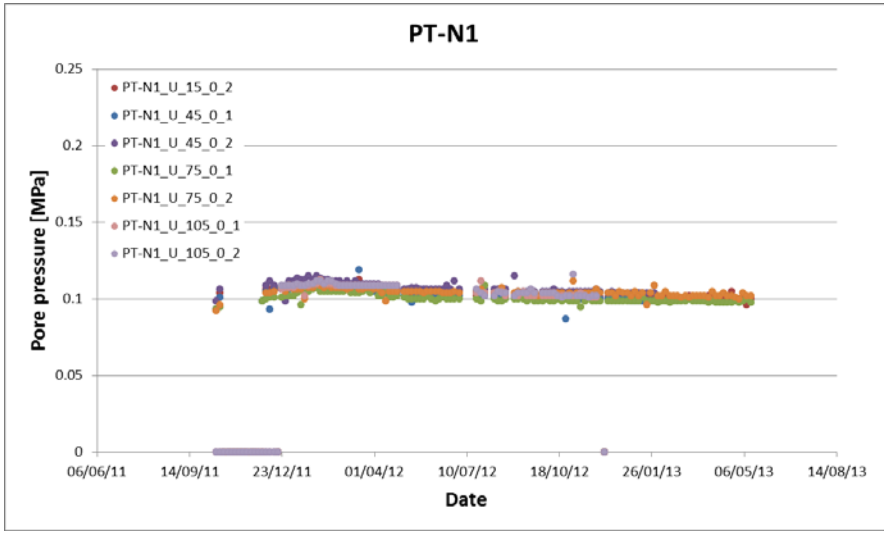
Rotation from vertical to horizontal position

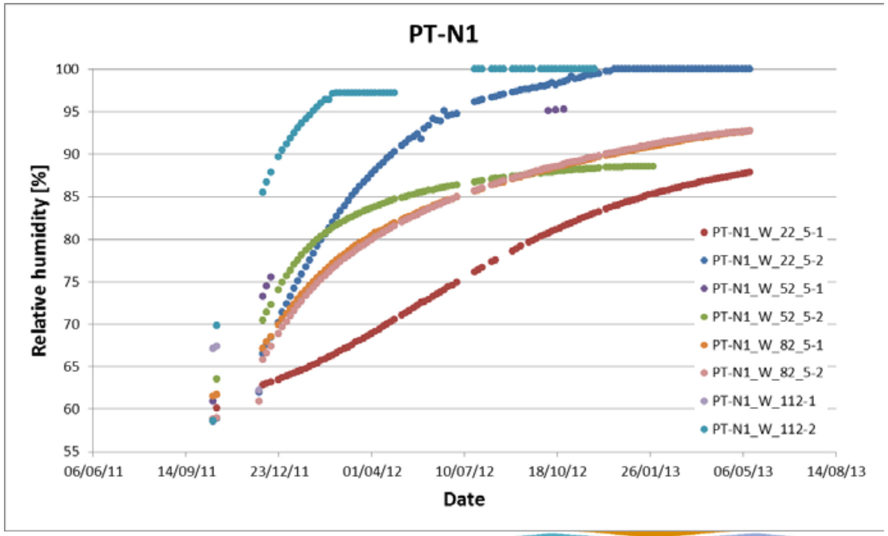
Insertion of full system in the 60cm borehole

Preliminary results of PT-N1 test









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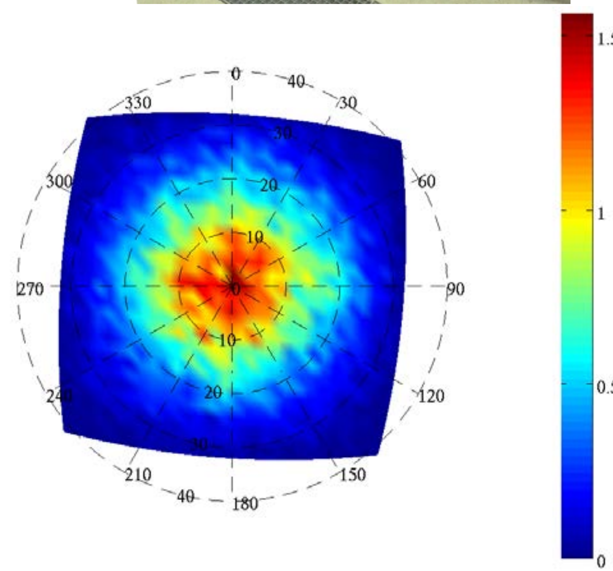
'Exploratory' research (1/2)

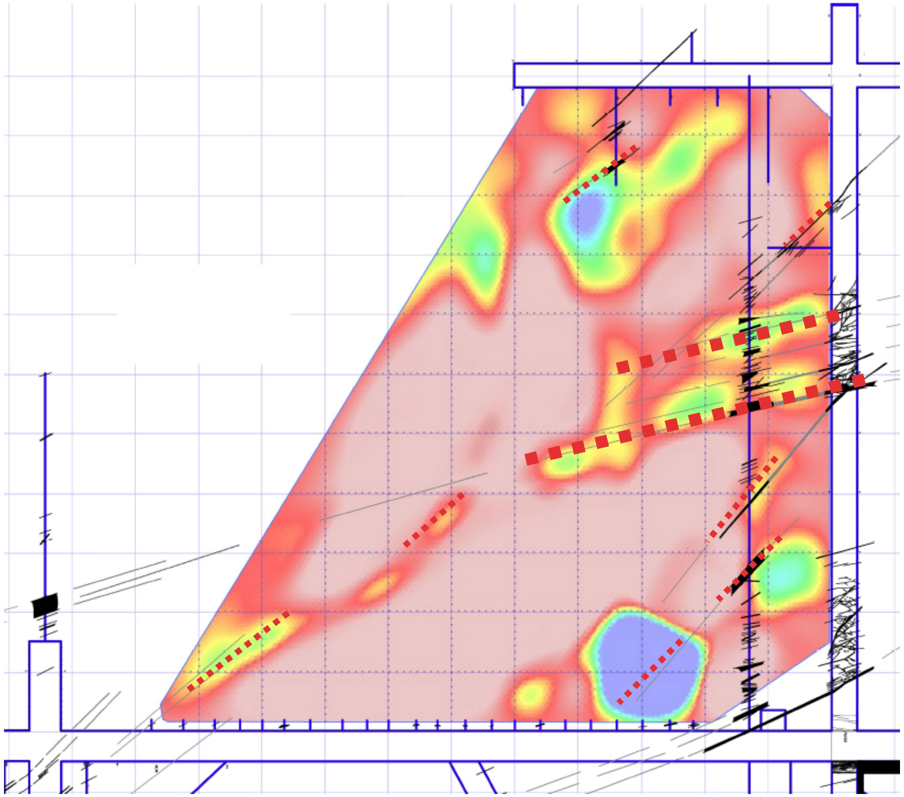
- Bio-corrosion (SRB, IRB & biofilms)
- Behaviour of natural fault upon pore pressure loading
- Monitoring properties (Ss, k) evolution via time series analysis
- Monitoring of density evolution via muons attenuation tomography



'Exploratory' research (2/2)

- Transfer properties across a fault zone
- Seismic tomography between undergoung works

see poster (Cabrera & Gélis)



P-wave velocity map

Last but not least… the acquired data are indeed used to carry out modelling

Thanks for your attention