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CCS EXPERTISE AND ENGINEERING

# Quantitative assessments of $CO_2$ injection risks for onshore large scale $CO_2$ storage

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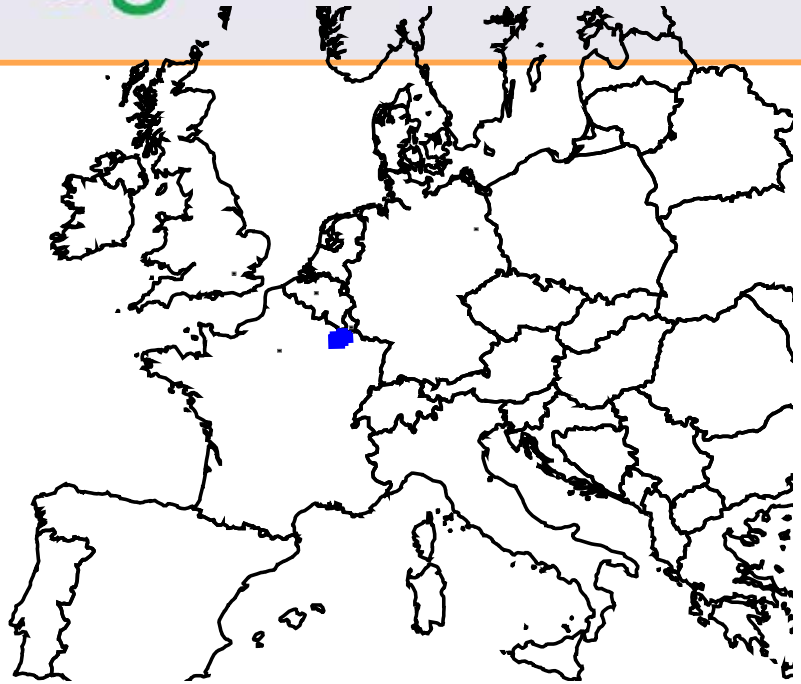
# Outline

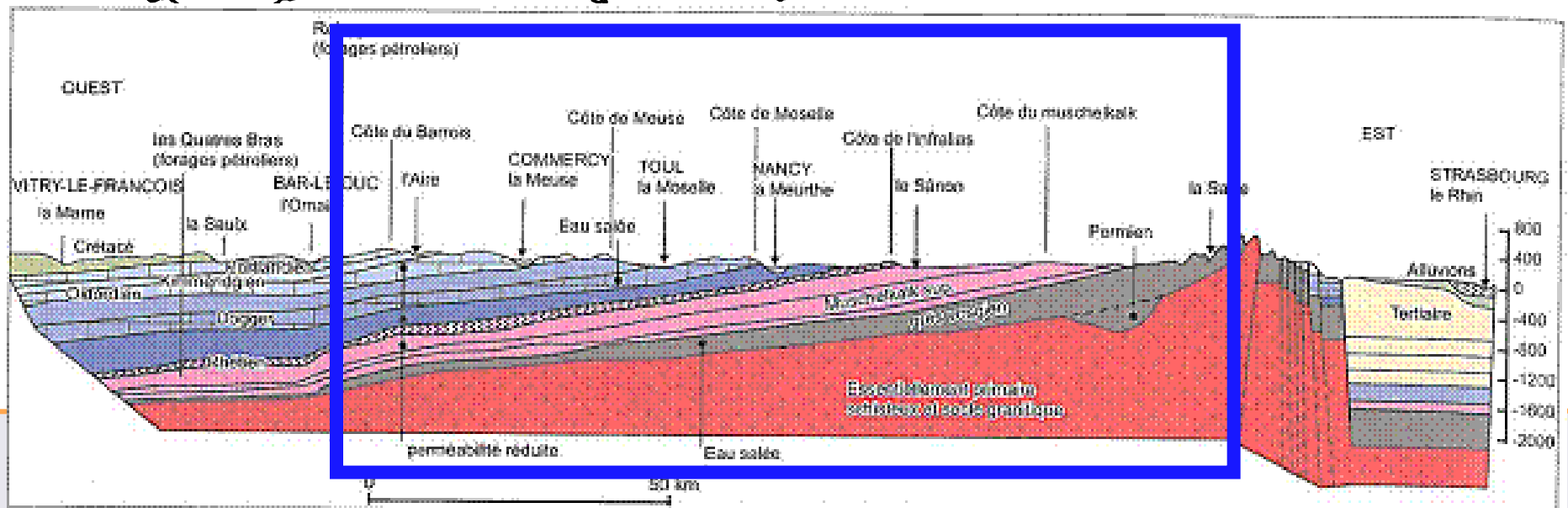
- Concept of the $CO_2$ storage project
- Expected long term $CO_2$ migration (normal behavior)
- Risk assessment methodology :
  - Identifying the Key Events
  - Quantifying the failure scenarios

# $CO_2$ STORAGE PROJECT

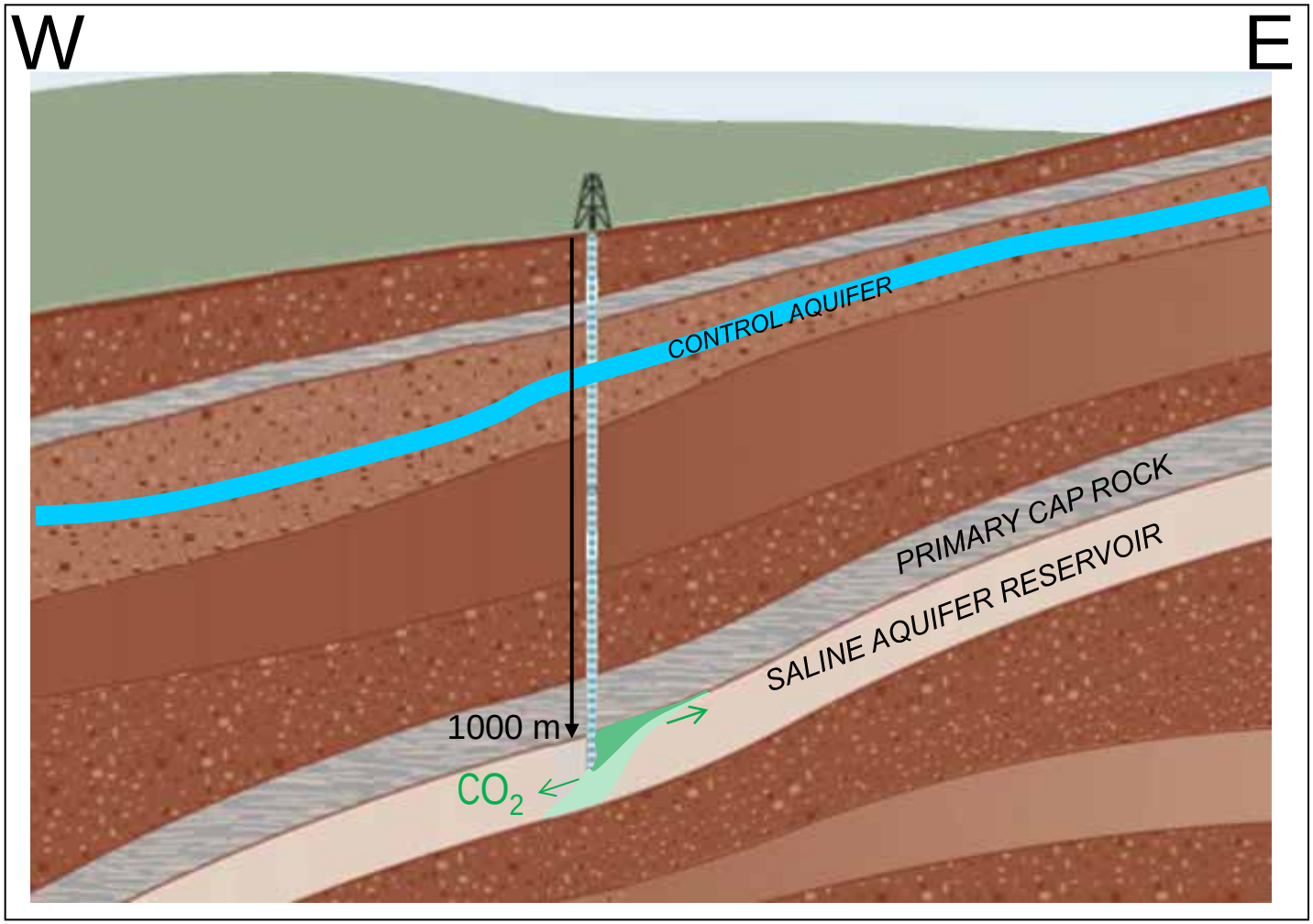
# Looking for the storage



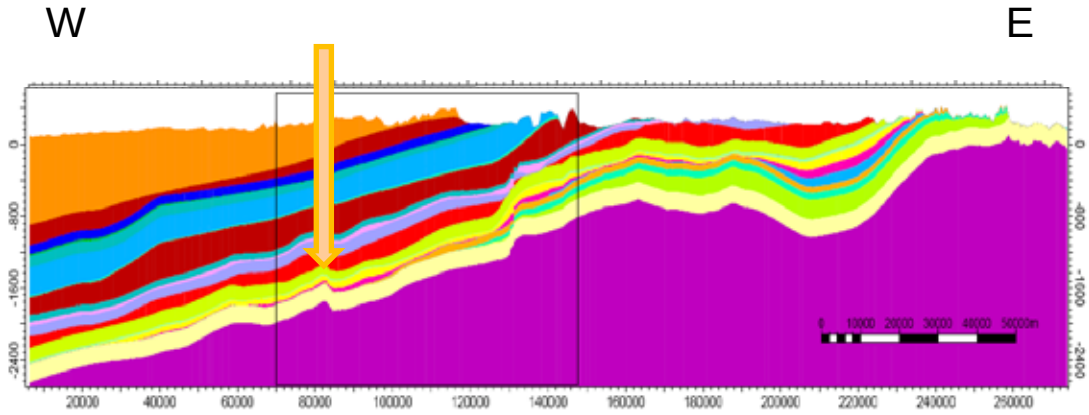
- Exploration license granted by the French authorities in 2011



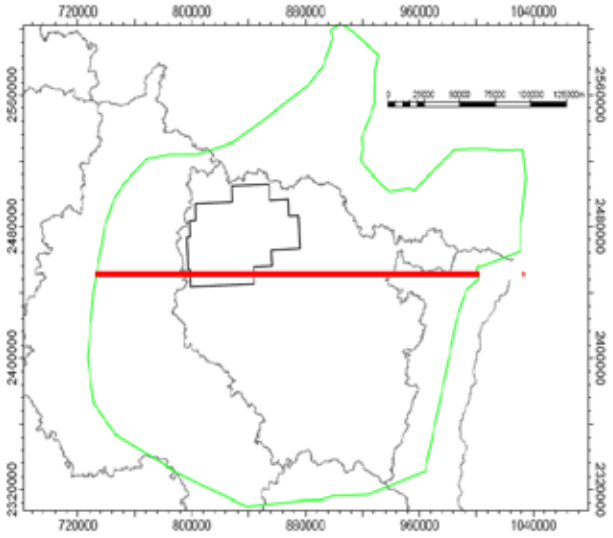
# Storage concept: Migration Assisted Storage



# Geological model



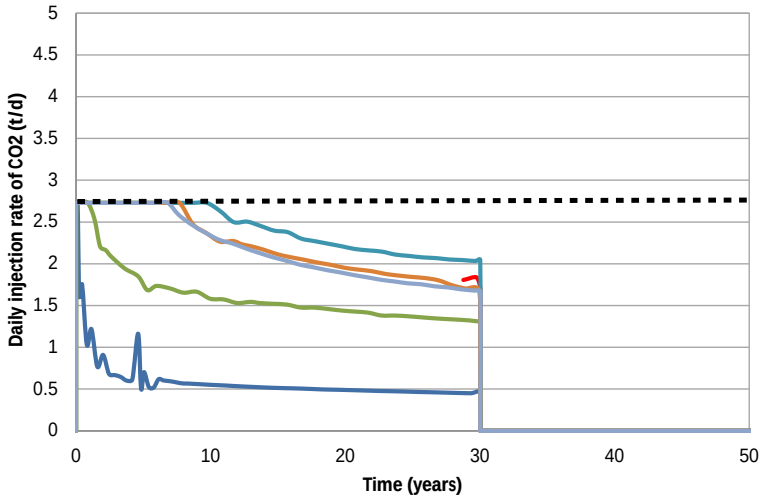


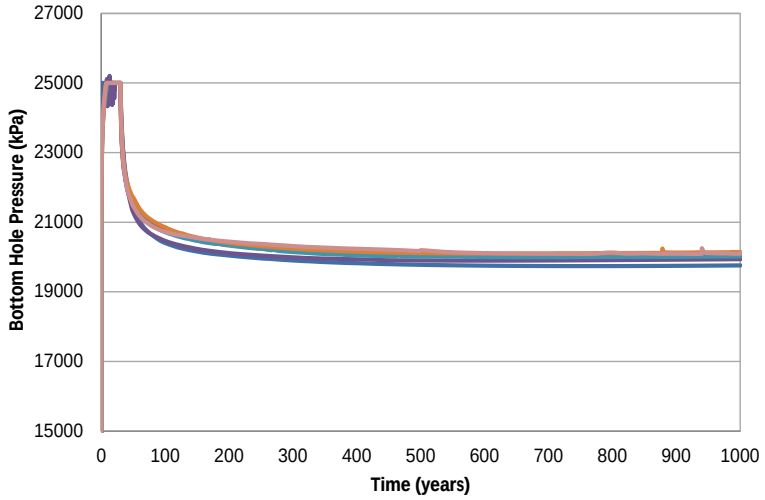


# EXPECTED LONG TERM $CO_2$ MIGRATION

# Modeling conditions

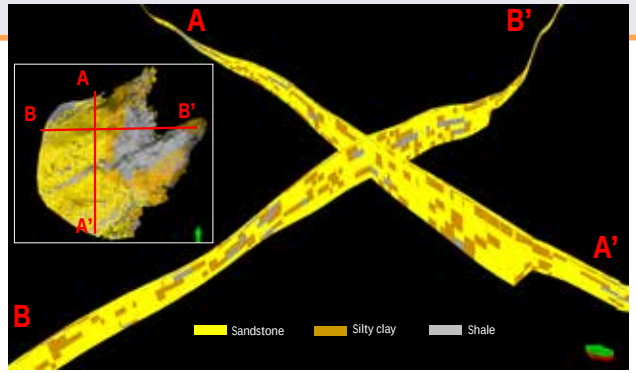
- Influence of petrophysical heterogeneities distribution (seeds) for facies, porosity, permeability on $CO_2$ migration (adjustments of the well trajectory to intersect channels)
- Injection conditions:
  - Max rate: 1 Mt/y during 30 years
  - Max BHP: 25 MPa (initial pressure ~20 MPa)



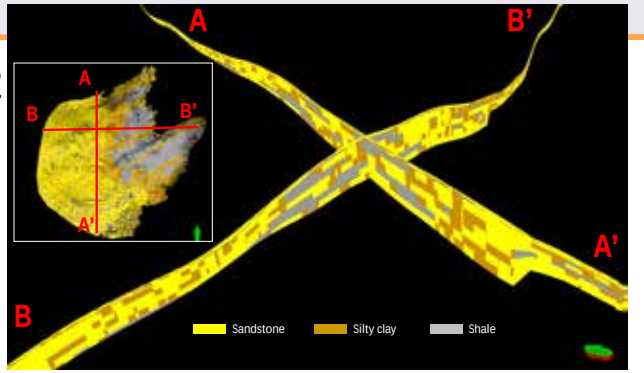



# Facies distributions for different realizations

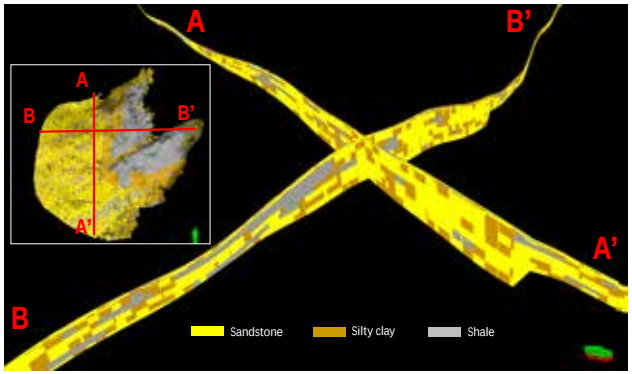
Average injected $CO_2$



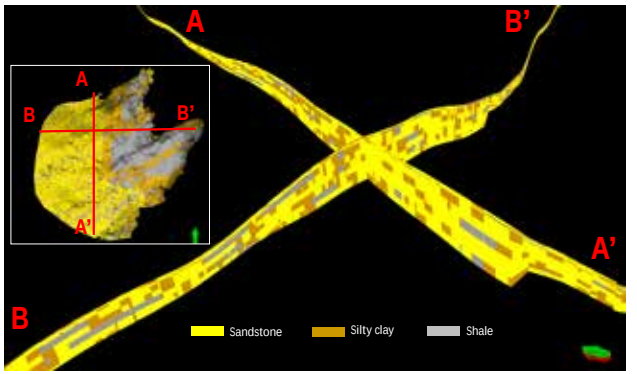

0,76 Mtpa



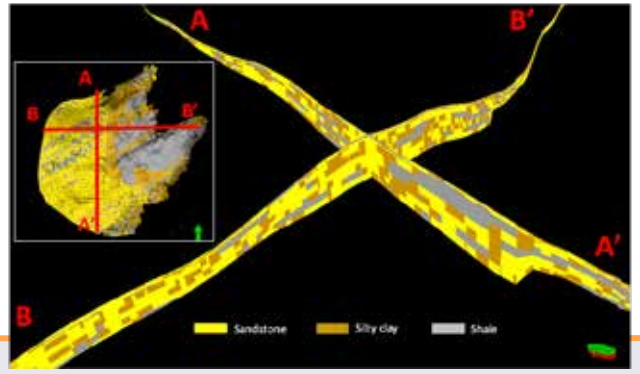

0,74 Mtpa



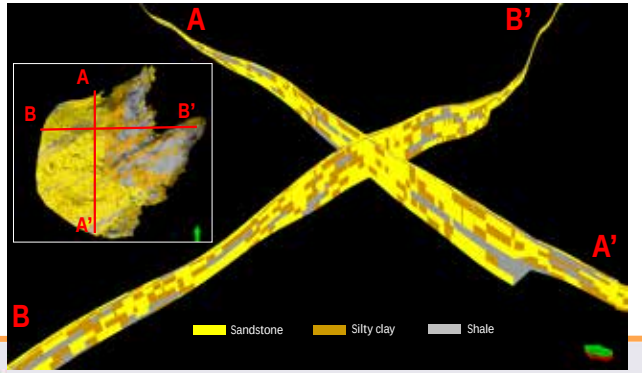

0,21 Mtpa




0,84 Mtpa

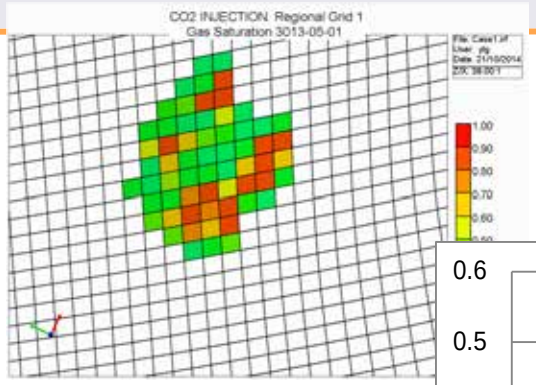



0,58 Mtpa



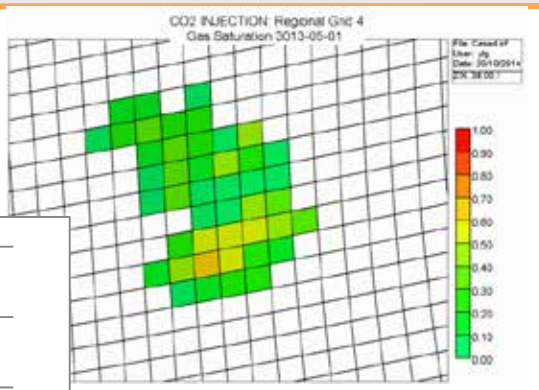

0,88 Mtpa

# $CO_2$ plume at 1000 years for different realizations

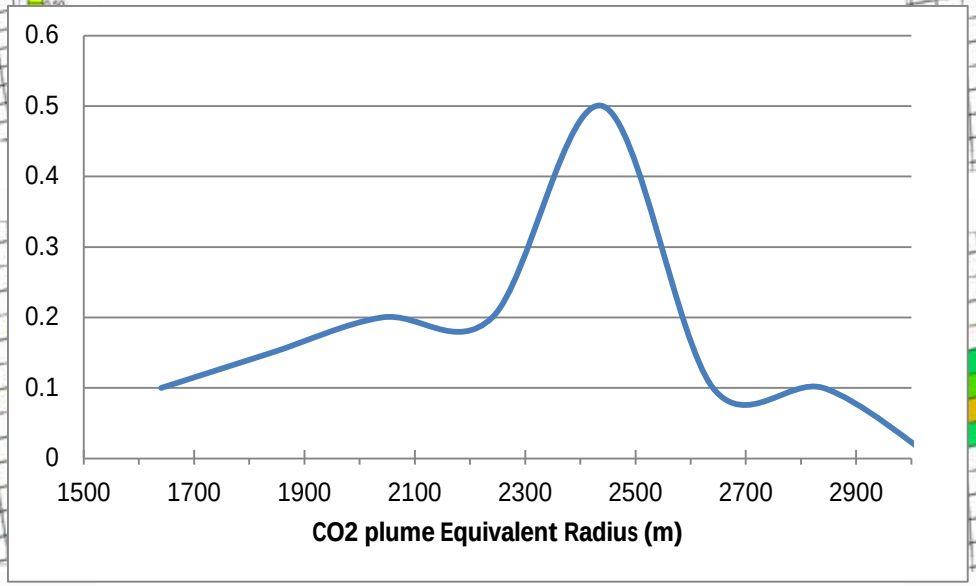


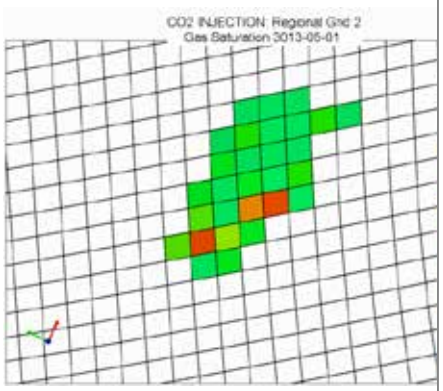

Average injected $CO_2$

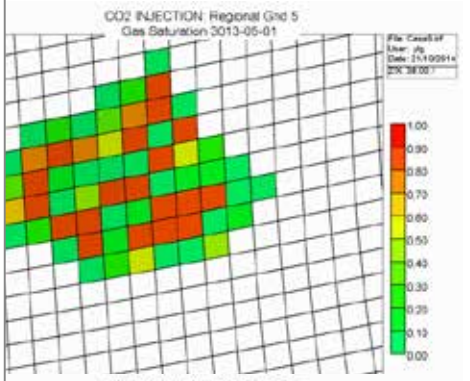
0,76 Mtpa

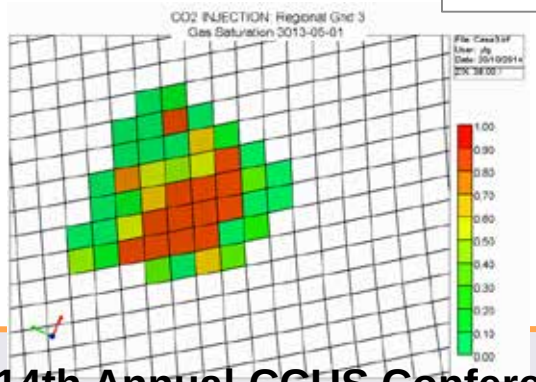



0,74 Mtpa



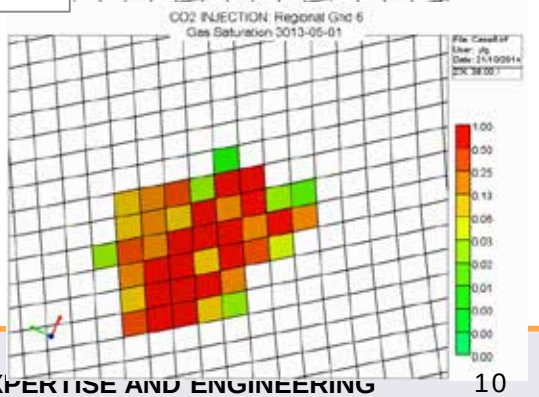




0,58 Mtpa

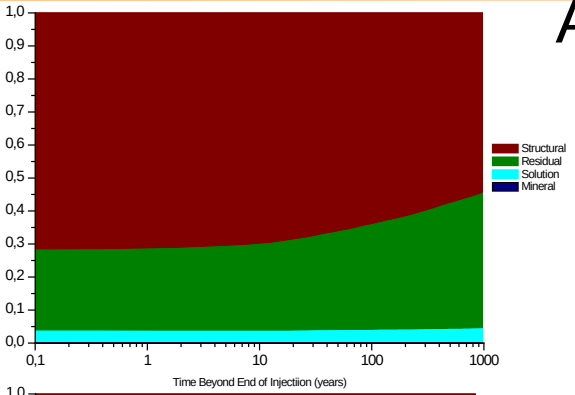
0,88 Mtpa

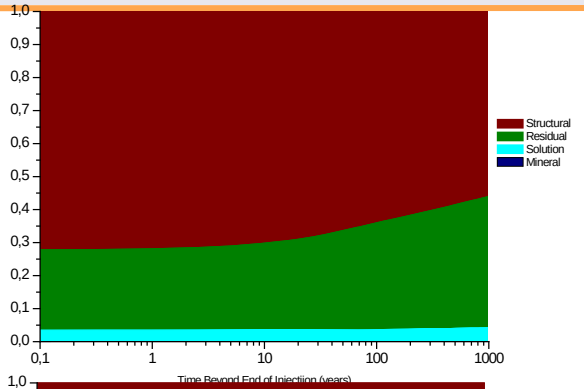


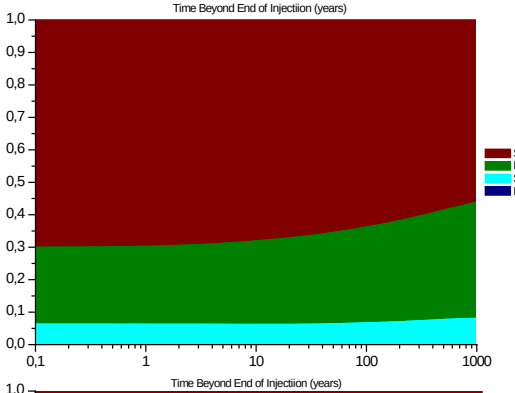
# Trapping mechanisms for different realizations

Average injected $CO_2$

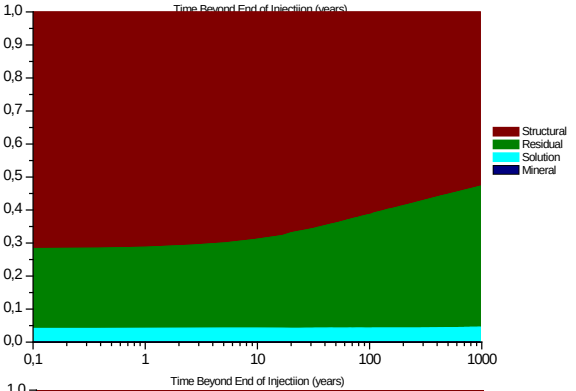
0,76 Mtpa 0,74 Mtpa

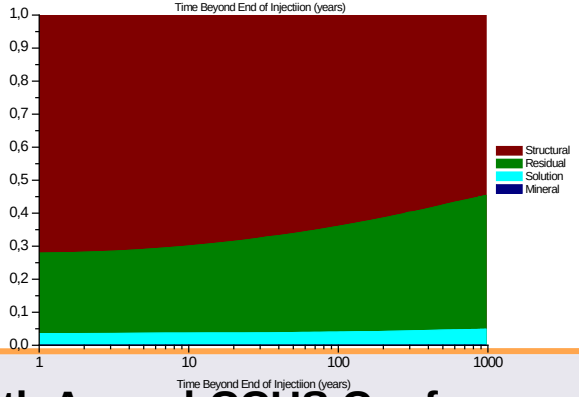


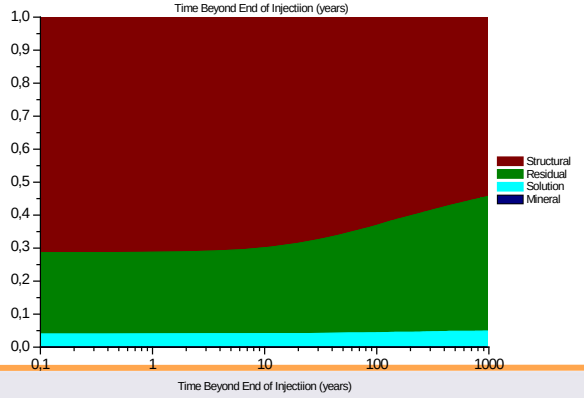




0,21 Mtpa 0,84 Mtpa




0,58 Mtpa 0,88 Mtpa



# QUANTITATIVE RISK ASSESSMENT

# Quantitative Risk Assessment

- Applying a rigourous risk assessment methodology based upon a functional analysis of the storage project

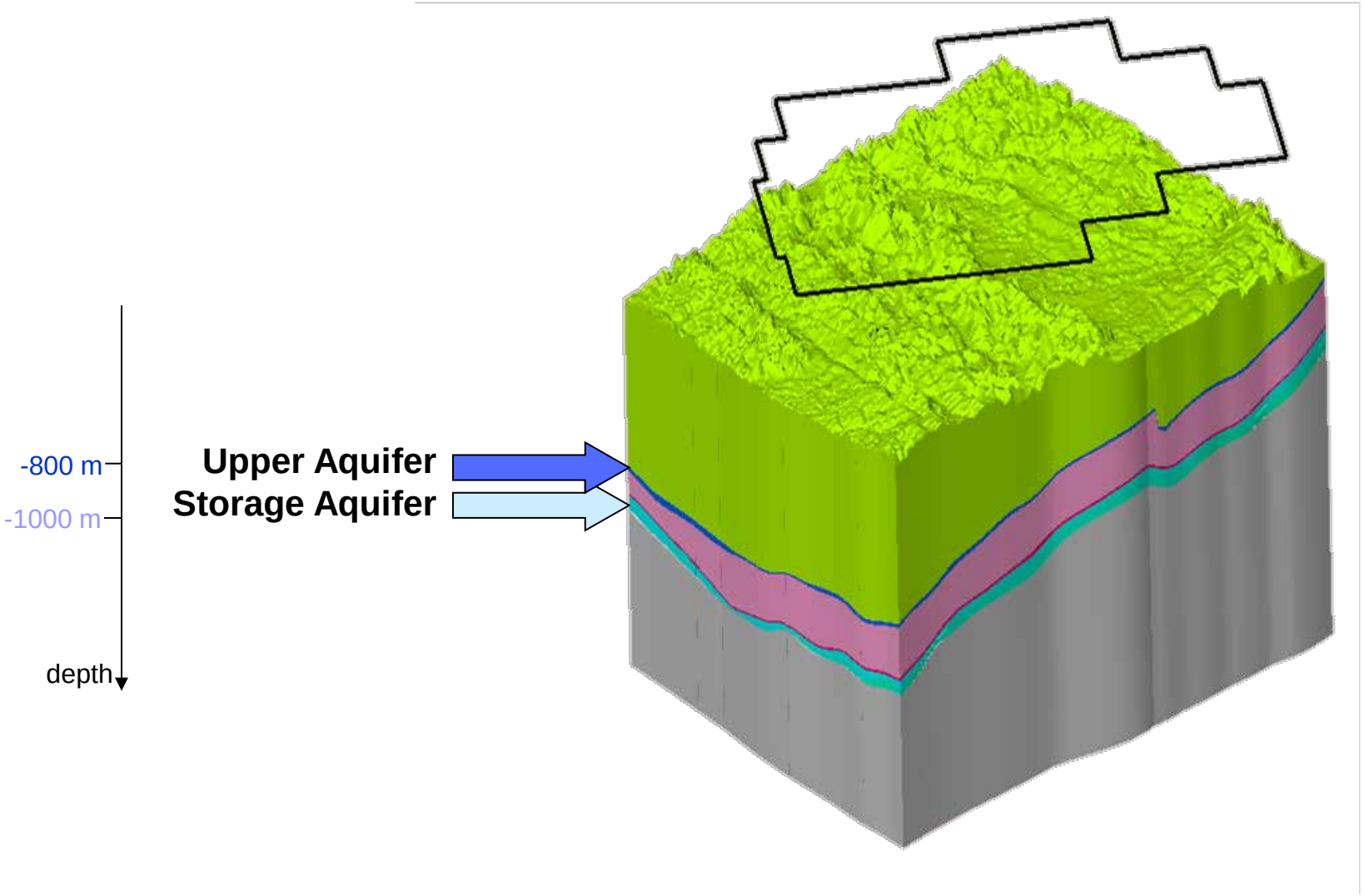
**CAUSES** ⟹ **KEY EVENTS** ⟹ **CONSEQUENCES** ⟹ **TARGETS**

- Plume extension
  - Average equivalent radius ~ 2.45km
  - Maximun extension < 5km
- Key events identified:
  - Fault migration
  - Mechanical impact

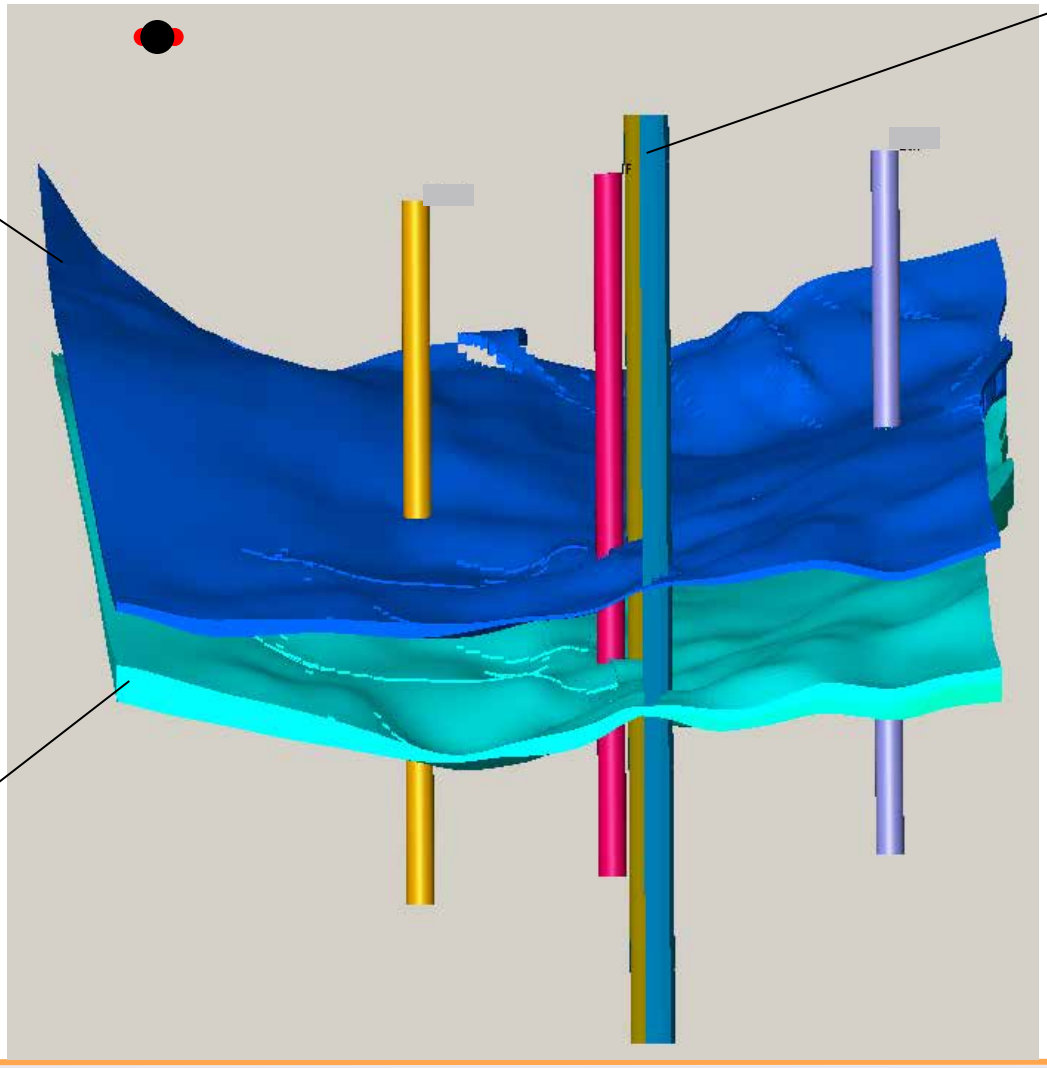
# Modeling Failure Scenarios

## Quantifying the migration along or through a fault

# Geological Model



# Migration along a fault



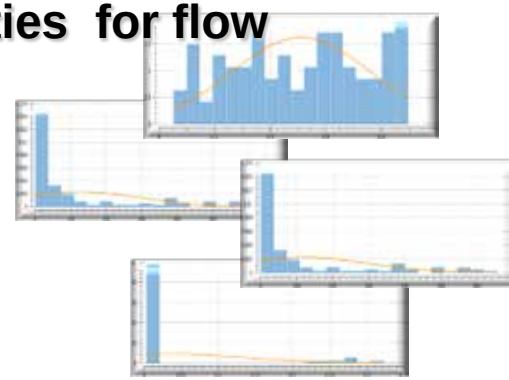
# Modeling the Uncertainties

**Dynamic Model**

**Compute fault properties as a function of Sgr**

PHIMECA

**Multiple Realizations with variable fault properties for flow**

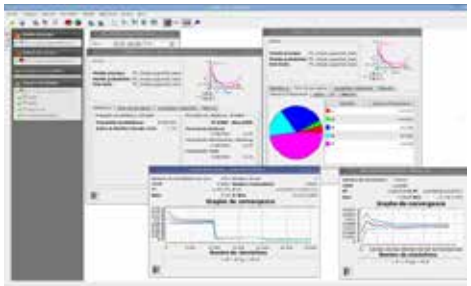


GEM

**Dynamic results:**

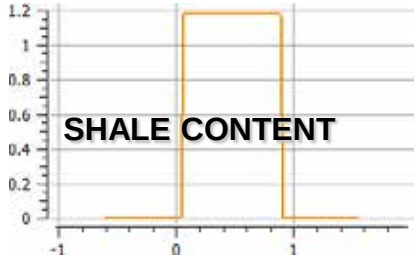
- $CO_2$ mole Fraction
- Transfert time

**Failure Analysis**

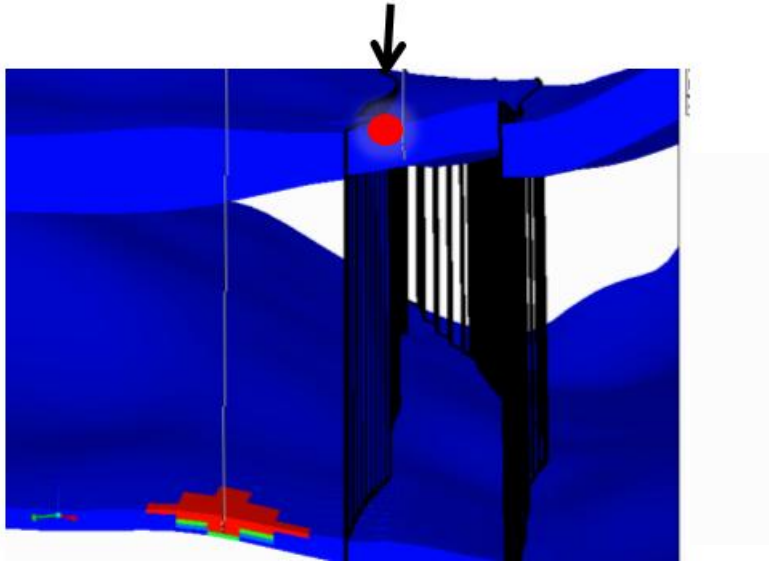


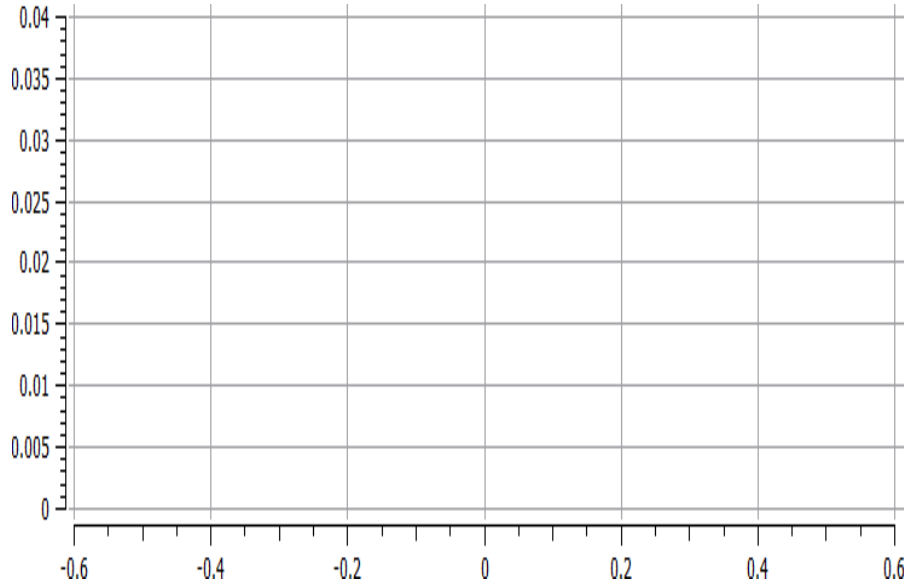
# $CO_2$ impact: time of concentration disturbance

**100 cases with different shale content (uniform distribution) in the fault (change in the fault permeability)**




$CO_2$ molar fraction in the upper aquifer

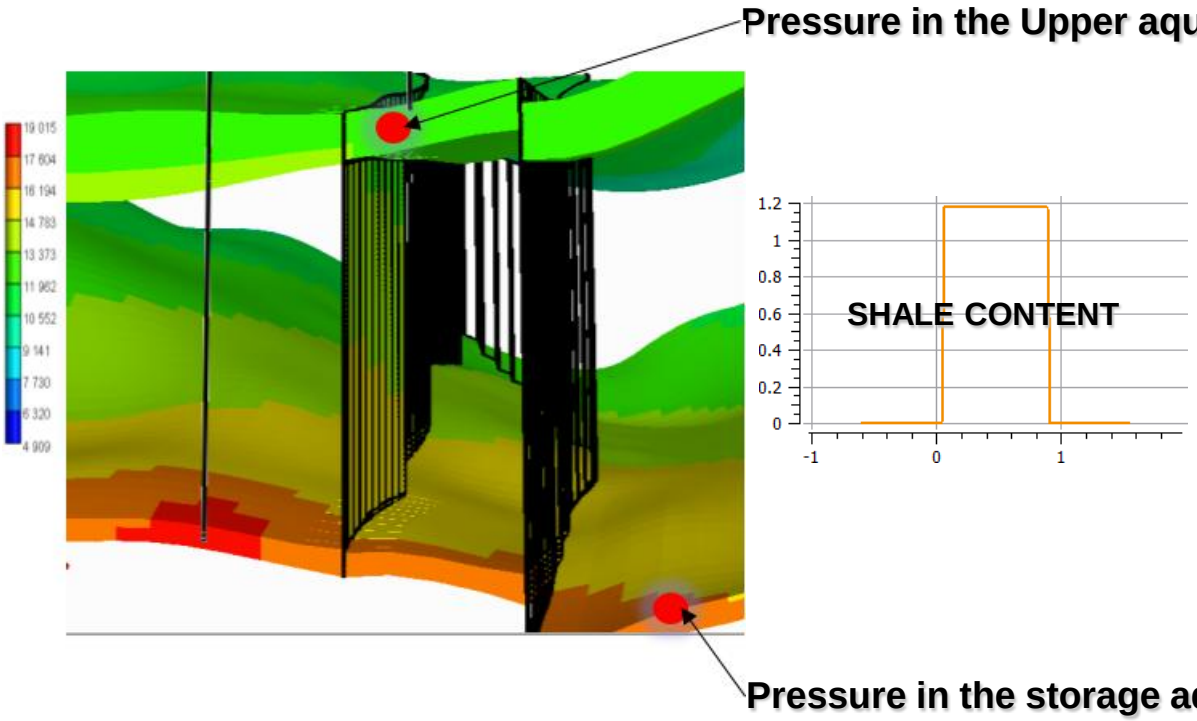


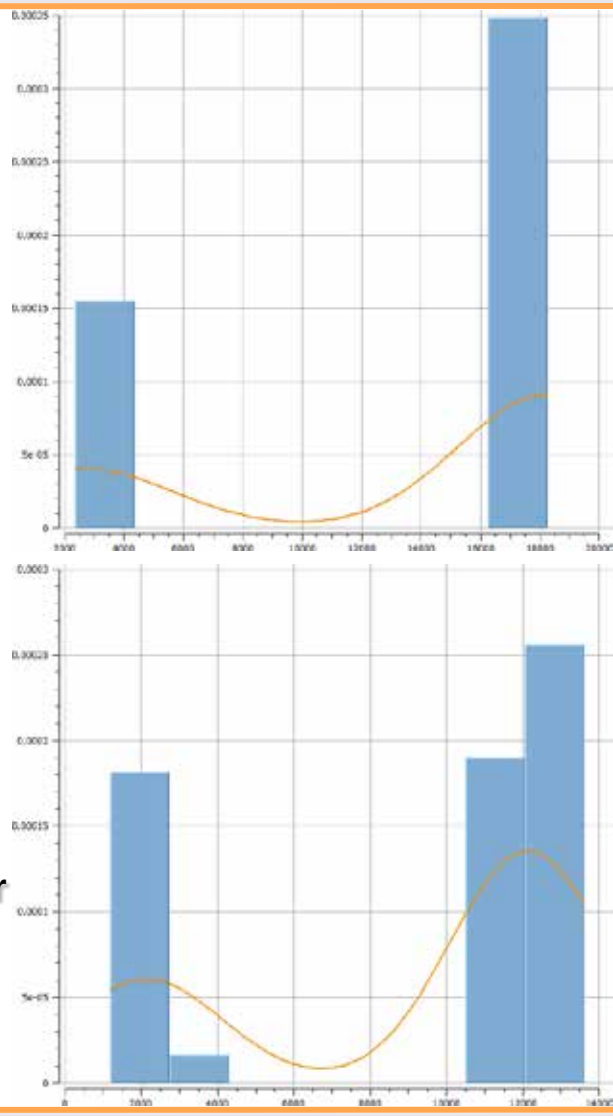



**Probability of occurrence of $CO_2$ concentration changes greater than desired ($10^{-3}$) in the upper aquifer (along the fault)**

# Pressure Impact: time of pressure disturbance

**Probability of occurrence of Pressure changes greater than desired (0.1MPa) in upper aquifer (along the fault)**



**Probability of occurrence of Pressure changes greater than desired (0.1MPa) in lower aquifer (across the fault)**

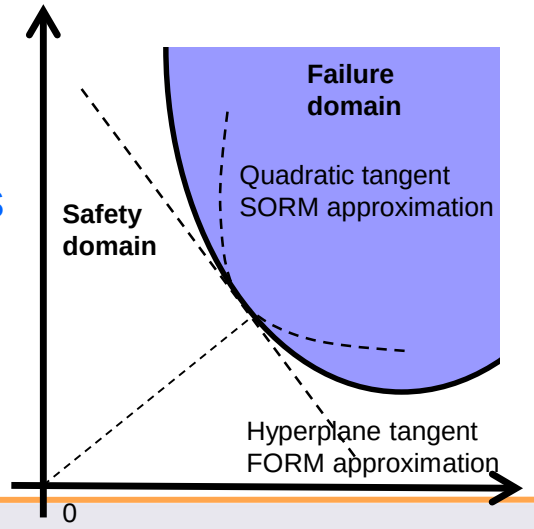
# Analysis of Failure Probability for Pressure with Metamodels

- Pressure variation in Upper Aquifer > 0.1MPa
  - Approximation method
    - MultiFORM 0.3096
    - FORM 0.3096
    - SORM 0.3078
  - Simulation method
    - Monte Carlo 0.32

30% of the cases

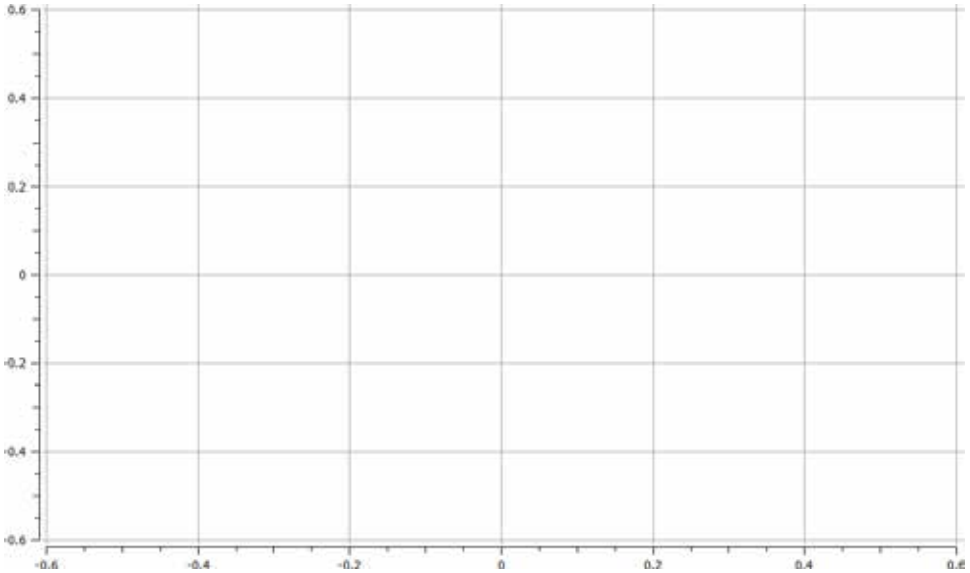
- Pressure variation in Storage Aquifer > 0.1MPa
  - Approximation method
    - MultiFORM 0.9817
    - SMART 0.9997
  - Simulation method
    - Monte Carlo 0.98

Always



# Analysis of Failure Probability for $CO_2$ Concentration with Metamodels

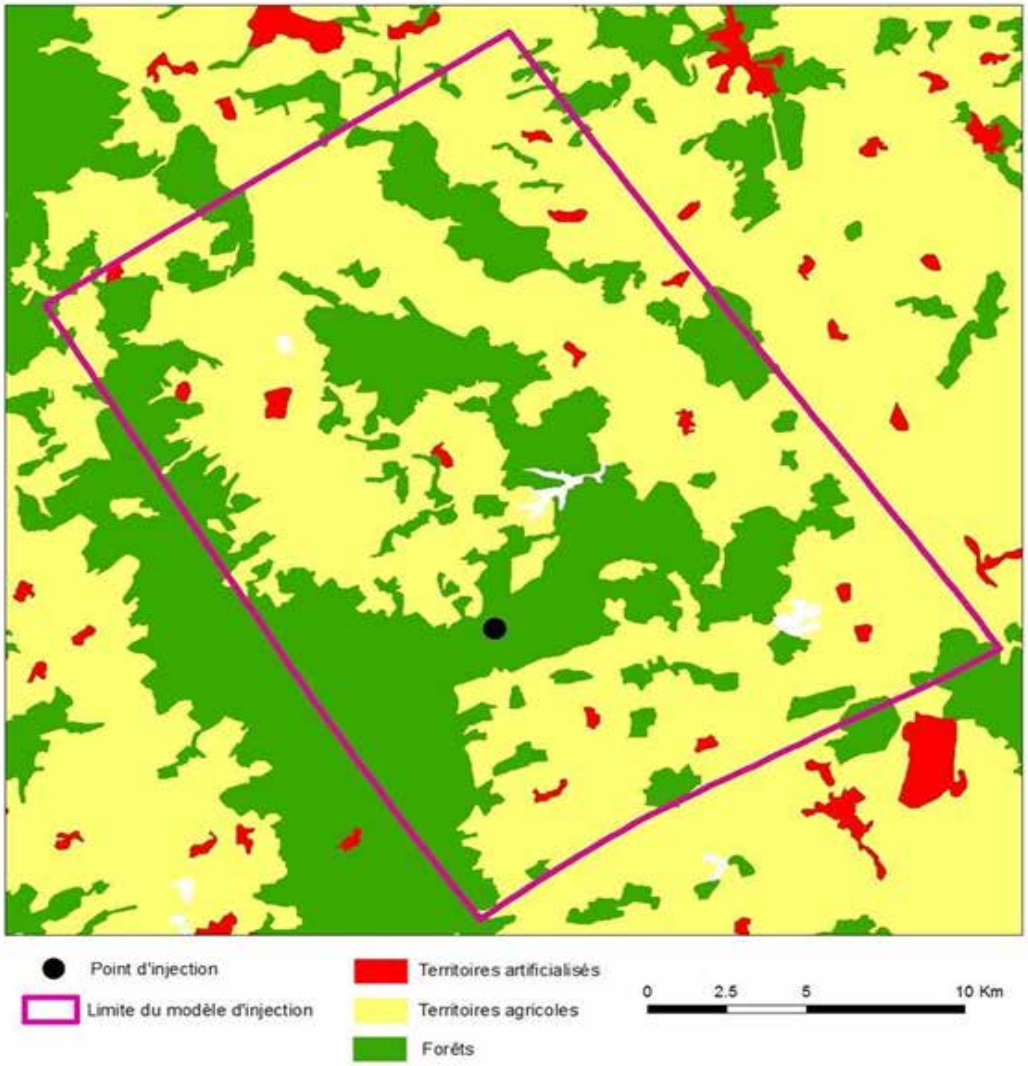
- $CO_2$ Concentration in Upper Aquifer > 0.001 mol/l
  - Never



# Modeling Failure Scenarios

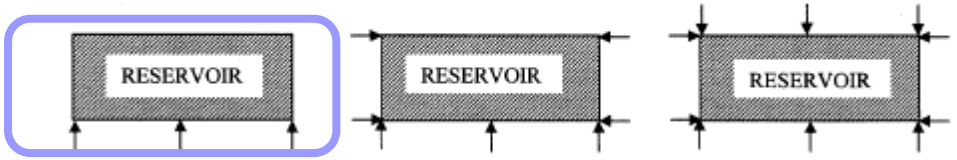
## Quantifying the ground deformation

# Land-use in the injection zone

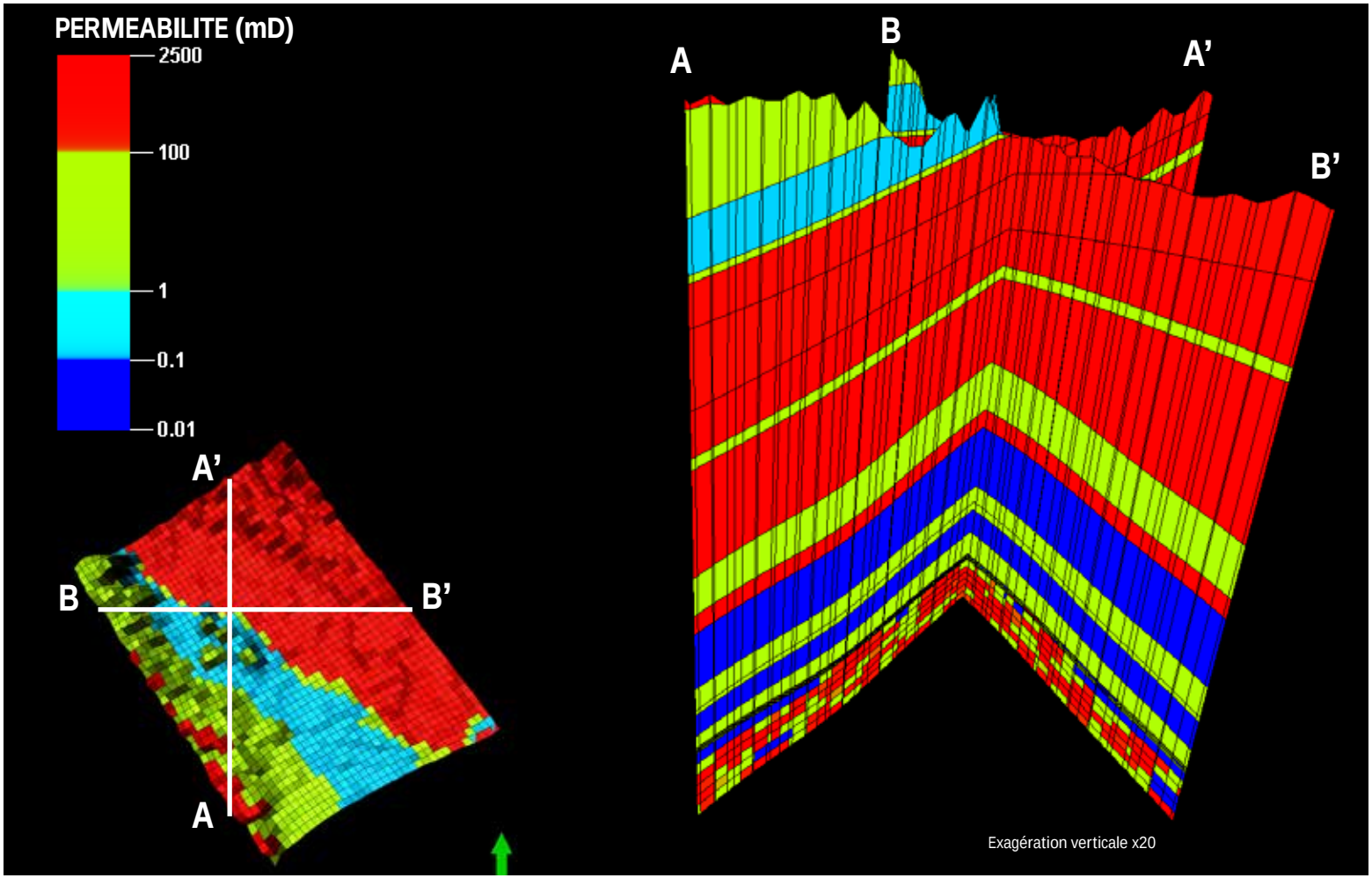


# Main modeling assumptions

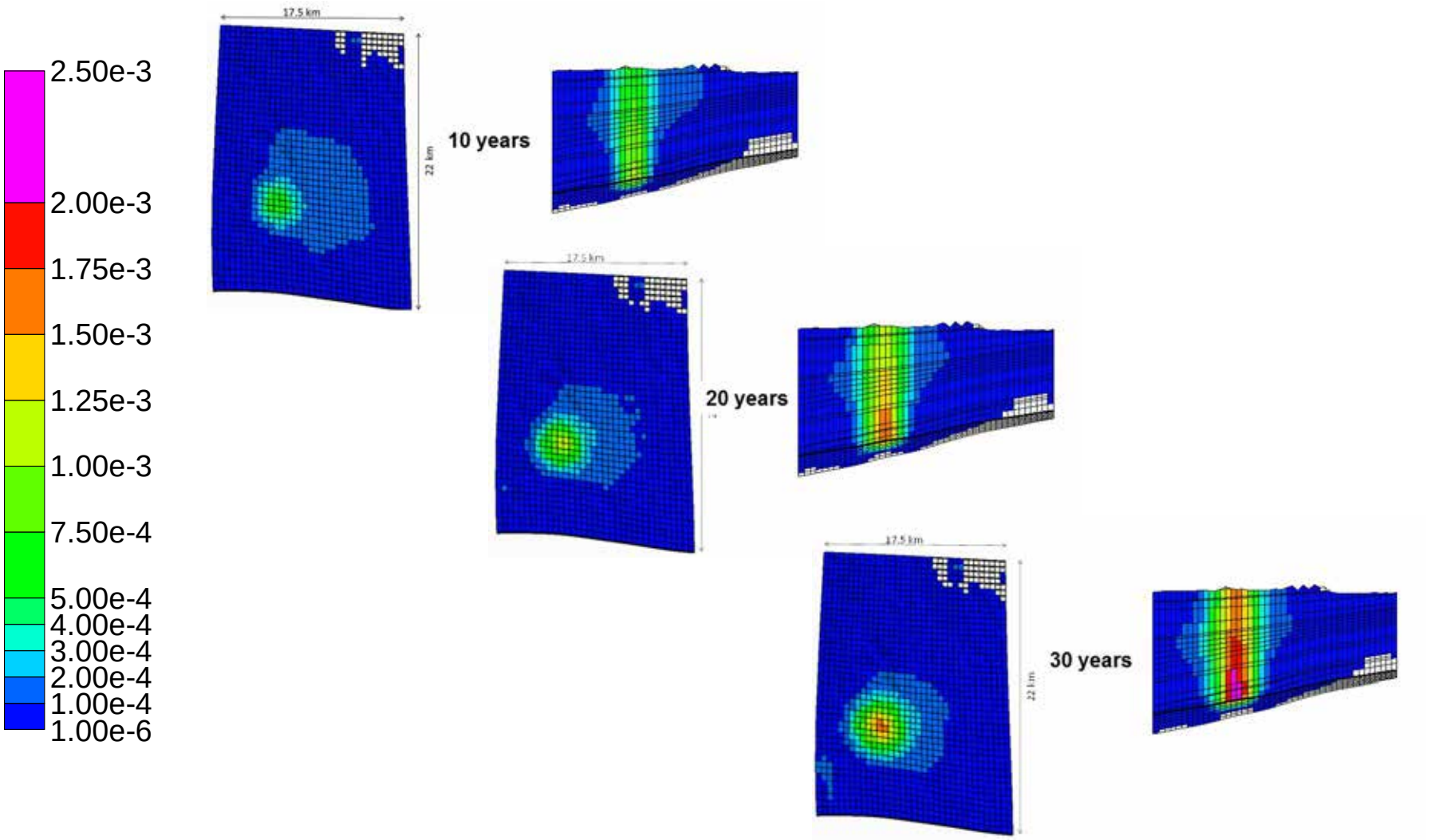
- Homogeneous properties (facies, porosity, permeability, mechanical properties) for each of the overburden formations
- Initial conditions :
  - Normal pressure, temperature (0.03°C/m) gradients
  - Stress ratio $s_h / s_V \sim 0.7$
- Boundary conditions :
  - Flow: numerical aquifers (side)
  - Mechanical:



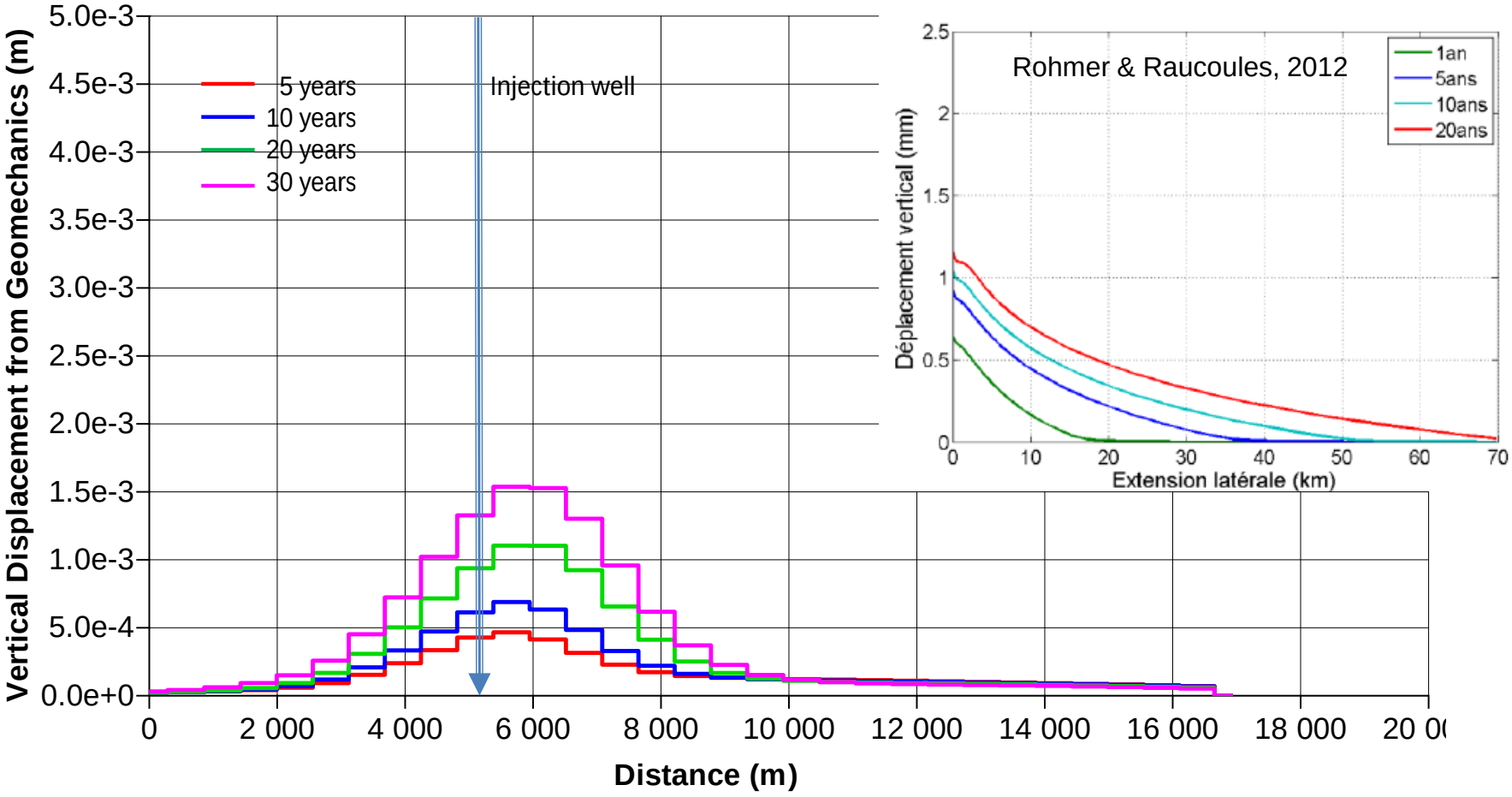
# Permeability distribution



# Vertical heave(m)

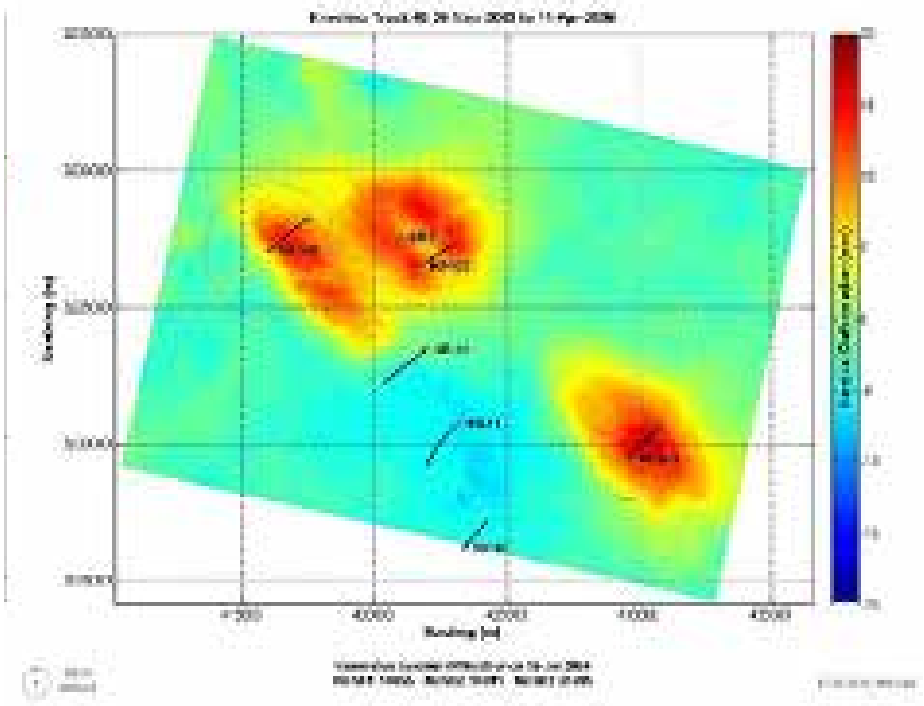


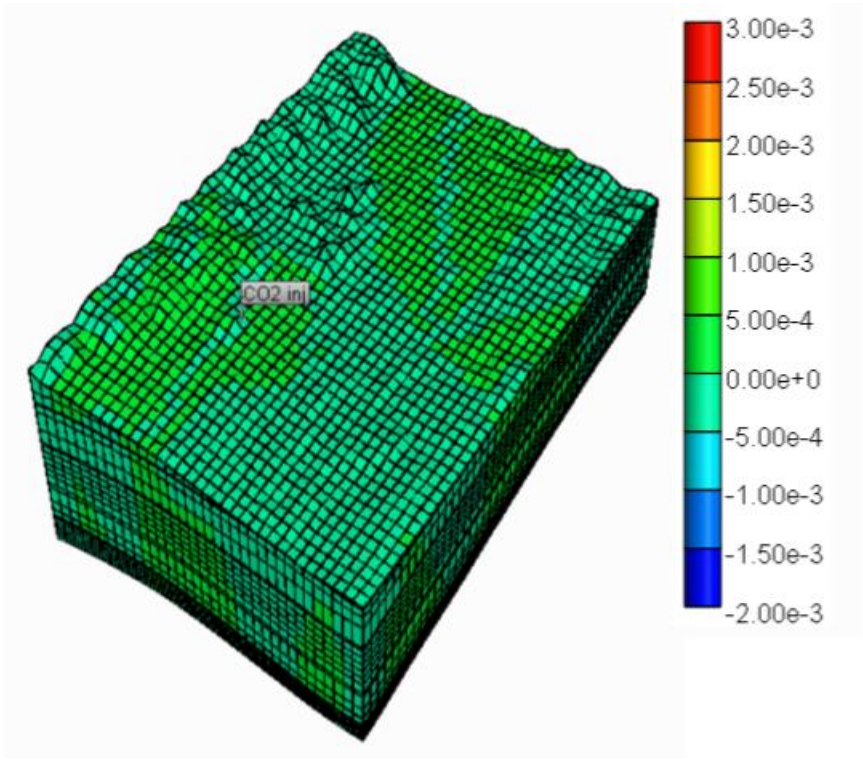
# surface up-lift above the injection well



# Average vertical deformation (m/an) after 5 years of injection

- In-Salah






Mathieson, 2012

# Conclusions

- Limited expected migration of the $CO_2$ (injection rate ~0.7 Mtpa)
- Risk assessment methodology applied to identify the possible Key Events (concerns):
  - migration along a fault,
  - ground deformation
- Quantification of the Key Events :
  - Fault migration scenario: computation of failure probabilities:
    - No $CO_2$ migration to the upper aquifer
    - 30% pressure impact (greater than threshold) in the upper aquifer
  - Ground heave: below detection level for INSAR methods

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# Thank you!

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Energy Management Agency

SEVENTH FRAMEWORK
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