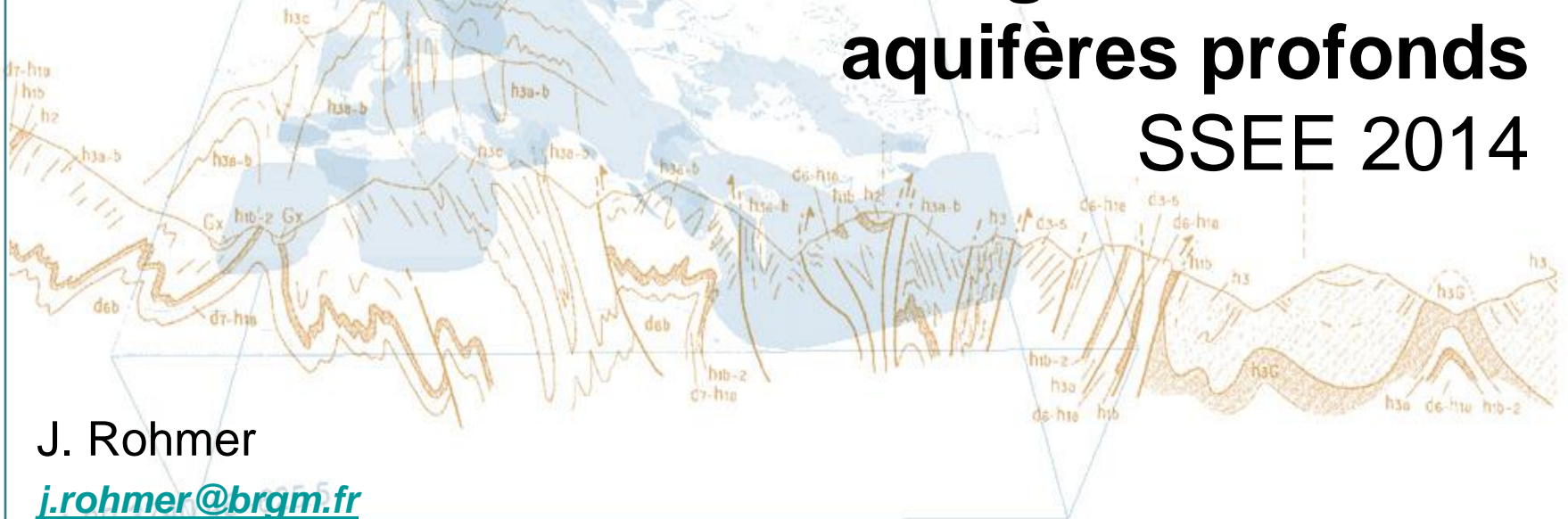




Risques de géomécaniques dans le contexte des stockages de CO2 en aquifères profonds SSEE 2014



J. Rohmer

j.rohmer@brgm.fr

Plan

- > **Contexte**
- > **Vision d'ensemble des risques géomécaniques en phase d'injection**
- > **La question du long terme**

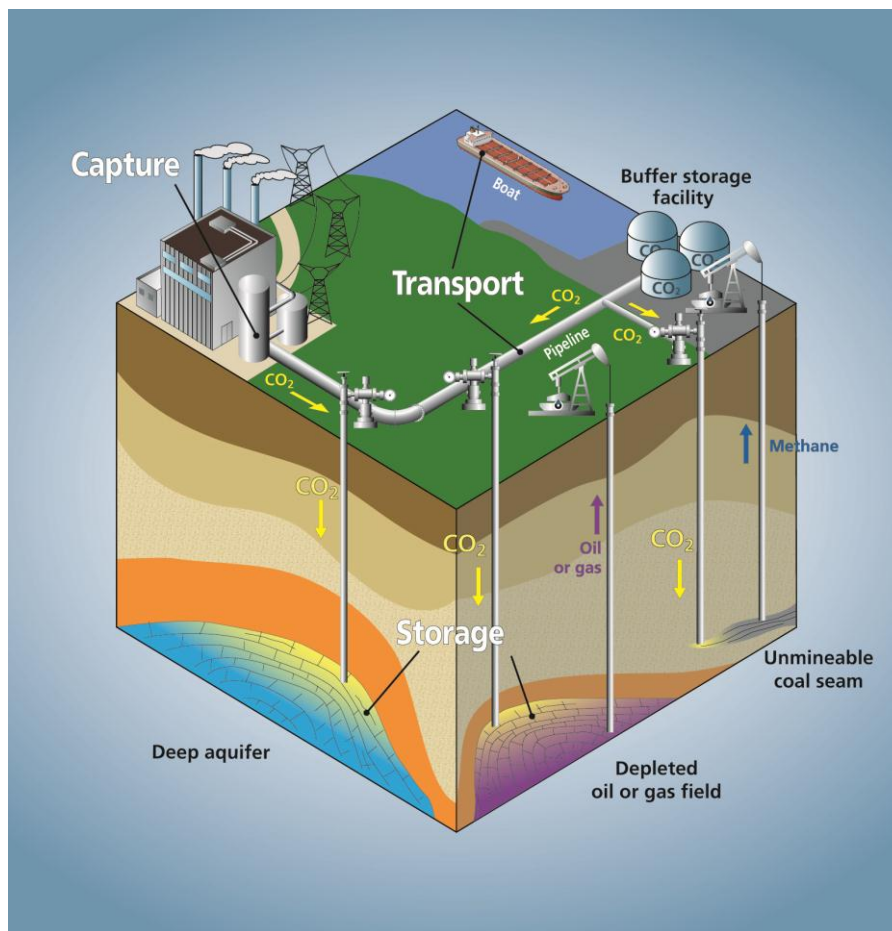
CONTEXTE

Capture – Transport – Stockage de CO₂

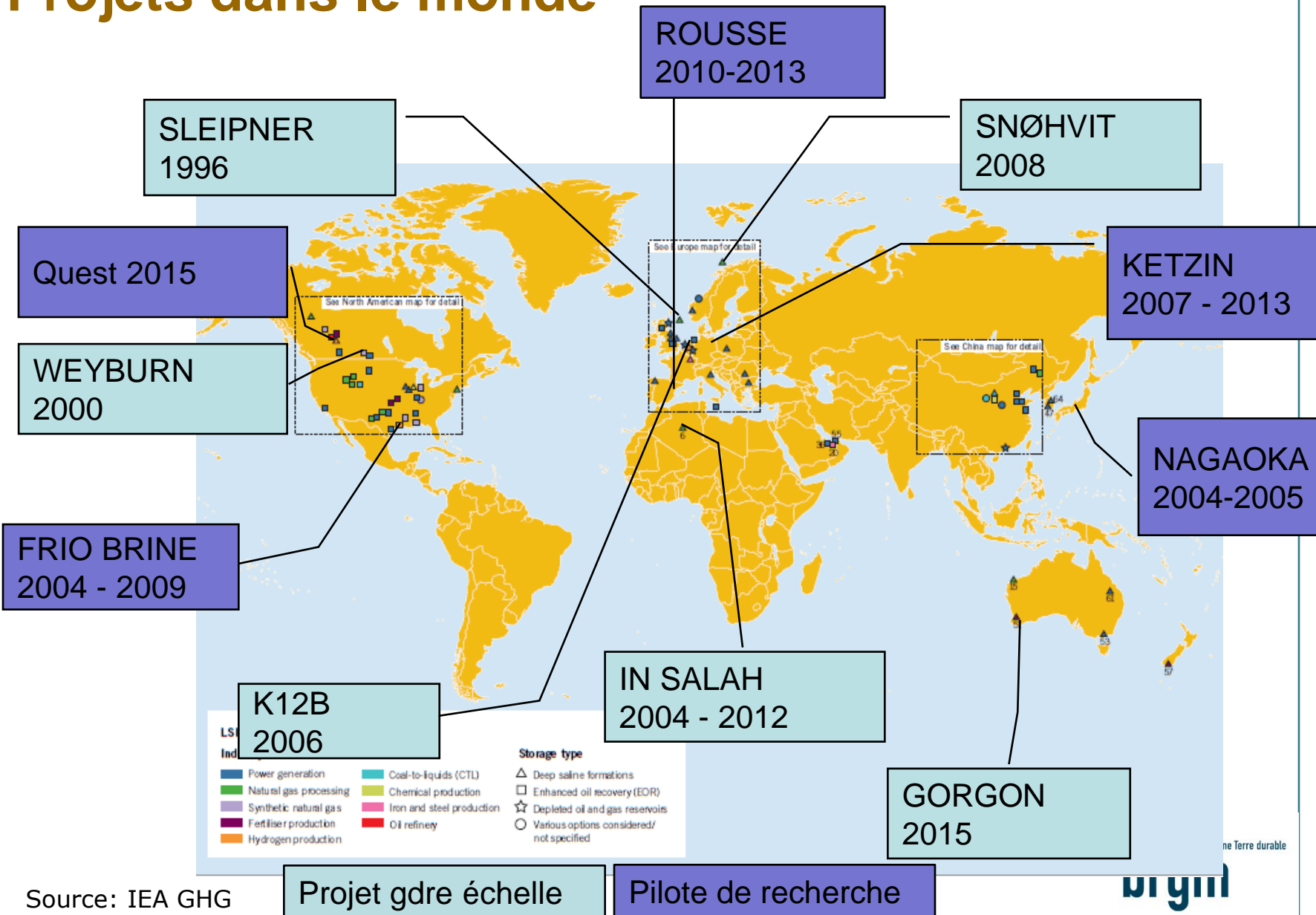
- > Une des solutions identifiées pour réduire les émissions de CO₂ (« Climate Change 2014: Mitigation of climate change », GIEC);
- > Devrait participer à leur réduction à hauteur de un cinquième d'ici 2050 (IEA, 2009);

> **Pré-requis (IEA-GHG, 2007)**

➔ **Démontrer la sécurité**



Projets dans le monde



Source: IEA GHG

Projet gdre échelle

Pilote de recherche



ne Terre durable

Projets « grande échelle »



Sleipner, deep saline aquifer, Norway, 1 Mt CO₂/y since 1996



In-Salah, gas reservoir, Algeria 1 Mt CO₂/y since 2004



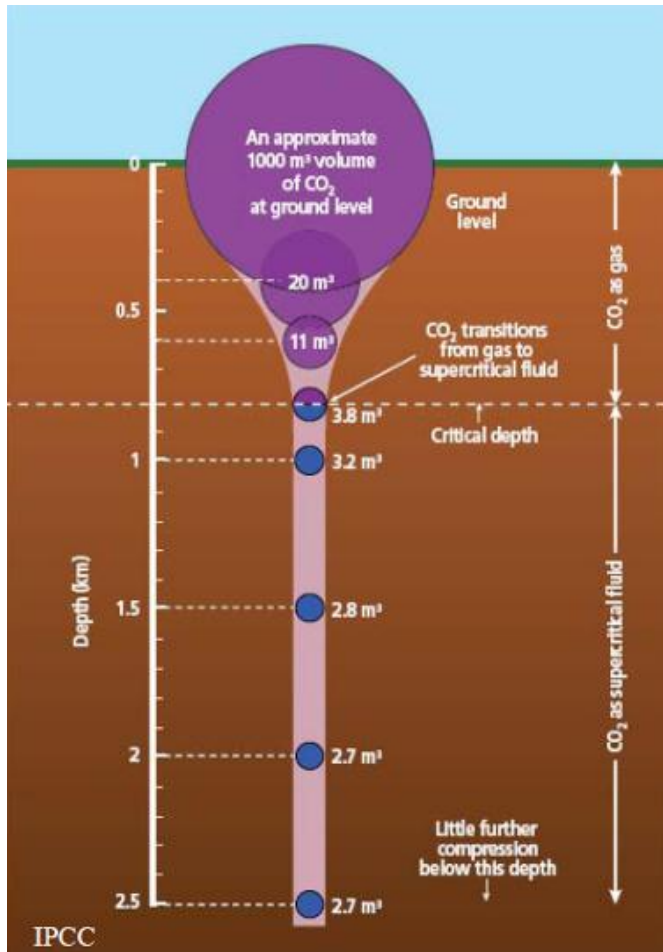
Weyburn-Midale, oil reservoir, Canada, 1.8 Mt CO₂/y since 2000

Courtesy CO2REMOVE, Statoil, PTRC



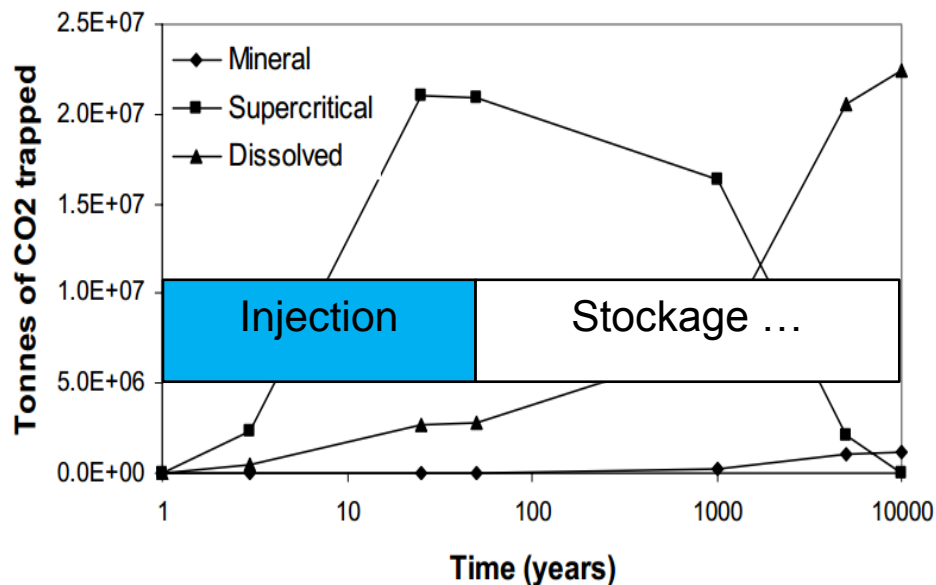
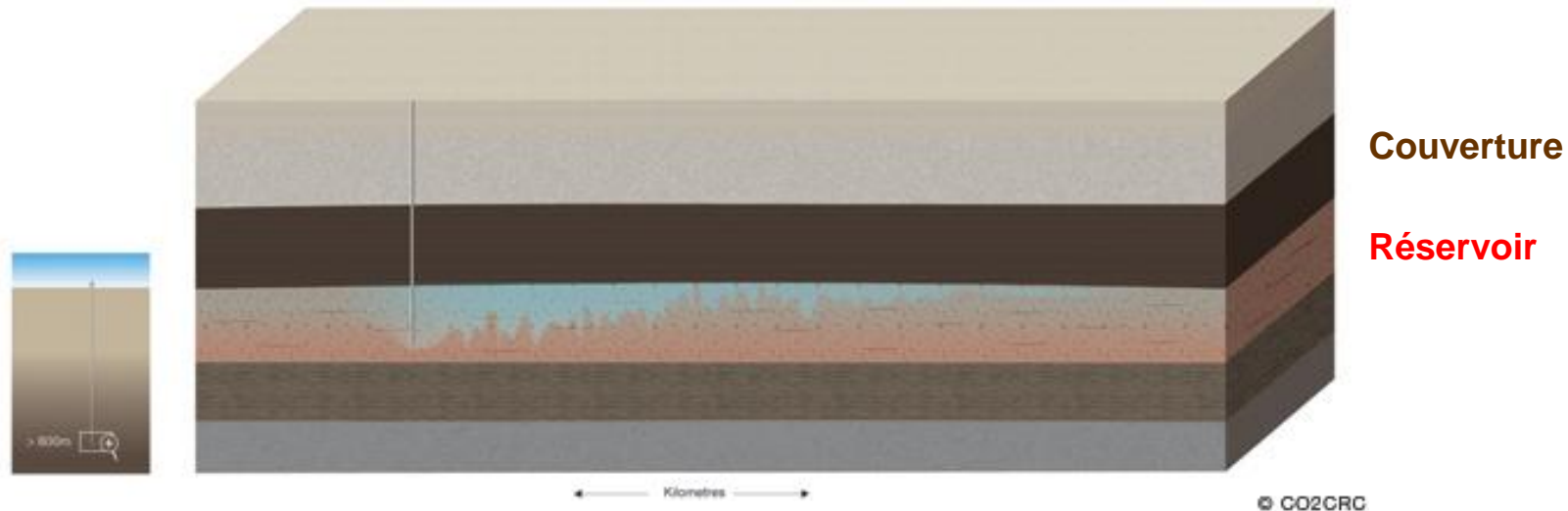
Snohvit, deep saline aquifer, Norway, 0.7 Mt CO₂/y since 2007

Le CO2 en profondeur: état supercritique



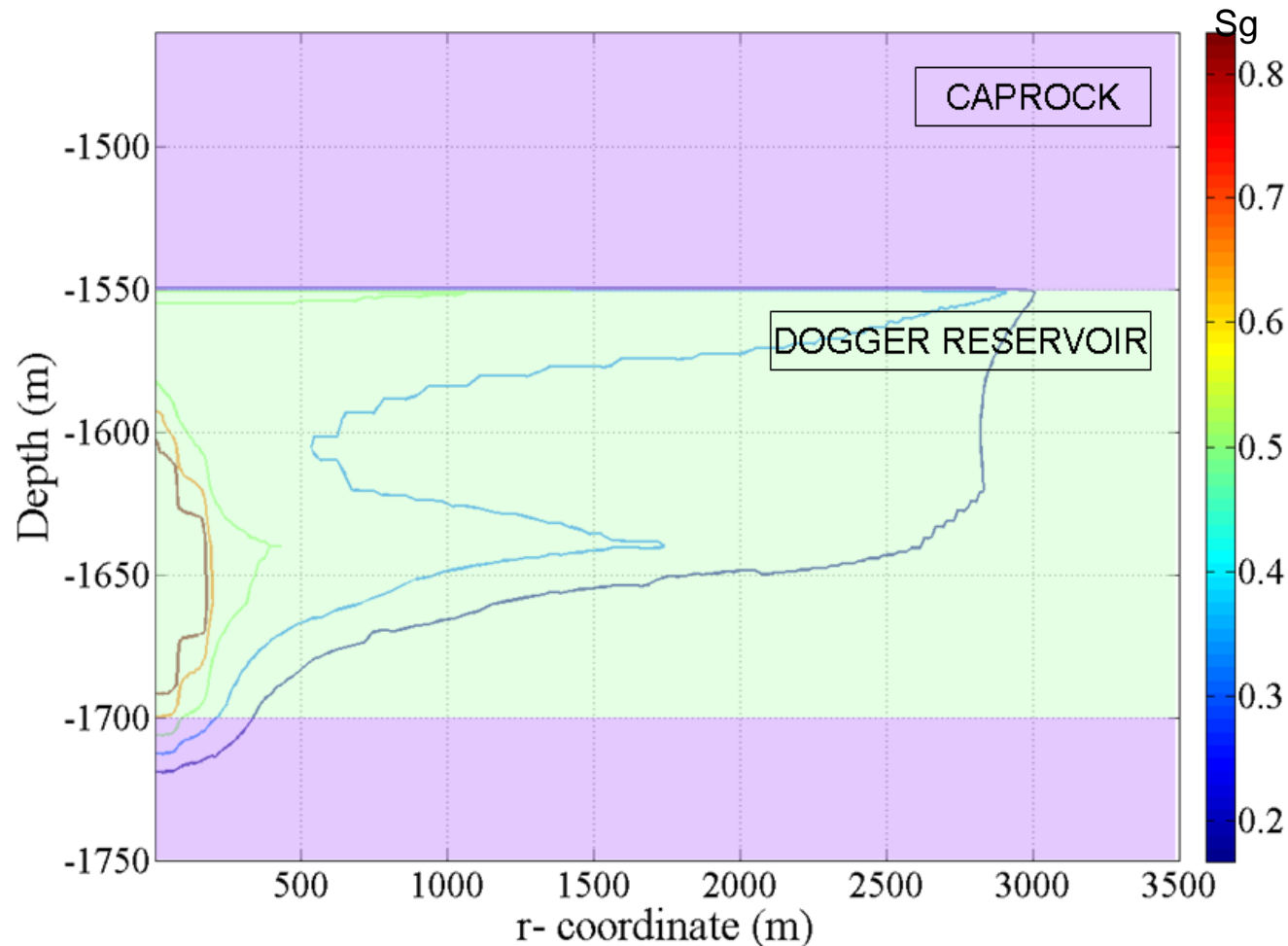
T=100° C, P=280bar (2800m)	density (kg/m ³)	viscosity (mPa·s)
supercritical CO ₂	615	0.05
water	804	0.16
methane	150	0.02

Le CO2 en profondeur: la solubilité



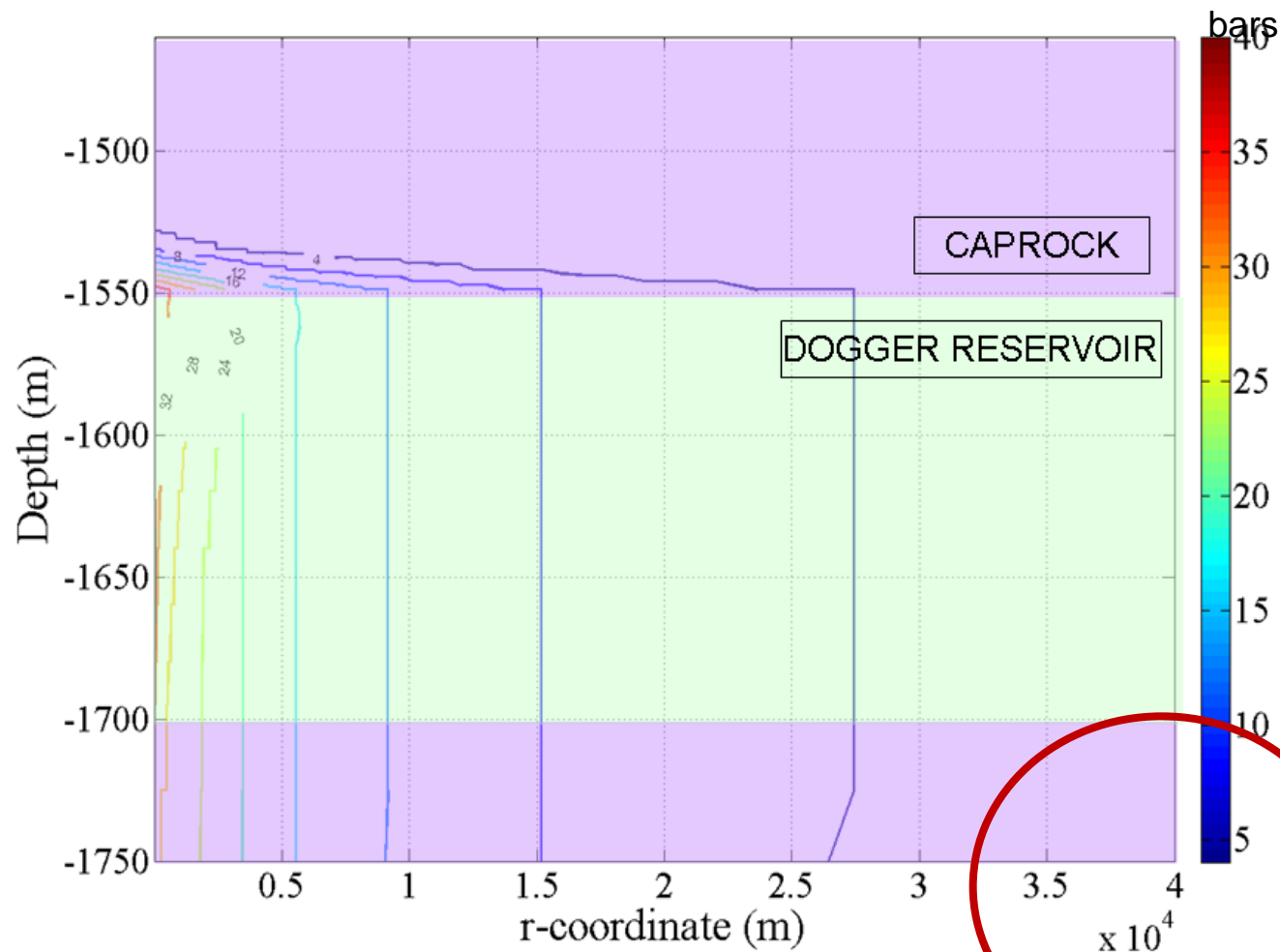
Simulations transport réactif à Sleipner (Mer du Nord), Audigane et al. 2007

L'étendue spatiale de la bulle de CO2



Injection massive de CO2 dans le Dogger (bassin de Paris); Rohmer et Seyedi 2010

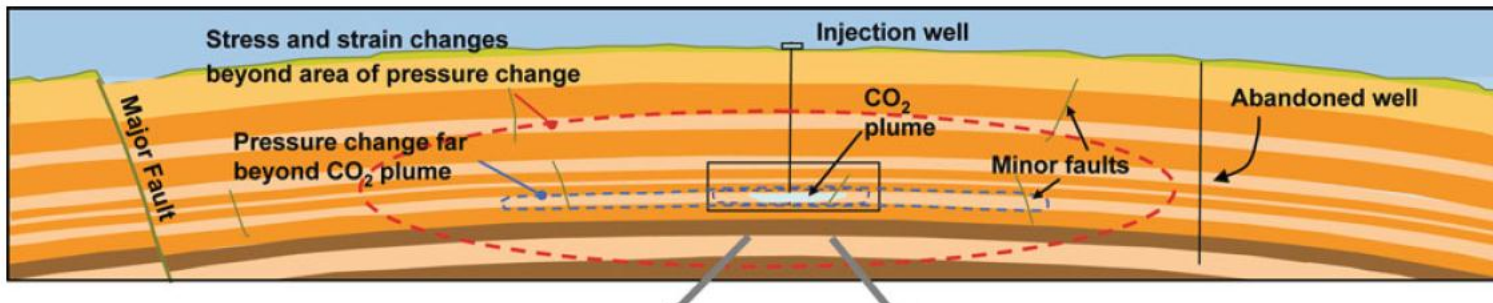
L'étendue spatiale de la surpression



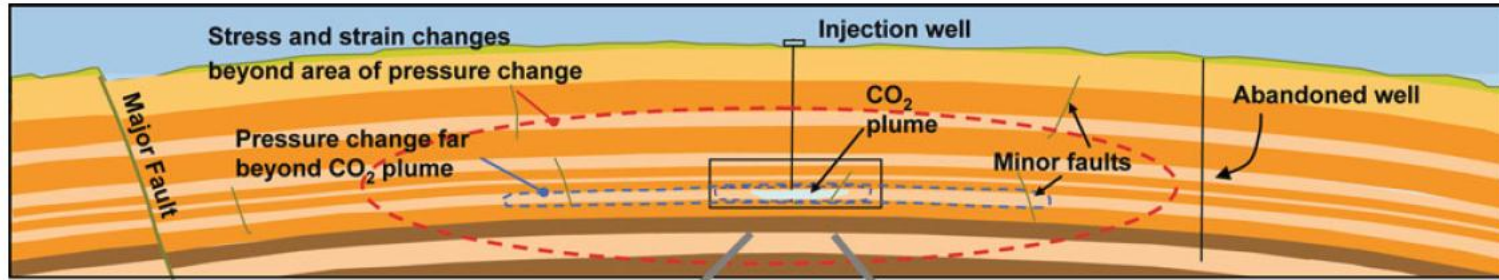
Injection massive de CO₂ dans le Dogger (bassin de Paris); Rohmer et Seyedi 2010

VISION D'ENSEMBLE

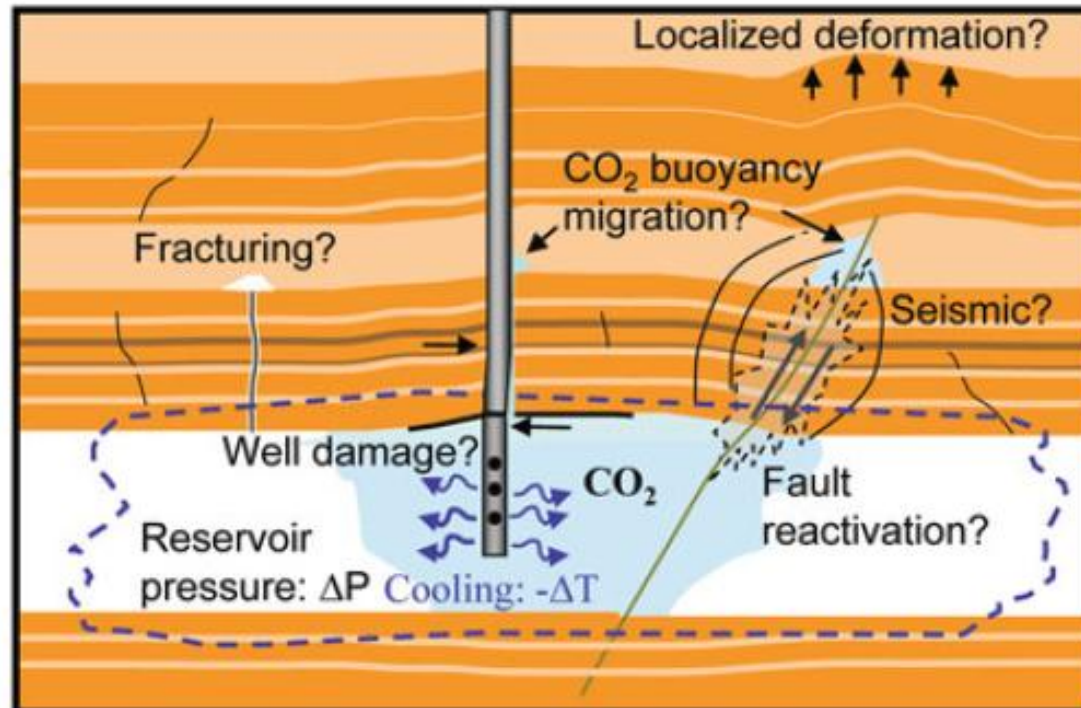
Multiple risks geomechanics



Multiple risks géomécaniques



Unwanted mechanical changes

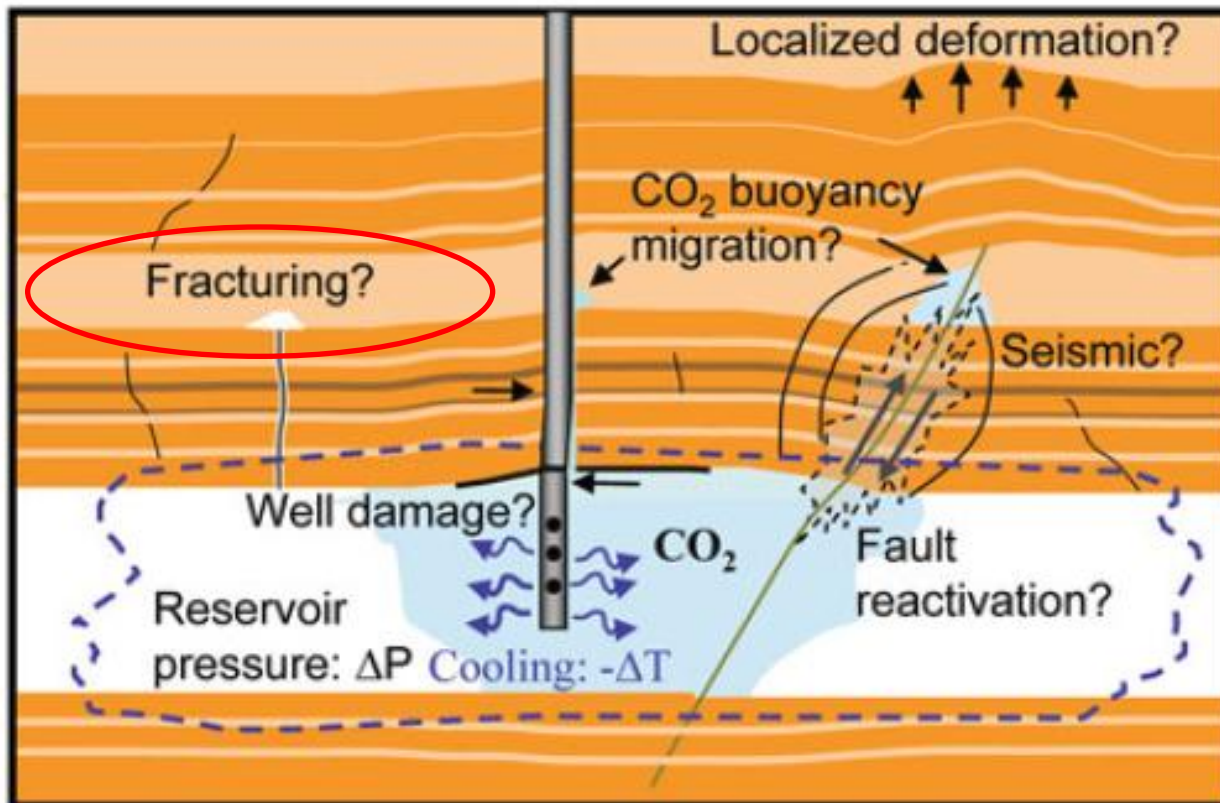


Géosciences pour une Terre durable

irgm

Multiple risks géomécaniques

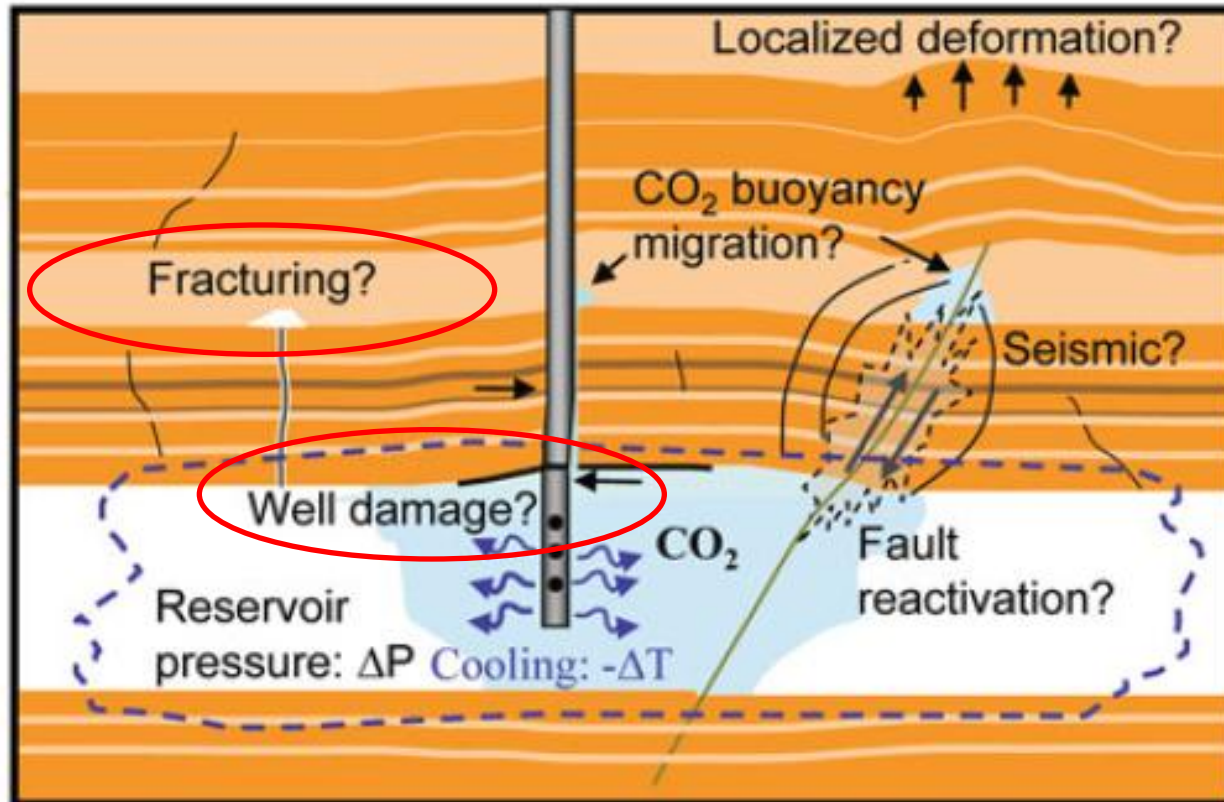
Unwanted mechanical changes



Risque lié à la perte d'intégrité de la couverture (fracturation / réactivation de failles mineures / fractures)

Multiple risks géomécaniques

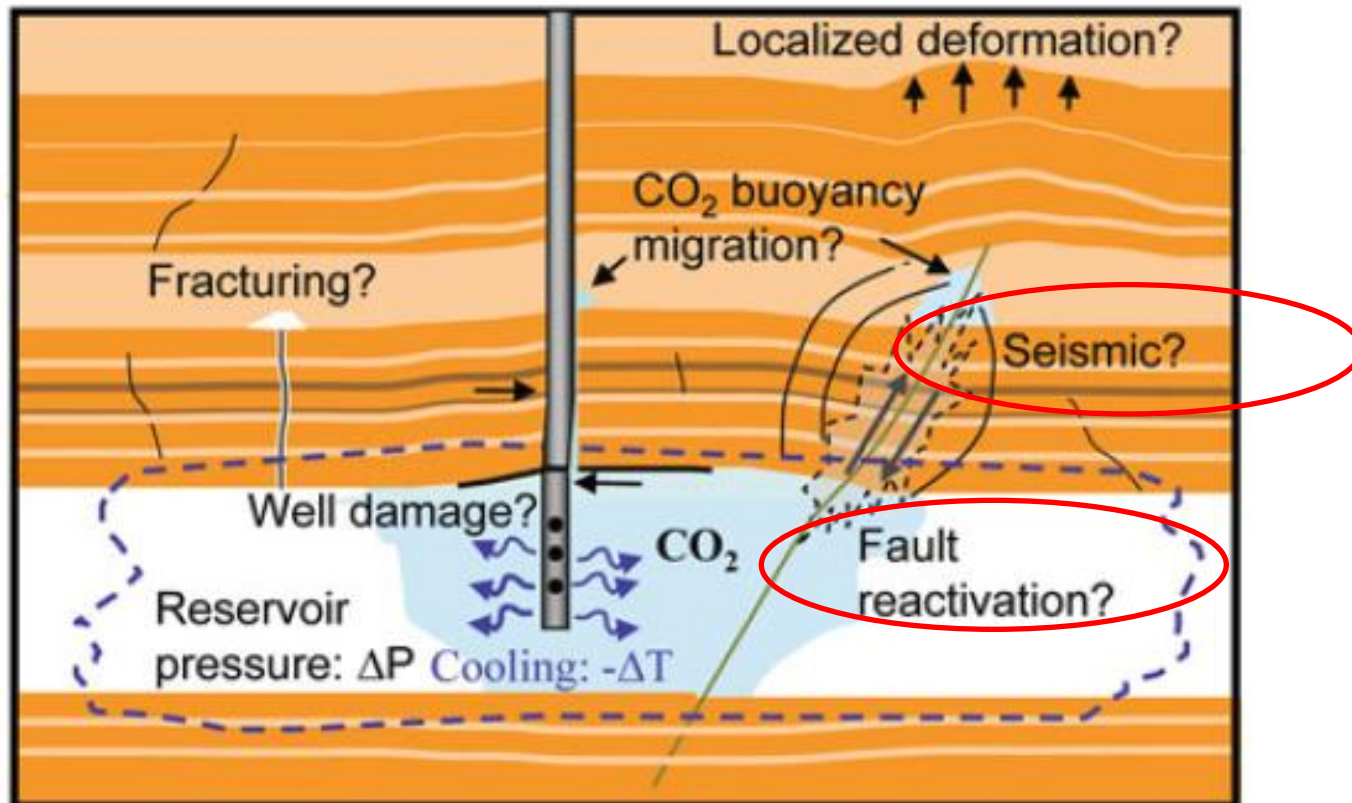
Unwanted mechanical changes



Risque lié perte d'intégrité du puits

Multiple risks géomécaniques

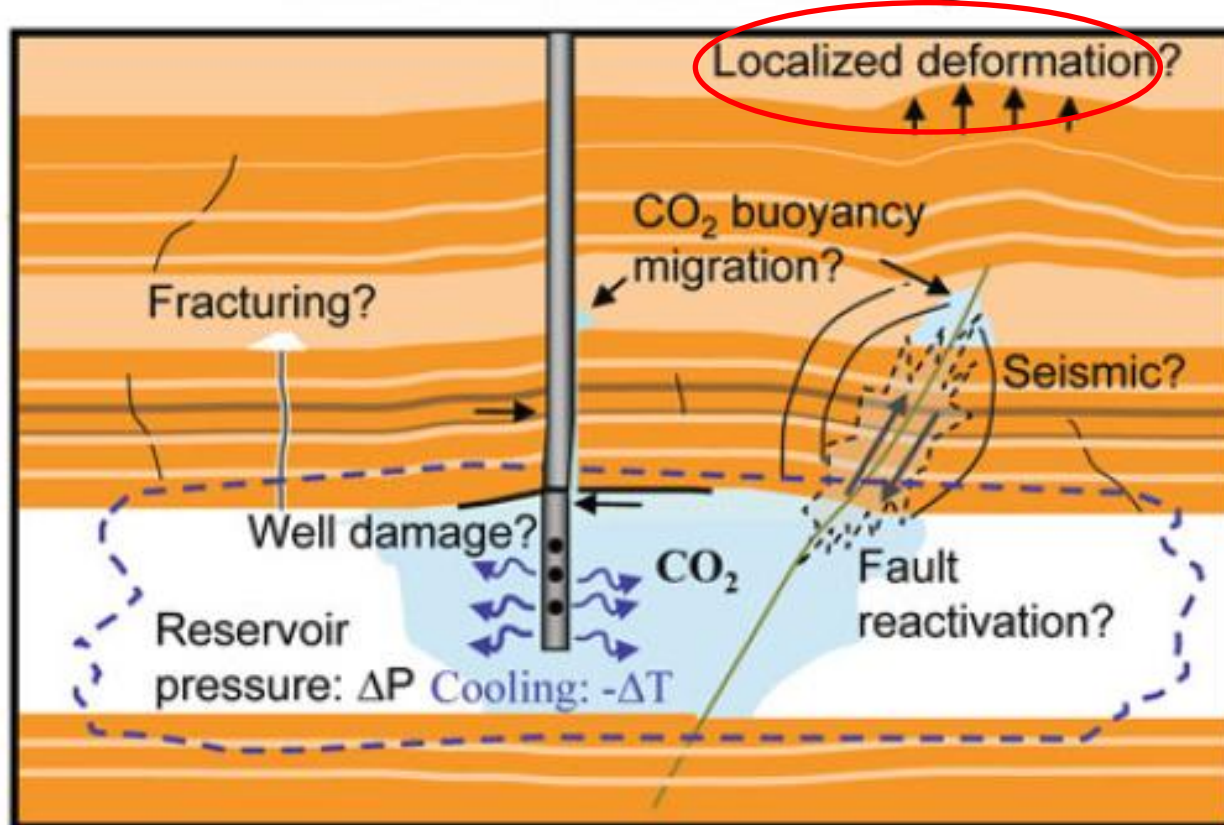
Unwanted mechanical changes



Risque lié à la réactivation de failles majeures et possible sismicité induite

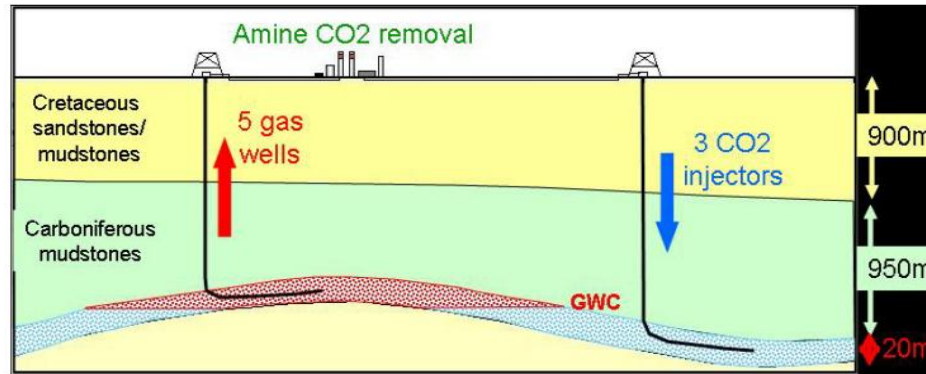
Multiple risks géomécaniques

Unwanted mechanical changes

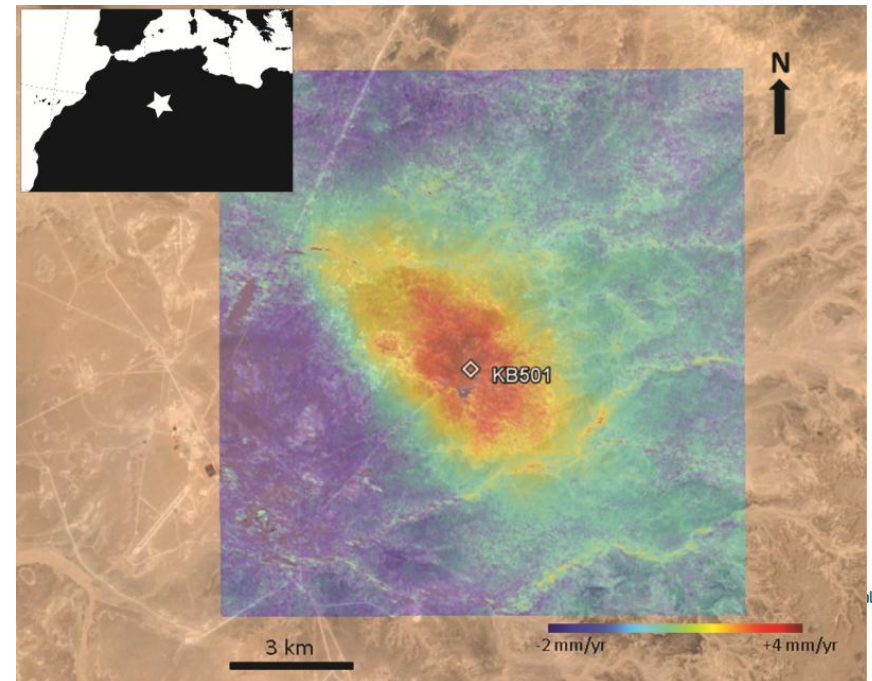


Risque de surrection des terrains

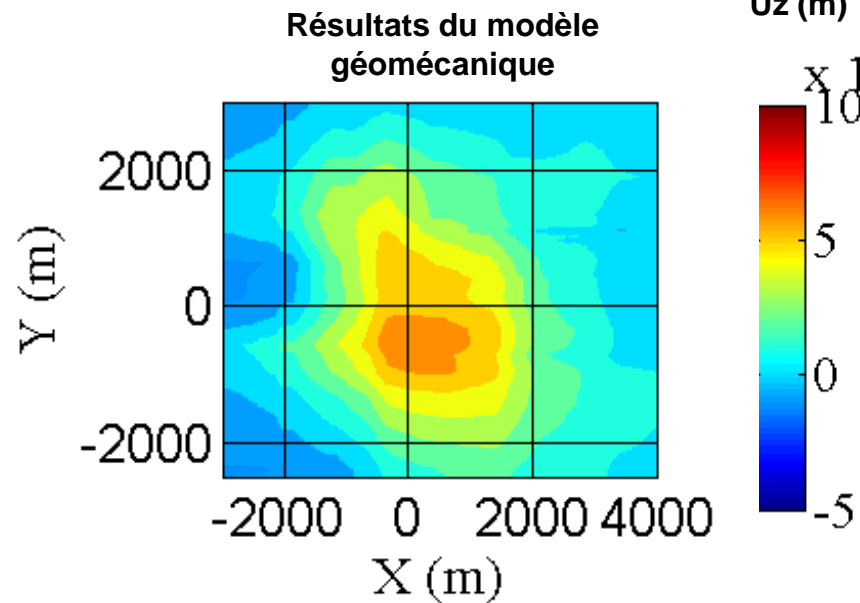
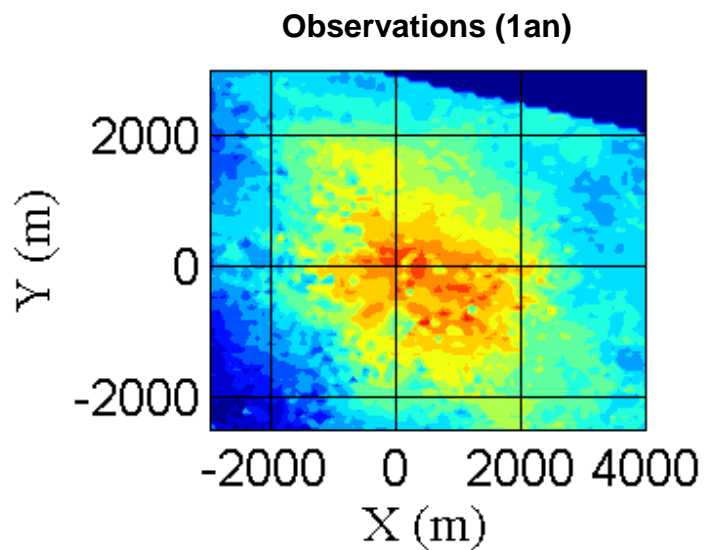
Cas concret: site de stockage de CO2 à In-Salah (Algérie)



- > Suivi de la **vitesse de déformation** lors de l'injection de CO2 à In-Salah pendant la période 2004-2009 (processing par BRGM des images Envisat, Raucoules et al., 2014)

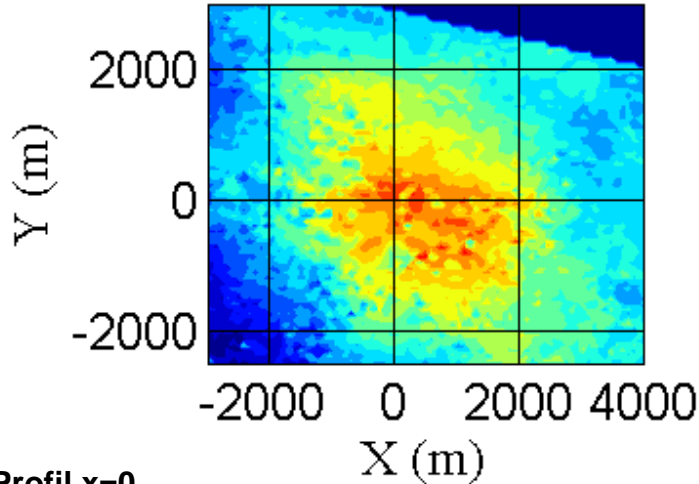


History-matching KB-501

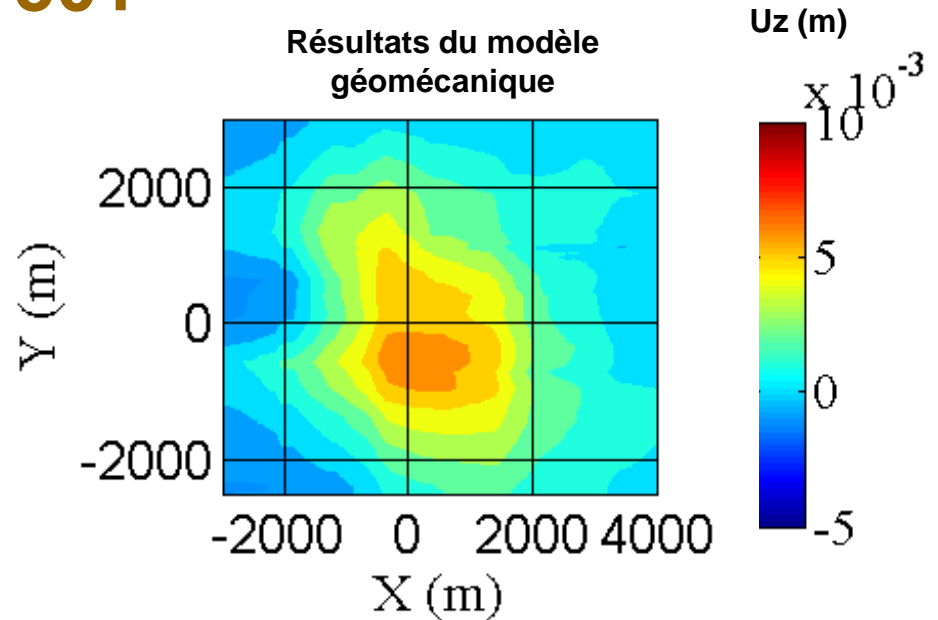


History-matching KB-501

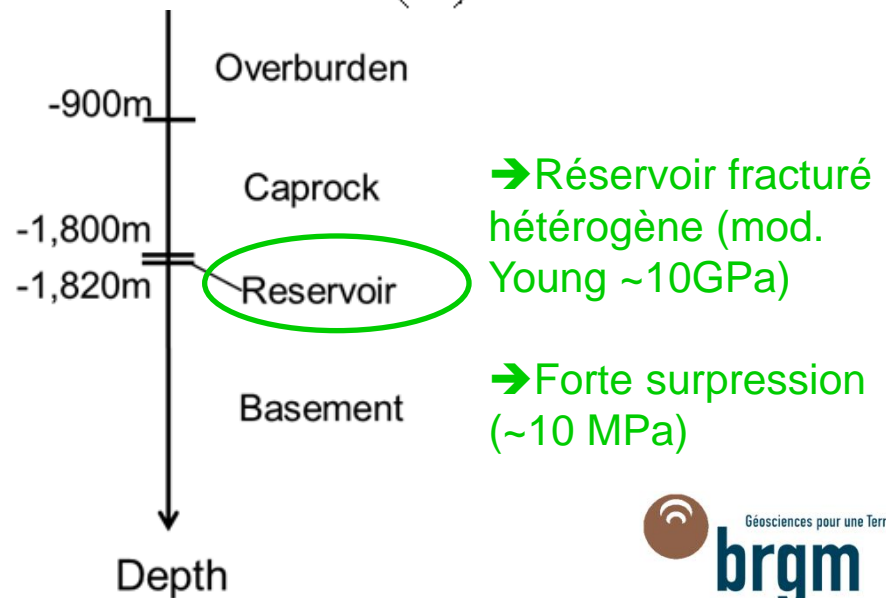
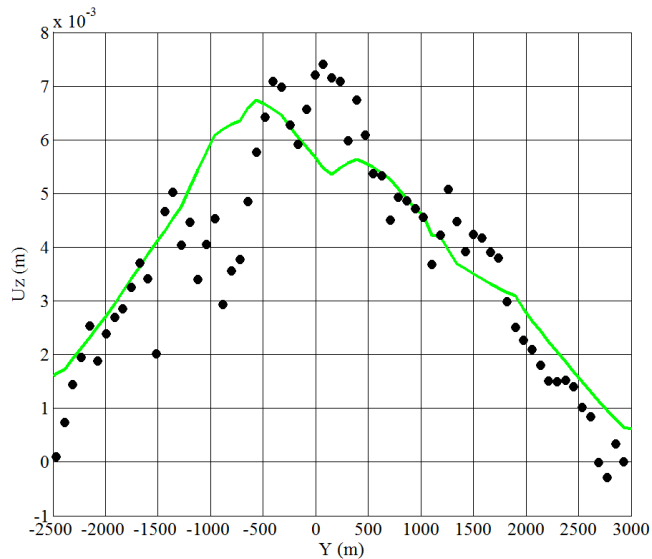
Observations (1an)



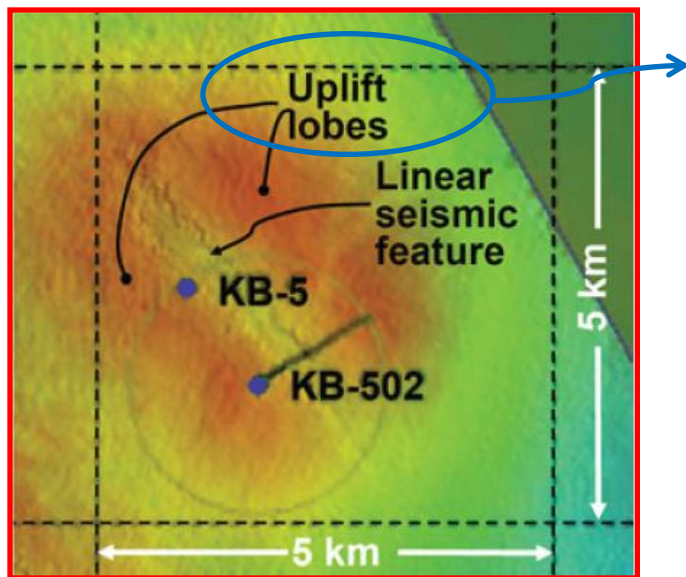
Résultats du modèle géomécanique



Profil x=0

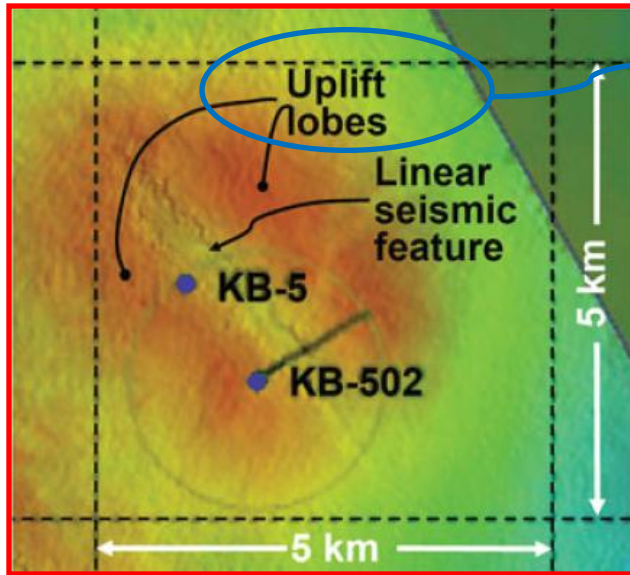


Comportement « anormal » - KB-502

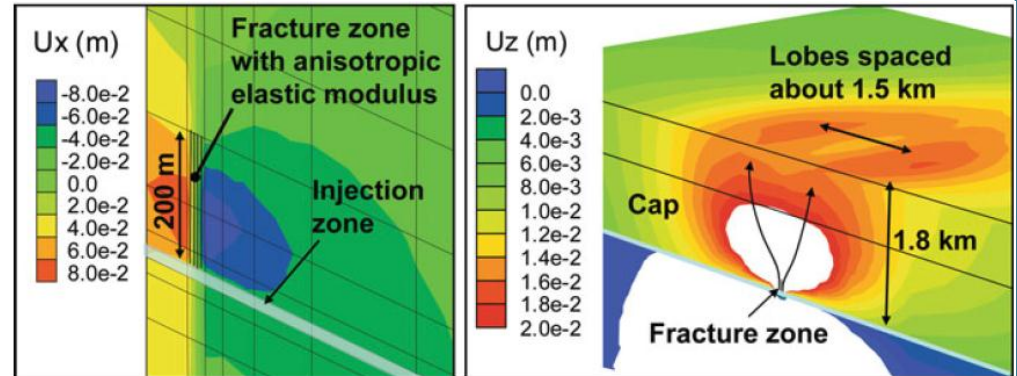


Données InSAR MDA &
Pinnacle tech. (Wright 2011)

Comportement « anormal » - KB-502



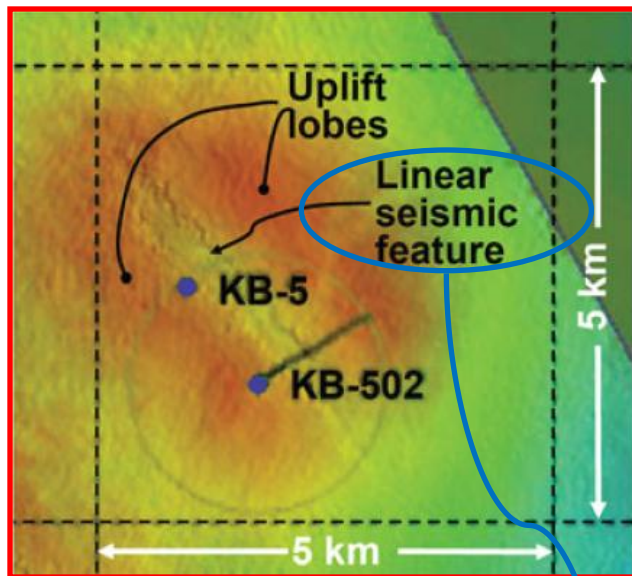
Possible explication: zone fracturée



Rutqvist et al. 2011

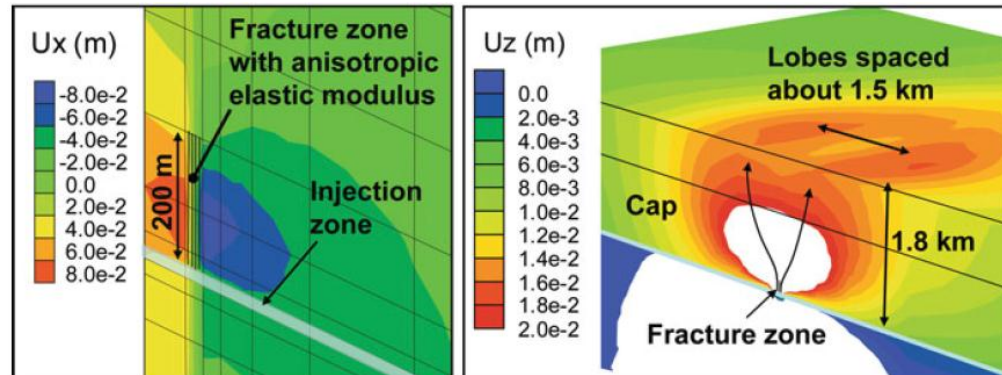
Données InSAR MDA & Pinnacle tech. (Wright 2011)

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Données InSAR MDA & Pinnacle tech. (Wright 2011)

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Rutqvist et al. 2011

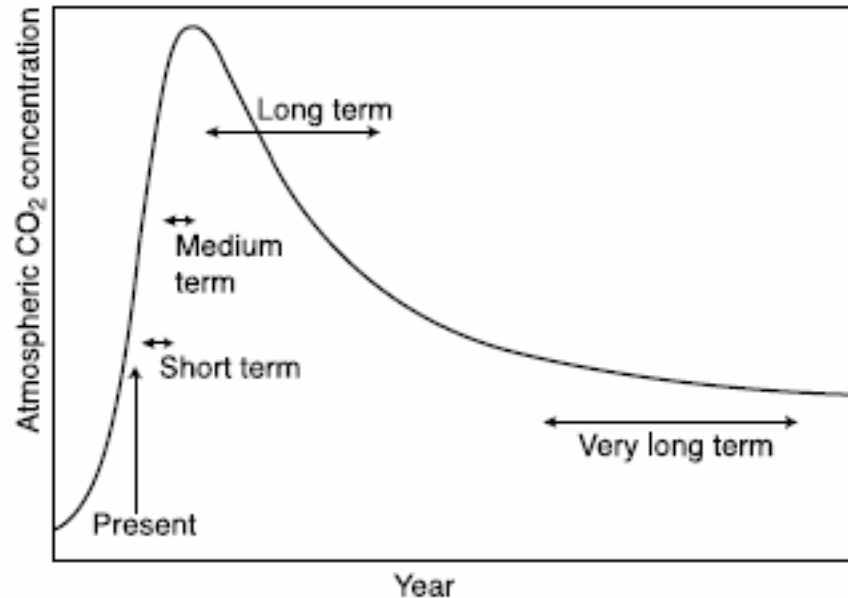
Campagne sismique: ouverture d'une zone fracturée, largeur ~ 100m ? (Gibson-Poole and Raikes, 2010)

LA QUESTION DU LONG TERME

What is long term?

> Duration

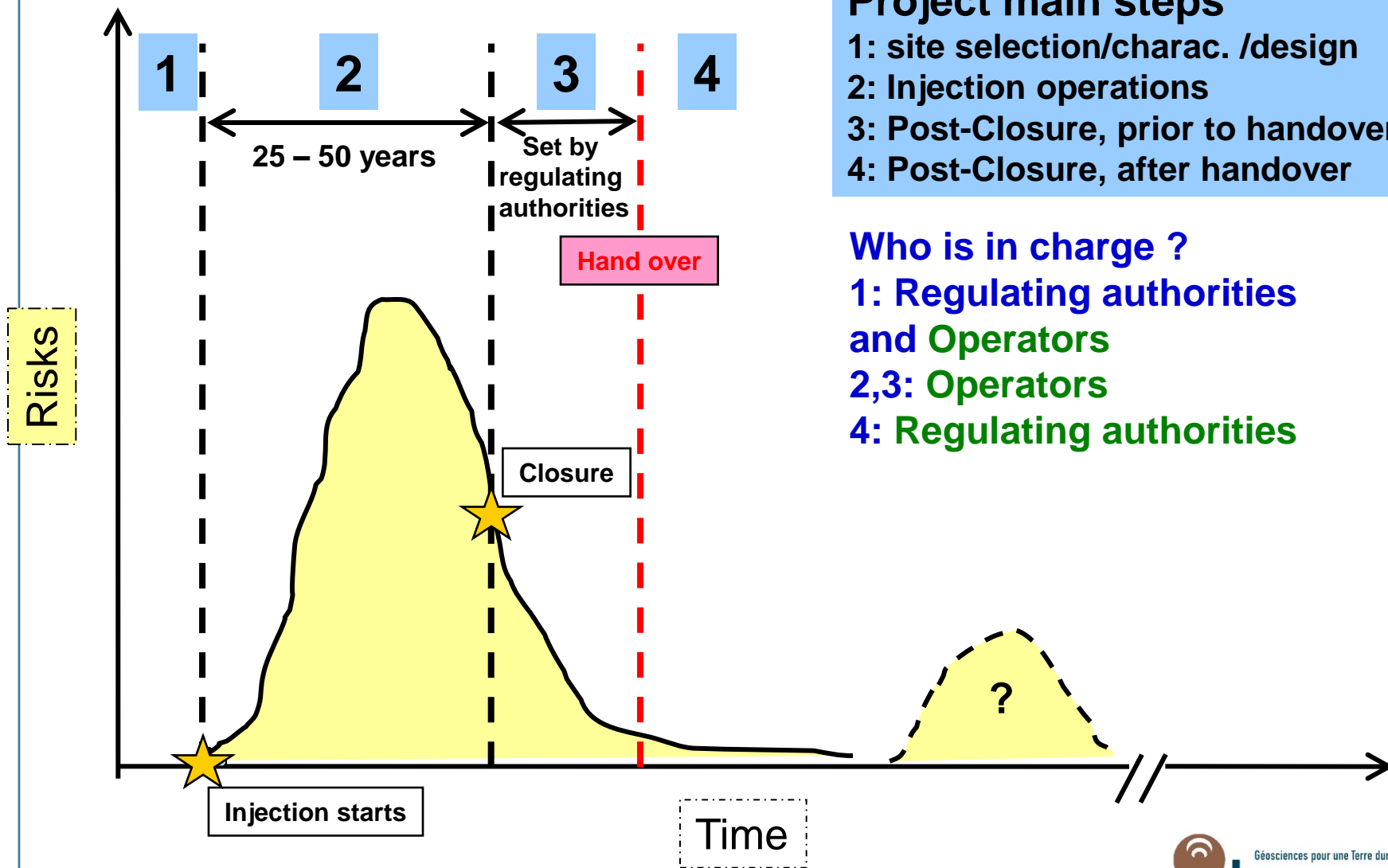
CO₂ atmospheric content evolution (from IPCC, 2005)



> **Global impact:** performance requirement to mitigate greenhouse gases emissions

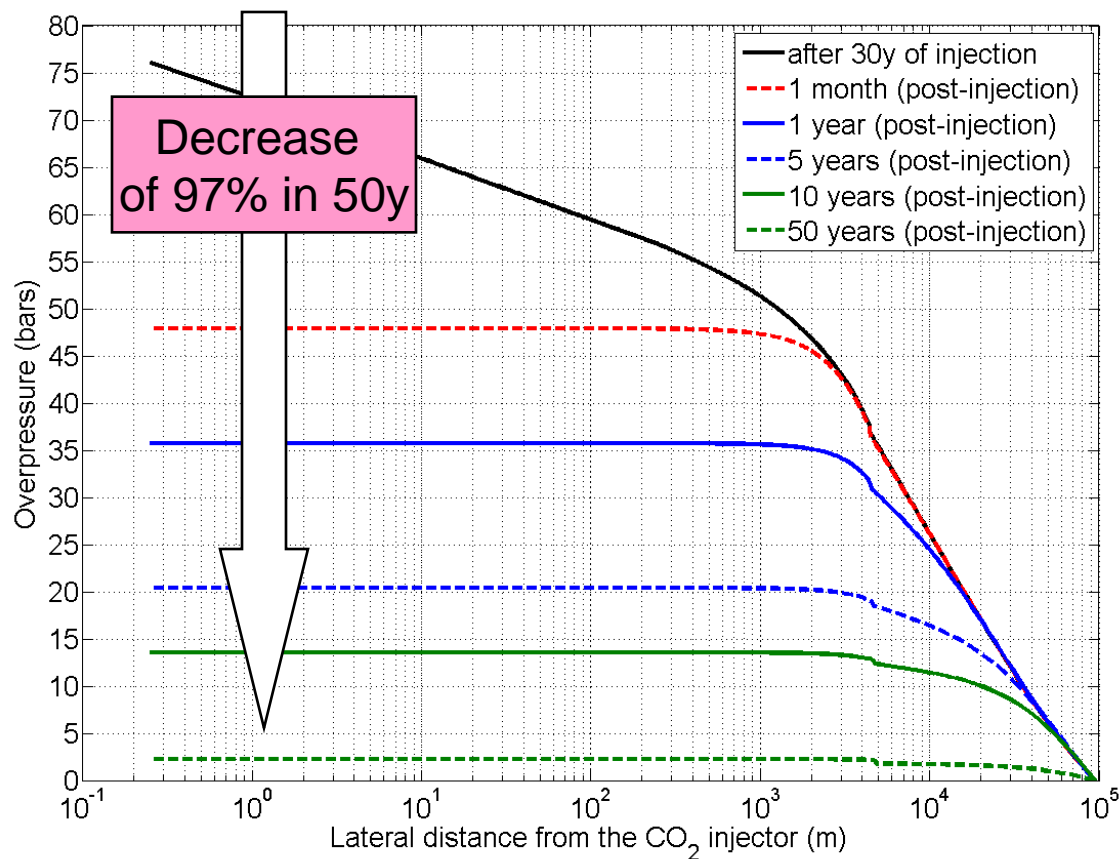
- At least 1000 years containment
- Mean leakage rate < 0.1 % / year

Risks over time



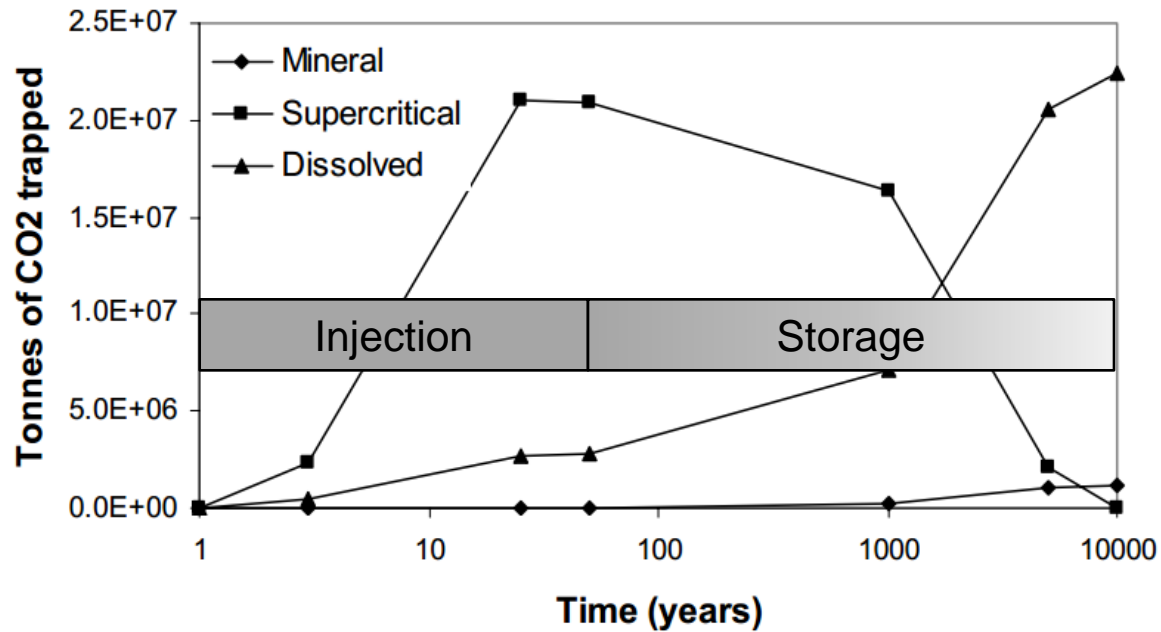
Adapted from Fouillac, 2009

Risque sur le long terme?



1D multiphase flow model of 1 Mt/y CO₂ injection in the Dogger (Paris basin)

Dissolution of CO2 over time



Simulations at Sleipner (North Sea),
Audigane et al. 2007

→ Dissolved CO2 → acidic fluid

Chemical-mechanical processes

A large variety...

- Dissolution processes
- Precipitation → Crystallization pressure
- Chemo-mechanical processes: Stress-enhanced dissolution (Pressure solution PS) and Sub-critical fracturing and stress corrosion (SC)
- Complex interactions with clay minerals
- Change of rock / fracture strength

Chemical-mechanical processes

A large variety...

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Crack propagation in reservoir rocks in the context of CO₂ storage

Thèse de Gisèle Suhett Helmer

Directeur : M. Jean Sulem (Navier)

M. Siavash Ghabezloo (Navier)

M. Jérémy Rohmer (BRGM)

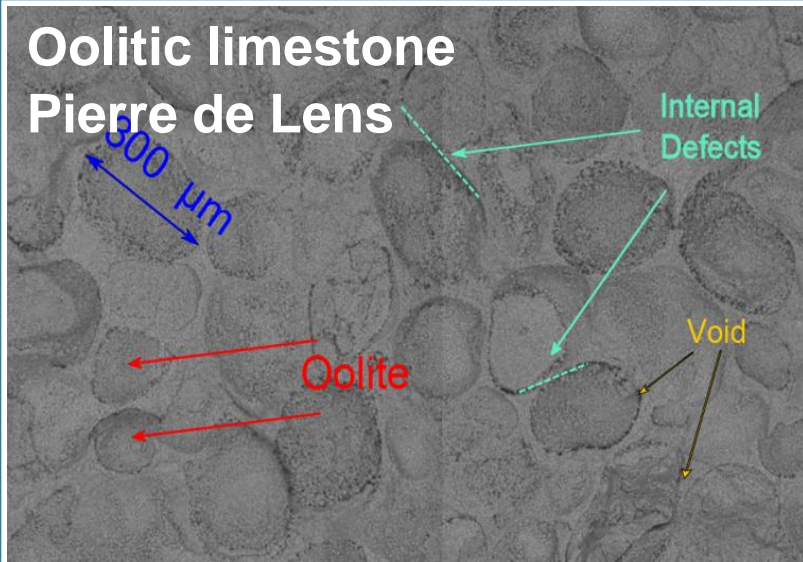
Cooperation with

LMT – M. François Hild

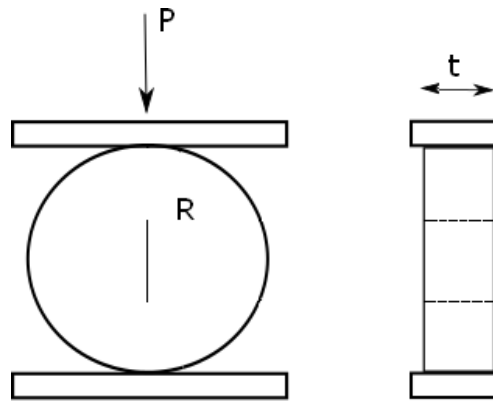
EIFER – M. Alain Dimier

IFSTTAR – Mme. Sylvine Guedon

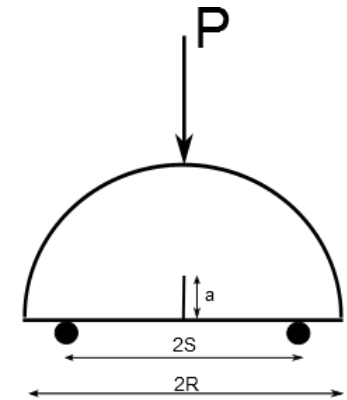
Soutenance
le 11/12/2014!



**Central Crack
Brazilian Disc CCBD**

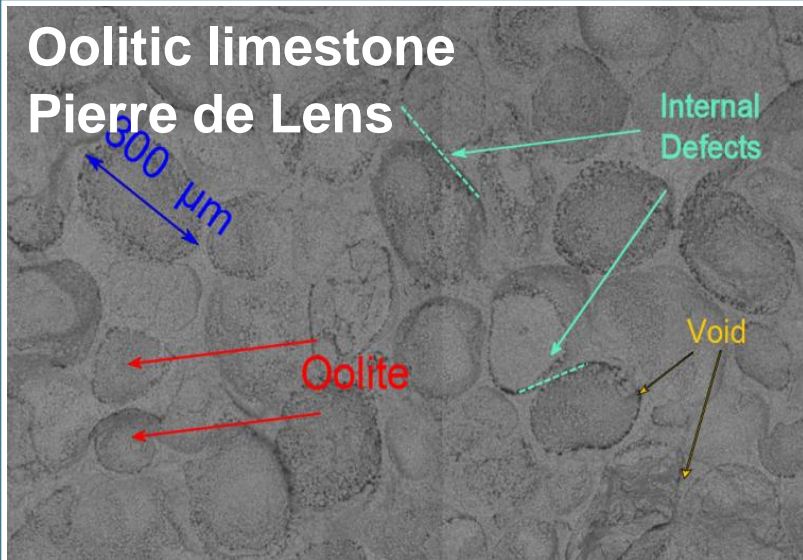


**Semi-Circular
Bending
SCB**

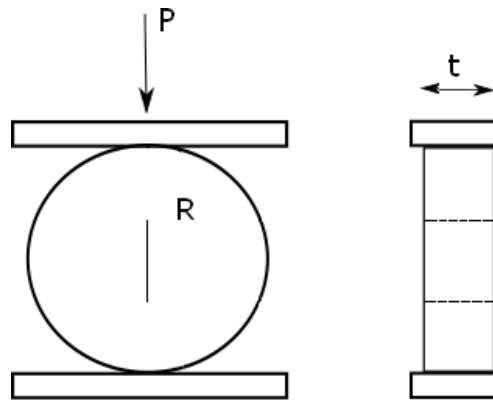


Estimate of fracture toughness via confrontation of several experimental tests, numerical modelling & digital image correlation technique

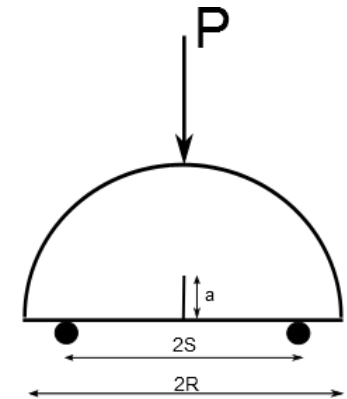
Oolitic limestone Pierre de Lens



Central Crack Brazilian Disc CCBD



Semi-Circular Bending SCB

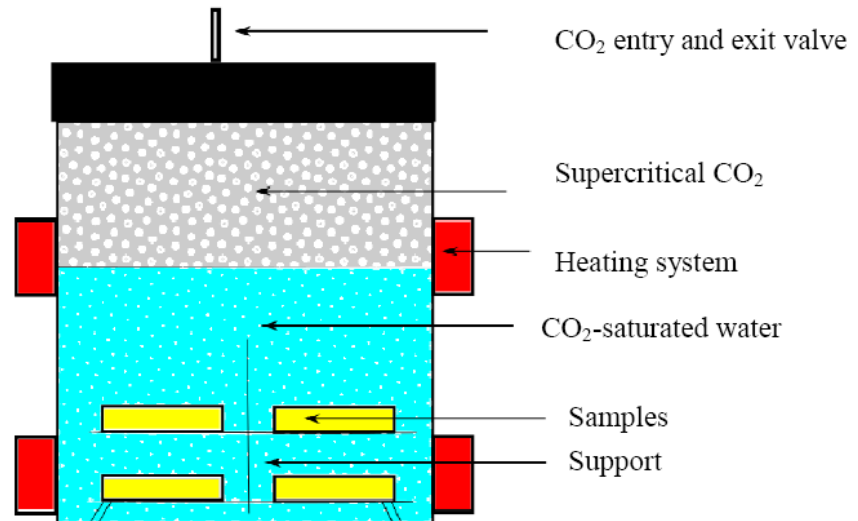


Estimate of fracture toughness via confrontation of several experimental tests, numerical modelling & digital image correlation technique

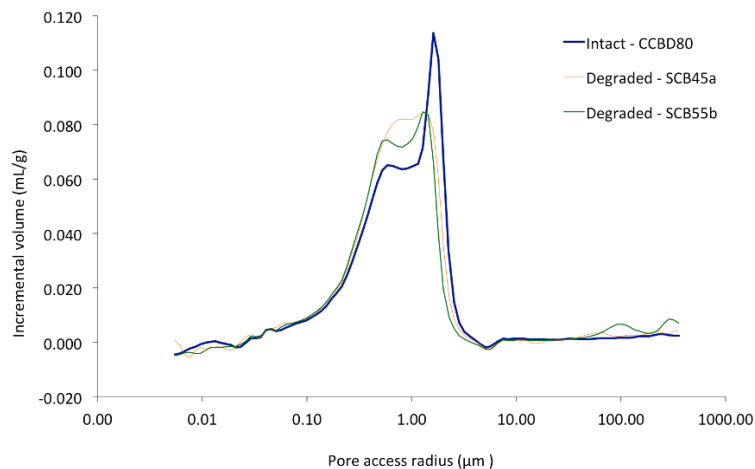
Autoclave

Duration : 1 month

P=150 bars, T=60 °C



Quelques résultats « positifs » / risque



After 4 weeks of exposure:
 14.5% → 14.9%
 Mean pore radius
 1.6 μm → 1 μm

Oolitic limestone (Pierre de Lens)	Intact		Exposed to CO ₂ (aqueous) during 4 weeks (autoclave, 150 bars, 60 °C)	
	SCB	CCBD	SCB	CCBD
Type of test	SCB	CCBD	SCB	CCBD
Number	14	11	14	4
Mean MPa.m ^{0,5}	0.65	0.61	0.58	0.58
Min-Max	0.51-0.77	0.55-0.68	0.46-0.69	0.54-0.66

Thèse de Gisèle Suhett Helmer 2014

~ -10%

RÉSUMÉ ET DISCUSSION

Risques géomécaniques dans le contexte des stockages de CO2

> Multiples:

- Réactivation de faille
- Perte d'intégrité de la couverture
- Perte d'intégrité des puits
- Mouvements du sol induits

> En phase opérationnelle (injection)

- Leur évaluation peut se baser sur les procédures / outils de l'ingénierie pétrolière;
- **Confrontation simulations versus observations en particulier à In-Salah, Weyburn**

Risques géomécaniques dans le contexte des stockages de CO2

> **MAIS...**

> Etendue **spatiale** des perturbations mécaniques peut aller beaucoup plus loin que celle de la bulle

- Intégrer dans l'analyse des failles « aveugles »

> Dimension **temporelle** via les processus chimie-mécaniques

- Multiples processus
- Besoin de recherche pour en comprendre les mécanismes

Merci de votre attention !

Remerciements:

ANR-FISIC



AMIRAL

