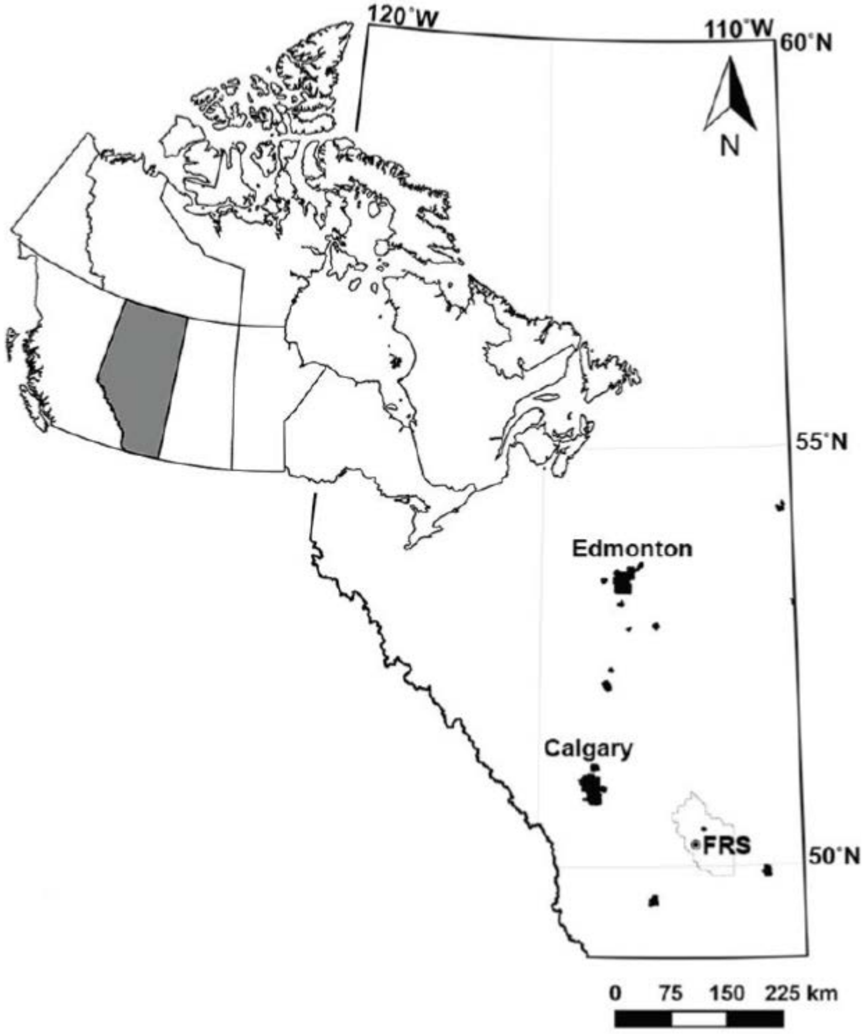
Reservoir simulations and feasibility study for seismic monitoring at CaMI.FRS

Marie Macquet and Donald C. Lawton

CREWES Annual Meeting, December 1st 2017, Banff, AB

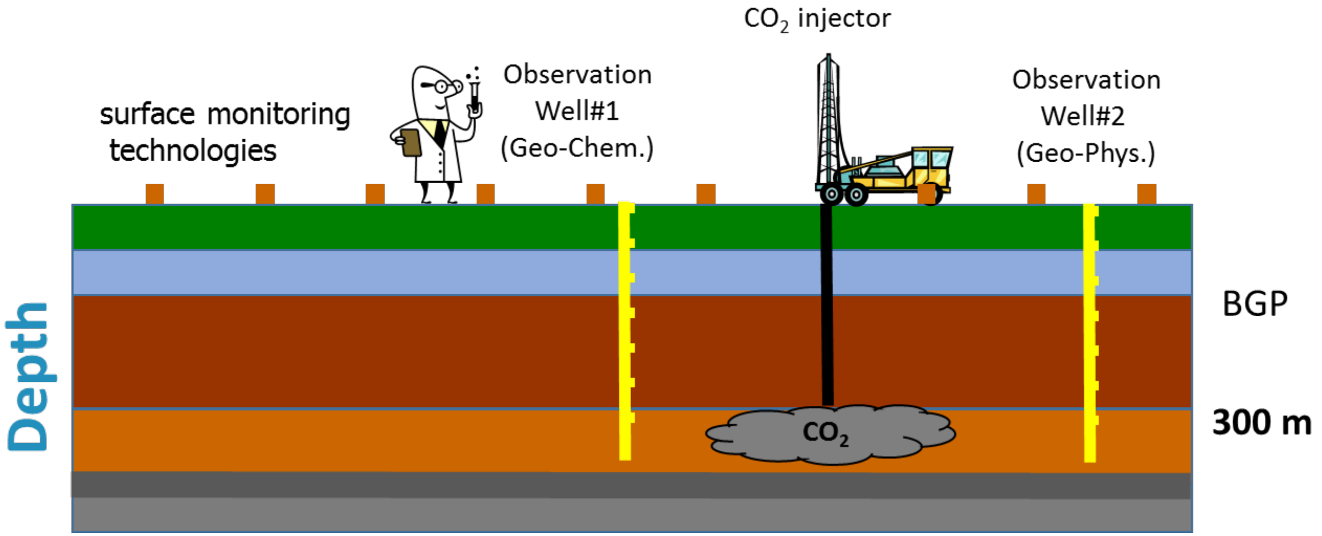
CaMI.FRS

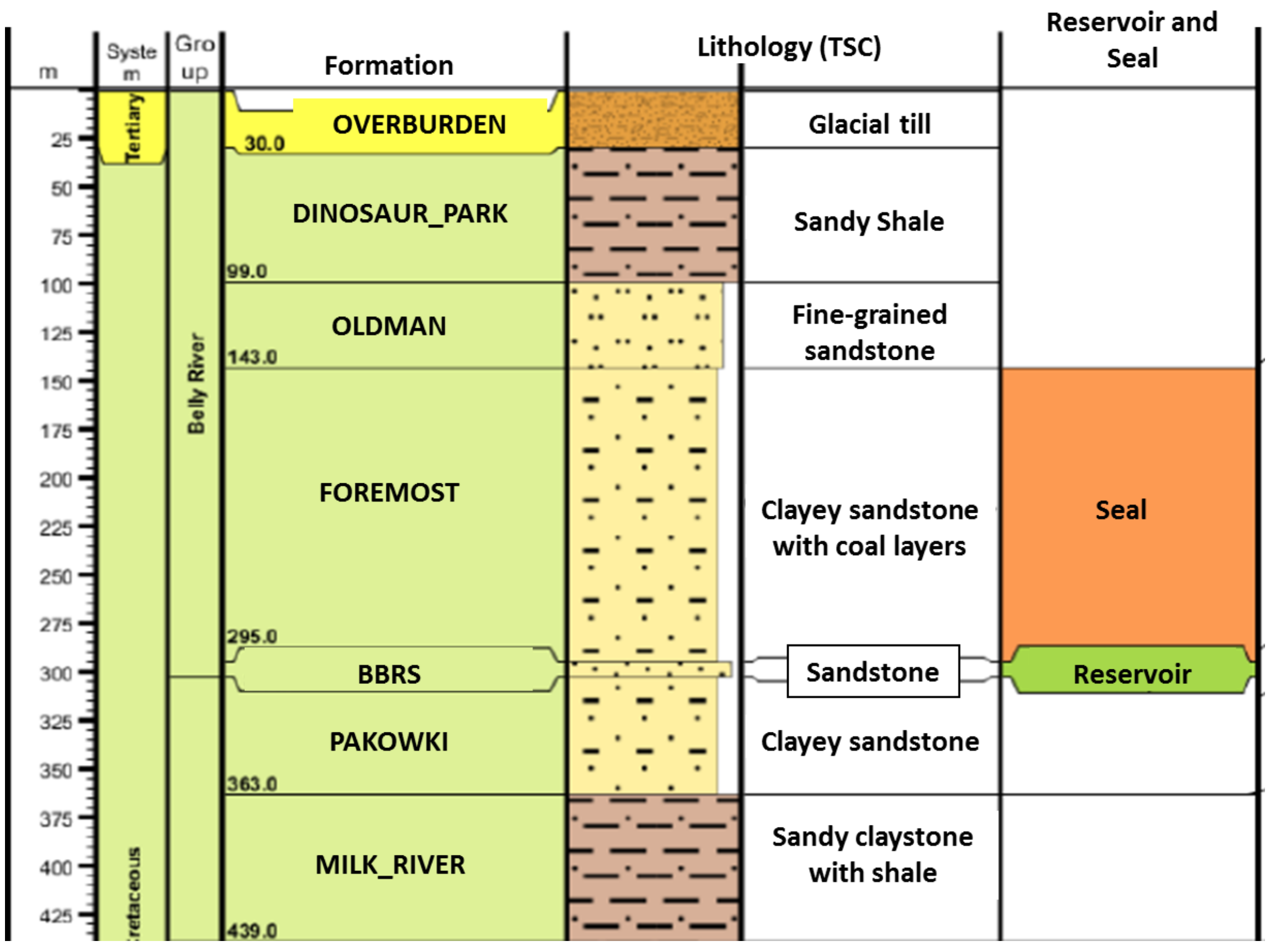


Purposes of CaMI.FRS :

- Develop improved monitoring technologies for early leakage detection ;
- Determine CO_2 detection thresholds.

=> Injection of a small amount of CO_2 (<1000/tons per year) at shallow depth (300m)



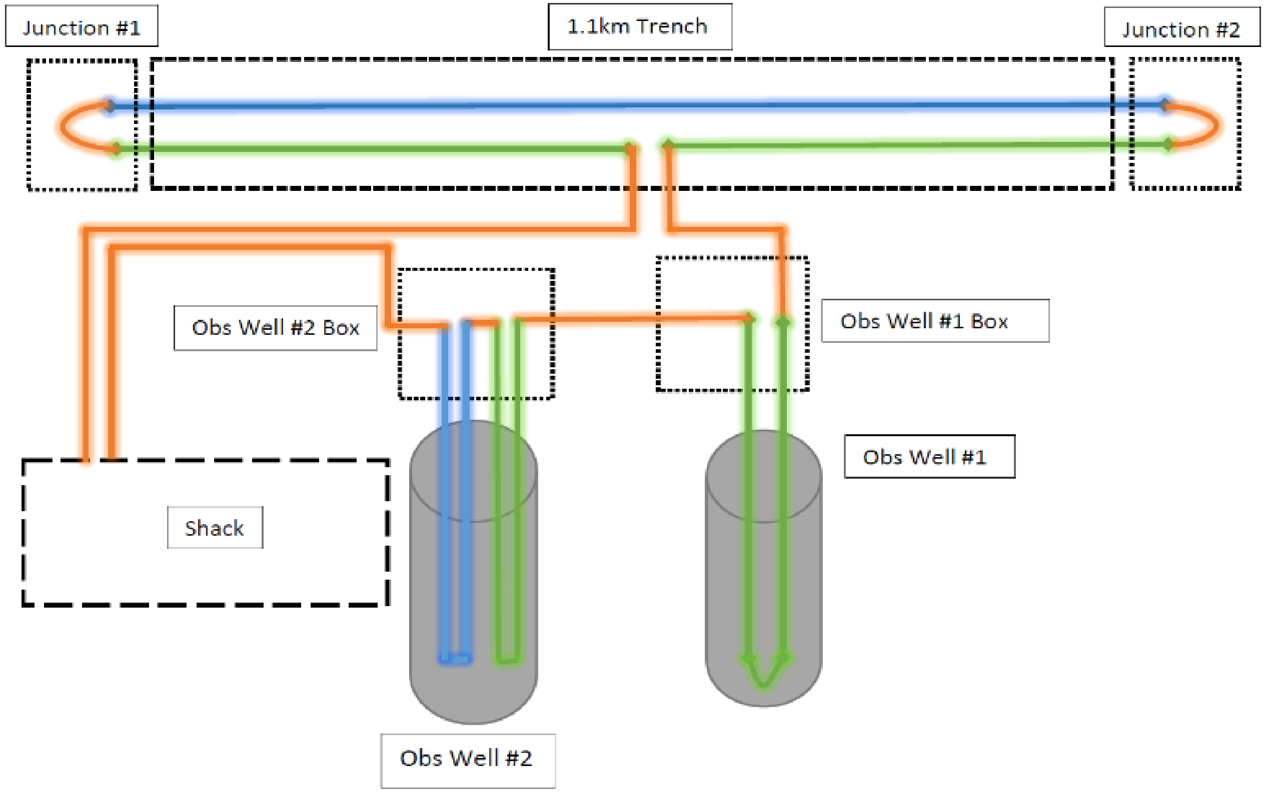


Reservoir target :
Basal Belly River Sandstone (BBRS) :
- 7m thickness (from 295 to 302m depth)
- Sandstone

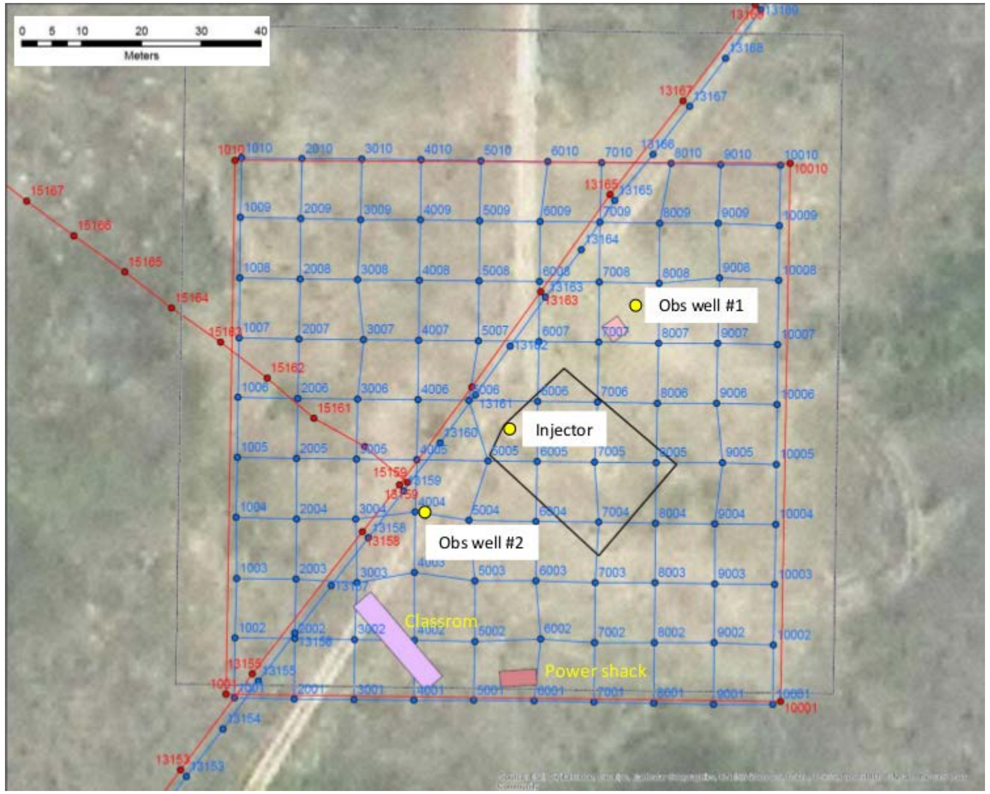
Seal :
Foremost formation
- 152m thickness (from 143 to 295m depth)
- Clayey sandstone with coal layers

CaMI.FRS – Geophysical installations

DAS (Harderman, Lawtown, Hall, Gordon presentations)



10x10 geophones array and continuous sources (Spackman presentation)



⇒ **Feasibility study for seismic monitoring using surface seismic reflection**

Feasibility study of seismic monitoring - Steps

1) Geomodelling	2) Fluid flow simulation	3) Fluid substitution	4) Seismic response simulation
HOW ?			
Combining well logs and 3D seismic, interpolating	Running injection simulations	Gassmann fluid substitution	3D final difference modeling
WHY ?			
To get 3D models of the porosity and permeability	To get CO_2 saturation and the pressure response	To get 3D models of the elastic parameters after CO_2 injection	To see if we can detect the CO_2 plume

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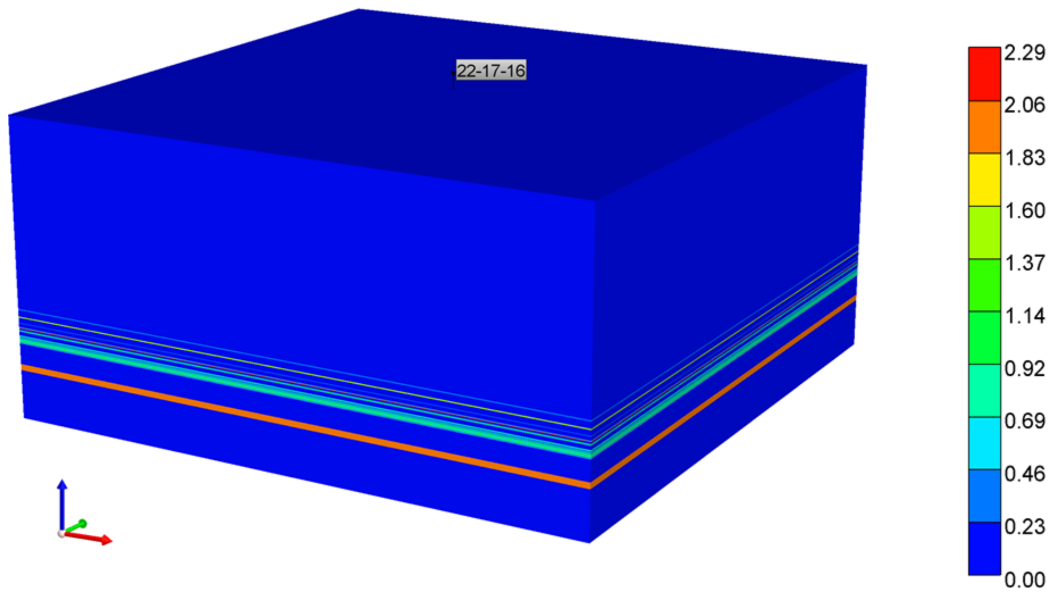
I - Geostatic models – J. Dongas and J. Barazza

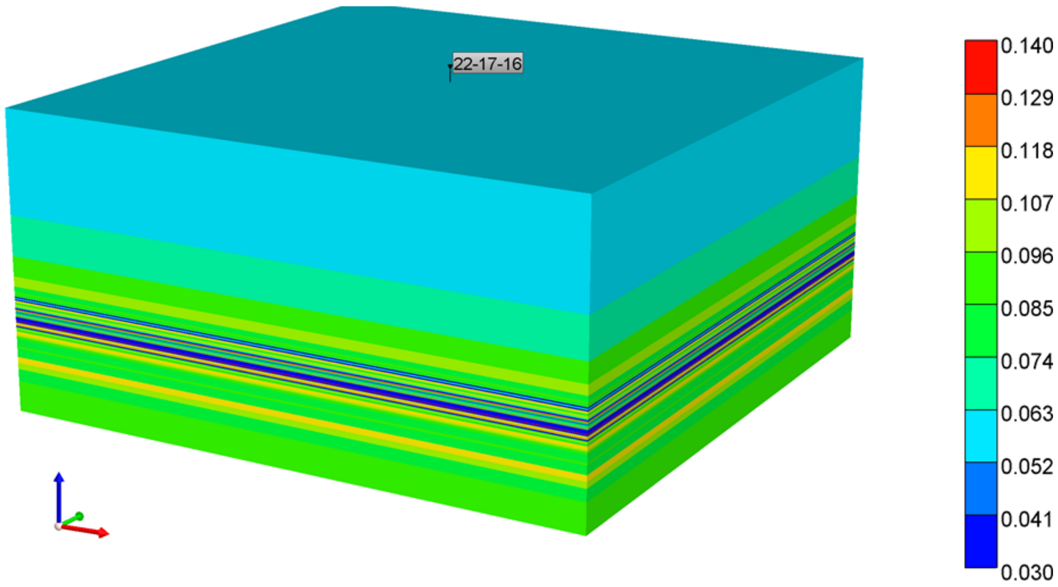
- Layer-cake model
- 1000m*1000m*250m
- built using wells logs and 3D seismic data

- K_v/K_h = 0.1
- Reservoir porosity ~ 0.1
- Reservoir permeability ~ 0.8 mD

Permeability (mD)



Porosity



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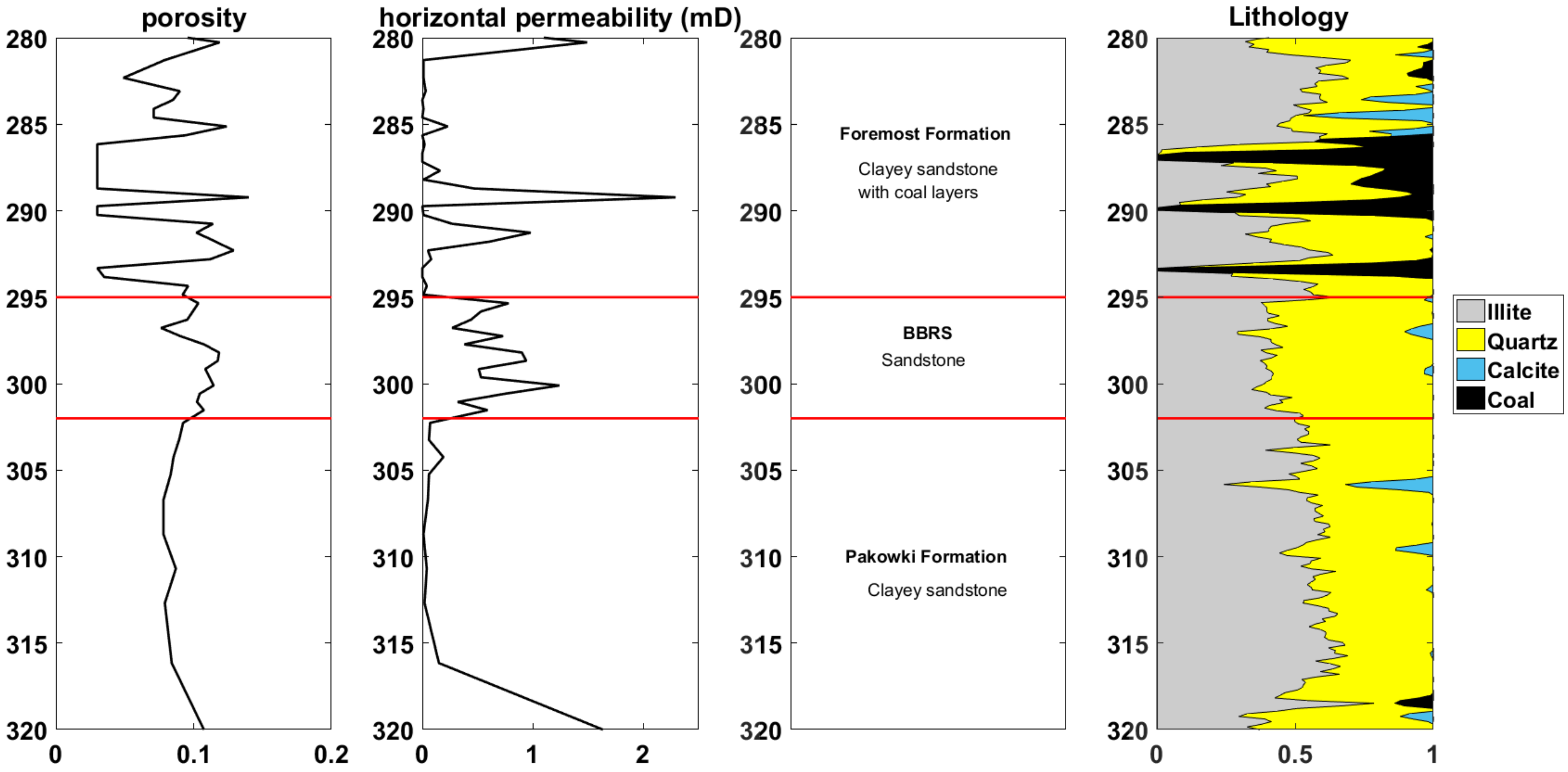

Average~ 0.1

Average: ~ 0.8 mD

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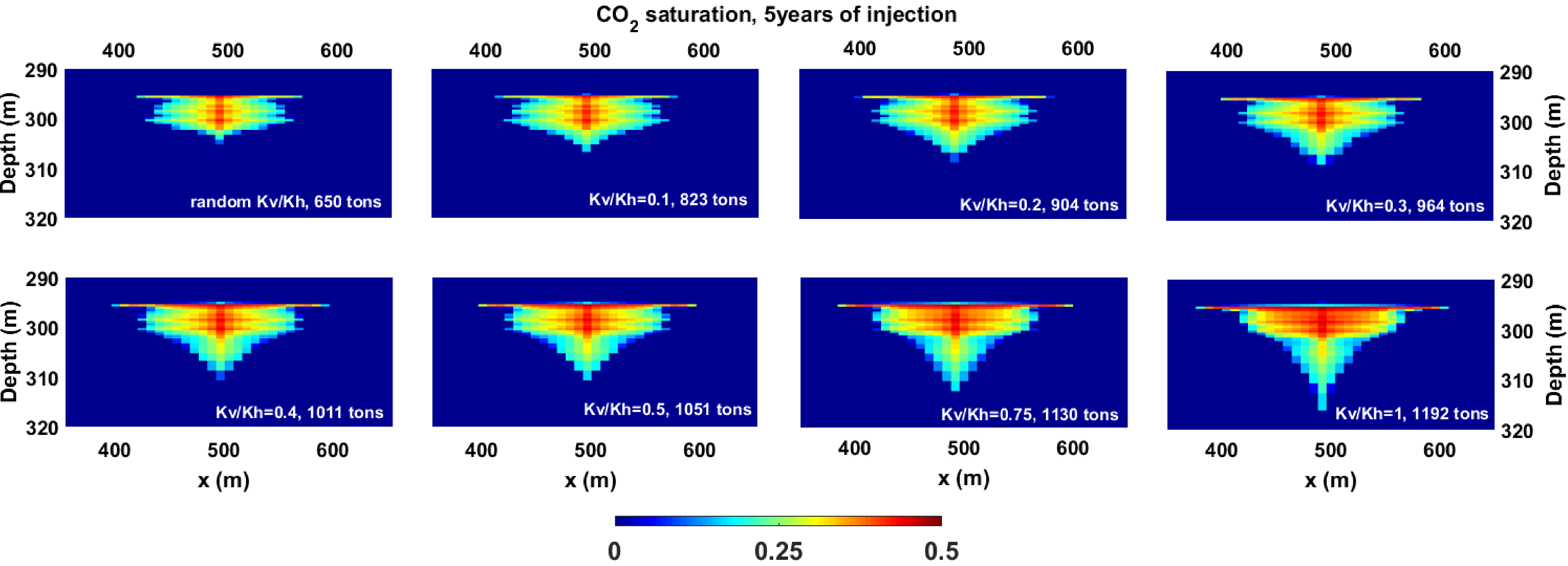
II - Injection simulations – Vertical permeability

Vertical permeability describes how the CO_2 can migrate vertically



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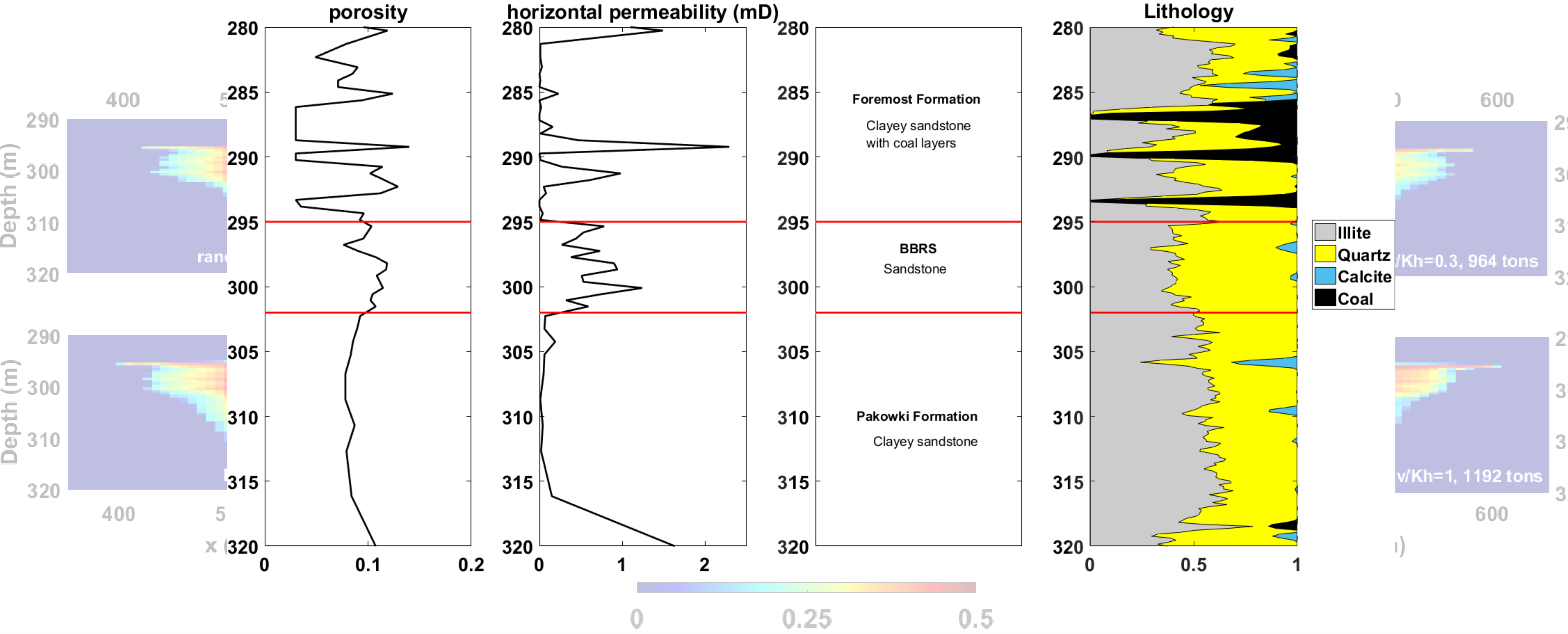
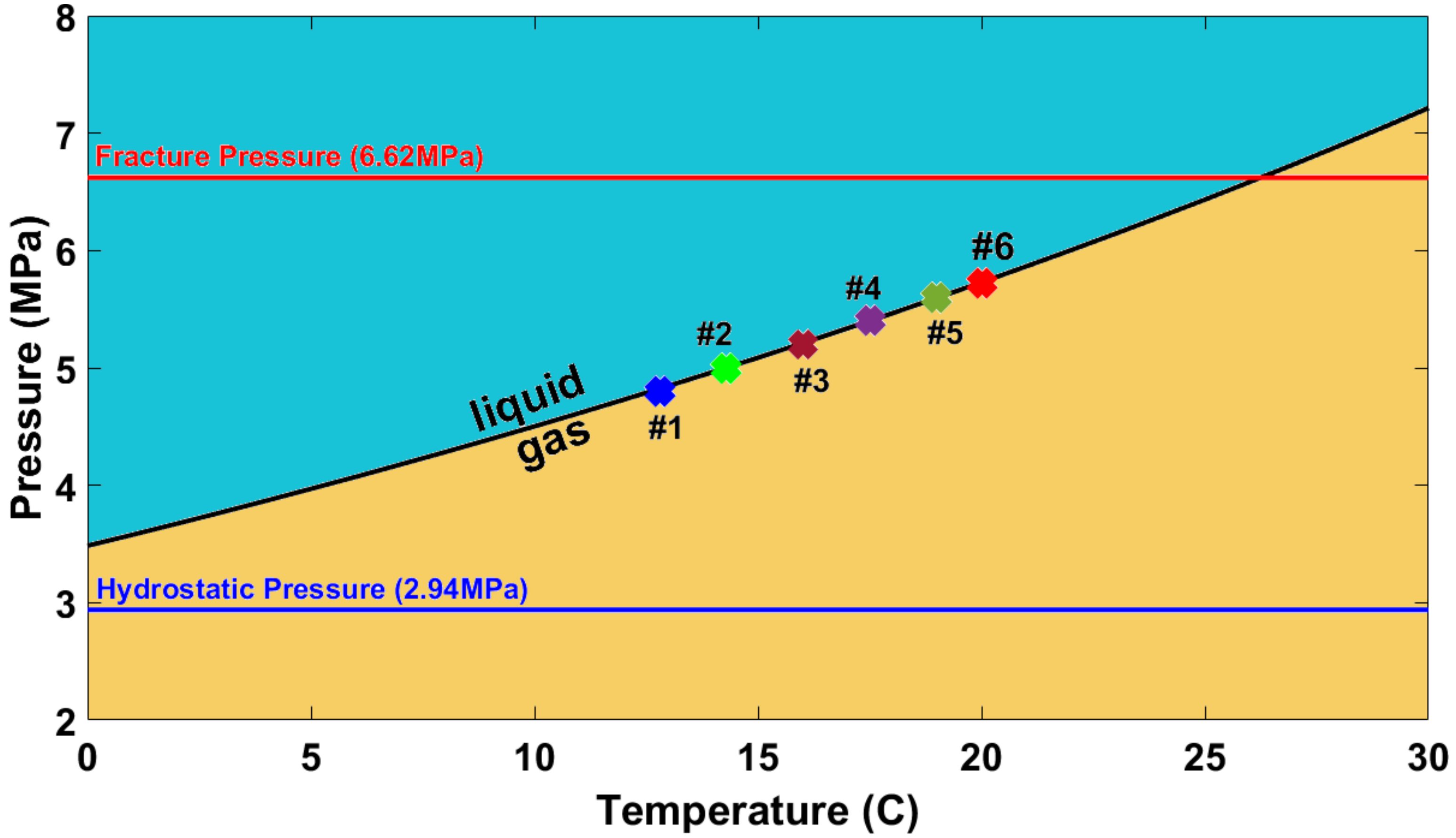


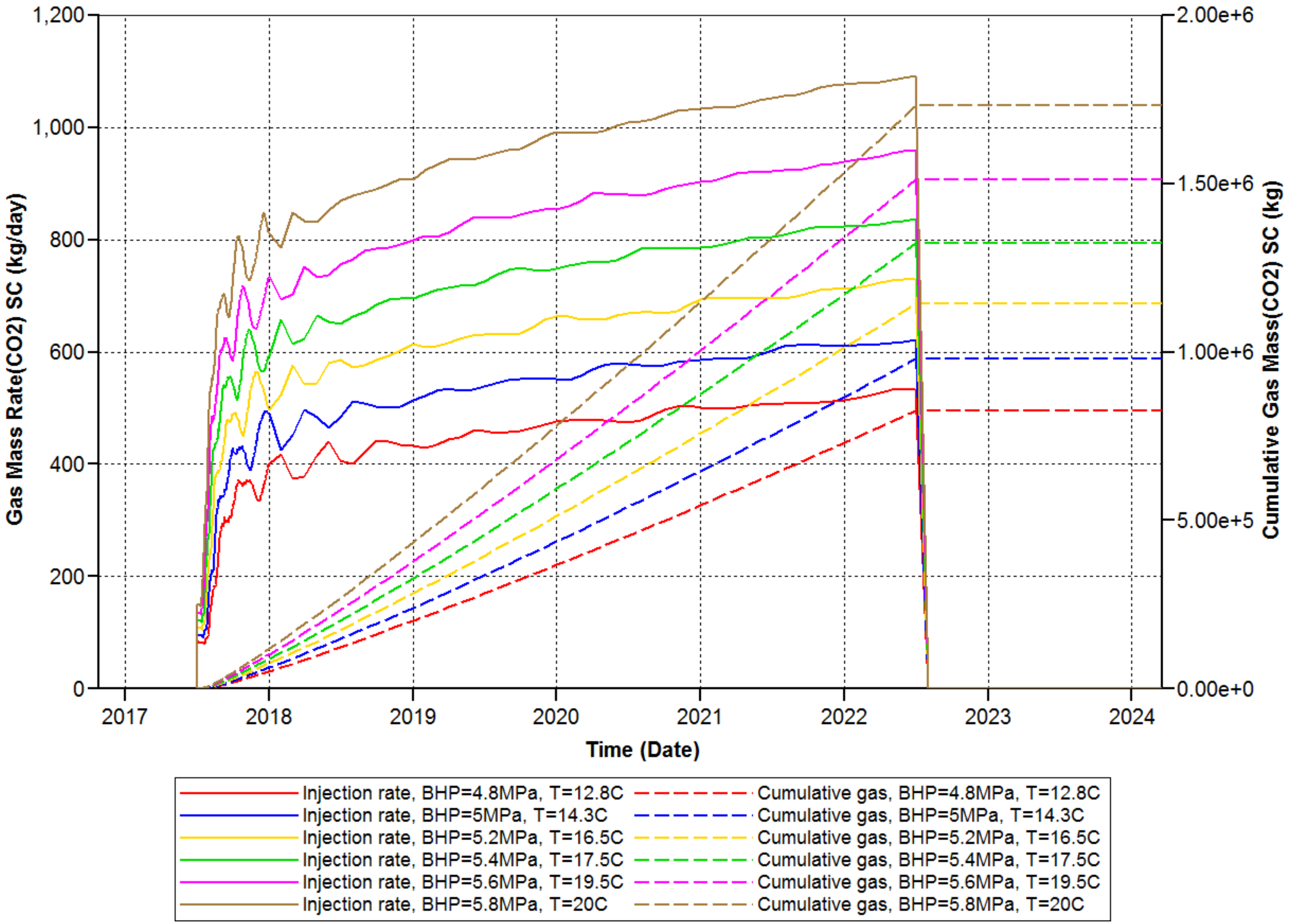
II - Injection simulations – Maximum Bottom-hole pressure



Constrains :

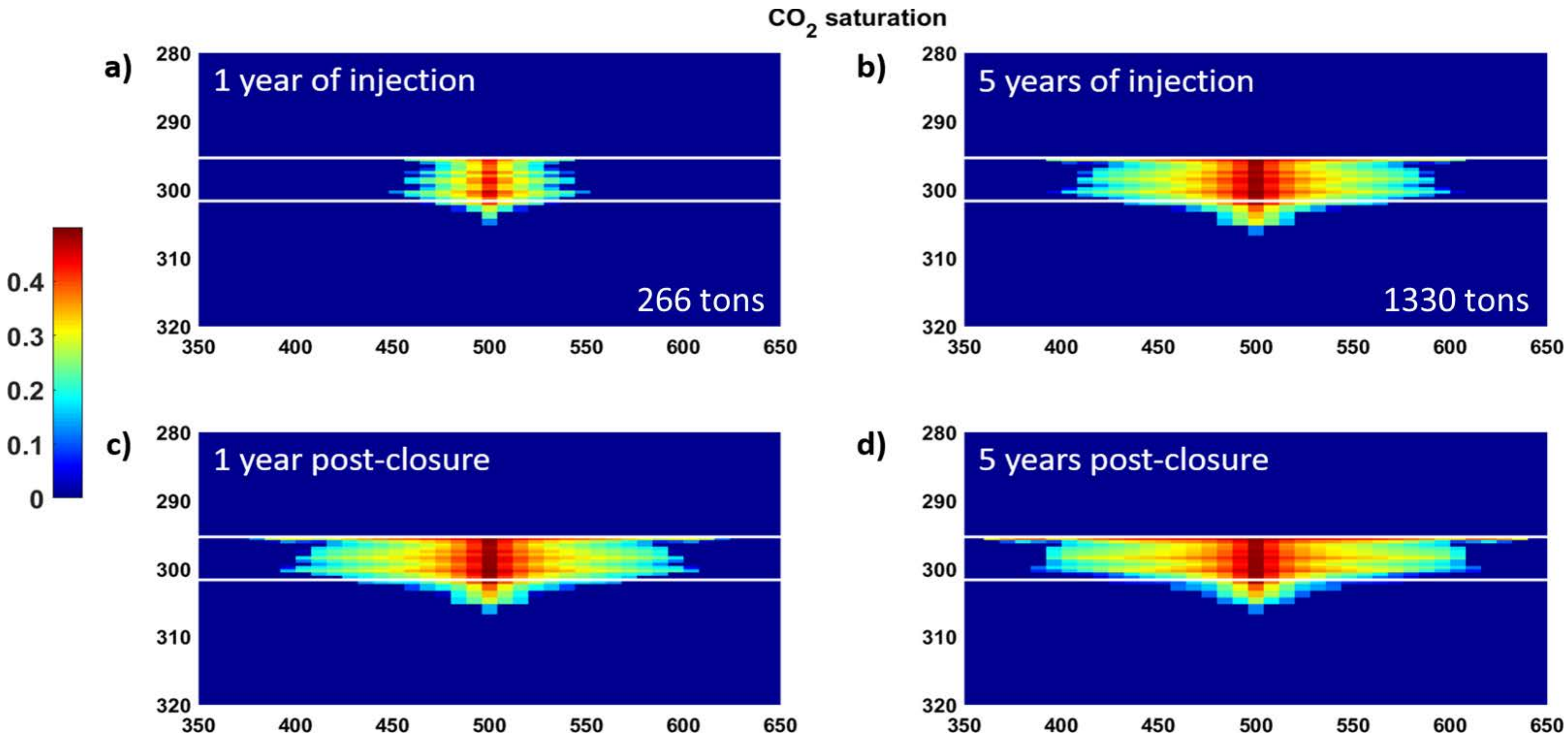
(1) CO_2 in gaseous phase
(2) Reservoir temperature = 12.8°C
(3) Fracture pressure is 6.62 MPa

II - Injection simulations – Maximum Bottom-hole pressure



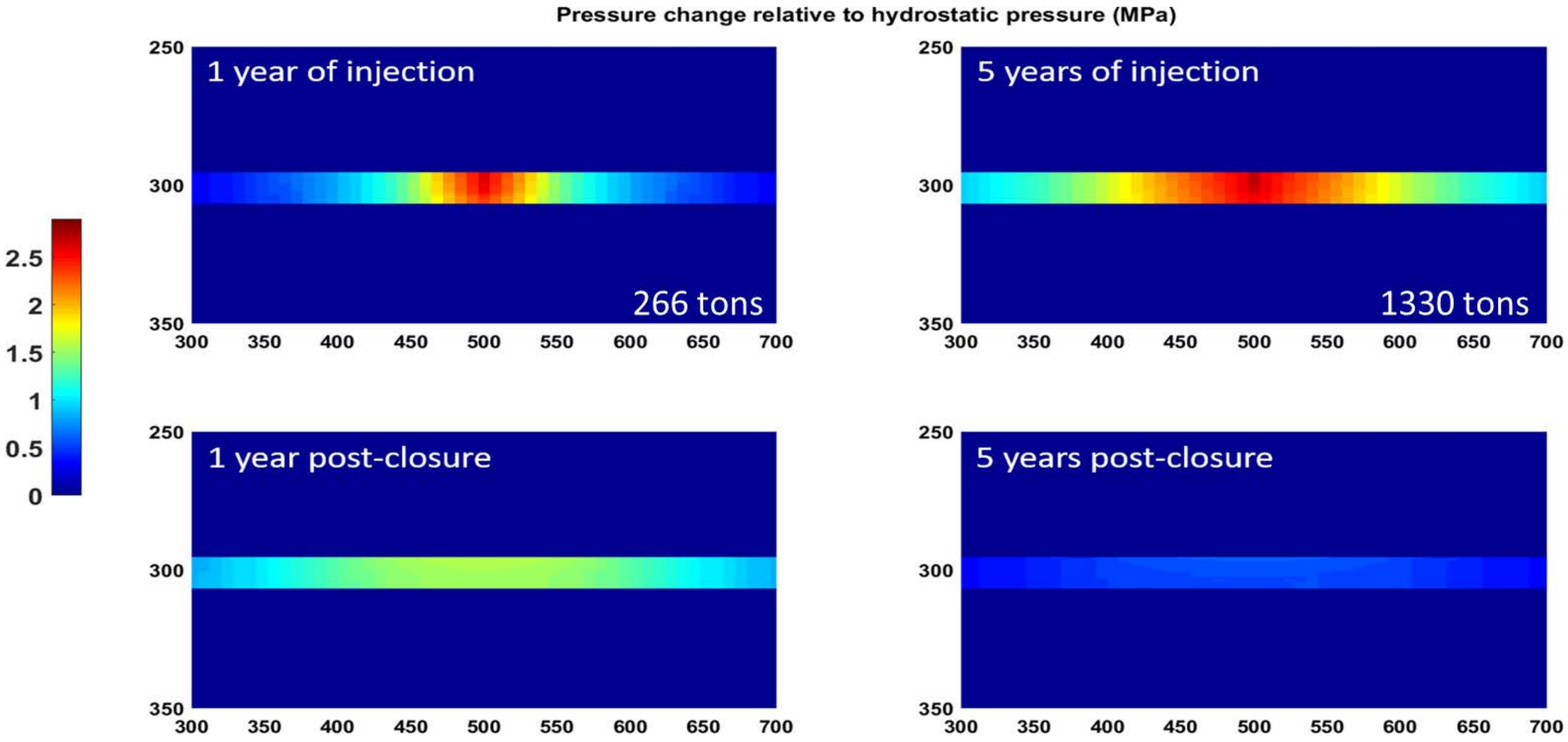
	Average rate (kg/day)	Total injected (tons)
4.8MPa	450	825
5.0MPa	535	980
5.2MPa	630	1145
5.4MPa	725	1320
5.6MPa	835	1520
5.8MPa	950	1730

II - Injection simulation used – CO_2 saturation, BHP = 5.8MPa



Estimated irreducible water saturation = 0.5
Gas and water permeability calculated using the Brooks-Corey model

II - Injection simulation used – Pressure



Hydrostatic pressure at 300m: 2.94MPa

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III - Fluid substitution – Modelling the elastic parameters variation

$$\boldsymbol{V_{P(new)}} = \sqrt{\frac{K_{sat(new)} + {}^{4}/_{3}\ \mu_{sat}}{\rho_{(new)}}}$$

Gassmann's equation links the bulk modulus of a rock to its pore, frame and fluid properties (Gassmann, 1951)

$$K_{sat} = K^{*} + \frac{\left[1 - \left(\frac{K^{*}}{K_{0}}\right)\right]^{2}}{\frac{\phi}{K_{fl}} + \frac{(1 - \phi)}{K_{0}} - \frac{K^{*}}{K_{0}^{2}}}$$

$$K_{sat_{(new)}} = \frac{K_{0}}{\left[\frac{K_{sat(init)}}{K_{0} - K_{sat(init)}} - \frac{K_{fluid(init)}}{\phi(K_{0} - K_{fluid_{(init)}})} + \frac{K_{fluid(new)}}{\phi(K_{0} - K_{fluid_{(new)}})}\right]^{-1} + 1}$$

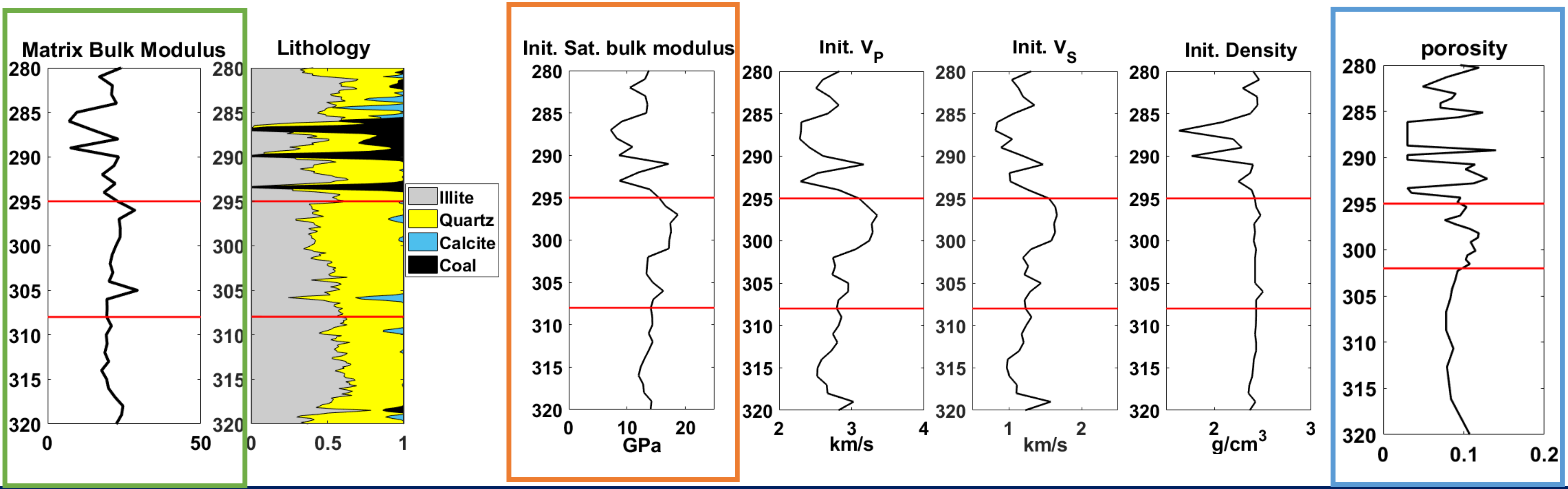
III - Fluid substitution – Input parameters

$$K_{sat(new)} = \frac{K_0}{\left[\frac{K_{sat(init)}}{K_0 - K_{sat(init)}} - \frac{K_{fluid(init)}}{\phi(K_0 - K_{fluid(init)})} + \frac{K_{fluid(new)}}{\phi(K_0 - K_{fluid(new)})}\right]^{-1} + 1}$$

K_0 is the matrix bulk modulus

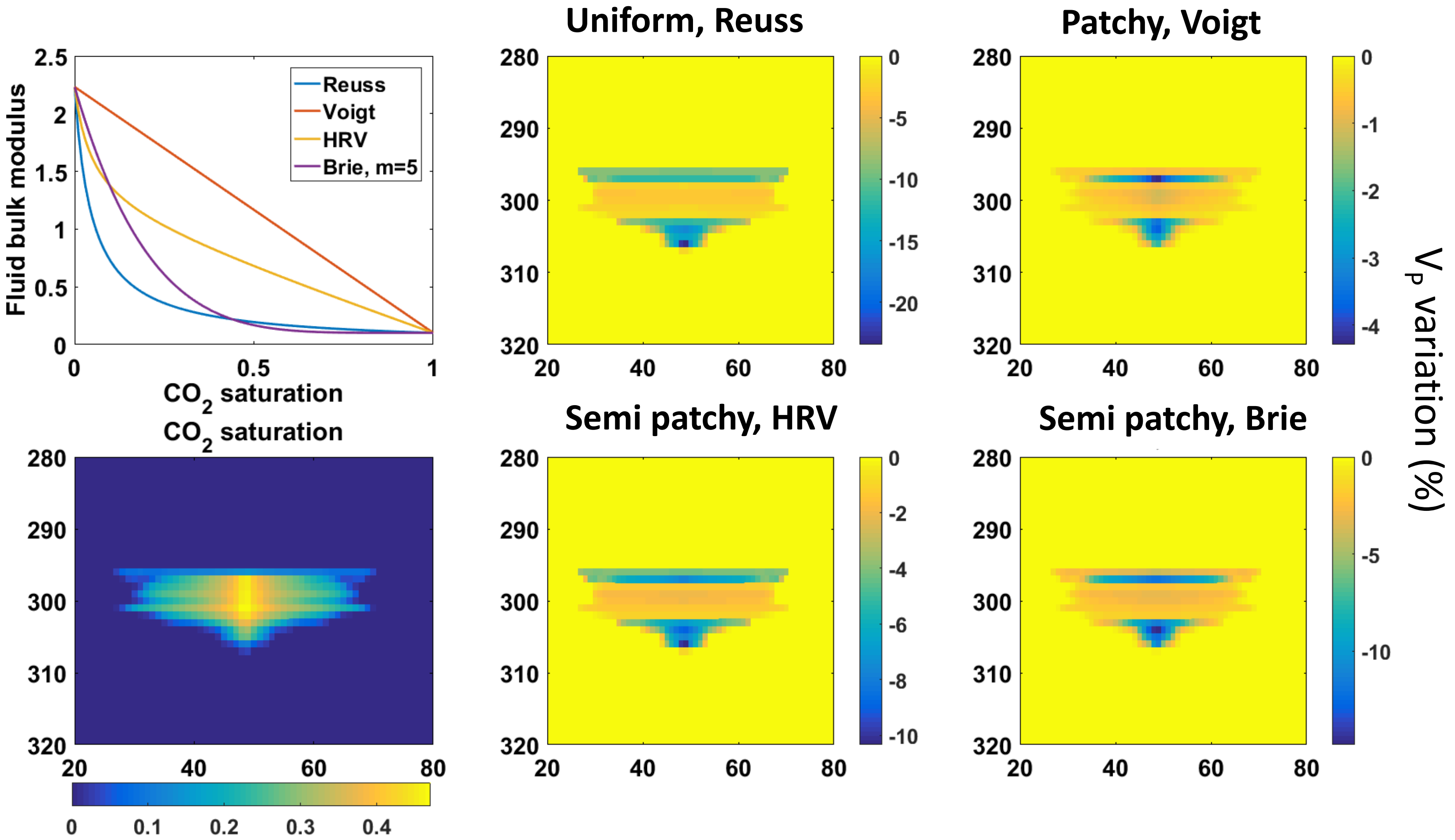
$K_{sat(init)}$ is the initial saturated bulk modulus

ϕ is the porosity



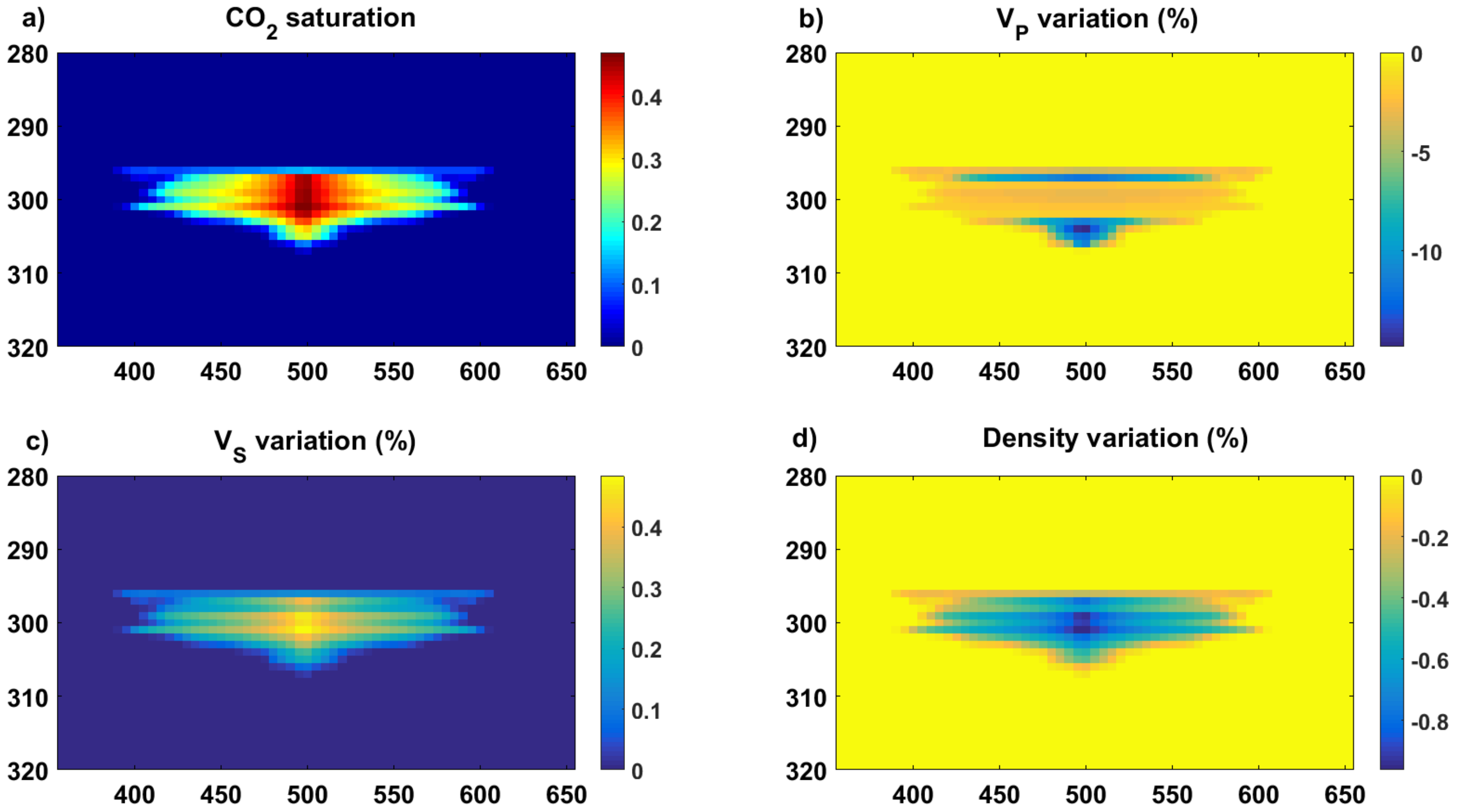
III - Fluid substitution – K_{fluid} - Which saturation behavior ?

$$K_{sat(new)} = \frac{K_0}{\left[\frac{K_{sat(init)}}{K_0 - K_{sat(init)}} - \frac{K_{fluid(init)}}{\phi(K_0 - K_{fluid(init)})} + \frac{K_{fluid(new)}}{\phi(K_0 - K_{fluid(new)})}\right]^{-1} + 1}$$



III - Fluid substitution – Final results

2D sections of elastic parameters variation, 5 years of injection



Average elastic parameters variation

	1 year of injection	5 years of injection
V_P	**-1.82%**	**-2.42%**
V_S	**0.12%**	**0.15%**
ρ	**-0.23%**	**-0.3%**

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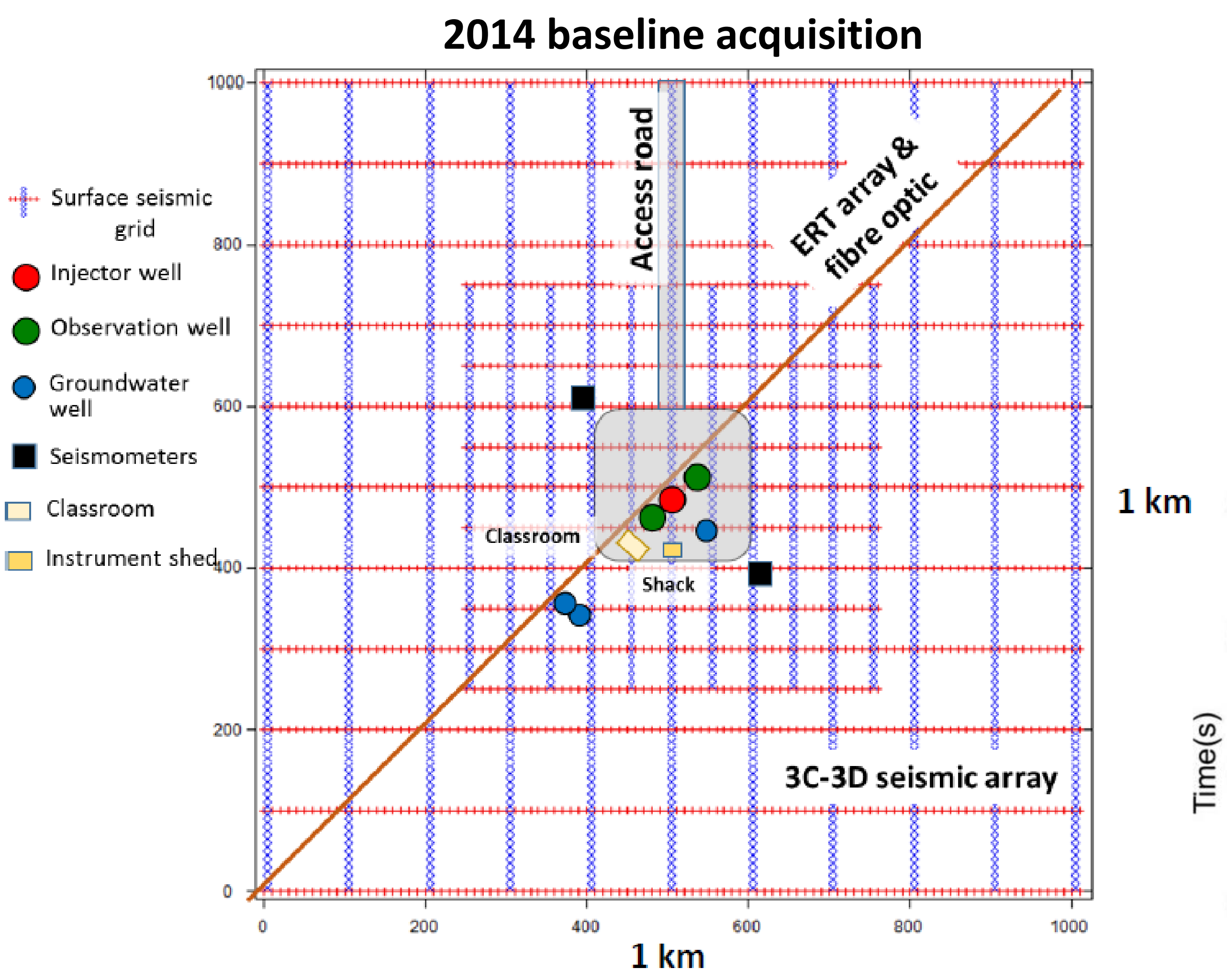
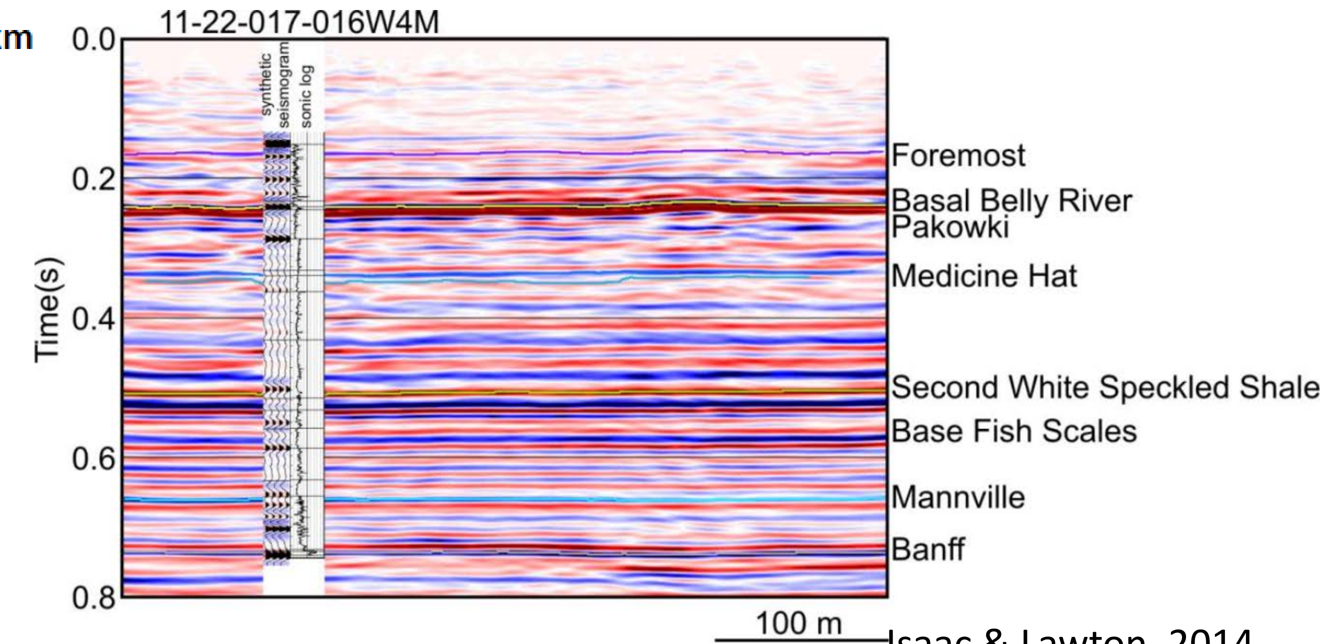
IV - Seismic simulation



- 1400 receivers **(blue)**
- 1434 shots **(red)**

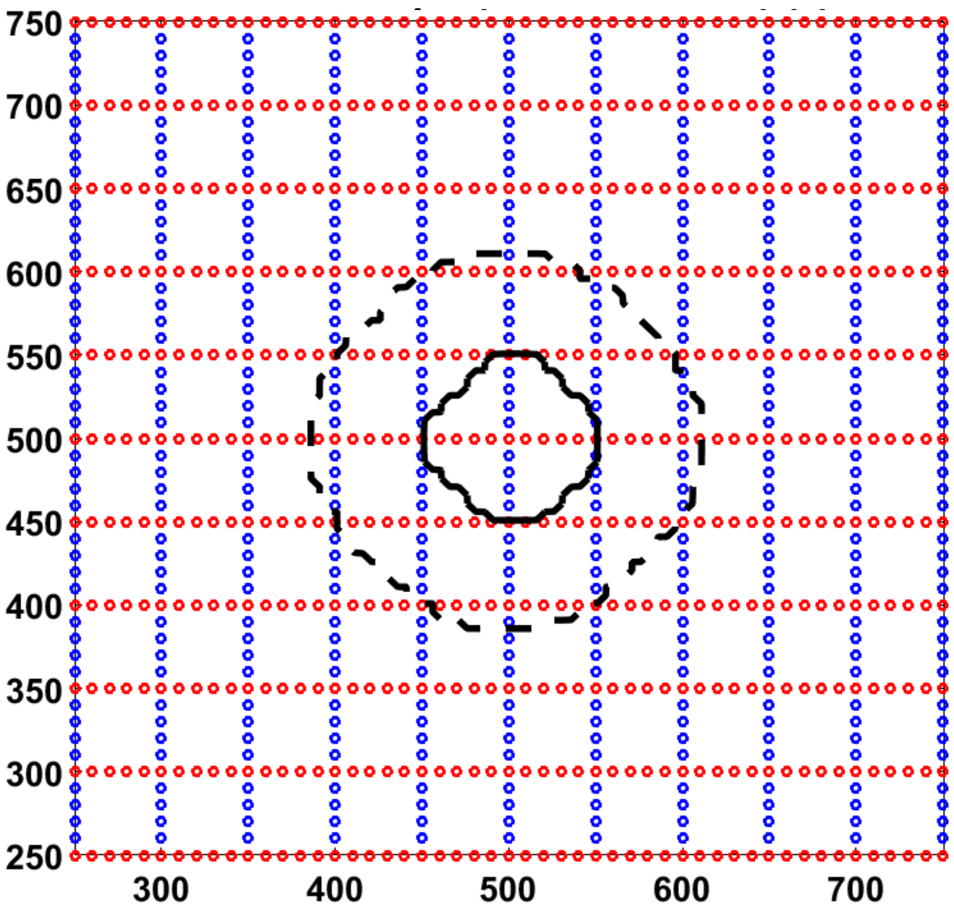
Bin size : 5m x 5m



Isaac & Lawton, 2014

IV - Seismic simulation

Data simulation with Tiger, a 3D anisotropic finite-difference modelling software (SINTEF)



- 561 receivers **(blue)**
- 561 sources **(red)**

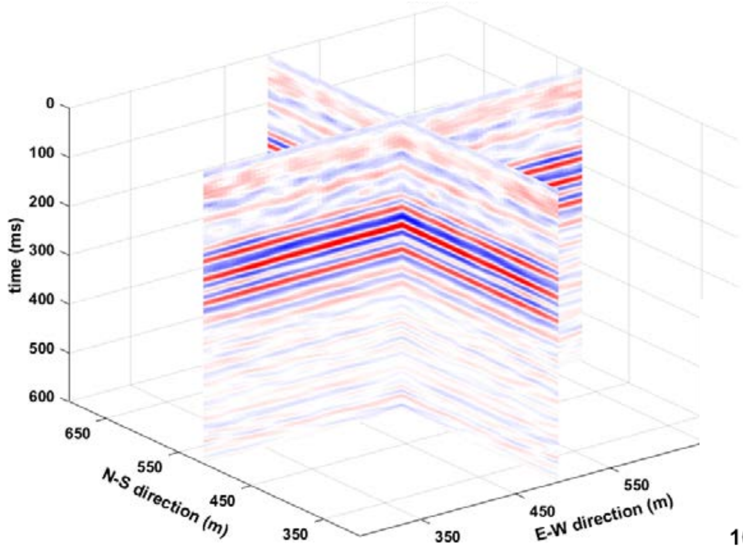
Standard processing with Vista

- Deconvolution
- NMO
- CMP stack
- Post-stack time migration

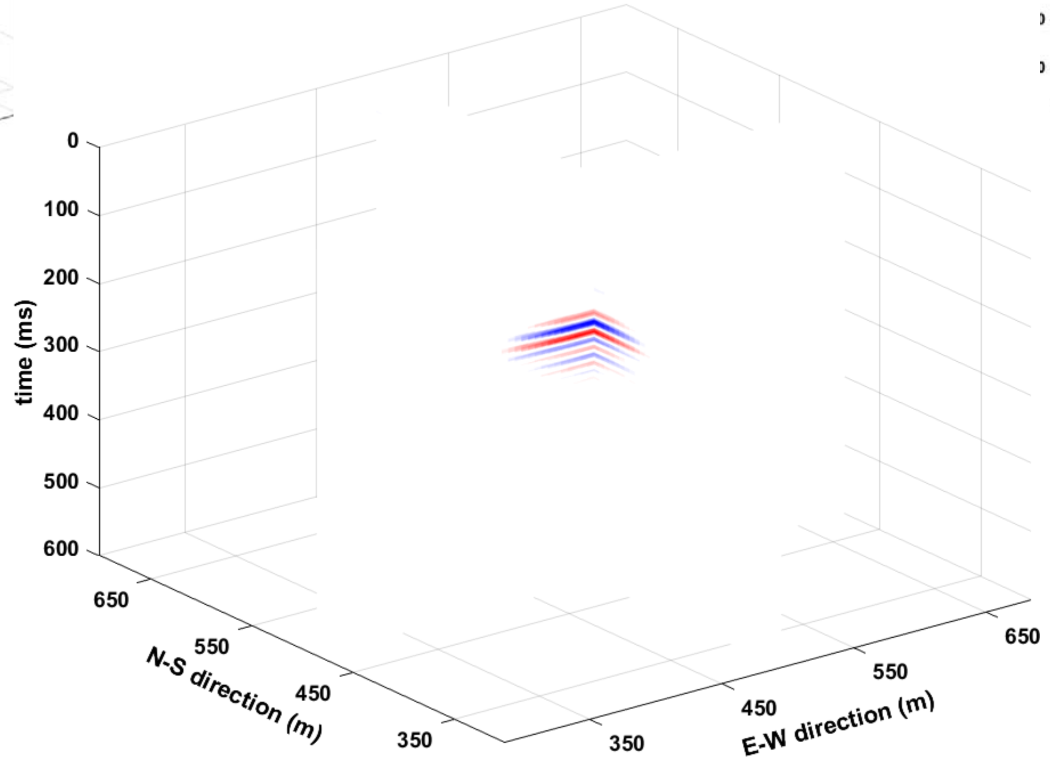
Bin size : 5m x 5m

IV - Seismic simulation

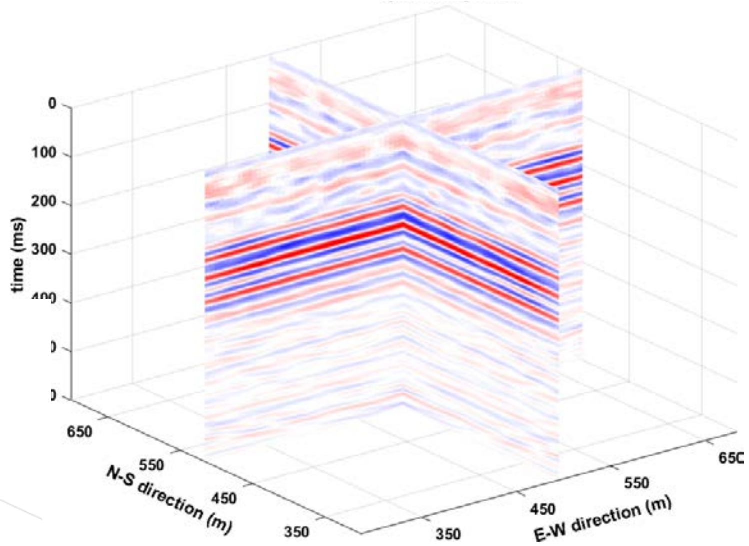
BASELINE



DIFFERENCE



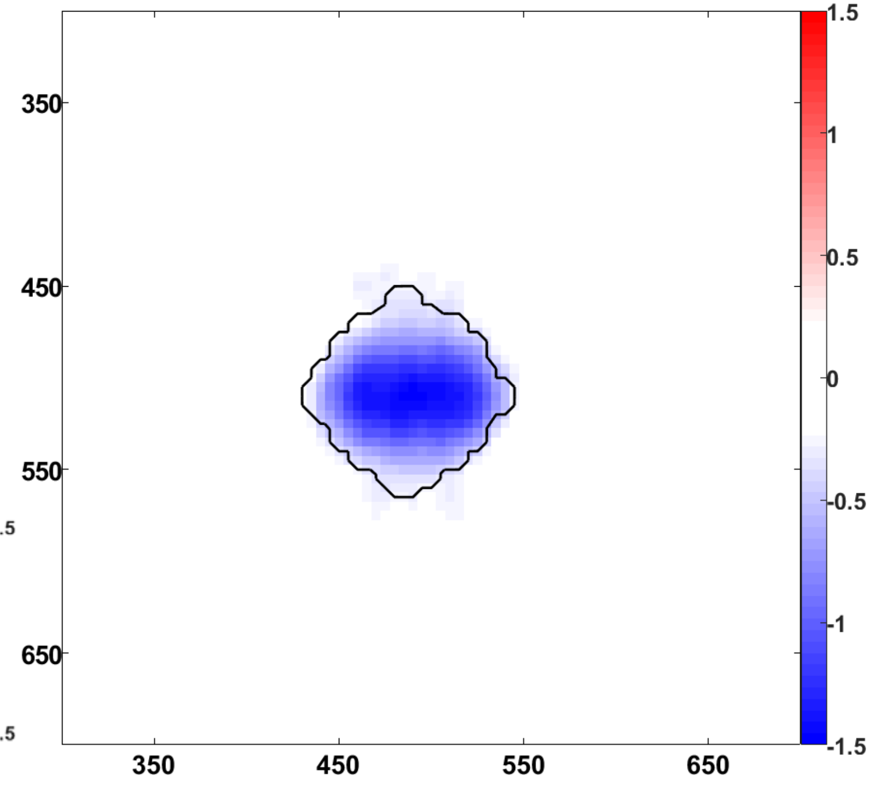
1 YEAR OF INJECTION

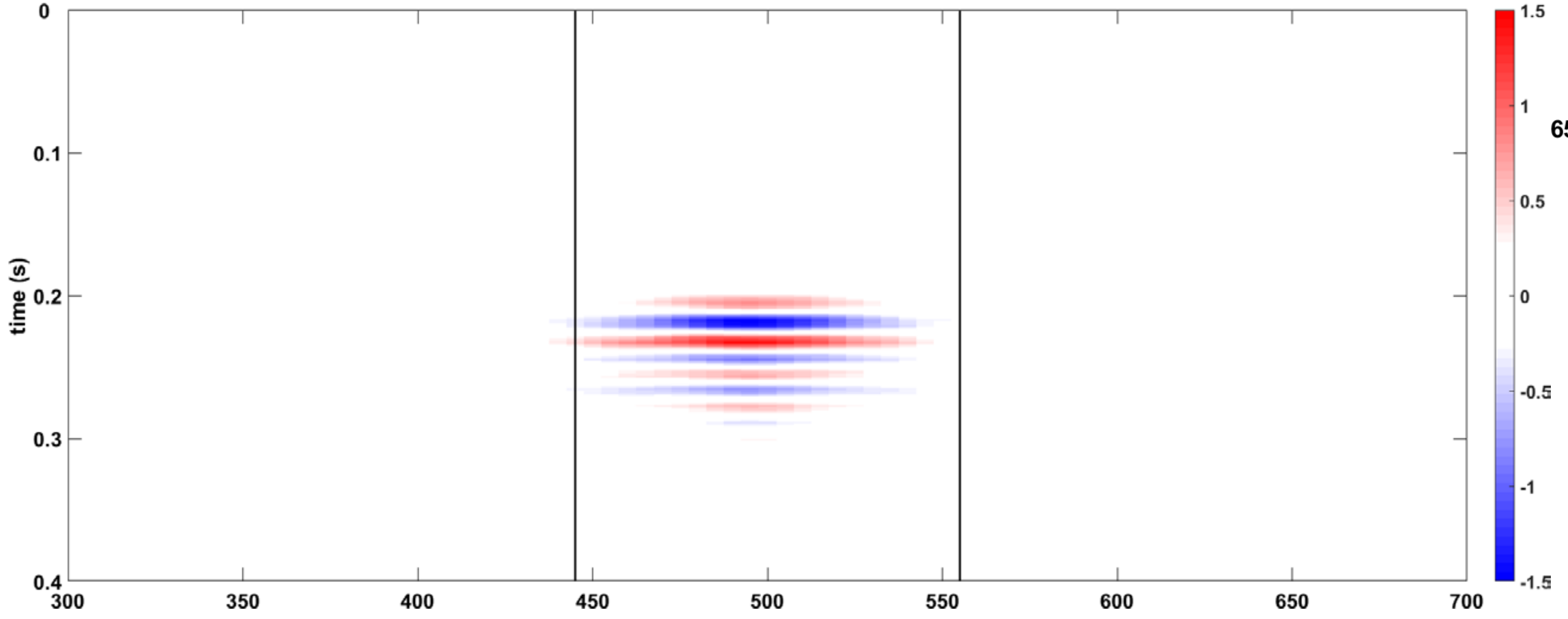


IV - Difference between 1 year of injection and the baseline

1 year of injection (266 tons), no noise added

→ perfect but impossible case





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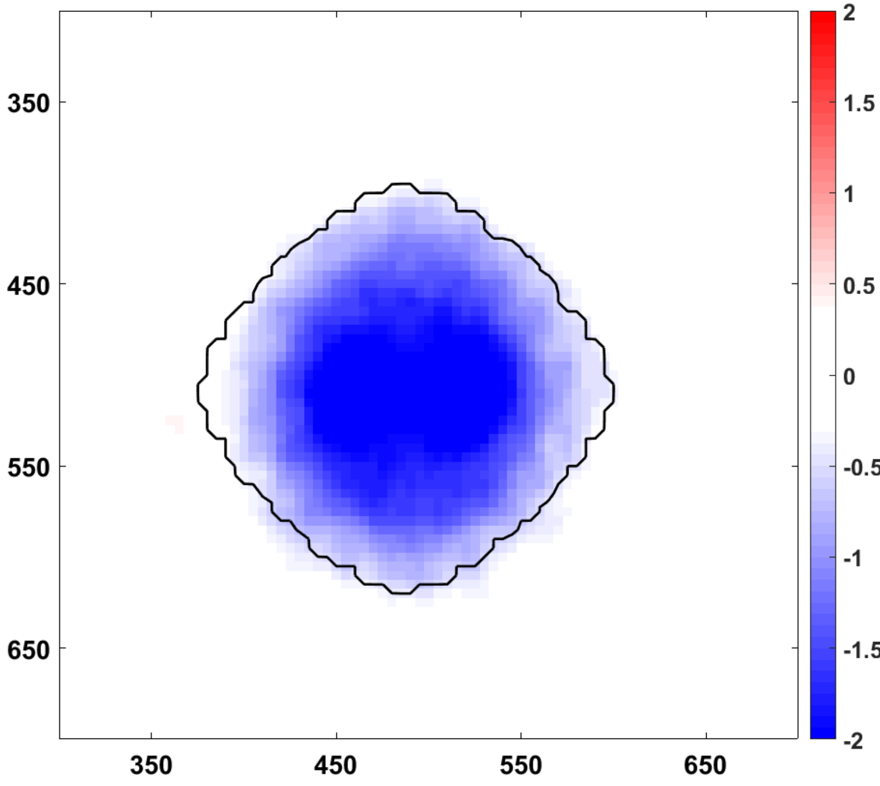
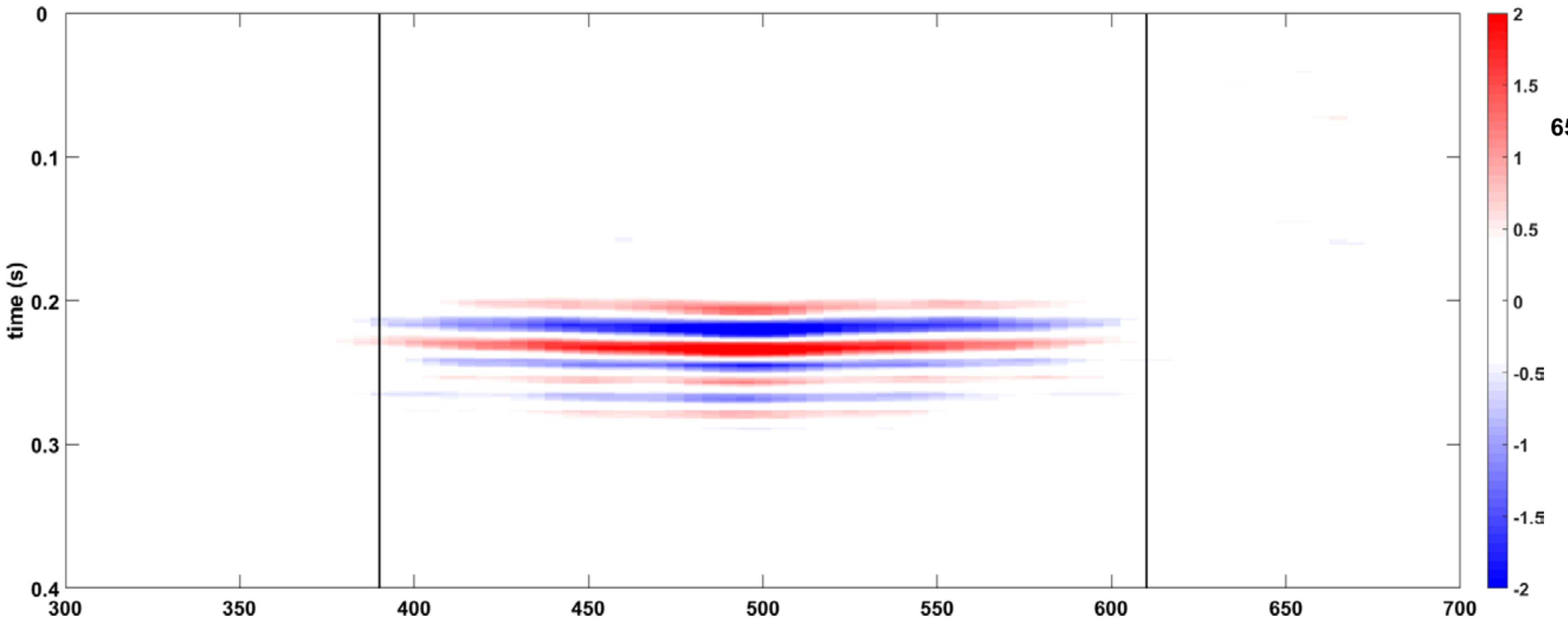
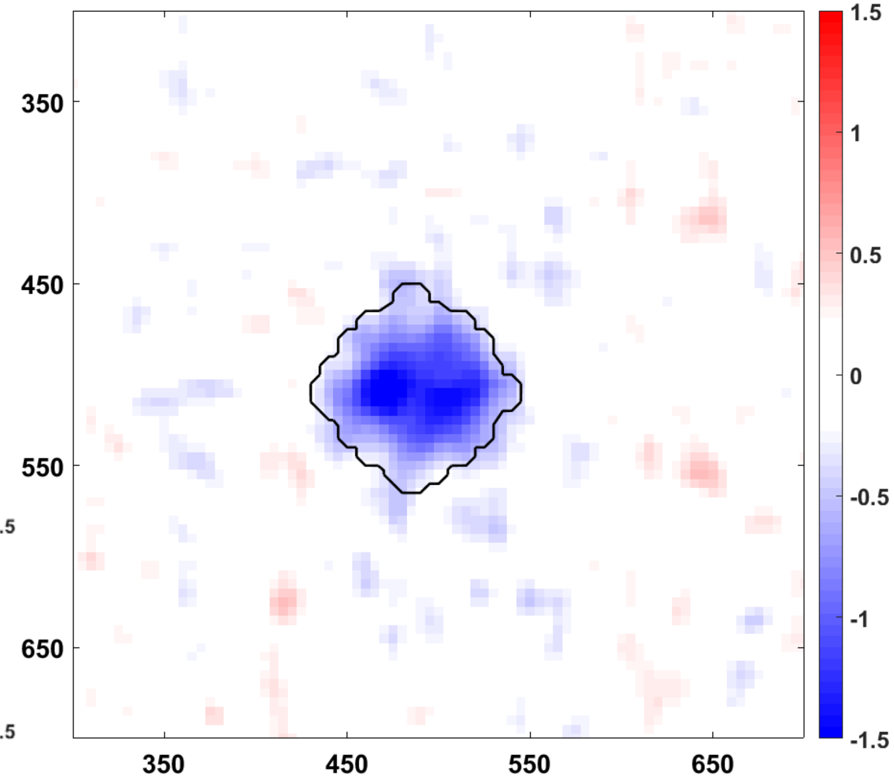
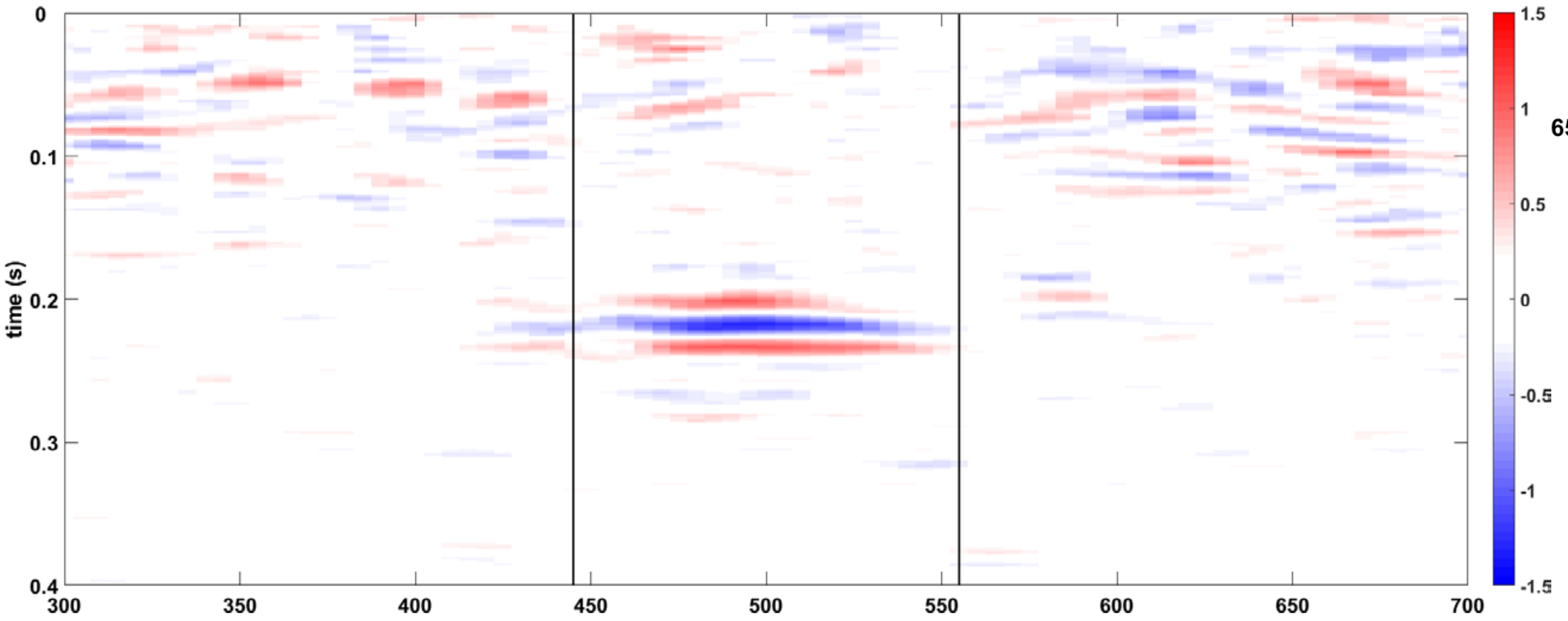




1 year of injection (266 tons), SNR = 20

→ realistic case, based on real data





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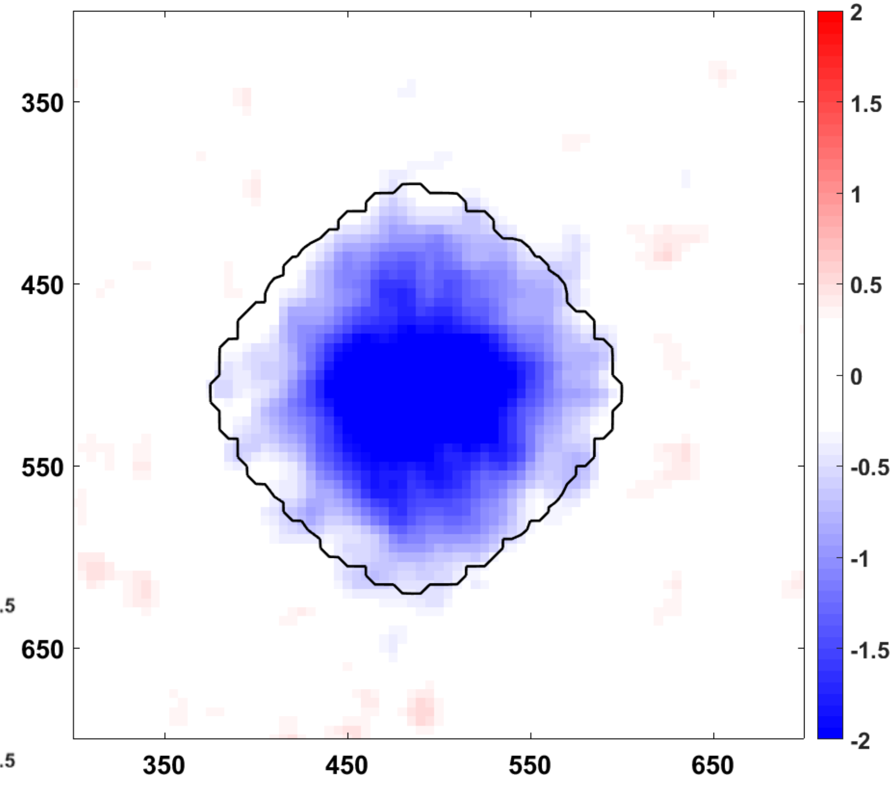
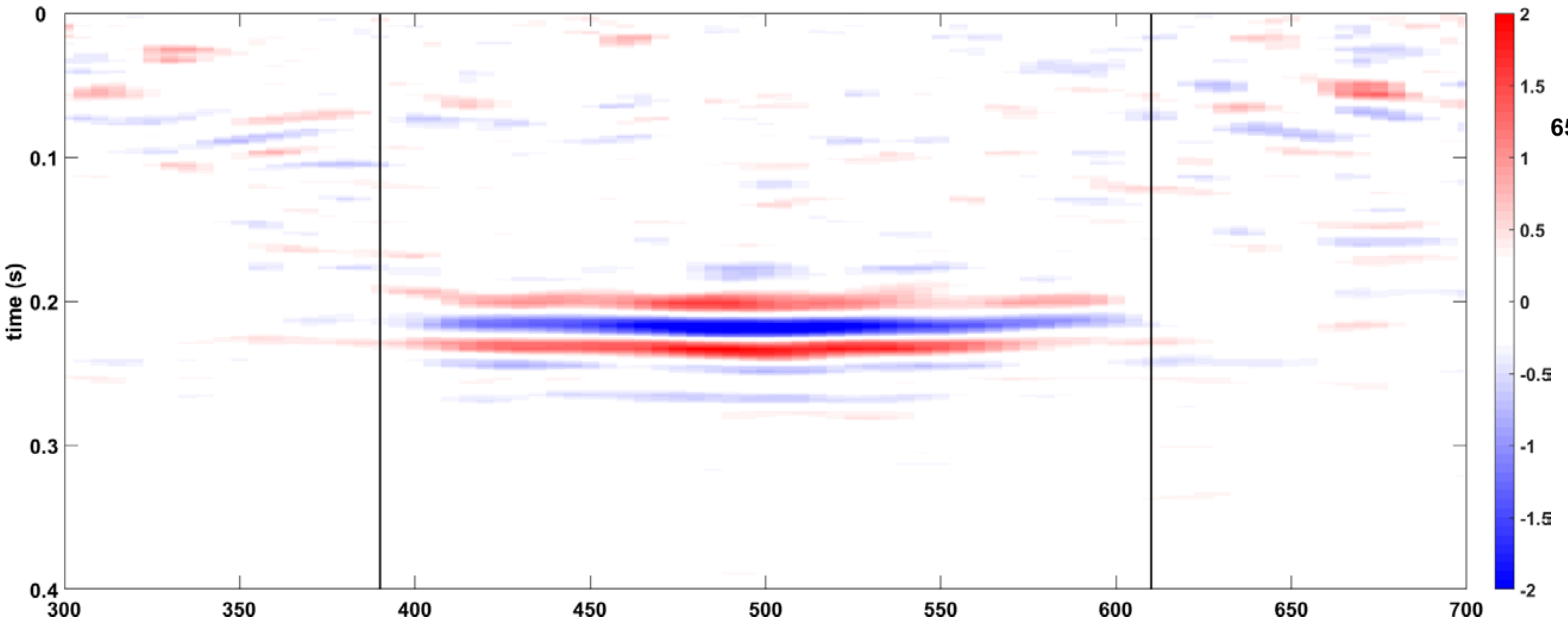
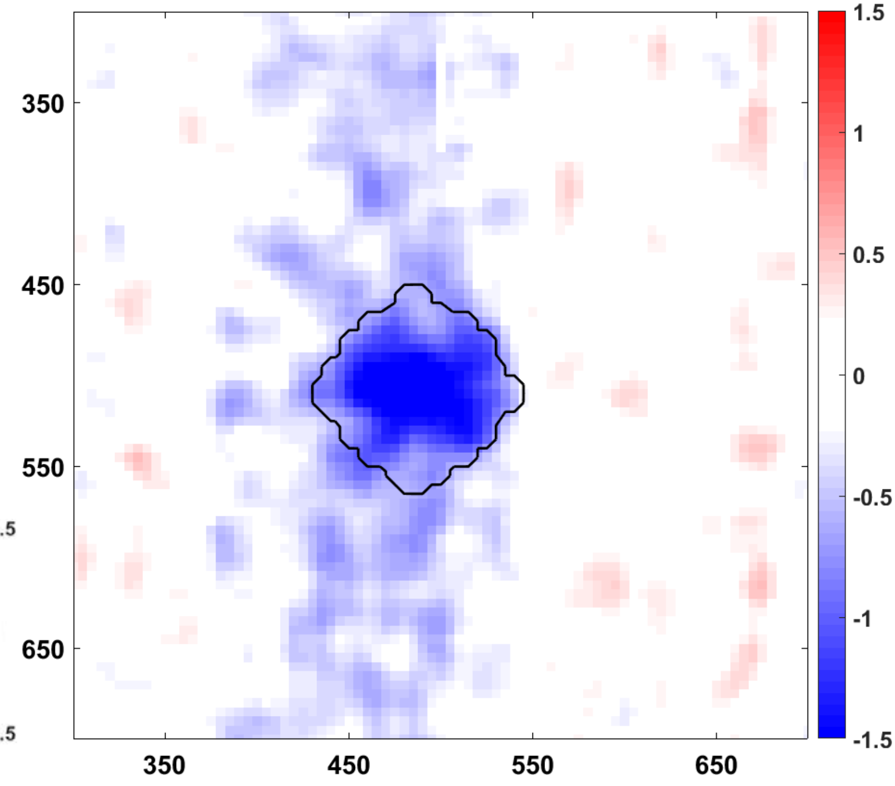


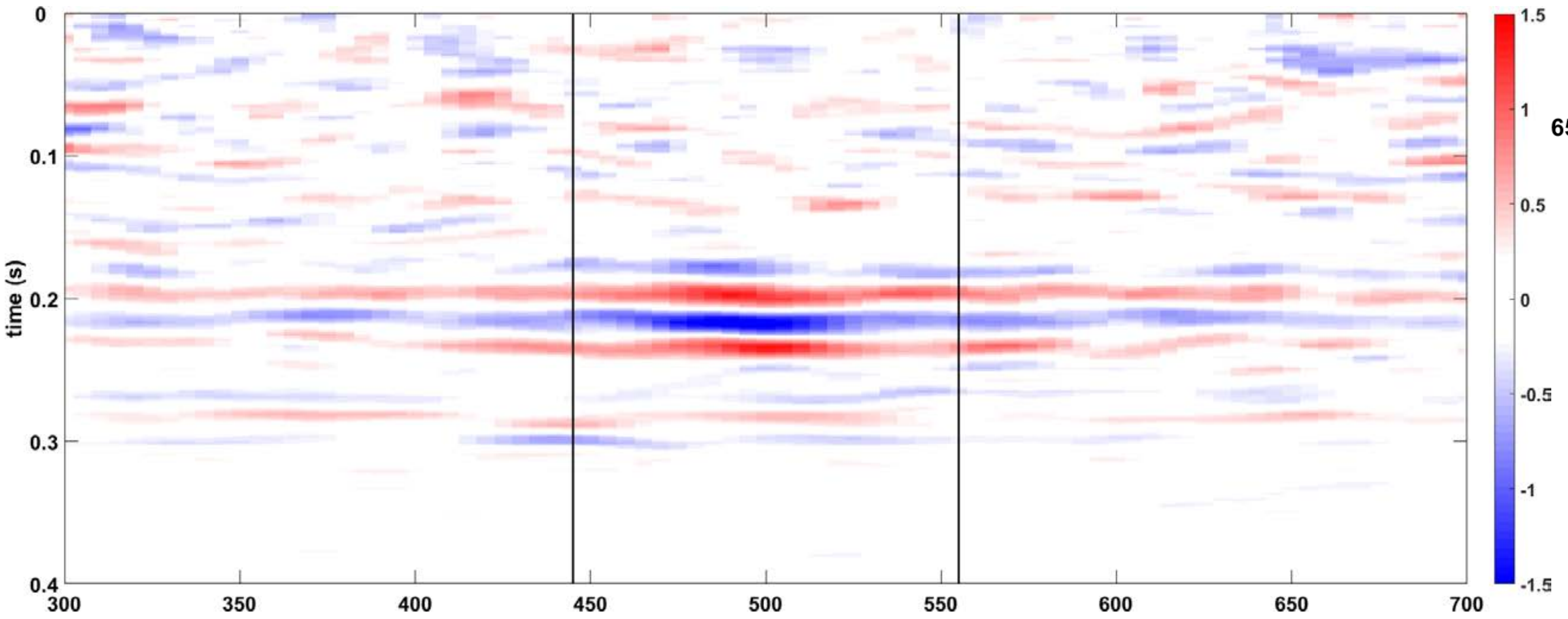


IV - Difference between 1 year of injection and the baseline

1 year of injection (266 tons), SNR = 10

➡ pessimistic case





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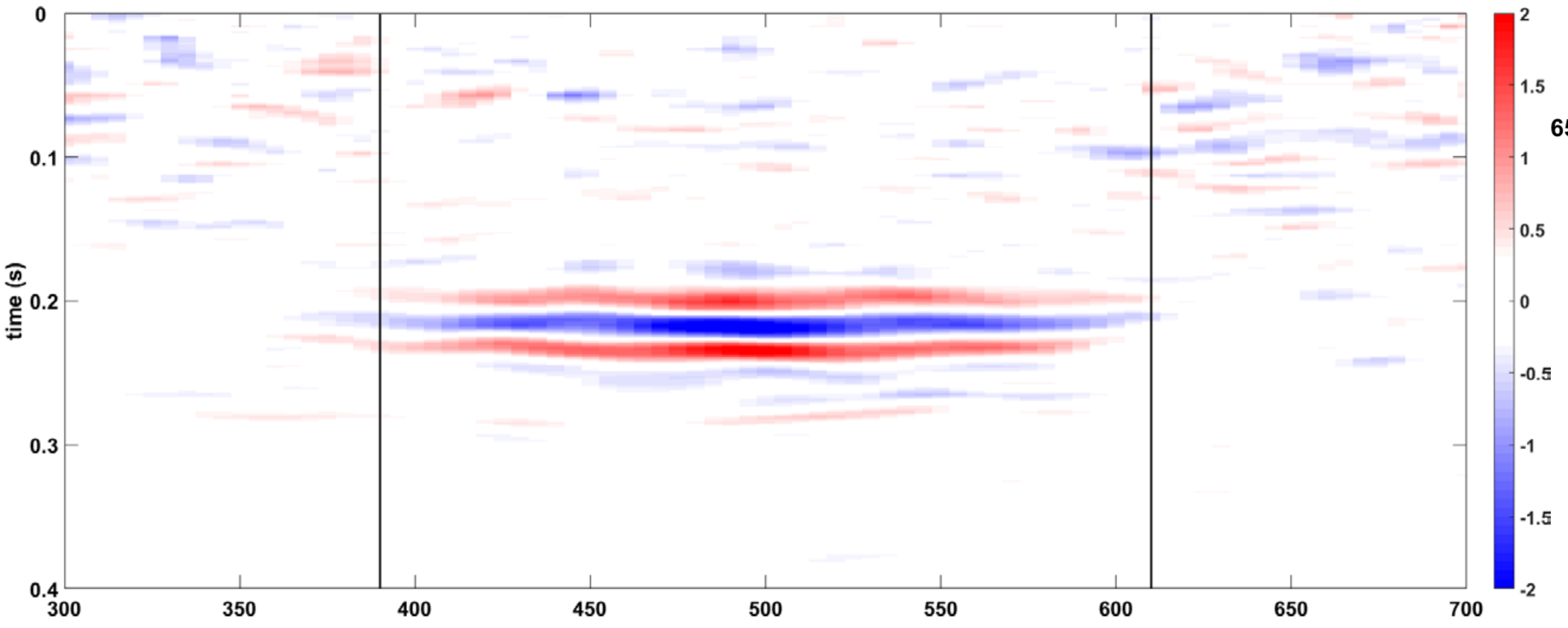

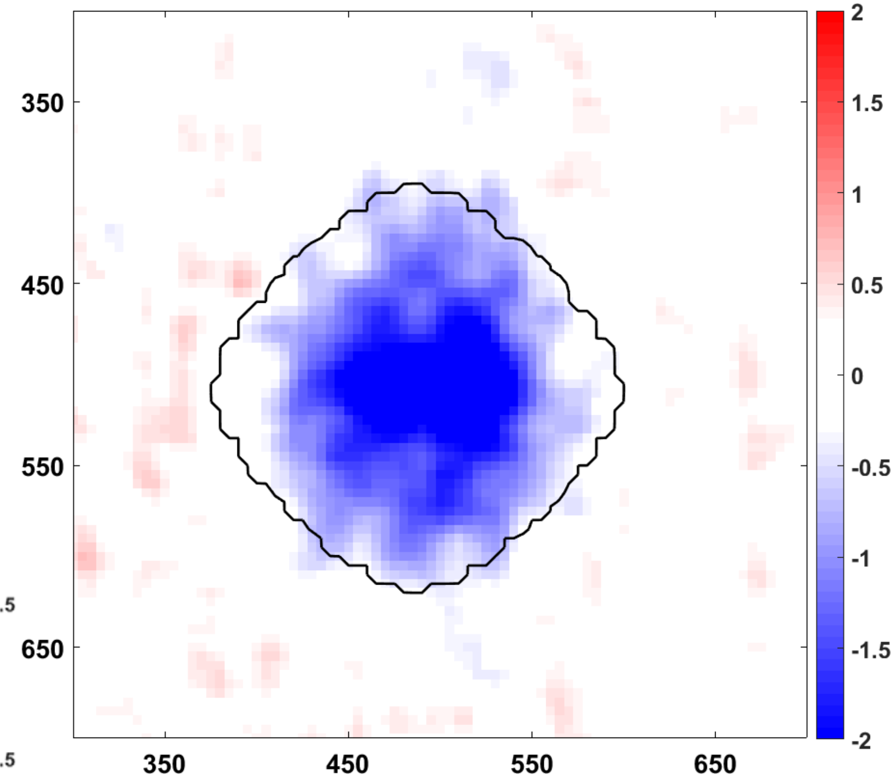

Summary

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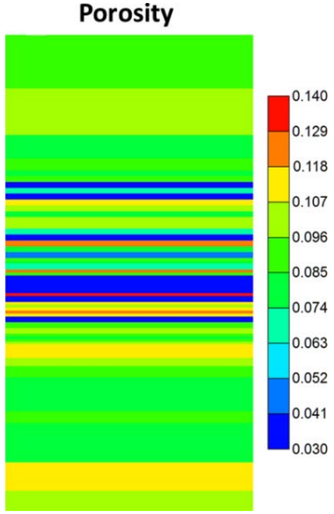
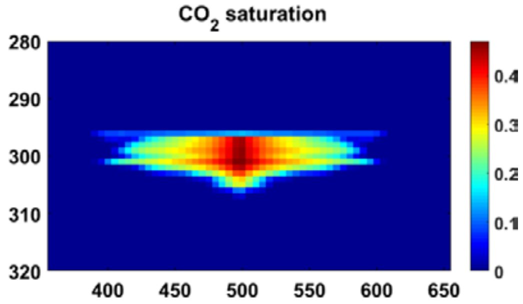
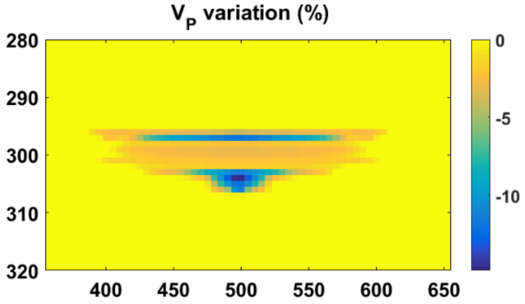
2) Fluid flow simulations

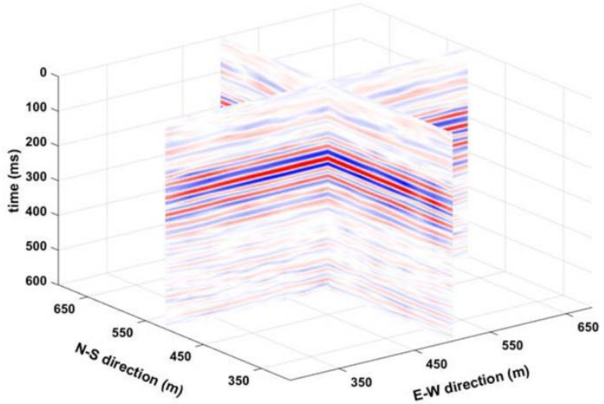
3) Fluid substitution

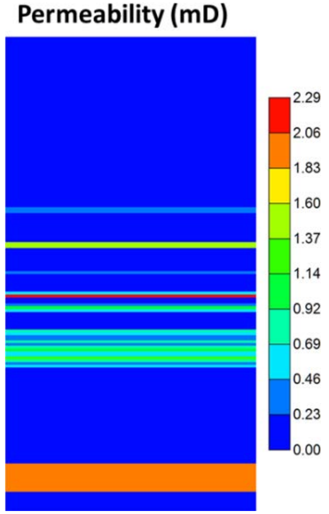
4) Seismic response simulation

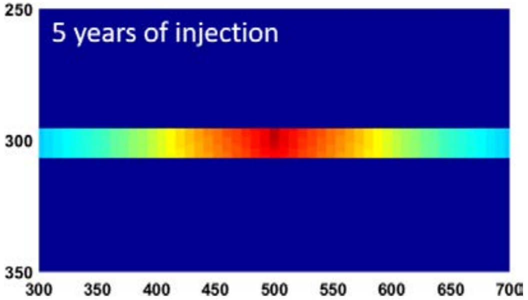


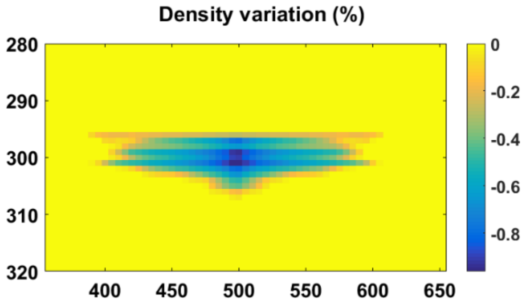


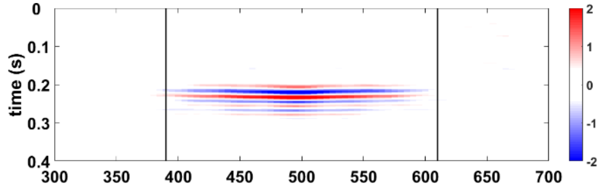












Conclusions & Future work

1) Geomodelling	2) Fluid flow simulation	3) Fluid substitution	4) Seismic response simulation

ASSUMPTIONS

Assumption on vertical permeability	Assumption on the maximum bottom-hole pressure	Assumption on the Saturation behavior	Assumption on perfect survey repeatability

WHAT WE CAN DO

History match and updating geostatic models	Better estimation with pressure data from injection on field	Lab tests to better understand saturation behavior	Estimate non-repeatability using 2 datasets acquired on field

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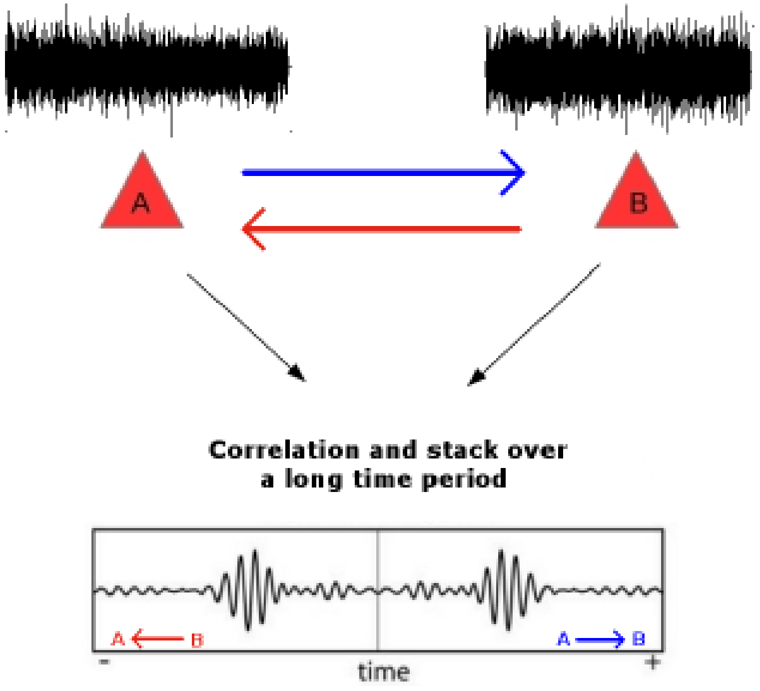
Acknowledgements

- CREWES sponsors
- CMC – CaMI sponsors
- NSERC - grant CRDPJ 461179-13
- CREWES staff and students,
- SINTEF for Tiger modelling software,
- Schlumberger for Vista processing software,
- CMG for the reservoir simulation software.

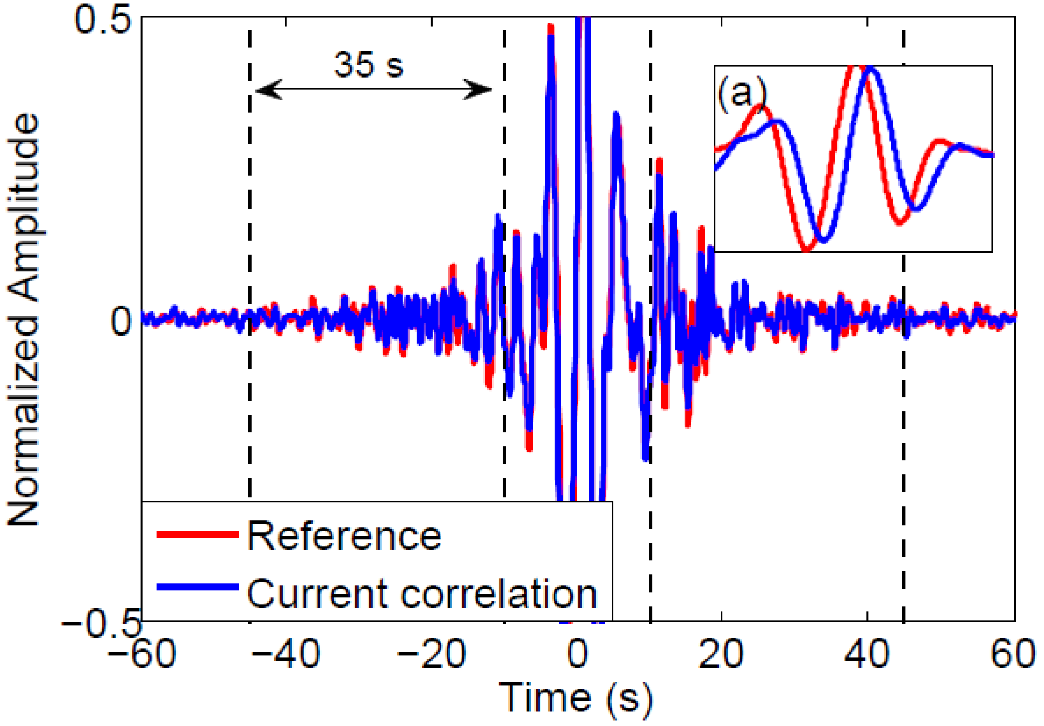
Thank you

Future work – Use Ambient Noise Correlation

Principle: Correlating the noise registered a two stations approximate the Green function between those two stations



If you change the medium between the two stations, the results of the correlation will change

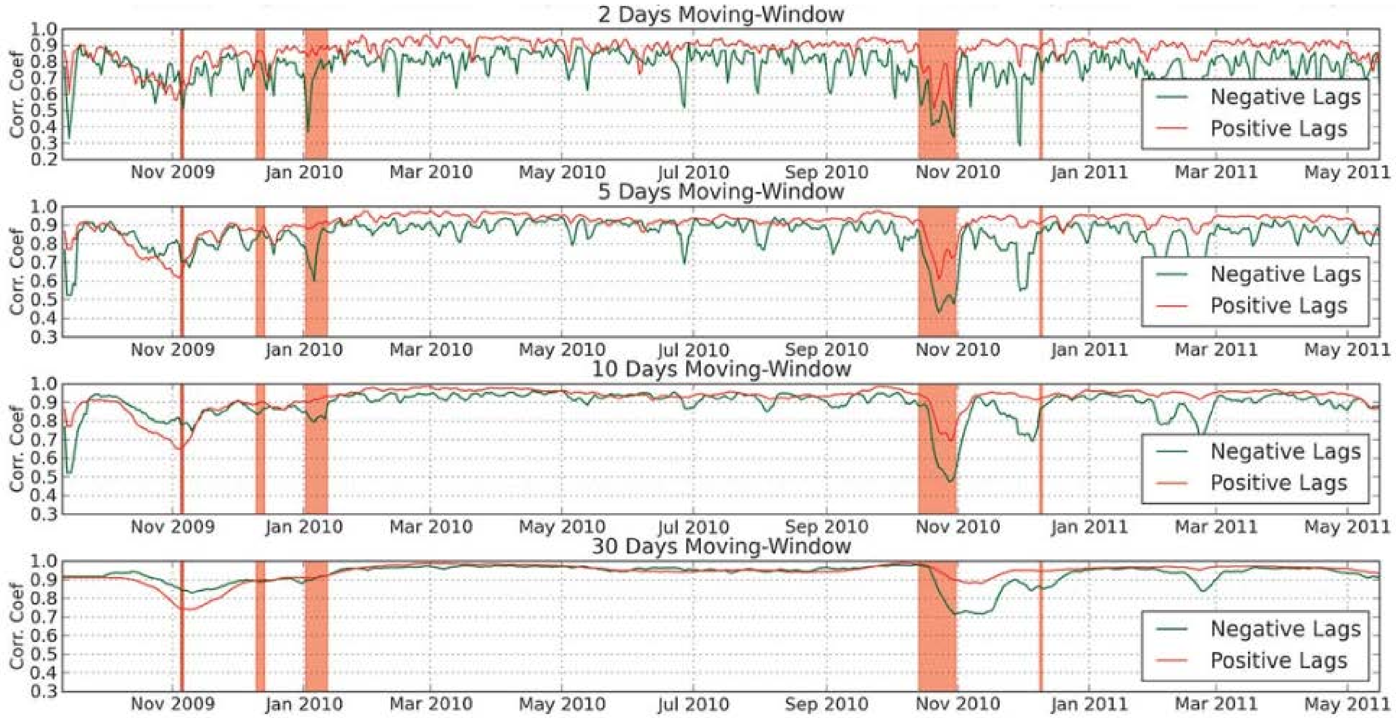


From Obermann et al., 2013

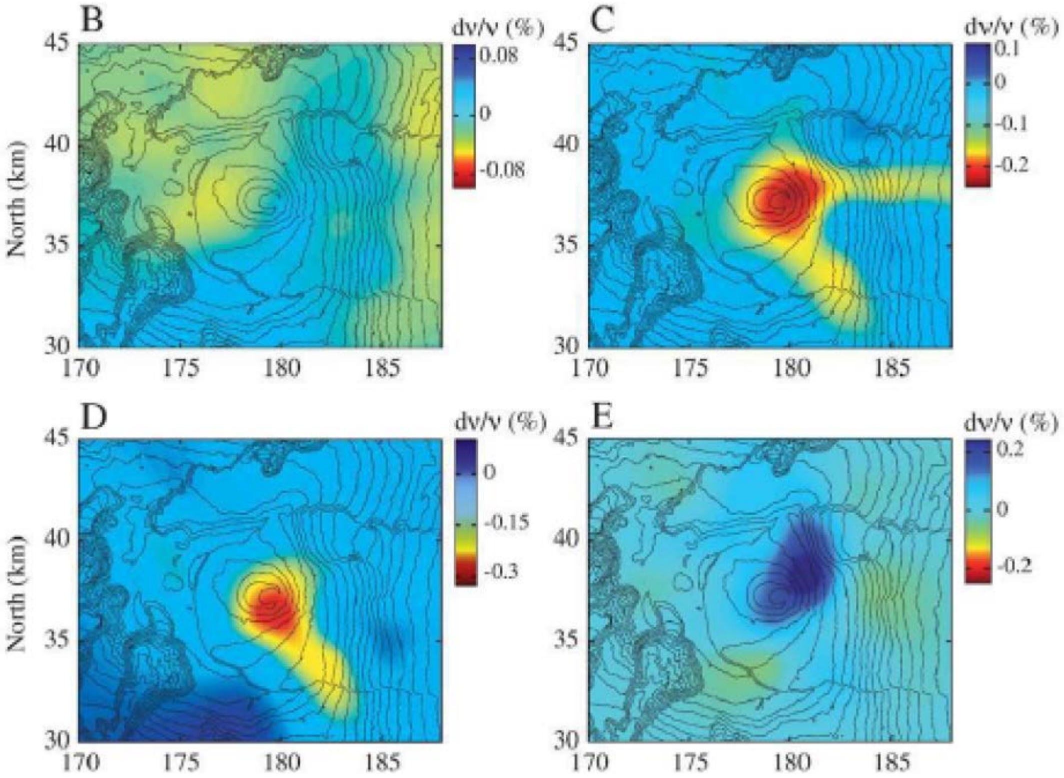
So far application of monitoring on volcanoes, on geothermal sites, on oil production field…

Future work – Use Ambient Noise Correlation

Computing the correlation function between a reference correlation and the current correlation (from Lecocq et al., 2014)



Regionalization of temporal changes (From Duputel et al., 2009)



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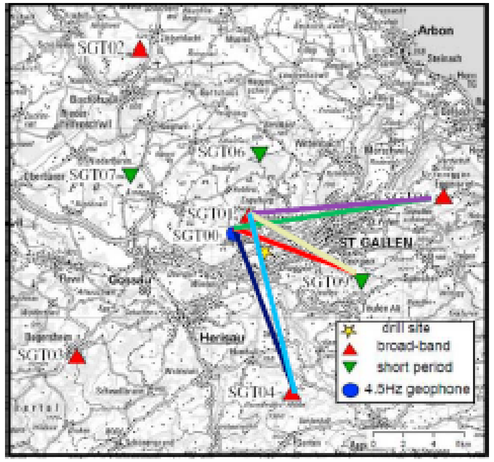
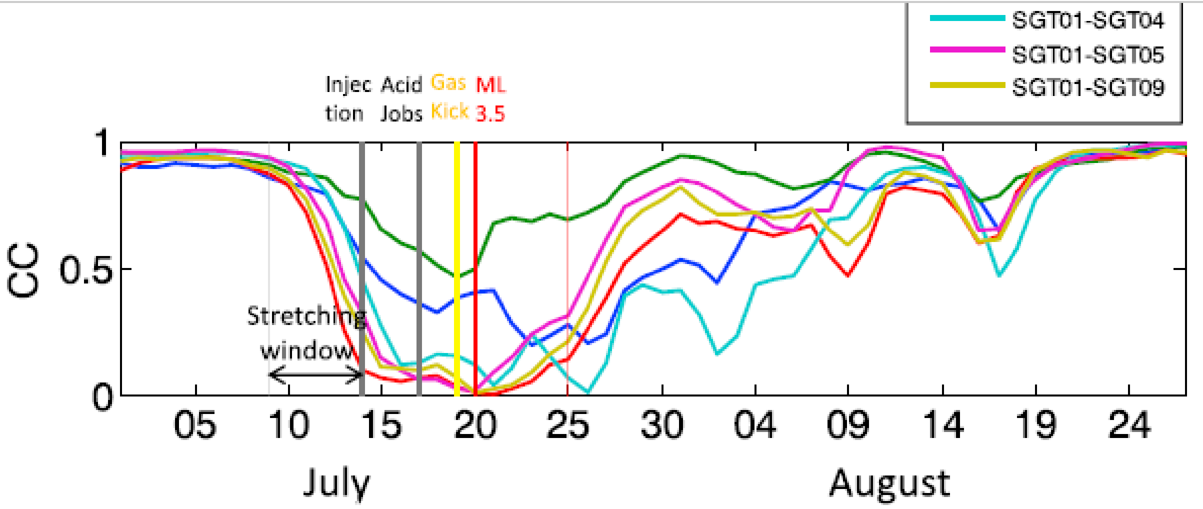
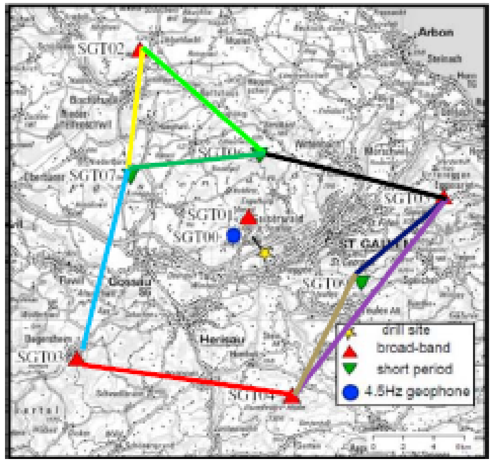
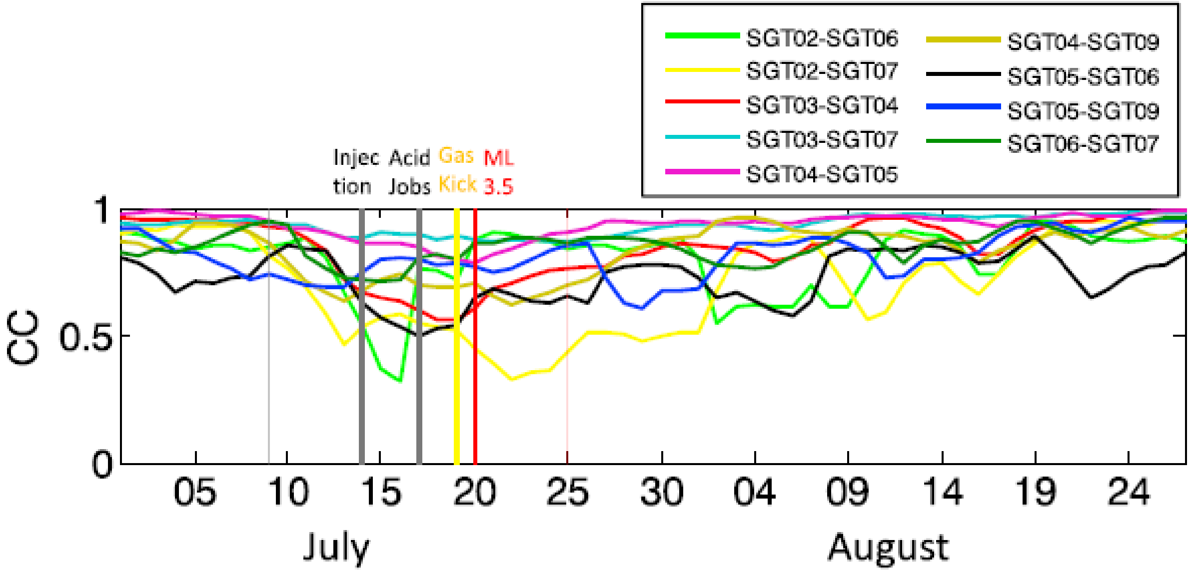




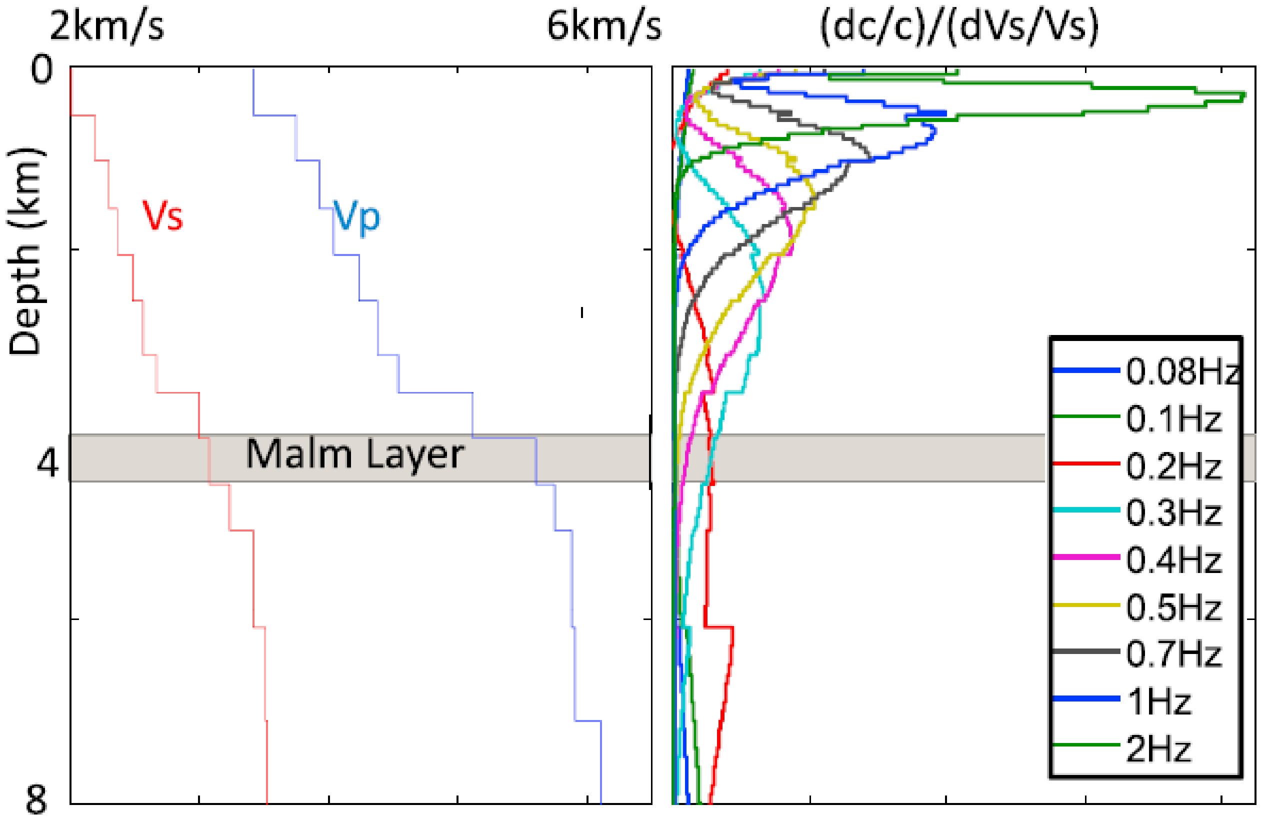
(b)





Obermann et al., 2015

Future work – Use Ambient Noise Correlation



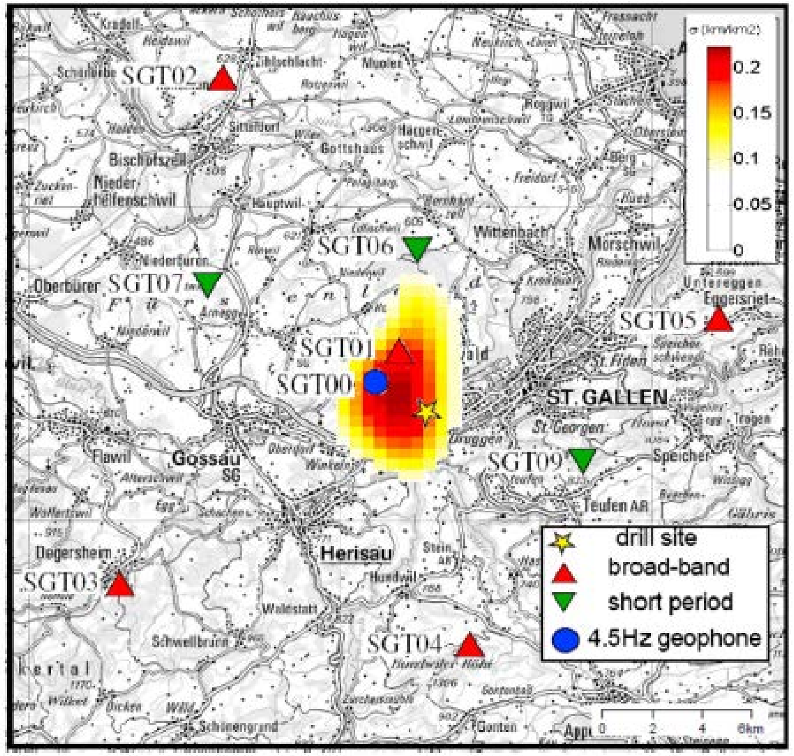


Figure 9. Scattering cross-section density changes derived by least squares inversion averaged over July 2013. The observed changes are around the injection well, indicating a causal relationship with the activities at the well.

Obermann et al., 2015

Future work – Use Ambient Noise Correlation

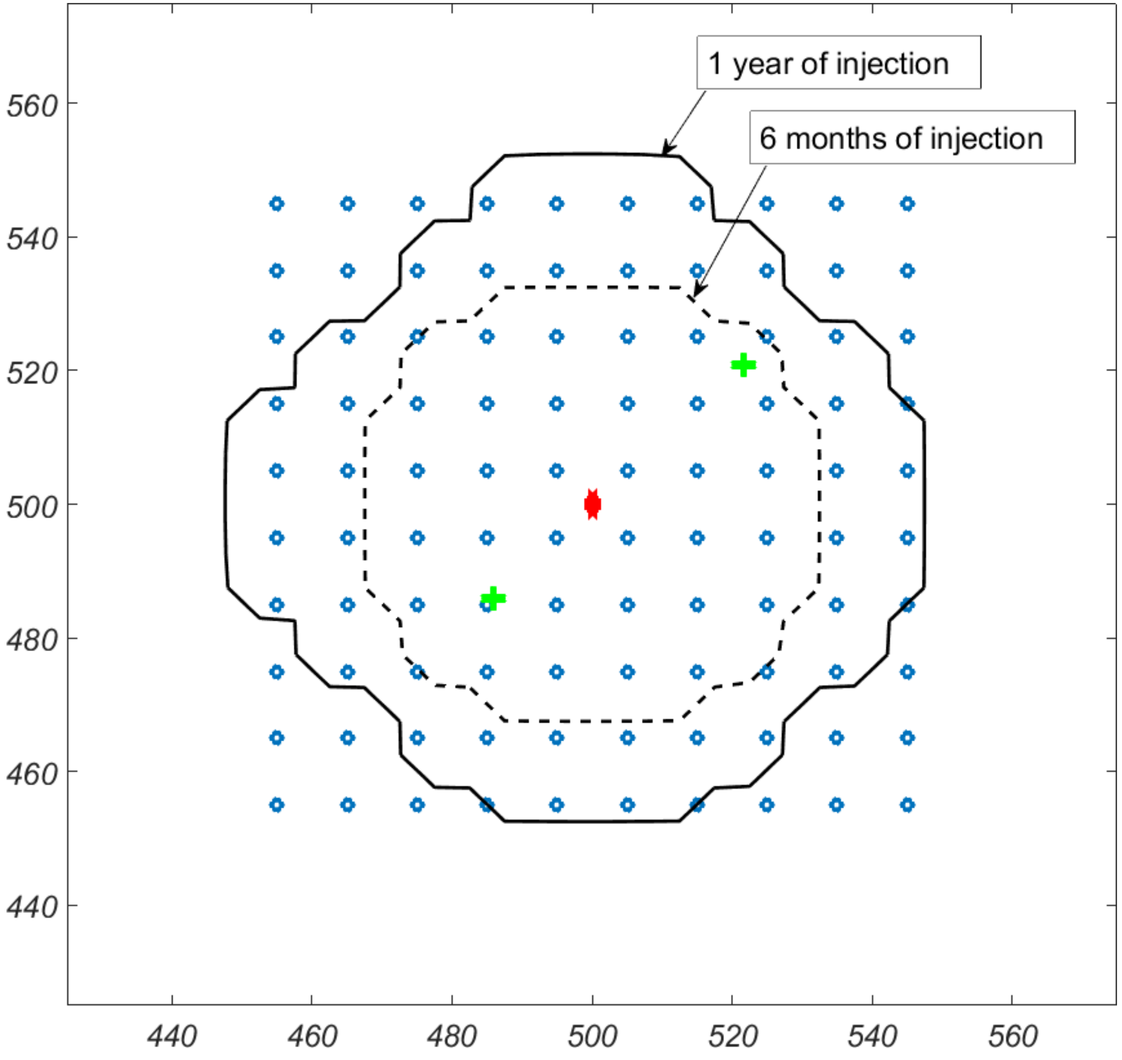
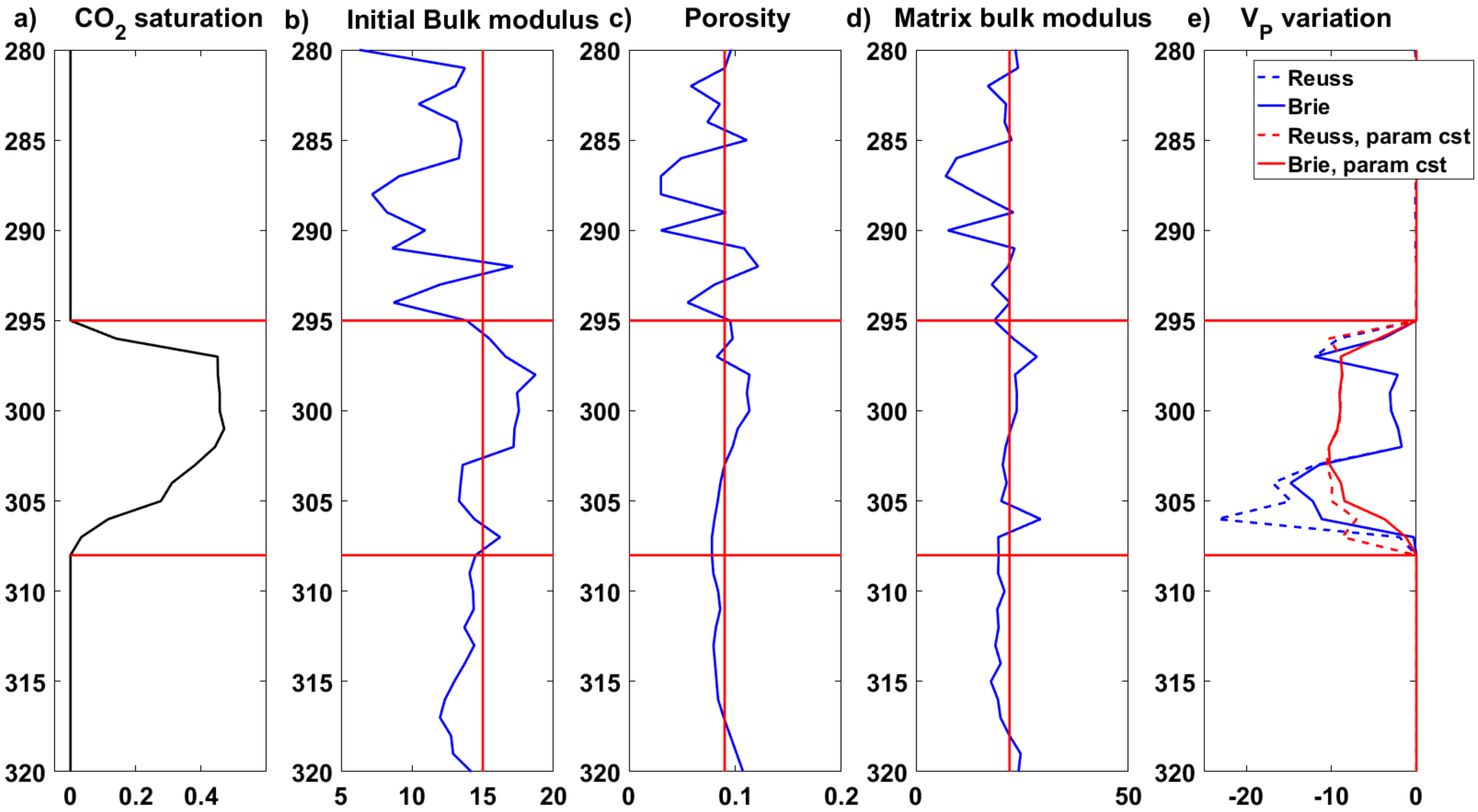
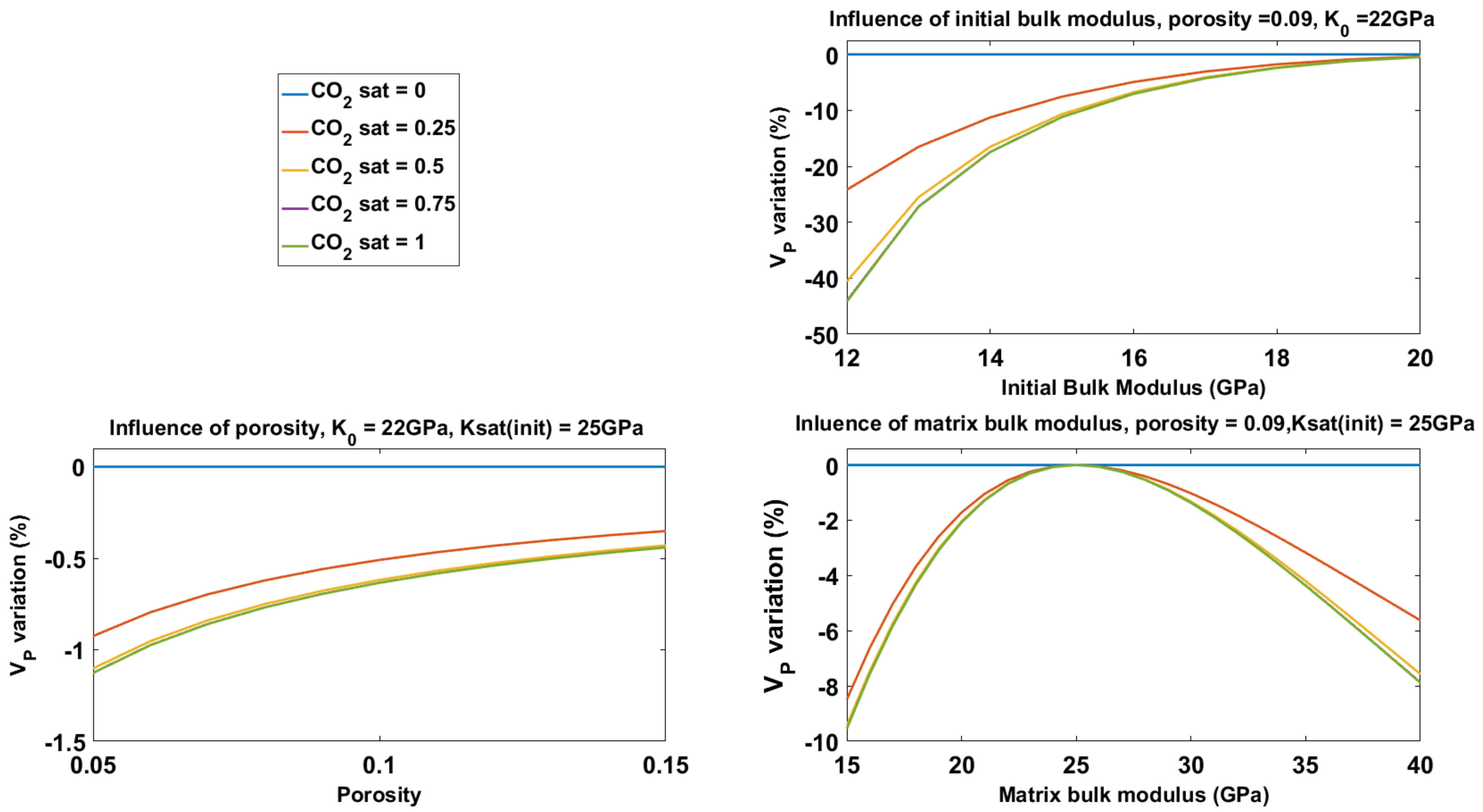


Fig. 14 CRR



a) CO_2 saturation
b) Initial Bulk modulus
c) Porosity
d) Matrix bulk modulus
e) V_P variation
280
285
290
295
300
305
310
315
320
0
0.2
0.4
5
10
15
20
0
0.1
0.2
0
50
-20
-10
0
Reuss
Brie
Reuss, param cst
Brie, param cst

Fig. 15 CRR



CO2 sat = 0
CO2 sat = 0.25
CO2 sat = 0.5
CO2 sat = 0.75
CO2 sat = 1
Influence of initial bulk modulus, porosity =0.09, K0 =22GPa
VP variation (%)
0
-10
-20
-30
-40
-50
12
14
16
18
20
Initial Bulk Modulus (GPa)
Influence of porosity, K0 = 22GPa, Ksat(init) = 25GPa
VP variation (%)
0
-0.5
-1
-1.5
0.05
0.1
0.15
Porosity
Inluence of matrix bulk modulus, porosity = 0.09,Ksat(init) = 25GPa
VP variation (%)
0
-2
-4
-6
-8
-10
15
20
25
30
35
40
Matrix bulk modulus (GPa)