Geomechanics for CO_2 storage sites: Longyearbyen (Arctic Norway) and In Salah (Algeria)

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Outline

- Introduction
- Geomechanical studies for Longyearbyen CO_2 lab- Svalbard
- Injection data vs geomechanics-In Salah
- Conclusions

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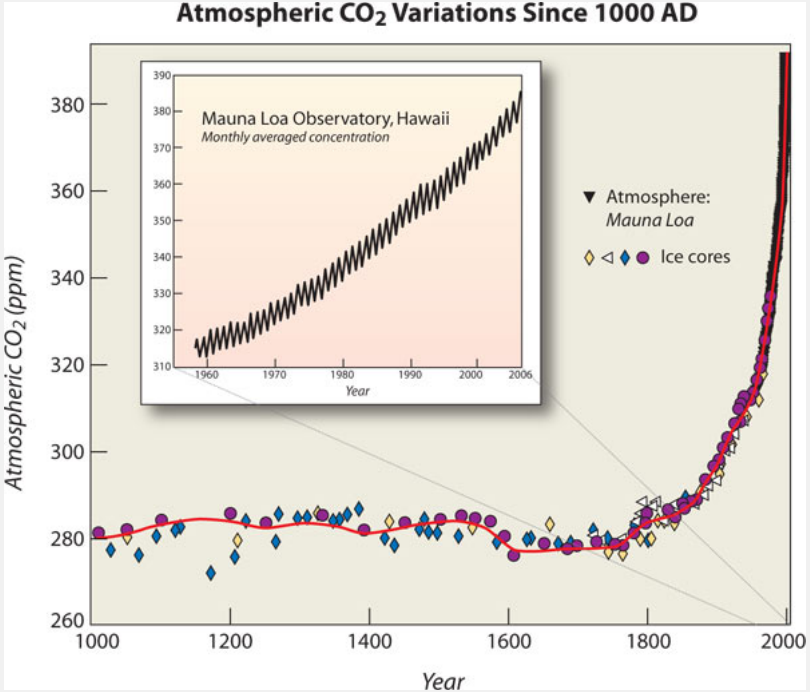
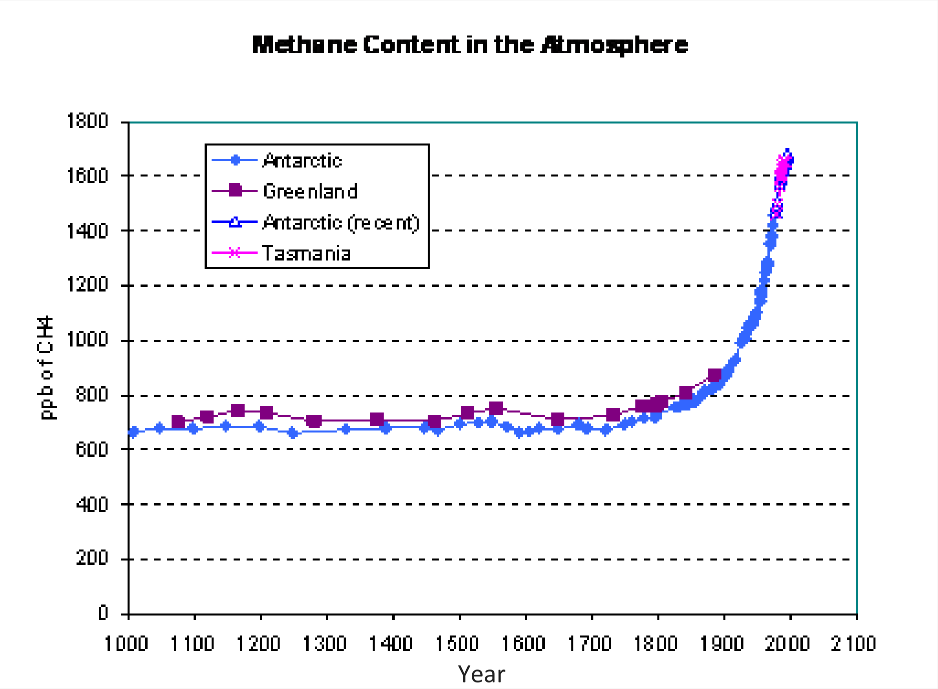
Intro: Greenhouse gases in the atmosphere



https://acidifyingoceans.weebly.com/



https://ecen.com/eee55/eee55e/growth_of%20methane_concentration_in_atmosphere.htm

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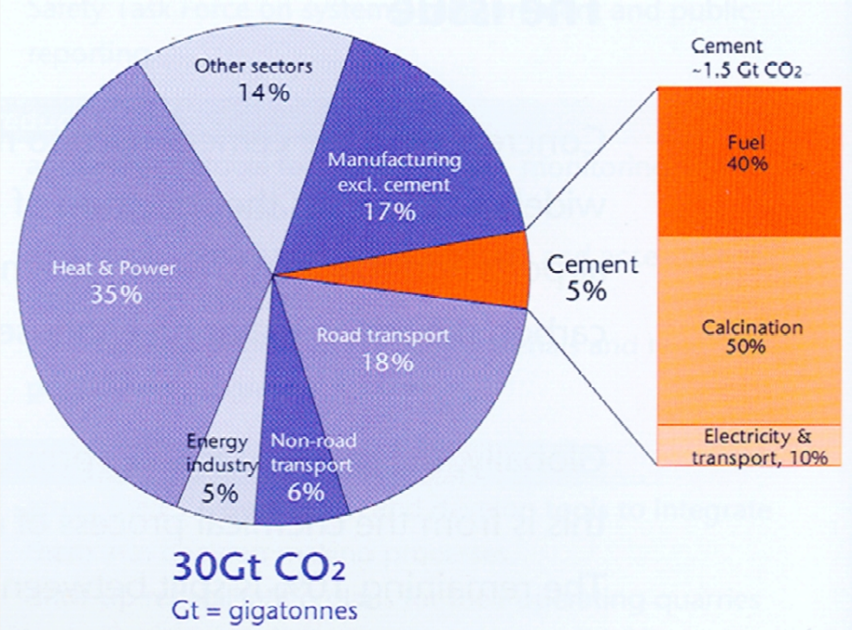
CO_2 emission from industrial processes

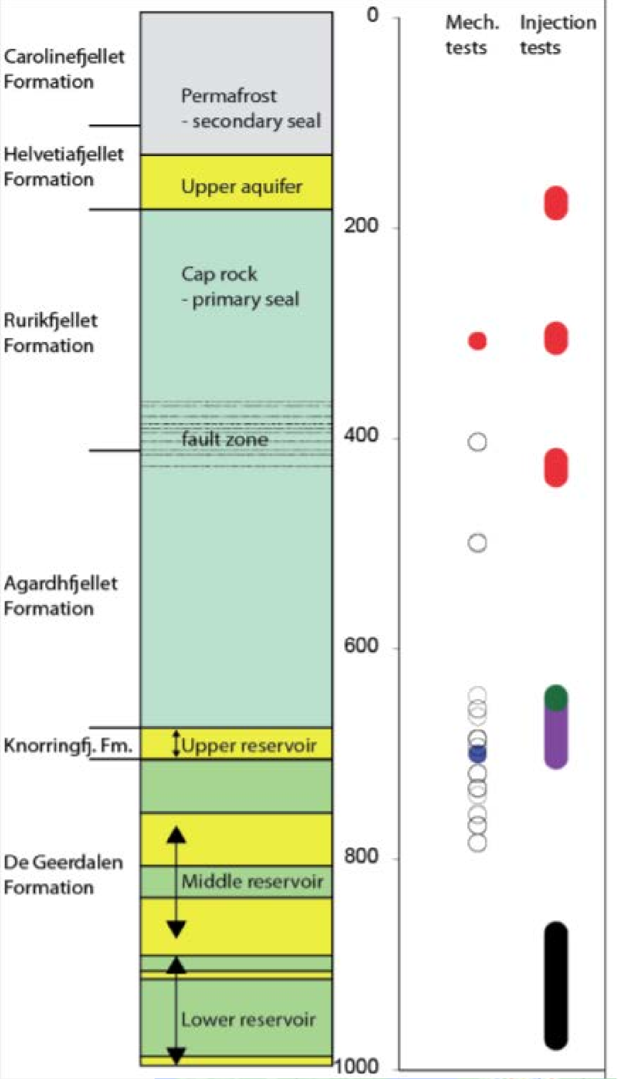
Cement production; double emissions, ca. 1500 Mt/y of CO2

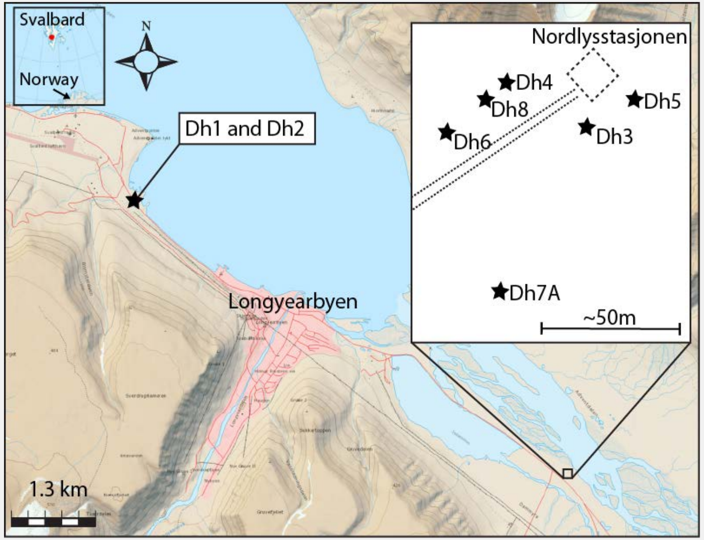
- Calcination of limestone: $CaCO_3 \rightarrow CaO + CO_2$ (≈ 50%)
- Heating from fossil fuels → CO_2 (≈ 40%)



Case 1: Longyearbyen CO_2 Lab Pilot, Svalbard

Geomechanical studies for Longyearbyen CO_2 Pilot

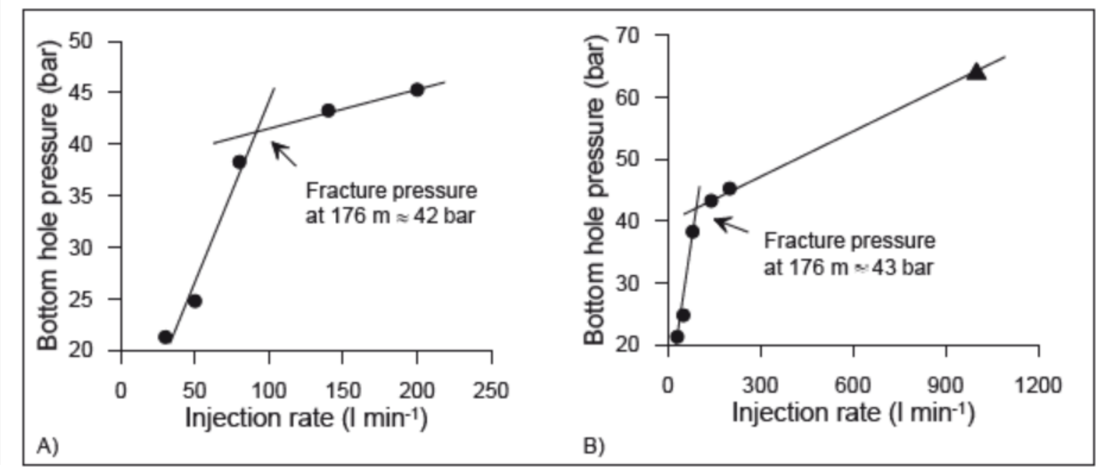




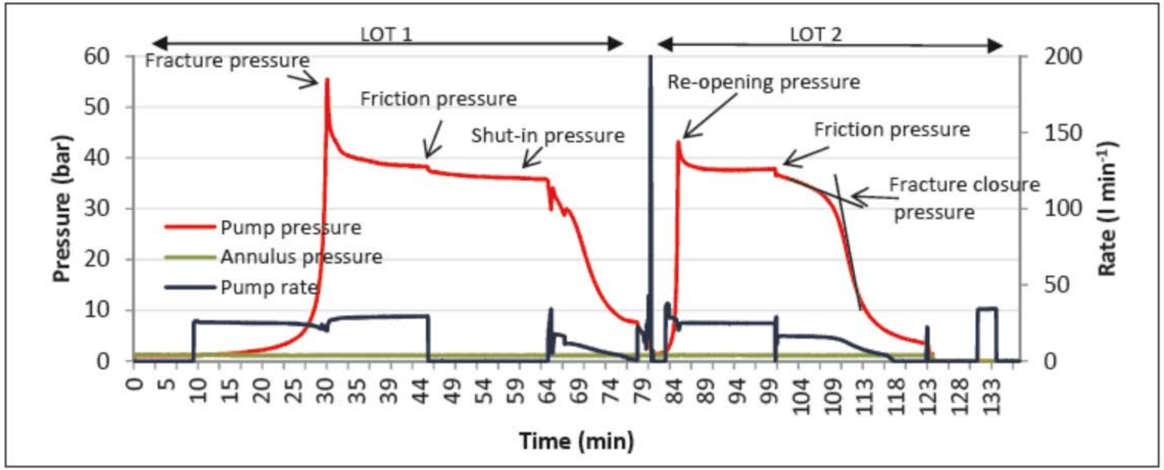
Geology profile

Q1: What is the max. allowable pressure?

- Injection/leak-off tests



@171-181 m depth interval

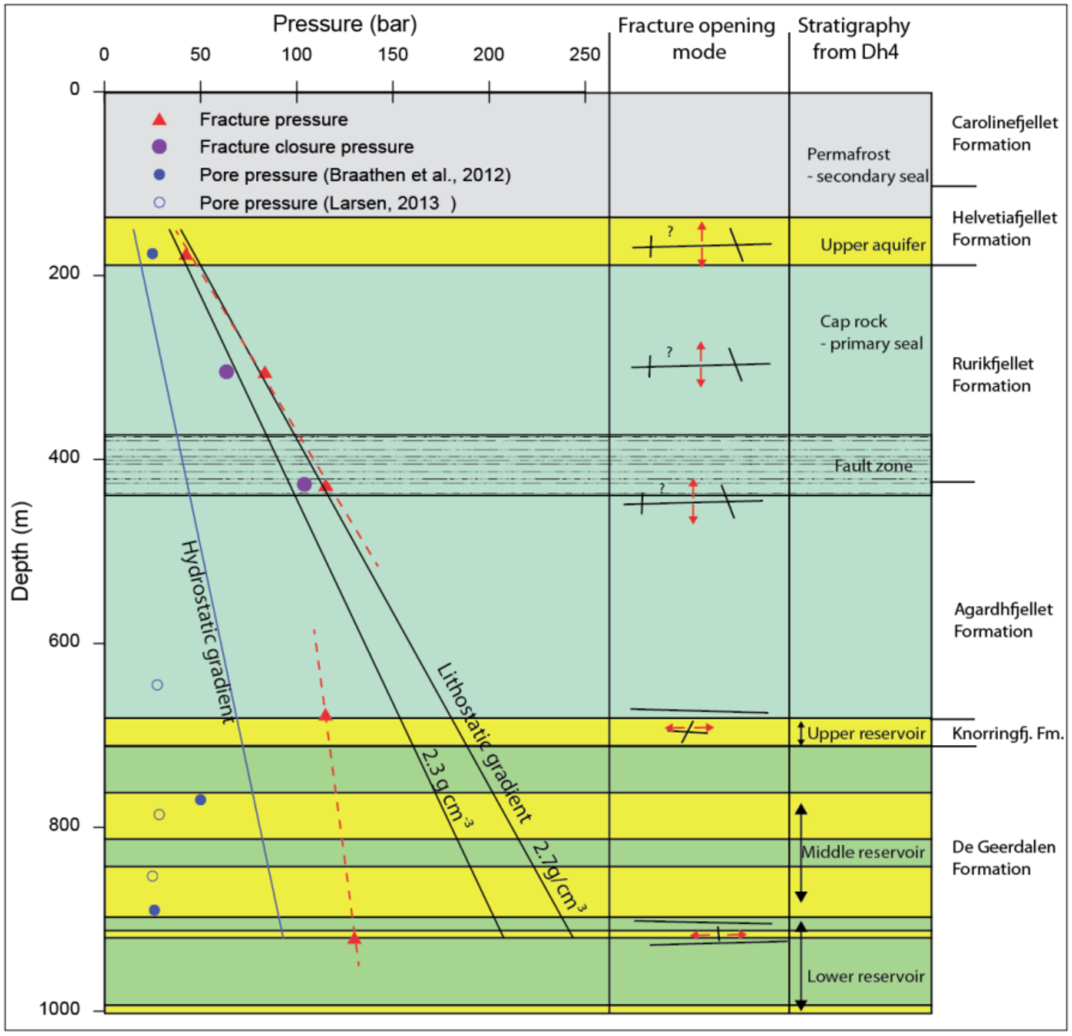


@300-309 m depth interval

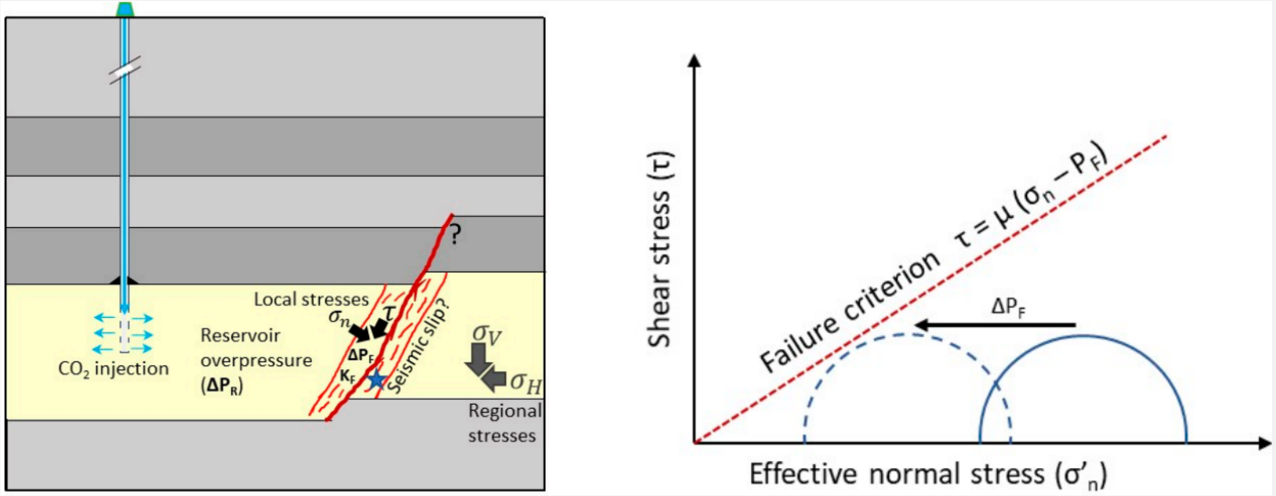
Q1: Max. allowable pressure (Cont.)?

Fracture orientation?

Section	Testing depth (m)/ Formation	Number and type of tests	Well No.
Overburden	171–181 Helvetia Fm.	Step rate test (SRT) Fracture test	Dh6
	300–309 Rurikfjellet Fm.	2 leak-off tests (LOT)	
	420–435 Agardhfjellet Fm.	2 leak-off tests (LOT)	
Reservoir	650–703 Lower Agardhfjellet Fm. Upper Knorringfjellet Fm.	2 step rate tests	Dh7A
	870–970 De Geerdalen Fm.	Step rate test	Dh4



Q2. Does fracture/fault slip create seismic event?



$$\mu = \mu_0 + a\ln(V/V_0) + b\ln(V_0\theta/d_c)$$

- Velocity step shear test-evolution of friction (μ):

With θ and (a-b):

$$d\theta/dt = 1 - (V_0\theta/d_c) \qquad (\boldsymbol{a}-\boldsymbol{b}) = \frac{\boldsymbol{\mu_0}-\boldsymbol{\mu}}{\mathbf{ln}(\boldsymbol{v}/\boldsymbol{v_0})}$$

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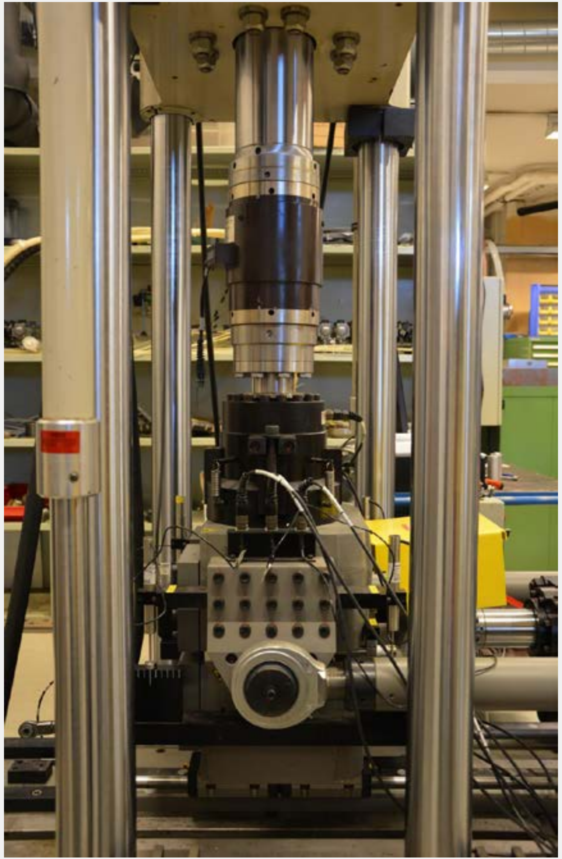
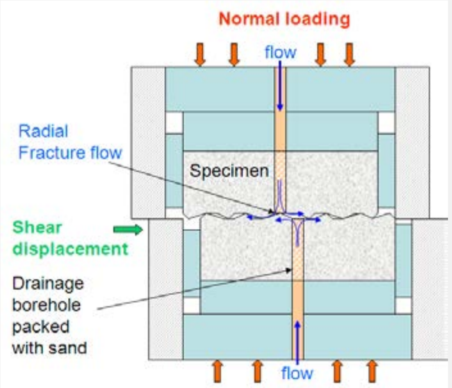
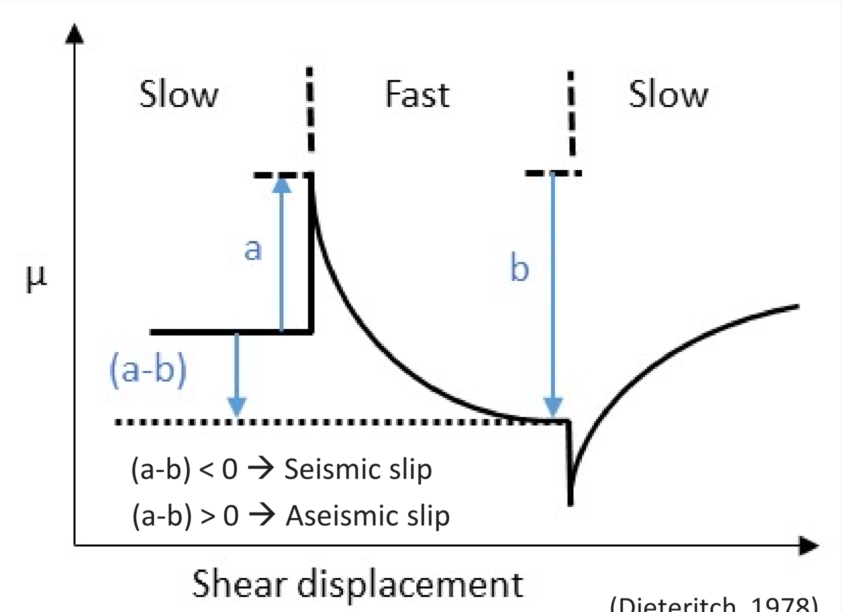
Direct shear test: a lab method used for evaluating the seismic potential



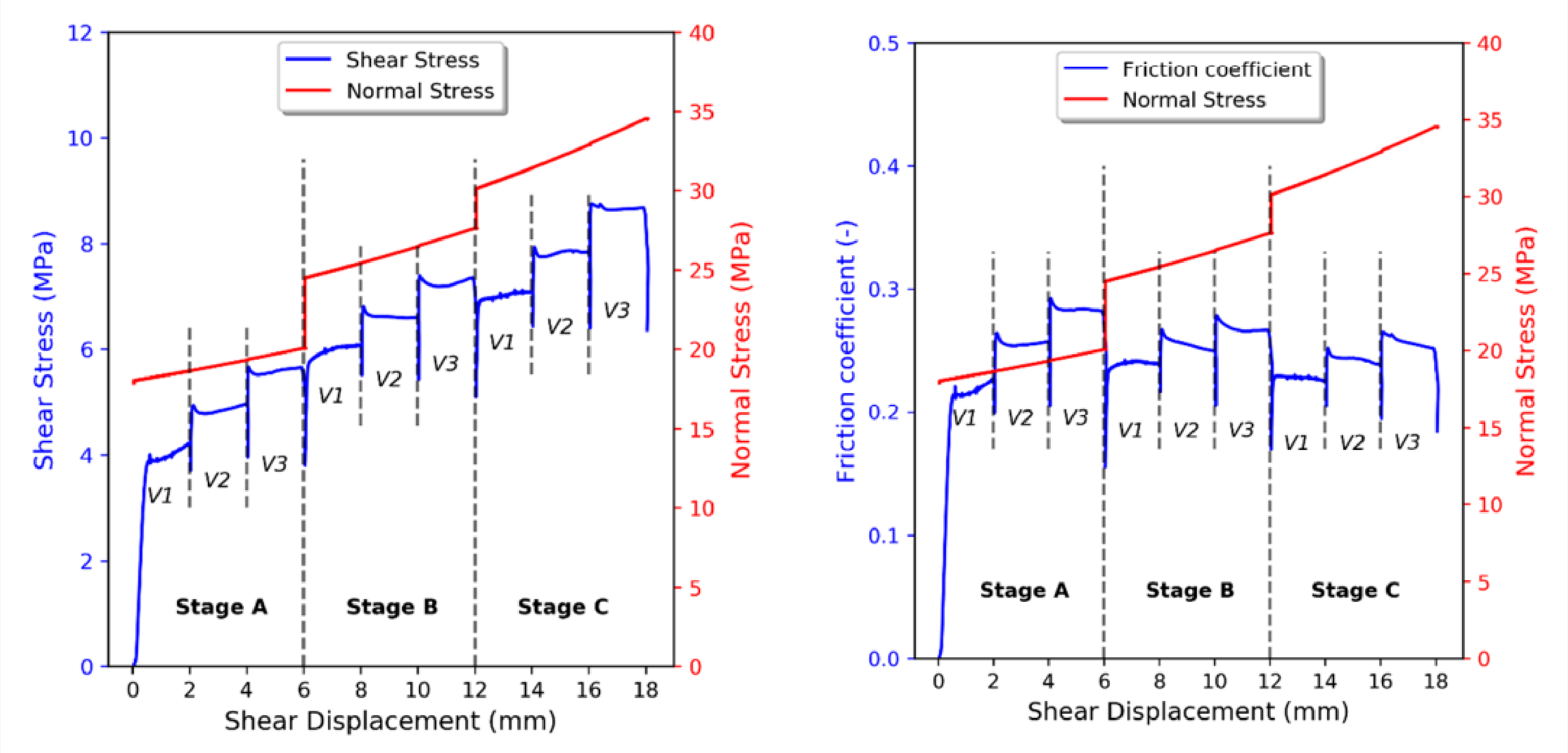


Rurikfjellet Cretaceous shale from Svalbard, TOC = 1%-2%



(Dieteritch, 1978)

Seismogenic potential of Svalbard/Rurikfjellet shale



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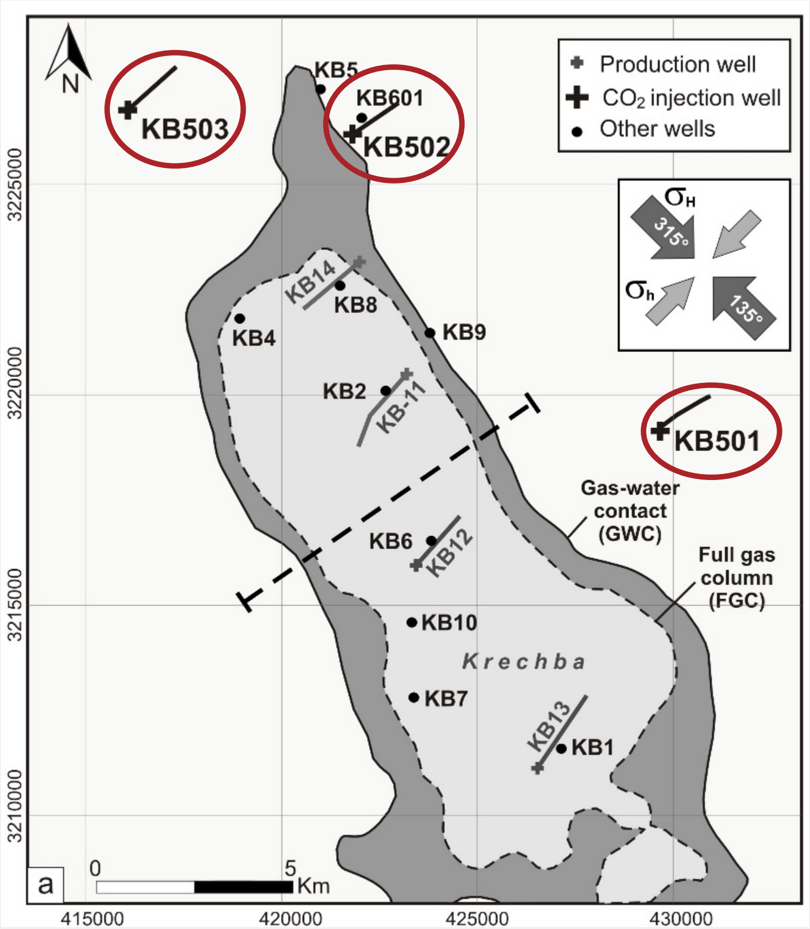
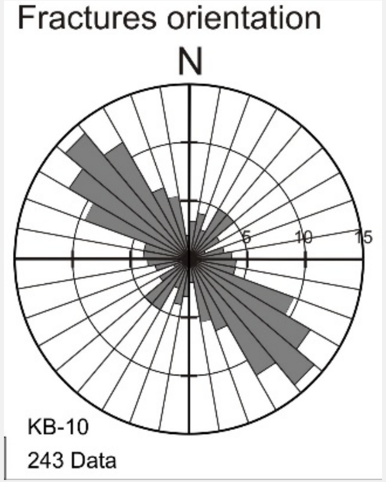
(a-b) > 0 → Aseismic slip

Case 2: In Salah CO_2 storage site





Ref.: Bjørnarå et al., 2018

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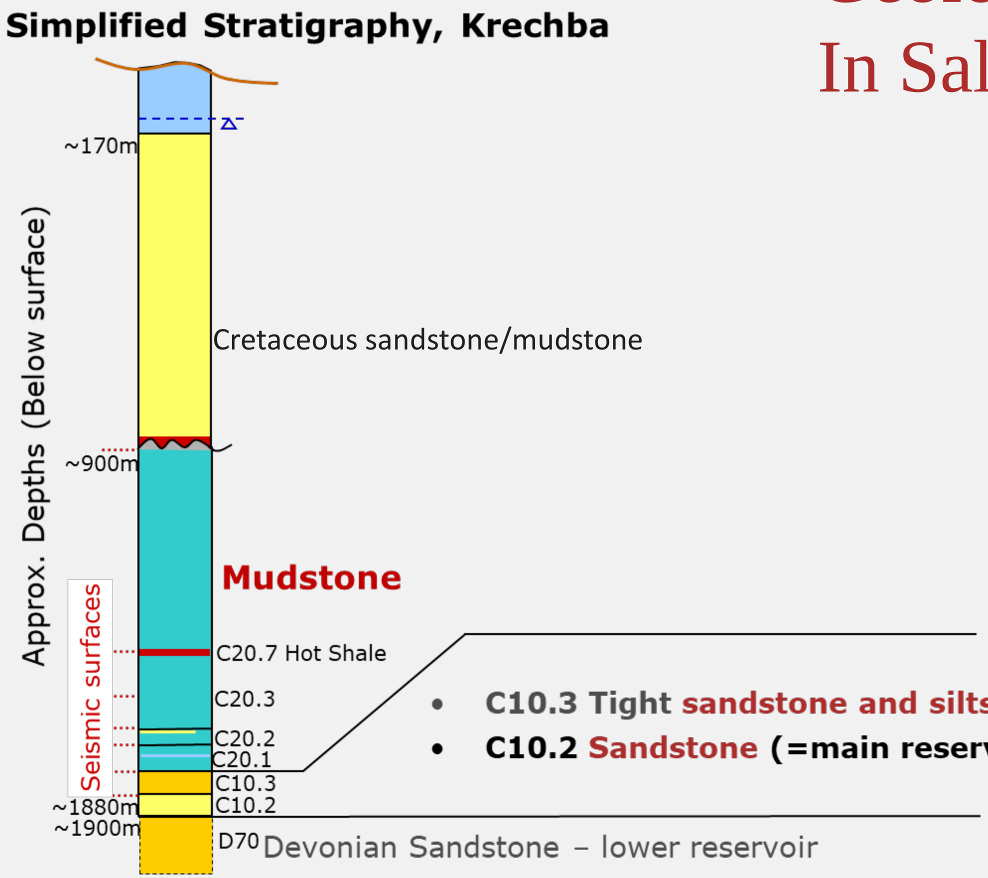
Geology of Krechba, In Salah



- **C10.3 Tight sandstone and siltstone**
- **C10.2 Sandstone (=main reservoir~20m thick)**

Ref: Geomechanical data and interpretation, (Bissell, 2009, modified)

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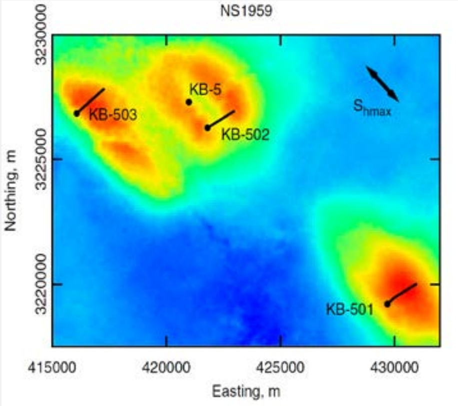
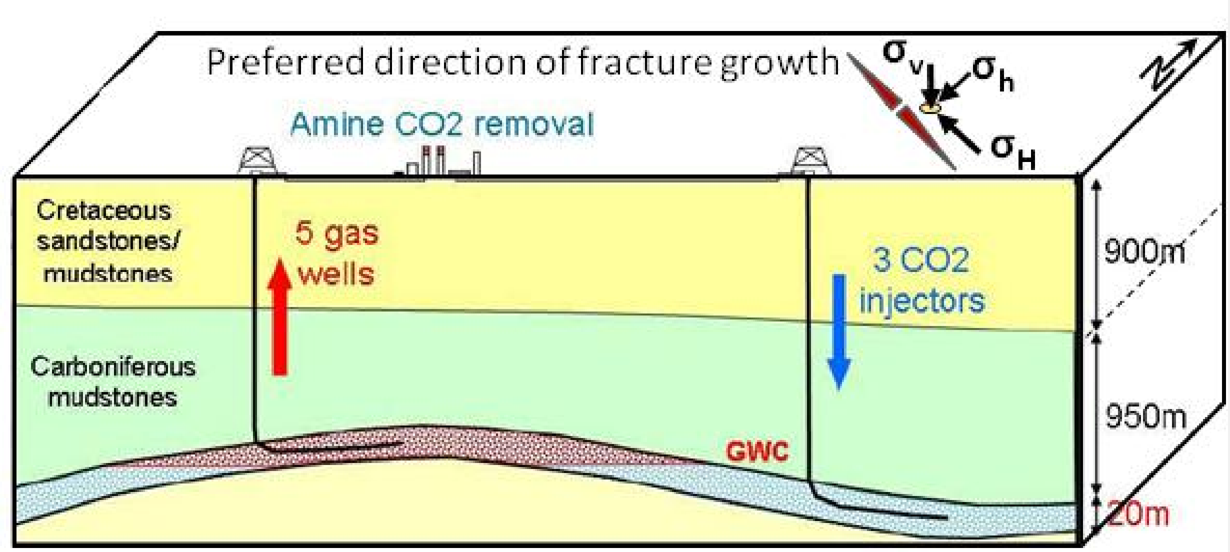
Gas production, CO_2 separation-injection and reservoir response



(White et al., 2014)



(Modified after Mathieson et al., 2011)

- How is the performance of reservoir against geomechanical constraints?

Geomechanics constraints - fracture pressure

- **Empirical method**: minimum, average and maximum fracture pressure (Eaton 1968, Zhang 2011):

(After Rutqvist et al., 2010)

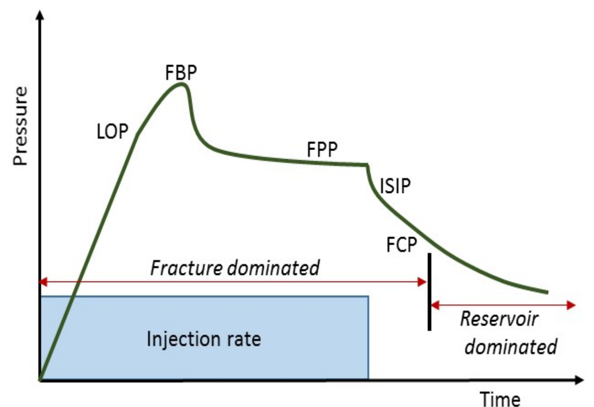
$$P_{\text{frac min}} = \sigma_3 = \frac{\nu}{1-\nu}(\sigma_v - P_p) + P_p$$

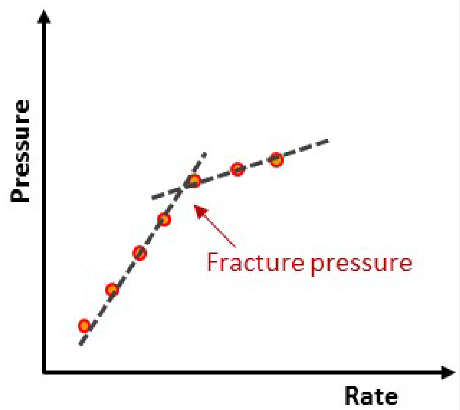
$$P_{\text{frac ave}} = \frac{3\nu}{2(1-\nu)}(\sigma_v - P_p) + P_p$$

$$P_{\text{frac max}} = \frac{2\nu}{1-\nu}(\sigma_v - P_p) + P_p$$

Layer	**Shallow overburden (0-900 m)**	**Caprock (900-1800 m)**	**Injection zone**
Lithology	Cretaceous sandstone and mudstones	Carboniferous mudstones	Carboniferous sandstones (C10.2)
Young's modulus, E (GPa)	1.5	20	6
Poisson's ratio, ν (-)	0.2	0.15	0.2
Effective porosity, ϕ (-)	0.1	0.01	0.17
Permeability, k (m^2)	$1*10^{-17}$	$1*10^{-21}$- $1*10^{-19}$	$1*10^{-14}$

- **Well tests**
  - Minifrac test
  - Step rate test (SRT)
- **Injection data**





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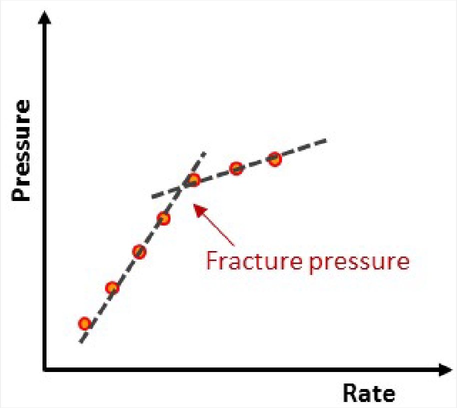
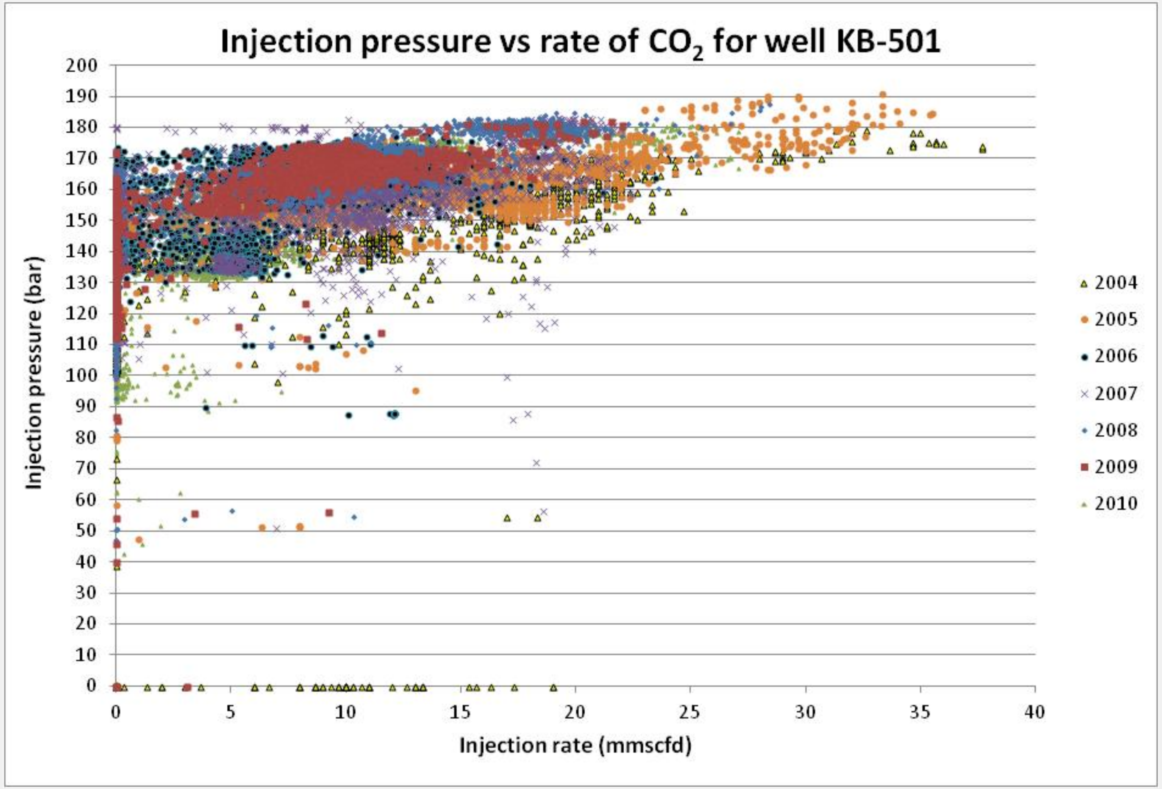
Fracture pressure: pressure-rate plot



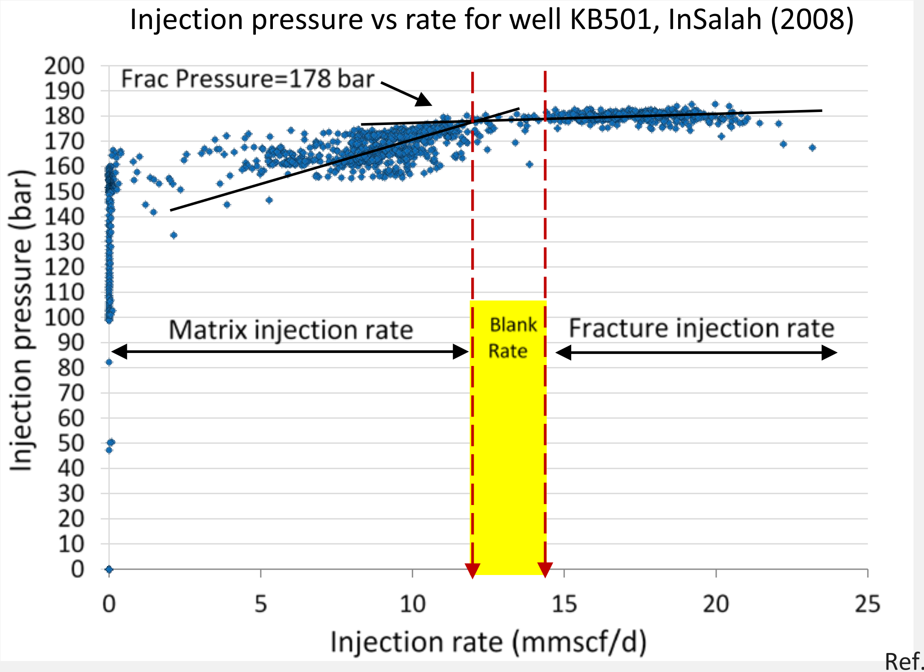
Step rate test (SRT)

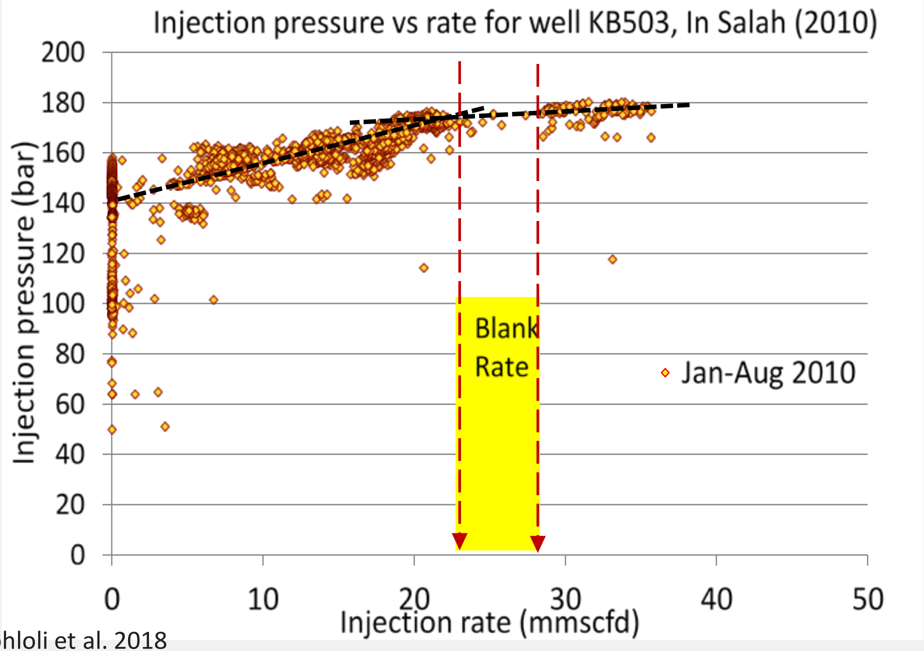


- Data from In Salah JV

Fracture pressure: pressure-rate plot (Pseudo SRT)

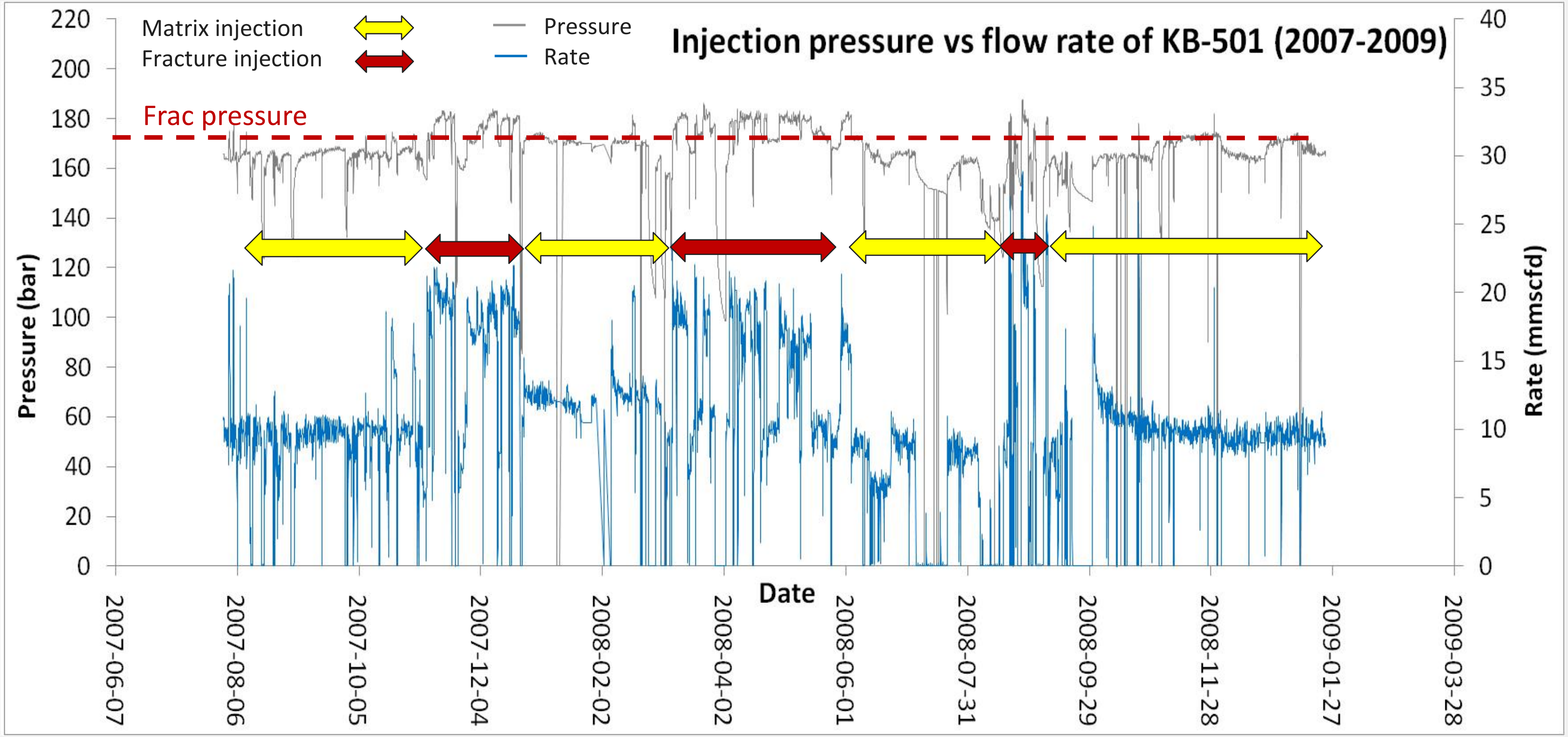
- Plot of pressure vs rate in specific time intervals shows distinct clouds of data points, intersection of their trend lines indicates fracture pressure.





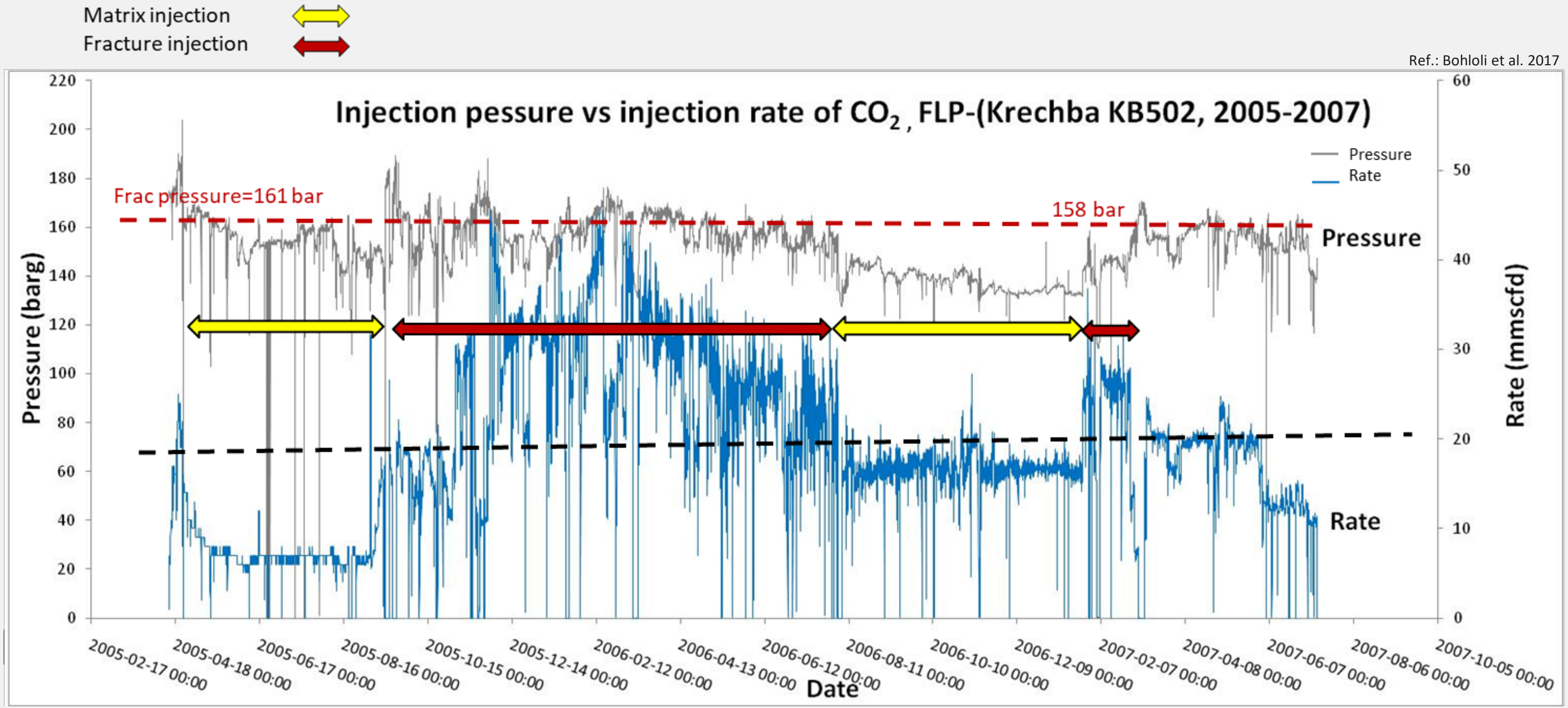
Ref.: Bohloli et al. 2018

Fracture pressure from injection time series



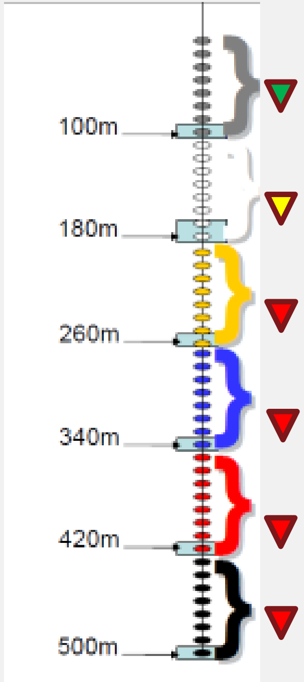
Ref.: Oye et al. 2013

Well KB502: a long-time fracturing episode. Fracture pressure almost constant over time.

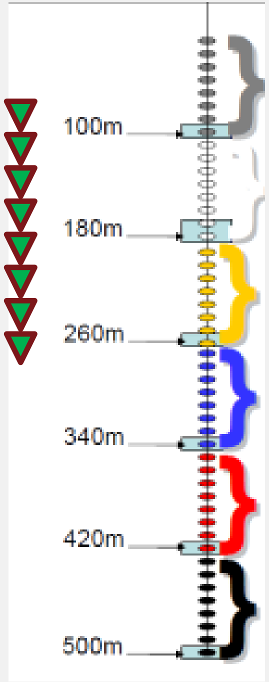


Microseismic at Kb-601

2009-2011



2012-



- Geophone array downhole
- All geophones on common GPS time
- Removed large electronic noise.

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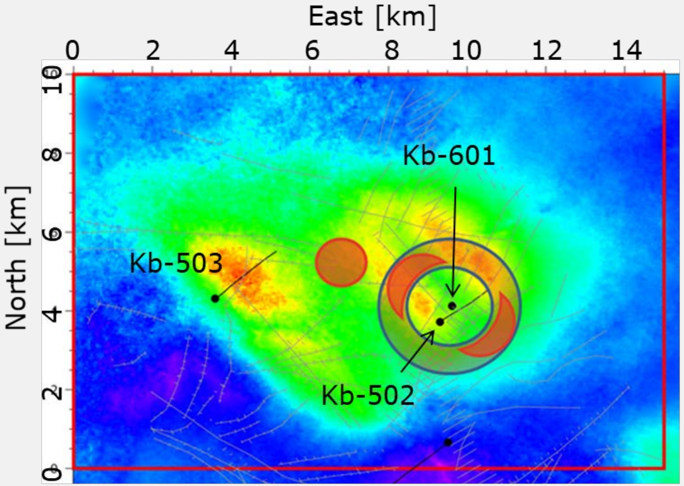
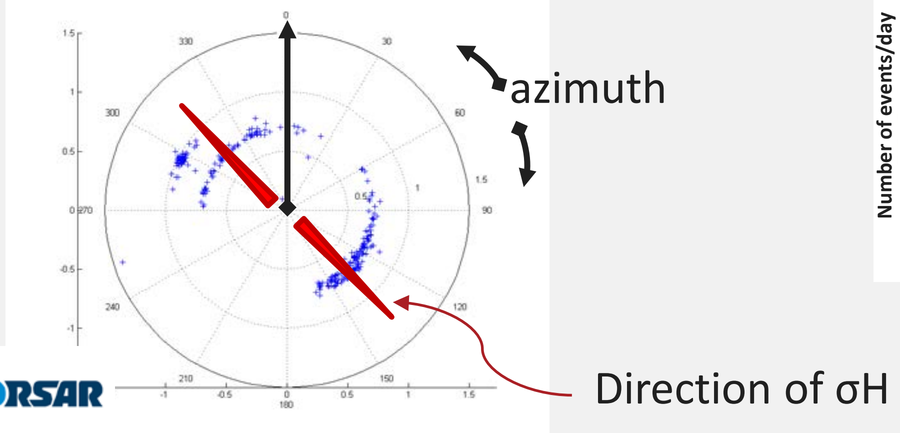
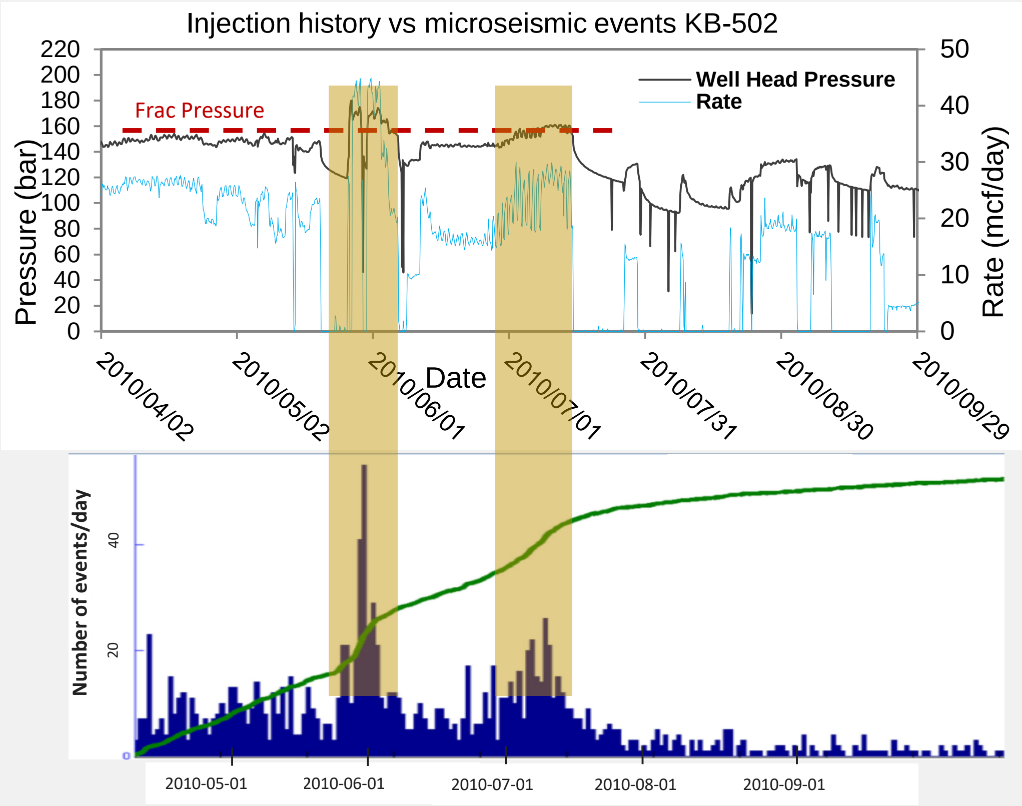
Correlation of fracture episodes with microseismicity







Microseismic events

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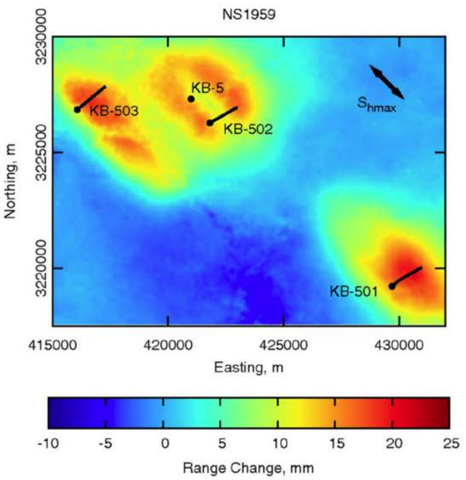
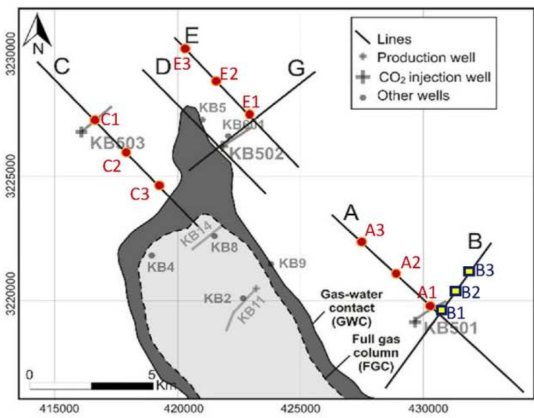
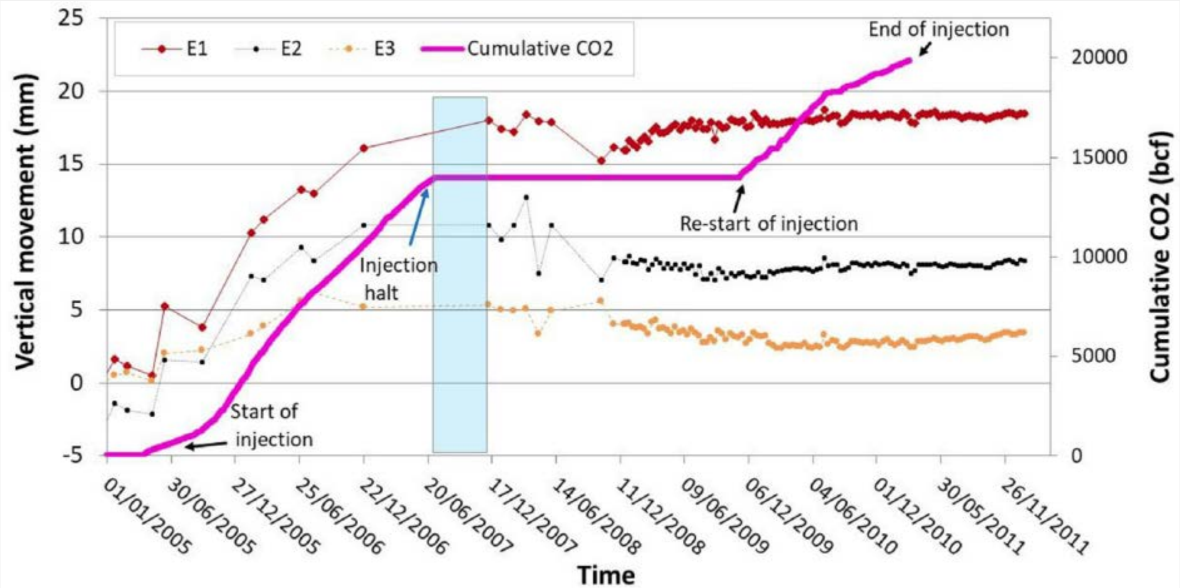
Oye et al. 2014

Ground surface monitoring- to understand reservoir behaviour







SENSE

Assuring integrity of CO_2 storage sites through ground surface monitoring

https://sense-act.eu/

Ref.: Bohloli et al. 2018

Summary

- In Salah and Longyearbyen CO_2 storage sites have provided **excellent knowledge and experience** to the geoscience/geoengineering community.
- It shows how performance of a reservoir can be monitored against **safe injection pressure-risk of fracturing**. Open questions:
  - How to obtain e.g. actual frac pressure in advance,
  - If case of fracturing, frac orientation/location in a cost effective way?
- Important to have **basic mechanical, in-situ stresses** and **workflows** for storage site monitoring.
- **Multidisciplinary approaches** (geological, geophysical, reservoir engineering, hydrogeological concepts) are essential for understanding reservoir performance & integrity.

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Thank you for your attention!

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SENSE

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The Research Council of Norway

Accelerating CCS Technologies

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CCS Research funding- possible programs

- Horizon Europe
- Accelerating CCS Technology (ACT)- a new format in 2022
- Bilateral research funds
- Research calls by the Research Council of Norway (CLIMIT, INTPART, etc.)

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