Fault hydromechanical characterization and CO_2-saturated water injection at the CS-D experiment (Mont Terri Rock Laboratory)

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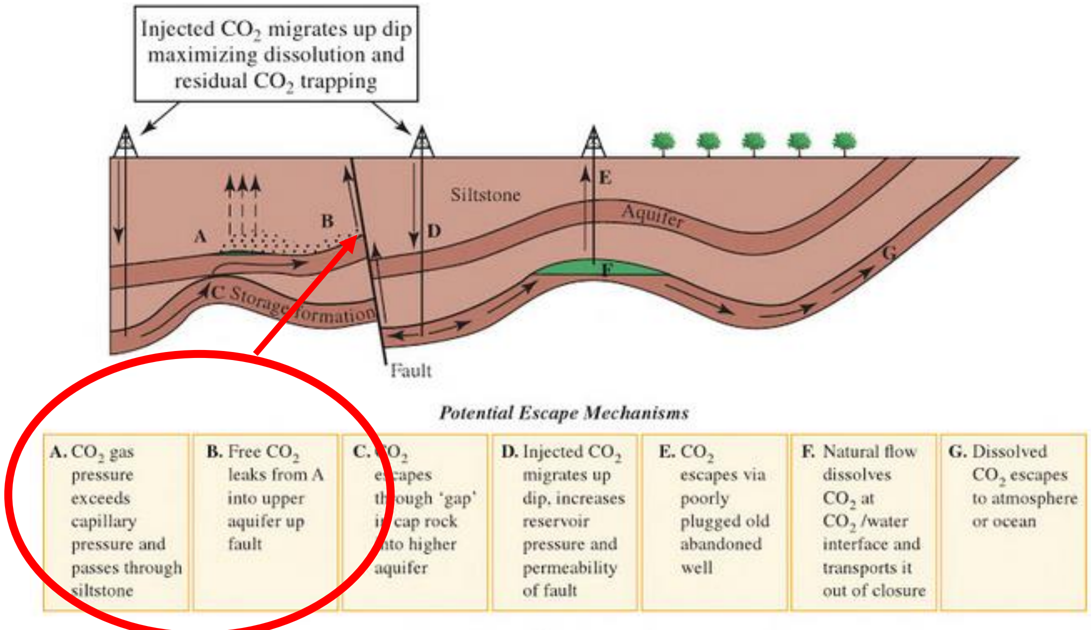
Scientific objectives



Metz et al., 2005, IPCC Special Report

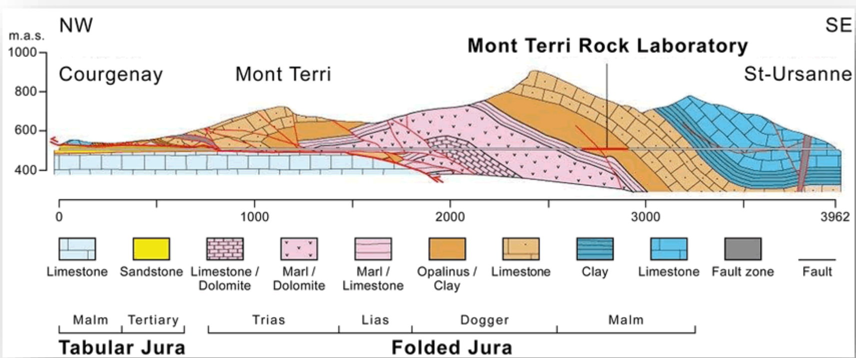
Understanding how exposure to CO_2-rich water affects **sealing integrity** of caprock (hosting a fault system): **permeability changes** - **induced seismicity**

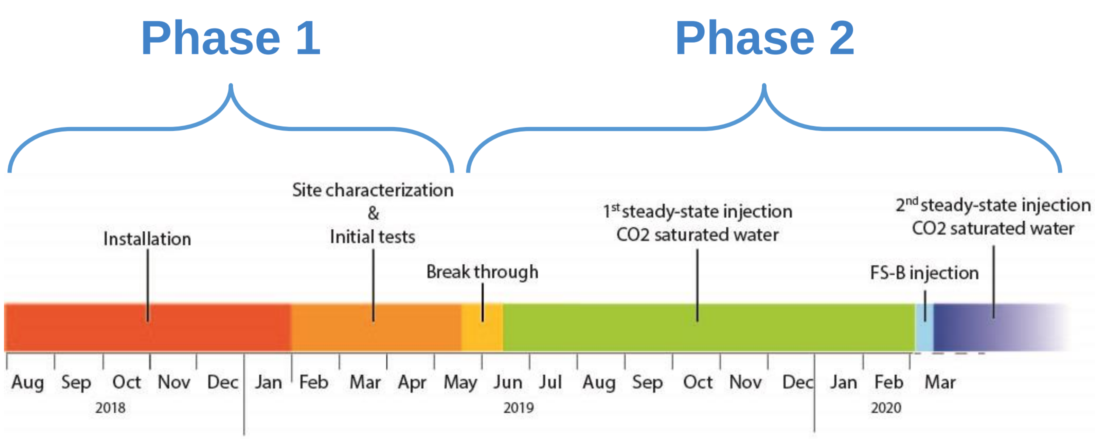
Direct observations of fluid migration along a fault and of its interaction with the surrounding environment

Validate instrumentation and methods for **monitoring** and imaging fluid transport

Validate Thermo-Hydro-Mechanical-Chemical **(THCM) simulations**

Concept





Inject CO_2 saturated water and tracers in Mont Terri Main Fault (Opalinus Clay):
- Continuous/long term (8-10 month)
- Pulse/ pressure increase steps (at beginning and at end of the injection phase)

Scale: 1-10 m^3 water/rock volume

Monitor injection effects:
- Electrical conductivity, tracers, fluid samples
- Strain = Extensometers, FO
- Pressure
- Microseismic events
- Vp,Vs changes

Numerical simulations (pre and post)

Wenning et al., 2020

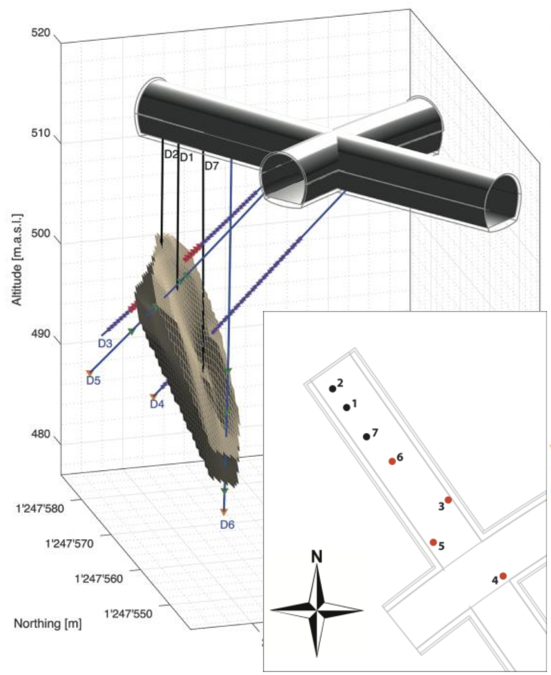
Instrumentation

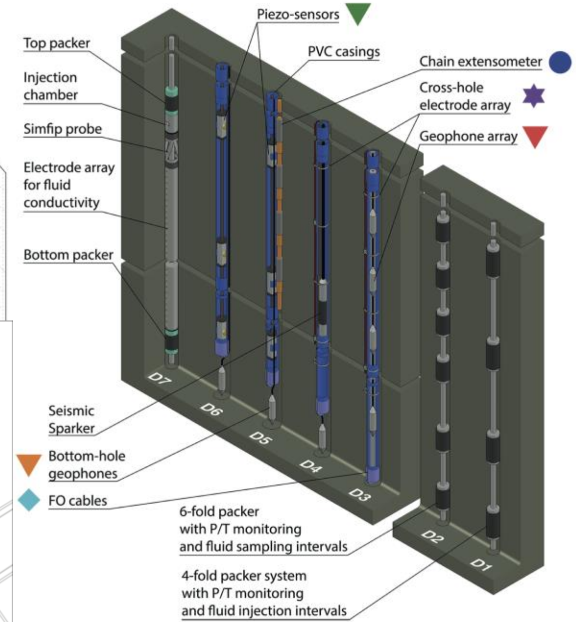
Geophysical borehole monitoring

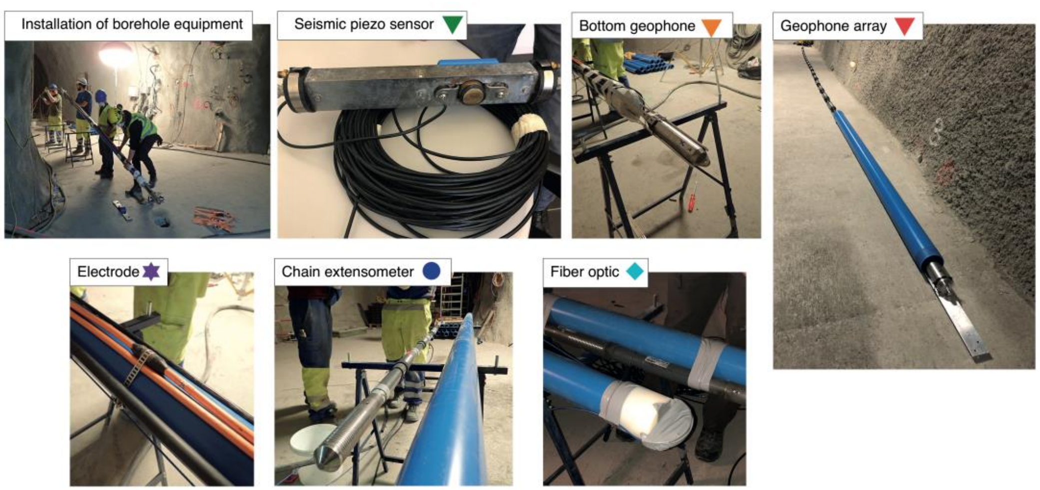
- 27 Borehole Geophones each with 3-components (0.1-2 kHz)
- 8 Piezosensors in the boreholes (1-200 kHz)
- Chain extensometers: 12 measuring sections for axial deformation and temperatures
- DSS FO in all boreholes
- SIMFIP (Gulgielmi et al., 2013) with distributed fluid electrical conductivity sensors.

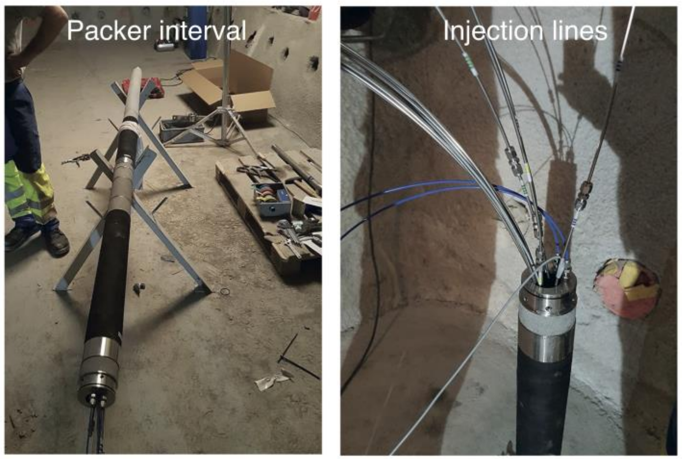
Hydrualic borehole borehole monitoring

- Injection borehole with 4-fold packer system
- Fluid monitoring borehole with 6-fold packer system, and two circulation lines for fluid sampling and analysis

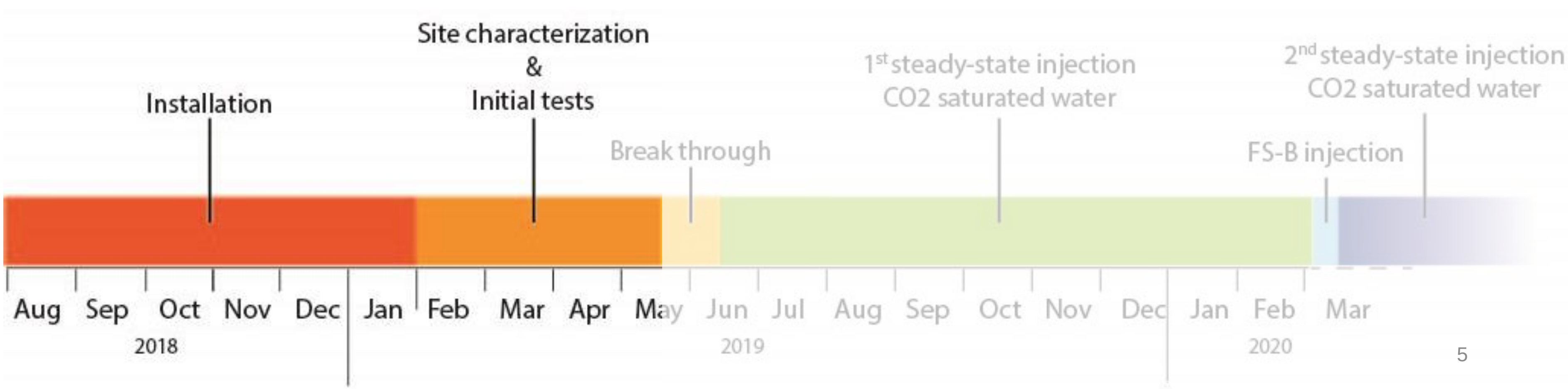




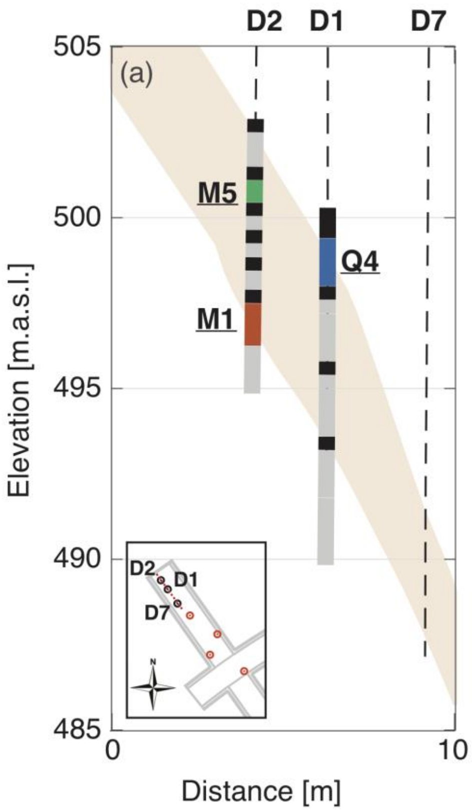


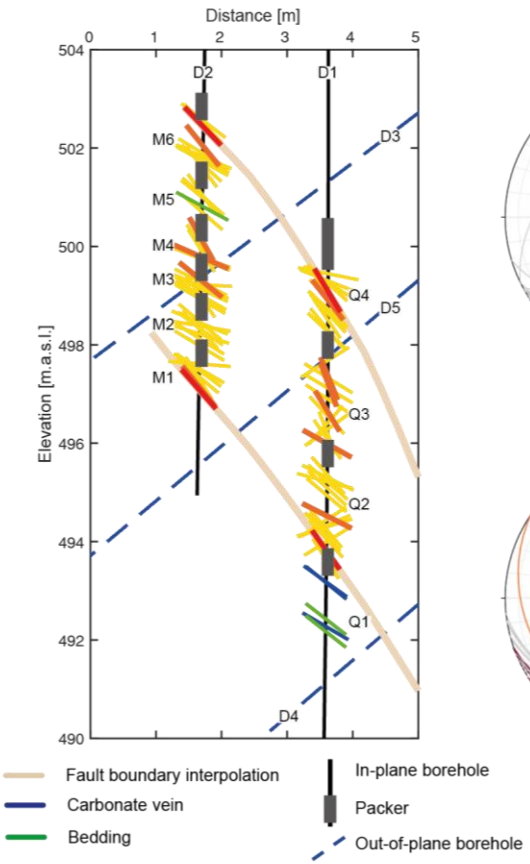


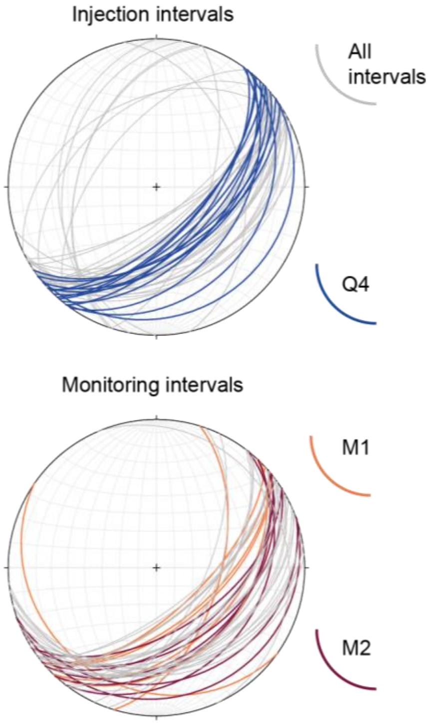
Phase 1:


Site characterization
&
Initial tests
Installation
Break through
1st steady-state injection
CO2 saturated water
2nd steady-state injection
CO2 saturated water
FS-B injection
Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar
2018
2019
2020

Fault characterization & injection tests

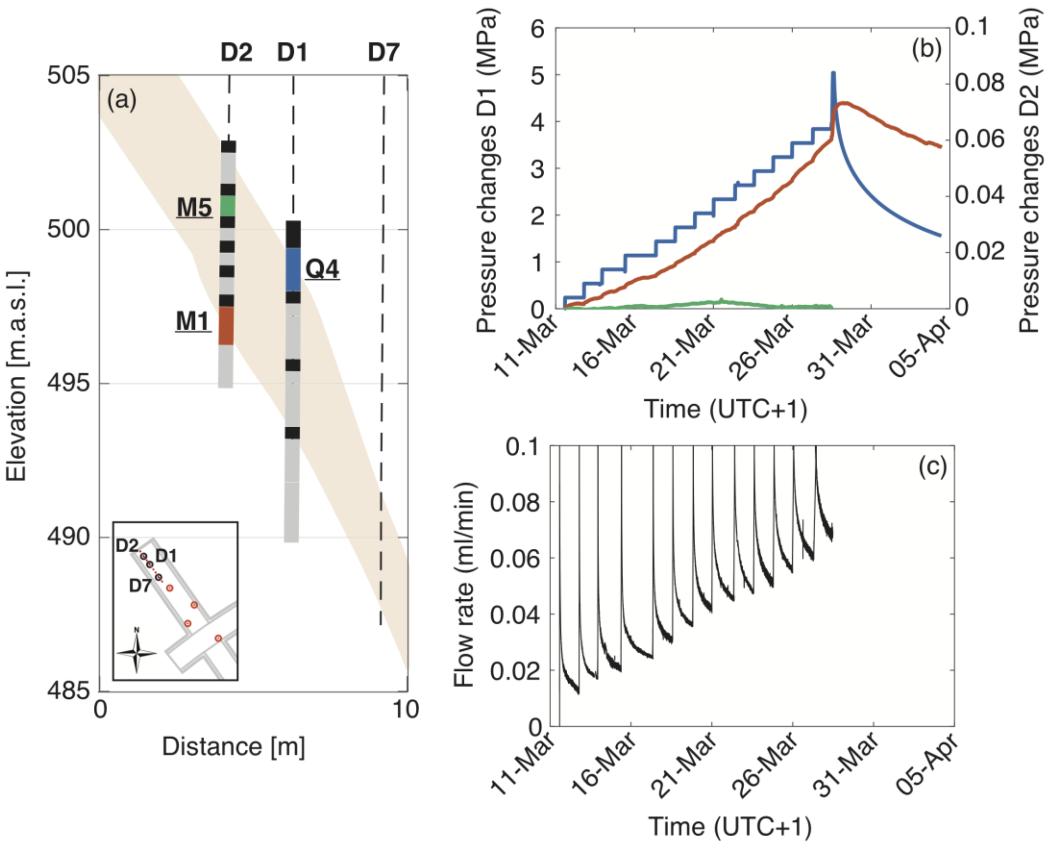






Wenning et al., 2020

Some observations from Phase 1



Prolonged step test:
- P increased by steps of 300 kPa,
- P_{max} 4.8 MPa.
- Step 28-30 hours

Aim: understand the system response to pressurization

Analysis of pressure decay (3 days) : transmissivity in the order of 10^{-13} m^2/s (~10^{-21} m^2 permeability)

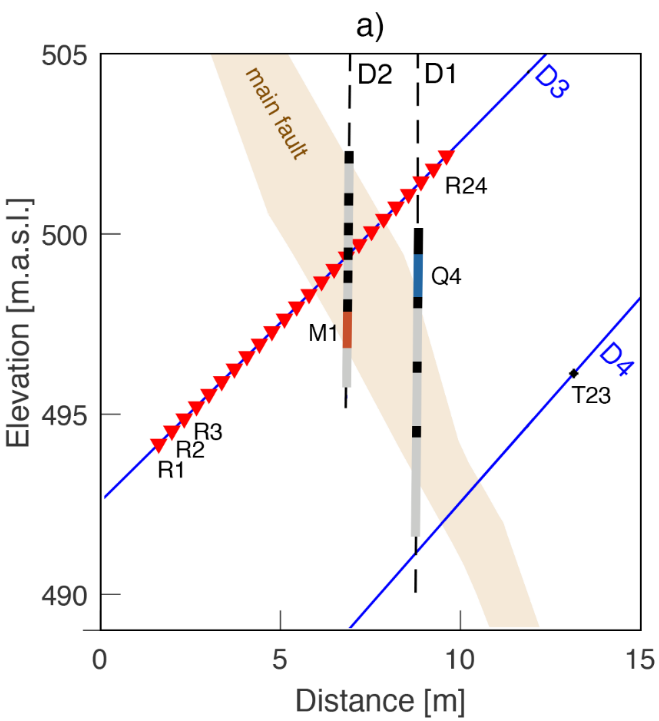
The value is closer to previous estimates (Marschall et al. 2003)

Fault Transmissivity: ~10^{-13} m^2/s ; Permeability: ~10^{-21} m^2

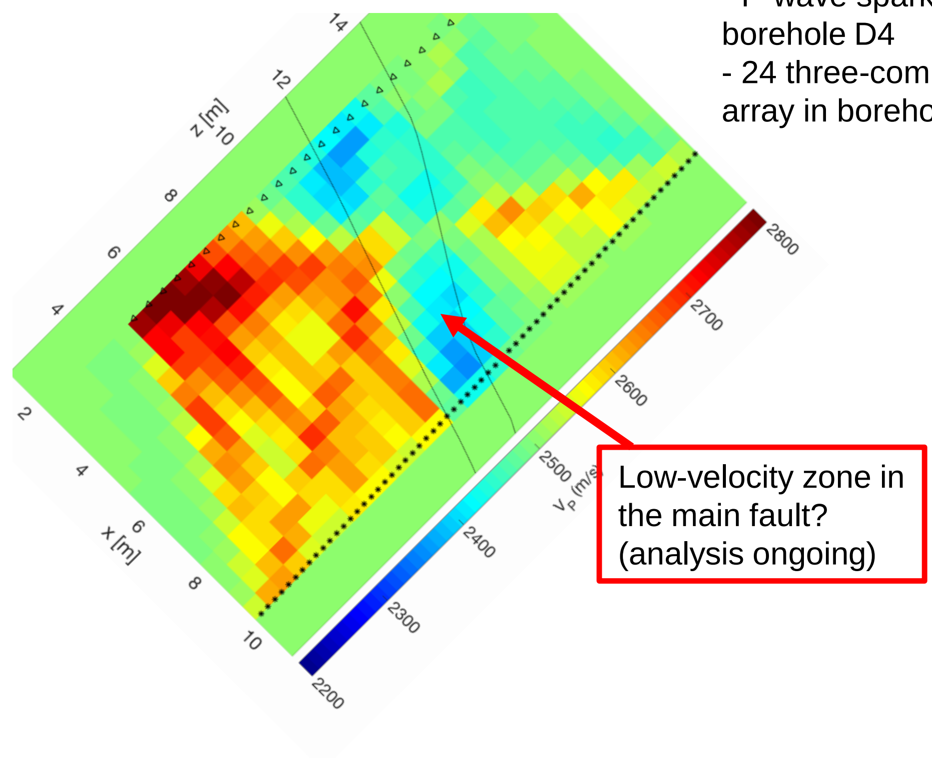
Wenning et al., 2020

Some observations from Phase 1

Geophysical monitoring with active seismics

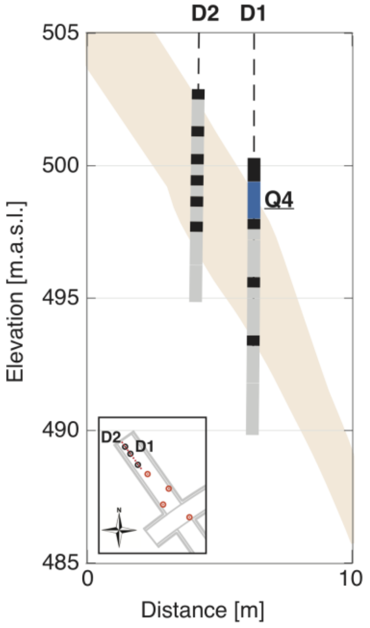


Cross-hole tomography
- P-wave sparker moved along borehole D4
- 24 three-componenet geophone array in borehole D3 (red triangles)



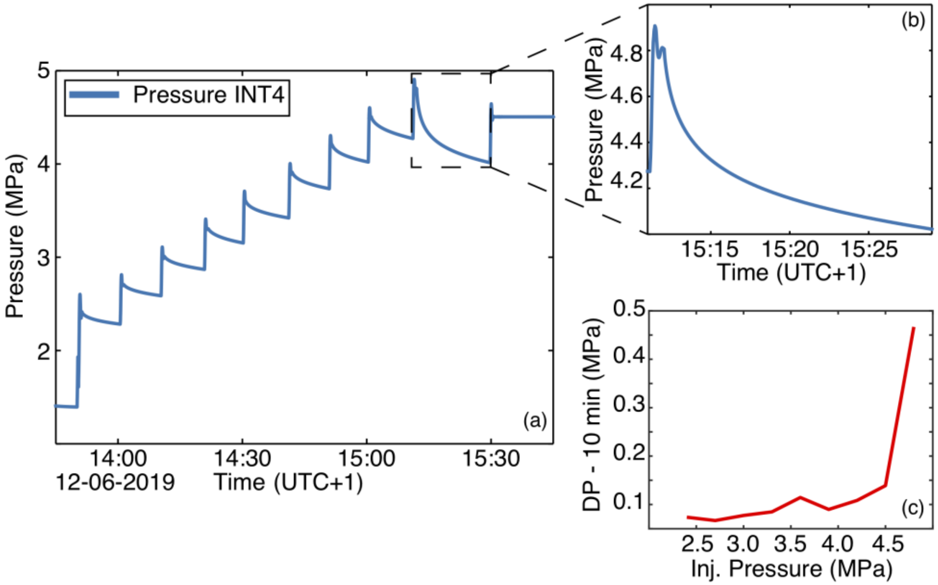
Wenning et al., 2020

Determining Fault Opening/Leakage Pressure



Testing for Fault Opening Pressure (FOP)

- FOP estimated greater than 4.5 MPa
- Estimated transmissivity at reactivation: $9 \cdot 10^{-12}$ m²/s



Thus, long term injection to be done at 4.5 MPa just below the FOP

Key results from Phase 1

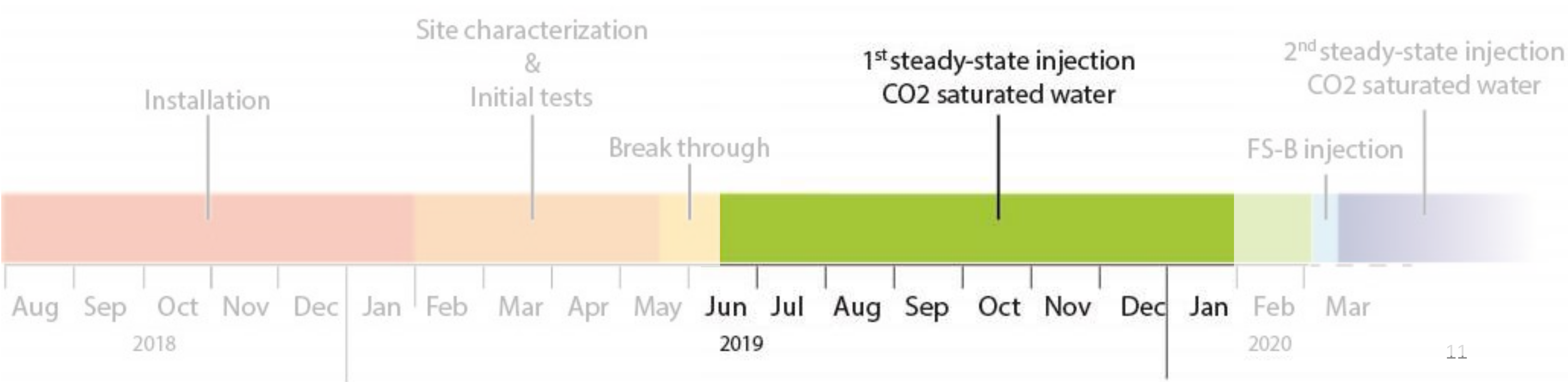
- Fault Transmissivity: ~10^{-13} m^2/s ; Permeability: ~10^{-21} m^2
- Fault opening pressure c.a. 4.8 MPa
- Seismic tomography easily reveal the fault structure due to velocity contrast
- Seismic velocities are sensible to pore pressure variation in the system with c.a. ~1 % variation (P waves)

  - EGU2020-21588: Grab et al., 2020, Active seismic monitoring of CO_2-saturated brine injection into a fault (CS-D experiment in the Mont Terri Rock Laboratory)

- No induced seismicity was detected during injection activities
- Hydromechanical analysis of borehole equilibrium (collaboration with FS-B)

  - EGU2020-18041: Rinaldi et al., 2020, Coupled processes in clay during tunnel excavation

Phase 2:



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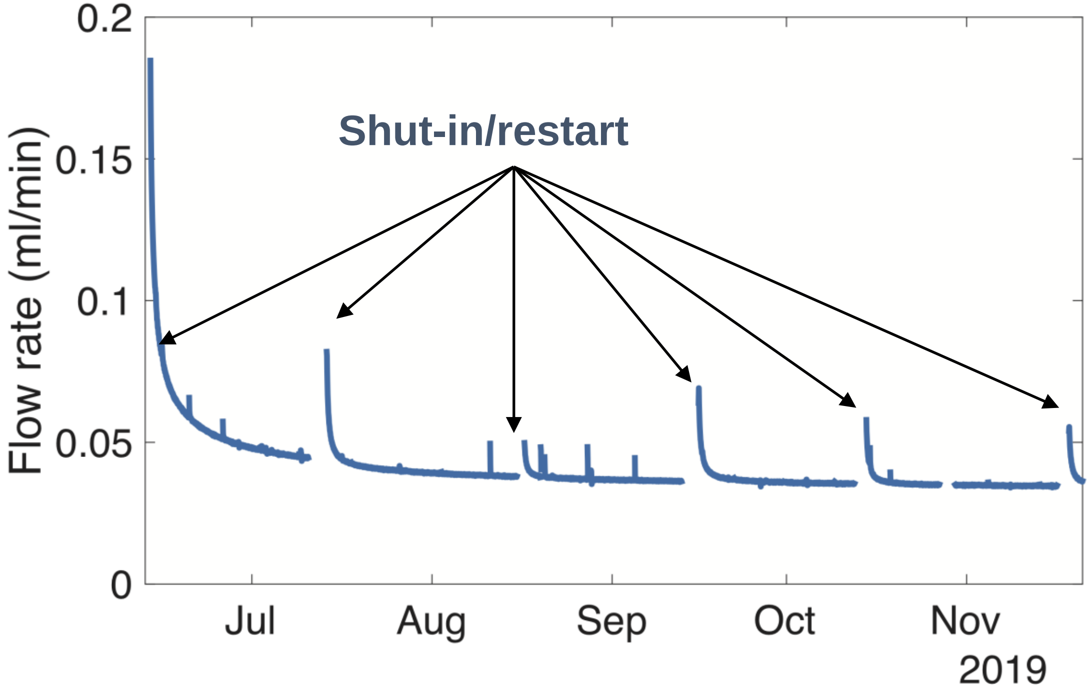
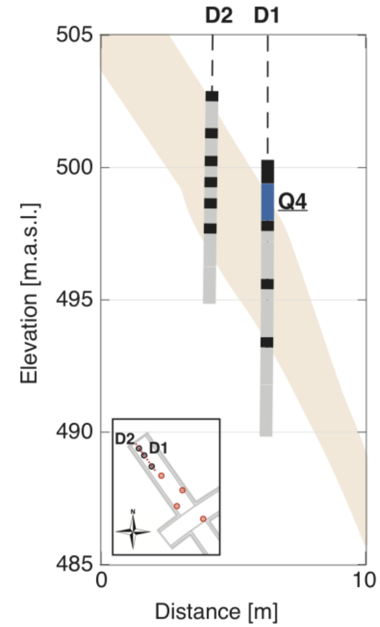
Injection of CO_2-saturated-fluid

Constant pressure Injection of CO_2-saturated-fluid

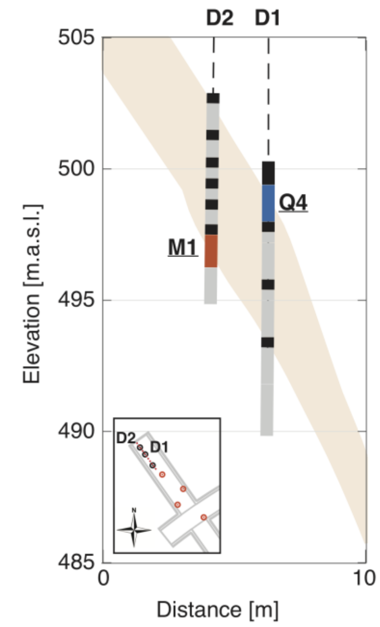


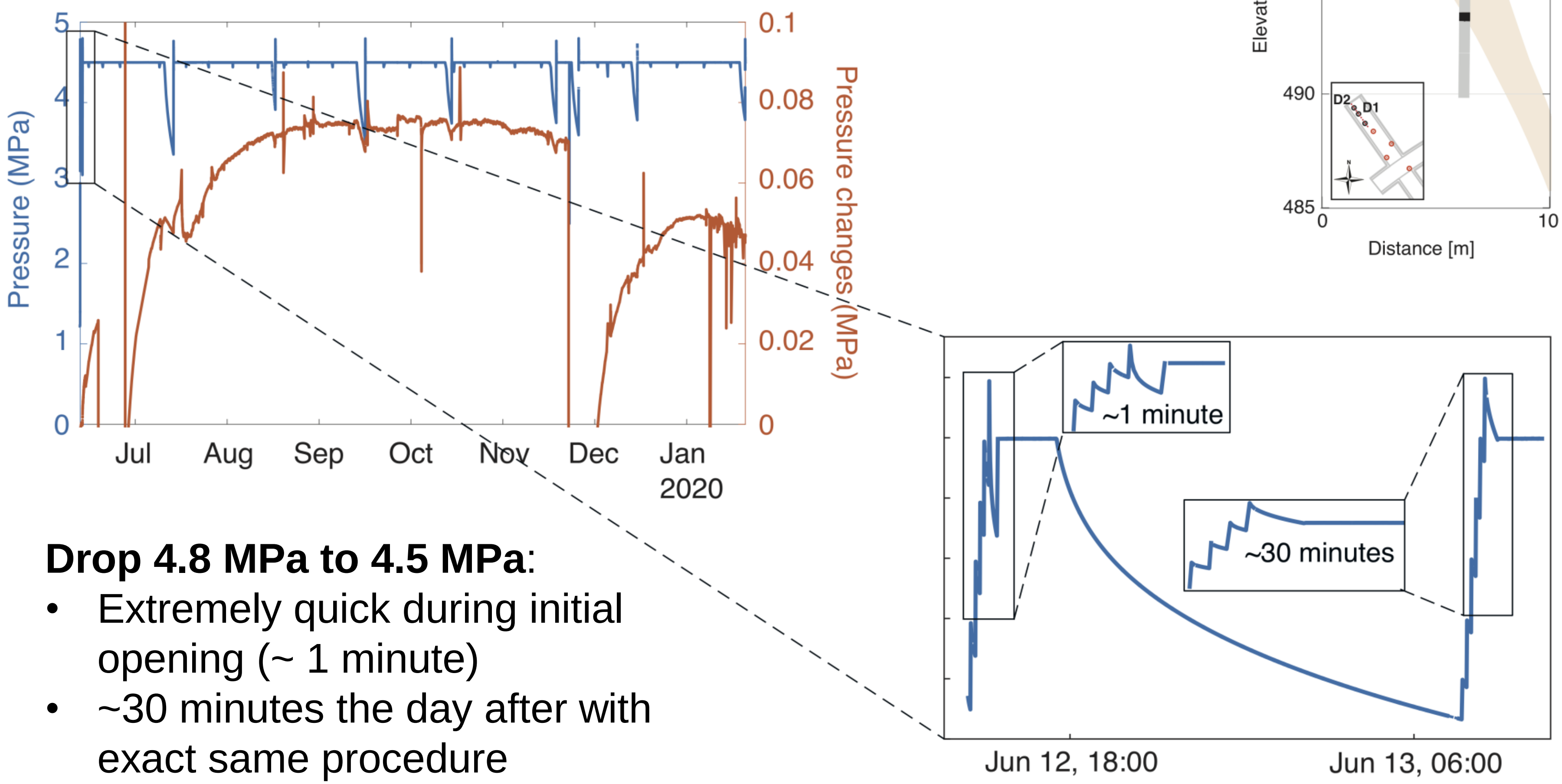


- Constant pressure of 4.5 MPa
- Injection fluid: Pearson water+Kr+CO_2 (mixed at about 2.2 MPa)

Wenning et al., 2020

Injection of CO_2-saturated-fluid



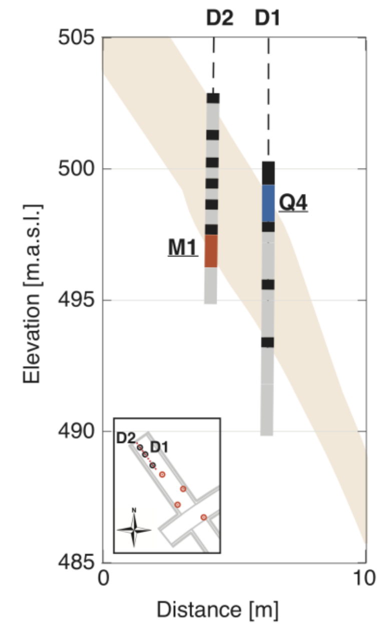


Drop 4.8 MPa to 4.5 MPa:

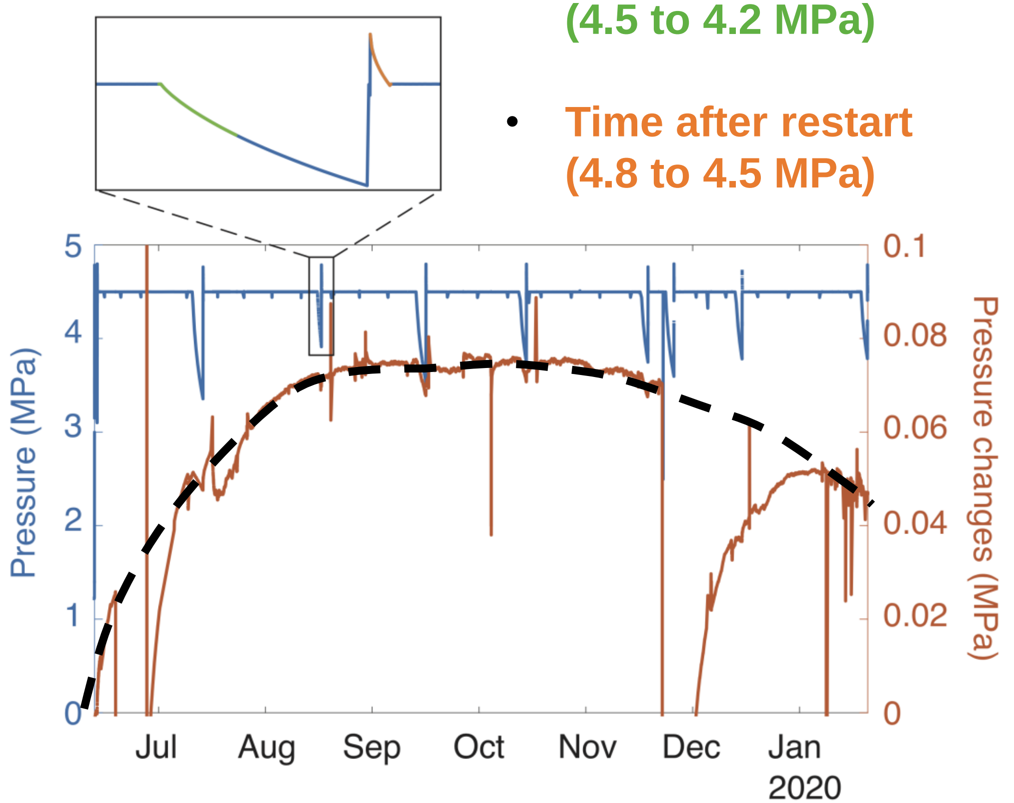
- Extremely quick during initial opening (~ 1 minute)
- ~30 minutes the day after with exact same procedure

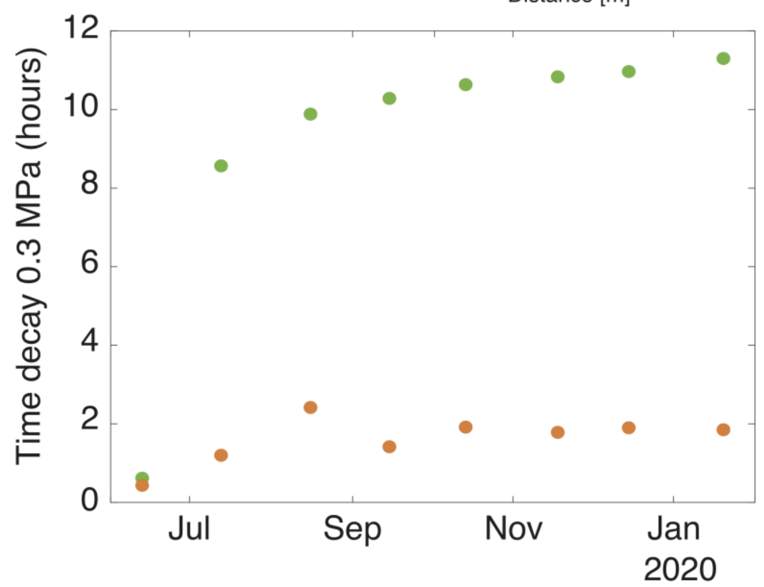
Wenning et al., 2020

Injection of CO_2-saturated-fluid



- **Time after shut-in (4.5 to 4.2 MPa)**
- **Time after restart (4.8 to 4.5 MPa)**





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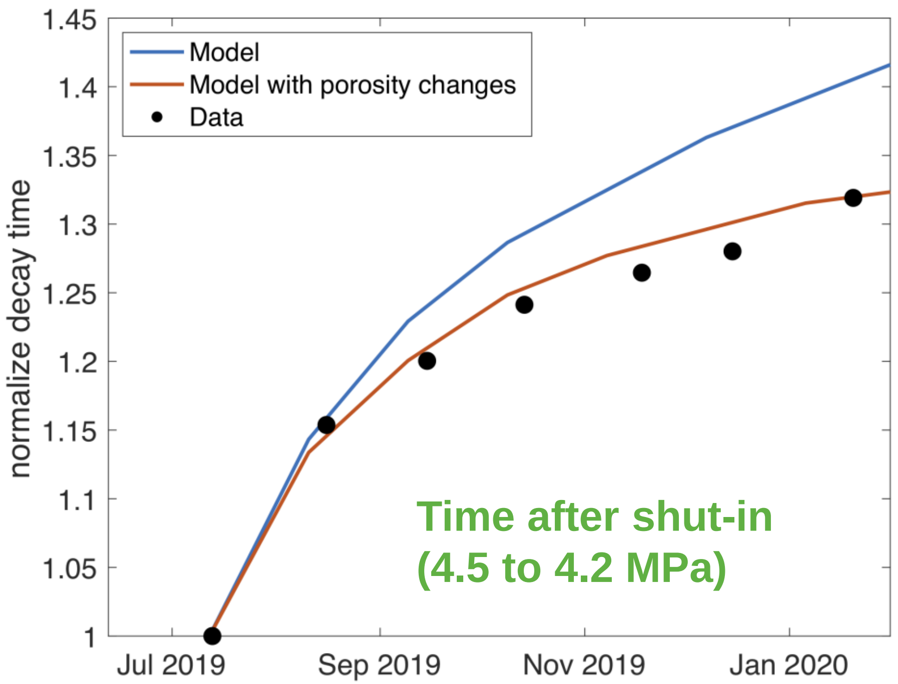
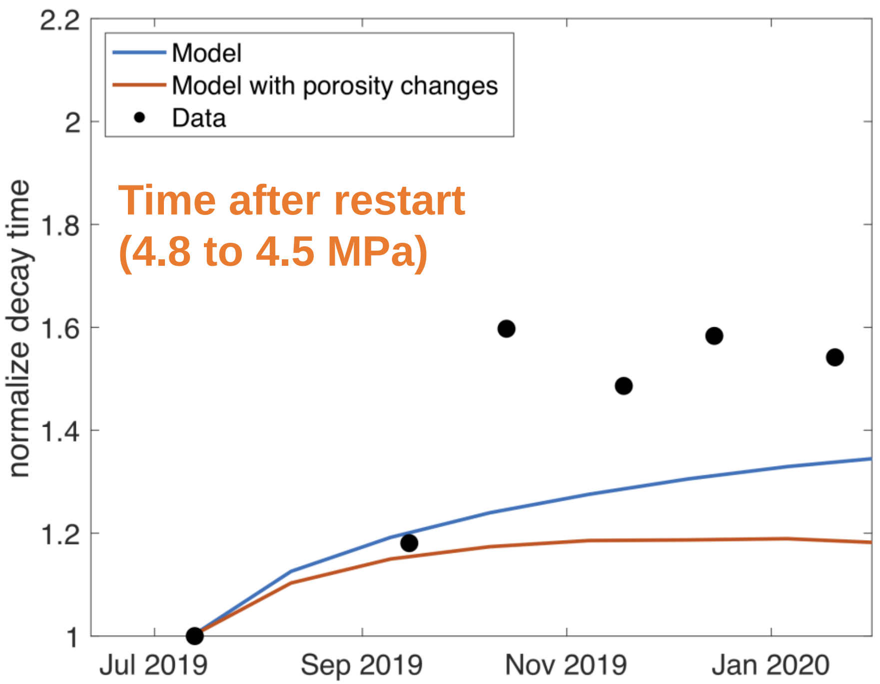
Fault self-sealing?
Swelling?

Injection of CO_2-saturated-fluid

Preliminary modelling:





- Axisymmetric, homogeneous model
- Calibrated only on data prior long-term injection
- Porosity changes 0.5% each month in the near well

NOTE: oversimplified model, no fit with pressure at monitoring point

Wenning et al., 2020

Key results from Phase 2

- Fault/fracture seals almost immediately (the day after).
- Long term injection of CO_2-saturated fluid shows quite interesting preliminary results. The system recovery could indicate some decrease in porosity.
- More complex, calibrated model will help better understanding the dynamic of the system (Work in progress).

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