CS-D at Mont Terri :

The support of the Mont Terri rock laboratory to low carbon economy

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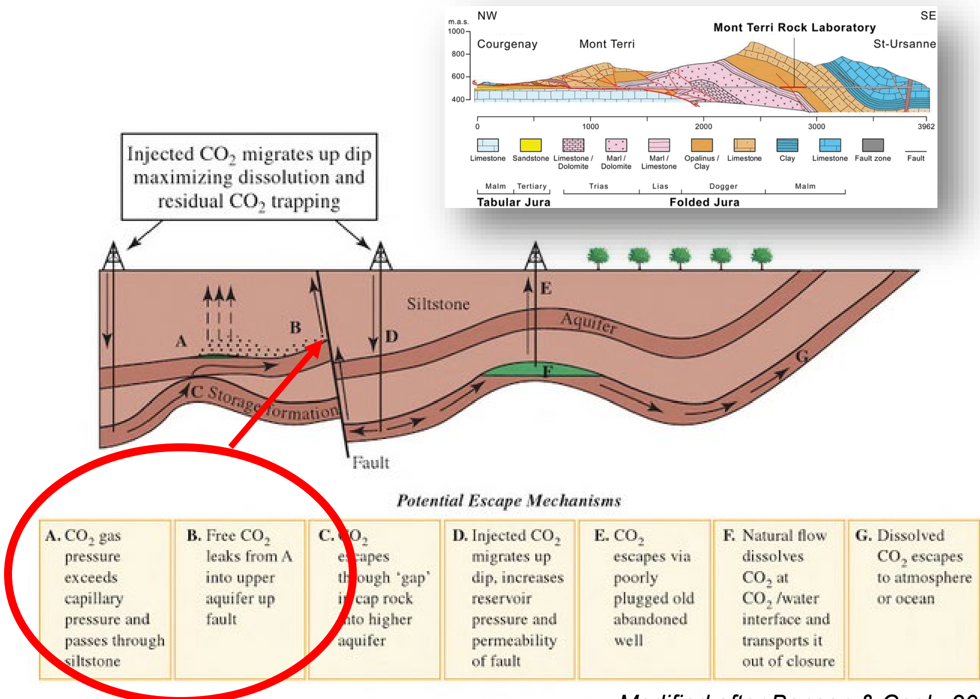
Mont Terri Project

What do we want to learn



Modified after Benson & Cook, 2005

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

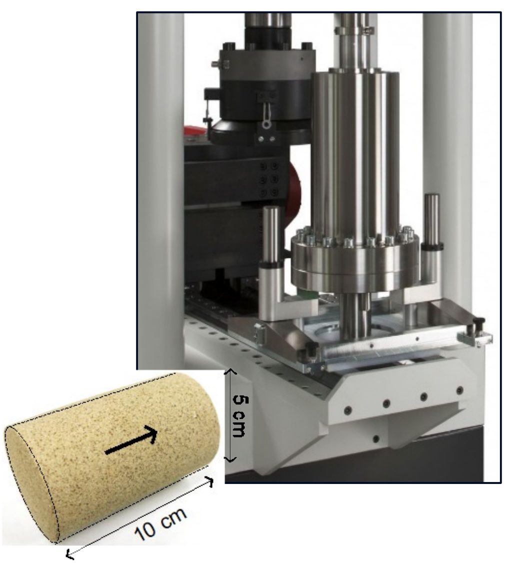
Validate instrumentation and methods for **monitoring** and imaging fluid transport

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

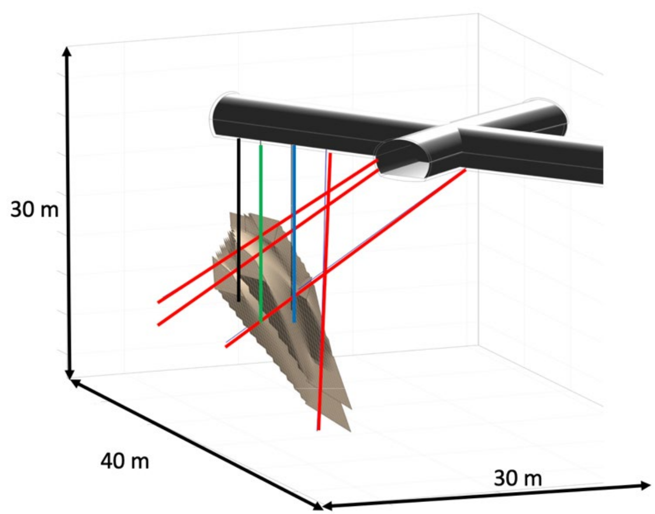
Why in Mont Terri

- Swiss geological environment
- Underground rock Labs are ideal to bridge between laboratory scale and reservoirscle.
- We can observe «in-situ» and in detail the processes.

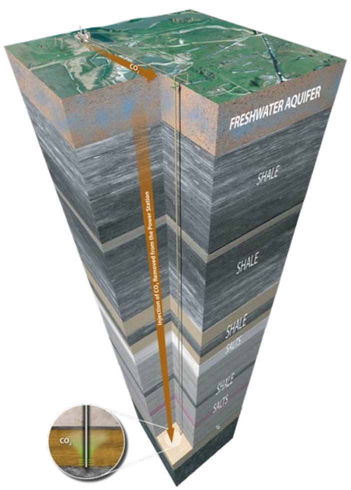
centimeter scale



decameter scale

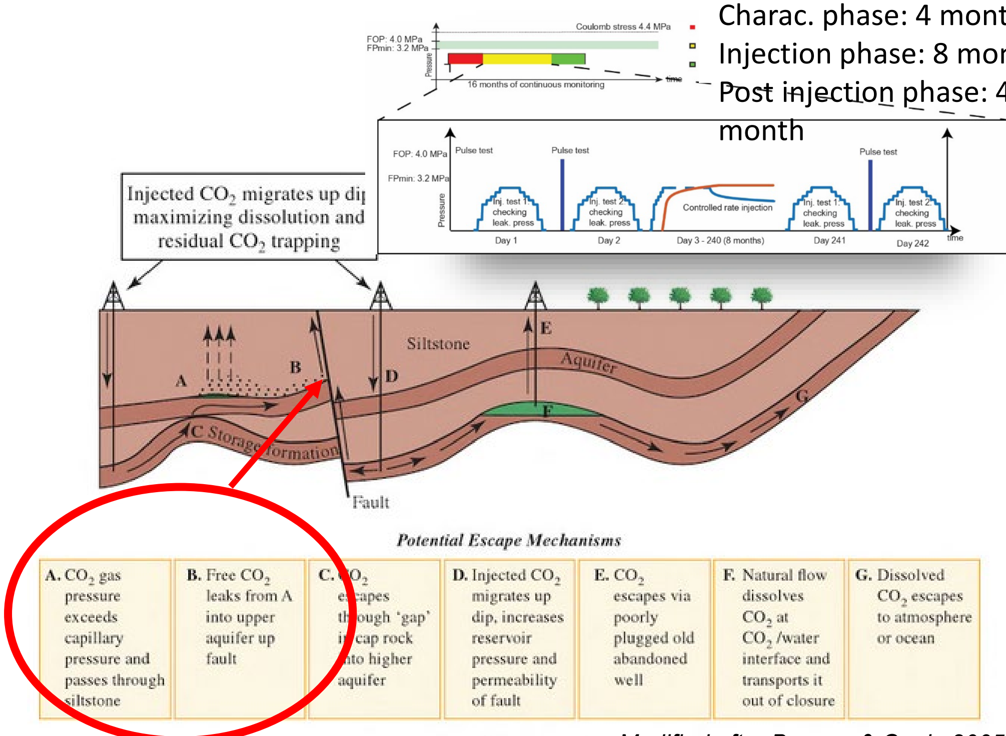


km scale



Concept

Charac. phase: 4 month
Injection phase: 8 month
Post injection phase: 4 month



Modified after Benson & Cook, 2005

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

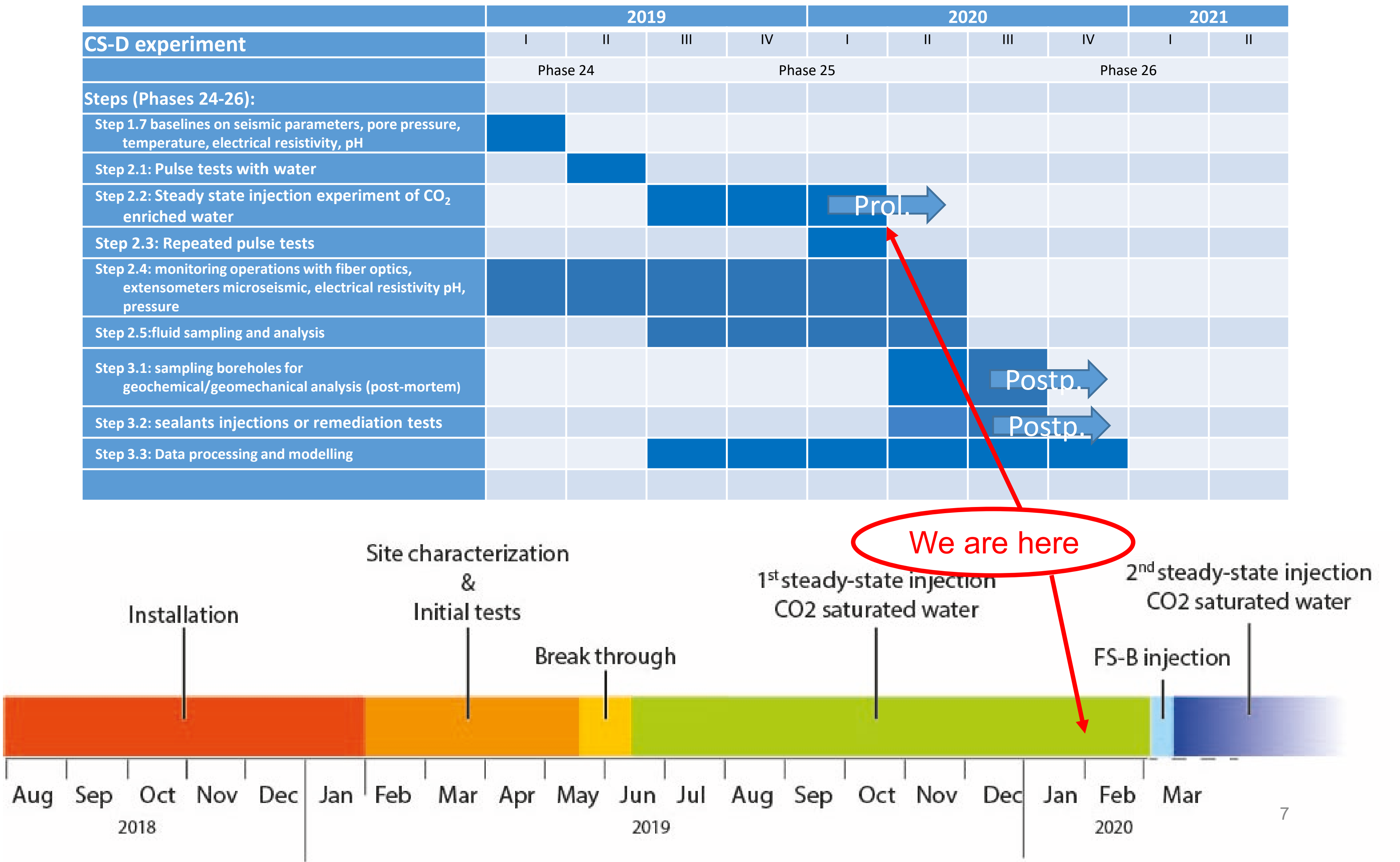
Scale: 1-10 m^3 water -> rock volume

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

Lab scale mechanical characterization

Numerical simulations (pre and post)

Timeline



2019
2020
2021
CS-D experiment
I
II
III
IV
I
II
III
IV
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II
Phase 24
Phase 25
Phase 26
Steps (Phases 24-26):
Step 1.7 baselines on seismic parameters, pore pressure, temperature, electrical resistivity, pH
Step 2.1: Pulse tests with water
Step 2.2: Steady state injection experiment of CO_2 enriched water
Prol.
Step 2.3: Repeated pulse tests
Step 2.4: monitoring operations with fiber optics, extensometers microseismic, electrical resistivity pH, pressure
Step 2.5:fluid sampling and analysis
Step 3.1: sampling boreholes for geochemical/geomechanical analysis (post-mortem)
Postp.
Step 3.2: sealants injections or remediation tests
Postp.
Step 3.3: Data processing and modelling
We are here
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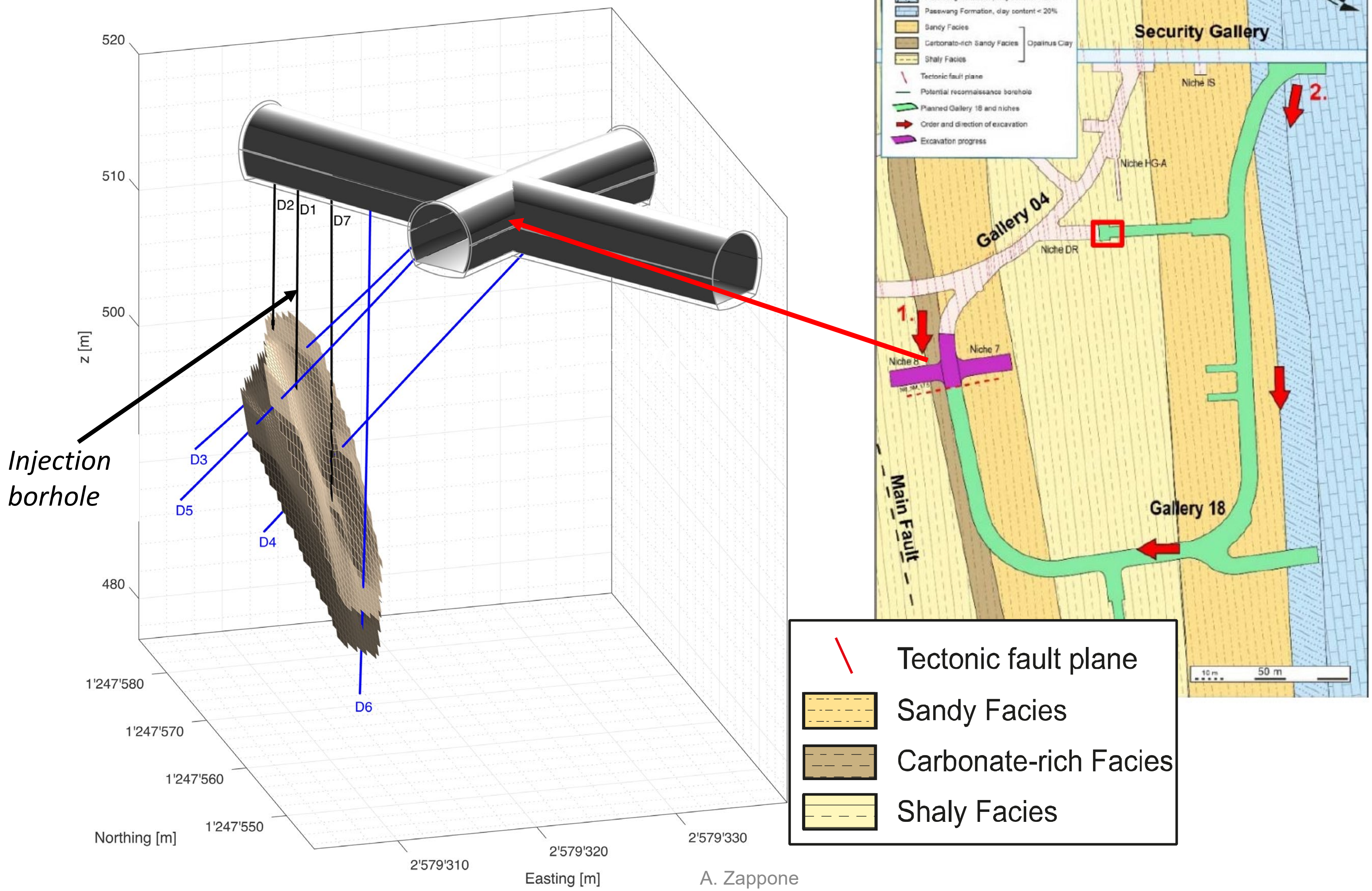
Installation Instrumentation

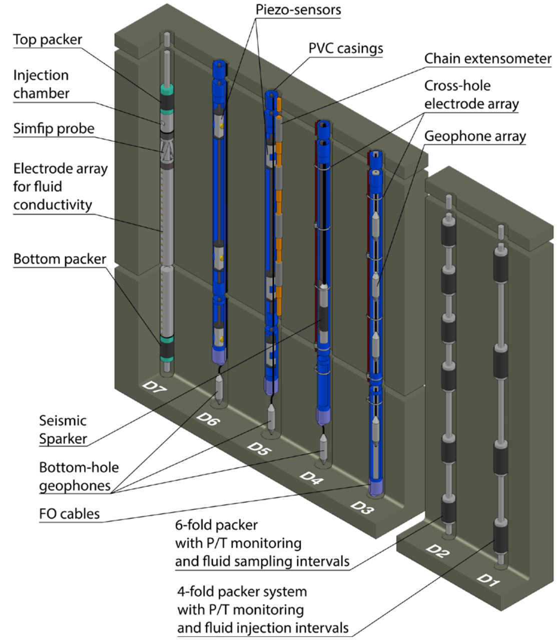


Instrumentation

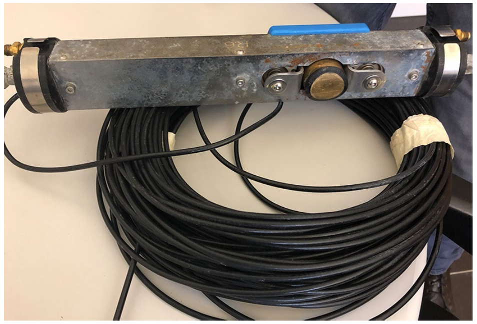
Geophysical borehole monitoring

- 27 Borehole Geophones each with 3-components
- 30 Geophones on the surface (1-component)
- 8 Piezosensors in the boreholes
- 16 Piezosensors on the surface
- Chain extensometers: 12 measuring sections for axial deformation and temperatures
- DSS FO in all boreholes

Geophones: 0.1-2 kHz; piezo: 1-100 kHz



Seismic piezo-sensors



Geophone array

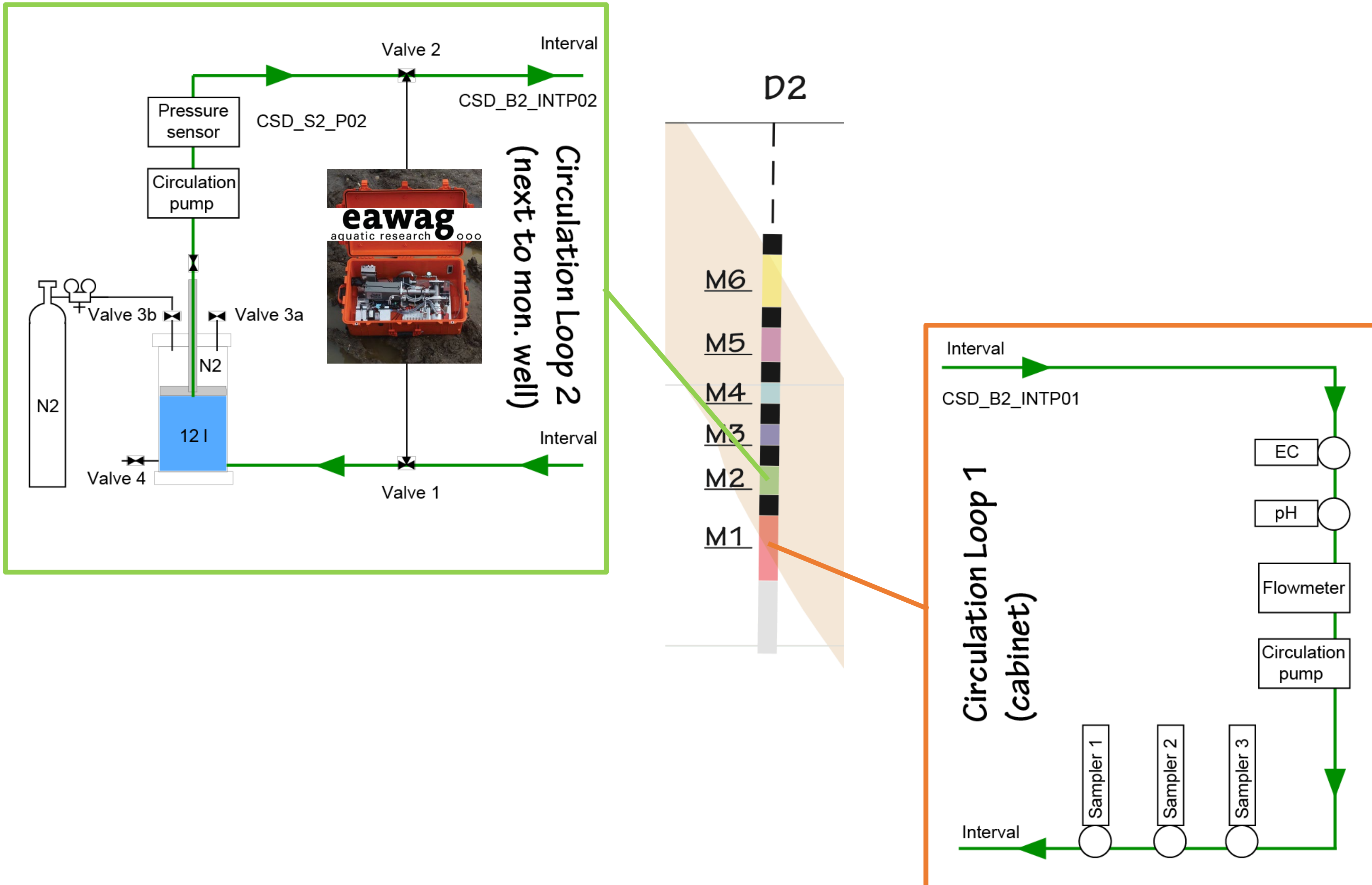
Bottom hole geophone

Electrical resistivity sensor

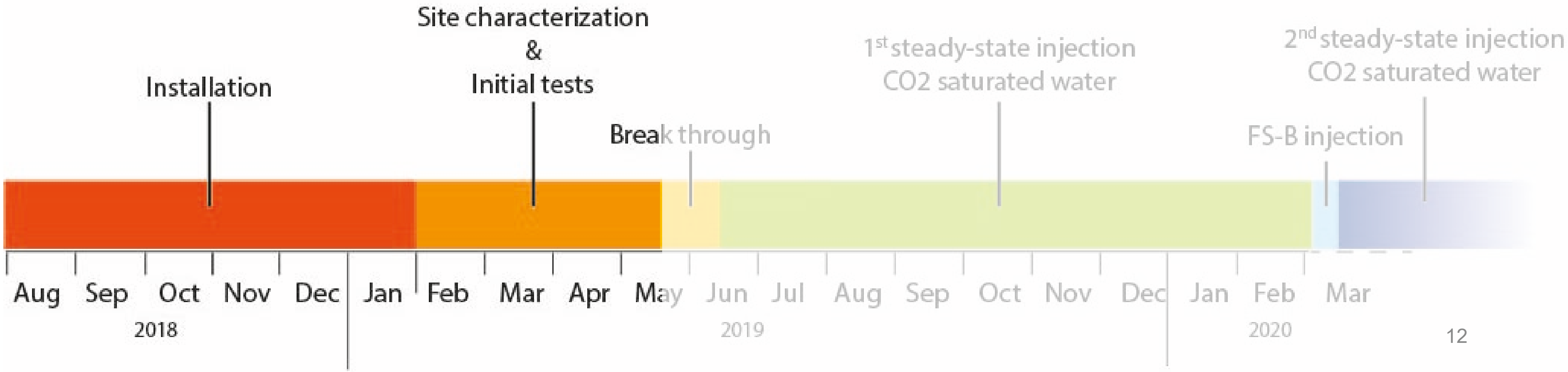
Chain extensometer

Fiber optic DSS

Instrumentation



Phase 1:



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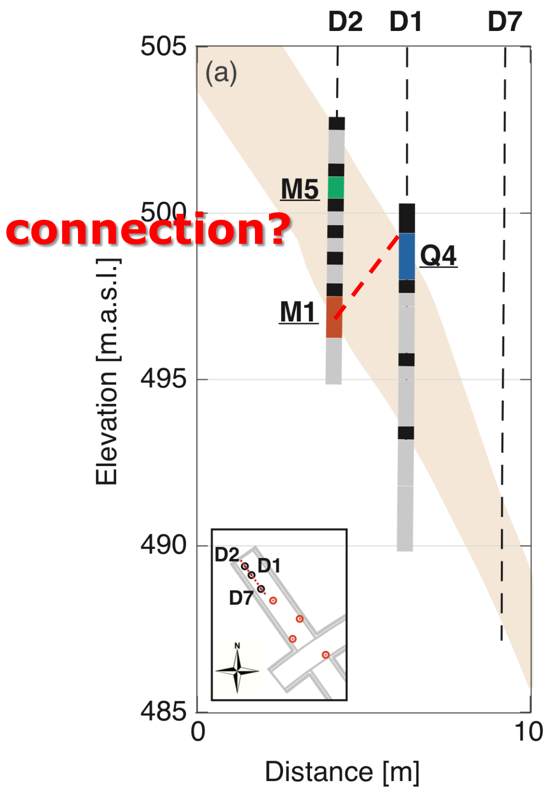
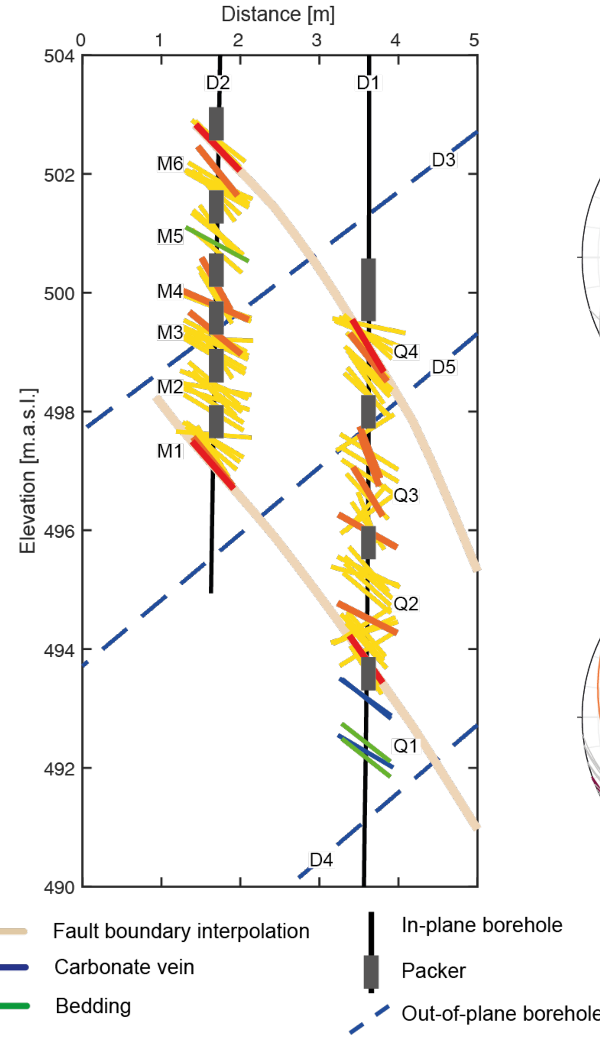
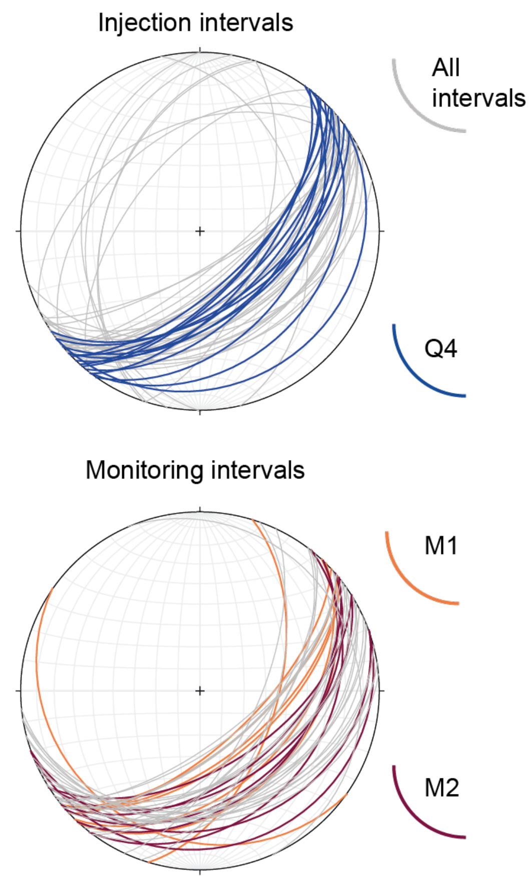
Fault characterization & injection tests

by Q. Wenning

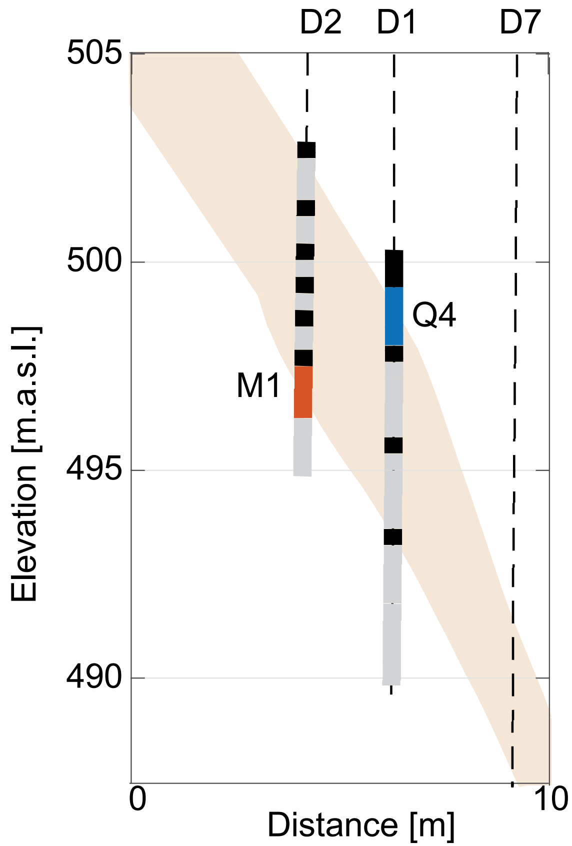


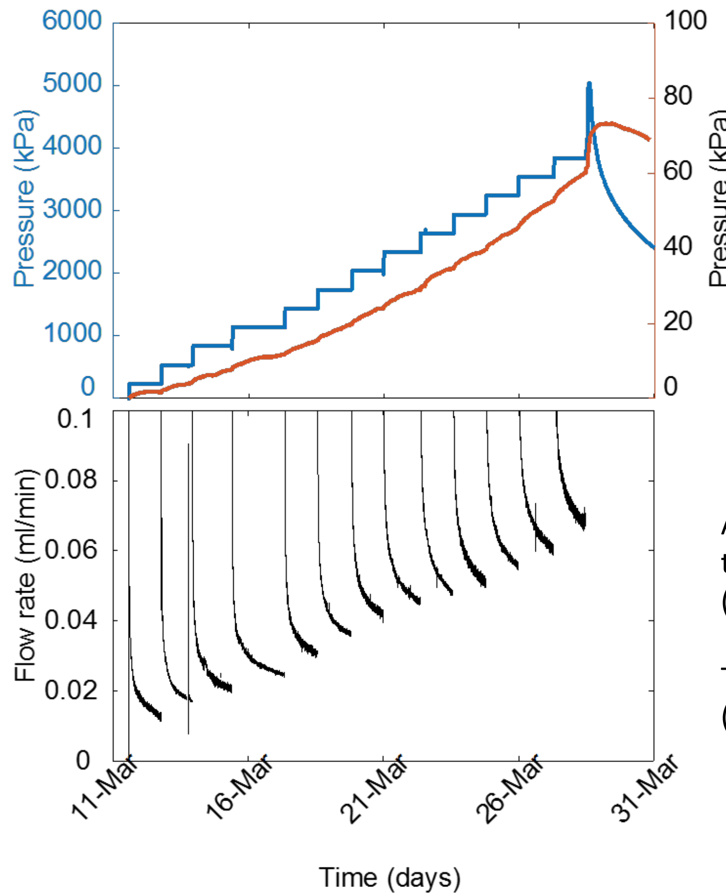




Hydraulic characterization

By AP. Rinaldi





Prolonged step test:
- P increased by steps of 300 kPa,
- Pmax 4800 kPa.
- 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)

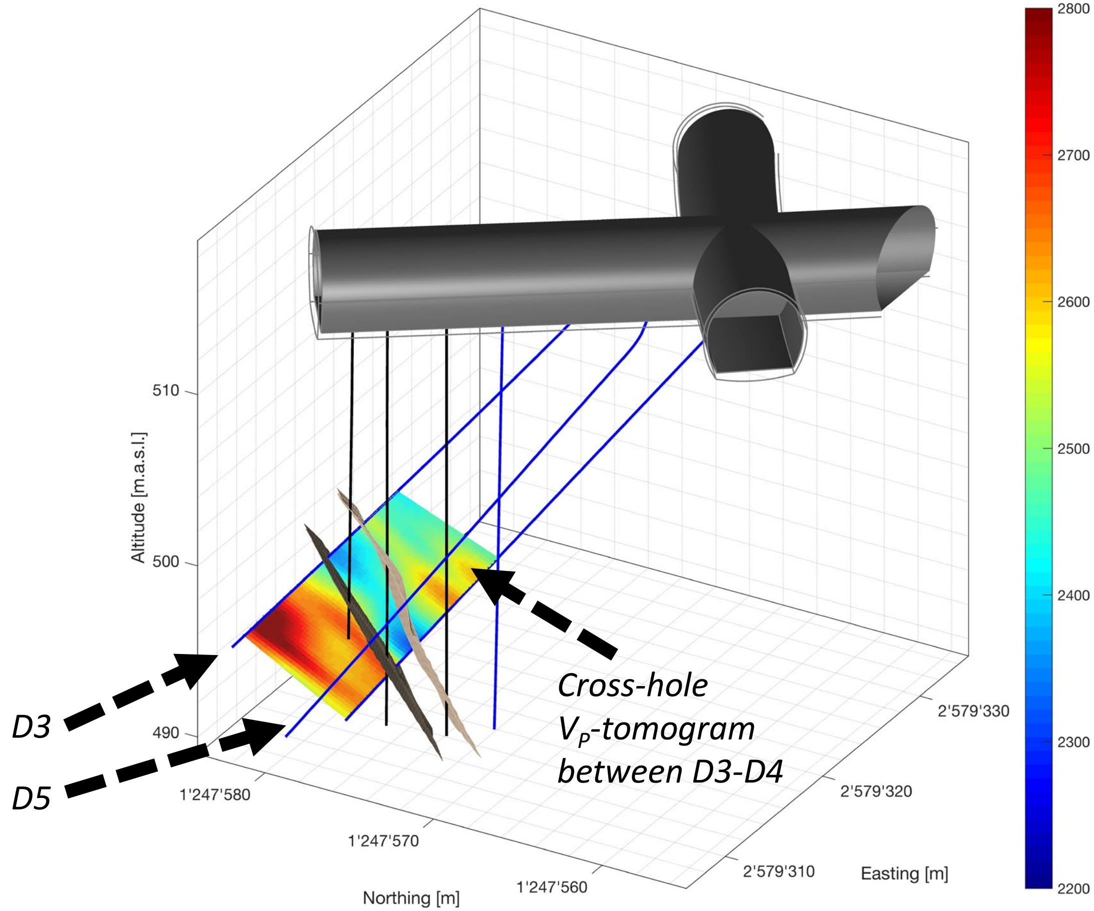
The value is closer to previous estimates (Marschall et al. 2003)

Seismic site characterization (D3-D4 crosshole, D3-D5 crosshole)

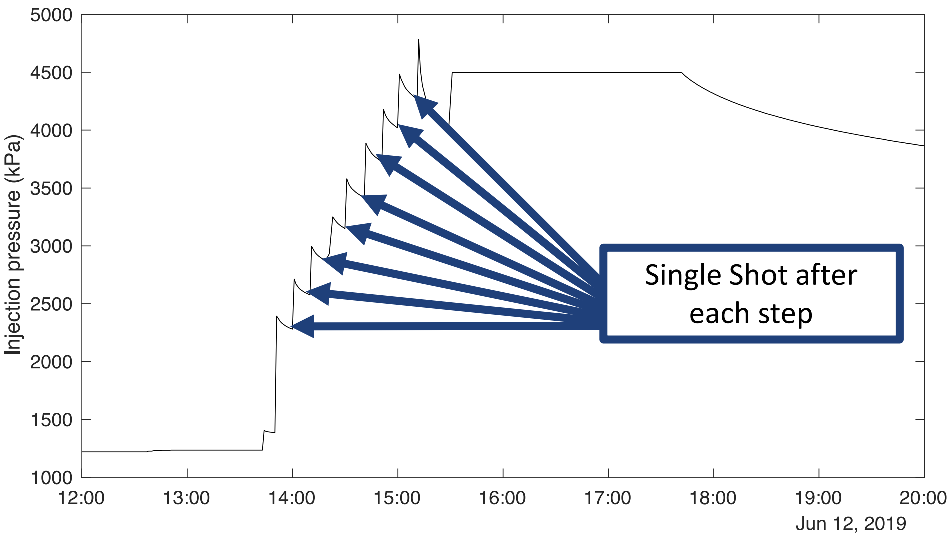
By M. Grab

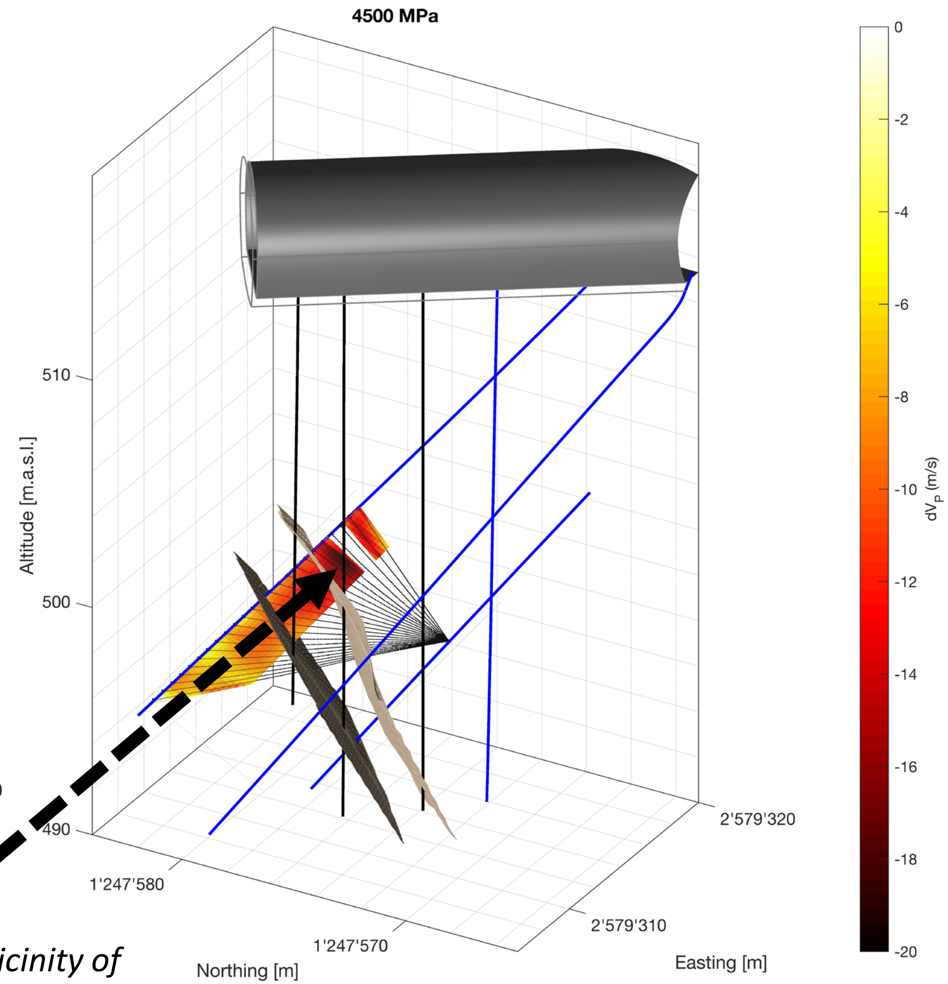
Findings:

- Main fault well detectable as a low velocity zone
  - within fault: V_P = 2200m/s
  - below and above: V_P > 2500 m/s
- Reduced anisotropy within the fault
- Anisotropy larger for the foot wall than for the hanging wall, and not a perfect transversely anisotropic media



Seismic experiments during step-up injection

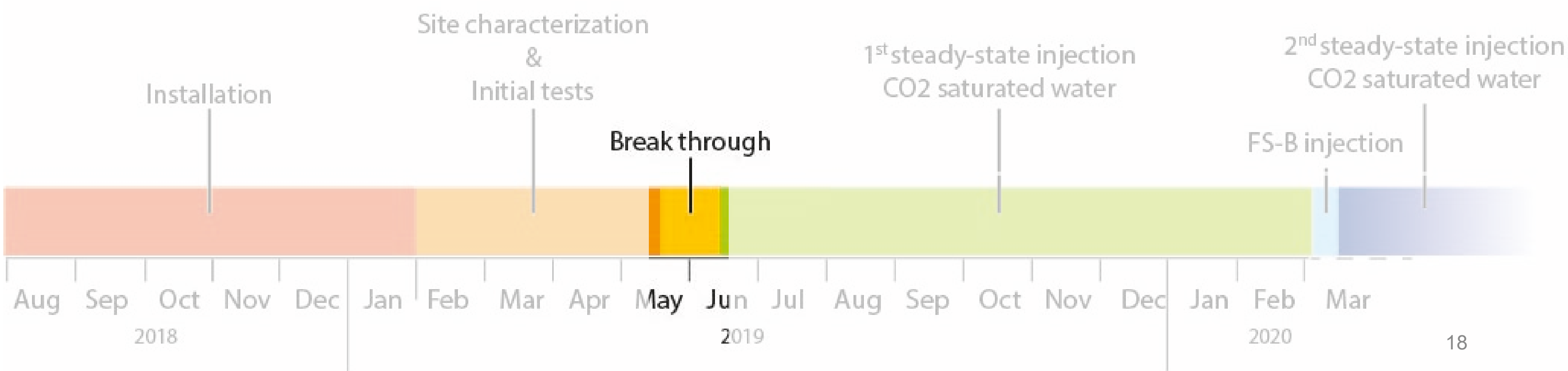




Decrease in V_P in the vicinity of the injection interval (c.a. 30 m/s)

Interpretation: poroelastic effects during increase of injection pressures (increase of pore pressure => reduction of effective pressure).

Phase 1:



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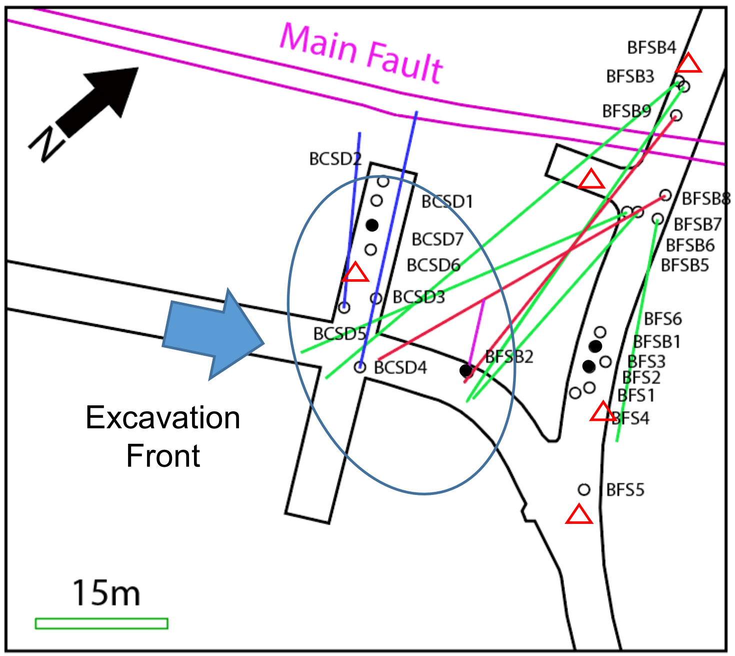
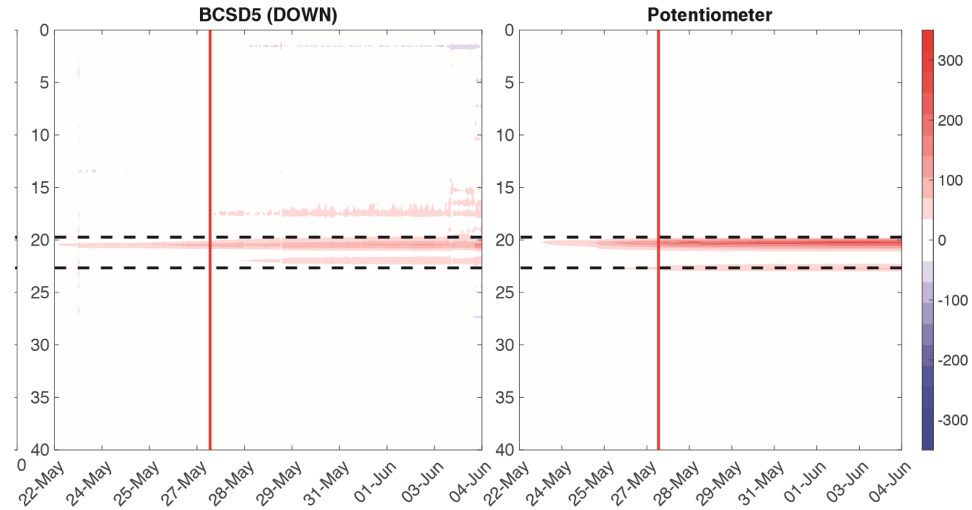
Deformation and slip during break through

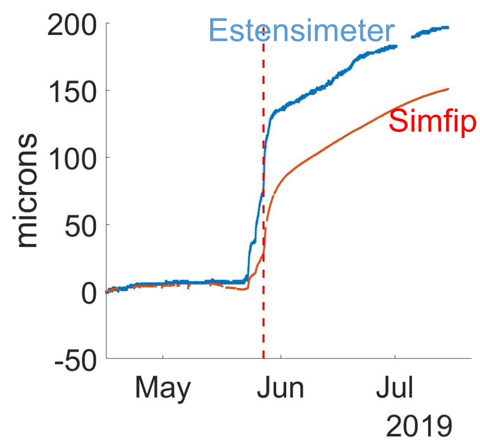
By Y. Guglielmi, D. Rebscher and A.P. Rinaldi

- Different types of optical fiber based sensors:
  - Bragg for local strain (SIMFIP) ●
  - Brillouin for distributed temperature and strain (DTS and DSS)
  - Rayleigh for distributed acoustic (DAS)

- 5 bi-axial tiltmeters set at the gallery floor △







Findings:
Reverse shear to the NW
During excavation

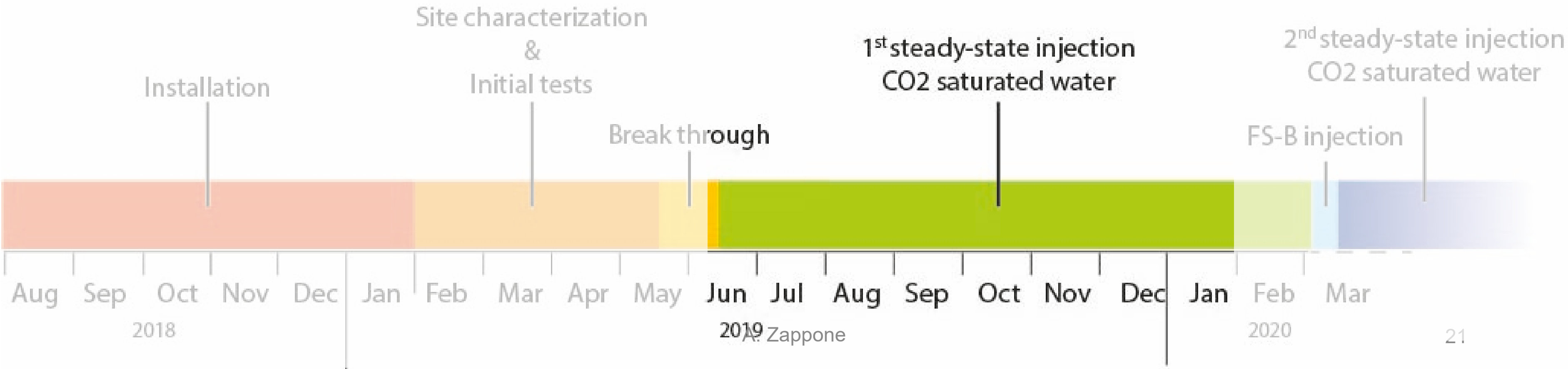
About 150 microns shear

Normal opening
After excavation

Some observations from Phase 1

- Fault Transmissivity: ~10^{-13} m^2/s ; Permeability: ~10^{-21} m^2
- Fault opening pressure c.a. 4.8 MPa
- Seismic velocities are sensible to pore pressure variation in the system with c.a. ~1 % variation (P waves)
- No seismicity was detected during injection activities
- Fault response to fault excavation (collaboration with FS-B & BGR)

Phase 2:



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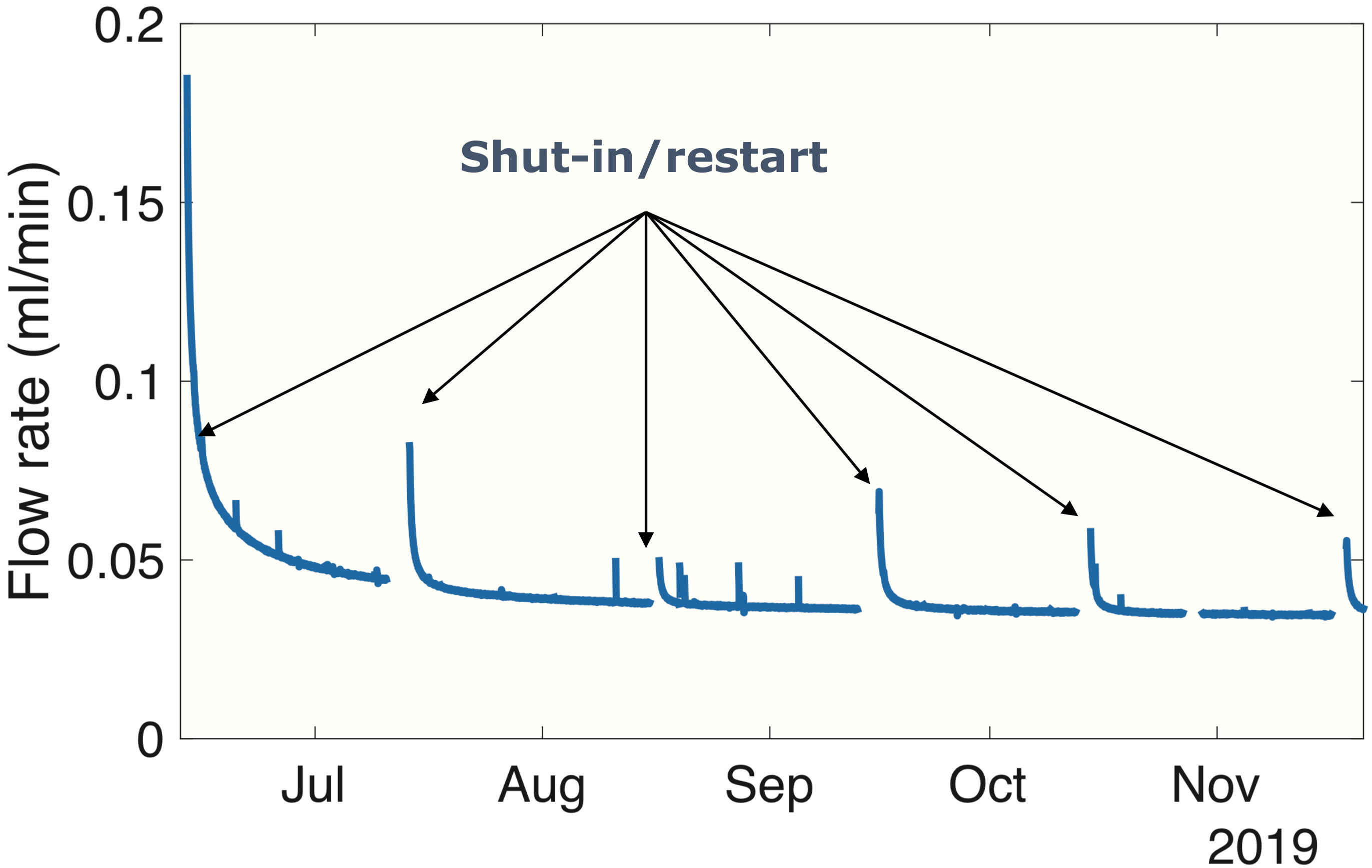
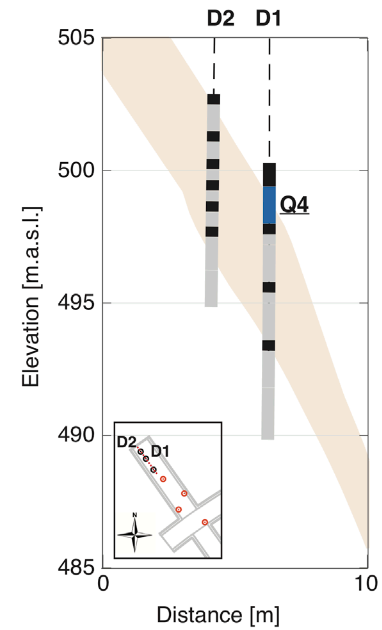
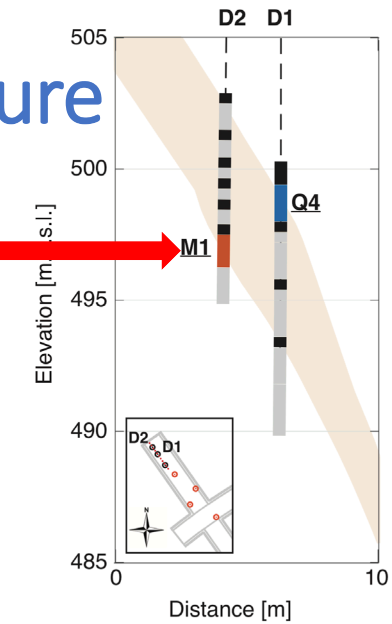
Injection of CO_2-saturated-fluid: flow-rate



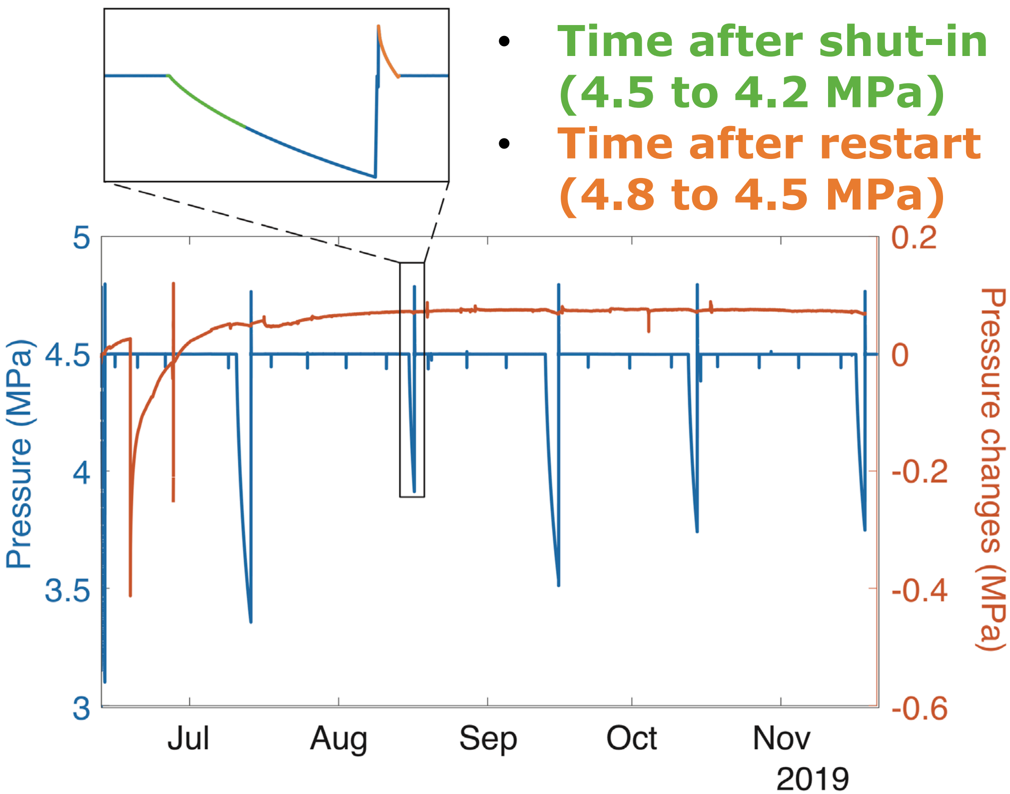


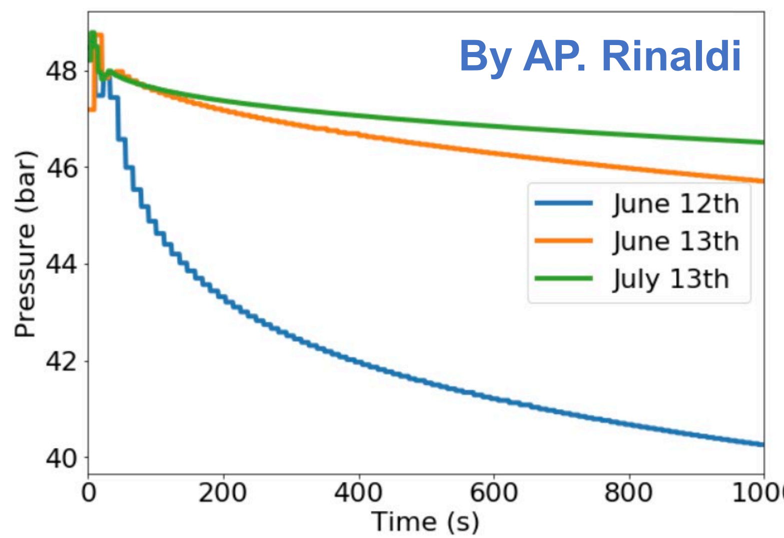
- Constant pressure of 4.5 MPa
- Injection fluid: Pearson water+Kr+CO_2 (mixed at about 2.2 MPa)

Injection of CO_2-saturated-fluid: pressure



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



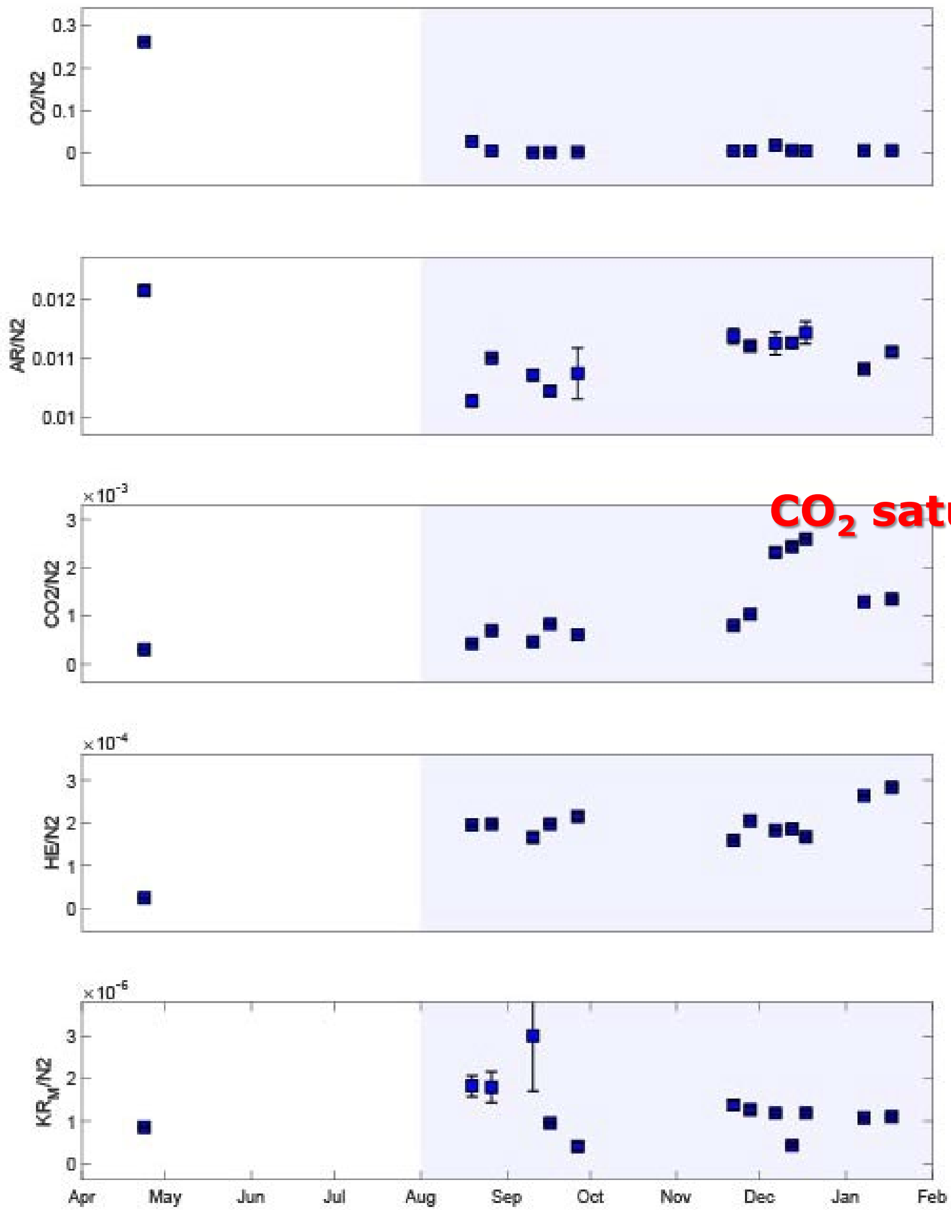


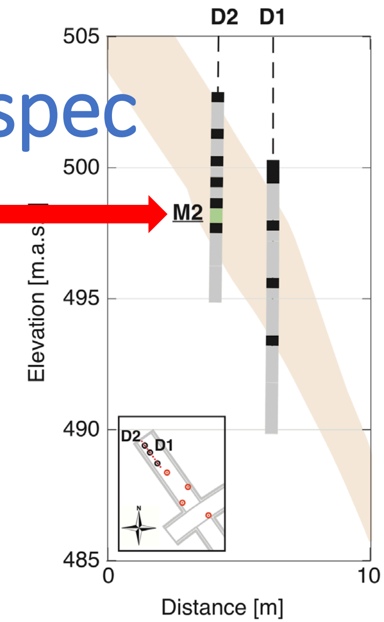
2019

Fault self-sealing?
Swelling?

A. Zappone

Monitoring dissolved gases with mass-spec





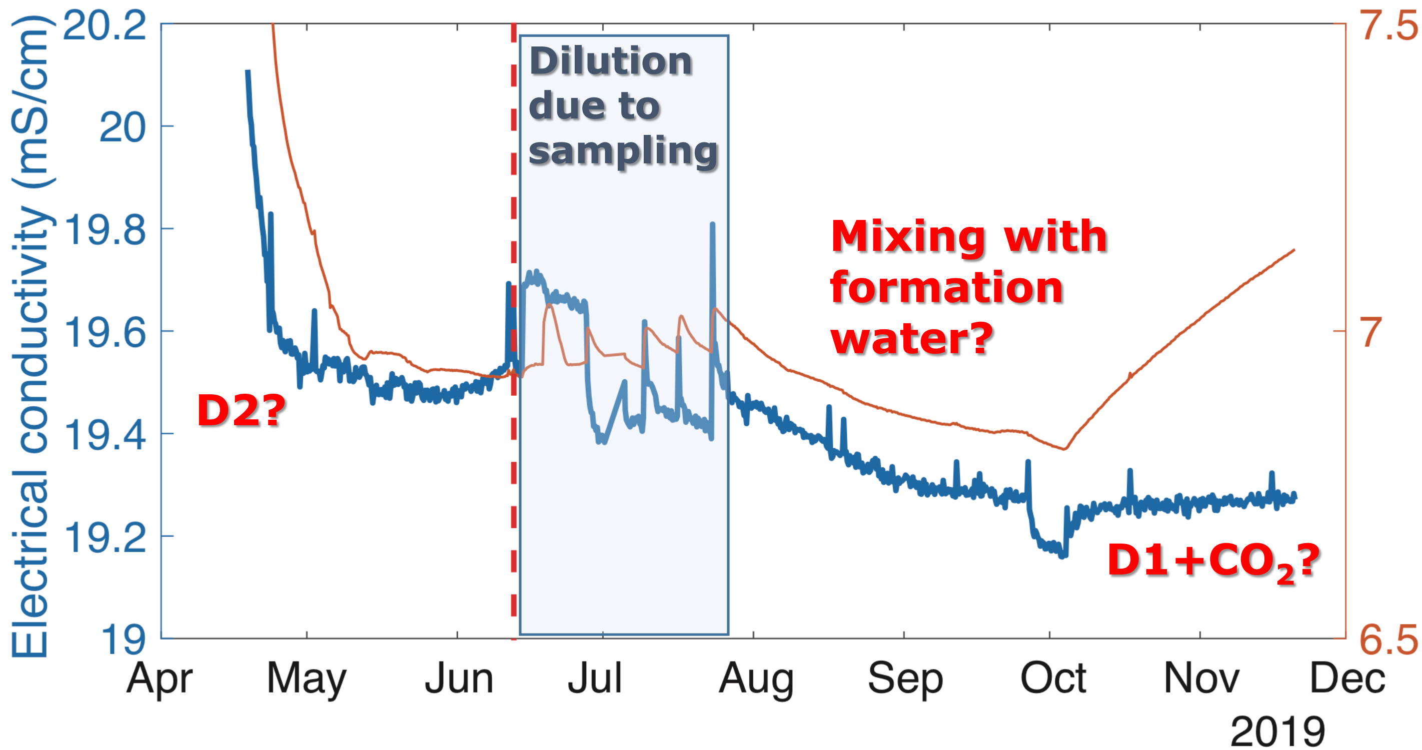
CO_2 saturated fluid ?

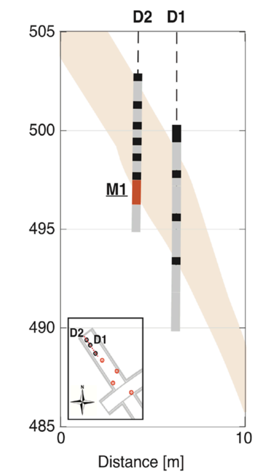
Evidence for injected fluid at monitoring well (CO_2)?

Increased *He*, indication for the fluid is mixed with formation water?

By C. Roques

Electrical conductivity and pH





	D1	D1+CO_2	D2
pH	7.05	5.5	7.7
El. Cond (mS/cm)	25.2	23.8	32

Values at atmospheric conditions

At installation: two different waters in boreholes D1 and D2

Values at equilibrium quite different from atmospheric

Hard to determine CO_2 arrival at monitoring well.

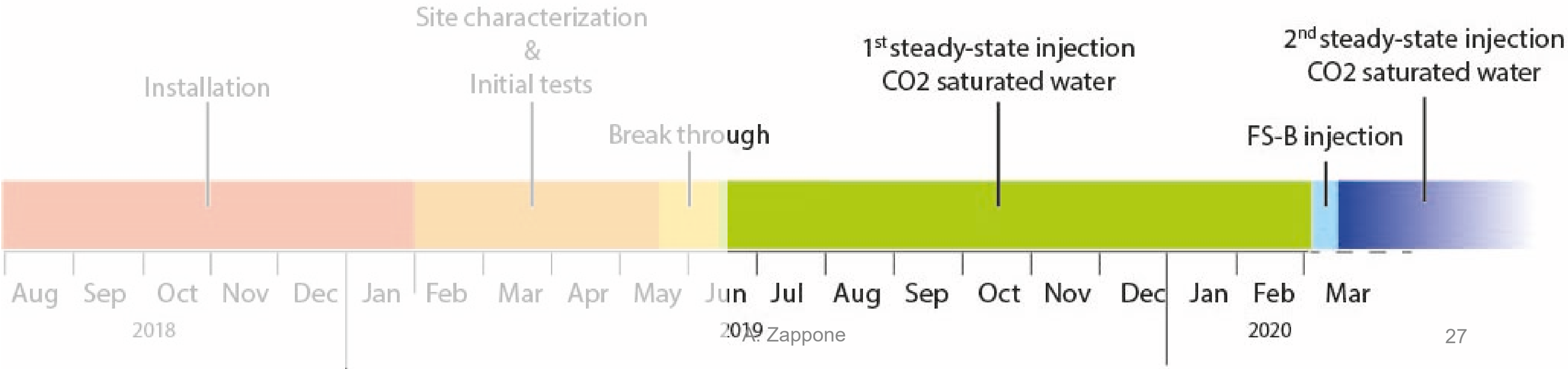
Some observations from Phase 2

- **Fault decreases in permeability almost immediately ?**
- The spectrometer detects **CO_2 at the monitoring borehole after December**.
- pH and EC are hard to interpret

  (The current increase in pH after **could indicate fluid-rock interaction).**

Moreover….new “perturbations” to the system are coming….

Phase 2:



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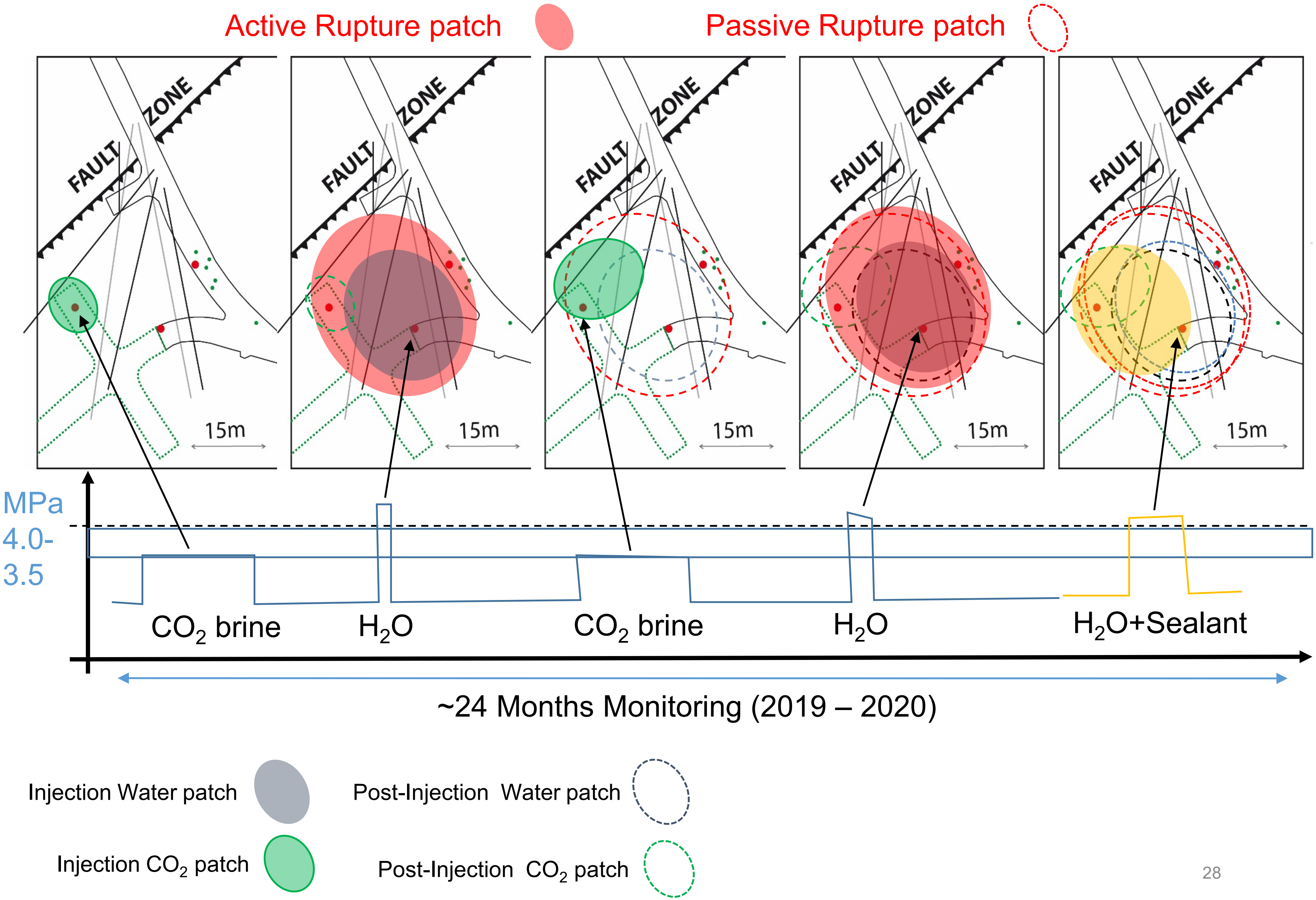
CS-D/FS-B collaboration



- We need to collect fluid sample from unaffected interval to better understand the evolution
- We need to collect further observation on gas contents
- We need to develop numerical simulation to better understand the pressure evolution

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