CO₂ sequestration within the ELEGANCY-ACT project: Progress of the CS-D experiment on faulted caprock integrity in Mont Terri

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Efficient generation of renewable \( H_2 \) from biomass, while harvesting geothermal heat and enabling negative \( CO_2 \) emissions
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WP 2: CO₂ transport and storage
Content:

1. Objectives of the CS-D experiment

2. Installed instrumentation

3. Preliminary results
   3.1 Fault characterization
   3.2 Injection tests
   3.3 Geophysical monitoring with active/passive seismic

4. Conclusions and Outlook
1. The CS-D experiment in Mont Terri

Flow through faults, potential leaks through a cap rock:

Simulating \( \text{CO}_2 \) (dissolved in formation water) leaking through a fault in a caprock

Objectives of the CS-D experiment

- investigating how the exposure to \( \text{CO}_2 \)-rich brine affects sealing integrity of a caprock, hosting a fault system (permeability changes, induced seismicity)
- observing directly the fluid migration along a fault and its interaction with the surrounding environment.
- testing instrumentation and methods for monitoring and imaging fluid transport.
1. The CS-D experiment in Mont Terri

**Inject** CO₂ saturated formation water and tracers in Mont Terri main fault:
- Pulse/pressure increase steps (at beginning and at end of the injection phase)
- Continuous/long term injection
- Activation of the fault by injecting water (FS-B experiment)

Scale: 1-10 m³ Rock volume

**Monitor** injection effects:
- Electrical conductivity, tracers, fluid samples
- Recording flow rates and pressures
- Strain (Extensometers, FO)
- Seismic velocity changes
- Microseismic events
1. The CS-D experiment in Mont Terri

M. Lukovic, Q. Wenning

Modified after NUSSBAUM et. al., 2017: Tectonic evolution around the Mont Terri rock laboratory, northwestern Swiss Jura: constraints from kinematic forward modelling. Swiss Journal of Geosciences

Swisstopo, www.mont-terri.ch
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2. Instrumentation

portable gas spectrometer – “miniRuedi” by eawag

gas tracer: krypton
2. Instrumentation

6-fold packer with P/T monitoring and fluid sampling intervals

4-fold packer system with P/T monitoring and fluid injection intervals
2. Instrumentation

Cross-hole electrode array
Geophone array

FO cables
6-fold packer with P/T monitoring and fluid sampling intervals
4-fold packer system with P/T monitoring and fluid injection intervals
2. Instrumentation

Cross-hole electrode array
Geophone array
Seismic Sparker
Bottom-hole geophones
FO cables
6-fold packer with P/T monitoring and fluid sampling intervals
4-fold packer system with P/T monitoring and fluid injection intervals
2. Instrumentation

- Piezo-sensors
- PVC casings
- Chain extensometer
- Cross-hole electrode array
- Geophone array
- Seismic Sparker
- Bottom-hole geophones
- FO cables
- 6-fold packer with P/T monitoring and fluid sampling intervals
- 4-fold packer system with P/T monitoring and fluid injection intervals
2. Instrumentation
2. Instrumentation

- Top packer
- Injection chamber
- Simfip probe
- Electrode array for fluid conductivity
- Bottom packer
- Piezo-sensors
- PVC casings
- Chain extensometer
- Cross-hole electrode array
- Geophone array
- Seismic Sparker
- Bottom-hole geophones
- FO cables
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- 4-fold packer system with P/T monitoring and fluid injection intervals
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3.1 Fault characterization

by Quinn Wenning

Structure mapping vertical boreholes

(a) Fracture density estimated from core mapping and logging for the vertical boreholes. The log confidence shows the depth range where image logs are of good quality.

Stereonets show the orientation of (b) bedding, (c) calcite fractures, (d) all other fractures, and (e) the main fault.
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3.2 Injection tests – Results from interval 4

by Antonio Rinaldi

- Pressure increase by steps of 300 kPa, up to 4800 kPa.
- Each step was about 28/30 hours long.
- Injectivity of the system is estimated as 0.015 ml/min/MPa.
3.2 Injection tests – Results from interval 4

by Antonio Rinaldi

- Analysis of constant head test with the Jacob and Lohman analytical solution
- Transmissivity: $\sim 10^{-12} \text{ m}^2/\text{s}$
- Permeability: $\sim 10^{-20} \text{ m}^2$

Not yet steady flow rate, but the estimate is only a little higher compared to previous estimates (Marschall et al., 2003)
3.2 Injection tests – Results from interval 4

by Antonio Rinaldi

- Analysis of pressure decay (3 days) with the Neuzil model (model for pulse tests)
- Transmissivity: $\sim 10^{-13} \text{ m}^2/\text{s}$
- Permeability: $\sim 10^{-21} \text{ m}^2$
  (comparable to Marschall et al. 2003)
3.2 Injection tests

Long-term injection started mid June 2019
• Maximum pressure: 4500 kPa (< FOP, estimated 4800 kPa)
• Maximum flow rate: 0.1 ml/min => approx. 1 liter/week
Currently:
• Constant pressure of 4500 kPa
• Injection rate approx 0.05 ml/min

Flow rate: ~0.05 ml/min

Currently:
• Constant pressure of 4500 kPa
• Injection rate approx 0.05 ml/min
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3.2 Active seismic experiments during injection tests

**Time 1** → 4.8 MPa in Q2

**Time 2** → 6.0 MPa in Q2

**Time 3** → 1.2 MPa in Q1

**Time 4** → 5.7 MPa in Q1
3.2 Active seismic experiments during injection tests

Injection intervals in Borehole D1:
- Q1
- Q2
- Q3
- Q4

Geophone Array in Borehole D3
Sparker in Borehole D4

Boreholes D3 and D4 around 2 meters off-plane
3.2 Active seismic experiments during injection tests
Significance of arrival time differences relative to sparker repeatability

Stacked trace

Same trace before stacking
3.2 Active seismic experiments during injection tests

Relative P-wave velocities

Sparker depth = 492.4m

Time 1 → 4.8 MPa in Q2
Time 2 → 1.2 MPa in Q1
Time 3 → 6.0 MPa in Q2
Time 4 → 5.7 MPa in Q1
3.2 Induced seismicity

- No seismicity detected during injection tests
- “Events” recorded with 3C geophones and piezos at the time after the break through
  - Related to deformation across the fault?
  - Related to work taking place in the lab gallery?
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4. Conclusions and Outlook
Conclusions

• Installation completed.
• Pre-characterization (core interpretation, geophysical baseline measurements, injection tests).
• Long-term injection since <3 months with constantly low flow rates accompanied with repeated geophysical measurements.

Outlook

• Data processing ongoing
• Will we observe an increase in flow rates?
• Stimulation of the fault by water injection, e.g. from borehole D7.
Thank you for your attention!
Questions?

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