Changes in Seal Integrity Induced by CO_2 Injection and Leakage in a Hydromechanically Reactivated Fault (FSC: Fault Slip and Chemistry)

(FWP-FP00013650, FY22-FY24)

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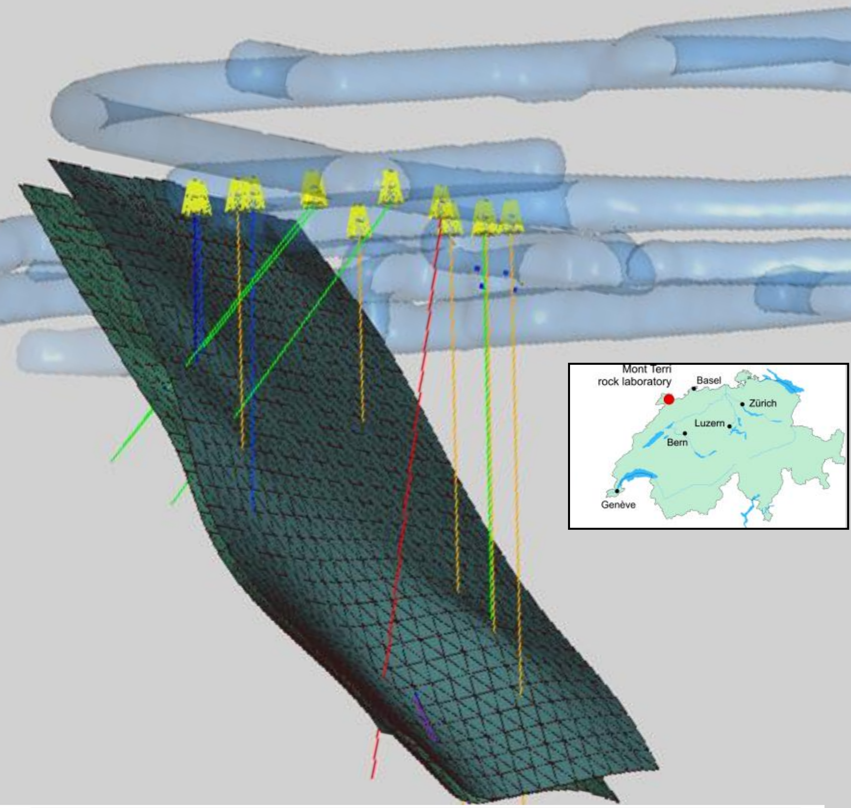
Key questions

- How easy CO_2 can leak into a caprock fault?

- How does CO_2 change the coupling between fault rupture and leakage at the tens of meter scale?

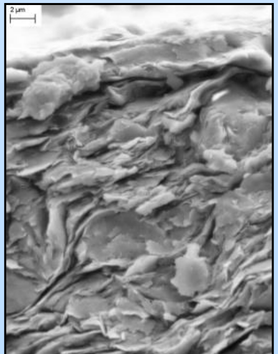
- Can we improve the monitoring?

Through the development of DCS optical fibers

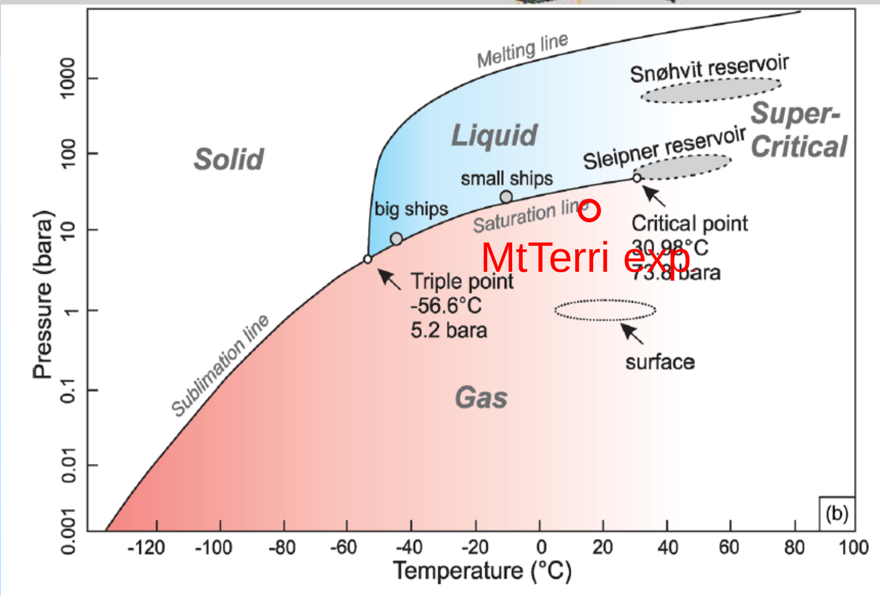


Concept

Field scale controlled
CO_2 leak in a slipping fault
affecting a caprock analogue

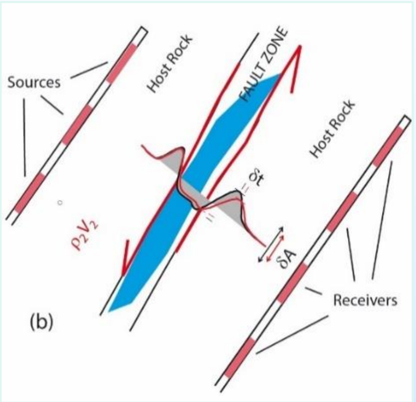


Opalinus Clay



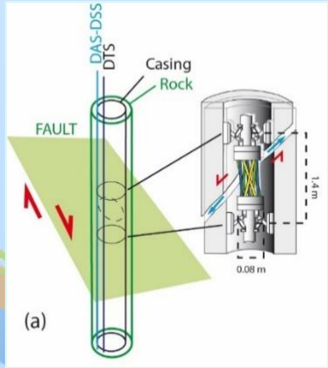
Monitoring Techniques

Different monitoring techniques are deployed to hydromechanically and chemically characterize a leakage pathway created in an initially very low permeable fault zone

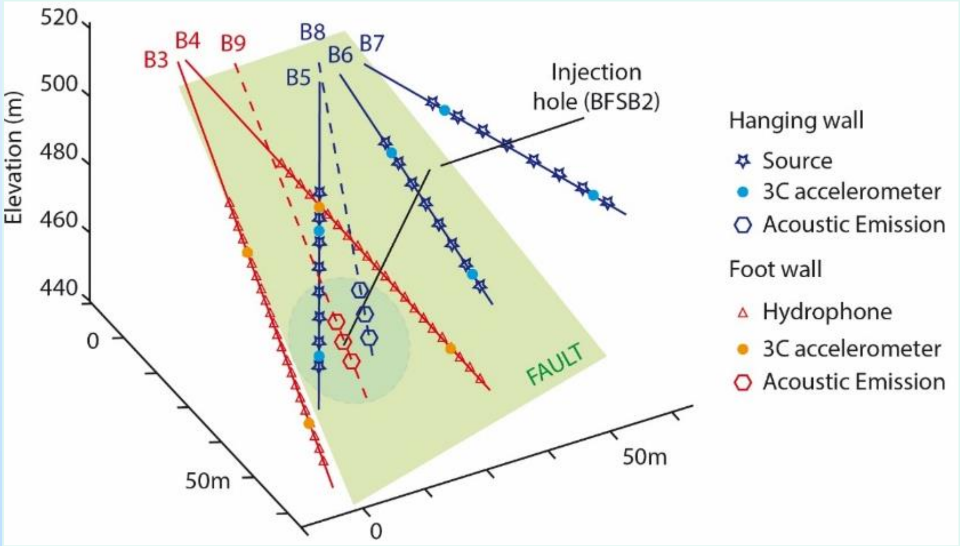


Time lapse imaging
Of leakage flow path
Active seismic

Partitioning of strain
Within the fault zone
Local slip monitoring
(SIMFIP, DORSA)
Distributed bulk strain
(DSS, DAS and RFS-DSS optical fibers)

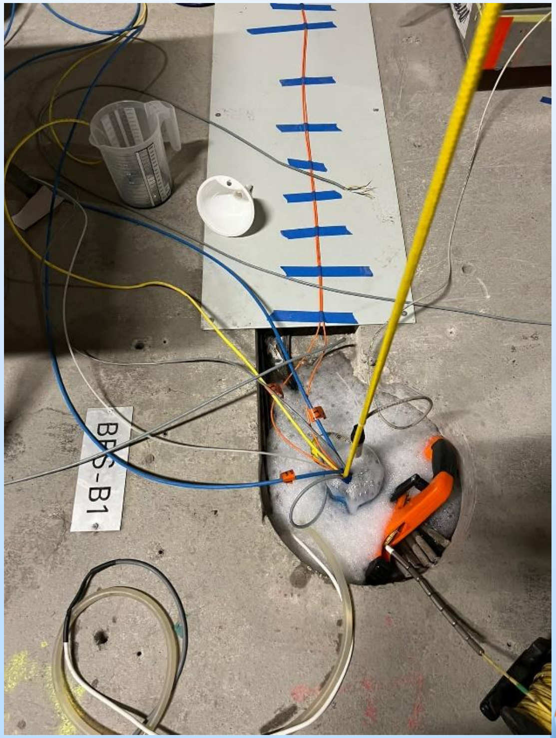


Passive induced seismicity
Pore pressures
Fluid chemistry
(DCS-DTS fibers, continuous gas analyses)



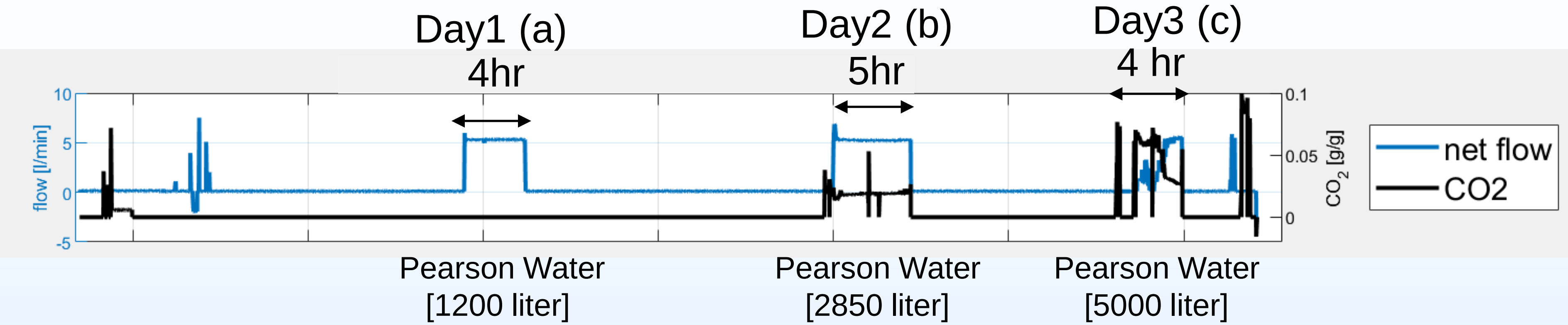
Characteristics of the 2023 CO_2 Injection

- Injection of CO_2g dissolved in water
- Injection depth = 370m
- Downhole temperature ~ 16.5 ± 0.1 °C
- Maximum pressure = [6.8 ± 0.2 MPa]
- Injection flowrate = [5.3 ± 0.1 l/min]
- Estimated total amount of injected CO_2 ~ 70kg



EARTH & ENVIRONMENTAL SCIENCES

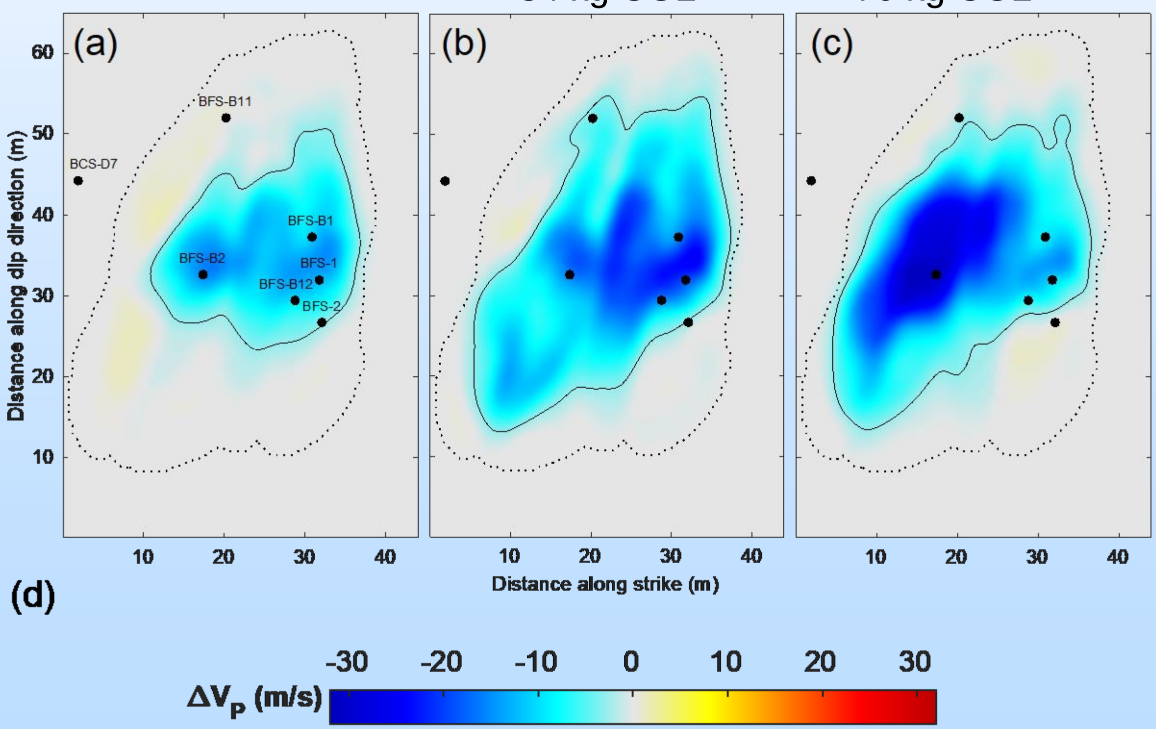
3 Phases in the along-fault CO_2 Leakage Flowpath's Propagation



(Phase a)
Along strike eastward

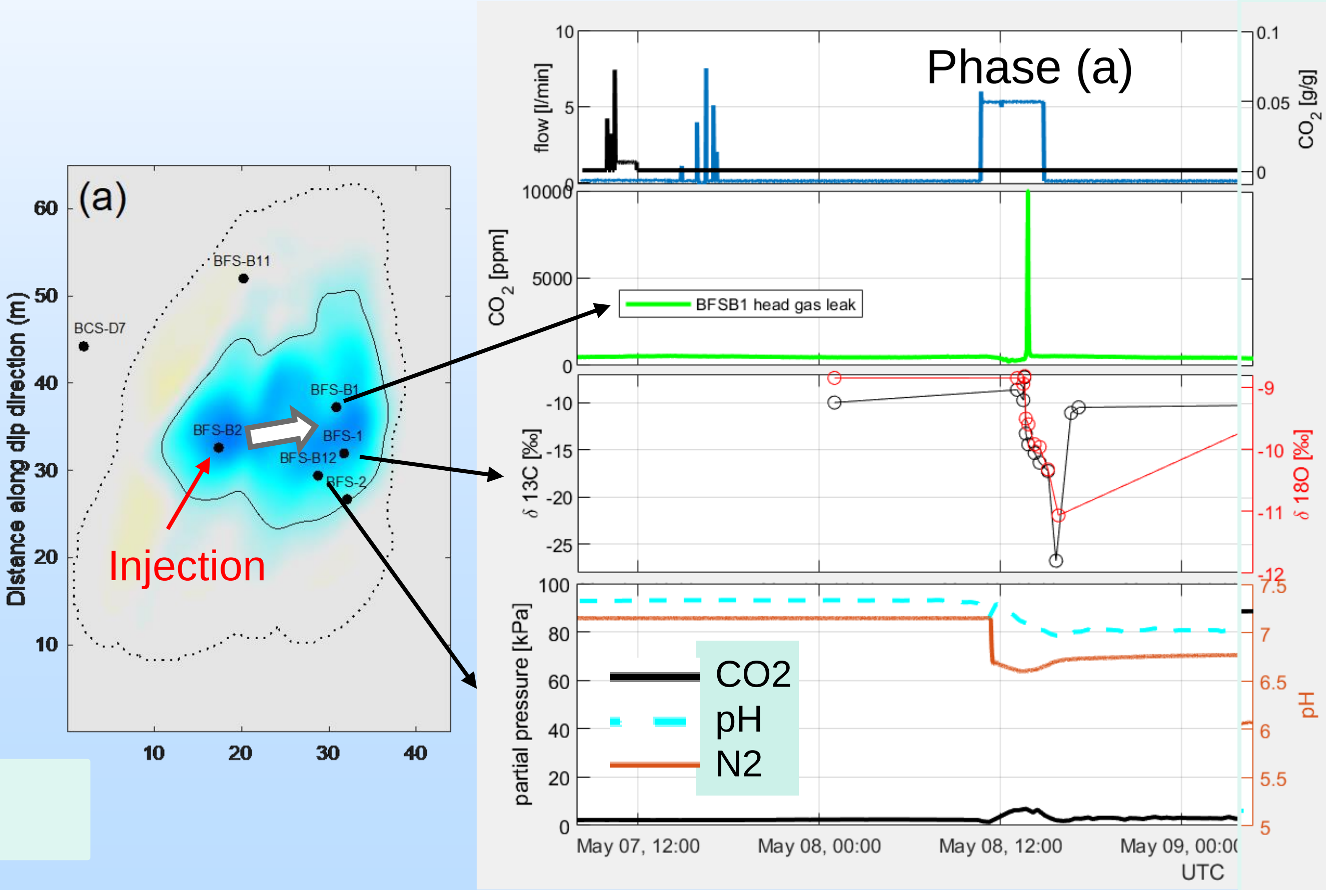
(Phase b)
Along dip upward and downward

(Phase c)
No propagation



Phase (a) Flow path creation driven by injection pressure

- Phase (a) – Pearson Water with a small CO_2 amount used as a Tracer
- CO_2 tracer breakthrough in ~21 minutes
- Isotopes show the dilution of initial pore waters by injected water
- CO_2 Gas tracer outflow at the open borehole BFSB1



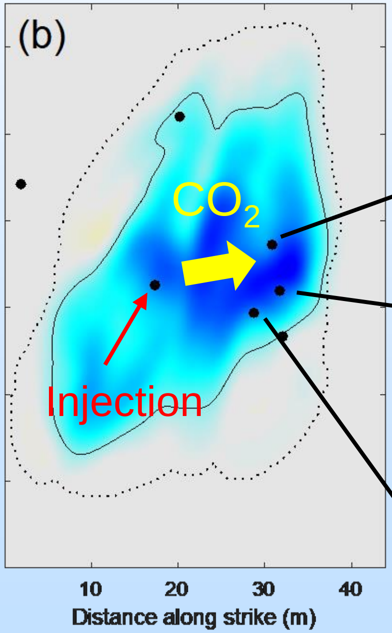
CO2 gas
δO_{18} = $^{0}/_{00}$
δC_{13} = -42.6 $^{0}/_{00}$

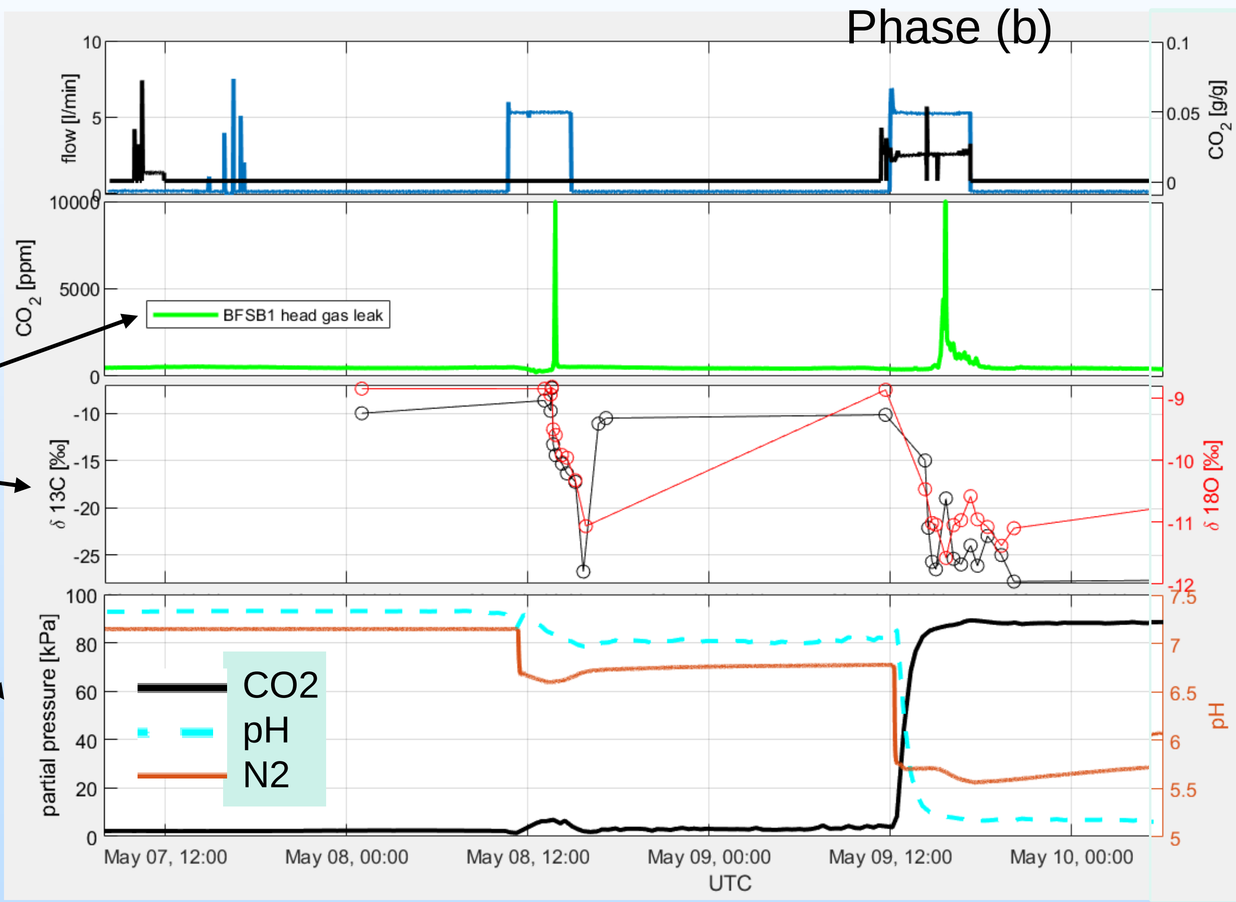
Pearson water
δO_{18} = -12.12 $^{0}/_{00}$
δC_{13} = -6.4 $^{0}/_{00}$

Initial Fault pore water
δO_{18} = -9 $^{0}/_{00}$
δC_{13} = -10 $^{0}/_{00}$

Phase (b) – CO_2 circulating through the flowpath

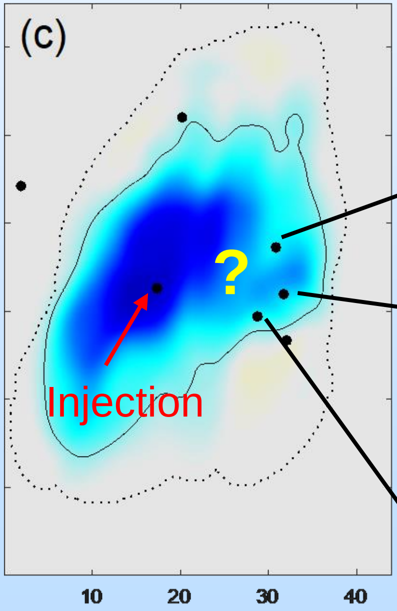
- Phase (b) – Pearson Water half saturated with CO_2
- CO_2 breakthrough in ~10 minutes
- Isotopes show the dilution and no/slow recovery after injection end
- Larger CO_2 Gas outflow at different boreholes

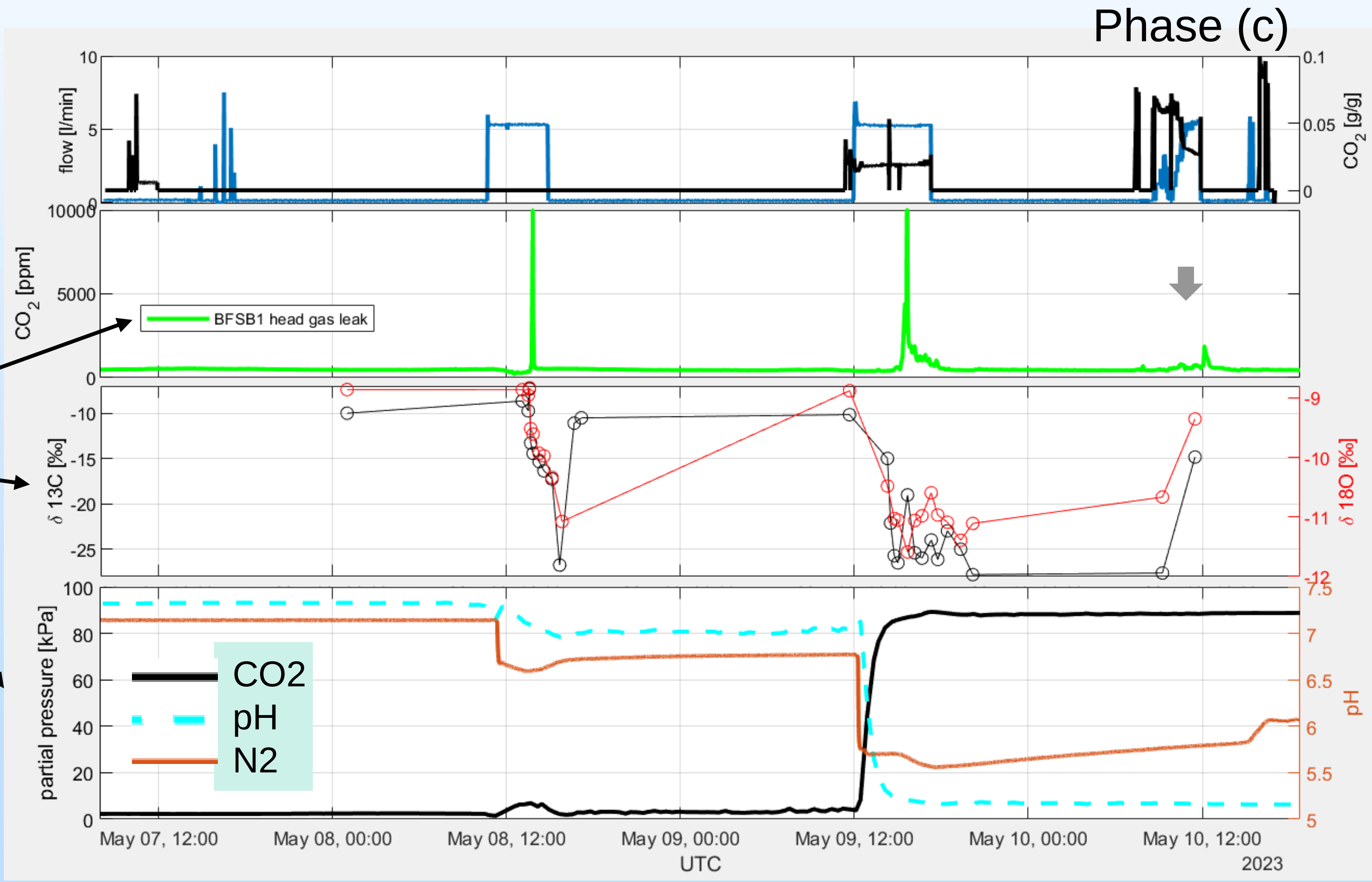




Phase (c) – No clear CO_2 circulation through the flowpath

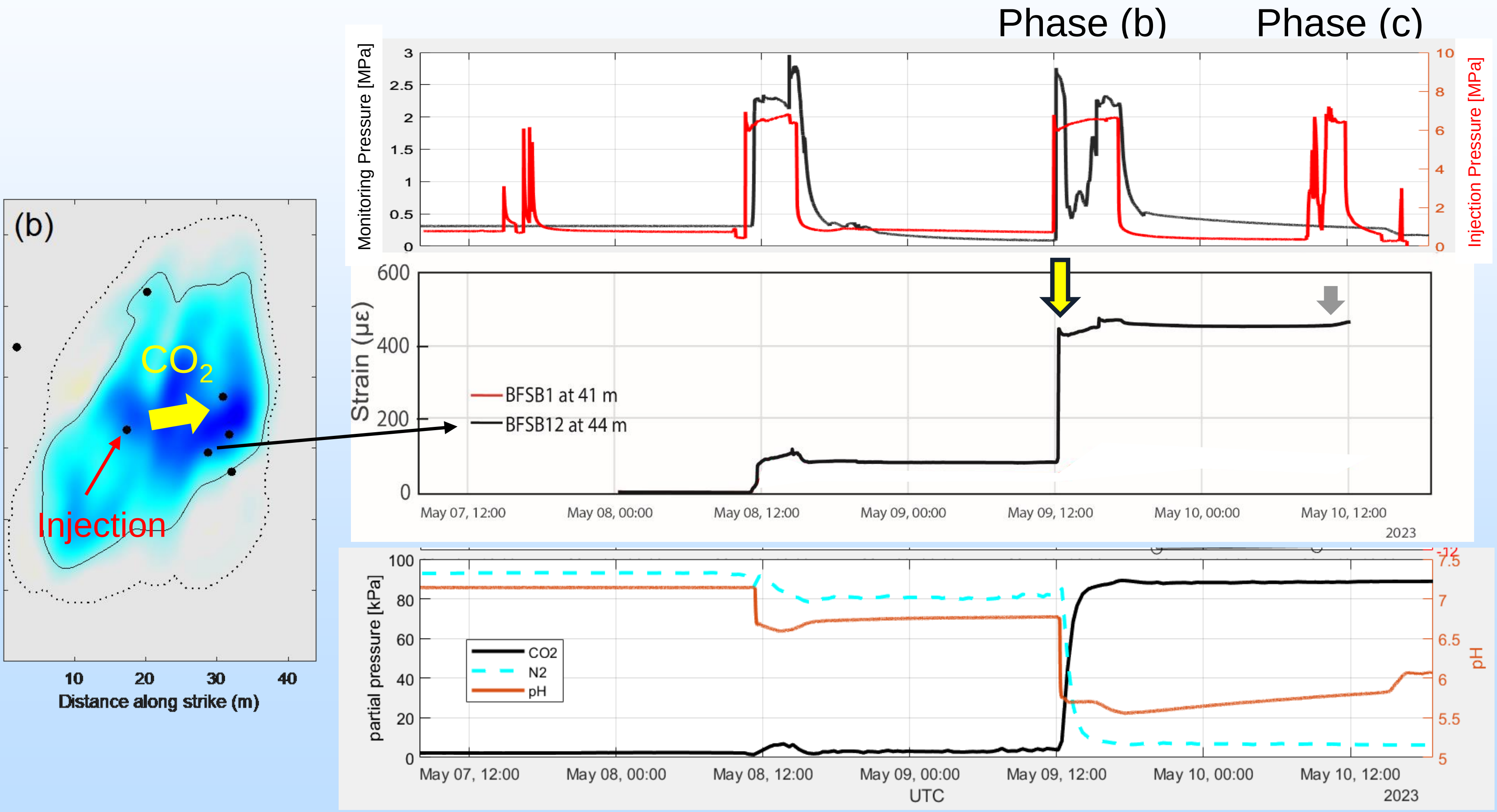
- Phase (c) – Pearson Water fully saturated with CO_2
- No clear or Small CO_2 breakthrough !
    - *Only a small CO_2 Gas outflow at the open borehole BFSB1*
- Isotopes show recovery towards initial pre-injection values



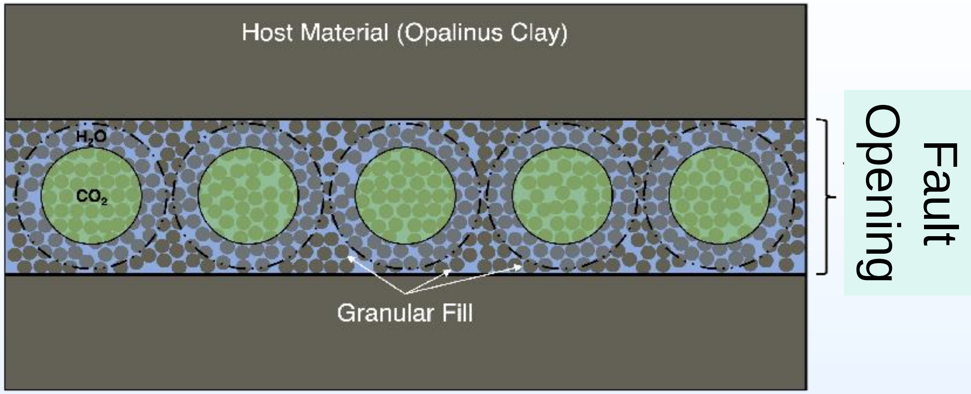


Fault Zone Pressure and Deformation

Following a large aseismic fault deformation at phase b
The flow channel stopped working at phase c

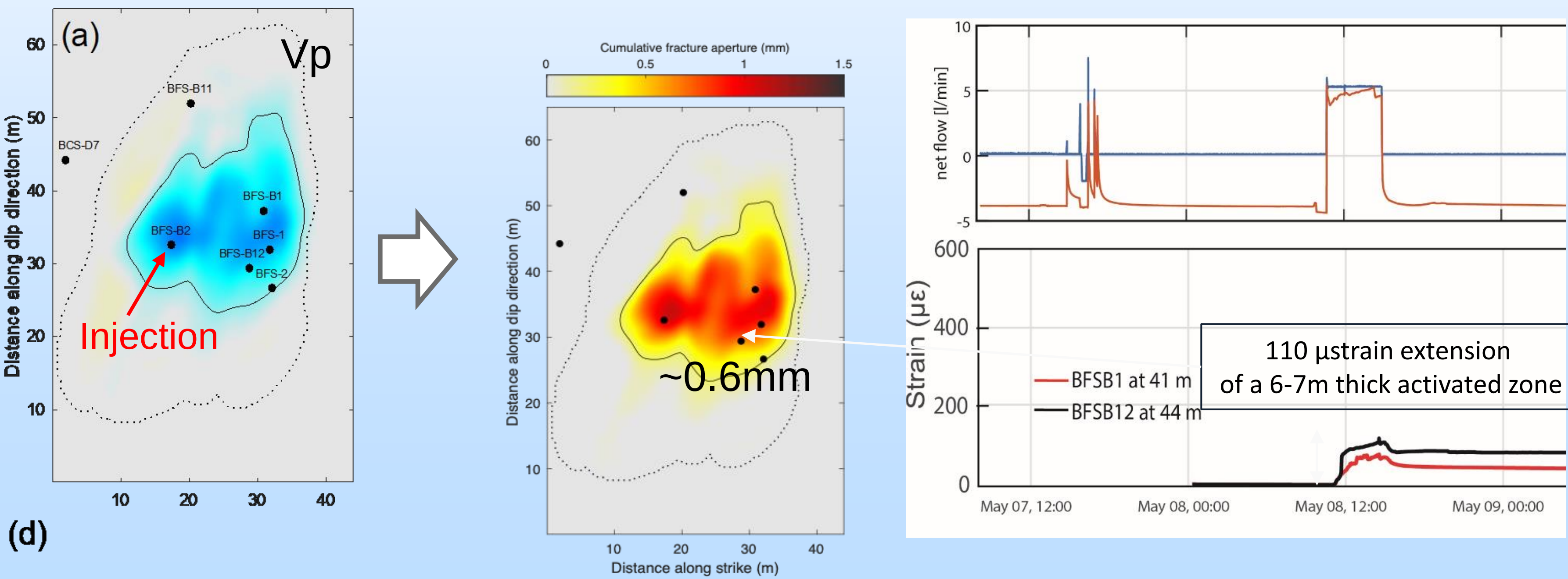


CO_2 Gas Saturation estimation from p-Waves velocity and fault opening



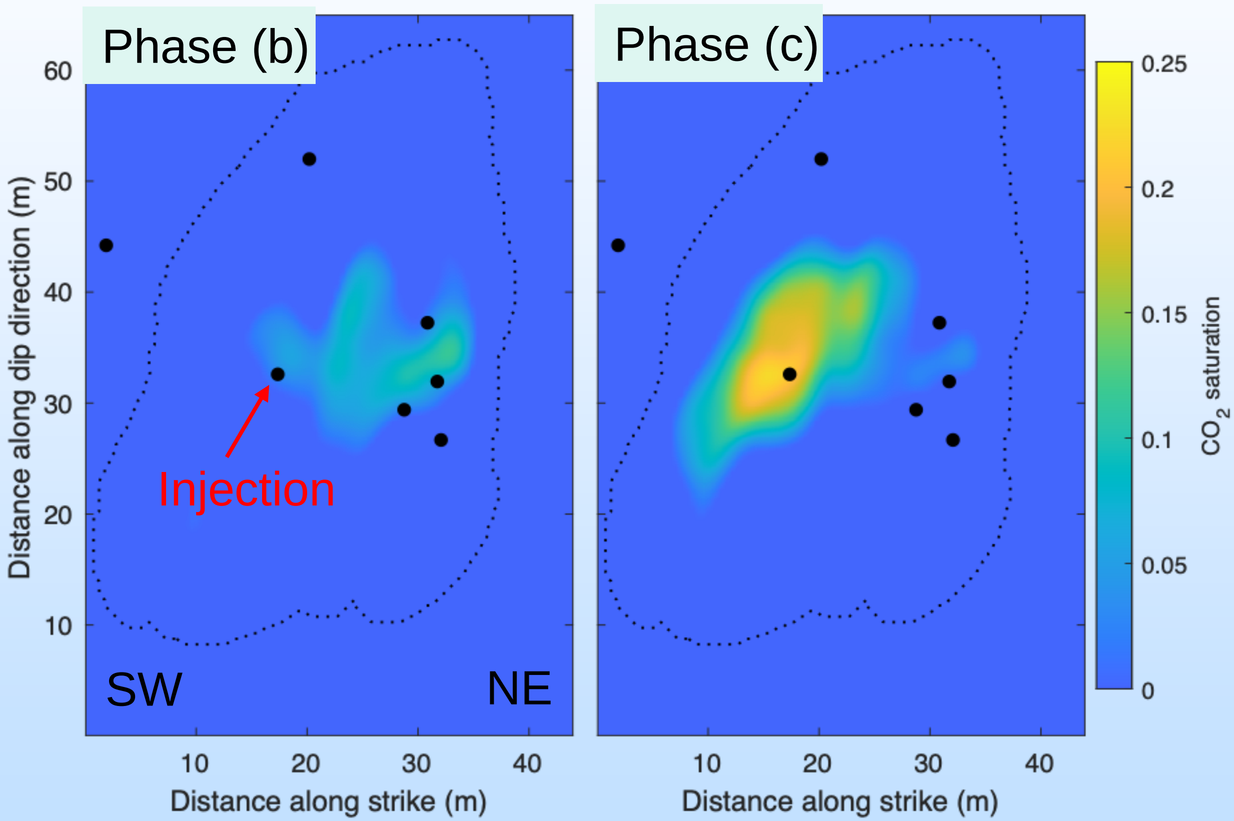
- Fault figured as a layer of spheres under poroelastic stress *(contact theory used to estimate compliance)*
- Equivalent media theory used to estimate Variations in Vp velocities vs fault thickness
- Patchy-saturation model to simulate P-waves velocity dispersion and attenuation caused by mesoscale heterogeneity (White, 1975)

1 – Calibration of Vp – Fault Opening using phase (a)



CO_2 Gas Saturation estimation from p-Waves velocity and fault opening

2 – Using the Vp and the measured fault "opening" with optical fibers, we then calculate the CO2 saturation in the fault zone



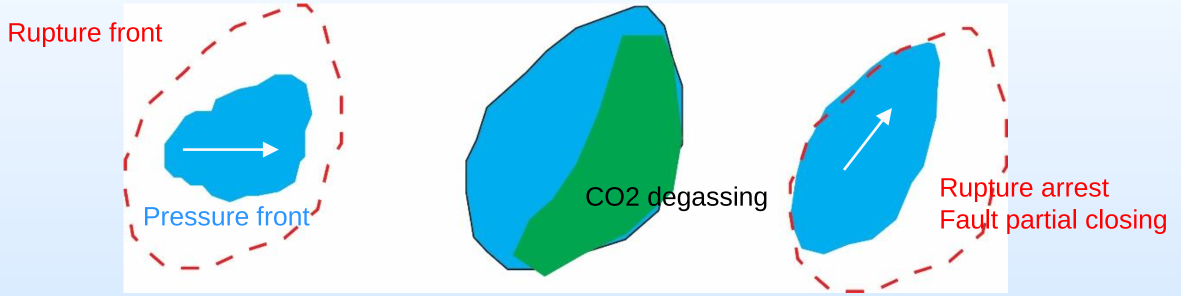
- Less CO_2 saturation in phase (b) and connection with the NE boreholes
- More CO_2 saturation in phase (c) and "accumulation" in the center of the Fault

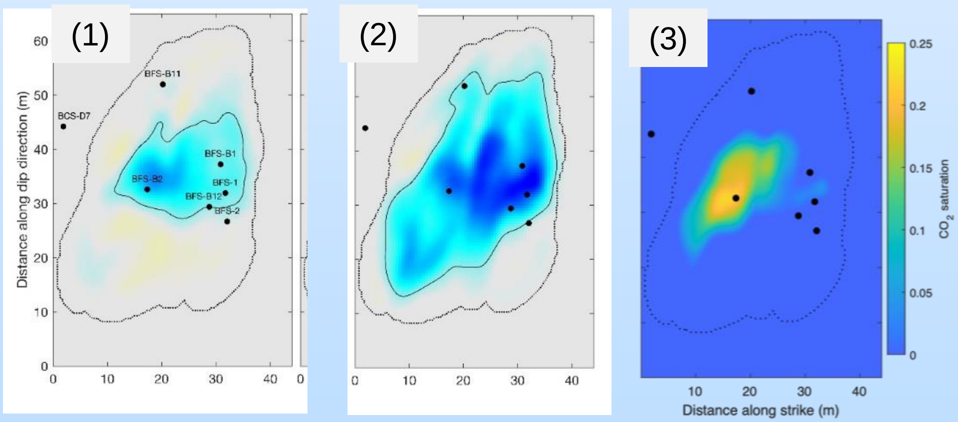
A complex coupled HM mechanism with fluid phase change

1- Dilation and Slip inducing Pressure Drop

2 – Pressure drop inducing CO_2 degassing

3 – CO_2 degassing inducing Fault depressurization and Closing of leakage flowpath





Accomplishments To Date

- Fault activation with CO_2 is different from pure water activation

- Our analyses to date, while preliminary, show that CO_2 circulated in the created leakage flowpath **for some time …. But may have "abandoned" the path at the last phase of the experiment**

- This experiment highlights how multiphase CO_2 plume – brine interaction may cause complex fault activation processes when entering a fault zone!

Synergy Opportunities:

Datasets and the Fault MtTerri test setting are used in several other projects

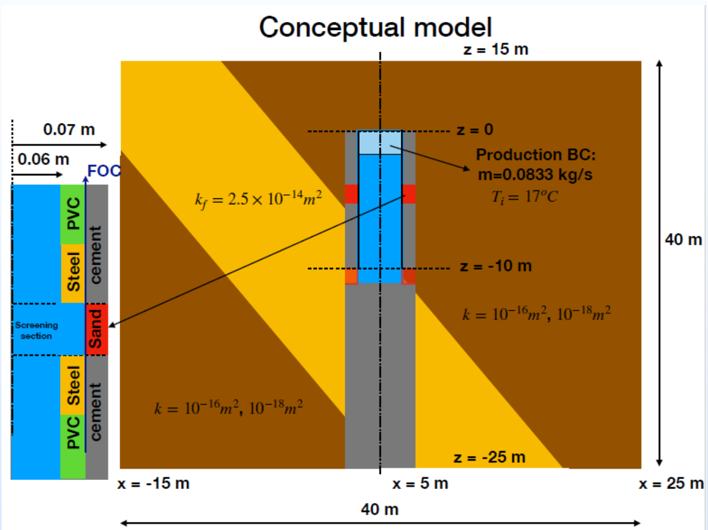
- High-Resolution Reservoir Seal Integrity Monitoring using Optimized Borehole Sources and Distributed Acoustic Sensing (FE0032058)
In situ testing of the new sources during a new fault activation experiment
Jonathan Ajo-Franklin (PI)

- NETL-ExxonMobil-DNV-LBNL Collaboration on Dense Phase CO2 Transportation
Providing data to test models developed for CO2 leakage along wells, and model the DTS and DCS fibers signals
Abdullah Cihan (PI) and Pramod Bhuvankar

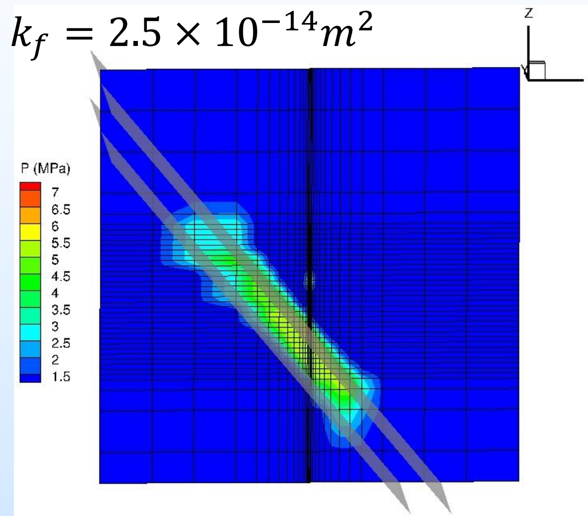
- Managing a Gigatone CCS Future: A Framework for Basin-scale Storage Optimization Based on Geomechanical Studies (FWP-FP000015629)
Upscaling the physics observed at MtTerri to faults affecting Basin scale Caprock layers
Yves Guglielmi and Jens Birkholzer

Synergy Opportunities:

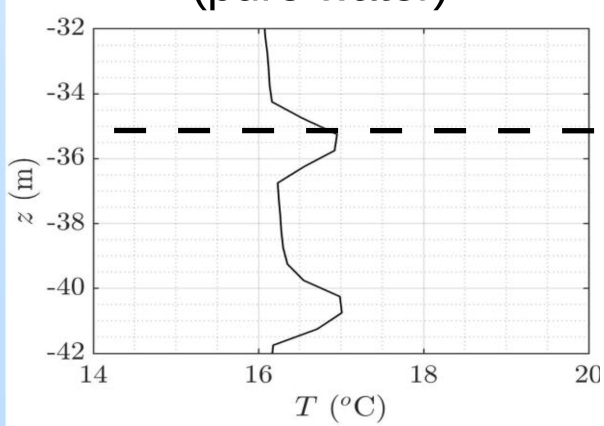
Flow and heat transport modeling of local well DTS/DCS measurements while considering well completion with a complex casing



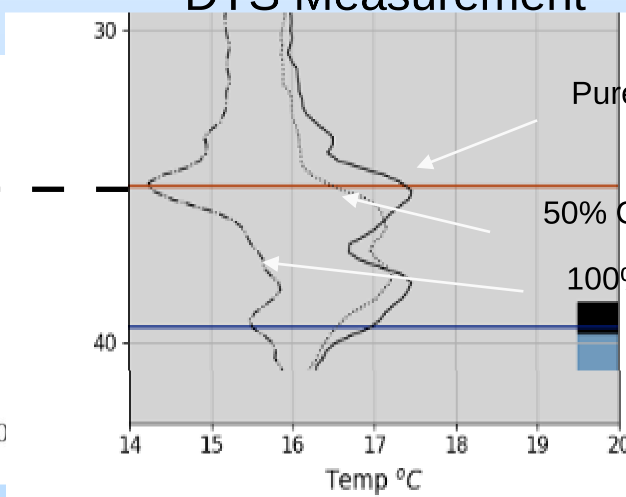
$k = 10^{-18} m^2$ *(surrounding rock)*



Model
(pure water)



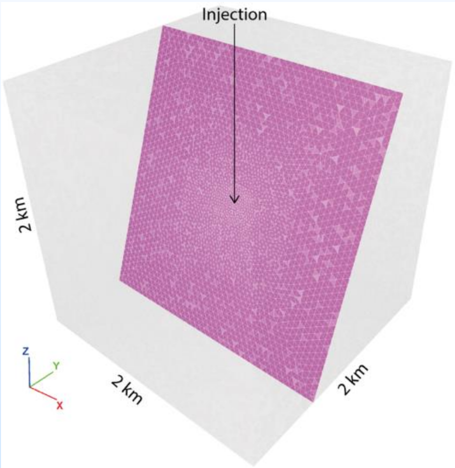
DTS Measurement



Synergy Opportunities:

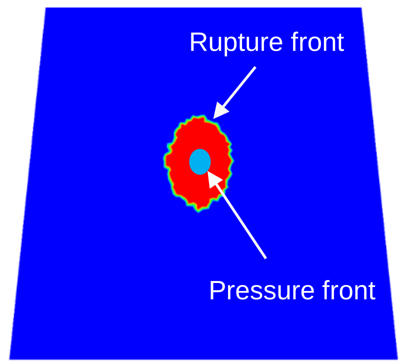
Upscaling the physics observed at MtTerri to faults affecting Basin scale Caprock layers

Kilometer scale
Fully coupled HM model
Critically stressed fault
0.1MPa/month injection

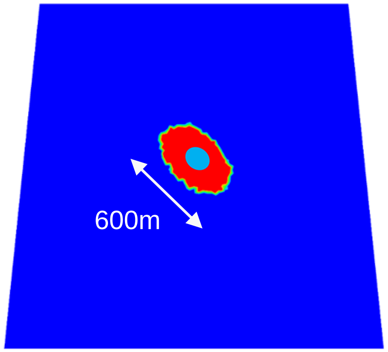


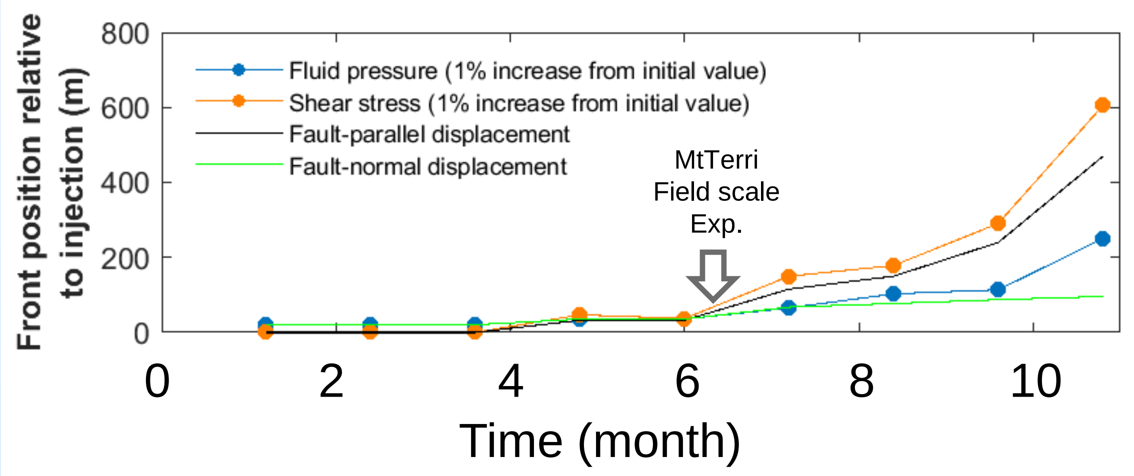
Size, direction and growth rate of leakage flowpath depend on weakening and stress regime

Normal Stress Regime



Strike Slip Stress Regime





Rupture front

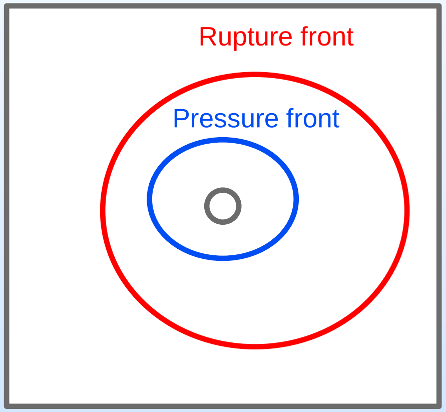
Pressure front

Perspectives

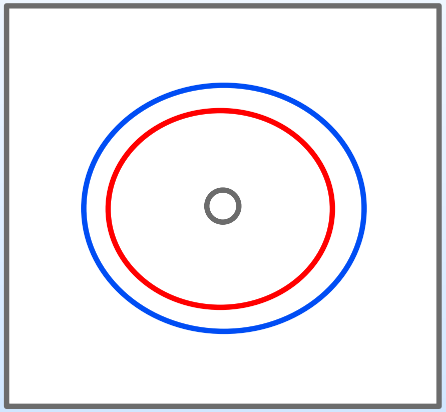
- Pressure rates applied in MtTerri fault zone are much higher (>0.5 MPa/min) than expected in deep storage conditions (0.1MPa/month) !

There is a need to test the effect of slower pressure rate on fault activation and leakage

High Pressure rate



Low Pressure rate ?



- Multiphase CO_2 entering a fault zone modify its activation mode!

There is a need to better "image" multiphase CO_2 propagation
Joint active seismic and electromagnetic monitoring could help!