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)

Yves Guglielmi, Jens Birkholzer (LBNL)

Plus many FSC Team Members from LBNL, Rice University, and Mt Terri Partners

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management Project Review Meeting

August 15 - 19, 2022

Overall Project Objectives

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

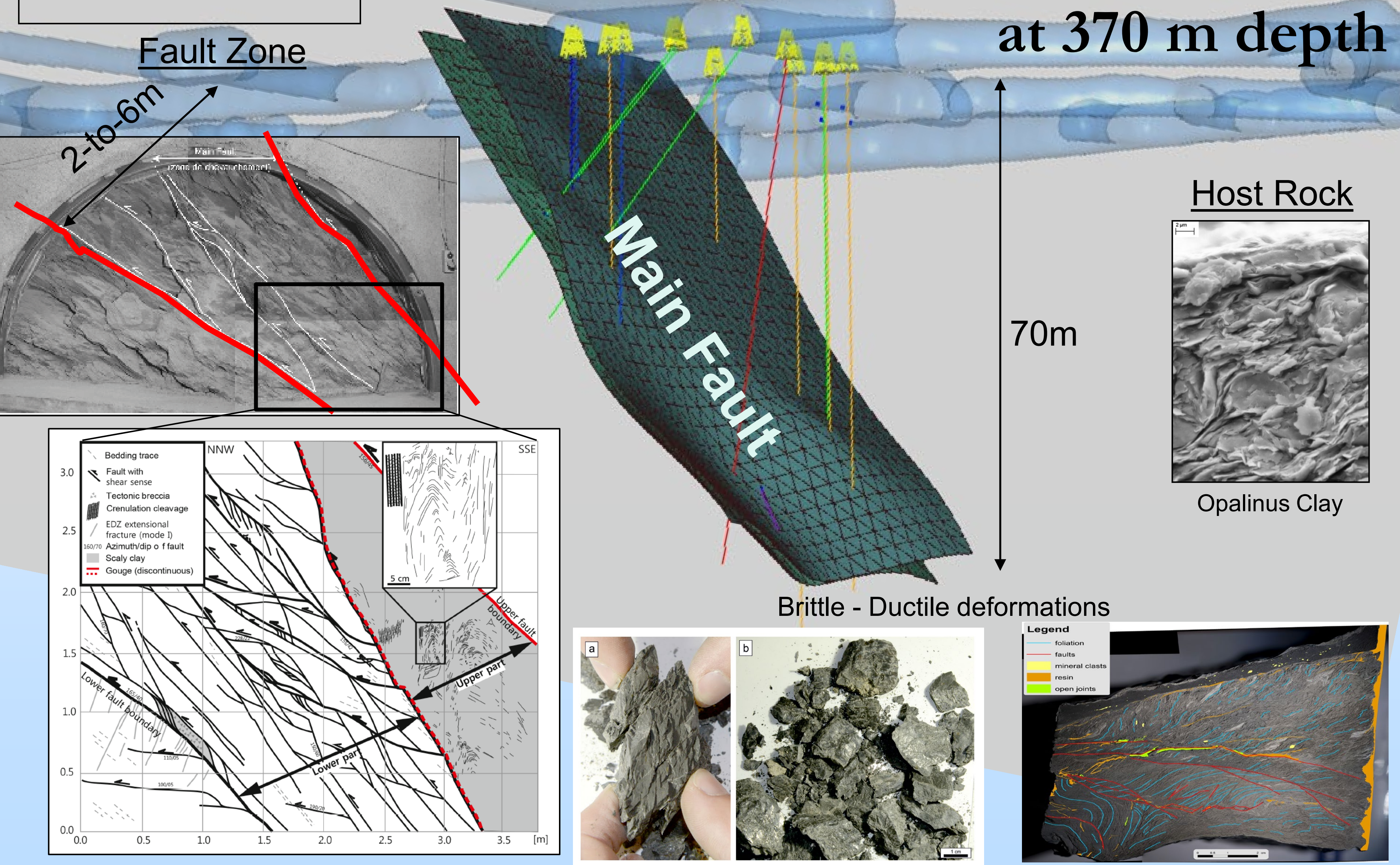
Concept

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

End Product

Relating DCS and other monitoring
Signals to CO_2 leak, fault slip
and seismicity

Mt Terri Testbed: A Thick Fault Zone in a Low-Permeability Argillite at 370 m depth

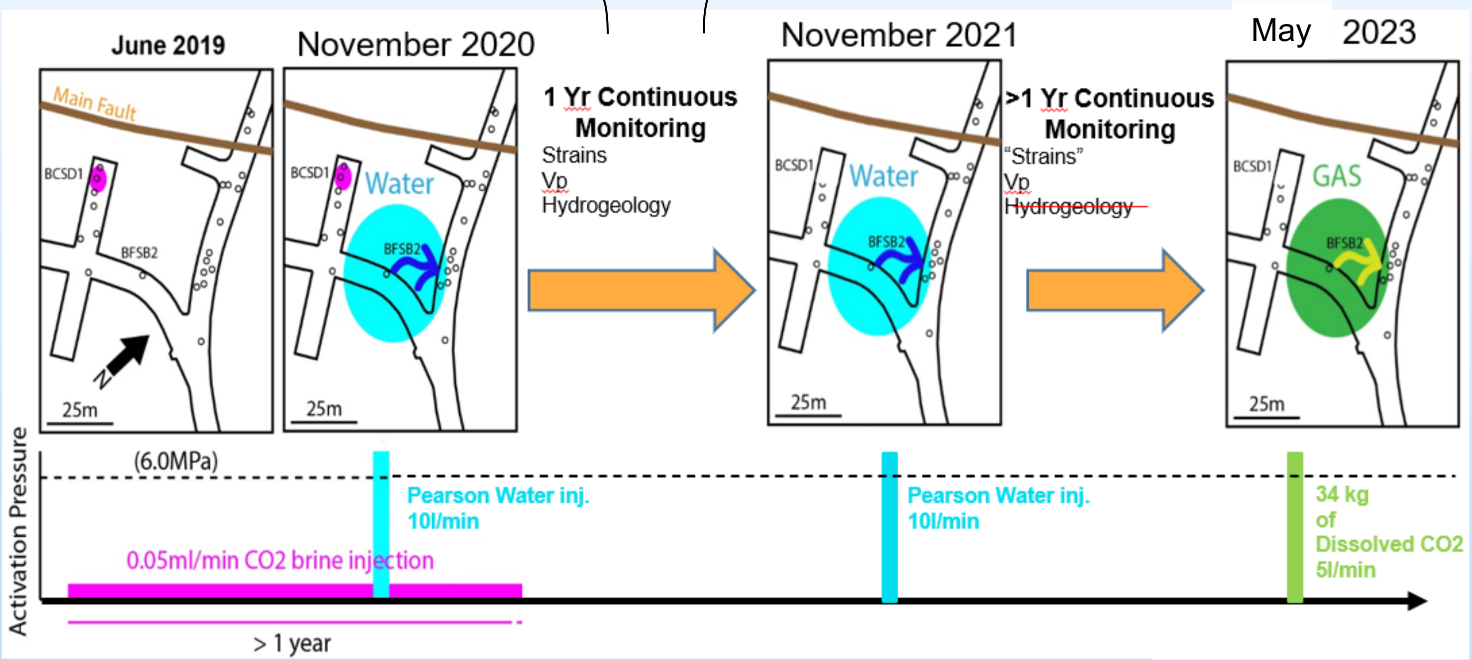


MtTerri Fault Injection Experiments in a Caprock Analog - Summary

18 Publications so far

FSB project
Validating a CASSM Monitoring System to image fault leakage

FSC project
CO_2 leak in an activated fault



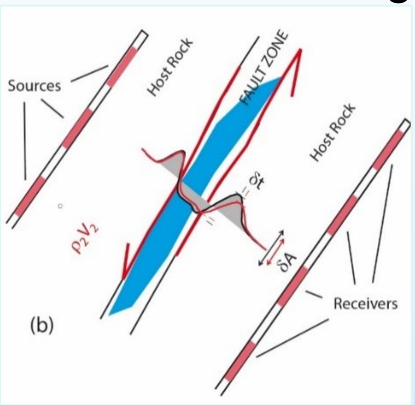
FSC Project

- **DOE funded follow-up project to FSB**
- **Started August 1, 2021 – End September 30, 2024**
  - Experiments of fault reactivation with CO_2 fluids
  - DCS (Distributed Chemical Sensing) Fiber Development
  - Advanced modeling of fault leakage and induced seismicity
- **Project Participants**
  - Y. Guglielmi, PI and J. Birkholzer, Co-PI
  - LBNL Team – J.Hammonds, Admin Asst; Chet Hopp Research Engineer; J. Rutqvist, Research Scientist; Paul Cook, Research Engineer; Florian Soom, Research Engineer; T. Wood, Scientific Engineering Associate; Michelle Robertson, Program Manager; Yuxin Wu, Research Scientist; …
  - Partnering with RICE University (Jonathan Ajo-Franklin, T. Shadoan)

  And with Helmholtz Centre Potsdam – German Research Center (Veronica Rodrigues Tribaldos)
- **Integrated into Mt Terri consortium project and including support/participation of multiple Mt Terri partners**

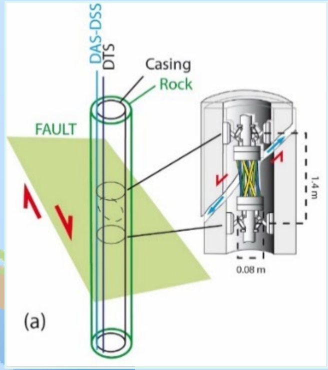
New Monitoring Techniques

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

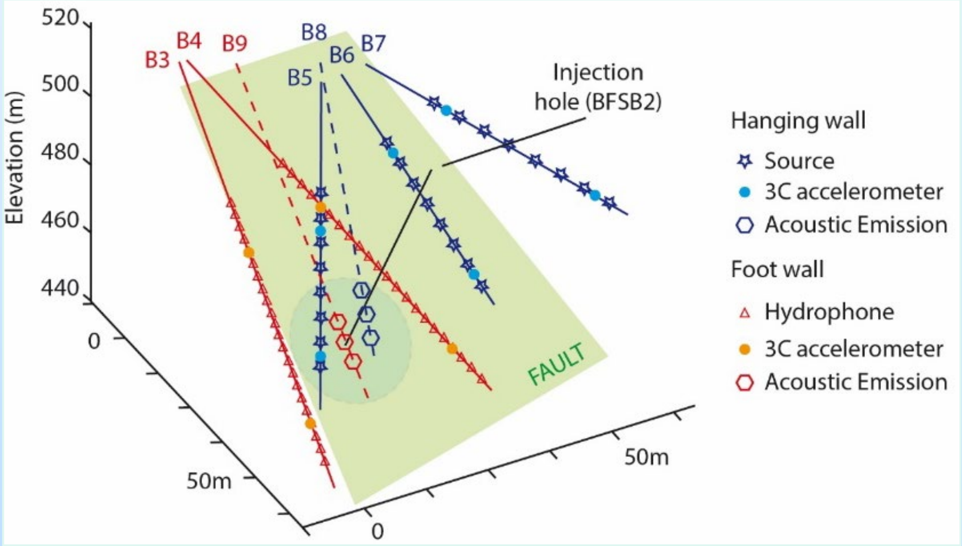


Time lapse imaging
Of leakage flow path
Active seismic

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)



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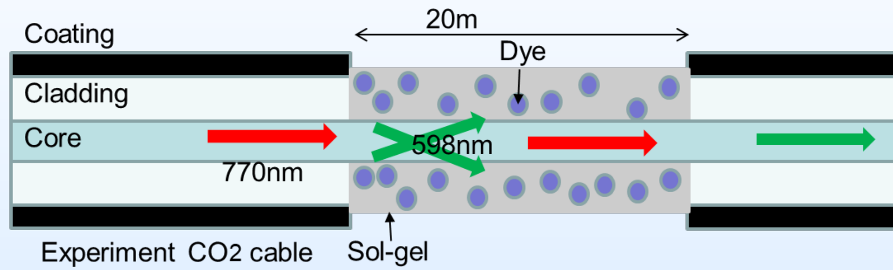
DCS Fibers

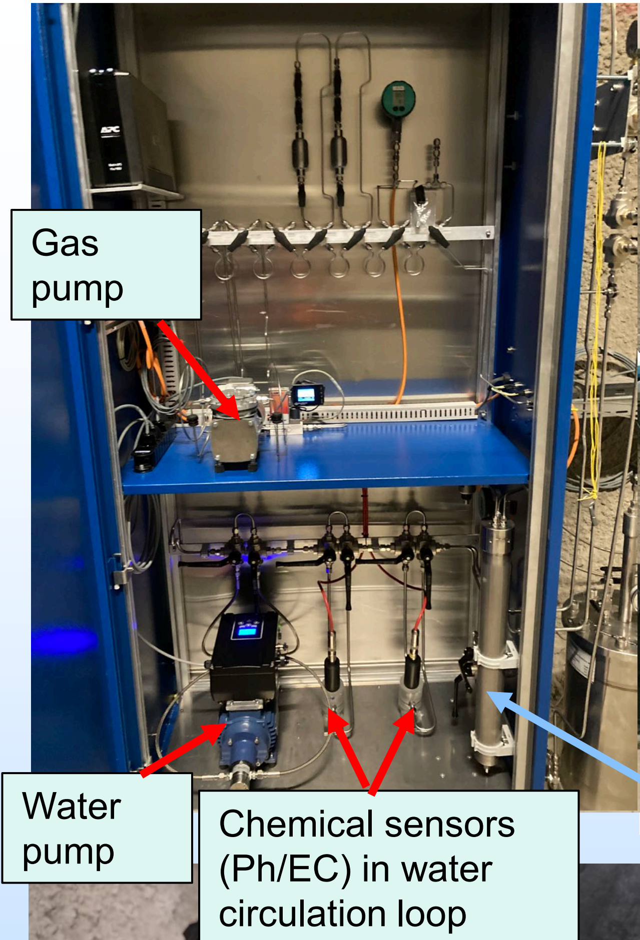
LBNL developed a Distributed Chemical Sensor (DCS) + Interrogator coupled with a borehole fault 3D displacement monitoring

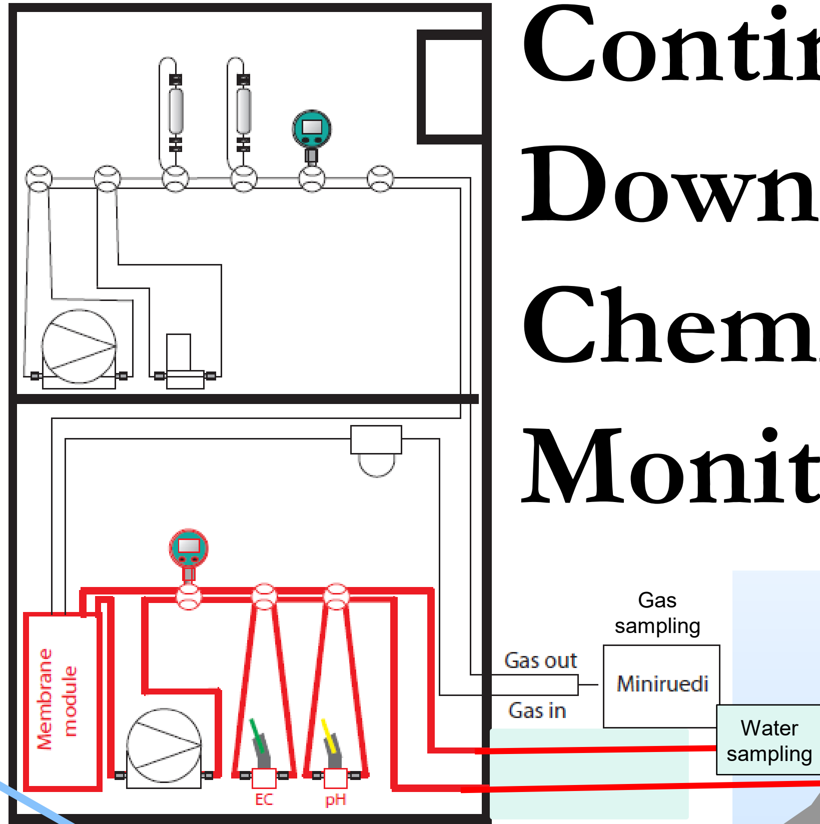
DCS cell installed on top of Dorsa at BFSB1

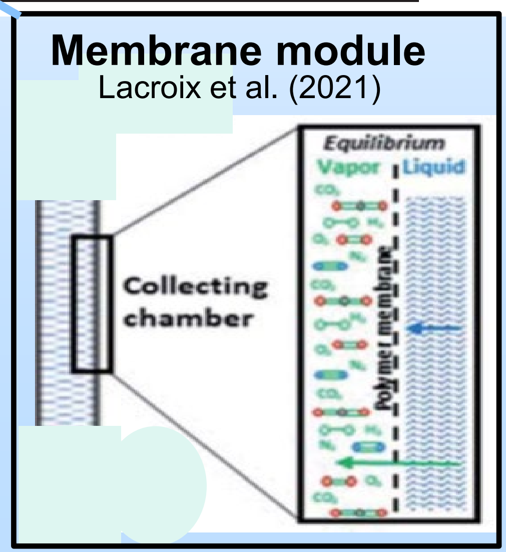


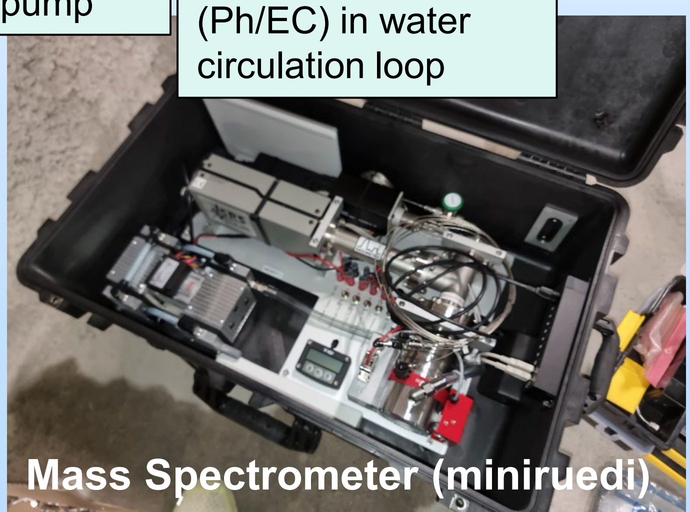
- Based on dye-based absorption cladding-less optical fiber.
- The difference of absorption of the selected wavelength of light and reference light are used to indicate the CO_2 concentration change.
- DCS prototypes were first extensively tested at lab. scale before deployment in the field experiment

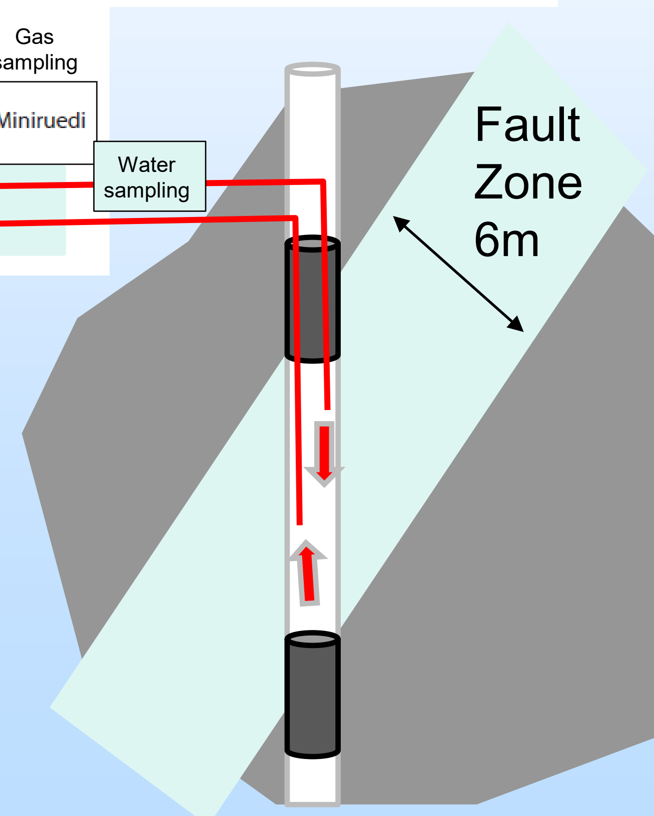
Continuous Downhole Chemical Monitoring





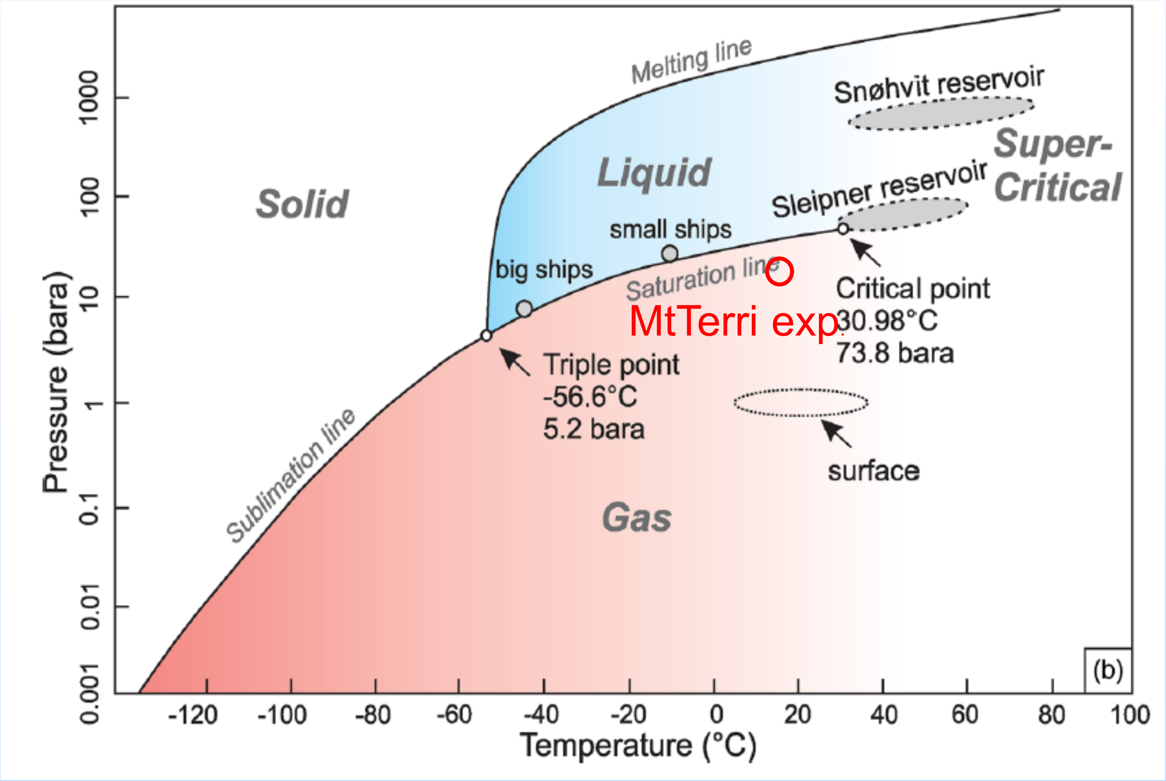






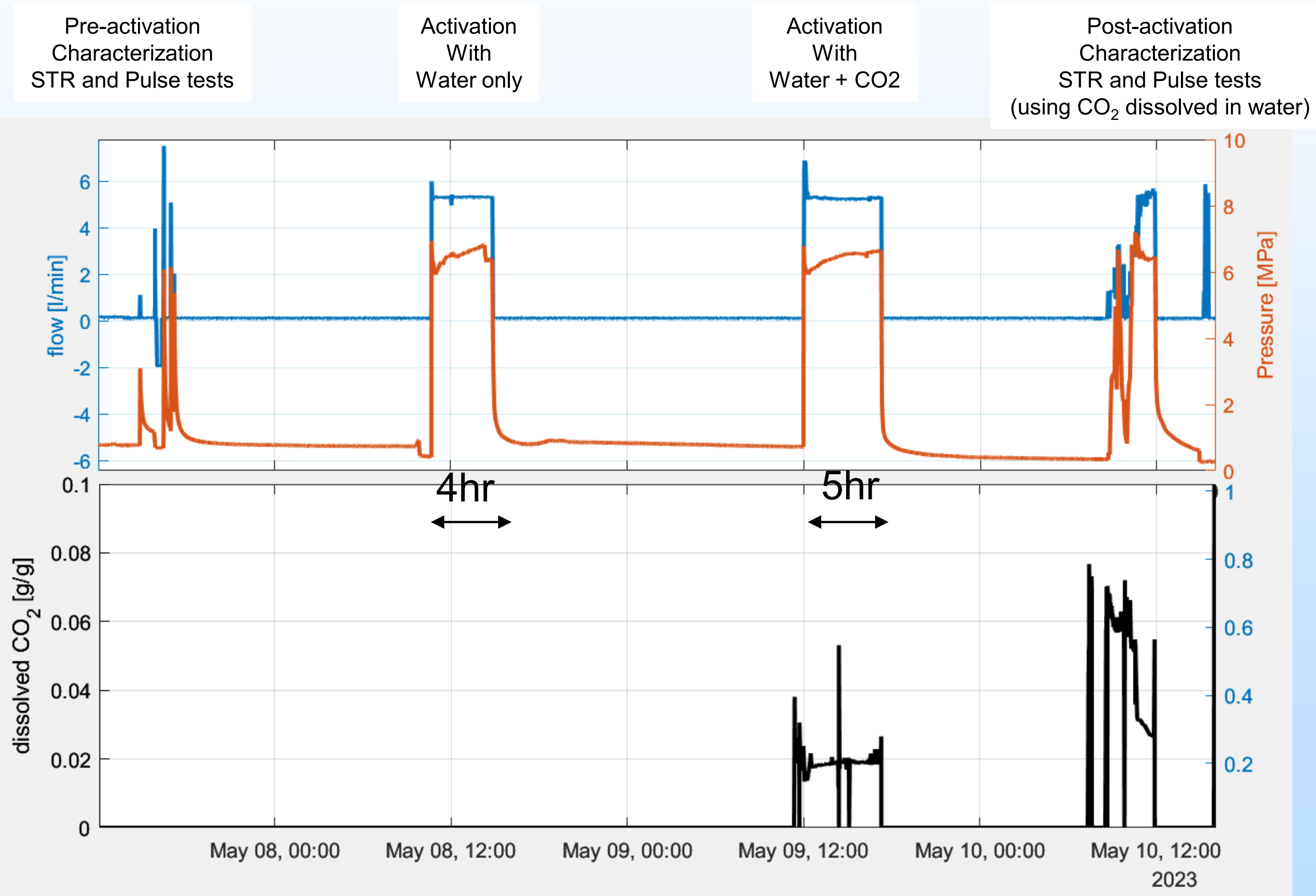
Characteristics of the 2023 CO_2 Injection

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 ~ 34kg



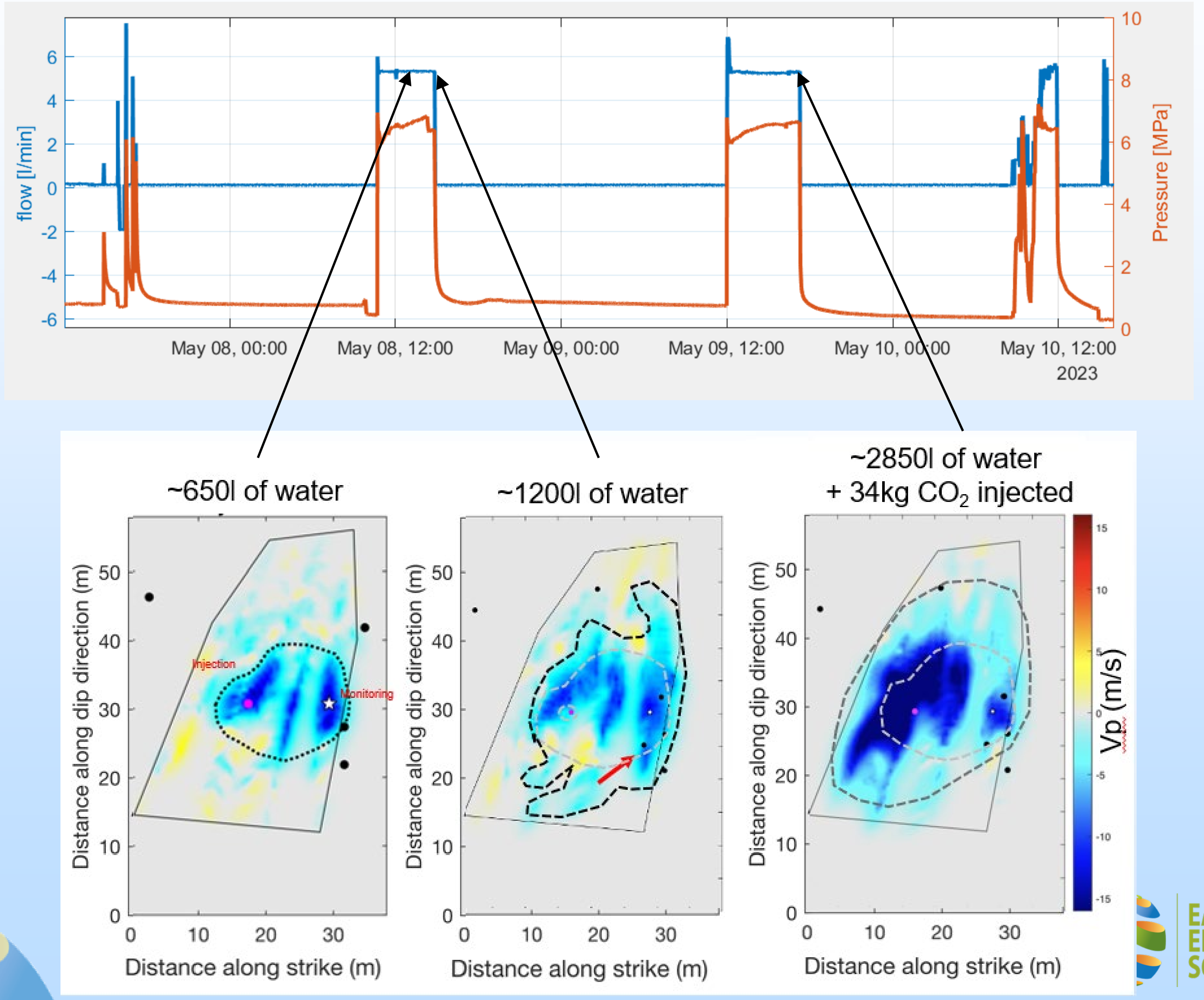
Injection Protocol

Injection of CO_2 dissolved in water at high pressure (6 MPa) and high flowrate (5 l/Min) to activate the fault



Asymmetric Growth of a Leakage flow path

Effect of the fault stress heterogeneity



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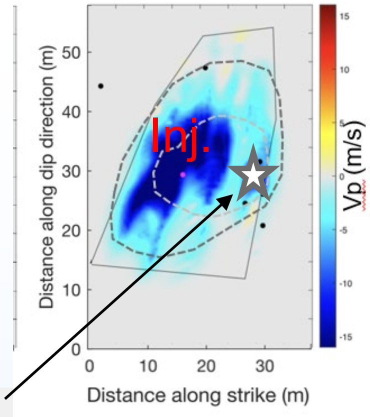
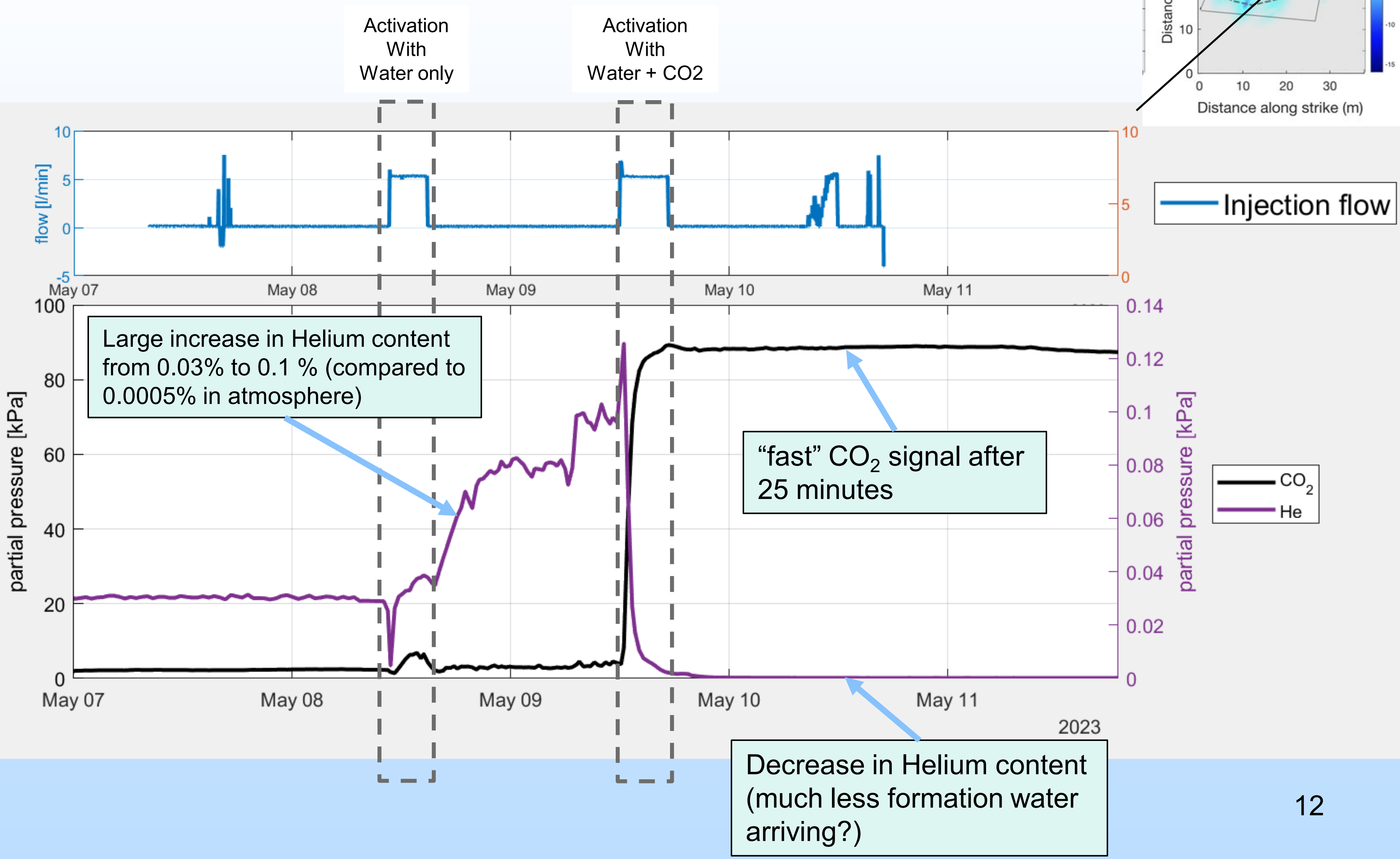
Fault Hydro-Chemical Response

Formation water flushed into the fault before CO_2 leakage





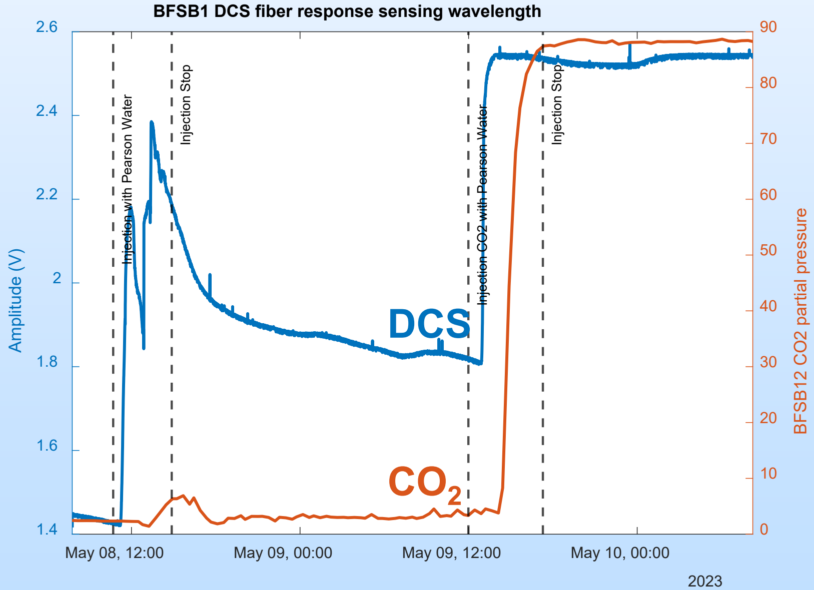
DCS Response to CO_2 injection

DCS signals looks affected by:

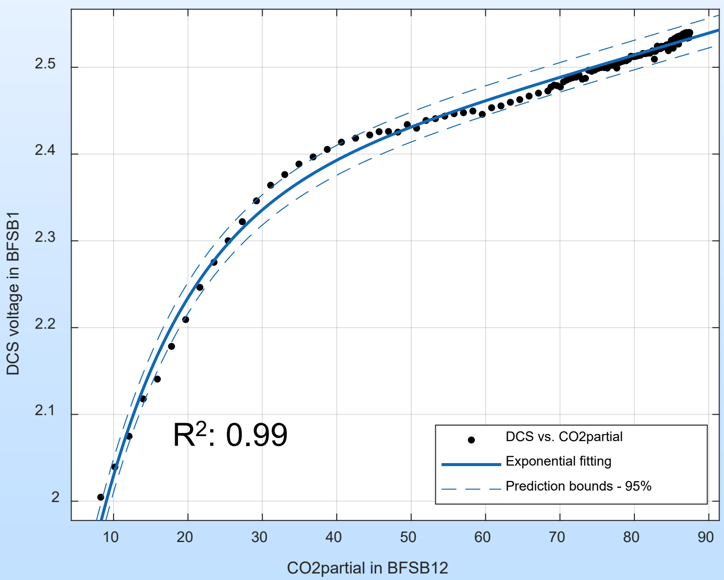
- **Temperature and humidity during the water injection cycle**

(This is also observed in the laboratory and can be corrected)

- **Apparently correlates well with CO_2 partial pressure during the dissolved CO_2 injection cycle**

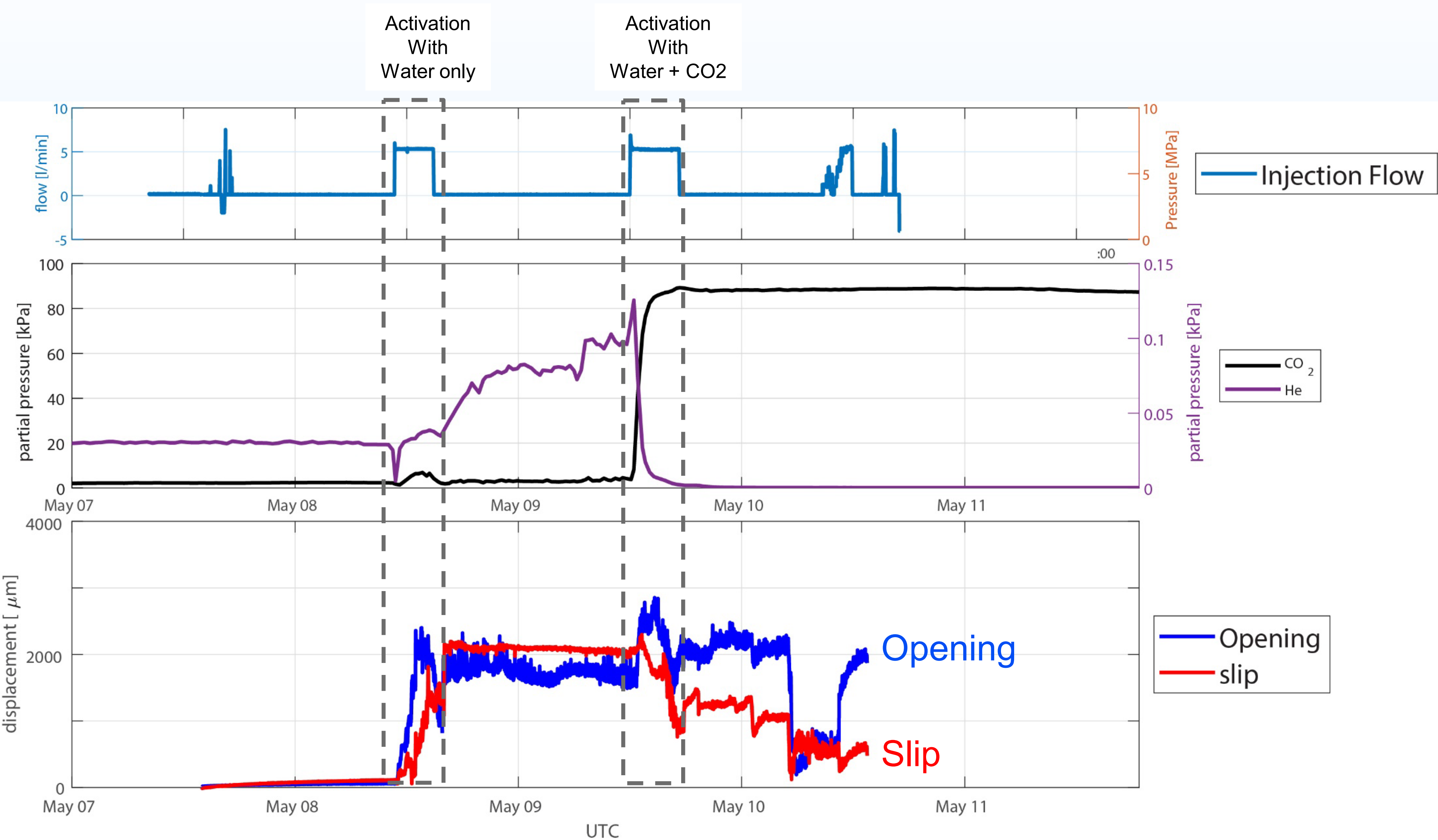


DCS fiber response in power or voltage (Blue) and the CO2 Partial pressure at **BFSB12**, which is close to BFSB1.



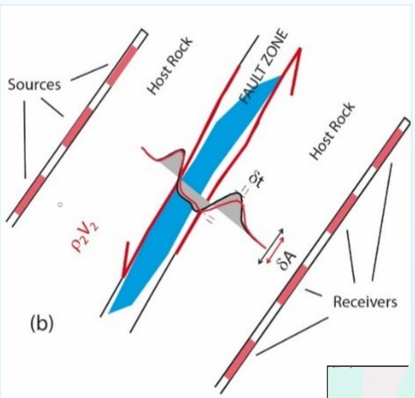
Fault Hydro-Chemical Mechanical Response

Significant decrease of fault slip when CO_2 gets in the fault, while fault is still opening

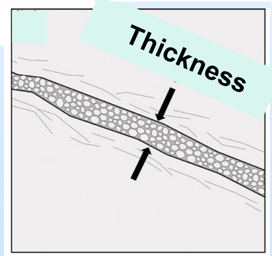


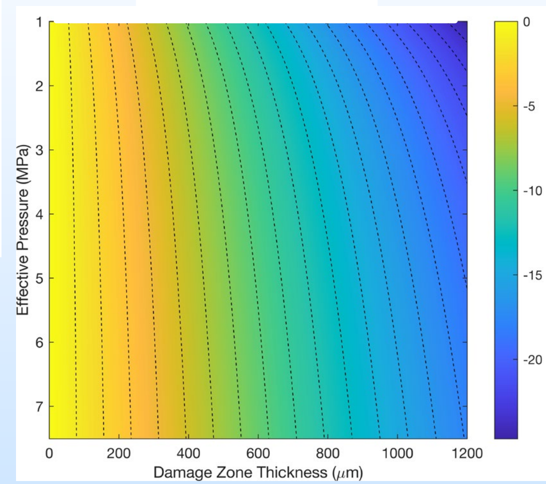
Partitioning of strain within the fault zone during fault activation

- **1 - Estimating "bulk" fault thickness variation from p-waves velocity and DSS fibers strains**

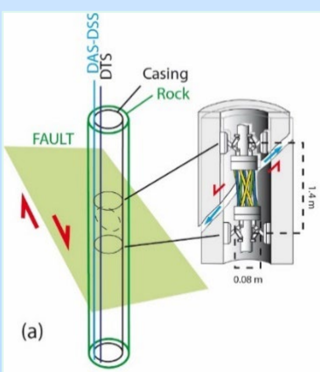


- Fault figured as a layer of spheres under poroelastic stress
(contact theory used to estimate compliance)
- Equivalent media theory used to estimate Variations in Vp velocities vs fault thickness





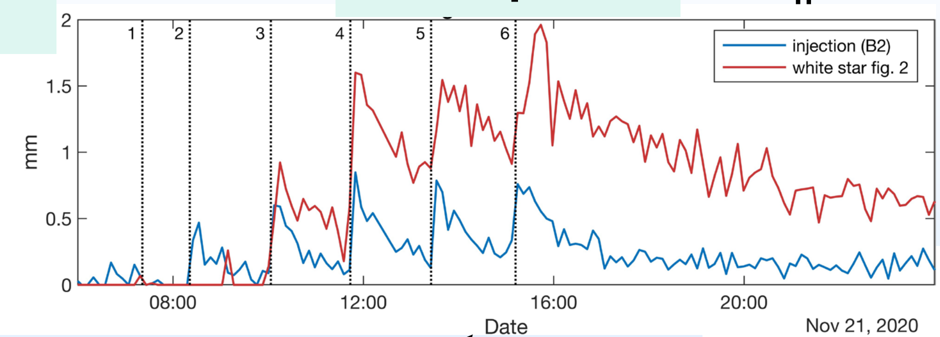
- **2 - Fault thickness variation versus fault slip**

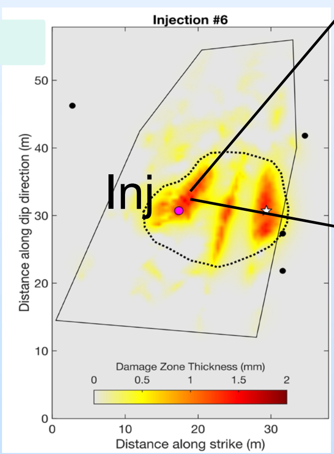


Local direct slip measurements with SIMFIP and DORSA probes

Estimating fault thickness variation from p-waves velocity and DSS fibers strains

Fault Normal Displacement U_n from δV_p

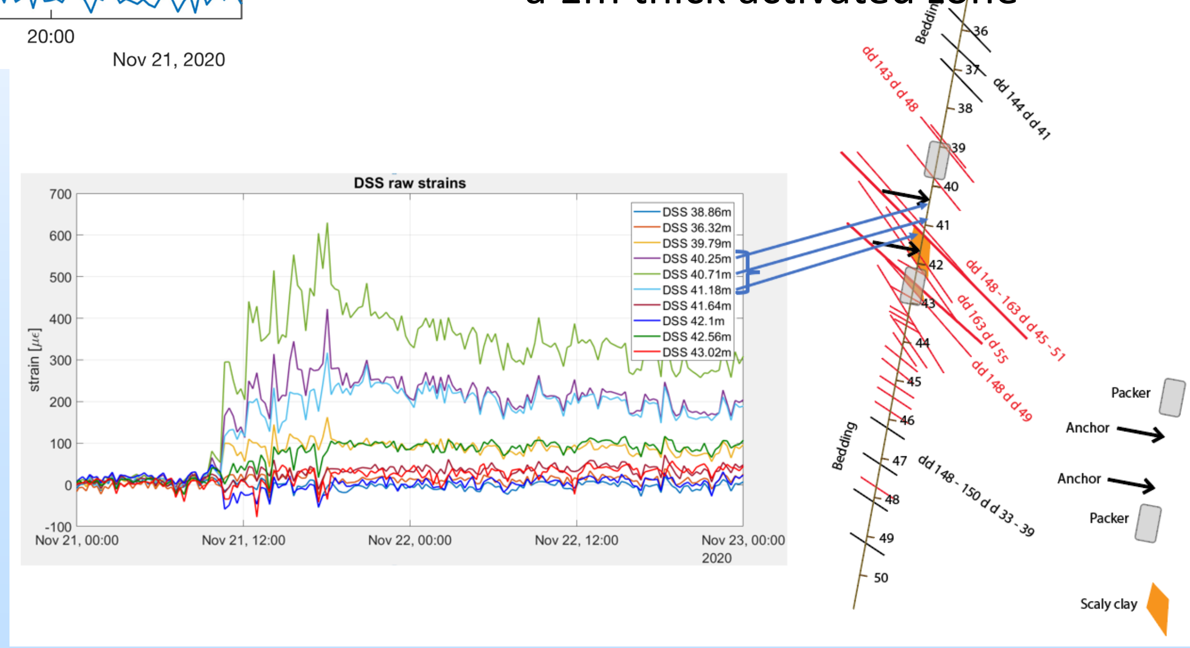




DSS fiber Strain at Injection

500-600µstrain extension

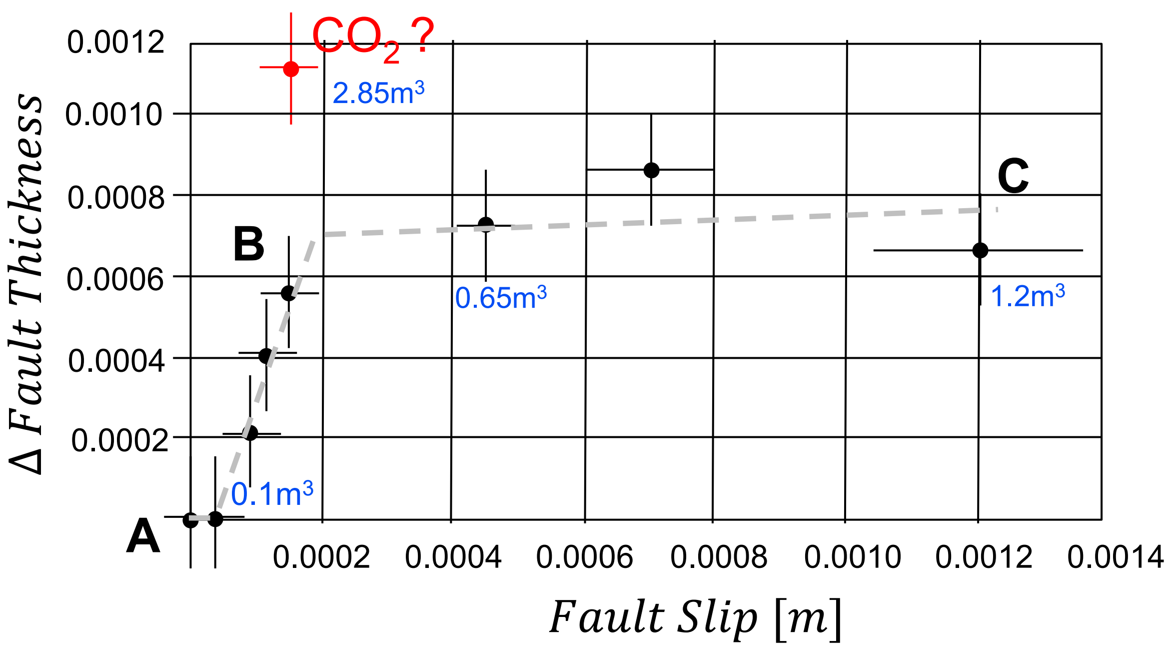
a 1m thick activated zone



Fault thickness variation vs Slip

Most of fault dilation occurs at low slip magnitude (slip<0.0003m)
0.0003m is close to the friction slip weakening distance observed at lab. Scale!

AB – Fault dilation dominates
BC – Fault slip dominates
CO_2 penetrating the fault "apparently" kills fault slip
Potentially related to the change in fluid viscosity?



Accomplishments To Date

- We successfully performed one of the first field scale CO_2 fault activation experiment
  Representative of CO_2 leakage in a fault affecting the overburden at a depth<800m

- A scenario where pressurized formation fluids "pre-opened" the caprock fault creating a flowpath for CO_2 leakage was observed at very high resolution

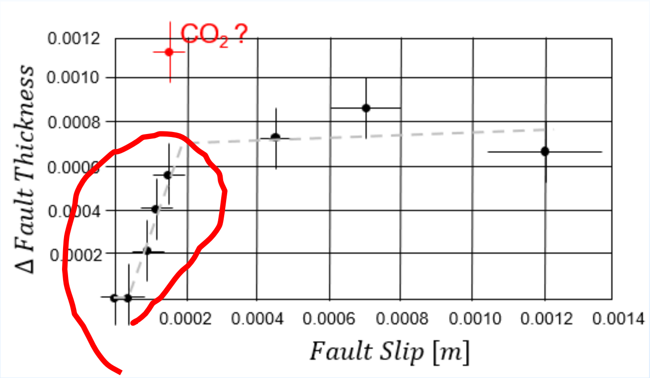
- Injected CO_2 "apparently" alters ("killed!") fault slip

- DCS prototype seems sensitive to CO_2 leak in a monitoring borehole

- One paper published about induced microseismicity observed during the MtTerri shale fault activations

Synergy Opportunities:

Inform LBNL Project on Basin-Scale Storage Optimization Using Geomechanical Studies

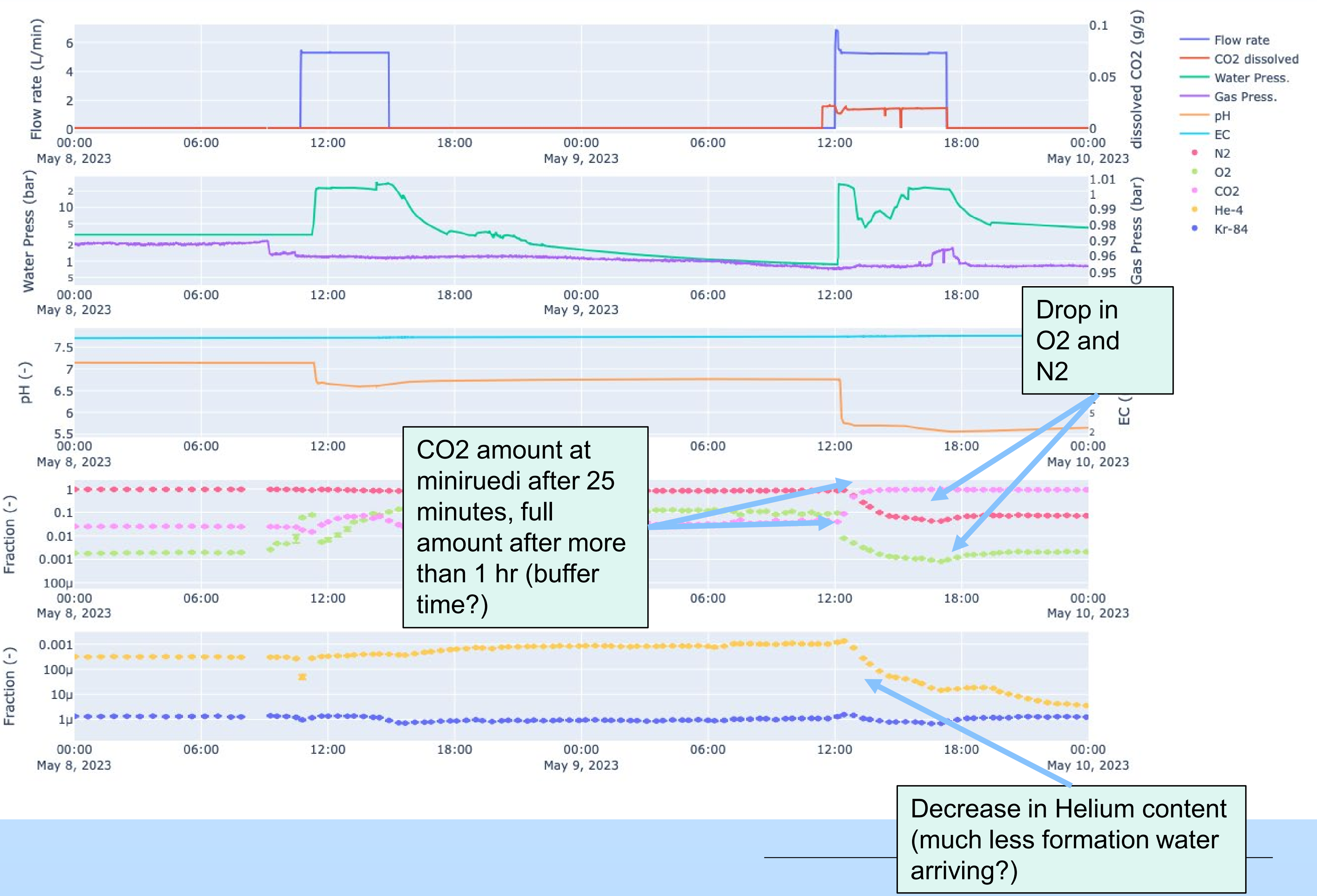


Experiments show how important it is to relate dilatancy/contractance with fault zone strain softening/hardening and slip

Objective is to apply such poro-plastic fault zone models deduced from MtTerri experiments to explore different modes of fault leakage and aseismic-seismic response in **the LBNL Project On Basin-Scale Storage Optimization**

Backup Slides

Second injection cycle – May 9th, 2023



Appendix

Organization Chart

- **Team members and their role:**

Task 1: Yuxin Wu, Research Scientist and a postdoctorant 1/SEA researcher.

Task 2: Y. Guglielmi, PI and Research Scientist; P. Cook, Scientific Engineering Associate; Postdoctorant 2; Yuxin Wu, Research Scientist and a postdoctorant 1/SEA researcher

Task 3: Y.Guglielmi, PI and Research Scientist; Veronica Rodriguez-Tribaldos Research Scientist, Chet Hopp Postdoc; P. Cook, Scientific Engineering Associate; F. Soom, Scientific Engineering Associate; T. Wood, Scientific Engineering Associate; Michelle Robertson, Program Manager.

Task 4: Y. Guglielmi, PI and Research Scientist; J. Birkholzer, PI and Research Scientist; Chet Hopp postdoc; J. Rutqvist, Research Scientist; Julia Correa, Research Scientist; Veronica Rodrigues Tribaldos, Posdoc 1 and 2.

Task 5: Y. Guglielmi, PI and Research Scientist; J. Birkholzer, PI and Research Scientist; H. Prieto, Admin Asst

Gantt Chart

FS-C experiment																
Steps:		**Q4 FY21**	**Q1 FY22**	**Q2**	**Q3**	**Q4**	**Q1 FY23**	**Q2**	**Q3**	**Q4**	**Q1 FY24**	**Q2**	**Q3**	**Q4**	**Q1 FY25**	**Q2**
Task 1 – DCS Fiber Design and Production																
Sub-Task 1.1 – OTDR design and construction																
Sub-Task 1.2 – Laboratory validation																
Task 2 – Field Test Preparation for Water Chemical Monitoring at Mt Terri																
Task 2.1 – Installation of water and gas chemical monitoring																
Task 2.2 – DCS installation at Mt Terri																
Task 3 – Experiments of Fault Reactivation with CO_2 fluids																
Task 3.1 – Perturbations of leakage water chemistry related to fault deformation																
Task 3.2 – Cyclic injection of CO_2-brine and CO_2-gas																
Task 4 – Data Analyses, Geomechanical and Chemical Modeling																