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Effects of $scCO_2$ on permeability and viscoplastic properties of unconventional formations

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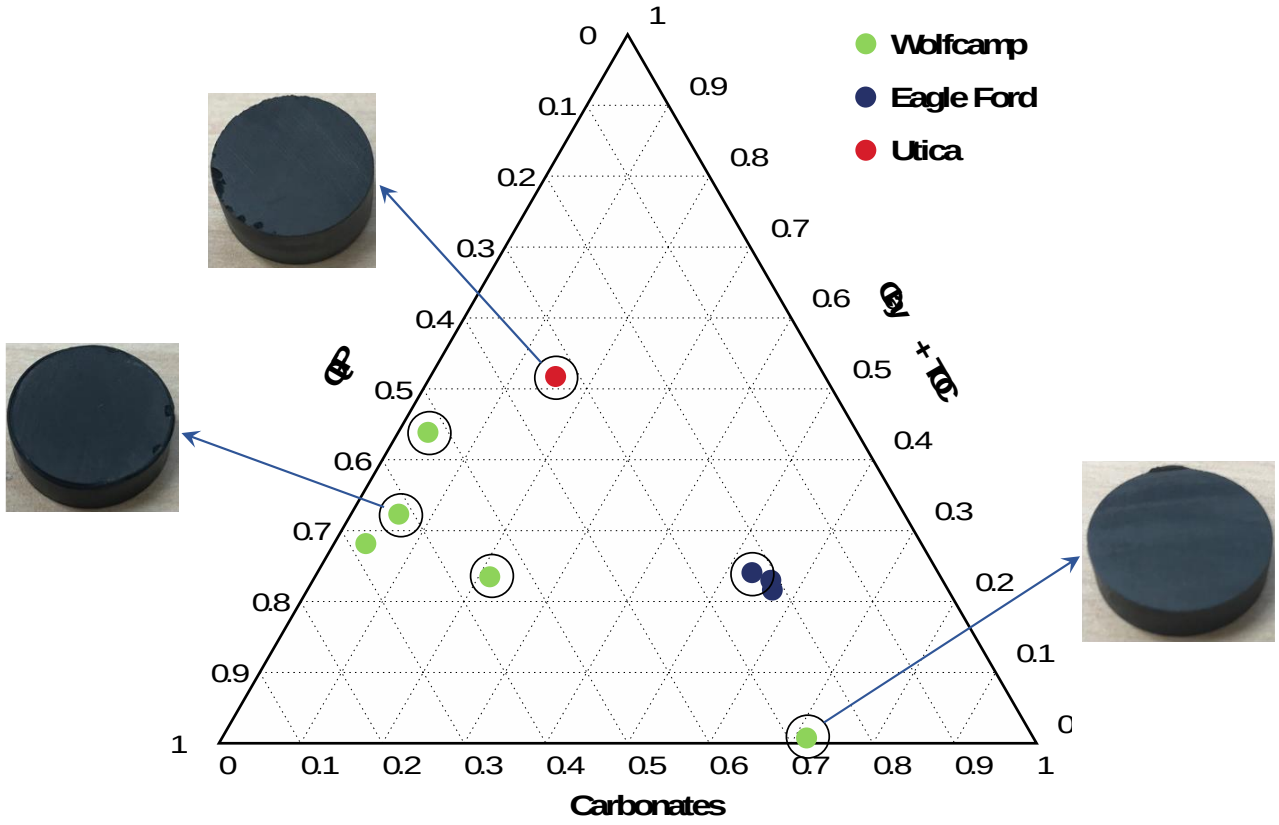
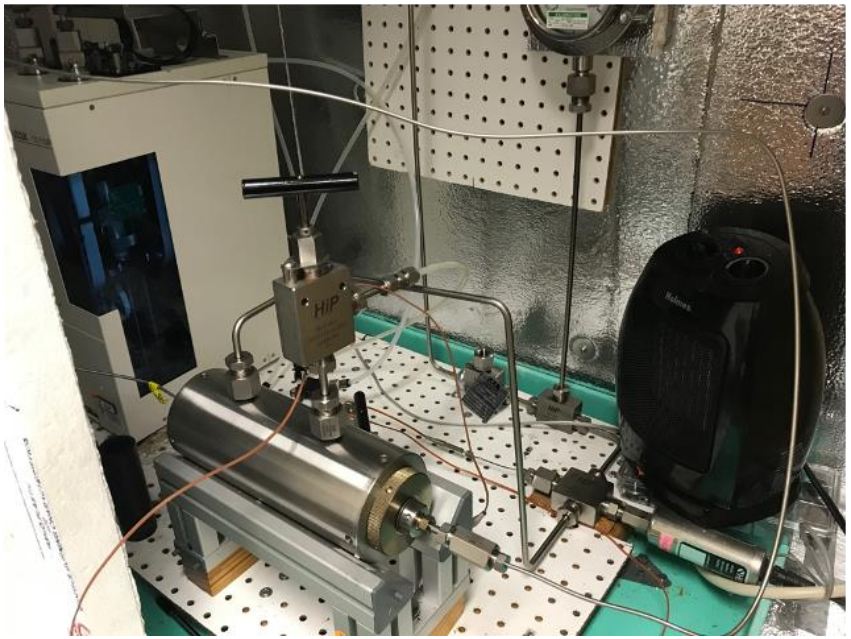
Samples

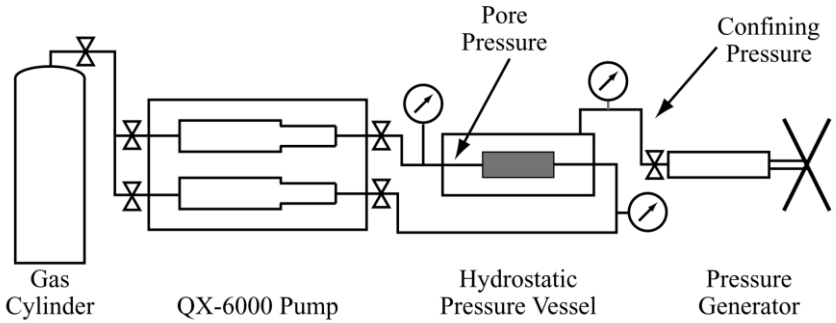
- Carb.: 4 – 71%
- “Clay + TOC”: 1-52%
- Diameter: 2.54 cm
- Length: 0.6 – 0.9 cm
- As-received, not dried



Experimental Set-up

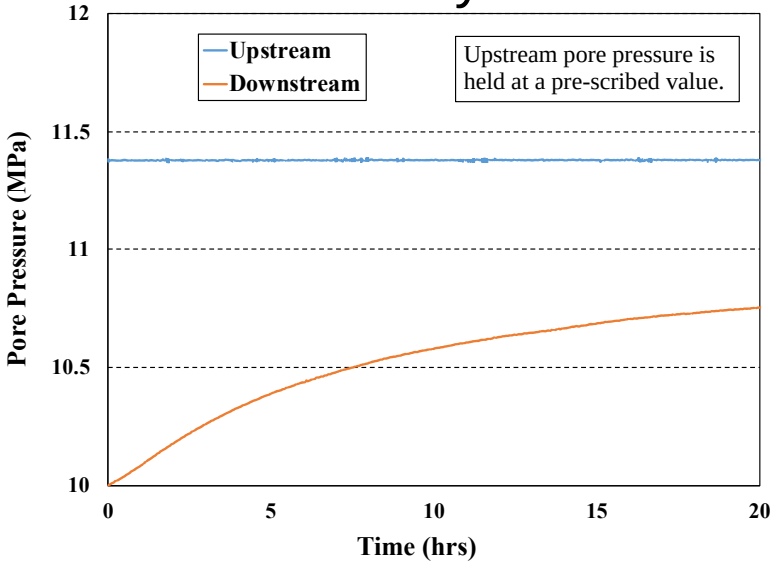


Thermally-insulated

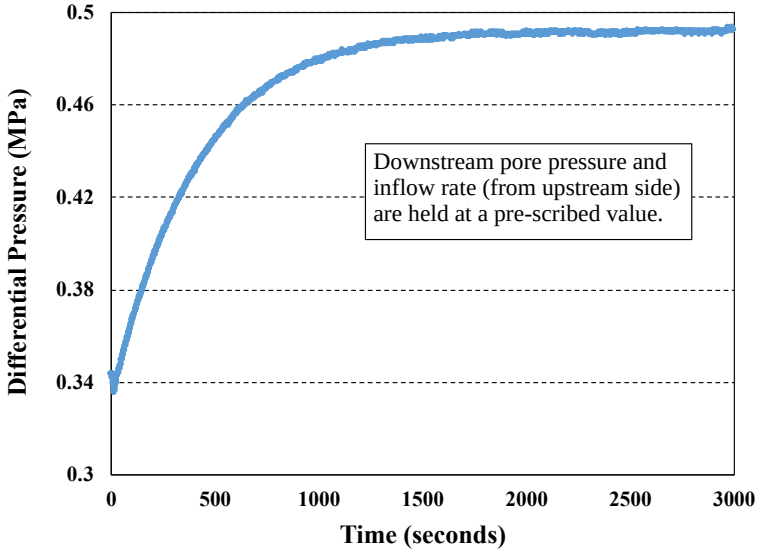


From Heller et al., 2014

Pulse-decay Method

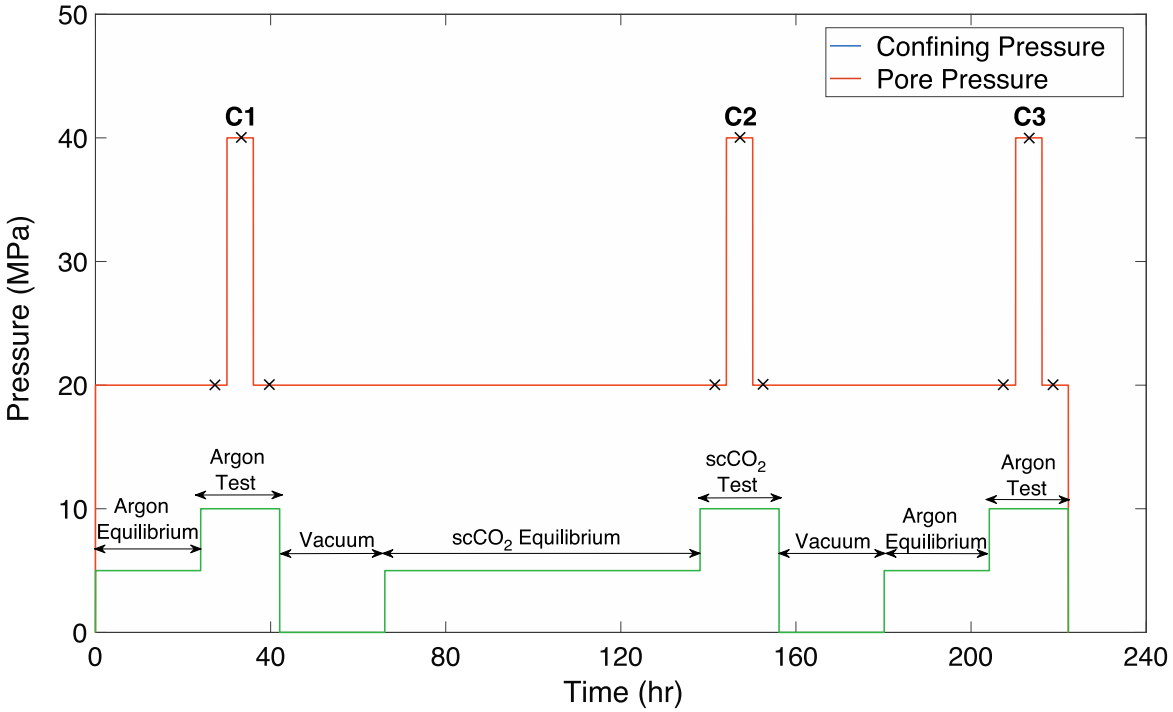


Steady-state Method



Experimental Path

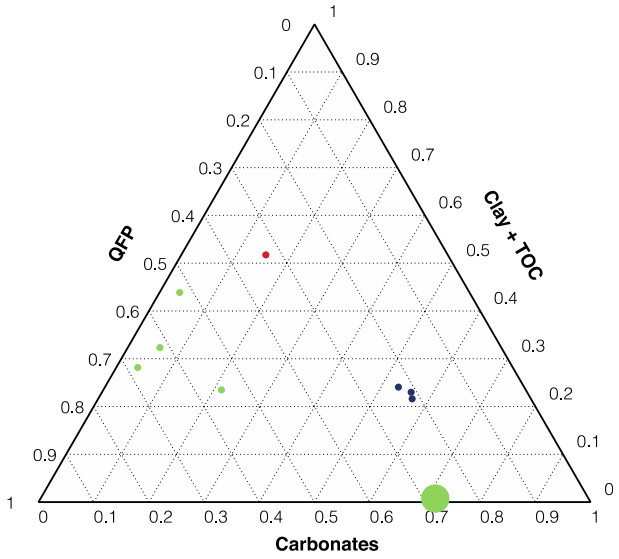
- CP = [20, 40, 20] MPa
- PP = 10 MPa
- 3 days of $scCO_2$ interaction
- Two argon cycles and one $scCO_2$ cycle
- Both pressure-dependency and hysteresis effects

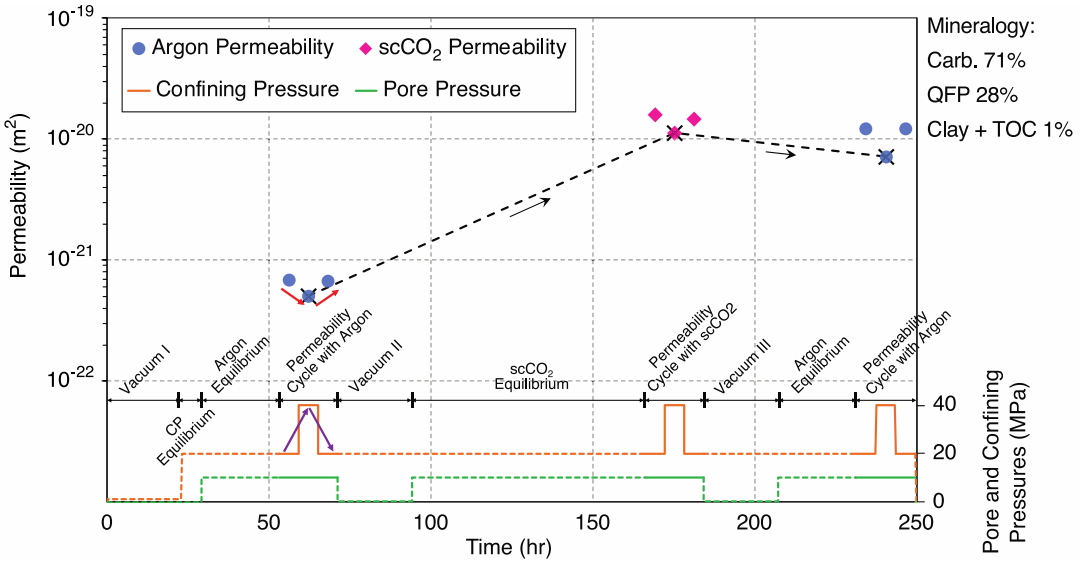


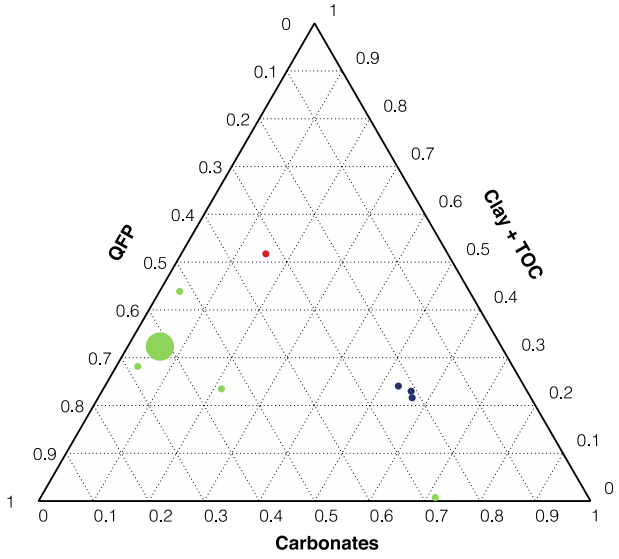
- In C2 ($scCO_2$) cycle both recoverable and irrecoverable effects of $scCO_2$ on permeability are present
- In C3 (post-CO_2) cycle, only irrecoverable effects of $scCO_2$ are present
- Comparing the permeability cycles might give us some insights on the processes that affect permeability

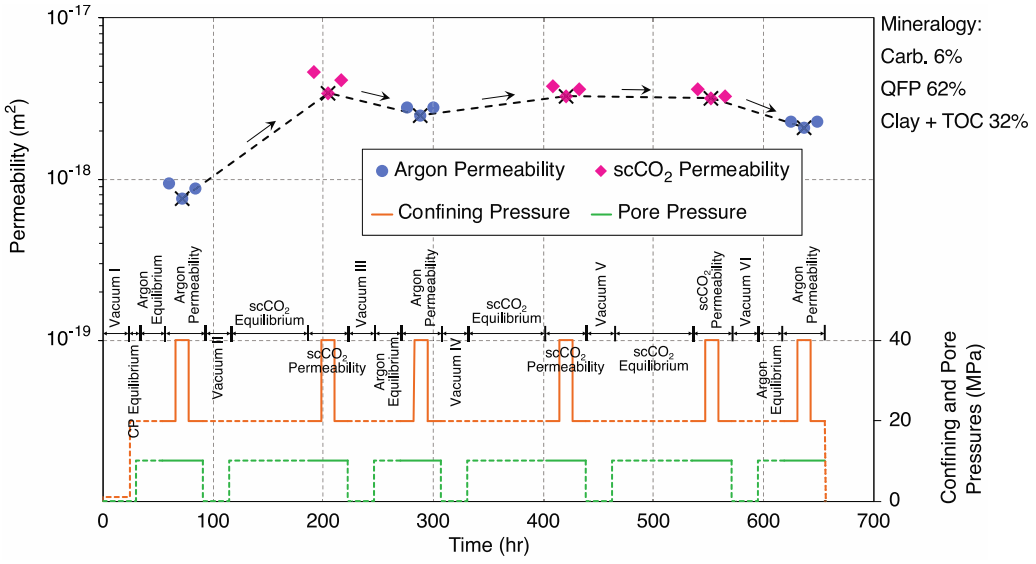
Carbonate Dissolution

Significant irreversible permeability increase



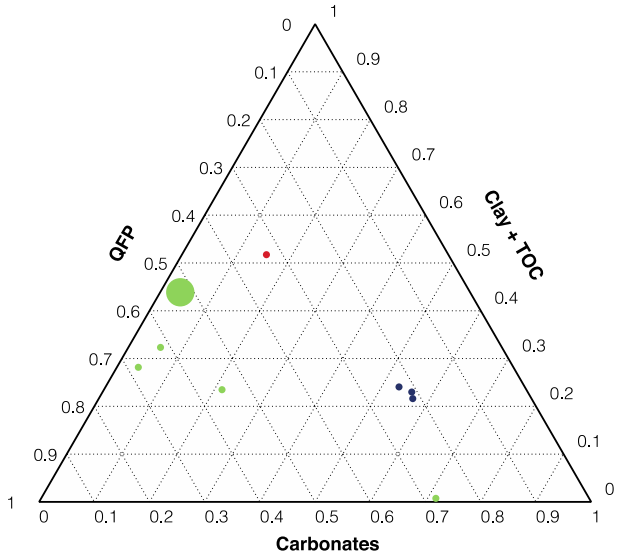


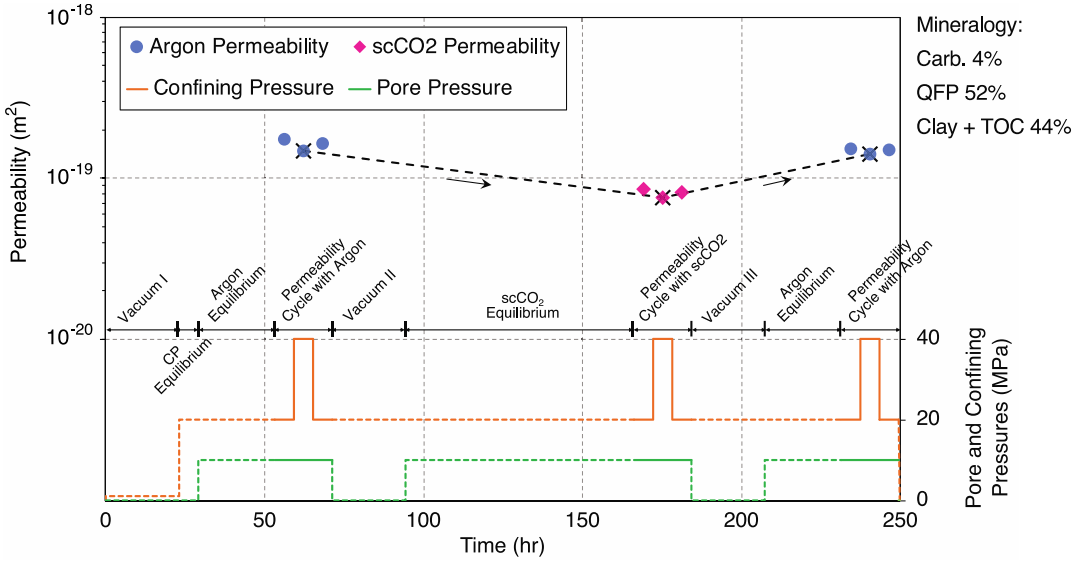




Adsorption into ”Clay+TOC”

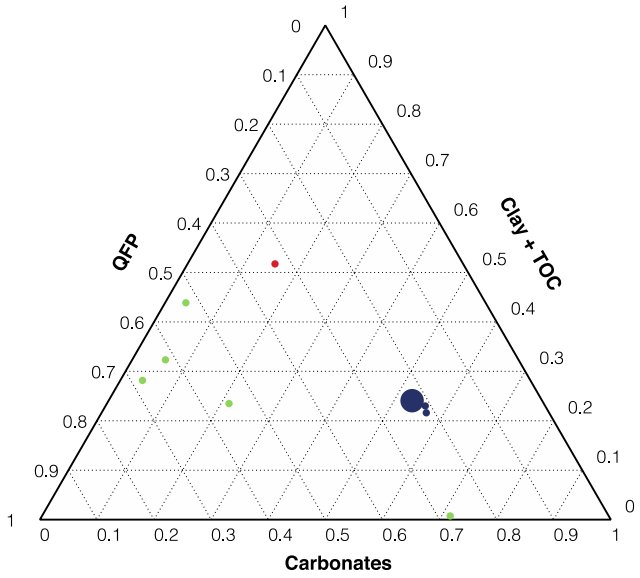
Slight recoverable permeability decrease

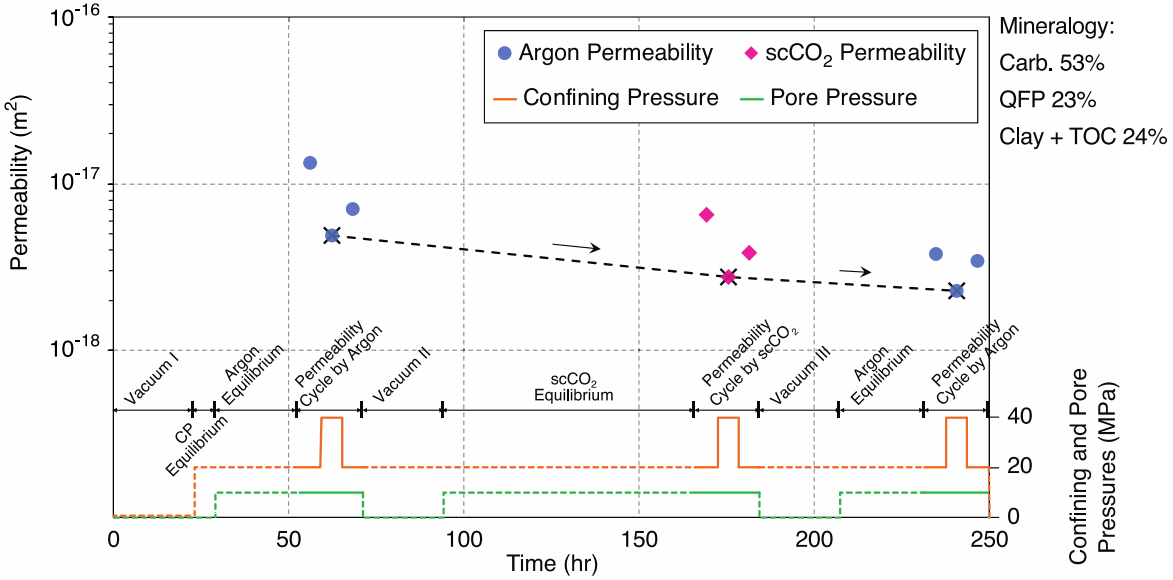




Matrix Weakening

Gradual decrease in permeability, regardless of fluid type





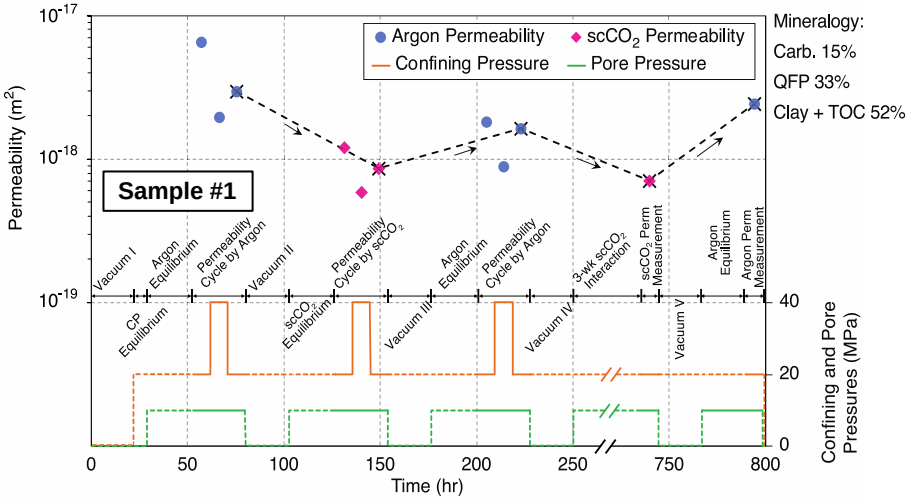
Pressure-dependency

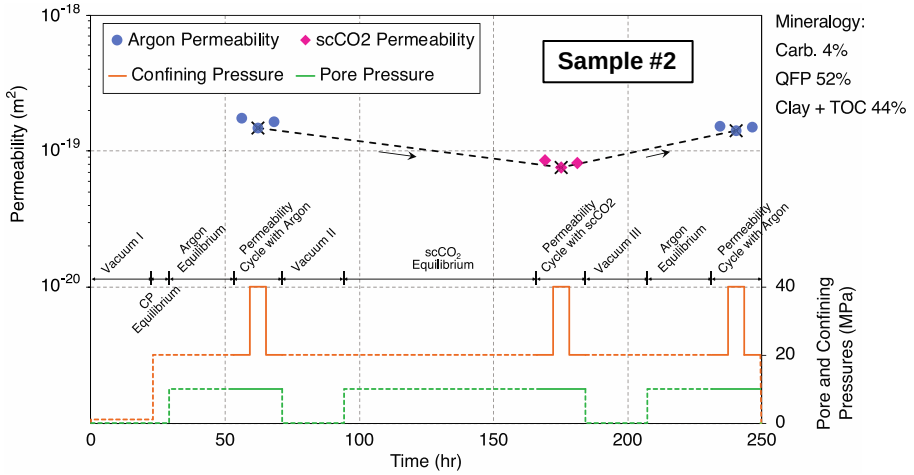
Samples #1 and #2 have highest “Clay + TOC”

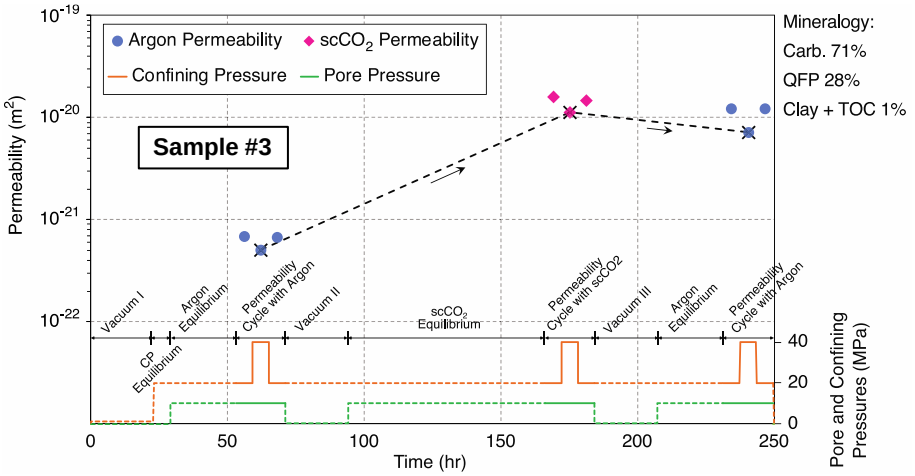
- Highest pressure dependency for Sample #1
- Lowest pressure dependency for Sample #2

Greater pressure dependency after interaction with $scCO_2$ for Samples #1 and #3

- Carbonate dissolution at pore and micro-crack scale

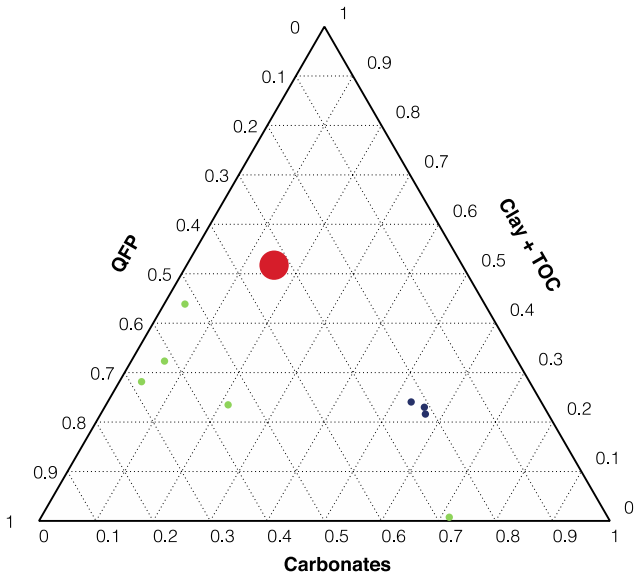


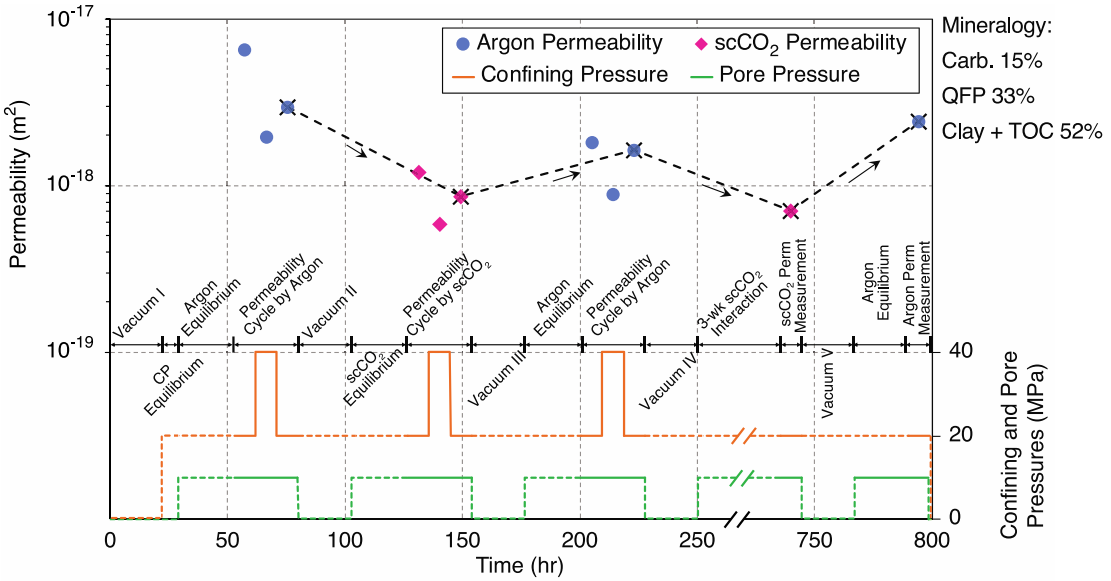




Time-dependent Dissolution

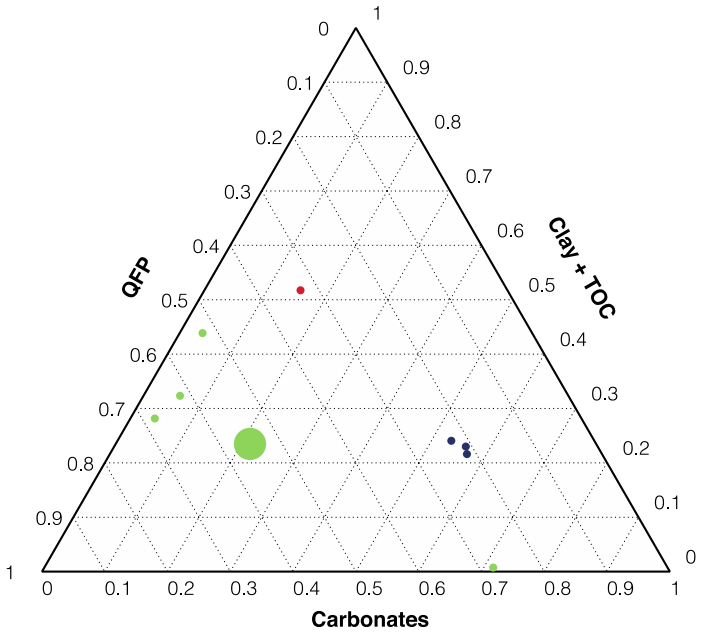
- Net Change: 50% dissolution-induced increase in permeability
- When $scCO_2$ present: 70% adsorption-induced decrease in permeability

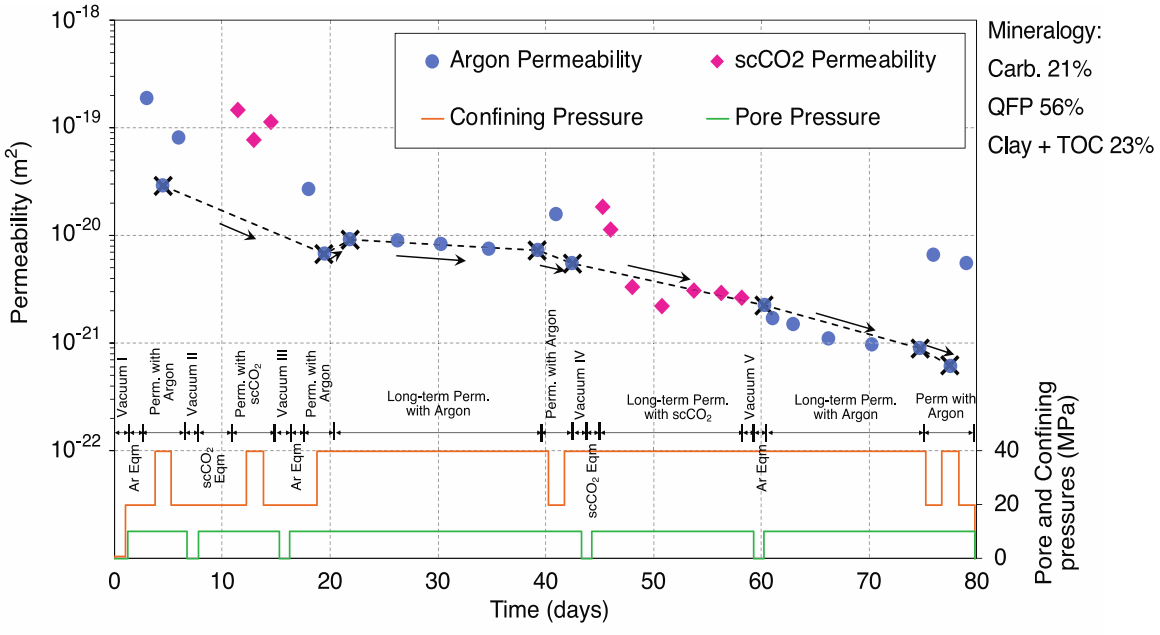




Long-term Permeability Evolution

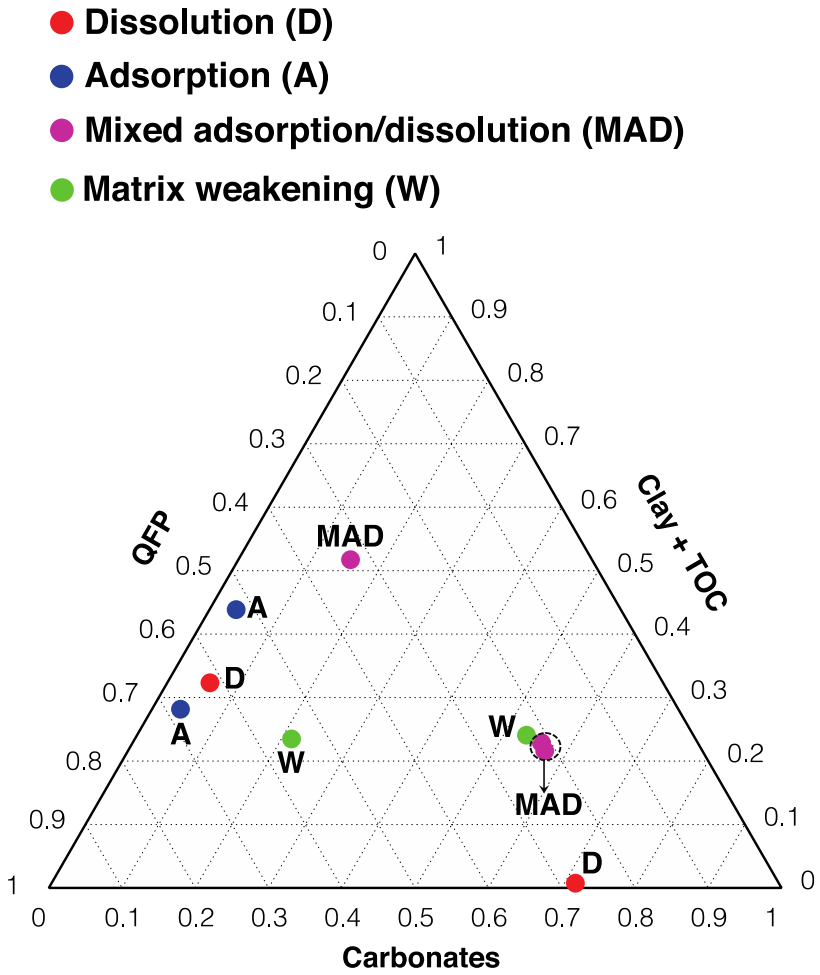
- Significant permeability reduction after interaction with $scCO_2$
- Enhanced rate of permeability reduction under constant stress conditions





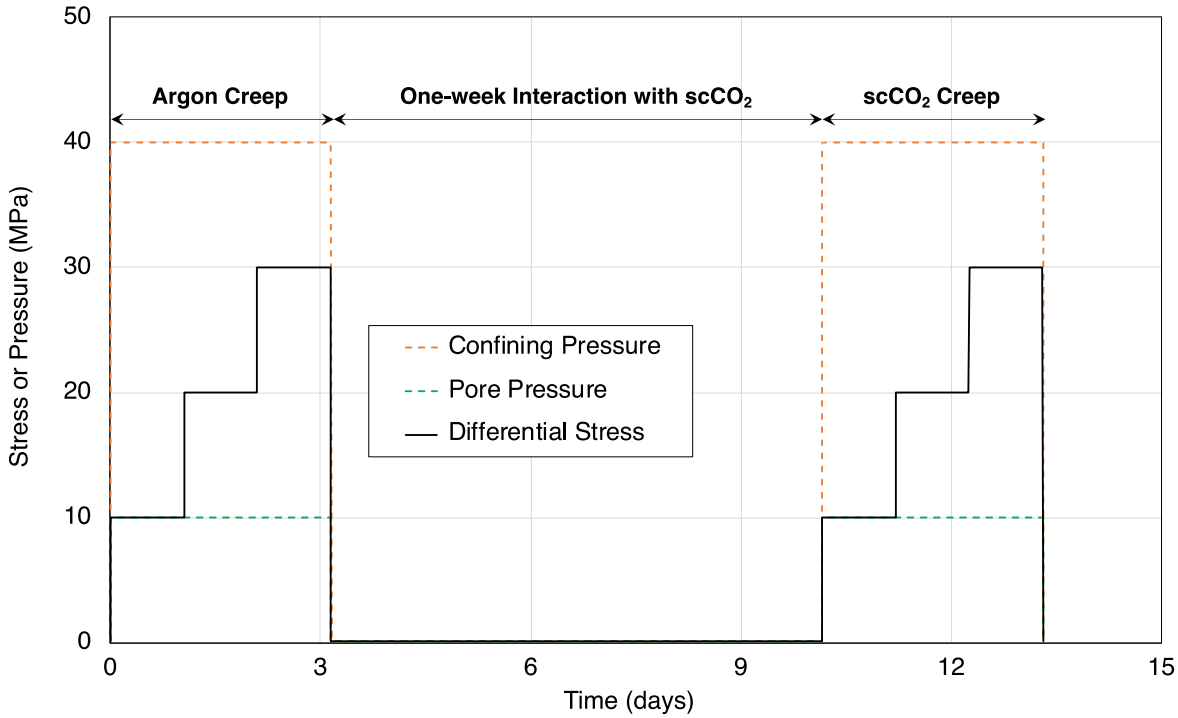
Mechanisms of Permeability Change

- Mineral composition is not the only factor determining $scCO_2$-induced changes in matrix permeability
- Dissolution of carbonate minerals causing irreversible permeability increase
- Adsorption causing reversible permeability decrease
- Weakening of the matrix leading to permanent enhanced compaction and decrease of permeability



Creep Experiments

- CP = 40 MPa
- PP = 10 MPa
- DS = [10,20,30] MPa
- 7 days of $scCO_2$ interaction
- Comparison will be made between creep data with argon and $scCO_2$



- Power-law model will be used to model the axial strain data, as follows:

$$\varepsilon = \sigma B t^n$$

where ε and σ are axial strain and differential stress, respectively. B and n are empirical parameters.

- Higher values of n imply higher ductility, while higher values of B imply higher compliance.

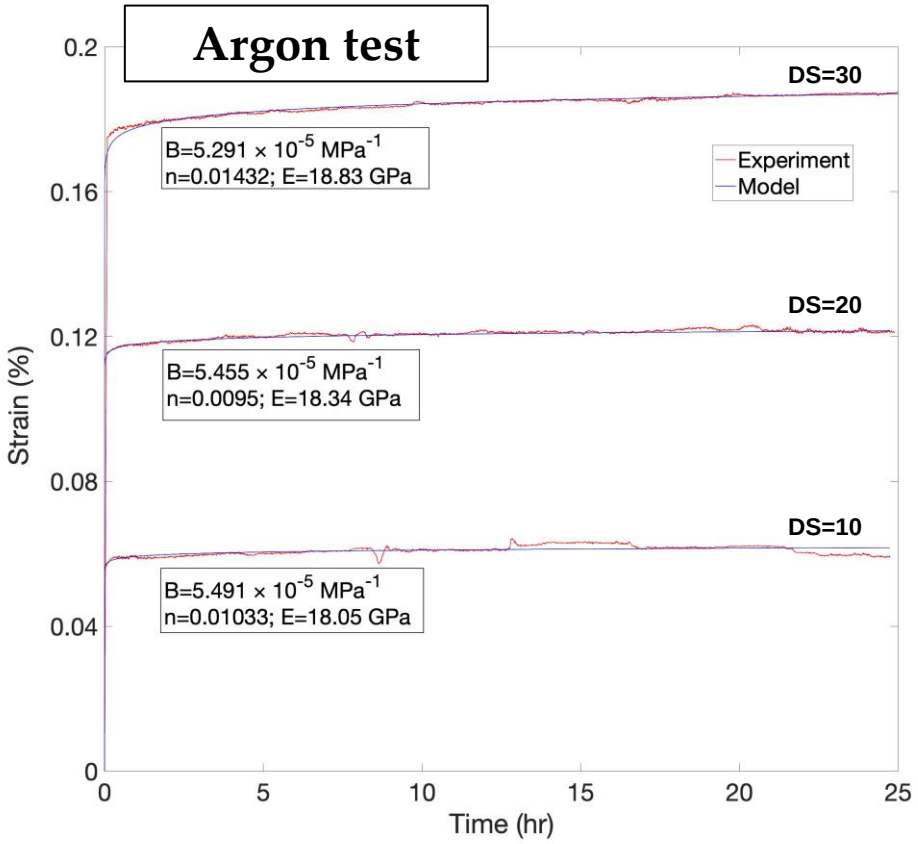
Mechanical creep test

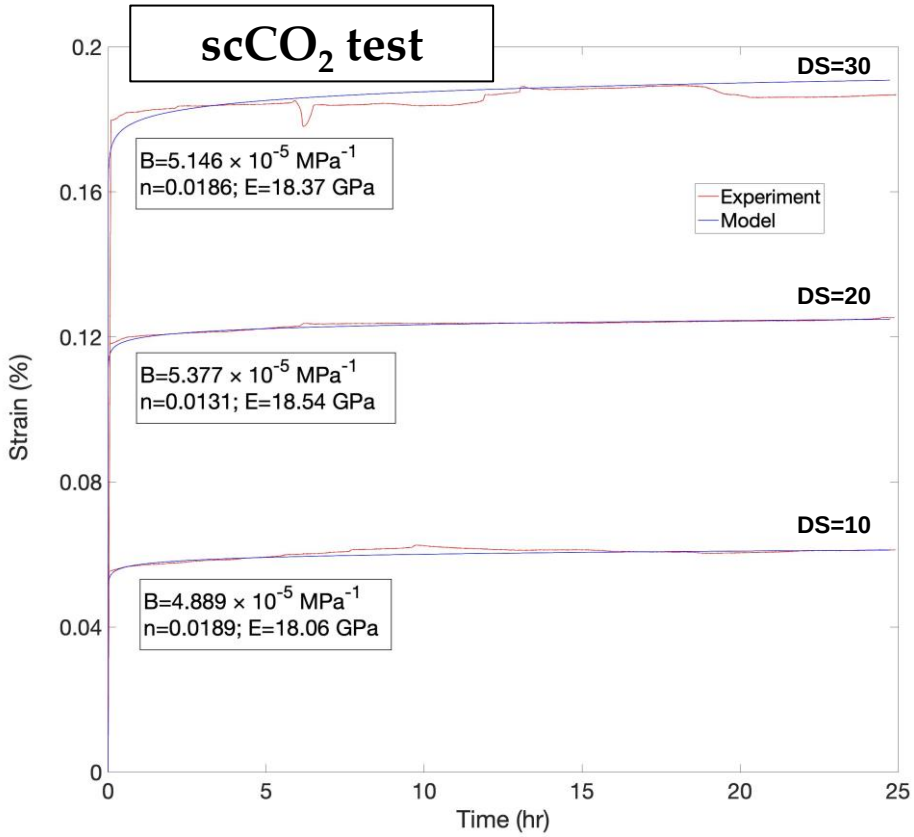
- Relatively constant Young's modulus for argon and $scCO_2$ tests
- Higher n values for the $scCO_2$ test, so higher ductility

QFP: 62%

Carbonate: 8%

Clay+TOC: 30%





Conclusions

❖ PERMEABILITY

➢ *Short-term:*

- Irreversible increase by carbonate dissolution
- Reversible decrease by adsorption into clays and kerogen
- Matrix weakening leading to enhanced compaction and decrease of permeability

➢ *Long-term:*

- Exposure to $scCO_2$ (~80 days) shows considerable permeability loss in a sample with relatively low carbonate content (21%), apparently due to dissolution and compaction induced by matrix weakening

❖ MECHANICAL CREEP

- Enhanced ductility due to 7-day interaction with $scCO_2$, as evident from creep tests using argon and $scCO_2$

Future Work

❖ PERMEABILITY

➢ *Pore Size Estimation:*

- Average pore size from Klinkenberg-type experiment and SEM imaging
- Pore size distribution obtained from CO_2/N_2 adsorption isotherms

➢ *Dry vs Saturated Samples:*

- Investigation of the effects of residual pore water on dissolution/adsorption

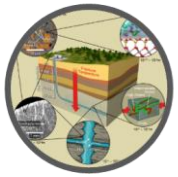
➢ *Continuing Long-term Tests:*

- Studying the role of mineralogy on long-term permeability evolution

❖ MECHANICAL CREEP

- Conducting creep tests on a wider range of samples with concurrent measurements of permeability and ultrasonic velocities

Acknowledgments



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This work was supported as part of the Center for Mechanistic Control of Water-Hydrocarbon-Rock Interactions in Unconventional and Tight Oil Formations (CMC-UF), an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science under DOE (BES) Award DE-SC0019165. I would also like to thanks SCCS to support this research.

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