Modeling CO_2-Water-Rock Reactions in a Basalt Fracture Network

CO_2 mineral trapping
Permeability alteration
Fracture network
Carbon sequestration

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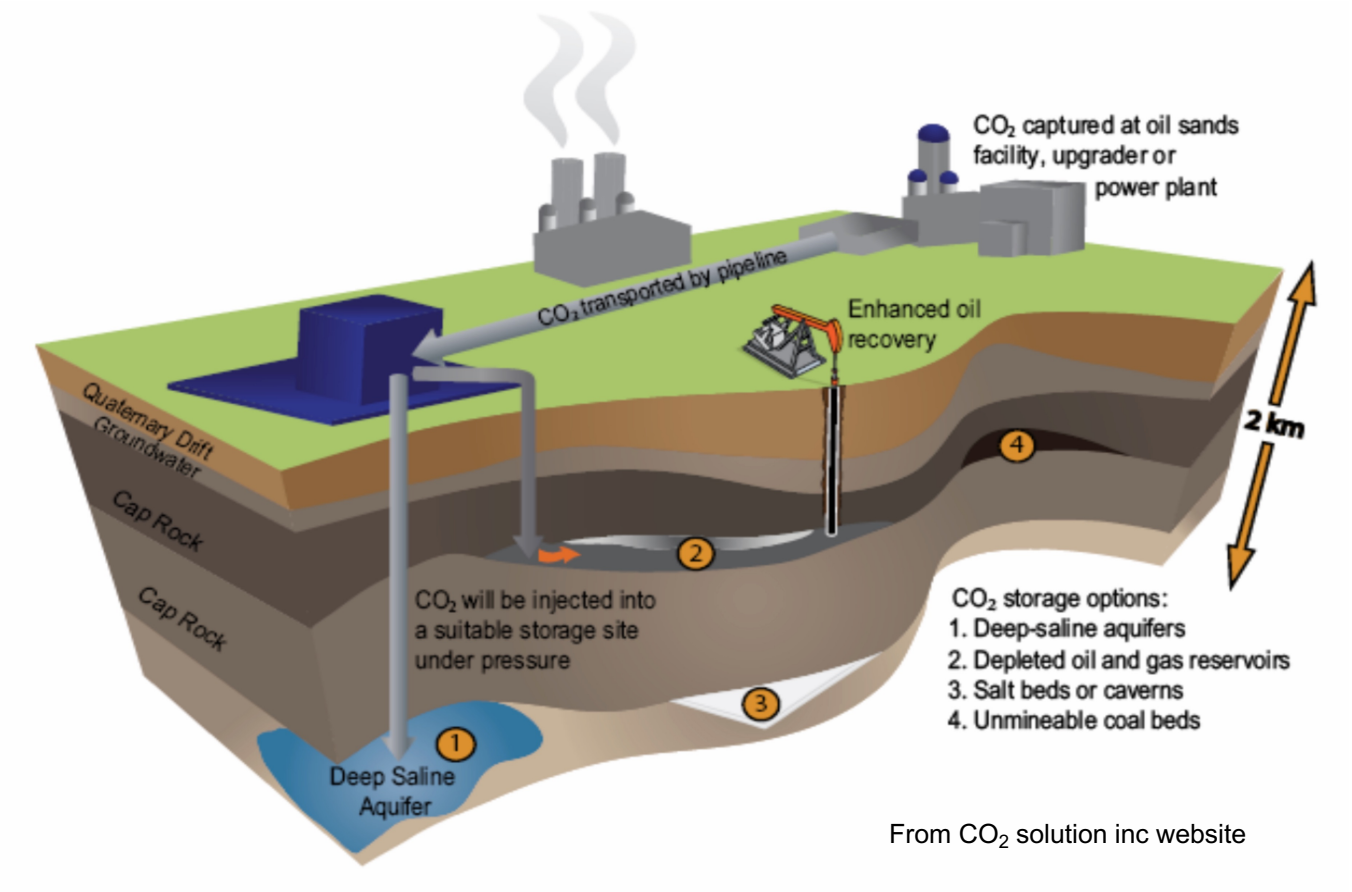
CARBON SEQUESTRATION

Carbon Capture and Storage (CCS)



From CO_2 solution inc website

- Structural trapping
- Capillary trapping
- Dissolution trapping
- <u>Mineral trapping</u>

Mineral Trapping in Basalt

Basalt reservoirs

- High concentration of cations (Ca, Mg, Fe)
- Worldwide distribution & immense volumes

  Columbia River Basalt Group: 164,000 km^2

  India's Deccan Volcanic Province (DVP): ~500,000 km^2

Pilot-scale CO_2 injection tests

- Iceland CarbFix Project

  95% of injected CO_2 mineralized in two years
- Wallula Basalt Sequestration Pilot Project

  carbon mineralization widespread in injection zone

Chemical Reactions

(1) CO_2 Dissolution

$$CO_2 + H_2O = H_2CO_3 = HCO_3^- + H^+ = CO_3^{2-} + 2H^+$$

(2) Basalt Dissolution (Icelandic basalt)

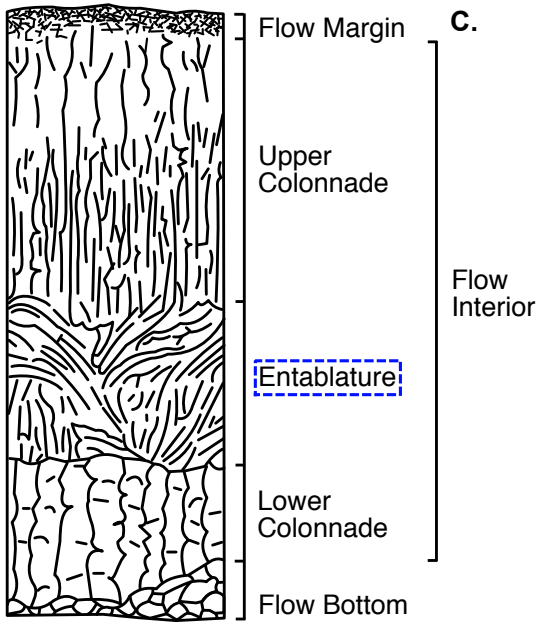
$$SiAl_{0.358}Fe_{0.190}Mg_{0.281}Ca_{0.264}Na_{0.079}K_{0.008}O_{3.315} + 2.630H^+ + 0.685H_2O$$
$$= H_4SiO_4 + 0.358Al^{3+} + 0.190Fe^{2+} + 0.281Mg^{2+} + 0.264Ca^{2+} + 0.079Na^+ + 0.008K^+$$

(3) Carbonate Precipitation

$$(Ca, Mg, Fe)^{2+} + HCO_3^- = (Ca, Mg, Fe)CO_3 + H^+$$
$$(Ca, Mg, Fe)^{2+} + CO_3^{2-} = (Ca, Mg, Fe)CO_3$$

From Matter & Kelemen (2009)
Pollyea & Rimstidt (2017)

BASALT FORMATIONS ARE HIGHLY FRACTURED

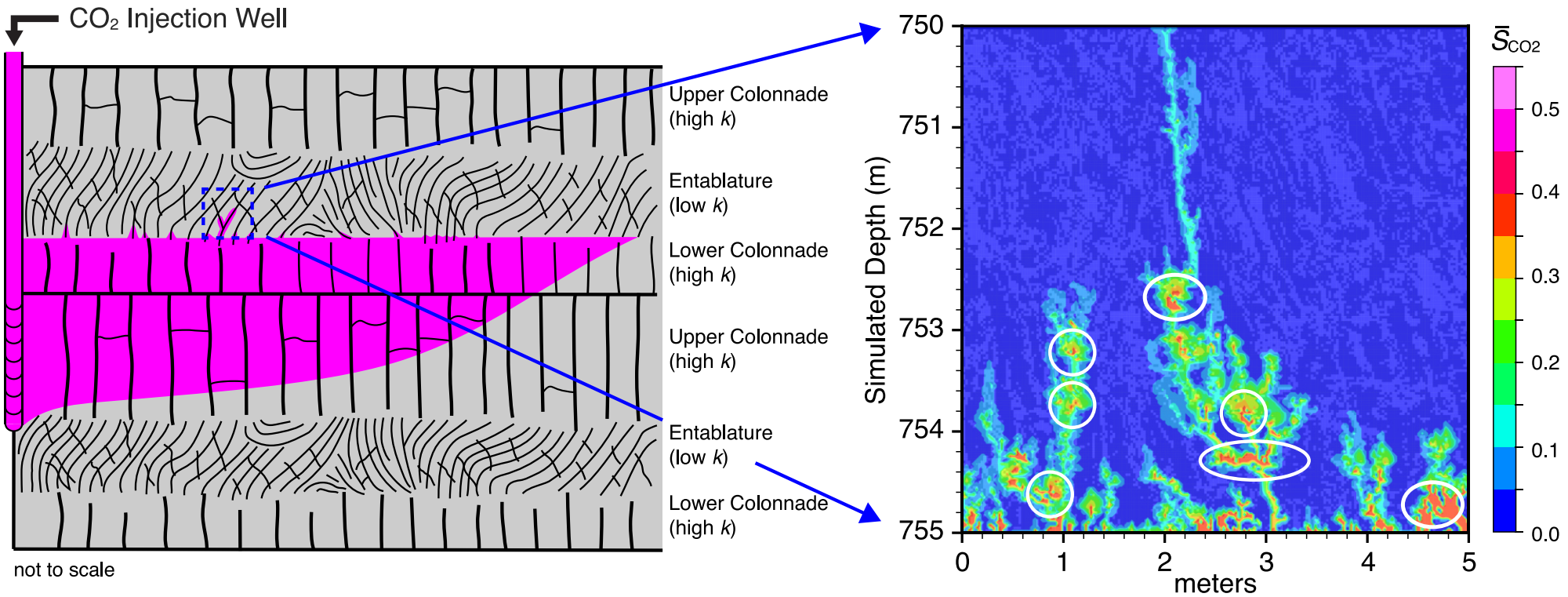


Morphology of Columbia River Basalt Group (CRBG)

Basalt bluffs of McConnell Hill, Canada

Columbia River Basalt Group, Washington

RESEARCH SHOWS THAT FREE-PHASE CO_2 TENDS TO ACCUMULATE AT FRACTURE INTERSECTIONS



Gierzynski & Pollyea (2017)

Stochastic simulations

50 permeability distributions

Conclusion

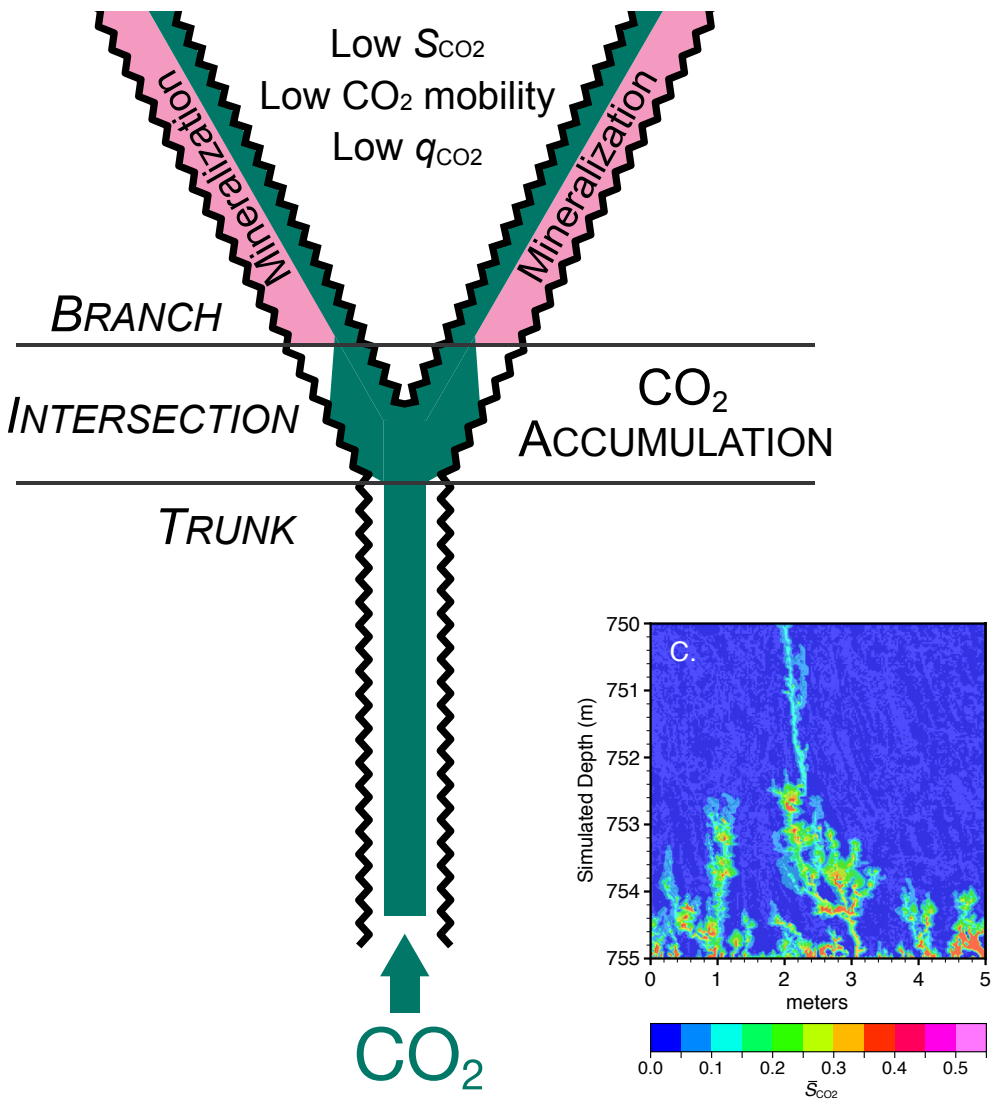
CO_2 accumulates at fracture intersections due to multiphase flow effects

HYPOTHESIS

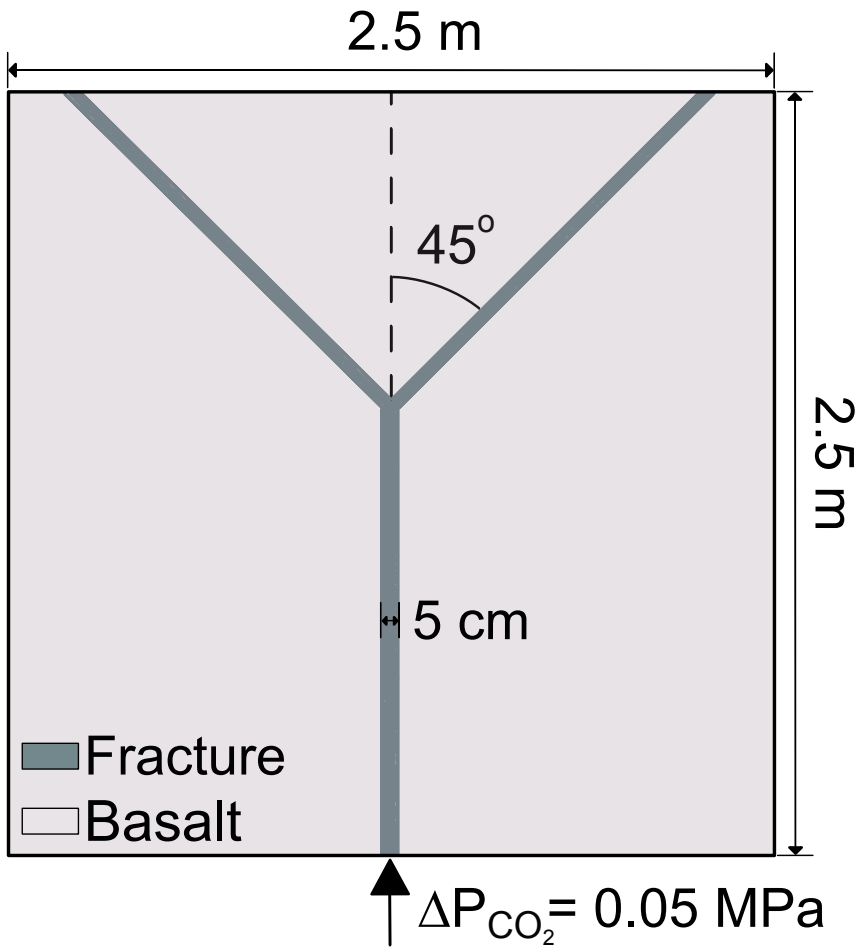
- Carbon mineralization is likely to focus at branching fractures.
- CO_2 vertical migration will be reduced due to carbon mineralization.

Hypothesis Test

Use numerical simulation to model how different permeability alteration scales effect this carbon mineralization process.



Model Domain



Boundary Condition

Top: open system

Bottom: 0.05 MPa over pressure

Initial Condition

33 °C

7.5 MPa

Permeability

Fracture: 5.78×10^{-16} m^2

Basalt: 10^{-20} m^2

Simulation

TOUGHREACT

Ten years

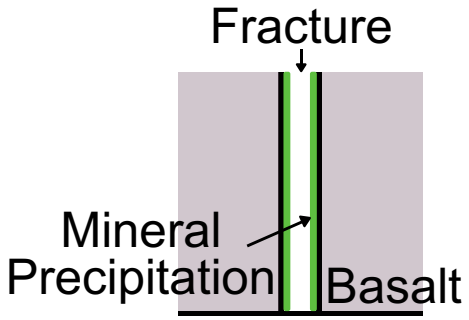
PERMEABILITY ALTERATION

$$k = k_o \left(\frac{\Phi}{\Phi_o}\right)^n$$

Verma & Pruess (1988)

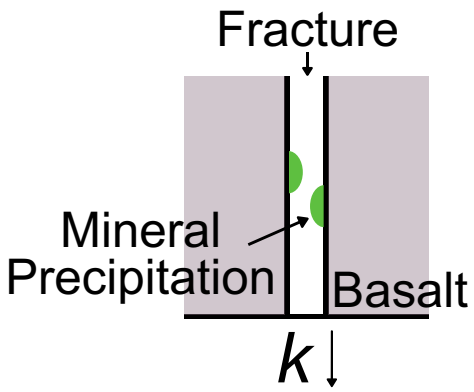
k	permeability
k_o	initial permeability
Φ	porosity
Φ_o	initial porosity
n	parameter control the different scales of permeability alteration

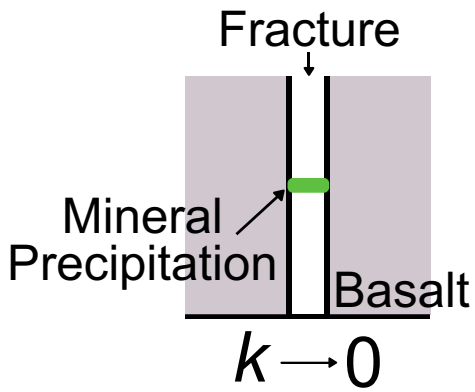
n: 0 → No alteration; 3, 6, 9, 15 ↓ More alteration



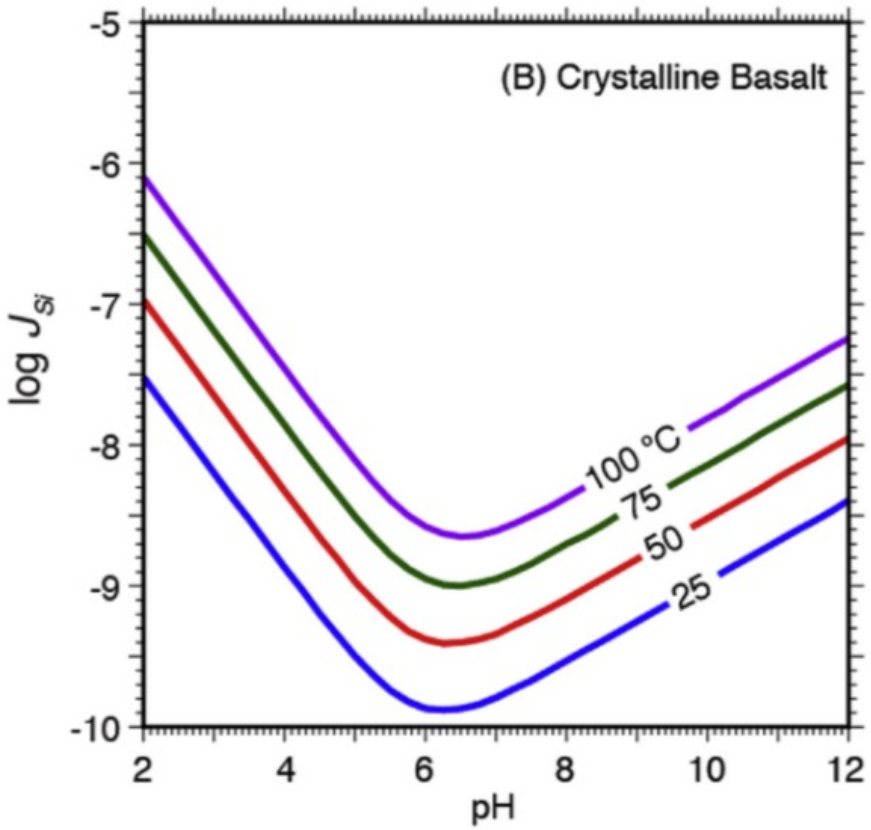
$$k = k_o \left(\frac{\Phi}{\Phi_o}\right)^3$$

Cubic Law

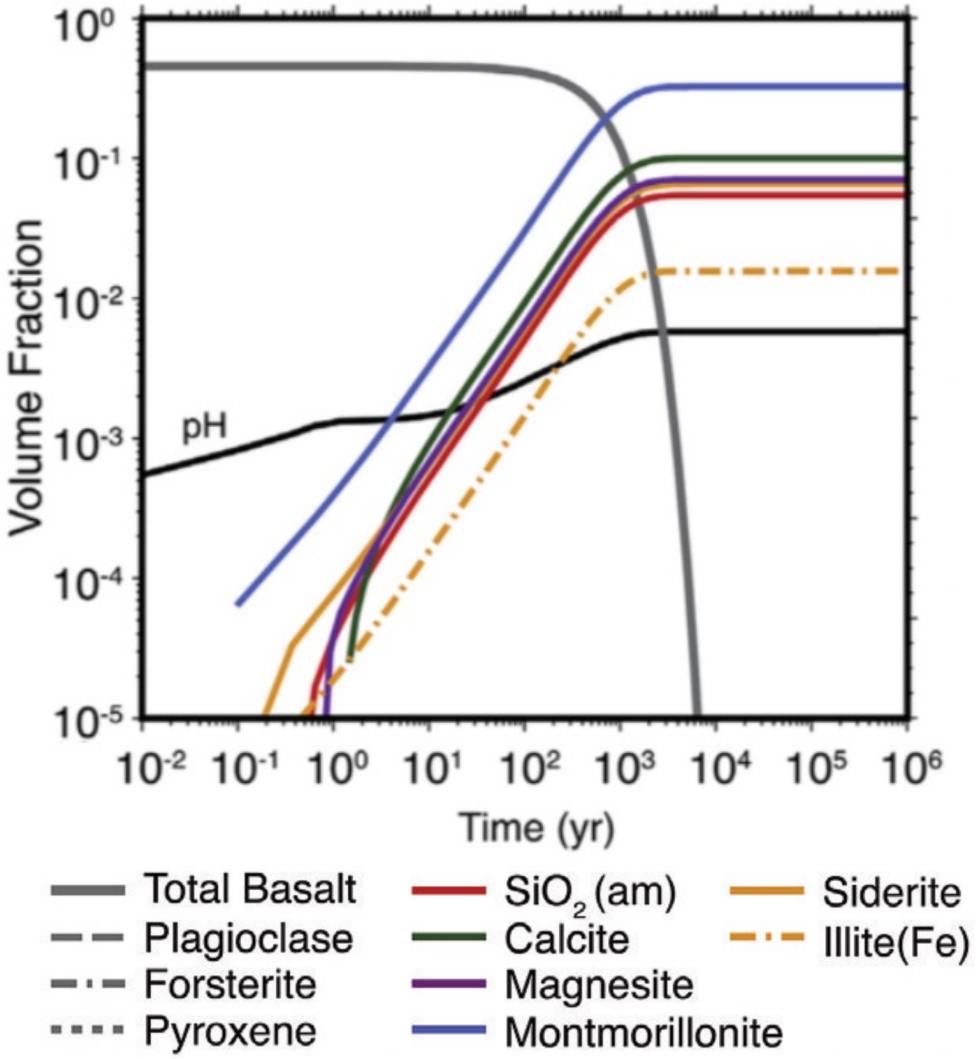




Basalt Dissolution Model



Pollyea & Rimstidt (2017)



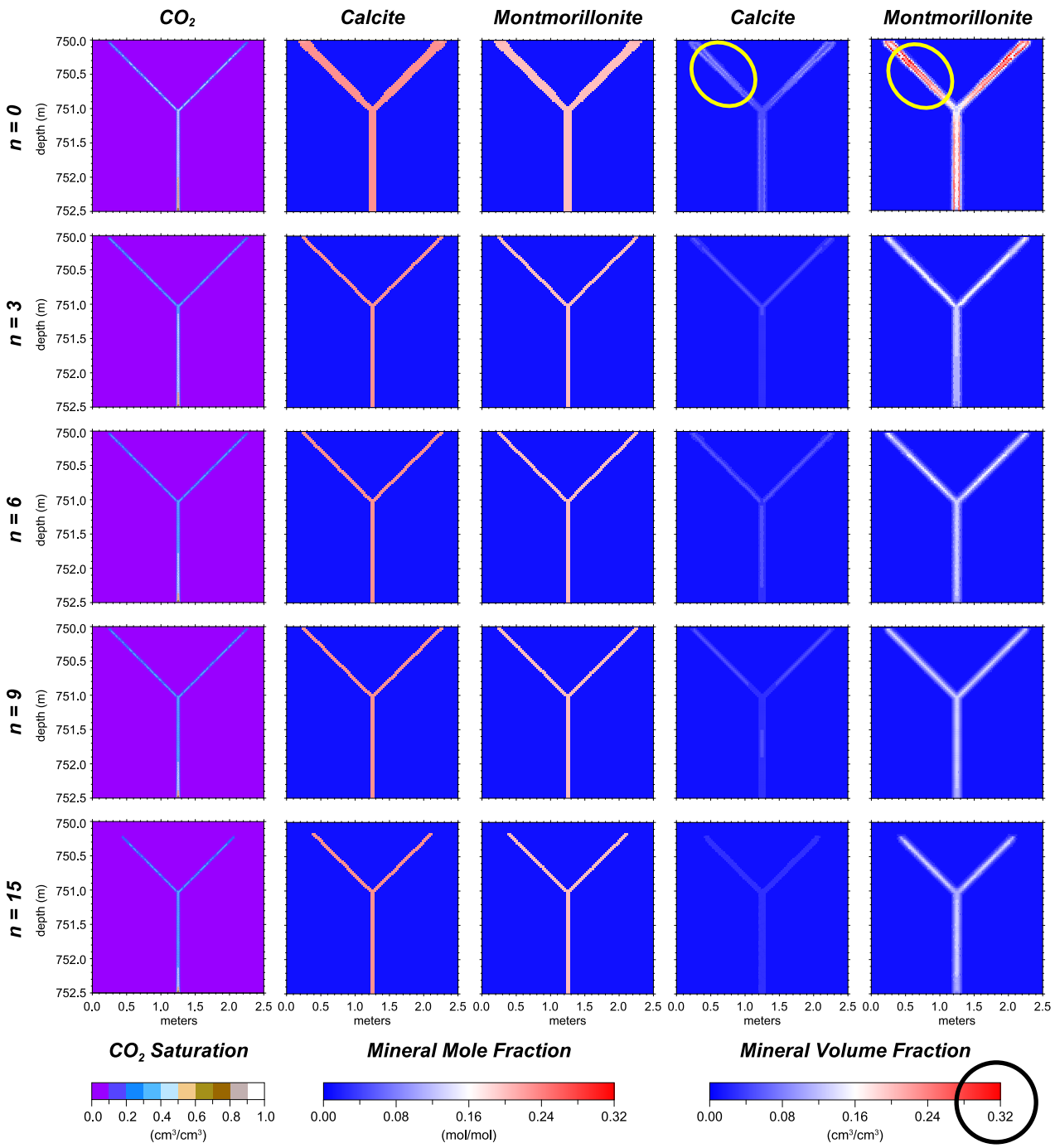
MINERAL PRECIPITATION ACCUMULATES at BRANCHING FRACTURE

Carbonate minerals:

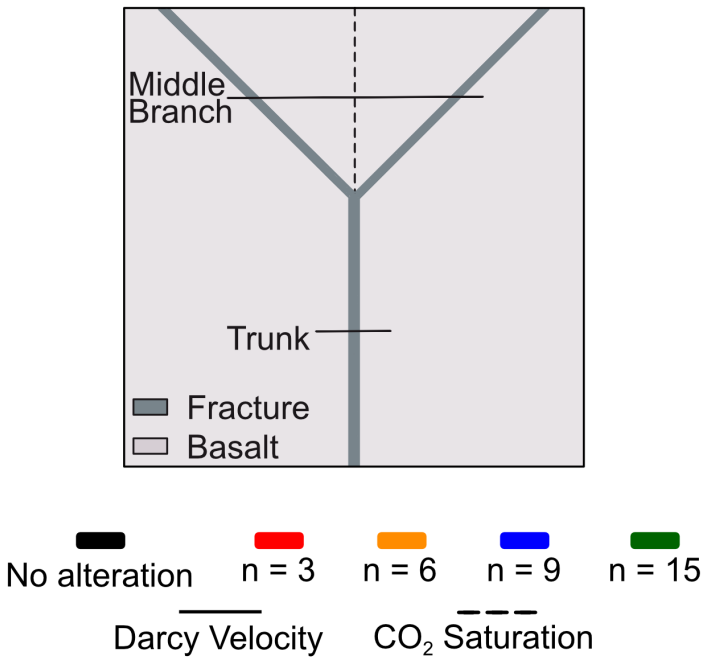
- <u>Calcite</u>
- Magnesite
- Siderite

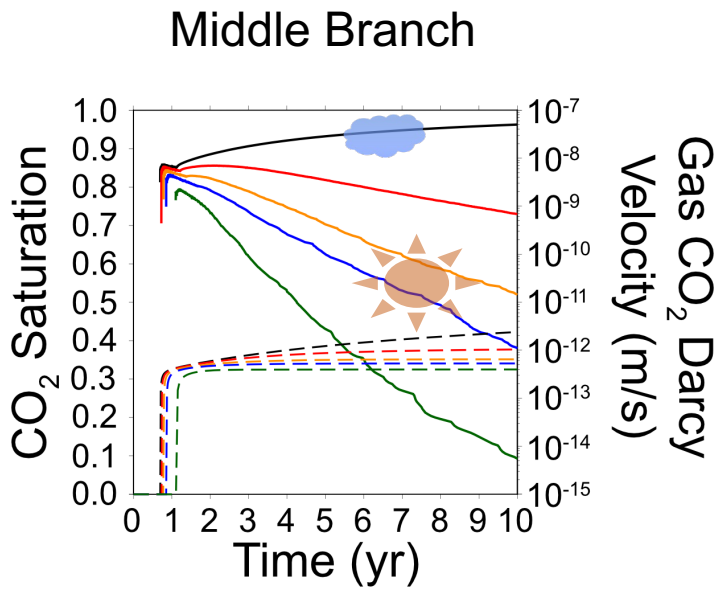
Clay minerals:

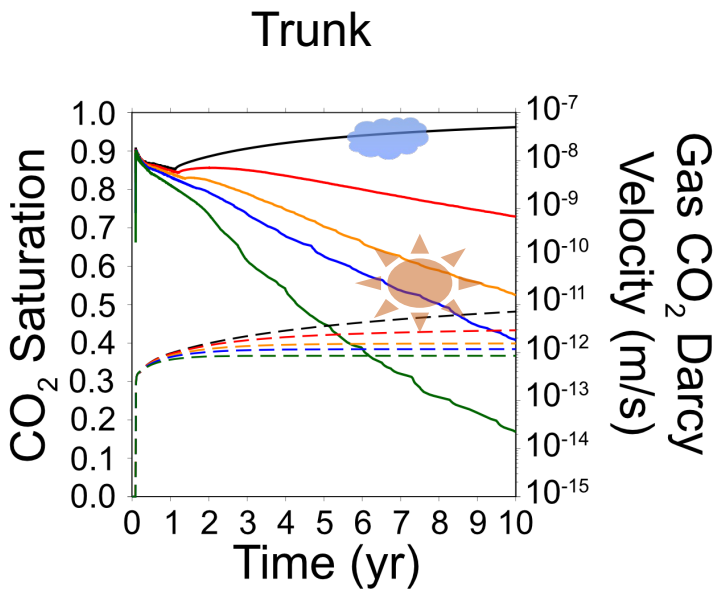
- <u>Montmorillonite (MgCa)</u>
- Illite (FeII)
- Amorphous_silica



Darcy Velocity of free-phase CO_2 shows maximum 6 orders of magnitudes decrease







No alteration: Darcy velocity increase

With alteration: Darcy velocity decrease

MASS BALANCE

n (mole)	0	3	6	9	15
Mineral	62.5	30.5	31.6	31.8	27.2
Aqueous	4.5	2.0	2.2	2.2	2.1
Gas	1.5	0.5	0.4	0.4	0.4
Boundary	40.9	4.6	1.2	0.4	-
Total	109.4	37.6	35.4	34.8	29.7
CMR (-)	**57%**	**81%**	**89%**	**91%**	**92%**

$$\text{Carbon Mineralization Ratio (CMR)} = \frac{Mineralized\ carbon}{Total\ carbon\ in\ the\ system}$$

CMR is >80% over ten years when considering permeability alteration

CONCLUSION

- Carbon mineralization focuses on branching fracture
- Fracture permeability decreases and slows the vertical migration of CO_2
- Different permeability alteration scales show important effects in this carbon mineralization process
- Fracture system may be self-sealing due to secondary mineral precipitation

THANK YOU