Subcritical fracturing of shales under chemically reactive conditions

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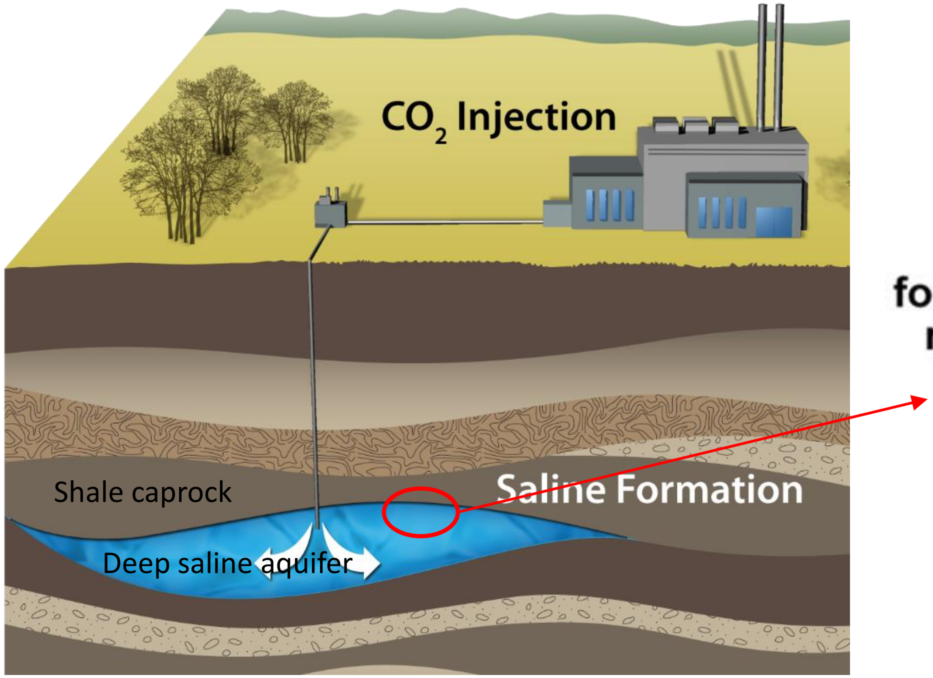
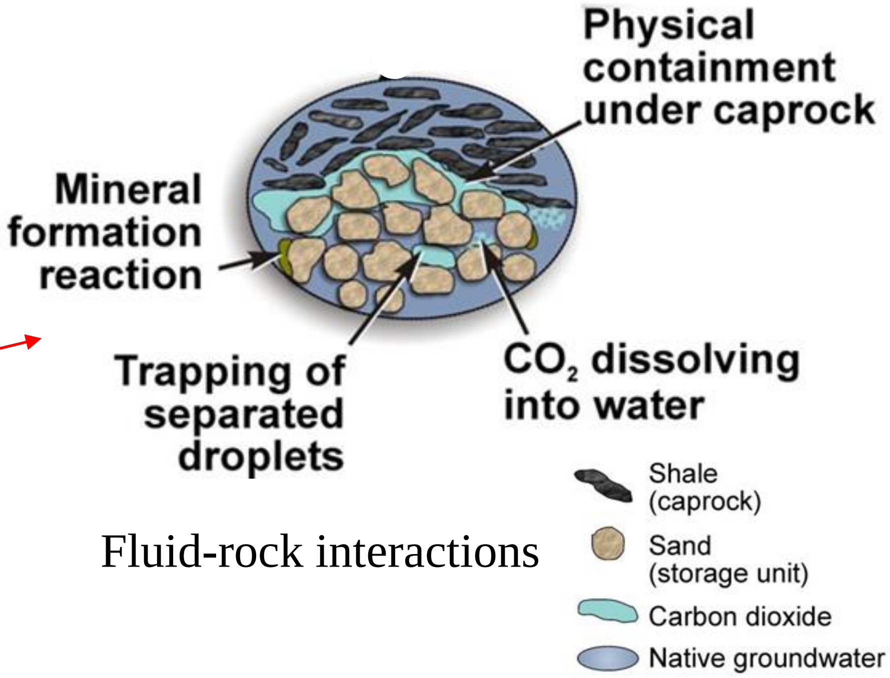
Introduction

<u>Problem</u>: long term seal integrity of subsurface CO_2 storage

- **<u>Material:</u>** Chemically reactive shaly caprocks
- **<u>Conditions:</u>** CO_2-charged brine *out of chemical equilibrium*
- **<u>Risk of top seal failure:</u>** Chemically assisted fracture (stress corrosion, dissolution)



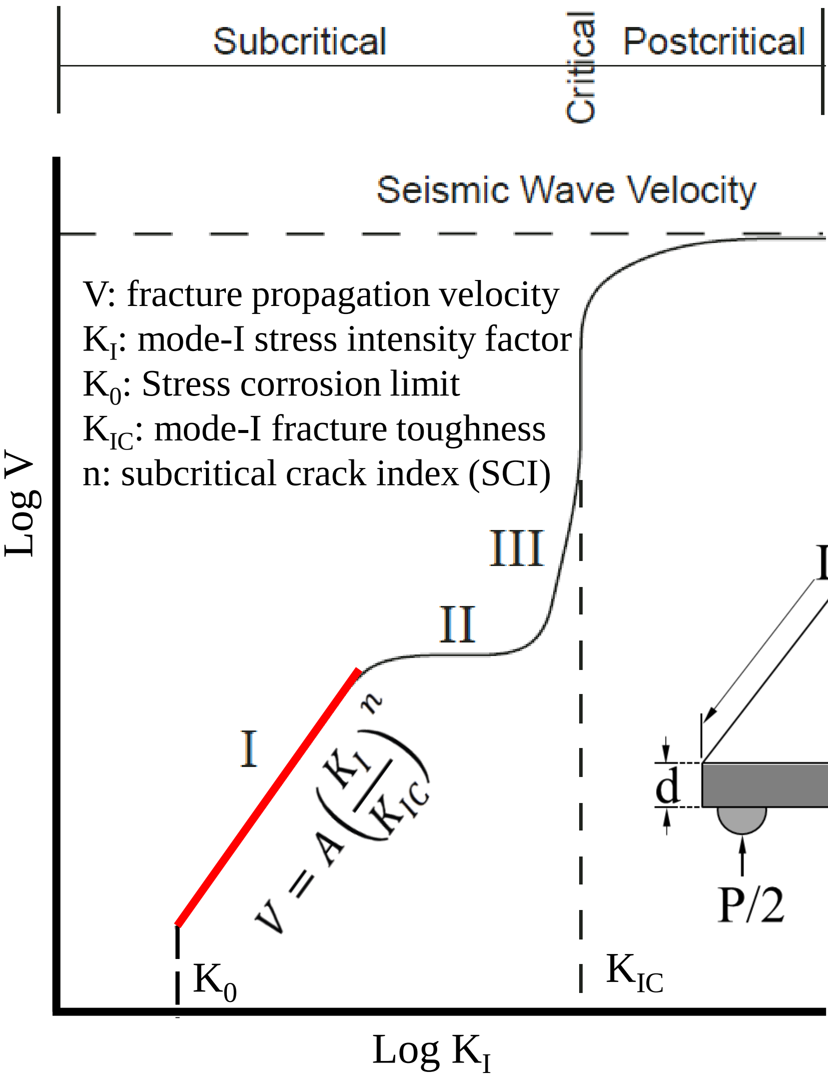
Geologic carbon sequestration



Fluid-rock interactions

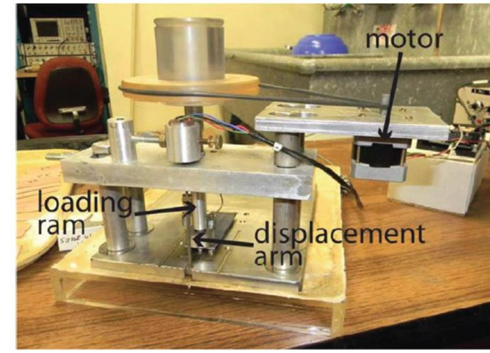
<u>Approach</u>: subcritical fracturing tests under chemically reactive environments

Fracture mechanics and experiments

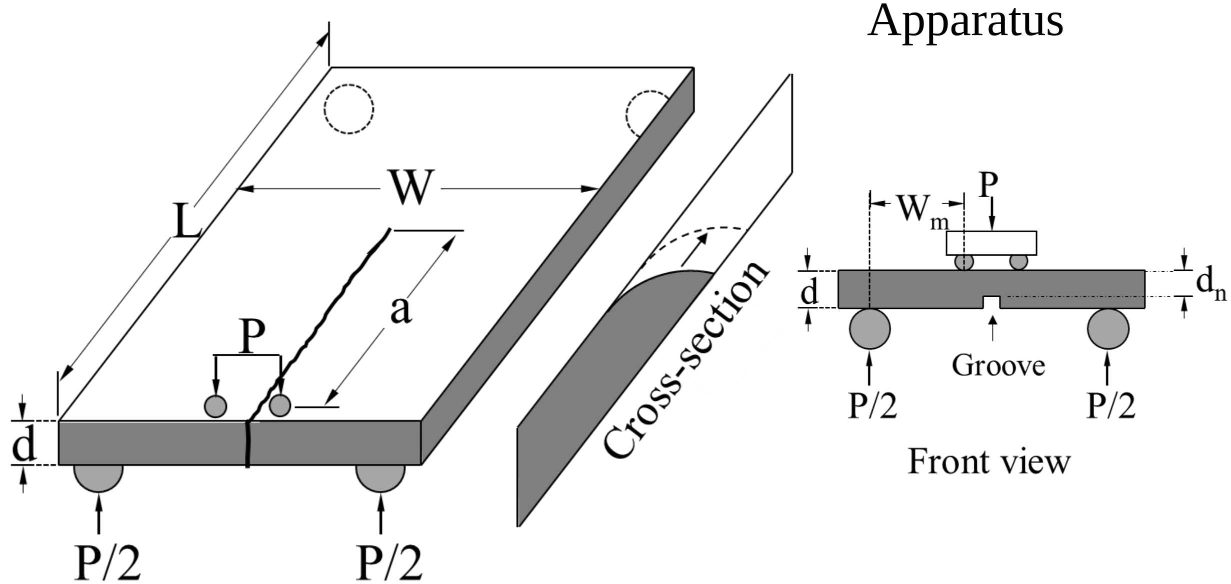


Savalli and Engelder, 2005

Sample geometry



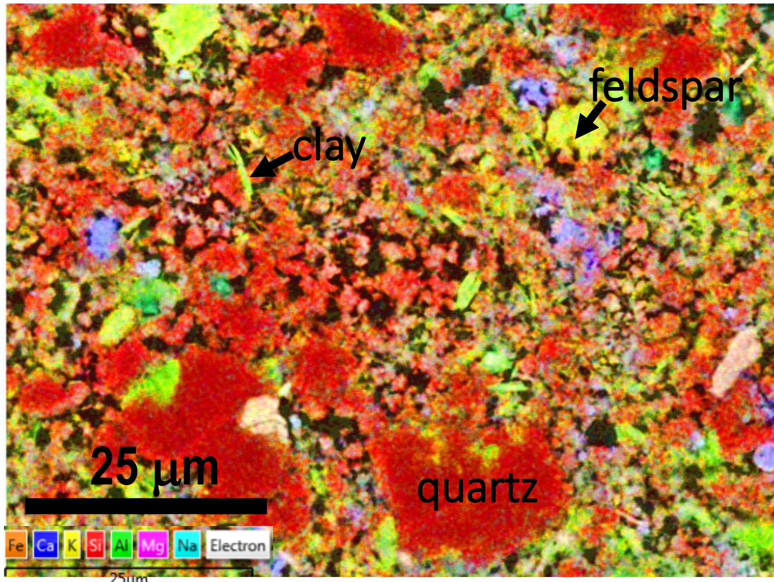
Apparatus

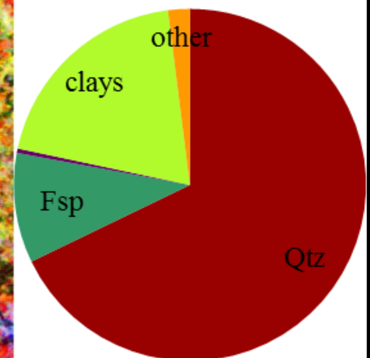


Loading configuration

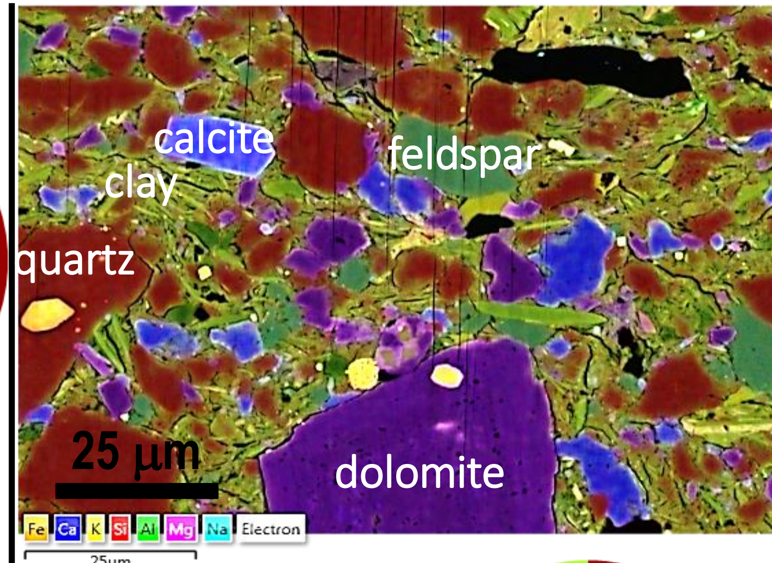
Holder et al., 2001 Rijken, 2005

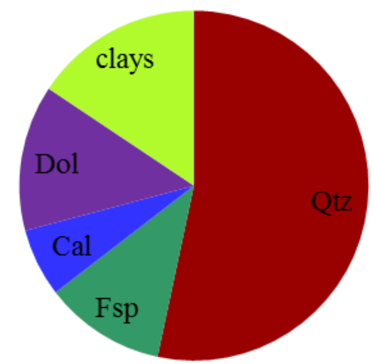
Mineralogy and microstructure



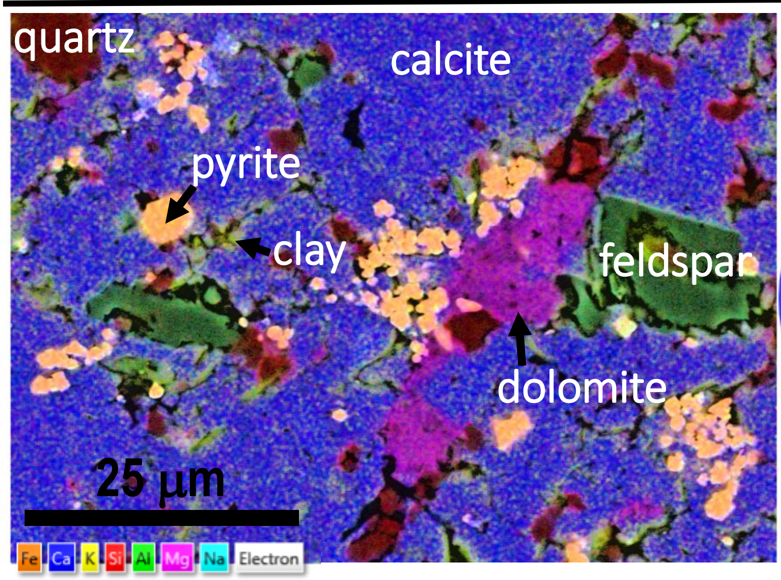


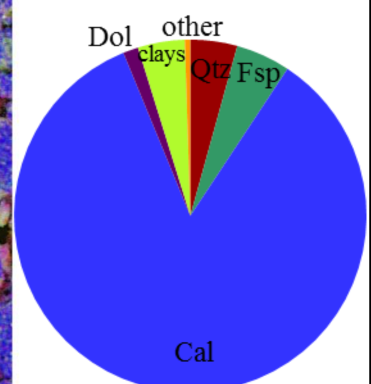
Woodford





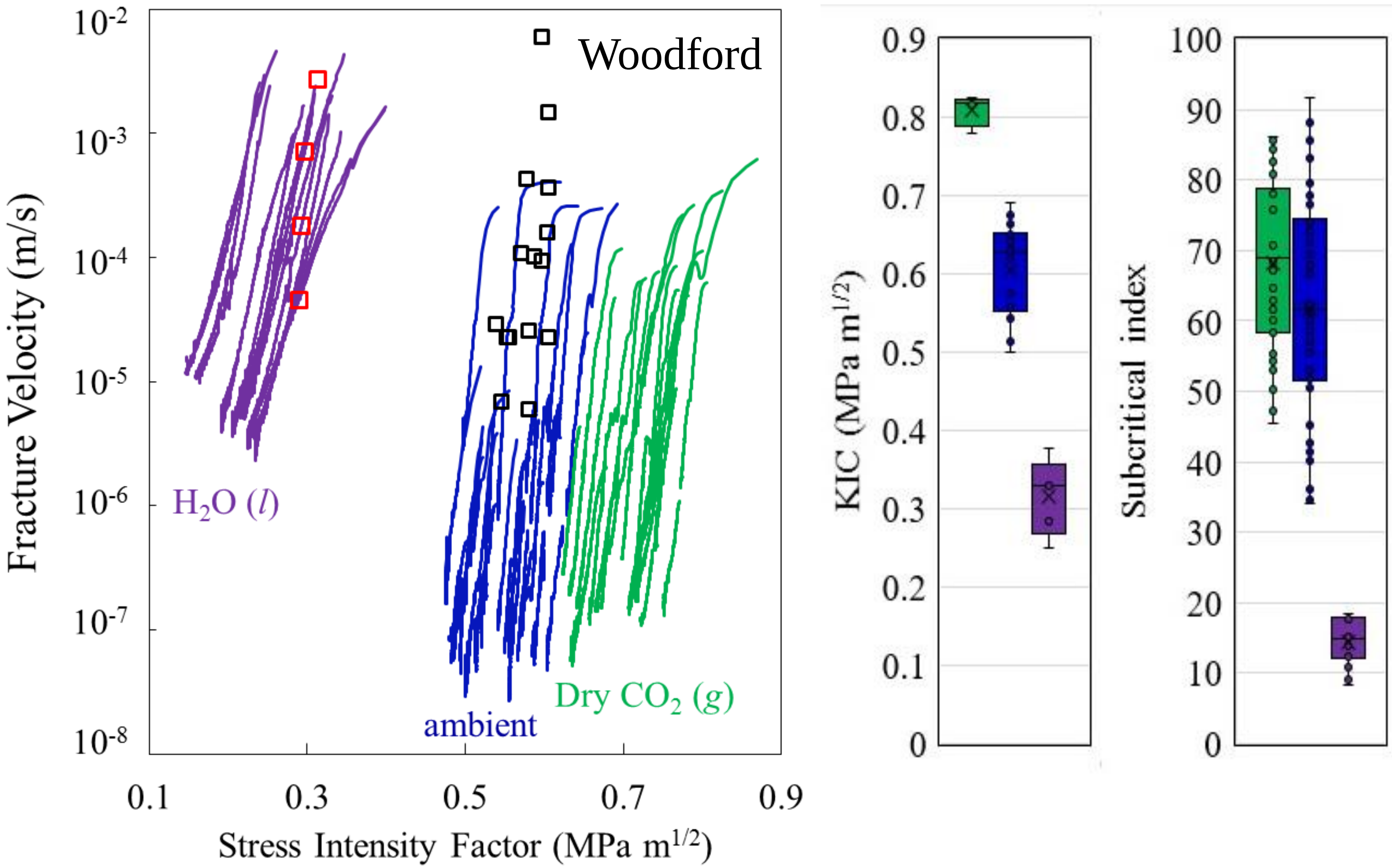
Mancos





Marcellus

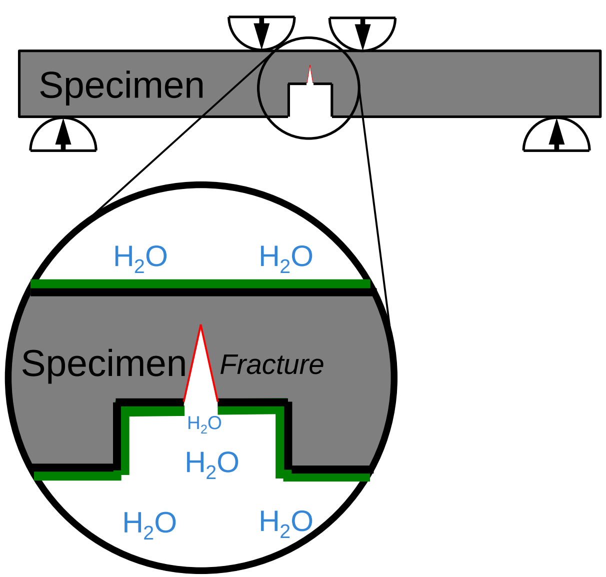
Effect of water content

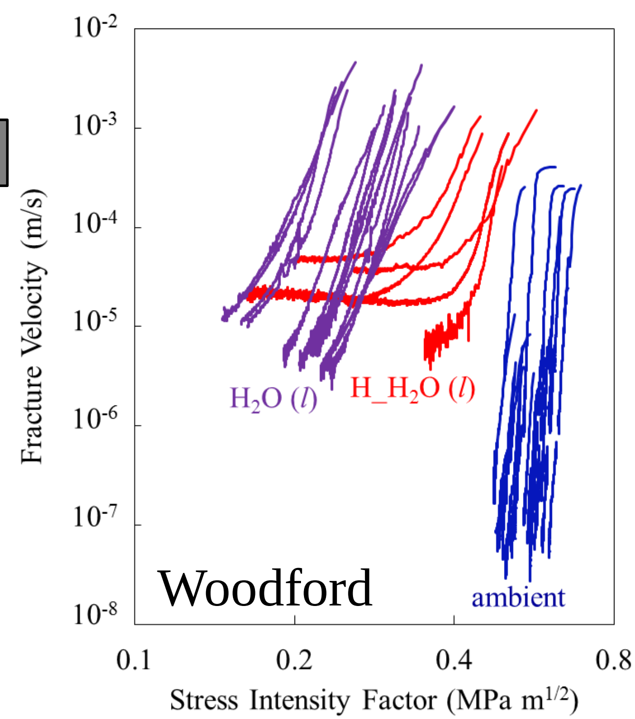


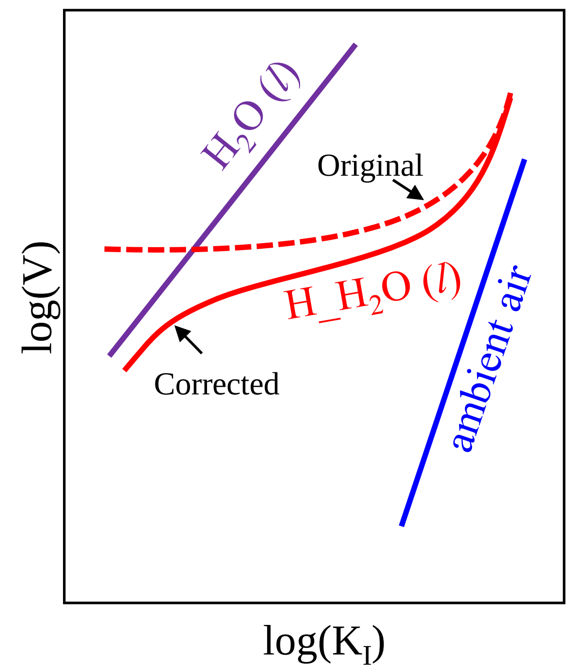
- Water-weakening enhances subcritical fracturing.
- Strong reduction of K_{IC} (48%) and SCI (75%) with increasing water content.
- K-V curves obey power-law, indicating fracturing in stress-corrosion regime (I)
- Load relaxation technique (lines) matches constant loading rate method (squares)

Water effect: hydrophobic coating

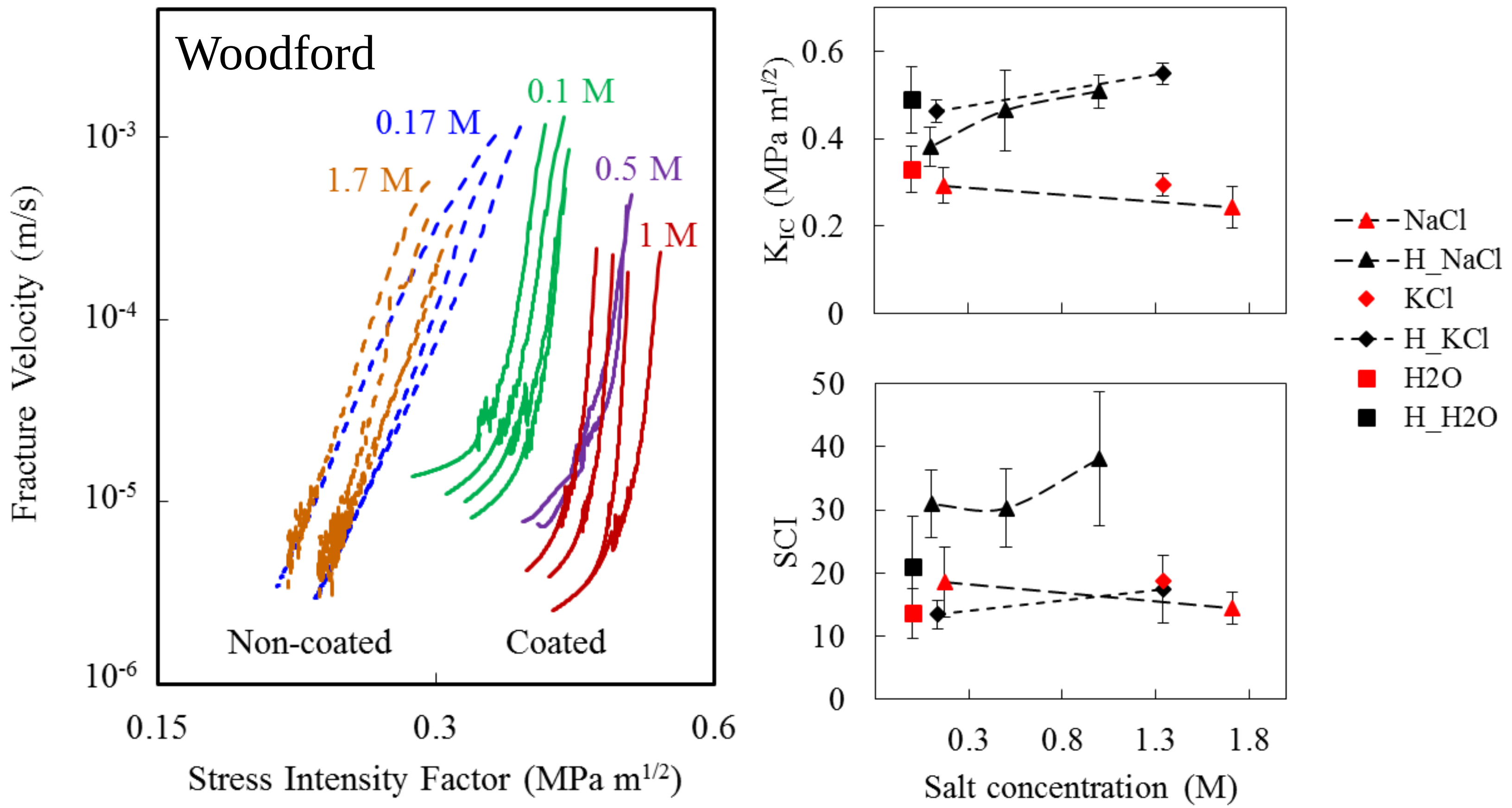
- Hydrophobic coating restricts water-sample interaction to the fracture tip
- Coating temporarily protects specimens from weakening except at fracture tip
- Transient K-V curves: needs correction.
- Only for clay-rich Woodford and Mancos shales







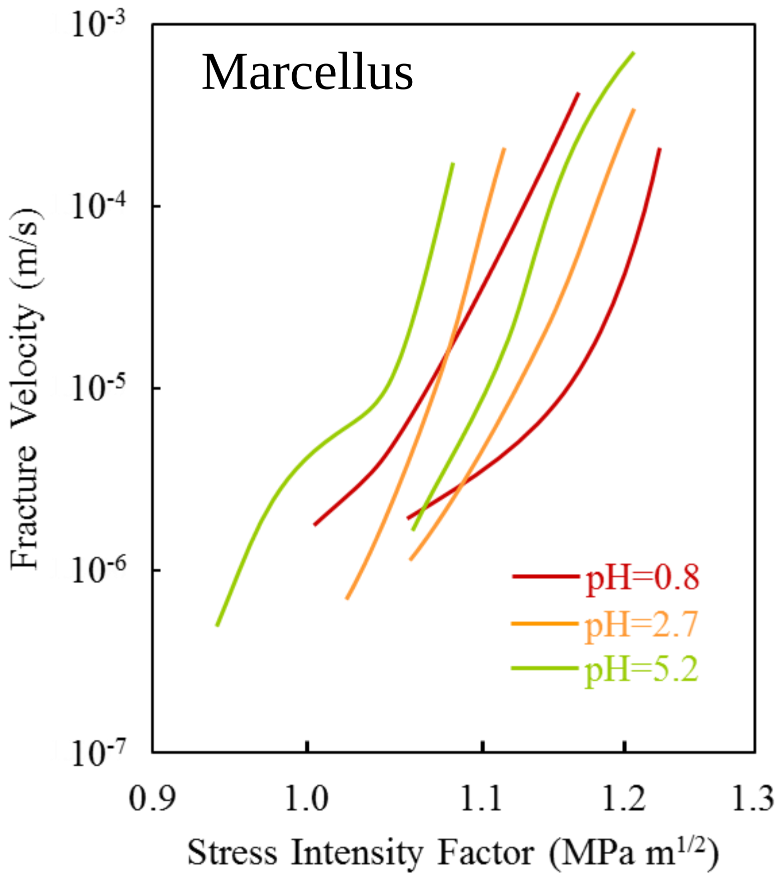
Salinity effect

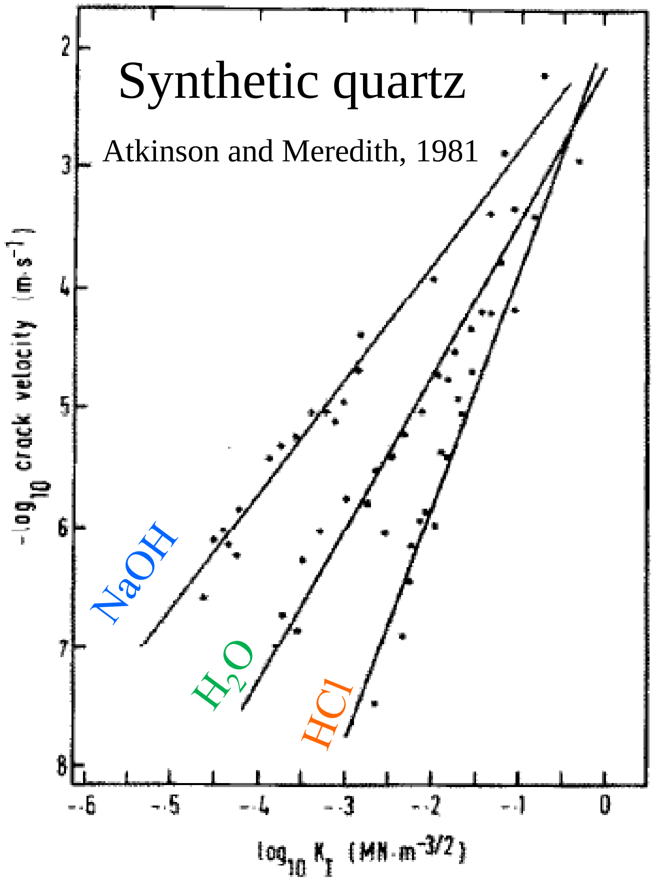


<u>Salinity has direct effect on coated clay-rich Woodford and Mancos shales:</u>

- Increase of fluid salinity increase K_{IC} and SCI
- Difference between KCl and NaCl salts
- Clay swelling: higher salinity suppress swelling; K^+ better than Na^+

pH effect

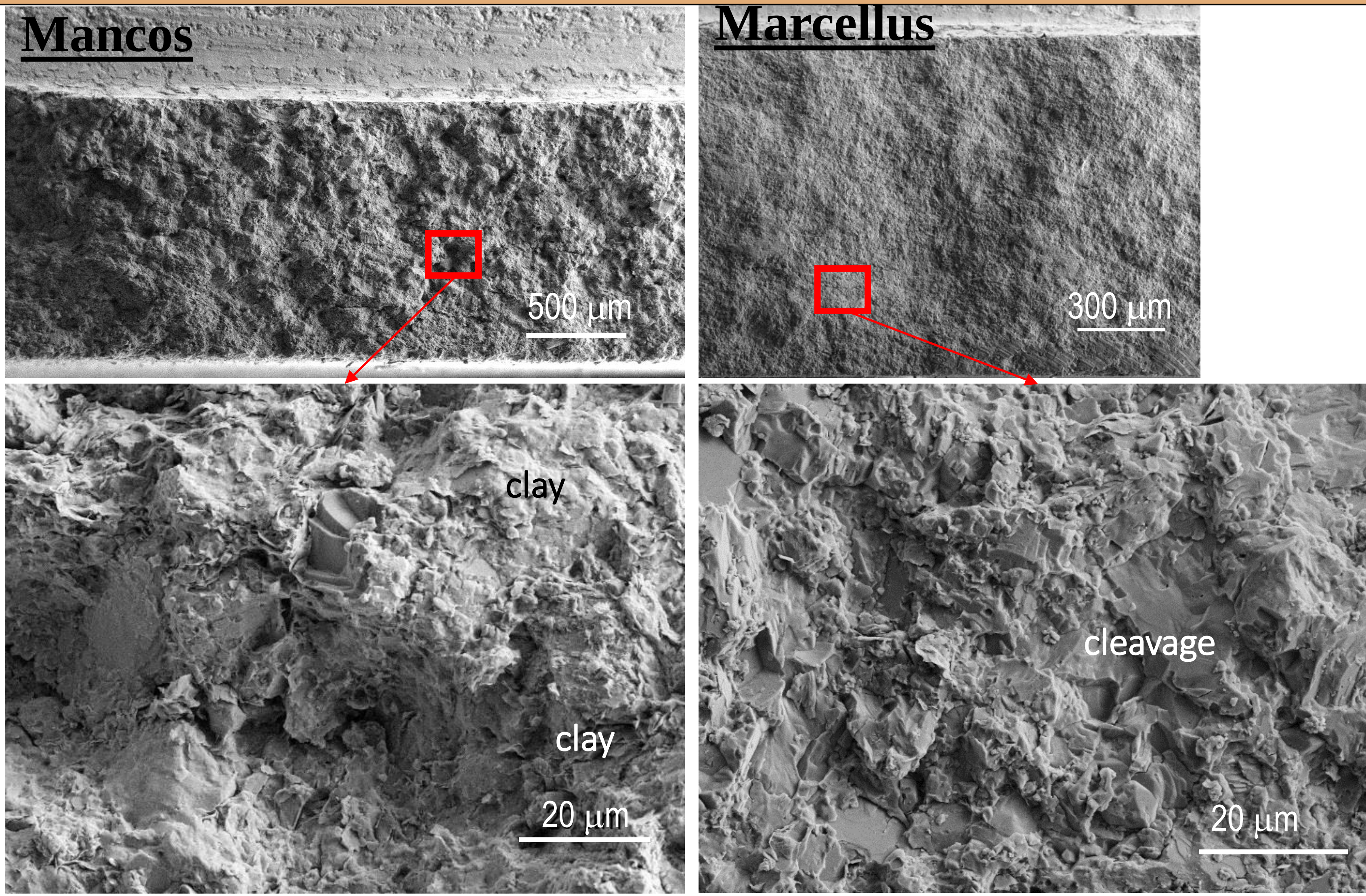




pH more effective on the carbonate-rich Marcellus shale:

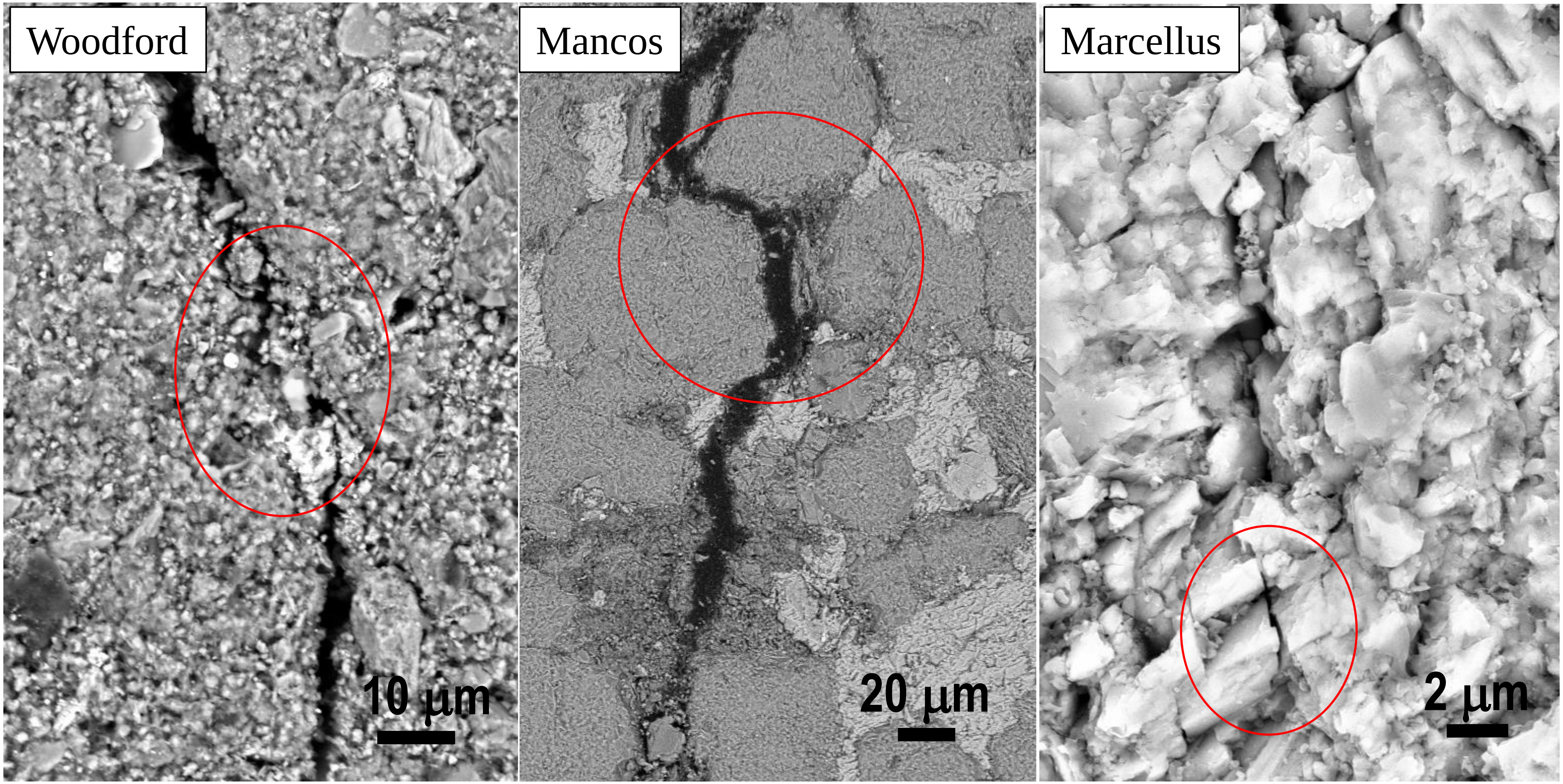
- K_{IC}: stable
- SCI: decreases as pH decreases in acidic fluid (**opposite to glass and quartzite**).
- Calcite dissolution

Fracture surface



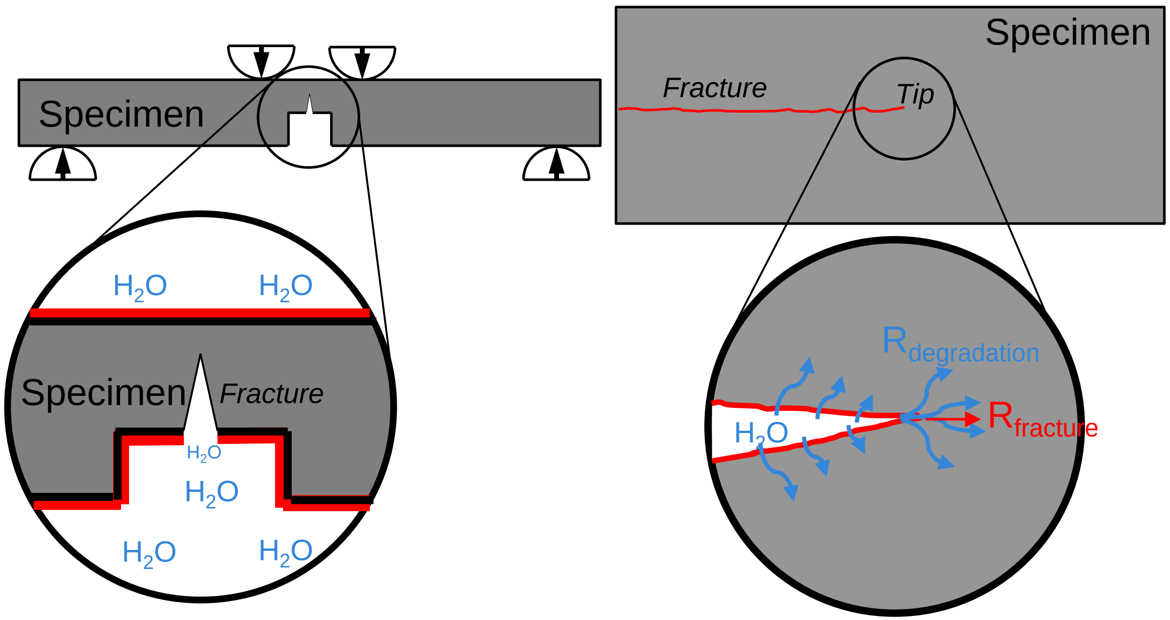
- Roughness variation, but no plumose structure
- grain boundary breakage vs transgranular breakage

Fracture trace



- Woodford, Mancos: Fracture between grains (clay matrix)
- Marcellus: fracture through grains

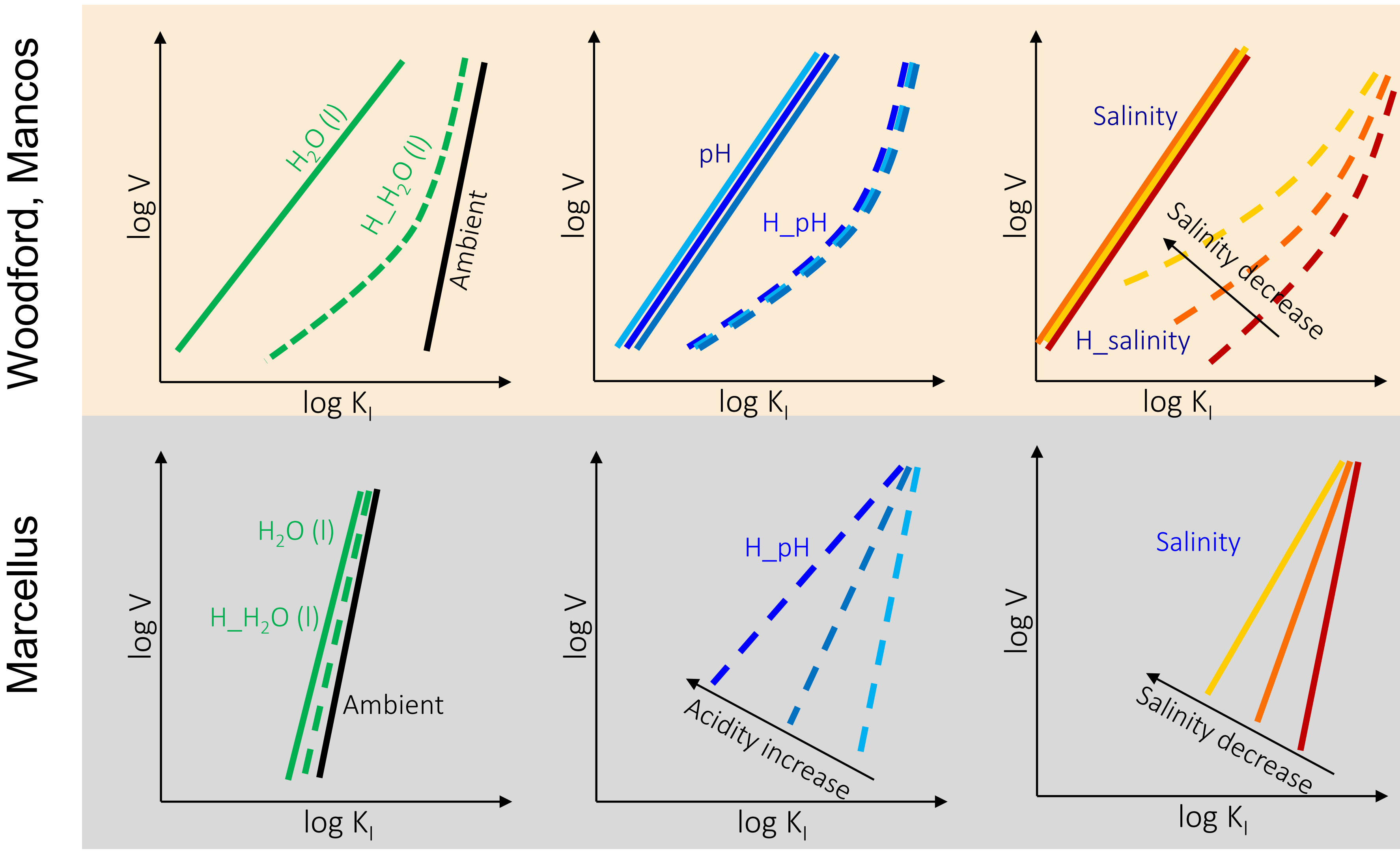
Rate-dependent K-V curves



Competition between fracture growth rate and rock degradation rate by H_2O-rock interaction:

- Marcellus, non-coated (soaked) Woodford & Mancos:
  - ❑ Power law K-V curves
  - ❑ $Rate_{fracture} >> Rate_{degradation}$
- Woodford & Mancos (hydrophobic coating):
  - ❑ Non-power law K-V curves
  - ❑ $Rate_{fracture} \approx Rate_{degradation}$ during later slow propagation of each load/decay cycle

Summary of K-V relations



no hydrophobic coating — hydrophobic coating

Conclusions

- Both *chemical environments* and rock *mineralogy* influence caprock subcritical fracture properties.
- Stronger water-weakening in *clay-rich* shales (Woodford and Mancos) than in *carbonate-rich* shale (Marcellus).
- Carbonate-rich Marcellus: carbonate dissolution
  - ❑SCI sensitive to acidic *pH*
  - ❑K_{IC} independent of chemical environment
- Woodford & Mancos: clay-fluid interaction
  - ❑K_{IC} and SCI sensitive to *water content* and *salinity*.
  - ❑Water-weakening enhances subcritical fracturing
- Environmental effects controlled by competition between fracture growth rate and rate of rock degradation by H_2O-rock interactions.

Implications for CO_2 seal integrity

- Dry tests potentially applicable to dry scCO_2 systems
  - ❑dry-out by CO_2 injection could strengthen caprock.
- Clay-rich caprocks:
  - ❑more sensitive to water-weakening.
  - ❑high salinity suppresses water-weakening.
  - ❑higher risk for seal failure with subcritical fracture growth.
- Carbonate-rich caprocks:
  - ❑more prone to subcritical fracture by pH decrease through dissolution of CO_2 in brine.