

Pore-to-Core Research in the Stanford Center for Carbon Storage

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Energy Resources Engineering

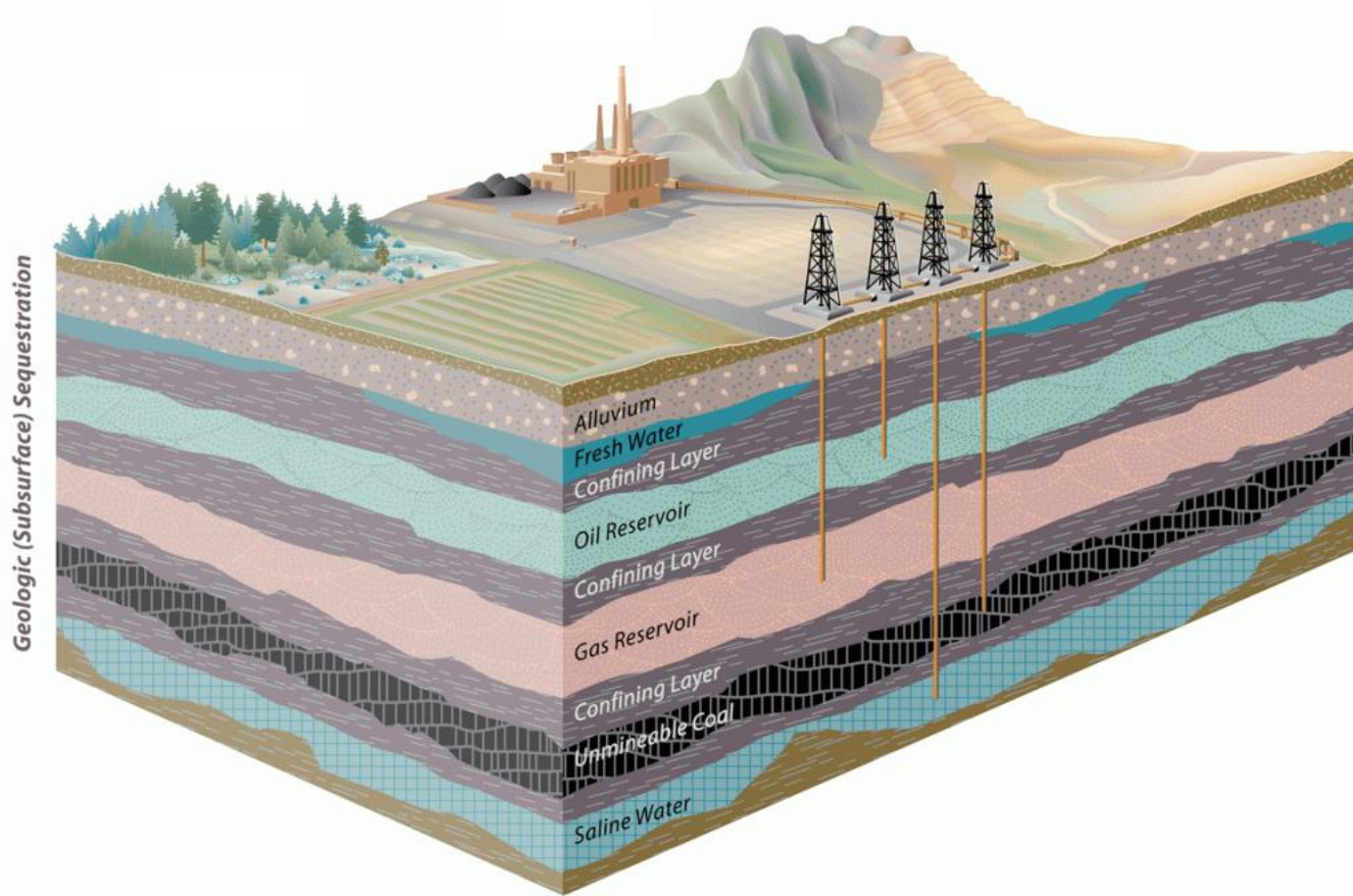
School of Earth, Energy, and Environmental Sciences



STANFORD UNIVERSITY

Pore-scale processes impact large-scale projects

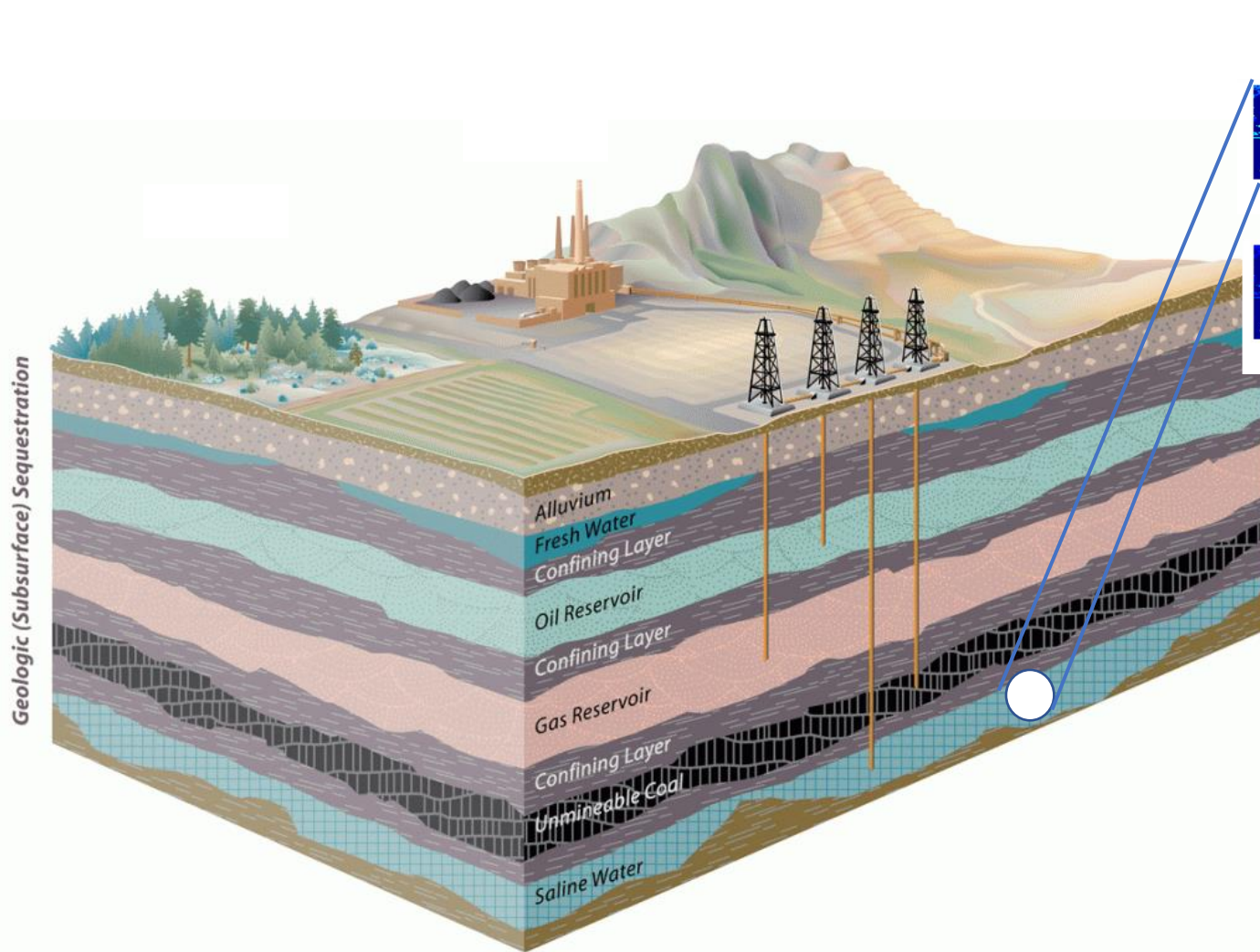
understanding pore-scale mechanisms key to success and storage assurance



- Representative processes of interest to SCCS
 - multiphase flow physics
 - hydrodynamically unstable flows
 - cobenefits of storage and hydrocarbon recovery
 - geochemical reactions that open or occlude pores
 - storage reservoir seal integrity
 - deep shale formations as a new storage horizon

Multiphase Flow Physics

Heterogeneity: Friend or Foe?



Last imbibition MP stage
With capillary heterogeneity trapping

$A = 0.79$

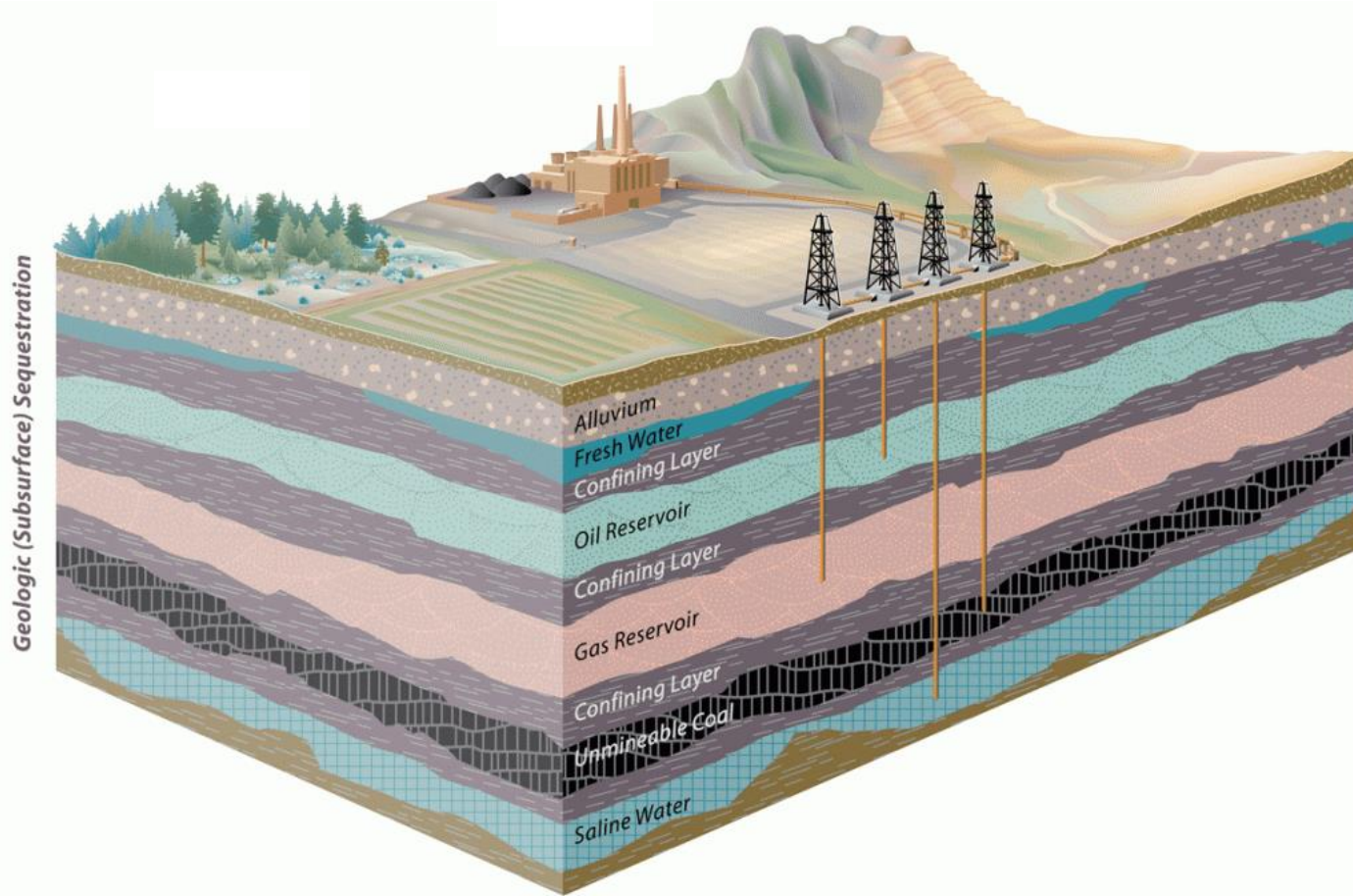
No capillary heterogeneity trapping

$A = 0.46$

- Greater heterogeneity leads to more trapped CO_2 and the contribution can be significant (Hailin Ni).
- Small-scale permeable horizontal laminations enhance CO_2 migration (Maartje Boon)
- Residual gas can remain stable over periods (10^5 years) relevant for CO_2 storage (Yaxin Li).

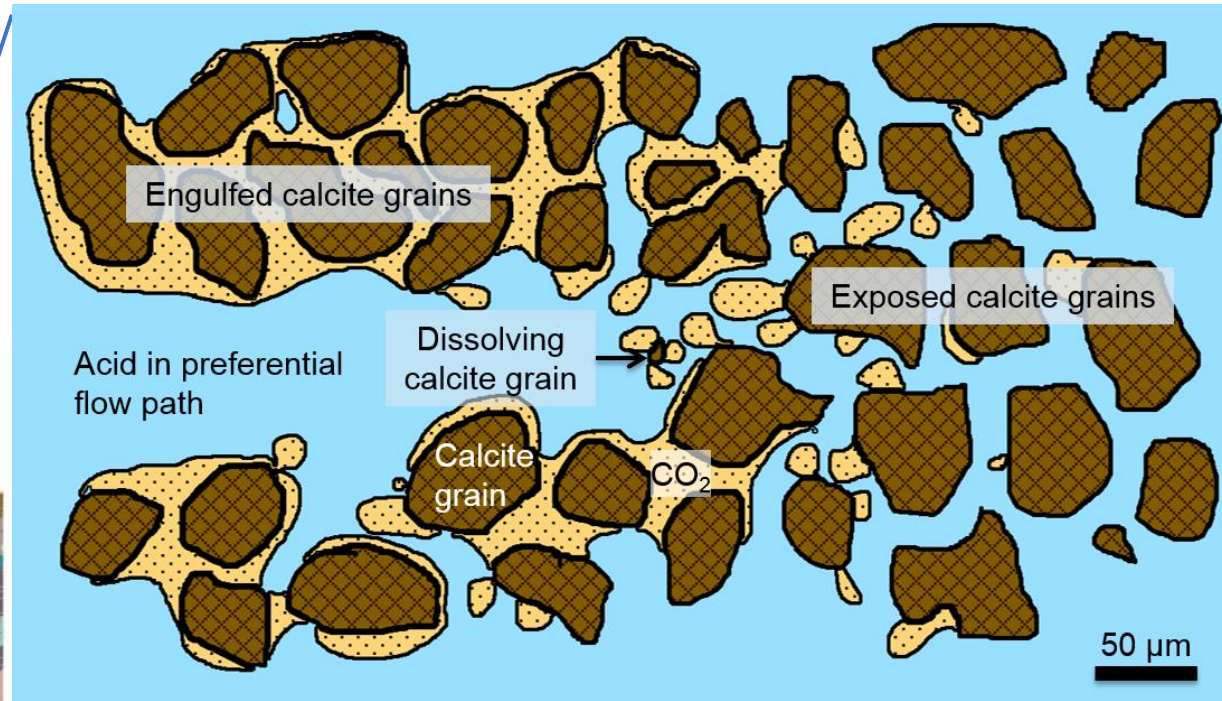
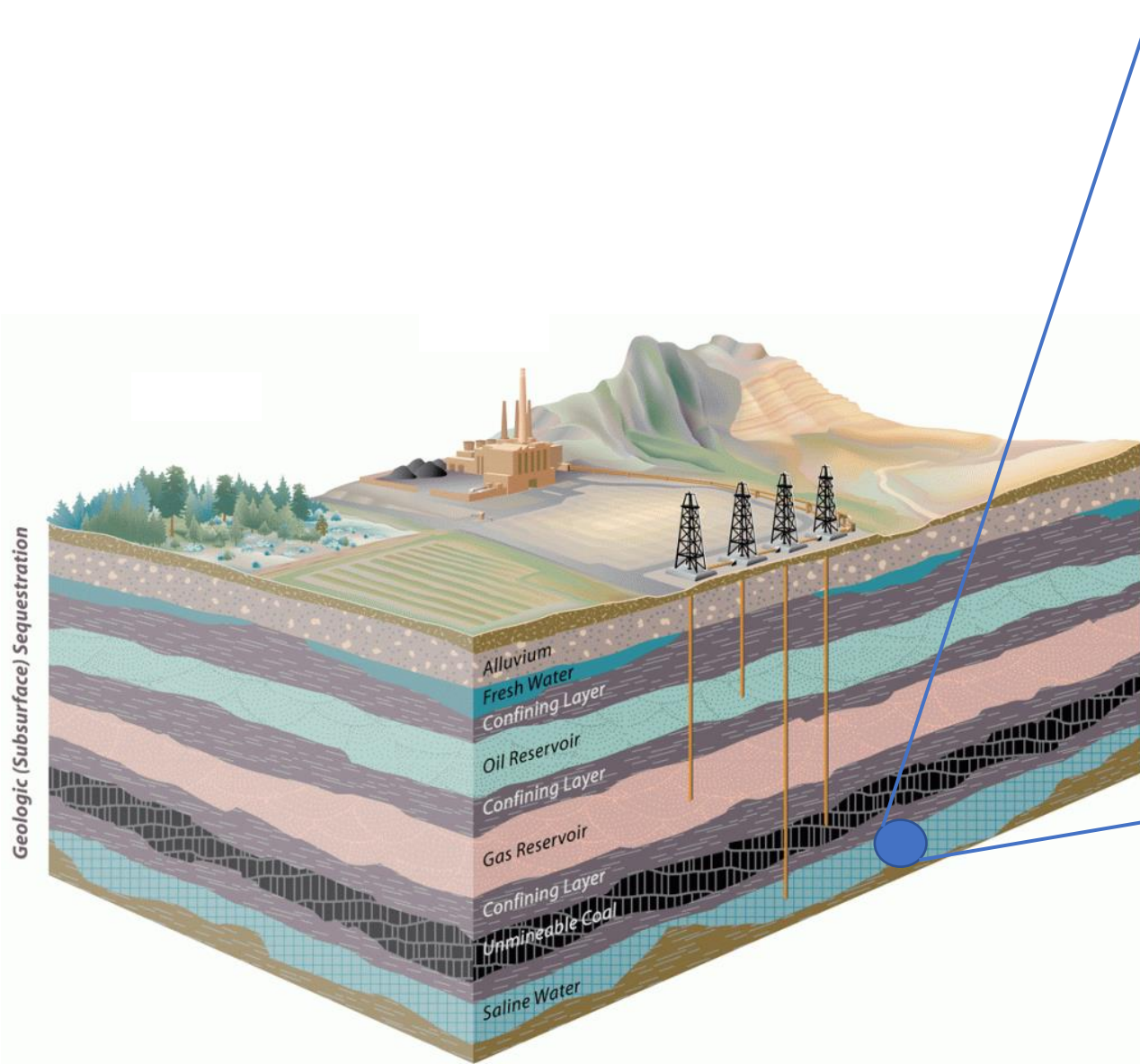
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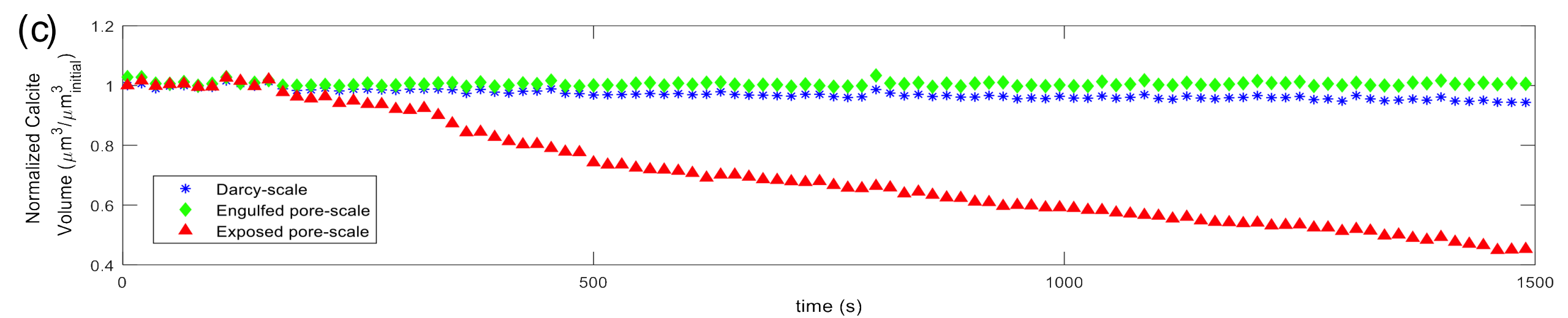
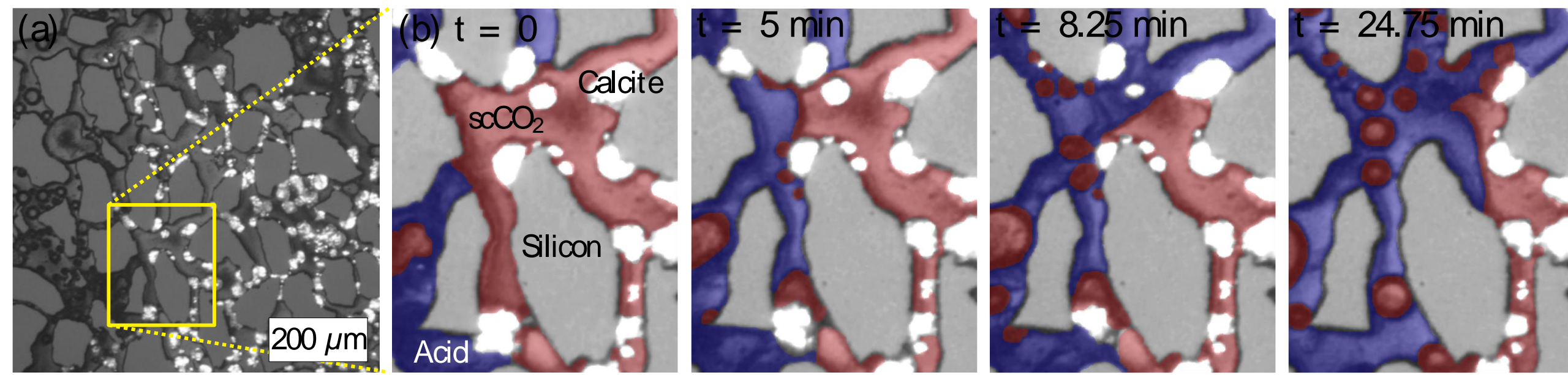


- Representative processes of interest to SCCS
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Geochemical reactions may produce free-phase CO₂



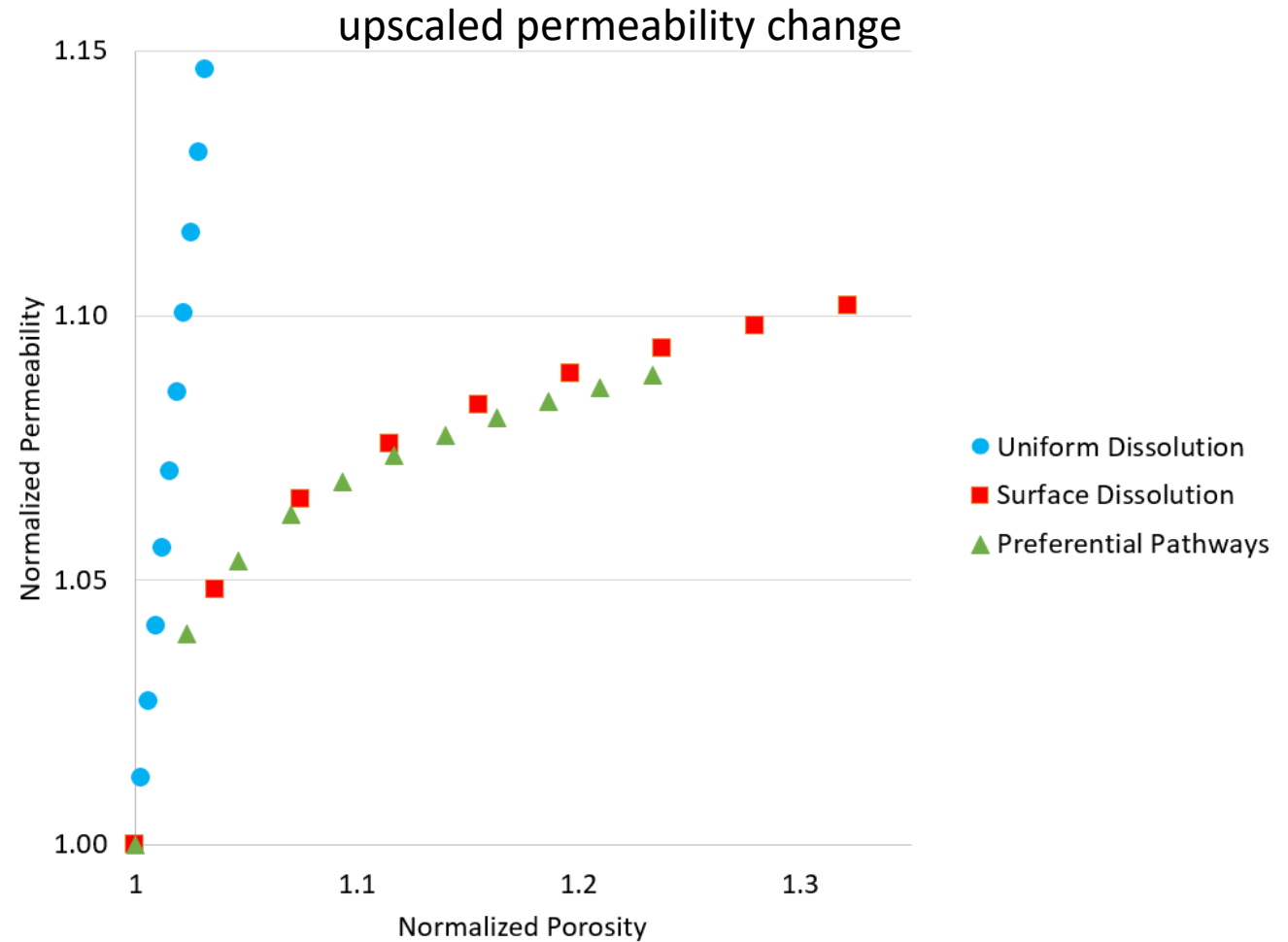
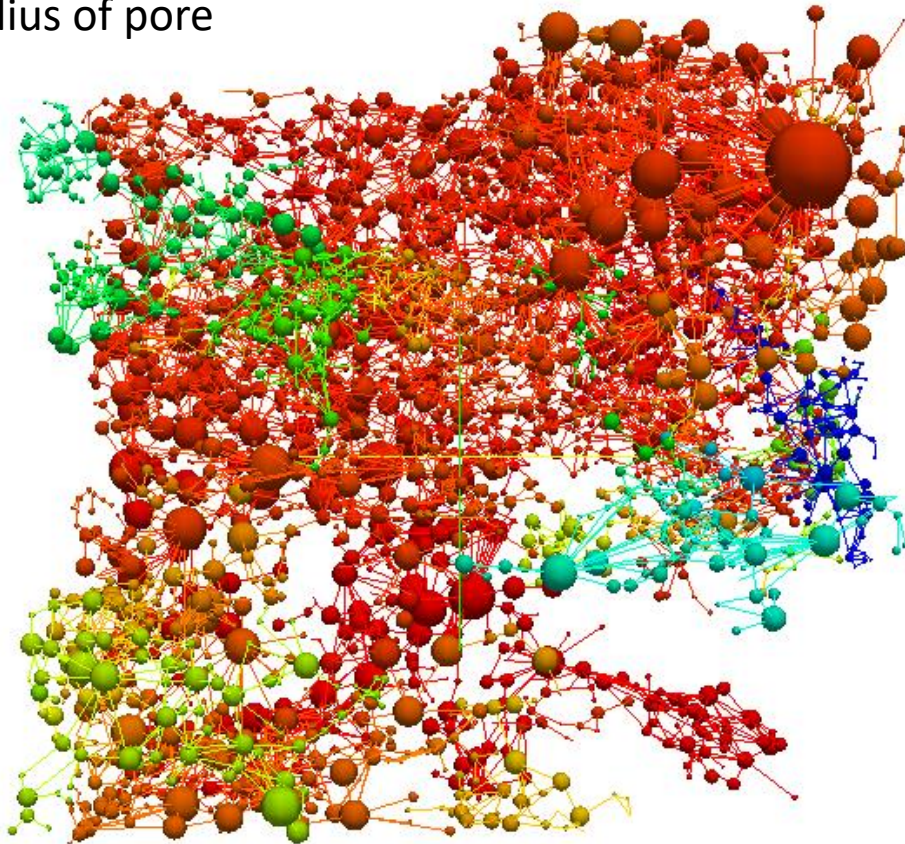
Pore-scale dissolution and evolution of scCO₂



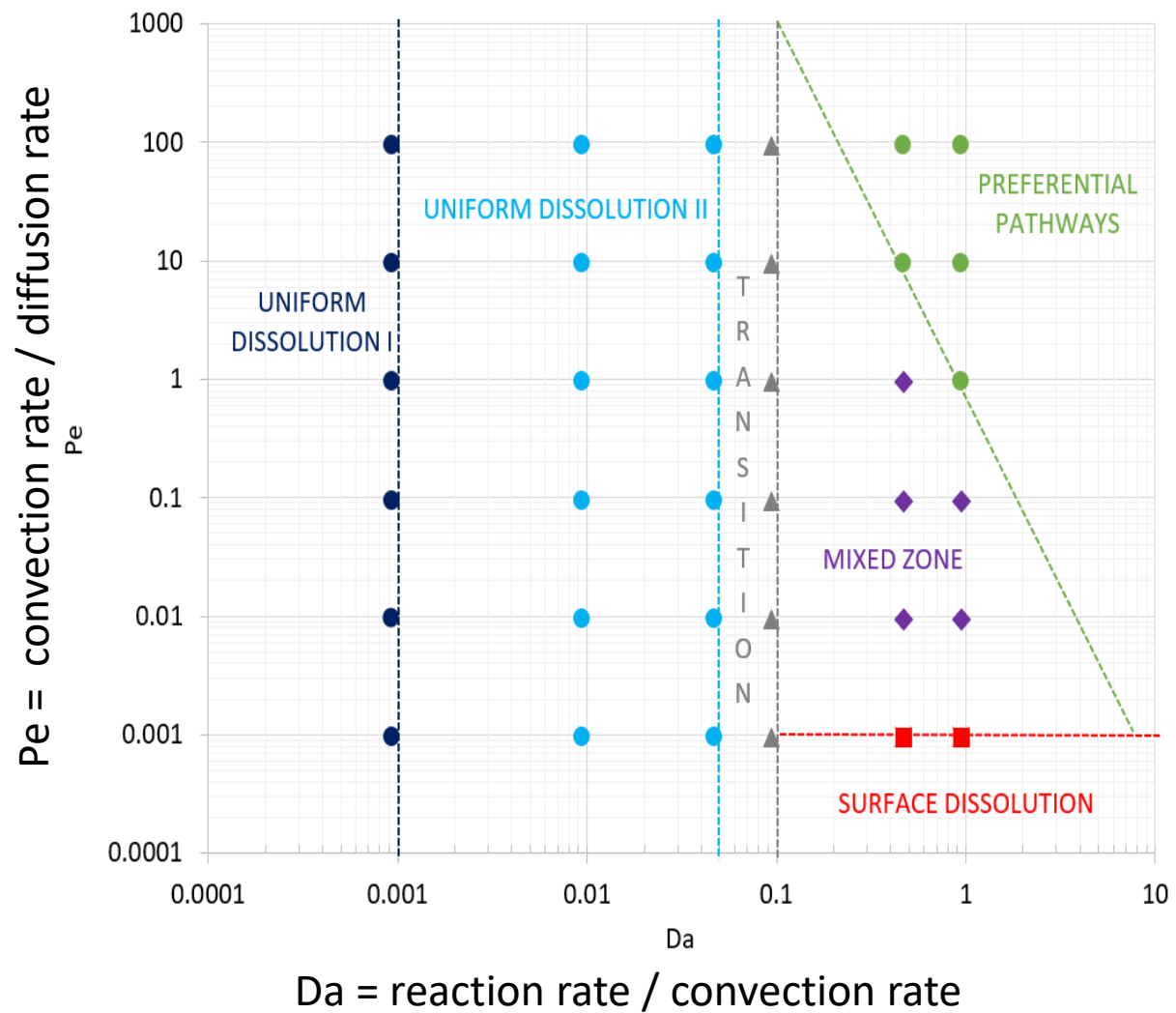
Dissolution at pore network scale

precipitation too

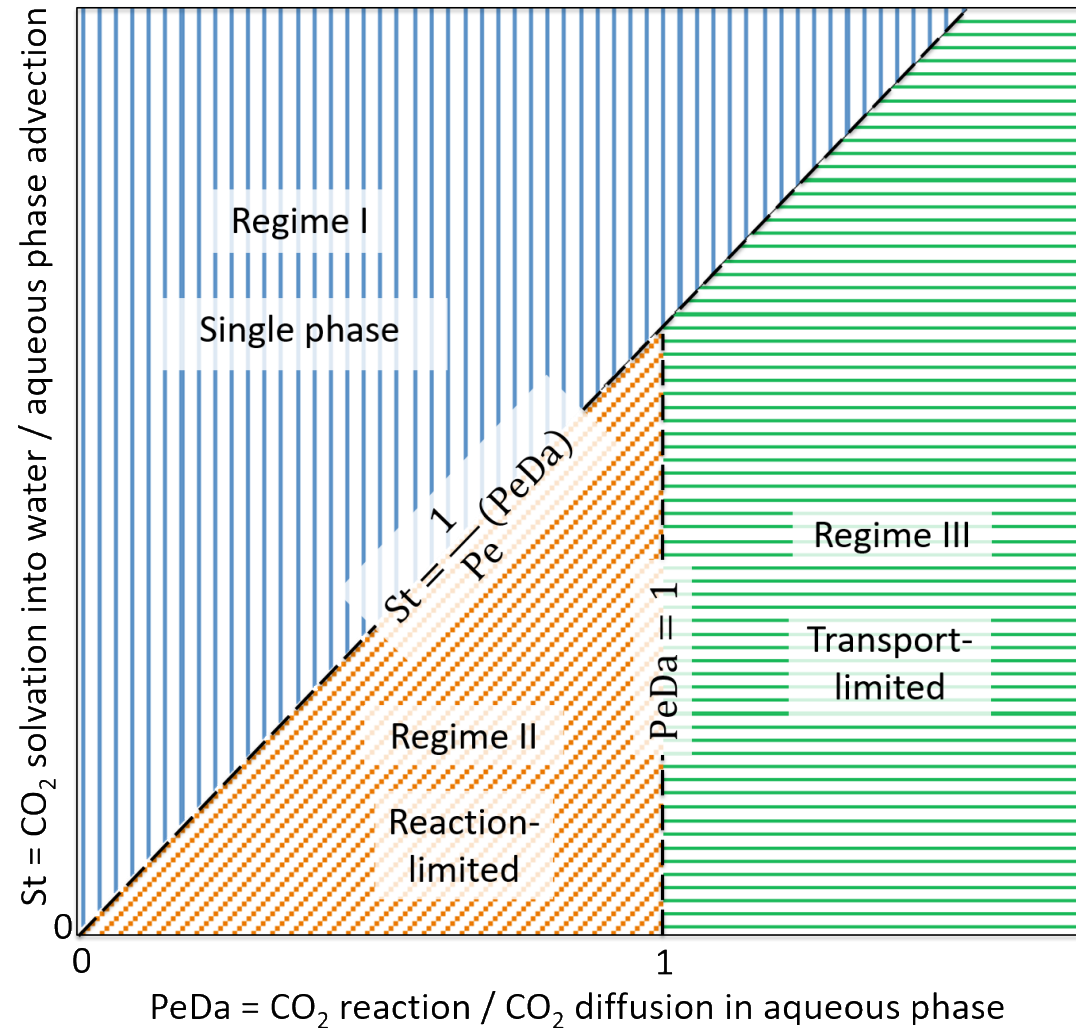
color: reactant concentration
size: radius of pore



Flowrate versus reactivity

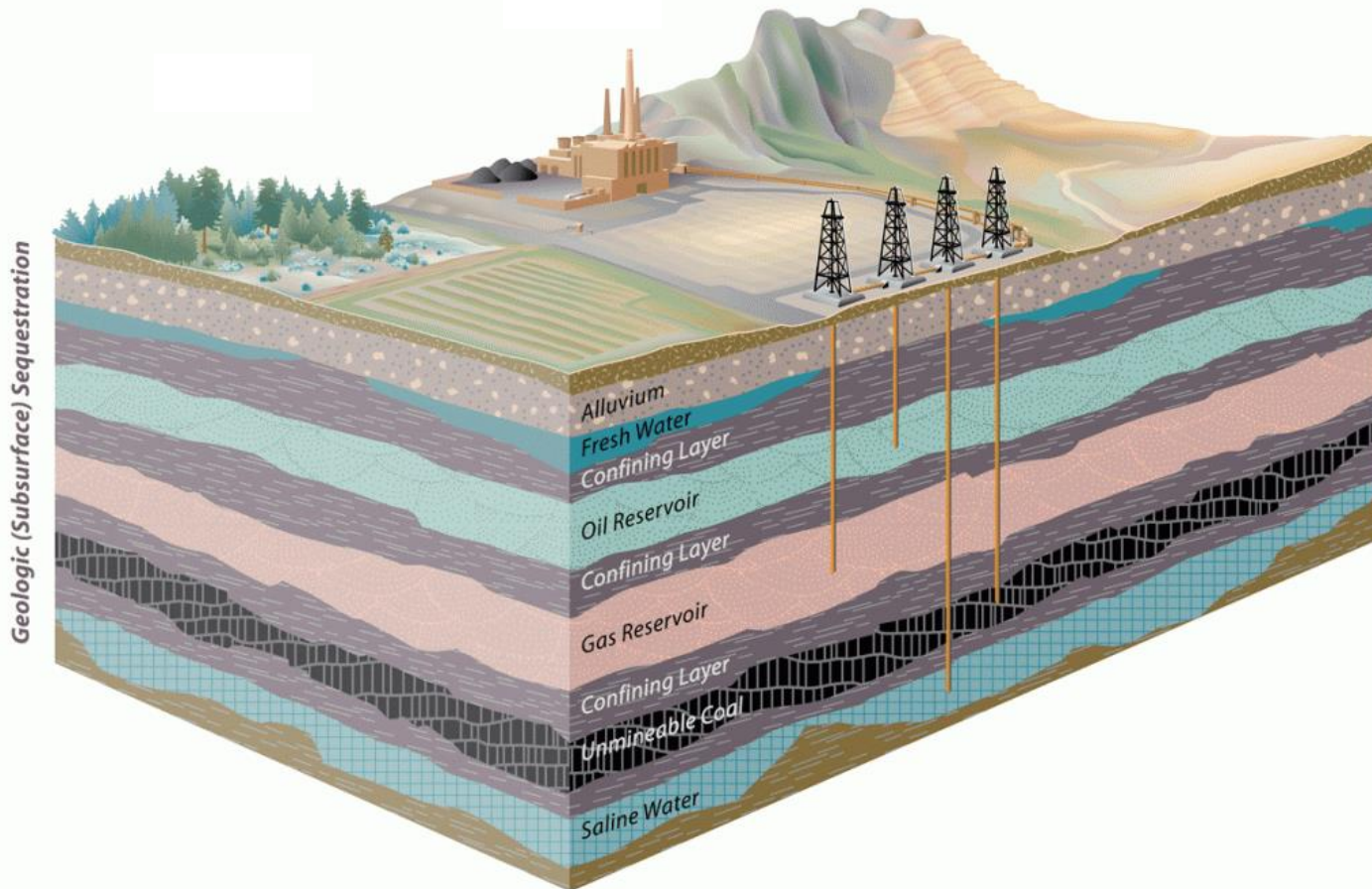


Solubility versus reactivity



Pore-scale processes impact large-scale projects

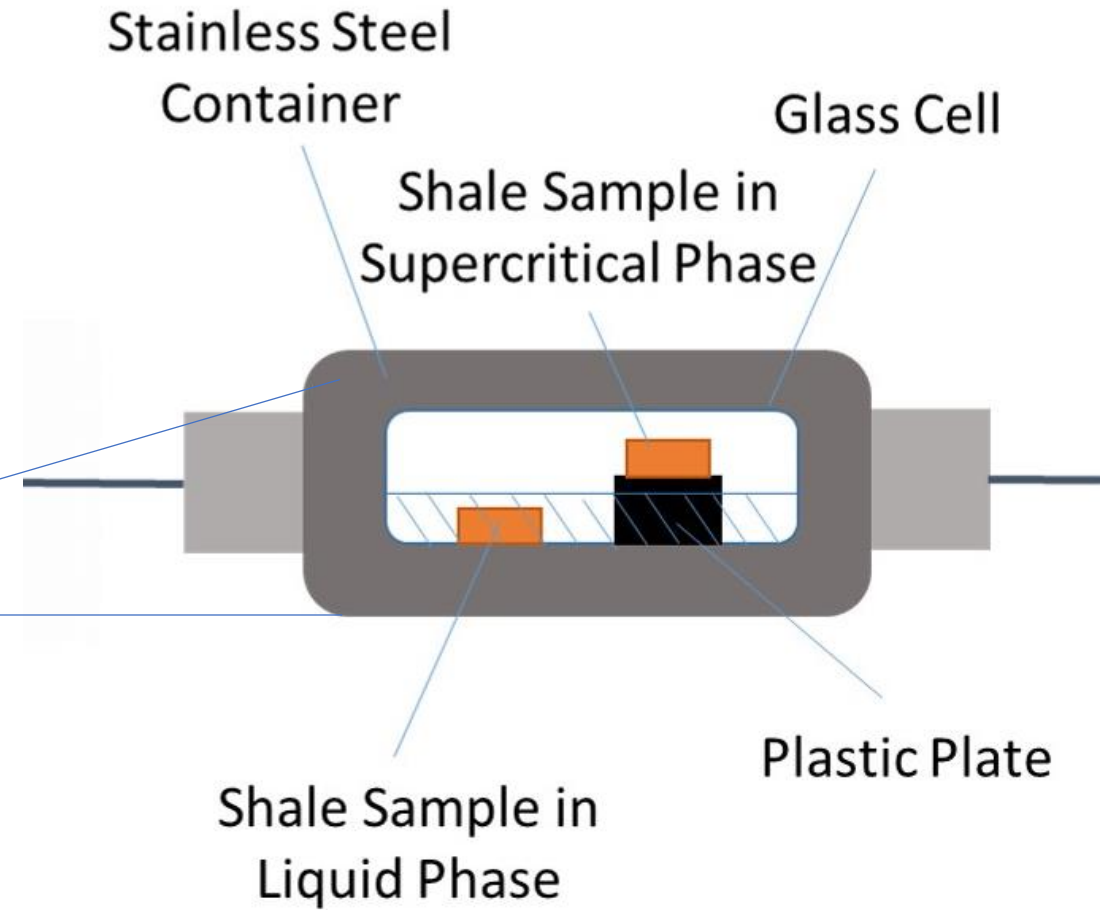
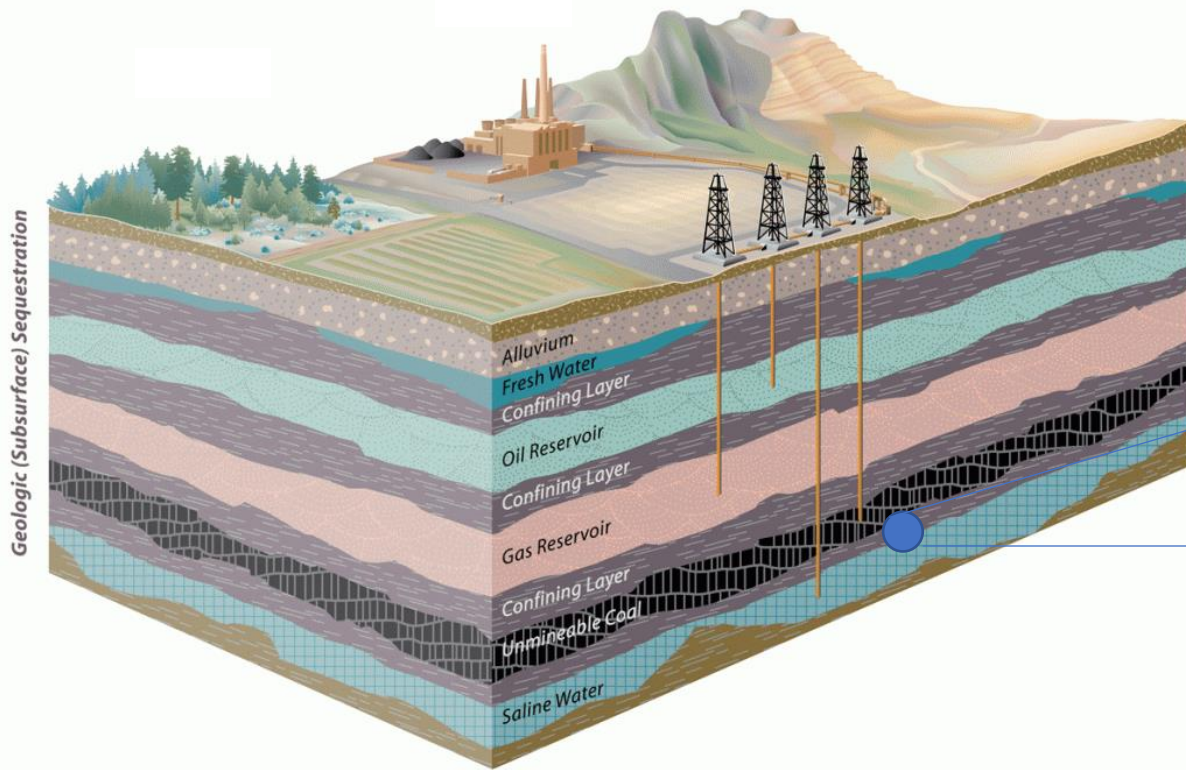
understanding pore-scale mechanisms key to storage integrity



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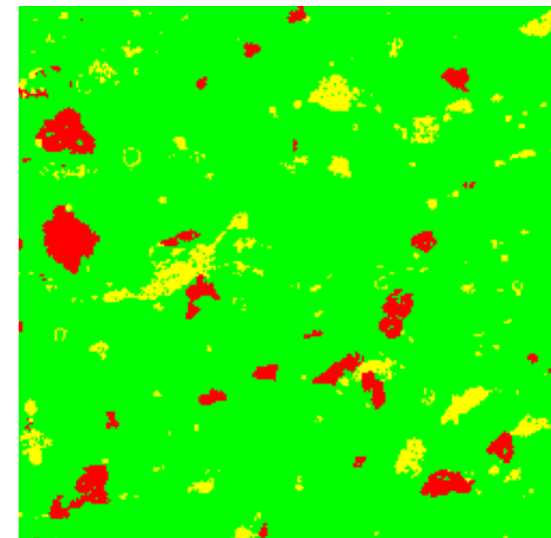
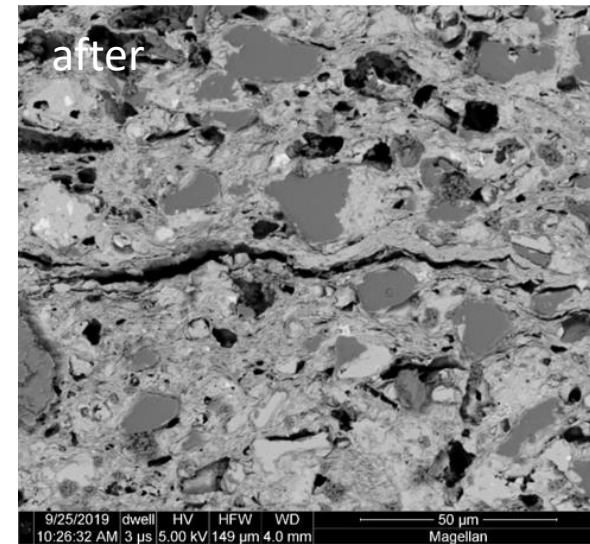
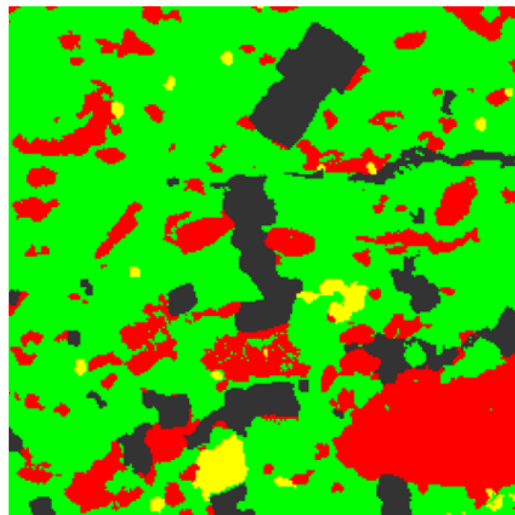
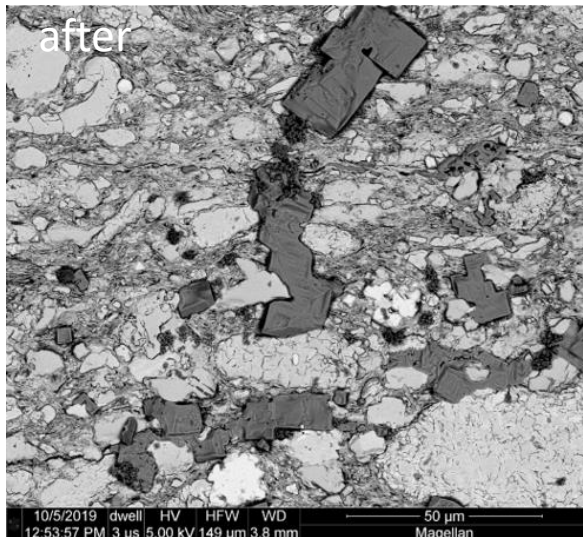
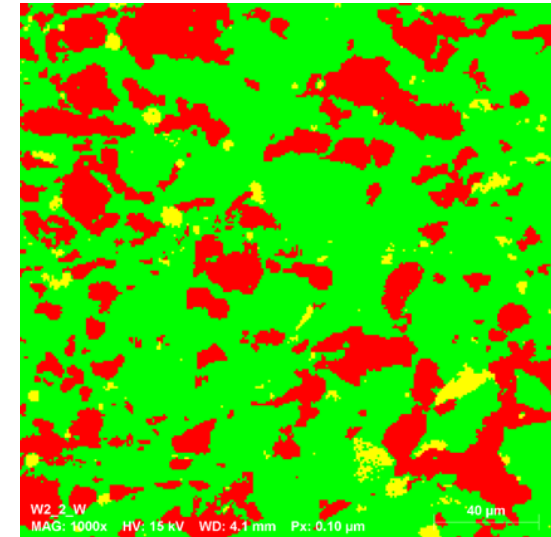
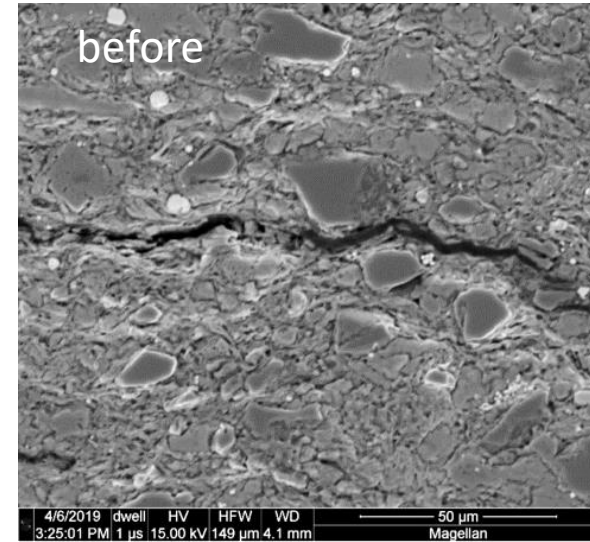
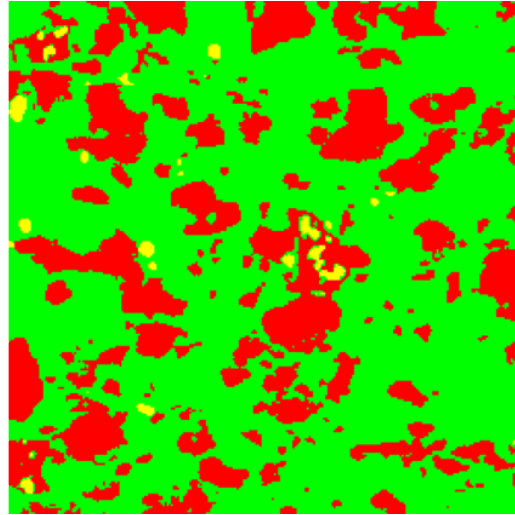
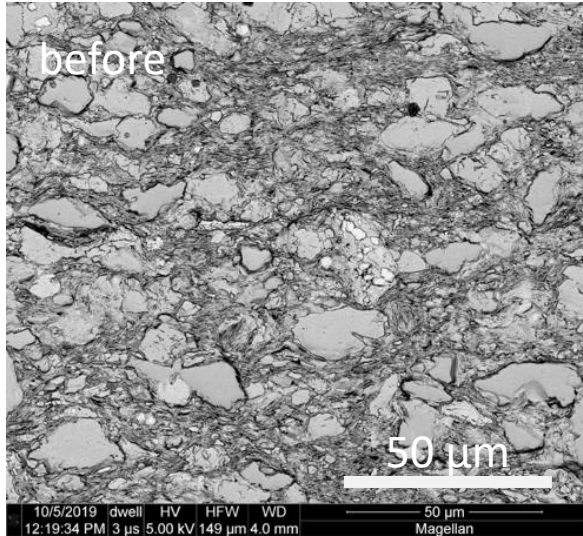
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6-month exposure to scCO₂ versus carbonated water

carbonate: red; silicate: green; salt: black; pyrite: yellow



Implications for reservoir seals

wet scCO₂

- few signs of dissolution
- no signs of pits and vugs
- ample salt precipitation
- wet scCO₂ may be protective of reservoir seals
- 10 nD before and after exposure

Carbonated water

- calcite dissolved
- dolomite persisted
- pits and vugs formed
- dissolution depth of 100 μm
- 15 nD before and after exposure

Summary

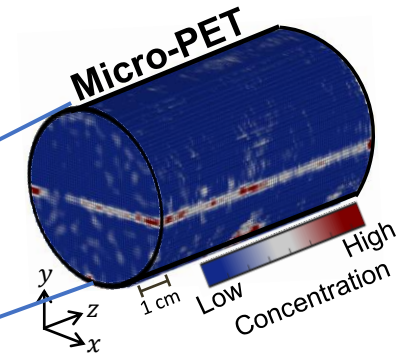
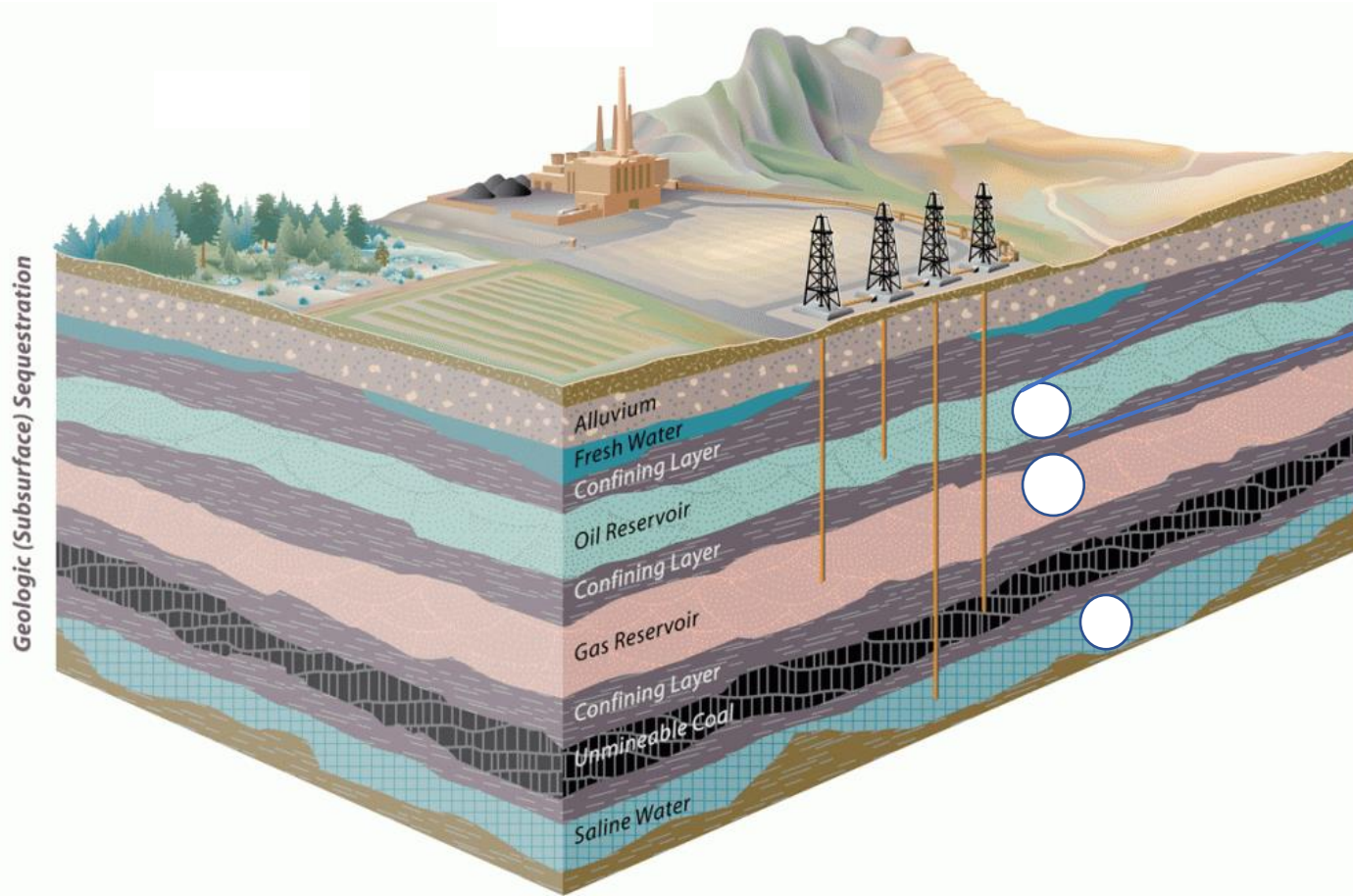
- The fundamental length scale of transport and reactions in porous media is the pore scale: 100's μm to 10's nm
- Detailed understanding of pore-scale processes, including seals, improves our ability to model and to provide storage assurance.

Image credits

- Slide 2. Geological storage volumes: https://geology.utah.gov/wp-content/uploads/snt44-1_sequestration-options-1030x773.gif
- Slide 3. Hailun Ni
- Slide 4: Markus Buchgraber and Sophie Roman
- Slides 6-7,9: Song, W., O. Ogunbanwo, M. Steinsbø, M. A. Fernø, and A. R. Kavscek, “Mechanisms of Multiphase Reactive Flow using Biogenically Calcite-Functionalized Micromodels,” *Lab on a Chip*, 18, 3881-3891 (2018). DOI: 10.1039/C8LC00793D
- Slides 8-9: Esteves, B.F., P.L.C. Lage, P. Couto and A.R. Kavscek, “Pore-Network Modeling of Single-Phase Reactive Transport and Dissolution Pattern Evaluation”, *Advances in Water Resources*, 145 (2020): 103741.
- Slides 11-12: Elkady, Y. and A. R. Kavscek, “Multiscale Study of the Impact of CO₂ on Fluid Transport and Carbonate Dissolution in Nano-Darcy Shale” *Journal of Petroleum Science and Engineering*, 195 (2020) 197867. DOI: <https://doi.org/10.1016/j.petrol.2020.107867>

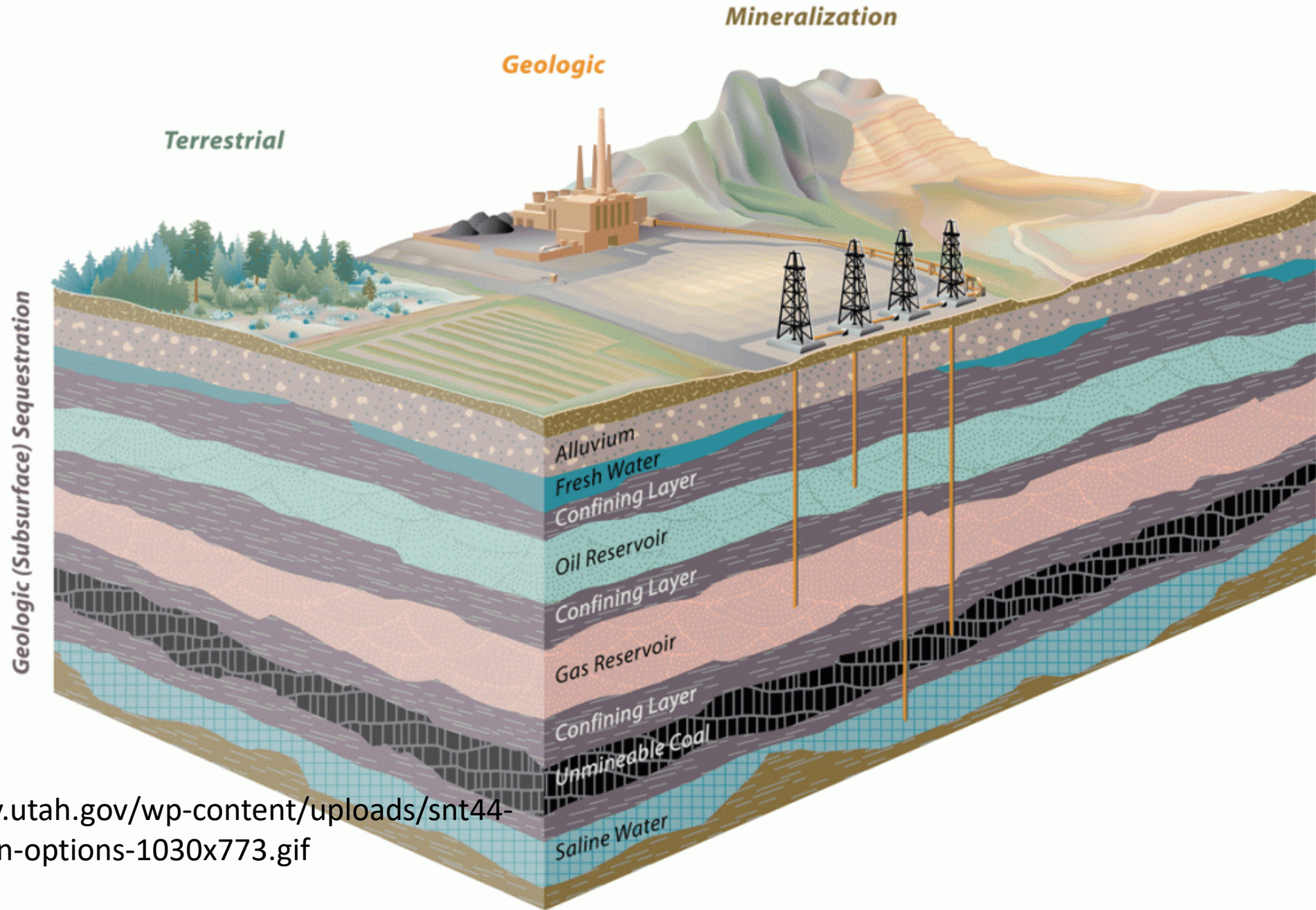
Multiphase Flow Physics

Heterogeneity: Friend or Foe?



- Local apertures important to reliable estimation of chemical and physical interactions between fluids, fractures and rock matrix. (Takeshi Kurotori)

Carbon Sequestration Options



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