

Assisi – May 2016

Dissolution and Precipitation

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KAUST



Nature: Precipitation



Nature: Dissolution & Precipitation

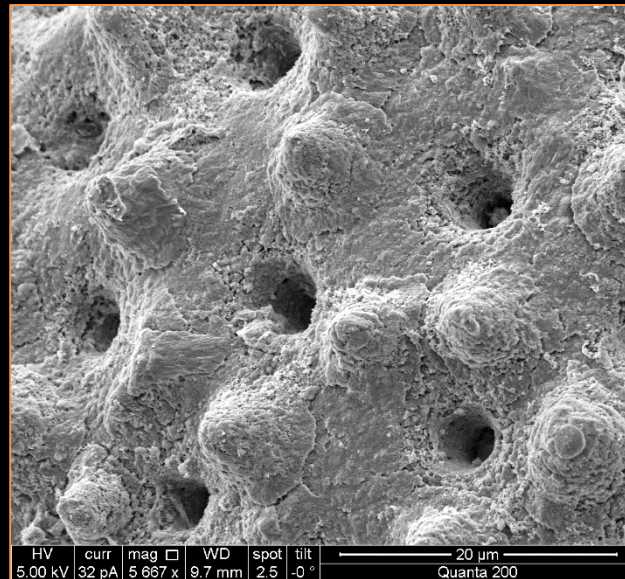
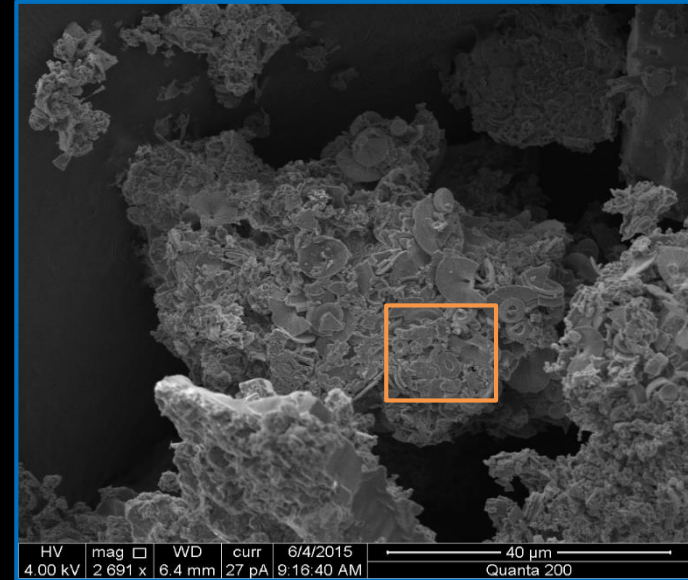
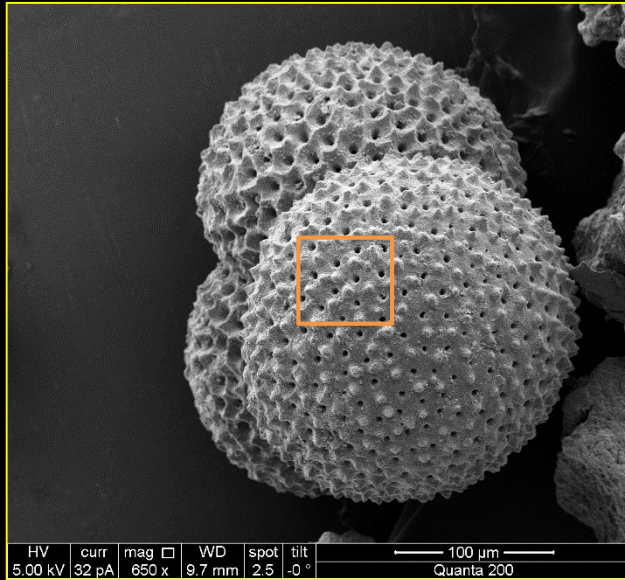


Nature: Dissolution & Precipitation



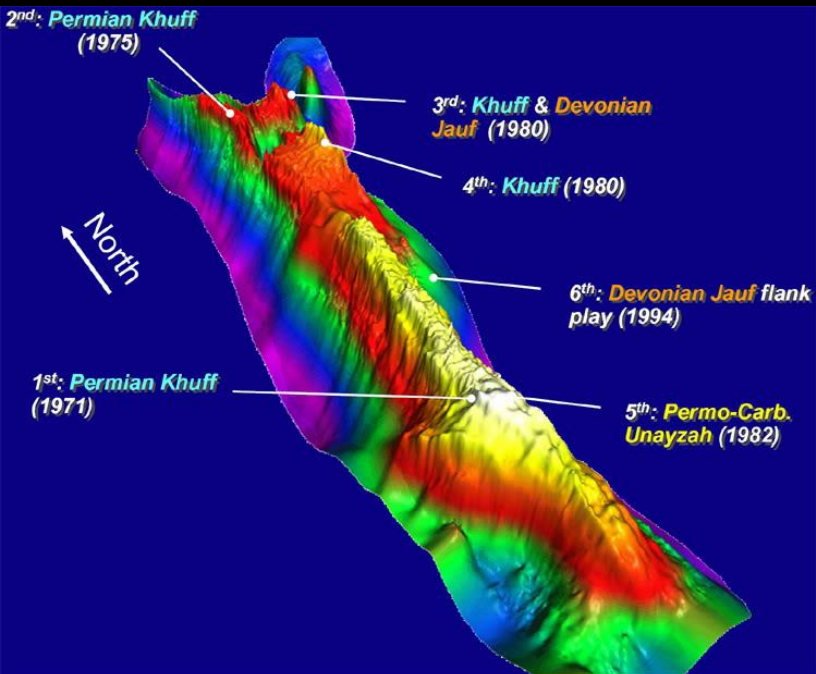
From Carbonate Sands...

Red Sea

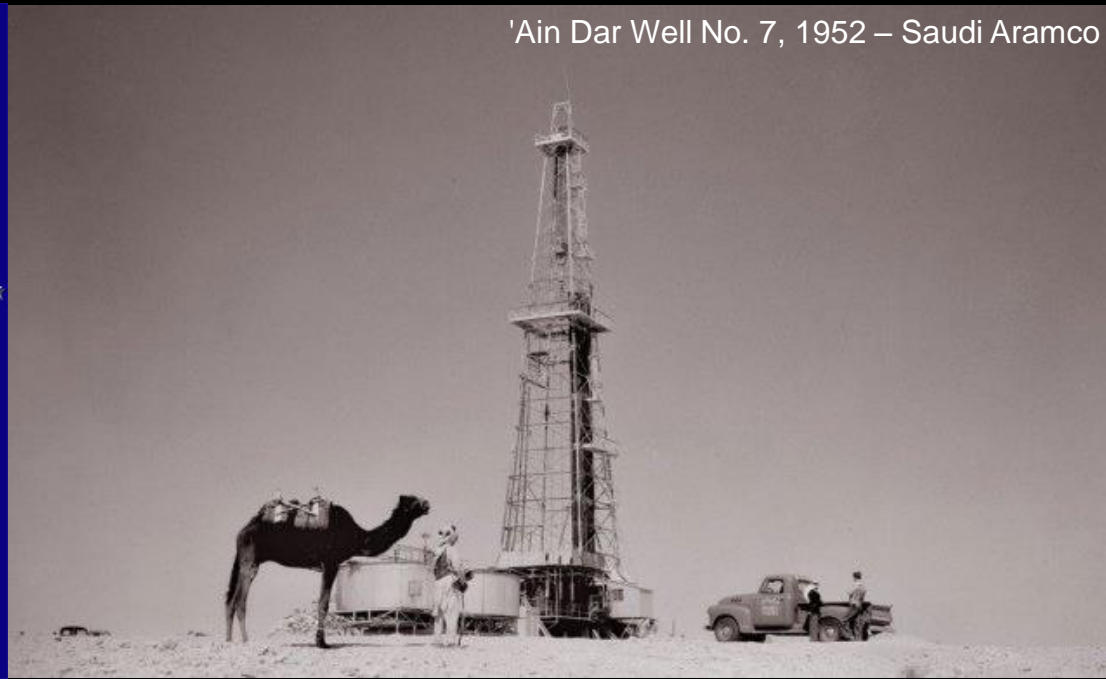


Foraminifera – Globigerinoides (Globigerinina)

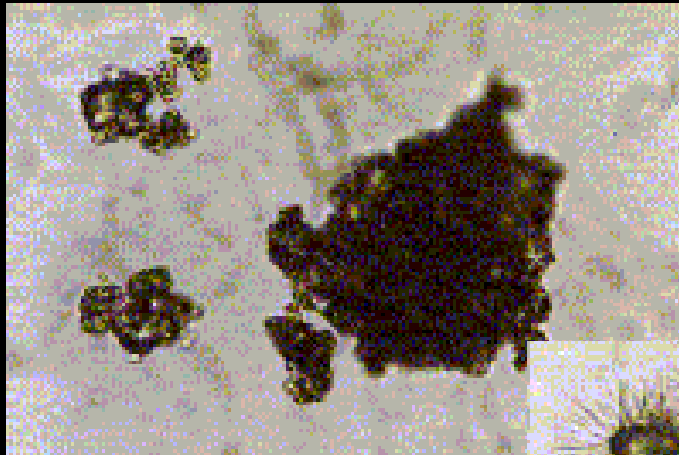
To Carbonate Oil Reservoirs



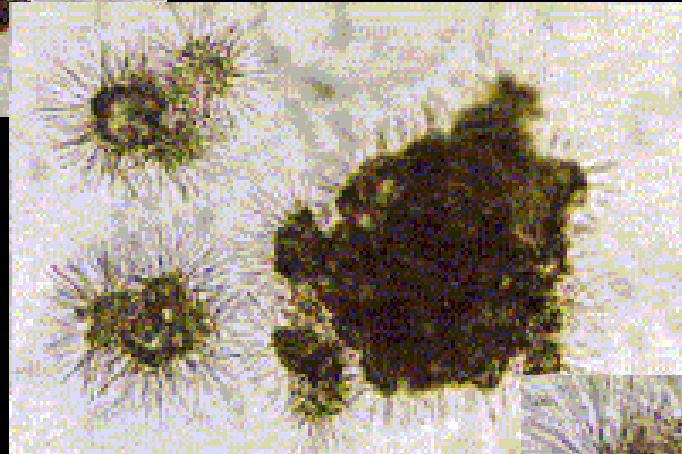
'Ain Dar Well No. 7, 1952 – Saudi Aramco



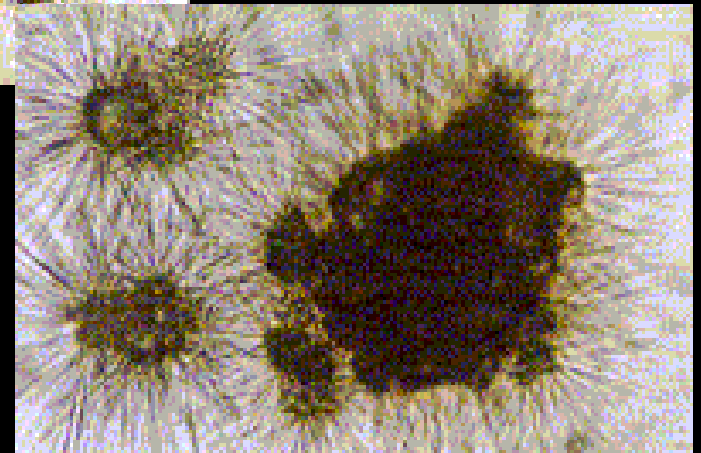
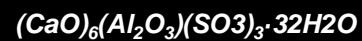
Portland Cement “Hydration”



C₃A in gypsum solution



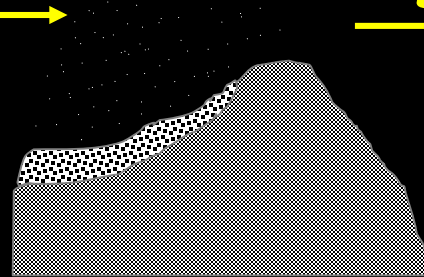
Ettringite



Formation of Volcanic Ash Soils



wind



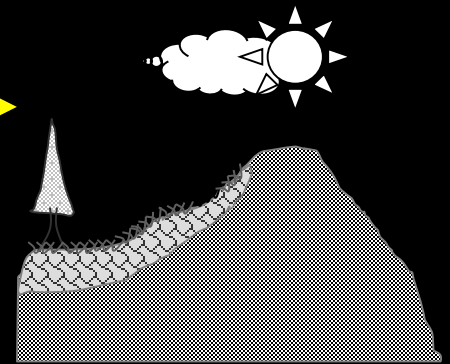
$$e = 0.8-1.5$$

$$S_s \sim 0.1-1 \text{ m}^2/\text{g}$$

volcanic glass

$$k_o = 1 - \sin\phi$$

time



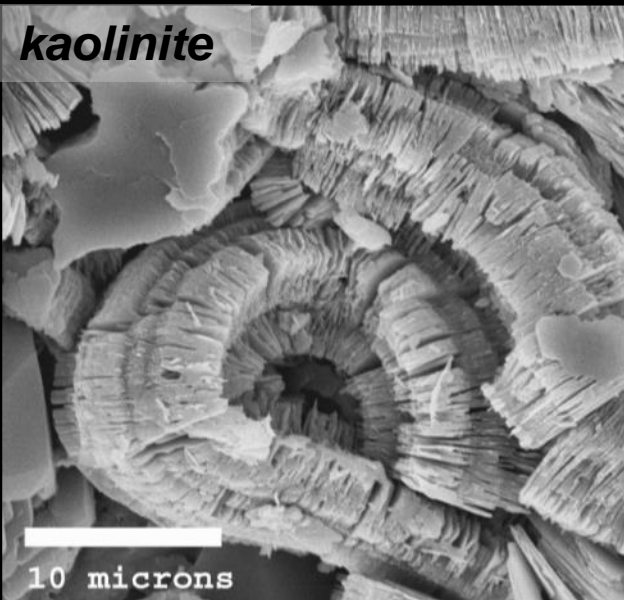
$$e = 2.0-7.0$$

$$S_s = 50\text{-to-}200 \text{ m}^2/\text{g}$$

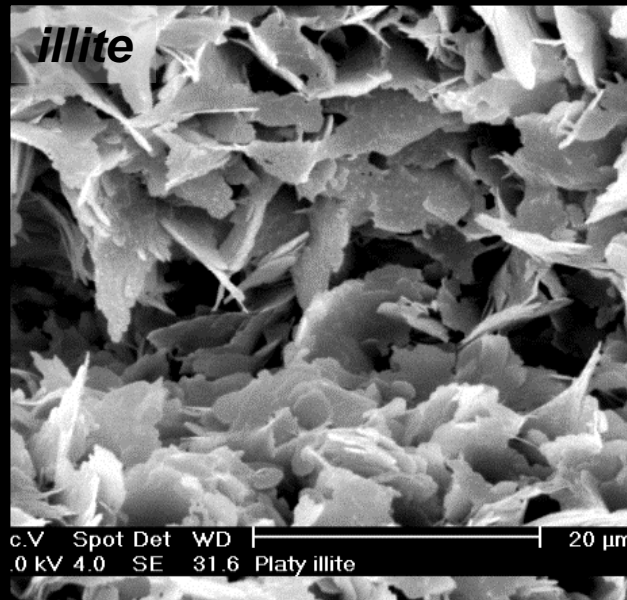
hallosite
imogolite
alophane

$$k_o = ??$$

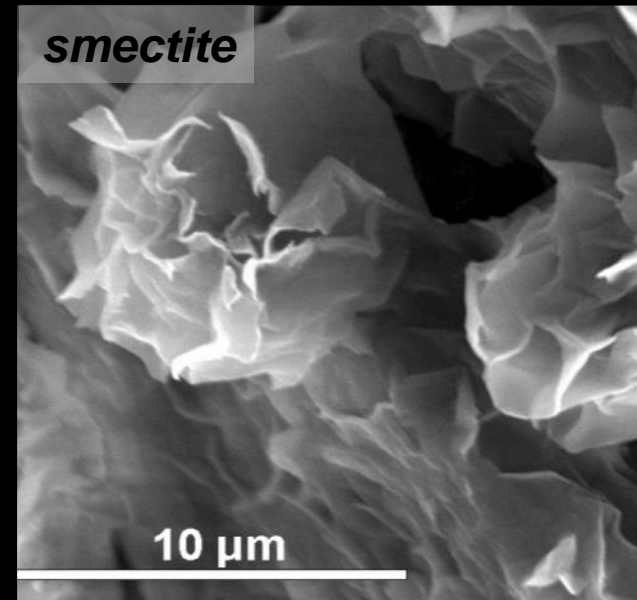
Formation of Clay Minerals



$S_s = 10 \text{ m}^2/\text{g}$

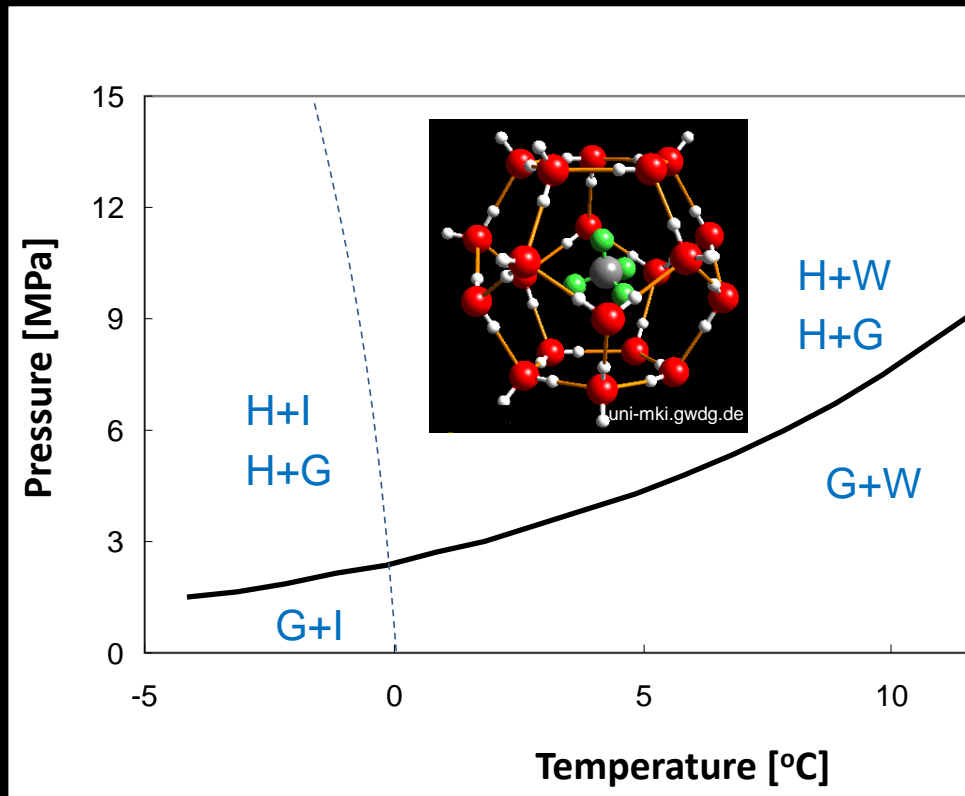


$S_s = 50 \text{ m}^2/\text{g}$



$S_s = 300 \text{ m}^2/\text{g}$

Phase Transformations: Ice or Hydrates

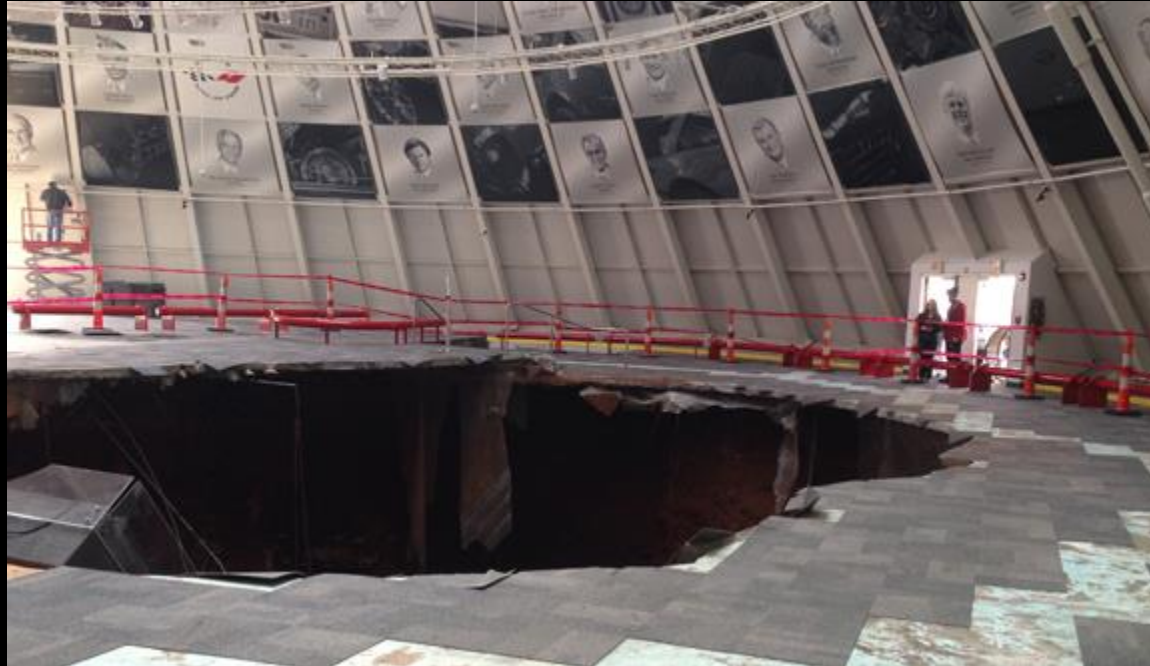


Engineering



National Corvette Museum in Bowling Green, Ky.

Engineering?



Feb 13, 2014

Engineering



Engineering



Plant Vogtle (GA) - Excavation Units 3 & 4 (Photo: Southern Company, 2010)

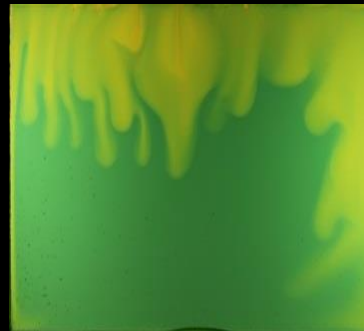
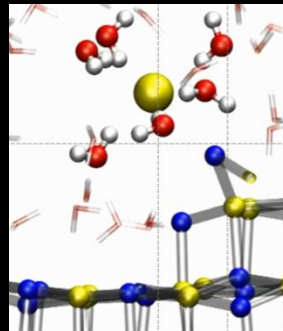
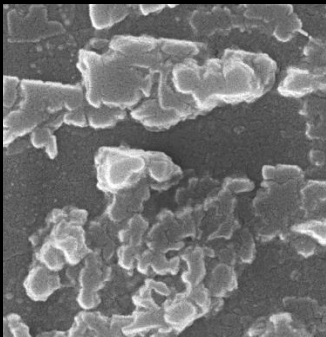
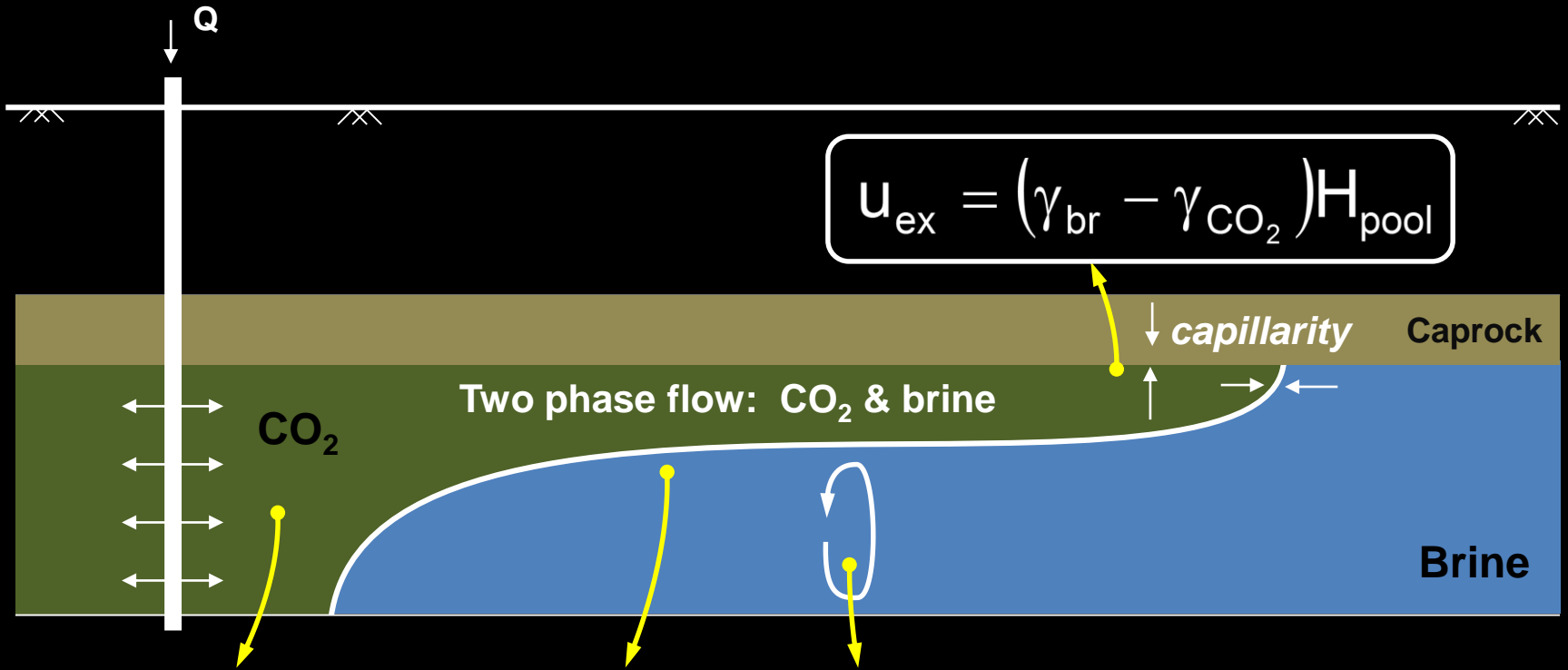
Also: DOE's Savannah River Site (SC)

Coal → Fly Ash Storage: Early Diagenesis



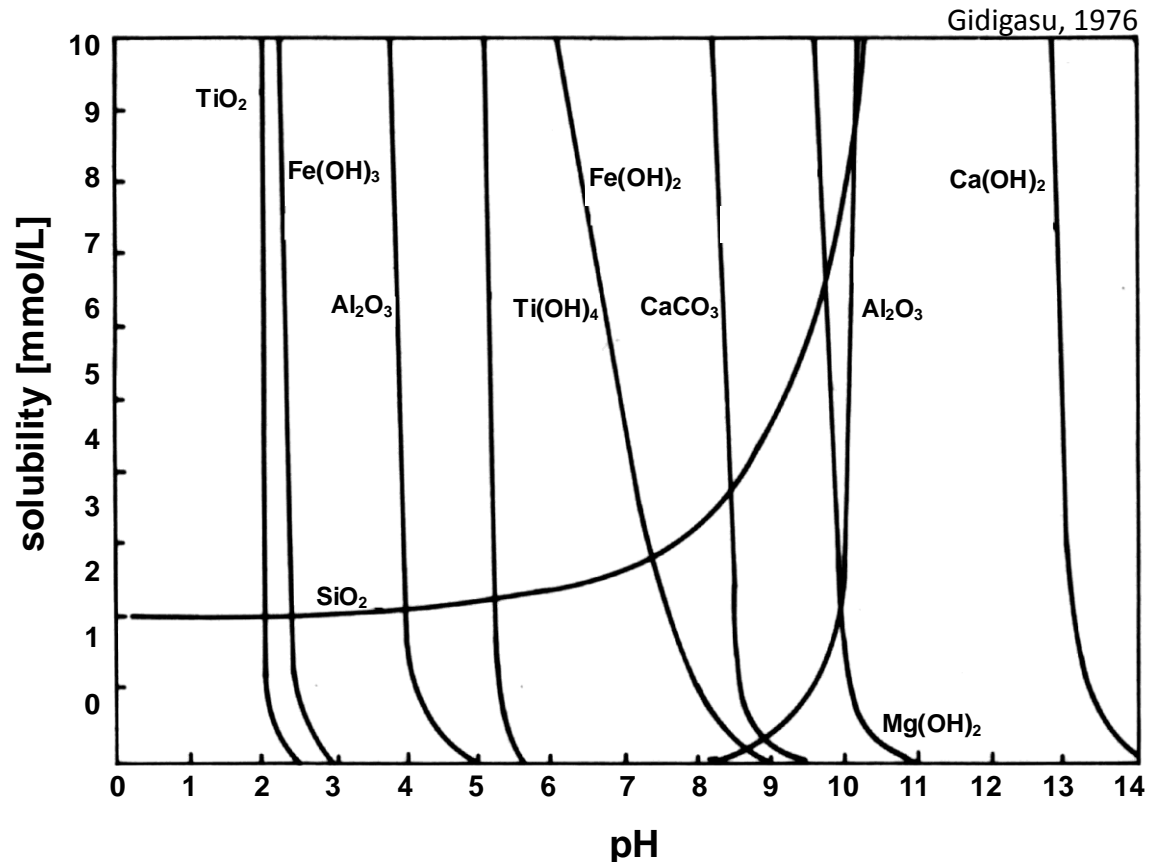
30 hectare – 22 m high dredged ash disposal cell (USEPA)

CO₂ Geo-storage *A Faustian bargain ?*

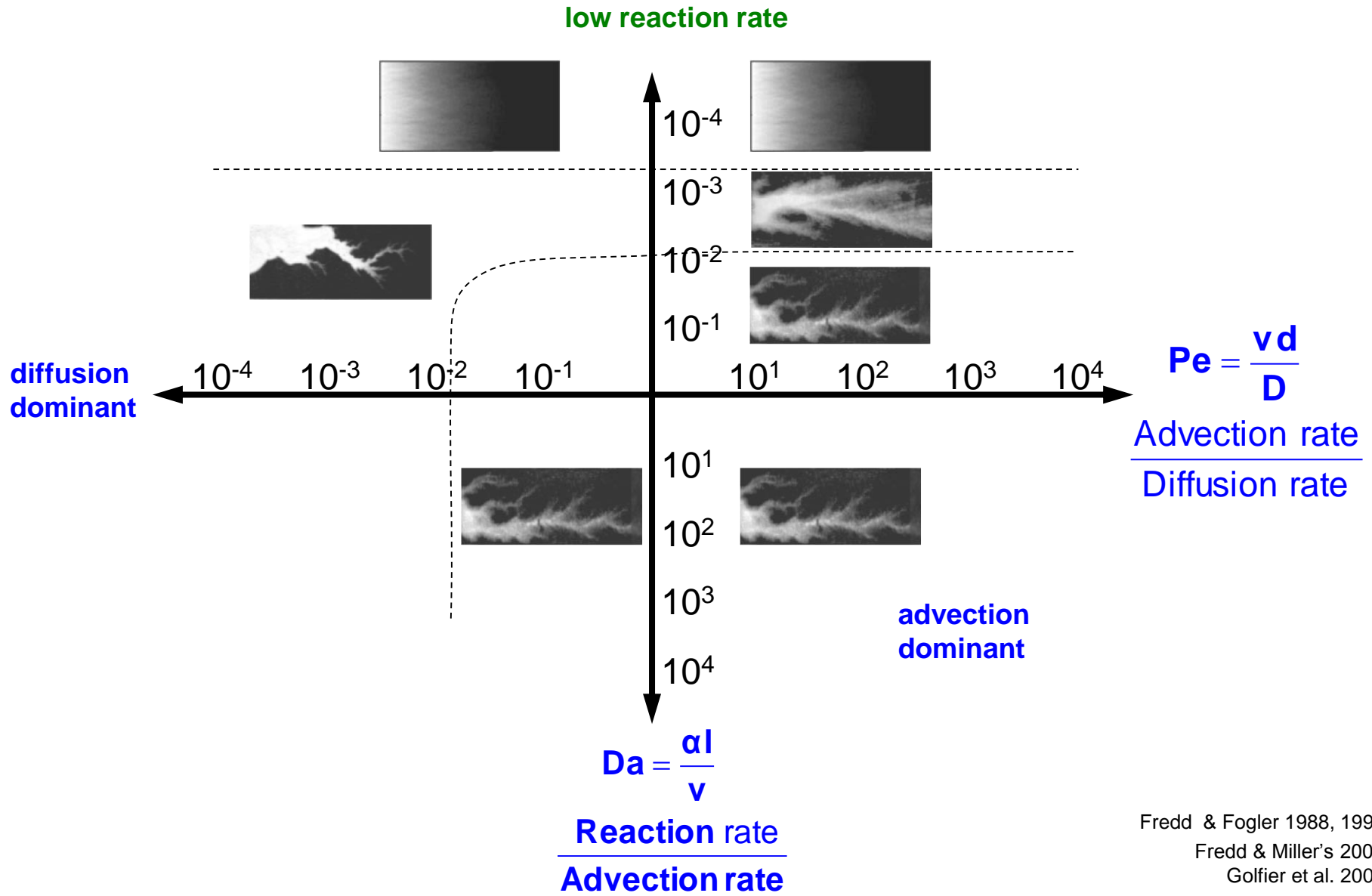


Dissolution

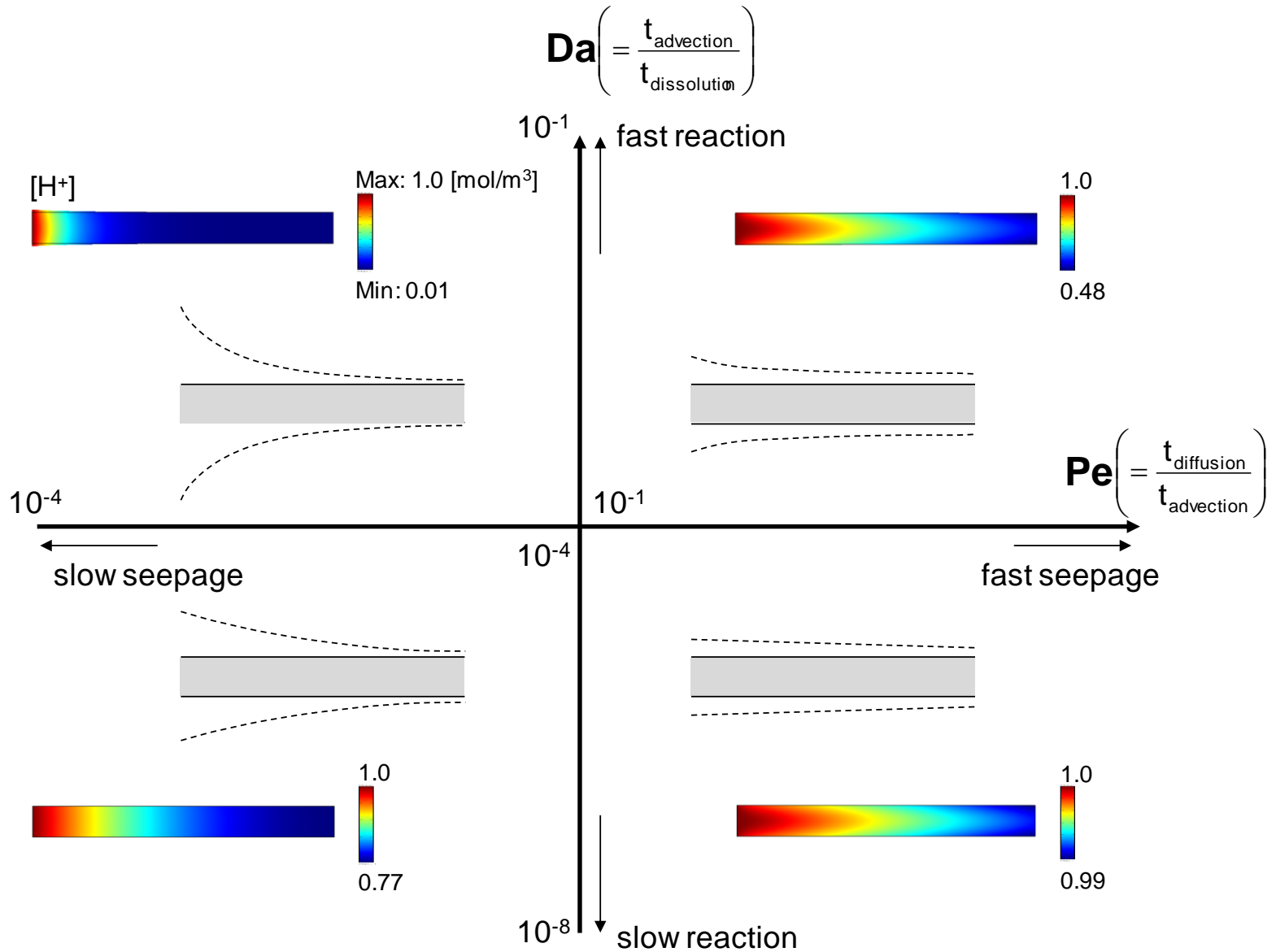
Solubility: pH



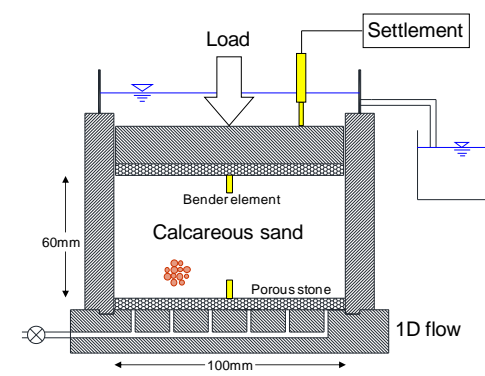
Dissolution Pore Habit



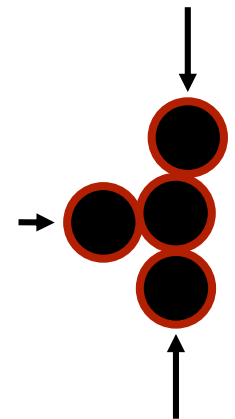
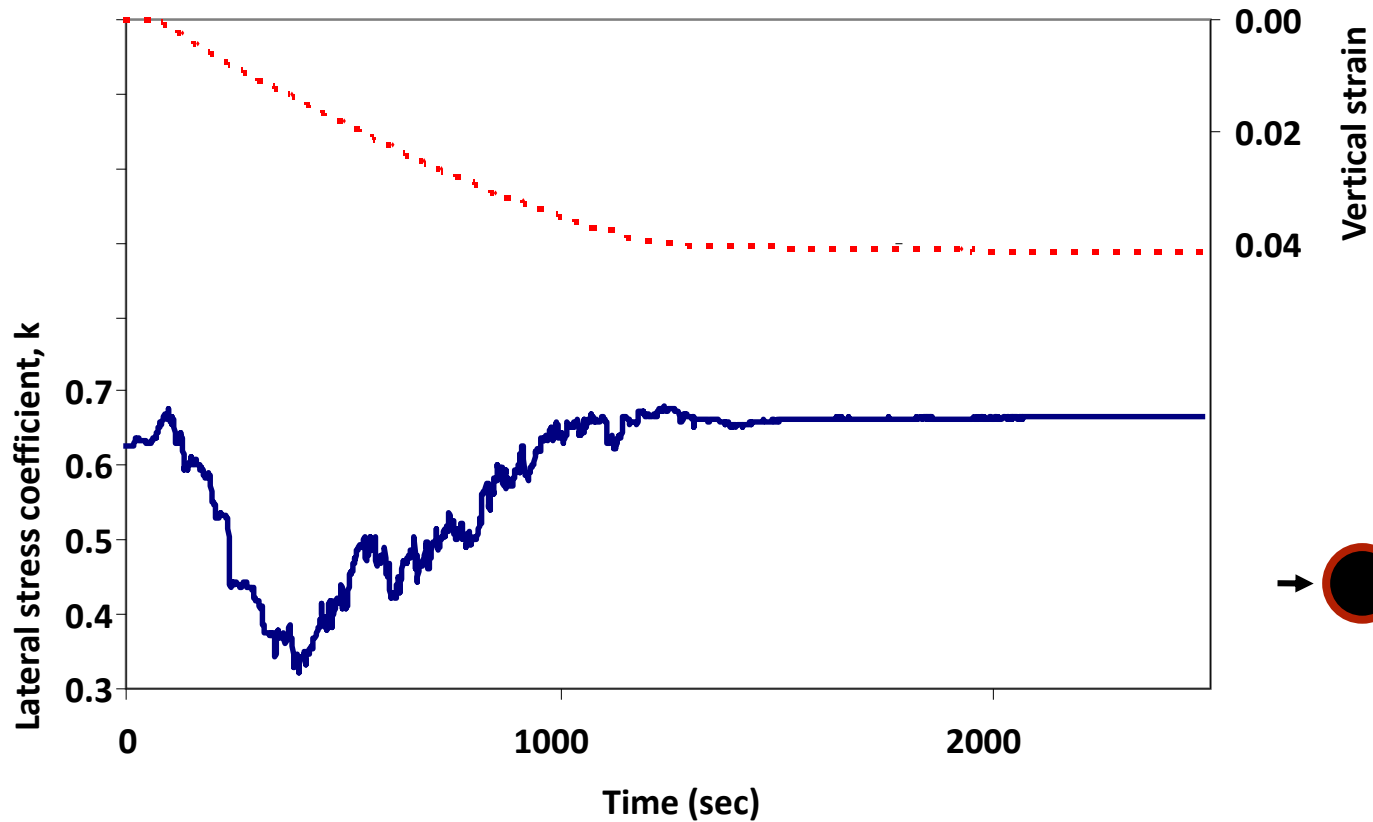
Fractured Rock



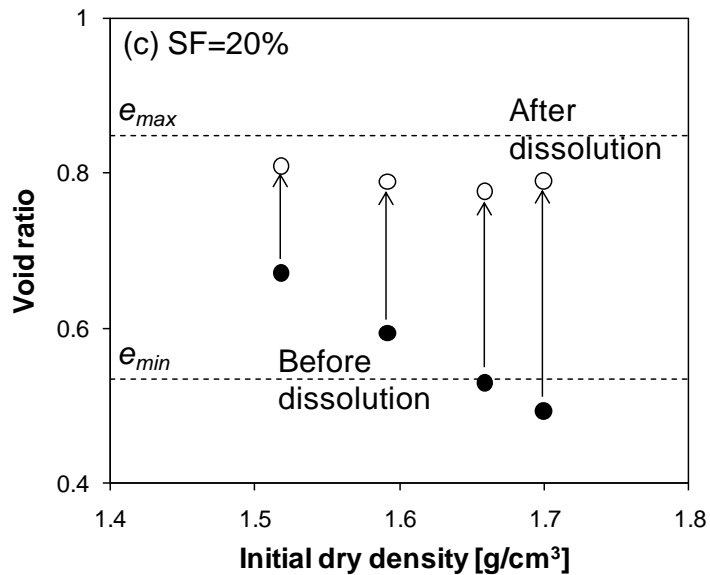
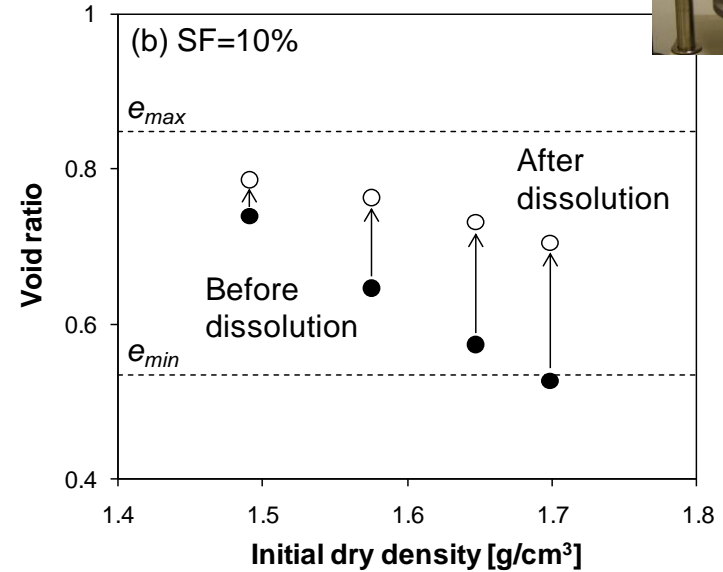
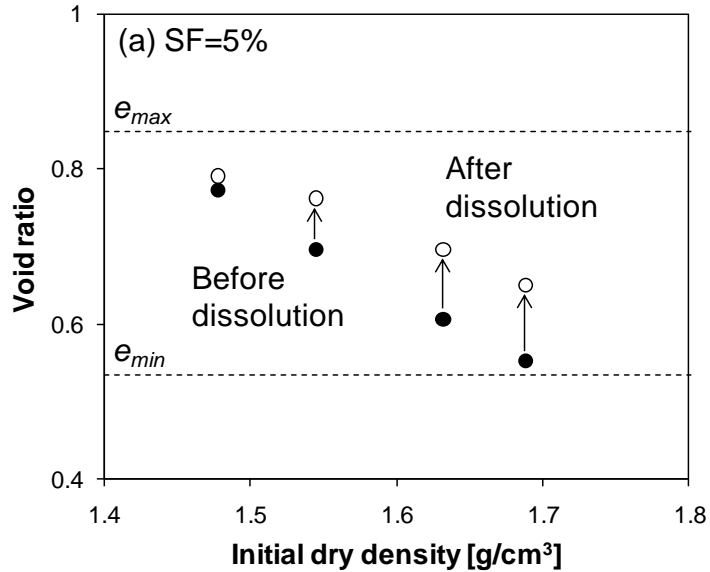
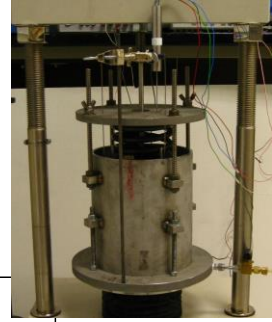
Sediments under $\sigma' \rightarrow \Delta V \downarrow$ & $\Delta \sigma'$



90% glass bead + 10% NaCl

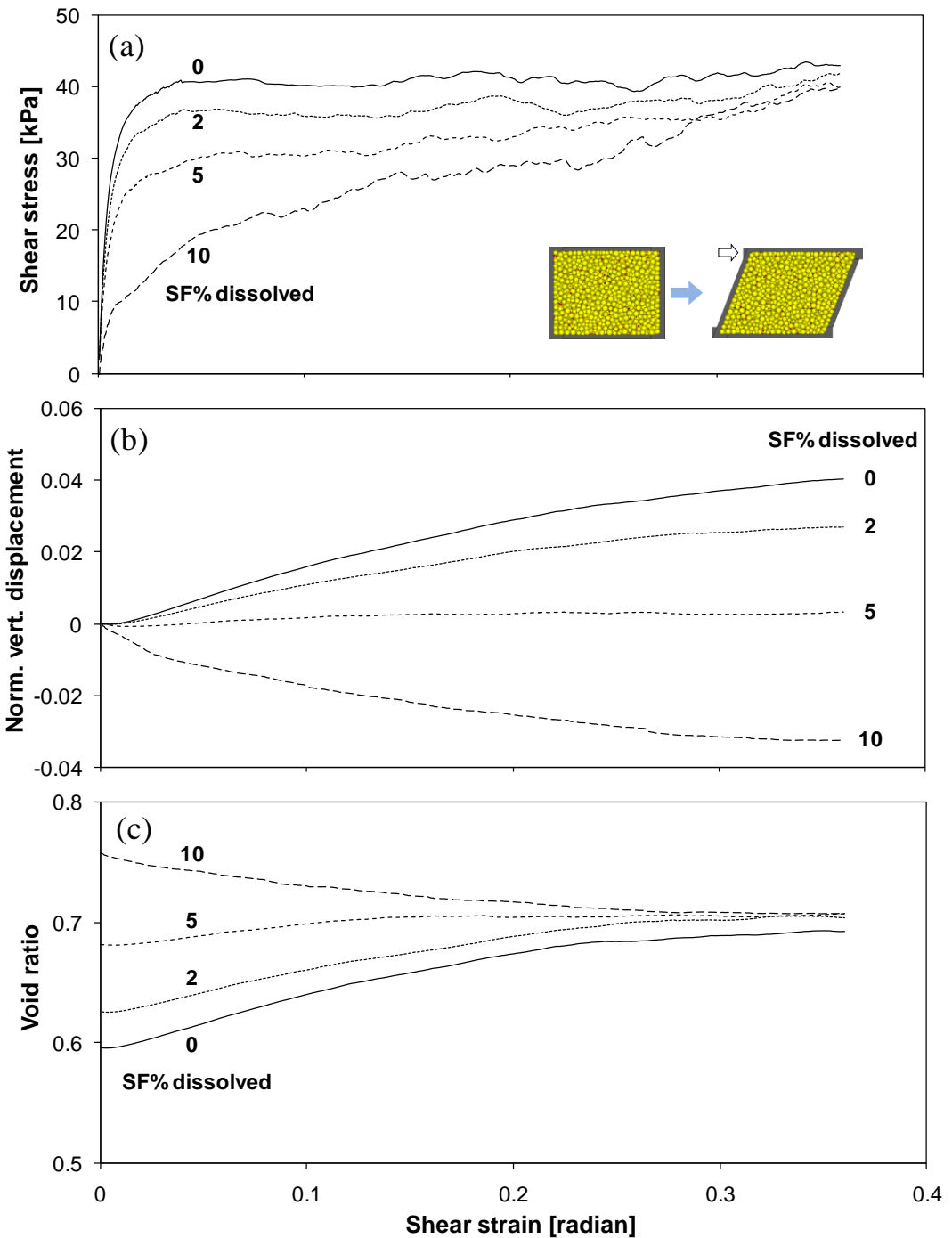


Sediments under $\sigma' \rightarrow e \uparrow$



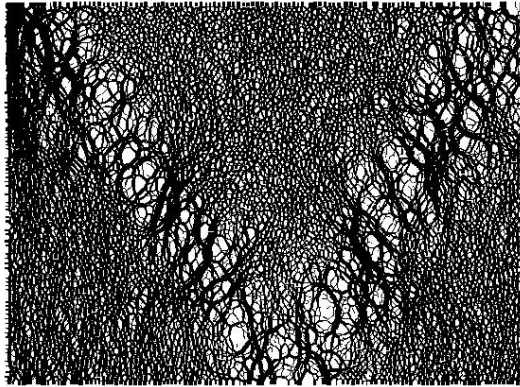
Post Dissolution Shear

homogeneous
distribution of
dissolvable mass

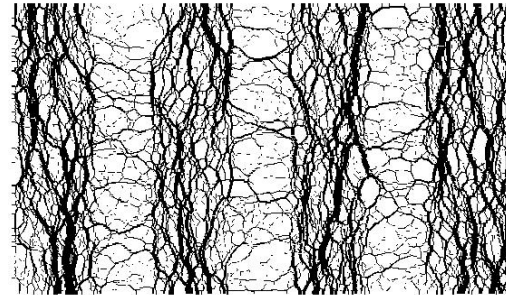


Dissolution Modes in Sediments

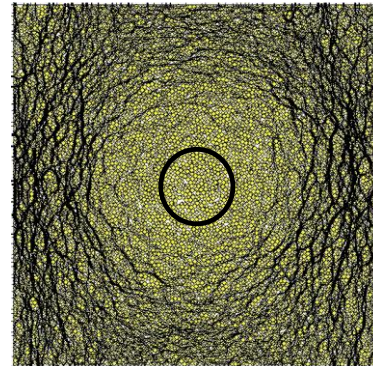
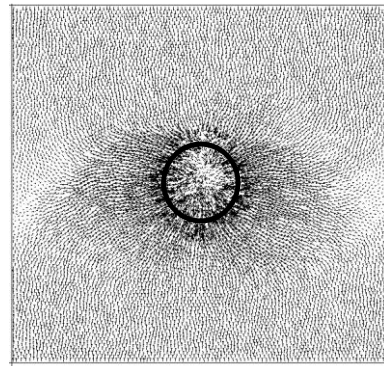
Pressure Solution



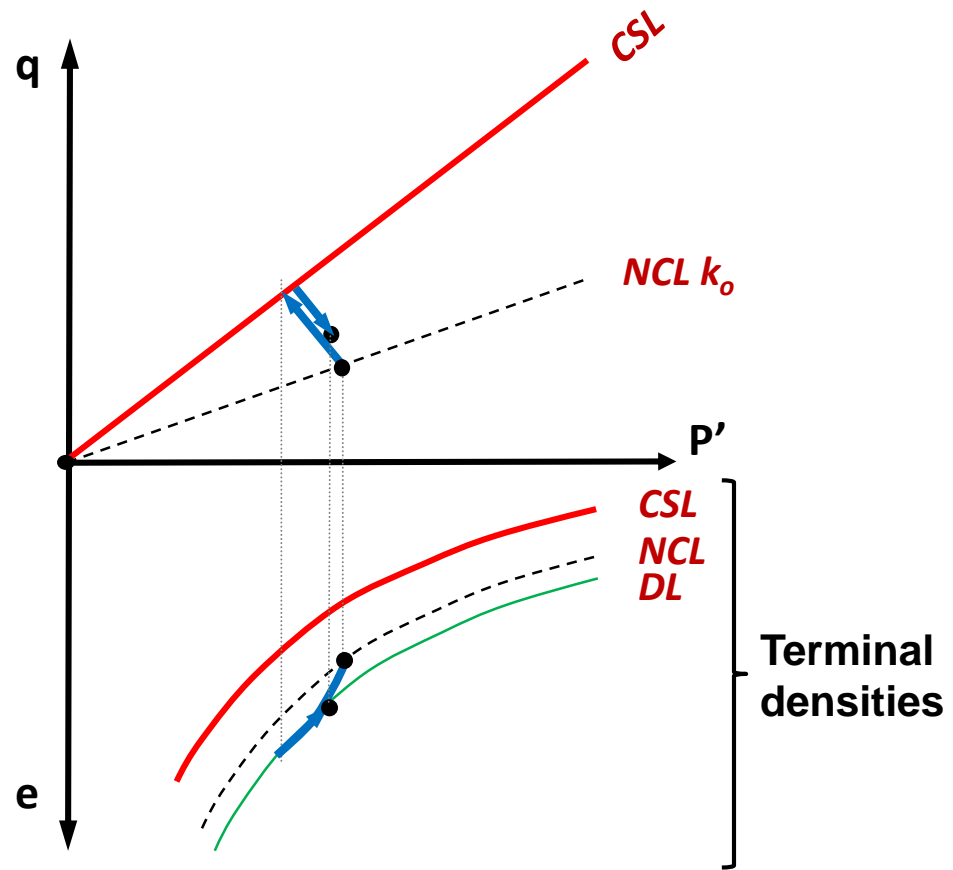
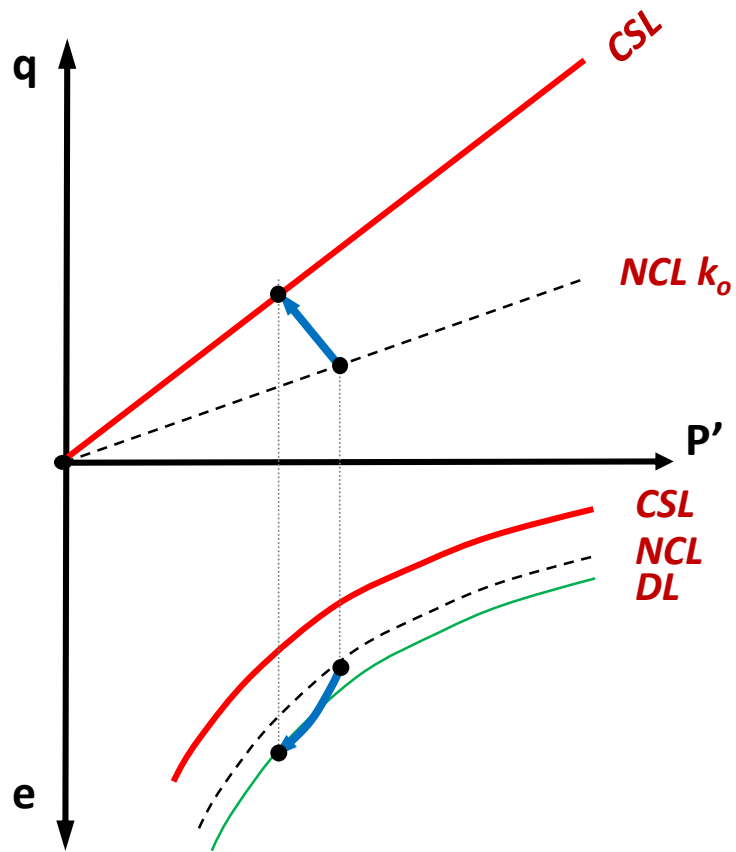
Fingers (advection)



Heterogeneous
distribution
dissolvable mass



Dissolution in eqp' Space

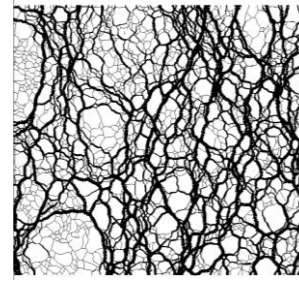
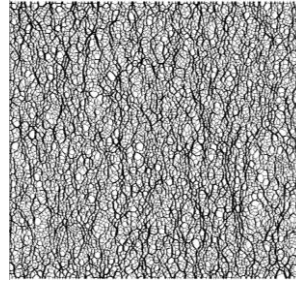


But...

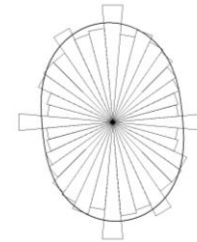
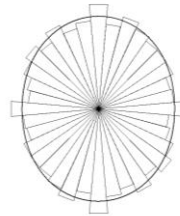
**Before
dissolution**

**After
dissolution**

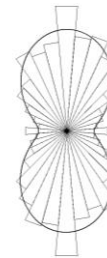
**Chains of contact
normal forces**



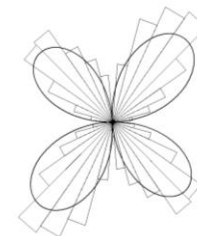
Number of contacts



**Average normal
contact forces**



**Average tangential
contact forces**



Drained dissolution ... undrained shear?

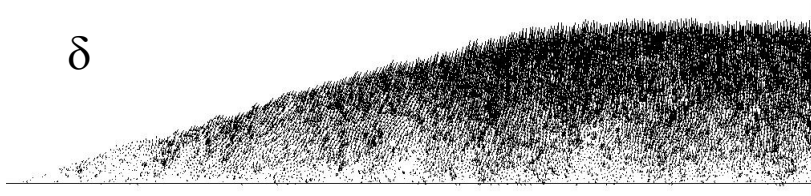
Initial N



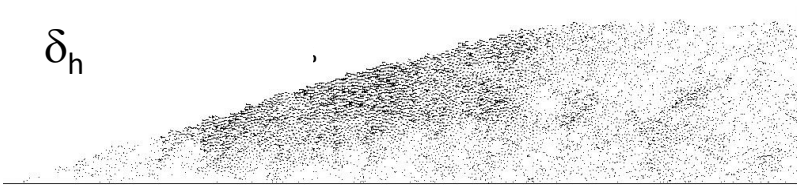
N after dis.



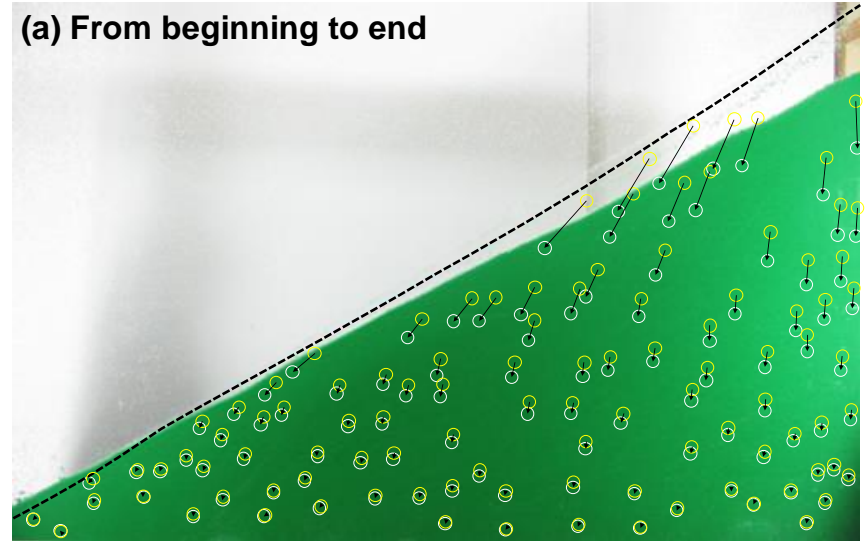
δ



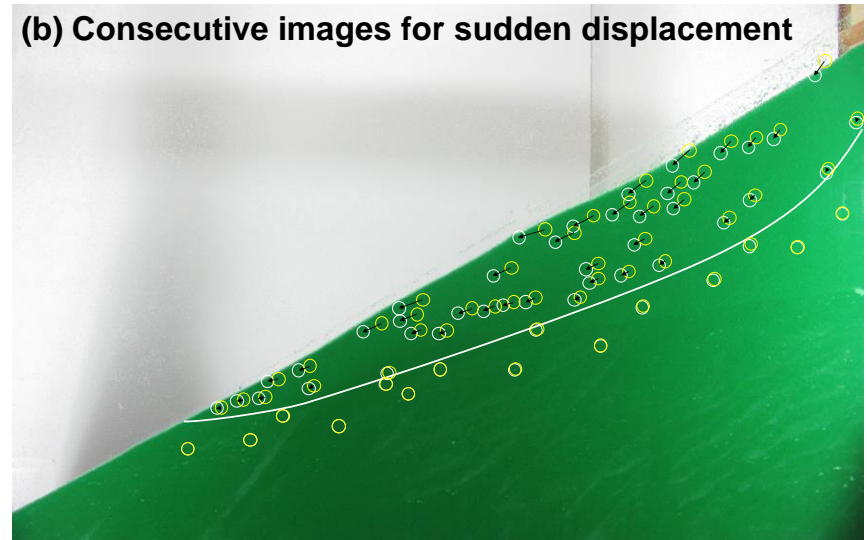
δ_h



(a) From beginning to end



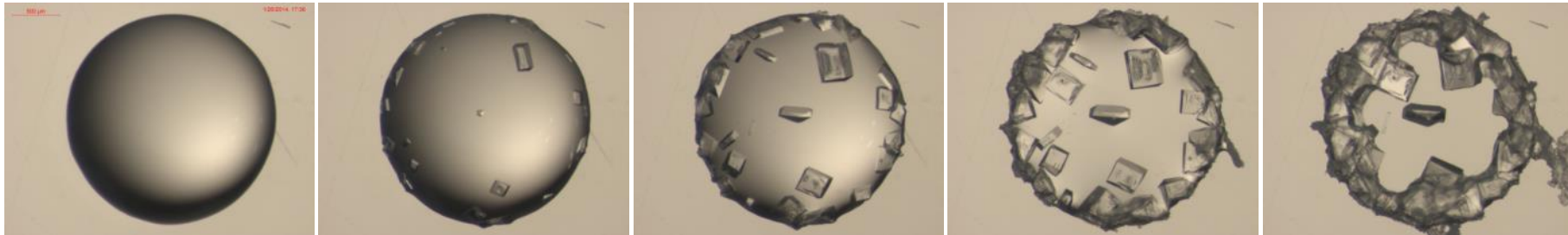
(b) Consecutive images for sudden displacement



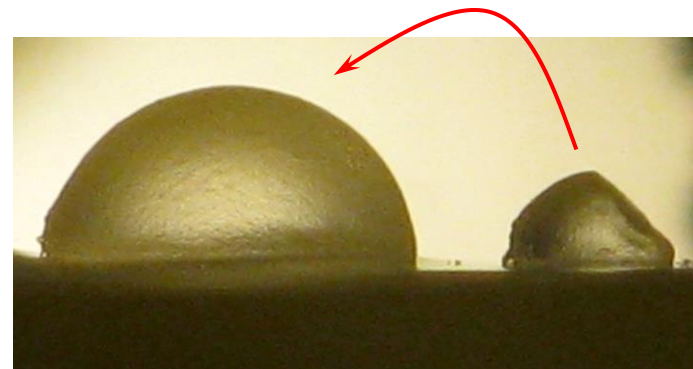
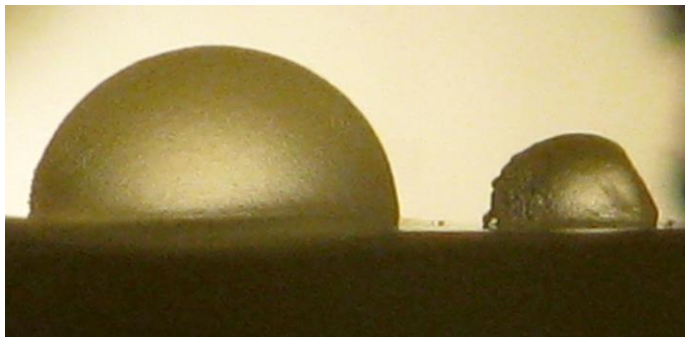
Precipitation

Precipitation

NaCl Precipitation



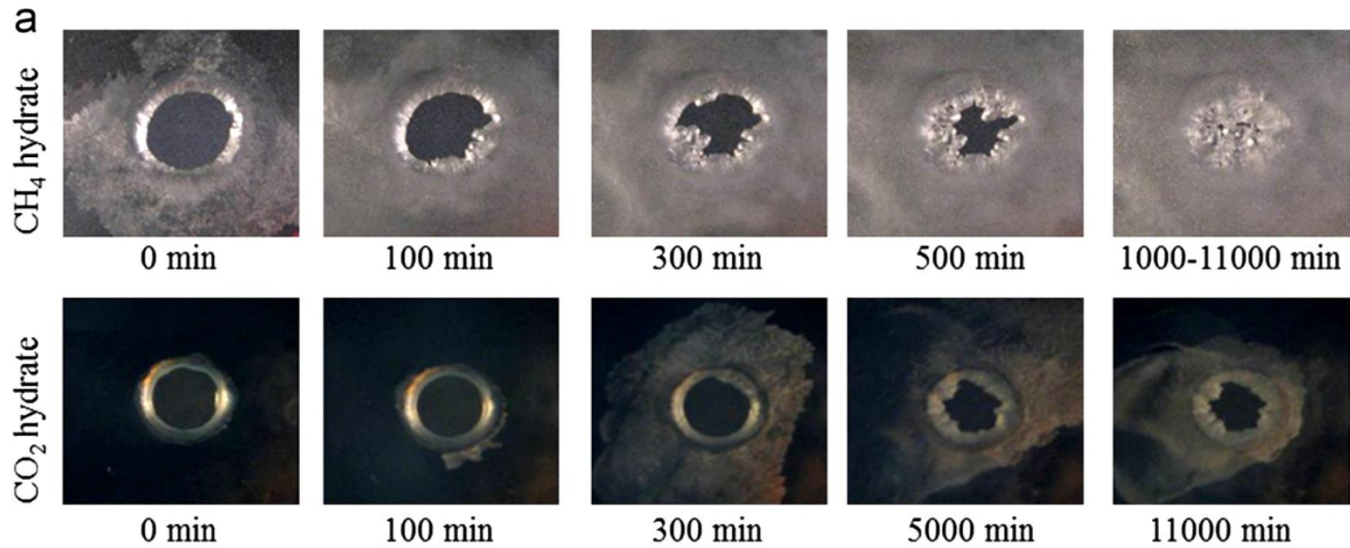
Ostwald Ripening (CO₂ Hydrate)



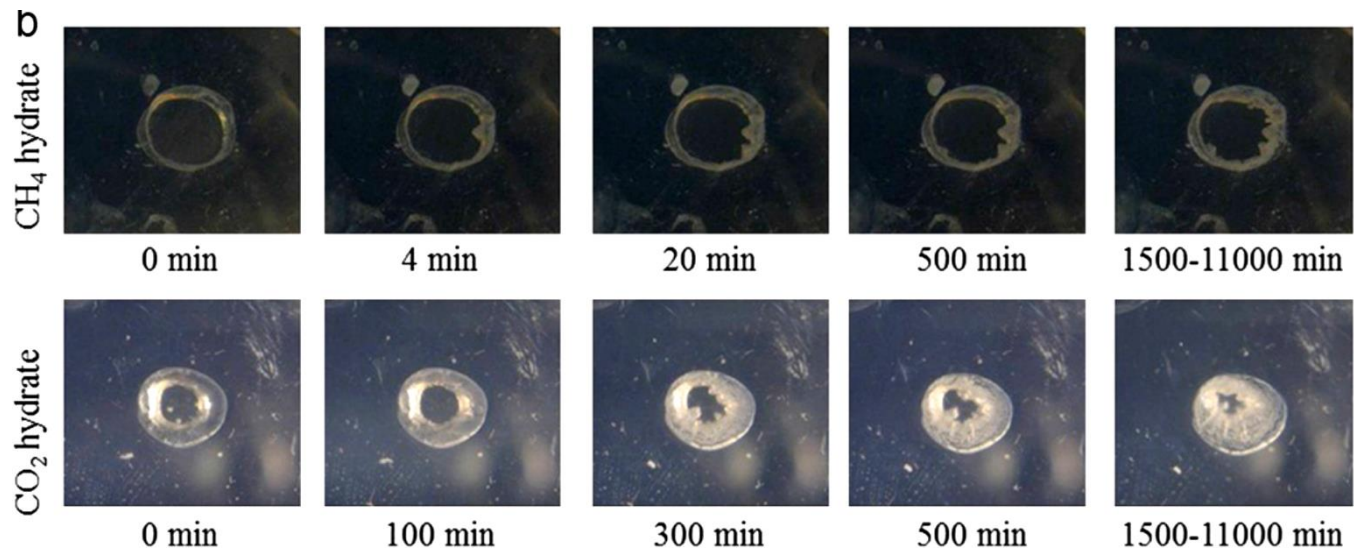
($P = 6\text{MPa}$, $T = 2.5\text{C}^\circ$)

Phase Transformation

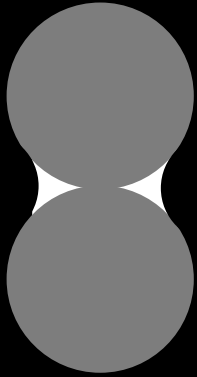
hydrophilic



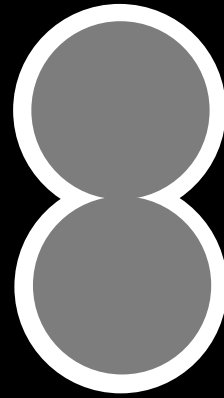
hydrophobic



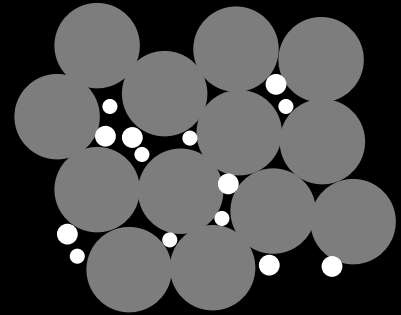
Precipitation – Pore Habit



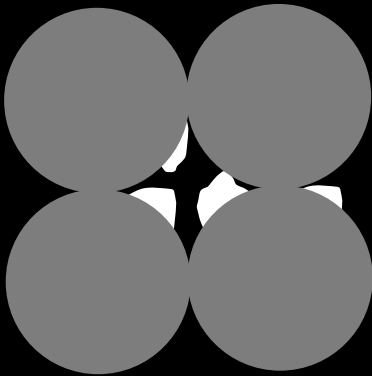
at contact



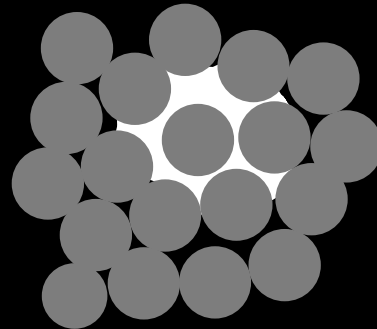
surface coating



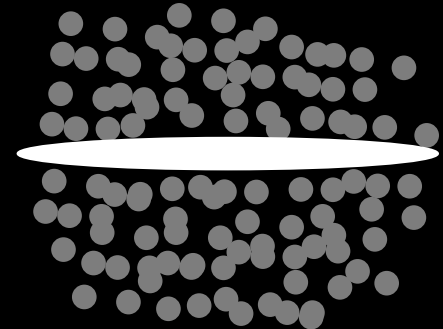
homogeneous nucleation



heterogeneous nucleation

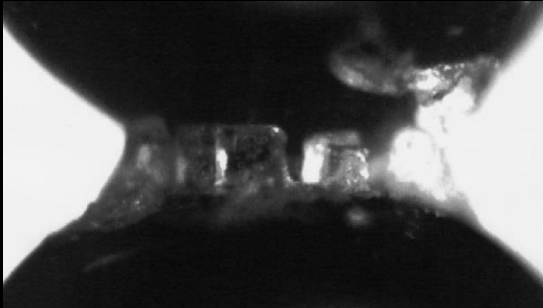


patchy (ripening)

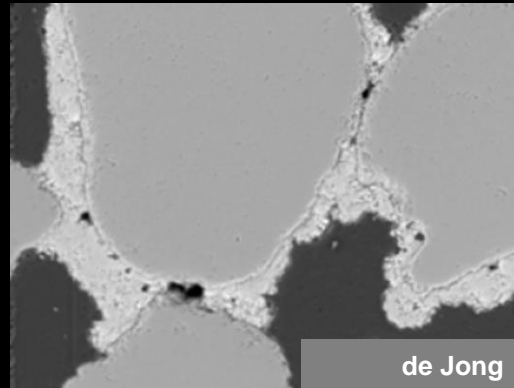


segregated (lenses)

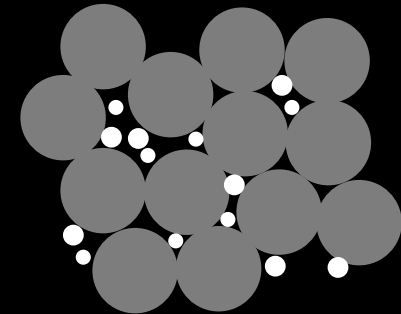
Precipitation – Pore Habit



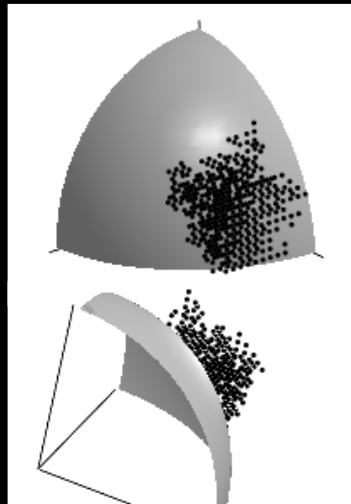
at contact



surface coating



homogeneous nucleation



heterogeneous nucleation

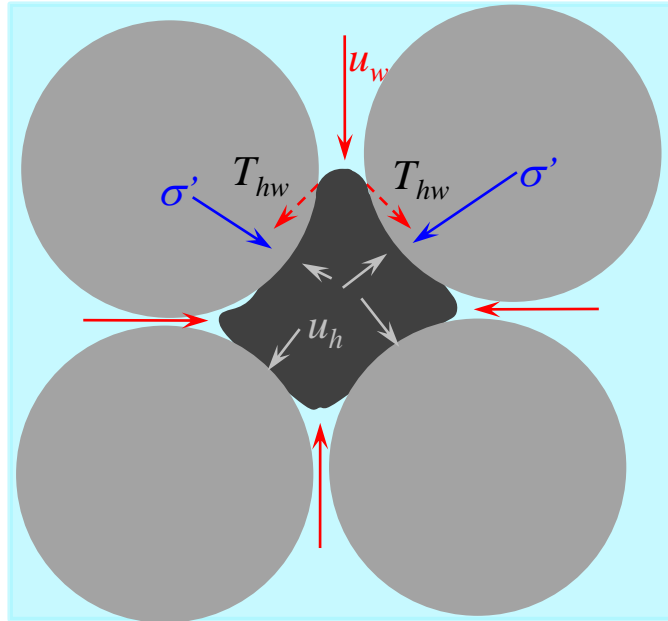


patchy (ripening)



segregated (lenses)

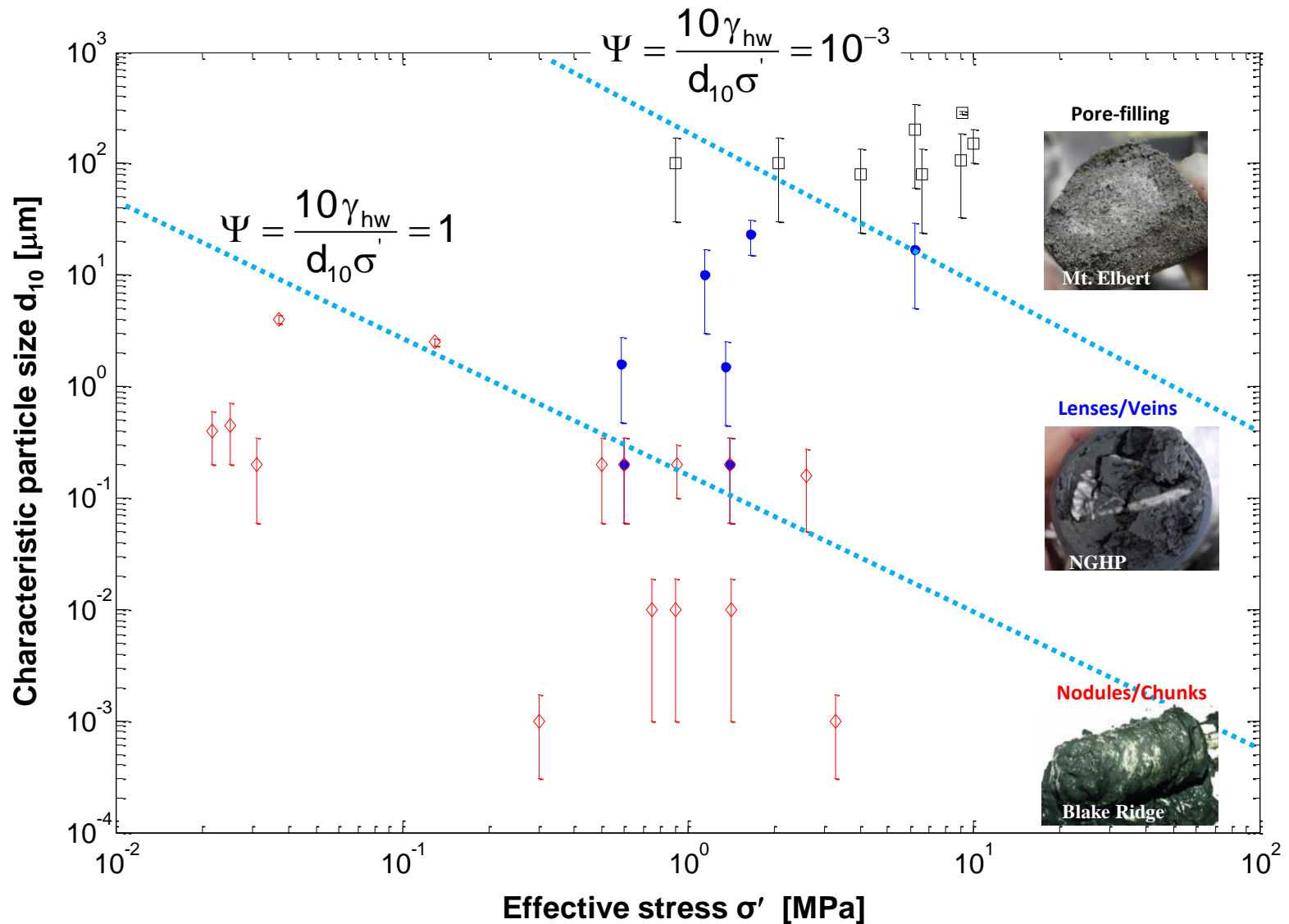
Pore Invasion or Grain Displacement?



$$\frac{F_{cap}}{F_{eff}} = \frac{2 \frac{\gamma_{hw}}{r_{pore}} d^2}{\sigma' d^2} = 12 \frac{\gamma_{hw}}{\sigma' d}$$

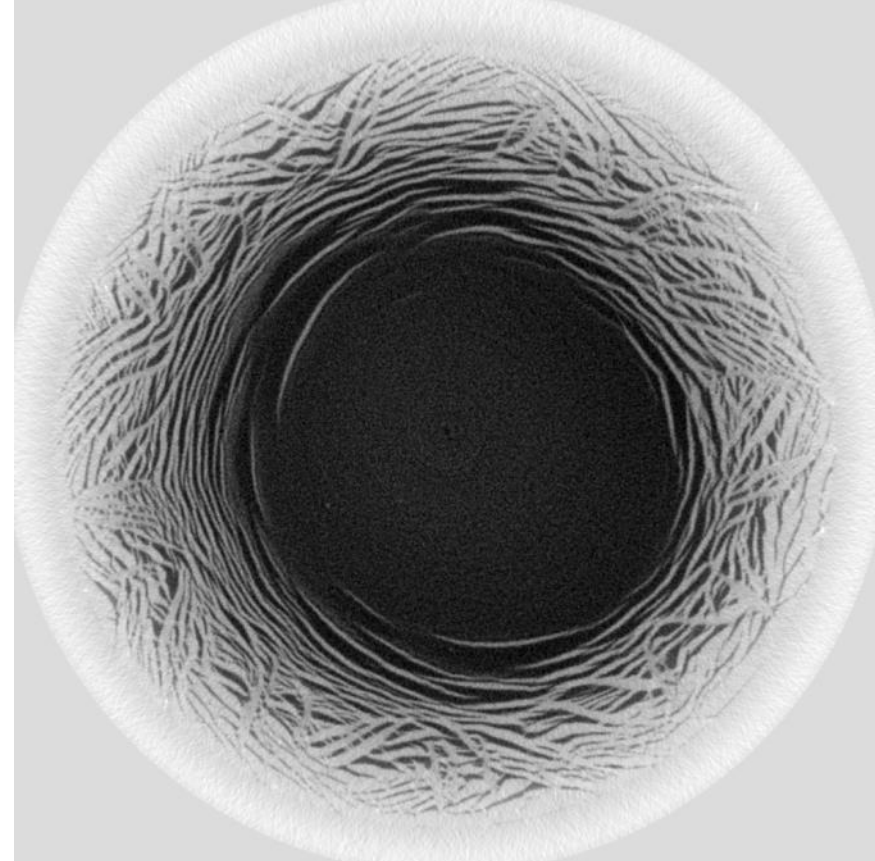
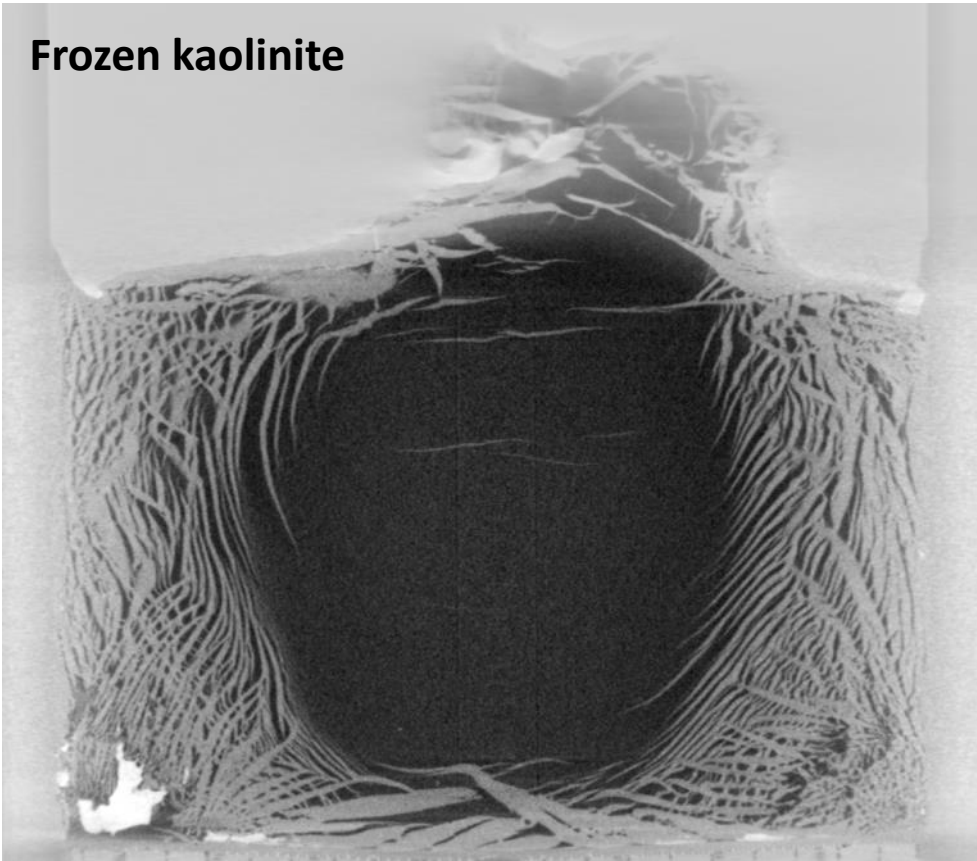
$$\gamma_{hw} = 0.032 \text{ N/m}$$

Pore Invasion or Grain Displacement?



Segregation: $\Delta\sigma'$ \leftrightarrow Precipitation Topology

Frozen kaolinite

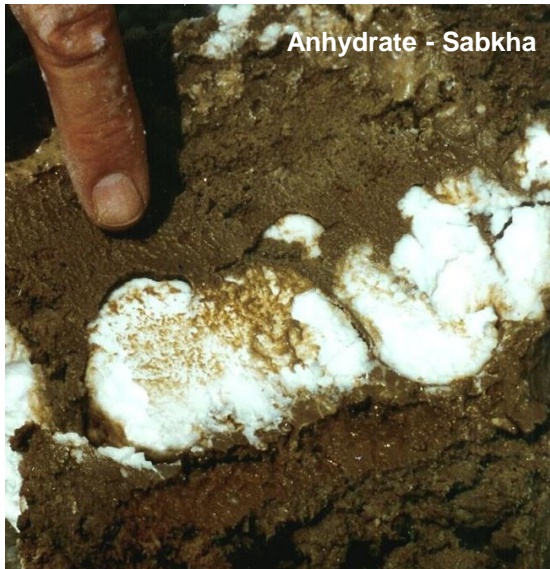


With Cino Viggiani & E. Ando

Segregated Precipitation



<http://whataearth.com/product/desert-rose>

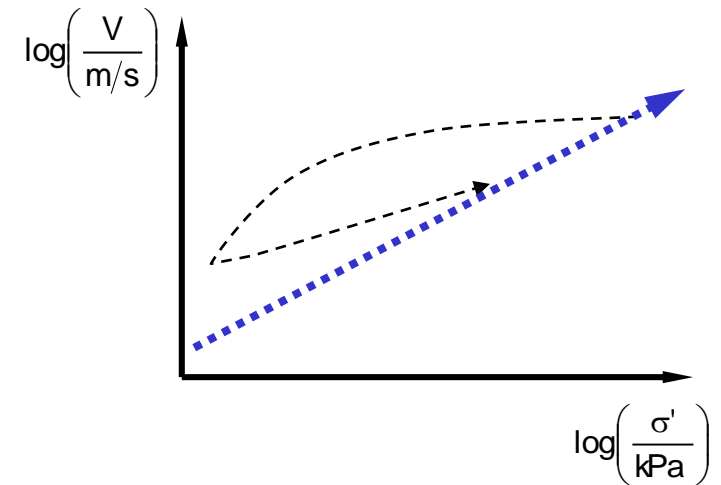
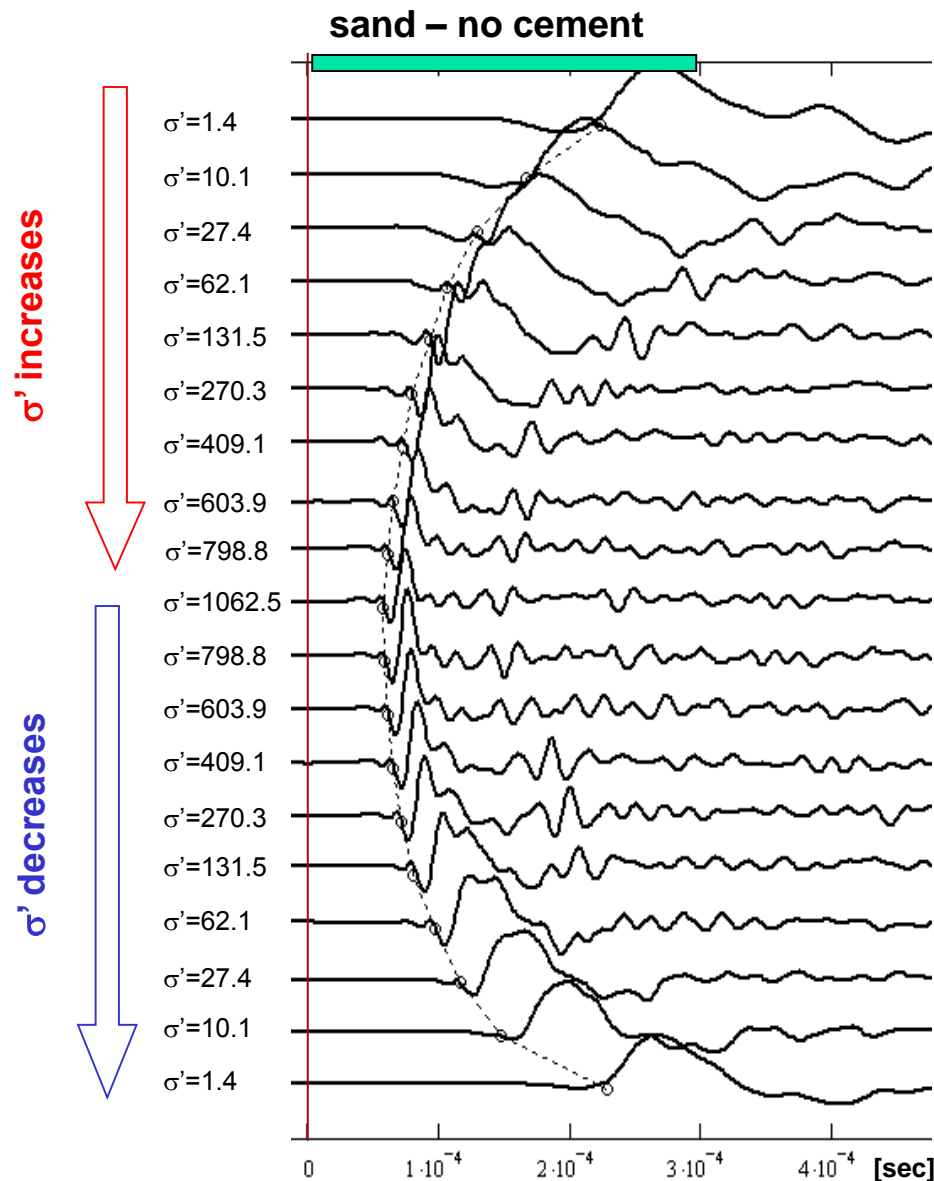


<http://www.southampton.ac.uk/~imw/Qatar-Sabkhas.htm>

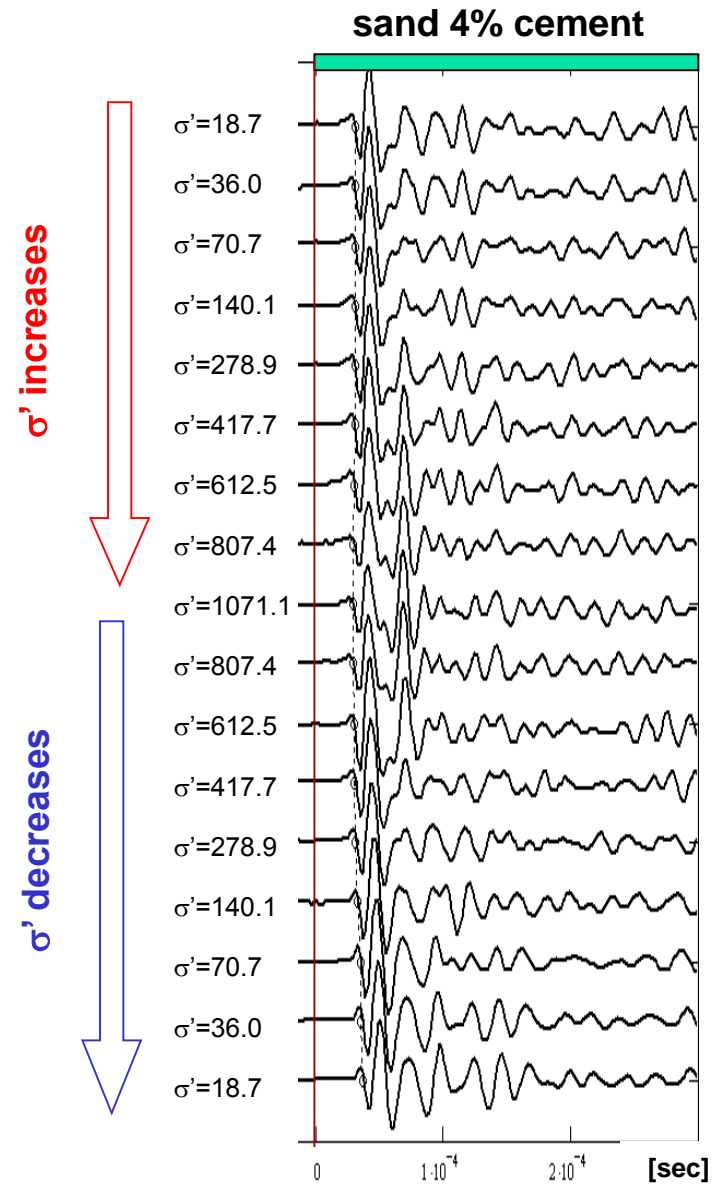
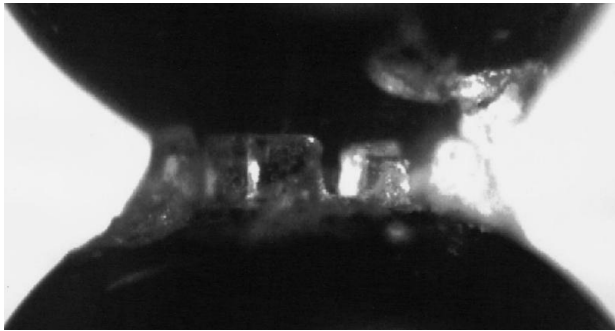


www.flickr.com/

No Precipitation: Effective stress

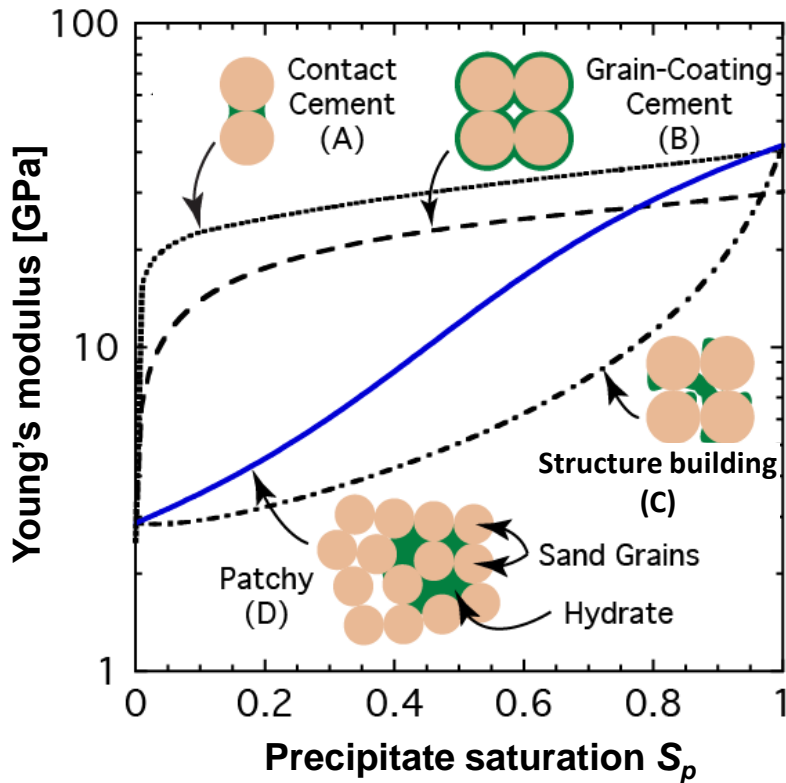


Contact Precipitation

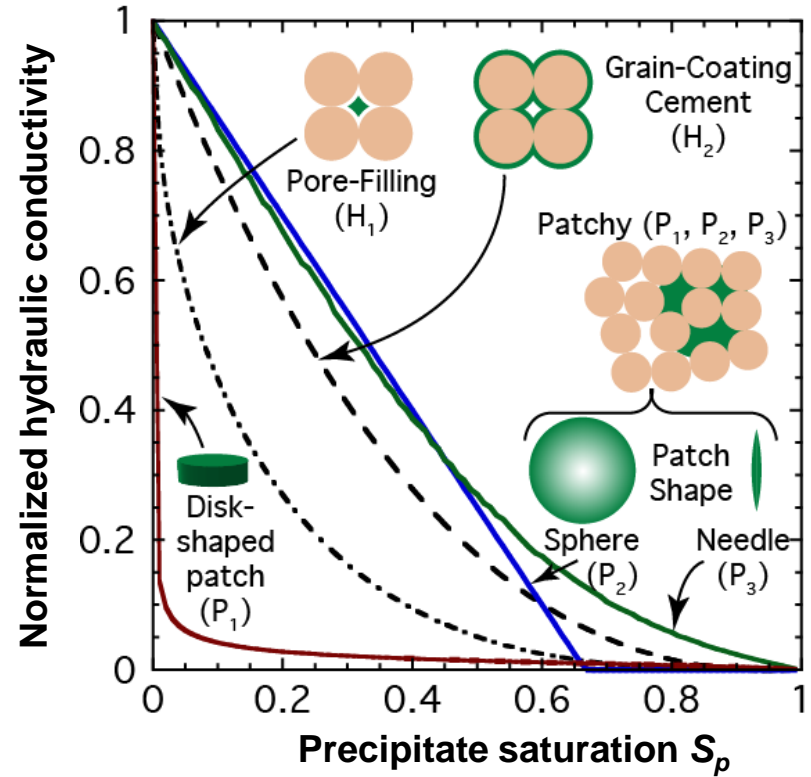


Effective Properties

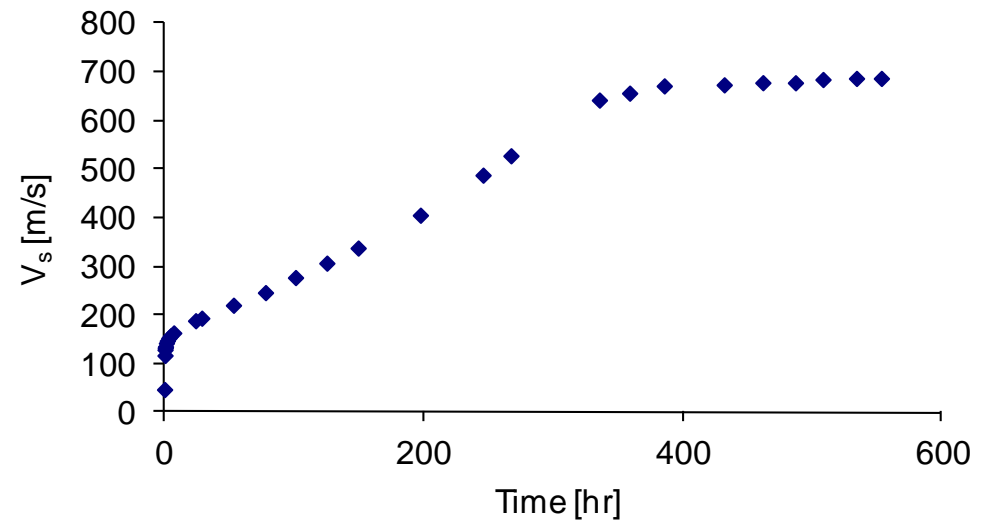
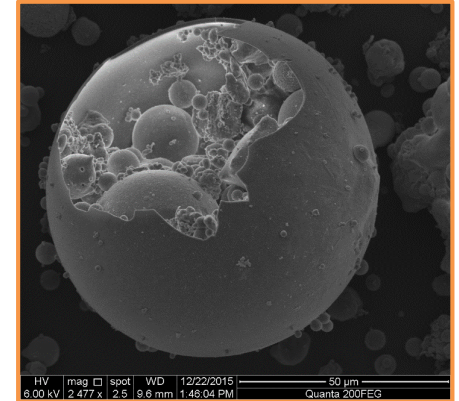
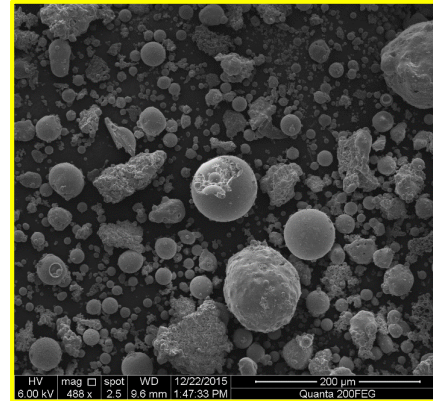
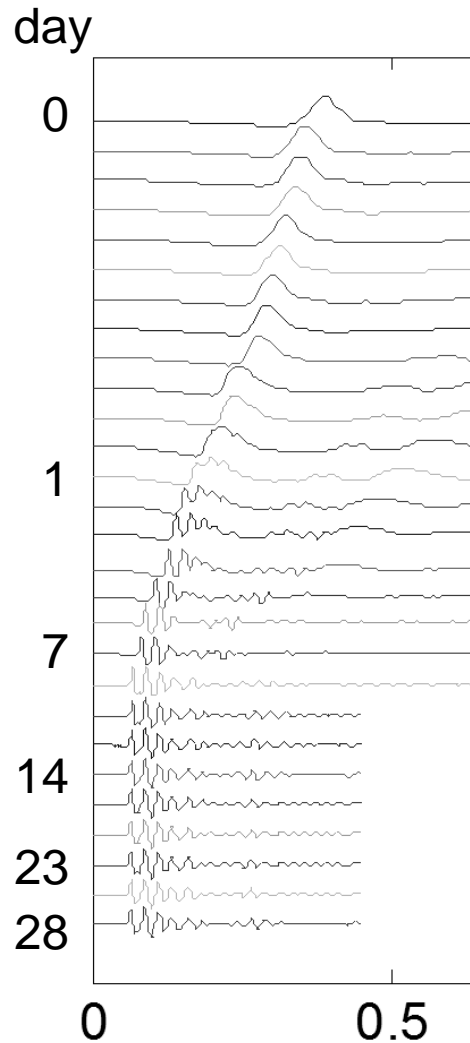
Stiffness



Hydraulic Conductivity



Time Scale for Diagenetic Cementation?



Closing Thoughts

Conclusions

Dissolution and precipitation:

Natural geological processes

Often triggered by engineered systems

Time scale: May be short (relative to engineering scale)

Pore habit Macroscale effects

Dissolution: Terminal condition $e \uparrow$ $k_o \downarrow$
Positive feedback in advection: localization
Increased brittleness

Precipitation: Terminal condition $e \rightarrow 0$
Increased stiffness
Increased dilatancy (even when $e_o > e_{cs}$)
Pore filling vs. grain displacement \rightarrow effective properties

A sunset scene over the ocean. The sun is a bright orange circle in the center of the sky. The sky transitions from a pale orange near the horizon to a darker, muted orange at the top. The ocean is a dark blue-grey color. In the foreground, there are silhouettes of palm fronds at the top and other foliage at the bottom.

Minsu Cha (TAMU)

Hosung Shin (Ulsan U.)

Liang Lei (GT/KAUST)

Thank you