

Hellenic Society For Soil Mechanics And Geotechnical Engineering

Athens

September 16, 2013

Thessaloniki

September 17, 2013

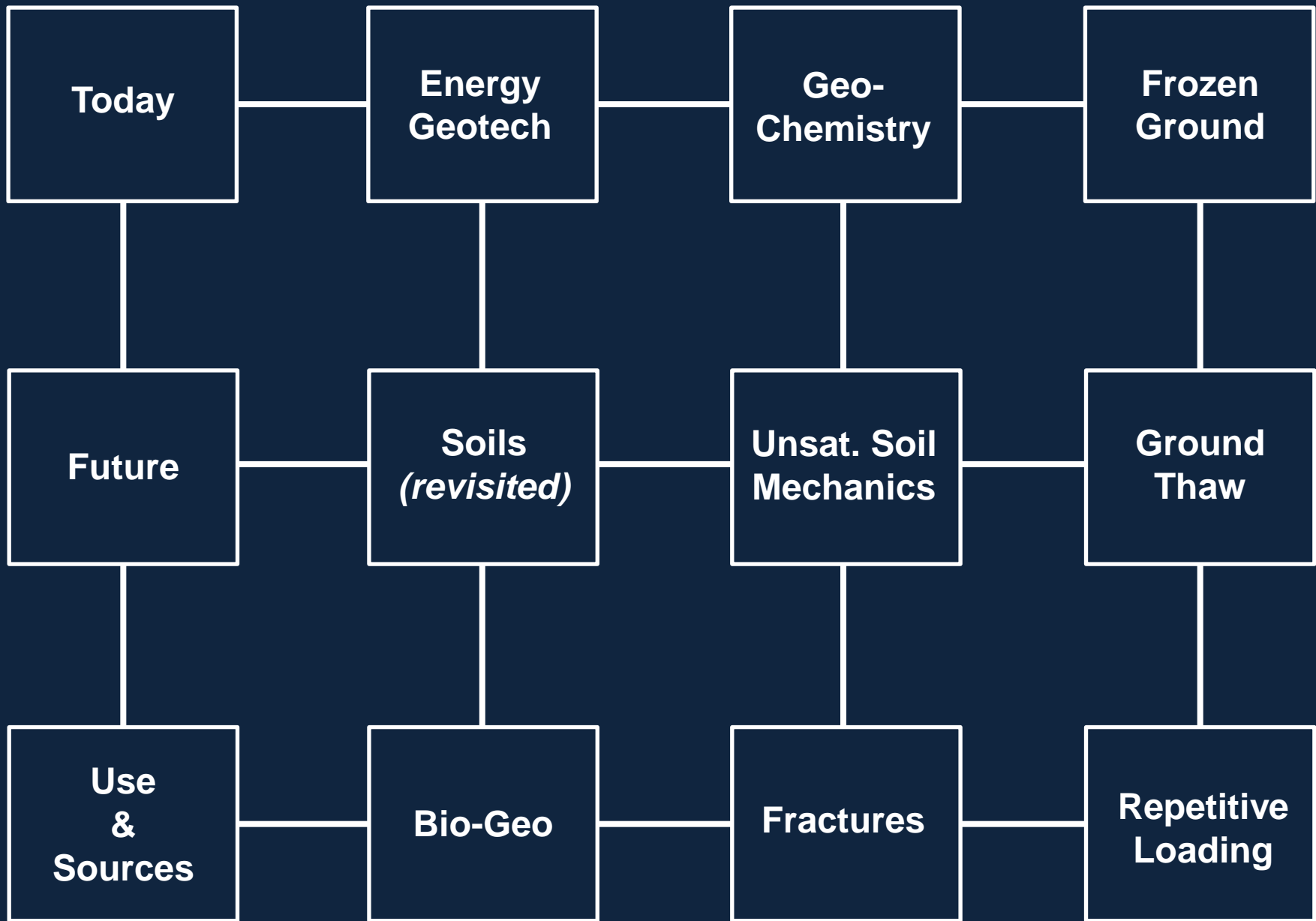
Energy Geotechnology

J. Carlos Santamarina

Georgia Institute of Technology

Distribution Copy:

References added for further reading
Click on links to see pdf files
Note: Academic use only



Energy: News

Deepwater Horizon (April 20, 2010)

Deepwater Horizon



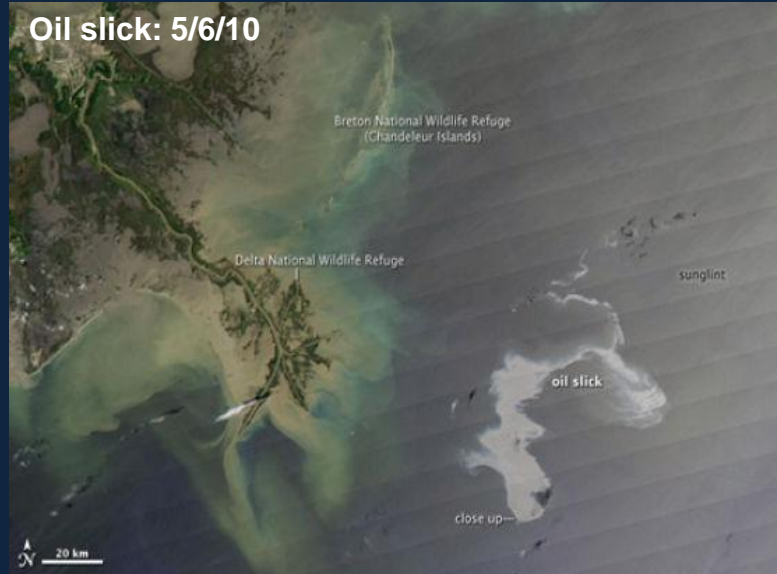
Explosion: 4/20/10 (@10 pm)



Sinks: 4/22/10 (~10 am)



Oil slick: 5/6/10



Energy: News

Fukushima I Nuclear Power Plant (March 11, 2011)



abcnews.go.com



www.dailykos.com



Energy: Civic Journalism



GASLAND

Energy: Civic Journalism



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Energy: Civic Journalism



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GASLAND

Energy: Advertisement

IN THE NEW ENERGY FUTURE, WE'LL NEED TO THINK THE IMPOSSIBLE IS POSSIBLE.

Shell

Carbon capture & storage

Every dollar invested in energy efficiency today could return two dollars in energy savings.

Chevron Human Energy®

I will finally get a programmable thermostat.

Efficiency and conservation

One way out of the energy fix: an energy mix.

bp beyond petroleum®

Alternative sources

intel Sponsors of Tomorrow™

Computing intelligence has changed the world. Now, for the power grid.

Smart grid

ABB

Connect emission-free power to the grid?

C-free energy & the grid

Algae-powered cars: Science fiction or science?

ExxonMobil Taking on the world's toughest energy challenges.™

Renewable sources



**Energy
Geotech**

**Geo-
Chemistry**

**Frozen
Ground**

Future

**Soils
(revisited)**

**Unsat. Soil
Mechanics**

**Ground
Thaw**

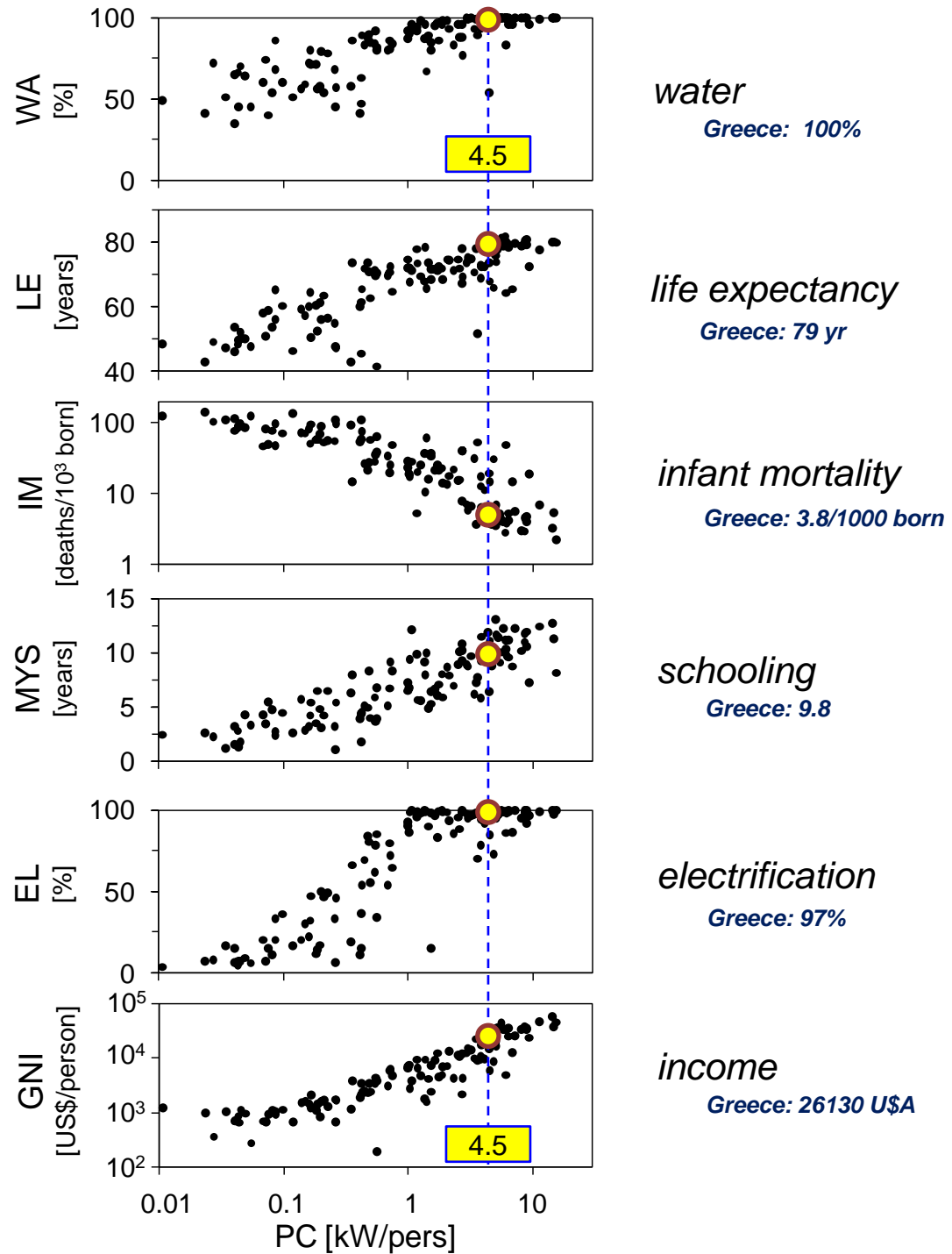
**Use
&
Sources**

Bio-Geo

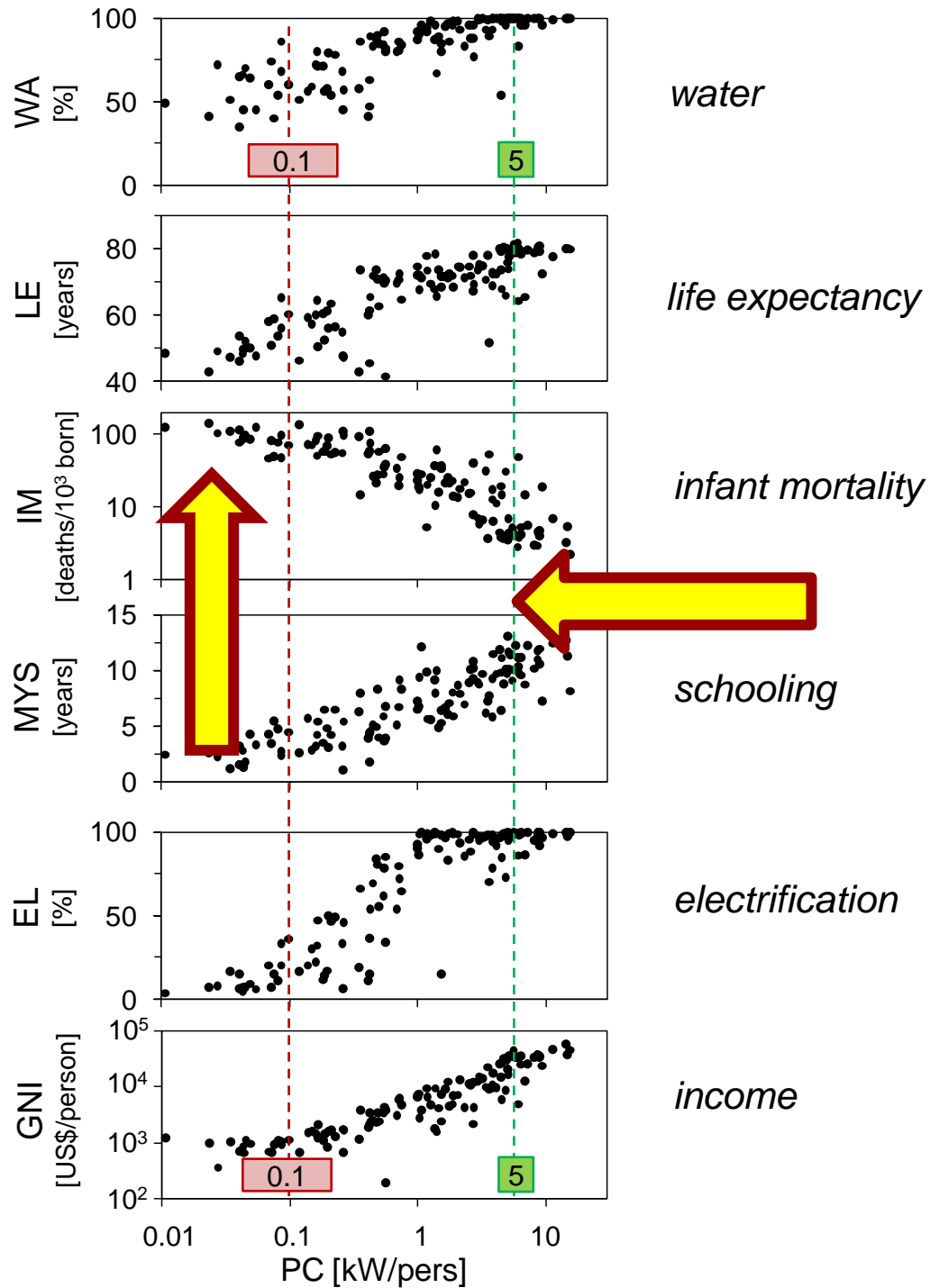
Fractures

**Repetitive
Loading**

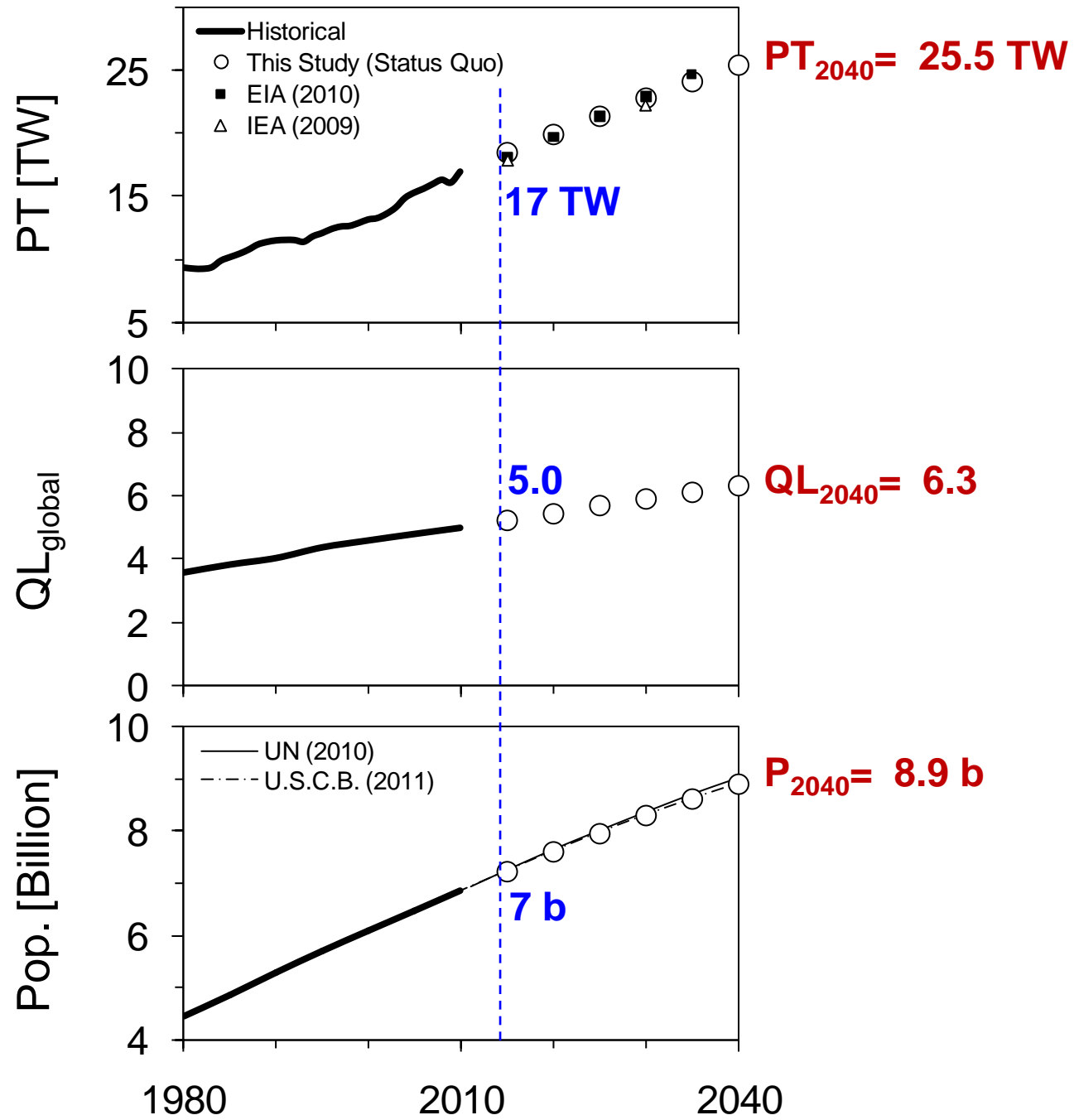
Energy and Life



Energy and Life



Status Quo





**Energy
Geotech**

**Geo-
Chemistry**

**Frozen
Ground**



**Soils
(revisited)**

**Unsat. Soil
Mechanics**

**Ground
Thaw**

**Use
&
Sources**

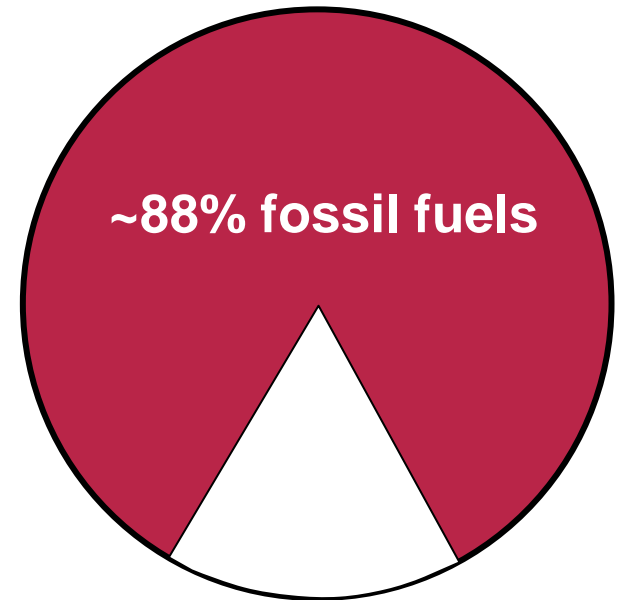
Bio-Geo

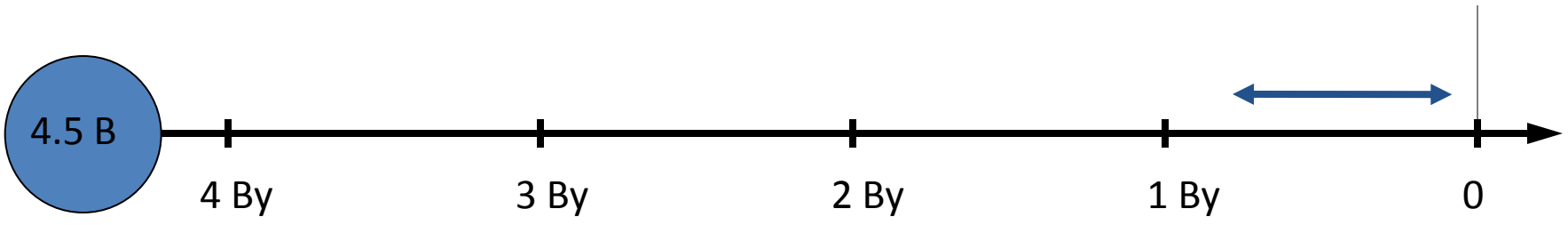
Fractures

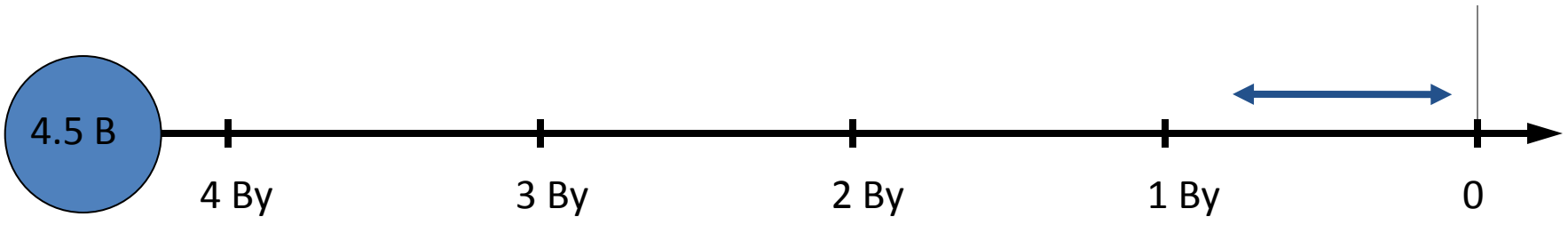
**Repetitive
Loading**

Sources

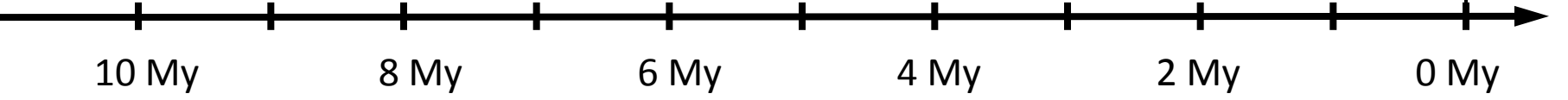
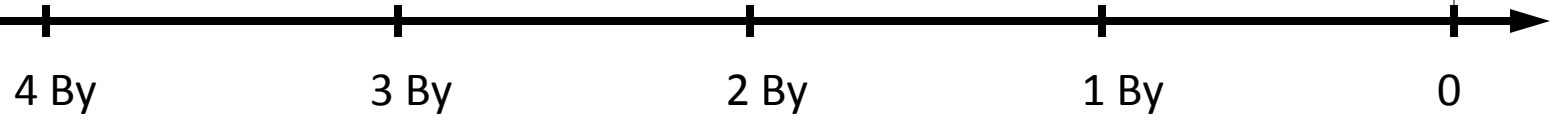
37%	petroleum	transport
24%	natural gas	heat&power
23%	coal	power
4 %	biomass (renewable)	industrial
<hr/>		
8%	nuclear power	power
2%	hydroelectric	power
< 2%	renewable non-hydro	power







4.5 B



4.5 B

4 By

3 By

2 By

1 By

0



10 My

8 My

6 My

4 My

2 My

0 My

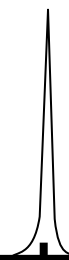
-6000 yr

-4000 yr

-2000 yr

0

2000 yr



Fossil Fuel: 88%



Summary: Energy and Life

Quality of life: current development patterns: HDI ↔ Energy

By 2040: Δ -energy ~50%

most of the growth: developing countries

Resources: adequate **C-dependency** → **global warming**

Sustainable energy system:

	quality of life > 1 kW/person
developing	technological leapfrogging
	QL ↑ → population growth ↓
developed	technological breakthroughs
	efficiency and conservation < 4 kW/person
world	energy-for-life efficient governments

FOSSIL FUELS (C-BASED)

RENEWABLE

Nuclear

Petroleum

Gas

Coal

Wind

Solar

- fines & clogging
- sand production
- shale instability
- EOR
- heavy oil & tar sand

- gas hydrates
- gas storage
- low-T LNG found.

- characterization
- optimal extraction
- subsurface conv.

- off/onshore
- periodic load
- ratcheting

??

- engineered soils
- decommission
- leak detect
- leak repair

- mixed fluid flow, percolation
- contact angle & surface tension = $f(u_a)$

GEOLOGICAL STORAGE (energy and waste)

CO₂ sequestration

(Fly Ash)

- mineral dissolution → shear faults
- long-term containment
- upscaling geological properties

Energy Storage

- for peak demand (e.g., compressed air)
- pile-exchangers
- phase-change mixtures

Waste storage

10⁵ yr BTHCM

GEO-ENVIRONMENTAL REMEDIATION

- Bio-chemo-geo phenomena and methods

CONSERVATION

- Energy efficient construction technology: "Embodied Energy" in infrastructure projects
- Bio-mimetization: ant excavation: tunneling and new infrastructure; tree roots: smart/adaptable foundations

- **Hydro-electric:** capacity almost saturated
- **Biofuels:** strongly geo-related, BUT: water? land? food? energy efficiency?
- **Geothermal:** viable in "hot-spots" (high T rock performance, tools, monitoring, processes)
- **Tidal:** foundation engineering
- **Electric grid:** critical for renewable sources, CO₂ capture and storage



**Energy
Geotech**

**Geo-
Chemistry**

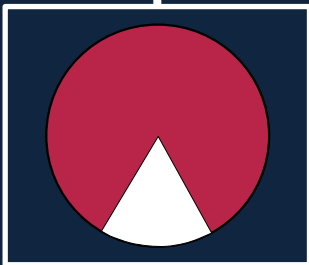
**Frozen
Ground**



**Soils
(revisited)
-pores-**

**Unsat. Soil
Mechanics**

**Ground
Thaw**



Bio-Geo

Fractures

**Repetitive
Loading**

Kingston Fossil Plant (12/22/2008)



Emory River

Amphibious Excavator
(~40 ft. long track,
~100 ft. boom reach)

Fly Ash Staging Ponds

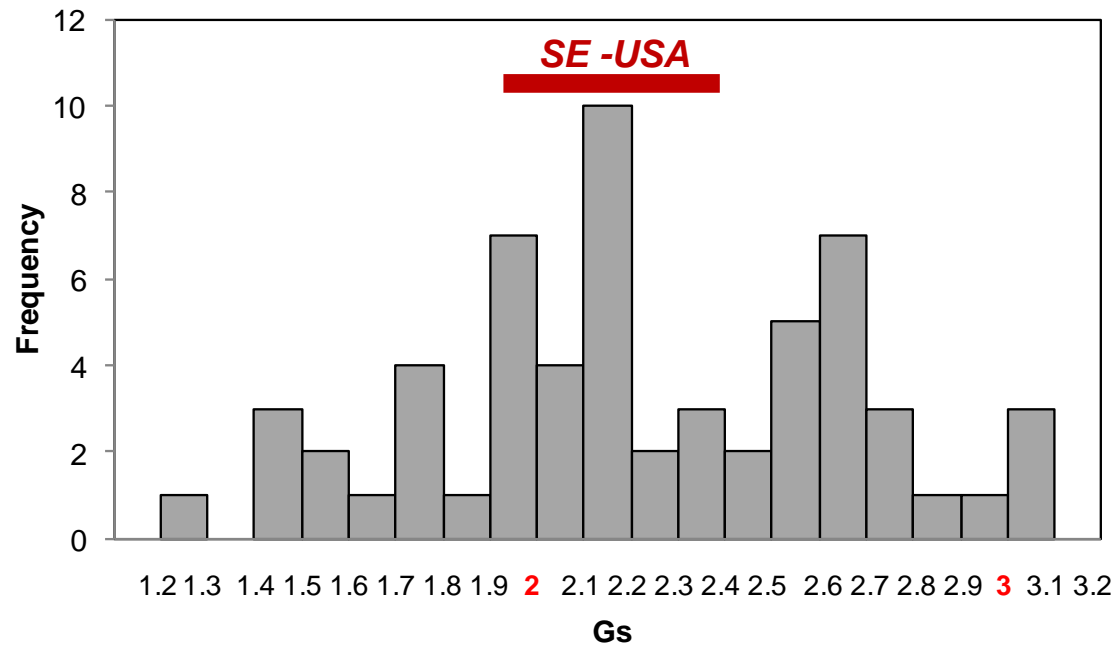
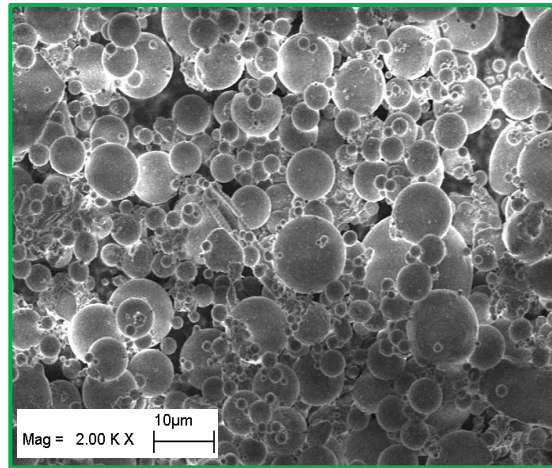
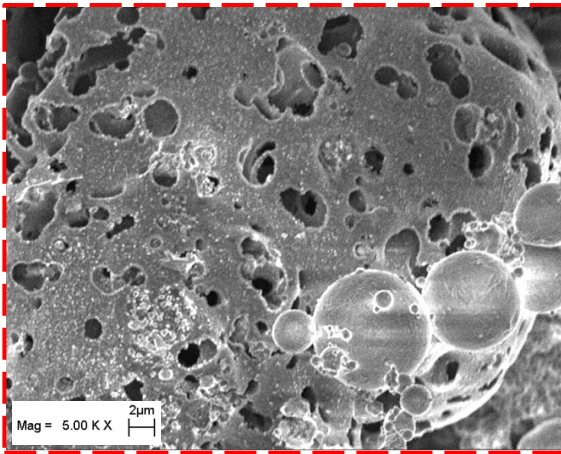
Fly Ash
Spill Area

Original
Fly Ash

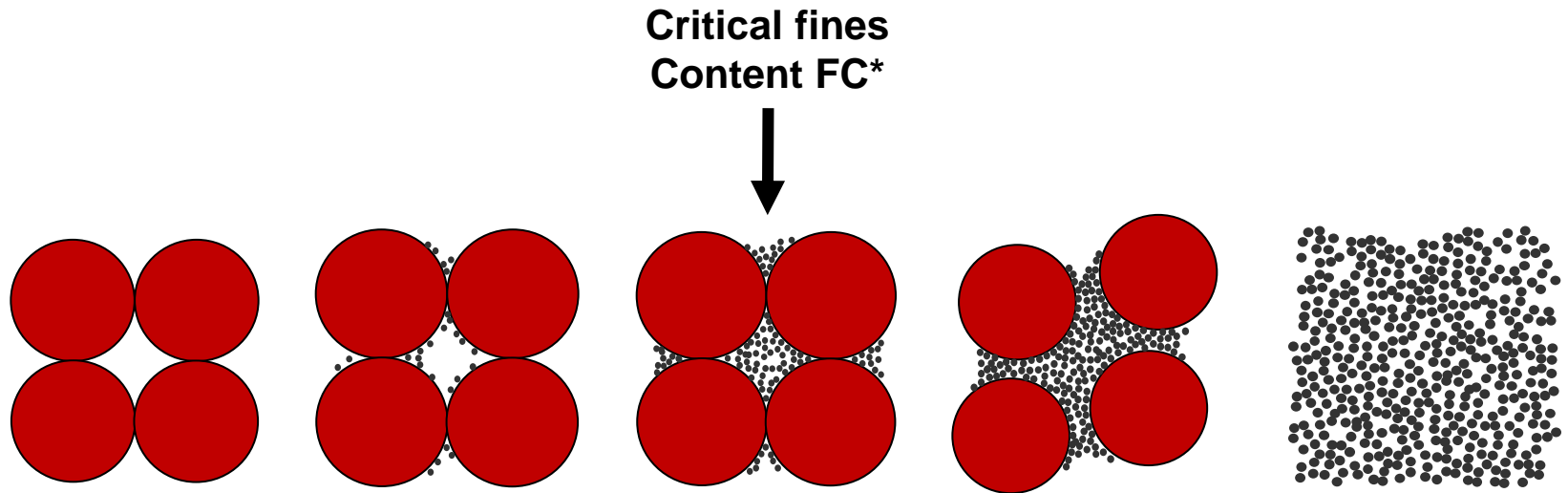
60 ft. relief

Freight Train

Specific Gravity

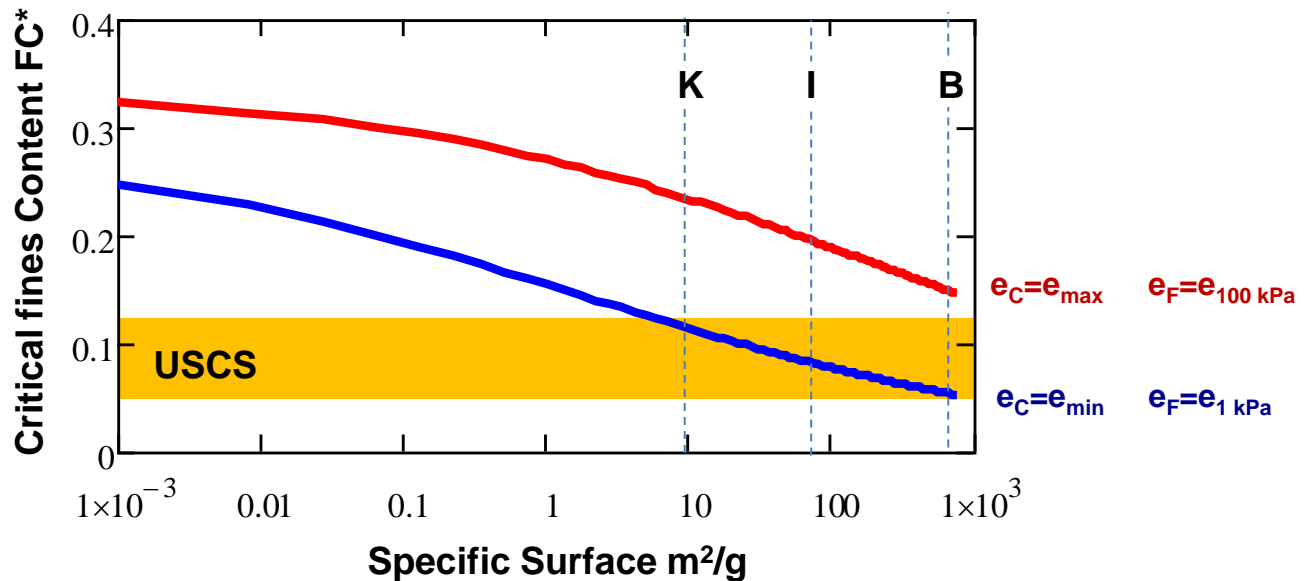
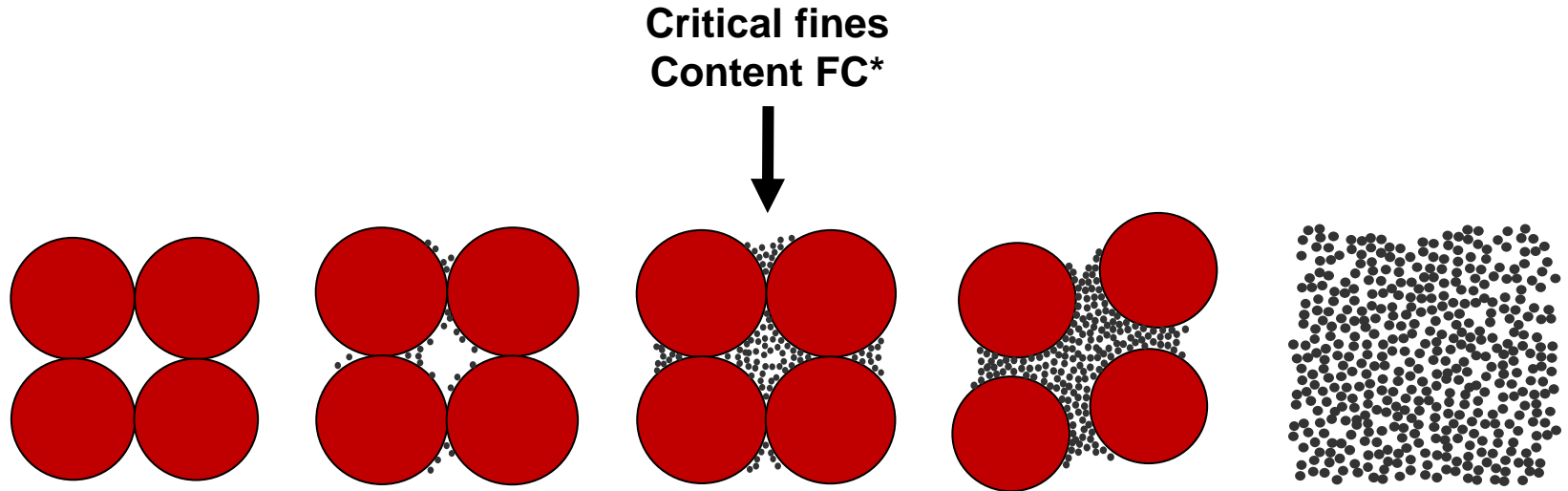


Grain Size Distribution: The Role of Fines

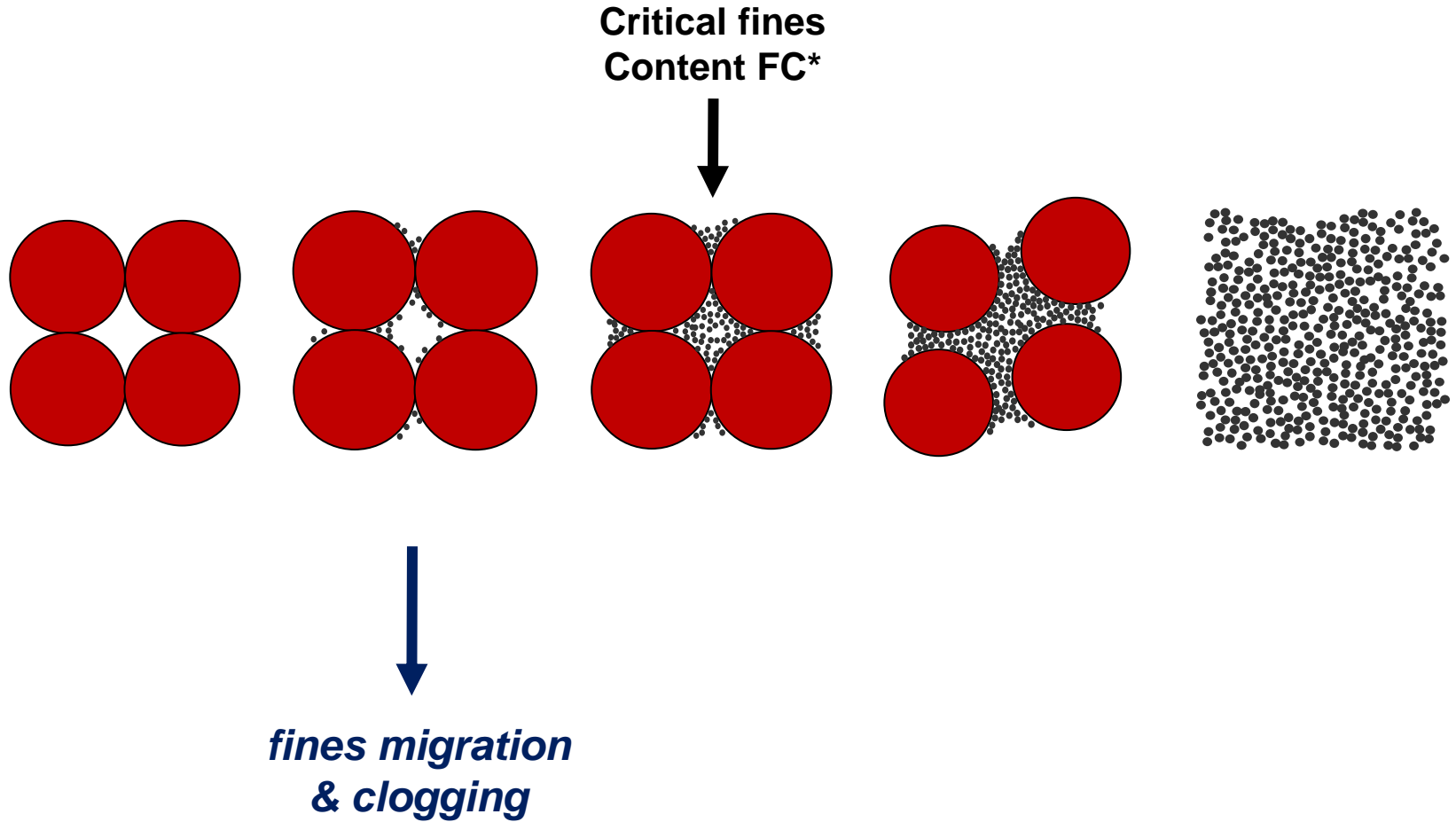


$$FC^* = \frac{M_{\text{fine}}}{M_{\text{total}}} = \frac{e_{\text{coarse}}}{1 + e_{\text{coarse}} + e_{\text{fine}}}$$

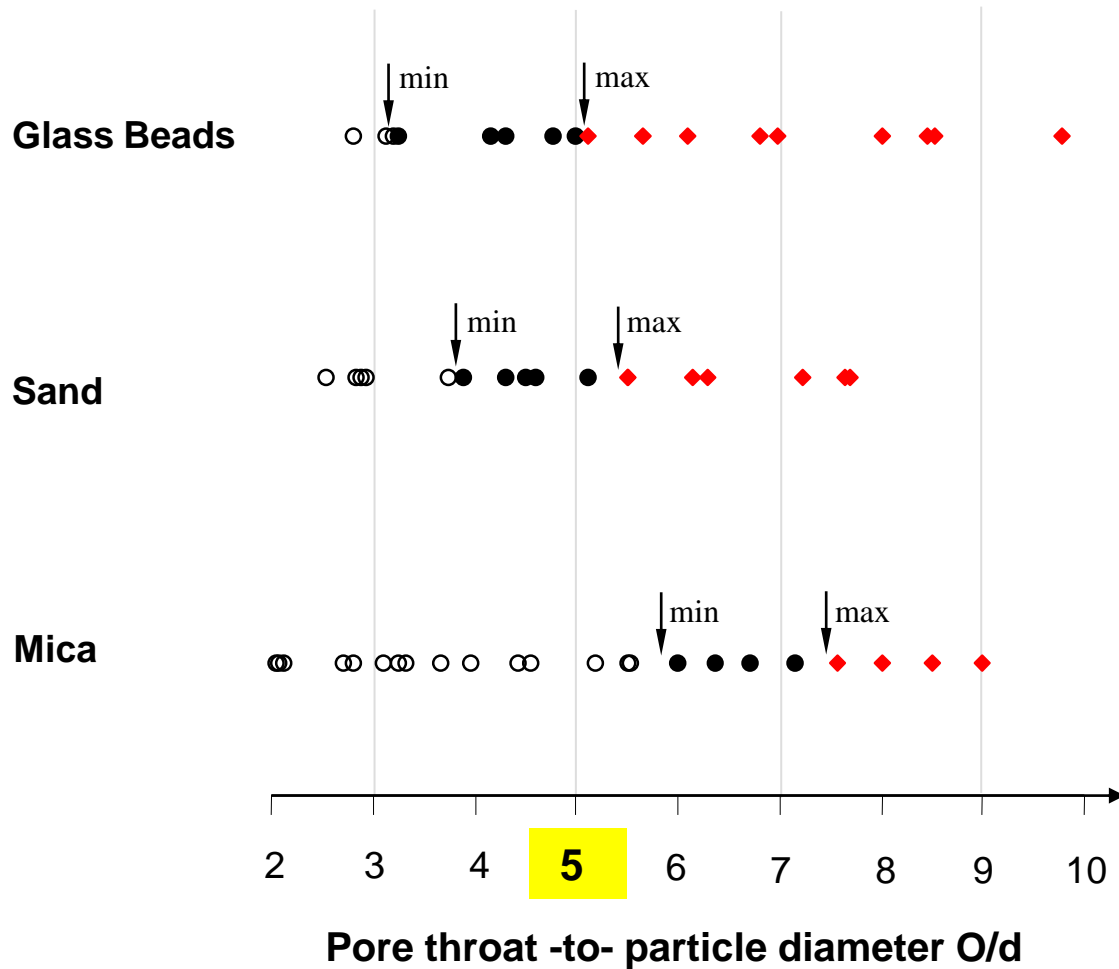
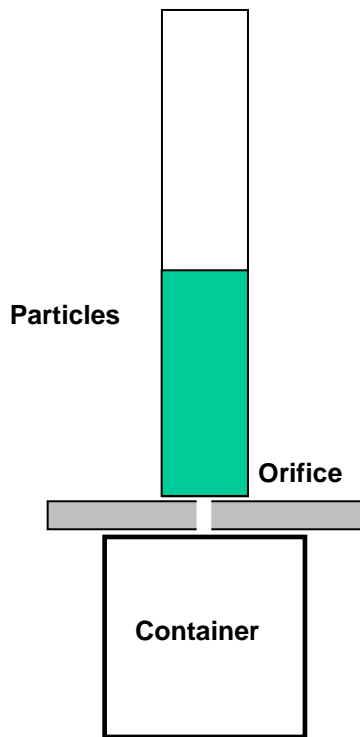
Critical Fines Content



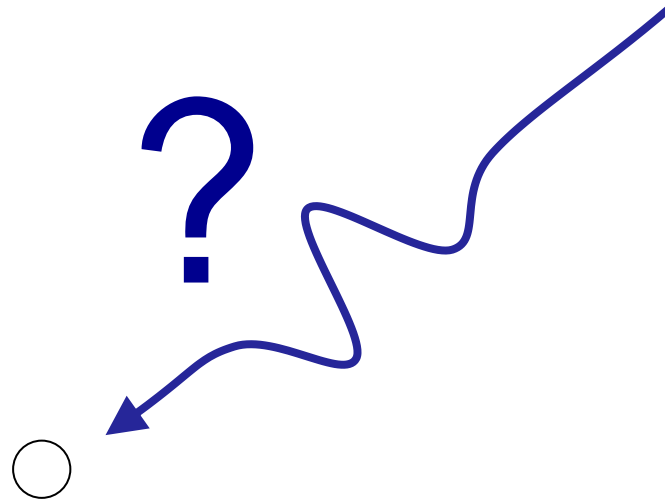
Fines Migration and Clogging



Bridges at Pore Throats



Clogging in radial flow



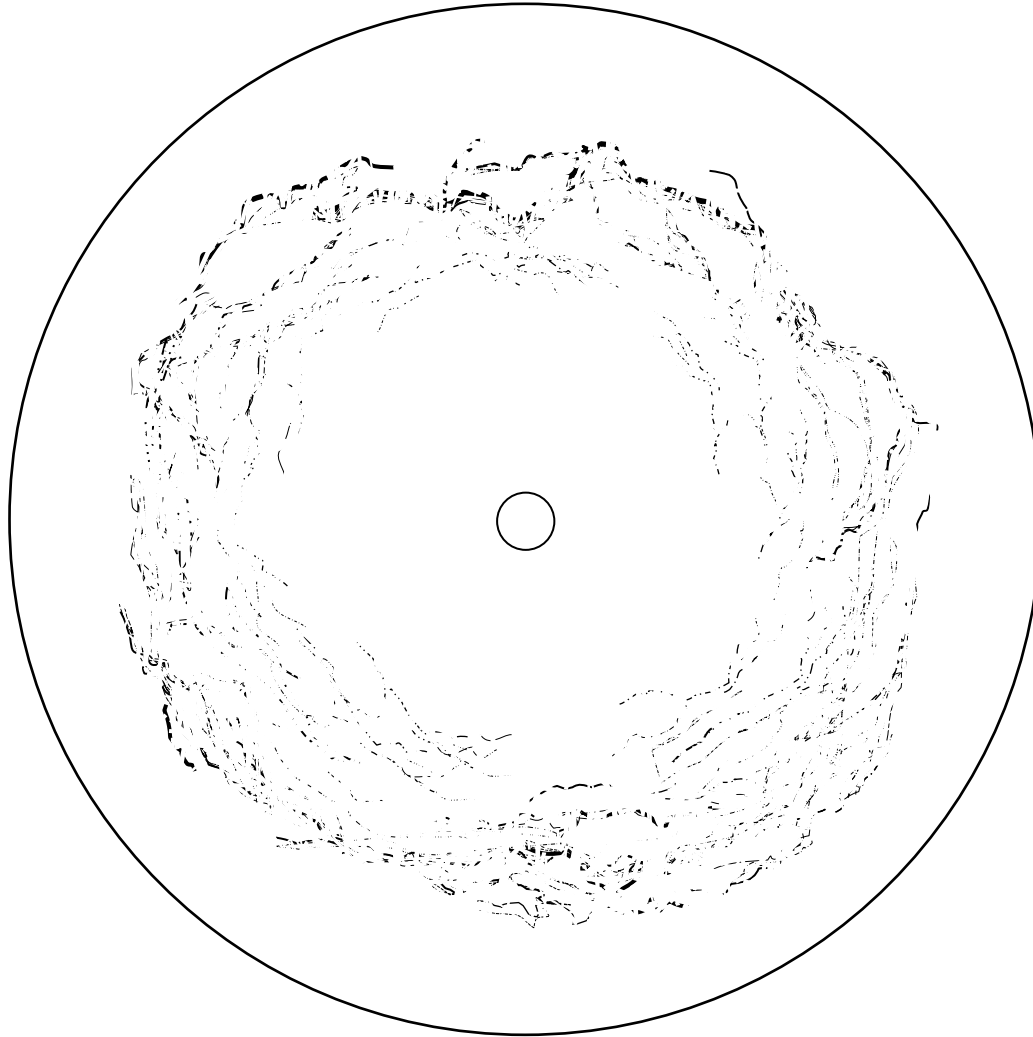
http://pmrl.ce.gatech.edu/papers/Valdes_2008c.pdf

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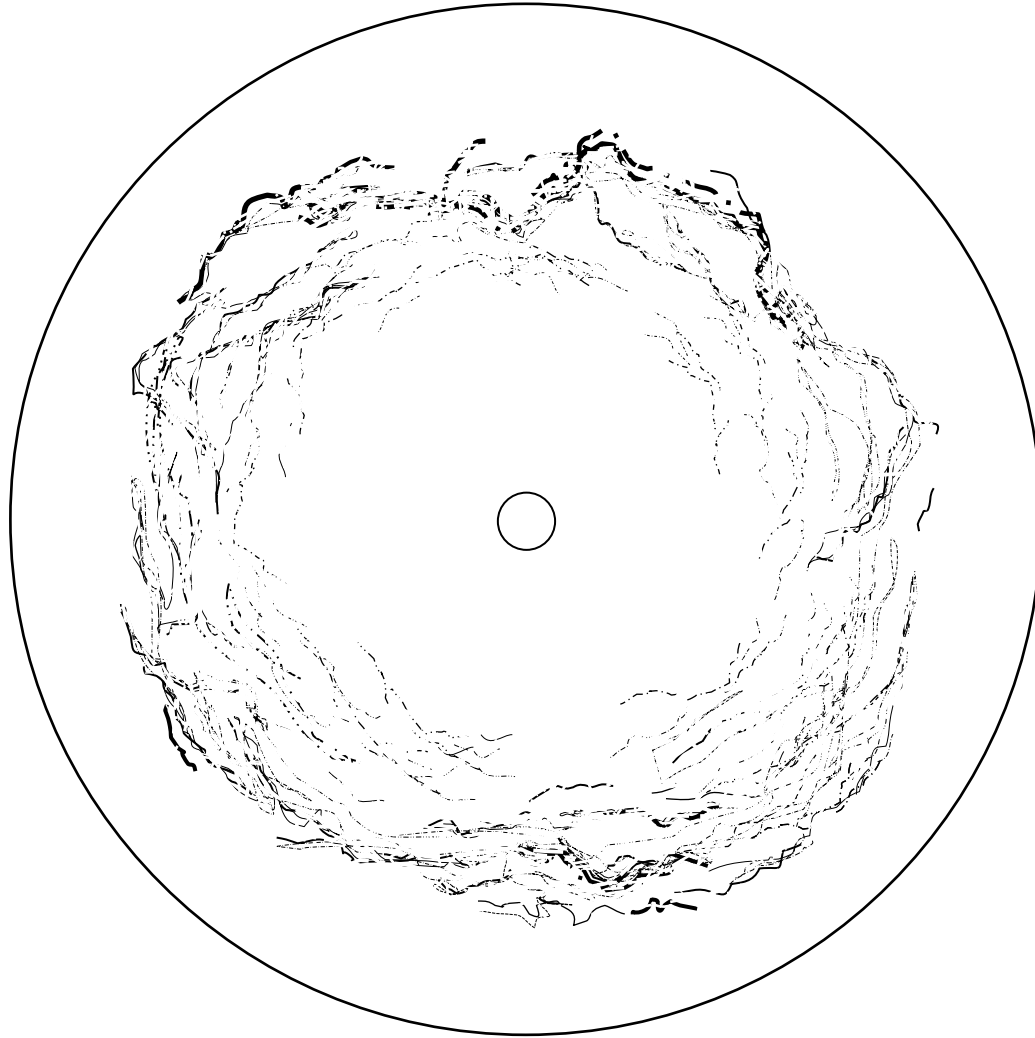
http://pmrl.ce.gatech.edu/papers/Valdes_2006b.pdf

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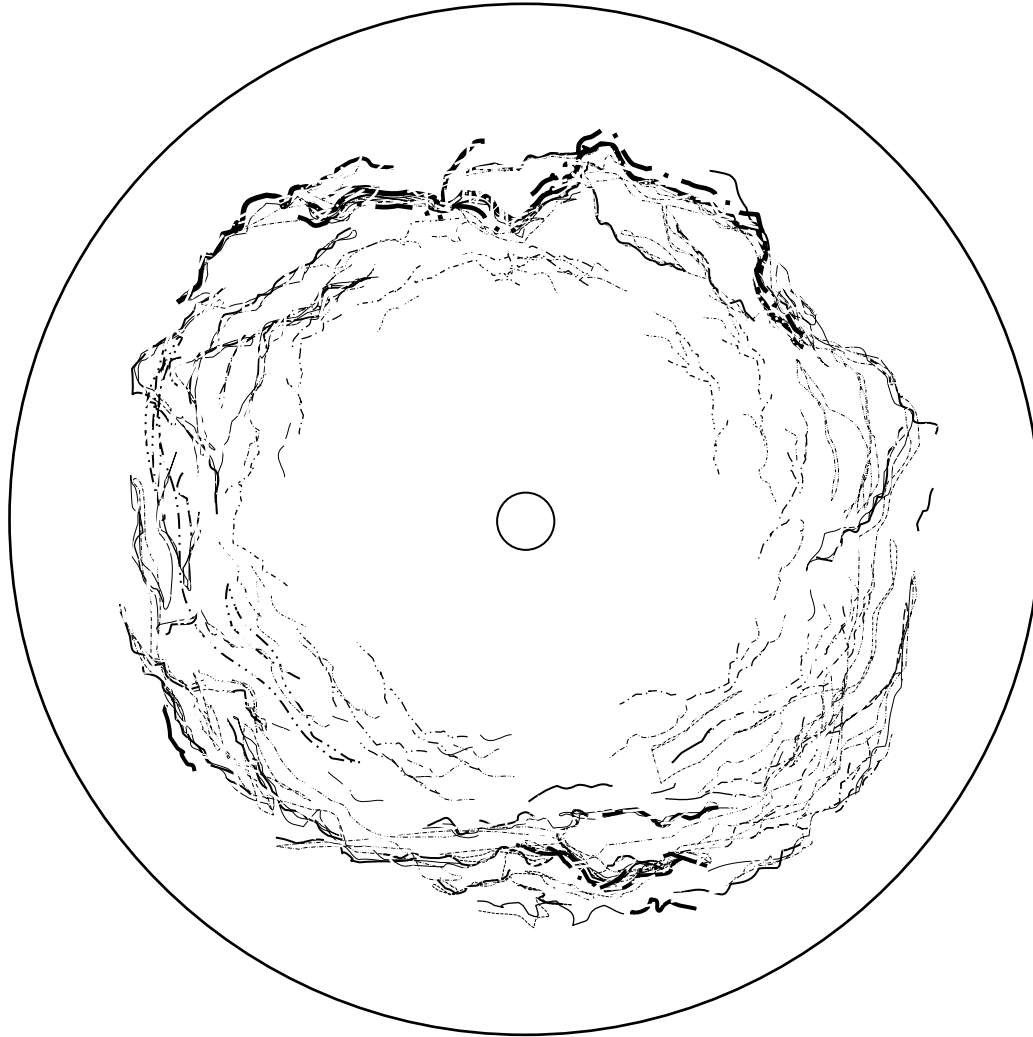
Clogging in radial flow



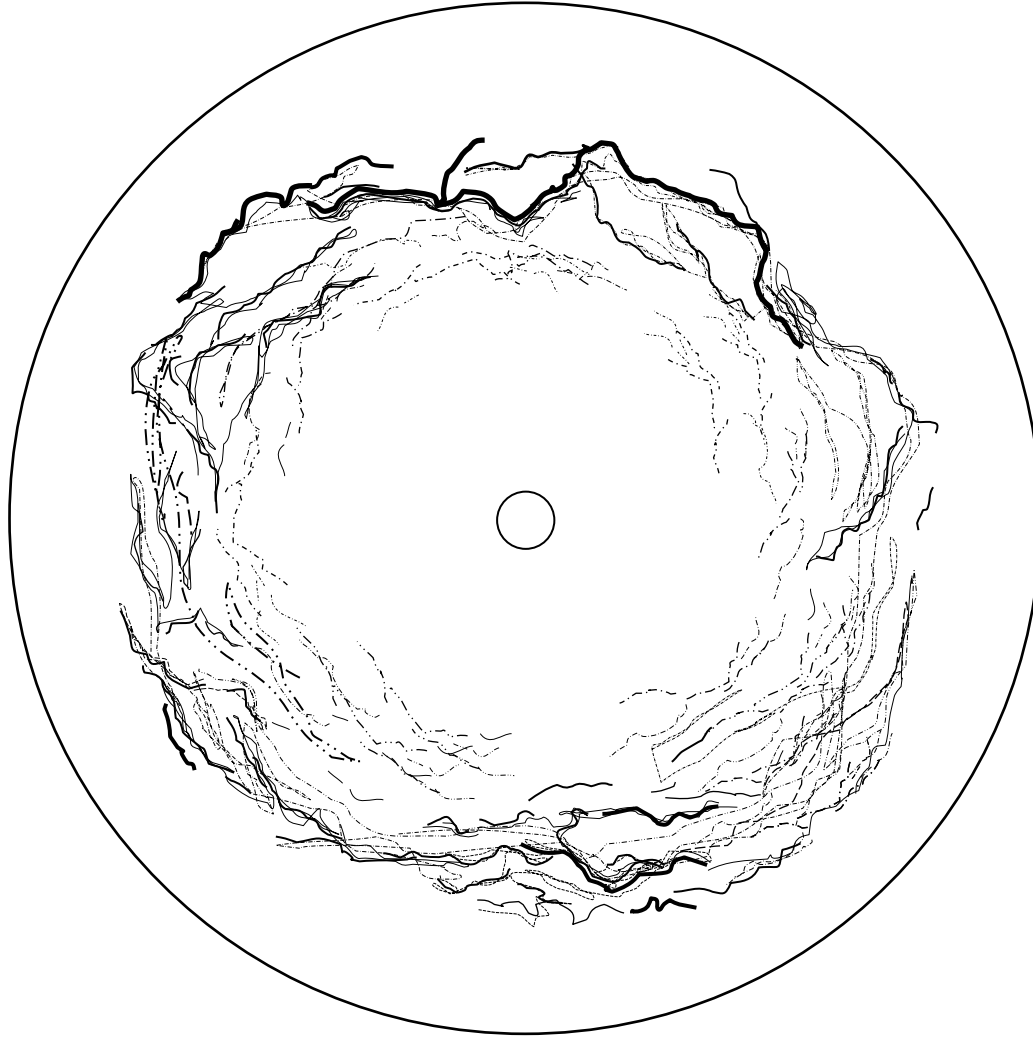
Clogging in radial flow



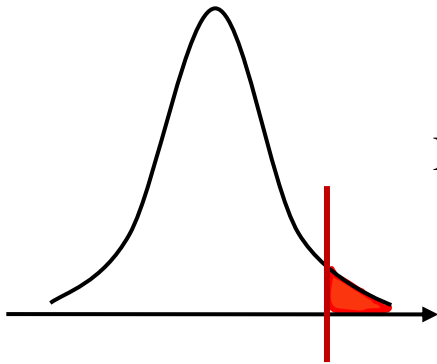
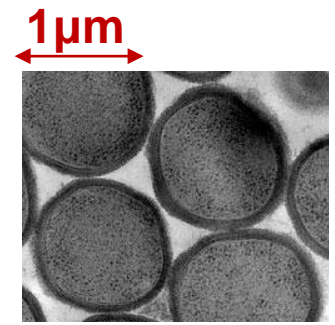
Clogging in radial flow



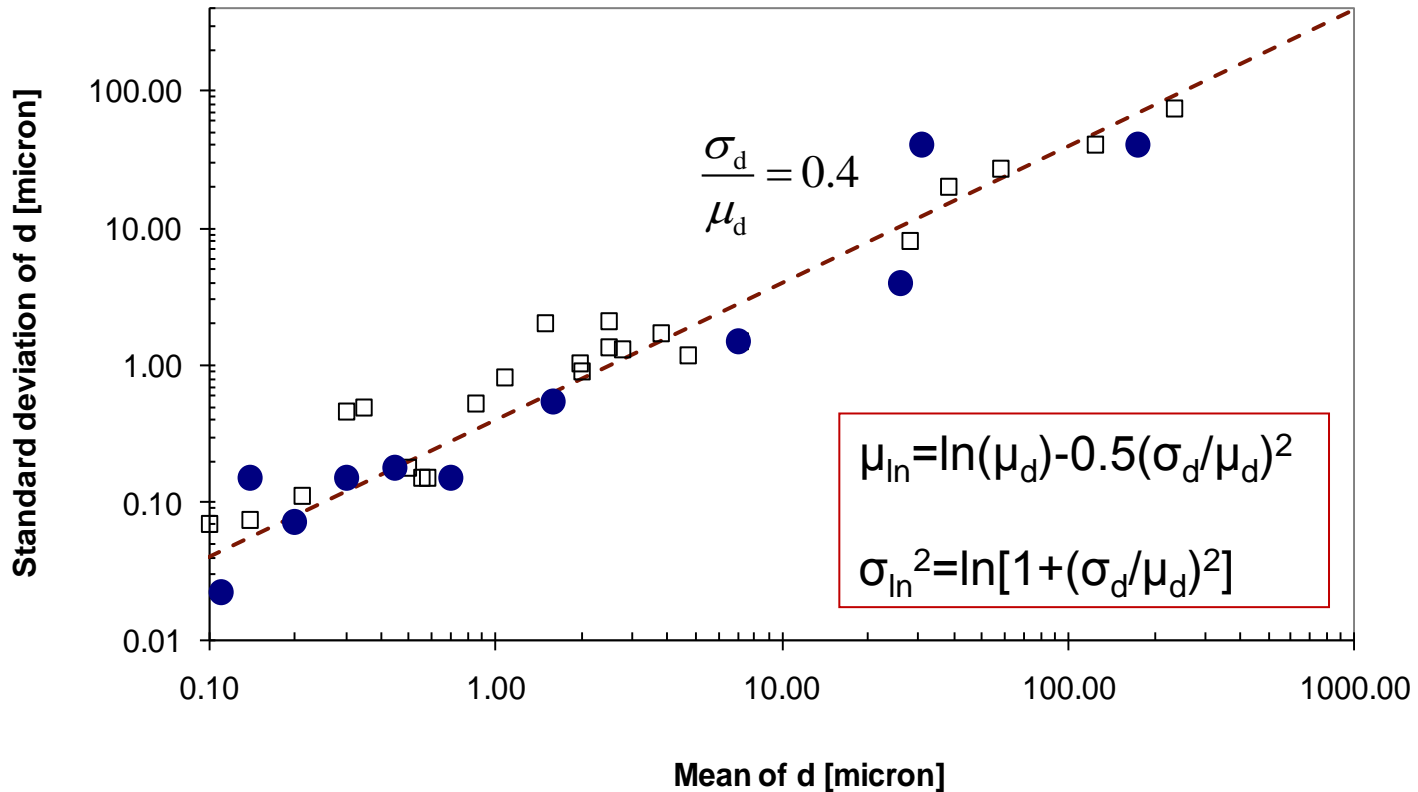
Clogging in radial flow

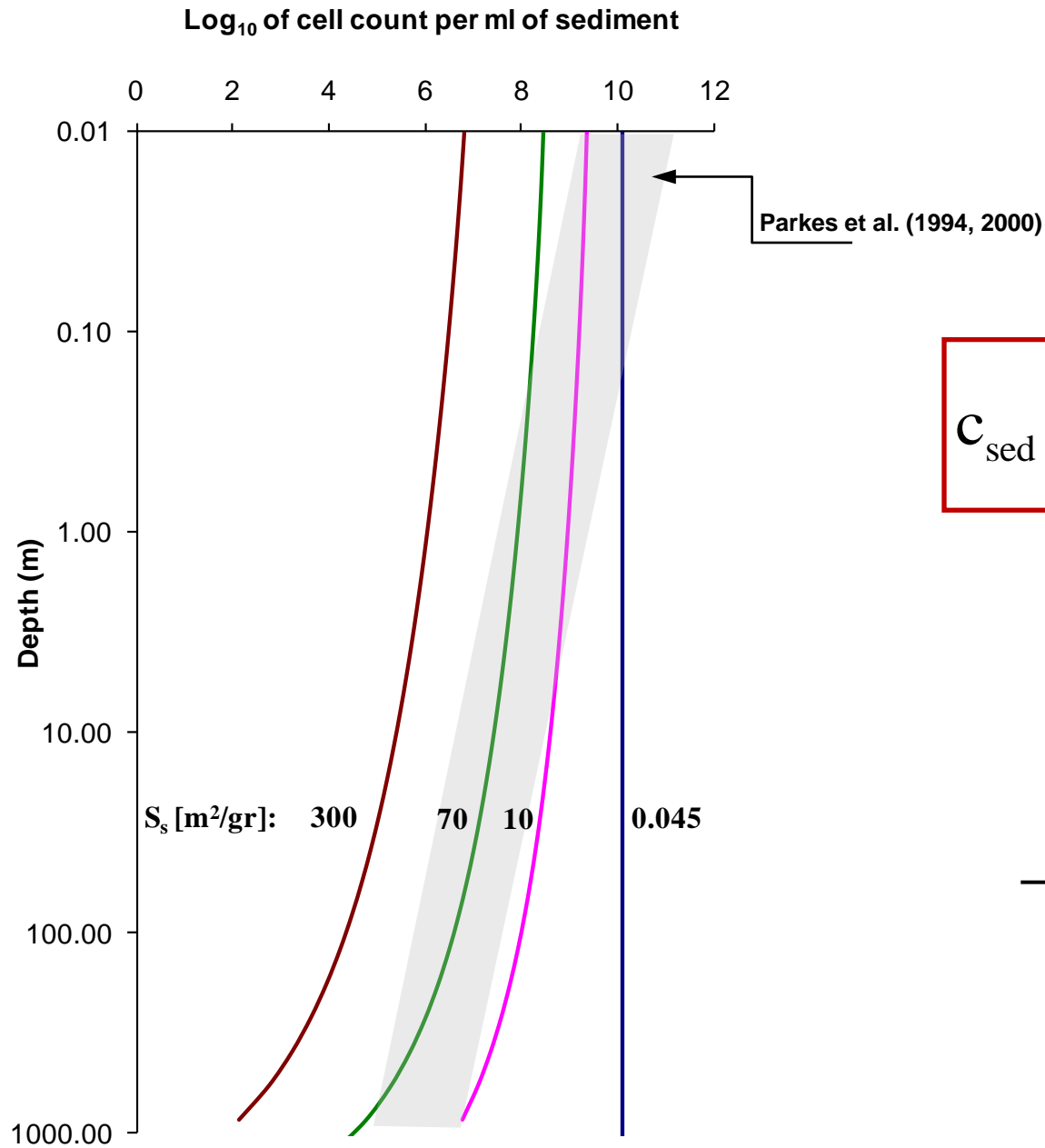


Bioactivity - Probabilistic

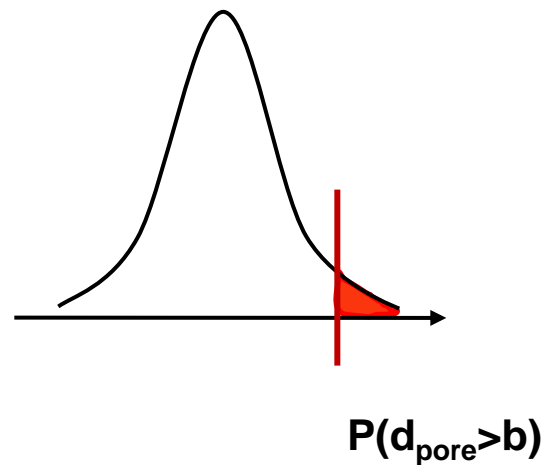


$$P(d \geq b) \cong \int_{\ln(b)}^{\infty} \exp \left\{ - \left[\frac{2.5}{4} \ln \left(\frac{d}{\mu_d} \right) + 0.05 \right]^2 \right\} dd$$

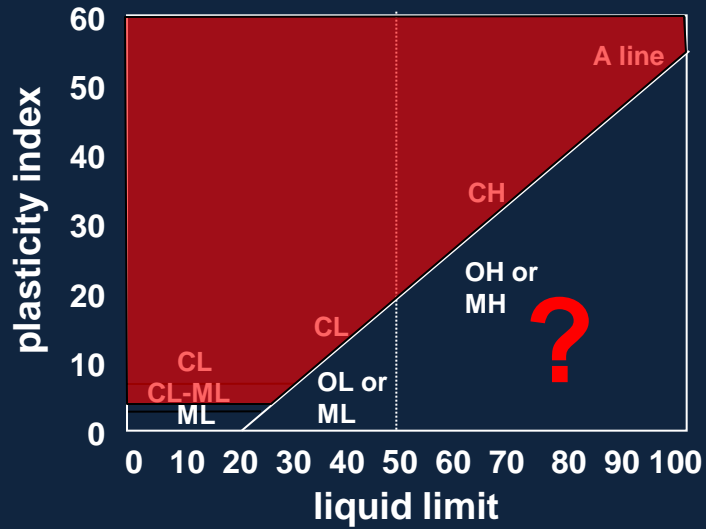




$$c_{\text{sed}} = c_{\text{fl}} \cdot n \cdot P(d \geq b)$$



COARSE	> 50% retained sieve #4	Gravel:	< 5% fines	$C_u > 4, 1 \leq C_c \leq 3$	GW
			else ...	GP	
		> 12% fines	Below 'A' line	GM	
	> 50% retained sieve #200	Sand:	< 5% fines	$C_u > 6, 1 \leq C_c \leq 3$	SW
				else ...	SP
			> 12% fines	Below 'A' line	SM
FINE	< 50% retained sieve #200	LL < 50	Above 'A' line	GC	
			Above 'A' line	SC	
			Below 'A' line	ML	
	< 50% retained sieve #200	LL > 50	OH or MH	OH or MH	MH
				OH or MH	CH
				OH or MH	OH

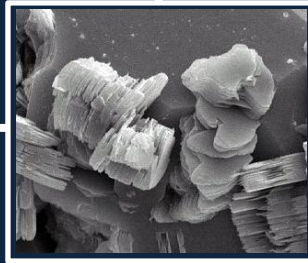




**Energy
Geotech**

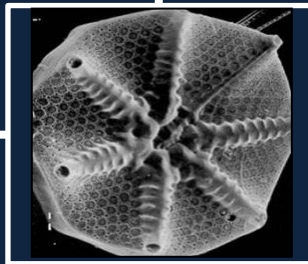
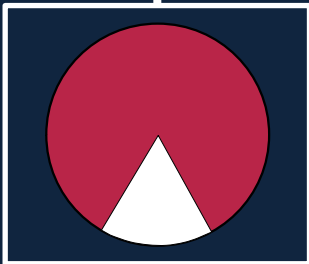
**Geo-
Chemistry**

**Frozen
Ground**



**Unsat. Soil
Mechanics**

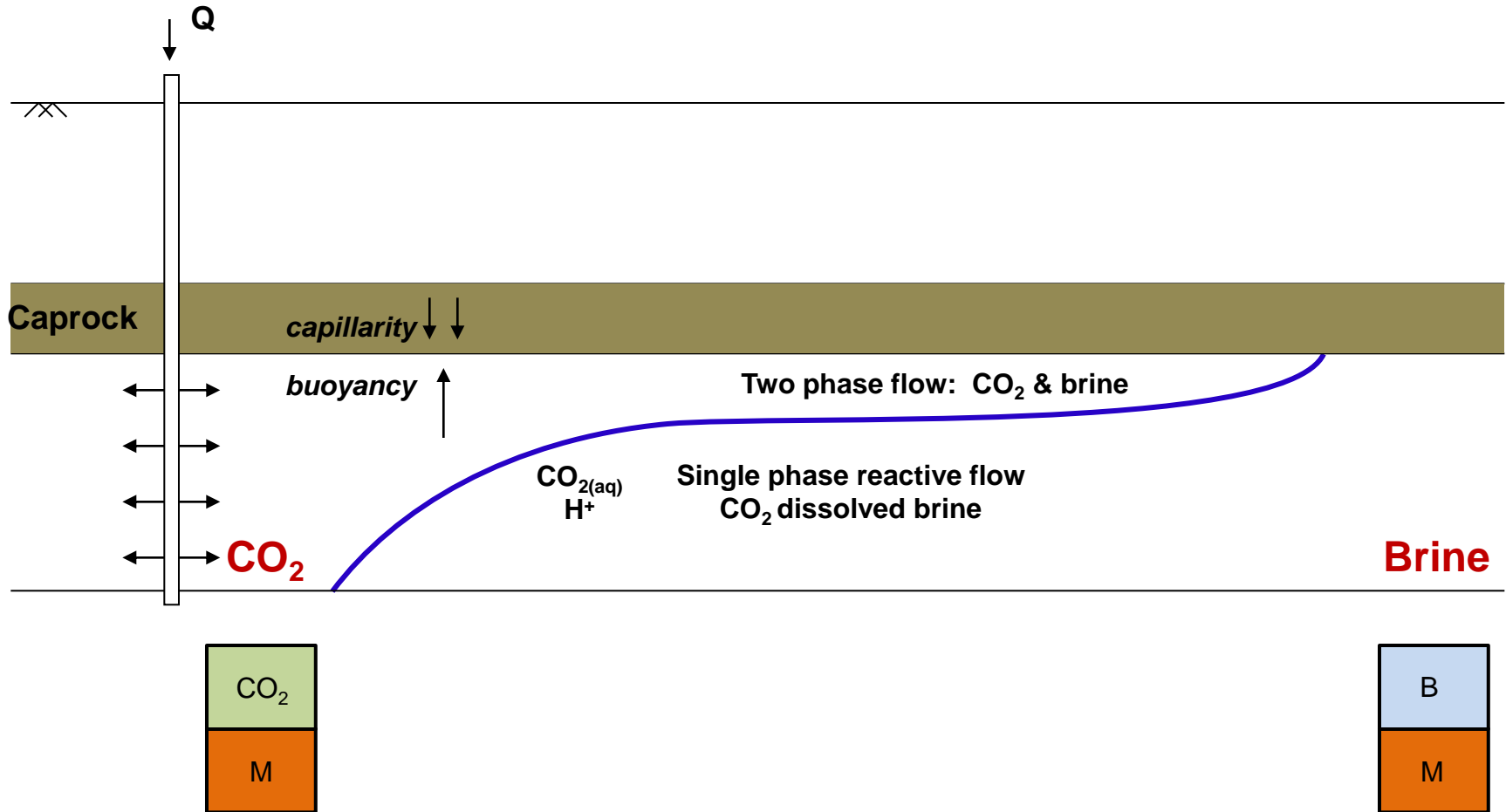
**Ground
Thaw**



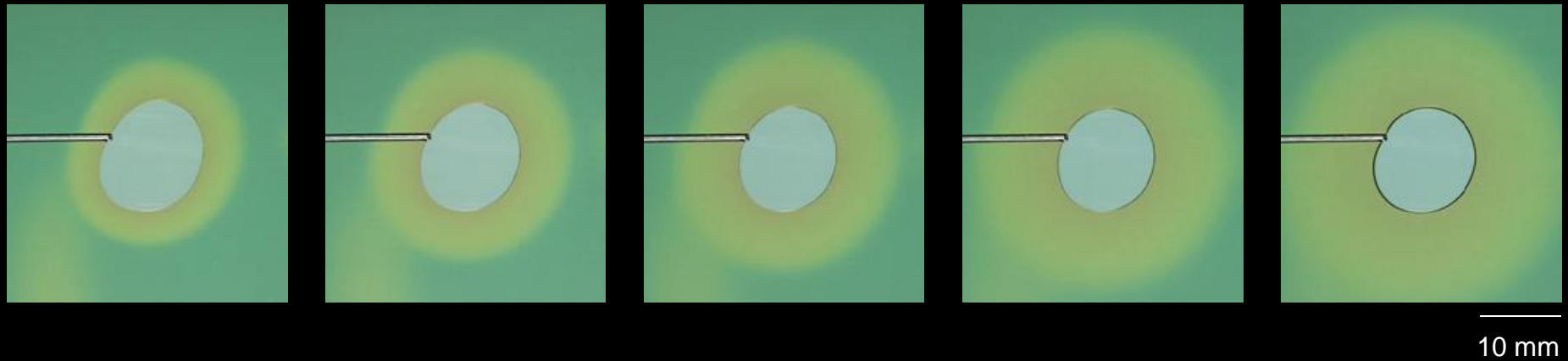
Fractures

**Repetitive
Loading**

CO₂ Storage

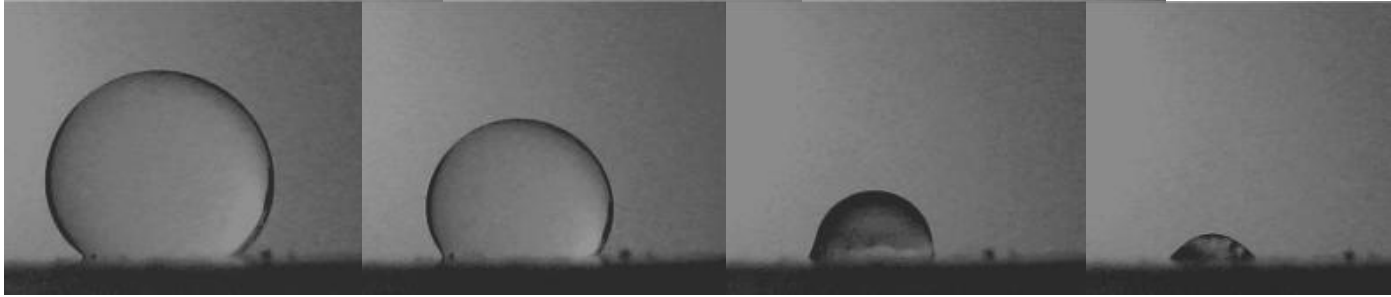


CO₂ Dissolution and H₂O Acidification

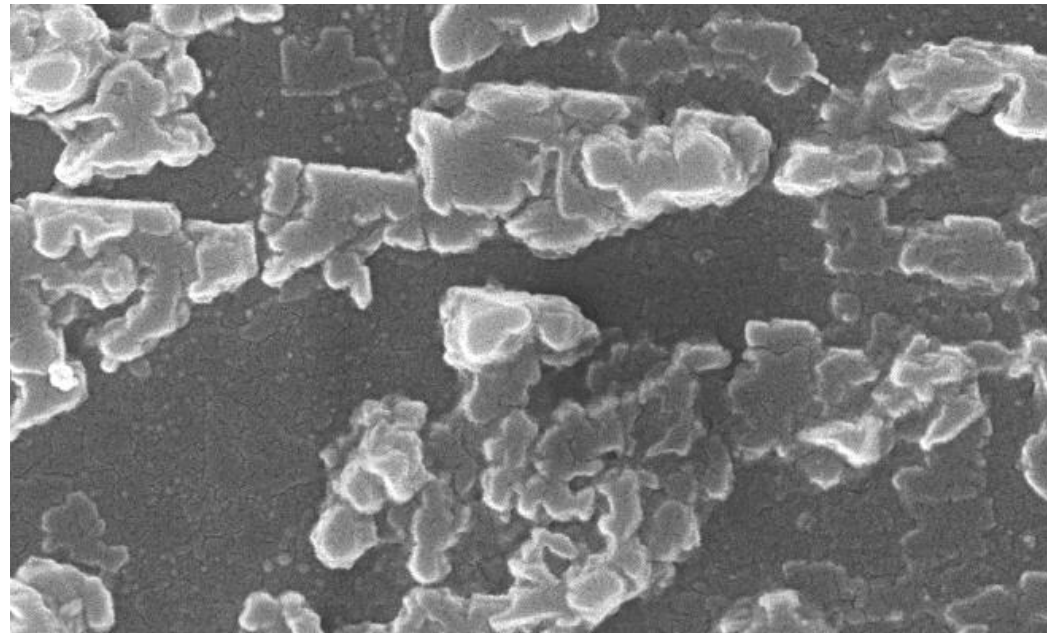


Water in CO₂

acidification → *dissolution* → *drying* → *precipitation*



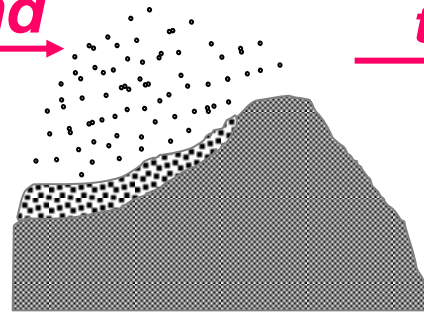
Calcite substrate



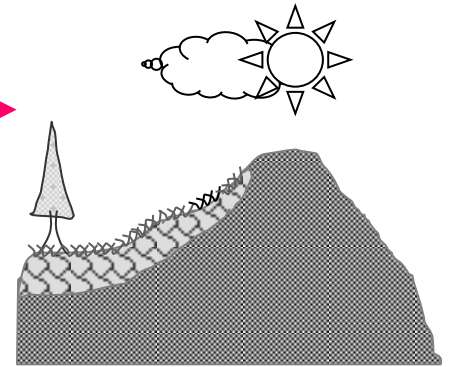
Volcanic Ash Soils: Formation



wind



time



$$e = 0.8-1.5$$

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

volcanic glass

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

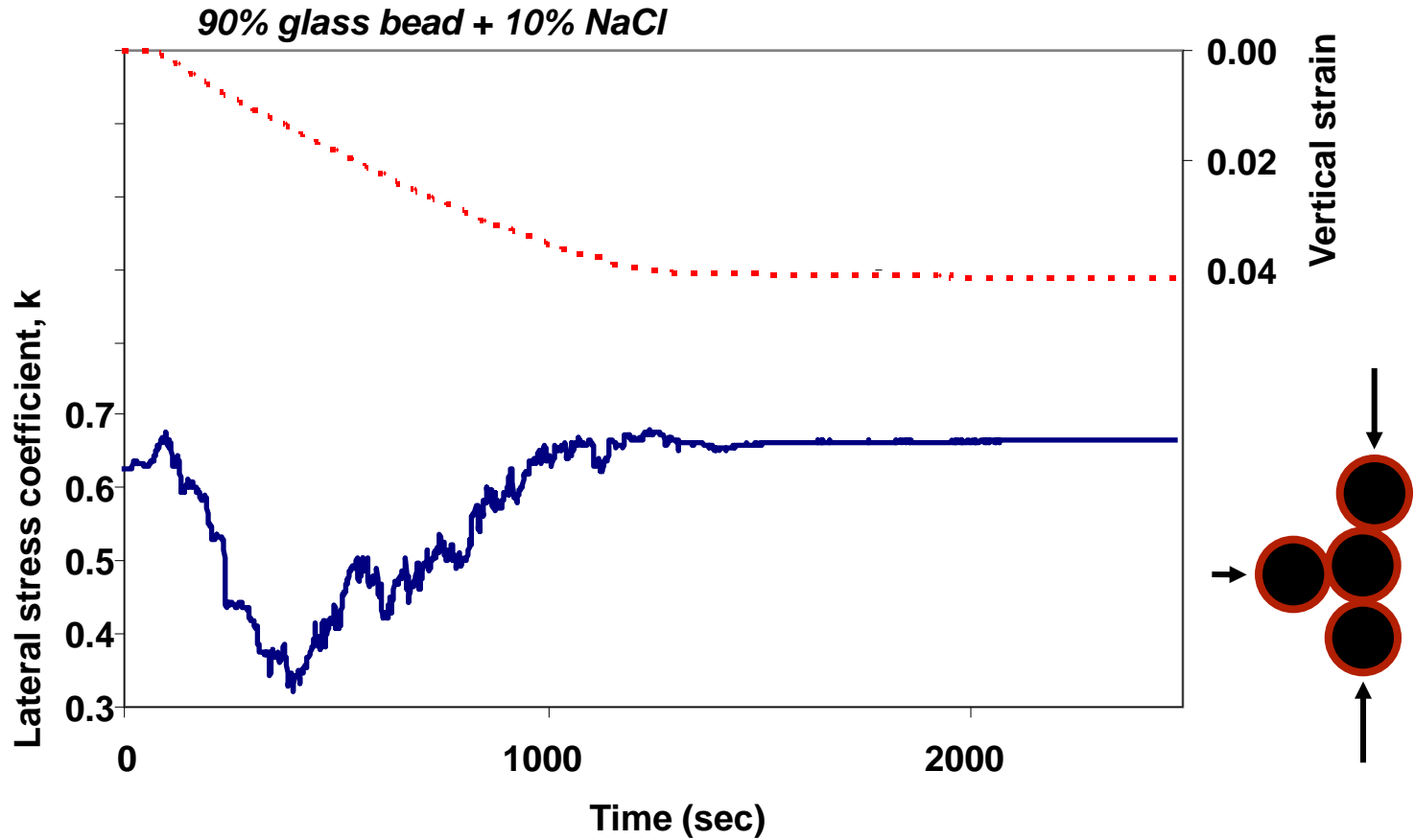
$$e = 2.0-7.0$$

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

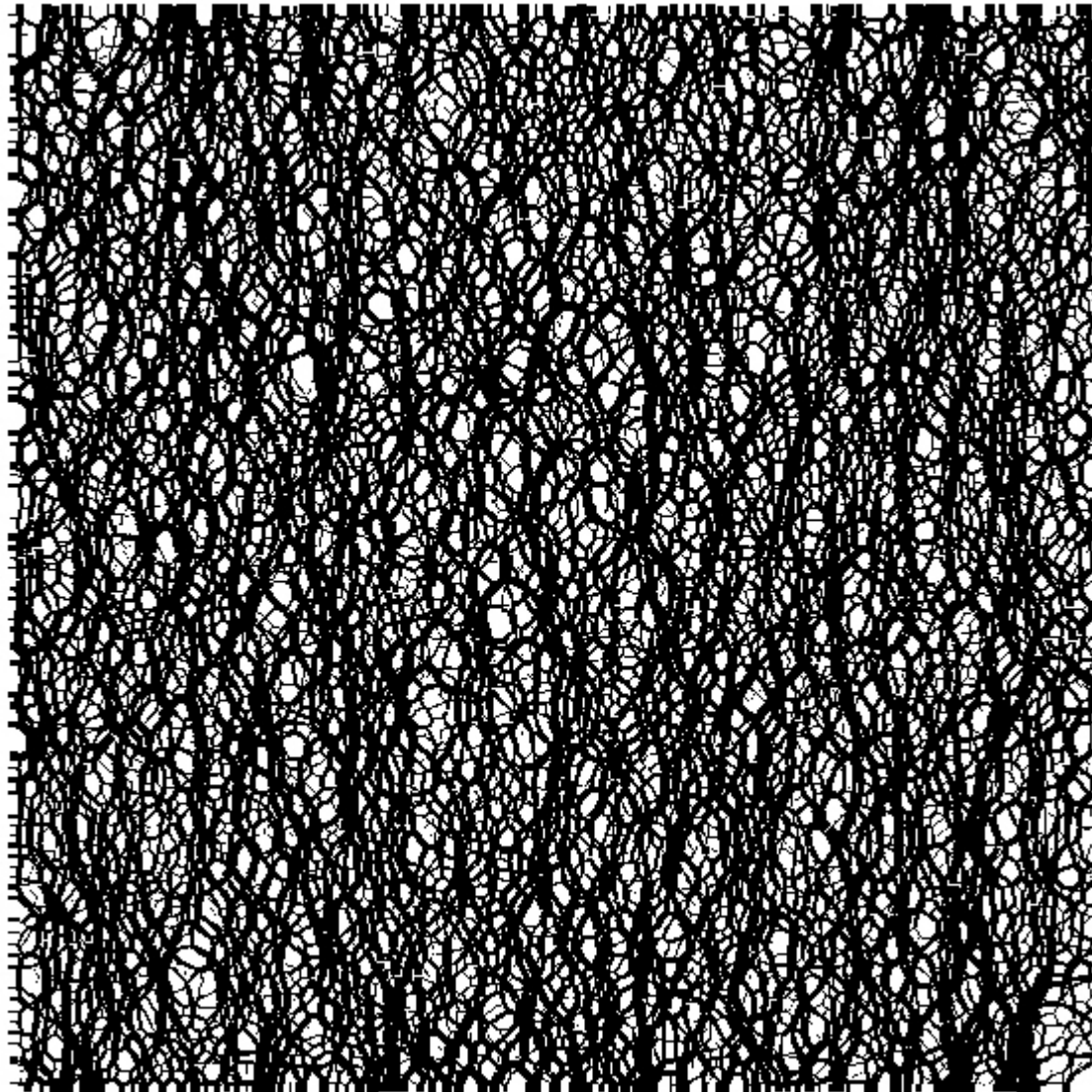
hallosite
imogolite
alophane

$$k_o = ??$$

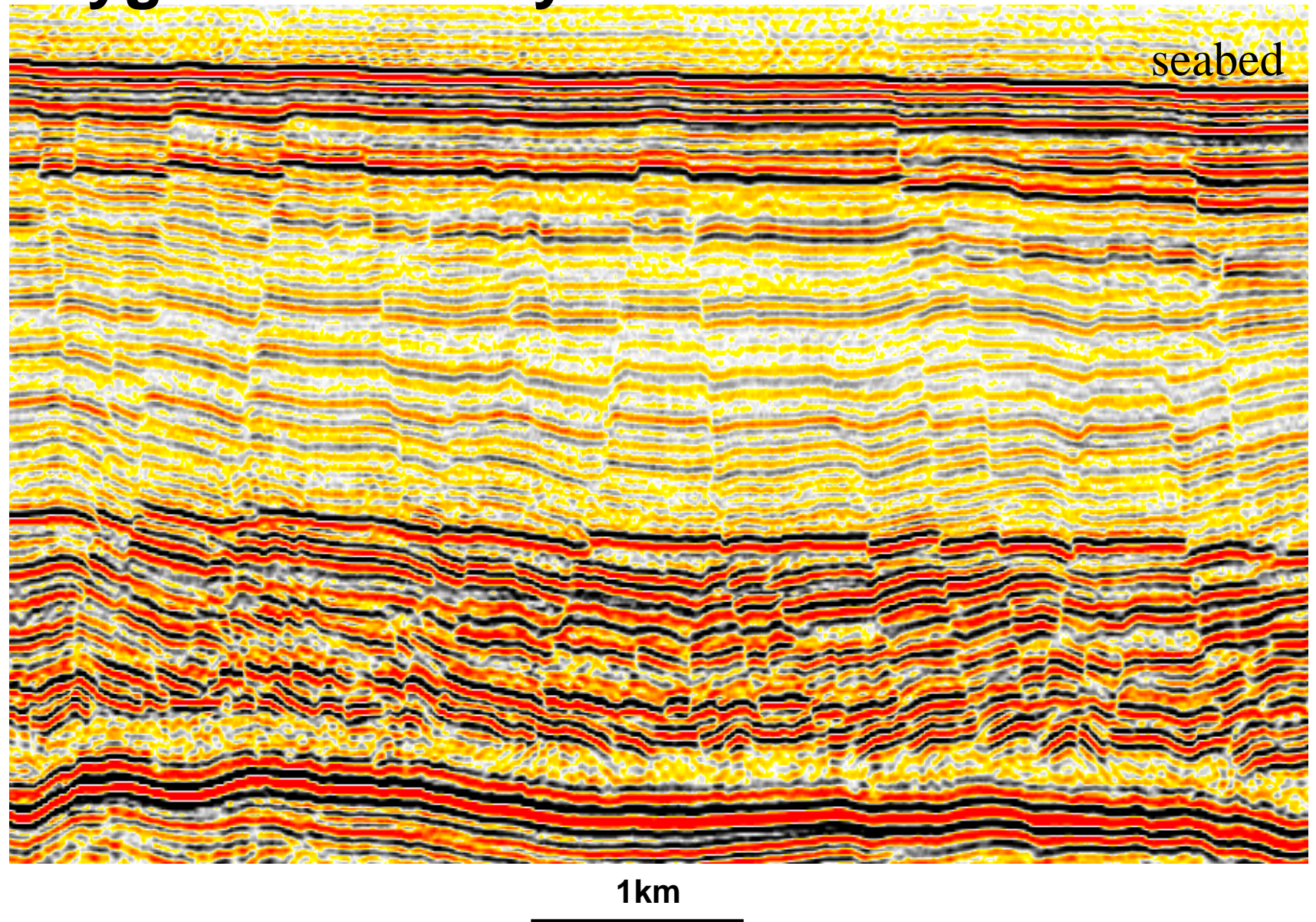
Experimental Results



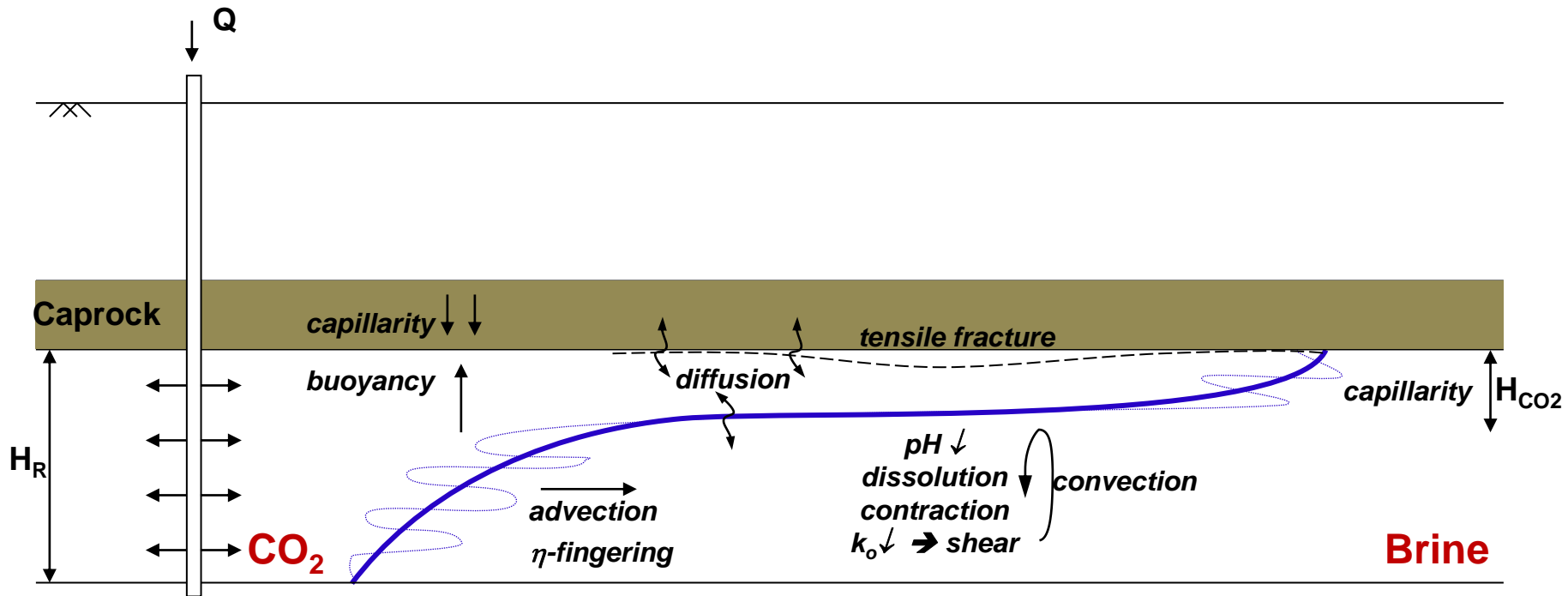
Emergent: Shear Localization



Polygonal Fault Systems



CO₂ Storage ?

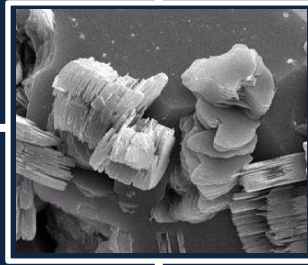




**Energy
Geotech**

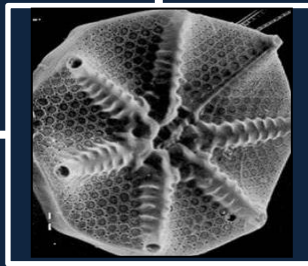
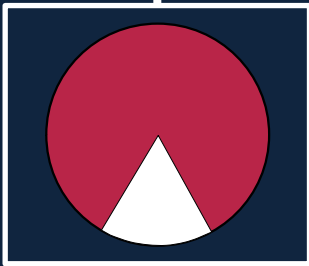


**Frozen
Ground**



**Unsat. Soil
Mechanics**

**Ground
Thaw**



Fractures

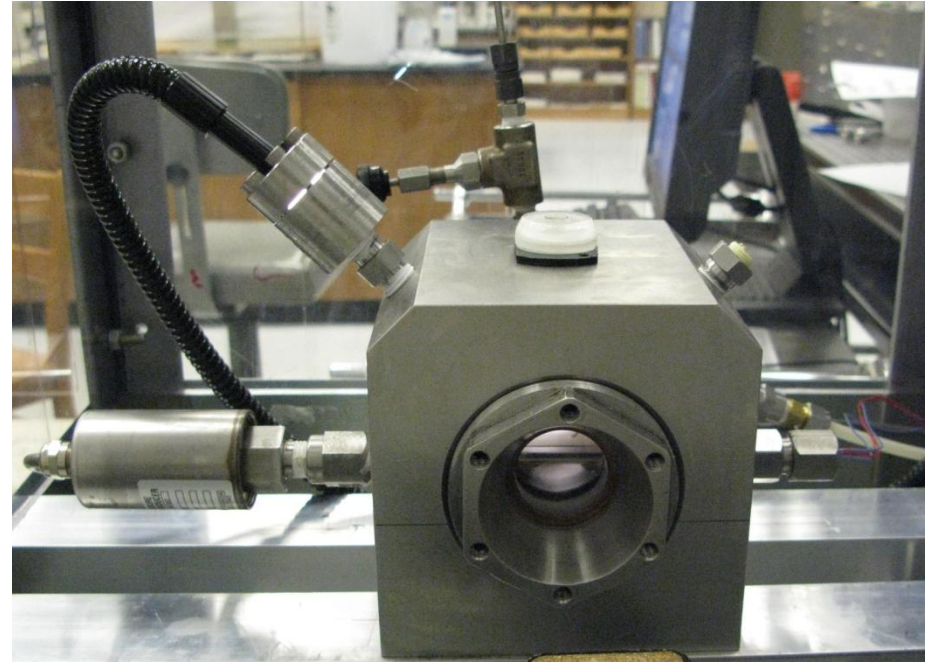
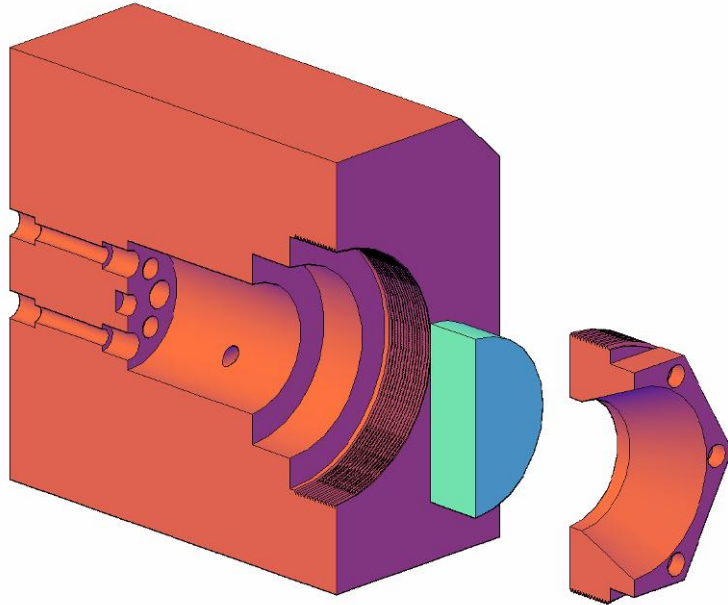
**Repetitive
Loading**

Mixed Fluids

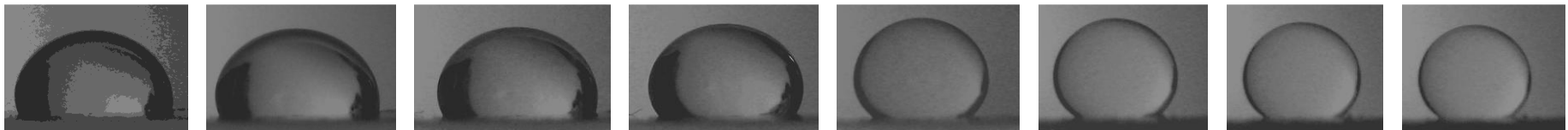


BBC News In pictures Visions of Science.jpg

Surface Tension & Contact Angle: H₂O-CO₂



water droplet in CO₂



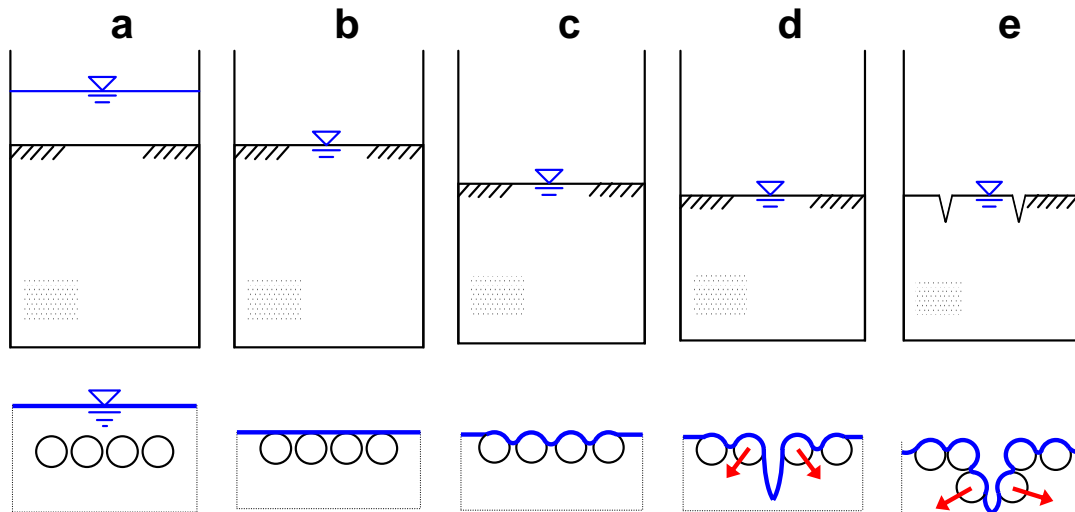
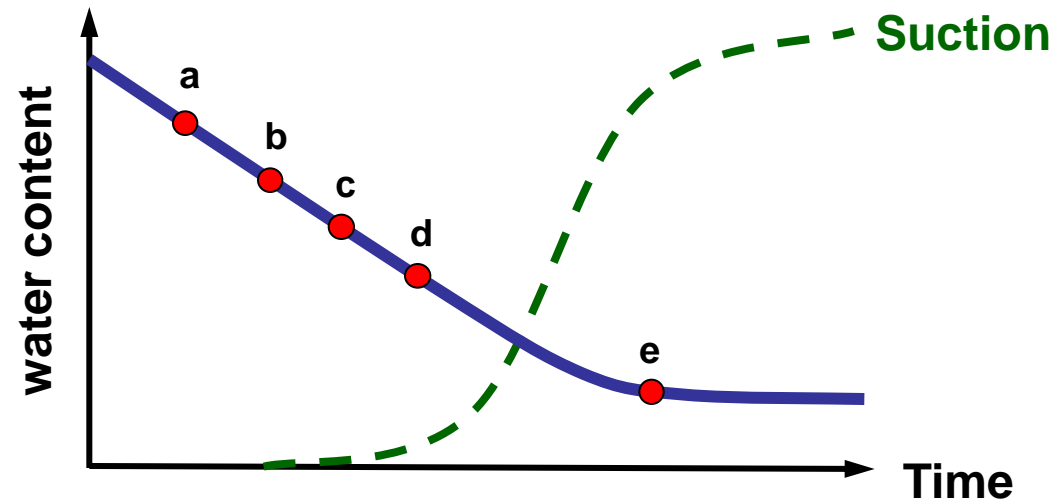
atm

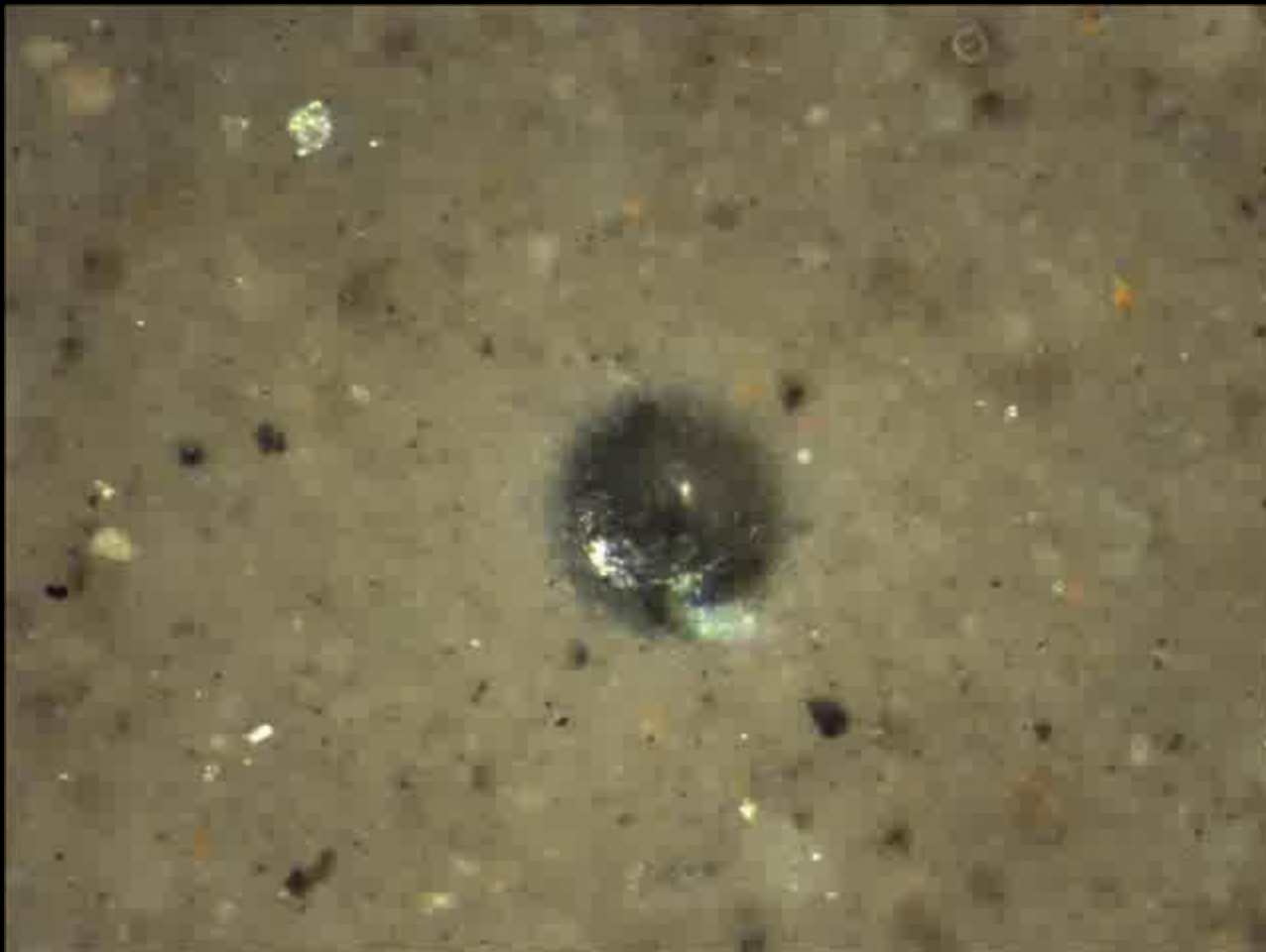
gas

liquid

20 MPa

Crack initiation





1 mm

http://pmrl.ce.gatech.edu/papers/Shin_2011b.pdf
http://pmrl.ce.gatech.edu/papers/Shin_2011a.pdf
http://pmrl.ce.gatech.edu/papers/Shin_2010e.pdf

Shale: structured rock



Thermogenic

$Z_{\text{history}} > 5000 \text{ m}$

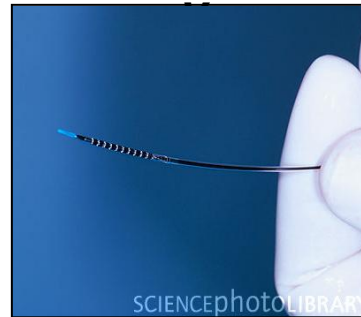
$Z_{\text{today}} \approx 1000\text{-}3000 \text{ m}$

Step 1: Drill

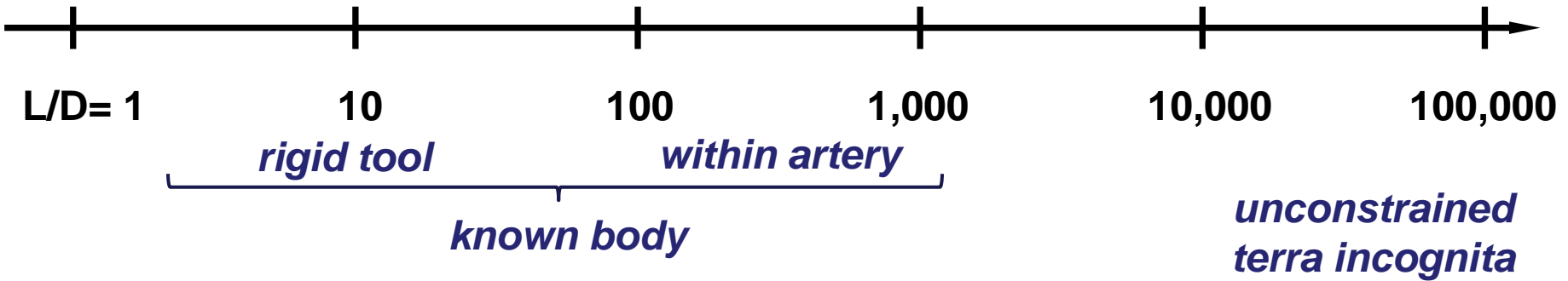
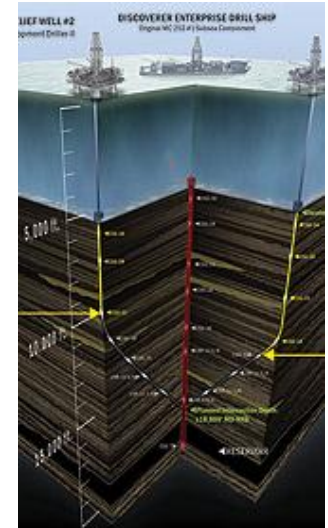
Laparoscopy



**Catheter
Angioplast**



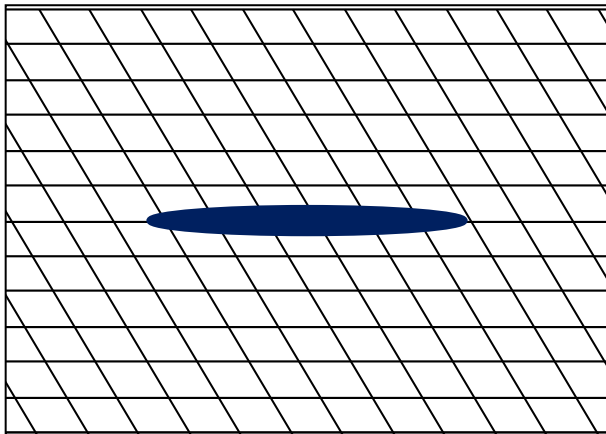
**Directional
Drilling**



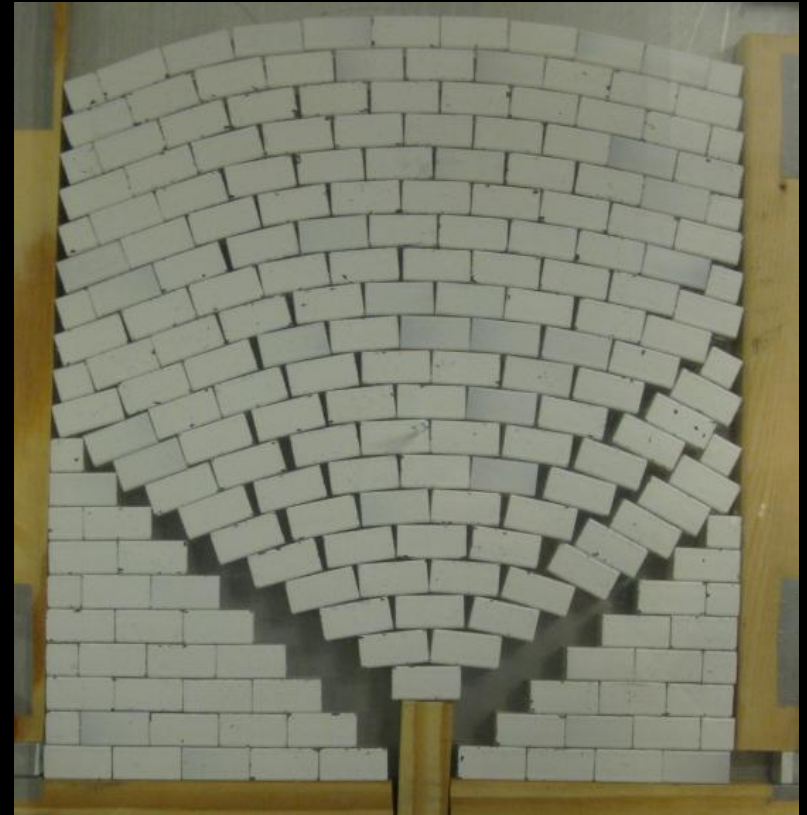
Step 2: HF

"fracking"

*But shales...
structured rock*

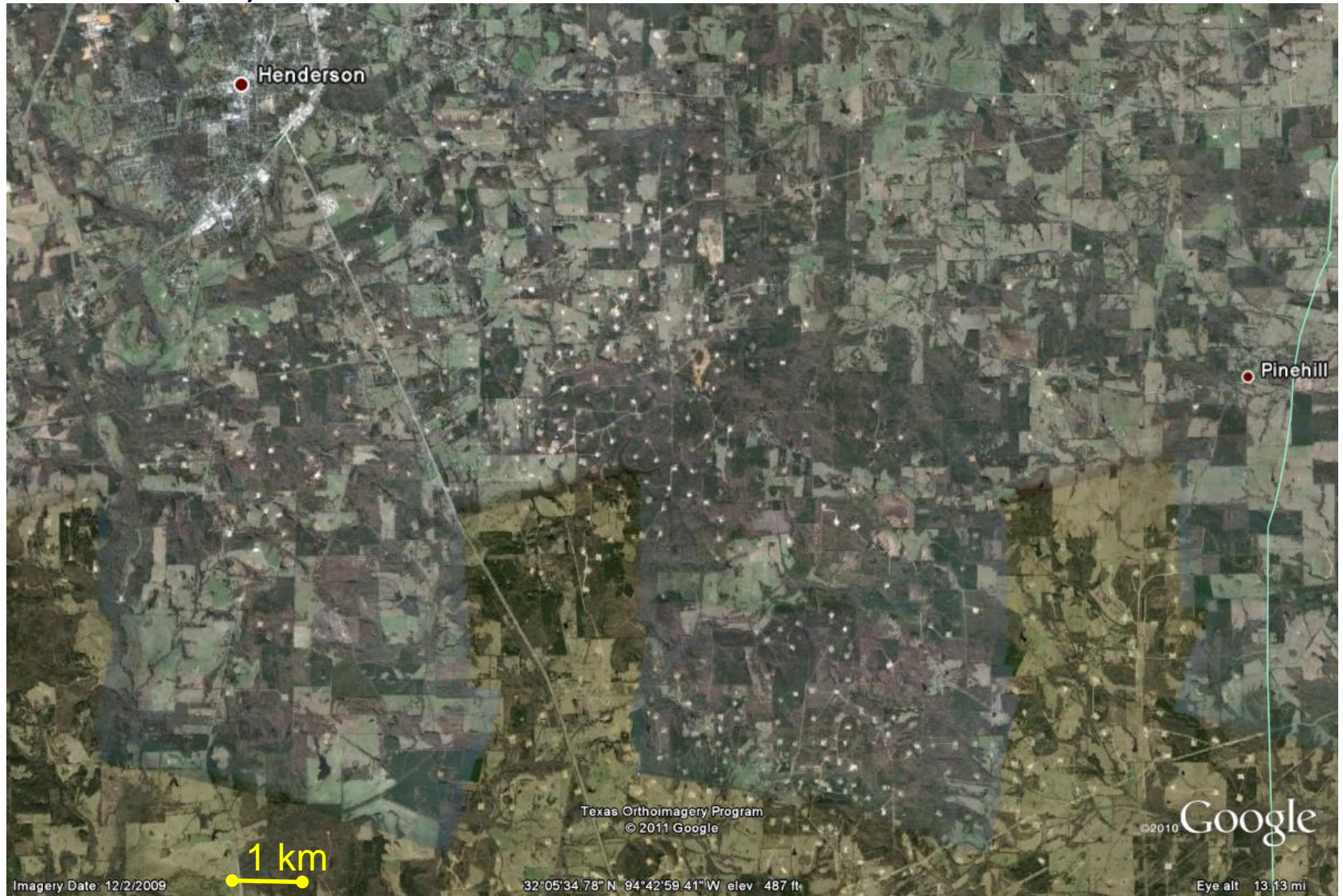


Kirsch (1898)
Griffith (1921)
Irwin (1957) ???



Pads (several wells per pad)

East Texas (2009)

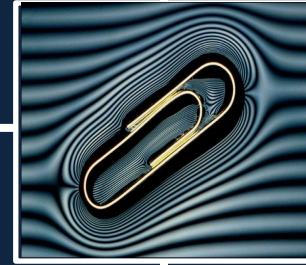
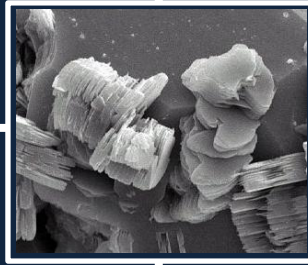




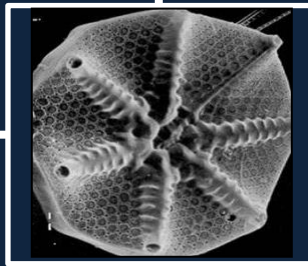
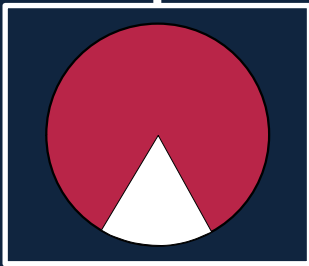
**Energy
Geotech**



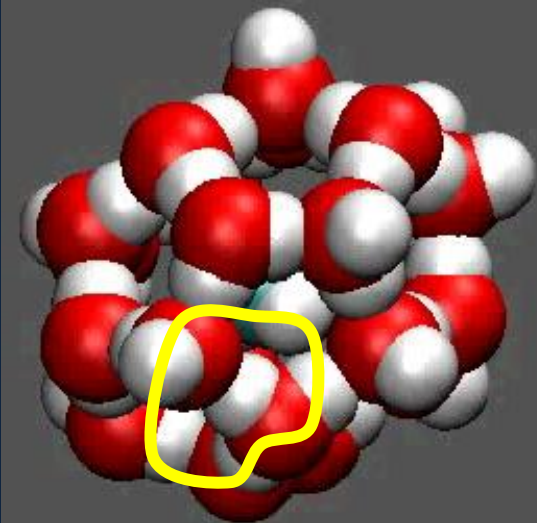
**Frozen
Ground**



**Ground
Thaw**

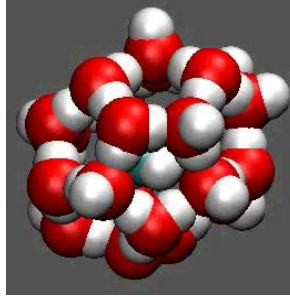


**Repetitive
Loading**

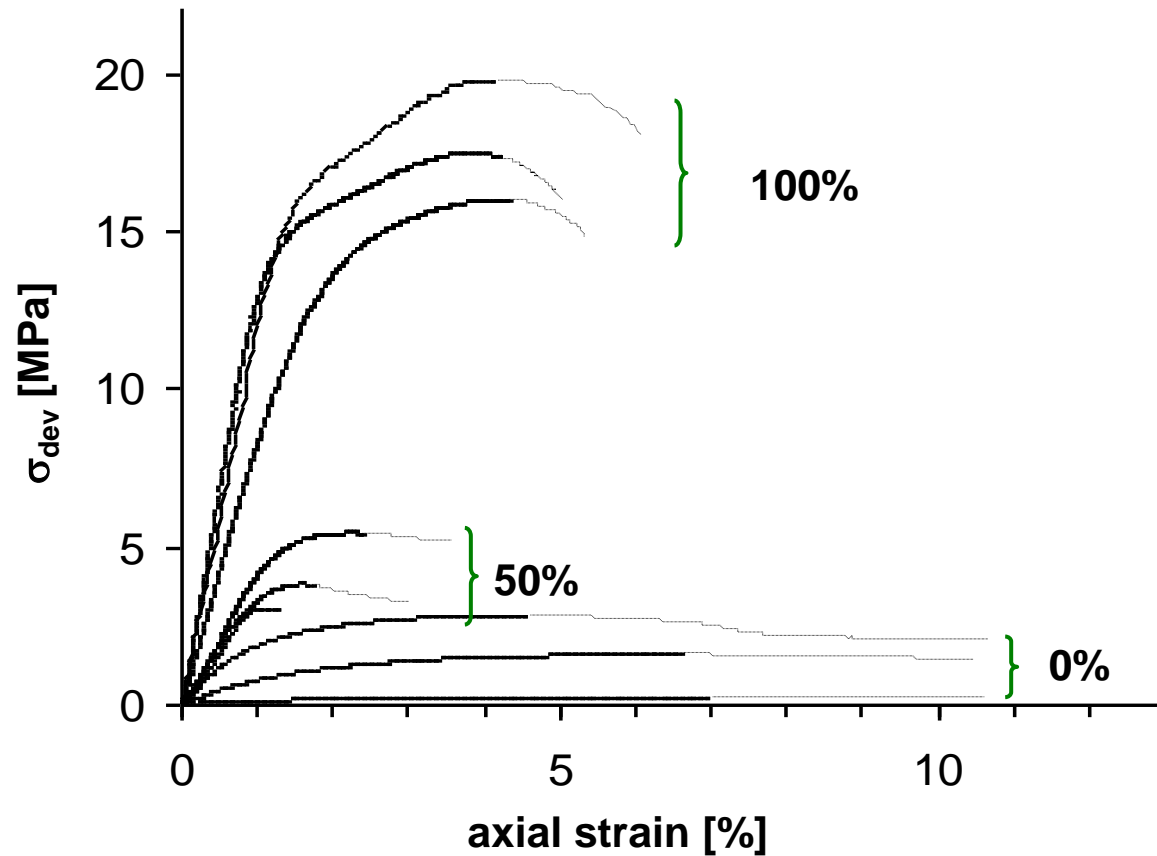


Multiple articles. Please, visit <http://pmrl.ce.gatech.edu> → go to publications → then, search for "hydrate"

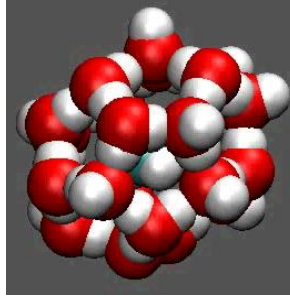
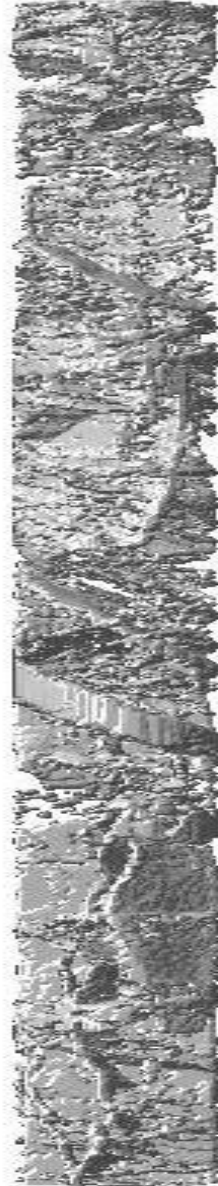
Sands



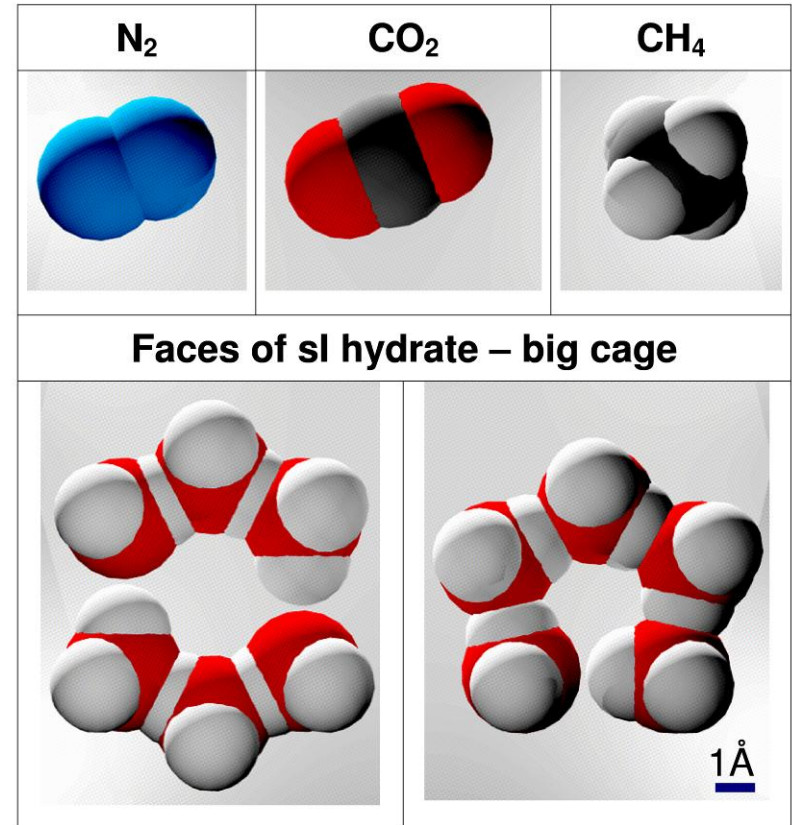
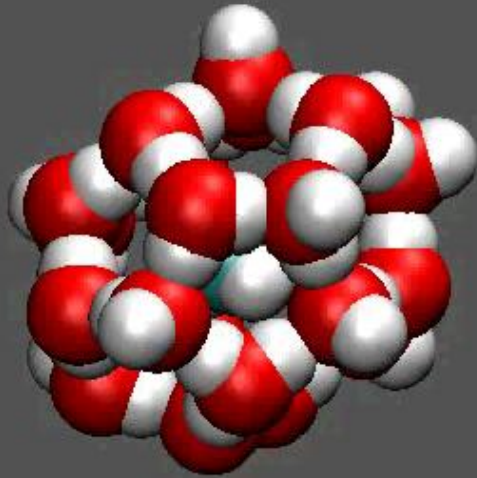
$$S_u = a\sigma'_o + bq_h \left(\frac{S_h}{n} \right)^2$$



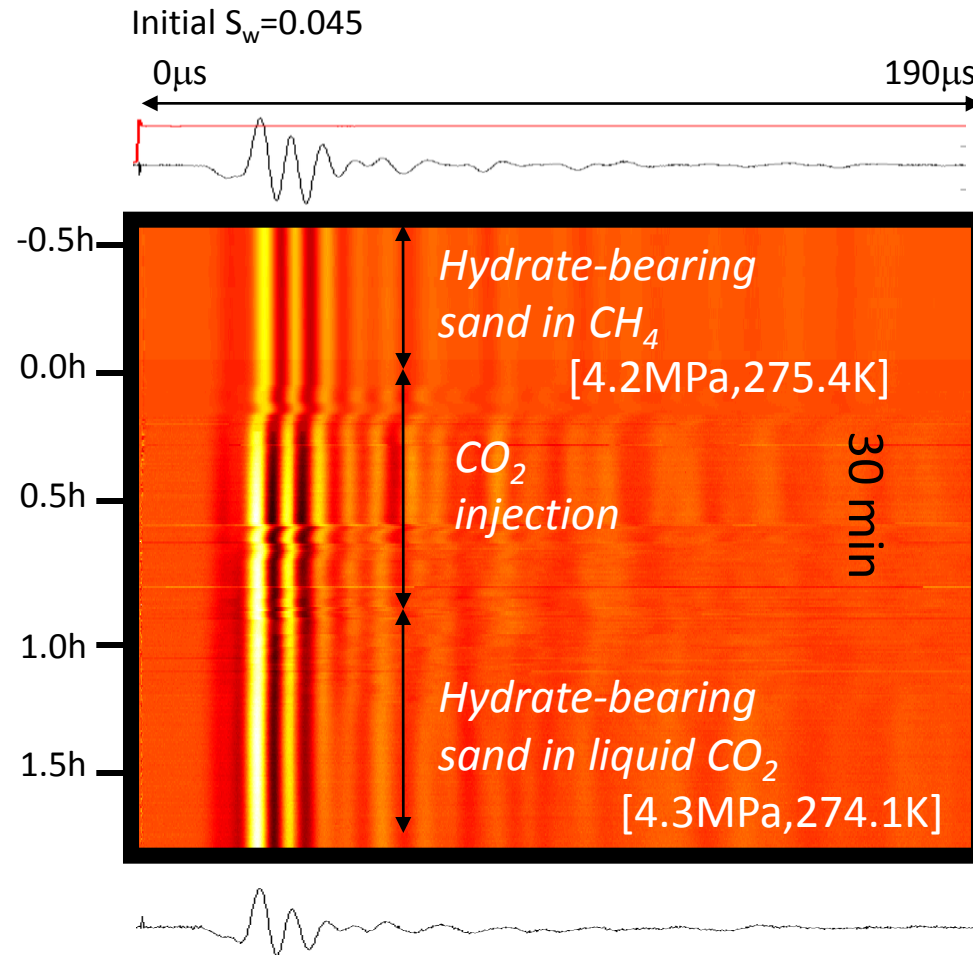
Clayey Sediments



Gas replacement in hydrates

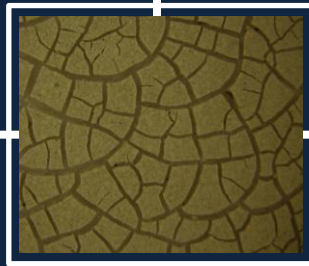
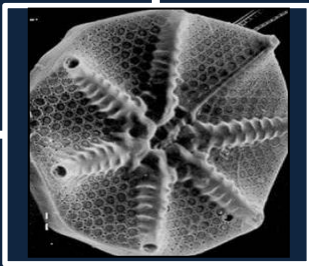
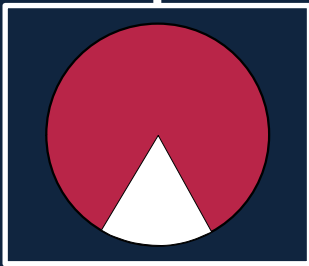
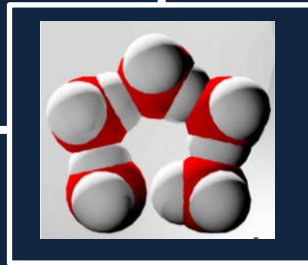
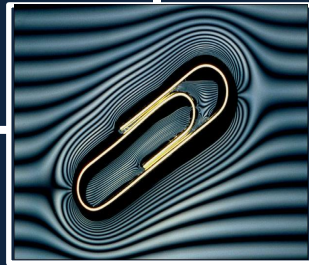
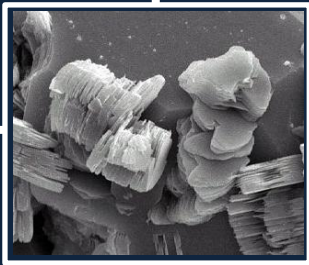
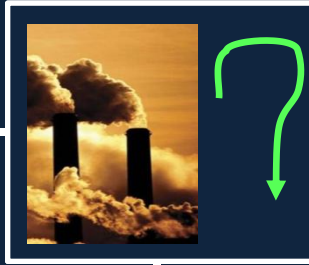


Gas replacement in hydrates





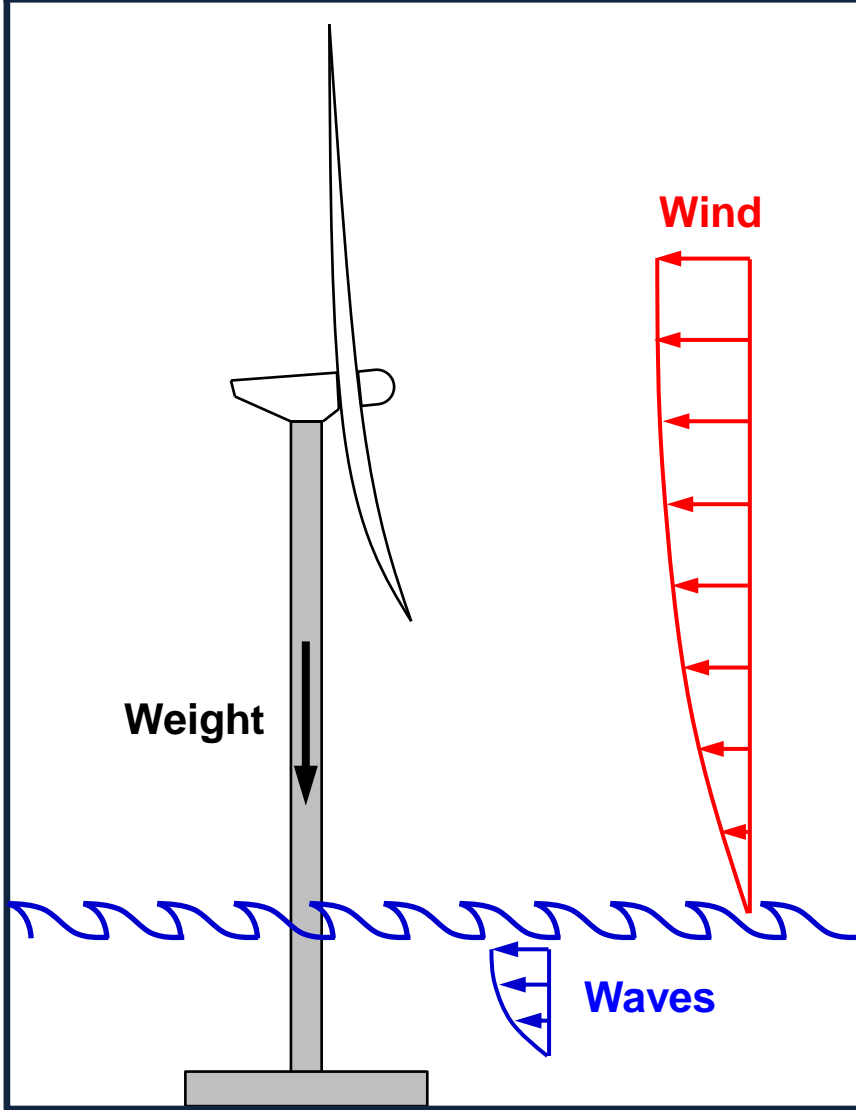
**Energy
Geotech**



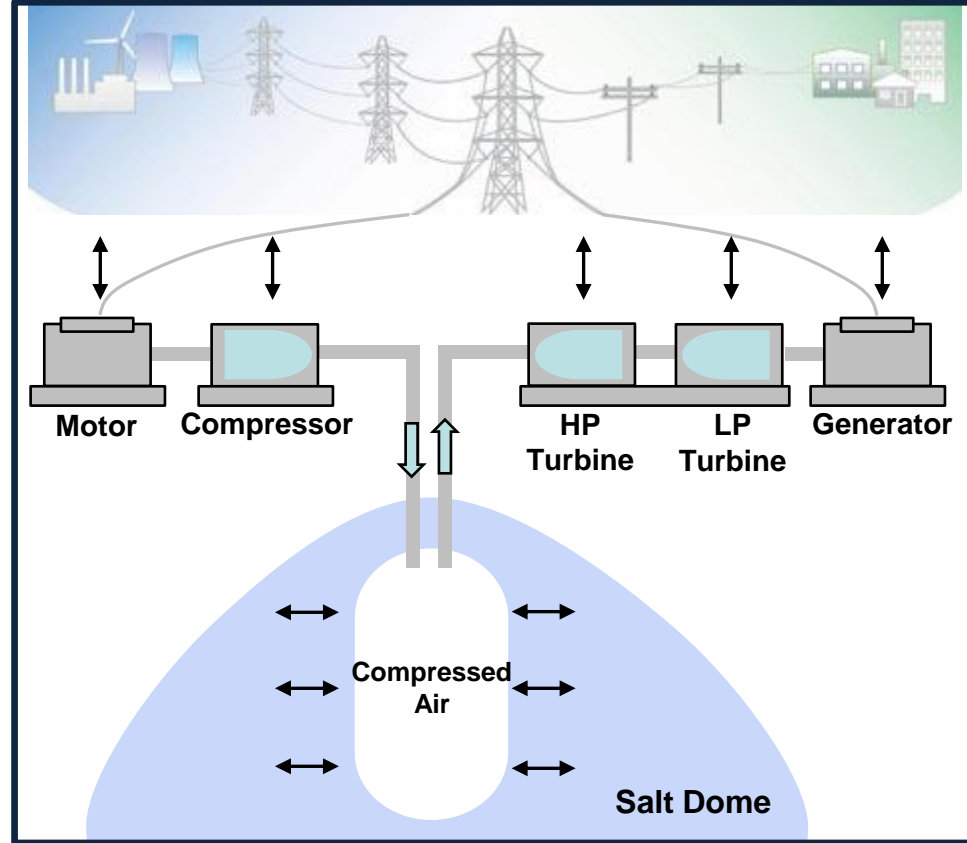
**Repetitive
Loading**

Repetitive Loading - Coupling

Wind Turbine



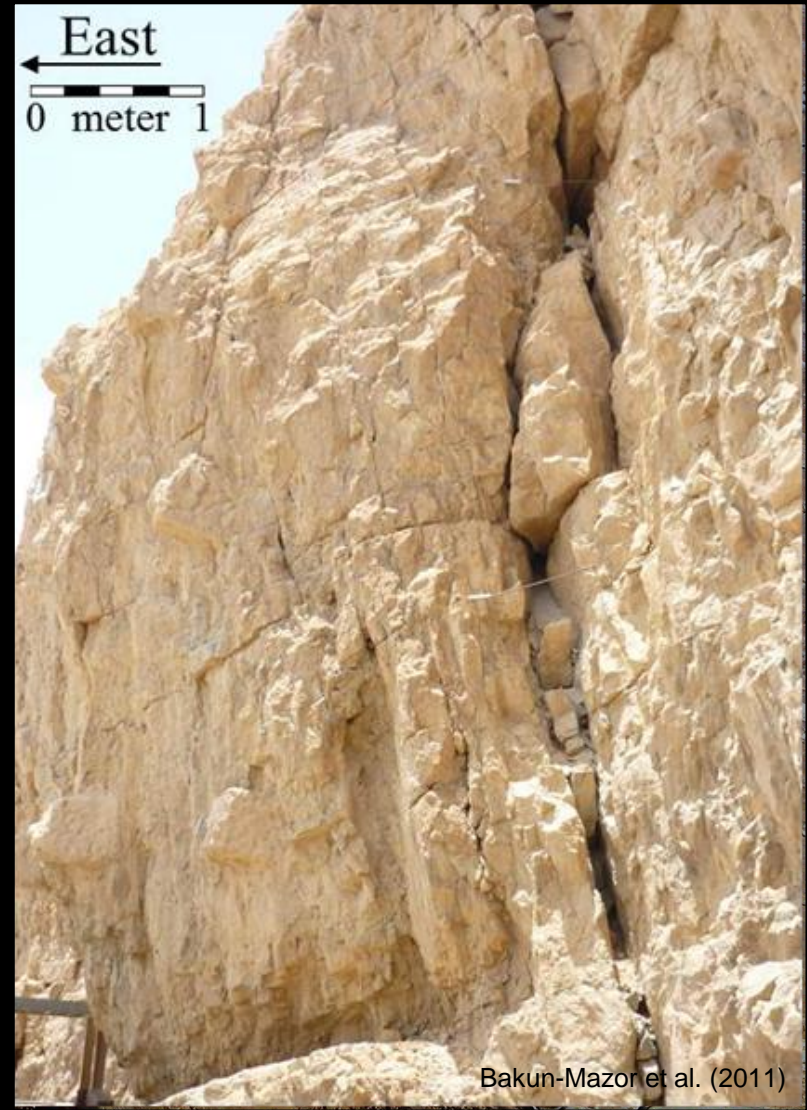
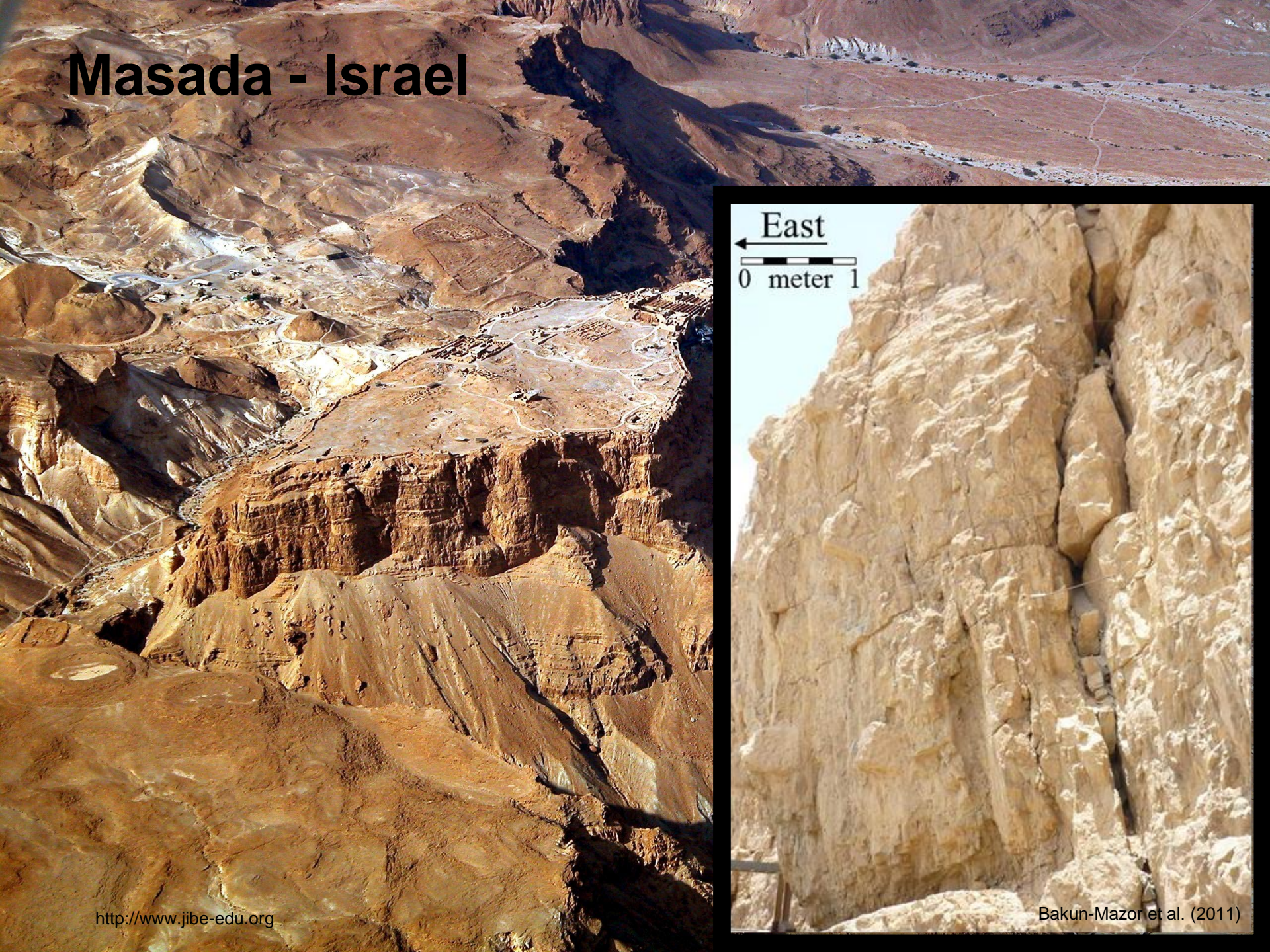
Compressed Air Energy Storage



Repetitive Loads:

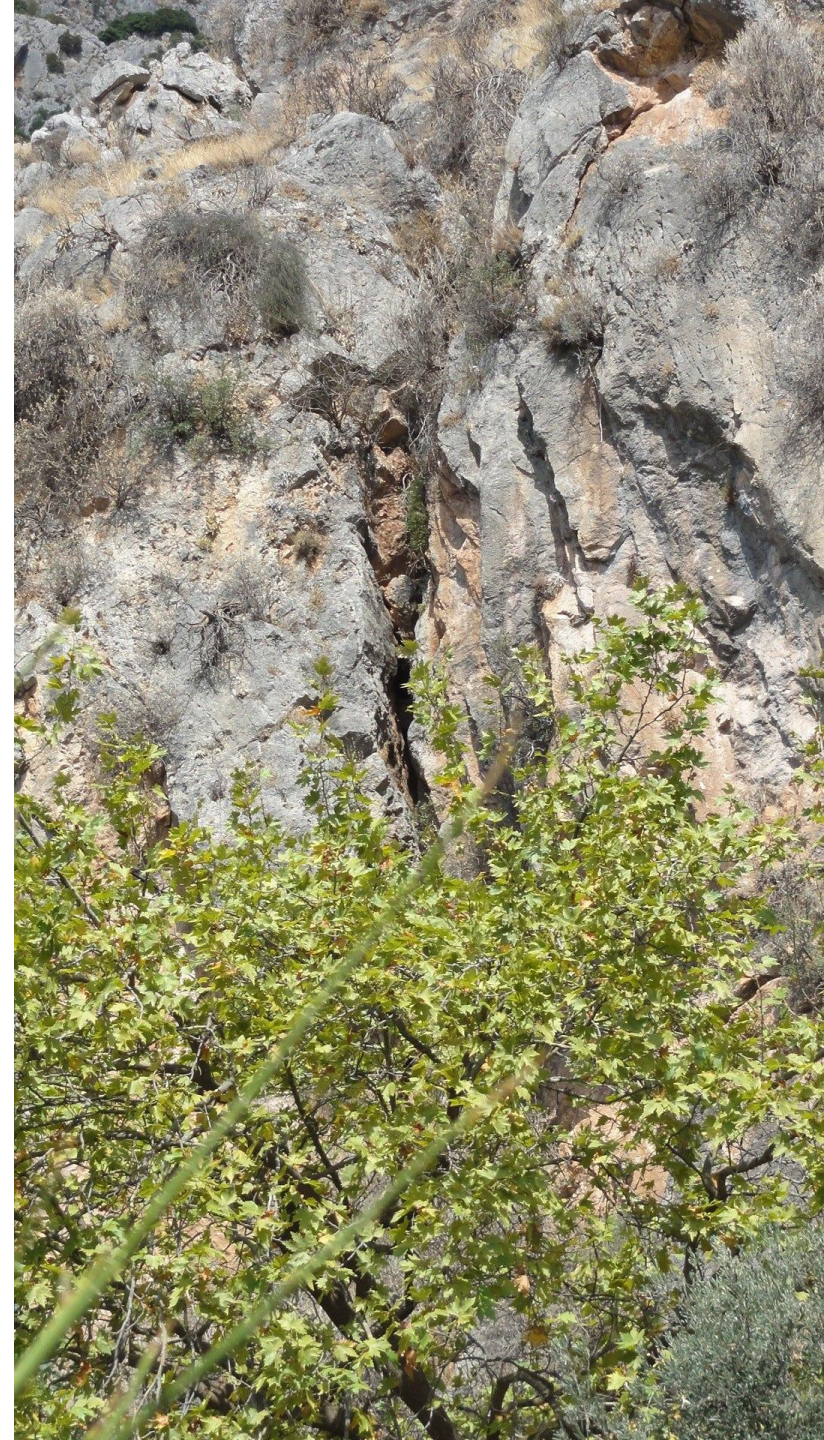
- Mechanical
- Thermal
- Wet-Dry
- Chemical

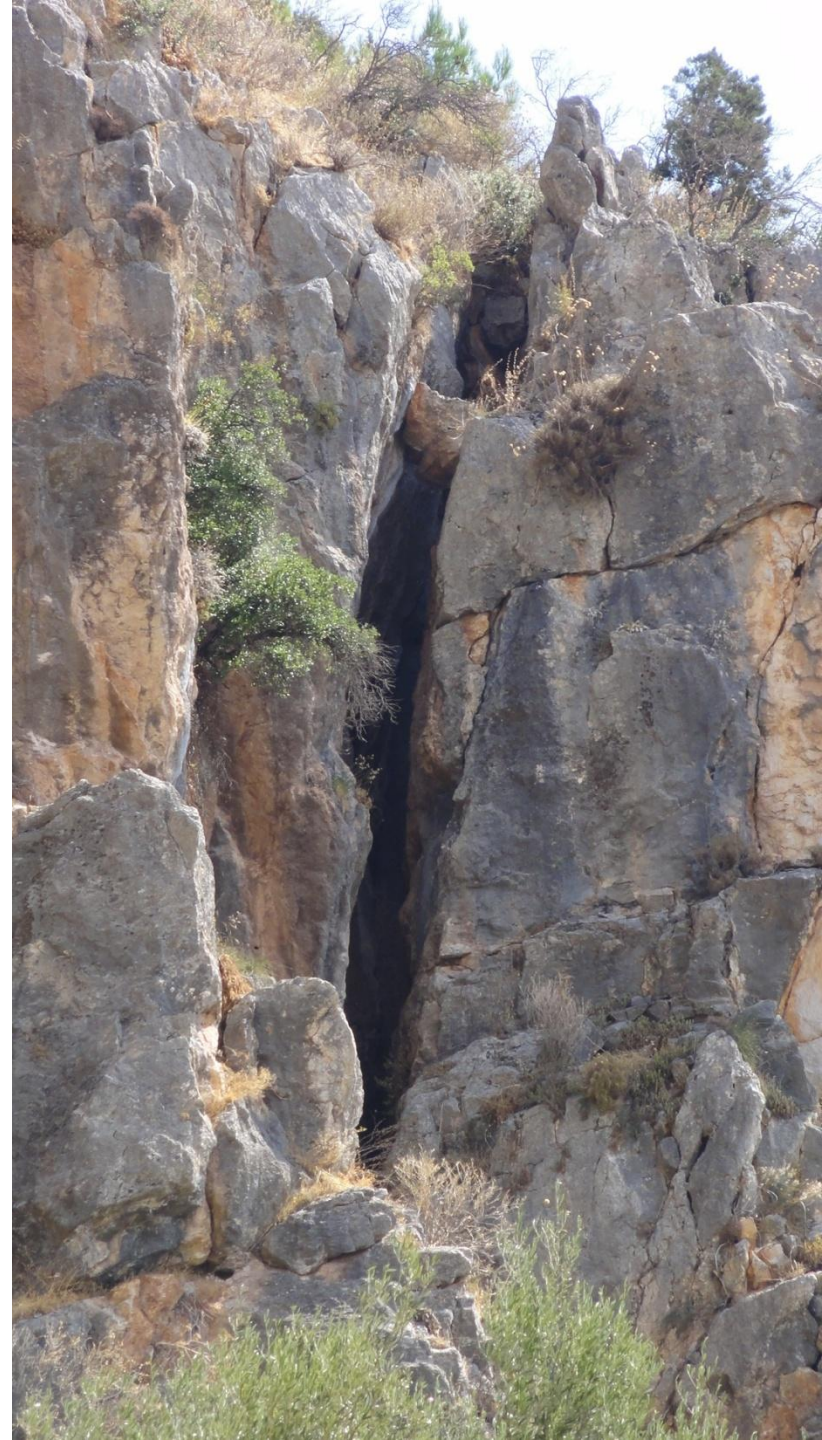
Masada - Israel



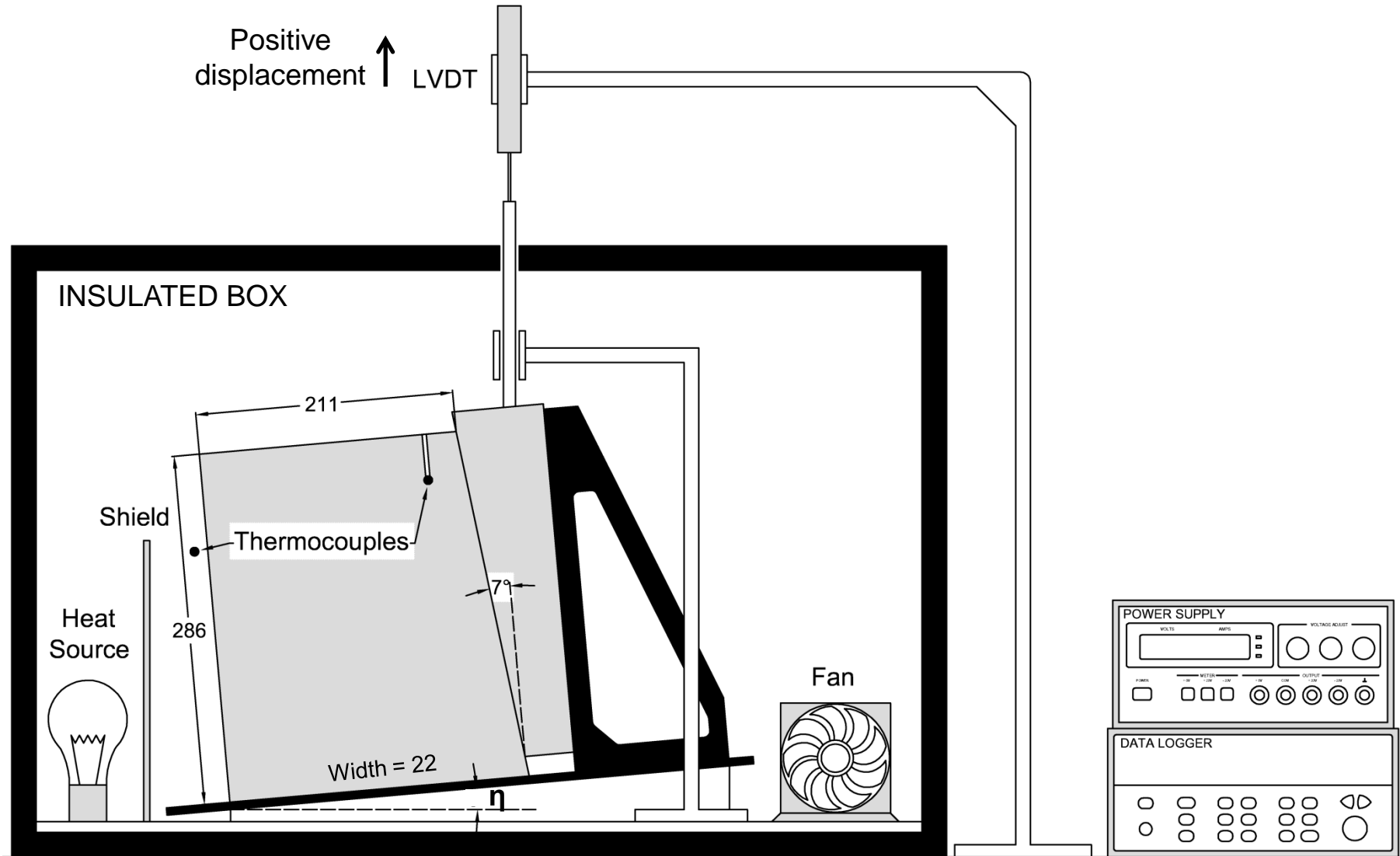
Delphi – Greece



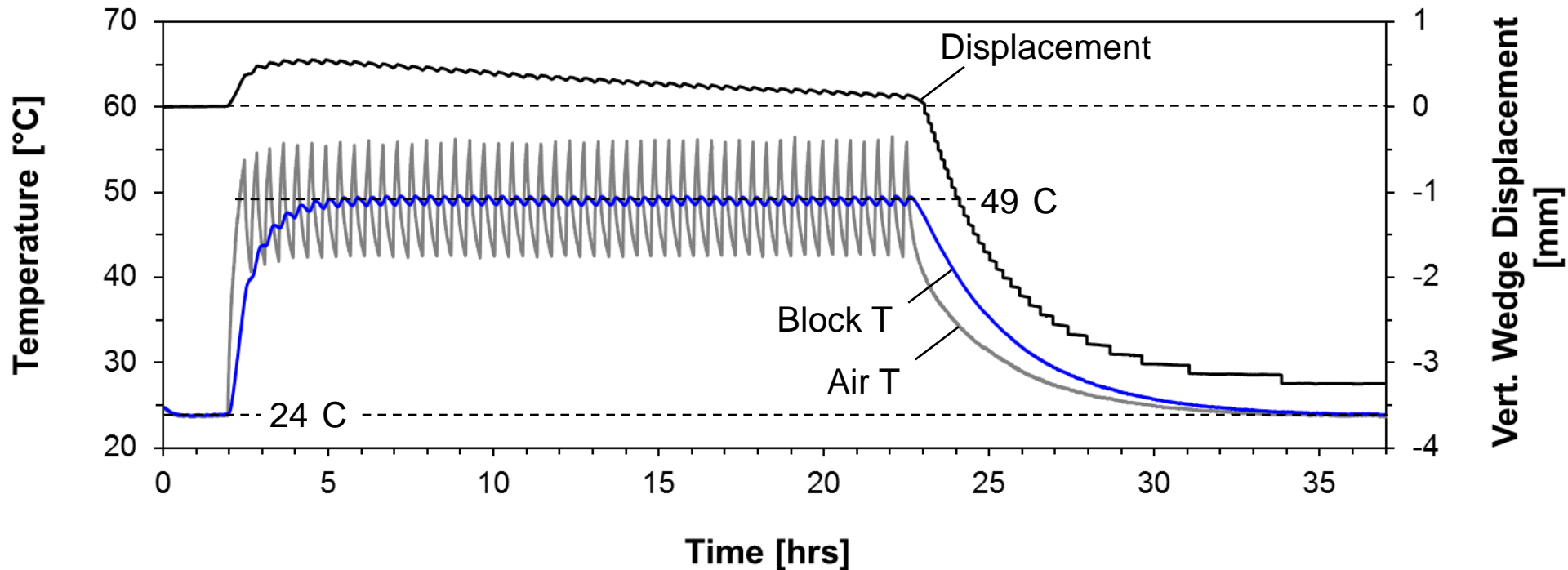




Thermo-Mechanical Ratcheting

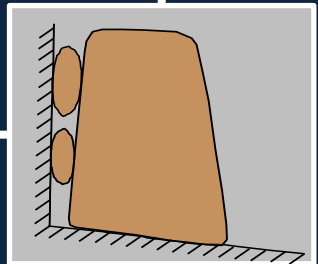
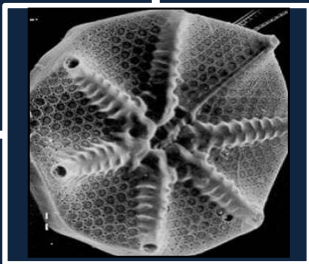
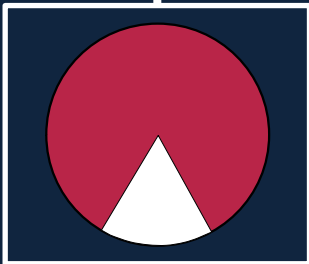
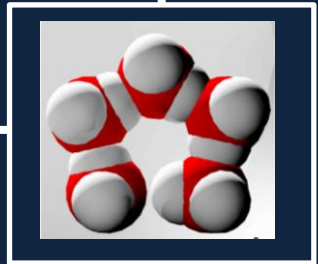
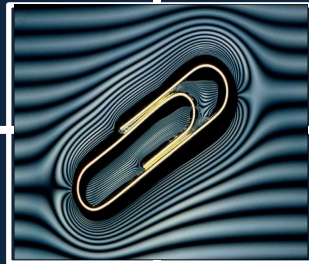
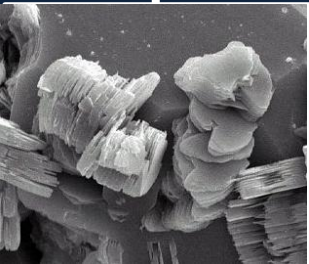
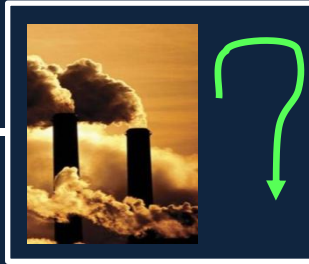


Thermo-Mechanical Ratcheting





Energy Geotech



Energy: critical for development

high increase in demand in next decades

resources: sufficient – but inadequate spatial distribution

C-economy → global warming

efficiency and conservation (primarily: top consumers)

Further developments in geotechnology: Rich & Complex

enhanced understanding of soil behavior

coupled processes

spatial variability and emergent phenomena

discontinuities

long time → many repetitions → ratcheting & terminal density

Geotechnology: central role

urgency fascinating !

Team



Hellenic Society For Soil Mechanics And Geotechnical Engineering

National Technical University of Athens

Aristotle University of Thessaloniki

Thank you !