Geomechanics of Reservoirs During CO_2 Injection

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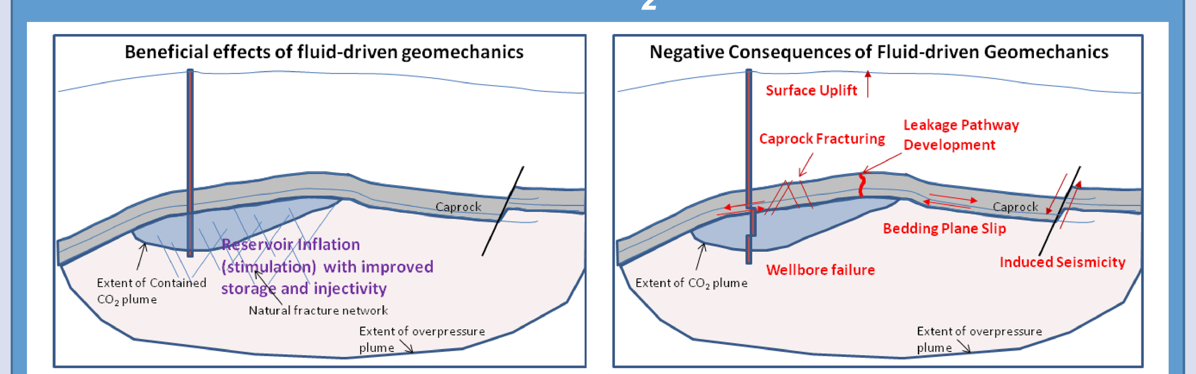
Introduction

Carbon Capture, Utilization, and Storage (CCUS) has been identified as a potential tool to offset anthropogenic emissions of carbon dioxide (CO_2) to help mitigate the effects of climate change. The goal is to capture CO_2 from large emission single point sources and to inject the emissions into the subsurface. CO_2 would be injected as a supercritical fluid into the reservoir and allowed to migrate throughout the subsurface. The goal of this project is to study changes in geomechanical behavior, including elastio-plastic, failure, and viscous reponses, of reservoir sandstones due to the presence of supercritical CO_2. Of interest here are offshore sandstones, which represent a potentially large volume for storage with proven sealing capabilities. We employ novel experimental and modeling methods, emphasizing chemical effects associated with scCO2 interacting with brine solutions.

Geomechanics and CO_2: Benefit or Hazard?

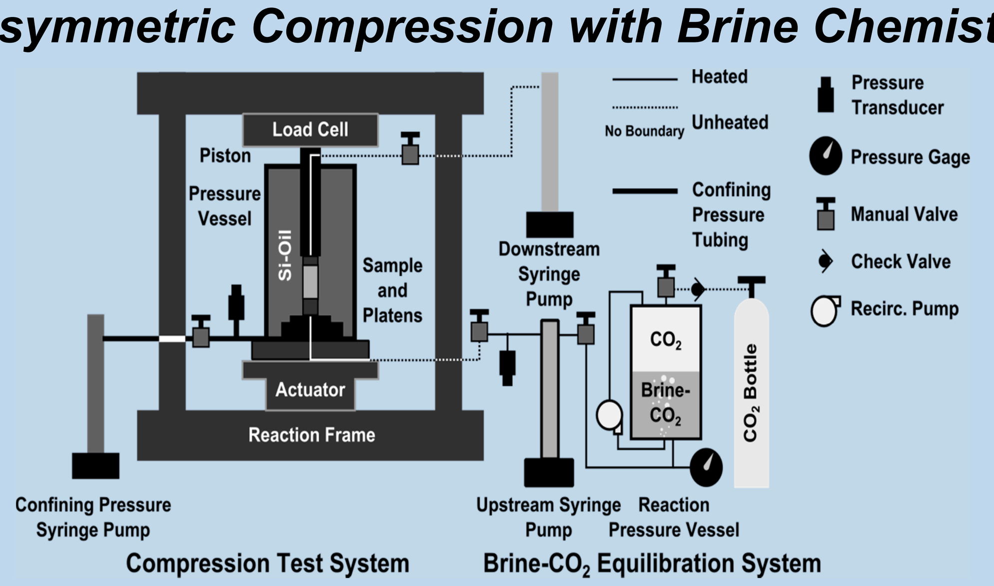


Research Plan

- *Develop understanding of mechanisms of reservoir damage and fracture initiation and propagation in the subsurface through experiment and constitutive modeling*
- *Translate that understanding into numerical models for reservoir deformation and related damage in heterogeneous geomaterials*
- *Use mathematical models together with observed data to make quantitative predictions of the location and extent of reservoir damage, leakage pathways, and potential for induced seismicity during CO_2 sequestration.*

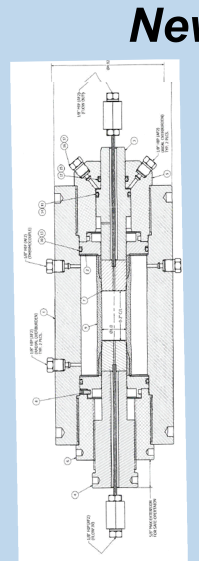
Methods

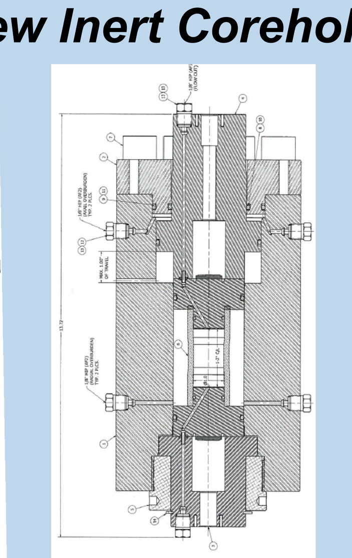
Axisymmetric Compression with Brine Chemistry

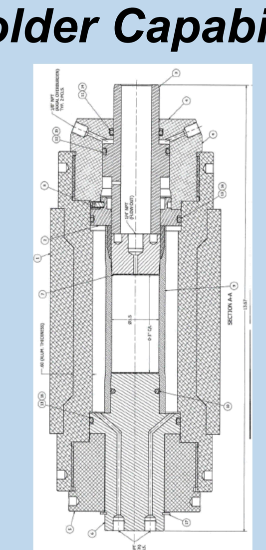


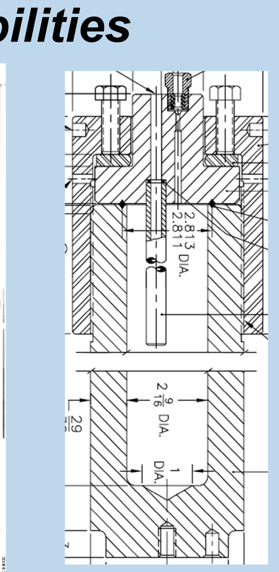
Compression Test System
Brine-CO_2 Equilibration System

New Inert Coreholder Capabilities


Triaxial hastelloy flow-through

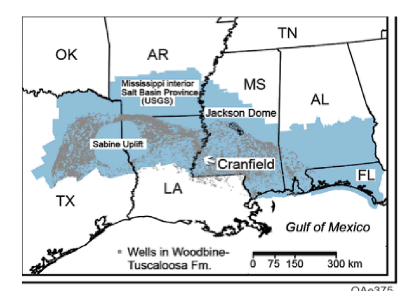

Triaxial titanium with ultrasonics

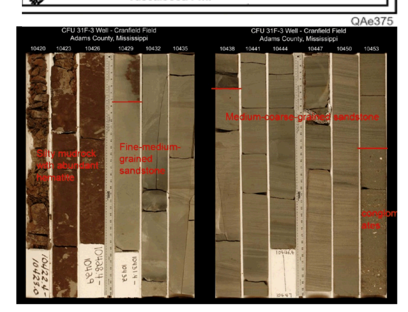

Aluminum-Carbon composite x-Ray

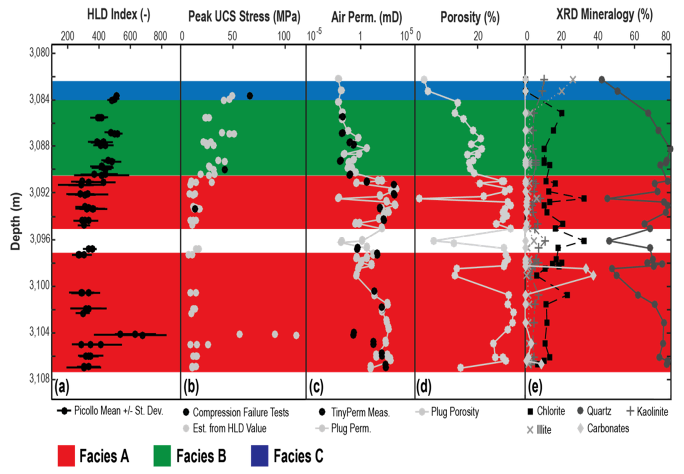

Hydrostatic cells for long-term creep

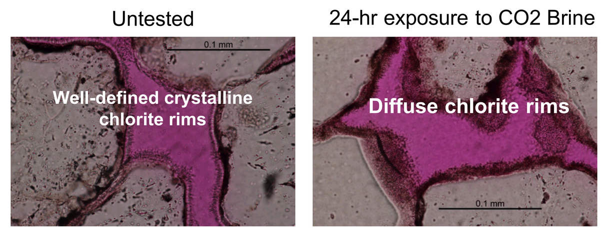
Chemo-Thermo-Elasto-Plastic Behavior

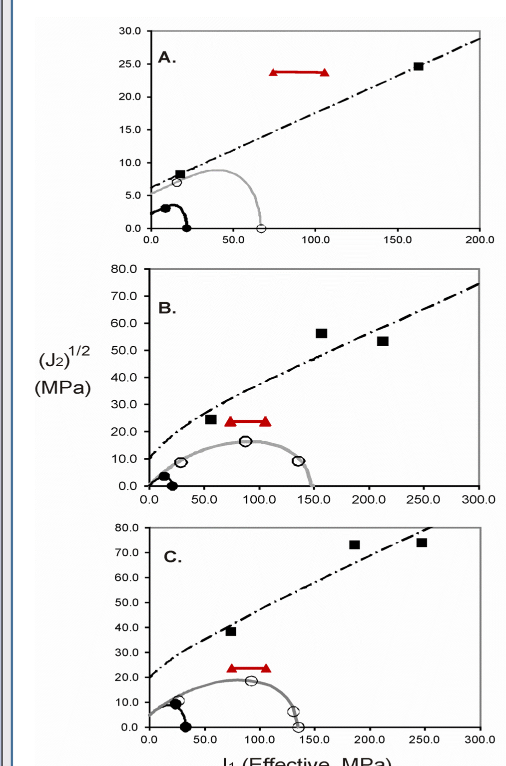
Yield and Failure of Tuscaloosa Sands at Cranfield





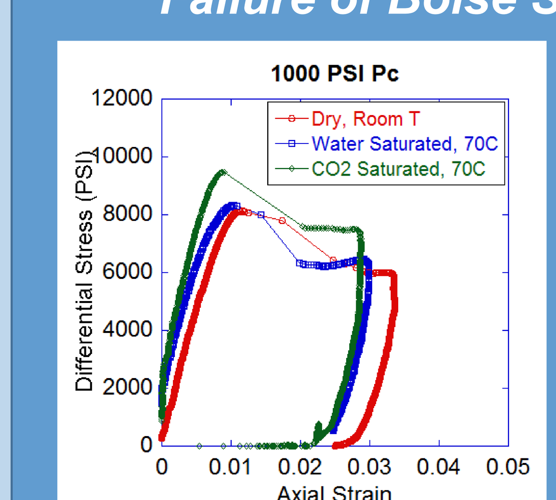


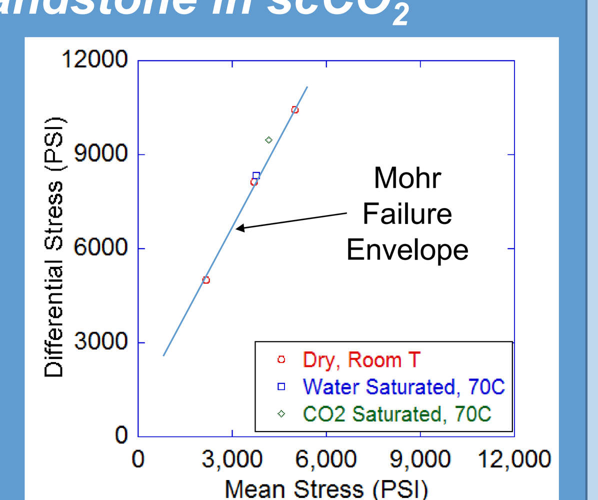




- Tuscaloosa facies first equilibrated with simulated in situ brine, followed by scCO2-saturated brine
- Mixed chlorite- and quartz-cemented muddy cross-bedded fine sandstone (Facies B), and quartz-cemented tabular very fine sandstone (Facies C) show yielding near in situ stresses at current depth of burial
- Chlorite-cemented conglomeratic sandstone (Facies A) is primary injection horizon and is much weaker
- Facies A shows failure below in situ stresses, suggesting that acidic CO2 brines weaken chlorite cements.
- Provides mechanism for "geomechanical event" observed just following injection at Cranfield

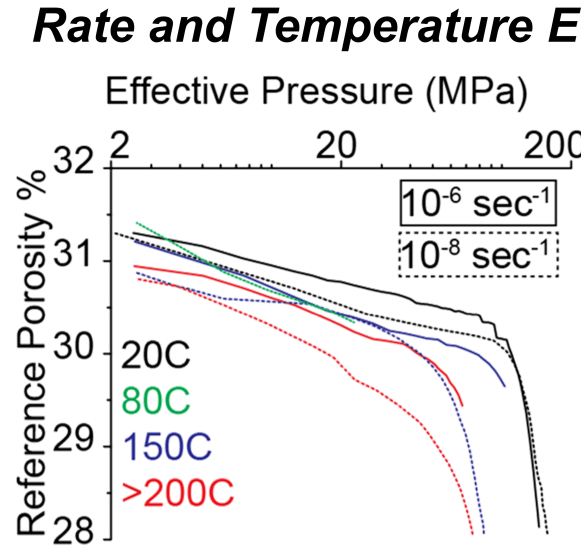
Failure of Boise Sandstone in $scCO_2$





Preliminary tests suggest Boise Sandstone, an analogue for off-shore Gulf Coast sands, is slightly stronger in dry $scCO_2$, and interestingly shows no weakening in water.

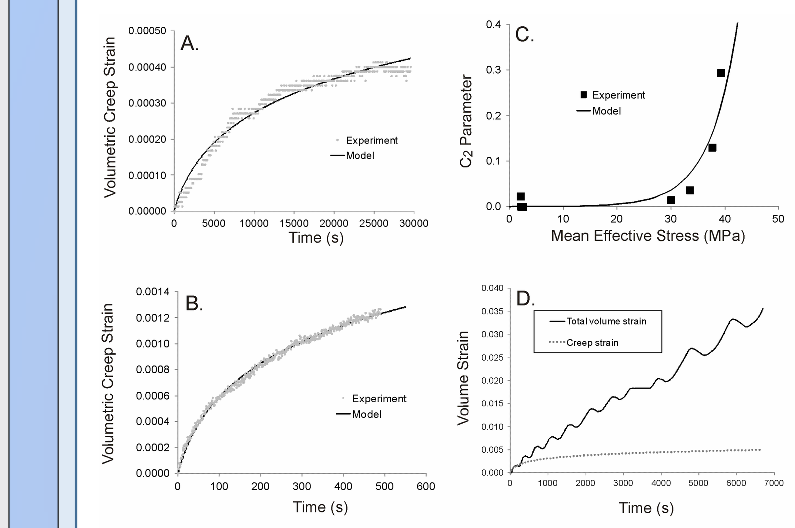
Rate and Temperature Effects on Pore Collapse



- Hydrostatic consolidation of quartz sand shows crushing behavior dependent on temperature and strain rate.
- Changes in either temperature or strain rate have small effects in reducing critical grain crushing pressure, but changes in both temperature and strain rate have pronounced, additive, effects.
- These are important considerations for extrapolating laboratory experiments to predict stability for long engineering and geologic time.

Chemo-Viscous Behavior

"Brittle Creep" in Tuscaloosa Sands



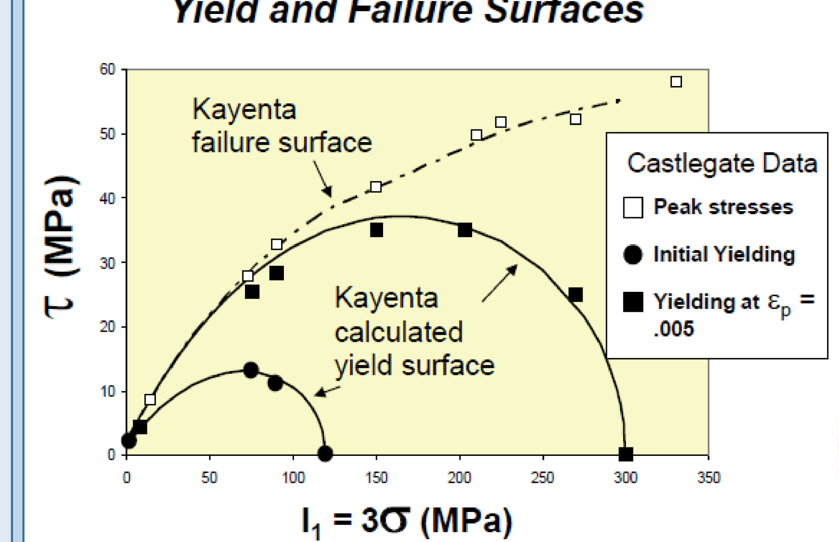
$$\frac{d\varepsilon^{vs}}{dt} = \frac{C_1}{C_2^{-1} + t} \qquad C_2 = z_1 e^{z_2 \sigma'}$$

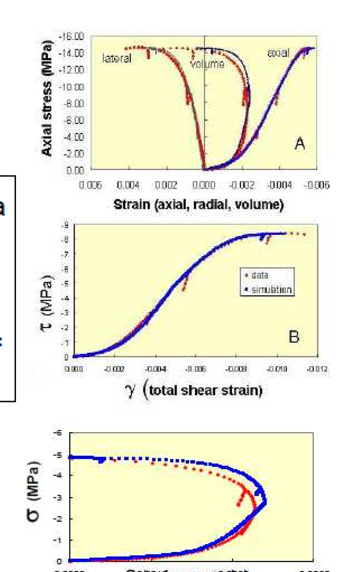
- Chlorite-bearing conglomerate facies from Cranfield shows initiation of time-dependent creep upon exposure to acidic CO2-bearing brines
- Strain rate is inverse-with-time, equivalent to log-time creep
- Creep law consistent with so-called "brittle creep" behavior associated with acid-enhanced sub critical crack growth

Constitutive Modeling

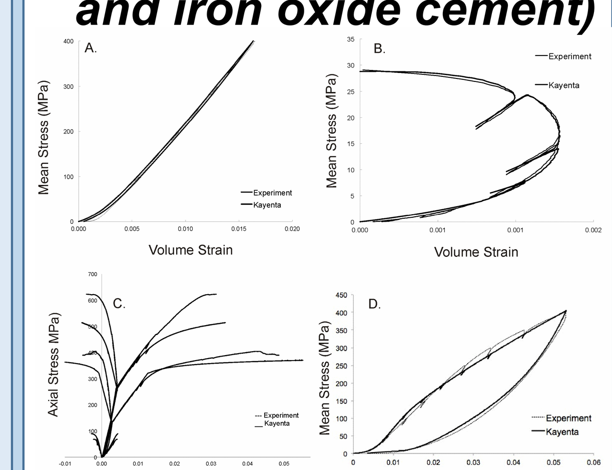
Mesaverde SS (carbonate and clay cement)

Yield and Failure Surfaces

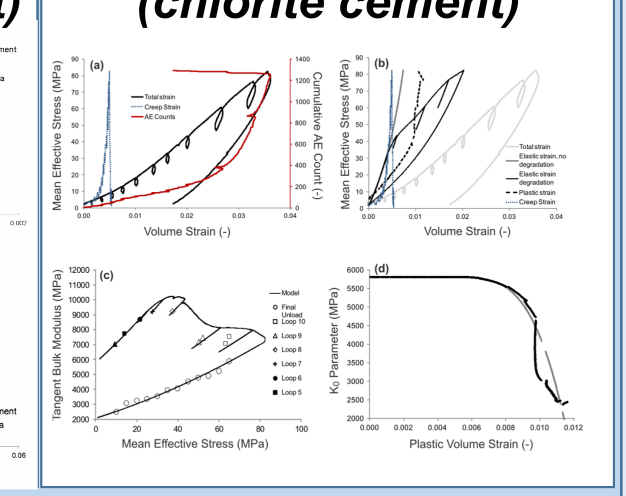




Mount Simon SS (silica and iron oxide cement)



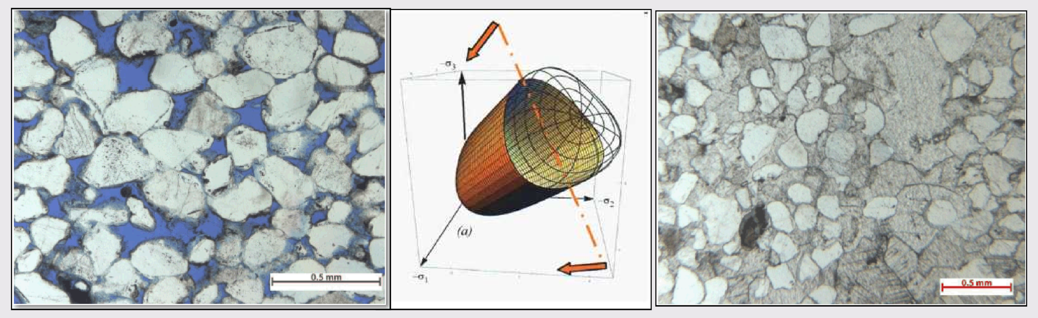
Tuscaloosa SS (chlorite cement)



- Kayenta Elasto-plastic constitutive model validated against multiple sandstone compositions and depositional environments
- Cement content is key, not just grain size and porosity
- Needs to be augmented to include transverse isotropy, chemical effects, and creep

Requirements for modeling reservoirs

- Non-Associative Plasticity
- Stress Invariant Dep. Failure
- Elliptical Cap Surface
- Kinematic Hardening
- Isotropic Hardening
- Nonlinear Elasticity
- Elastic-Plastic Coupling



Conclusions

- We investigate elasto-plasto-thermo-chemo-viscous deformation of sandstones relevant as reservoir lithologies for geologic carbon storage. We examine sands from a variety of depositional environments and geologic ages.
- These display a range of behaviors – Cambrian Mt. Simon is amazingly strong and basically poroelastic, while Cretaceous and Tertiary sands display elasto-plastic and viscous behavior, some sensitive to CO_2-perturbed chemistry.
- The Kayenta constitutive model describes elasto-plastic behavior, and could be used for some viscous behavior, although we have not attempted this as yet. Kayenta can be used in any finite element model.
- The influence of chemistry on rock strength demonstrated here could be used as an engineering control on reservoir behavior in the subsurface, mitigating hazards and improving injectivity and sweep efficiency during carbon storage.

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Acknowledgements

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