Welcome!

The program will begin soon.

You will not hear audio until we begin.

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Geochemical Effects of CO2 Saturated Brine on Reservoir and Seal Rocks

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15 June 2023

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Outline

- General Comments on CO_2 Changes to Rock and Fluids
- Methods to Investigate Changes to Formation Rocks
- Fluid-Fluid and Rock-Fluid Modeling Software
- Static CO_2 Saturated Brine Exposure for Low K Rocks
- Dynamic CO_2 Saturated Brine Injectivity Testing

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CO_2 Effects on Seal and Target Zone

- CO2 Saturated brine can reach a pH as low as approximately 3.5 in relatively fresh waters.
- The pH will be less affected as the brine salinity increases and as pressure and temperature increase.
- These acidic effects could be important in both the target and seal layers
- Geochemical Reactions of the rock minerals should be investigated by modeling and various testing methods

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Thoughts to Consider for CO_2 Injection

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- Carbonic acid is formed when CO_2 contacts water/brine
- Approximately 2 mole percent CO_2 is the maximum CO_2 water can carry
- Dry CO_2 injection will vaporize some fraction of contacted water, which will increase salinity (lowers CO2 content and raises pH)
- Acids begin to react (spend) as soon as they contact minerals
- Reaction will depend on mineral (most reactive minerals are calcite, potassium feldspars, and high surface area clays)
- Water saturation fraction will reduce near injection well with CO_2 injection
- Reservoir Pressure will increase with CO_2 injection

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Determining CO_2 Effects on Seal and Target Zone

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After periods of CO2 saturated brine exposure carbonic acid effects can be investigated by various standard core analysis methods

- Visual inspection
  - CT or MicroCT Scan
  - Petrographic Description (Thin Section and SEM)
- Porosity and Permeability Determination
- Formation Damage – Permeability vs Throughput Testing
- Mercury Injection Capillary Pressure – Including Threshold Entry Pressure
- Geomechanics Testing for Rock Strength

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USGS Sponsored Geochemical Software Example

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- Z. Duan et al., "An improved model for the calculation of CO_2 solubility in aqueous solutions containing Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-}, Marine Chemistry (Elsevier) February 2006
- CO2-H2O mixtures in the geological sequestration of CO2. I. Assessment and Calculation of mutual solubilities from 12 to 100°C and up to 600 bar, N Spycher et al., Geochemica et Cosmochimica Acta, Volume 67, Issue 16, August 2003, Pages 3015-3031.

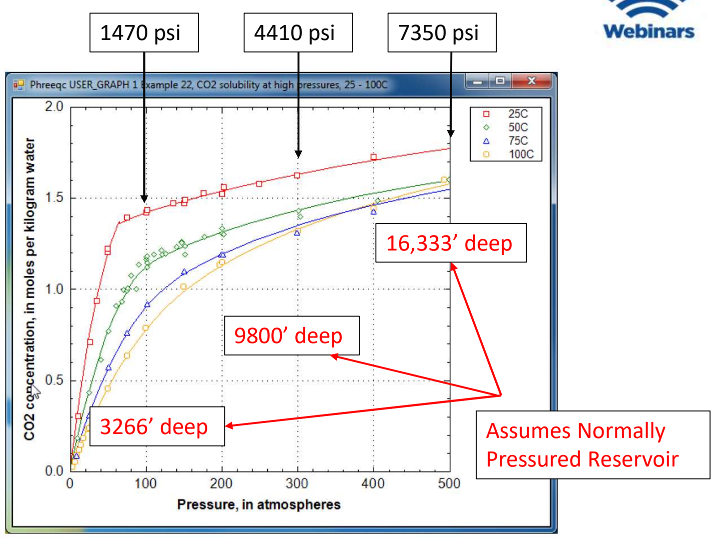

Figure 27. Solubility of CO_2 gas as a function of gas pressure at 25, 50, 75 and 100 °C. Data points are from compilations by Duan and others (2006) and Spycher and others (2003); lines are calculated with PHREEQC.

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Commercial Software Example of CaCo3 Solubility/Deposition

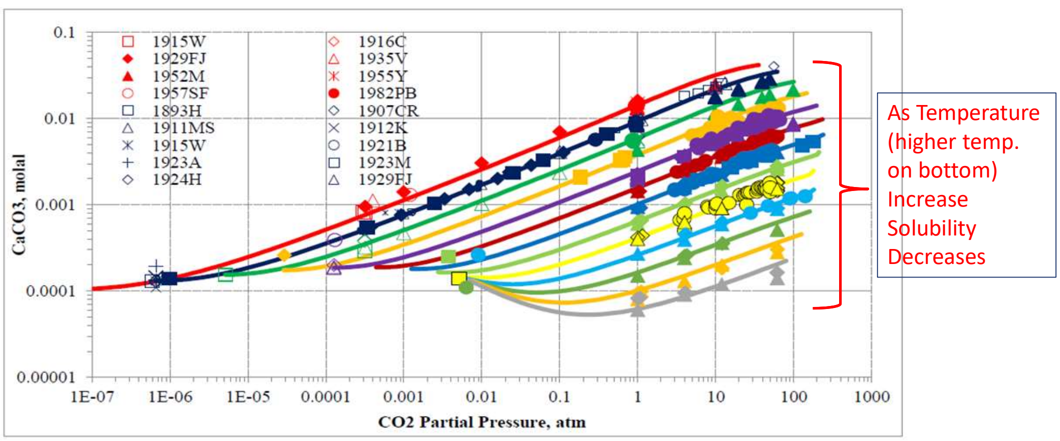

Figure 11 – Predicted solubility of calcite scale as a function of temperature, pressure, and CO_2. Symbols are the measured values and lines are OLI predictions

Graph Source: OLI software marketing correspondence

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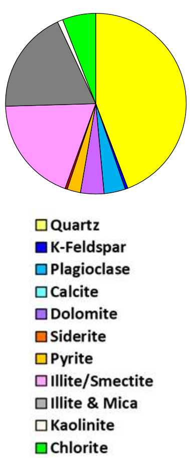
CO_2 Extended Exposure Methodology

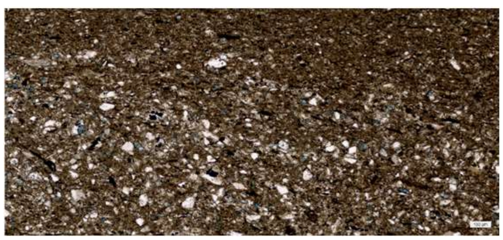
- Samples drilled from whole core material if possible and trimmed to 1.5-inch diameter right cylinders (horizontal and vertical). Test samples can vary from right cylinder plugs to small chunks of rock.
- Synthetic formation brine was prepared based on the provided analysis using deionized water and reagent grade chemicals. The brine was filtered to 0.45 microns and degassed.
- Each sample was placed in a labeled bag and loaded into a stainless-steel vessel filled with test brine.
- The vessel was capped and pressurized to 100 psi with carbon dioxide (CO_2).
- The vessel was heated to 150°F while monitoring pressure. Pressure was not allowed to exceed 1500 psi during this process.
- Once temperature stabilized at 150°F, pressure was maintained at 1500 psi using CO_2.
- Exposure time (1 month, 6 months, ??) for each of the samples.
- Upon completion, samples were slowly depressurized, unloaded and dried in a convection oven.

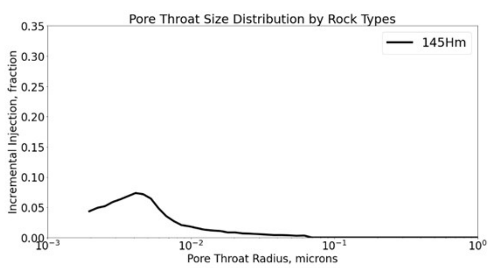
Silty Mudrock Seal

ϕ = 5.3%; $K_{Swanson}$ = 6.47E-05 mD; GD_{XRD} = 2.664 g/cc; $Pd_{10}CO_2$ = 972 psi

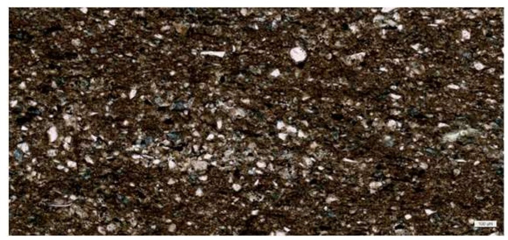


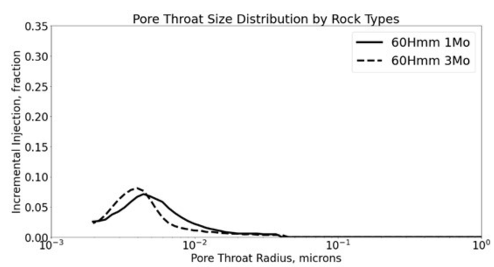
Pre-CO_2 Exposure





Month Post-CO_2 Exposure





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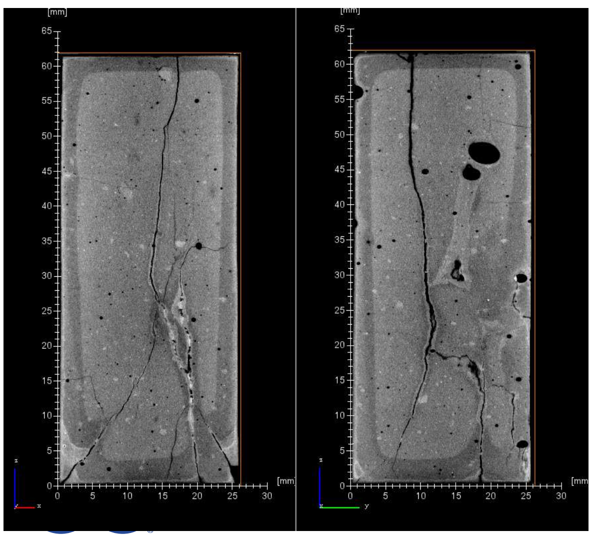
Cement - Post Exposure CT Scan



- Cement contain approximately 60% calcite
- Areas of brine contact can be seen by darker colors around the edge of the sample and near fractures
- Bright colors are indications of high-density material left behind after CO_2 dissolution

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Dynamic Exposure for Higher Permeability Samples (contact to all primary flow pathways)

- Measure Grain Volume and Sample Weight
- Saturate Sample with Reservoir Formation Brine
- Measure Baseline Permeability to Reservoir Brine (Reservoir Temperature)
- Inject CO2 Saturated Brine and Monitor Permeability Changes vs Pore Volumes of Throughput (Reservoir Temperature)
- Slowly Reduce Test to Ambient Conditions
- Dry Sample
- Measure Grain Volume and Sample Weight

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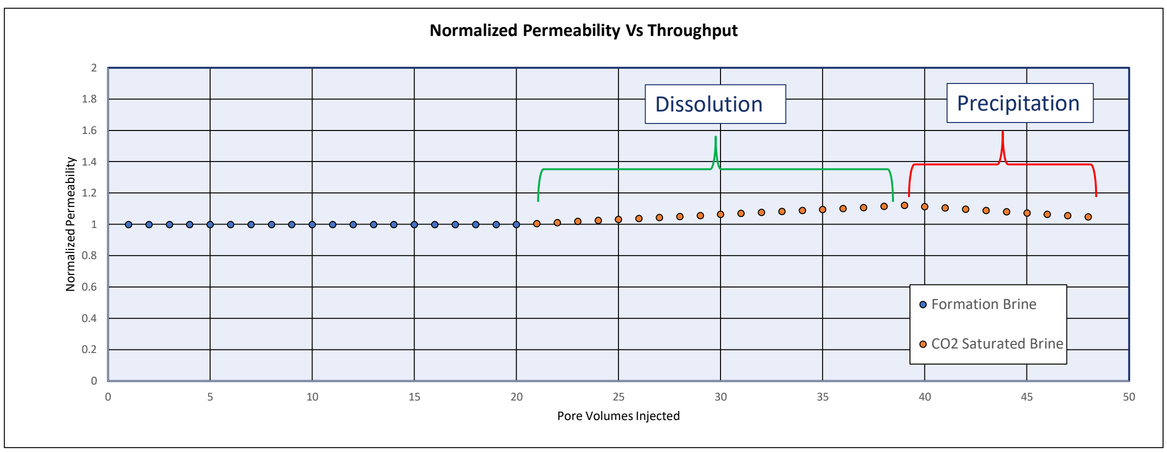
Permeability Vs Throughput



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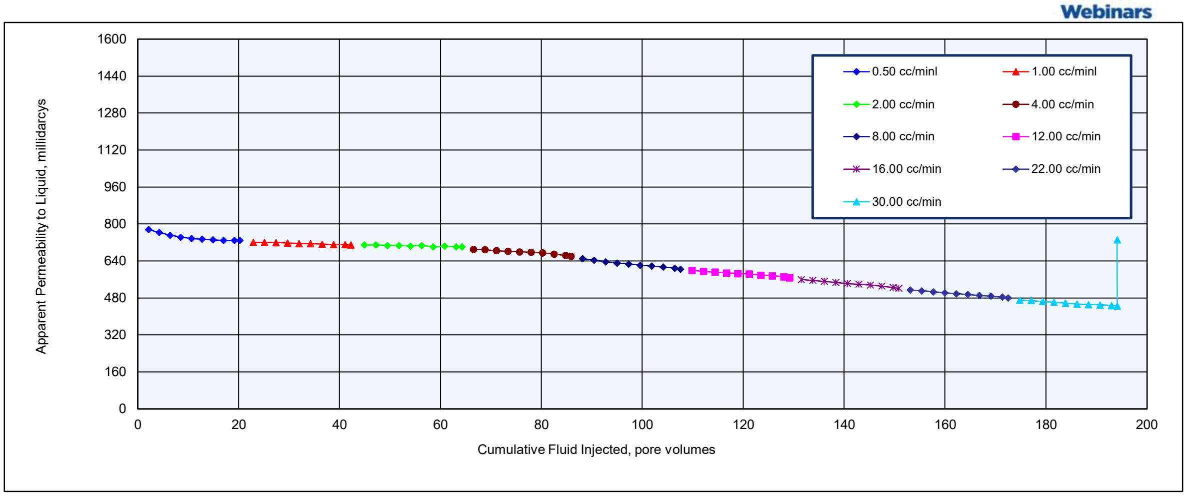
Critical Velocity from Liberated Fines



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CO2 and Brine Co-Injection on Inlet Face

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10 PV of Injection

56 PV of Injection

155 PV of Injection

Pore Volume Increased from 56.74 to 66.9 cc (24.8% Increase)

SCA2003-19: CO-INJECTED CO_2-BRINE INTERACTIONS WITH INDIANA LIMESTONE
Reid B. Grigg and Robert K. Svec, New Mexico Petroleum Recovery Research Center

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CO2 and Brine Co-Injection – Permeability Changes

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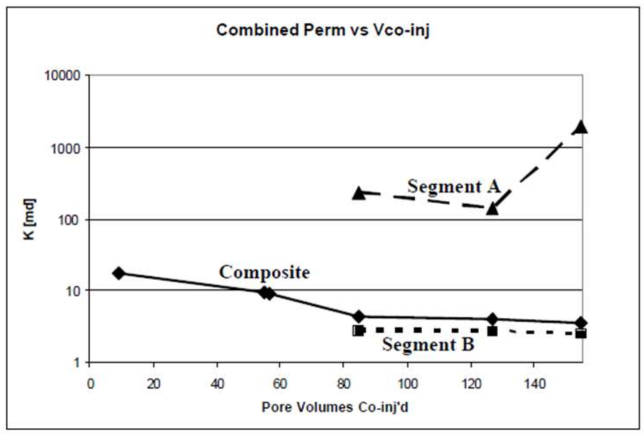
- Initial Total Injection Rate was 80 cc/hour for the first 55 Pore Volumes of Injection
- Injection Rate was Reduced to 40 cc/hour from 55 Pore Volumes to 155 Pore Volumes



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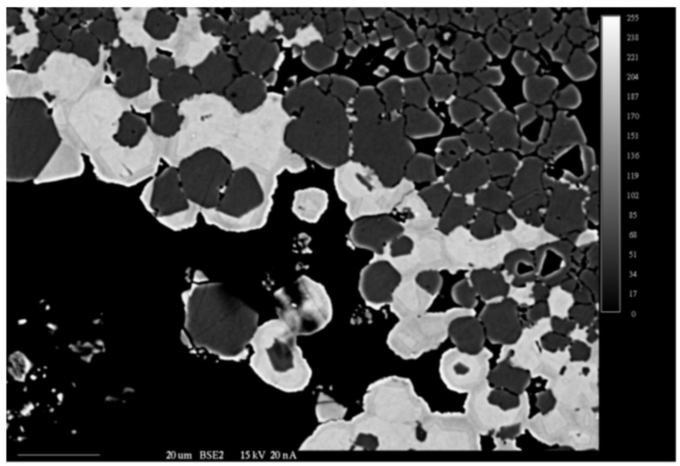
CO2 and Brine Co-Injection Mineral Deposition

The White Areas in Backscattered Electron Image are Rich in Strontium from the Brine (5000 ppm $SrCl_2$)



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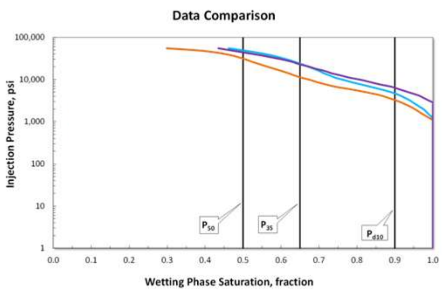
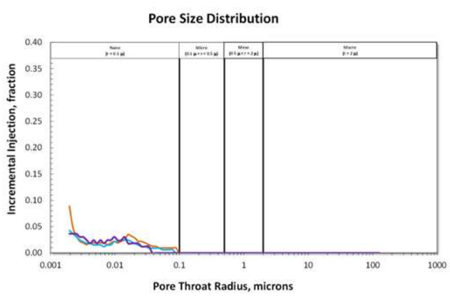
Capillary Pressure – Mercury Injection

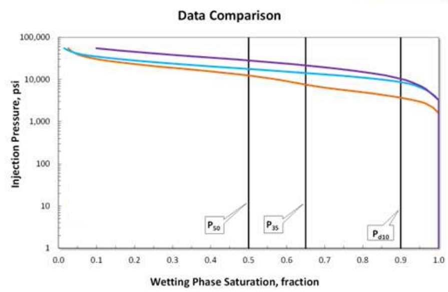
(CO_2 Exposure)

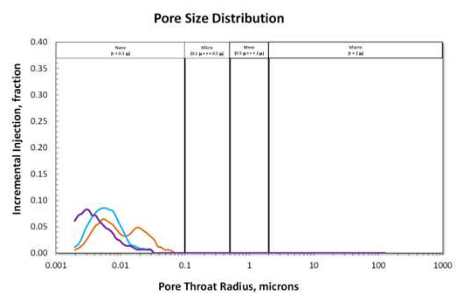
Sample #1





Sample #2





Baseline
1 - Month
3 - Month

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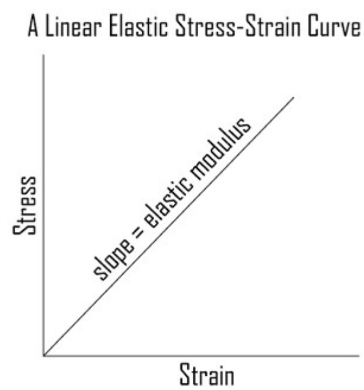
Triaxial Test

A stress-strain curve is a basic tool used to interpret rock mechanical data such as

- Young's modulus (E)
- Poisson's ratio (v)
- Compressive Strength



Young’s modulus E from σ-ε curves

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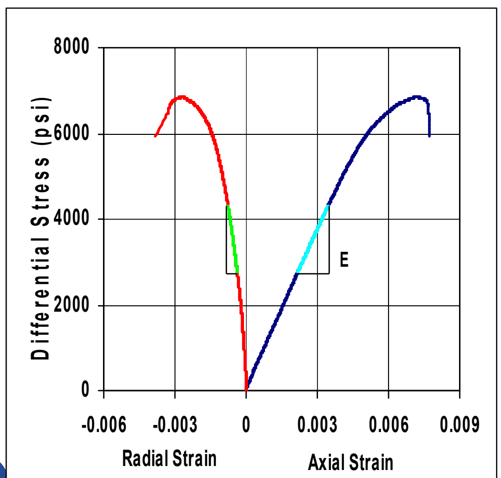

Young’s modulus

$$E = \frac{\Delta\sigma}{\Delta\varepsilon_a} = 1.2\text{x}10^6 \text{ psi}$$

= slope of axial curve

[slope taken at ½ max stress]

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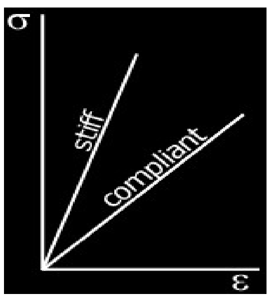
What does Young's Modulus tell us?



Young's modulus (as well as the bulk and shear moduli) tells us about the stiffness of the rock

TABLE 3.1—TYPICAL ELASTIC PROPERTIES OF ROCK[3]

Rock Type	Young's Modulus (10^6 psi)	Poisson's Ratio
Granite	3.7 to 10.0	0.125 to 0.250
Dolomite	2.8 to 11.9	0.08 to 0.20
Limestone	1.4 to 11.4	0.10 to 0.23
Sandstone	0.7 to 12.2	0.066 to 0.30
Shale	1.1 to 4.3	0.1 to 0.50

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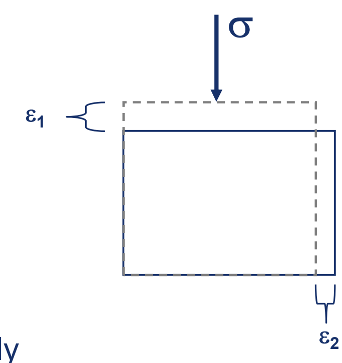
Poisson's Ratio (ν)

Ratio of lateral expansion to longitudinal contraction.

$\nu = - \varepsilon_2 / \varepsilon_1$



The measure of the rocks tendency to expand radially as it is compressed axially

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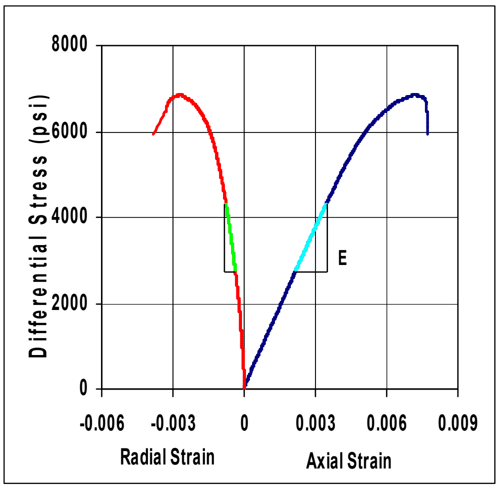
Poisson's Ratio ν from σ-ε curves



Poisson's ratio

$$\nu = -\frac{\dfrac{\Delta\sigma}{\Delta\varepsilon_a}}{\dfrac{\Delta\sigma}{\Delta\varepsilon_r}}$$

$$= -\frac{\text{slope of axial curve}}{\text{slope of radial curve}}$$

= 0.30

Triaxial Test Data

For these example data graphs, Pc is defined as confining pressure

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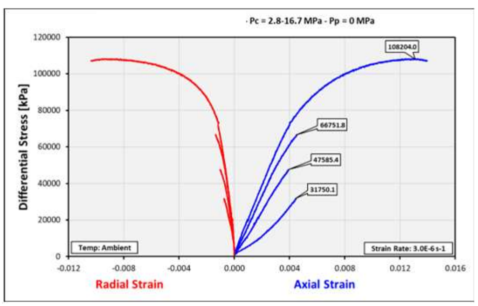

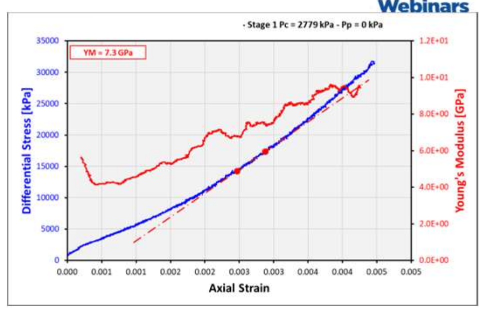

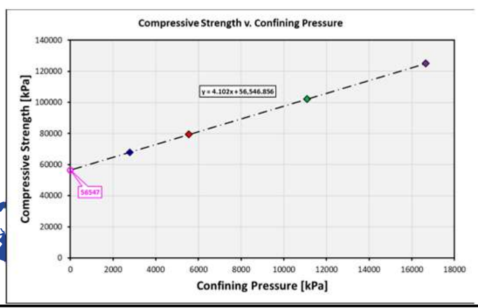

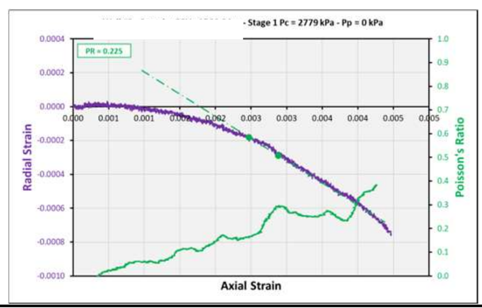

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Triaxial Test Comparison (Shell Peterhead data)

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- 2-3% Calcite cement was dissolved (confirmed by MicroCT, SEM, XRD and effluent analysis)
- No significant change in rock mechanical properties (Young's modulus, Poisson's ratio, bulk modulus, and velocities)
- Possibly indicating the loss of calcite did not alter the grain-to-grain contact strength of the sand

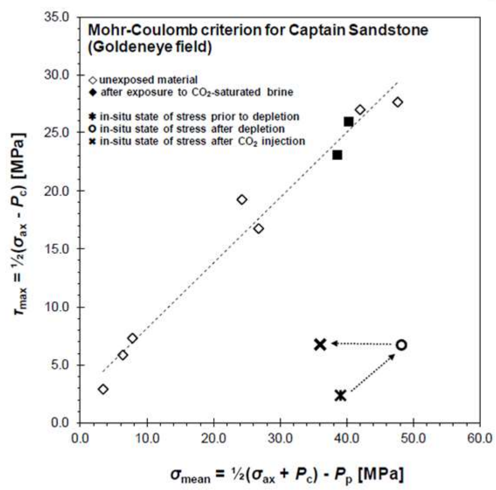

Fig. 3-12—Failure envelope for Captain Sandstone in P'-Q stress space obtained using data from a previous study[4], as well as data obtained in this study.

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Peterhead CCS Project (Shell), Special Core Analysis (SCAL) Report and Geomech / Reactive Transport Modelling (RTM) Core Analysis Reports, Doc No. PCCS-05-PTD-ZP-9034-00001 Rev-KO2

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Summary

- Various freeware and commercial software packages are available to predict dissolution and potential precipitation of rock minerals due to lowering of pH caused by CO2 injection
- The Geochem software packages are fairly-robust, but usually don’t use laboratory measured data to constrain the data
- Static and/or Dynamic exposure testing should be conducted on reservoir rocks (and cement) to constrain the modeled and upscaled data

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