University of Texas 5th Conference on Carbon Capture and Storage

Uniaxial Strain Unloading Compressibility of Frio Sand: Implications on Reservoir Pressure Management for CO_2 Storage

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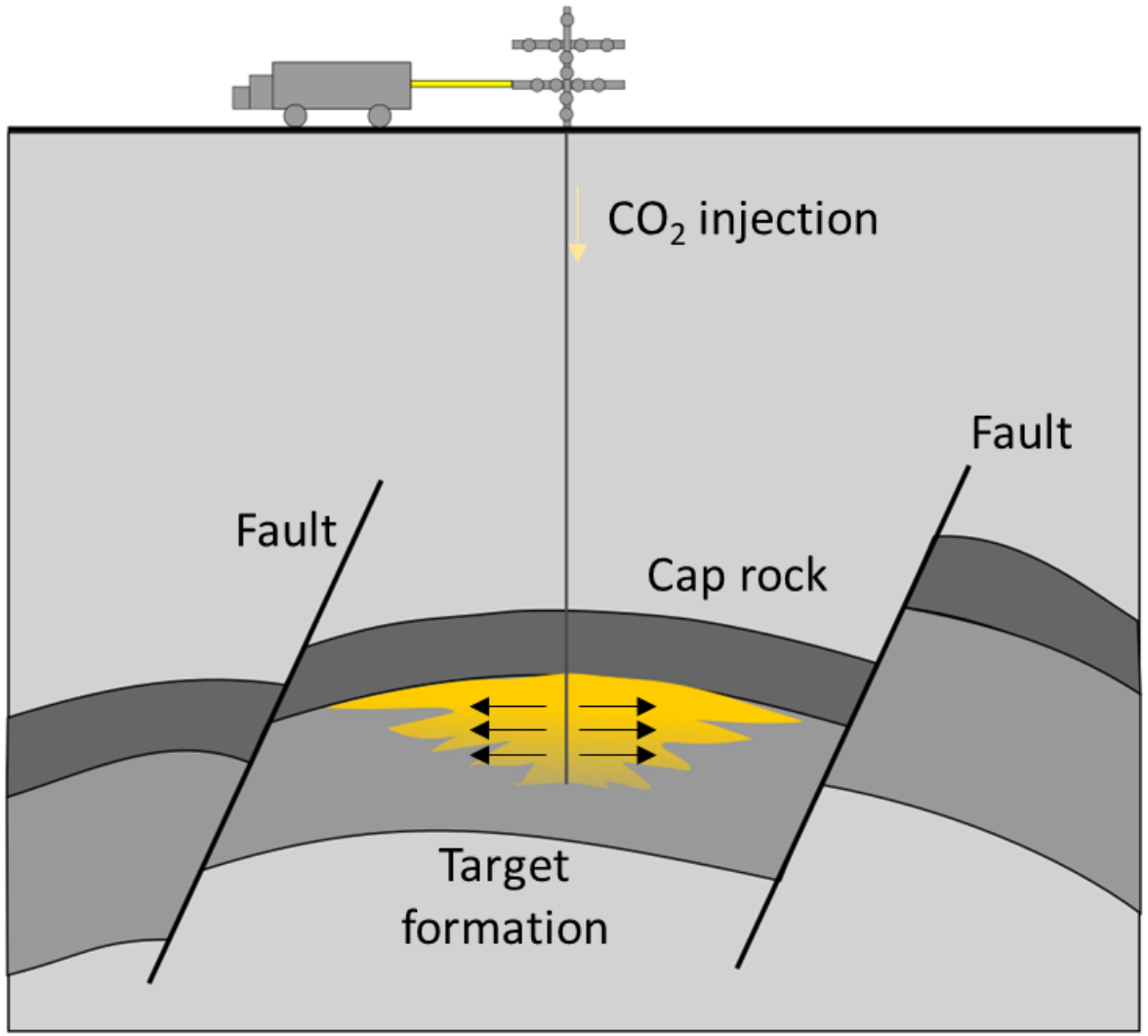
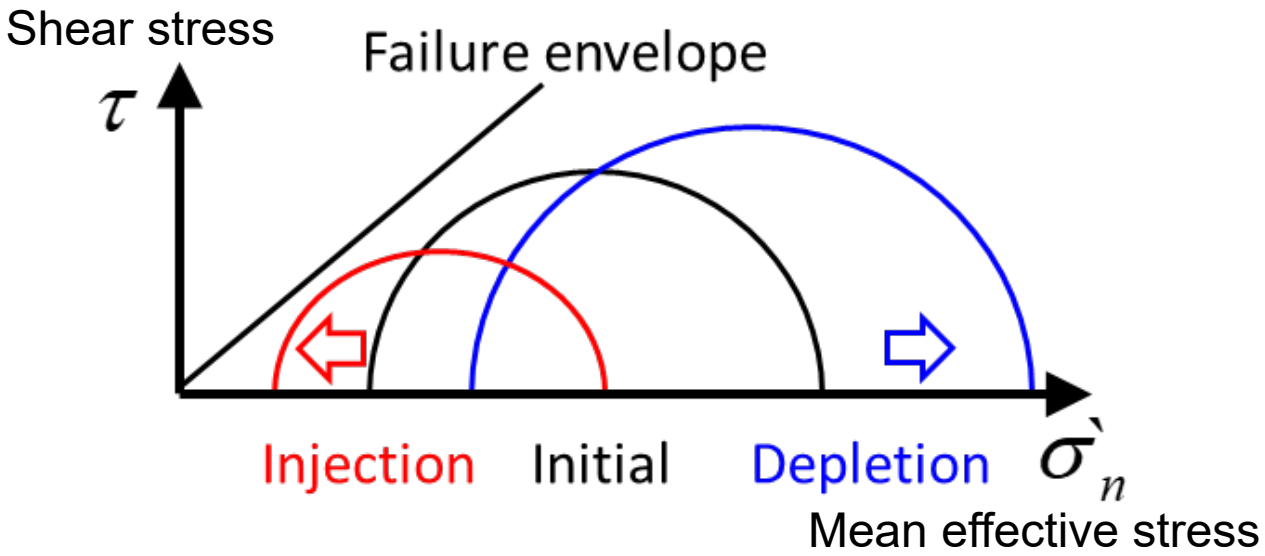
Petroleum and Geosystems Engineering
Cockrell School of Engineering

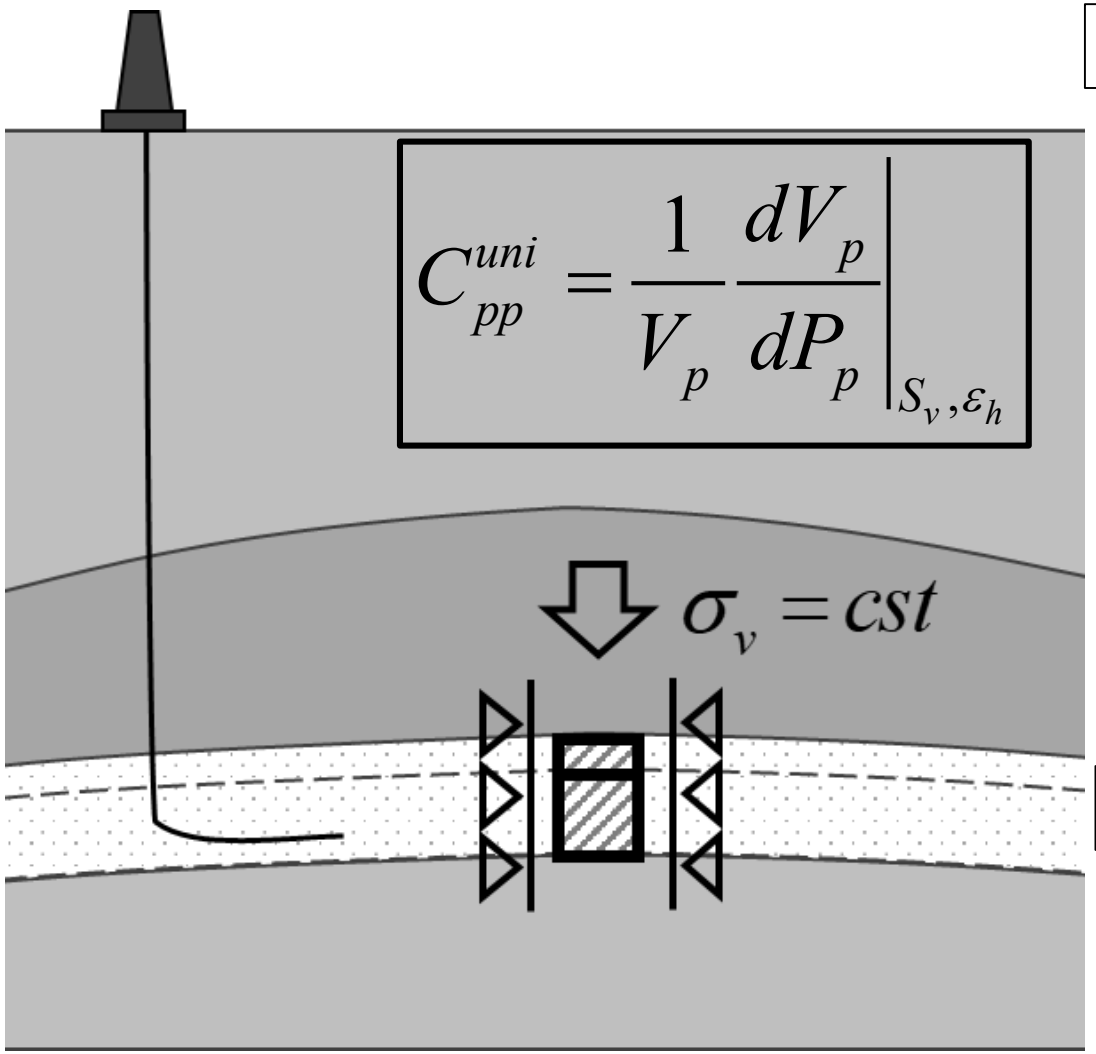
Reservoir pressure management

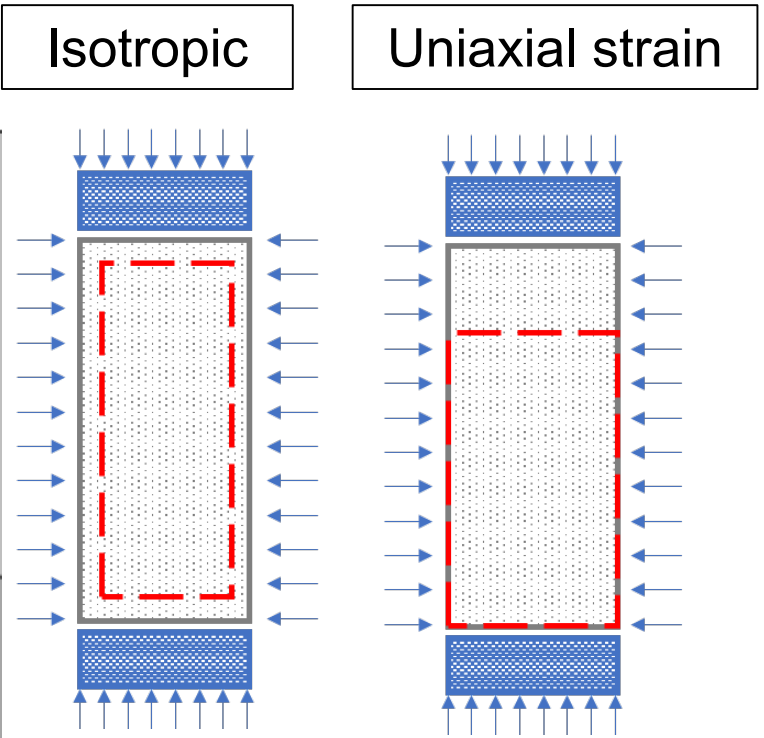




- CO_2 injection may increase reservoir pressure and induce fault reactivation.
- Reservoir pressure increase is related to (1) reservoir size, (2) reservoir compartmentalization, and (3) reservoir compressibility.

Uniaxial strain unloading compressibility





Rock is under **uniaxial strain** status.

CO_2 injection **unloads** the stress on rocks.

Compressibility for CO_2 injection:

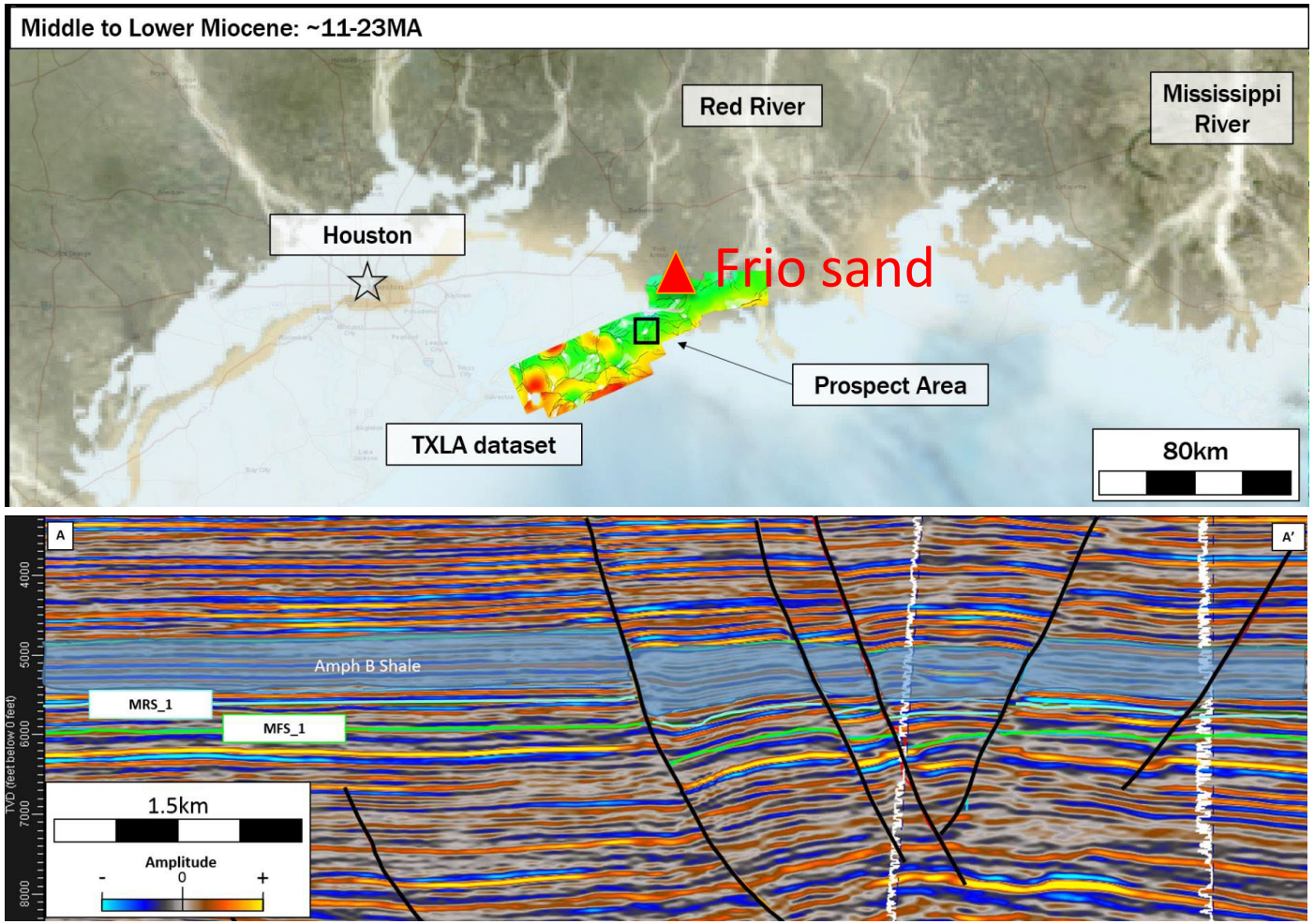
- ✗ Isotropic loading compressibility
- ✗ Isotropic unloading compressibility
- ✗ Uniaxial strain loading compressibility

Wrong and not conservative

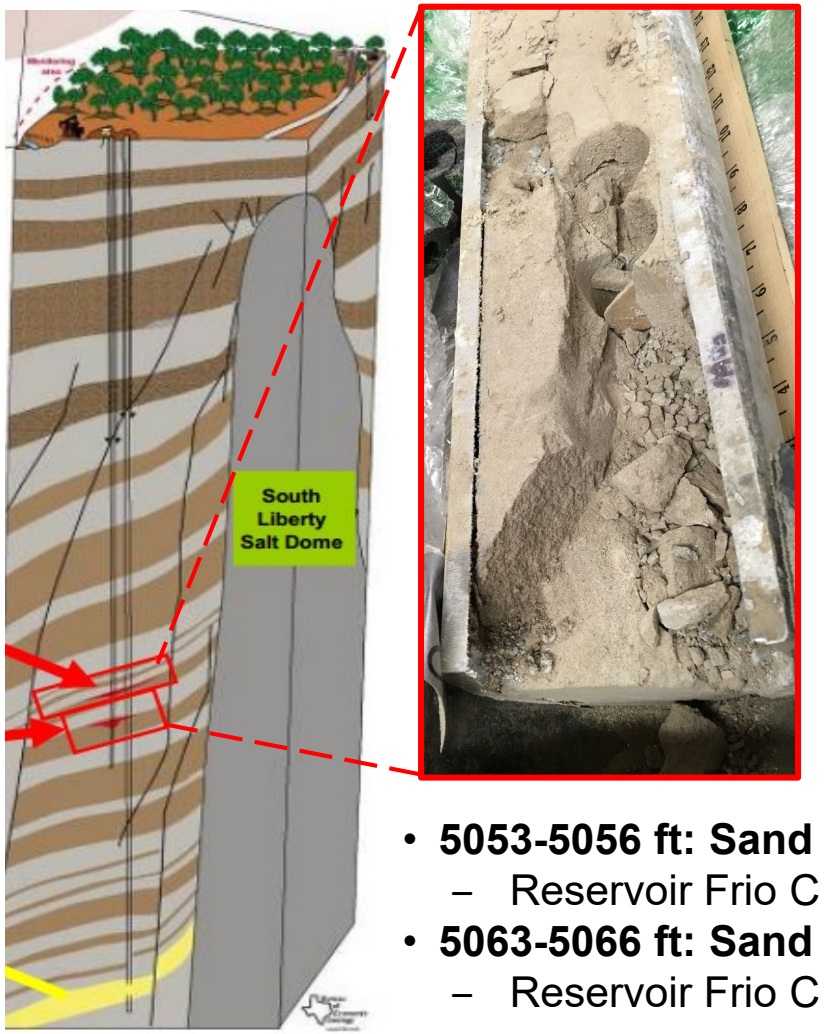
- ✓ **Uniaxial strain unloading compressibility**

Experimental cores

Sand rich intervals in Gulf of Mexico basin



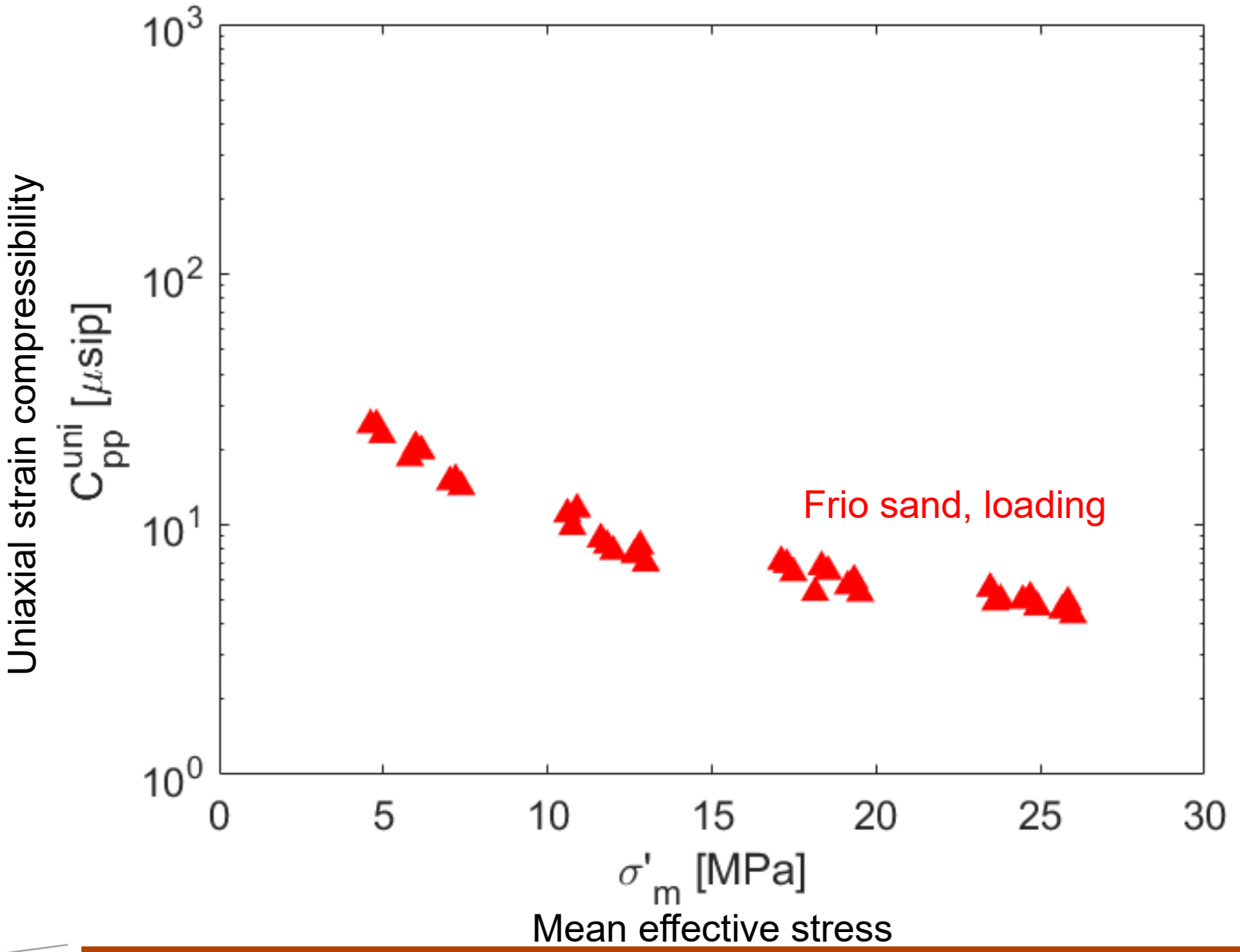
(Emily Beckham, MS thesis, 2018)



- **5053-5056 ft: Sand**
  - Reservoir Frio C
- **5063-5066 ft: Sand**
  - Reservoir Frio C

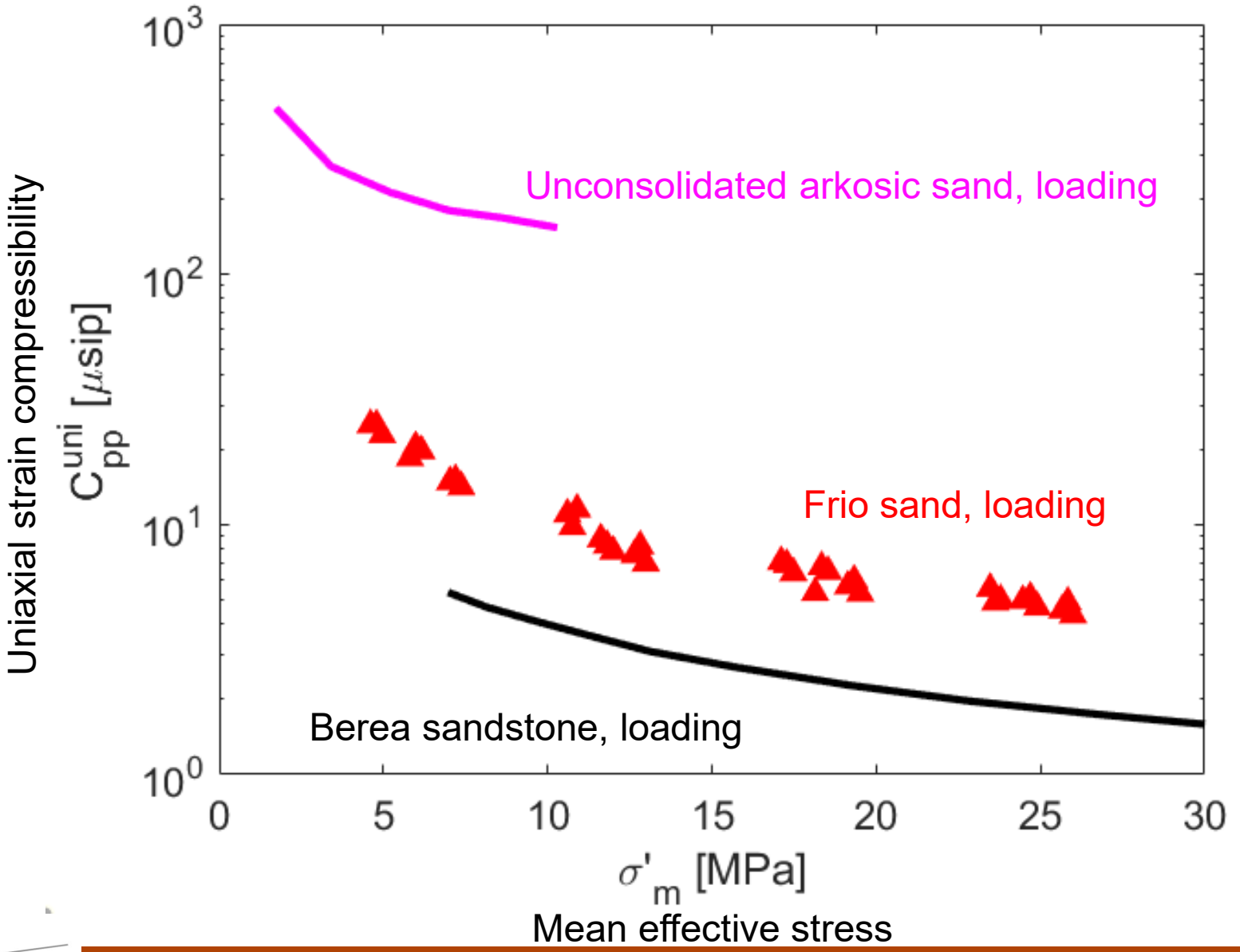
- South Liberty oil field, a region of the Gulf Coast
- Unconsolidated sand: courtesy of GCCC-BEG

Results of uniaxial strain compressibility test



- Uniaxial strain compressibility is non-linearly stress-dependent (4 - 6 μsip at 25 MPa).

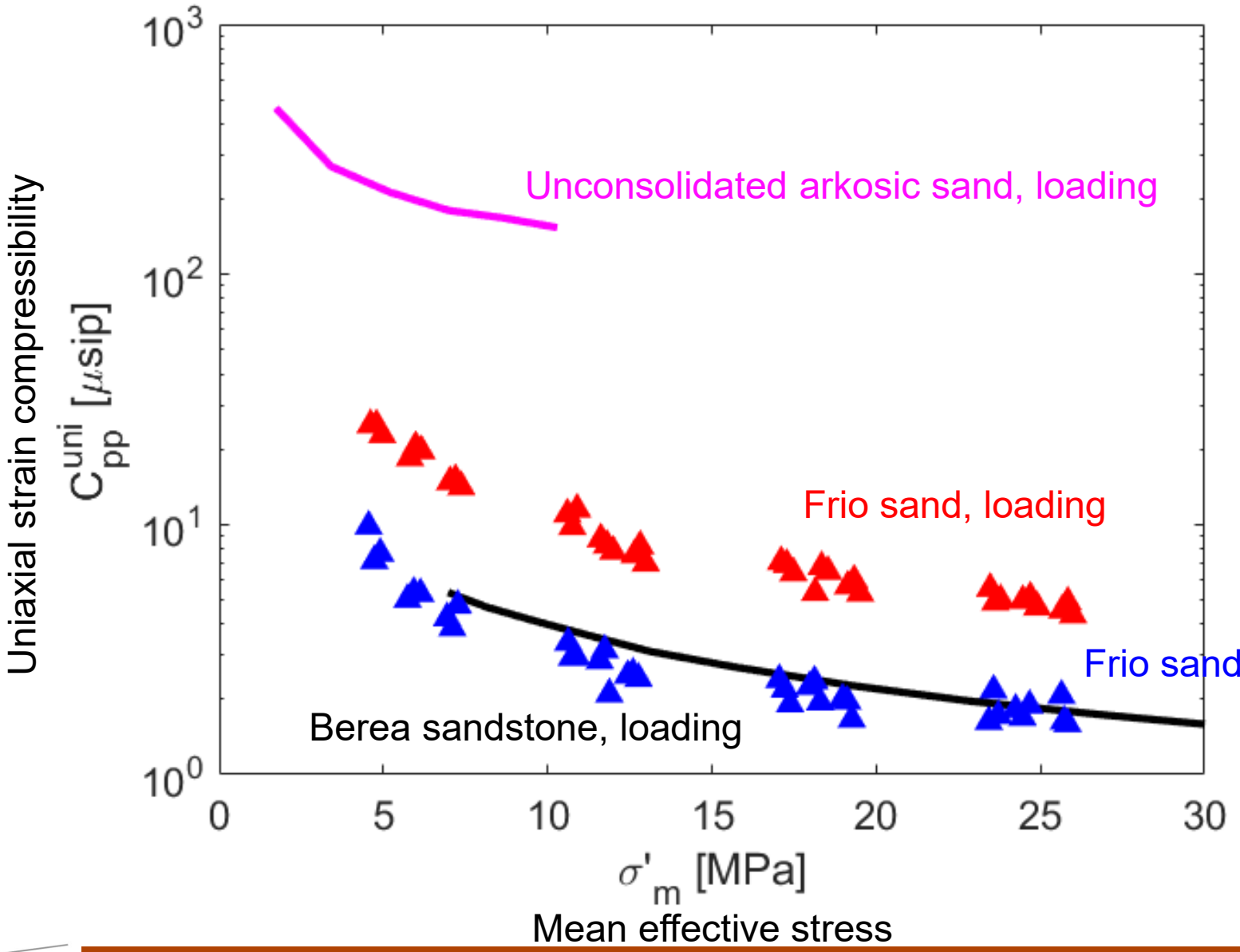
Results of uniaxial strain compressibility test



- Uniaxial strain compressibility is non-linearly stress-dependent (4 - 6 μsip at 25 MPa).
- Cemented rock has lower compressibility.

(Unconsolidated arkosic sand, Sawabini, 1974; Berea sandstone, Andersen,1985)

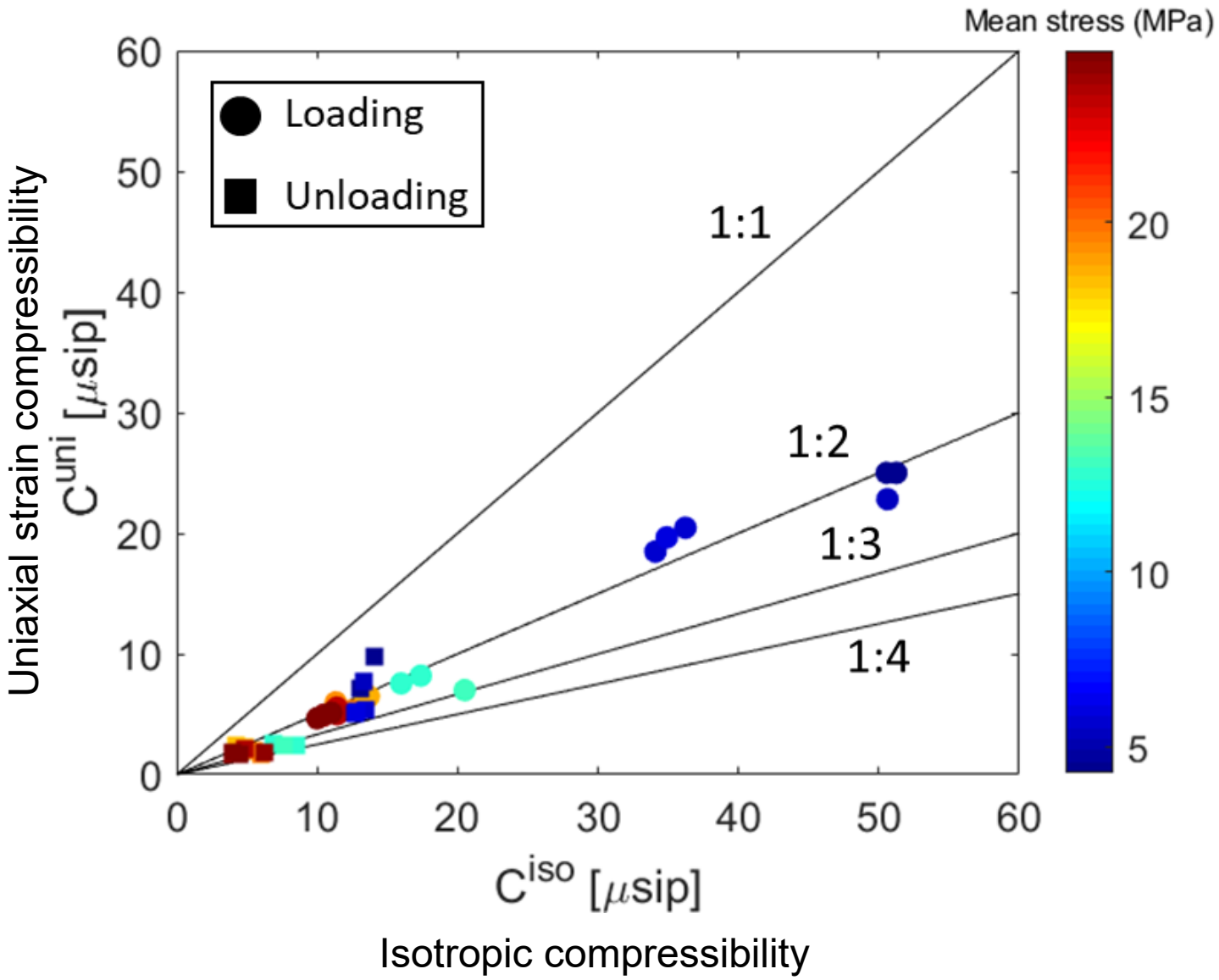
Results of uniaxial strain compressibility test



- Uniaxial strain compressibility is non-linearly stress-dependent (4 - 6 μsip at 25 MPa).
- Cemented rock has lower compressibility.
- Unloading compressibility is smaller than loading compressibility.
- $C_{\text{Berea sandstone, loading}} \sim C_{\text{Frio sand, unloading}}$

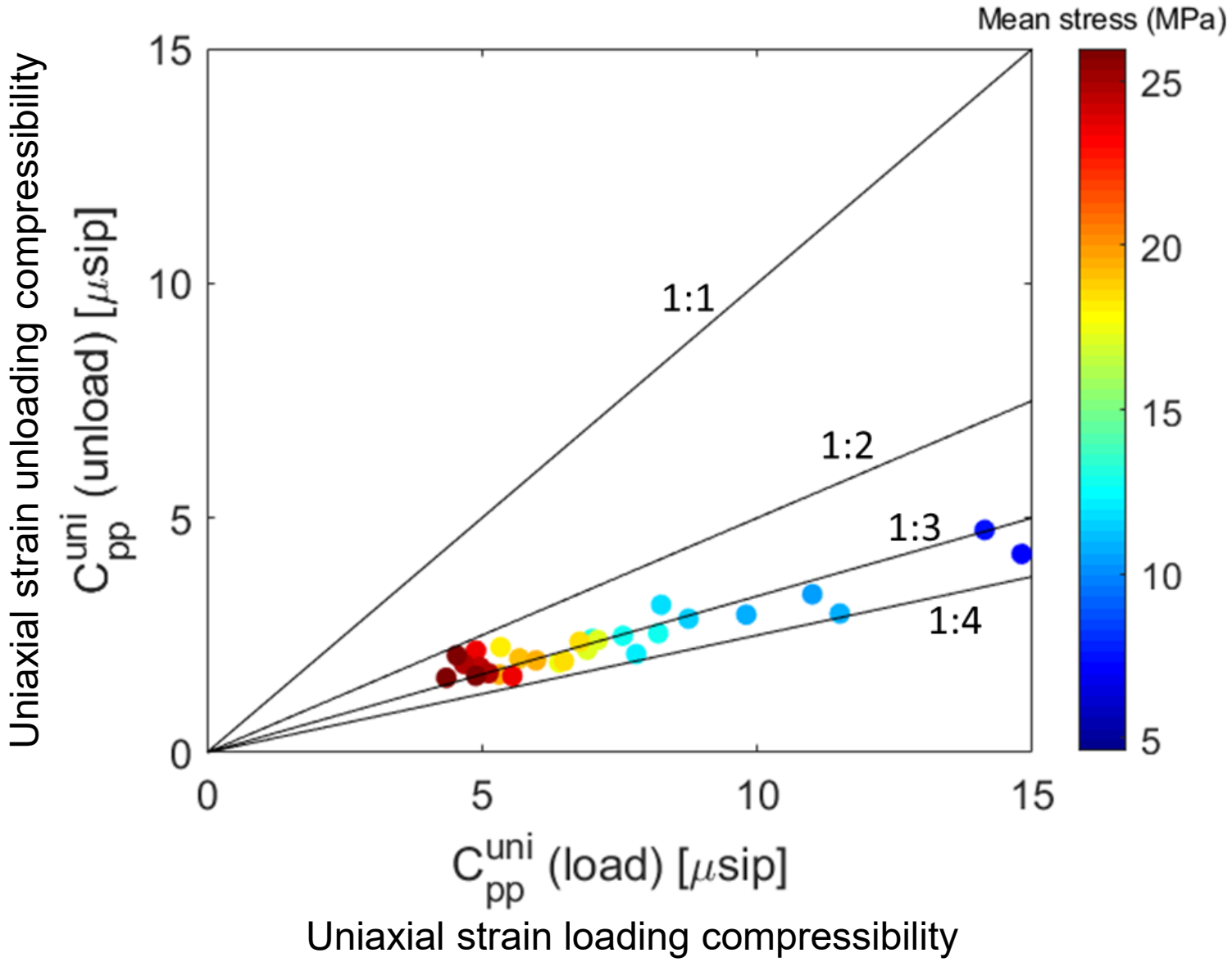
(Unconsolidated arkosic sand, Sawabini, 1974; Berea sandstone, Andersen,1985)

Isotropic vs uniaxial strain compressibility



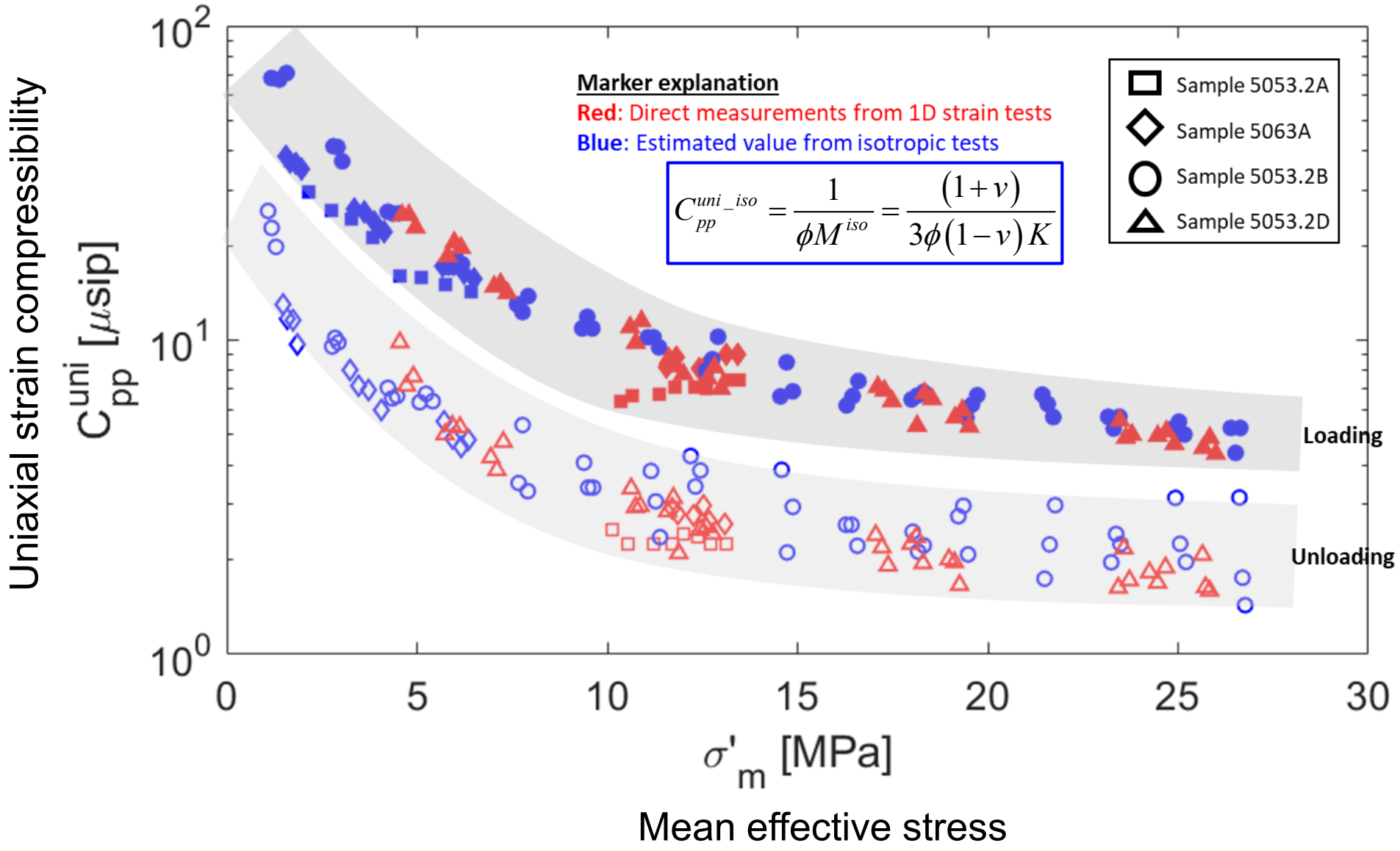
Uniaxial strain compressibility is about **one half** of isotropic compressibility at comparable mean effective stress.

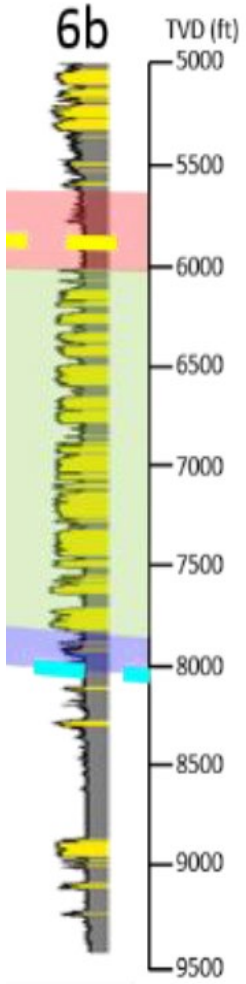
Loading vs unloading compressibility



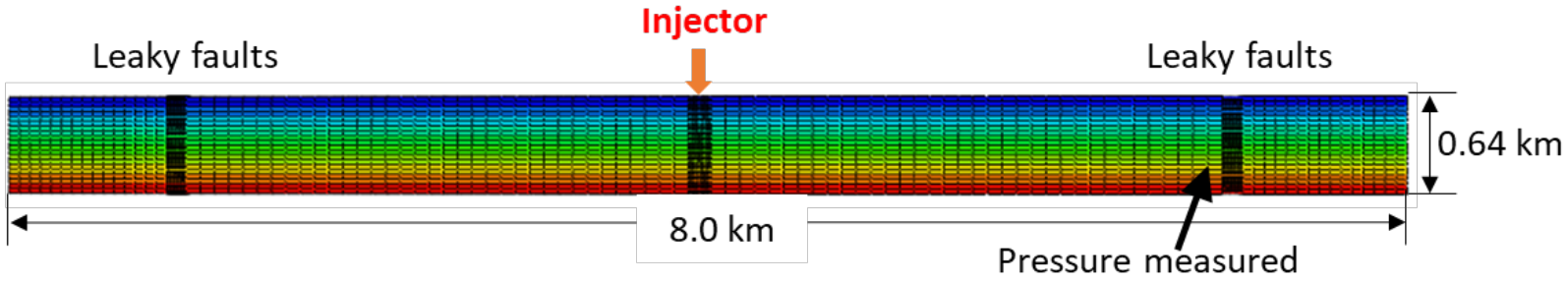
Unloading compressibility is about **1/3** of the loading compressibility at comparable mean effective stress.

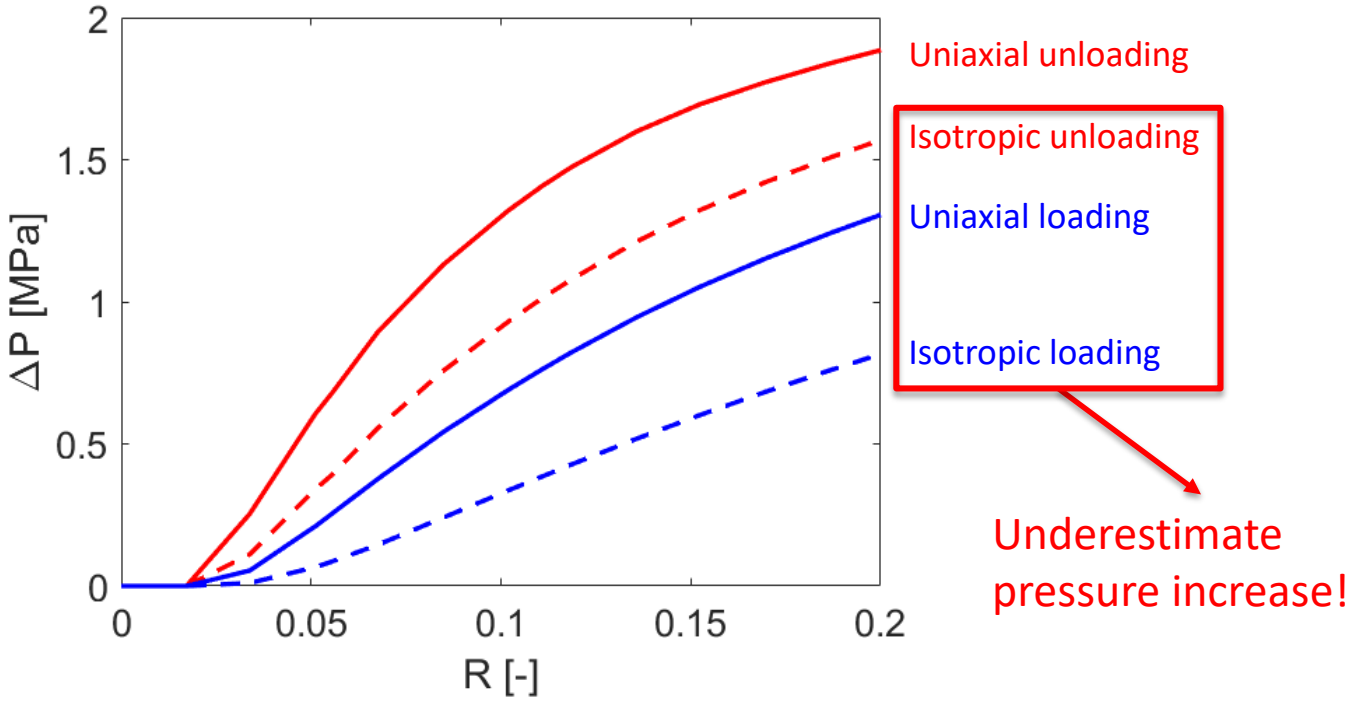
Compressibility summary





(High Island field example)





- Sand porosity: 0.34
- Fault porosity: 0.1
- Sand perm: 100 mD
- Fault perm: 0.1 mD
- Injection rate: 0.9×10^6 tonnes CO_2 / year
- Injection period: 1 year

Ratio of pore space utilization $R = \frac{V_{inj}}{V_p}$

Conclusions

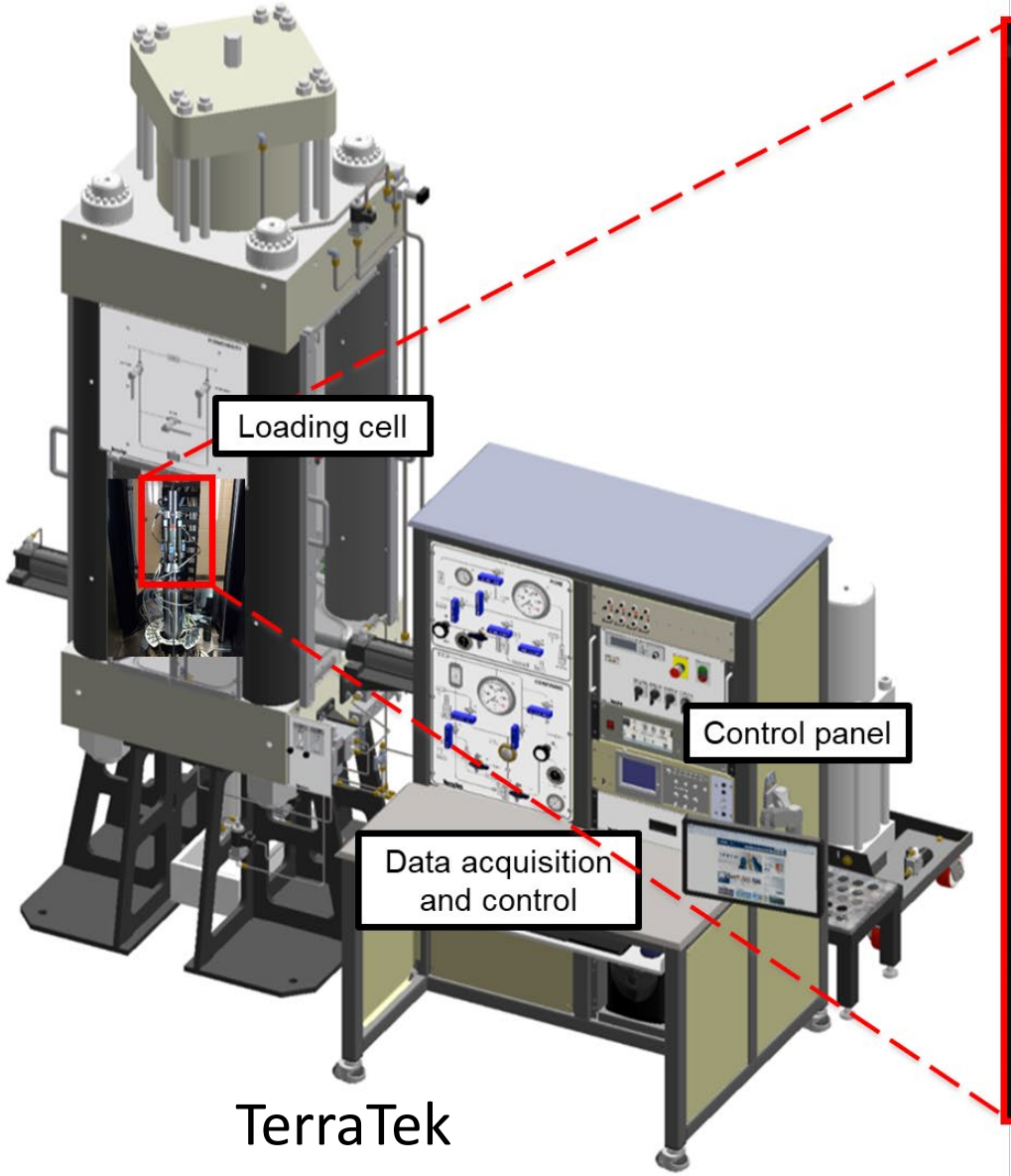
- **Uniaxial strain unloading compressibility** should be used in reservoir simulation of CO_2 injection.
- Uniaxial strain compressibility is **pressure-dependent**. Frio sand compressibility can be modeled with the porosity as a function of logarithm of mean stress.
- Uniaxial strain unloading compressibility is about **one third** of the uniaxial strain loading compressibility at comparable levels of effective mean stress.
- Uniaxial strain compressibility is about **one half** of the isotropic compressibility at comparable levels of effective mean stress.
- Incorrect compressibility input for CO_2 storage projects will result in non-conservative estimation of pore pressure increase, which may increase the risk of fault reactivation.

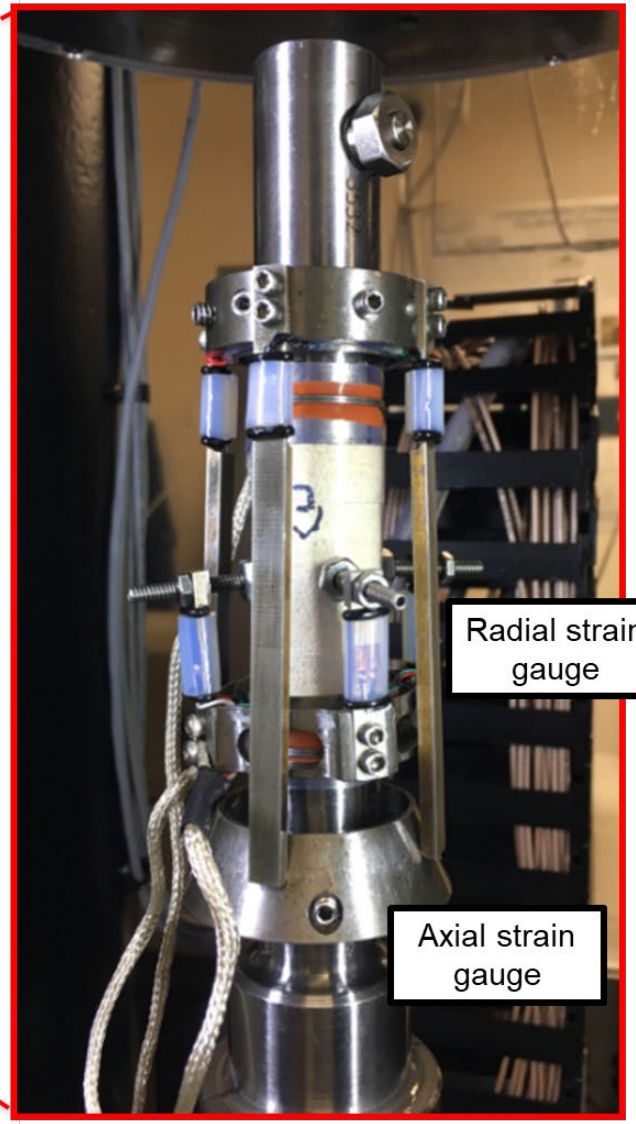
Acknowledgements

- Financial support for this research was provided by the UT-ExxonMobil CO_2 Sequestration Research Project.
- This work was supported by ExxonMobil through its membership in The University of Texas at Austin Energy Institute.
- The authors are thankful to Ganeswara R. Dasari and the ExxonMobil team for providing meaningful comments that helped guide this research.

Backup slides

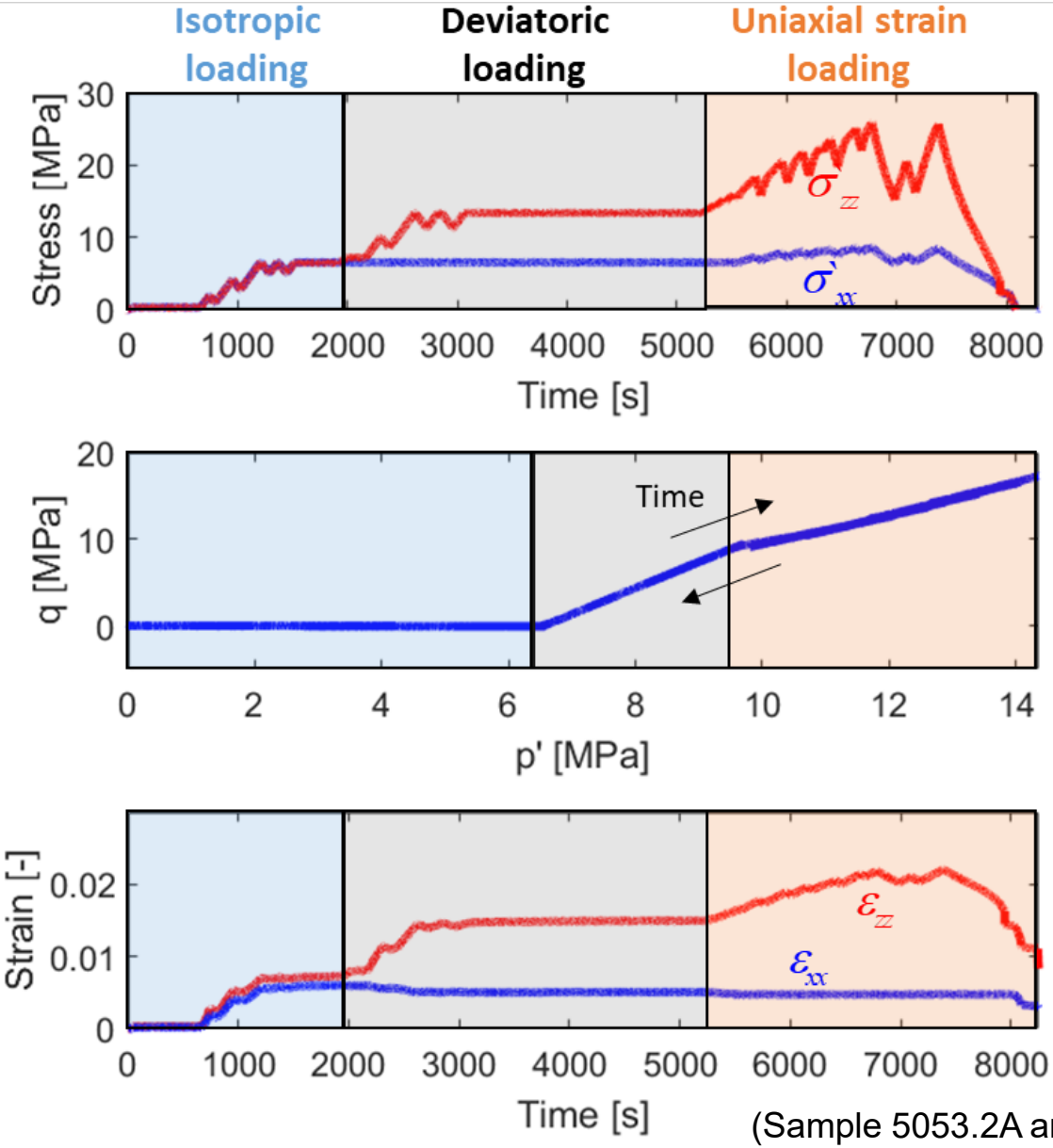
TerraTek triaxial frame

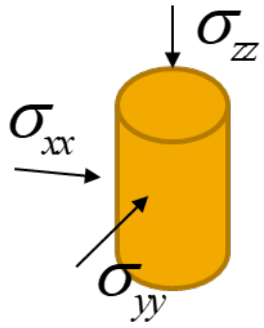




- PID control
- Capable of applying up to 2,205 kN axial load and total radial stresses up to 138 MPa
- Temperature up to 150°C (300°F)

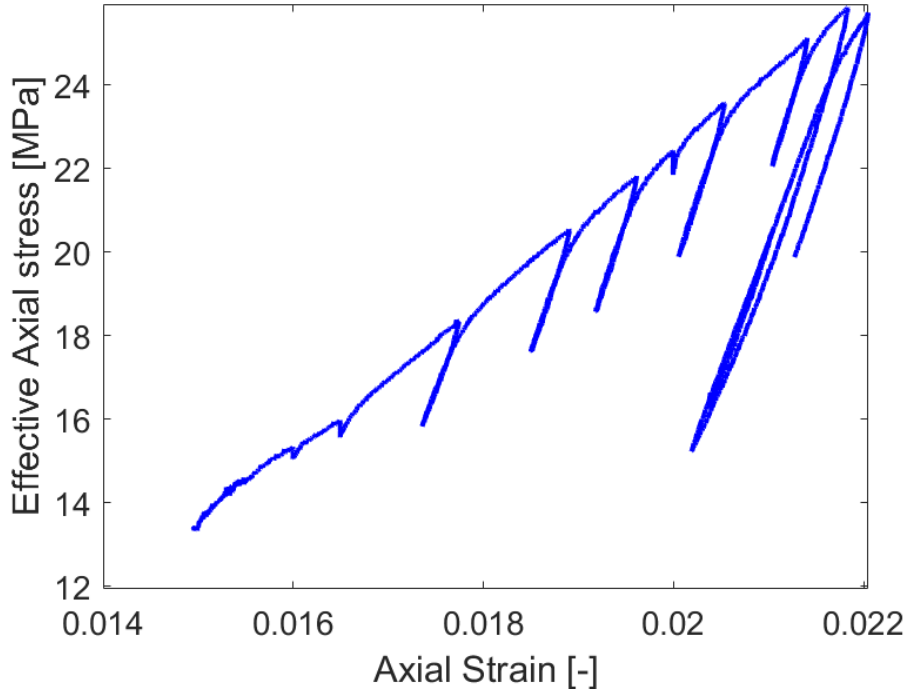
Stress path





$$q = \sigma_{zz} - \sigma_{xx}$$

$$p` = \frac{\sigma`_{xx} + \sigma`_{yy} + \sigma`_{zz}}{3}$$



Key characteristics

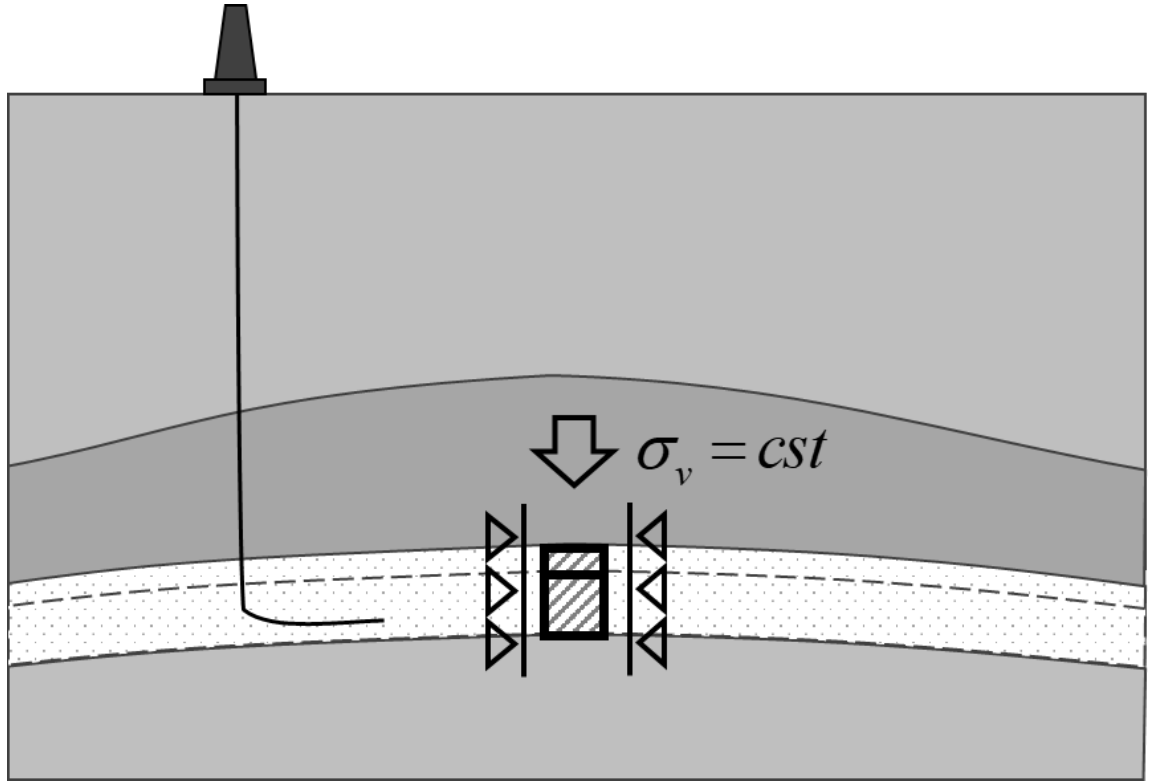
- Isotropic path: isotropic change of stress
- Deviatoric path: constant confining pressure
- Uniaxial strain path: constant radial strain

(Sample 5053.2A and 5063A)

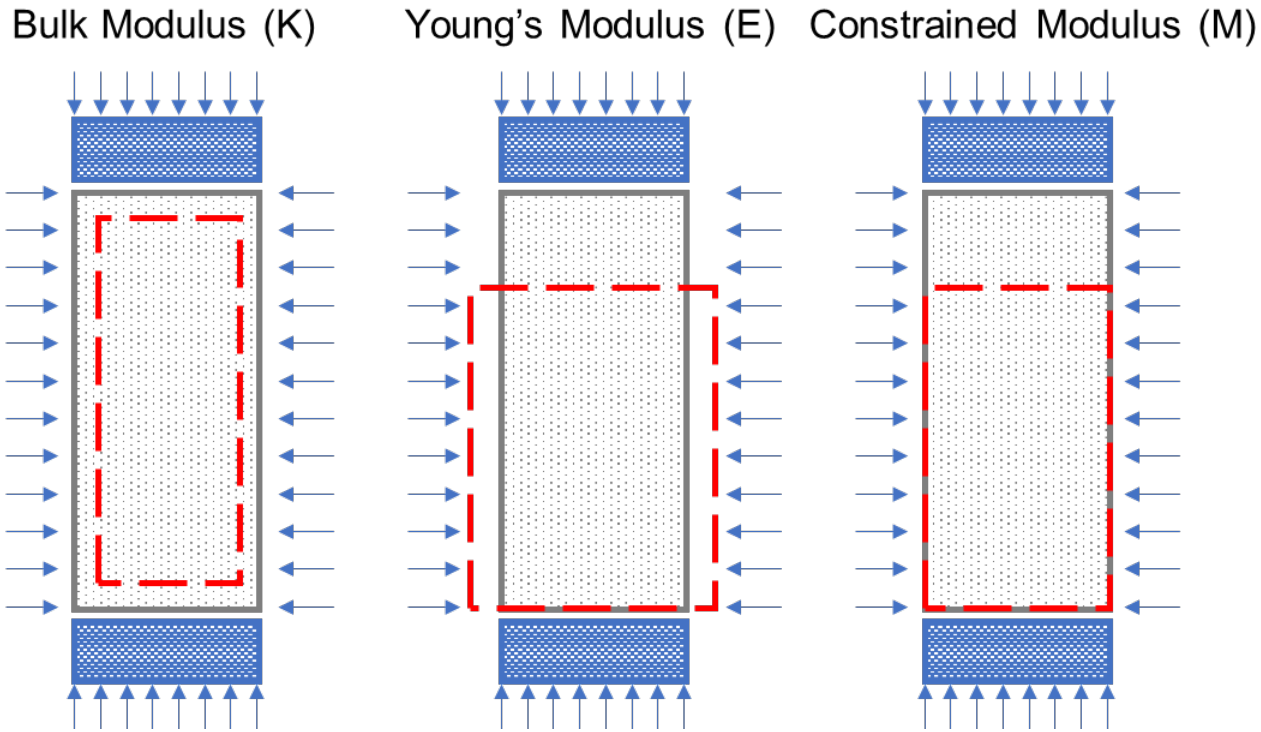
Uniaxial strain compressibility and constrained modulus

$$C_{pp}^{uni} = \frac{1}{V_p}\frac{dV_p}{dP_p}\bigg|_{S_v,\varepsilon_h} \qquad C_{pp}^{uni} = \frac{\alpha}{\phi M} \qquad \alpha = 0.944 \qquad C_{pp} \approx \frac{1}{\phi M}$$

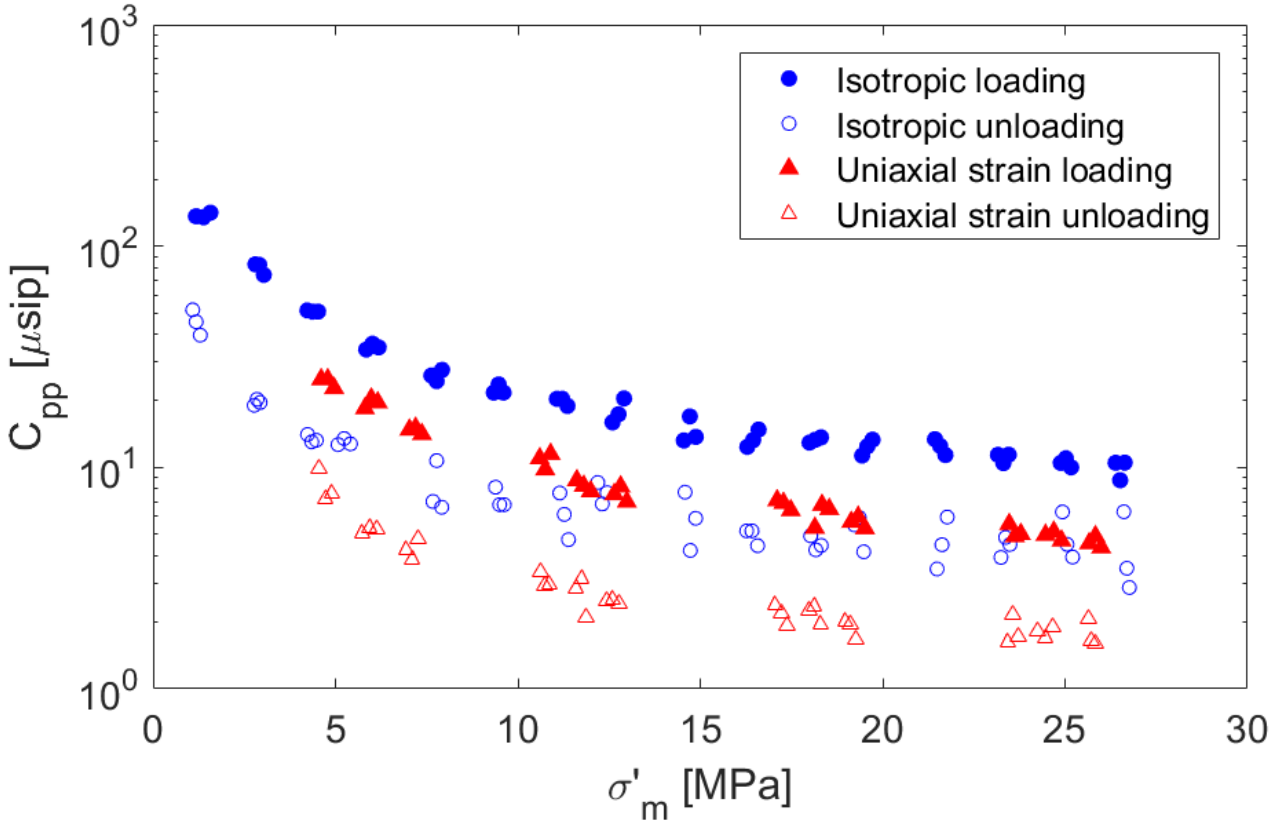
Uniaxial strain compressibility

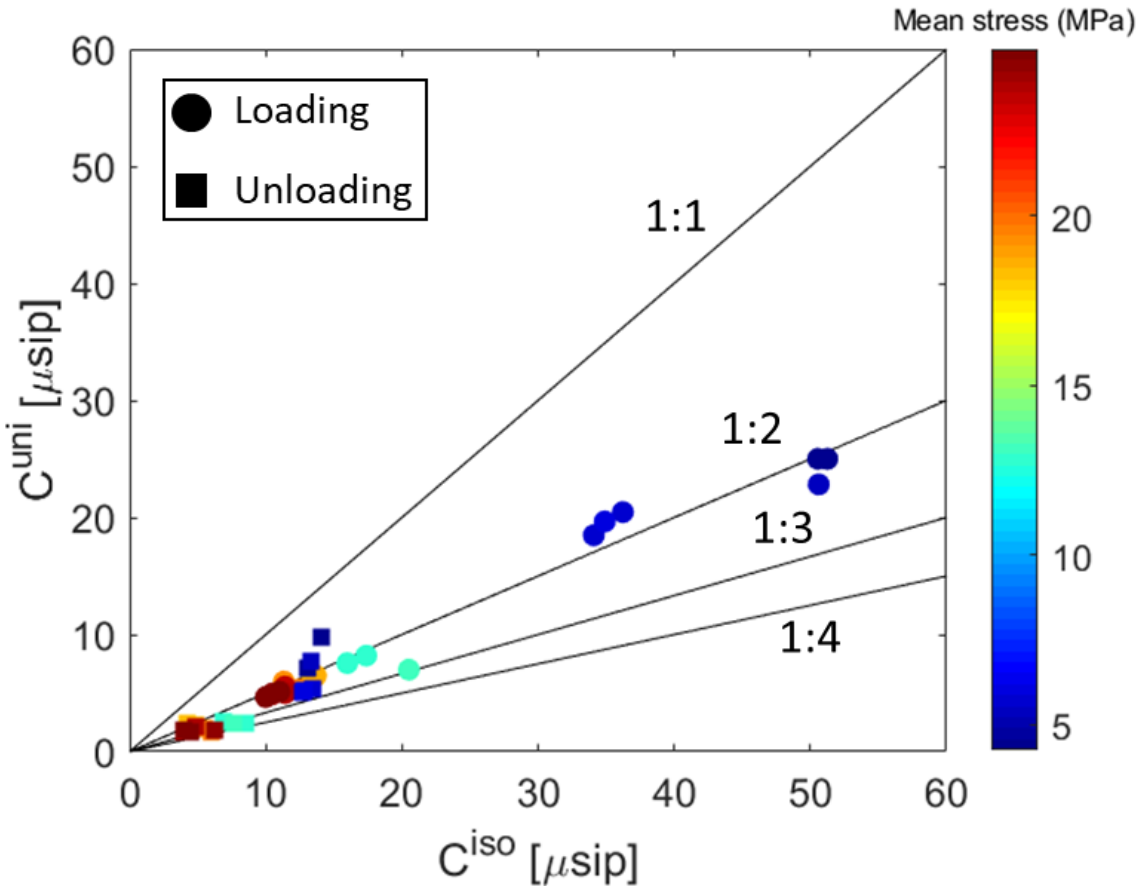


Constrained modulus



Isotropic vs uniaxial strain compressibility



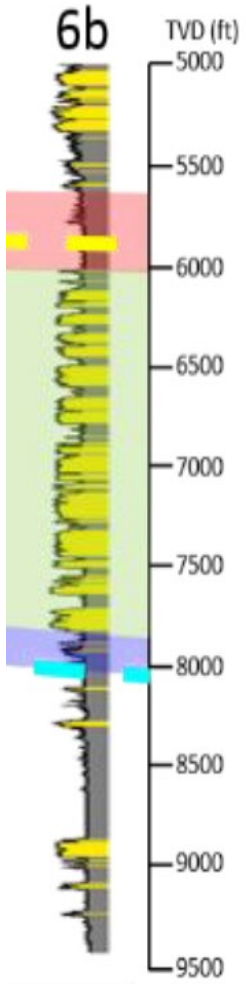


Fitting result: $C^{uni} = 0.51 C^{iso}$

Linear elasticity prediction: $C^{uni} = \frac{(1+\nu)}{3(1-\nu)} C^{iso}$

Equivalent Poisson ratio: $\nu = 0.211$

Reservoir simulation



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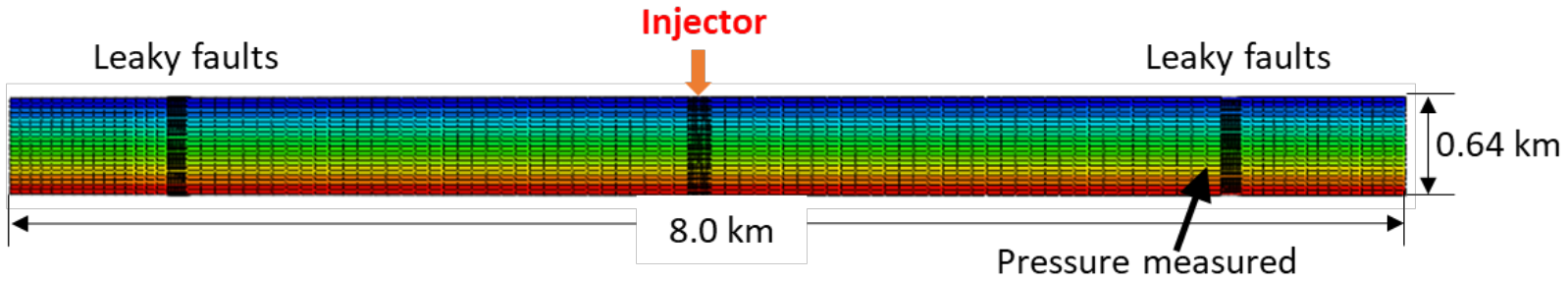

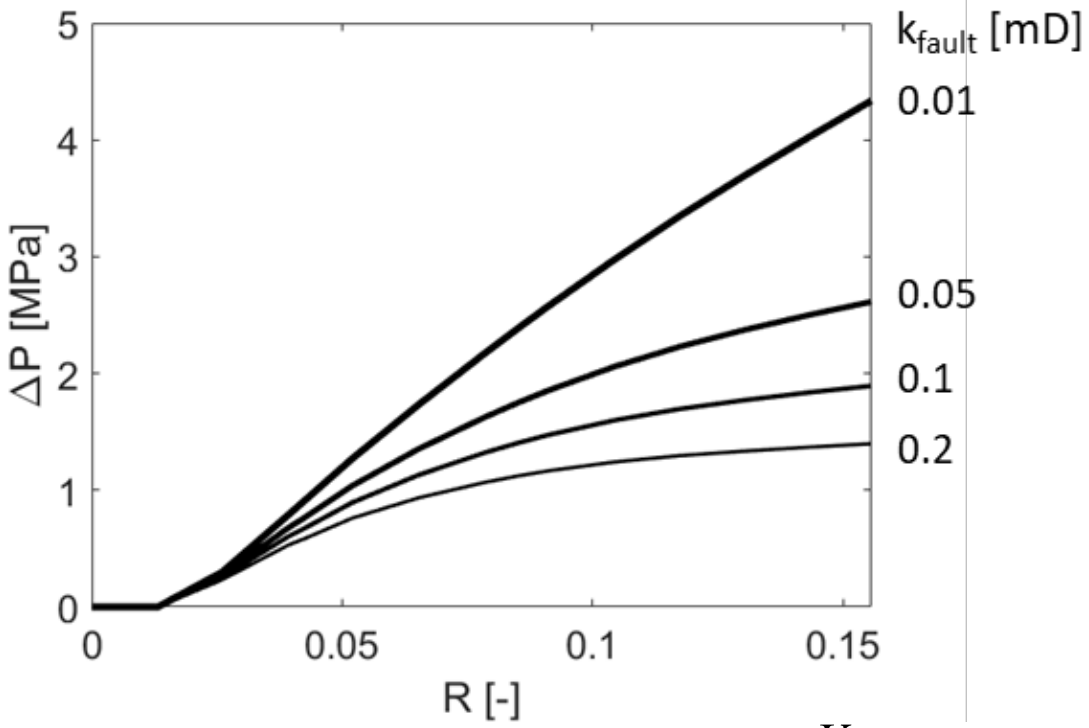

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