Proof-of-Feasibility of Using Wellbore Deformation as a Diagnostic Tool to Improve CO2 Sequestration

DE FE0004542

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Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS
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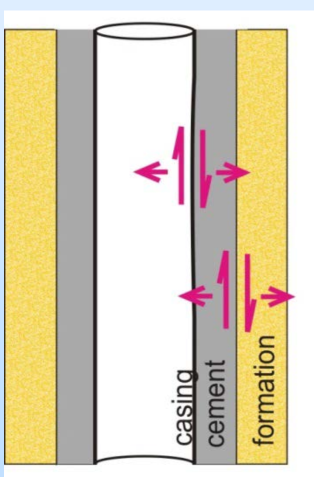
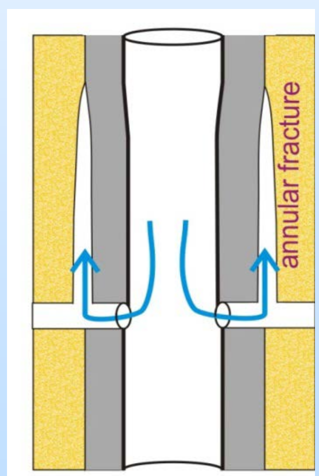
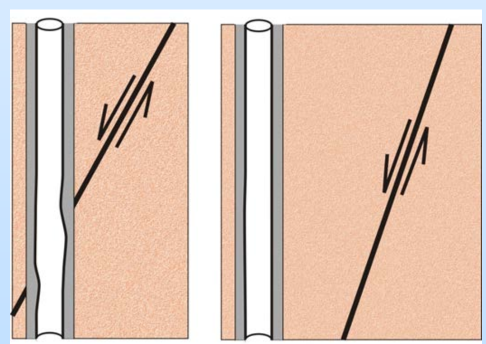
Presentation Outline

- Preliminaries
- Current project status
- Plans







Improve characterization

Anticipate problems

Benefit to the Program

Measuring and interpreting casing deformation should improve the ability to characterize flow and geomechanical properties of injection zones and confining units, as well as help identify problems with wellbore integrity that could lead to leakage.

Program Goal:

- Develop technologies that will support industries' ability to predict CO_2 storage capacity in geologic formations to within ±30 percent
- Develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones

Project Overview: Goals and Objectives

Evaluate feasibility of using wellbore deformation as a diagnostic tool.

1. What deformation should be expected?
   – FEM analyses, Task 2
2. Can that deformation be measured?
   – Instrumentation assessment, Task 4
3. Can the measurements be interpreted?
   – Inverse analyses, Task 3

What can be measured? Task 4

Goal: Assess capabilities to measure deformation (components, magnitudes, rates) of wellbores under field conditions.

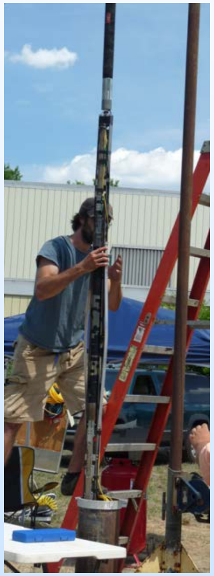
Resolution ⟷ Logistics

Gladwin Borehole Strain Meter (BSM)

- 4 axis, horizontal
- <0.001 $\mu\varepsilon$ resolution
- Grouted in place
- Tectonic strain

Clemson *Tilt-X*

- Axial+tilt
- ~0. 01$\mu\varepsilon$ resolution
- Electrical
- AGI tiltmeter
- Removable
- Well testing

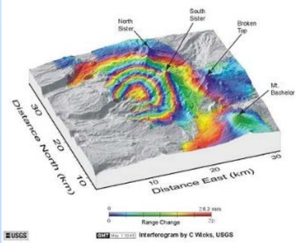


Clemson *5DX*

- 3D + shear
- ~0. 1$\mu\varepsilon$ resolution
- Optical
- Removable
- Well testing

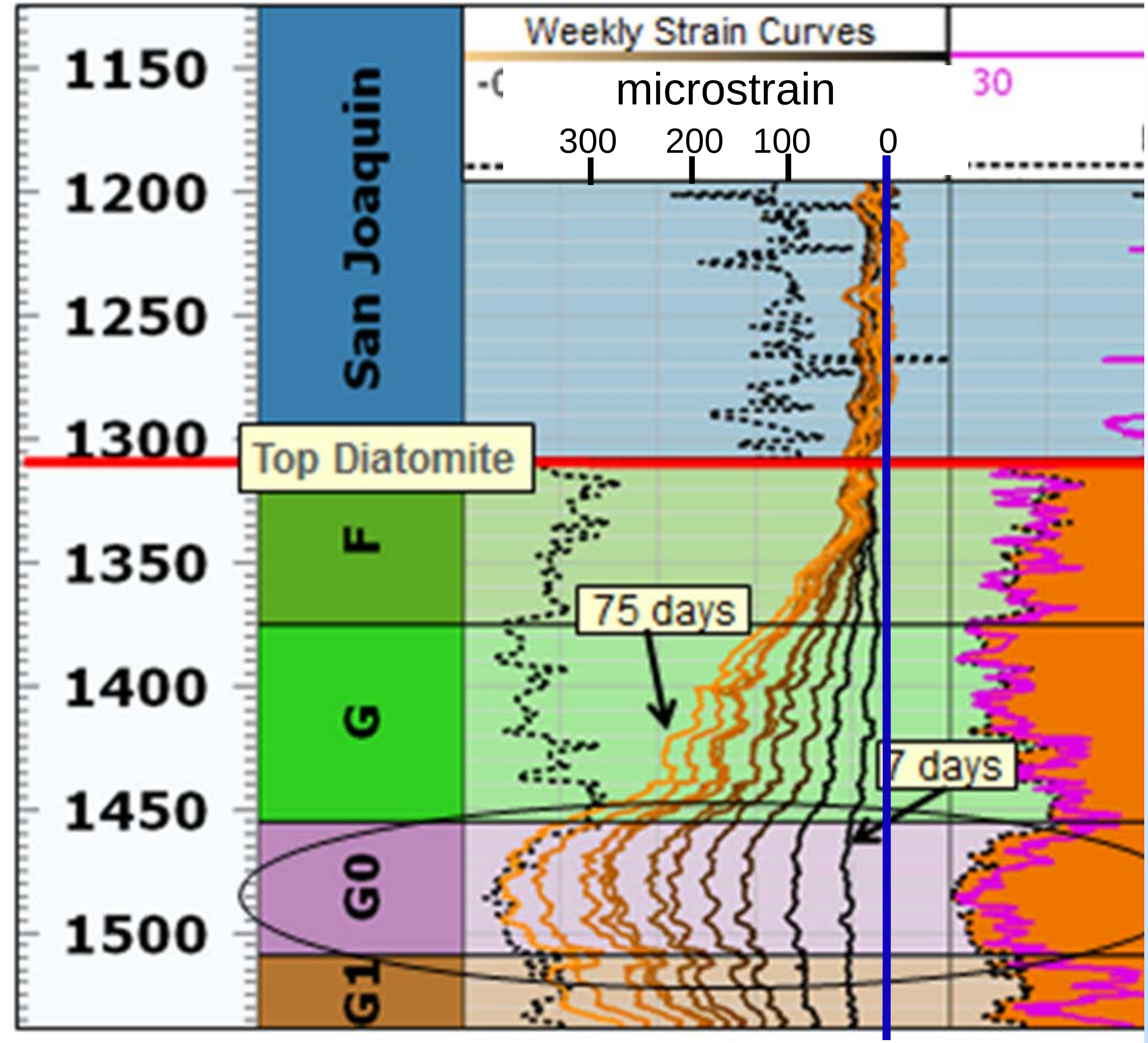
Baker *WIRE*

- Multicomponent
- ~1 μe
- Optical
- Outside casing



In SAR

Geodetic GPS

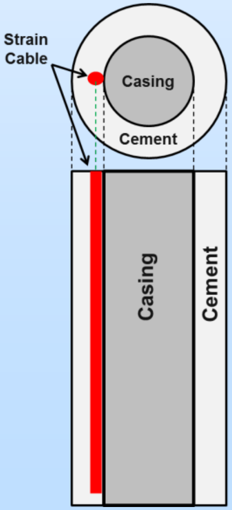


Field Test of *WIRE* in Belridge Field, California

from Roger Duncan, Baker Hughes

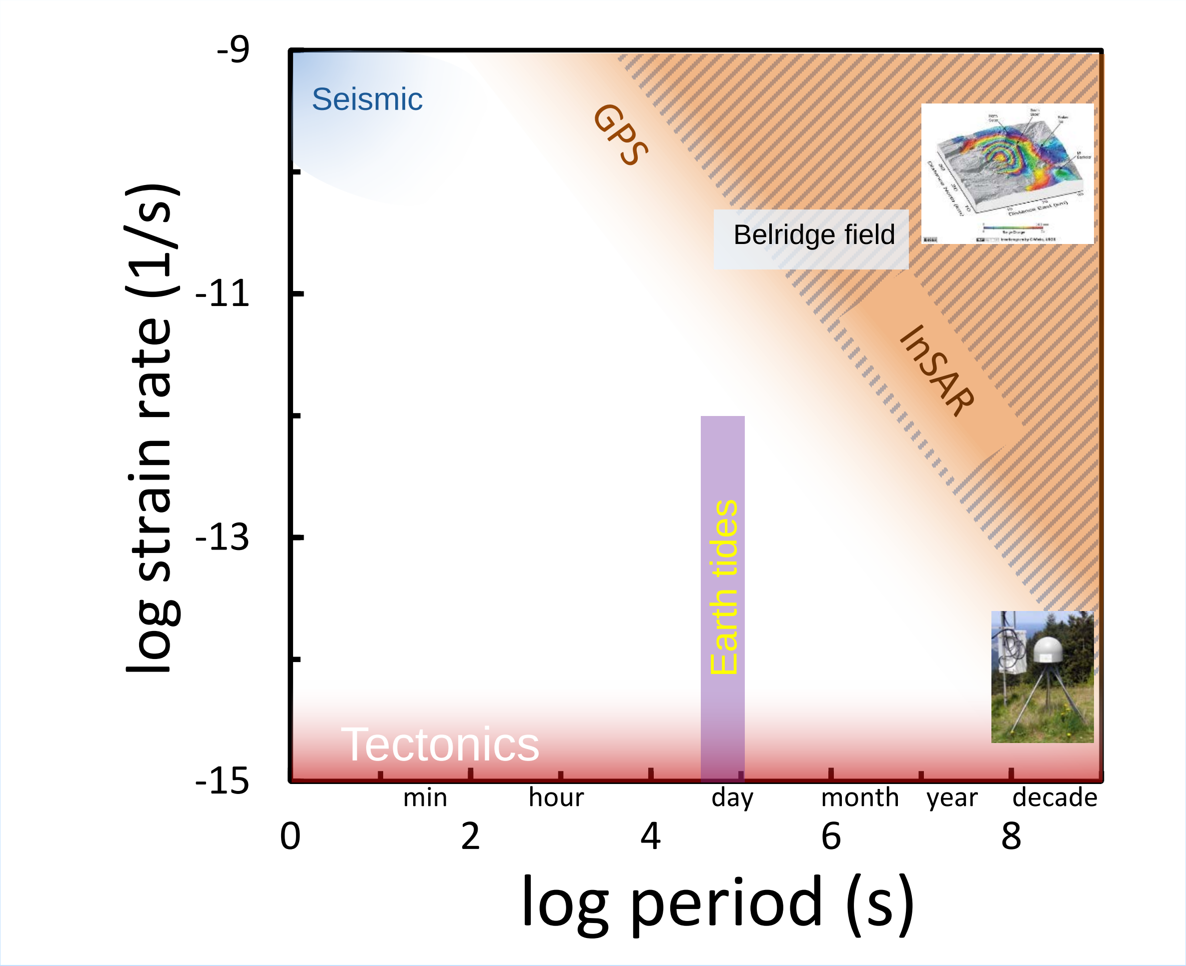
Baker *WIRE*

- Multicomponent
- ~1 μe
- Optical
- Part of casing



Strain Measurement Overview

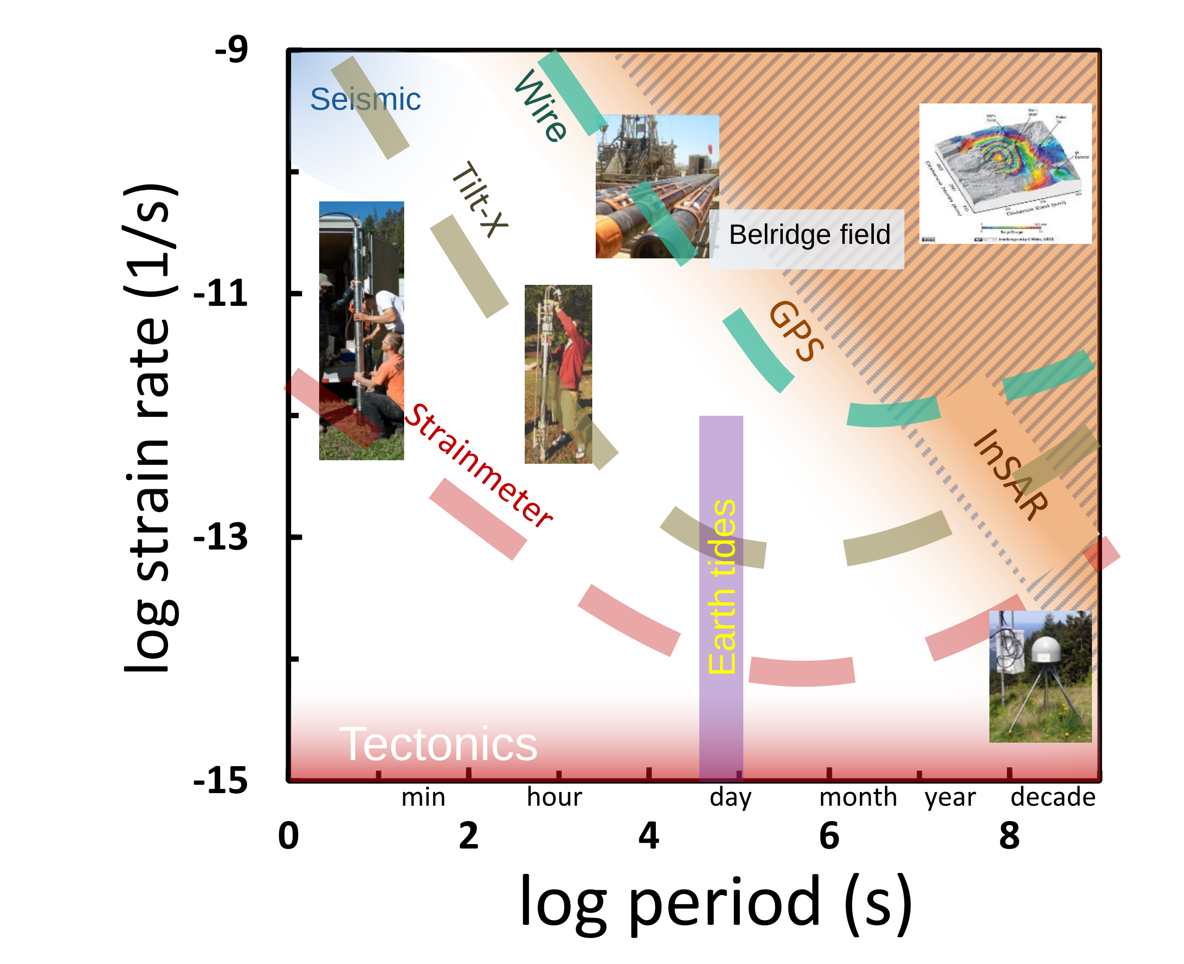
Reference Values and Surface Methods



Based on *Plate Boundary Observatory Report* [1999]

Strain Measurement Overview

Borehole methods

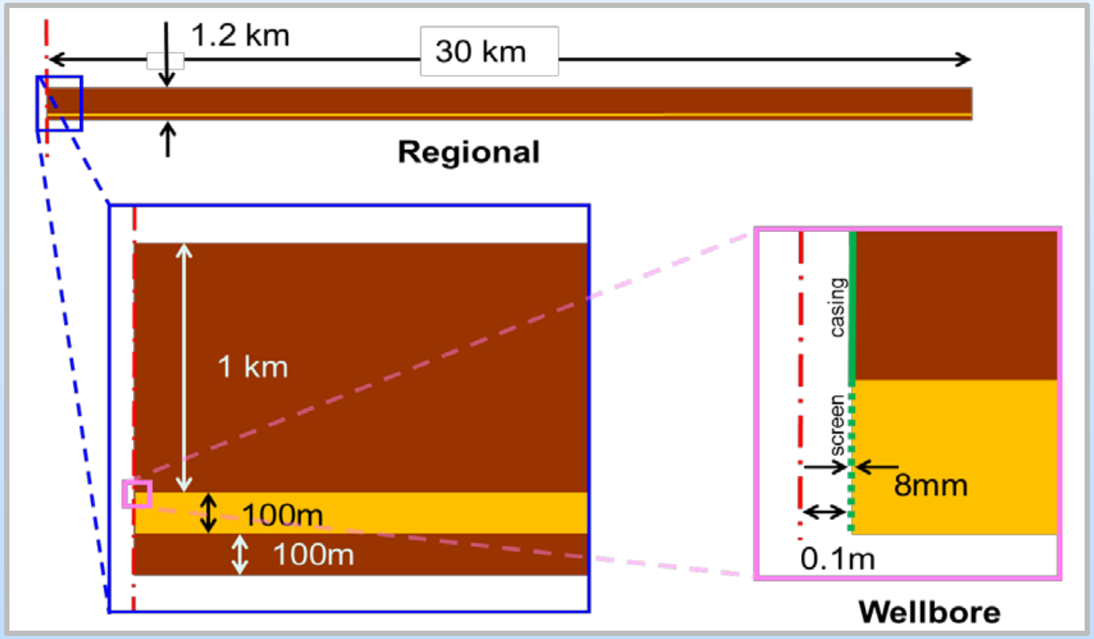


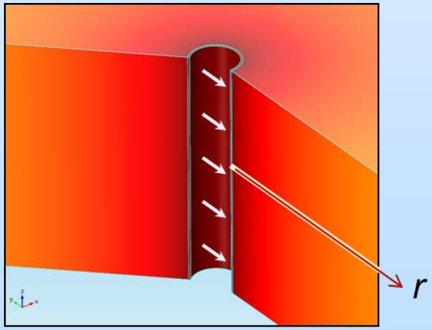
Based on *Plate Boundary Observatory Report* [1999]

What deformation is expected? Task 2

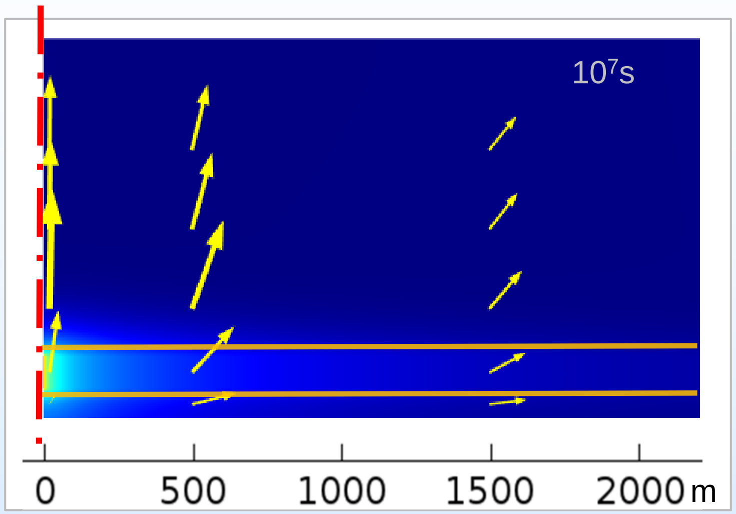
Goal: characterize deformation in the vicinity of wellbores used for storage.

Injection, 1MPa, 6 lps ~100gpm, Axial symmetry
Aquifer: k: 10^{-13}m^2, b: 100m, E: 15GPa , R = 30km
Confining : k: 10^{-16}m^2, b: 1000 m; E: 15GPa
Casing: k: 1nd; 8-inch, 8mm wall, E: 200GPa
Screen: k: 10^{-13}m^2; 8-inch, 8mm wall, E: 200GPa

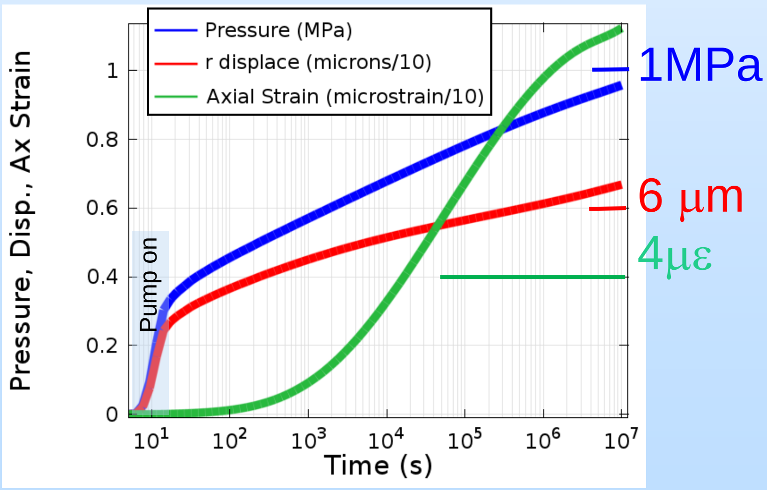




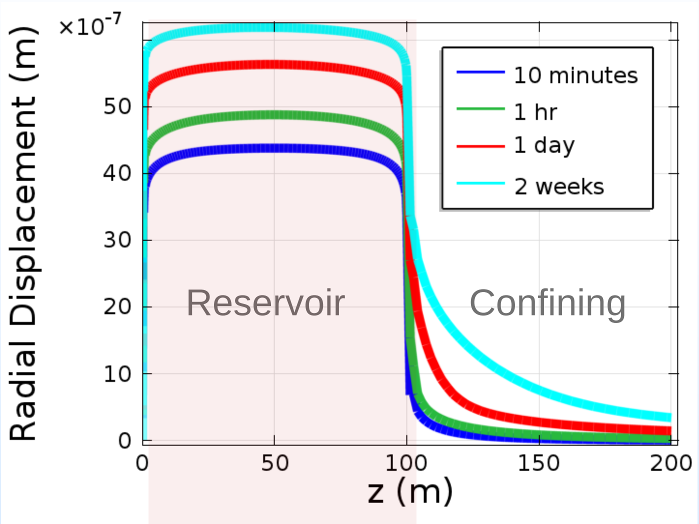
Response in Injection Well

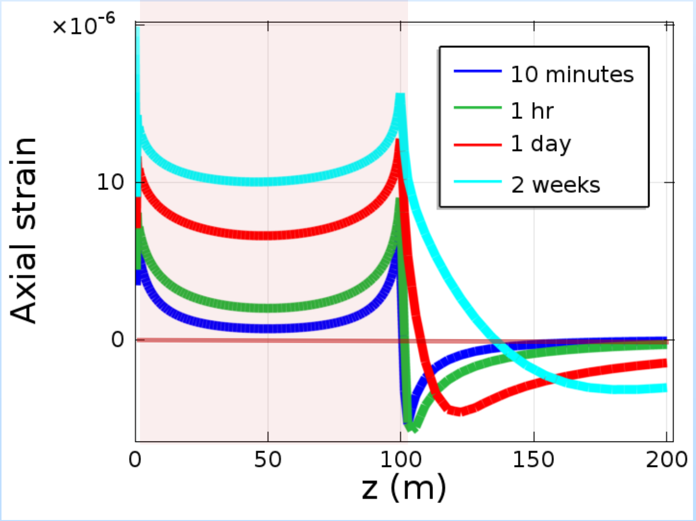


Hydromechanical type curves



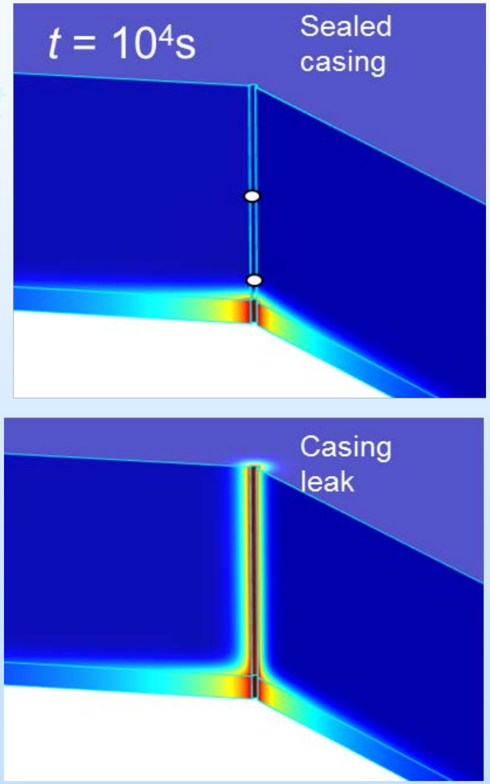
Vertical Profiles on Wellbore



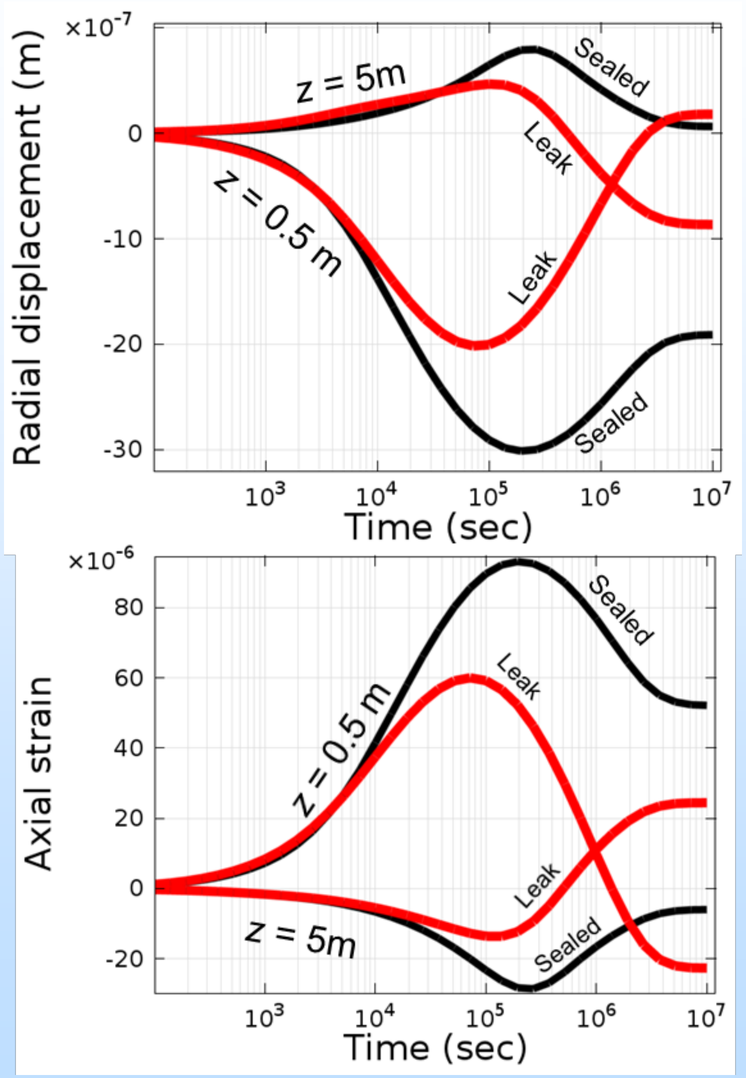


Wellbore Integrity

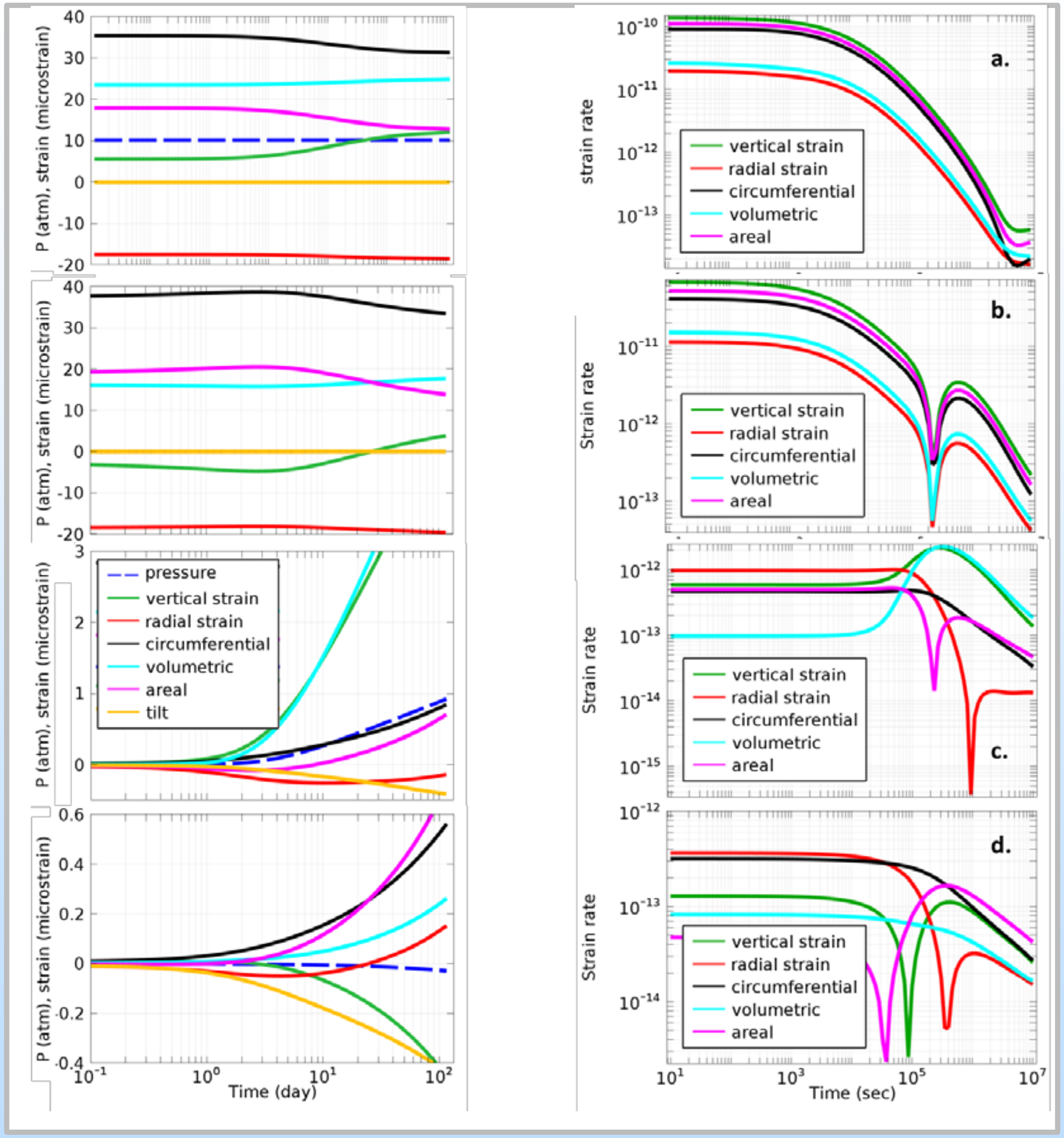
Increase *k*
Increase *E*

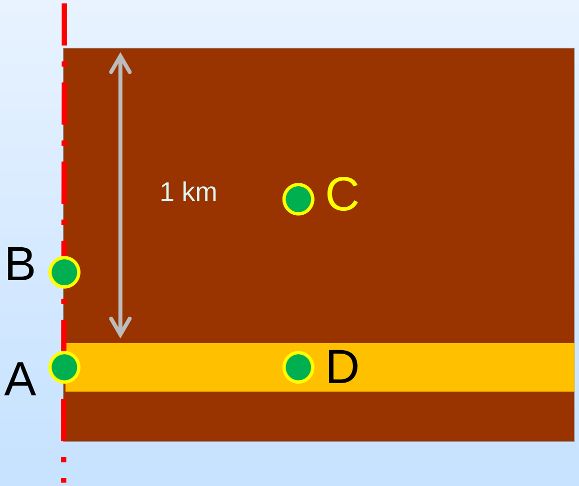


Constant *P* injection, 1MPa
Confining: *k*: 10μD



Magnitudes and Rates of Strain





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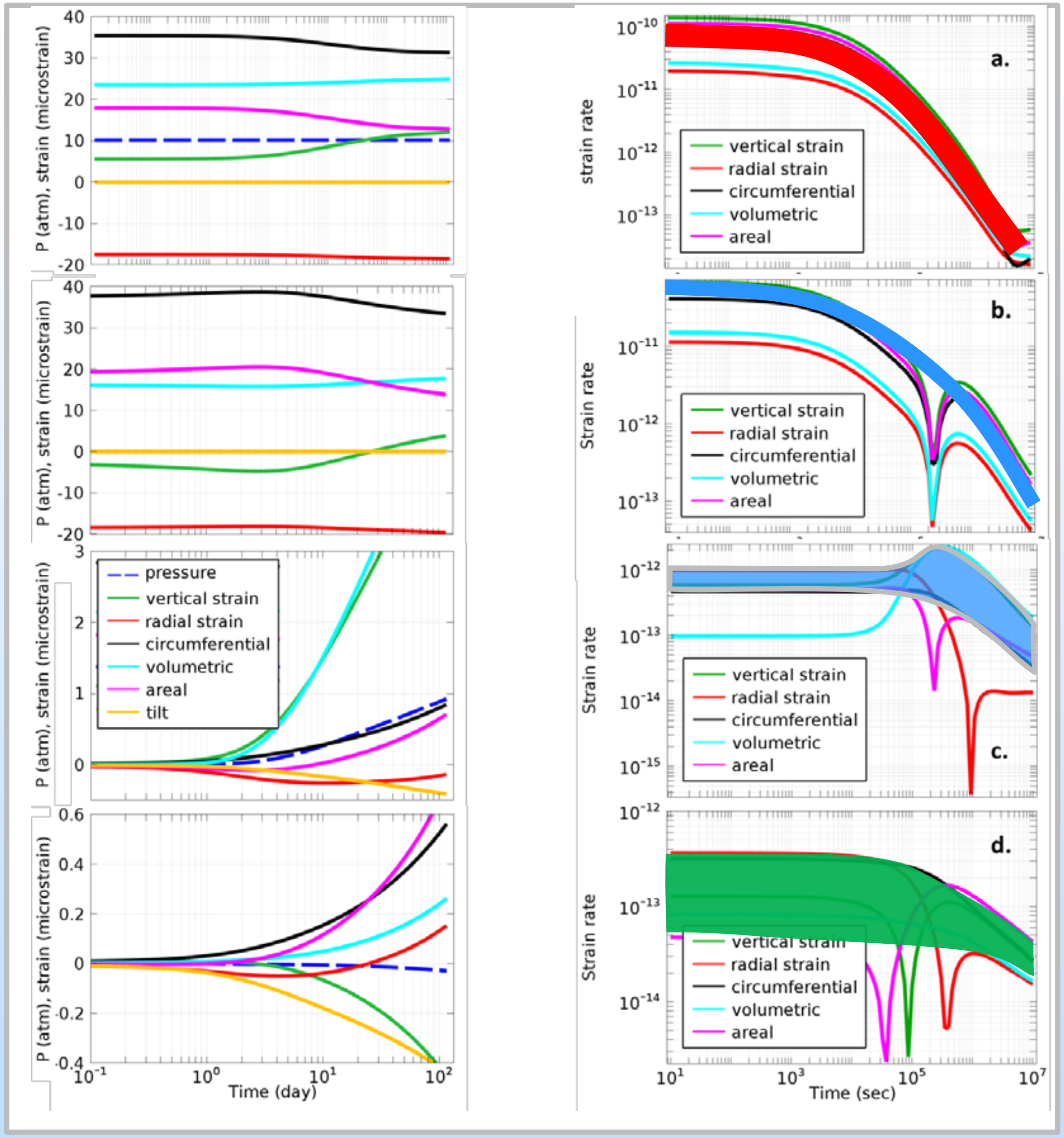
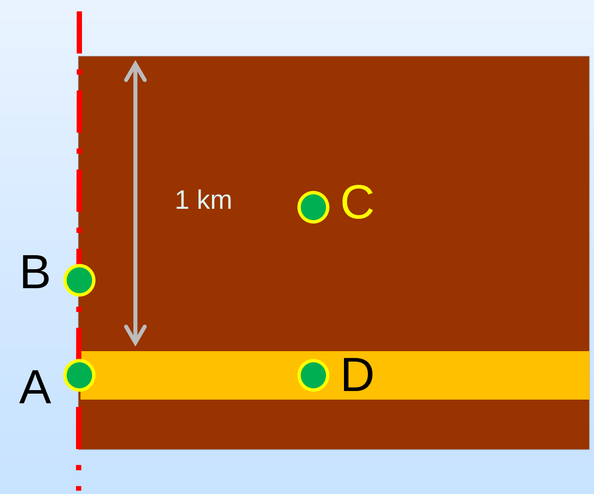
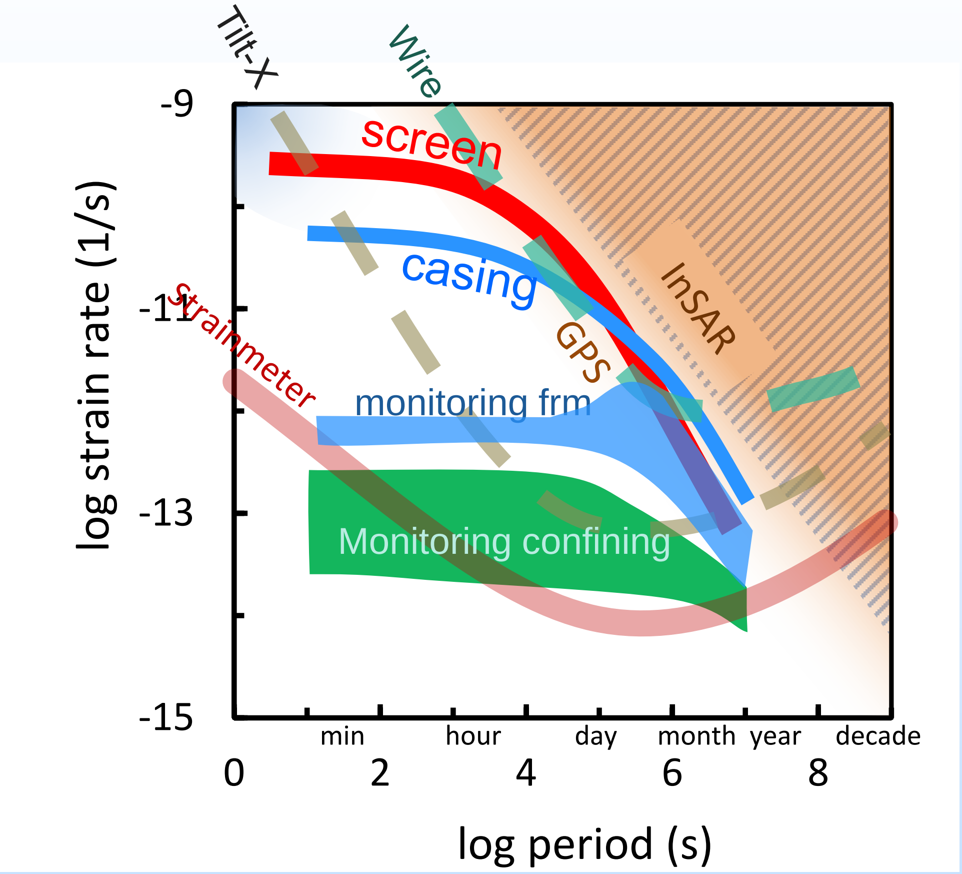




Expected Strain Rates and Measurement Capabilities



Injection rate
Q=100 gpm

Strain rate ∝Q

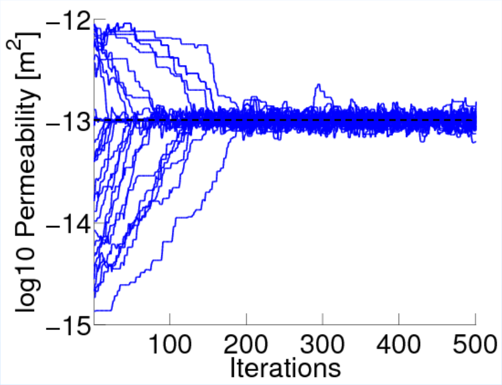
Based on *Plate Boundary Observatory Report* [1999]

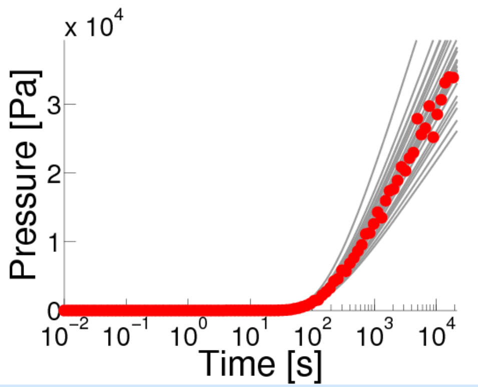
How can measurements be interpreted? Task 3:

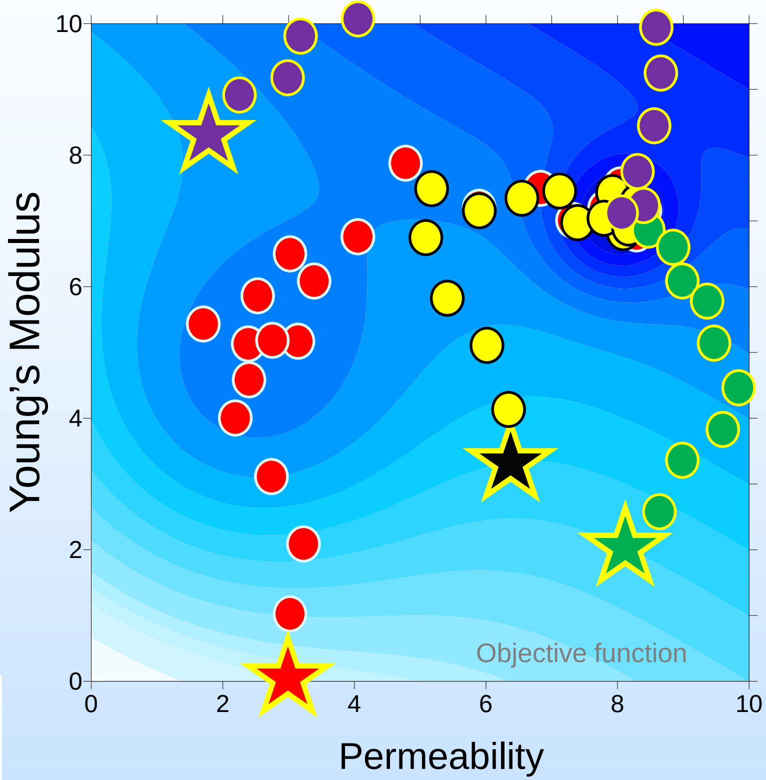
Goals: a.) Quantify ability of data to constrain model parameters, b.) assess how uncertainty in parameters translates into risks; c.) optimize methods for efficient large-scale reservoir characterization

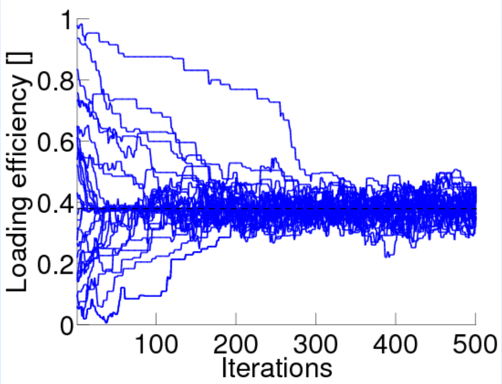
Reservoir Parameters

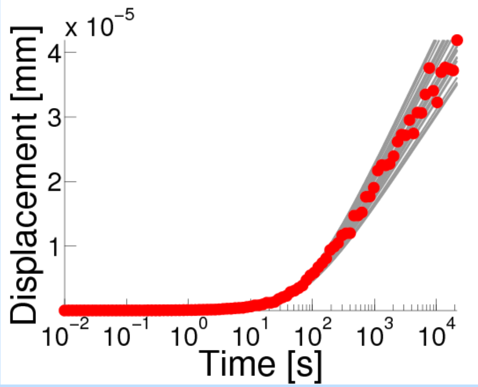
Geomechanical Signals





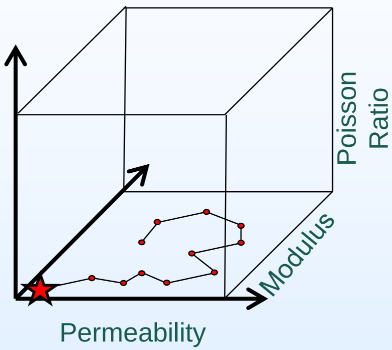


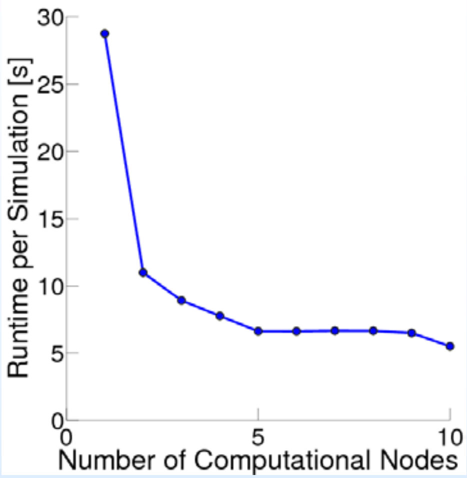


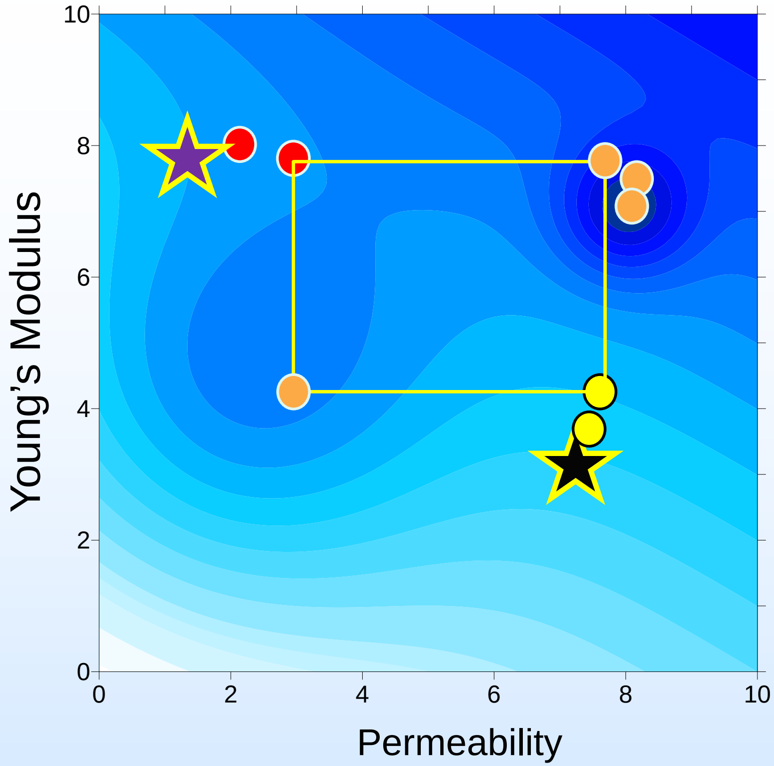


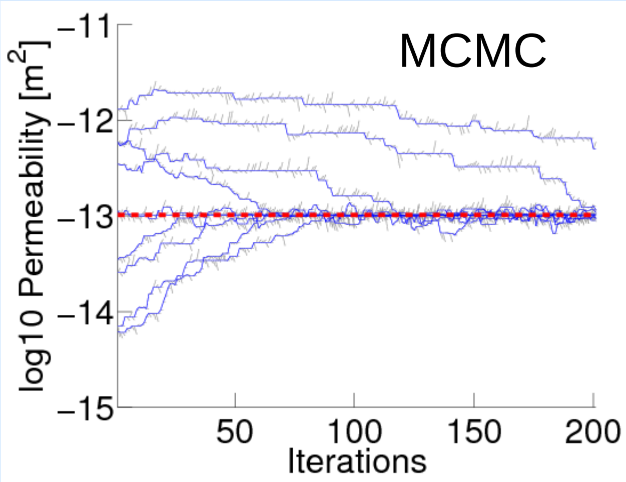
MCMC: Good search of parameter space. Avoid traps in local minima.

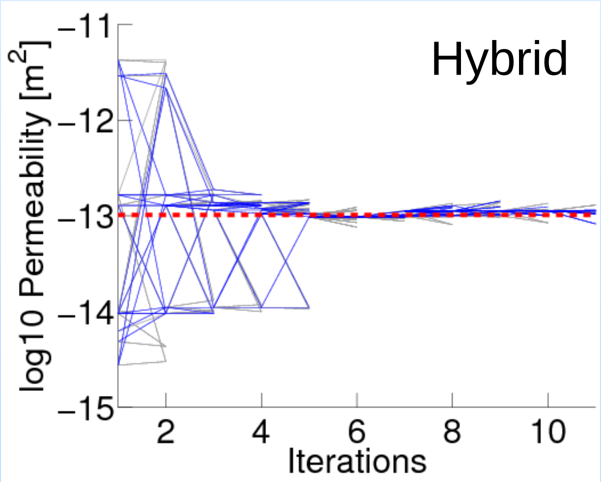
MCMC+Genetic →
Hybrid Optimization







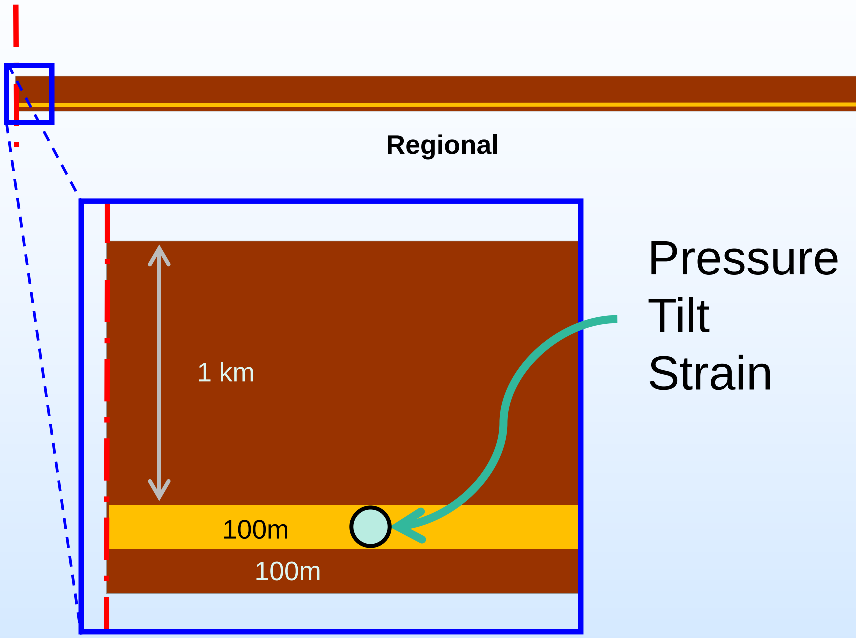




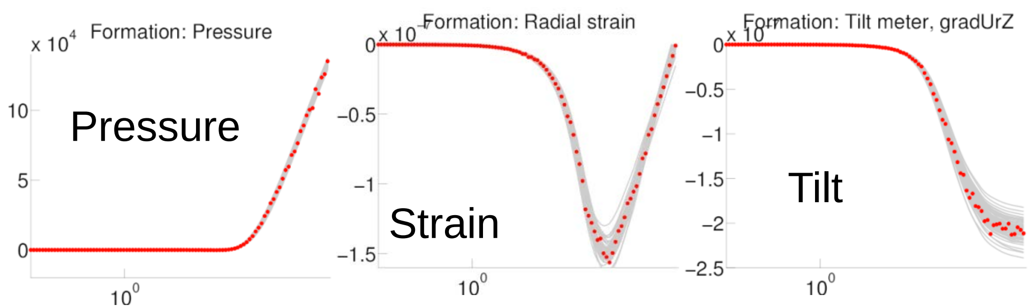
MCMC: Good coverage of parameter space
Genetic: Good convergence
Hybrid: Best of both

Applications

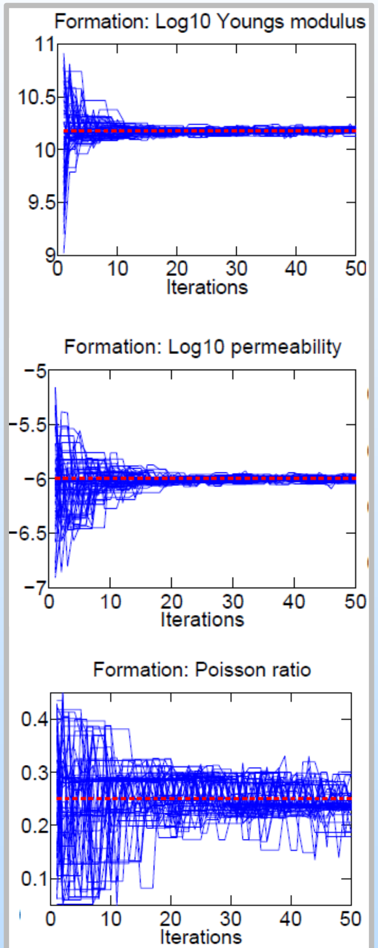
Data Location, Measurement Type, Heterogeneity



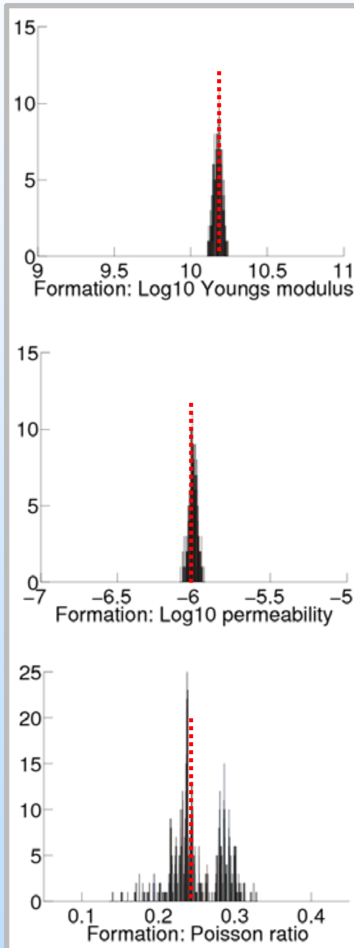
Data (Observed + Fit)



Iterations



Estimated Parameters



Applications

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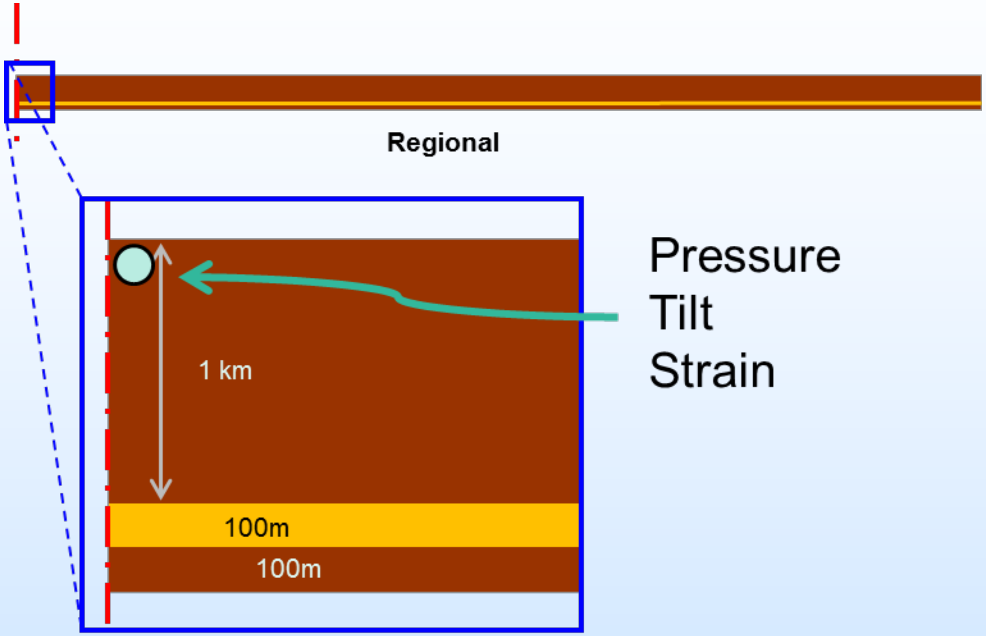

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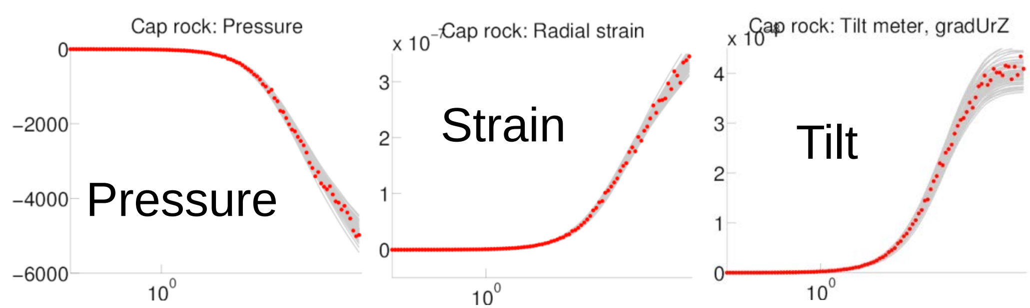
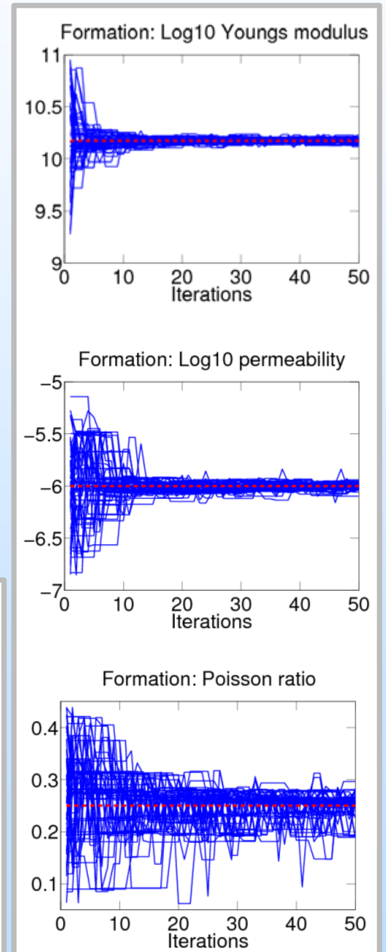


Iterations



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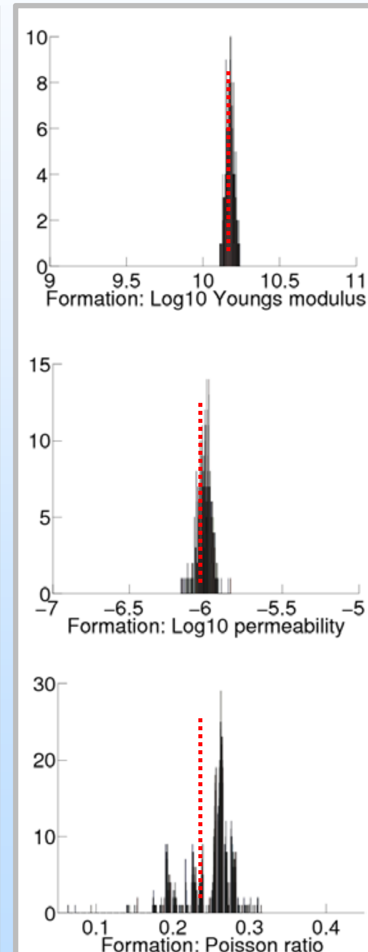

Applications

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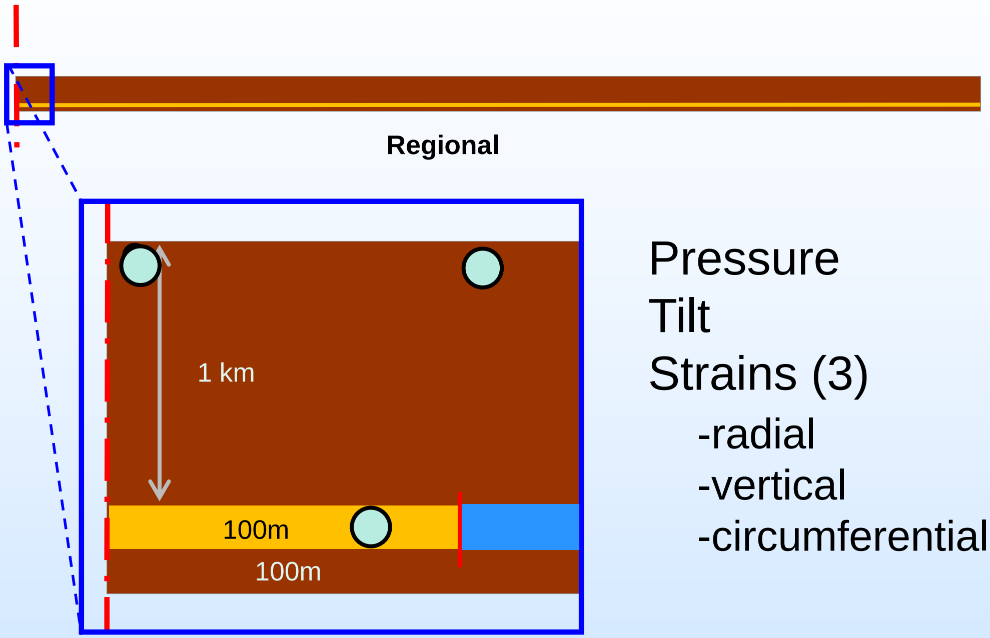
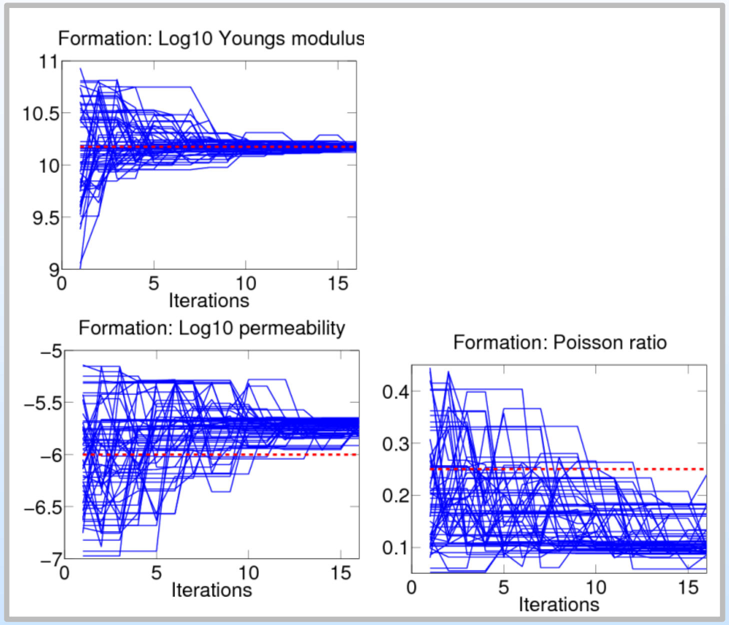
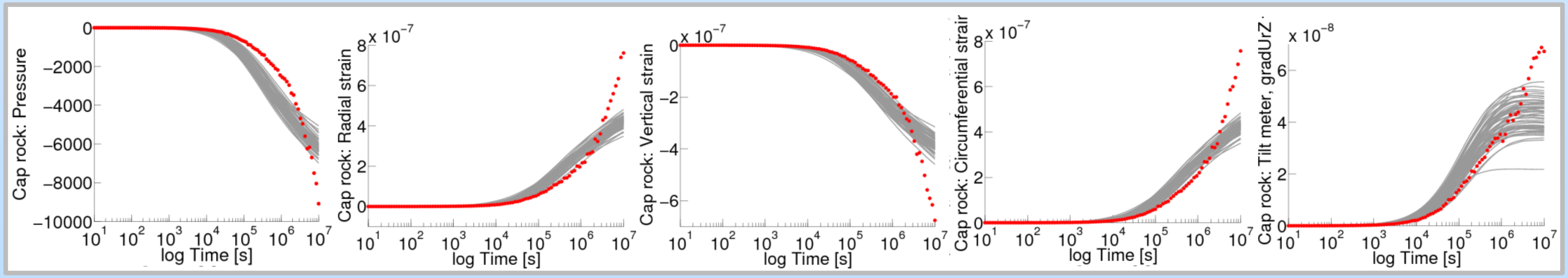


Pressure
Tilt
Strains (3)
- -radial
- -vertical
- -circumferential

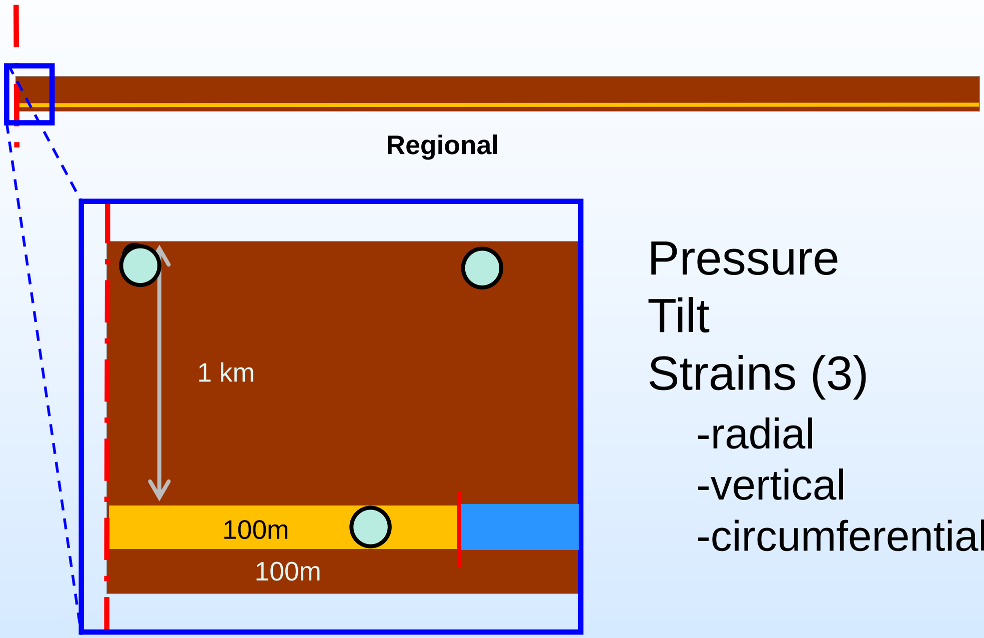


Cap rock Data



Applications

Data Location, Measurement Type, Heterogeneity



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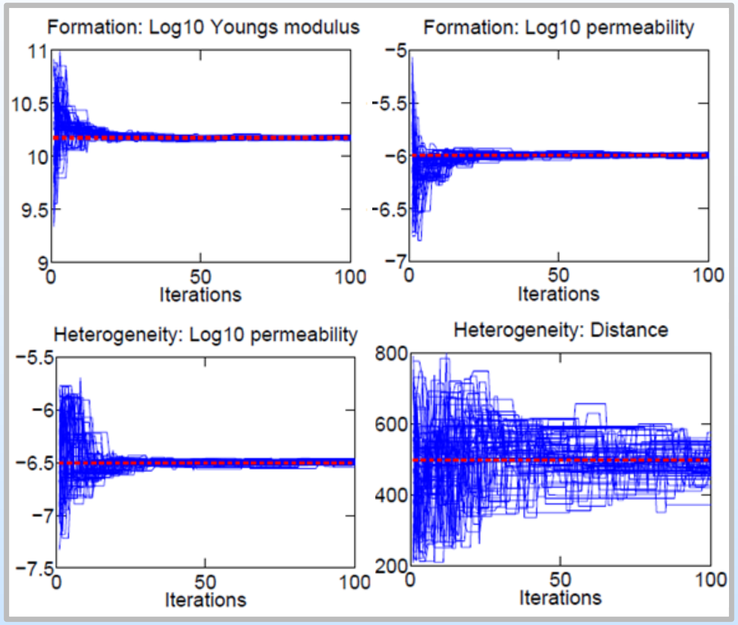
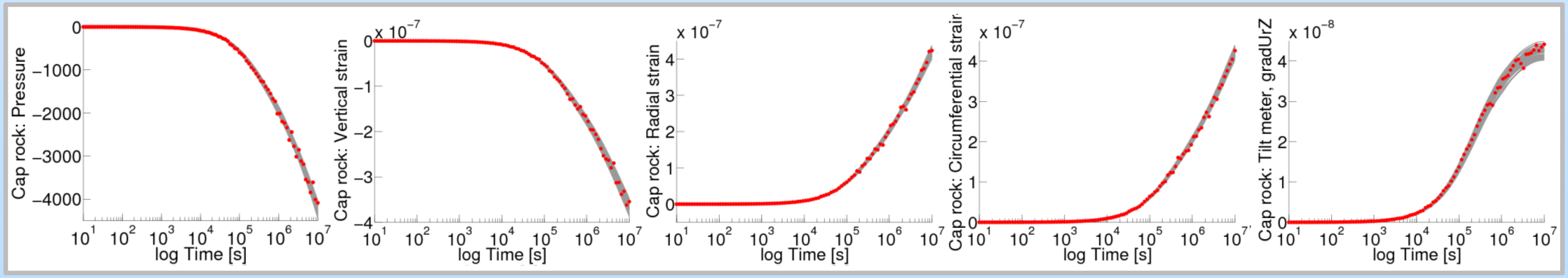


Formation Data (near)
Cap rock Data (far)



Status of Inverse Analyses

	2D	3D	Interpretation
Measurement Type			
Pressure vs. Geomech	X		Geomechanical data constrains parameters better than pressure alone, combination is best
Strain versus tilt	X		Strain data constrains better than tilt meter, combination is best
Data Location			
Reservoir	X		Instruments in reservoir can constrain parameters
Caprock	X		Instruments in cap rock can constrain parameters
Well Bore	X		Forward model ready
Heterogeneity			
Radial Contact	X		Geometry and physical parameters constrained
Compartmental Fault	X		Can identify model error, investigating non-uniqueness of parameters
Leaky Fault	X		Investigating non-uniqueness of parameters
Channel Hetergoeneity	X		Geometry and physical parameters constrained
Channel Heterogeneity		X	Forward model ready
Stresses on Fault		X	Forward model under development

Accomplishments to Date

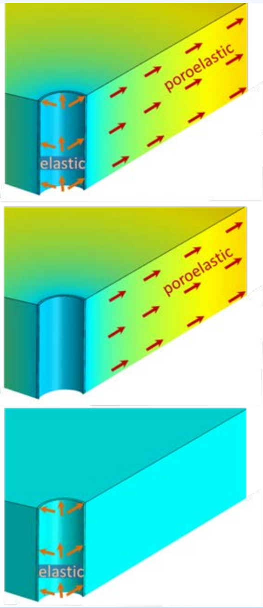
- Measurement
  - Instruments to measure axial, radial, 3D
  - Resolution/Logistics: 1 $\mu\varepsilon \rightarrow$ 0.001 $\mu\varepsilon$
  - Demonstrated in the field
- Analyses
  - Benchmarks, Verification, 2D axial, 3D
  - Patterns of deformation; Magnitudes: ~ 1μm, strain: ~1$\mu\varepsilon$, strain rate: measurable
  - Sensitivity, Uncertainty analysis; factor of 2 ~ 3
- Interpretation
  - MCMC 1 chain, Analytical, numerical
  - MCMC multi-chain, HPC
  - MCMC/Multiobjective genetic algorithm→ hybrid
  - Parameters constrained with geomechanical data
  - Parameters constrained with shallow cap rock observations
  - Heterogeneities identified, parameters and geometry constrained

Summary

– Key Findings
  - Expect μm/με-scale displacements
  - Possible to measure magnitudes and rates
  - Interpretation appears feasible
    - Remote sensing of change in pressure
    - Formation properties, heterogeneities, geomechanics
    - Leakage, casing integrity

– Future Plans
  - Forward analyses; reservoir structure, casing-cement-formation
  - Instrument evaluation; multi-axis strain
  - Hybrid optimization; wellbore, heterogeneities, non-uniqueness, real field data

Radial Displacement

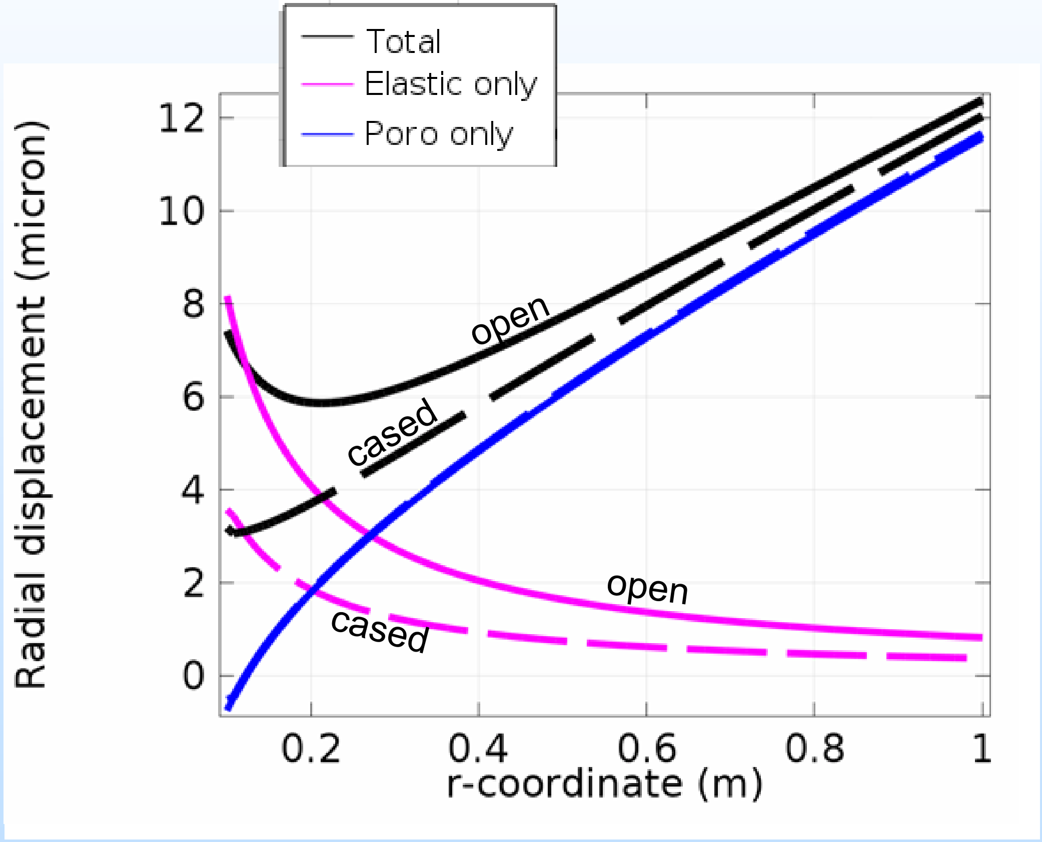


TOTAL
- P in casing, elastic load
- P in frm, poroelastic load

Poroelastic only
- No Pressure in Casing

Elastic only
- No pressure in formation

Open Hole and Cased Hole



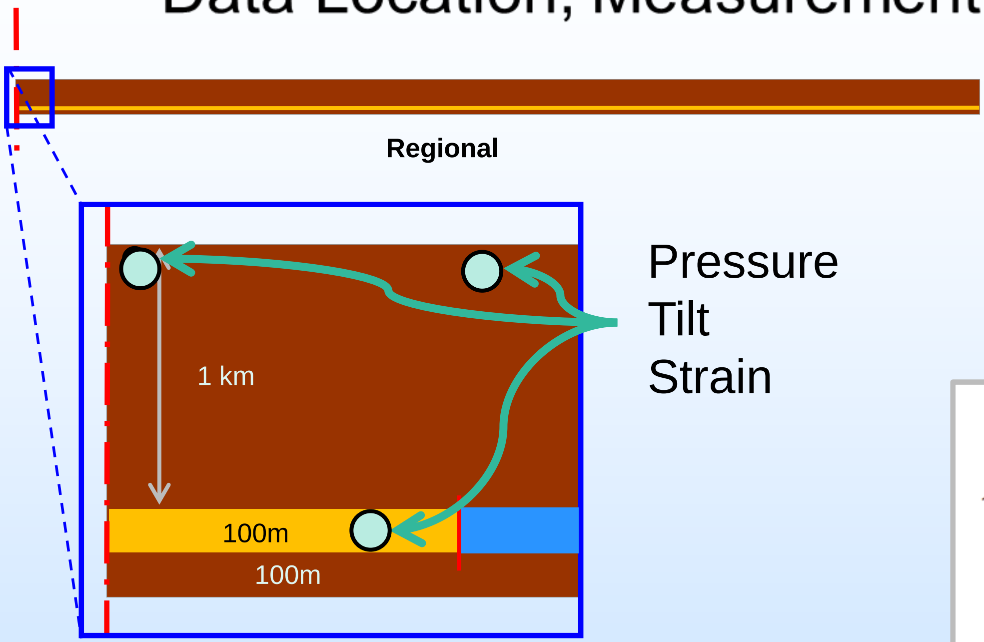
What deformation is expected? Task 2

Goal: characterize deformation in the vicinity of wellbores used for sequestration.

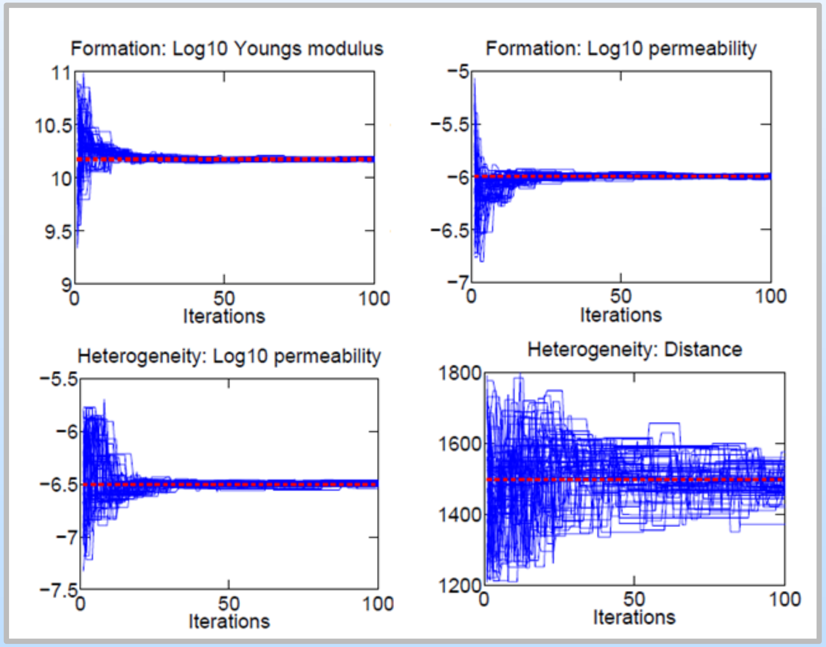
- Benchmark simulations
  - FLAC, Abaqus, Comsol, GMI Wellcheck…
- Response Scenarios
  - Reservoir types
  - Heterogeneities
  - Wellbore completion

Applications

Data Location, Measurement Type, Heterogeneity



Iterations



Applications

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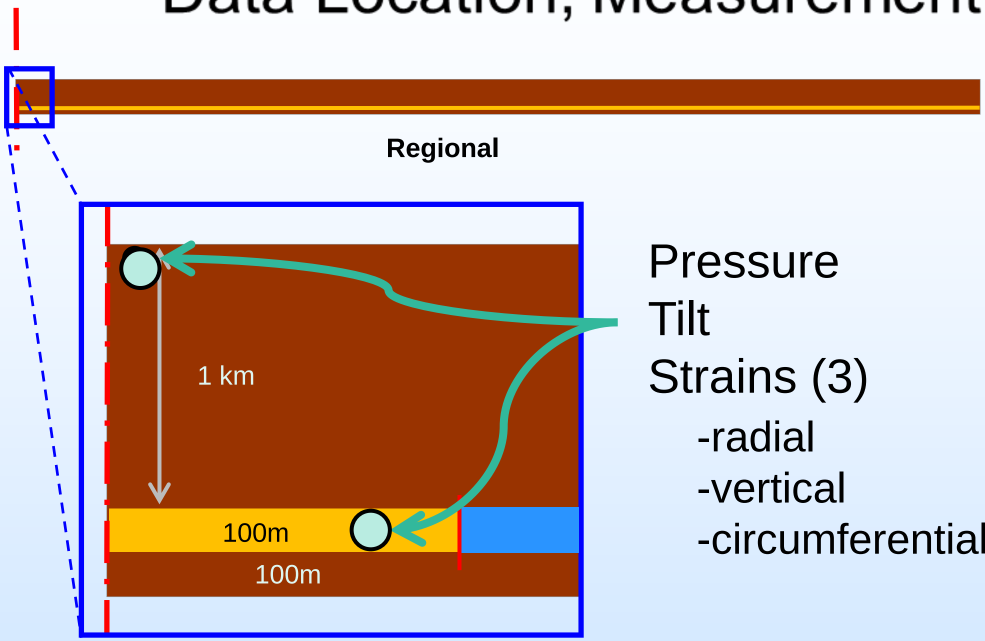

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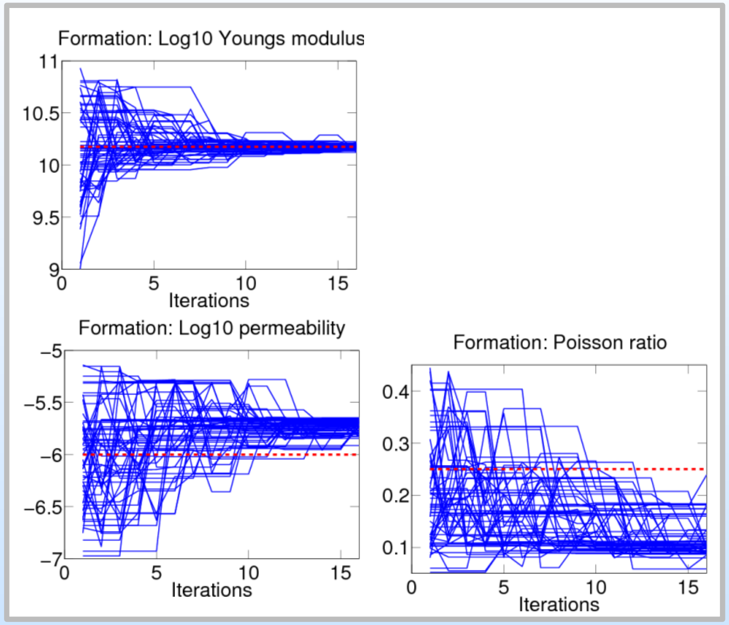

Formation Data