Monitoring and Verification at the Frio Pilot Test

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Second Annual Conference on Carbon Sequestration

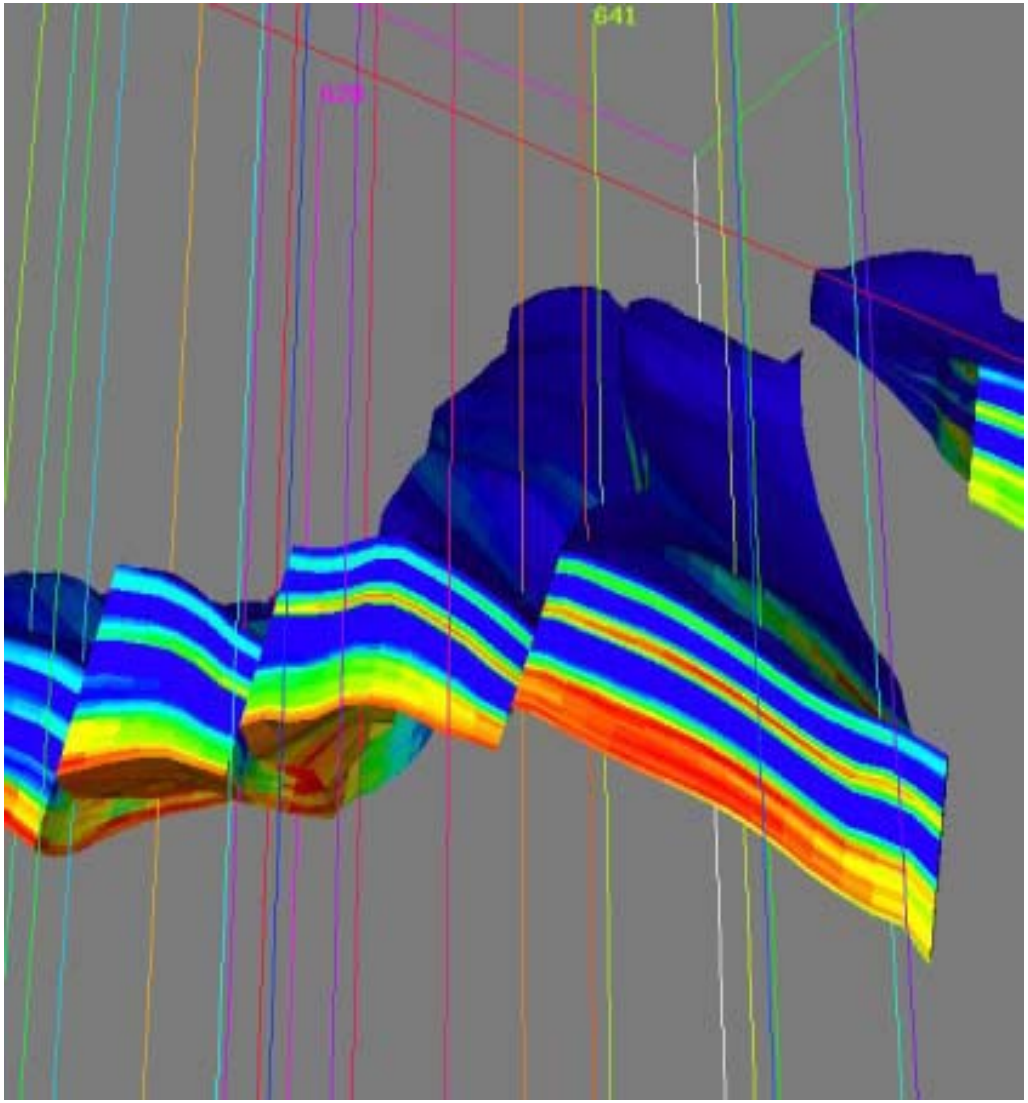
May 6, 2003

Outline

- Objectives and approach
- Flow and transport modeling, monitoring
- Geophysical monitoring
- Surface monitoring
- Summary

Objective and Approach

- **Objectives:**
  - **Demonstrate CO_2 injection without adverse impacts**
  - **Confirm predictive models**
  - **Demonstrate monitoring**
- **Approach:**
  - **Build upon existing data**
  - **Use modeling to guide design**
  - **Integrate disciplines, experience**



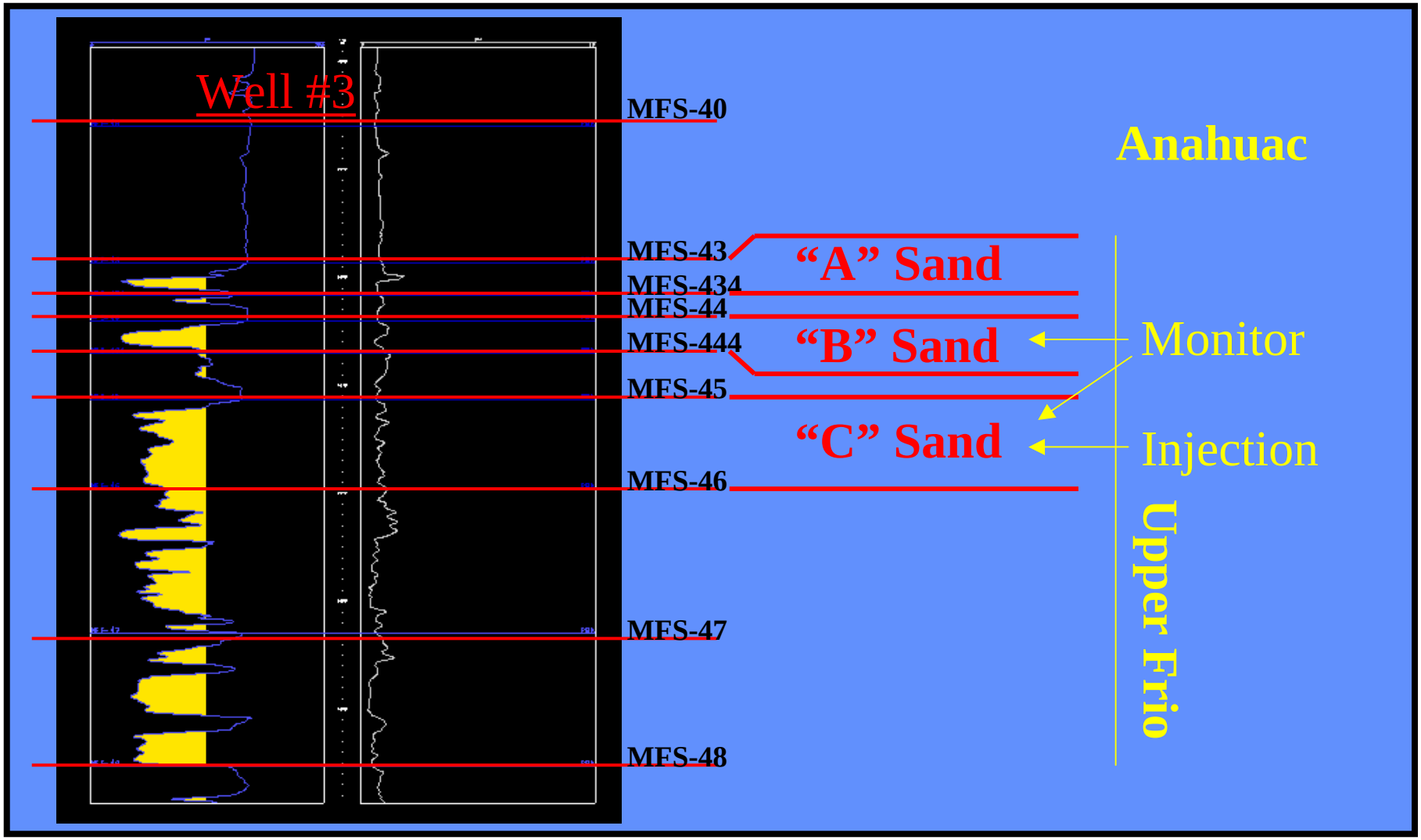
Multiple Measurements Provide Additional Characterization Information

	New Well Logs	New Well Core	Seismic and Electrical Geophysics	Surface Tilt	Pressure Transient Rates	Wellbore Fluid Sampling	Wellbore Pressure	Tracers
Rock type, thickness, dip	X	X	X	X				
Layer Continuity			X		X	X	X	X
Faulting and fracturing	X	X	X	X	X	X	X	X
Porosity and permeability	X	X	X		X	X		X
Baseline mineral and fluid composition	X	X				X		

Multiple Measurements for Monitoring Results of CO_2 Injection

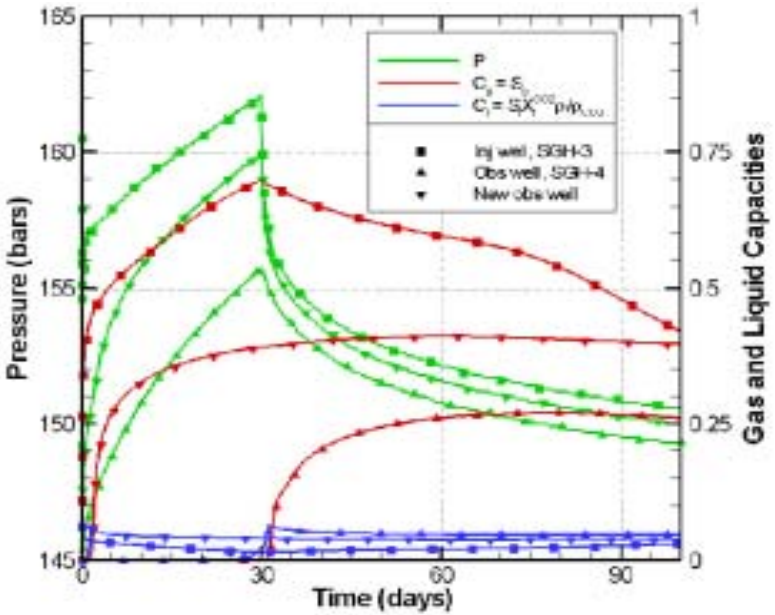
	New Well Logs	New Well Core	Seismic and Electrical Geophysics	Surface Tilt	Pressure Transient Tests	Wellbore Fluid Sampling	Wellbore Pressure	Tracers
Evolution Of fluid pressure			X	X	X	X	X	
Evolution of CO_2, brine saturation	X		X		X	X		X
Mineral dissolution, precipitation; fluid chemistry changes						X		X

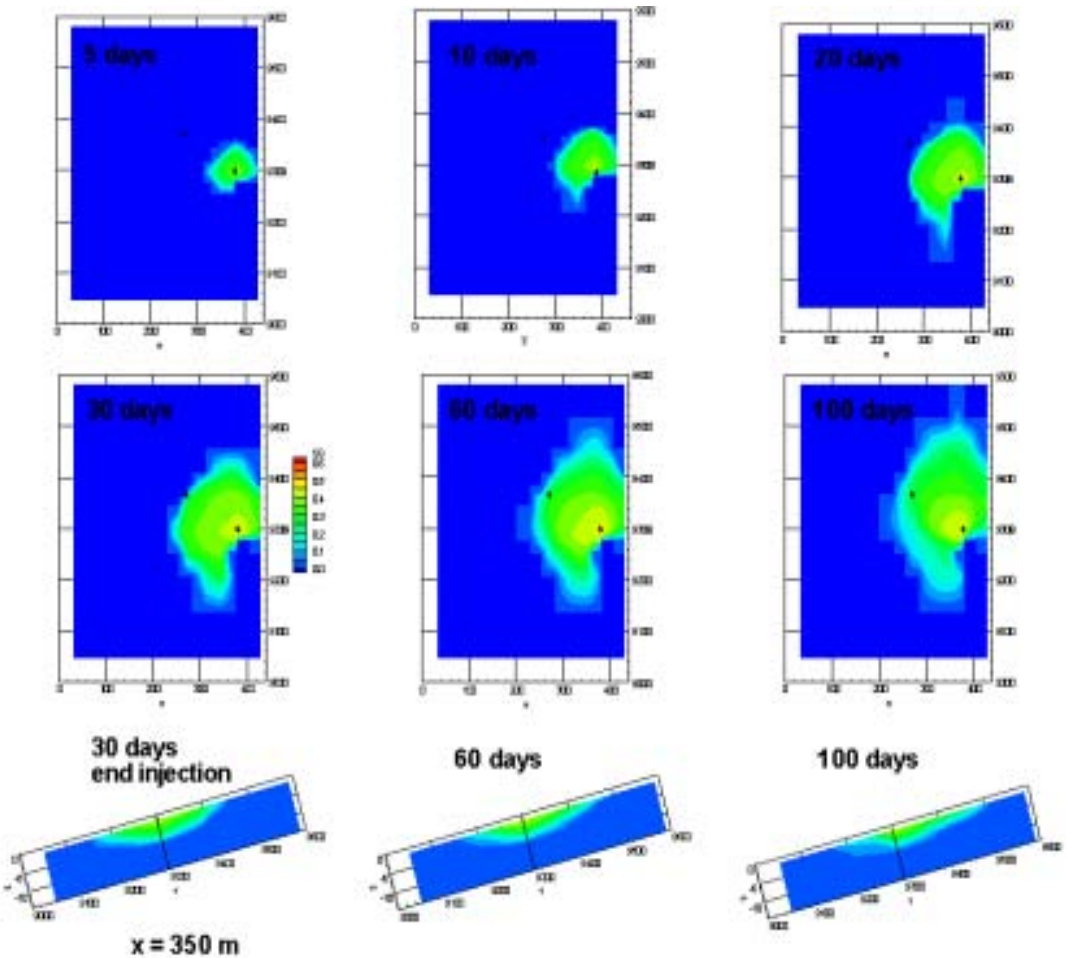
Stratigraphy



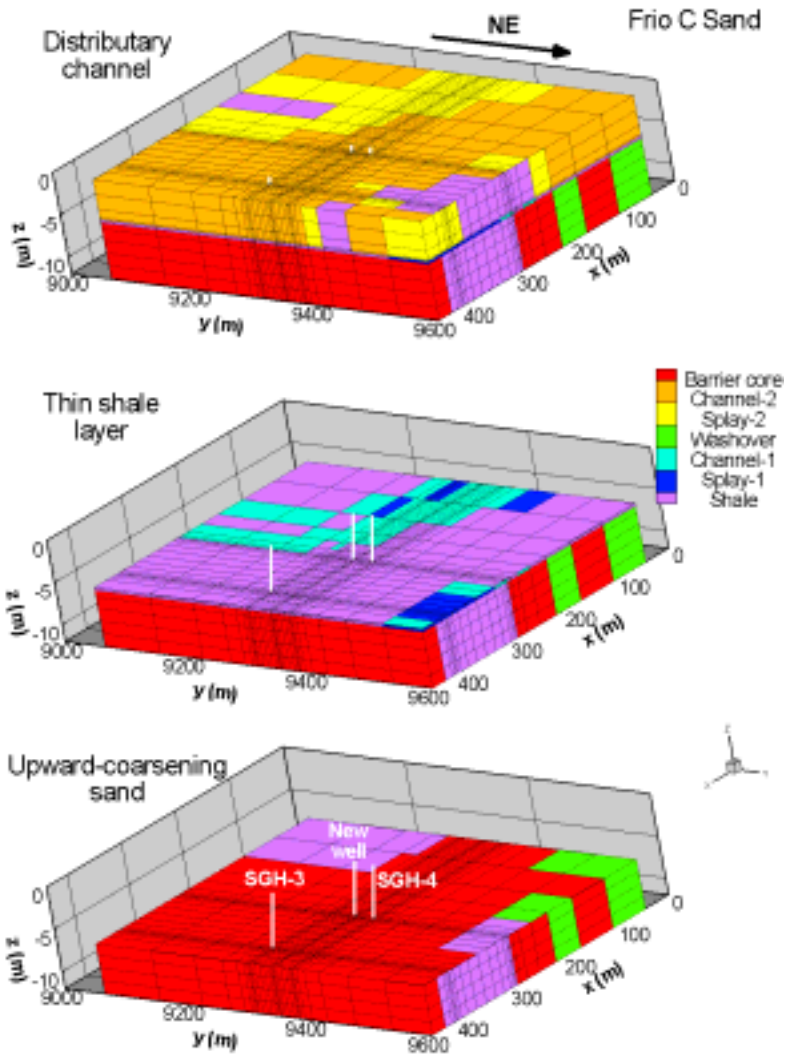
Early Model Results Supported New Well Concept

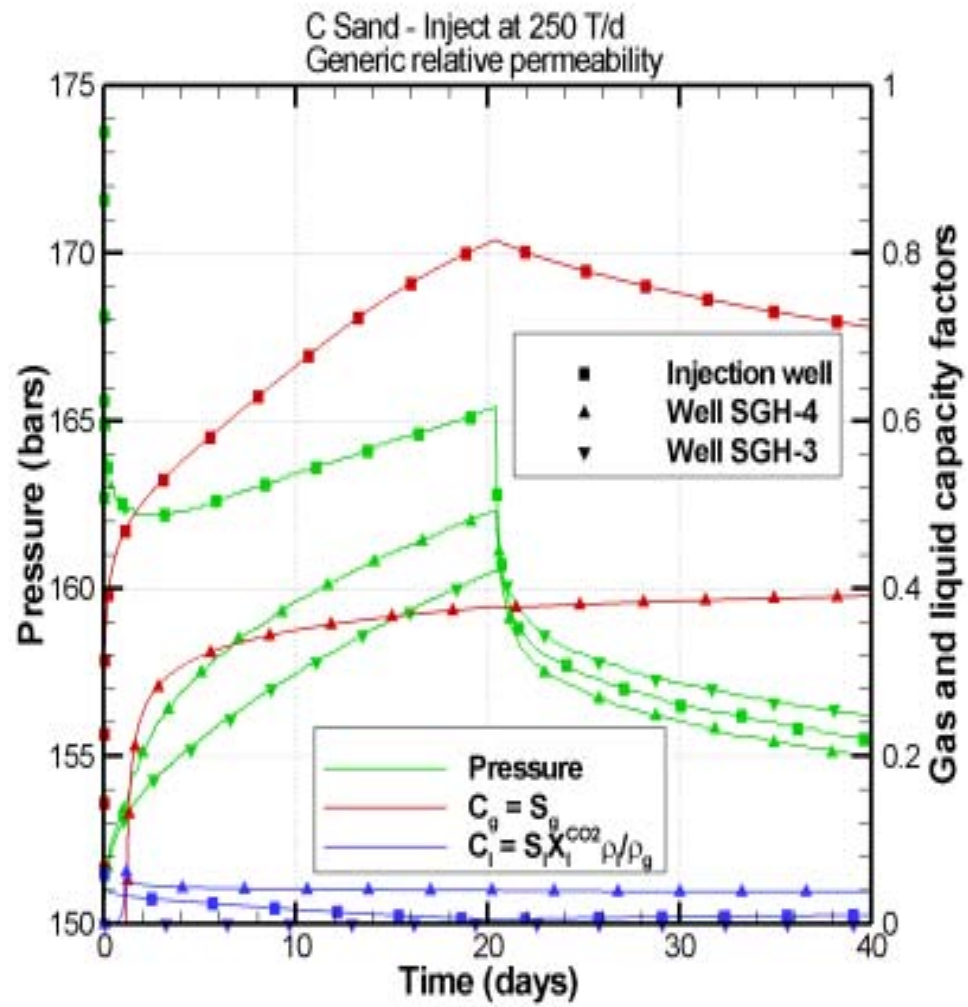
- **7,500 tonnes, 30 day injection**
- **15º dip**
- **Plume just reaches SGH-4; moves preferentially updip**



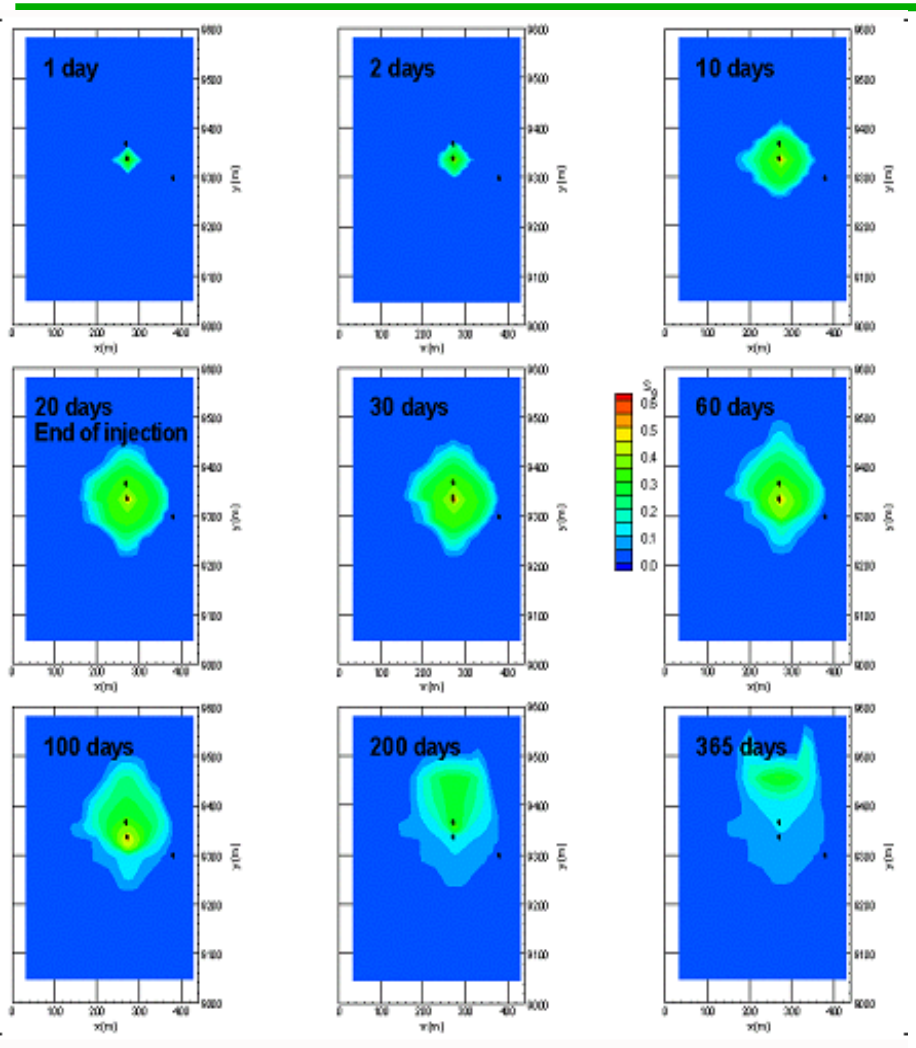


C Sand Selected for Injection

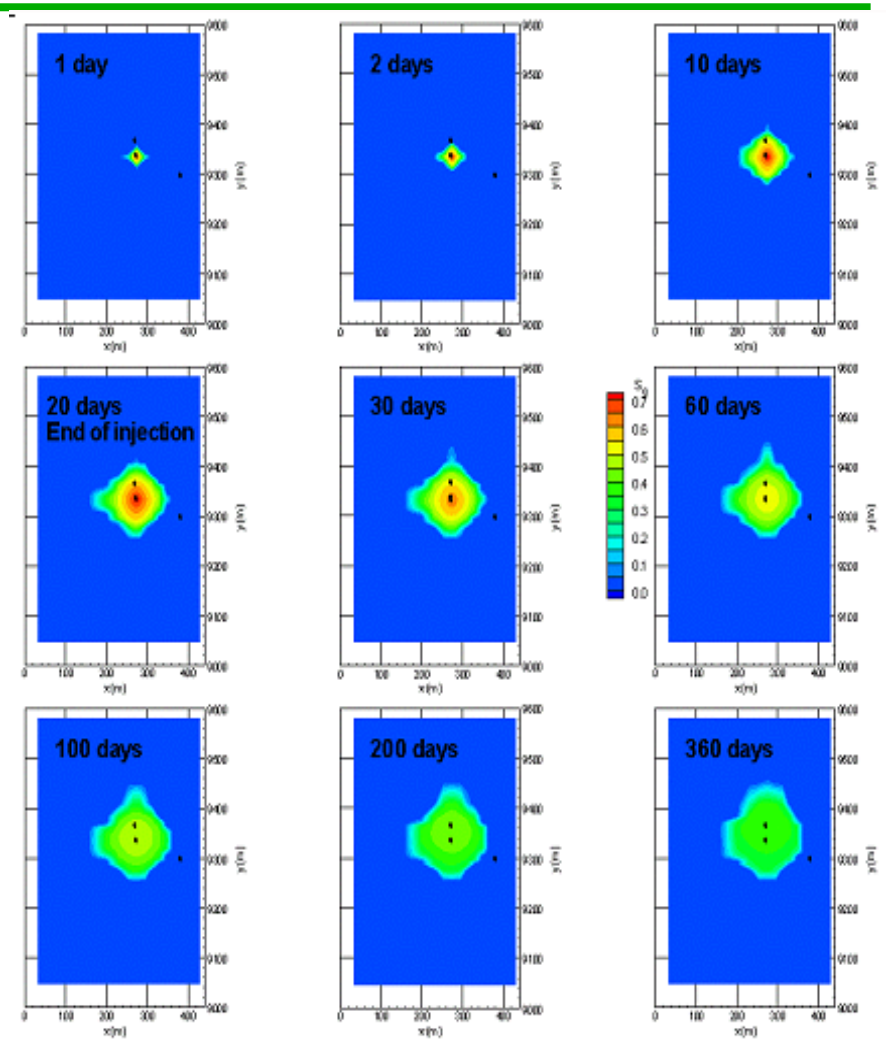




Residual Saturation Affects Plume



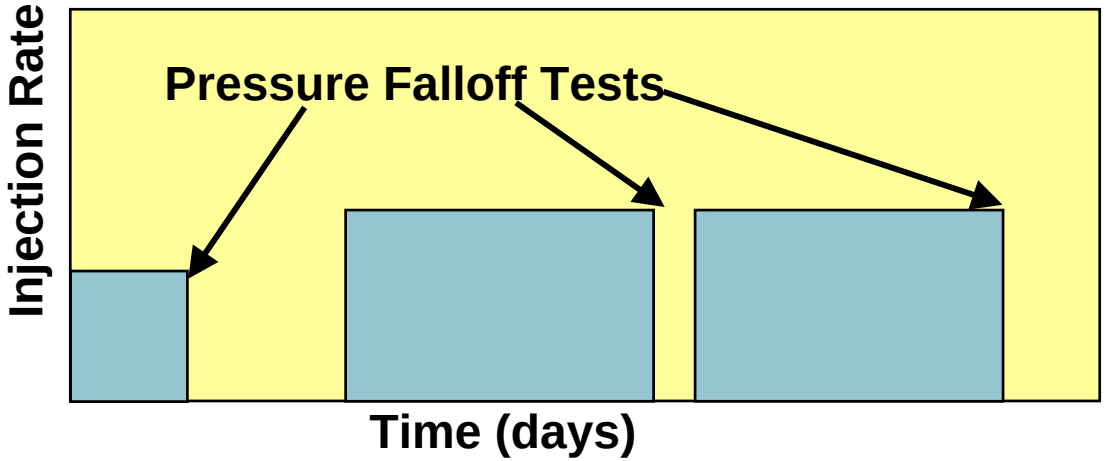
S_{lr}=0.3 S_{gr}=0.05

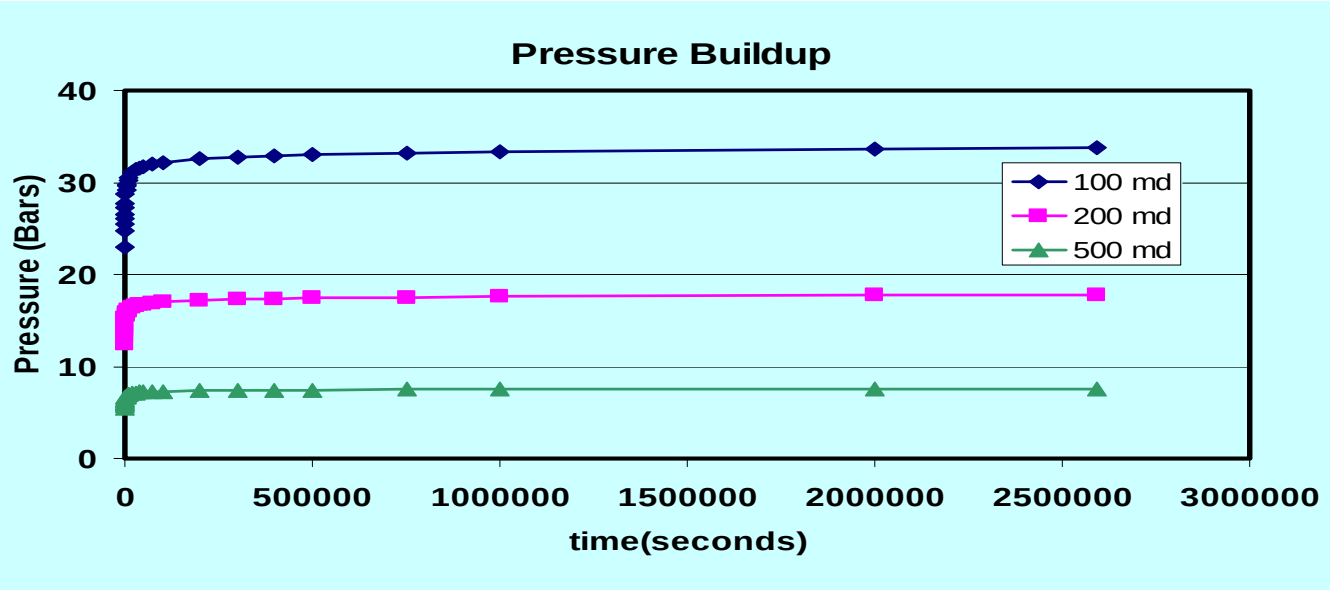


S_{lr}=0.2 S_{gr}=0.30

Laboratory relative permeability tests are underway

Well Tests During CO_2 Injection Provide Additional Information

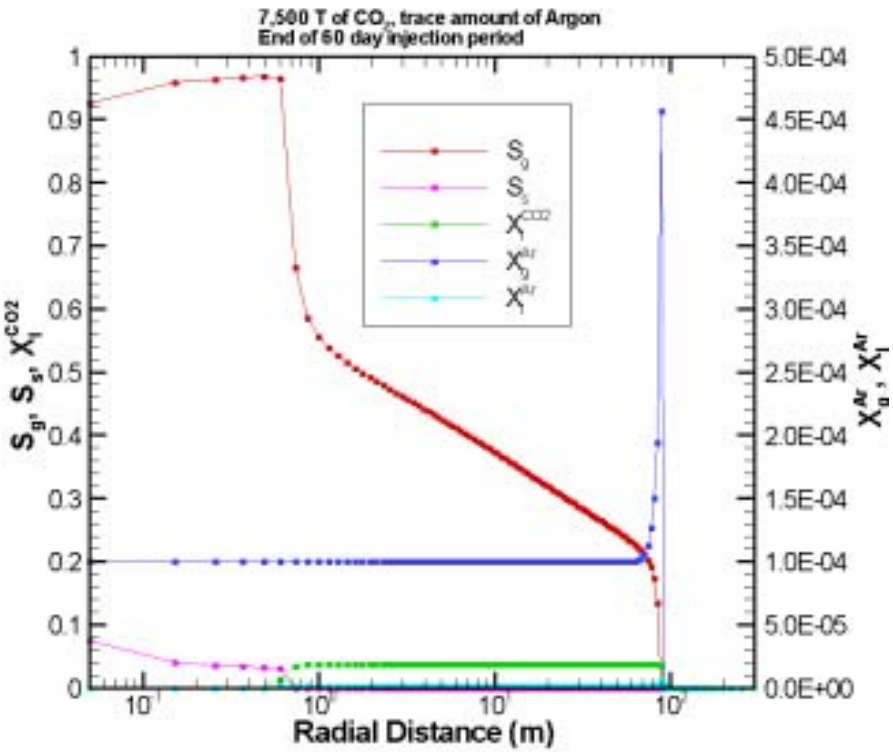


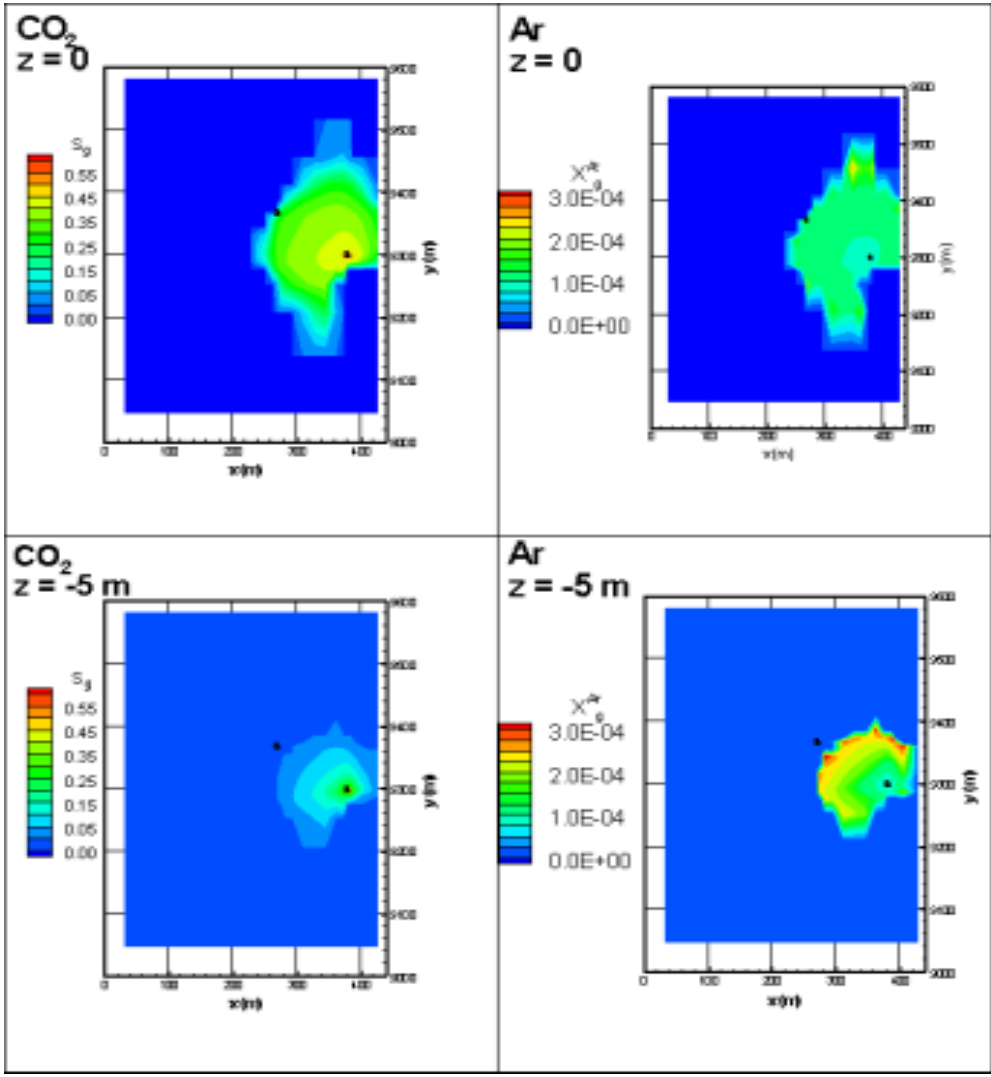


New solution for calculating pressure buildup or falloff during CO_2 injection

Tracers Provide Information on Reservoir Processes

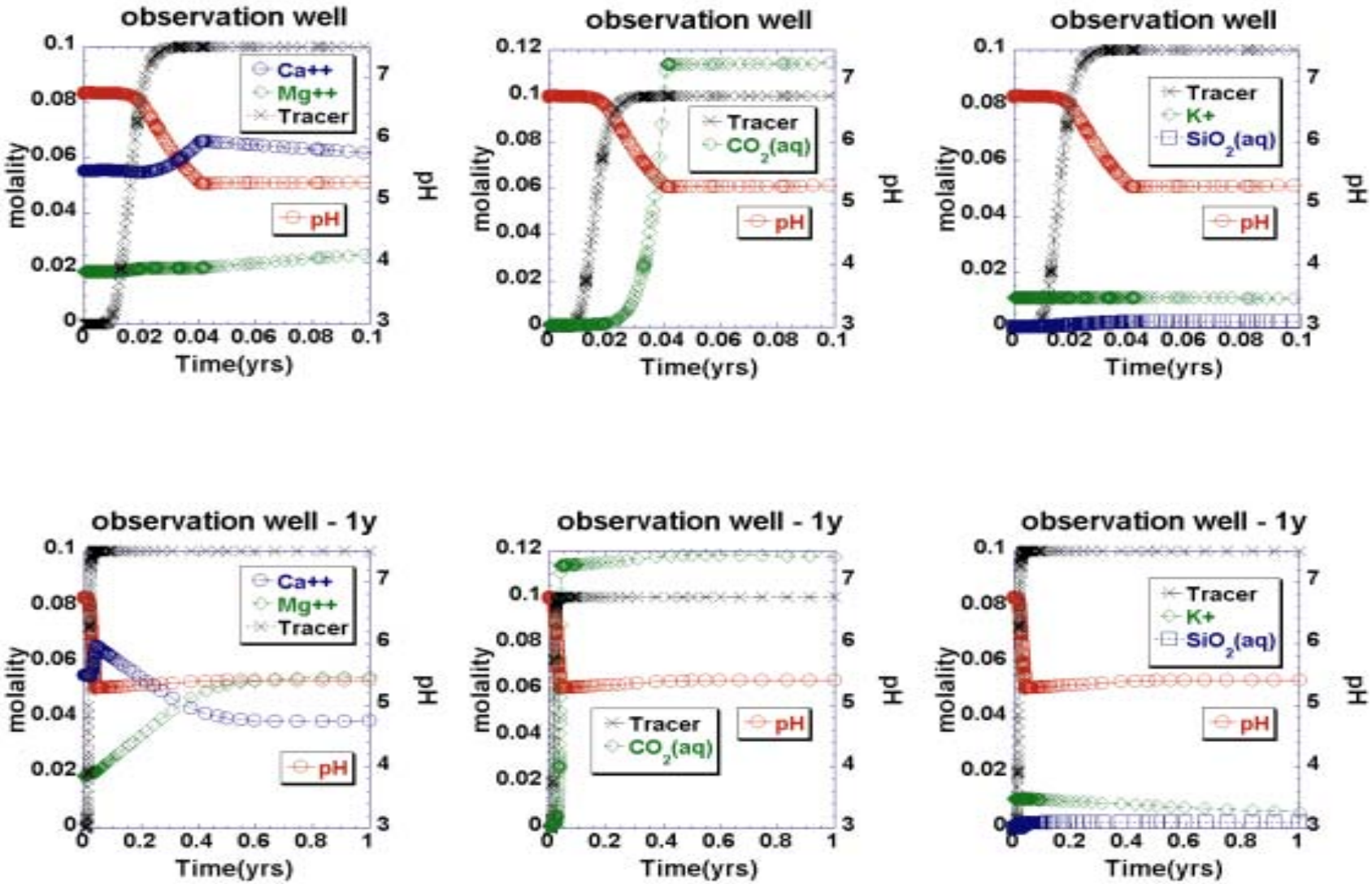
- **Noble gas cocktail**
  Ne, Ar, Kv, Xe
- **Carbon and oxygen isotopes**
- **PFTs**



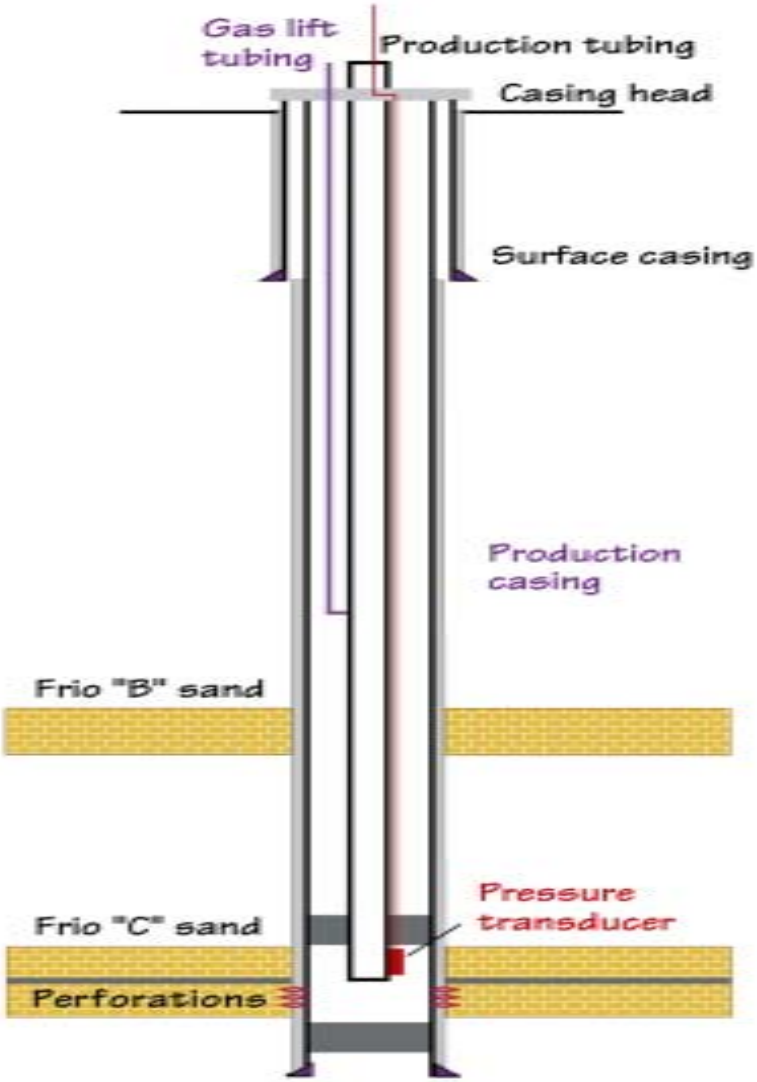


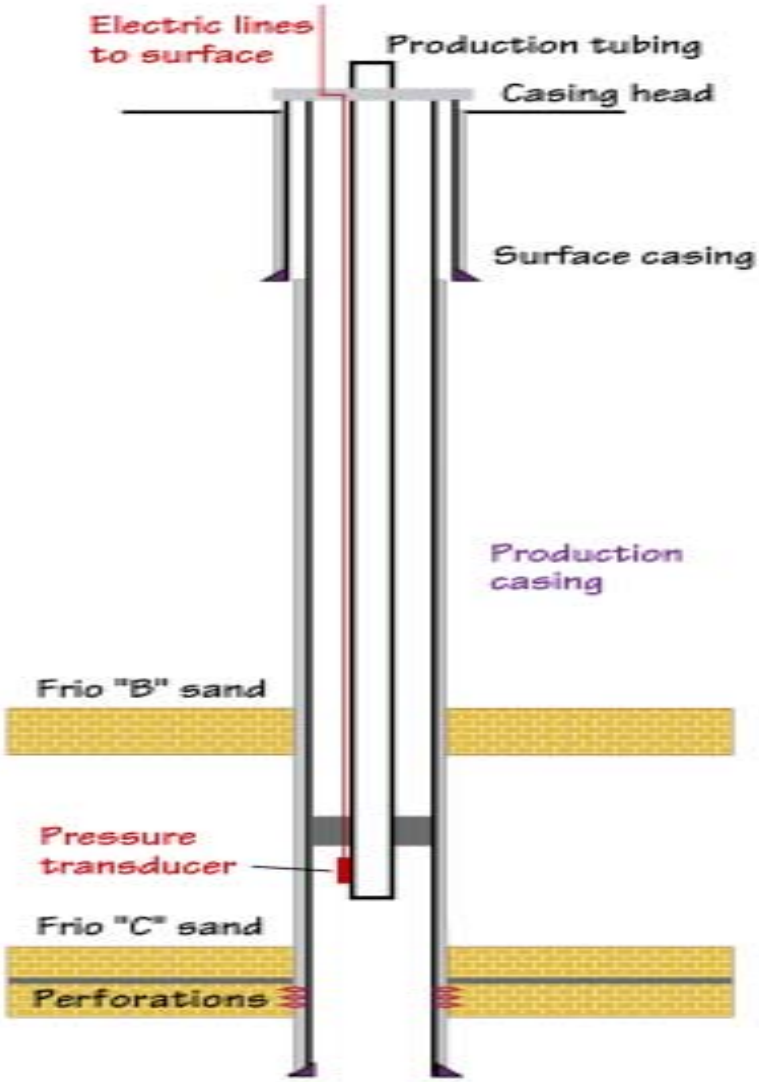
Results from B sand model, 60 day injection of 7,500 tonnes

Reactive Chemical Transport Modeling Shows Aqueous Chemical Changes



Well Completion Schematics



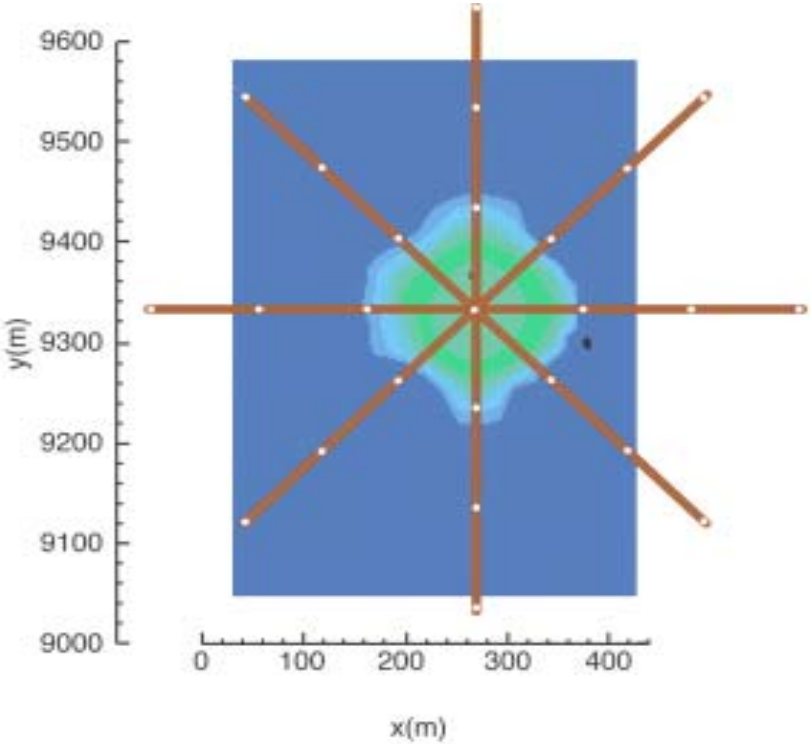


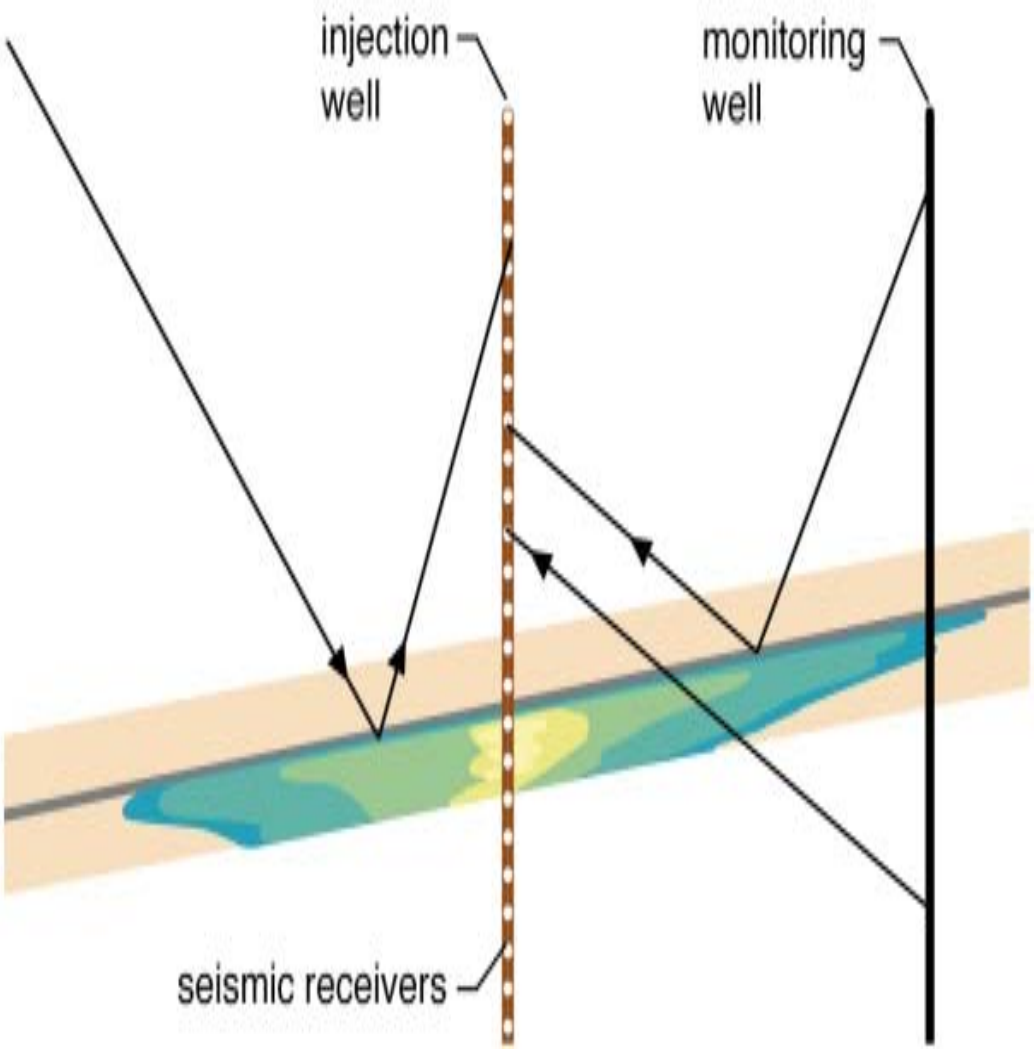
Geophysics

- Vertical Seismic Profiling (VSP)
- Crosswell Seismic
- Streaming Potential
- Surface Tilt

Crosswell Seismic and VSP Will Image Interwell Region

- **Surveys before, during, and after CO_2 injection**
- **Orbital source from Crosswell**
- **Surface dynamite for VSP**
- **3-Component string cemented in injection well**

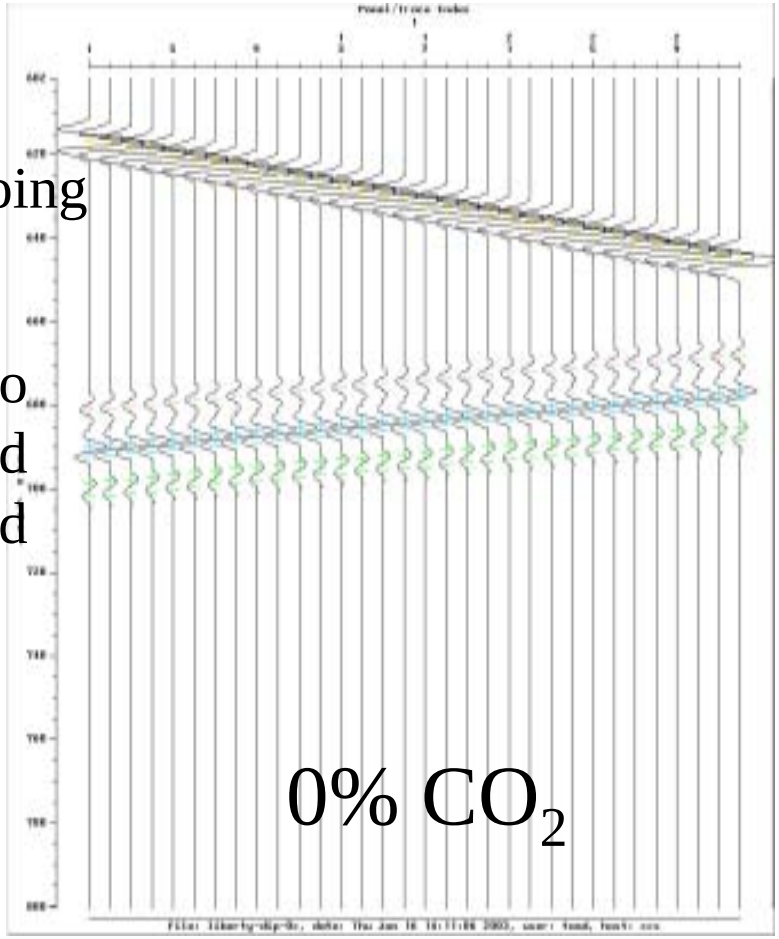


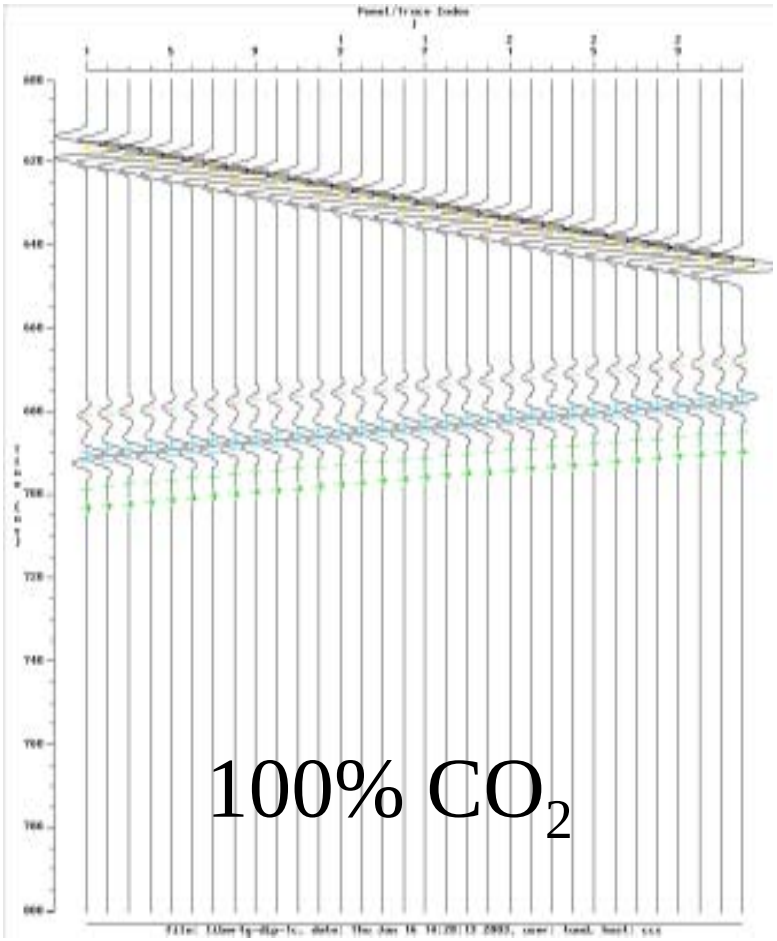


Model Results Support VSP Design

Downgoing

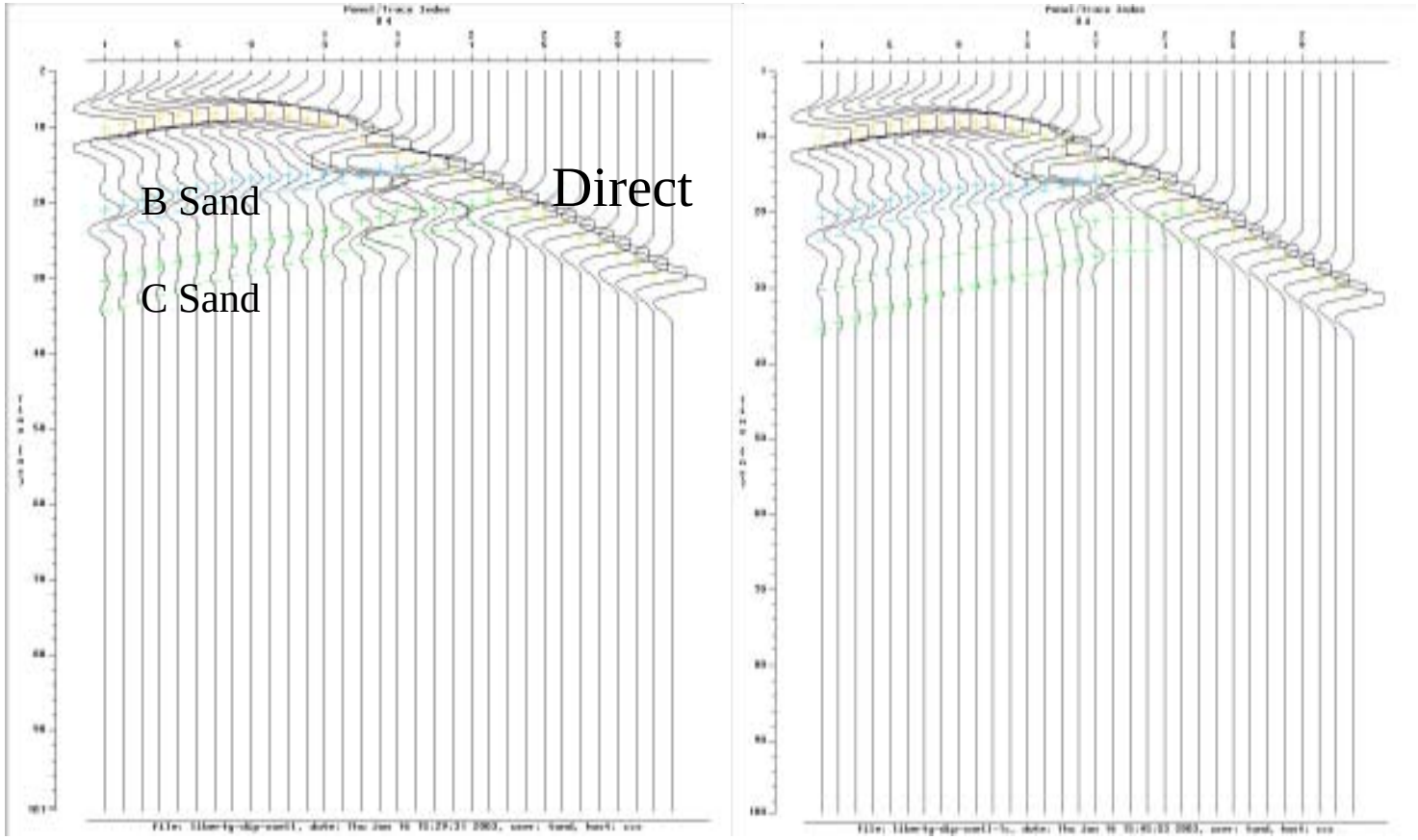
Top Frio
B Sand
C Sand





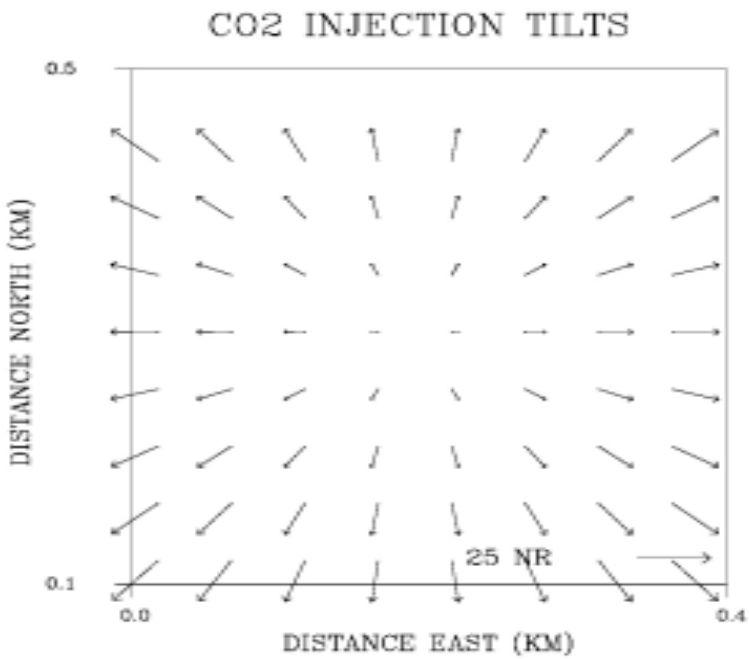
Model Results Support Design of Crosswell Seismic Survey

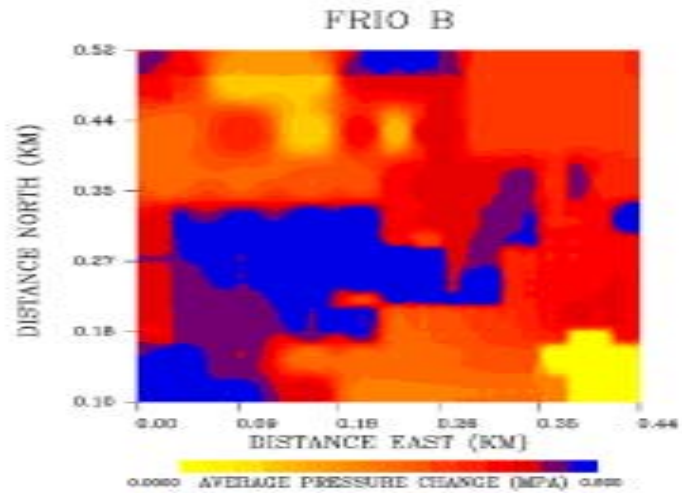
0% CO_2 100% CO_2

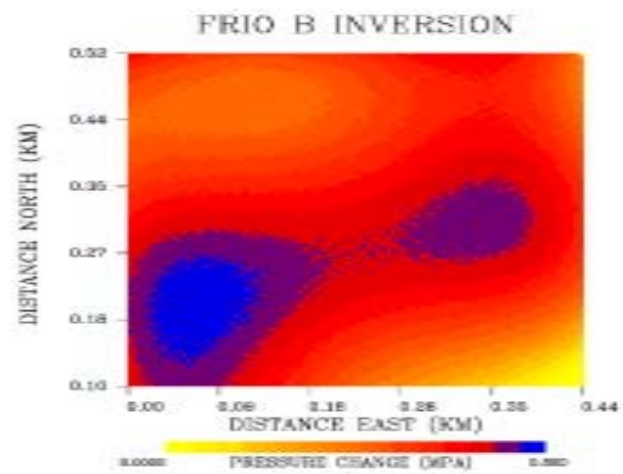


Surface Tilt Related to Pressure Change Due to Injection

- **Modeling predicts surface tilt ~ 10 nano-radians**
- **Inversion yields low resolution image of pressure distribution**

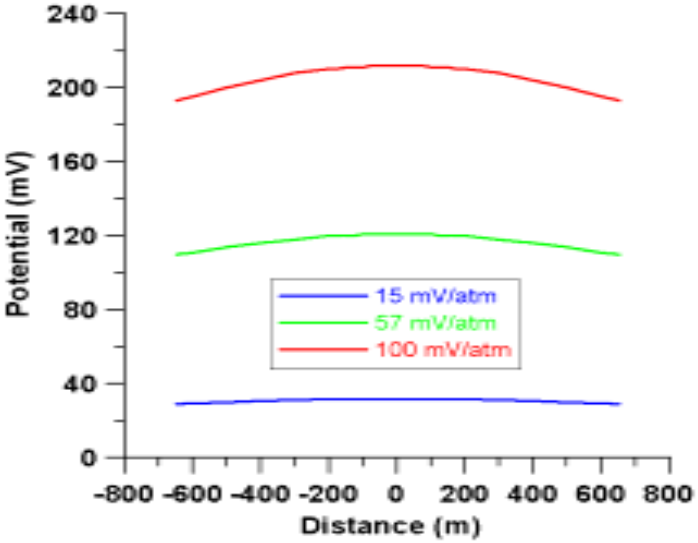


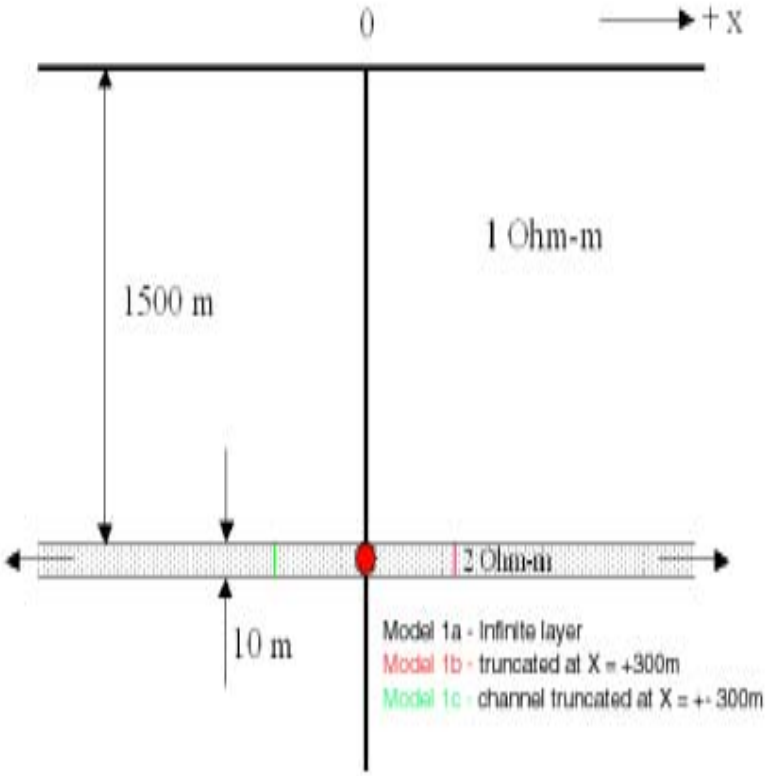




Liberty Field SP Model

- 2D solution of coupled flow & electric potential problem
- CO_2 injection rate
  - 4.0 l/s (250,000 kg/day)
- Lab measurements of CO_2 SP underway





Surface Measurements

- Water well sampling
- Passive seismic (strong motion)
- CO_2 monitoring
  - Soil gas, including tracers
  - Eddy flux

Summary

- CO_2 injection in fall of ’03
- Design of integrated monitoring and verification program in final stages
- Practical design guided by modeling
- Results will provide important baseline experience for larger scale brine formation sequestration tests