Linking the Chemical and Physical Effects of CO2 Injection to Geophysical Parameters

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Team

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Motivation: Monitoring of CO$_2$ Sequestration

- Map properties of original site – is it suitable for sequestration?
- Where is the injected CO$_2$ going once injection begins?
- What is the fate of CO$_2$: gas, liquid, or solid phases?

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Monitoring Challenges for CO$_2$ Sequestration

Changes associated with CO$_2$ injection have been successfully detected in the field using time-lapse seismic data. Converting seismic properties to CO$_2$ saturation can be problematic.

- Are we seeing changes in CO$_2$ content, pressure, mineral frame?
- What is the sensitivity? – what are we missing? – quantify risk.
- Current methods ignore fluid state and reactivity of fluid-frame.

Images from 4th Wave Imaging, DOE NETL Contract DE-FC26-03NT15417
Demonstrate techniques for quantitatively interpreting seismic images before, during, and after subsurface injection of CO$_2$. Specifically, determine

- CO$_2$ saturation (content)
- Pore fluid pressure
- Precipitation/dissolution of mineral

*Develop models that account for both mechanical and chemical interactions between pore fluids and solid rock frame.*
Conventional Seismic Rock-Fluid Model

Currently, seismic monitoring of injected CO$_2$ saturation is based on the equations of Gassmann (1951), which predict the change in elastic moduli of a rock upon exchange of one pore fluid with another.

These treat the rock-fluid mechanical interaction, but assume that the system is chemically inert, i.e., constant rock/mineral frame stiffness.
What does CO$_2$ in a rock look like seismically?

**Conventional Interpretation**

Function of pore fluid density, compressibility and elastic properties of the rock “frame.”
What does CO$_2$ in a rock look like seismically?

Real case is more complicated
Project Approach

1. Laboratory Measurements
   • Sample selection (Carbonate, Calcite-Sand, Sandstone)
   • Characterization transport and microstructure
   • Exposure to CO$_2$-brine, while monitoring Vp, Vs
   • Dissolution Kinetics

2. Chemical-Physical modeling

3. Numerical modeling of fluid signatures, including changes to the rock mineralogy
Laboratory Experiment: method

- The fluid is injected with a flow rate of about 8 mL/min and under \( P_c = 1.1 \) MPa.
- Saturated velocities are taken under a pore fluid pressure \( P_f = 1 \) MPa (no flow).
- Sample can be dried in situ.
Monitored Parameters

During Injection we monitor

• Ultrasonic P- and S- wave velocities (dry & saturated)
• length changes (apparent compaction)
• chemical composition of the output fluid (calcium and total hardness).
Porosity Variation with Injection

Micrite-rich carbonate grainstone

Porosity is changed both mechanically and chemically

Vanorio, Ebert, Grombacher, Geol. Soc. London
–AAPG Special Publication
Stiffness Variations with Porosity & Pressure

Frame stiffness depends on porosity & pore pressure

Micrite-rich carbonate grainstone

Elastic Modulus (GPa)

Pore pressure

Injected Pore Volumes

Vanorio, Ebert, Grombacher, Geol. Soc. London –AAPG Special Publication
Porosity Variation with Injection

Tight Limestone

Porosity (%) vs. Injected pore volumes

- Dissolution
- Compaction + Dissolution
- Compaction

Vanorio, Ebert, Grombacher, Geol. Soc. London – AAPG Special Publication
Stiffness Variations with Porosity & Pressure

Tight Limestone

![Graph showing elastic modulus (Gpa) with pore pressure and injected pore volumes.](image)

Vanorio, Ebert, Grombacher, Geol. Soc. London –AAPG Special Publication
Injection-induced trends mimic natural trends

P-wave Velocity (m/s)

Porosity (%)
Permeability trend mimics natural trend
Stiffness Variations with Porosity & Pressure

Tuscaloosa Sandstone

P-wave Velocity (m/s)

Porosity (%)
Time-lapse SEM imaging

Pits of dissolution
Enlargement of the bigger pores
Welded grains at grains contacts
Muddy surface
Enlargement of the bigger pores
Seismic Modeling in Thinly Layered Aquifer

Conventional rock models deal with one facies at a time. Errors arise when layer thickness is below measurement resolution.

- Brine-saturated sand/shale layers
- Upscaled brine-saturated interval
- CO₂ invades sandy layers but not shale
- Upscaled with CO₂
- Conventional fluid modeling approach
Embedded bound solid substitution

Substitution to a stiffer solid in the pore space.
Summary

Seismic (elastic) properties change with CO$_2$-water injection.
- Depend on *compressibility* and *density* of water-CO$_2$ mix, which vary with CO$_2$ content, free-vs.-dissolved state, scale of mixing, pore pressure, temperature.
- Depend also on stiffness of mineral framework of rock.

Conventional interpretations of time-lapse seismic data suffer from ignoring chemical and mechanical changes to the rock frame.

New models provide quantitative prediction of solid changes to the rock, plus a strategy for appropriate upscaling.
Thank you!