3D Time-lapse Seismic Modeling for CO$_2$ Sequestration

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Outline

• Background/Introduction
• Methods
• Preliminary Results
• Future Work
Goal

Flow simulation for time-lapse seismic modeling

To monitor:
- CO₂ movement and containment
- Long term CO₂ stability

To evaluate:
- Effectiveness of 4D seismic (CO₂ injection causes change of seismic response)
Flow Simulation

- Simulate liquid and gas flow in real world conditions

- Generalized equation of state compositional simulator (GEM) - by CMG (computation modeling group). Used for:
  - CO2 capture and storage (CCS)
  - CO2 enhanced oil recovery
Geological grid → Reservoir flow simulation cell → Seismic grid

Petrel modeling: porosity, permeability → Input top maps and thickness isopachs, porosity and permeability from the petrel model → In each grid cell: fluid properties

Vp, Vs, density calculation via Gassmann’s Equation → Calculate reflectivity at zero offset

Depth-time conversion: Time-Depth table from well log → 1D forward modeling: convolutional model → Upscale to seismic bin size (x and y direction)

Calibration

Log scale → reservoir scale → seismic scale
Background

• Study area: Dickman Field, Kansas

• Geology: carbonate build-ups, karst feature

• Two CO₂ capture and storage targets
  • Deep Saline Aquifer - primary
  • Shallower depleted oil reservoir - secondary
Dickman Field

Location: Ness County
Kansas State

Field Site

- 3D Seismic
  - 3.325 sq.mi.
- 142 wells
  - 54 in 3D area
  - 45 with digital logs
    - GR (43), Resistivity (25), Neutron (27), P-Sonic (6), Density (3), S-Sonic (1)
    - 7 with core
      - porosity and permeability
    - 3 full deep saline aquifer penetration

Channel

Disc. 1962  Cumm: 1.7 MMBO
CO2 Properties

• Reservoir conditions at Dickman Field:
  Temperature: 31.7-48.8339°C
  Pressure: 8.53~16.25 mpa

• CO2: Supercritical fluid beyond dynamic critical point:
  (T>31.1°C & P >7.38 MP, Density: >0.469 g/cm³)

  - Gas phase
  - Liquid phase

(Han et al., 2010)
### Flow Simulation Grid

NX=33 dx=500ft; NY=31 dy=500ft; NZ=32, dz: variable

<table>
<thead>
<tr>
<th>Sim Layer No.</th>
<th>VerticalPerm</th>
<th>Porosity(%)</th>
<th>Formation Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>10 md</td>
<td>18.2</td>
<td>Shallow Reservoir layers</td>
</tr>
<tr>
<td>7-8</td>
<td>0.01 md</td>
<td>20.0</td>
<td>Two Seal Layers</td>
</tr>
<tr>
<td>9-10</td>
<td>0.7 Horizontal Perm</td>
<td>10.3</td>
<td>Ford Scott Limestone</td>
</tr>
<tr>
<td>11-13</td>
<td>0.5 Horizontal Perm</td>
<td>19.1</td>
<td>Cherokee</td>
</tr>
<tr>
<td>14-15</td>
<td>0.5 Horizontal Perm</td>
<td>16.5</td>
<td>Lower Cherokee</td>
</tr>
<tr>
<td>16</td>
<td>0.7 Horizontal Perm</td>
<td>14.8</td>
<td>Mississippian Unconformity</td>
</tr>
<tr>
<td>17-20</td>
<td>0.7 Horizontal Perm</td>
<td>20.0</td>
<td>Mississippian Porous Carbonate</td>
</tr>
<tr>
<td>25-32</td>
<td>0.7 Horizontal Perm</td>
<td>22.45</td>
<td>Mississippian Osage and Gillmor City</td>
</tr>
</tbody>
</table>
CO2 monitoring

Scenario: CO2 is injected for 50 yrs, then the injection well is shut in and flow modeling continues for 150 yrs

Input:
• Fluid simulation results for 150 yrs: (2002’-2155’)
  grid cells: 33(x)*31(y)*32(z)
  dx=500ft, dy=500ft, dz: variable
  fluid properties data (porosity, CO2 saturation, etc.)

Output:
• Seismic simulation for 150yrs
  - implemented by MATLAB: binary file
  - Seismic Unix: headers correctly added and sorted and interpolated into the field seismic data bin size(82.5ft x 82.5ft)

• Comparison of seismic response due to CO2 injection (between year 2002’ and 2155’)
Figure 1. CO2 saturation for simulation layers from 1 through 16 for years 2002 (L) and 2155 (R). Two seismic lines (inline 86 and crossline 98) in sim layer 9 have been pulled out for comparison.
Figure 3a. Seismic data (inline86) at the different simulation time (2002′ and 2155′) and the difference. Displayed from 500ms to 800ms. It caused 4% impedance change.
Seismic Data Xline 98 (Yr 2002’ and 2155’) and Difference

Figure 3b. Seismic data (crossline 98) at the different simulation time (2002’ and 2155’) and the difference. Displayed from 500ms to 800ms.
Future Work

• To perform a full wave forward modeling to obtain more realistic result

• A smoother and better-defined porosity distribution may help improve the seismic data quality
Acknowledgement

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• Po Geng (Flow simulation)
• June Zeng (Geologist)
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  • Qiong Wu
  • Shannon Leblanc
  • Johnny Seals
  • Tim Brown
  • Eric Swanson
END
Extra slides
Geology Model

Petrel modeling:

- faults interpretation \textit{constrained} by seismic volume attributes
- \textit{up-scaled} log porosity based on lithozones
- relationship between:
  1) core porosity and log porosity
  2) core porosity and permeability
  3) seismic impedance and neutron porosity

Guiding propagation of permeability in property modeling

(Zeng, 2009)
CO₂ Storage

- T=121F & P=2200 psi:
  Density=0.7 ton/m³
Brine solubility= 64 ton per acre-ft
- Porosity=0.2, Sw=20%, CO₂ trapped in 1 acre-ft:
  $1233(\text{m}^3 \text{ per acre-ft}) \times 0.2 \times (1-0.2) \times 0.7 \text{ ton/m}^3 = 140 \text{ tons}$
Dickman Field

Acreage = 240 acres

Net Pay Zone Thickness = 7 feet

Average depth = 4424 feet in MD

Oil API gravity = 37 API (0.84 g/cm³)

The reservoir average temperature = 113 °F

The reservoir average pressure = 2066 psi

TDS (Total Dissolved Solid) salinity = 45,000 ppm
CO$_2$ Safe Storage

- Trapping Mechanisms
  - Structural trapping
  - Solubility trapping (CO$_2$ highly soluble in brine)
  - Residual gas trapping (immobile gas in porous media)
  - Mineral trapping (chemical changes)

(Geng, 2009)
Flow Simulation Model

Acquifer model (from top to base)

1. Fort Scott Limestone → CO$_2$ storage target
2. Cherokee Group
3. Lower Cherokee Sandstone
4. Mississippian Carbonate → CO$_2$ storage target
5. Lower Mississippian Carbonate
Figure 2. Vertical sections related to inline 86 for year 2155.

(a) Porosity distribution.  (b) CO2 saturation
Discussion

After CO2 being injected for 150yrs, at the location where has the highest change for CO2 saturation:

$\text{Sc}O_2$ change: 0% ~ 42%
Impedance change: 4%
Reflection coefficient change: 41% (non-linear)