Using Multi Scale Seismic Measurements for CO₂ Monitoring in CCUS/EOR Project - Farnsworth

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Outline

- Southwest Regional Partnership (SWP)
- Project Goals
- Project Site
- Target Reservoir
- Farnsworth Seismic Program
  - 3D surface seismic
  - 3D vertical seismic profile (VSP)
  - Cross-well seismic
- Discussion
Southwest Regional Partnership (SWP)

- SWP is one of seven Regional Carbon Sequestration Partnerships.
- Established in 2003 by the US Department of Energy.
- The SWP’s Phase III project is a large-scale EOR-CCUS test.
- The SWP has been charged with:
  - Determining the best geologic and terrestrial storage approaches for its region.
  - Demonstrating technologies to safely and permanently store CO$_2$. 
Project’s Goals

- Main goal is to study the feasibility of capturing and permanently storing carbon dioxide (CO$_2$) in the deep subsurface.

- Blueprint for CCUS in southwestern United States.

- General Goals:
  - One million metric tons CO$_2$ storage,
  - Optimization of storage engineering,
  - Optimization of monitoring design,
  - Optimization of risk assessment.
500,00 to 600,000 tonnes of anthropogenic CO$_2$ supplied per year
The Farnsworth EOR target is the Morrow Formation,

- An incised valley-fill sandstone,

- Extends from eastern Colorado and western Kansas through Oklahoma and into the Texas panhandle,

- Morrow B is a thin sandstone that is challenging to image.
Morrow B reservoir (Modified from Ball et al., 1991).
Farnsworth Seismic Program

- 3D high resolution surface seismic – ~ 42 miles$^2$ (67.6 km$^2$) in 2013

- 3D Vertical Seismic profile (VSP):
  - Two pre injection baseline surveys acquired simultaneously – 2014
  - One monitor (time-lapse), post injection of CO$_2$ ~30,000 metric tons, one baseline – 2015. Another monitor post injection of ~80,000 metric tons in 2016

- Cross Well Seismic:
  - Three baseline pre injection – 2014
  - Two monitors (time-lapse) post injection, one baseline – 2015

- Micro-seismic monitoring – not covered in this presentation
Seismic Program

Detailed in SPE 180408
3D High Resolution Surface Seismic – Acquisition

- 42.192 miles$^2$ (67.6 km$^2$) – acquired in January 2013

- Acquisition parameters:
  - Source:
    - Vibroseis
    - Source interval: 165 feet (50.3 m)
    - Source line interval: 1320 feet (402.34 m) – East/West
    - Vibroseis sweep: 2 sweeps. 2 Hz – 100 Hz (non linear)
  - Receiver:
    - Point receiver – accelerometers
    - Receiver interval: 33 feet (10.06 m)
    - Receiver line interval: 825 feet (251.5 m) – North/South
Source and Receiver Locations – Fold
3D High Resolution Surface Seismic – Processing

● Objectives:
  — Produce a 3D Seismic volume that is controlled amplitude suitable for post image reservoir characterization.
  — Produce a 3D seismic volume that is suitable for interpretation work.

● Challenges:
  — Noise (wind).
  — Statics – Near surface varies from east to west of survey area.
  — First break picking – to derive statics solution.
Field Statics Vs. Refraction Statics
Time Imaging Vs. Depth imaging
3D VSP – Acquisition

- Ray trace modeling survey design for baseline surveys.
- Baseline surveys for two wells were acquired simultaneously reducing turnaround time and cost, as well as number of sources (from 5,000 to 2,900).
- Source locations from baseline survey for one of the wells were repeated for the two monitor surveys, same downhole tool and source parameters.

Acquisition parameters:
- **Source:**
  - Vibroseis
  - Source interval: 200 feet (60.96 meters)
  - Source line interval: 200 feet (60.96 meters)
  - Vibroseis sweep: 3 sweeps. 2 Hz – 100 Hz (non linear)
- **Receiver:**
  - 40 level three-component geophones
  - Receiver interval: 50 feet (15.24 meters)
Ray Tracing Modeling Survey Design
3D Vertical Seismic Profile – Processing

Objectives:
● Produce a 3D Seismic volume that is controlled amplitude suitable for post image reservoir characterization and analysis
● Produce a 3D seismic volume to integrate with the other measurements. Velocity model was used to calibrate near surface depth velocity model for the 3D surface seismic

Challenges:
● Repeatability – ground conditions, new infrastructure
3D VSP Source Gathers

EW

NS

Vertical
Time Lapse Analyses
Cross Correlation – Overburden Vs. Reservoir

Baseline – Monitor2
Predictability – Overburden Vs. Reservoir

Baseline – Monitor2
NRMS – Overburden Vs. Reservoir

Baseline – Monitor2
Displacement field - 7800 ft, 8110 ft, 8200 ft.

Baseline – Monitor2
Cross Well Seismic - Acquisition

- Orthogonal dipoles downhole vibrating source
- High cost – stop operations
- Acquisition parameters:
  - Source:
    - Orthogonal dipoles vibroseis
    - Source interval: 5 feet (1.5 m)
    - Vibroseis sweep: 30 Hz – 600 Hz
  - Receiver:
    - 40 level three-component geophones
    - Receiver interval: 5 feet (1.5 m)
Cross Well Seismic - Acquisition
Cross Well Seismic – Processing

Objectives:

● Produce high resolution subsurface image to be integrated with other seismic measurements

Challenges:

● Repeatability
Monitor Survey Composite Image
Extracted Seismic Attribute, Shuey amplitude versus offset term (vertical cross sections) and eXchromaSG* chromatic geology extraction software attributes (projected on sub-Morrow depth horizon).
Integrated Cross-Section

Top Morrow B
Multi-scale seismic measurements with varying vertical and lateral resolution can play an important role in site characterization and CO₂ plume monitoring in a CCS or for CCUS/EOR projects.

Integrating the measurement could help to produce an accurate velocity model and reduce uncertainty in structural interpretation.

Extensive survey evaluation and design was beneficial in acquiring the required data to properly image the subsurface at the target reservoir.

Field testing is recommended for choosing acquisition parameters that will achieve the projects goals.

Experience gained from the Farnsworth Project could potentially serve as a guide to reduce operational cost of monitoring programs for future CCS/CCUS/EOR projects.