Using 3D Vertical Seismic Profile to Monitor the CO_2 Plume in a CCUS/EOR Project

George El-kaseeh, Xinyuan Li, Gabriel Velasquez, Robert Balch

Schlumberger Carbon Services

Abstract

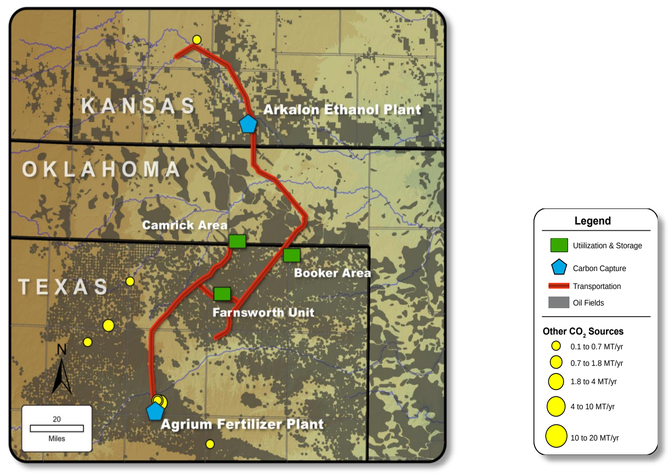
An extensive geophysical program was conducted in the in the Anadarko Basin in Ochiltree county, Texas, partnering with the Southwest Regional Partnership on Carbon Sequestration (SWP) and Chaparral Energy, LLC (CELLC). Implementation of a cost-effective approach includes a combination of 3D surface seismic, 3D vertical seismic profiles (VSPs), as well as cross-well seismic surveying. The program's aim is to utilize geophysical methods with varying imaging scales for site characterization and time-lapse monitoring of CO_2 plume movement.

Two baseline 3D VSP surveys for two wells were acquired simultaneously in 2014, and a third one in 2015. Two monitor (time-lapse) surveys for one of the wells were acquired, January 2015 (~30,000 tons of CO_2 injected), and November 2016 (~80,000 tons CO_2 injected). Ray tracing based survey evaluation and design (SED) was performed to optimize acquisition parameters, reduce acquisition cost and minimize production downtime. Data from baseline and monitor surveys were processed simultaneously and time-lapse analyses were performed to identify potential 4D effect caused by the injection and presence of CO_2 in the reservoir.

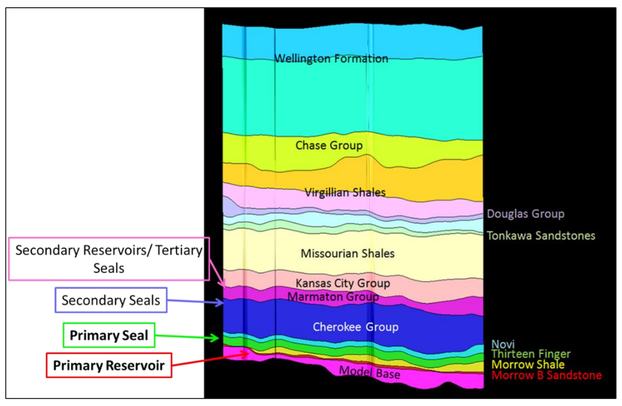
Three time lapse analyses approaches were implemented, and are illustrated in this poster:

1. Amplitude analysis: Cross Correlations, Predictability and Normalized Root Mean Square (NRMS) attributes were generated
2. Displacement Field computation: Using Non Rigid Matching (NRM) to quantify depth shifts as an indicator of travel-time differences caused by fluid replacement within the injection zone
3. Z-Tomography update: Use baseline velocity model as input for Z-Tomography update to quantify the difference in P velocity (delta Vp) as an indicator of fluid replacement

Project Site and Target Reservoir

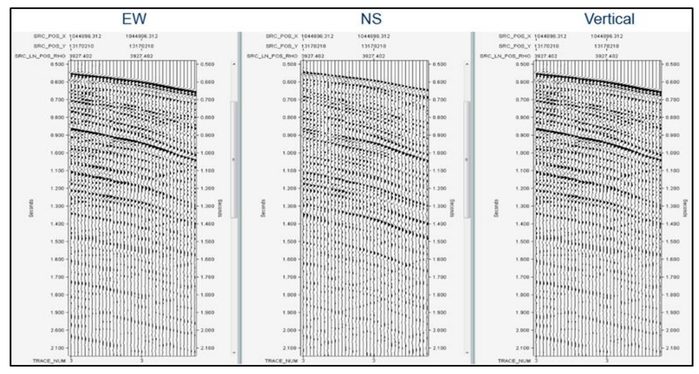


500,00 to 600,000 tonnes of anthropogenic CO_2 supplied per year

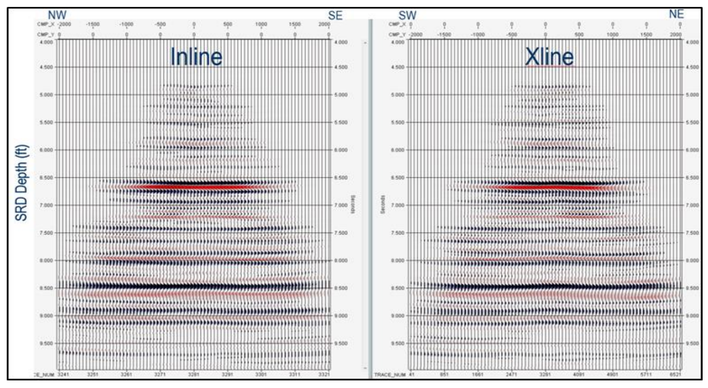


The reservoir, caprock, and overlying formations at the Farnsworth Unit (FWU)

Data Processing



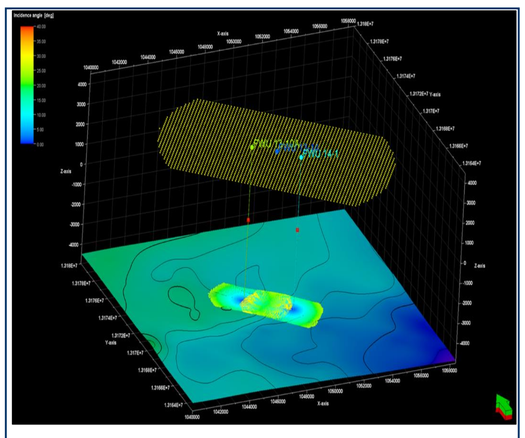
3D VSP Source Gathers (three components).



3D VSP imaged data

Baseline, monitor 1 and monitor 2 were simultaneously processed, using the same processing sequence. This approach reduced uncertainty in analyses of time lapse attributes

Survey Evaluation, Design, and Acquisition



Ray tracing based SED, Hit Count map at Target (Morrow B). Baseline surveys for two wells were acquired simultaneously reducing turnaround time and cost, as well as number of source points (from 5,000 to 2,900)..

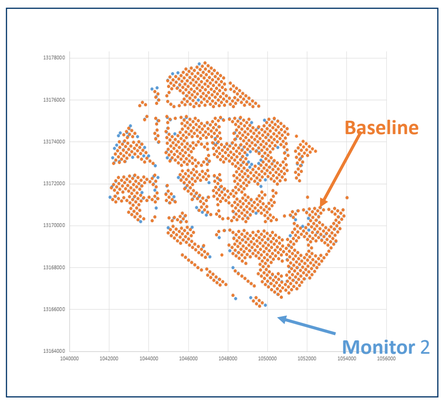
Acquisition Parameters

3D VSP Source Parameters.

Source	
Type	Vibroseis
Source Point Interval	60.1 meters (200 feet)
Source Line Interval	60.1 meters (200 feet)
Sweep	3 sweeps. 2 Hz – 100 Hz (nonlinear)

3D VSP Receiver Parameters.

Receivers	
Type	40 level three component geophones
Receiver Interval	15 meters (50 feet)



Acquisition parameters were determined based on analysis of the results from the survey evaluation and design study.. Optimal survey planning was determined based on existing infrastructure and accessibility within the survey area. To ensure repeatability and reduced uncertainty in time lapse analysis, source locations from baseline survey for one of the wells were repeated for the two monitor surveys, same downhole tool and source parameters. At the early stages of processing, co-located sources from the three surveys were selected for subsequent processing

Time-lapse Analysis

Predictability

- A measure of similarity or coherence between two traces (0-100)
- Autocorrelation for baseline and repeat Acor1(t) and Acor2(t)
- Cross correlation between baseline and repeat Xcor(t)

$$\text{Predictability} = \frac{\sum Xcor(t)^2 * 100}{\sum (Acor1(t) * Acor2(t))}$$

Normalized RMS

- A measure of difference between two traces (0-200)

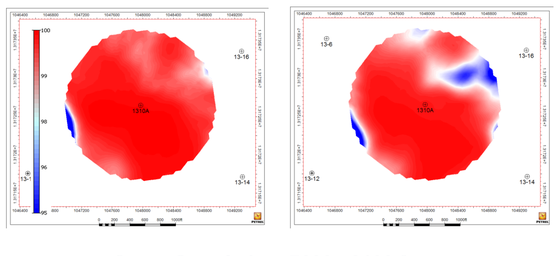
$$\text{NRMS}\% = \frac{100 * \sqrt{\frac{\sum (X1(t) - X2(t))^2}{n}}}{\frac{\sqrt{\sum X1(t)^2}}{n} + \frac{\sqrt{\sum (X2(t)^2}}{n}}{2}$$

Several time-lapse attributes were generated to evaluate any time-lapse signature that might be caused the presence of injected CO_2 in Morrow B. Cross correlation, predictability and NRMS are qualitative attributes and are amplitude sensitive. Displacement field computed using non rigid matching (NRM) and Z tomography update (Delta V) are quantitative attributes and are velocity sensitive.

Time-lapse Analysis

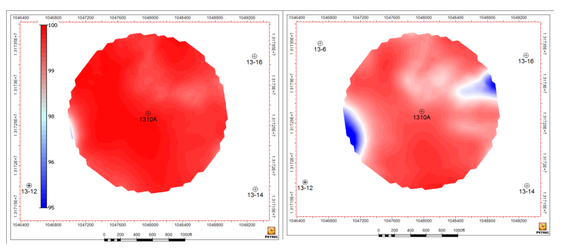
Cross Correlation: 7100 - 7600 ft.

Baseline – Monitor1 | Baseline – Monitor2



Cross Correlation: 7600 - 8100 ft.

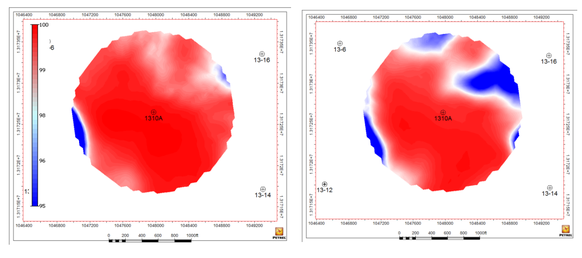
Baseline – Monitor1 | Baseline – Monitor2



Cross Correlation Attribute

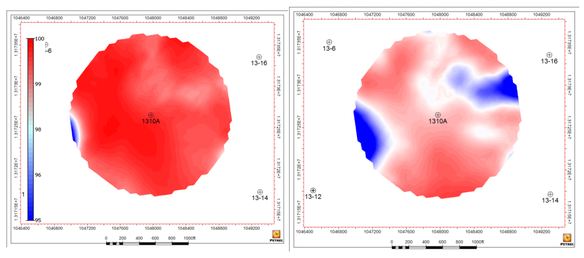
Predictability: 7100 - 7600 ft.

Baseline – Monitor1 | Baseline – Monitor2



Predictability: 7600 - 8100 ft.

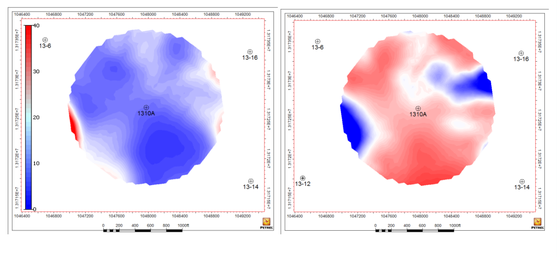
Baseline – Monitor1 | Baseline – Monitor2



Predictability Attribute

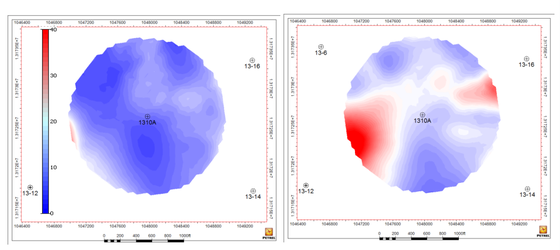
NRMS: 7100 - 7600 ft.

Baseline – Monitor1 | Baseline – Monitor2



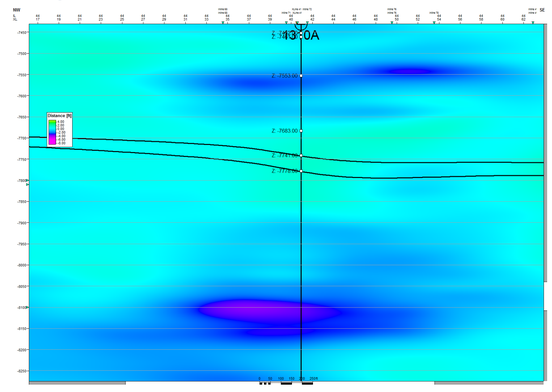
NRMS: 7600 - 8100 ft.

Baseline – Monitor1 | Baseline – Monitor2

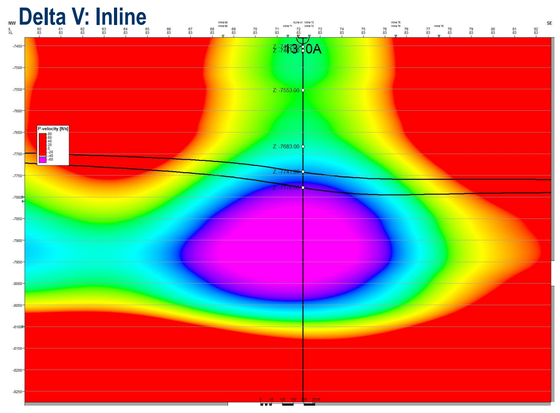


NRMS Attribute

Displacement Field: Inline



Delta V: Inline

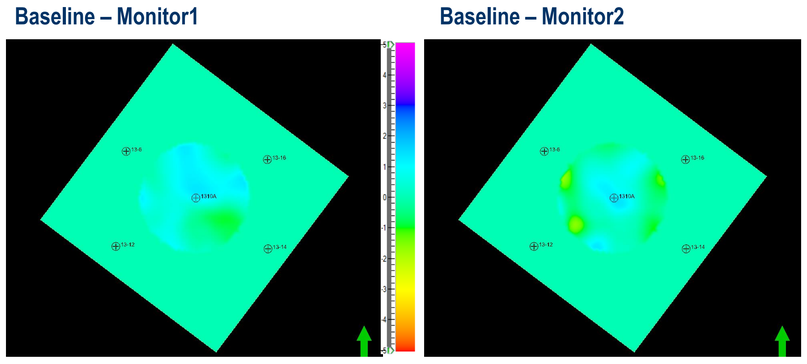


Z Tomography update

Displacement Field

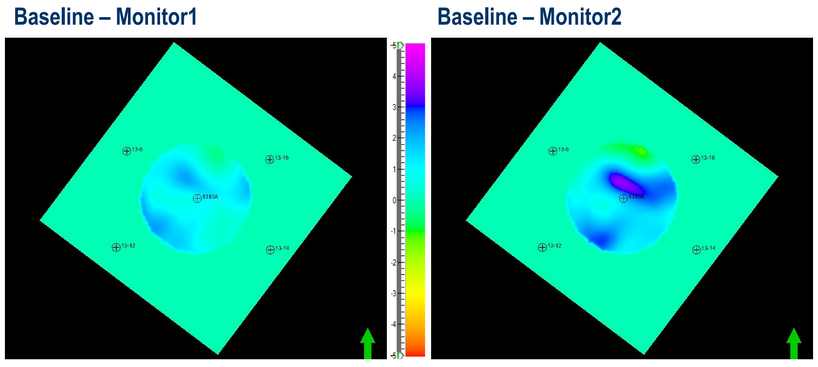
7500 ft.

Baseline – Monitor1 | Baseline – Monitor2



8100 ft.

Baseline – Monitor1 | Baseline – Monitor2



DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

SWP

NATIONAL ENERGY TECHNOLOGY LABORATORY

Chaparral ENERGY