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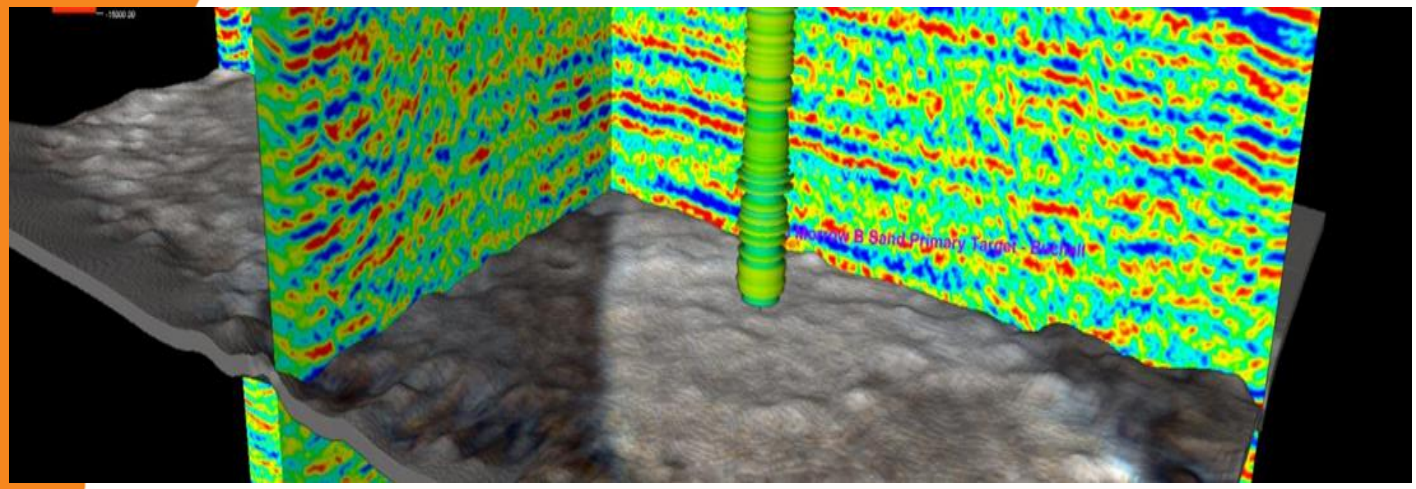

Using Multi Scale Seismic Measurements for CO_2 Monitoring in CCUS/EOR Project - Farnsworth

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5 October 2017

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Acknowledgement

Funding for this project is provided by the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) through the Southwest Regional Partnership on Carbon Sequestration (SWP) under Award No. DE-FC26-05NT42591. Additional support has been provided by site operator Chaparral Energy, L.L.C. and Schlumberger Carbon Services.

Outline

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- 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)

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- 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

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- 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.

Project Site

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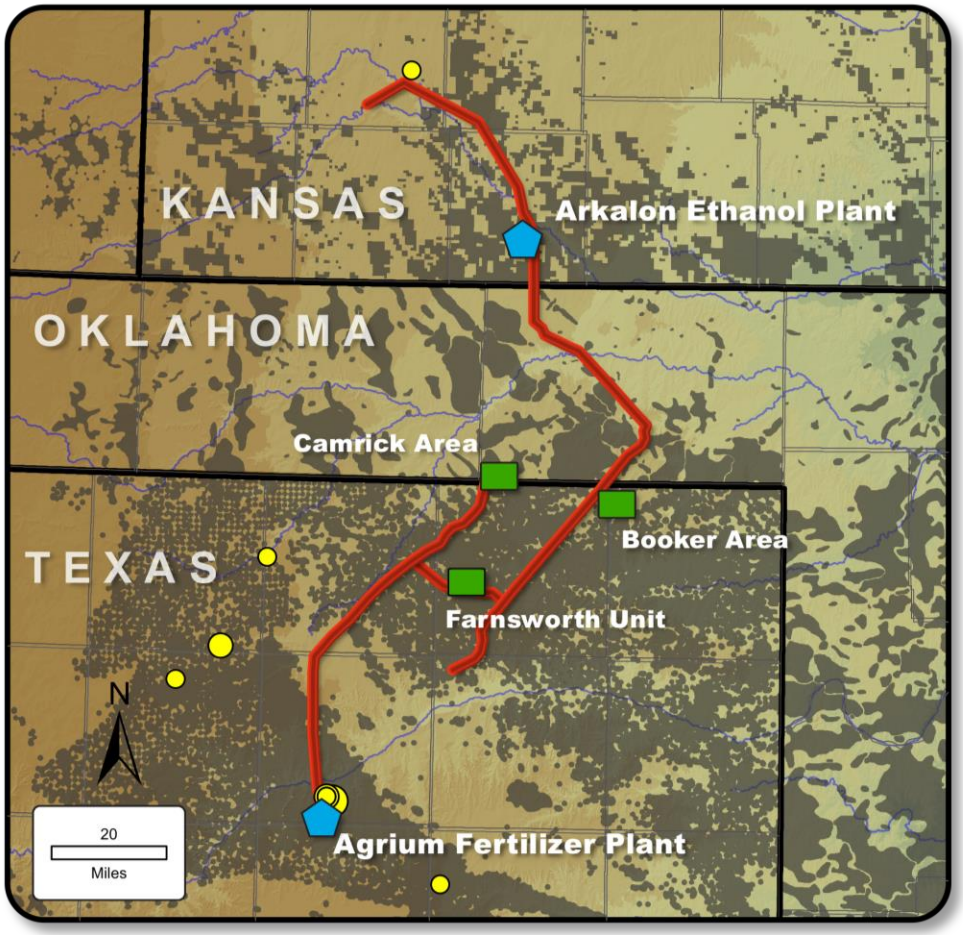
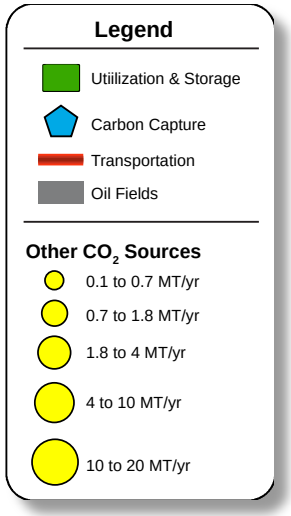
- 500,00 to 600,000 tonnes of anthropogenic CO_2 supplied per year





Target Reservoir

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- 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

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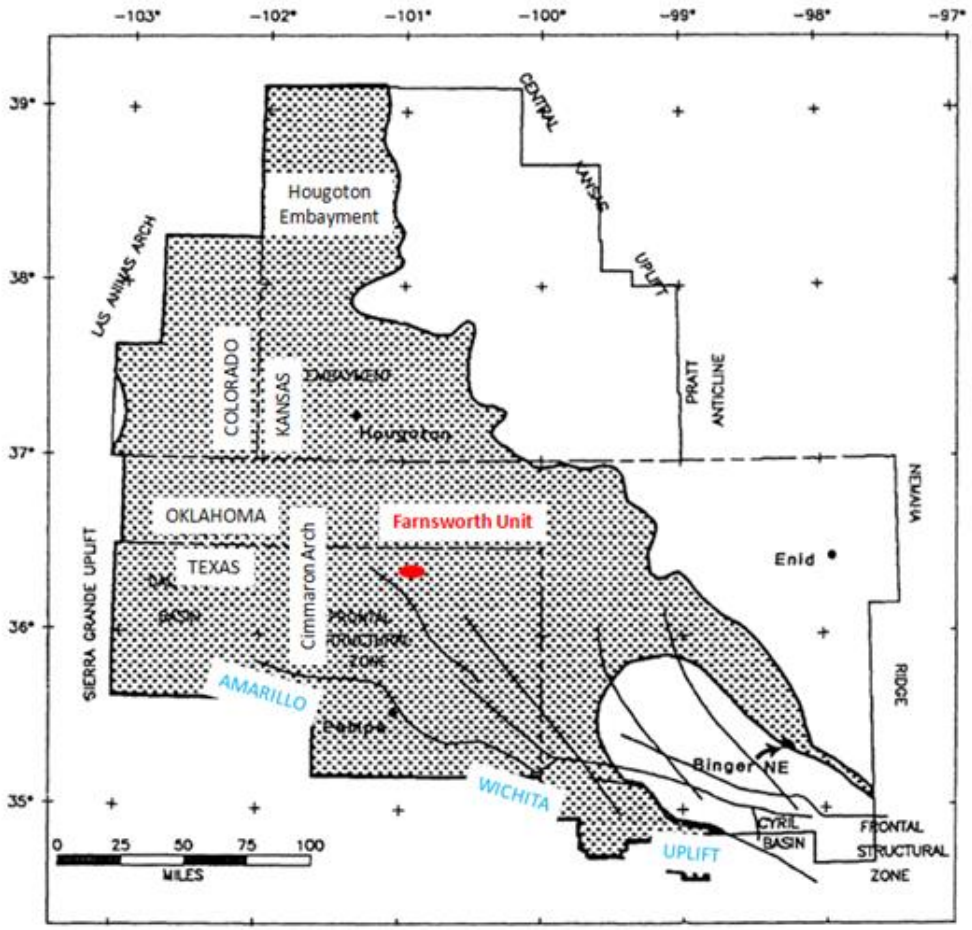

Morrow B reservoir (Modified from Ball et al., 1991).

Farnsworth Seismic Program

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- 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

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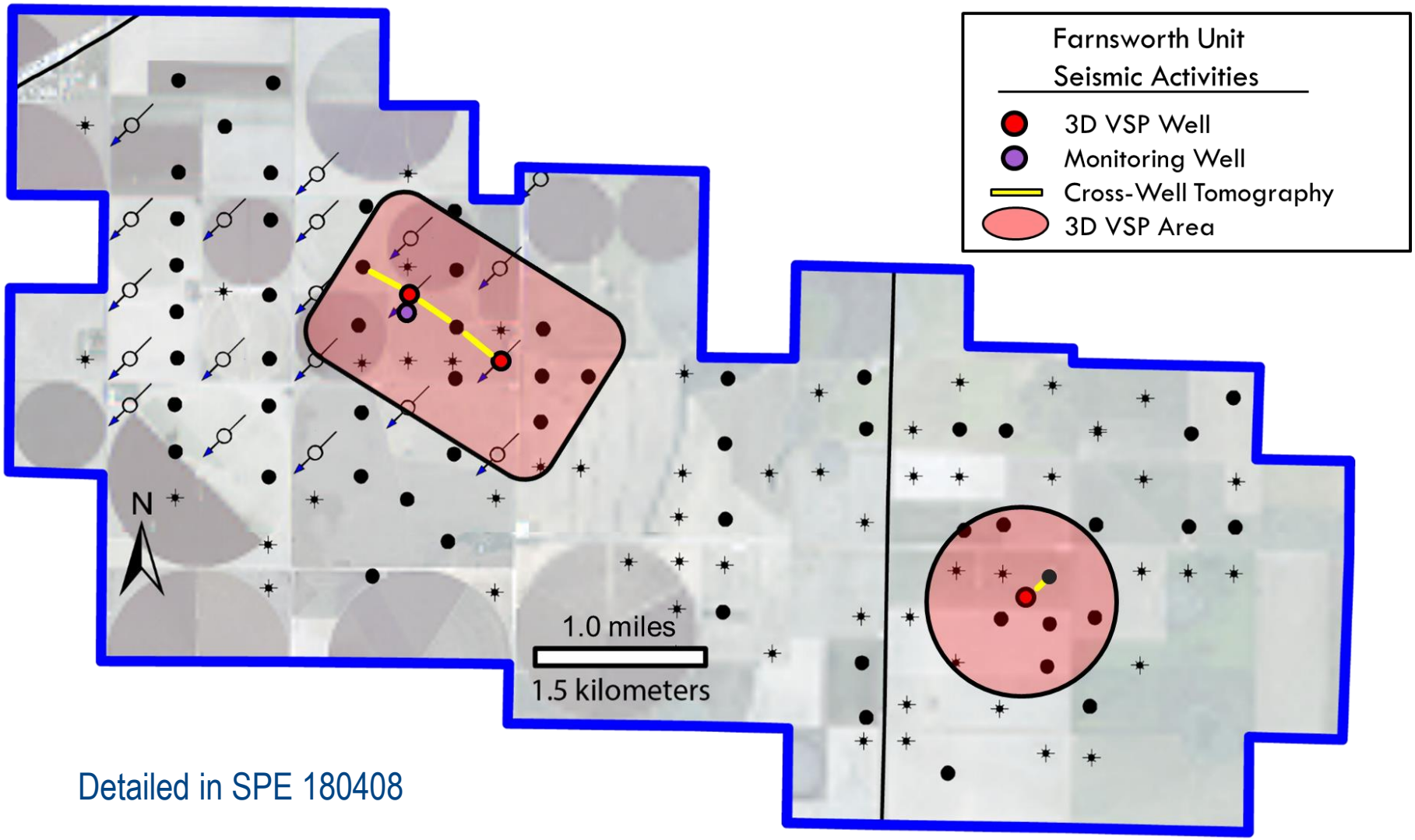

Detailed in SPE 180408

3D High Resolution Surface Seismic – Acquisition

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- 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

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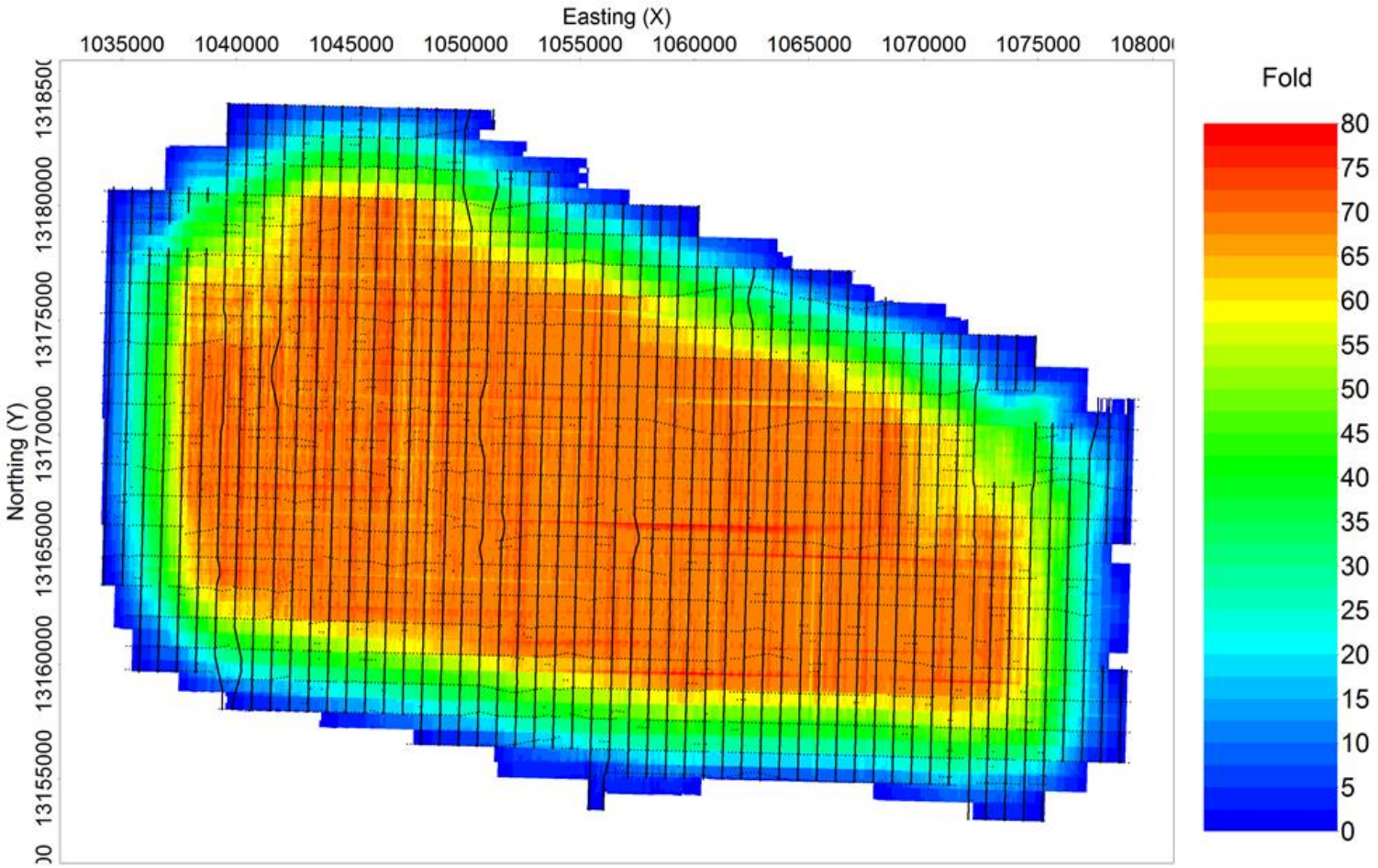

3D High Resolution Surface Seismic – Processing

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- **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

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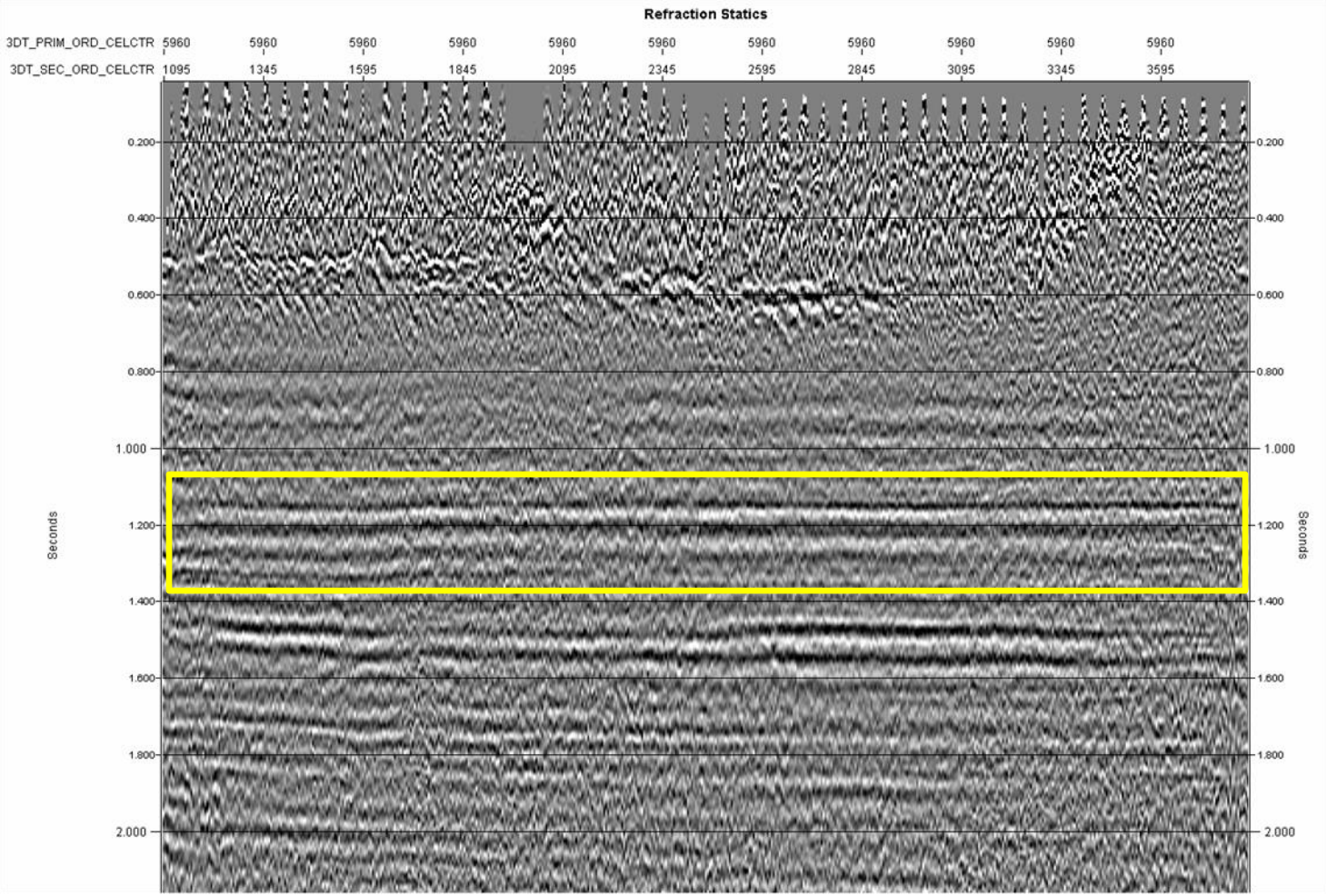

Time Imaging Vs. Depth imaging

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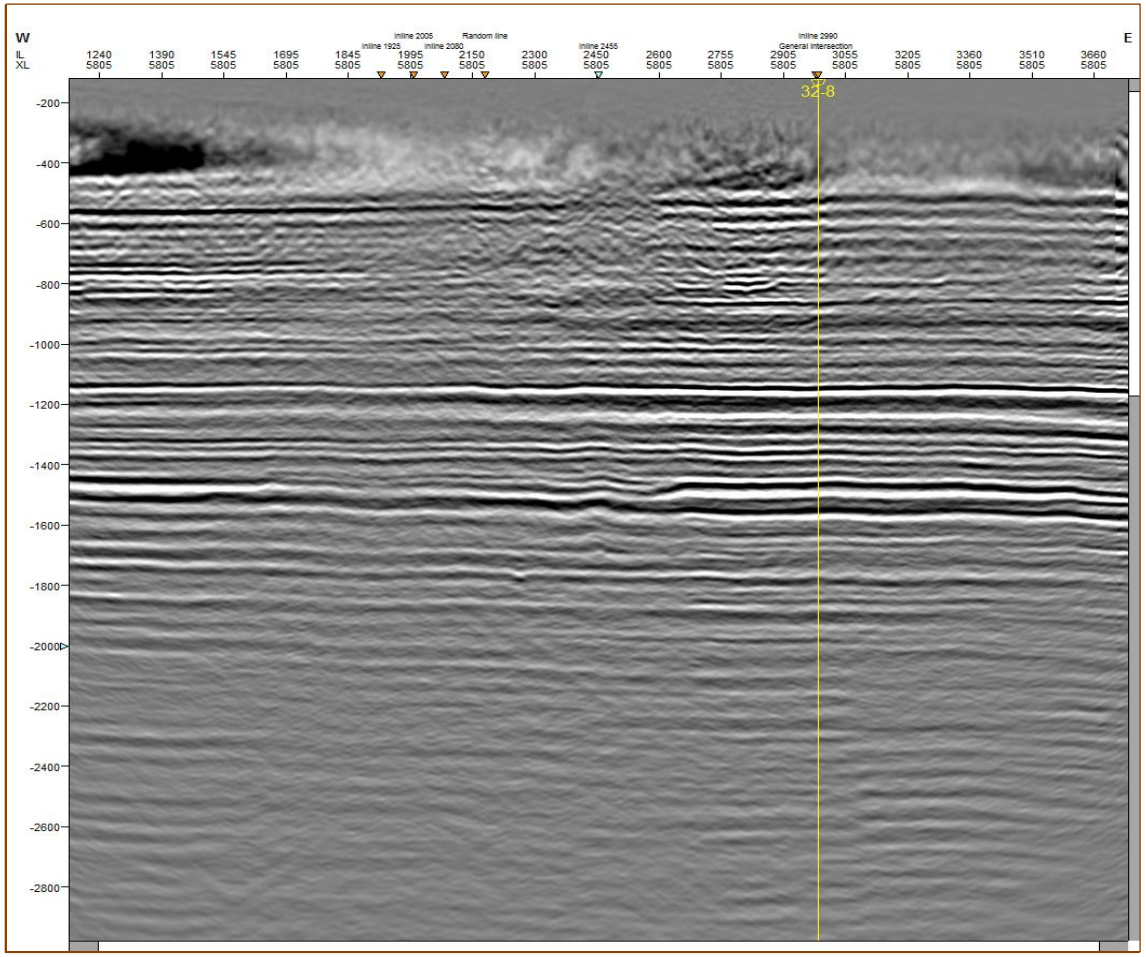

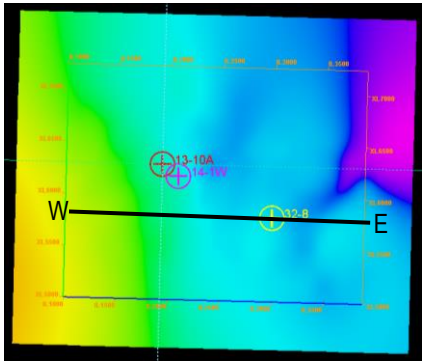

3D VSP – Acquisition

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- 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

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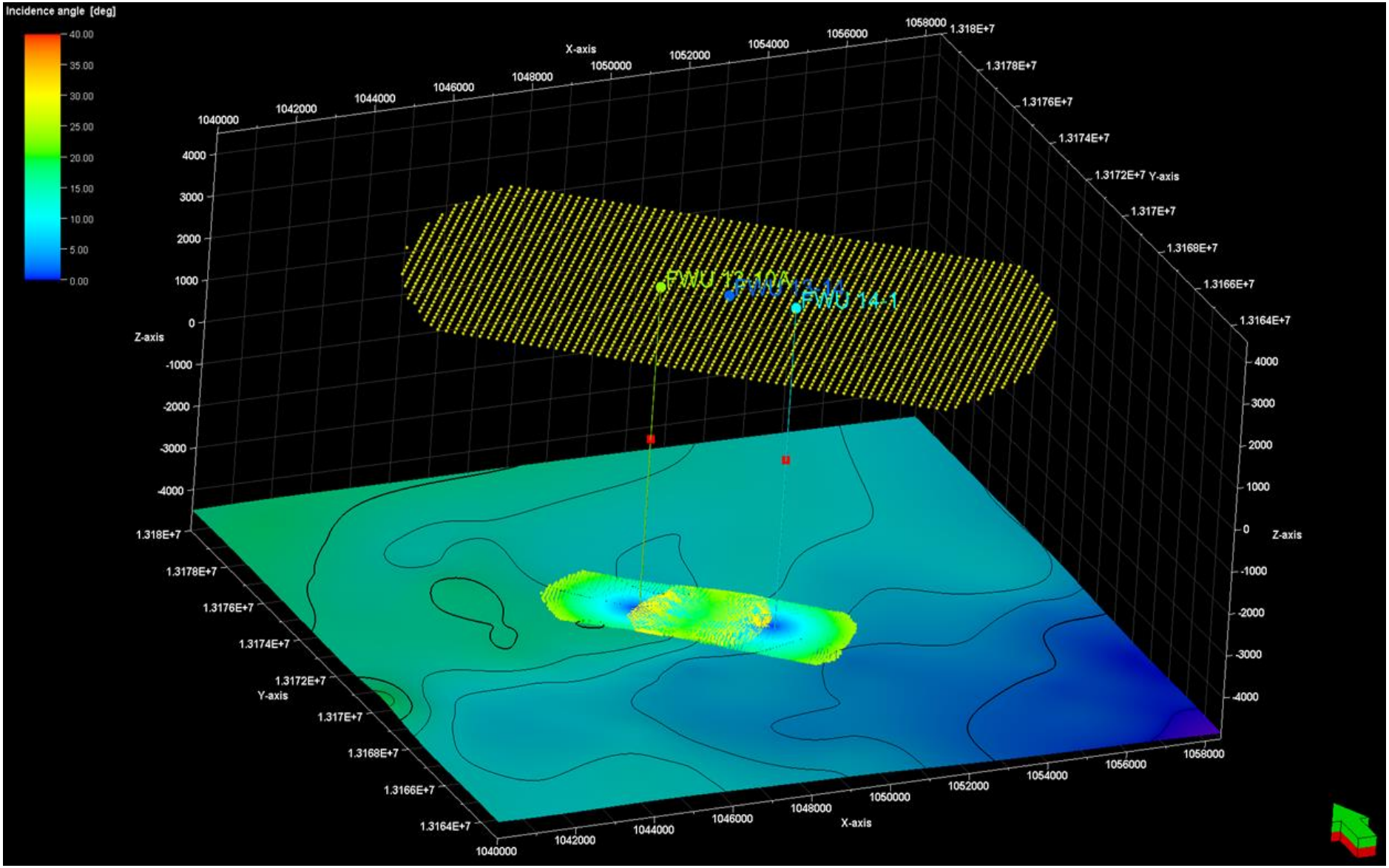

3D Vertical Seismic Profile – Processing

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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

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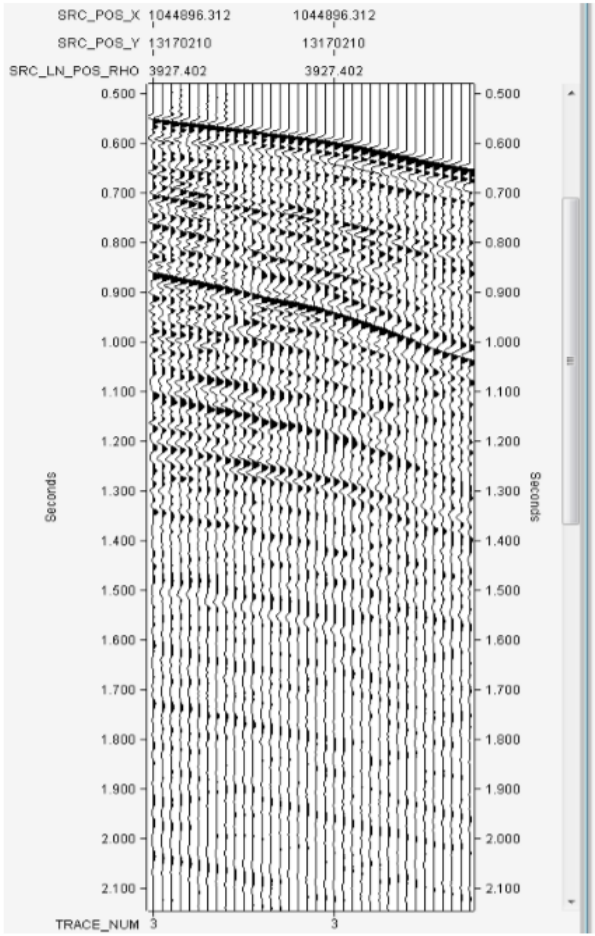
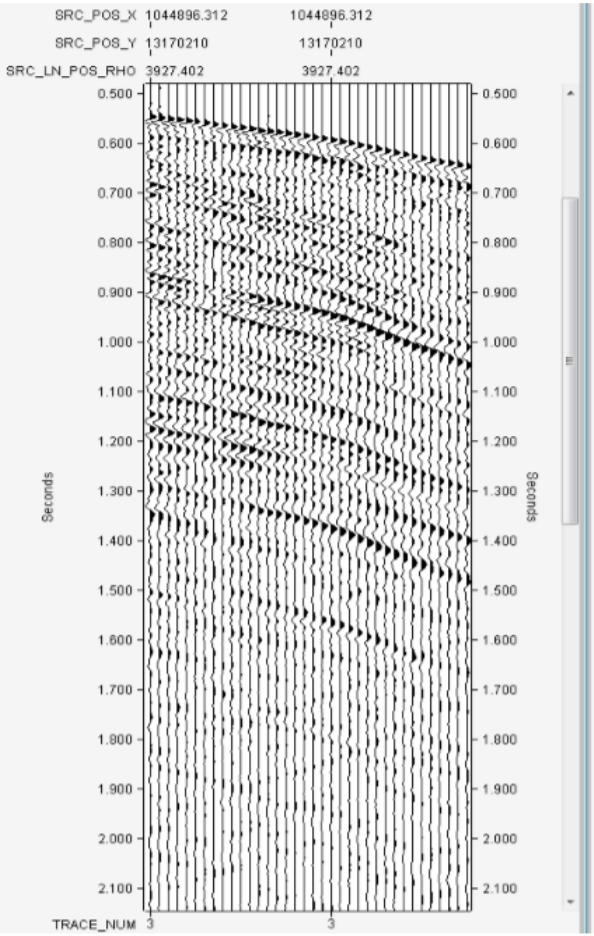
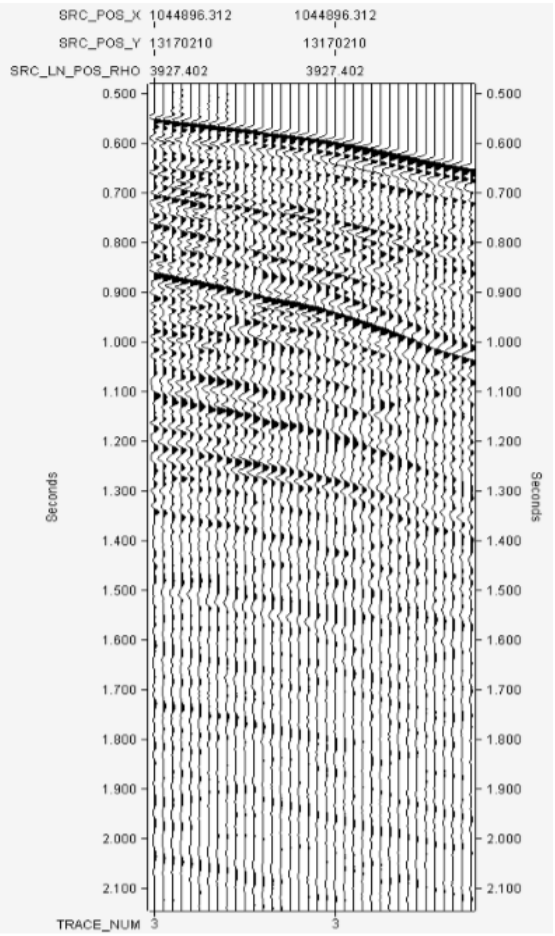
EW



NS



Vertical



Time Lapse Analyses

Cross Correlation – Overburden Vs. Reservoir

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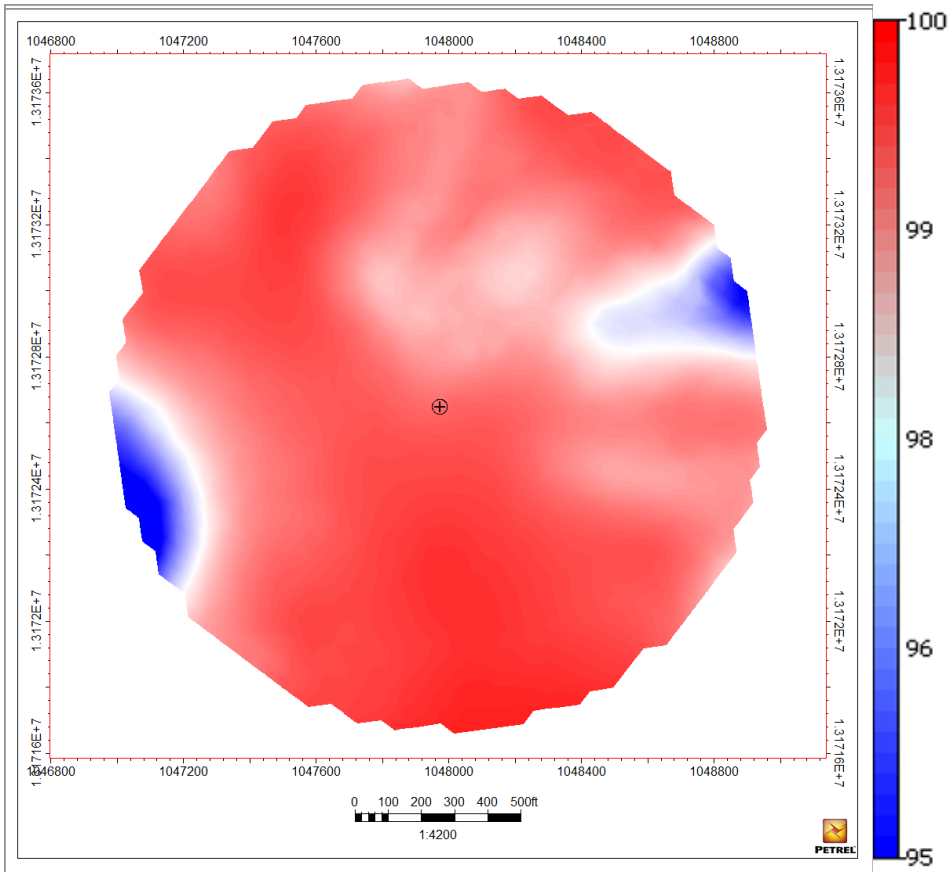
Baseline – Monitor2



Predictability – Overburden Vs. Reservoir

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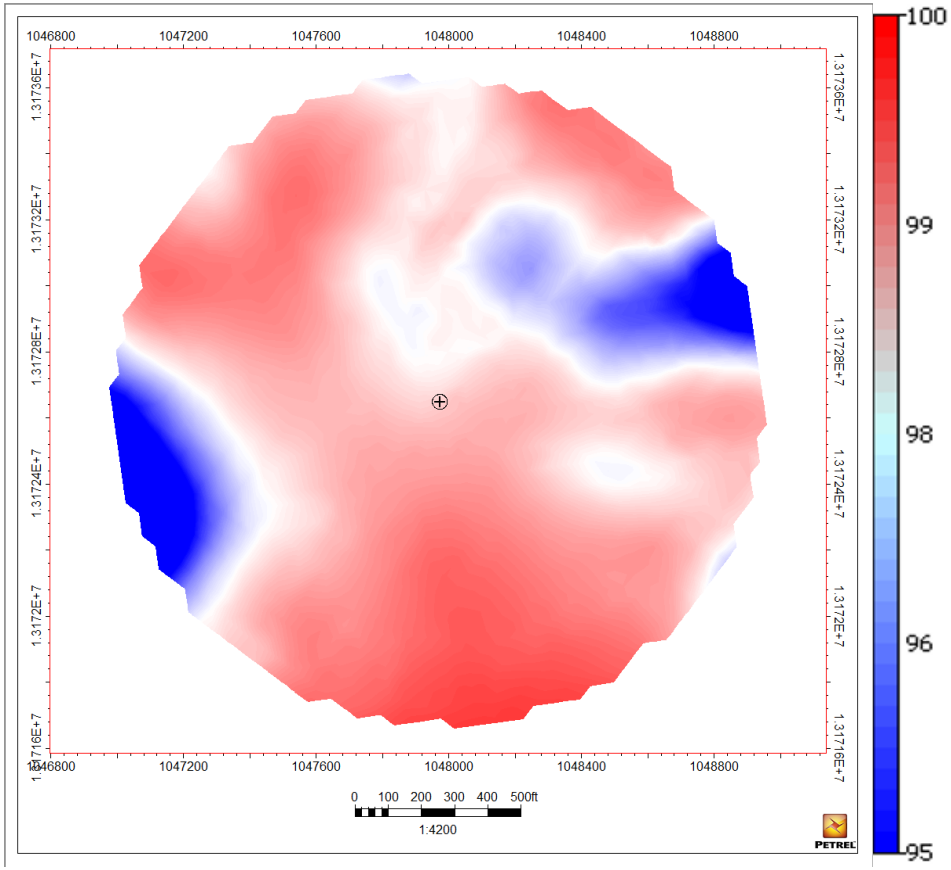
Baseline – Monitor2



NRMS – Overburden Vs. Reservoir

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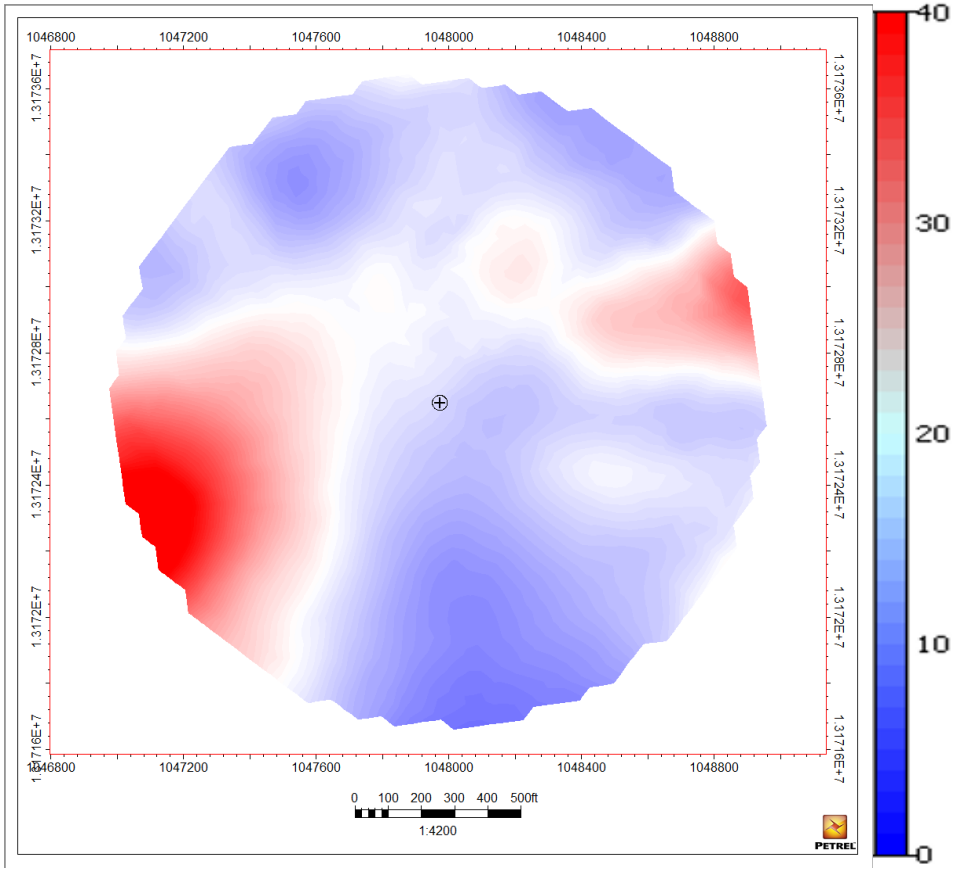
Baseline – Monitor2



Displacement field - 7800 ft, 8110 ft, 8200 ft.

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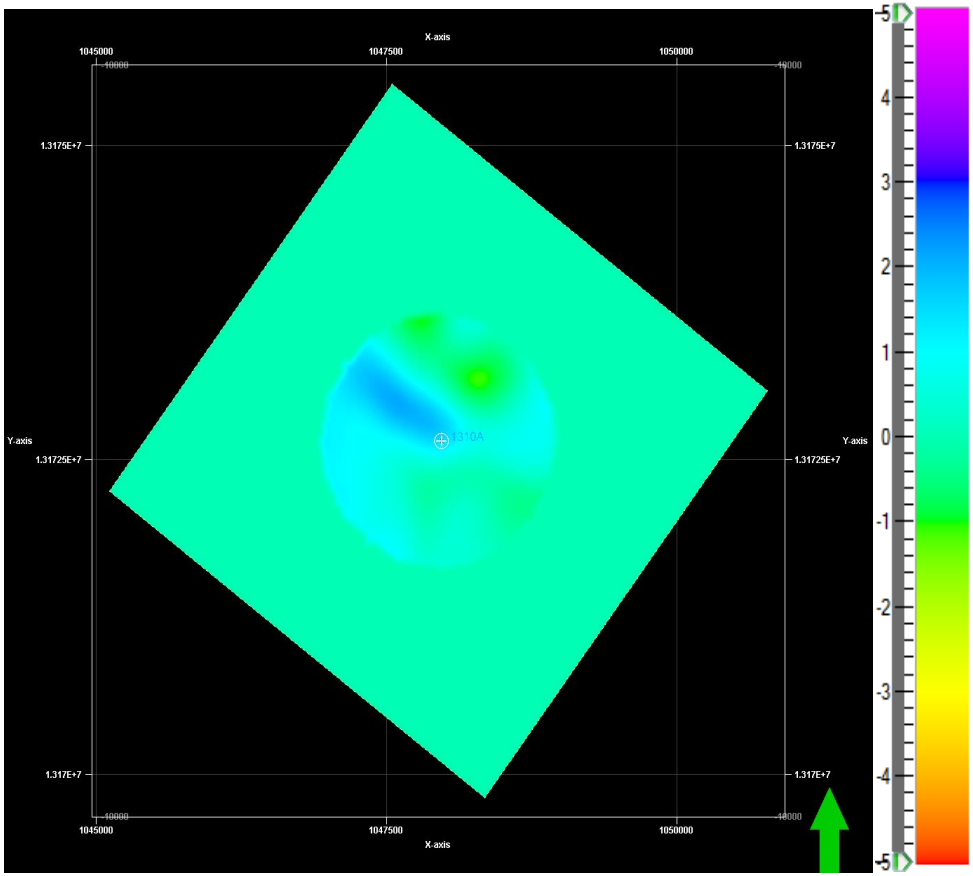
Baseline – Monitor2



Cross Well Seismic - Acquisition

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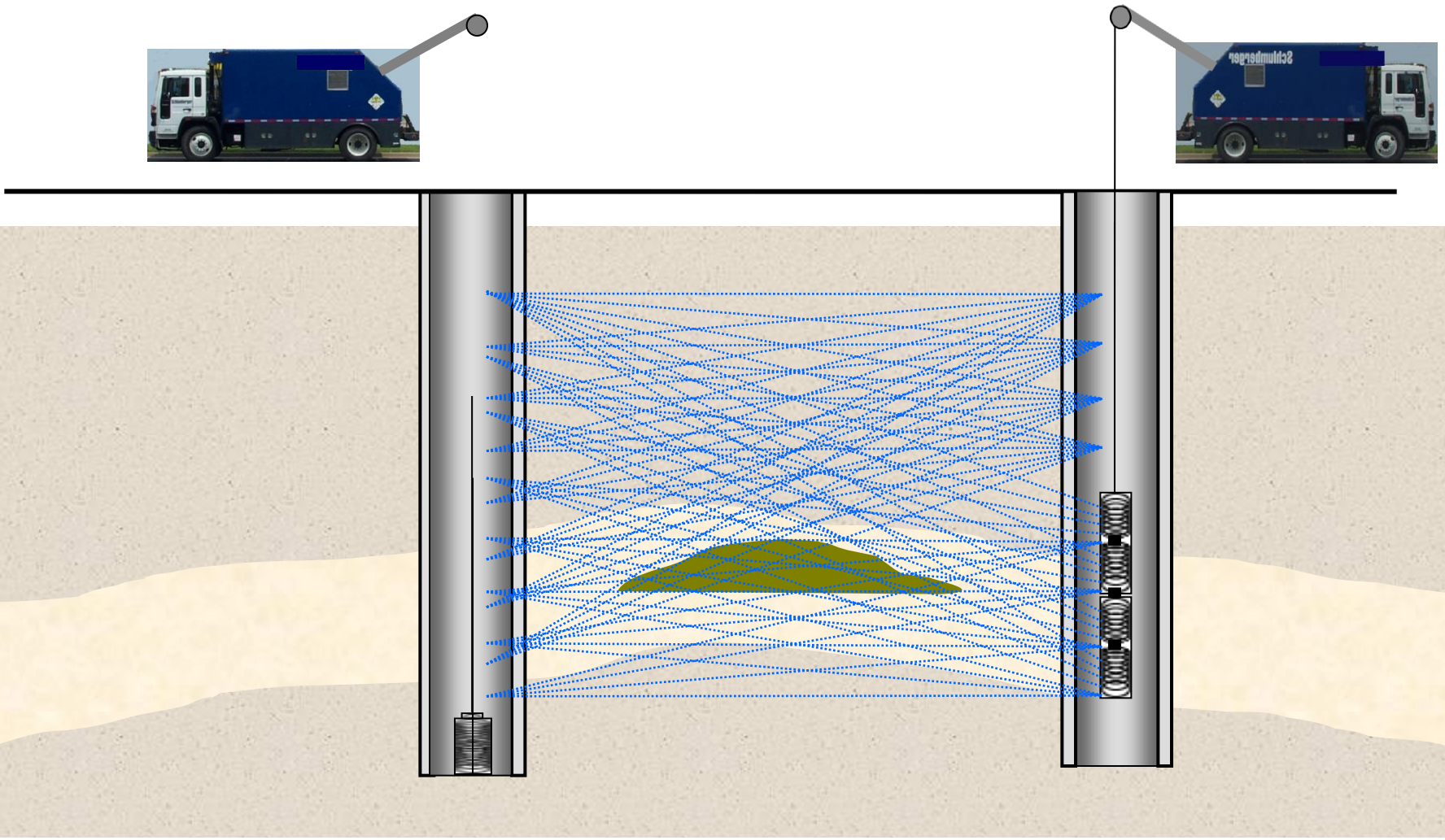
- Orthogonal dipoles downhole vibrating source
- High cost – stop operations
- Acquisition parameters:
  - Source:
    - Orthogonal dipoles vibroseis
    - Source interval: 5 feet (1.5 m)
    - Vibroseis sweep: 30 Hz – 600 Hz
  - Receiver:
    - 40 level three-component geophones
    - Receiver interval: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

:

Cross Well Seismic - Acquisition



Cross Well Seismic – Processing

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Objectives:

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

Challenges:

- Repeatability

Monitor Survey Composite Image

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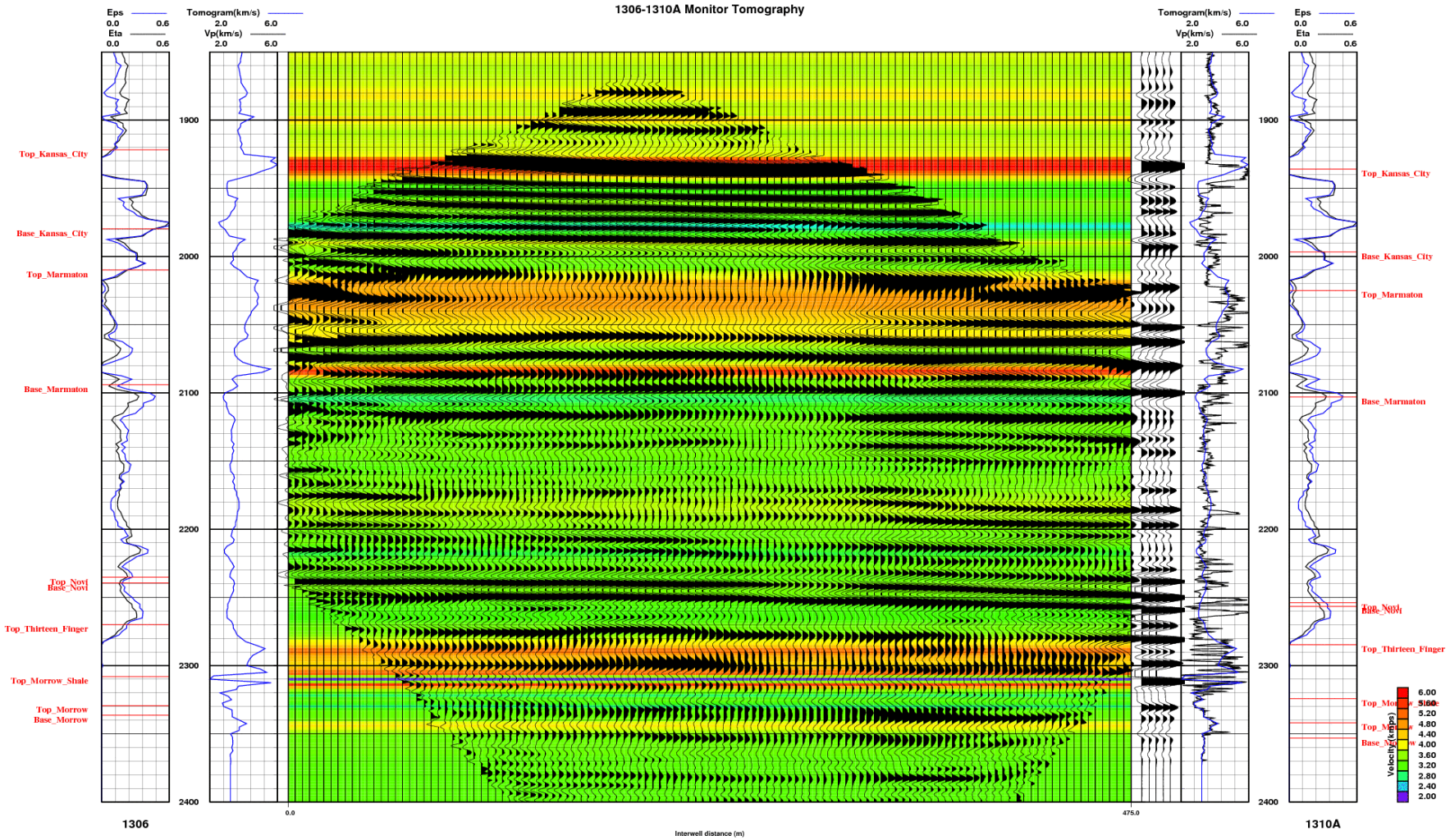

Combined Attributes

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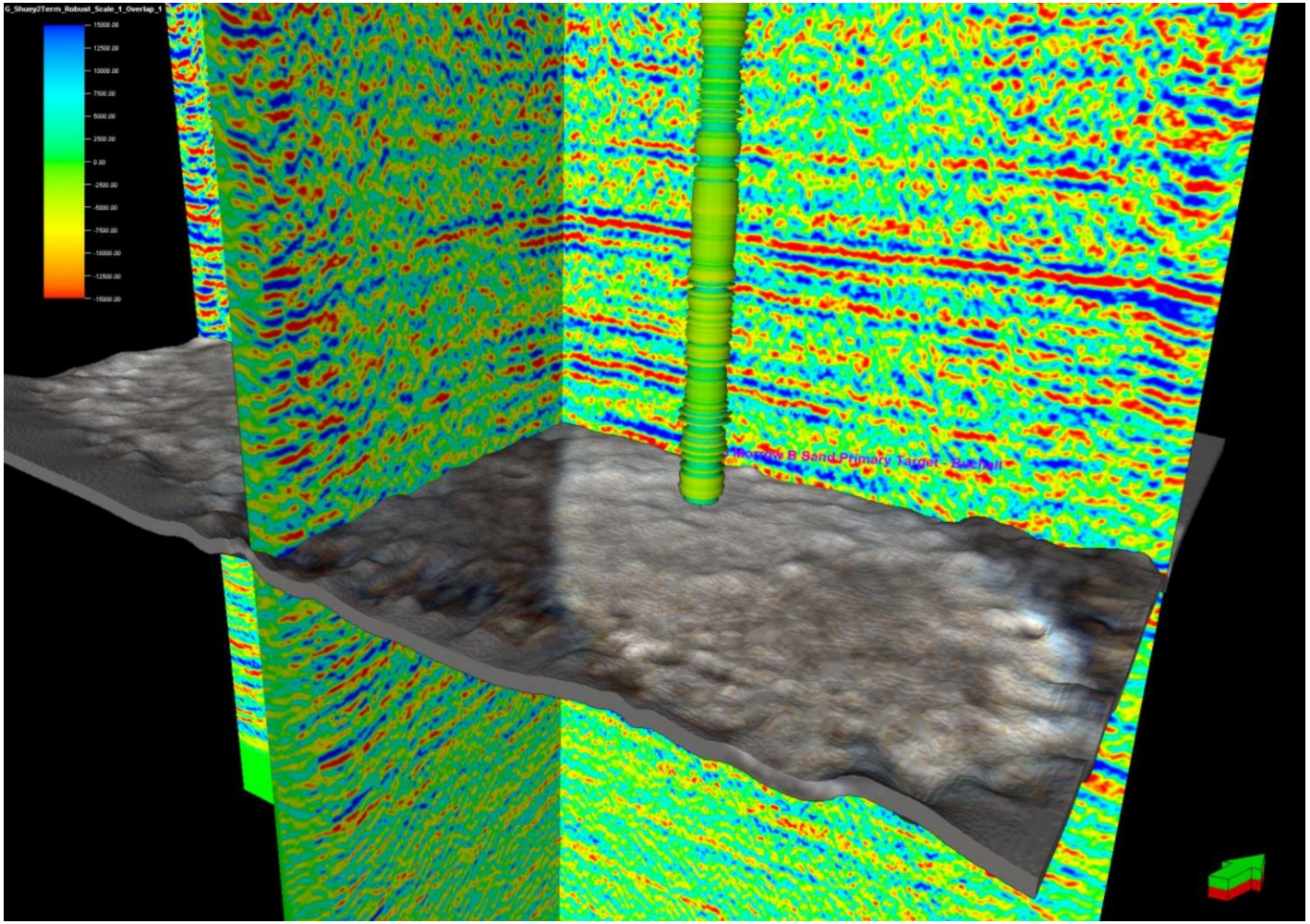

Extracted Seismic Attribute, Shuey amplitude versus offset term (vertical cross sections) and eXchroma^{SG}* chromatic geology extraction software attributes (projected on sub-Morrow depth horizon).

Integrated Cross-Section

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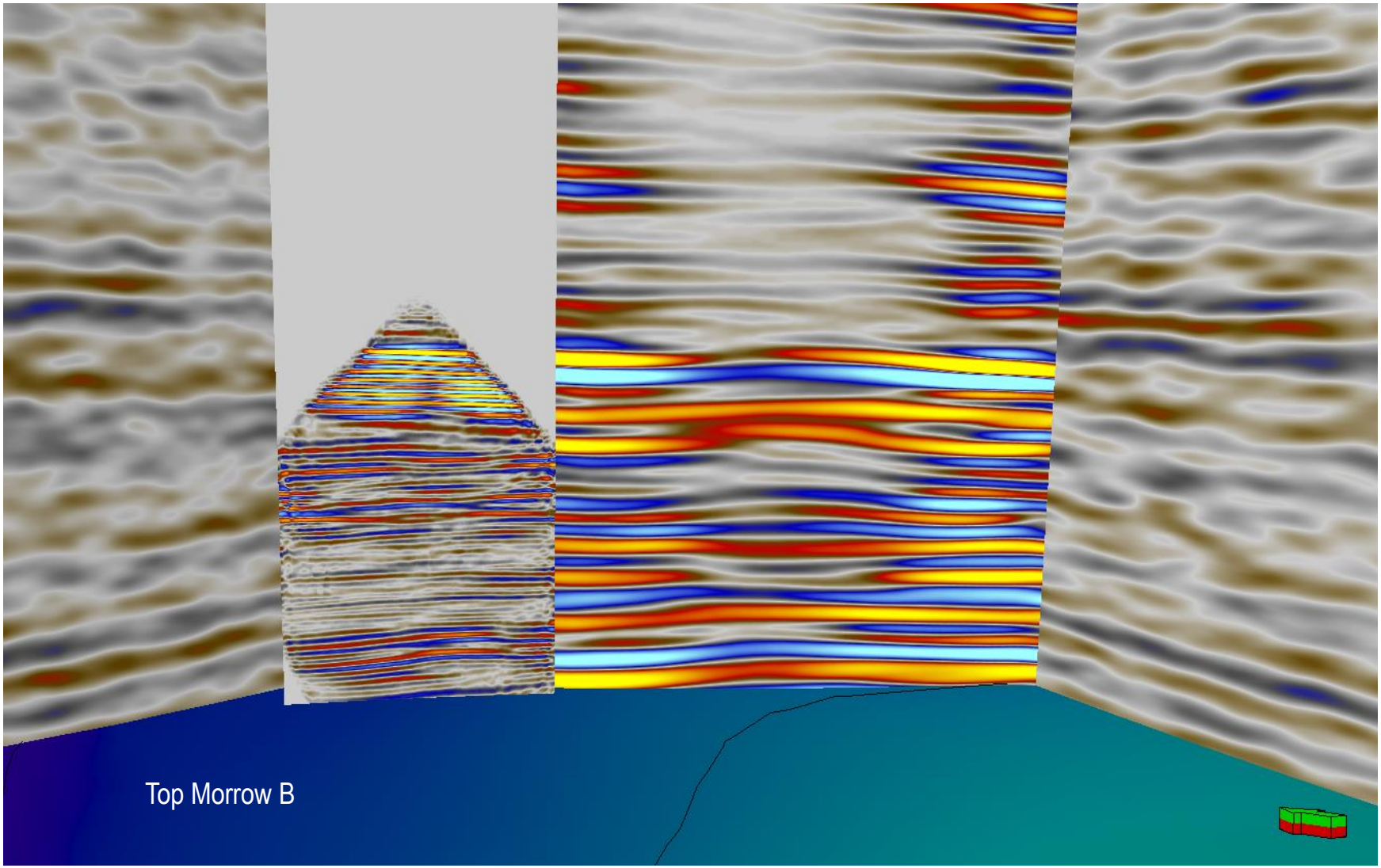

Discussion

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- Multi-scale seismic measurements with varying vertical and lateral resolution can play an important role in site characterization and CO_2 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.