Detailed CO2 Injection and Sequestration Monitoring Through Crosswell Imaging

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Z-Seis Corporation
Who We Are

- **TomoSeis**: 1992 – 1999
  - Innovators in Practical, Low-Cost Crosswell

- **TomoSeis Division of Core Lab**: 2000 – 2003

- **Z – Seis**: 2003 --
  - Continuing the Crosswell Seismic Tradition
  - Improving and Innovating Technology
  - Broadening into Reservoir Seismic Services
  - Z-Seis Canada Ltd formed in 2004
Surface Seismic Technique
4D Surface Seismic

Production time

Lapse 1

Lapse 2

Lapse 3
Crosswell: Moving Seismic Into the Reservoir

After Ed Stoessel / BP
Crosswell Seismic Operations - High-Speed Data Acquisition

- Single-Component Multi-Level (10 or 20) Receiver Array
- Receiver Array Stationed at Position of Deepest Zone
- Receiver Array Moved 50 or 100 Ft
- Level Spacing 2.5, 5 or 10 ft

Wireline Deployed Fluid-Coupled Seismic Source
Each Complete Source Travel Results in a “Fan”

Receiver Array Position of 2nd Fan

• Properties
• Structure

Advanced Interpretation
Raw Data Set From CO2 Sequestration Project Charlton, MI
Crosswell Operations

Powerful Piezoelectric Source
Efficient Multi-level Receivers

Typical Operating Envelope:

Well depth 20,000+ ft
Well spacing ½ mile
Temperature 350°F
Receivers OD 1-11/16”
Source OD 3-1/2”
Why Crosswell Seismic?

Maximun Vertical Seismic Resolution

- 1 mm
- 10 mm
- 10 cm
- 1 m
- 10 m
- 100 m
- 1 km

Reservoir Coverage

- .0001%
- 0.01%
- 0.01%
- 1.00%
- 100%
- 100%

Increasing Resolving Power

Cores
Wireline Logs
Sonic Logs

Geostatistics vs. Data
Crosswell Seismic Imaging

Vertical Seismic Profiling
3-D Surface Seismic
High Resolution Reservoir Imaging
CO$_2$ EOR and Sequestration

• Site Selection
  – Reservoir Characterization
  – Cap Rock/Seal Integrity
  – Thief Zone Identification

• Injection Period
  – Sweep Efficiency
  – Model Fit
  – Problem Identification
CO₂ EOR and Sequestration

- Post Injection
  - Long Term Monitoring
  - Movement of CO₂ Plume
  - Measure Stress Changes in Reservoir
Crosswell reveals unexpected complexity in a West Texas Wolfcamp reef.

Clinoforms and structure observed in outcrops and crosswell seismic compartmentalize the reef.

Horizontal drilling strategy is made possible by enhanced understanding of reservoir architecture through crosswell seismic.
Horizontal drilling strategy is made possible by Crosswell reservoir imaging increased production 300%.
FACT - Attenuation Coefficient Tomogram
FACT - Q-Values Distribution
Raw Data Provides Evidence of 10% Decrease in Velocity or 10% Increase in Travel Time After Injection of CO₂
• CO₂ Flood Monitoring
• Understanding Reservoir Heterogeneity
SACROC Location Map

Modified from Vest (1970)
SACROC 3-D Structure

- Platform (Cross-well Area)
- Central Plain
- Southwestern Area
Structural Variation: Pinnacle Example

Cross-well Line: Log Picks

Dip Line

SW

NE
Cross-well Line: One Possible Interpretation

*Dip Line*

**SW**

**NE**
Outcrop Vs. Crosswell
SACROC Cross-well Project

Shales and a Sand
Time-Lapse (4D) Example

420° out of Plane

Kft/sec

<381FT> <374FT> <1,075FT> <718FT> <520FT> <550FT>
Steam Monitoring Applications

- Steam Assisted Gravity Drain (SAGD)
- Cyclic Steam Operations
Steam assisted gravity drainage

Producing Well

Steam Injection Well

~700m

~100m

~50m
Reality: Outcrop of McMurray
Shale Continuity / Channels

Zhang, et al, CSEG 2002

Dip angle ~10º
dir: SE to NW

Upper
Mid.
Paleo.

Dip NW: ~12º
IHS Beds

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Upper
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OB wells drilled only to the Paleo
Reflection tomography provides coverage
Steam Reflectivity

Top Steam

Base Steam
Time-Lapse Monitoring of Steam Injection
Monitoring Steam in a Faulted Reservoir
Summary

- Outcrop scale detail of reservoir architecture
- Ability to see very small changes in reservoir from optimization processes
- Crosswell is Proven and Reliable Technology

400+ Surveys