An Adaptive Management Approach to CO_2 Storage Projects

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Acknowledgment

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Disclaimer

Plains CO_2 Reduction (PCOR) Partnership

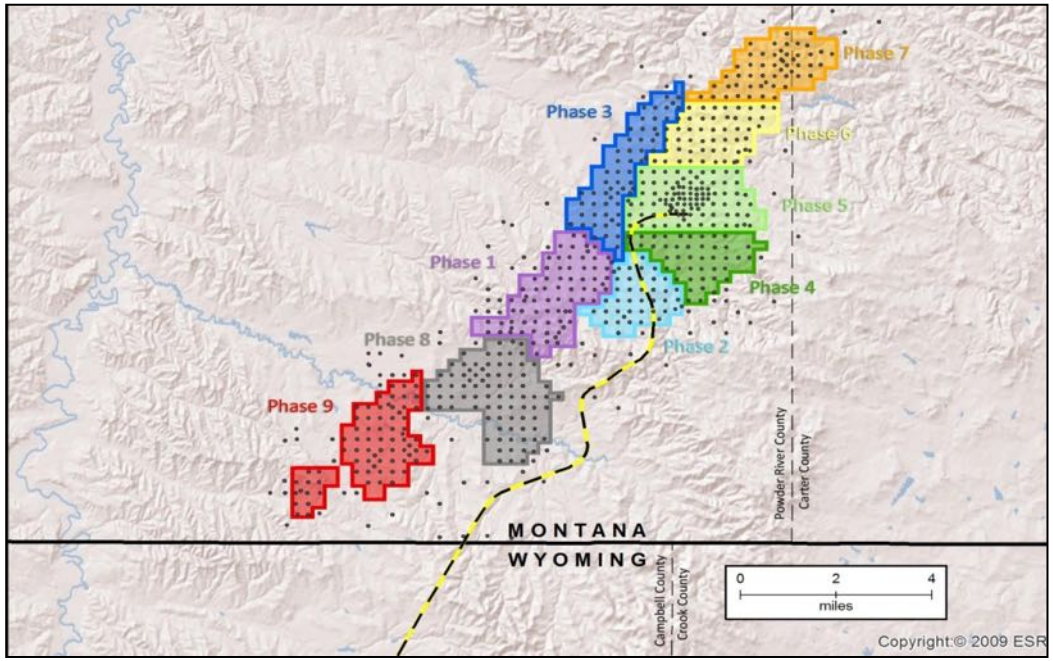
- Nine states
- Four Canadian provinces
- 1,382,089 square miles
- More than 100 partners

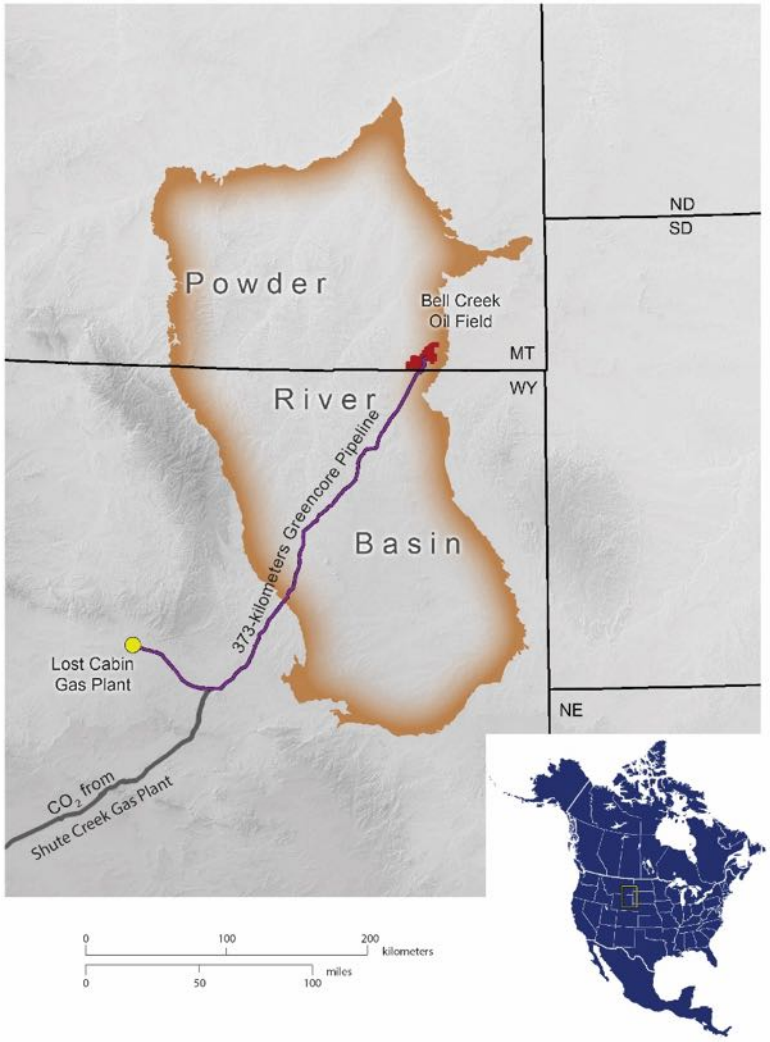
PCOR Partnership Objectives

- Safely and permanently demonstrate associated CO_2 storage on a commercial scale in conjunction with enhanced oil recovery (EOR).
- Demonstrate that oil-bearing formations are viable sinks with significant storage capacity to help meet near-term CO_2 storage objectives.
- Establish monitoring, verification, and accounting (MVA) methods to safely and effectively monitor and account for associated CO_2 storage in context of commercial-scale CO_2 EOR.
- Use commercial oil/gas practices as the backbone of the MVA strategy, and augment with additional cost-effective techniques.
- Share lessons learned for the benefit of similar projects across the region.
- Establish a relationship between the CO_2 EOR process and long-term associated CO_2 storage.

Bell Creek Field

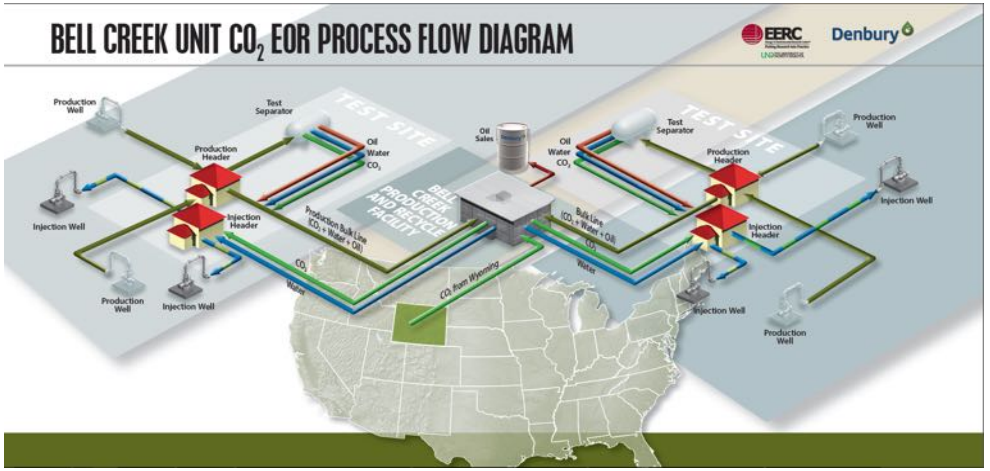
- The Bell Creek oil field is operated by Denbury Onshore LLC.
- CO_2 is sourced from ConocoPhillips' Lost Cabin natural gas-processing plant and Exxon's Shute Creek gas-processing plant.
- The EERC, through the PCOR Partnership, is studying associated CO_2 storage with regards to a commercial CO_2 EOR project.





NETL PCOR Partnership

How do you develop MVA strategies that are practical and meaningful at a commercial scale?

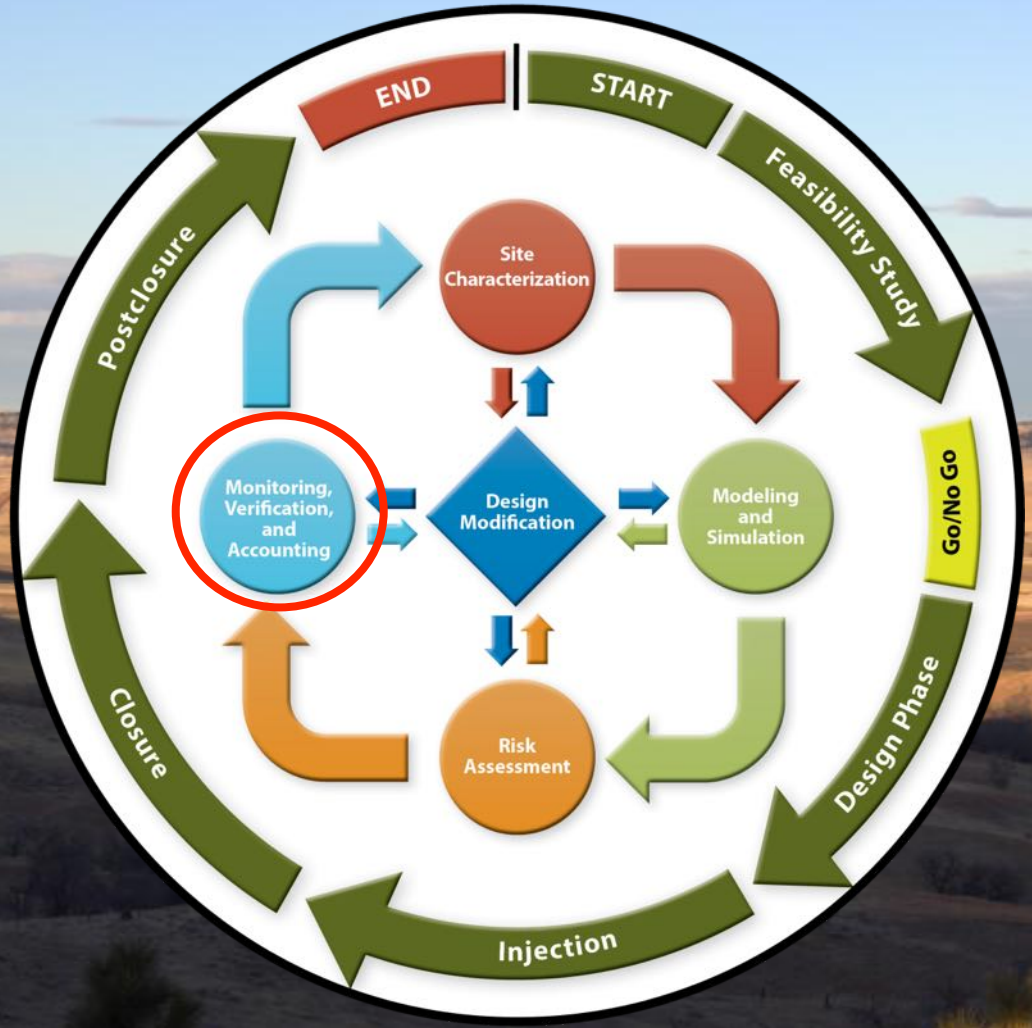


Bell Creek (above), Permian Basin Examples (below)

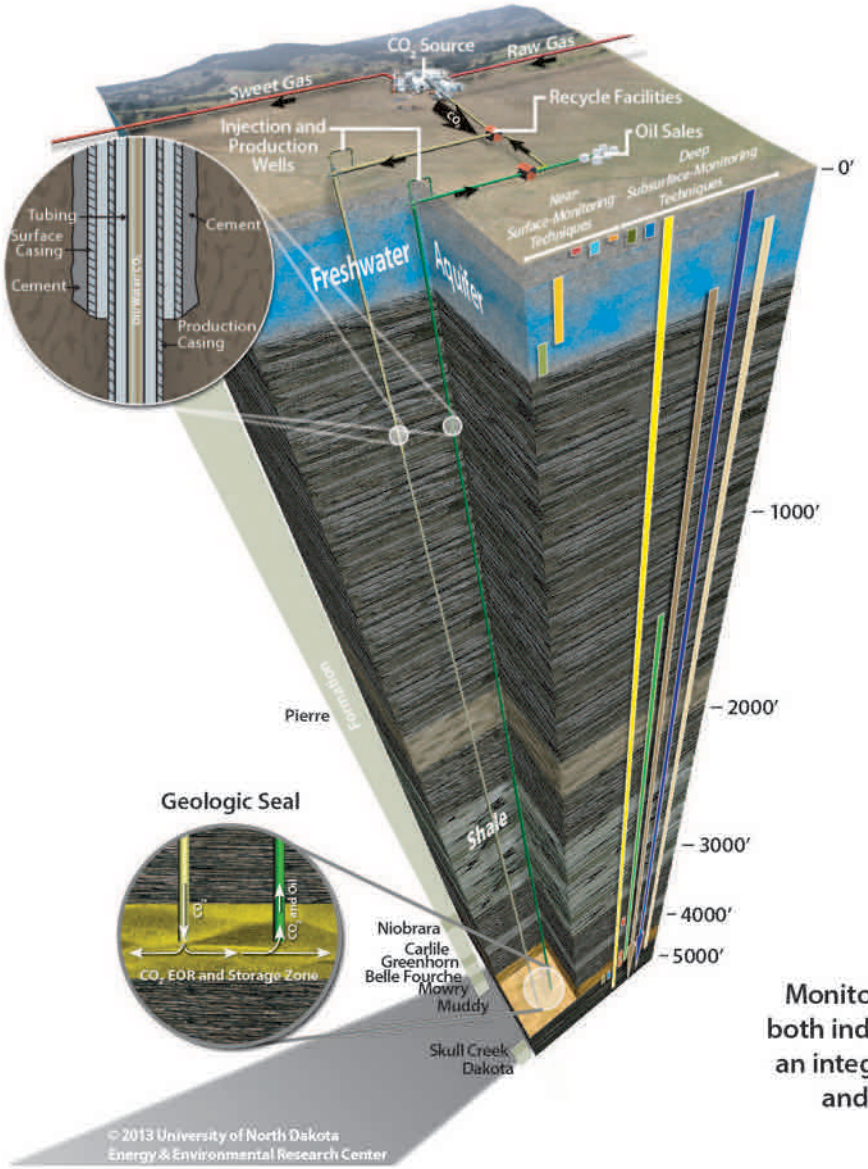
Permain Basin oilfield, from Texas Oil: Landscape of an Industry. CLUI photo

The PCOR Partnership's Integrated Approach to Program Development

Focused on Site Characterization, Modeling and Simulation, and Risk Assessment to Guide MVA Strategy



Research Monitoring, Verification, Accounting, and Surveillance Program Deployed at Bell Creek



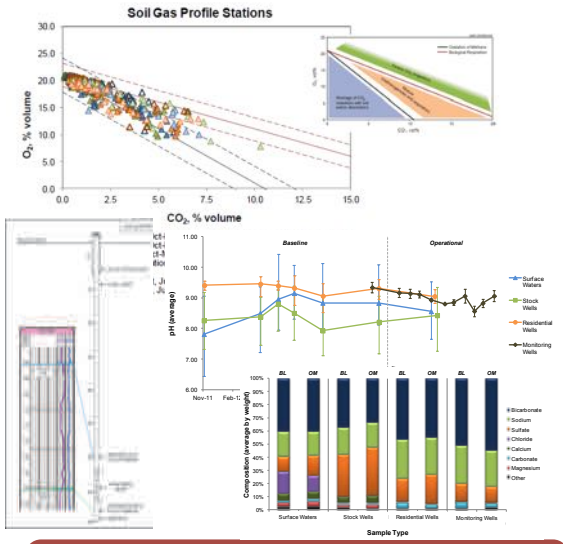
- Fox Hills Groundwater Wells
- Groundwater Wells
- Surface Water
- Soil Gas Profile Stations
- Soil Gas Probes
- Production and Injection Rates
- Wellhead Pressure Monitoring
- Temperature PDM
- Pressure PDM
- 3-D Time-Lapse VSP
- 3-D Time-Lapse Seismic
- Passive Seismic Monitoring
- Neutron Logging

Monitoring data are interpreted both independently and as part of an integrated geologic modeling and simulation workflow.

EERC Energy & Environmental Research Center® Putting Research into Practice

NETL PCOR Partnership

Near-Surface Monitoring
Soil Gas and Water Chemistry



Surveillance

- Naturally occurring variability of soil gas and water compositions in the near-surface environment
- Provide a scientifically defensible source of data capable of monitoring for and characterizing anomalies within these environments

Site Characterization

- Annual and interannual variability of soil gas and water chemistries
- Near-surface environments, chemistries, and mineralogy

Modeling and Simulation

- Geochemical modeling
- Hydrogeological modeling

Assurance Monitoring

- Demonstrate safe/effective associated storage
- Demonstrate no impact to near-surface environments

Near-Surface MVA

Activity	Date
Prep and Planning	February-11
Baseline	November-11
Operational Monitoring 1	June-13
Operational Monitoring 2	June-14

Qtr 1, 2011 | Qtr 3, 2011 | Qtr 1, 2012 | Qtr 3, 2012 | Qtr 1, 2013 | Qtr 3, 2013 | Qtr 1, 2014 | Qtr 3, 2014 | Qtr 1, 2015 | Qtr 3, 2015

Prep and Planning

- Site access agreements
- Site reconnaissance
- Training and methods development
- Equipment procurement

Baseline

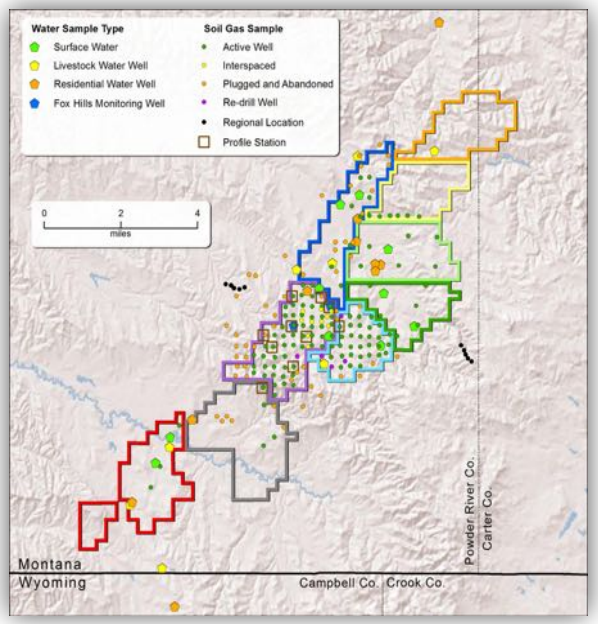
- Quarterly full-field water and soil gas sampling and analysis
- Transitioning to include monthly soil gas sampling and analysis at Phase 1 locations

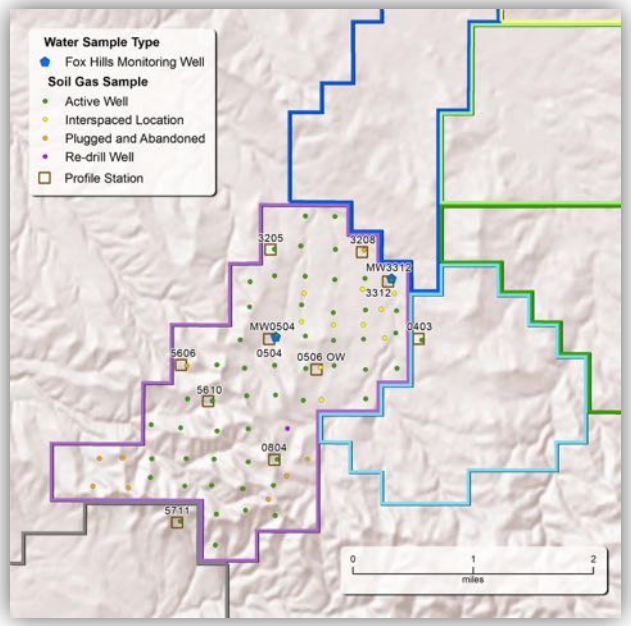
Operational Monitoring 1

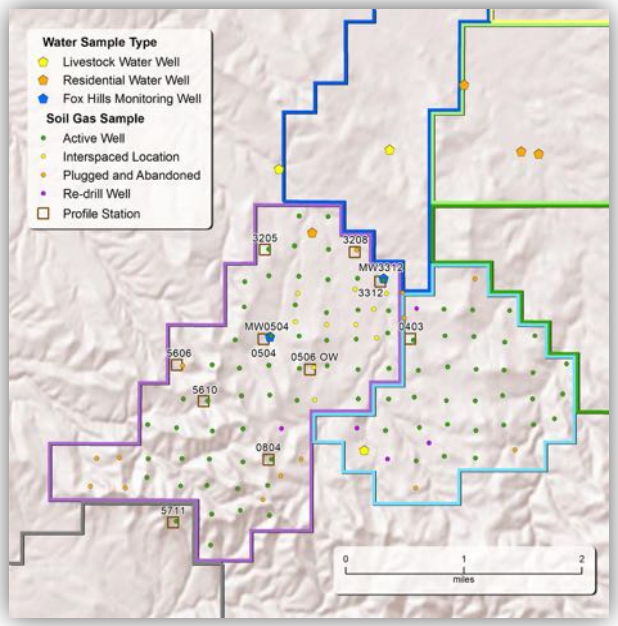
- Monthly water and soil gas sampling and analysis at Phase 1 locations
- Annual full-field water and soil gas sampling and analysis

Operational Monitoring 2

- Quarterly soil gas and water sampling and analysis alternating between select locations (Phase 1 and 2) and full-field events







Near-Surface Assurance Monitoring

- Successfully demonstrating **NO IMPACT** to near-surface environments.
- Chemical modeling and laboratory exposure testing indicate sufficient sensitivity to detect a hypothetical out-of-zone fluid migration, providing area of influence transects a monitoring point.
- Monitoring program was sufficient to detect, characterize, and attribute multiple anomalies to naturally occurring processes.
- Workflows were developed to semiautomate the analysis and characterization process that can be adapted into site-specific intelligent monitoring approaches.
- Baseline data set spanning 18-month period prior to injection providing a scientifically defensible data set of natural variability of near-surface environments supplemented by ~2 years of operational monitoring data.
- First years of operational monitoring have provided key insight regarding how the research monitoring program could be transitioned toward a more commercially viable long-term assurance-monitoring strategy.
- Landowner relations key to **<u>success</u>.**

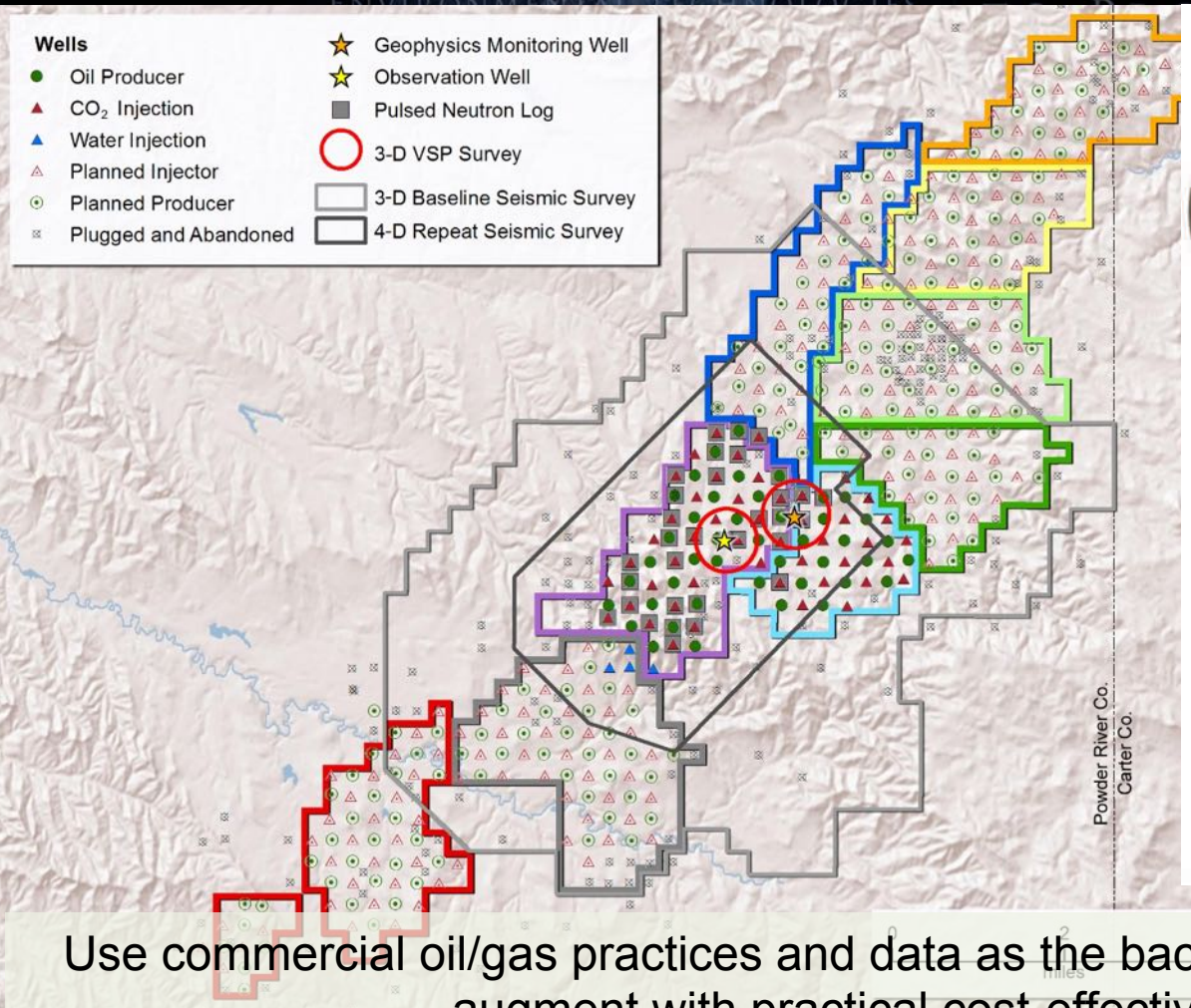


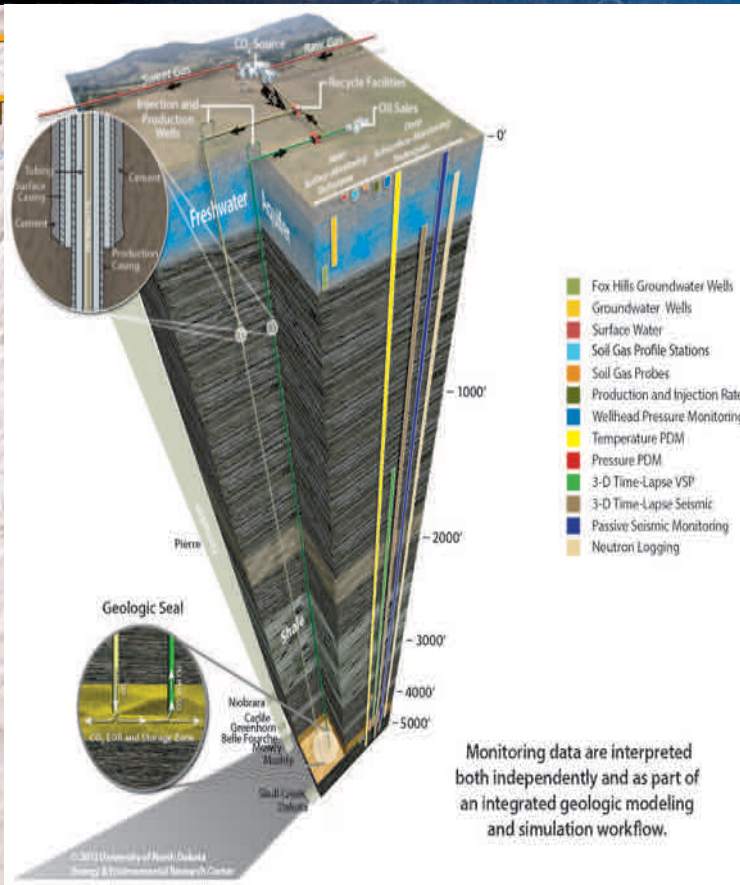






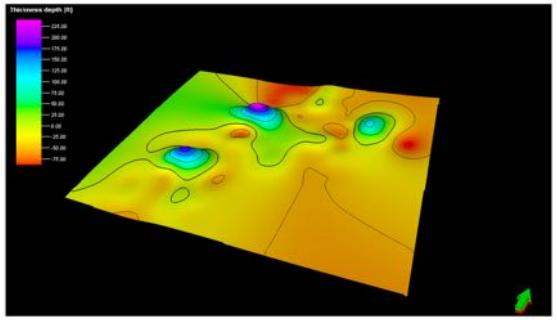

Subsurface MVA Program





Use commercial oil/gas practices and data as the backbone of the MVA strategy, then augment with practical cost-effective techniques.

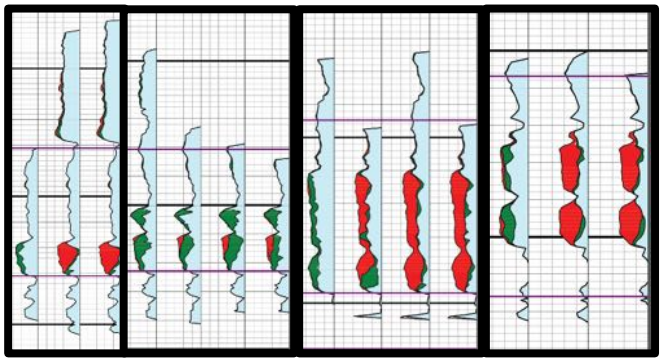
Pulsed-Neutron Logging (PNL) Applications



Thickness Between Old Pierre Surface Tops and New Surface Tops
(in Petrel, 5x vertical exaggeration, 50-ft contours)

Surveillance

- Water/oil/gas saturation changes
- Residual water saturation
- Oil mobilization
- Conformance
- Storage/sweep efficiency
- Guide surveillance activities (go/no go)
- Vertical and lateral flow



Site Characterization

- Structural interpretation
- Reservoir and overlying strata properties
- Regional variability within reservoir and overlying zones

Modeling and Simulation

- History match
- Formation tops
- Porosity
- Tune and calibrate geomodel
- Synthetic logs
- Enhanced seismic interpretations

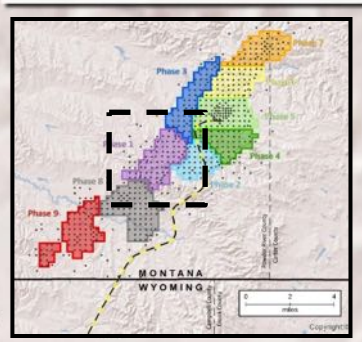
Assurance Monitoring

- Monitor for out-of-zone vertical migration (accumulation zones)
- Wellbore integrity monitoring
- Demonstrate safe/effective associated CO_2 storage

Baseline Pulsed Neutron Log

Wells
- Oil Producer
- CO_2 Injection
- Water Injection
- Planned Injector
- Planned Producer
- Plugged and Abandoned
- Observation Well
- PNL Baseline Well

0 0.5 1
miles



32-03 32-02 32-01
32-06 32-07
31-09 32-11 33-12
31-16 33-13 33-14R 33-15
56-01 05-01 04-04 04-03
56-08 05-05 05-07 04-05
05-06 OW
56-11 56-09
56-14R 04-13
57-03 57-01 08-04
57-05 57-07 57-08 08-05
57-09

33 Wells

PNL Repeat–Oct. 2013

4 Wells

PNL Repeat–Jan. 2014

4 Wells

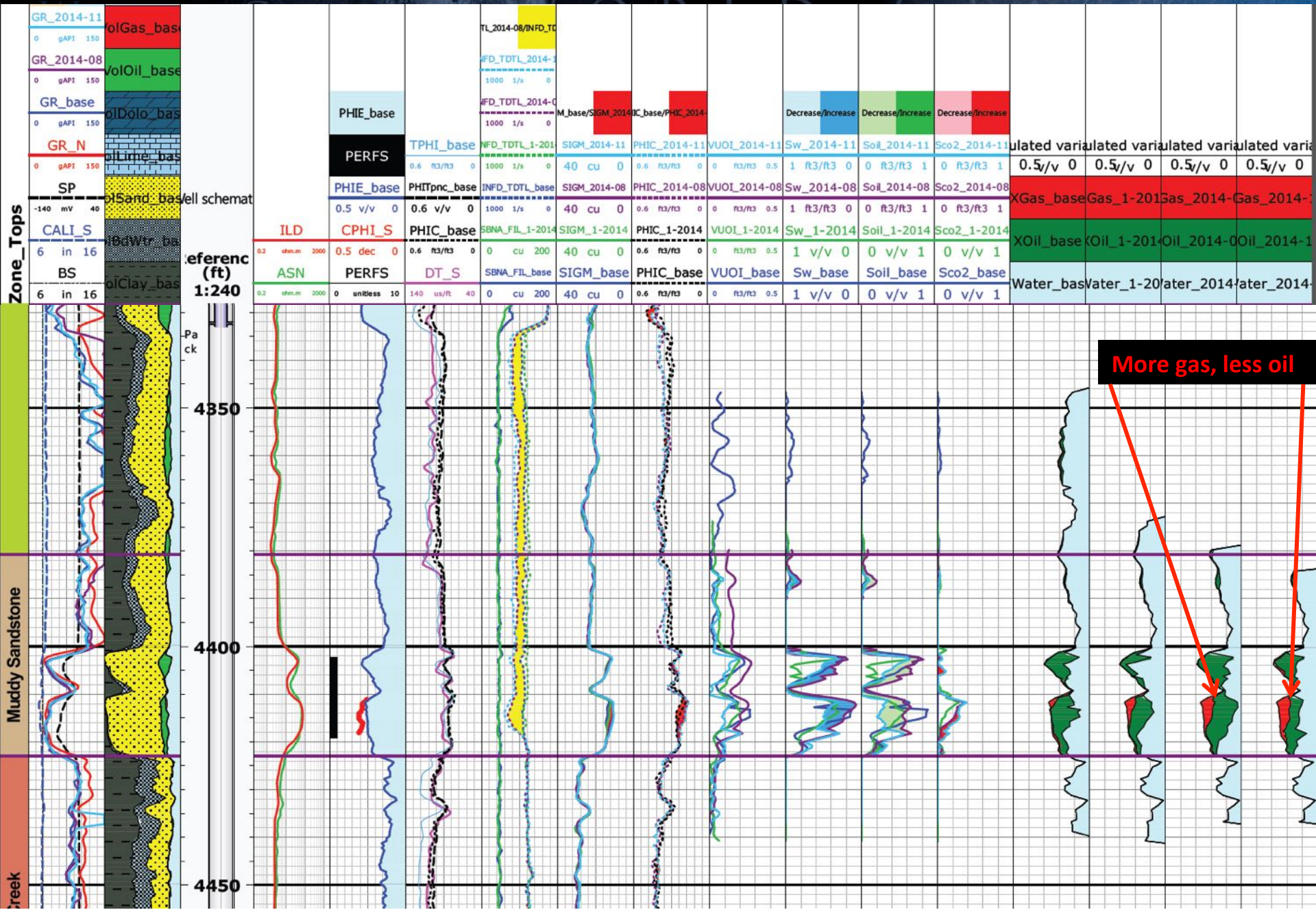
PNL Repeat–Aug. 2014

19 Wells

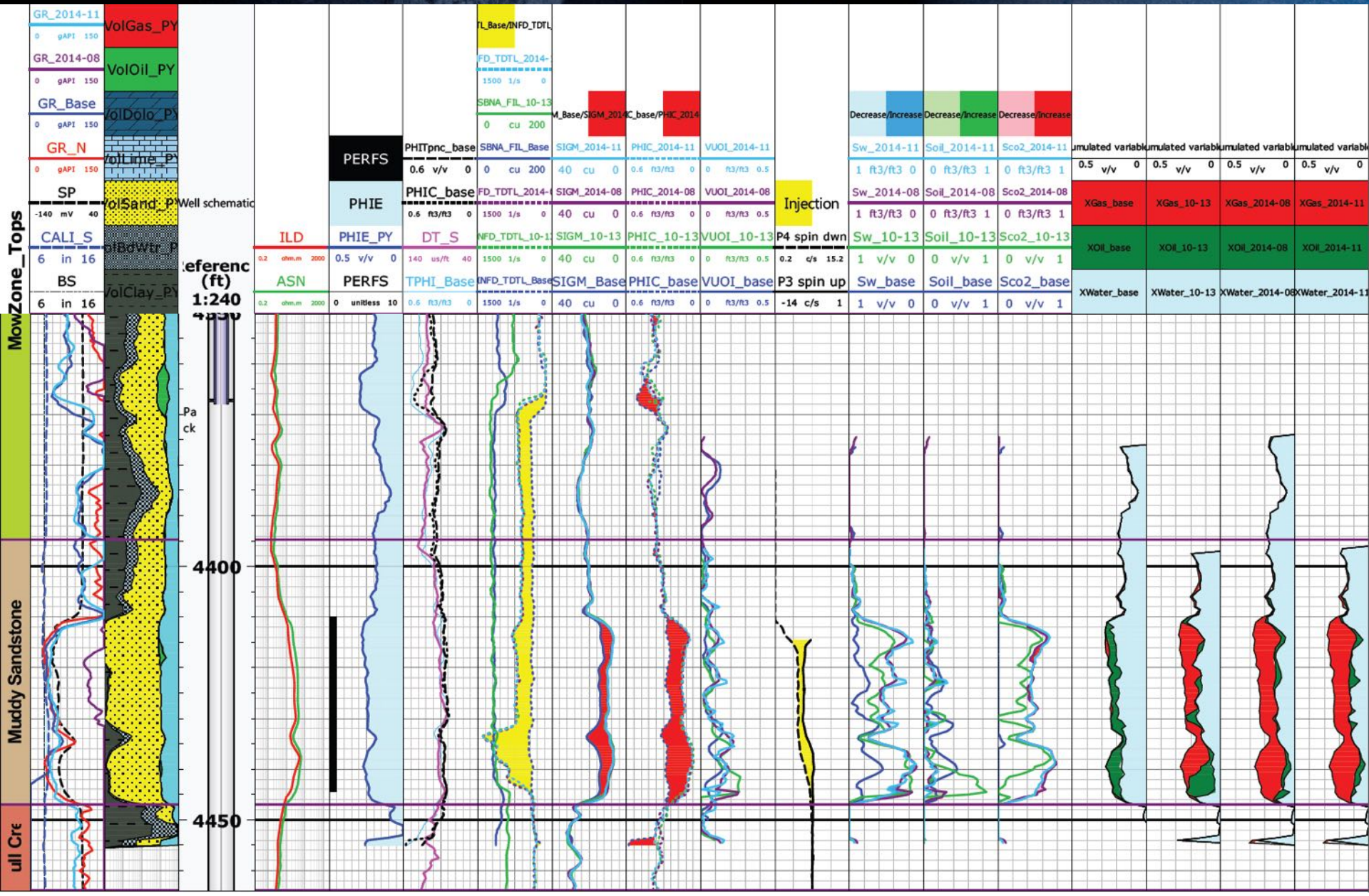
PNL Repeat–Nov. 2014

4 Wells

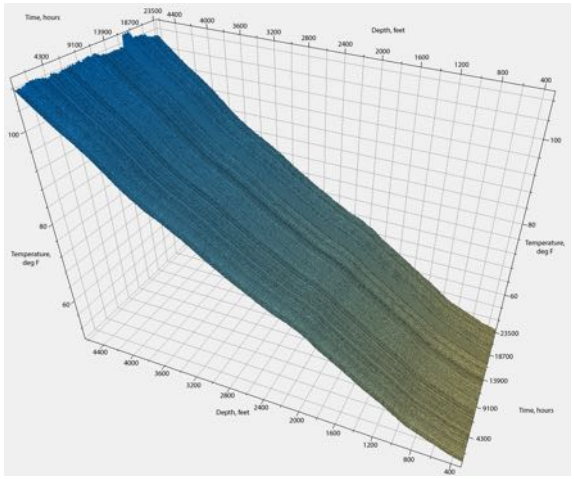
Producer Time-Lapse PNL



Injector Time-Lapse PNL

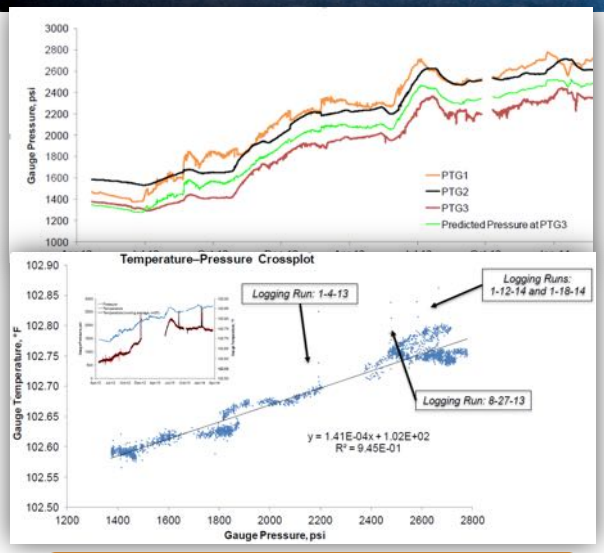


Pressure/Temperature



Surveillance

- Reservoir pressure/temperature
- Fluid phase behavior conditions
- Aquifer support
- Well testing/pressure communication
- Reservoir behavior vs. injection/ production rates



Site Characterization

- Lateral and vertical zonal pressure isolation

Modeling and Simulation

- History match
- Phase behavior and equation of state (EOS)

Assurance Monitoring

- Monitor for vertical pressure communication
- Demonstrate safe/effective associated CO_2 storage

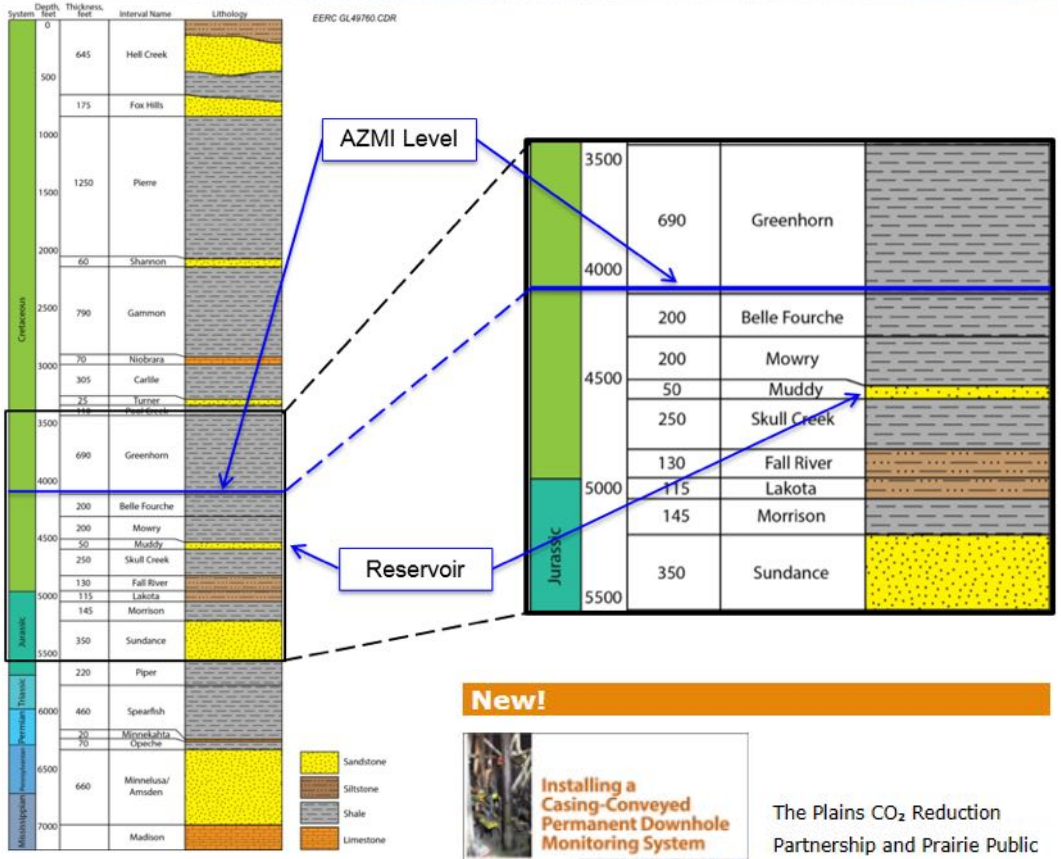
Permanent Downhole Monitoring (PDM)

- Three casing-conveyed pressure–temperature gauges (PTGs)
  - Three monitoring zones record data at 5-minute intervals:
    - PTG1: BC30 at 4535.5 feet MD
    - PTG2: BC10 at 4515.5 feet MD
    - PTG3: Belle Fourche/AZMI at 4110.0 feet MD

- Casing-conveyed fiber optic distributed-temperature system (DTS) records temperature traces at 4-hour intervals:
  - DTS anchor at 4750 feet MD
  - Temperature data every 1 meter (3.3 feet)

- Installed January 2012; continuous operation since April 20, 2012.

For more information and a detailed overview of the PDM system, a videographic documentary can be viewed at http://www2.undeerc.org/website/PCORP/.



New!

The Plains CO_2 Reduction Partnership and Prairie Public Broadcasting have coproduced a video describing the basics of casing-conveyed permanent downhole monitoring.

Click here to view the video.

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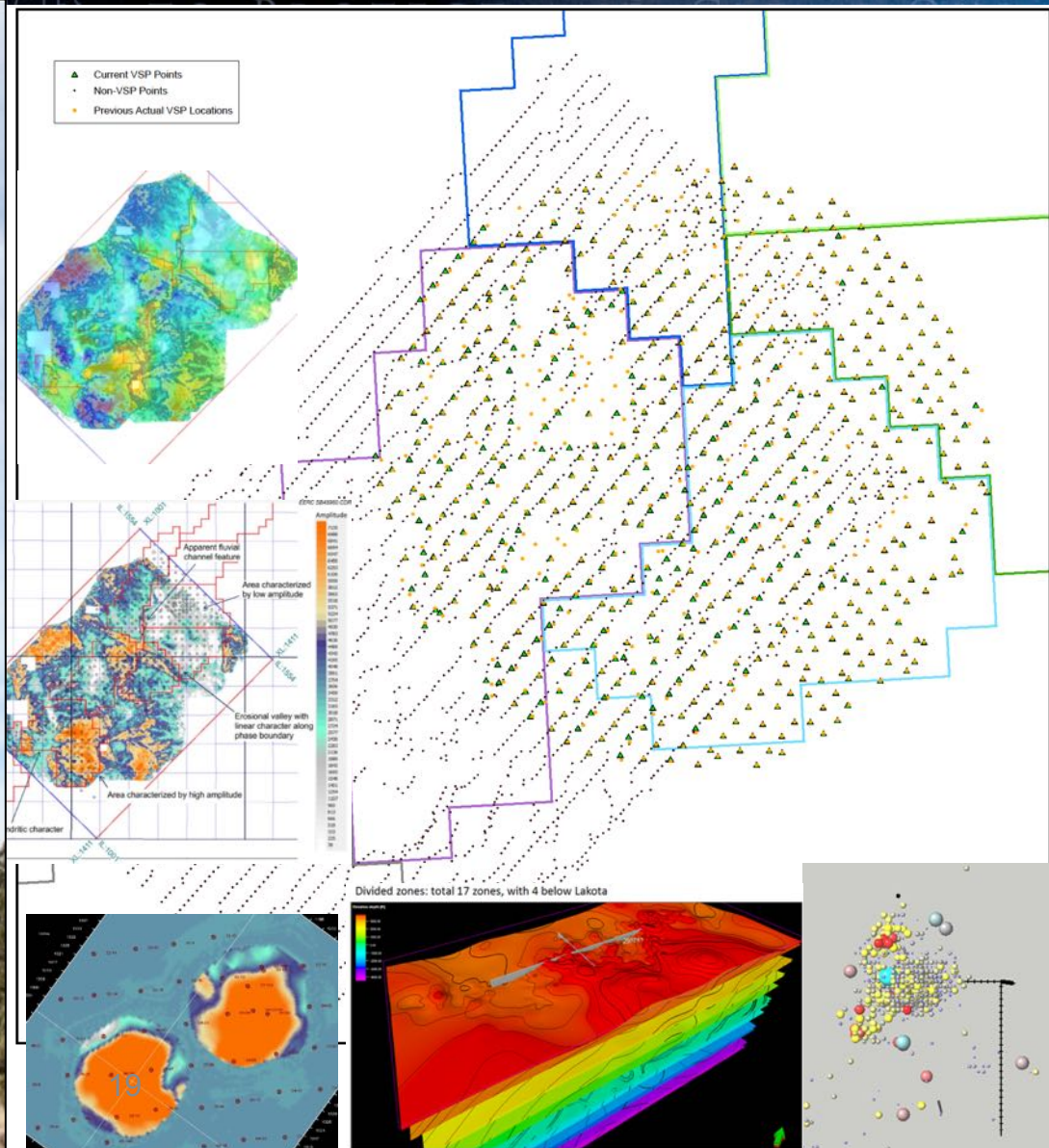
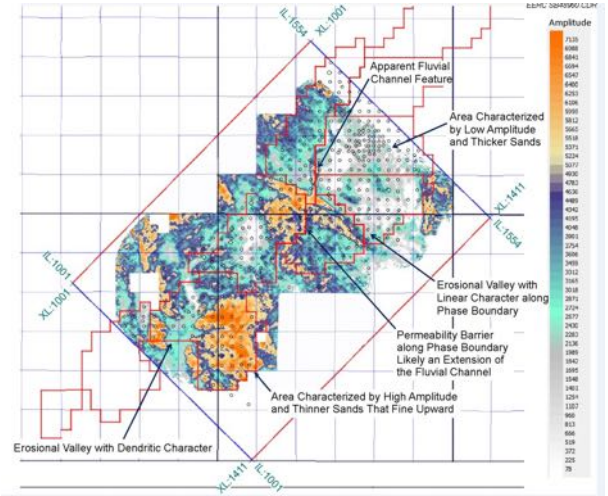
Putting Research into Practice

Geophysics Portfolio

- 3-D and 4-D surface seismic
  - Baseline survey (May 2013, 45 square miles)
  - Monitor survey (October 2014, 11.5 square miles)
  - 4-D analysis
- 3-D and 4-D vertical seismic profile (VSP)
  - Baseline survey (May 2013, 05-06 OW and 04-03 OW)
  - Monitor survey (October 2014, 04-03 OW only)
  - 4-D analysis
- Passive seismic monitoring
  - Approaching 2 years of data collection
  - First year of data processed; interpretation is ongoing

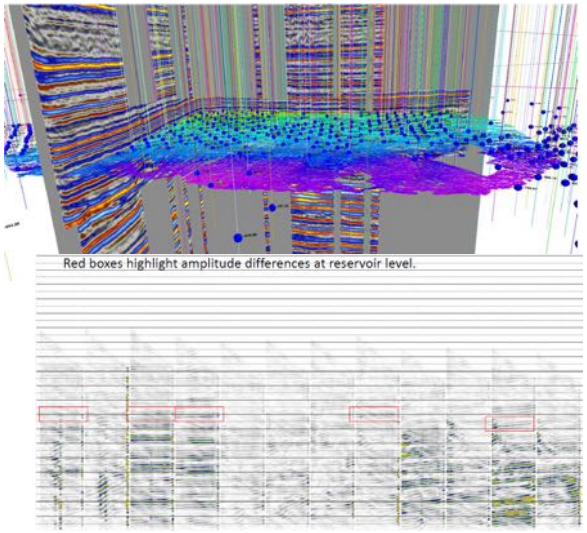


3-D Seismic



Surveillance

- Gas saturation changes
- Conformance
- Areal extent of gas plume
- Surveillance boundaries



Site Characterization

- Structural interpretation
- Sequence stratigraphy and depositional environment
- Permeability barrier locations
- Fault and fracture identification
- Geomechanical properties from seismic inversion

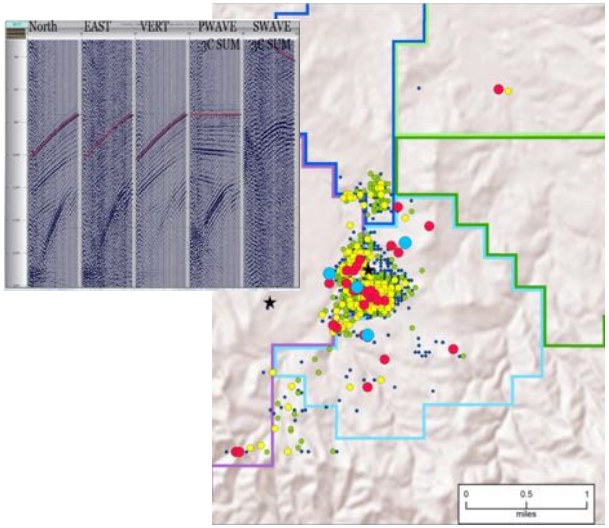
Modeling and Simulation

- Refined history matching
- Tune and calibrate the geologic model
- Geomechanical modeling and simulation

Assurance Monitoring

- Show that out-of-zone migration, vertically or laterally, is not occurring
- Demonstrate safe/effective associated CO_2 storage

Passive Seismic



Surveillance

- Source and depth of seismic emissions
- Lateral or vertical out-of-zone pressure communication

Site Characterization

- Variability within reservoir and overlying zones
- Fault identification
- Pressure communication
- Correlation of events with geomechanical models

Modeling and Simulation

- History match
- Geomechanical models
  - Understand stress
  - Calibrate
  - Fine-tune

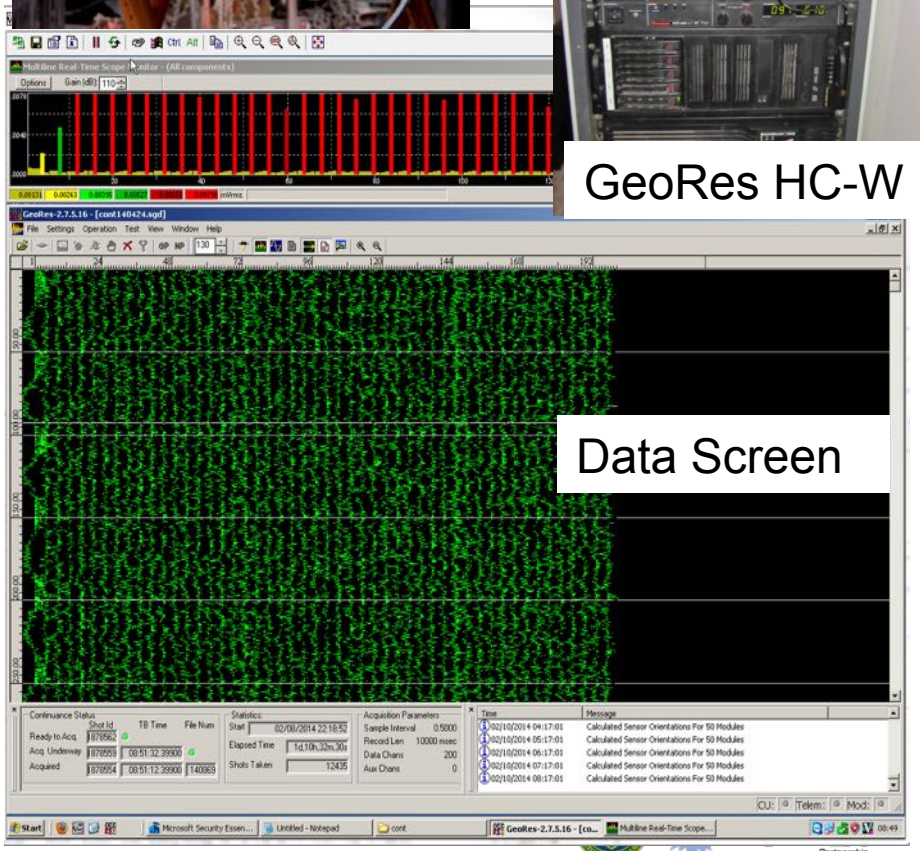
Assurance Monitoring

- Monitor, identify, and locate induced seismic emissions vs. natural seismic events
- Monitor for vertical migration to overlying accumulation zones
- Monitor for fault activation
- Demonstrate safe/effective associated CO_2 storage

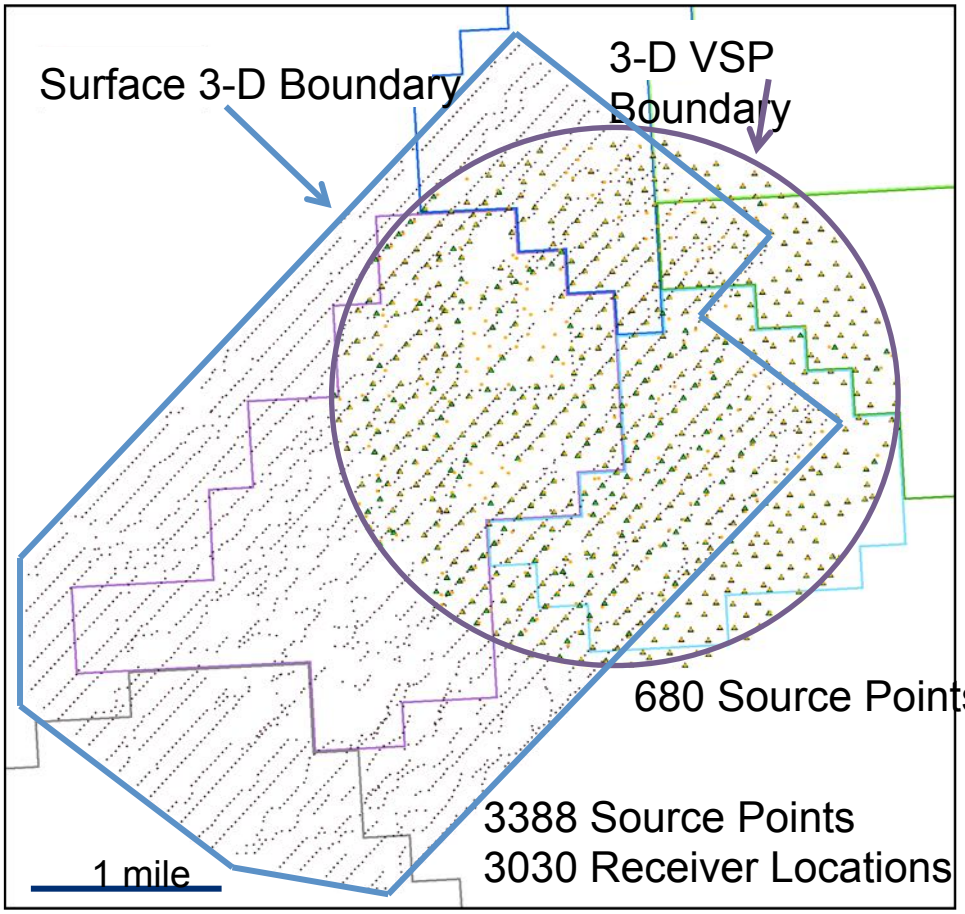
Passive Monitoring

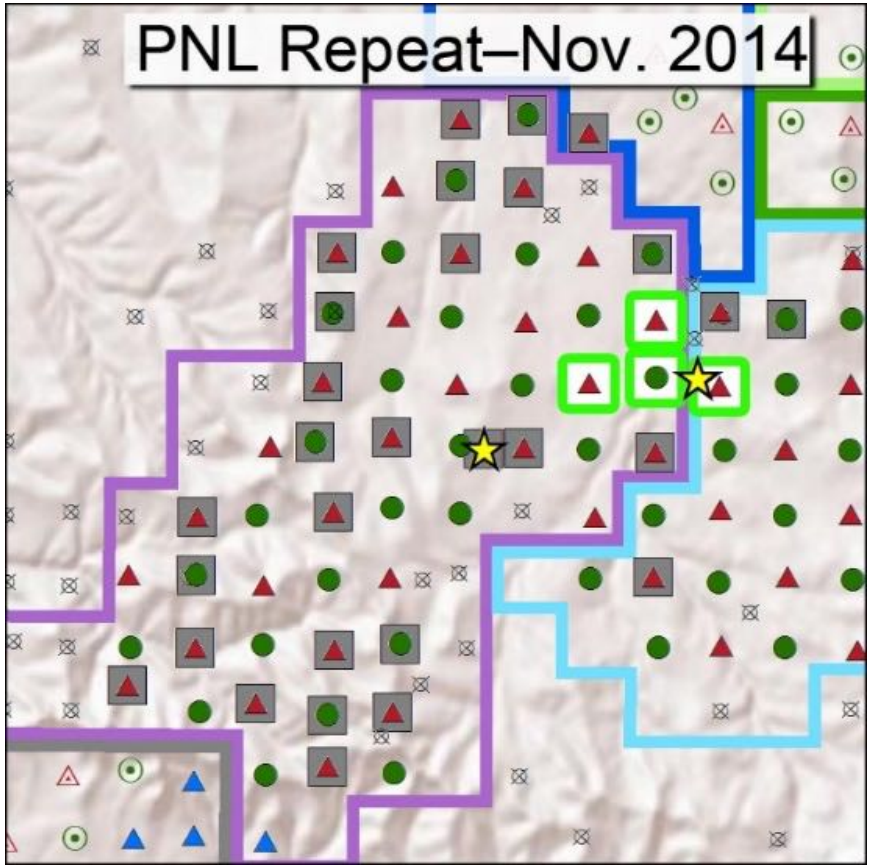
- Monitoring Well 04-03 OW
  - 50 three-component geophones + hydrophone cemented in the wellbore.
  - Total depth: 2471 ft
  - 15-m sensor pod spacing (49.2 ft)
    - First level at 60-ft depth
  - System status e-mail every 4 hours
  - Data collected from May 2013 to present
    - First year of data processed

GeoRes HC-W



Integrating MVA Techniques





Developing Successful Monitoring Strategies

- **Clear objectives/purpose that lead to actionable decisions.**
- Site-specific strategies and site-compatible technologies.
- Talk to your service providers about objectives, not tools. Use due diligence in selection (good data are a win/win).
- Have sufficient expertise and resources to process, interpret, and analyze acquired data.
- Deploy cost-effective monitoring strategies with clear and robust interpretation techniques that can enhance project.
- Minimize impact to operations and manage risk/liability of deployment.
- Use commercial oil/gas data as a backbone to build enhanced monitoring programs and interpretations and to validate technologies.
- Interpret data in context of overall project.

Enhanced value through an integrated project approach to MVA, technical risk assessment, characterization, modeling, and predictive simulation.

EOR at the Bell Creek Oil Field

Minimal Visual Impact

EOR at the Bell Creek Oil Field

Minimal Visual Impact – Over 25 Wells in this View

Thank You!

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